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Virtuoso Simulator Components and Device Models Reference

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Contents

Preface

This manual assumes that you are familiar with the development, design, and simulation of integrated circuits and that you have some familiarity with SPICE simulation.

This manual describes equations and parameters for models suppoted by the Virtuoso® Spectre circuit simulator, Virtuoso® UltraSim™ simulator, and the Virtuoso® BSIMProPlus model extractor.

Spectre is an advanced circuit simulator that simulates analog and digital circuits at the differential equation level. The simulator uses improved algorithms that offer increased simulation speed and greatly improved convergence characteristics over SPICE. Besides the basic capabilities, the Spectre circuit simulator provides significant additional capabilities over SPICE. Verilog®-A uses functional description text files (modules) to model the behavior of electrical circuits and other systems. Virtuoso® SpectreRF Simulation Option adds several new analyses that support the efficient calculation of the operating point, transfer function, noise, and distortion of common RF and communication circuits, such as mixers, oscillators, sample holds, and switched-capacitor filters.

The UltraSim simulator is a fast and multi-purpose single engine, hierarchical simulator, designed for the verification of analog, mixed signal, and digital circuits. Covering a wide range of applications, the Virtuoso UltraSim simulator can be used for functional verification of billion-transistor memory circuits, as well as for high-precision simulation of complex analog circuits. Because of its true hierarchical simulation approach, the Virtuoso UltraSim simulator is faster and uses less memory than traditional circuit simulators, while maintaining near SPICE accuracy. The Virtuoso UltraSim simulator has powerful deep-submicron analysis capabilities, including timing, power, noise, and reliability. The Virtuoso UltraSim simulator recognizes a variety of netlist formats, including HSPICE (registered trademark of Synopsys, Inc.), Virtuoso Spectre®, and supports Virtuoso RelXpert format for reliability simulation.

The BSIMProPlus model extractor is a new generation SPICE model generator that is used to extract and optimize model parameters.

This preface discusses the following topics:

Related Documents

The following can give you more information about the Spectre circuit simulator and related products:

- The Spectre circuit simulator is often run within the Virtuoso® analog design environment, under the Cadence® design framework II. To see how the Spectre circuit simulator is run under the analog circuit design environment, read the *Cadence Analog Design Environment User Guide.*
- To learn more about specific parameters of components and analyses, consult the Spectre online help (`spectre -h`) or the *Virtuoso Spectre Circuit Simulator Reference* manual.
- For more information about using the Spectre circuit simulator with Verilog-A, see the *Verilog-A Language Reference* manual.
- If you want to see how SpectreRF is run under the analog circuit design environment, read *SpectreRF Simulation Option User Guide*.
- For more information about RF theory, see *SpectreRF Simulation Option Theory*.
- For more information about how you work with the design framework II interface, see *Design Framework II Help*.
- For more information about specific applications of Spectre analyses, see *The Designer's Guide to SPICE & Spectre*[1].

The following can give you more information about the UltraSim simulator and related products:

- *Virtuoso UltraSim Simulator User Guide*
- *Virtuoso Unified Reliability Interface Reference*
- *Virtuoso UltraSim Waveform Interface*
- *Virtuoso UltraSim Simulator: What's New*
- *RelXpert Reliability Simulator User Guide*

The following can give you more information about the BSIMProPlus model extractor and related products:

- *Virtuoso BSIMPro User's Manual*

1. Kundert, Kenneth S. *The Designer's Guide to SPICE & Spectre.* Boston: Kluwer Academic Publishers, 1995.

- *Virtuoso BSIMProPlus Basic Operations Guide*
- *Virtuoso BSIMProPlus Model Extractor: What's New*
- *BSIM3v3.2.2 MOSFET Model: User's Manual* (Department of Electrical Engineering and Computer Sciences, University of California, Berkeley)
- *BSIM4 User's Manual*
- *BSIMPD User's Manual*
- Taur, Y., Zicherman, D. S., et al (1992). *A new shift and ratio method for MOSFET channel-length extraction*, IEEE Electron Device Let.: Vol. 12, page 267

Typographic and Syntax Conventions

This list describes the syntax conventions used for the Spectre circuit simulator.

`literal`	Nonitalic words indicate keywords that you must enter literally. These keywords represent command (function, routine) or option names, file names and paths, and any other sort of type-in commands.
`argument`	Words in italics indicate user-defined arguments for which you must substitute a name or a value. (The characters before the underscore (_) in the word indicate the data types that this argument can take. Names are case sensitive.
|	Vertical bars (OR-bars) separate possible choices for a single argument. They take precedence over any other character.
`[ ]`	Brackets denote optional arguments. When used with OR-bars, they enclose a list of choices. You can choose one argument from the list.
`{ }`	Braces are used with OR-bars and enclose a list of choices. You must choose one argument from the list.
`...`	Three dots (...) indicate that you can repeat the previous argument. If you use them with brackets, you can specify zero or more arguments. If they are used without brackets, you must specify at least one argument, but you can specify more.

Important

The language requires many characters not included in the preceding list. You must enter required characters exactly as shown.

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Circuit Components

This chapter contains component statements for the following:

Current Sources

Linear Current Controlled Current Source (cccs)

A current-controlled source senses the current with a probe device. A valid probe is a component instance in the circuit that naturally computes current. For example, probes can be voltage sources (independent or controlled), inductors, transmission lines, microstrip lines, N-ports, and transformers. If the probe device computes more than one current (such as transmission lines, microstrip lines, and N-ports), the index of the probe port through which the controlling current flows needs to be specified. Positive current exits the source node and enters the sink node of the controlled source.

This device can also model ideal digital gates.

This device is supported within altergroups.

Sample Instance Statement

```
vcs (pos gnd) cccs gain=2.5 probe=v1 m=1 //Note that v1 is an instance of a voltage
source
```

Instance Definition

```
Name  sink  src cccs parameter=value ...
```

Instance Parameters

1	`m=1`	Multiplicity factor.
2	`probe`	Device through which the controlling current flows.
3	`mprobe`	The mprobe functions the same as probe except that it will divide the input current by the mfactor.
4	`port=0`	Index of the probe port through which the controlling current flows.
5	`probes=[...]`	Devices through which the controlling currents flow. For multi-input digital gates only.
6	`mprobes=[...]`	The mprobes function the same as probes except that they will divide the input currents by the mfactor.

7 `ports=[...]`	Indices of the probe ports through which the controlling currents flow. For multi-input digital gates only.
8 `type=cccs`	Type of the source. Possible values are `cccs`, `and`, `nand`, `or`, or `nor`.
9 `delta=0`	Smoothing parameter. This may lead to circuit convergence. Its value should be in the range between 0 and 0.5, both ends included. The smaller the delta is, the sharper the corner is.

Linear source parameters

10 `gain=0 A/A`	Current gain.
11 `td=0.0 s`	Time delay.
12 `min (A)`	Minimum output current.
13 `max (A)`	Maximum output current.
14 `abs=off`	Output current is absolute value if `abs` is set to `on`. Possible values are `off` or `on`.

PWL source parameters

15 `file`	Name of file containing current/current pairs that define the PWL transfer function.
16 `pwl=[...]`	Vector of current/current pairs that defines the PWL transfer function. The format of the vector is `[in1 out1 in2 out2 ... ]`.
17 `scale=1`	Scale factor for the PWL output current.
18 `stretch=1`	Scale factor for the PWL controlling current.

Temperature effects parameters

19 `tc1=0 1/C`	Linear temperature coefficient.
20 `tc2=0` C^{-2}	Quadratic temperature coefficient.

The Smoothing Factor

The parameter delta is the smoothing factor. When it is nonzero, a curve is introduced to smooth the corner. The value of delta defines the position of the starting and ending points of the curve that is used to smooth the corner. The minimum value 0 means no smoothing curve is introduced. The maximum value 0.5 means the distance between the starting point of the curve and the corner point is half of the shortest distance. The shortest distance is the length of the shortest segment of the piecewise linear function. Or, when there is no shortest segment in the controlling function, i.e. only `abs=on` is specified, spectre uses 1 as the shortest distance.

Operating-Point Parameters

1 `i (A)`	Input current.
2 `v (V)`	Output voltage.
3 `pwr (W)`	Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Linear Current Controlled Voltage Source (ccvs)

A current-controlled source senses the current with a probe device. A valid probe is a component instance in the circuit that naturally computes current. For example, probes can be voltage sources (independent or controlled), inductors, transmission lines, microstrip lines, N-ports, and transformers. If the probe device computes more than one current (such as transmission lines, microstrip lines, and N-ports), the index of the probe port through which the controlling current flows needs to be specified. Current through the controlled voltage source is calculated and is defined to be positive if it flows from the positive terminal, through the source, to the negative terminal.

This device can also model ideal digital gates.

This device is supported within altergroups.

Sample Instance Statement

```
vvs (pos gnd) ccvs rm=1 probe=v1 m=1   //Note that v1 is an instance of a voltage
source
```

Instance Definition

```
Name  p  n ccvs parameter=value ...
```

Instance Parameters

1	`m=1`	Multiplicity factor.
2	`probe`	Device through which the controlling current flows.
3	`mprobe`	The mprobe functions the same as probe except that it will divide the input current by the mfactor.
4	`port=0`	Index of the probe port through which the controlling current flows.
5	`probes=[...]`	Devices through which the controlling currents flow. For multi-input digital gates only.
6	`mprobes=[...]`	The mprobes function the same as probes except that they will divide the input currents by the mfactor.

7 `ports=[...]` — Indices of the probe ports through which the controlling currents flow. For multi-input digital gates only.

8 `type=ccvs` — Type of the source.
Possible values are `ccvs`, `and`, `nand`, `or`, or `nor`.

9 `delta=0` — Smoothing parameter. This may lead to circuit convergence. Its value should be in the range between 0 and 0.5, both ends included. The smaller the delta is, the sharper the corner is.

Linear source parameters

10 `rm=0` Ω — Trans resistance.

11 `td=0.0 s` — Time delay.

12 `min (V)` — Minimum output voltage.

13 `max (V)` — Maximum output voltage.

14 `abs=off` — Output voltage is absolute value if `abs` is set to `on`.
Possible values are `off` or `on`.

PWL source parameters

15 `file` — Name of file containing current/voltage pairs that define the PWL transfer function.

16 `pwl=[...]` — Vector of current/voltage pairs that defines the PWL transfer function. The format of the vector is [`in1 out1 in2 out2 ...`].

17 `scale=1` — Scale factor for the PWL output voltage.

18 `stretch=1` — Scale factor for the PWL controlling current.

Temperature effects parameters

19 `tc1=0 1/C` — Linear temperature coefficient.

20 `tc2=0` C^{-2} — Quadratic temperature coefficient.

The Smoothing Factor

The parameter delta is the smoothing factor. When it is nonzero, a curve is introduced to smooth the corner. The value of delta defines the position of the starting and ending points of the curve that is used to smooth the corner. The minimum value 0 means no smoothing curve is introduced. The maximum value 0.5 means the distance between the starting point of the curve and the corner point is half of the shortest distance. The shortest distance is the length of the shortest segment of the piecewise linear function. Or, when there is no shortest segment in the controlling function, i.e. only `abs=on` is specified, spectre uses 1 as the shortest distance.

Operating-Point Parameters

1 `i (A)`	Output current.
2 `v (V)`	Output voltage.
3 `pwr (W)`	Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Independent Current Source (isource)

The value of the DC current as a function of the temperature is given by:

```
I(T) = I(tnom) * [1 + tc1 * (T - tnom) + tc2 * (T - tnom)^2].
```

Sample Instance Statement

```
i1 (in 0) isource dc=0 type=pulse delay=10n val0=0 val1=500u period=500n rise=1n
fall=1n width=250n
```

Instance Definition

```
Name  sink  src  [ctlp]  [ctln] isource parameter=value ...
```

Positive current exits the source node and enters the sink node.The third node (`ctl`) is used as a switch only for prbs.

Instance Parameters

1	`dc=0 A`	DC value.

General waveform parameters

2	`type=dc`	Waveform type. Possible values are `dc`, `pulse`, `pwl`, `sine`, `exp`, `bit`, `prbs`, `pwlz`, and `sigbus`.
3	`fundname`	Name of the fundamental frequency. Must be specified if the source is active during a pdisto analysis or it is the active clock during an envlp analysis.
4	`delay=0 s`	Waveform delay time.
5	`edgetype=linear`	Type of the rising and falling edges, effective for pulse, pulse-like piecewise linear, bit and prbs sources. Possible values are `linear` and `halfsine`.

Pulse waveform parameters

6	`val0=0 A`	Zero value used in pulse and exponential waveforms.
7	`val1=1 A`	One value used in pulse and exponential waveforms.

8 `period=∞ s`	Period of waveform. When `type=prbs`, period defines the bit duration.
9 `rise (s)`	Rise time for pulse waveform (time for transition from `val0` to `val1`). If parameter rise is not given, then the rise time will be the same as fall time; if fall time is not given either, then the rise time will be 1/100 of the waveform period; if the waveform is not periodic, then the rise time will be 1/100 of the simulation interval; if `type=prbs`, the rise time is 1/10 of the bit duration.
10 `fall (s)`	Fall time for pulse waveform (time for transition from `val1` to `val0`). If parameter fall is not given, then the fall time will be the same as rise time; if rise time is not given either, then the fall time will be 1/100 of the waveform period; if the waveform is not periodic, then the fall time will be 1/100 of the simulation interval; if `type=prbs`, the fall time is 1/10 of the bit duration.
11 `width=∞ s`	Pulse width (duration of `val1`).

PWL waveform parameters

12 `file`	Name of file containing waveform.
13 `wave=[...]`	Vector of time/value pairs that defines waveform.
14 `offset=0 A`	DC offset for the PWL waveform.
15 `scale=1`	Scale factor for the PWL waveform.
16 `stretch=1`	Scale factor for time given for the PWL waveform.
17 `rms`	Desired rms (root of mean square) value of the PWL waveform.
18 `pwlfilter=none`	Add filter to pwl source, where the pwl data should be equal space sampled. Possible values are 'nrc'(normal raised cosine filter) and 'none'. Possible values are `none` and `nrc`.
19 `rolloff`	Desired rolloff factor for the raised cosine filter, default value is 0.2. Only valid when 'pwlfilter' is set to nrc.
20 `pwlbandwidth`	Bandwidth of the pwl input signal. Be used when 'pwlfilter' is set to nrc.

21 `allbrkpts` All the points in the PWL waveform are breakpoints if set to yes. Default is yes if the number of points is less than 20. Possible values are `no` and `yes`.

22 `pwlperiod (s)` Period of the periodic PWL waveform.

23 `pwlperiodstart (s)` Period start time of the periodic PWL waveform.

24 `twidth=pwlperiod/1000 s`
Transition width used when making PWL waveforms periodic.

25 `highz=1e12` The impedance of high z state.

26 `min_z_transition_width=10e-12 s`
Minimum width of transition from z-state to non z-state. The width of transition is set as 1e-3*(z-sate duration).

Sinusoidal waveform parameters

27 `sinedc=dc A` DC level for sinusoidal waveforms.

28 `ampl=1 A` Peak amplitude of sinusoidal waveform.

29 `freq=0 Hz` Frequency of sinusoidal waveform.

30 `sinephase=0 °` Phase of sinusoid when `t=delay`.

31 `ampl2=1 A` Peak amplitude of second sinusoidal waveform.

32 `freq2=0 Hz` Frequency of second sinusoidal waveform.

33 `sinephase2=0 °` Phase of second sinusoid when `t=delay`.

34 `fundname2` Name of the fundamental frequency associated with freq2. Must be specified if freq2 is used in a pdisto analysis.

35 `iqmodfiles=[...]` Two file names which containing pwl I/Q source waveform.

36 `fmmodindex=0` FM index of modulation for sinusoidal waveform.

37 `fmmodfreq=0 Hz` FM modulation frequency for sinusoidal waveform.

38 `fmmodfiles=[...]`	One or two file names: containing FM waveform for one file case, and FM I/Q signals for two files with I file first.
39 `ammodindex=0`	AM index of modulation for sinusoidal waveform.
40 `ammodoffset=1`	AM offset of modulation for sinusoidal waveform.
41 `ammodfreq=0 Hz`	AM modulation frequency for sinusoidal waveform.
42 `ammodphase=0 °`	AM phase of modulation for sinusoidal waveform.
43 `damp=0 1/s`	Damping factor for sinusoidal waveform.
44 `freqvec=[...] Hz`	Vector of support frequency of sinusoid channel source.
45 `amplvec=[...] A`	Vector of Peak amplitude of sinusoid channel source.
46 `phasevec=[...] °`	Vector of Phase of sinusoid channel source.
47 `maxharms=[...]`	Array of number of harmonics of each frequency.

Exponential waveform parameters

48 `td1=0 s`	Rise start time for exponential wave.
49 `tau1 (s)`	Rise time constant for exponential wave.
50 `td2 (s)`	Fall start time for exponential wave.
51 `tau2 (s)`	Fall time constant for exponential wave.
52 `expperiod (s)`	Period of the periodic EXP waveform.

Pattern parameters

53 `data`	The bit string. A string that contains a series of the four states, 1 0 m z. For prbs, it can contain only 0 and 1, and m, z is not supported.
54 `rptstart=1`	The starting bit when repeating. The data repeats from the specified bit to the end of the bit string. The parameter should be an integer from 1 to the length of the bit string.

55 `rpttimes=0`	The repeat times. The output will maintain the state of the last bit after the last repeat. If its value is negative, the string repeats forever.

Prbs parameters

56 `ref (A)`	Sets the crossing reference for the control node. This parameter applies only when the Prbs source operates as a 3 or 4 terminal device. When the voltage across terminals 3 and 4 drops below ref, the output of the source is set to 0. If terminal 4 is not specified, it is assumed to be connected to ground.
57 `jitter (s)`	The parameter jitter is obsolete. It has no effect on the output.
58 `rjseed=1`	The seed for random number generator, used in generating random jitter for PRBS sources. The default value is 1.
59 `rjrms (s)`	When set for PRBS source or Bit source, the source has a normally distributed random jitter, whose mean is zero and whose standard deviation is rjrms.
60 `pjamp=[...] s`	When set for PRBS source or Bit source, the source has multiple periodic jitters, whose amplitudes are defined by pjamp and frequencies are defined by pjfreq.
61 `pjfreq=[...] Hz`	When set for PRBS source or Bit source, the source has multiple periodic jitters, whose amplitudes are defined by pjamp and whose frequency are defined by pjfreq.
62 `pjtype="sine"`	For PRBS source or Bit source, pjtype defines the types of periodic jitters. Possible valudes are 'sine', 'sawtooth', or 'square'.
63 `seed`	This parameter is obsolete but retained for backward compatability. Set registerlength=[2 ... 32] to choose a Maximum Length Sequence or define a custom PRBS by use of the parameters, lfsrtaps and lfsrseed.
64 `taps=[...]`	The use of taps is discouraged. For PRBS, taps is an integer array which sets the locations of the LFSR taps. Please use lfsrtaps instead. Please see the section, 'PRBS Type Waveform' below for details of the PRBS operation.

65 `lfsrtaps=[...]` For PRBS source, lfsrtaps is an integer array which sets the location of LFSR taps. Locations are 1-based and ordered form MSB to LSB of the LFSR. The largest element of the taps array is equal to the width of the LFSR. Please see the section, 'PRBS Type Waveform' for details of PRBS source operation.

66 `lfsrseed=[...]` For PRBS source, lfsrseed is an integer array which sets the initial state of the LFSR. Array elements sets the locations of non-zero bits. Locations are 1-based and ordered from MSB to LSB of the LFSR. For example, assume lfsrtaps=[6] and lfsrseed=[1 3 5]. The width of the register is then 6 bits and the initial state is '101010'.

67 `registerlength` When set for PRBS, the registerlength defines the width of the LFSR and the LFSR works in Maximum Length Sequence mode. Please see the section 'PRBS Type Waveform' below for details of MLS setting.

68 `triggerthreshold (A)`
For PRBS, when triggerthreshold is set and the source is instantiated with optional control terminals (terminals 3 and optionally 4; if terminal 4 is unspecified it is assumed to be connected to ground), triggerthreshold defines the crossing threshold for the trigger event. The event causes the emission of the next PRBS pulse.

69 `triggerdelthresh (A)`
For PRBS in external triggering mode, triggerdelthresh is used with triggerthreshold to define the crossing threshold. For rising edge triggering, the actual threshold is (triggerthreshold + triggerdelthresh); for falling edge triggering, the threshold is (triggerthreshold - triggerdelthresh). The default value is zero.

70 `triggerdirection="both"`
For PRBS in external triggering mode, trigger direction defines the direction of the control signal at the crossing event. Possible valudes are 'rise', 'fall', or 'both'.

71 `transitionreference`
Defines the voltage swing for the duration of rise and fall time, as a percentage of val1 - val0. For example, transitionreference =100 means that the output voltage transitions from val0 to val1 in rise seconds. 90 means that it transitions from 0.1*(val1-val0)

to 0.9*(val1-val0) in rise seconds, 80 means from 0.2*(val1-val0) to 0.8*(val1-val0), etc. Possible values are 100, 90, 80, 70 and 60.

Noise Parameters

72 `noisefile` — Name of file containing excess spot noise data in the form of frequency-noise pairs. The noise can be specified as the spectral density in V^2/Hz, or as single-sideband phase noise in dBc. The parameter noisetype determines how Spectre interprets the noise data..

73 `noisevec=[...] A`^{2}`/Hz` — Excess spot noise as a function of frequency in the form of frequency-noise pairs. The parameter noisetype determines how Spectre interprets the noise data..

74 `noisetype=noisevoltage`
When set to noisevoltage, the noise data represents the noise spectral density in V^2/Hz. When set to ssbphasenoise, the noise data represesnets single-sideband phase noise in dBc. When set to noisevoltage, the frequencies are absolute. For ssbphasenoise, the frequencies are offset from carrier..
Possible values are `noisevoltage` and `ssbphasenoise`.

75 `noiseinterp=linear`
Determine how the specified noise data is interpolated. This parameter only applies to noisetype=noisevoltage. When set to linear, interpolation is linear over both axes. When set to loglog, Spectre uses log interpolation over both axes..
Possible values are `linear` and `loglog`.

76 `isnoisy=yes` — Should isource generate noise.
Possible values are `no` and `yes`.

Small signal parameters

77 `mag=0 A` — Small signal current.

78 `phase=0 ·` — Small signal phase.

79 `xfmag=1 A/A` — Transfer function analysis magnitude.

80 `pacmag=0 A` Periodic AC analysis magnitude.

81 `pacphase=0 ·` Periodic AC analysis phase.

Multiplication factor parameters

82 `m=1` Multiplicity factor.

Temperature effects parameters

83 `tc1=0 1/C` First order temperature coefficient.

84 `tc2=0` C^{-2} Second order temperature coefficient.

85 `tnom=27 C` Parameter measurement temperature. Default set by options.

86 `trise=0.0 C` Temperature rise from ambient.

If you do not specify the DC value, it is assumed to be the `time`=0 value of the waveform.

Sinusoidal waveform in the time interval `0<t<delay` has constant value equal to that at `t=delay`.

In DC analyses, the only active parameters are `dc`, `m`, and the temperature coefficient parameters. In AC analyses, the only active parameters are `m`, `mag` and `phase`. In transient analyses, all parameters are active except the small signal parameters and the noise parameters. The `type` parameter selects which type of waveform is generated. You may specify parameters for more than one waveform type, and use the alter statement to change the waveform type between analyses. There is one exception for type `bit`. You cannot change `bit` type to other types or other types to `bit`.

PWL Type Waveform

A vector of time-value pairs describes the piecewise linear waveform. As an alternative, you can read the waveform from a file. In this case, you give time-value pairs one pair per line with a space or tab between the time and the value.

If you set `allbrkpts` to `yes`, you force the simulator to place time points at each point specified in a PWL waveform during a transient analysis. This can be very expensive for waveforms with many points. If you set `allbrkpts` to `no`, Spectre inspects the waveform, looking for abrupt changes, and forces time points only at those changes.

The PWL waveform is periodic if you specify `pwlperiod` and/or `pwlperiodstart`. If both `pwlperiod` and `pwlperiodstart` are specified, `pwlperiod` should be longer than (`wavelength` - `pwlperiodstart`), where wavelength means the last time point. If only `pwlperiod` is specified and `pwlperiodstart` is undefined, then the period will start at first time point or (`wavelength` - `pwlperiod`), whichever is greater. If only `pwlperiodstart` is specified and `pwlperiod` is undefined, then the period will end at the last time point in the waveform vector. If the value of the waveform specified is not exactly the same at both the period beginning and the period end, then you must provide a nonzero value `twidth`. Before repeating, the waveform changes linearly in an interval of `twidth` from its value at (`period` - `twidth`) to its value at the beginning of the waveform. Thus, `twidth` must always be less than `period`.

Bit Type Waveform

Bit type waveform is the analog waveform of a series of digital logic state. It uses the pattern parameters to provide the digital state sequence, and some pulse waveform parameters to define the waveform characteristics.

To define the waveform characteristics, use parameters: val1, val0, rise, fall, and period. Note that parameter period here defines the length of a bit and it must be given. The general parameter delay can also be used for bit type to define the delay time from the beginning of the transient interval to the beginning of the first bit. The state during the delay time is the same as the first state specified in data.

Pattern parameters are used to specify the digital bit string. The pattern parameters of sources are the same as those of a pattern, except that you can specify `rpttimes` to a negative number for sources but not for patterns. Type `spectre -h pattern` for details on how to use pattern parameters.

PRBS Type Waveform

When `type=prbs`, the source emits a pseudo-random bit sequence. The sequence is defined by the LSB of a Fibonacci Linear Feedback Shift Register (LFSR) at trigger events.

The LFSR is initially loaded by a 'seed'. The value fed back to the input (MSB) is given by feedback=tap_1 ^ tap_2 ^...^ tap_N, where ^ represents an exclusive-or operation, and tap_i represents the i-th bit of the register, counting from 1 and starting from the MSB. At a trigger event, the LFSR is shifted to the right and the MSB is given by the 'feedback'.

LFSR Modes

The sequence can be defined by custom values of seeds and taps. Alternatively, you can specify a maximum length sequence by setting the length of the LFSR. To specify custom seeds and taps, use the lfsrseed and lfsrtaps arrays. To specify a maximum length sequence, use the parameter, registerlength=[2 ... 32]. Spectre sets the seeds and taps automatically. You can optionally set lfsrseed to override the automatically chosen seed.

Triggering Mode

By default, the sequence is triggered by an internal clock and pulses are emitted every 'period' seconds, excluding the optional jitter. Alternatively, you can apply an external clock to the optional 3rd and 4th terminals. In external trigger mode, the pulses are emitted when the clock crossed the specified threshold in the specified direction. The threshold is defined by the triggerthreshold parameter; the direction is specified by `triggerdirection`. In external trigger mode, jitter and bit period parameters are ignored.

Jitter

Let {s_i} be a sequence of ones and zeros whose transitions occur at intervals given by n*T + j(t), where T is the bit duration. Then, borrowing Verilog-A terminology, the jittered output is given by s(t+j(t)) = transition(s_i? Vhigh : Vlow, rise, fall). j(t) = rj(t) + pj(t), where rj (random jitter) is a normally distributed random variable whose mean is 0 and standard deviation is given by the parameter rjrms; and pj is the periodic jitter whose amplitude is pjamp and whose frequency is pjfreq. The parameter, pjtype, defines the type of jitter waveform. For sine, the periodic jitter is given by pj(t) = pjamp*cos(2*pi*pjfreq*t). Other types are square and sawtooth.

Noise of the source

You can give the excess noise of the source as a file or specify it with a vector of frequency-noise pairs. For a file, give the frequency-noise pairs one pair per line with a space or tab between the frequency and noise values.

Output Parameters

1 `tempeff (C)` Effective temperature for a single device.

Operating-Point Parameters

1 `i (A)` Current through the source.

2 `v (V)` Voltage across the source.

3 `pwr (W)` Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Polynomial Current Controlled Current Source (pcccs)

A vector of coefficients specifies the polynomial function that defines the relationship between the output current and the controlling currents. You must specify at least one coefficient.

This device is supported within altergroups.

For a polynomial in M variables a1, a2, ... am, the polynomial function F(a0,a1,...,am) is given by

F = c0 + c1 * a1 + c2 * a2 + ...

+ c(m+1) * a1^2 + c(m+2) * a1 * a2 +...

+ c(2m+1) * a2^2 + c(2m+2) * a2 * a3 +...

where the `c`s are coefficients of the polynomial terms.

Sample Instance Statement

```
vpc (net1 0) pcccs probes=[vb vc ve vlp vpn] coeffs=[0 8.8e6 -8.8e6 9e6 8e6 -9e6]
```

Instance Definition

```
Name  sink  src pcccs parameter=value ...
```

Instance Parameters

1 `m=1`	Multiplicity factor.
2 `gain=1`	Gain Parameter.
3 `probes=[...]`	Devices through which the controlling currents flow.
4 `mprobes=[...]`	The mprobes function the same as probes except that they will divide the input currents by the mfactor.
5 `ports=[...]`	Indices of the probe ports through which the controlling currents flow.
6 `coeffs=[...]`	Polynomial coefficients. At least one must be given.
7 `file`	File that contains nonzero polynomial coefficients.
8 `min (A)`	Minimum output current.
9 `max (A)`	Maximum output current.
10 `abs=off`	Absolute output current. Possible values are `off` or `on`.
11 `delta=0`	Smoothing parameter. This may lead to circuit convergence. The smaller the delta is, the sharper the corner is.

Temperature effects parameters

12 `tc1=0 1/C`	Linear temperature coefficient.
13 `tc2=0` C^{-2}	Quadratic temperature coefficient.

Operating-Point Parameters

1	`i (A)`	Output current.
2	`v (V)`	Output voltage.
3	`pwr (W)`	Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

abs	I-10	gain	I-2	min	I-8	pwr	OP-3
coeffs	I-6	i	OP-1	mprobes	I-4	tc1	I-12
delta	I-11	m	I-1	ports	I-5	tc2	I-13
file	I-7	max	I-9	probes	I-3	v	OP-2

Polynomial Voltage Controlled Current Source (pvccs)

A vector of coefficients specifies the polynomial function that defines the relationship between the output current and the controlling voltages. You must specify at least one coefficient. Current exits the source node and enters the sink node.

This device is supported within altergroups.

For a polynomial in M variables a1, a2, ... am, the polynomial function F(a0,a1,...,am) is given by

F = c0 + c1 * a1 + c2 * a2 + ...

+ c(m+1) * a1^2 + c(m+2) * a1 * a2 +...

+ c(2m+1) * a2^2 + c(2m+2) * a2 * a3 +...

where the `c`s are coefficients of the polynomial terms.

Sample Instance Statement

v2 (net1 0 net2 0) pvccs coeffs=[0 -2e-3 - 10e-3] gain=2 m=1

Instance Definition

```
Name  sink  src  ps1  ns1 ... pvccs parameter=value ...
```

Instance Parameters

1 `m=1`	Multiplicity factor.
2 `type=pvccs`	Type of the source. Possible values are `pvccs`, `vcr` or `vccap`.
3 `gain=1`	Gain Parameter.
4 `coeffs=[...]`	Polynomial coefficients. At least one must be given.
5 `file`	File that contains nonzero polynomial coefficients.
6 `min (A)`	Minimum output current.
7 `max (A)`	Maximum output current.
8 `abs=off`	Absolute output current. Possible values are `off` or `on`.
9 `delta=0`	Smoothing parameter. This may lead to circuit convergence. The smaller the delta is, the sharper the corner is.

Temperature effects parameters

10 `tc1=0 1/C`	Linear temperature coefficient.
11 `tc2=0` C^{-2}	Quadratic temperature coefficient.

Operating-Point Parameters

1 `i (A)`	Output current.
2 `v (V)`	Output voltage.
3 `pwr (W)`	Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.ss-Domain Linear Current Controlled Current Source (scccs)

abs I-8	gain I-3	min I-6	type I-2
coeffs I-4	i OP-1	pwr OP-3	v OP-2
delta I-9	m I-1	tc1 I-10	
file I-5	max I-7	tc2 I-11	

s-Domain Linear Current Controlled Current Source (scccs)

The device output is defined through a transfer function given as a ratio of two polynomials in the complex variable s. Polynomials can be specified in terms of either coefficients or roots. The roots of the numerator are the zeros of the transfer function and the roots of the denominator are the poles.

To specify the polynomial in terms of the coefficients, you enter them as a vector in ascending order of the power of the variable s, starting from the constant term. For example, to specify a denominator of 3s^2 + 4s + 1, use `denom=[1 4 3]`.

To specify a polynomial in terms of its roots, you give the roots as a vector of complex frequencies (frequencies should be in radians/second). You must give both the real and imaginary parts of the root, even when the root is real. For the transfer function to be stable, all poles must have negative real values. When specifying a complex root, you should also specify its complex conjugate. However, if you omit the conjugate root, Spectre will supply the missing root and print a warning that a missing root was supplied. The order of the roots is not important. For example, to specify poles of s = -1, s = 4j, s = -4j, s = -2 + 2j, and s = -2 - 2j; use `poles=[-1 0 0 4 0 -4 -2 2 -2 -2]`.

Either the numerator or the denominator specification can be omitted. An omitted denominator or numerator is taken to be 1.

Notes on gain and gainfactor

The parameter `gain` is interpreted either as the DC gain or, if the function has zeros or poles at the origin, as a constant factor. Note that `gain` has a default value of 1, so if you do not want to specify the DC gain, you should always use parameter `gainfactor` to disable parameter `gain`. When `gainfactor` is specified, `gain` is not valid any more. For example, if the instant statement is:

s1 (1 0 control 0) svcvs numer=[1 2] denom=[3 4]

the transfer function will be 2*(2s+1)/(4s+3). Factor 2 is applied to make the DC gain of the transfer function to be 1. If you just want the transfer function to be (2s+1)/(4s+3), specify `gainfactor=1` to disable the default value of `gain`. In this example, the statement will be:

s1 (1 0 control 0) svcvs numer=[1 2] denom=[3 4] gainfactor=1

where the transfer function is 1*(2s+1)/(4s+3). 1 is the gainfactor.

This device is not supported within altergroup.

Sample Instance Statement

I1 (2 1) inductor l=15

sc1 (1 0) scccs probe=I1 zeros=[0 6 0 -6 2 -8 2 8] poles=[-1 0 0 64 0 -64 -2 8 -2 -8]

Instance Definition

```
Name  sink  src scccs parameter=value ...
```

Instance Parameters

1 `probe` Device through which the controlling current flows.

2 `mprobe`	The mprobe functions the same as probe except that it will divide the input current by the mfactor.
3 `port=0`	Index of the probe port through which the controlling current flows.
4 `gain=1`	DC gain or constant transfer function factor. See `notes on gain and gainfactor` for details.
5 `gainfactor`	Constant factor applied to transfer function. It disables the parameter gain.
6 `numer=[...]`	Vector of numerator coefficients.
7 `denom=[...]`	Vector of denominator coefficients.
8 `zeros=[...]`	Vector of complex zeros.
9 `poles=[...]`	Vector of complex poles.
10 `m=1`	Multiplicity factor.
11 `tc1=0 1/C`	Linear temperature coefficient.
12 `tc2=0` C^{-2}	Quadratic temperature coefficient.

Operating-Point Parameters

1 `i (A)`	Input current.
2 `v (V)`	Output voltage.
3 `pwr (W)`	Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

s-Domain Linear Voltage Controlled Current Source (svccs)

The device output is defined through a transfer function given as a ratio of two polynomials in the complex variable s. Polynomials can be specified in terms of either coefficients or roots. The roots of the numerator are the zeros of the transfer function and the roots of the denominator are the poles.

To specify the polynomial in terms of the coefficients, you enter them as a vector in ascending order of the power of the variable s, starting from the constant term. For example, to specify a denominator of 3s^2 + 4s + 1, use `denom=[1 4 3]`.

To specify a polynomial in terms of its roots, you give the roots as a vector of complex frequencies (frequencies should be in radians/second). You must give both the real and imaginary parts of the root, even when the root is real. For the transfer function to be stable, all poles must have negative real values. When specifying a complex root, you should also specify its complex conjugate. However, if you omit the conjugate root, Spectre will supply the missing root and print a warning that a missing root was supplied. The order of the roots is not important. For example, to specify poles of s = -1, s = 4j, s = -4j, s = -2 + 2j, and s = -2 - 2j; use `poles=[-1 0 0 4 0 -4 -2 2 -2 -2]`.

Either the numerator or the denominator specification can be omitted. An omitted denominator or numerator is taken to be 1.

Notes on gain and gainfactor

The parameter `gain` is interpreted either as the DC gain or, if the function has zeros or poles at the origin, as a constant factor. Note that `gain` has a default value of 1, so if you do not want to specify the DC gain, you should always use parameter `gainfactor` to disable parameter `gain`. When `gainfactor` is specified, `gain` is not valid any more. For example, if the instant statement is:

s1 (1 0 control 0) svccs numer=[1 2] denom=[3 4]

the transfer function will be 2*(2s+1)/(4s+3). Factor 2 is applied to make the DC gain of the transfer function to be 1. If you just want the transfer function to be (2s+1)/(4s+3), specify `gainfactor=1` to disable the default value of `gain`. In this example, the statement will be:

s1 (1 0 control 0) svccs numer=[1 2] denom=[3 4] gainfactor=1

where the transfer function is 1*(2s+1)/(4s+3). 1 is the gainfactor.

This device is not supported within altergroup.

Sample Instance Statement

```
s2 (1 0 control 0) svccs gain=0.4 numer=[2 3] denom=[4 5 1]
```

Instance Definition

```
Name  sink  src  ps  ns svccs parameter=value ...
```

Instance Parameters

1	`gain=1`	DC gain or constant transfer function factor. See `notes on gain and gainfactor` for details.
2	`gainfactor`	Constant factor applied to transfer function. It disables the parameter gain.
3	`numer=[...]`	Vector of numerator coefficients.
4	`denom=[...]`	Vector of denominator coefficients.
5	`zeros=[...]`	Vector of complex zeros.
6	`poles=[...]`	Vector of complex poles.
7	`m=1`	Multiplicity factor.
8	`tc1=0 1/C`	Linear temperature coefficient.
9	`tc2=0` C^{-2}	Quadratic temperature coefficient.

Operating-Point Parameters

1	`i (A)`	Output current.

2 `v (V)` Output voltage.

3 `pwr (W)` Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

denom I-4	i OP-1	poles I-6	tc2 I-9
gain I-1	m I-7	pwr OP-3	v OP-2
gainfactor I-2	numer I-3	tc1 I-8	zeros I-5

Linear Voltage Controlled Current Source (vccs)

Positive current exits the source node and enters the sink node.

This device can also model ideal digital gates, voltage controlled resistors and voltage controlled capacitors.

Type of vccs:

You can use vccs to model three types of devices.

When `type=vccs`, the device is a regular voltage controlled current source. This is also the default type.When `type=vcr`, the device is a voltage controlled resistor. When `type=vccap`, the device is a voltage controlled capacitor.

Input type of vccs:

You can use vccs to model ideal digital gates. Ideal digital gates have more than one inputs. The parameter `inputtype` is used to specify which input is going to control the vccs (or vcr, or vccap, specified by parameter type).

When `inputtype=single`, the device has only one input. This is also the default `inputtype`. When `inputtype=and/nand`, the smallest input controls the device. When `inputtype=or/nor`, the largest input controls the device. When `inputtype=npwl`, node ns should be connected to either src or sink. if v(src,sink)>0, then the controlling voltage would be v(ps,sink). Otherwise, the controlling voltage is v(ps,src). When `inputtype=ppwl`, node ns should be connected to either src or sink. if v(src,sink)>0, then the controlling voltage would be v(ps,src). Otherwise, the controlling voltage is v(ps,sink). If `inputtype` is `npwl` or `ppwl` but node ns is not connected to src or sink, then spectre change `inputtype` to `pwl`.

When you are using regular vccs, you can specify and/nand/or/nor in either type parameter of `inputtype` parameter. Please also note that spectre does not check if the gate behaves like an and or an nand, it just take the smallest input as the controlling voltage. And so is the case for or/nor.

This device is supported within altergroups.

Sample Instance Statement

```
v1 (1 0 2 3) gm=-1 m=2
```

Instance Definition

```
Name  sink  src  ps  ns ... vccs parameter=value ...
```

Instance Parameters

1 `m=1`	Multiplicity factor.
2 `type=vccs`	Type of the source. Possible values are `vccs`, `vcr`, `vccap`, `and`, `nand`, `or`, `nor`, or `vcrspice`.
3 `inputtype=single`	Type of the input of the source. Possible values are `single`, `and`, `nand`, `or`, `nor`, `npwl`, or `ppwl`.
4 `delta=0`	Smoothing parameter. This may lead to circuit convergence. Its value should be in the range between 0 and 0.5, both ends included. The smaller the delta is, the sharper the corner is.

Linear source parameters

5 `gm=0 S`	Transconductance.

6 `td=0.0 s` Time delay.

7 `min (A)` Minimum output current.

8 `max (A)` Maximum output current.

9 `abs=off` Output current is absolute value if abs is set to on. Possible values are `off` or `on`.

PWL source parameters

10 `file` Name of file containing voltage/current pairs that define the PWL transfer function.

11 `pwl=[...]` Vector of voltage/current pairs that defines the PWL transfer function. The format of the vector is [in1 out1 in2 out2 ...].

12 `scale=1` Scale factor for the PWL output current.

13 `stretch=1` Scale factor for the PWL controlling voltage.

14 `logslope=1e3` Used for PWL VCR only. If the slope between PWL points is larger than logslope, then log scale interpolation is used between the points.

Temperature effects parameters

15 `tc1=0 1/C` Linear temperature coefficient.

16 `tc2=0` C^{-2} Quadratic temperature coefficient.

The Smoothing Factor:

The parameter delta is the smoothing factor. When it is nonzero, a curve is introduced to smooth the corner. The value of delta defines the position of the starting and ending points of the curve that is used to smooth the corner. The minimum value 0 means no smoothing curve is introduced. The maximum value 0.5 means the distance between the starting point of the curve and the corner point is half of the shortest distance. The shortest distance is the length of the shortest segment of the piecewise linear function. Or, when there is no shortest segment in the controlling function, i.e. only abs=on is specified, spectre uses 1 as the shortest distance.

Operating-Point Parameters

1 `i (A)` Output current.

2 `v (V)` Output voltage.

3 `pwr (W)` Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

abs I-9	inputtype I-3	pwl I-11	tc2 I-16
delta I-4	logslope I-14	pwr OP-3	td I-6
file I-10	m I-1	scale I-12	type I-2
gm I-5	max I-8	stretch I-13	v OP-2
i OP-1	min I-7	tc1 I-15	

z-Domain Linear Current Controlled Current Source (zcccs)

The output is defined with a transfer function given as the ratio of two polynomials in the complex variable z. Each polynomial can be specified using either its coefficients or its roots. The roots of the numerator are the zeros of the transfer function and the roots of the denominator are the poles.

You may specify polynomials either in the complex variable z or 1/z by setting optional parameter `polyarg` to `z` or `inversez` respectively. By default, it is set to `inversez`. If you choose to provide the coefficients of a polynomial, enter them as a vector in ascending order of the power of the variable z or 1/z, starting from the constant term. For example, to specify a denominator of 3z^-2 + 4z^-1 + 1, use `denom=[1 4 3]`. Or to specify a denominator of 4z^2 + 3z - 2, use `polyarg=z denom=[2 3 4]`.

To specify transfer function in terms of its zeros and poles in z-plane, give them as vectors of complex numbers. You must always give the real and imaginary portions of the root, even when the root is real. You may give either both roots of a complex-conjugate pair or only one. In the latter case the conjugate complex root will be generated automatically. The order of the roots is not important. For example, to specify poles of z = 1, z = 4j, z = -4j, z = 2 + 2j, and z = 2 - 2j, use `poles=[1 0 0 4 0 -4 2 2 2 -2]` or, omitting conjugate poles, `poles=[1 0 0 4 2 2 ]`.

Either the numerator or the denominator specification can be omitted. An omitted denominator or numerator is taken to be 1.

Transition time (`tt`) is an optional parameter that at each sampling point forces linear transition of the output to a new value within the specified time range. By default, it is set to one percent of the sampling period.

The sampling delay (`td`) is another optional parameter, with the default value of 0, that lets you set asynchronous sampling rates.

To use the `s` to `z` transformation, set the optional `sxz` parameter to one of the transformation methods - forward differences, backward differences, or bilinear. When the `sxz` parameter is specified, the transfer function specification is assumed to be given in the complex variable s and it will be transformed to the complex variable z using the indicated method.

Notes on gain and gainfactor

The parameter `gain` is interpreted either as the DC gain or, if the function has zeros or poles at the origin, as a constant factor. Note that `gain` has a default value of 1, so if you do not want to specify the DC gain, you should always use parameter `gainfactor` to disable parameter `gain`. When `gainfactor` is specified, `gain` is not valid any more. For example, if the instant statement is:

s1 (1 0 control 0) svcvs numer=[1 2] denom=[3 4]

the transfer function will be 2*(2s+1)/(4s+3). Factor 2 is applied to make the DC gain of the transfer function to be 1. If you just want the transfer function to be (2s+1)/(4s+3), specify `gainfactor=1` to disable the default value of `gain`. In this example, the statement will be:

s1 (1 0 control 0) svcvs numer=[1 2] denom=[3 4] gainfactor=1

where the transfer function is 1*(2s+1)/(4s+3). 1 is the gainfactor.

This device is not supported within altergroup.

Sample Instance Statement

```
va (1 0) vsource type=sine freq=10K
z2 (2 0) zcccs probe=va gain=1 ts=4.9e-5 tt=1e-5 polyarg=inservez
numer=[1 -1] denom=[1 0]
```

Instance Definition

```
Name  sink  src zcccs parameter=value ...
```

Instance Parameters

1 `probe`	Device through which the controlling current flows.
2 `mprobe`	The mprobe functions the same as probe except that it will divide the input current by the mfactor.
3 `port=0`	Index of the probe port through which the controlling current flows.
4 `ts=1 s`	Sampling period.
5 `td=0 s`	Sampling delay.
6 `tt=0.01 ts s`	Transition time.
7 `gain=1`	DC gain or constant transfer function factor. See `notes on gain and gainfactor` for details.
8 `gainfactor`	Factor applied to transfer function. It overwrites the parameter gain.
9 `polyarg=inversez`	Polynomial argument. Possible values are `z` or `inversez`.
10 `sxz=none`	s to z transformation. Possible values are `none`, `backward`, `forward`, or `bilinear`.
11 `numer=[...]`	Vector of numerator coefficients.
12 `denom=[...]`	Vector of denominator coefficients.
13 `zeros=[...]`	Vector of complex zeros.

14 `poles=[...]` Vector of complex poles.

15 `m=1` Multiplicity factor.

16 `tc1=0 1/C` Linear temperature coefficient.

17 `tc2=0 C`$^{-2}$ Quadratic temperature coefficient.

Operating-Point Parameters

1 `i (A)` Input current.

2 `v (V)` Output voltage.

3 `pwr (W)` Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

denom I-12	mprobe I-2	probe I-1	td I-5
gain I-7	numer I-11	pwr OP-3	ts I-4
gainfactor I-8	poles I-14	sxz I-10	tt I-6
i OP-1	polyarg I-9	tc1 I-16	v OP-2
m I-15	port I-3	tc2 I-17	zeros I-13

z-Domain Linear Voltage Controlled Current Source (zvccs)

The output is defined with a transfer function given as the ratio of two polynomials in the complex variable z. Each polynomial can be specified using either its coefficients or its roots.

The roots of the numerator are the zeros of the transfer function and the roots of the denominator are the poles.

You may specify polynomials either in the complex variable z or 1/z by setting optional parameter `polyarg` to `z` or `inversez` respectively. By default, it is set to `inversez`. If you choose to provide the coefficients of a polynomial, enter them as a vector in ascending order of the power of the variable z or 1/z, starting from the constant term. For example, to specify a denominator of 3z^-2 + 4z^-1 + 1, use `denom=[1 4 3]`. Or to specify a denominator of 4z^2 + 3z - 2, use `polyarg=z denom=[2 3 4]`.

To specify transfer function in terms of its zeros and poles in z-plane, give them as vectors of complex numbers. You must always give the real and imaginary portions of the root, even when the root is real. You may give either both roots of a complex-conjugate pair or only one. In the latter case the conjugate complex root will be generated automatically. The order of the roots is not important. For example, to specify poles of z = 1, z = 4j, z = -4j, z = 2 + 2j, and z = 2 - 2j, use `poles=[1 0 0 4 0 -4 2 2 2 -2]` or, omitting conjugate poles, `poles=[1 0 0 4 2 2 ]`.

Either the numerator or the denominator specification can be omitted. An omitted denominator or numerator is taken to be 1.

Transition time (`tt`) is an optional parameter that at each sampling point forces linear transition of the output to a new value within the specified time range. By default, it is set to one percent of the sampling period.

The sampling delay (`td`) is another optional parameter, with the default value of 0, that lets you set asynchronous sampling rates.

To use the `s` to `z` transformation, set the optional `sxz` parameter to one of the transformation methods - forward differences, backward differences, or bilinear. When the `sxz` parameter is specified, the transfer function specification is assumed to be given in the complex variable s and it will be transformed to the complex variable z using the indicated method.

Notes on gain and gainfactor

The parameter `gain` is interpreted either as the DC gain or, if the function has zeros or poles at the origin, as a constant factor. Note that `gain` has a default value of 1, so if you do not want to specify the DC gain, you should always use parameter `gainfactor` to disable parameter `gain`. When `gainfactor` is specified, `gain` is not valid any more. For example, if the instant statement is:

s1 (1 0 control 0) svcvs numer=[1 2] denom=[3 4]

the transfer function will be 2*(2s+1)/(4s+3). Factor 2 is applied to make the DC gain of the transfer function to be 1. If you just want the transfer function to be (2s+1)/(4s+3), specify `gainfactor=1` to disable the default value of `gain`. In this example, the statement will be:

s1 (1 0 control 0) svcvs numer=[1 2] denom=[3 4] gainfactor=1

where the transfer function is 1*(2s+1)/(4s+3). 1 is the gainfactor.

This device is not supported within altergroup.

Sample Instance Statement:

va (1 0) vsource type=sine freq=10K

z1 (2 0 1 0) zvccs gain=2 ts=4.5e-5 tt=1e-5 zeros=[-1 0] poles=[0 0]

Instance Definition

Name sink src ps ns zvccs parameter=value ...

Instance Parameters

1	`ts=1 s`	Sampling period.
2	`td=0 s`	Sampling delay.
3	`tt=0.01 ts s`	Transition time.
4	`gain=1`	DC gain or constant transfer function factor. See `notes on gain and gainfactor` for details.
5	`gainfactor`	Factor applied to transfer function. It overwrites the parameter gain.
6	`polyarg=inversez`	Polynomial argument. Possible values are `z` or `inversez`.

7 `sxz=none`	s to z transformation. Possible values are `none`, `backward`, `forward`, or `bilinear`.
8 `numer=[...]`	Vector of numerator coefficients.
9 `denom=[...]`	Vector of denominator coefficients.
10 `zeros=[...]`	Vector of complex zeros.
11 `poles=[...]`	Vector of complex poles.
12 `m=1`	Multiplicity factor.
13 `tc1=0 1/C`	Linear temperature coefficient.
14 `tc2=0` C^{-2}	Quadratic temperature coefficient.

Operating-Point Parameters

1 `i (A)`	Output current.
2 `v (V)`	Output voltage.
3 `pwr (W)`	Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

i	OP-1	pwr	OP-3	ts	I-1
m	I-12	sxz	I-7	tt	I-3

Voltage Sources

Polynomial Current Controlled Voltage Source (pccvs)

The polynomial function defining the relationship between the output voltage and the controlling currents is specified by a vector of coefficients. At least one coefficient must always be specified. Current through the voltage source is calculated and is defined to be positive if it flows from the positive terminal, through the source, to the negative terminal.

This device is supported within altergroups.

For a polynomial in M variables a1, a2, ... am, the polynomial function F(a0,a1,...,am) is given by

F = c0 + c1 * a1 + c2 * a2 + ...

+ c(m+1) * a1^2 + c(m+2) * a1 * a2 +...

+ c(2m+1) * a2^2 + c(2m+2) * a2 * a3 +...

where the `c`s are coefficients of the polynomial terms.

Sample Instance Statement

```
ixy (net1 0) pccvs coeffs=[0 1 0 1] probes=[vin1 vin2] gain=2
```

Instance Definition

```
Name  p  n pccvs parameter=value ...
```

Instance Parameters

1 `m=1` Multiplicity factor.

2 `gain=1` Gain Parameter.

3 `probes=[...]`	Devices through which the controlling currents flow.
4 `mprobes=[...]`	The mprobes function the same as probes except that they will divide the input currents by the mfactor.
5 `ports=[...]`	Indices of the probe ports through which the controlling currents flow.
6 `coeffs=[...]`	Polynomial coefficients. At least one must be given.
7 `file`	File that contains nonzero polynomial coefficients.
8 `min (V)`	Minimum output voltage.
9 `max (V)`	Maximum output voltage.
10 `abs=off`	Absolute output voltage. Possible values are `off` or `on`.
11 `delta=0`	Smoothing parameter. This may lead to circuit convergence. The smaller the delta is, the sharper the corner is.

Temperature effects parameters

12 `tc1=0 1/C`	Linear temperature coefficient.
13 `tc2=0` C^{-2}	Quadratic temperature coefficient.

Operating-Point Parameters

1 `i (A)`	Output current.
2 `v (V)`	Output voltage.
3 `pwr (W)`	Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the

description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

abs I-10	gain I-2	min I-8	pwr OP-3
coeffs I-6	i OP-1	mprobes I-4	tc1 I-12
delta I-11	m I-1	ports I-5	tc2 I-13
file I-7	max I-9	probes I-3	v OP-2

Polynomial Voltage Controlled Voltage Source (pvcvs)

A vector of coefficients specifies the polynomial function that defines the relationship between the output voltage and the controlling voltages. You must specify at least one coefficient. Current through the voltage source is calculated and is defined to be positive if it flows from the positive terminal, through the source, to the negative terminal.

This device is supported within altergroups.

For a polynomial in M variables a1, a2, ... am, the polynomial function F(a0,a1,...,am) is given by

F = c0 + c1 * a1 + c2 * a2 + ...

+ c(m+1) * a1^2 + c(m+2) * a1 * a2 +...

+ c(2m+1) * a2^2 + c(2m+2) * a2 * a3 +...

where the `c`s are coefficients of the polynomial terms.

Sample Instance Statement

```
v1 (p 0 c1 0) pvcvs coeffs=[0 0 0 0.1 1 1] gain=1
```

Instance Definition

```
Name  p  n  ps1  ns1 ... pvcvs parameter=value ...
```

Instance Parameters

1 `m=1`	Multiplicity factor.
2 `gain=1`	Gain Parameter.
3 `coeffs=[...]`	Polynomial coefficients. At least one must be given.
4 `file`	File that contains nonzero polynomial coefficients.
5 `min (V)`	Minimum output voltage.
6 `max (V)`	Maximum output voltage.
7 `abs=off`	Absolute output voltage. Possible values are `off` or `on`.
8 `delta=0`	Smoothing parameter. This may lead to circuit convergence. The smaller the delta is, the sharper the corner is.

Temperature effects parameters

9 `tc1=0 1/C`	Linear temperature coefficient.
10 `tc2=0` C^{-2}	Quadratic temperature coefficient.

Operating-Point Parameters

1 `i (A)`	Output current.
2 `v (V)`	Output voltage.
3 `pwr (W)`	Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

s-Domain Voltage Controlled Voltage Source (svcvs)

The device output is defined through a transfer function given as a ratio of two polynomials in the complex variable s. Polynomials can be specified in terms of either coefficients or roots. The roots of the numerator are the zeros of the transfer function and the roots of the denominator are the poles.

To specify the polynomial in terms of the coefficients, you enter them as a vector in ascending order of the power of the variable s, starting from the constant term. For example, to specify a denominator of 3s^2 + 4s + 1, use `denom=[1 4 3]`.

To specify a polynomial in terms of its roots, you give the roots as a vector of complex frequencies (frequencies should be in radians/second). You must give both the real and imaginary parts of the root, even when the root is real. For the transfer function to be stable, all poles must have negative real values. When specifying a complex root, you should also specify its complex conjugate. However, if you omit the conjugate root, Spectre will supply the missing root and print a warning that a missing root was supplied. The order of the roots is not important. For example, to specify poles of s = -1, s = 4j, s = -4j, s = -2 + 2j, and s = -2 - 2j; use `poles=[-1 0 0 4 0 -4 -2 2 -2 -2]`.

Either the numerator or the denominator specification can be omitted. An omitted denominator or numerator is taken to be 1.

Notes on gain and gainfactor

The parameter `gain` is interpreted either as the DC gain or, if the function has zeros or poles at the origin, as a constant factor. Note that `gain` has a default value of 1, so if you do not want to specify the DC gain, you should always use parameter `gainfactor` to disable parameter `gain`. When `gainfactor` is specified, `gain` is not valid any more. For example, if the instant statement is:

s1 (1 0 control 0) svcvs numer=[1 2] denom=[3 4]

the transfer function will be 3*(2s+1)/(4s+3). Factor 3 is applied to make the DC gain of the transfer function to be 1. If you just want the transfer function to be (2s+1)/(4s+3), specify `gainfactor=1` to disable the default value of `gain`. In this example, the statement will be:

s1 (1 0 control 0) svcvs numer=[1 2] denom=[3 4] gainfactor=1

where the transfer function is 1*(2s+1)/(4s+3). 1 is the gainfactor.

This device is not supported within altergroup.

Sample Instance Statement

```
e1 (1 0 control 0) svcvs gain=5 poles=[-1 0 1 0] zero=[0 0 1 0]
```

Instance Definition

```
Name  p  n  ps  ns svcvs parameter=value ...
```

Instance Parameters

1	`gain=1`	DC gain or constant transfer function factor. See `notes on gain and gainfactor` for details.
2	`gainfactor`	Factor applied to transfer function. It disables the parameter gain.
3	`numer=[...]`	Vector of numerator coefficients.
4	`denom=[...]`	Vector of denominator coefficients.
5	`zeros=[...]`	Vector of complex zeros.
6	`poles=[...]`	Vector of complex poles.
7	`m=1`	Multiplicity factor.
8	`tc1=0 1/C`	Linear temperature coefficient.
9	`tc2=0` C^{-2}	Quadratic temperature coefficient.

Operating-Point Parameters

1	`i (A)`	Output current.

2 `v (V)` Output voltage.

3 `pwr (W)` Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

denom I-4	i OP-1	poles I-6	tc2 I-9
gain I-1	m I-7	pwr OP-3	v OP-2
gainfactor I-2	numer I-3	tc1 I-8	zeros I-5

Linear Voltage Controlled Voltage Source (vcvs)

Current through the voltage source is calculated and is defined to be positive if it flows from the positive terminal, through the source, to the negative terminal.

This device can also model ideal digital gates.

This device is supported within altergroups.

Sample Instance Statement

```
e1 (out1 0 pos neg) vcvs gain=10
```

Instance Definition

```
Name  p  n  ps  ns ... vcvs parameter=value ...
```

Instance Parameters

1 `m=1` Multiplicity factor.

2 `type=vcvs` — Type of the source.
Possible values are `vcvs`, `and`, `nand`, `or`, or `nor`.

3 `delta=0` — Smoothing parameter. This may lead to circuit convergence. Its value should be in the range between 0 and 0.5, both ends included. The smaller the delta is, the sharper the corner is.

Linear source parameters

4 `gain=0 V/V` — Voltage gain.

5 `td=0.0 s` — Time delay.

6 `min (V)` — Minimum output voltage.

7 `max (V)` — Maximum output voltage.

8 `abs=off` — Output voltage is absolute value if `abs` is set to on.
Possible values are `off` or `on`.

PWL source parameters

9 `file` — Name of file containing voltage/voltage pairs that define the PWL transfer function.

10 `pwl=[...]` — Vector of voltage/voltage pairs that defines the PWL transfer function. The format of the vector is [in1 out1 in2 out2 ...].

11 `scale=1` — Scale factor for the PWL output voltage.

12 `stretch=1` — Scale factor for the PWL controlling voltage.

Temperature effects parameters

13 `tc1=0 1/C` — Linear temperature coefficient.

14 `tc2=0` C^{-2} — Quadratic temperature coefficient.

The Smoothing Factor

The parameter delta is the smoothing factor. When it is nonzero, a curve is introduced to smooth the corner. The value of delta defines the position of the starting and ending points of the curve that is used to smooth the corner. The minimum value 0 means no smoothing curve is introduced. The maximum value 0.5 means the distance between the starting point of the curve and the corner point is half of the shortest distance. The shortest distance is the length of the shortest segment of the piecewise linear function. Or, when there is no shortest segment in the controlling function, i.e. only `abs=on` is specified, spectre uses 1 as the shortest distance.

Operating-Point Parameters

1 `i (A)`	Output current.
2 `v (V)`	Output voltage.
3 `pwr (W)`	Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Independent Voltage Source (vsource)

Current through the source is computed and is defined to be positive if it flows from the positive node, through the source, to the negative node.

This device is supported within altergroups.

The value of the DC voltage as a function of the temperature is given by:

V(T) = V(tnom) * [1 + tc1 * (T - tnom) + tc2 * (T - tnom)^2].

Sample Instance Statement

```
vpulse1 (1 0) vsource type=pulse val0=0 val1=5 period=100n rise=10n fall=10n
width=40n
vpwl1 (1 0) vsource type=pwl wave=[1n 0 1.1n 2 1.5n 0.5 2n 3 5n 5] pwlperiod=5n
vpwlz1 (1 0) vsource type=pwlz wave=[1n 0 1.1n z 1.5n 0.5 2n z 5n 5] pwlperiod=5n
```

Instance Definition

```
Name  p  n vsource parameter=value ...
```

Instance Parameters

1 `dc=0 V`	DC value.

General waveform parameters

2 `type=dc`	Waveform type. Possible values are `dc`, `pulse`, `pwl`, `sine`, `exp`, `bit`, `prbs`, `pwlz`, and `sigbus`.
3 `fundname`	Name of the fundamental frequency. Must be specified if the source is active during a pdisto analysis or it is the active clock during an envlp analysis.
4 `delay=0 s`	Waveform delay time.
5 `edgetype=linear`	Type of the rising and falling edges. This is for pulse waveform and pulse-like piecewise linear waveform. Possible values are `linear` and `halfsine`.

Pulse waveform parameters

6 `val0=0 V`	Zero value used in pulse and exponential waveforms.
7 `val1=1 V`	One value used in pulse and exponential waveforms.

8 `period=∞ s` Period of waveform.

9 `rise (s)` Rise time for pulse waveform (time for transition from `val0` to `val1`). If parameter rise is not given, then the rise time will be the same as fall time; if fall time is not given either, then the rise time will be 1/100 of the waveform period; if the waveform is not periodic, then the rise time will be 1/100 of the simulation interval.

10 `fall (s)` Fall time for pulse waveform (time for transition from `val1` to `val0`). If parameter fall is not given, then the fall time will be the same as rise time; if rise time is not given either, then the fall time will be 1/100 of the waveform period; if the waveform is not periodic, then the fall time will be 1/100 of the simulation interval.

11 `width=∞ s` Pulse width (duration of `val1`).

PWL waveform parameters

12 `file` Name of file containing waveform.

13 `wave=[...]` Vector of time/value pairs that defines waveform.

14 `offset=0 V` DC offset for the PWL waveform.

15 `scale=1` Scale factor for the PWL waveform.

16 `stretch=1` Scale factor for time given for the PWL waveform.

17 `rms` Desired rms (root of mean square) value of the PWL waveform.

18 `pwlfilter=none` Add filter to pwl source, where the pwl data should be equal space sampled. Possible values are 'nrc'(normal raised cosine filter) and 'none'.
Possible values are `none` and `nrc`.

19 `rolloff` Desired rolloff factor for the raised cosine filter, default value is 0.2. Only valid when 'pwlfilter' is set to nrc.

20 `pwlbandwidth` Bandwidth of the pwl input signal. Be used when 'pwlfilter' is set to nrc.

21 `allbrkpts` — All the points in the PWL waveform are breakpoints if set to yes. Default is yes if the number of points is less than 20. Possible values are `no` and `yes`.

22 `pwlperiod (s)` — Period of the periodic PWL waveform.

23 `pwlperiodstart (s)` — Period start time of the periodic PWL waveform.

24 `twidth=pwlperiod/1000 s`
Transition width used when making PWL waveforms periodic.

25 `highz=1e12` — The impedance of high z state.

26 `min_z_transition_width=10e-12 s`
Minimum width of transition from z-state to non z-state. The width of transition is set as 1e-3*(z-sate duration).

Sinusoidal waveform parameters

27 `sinedc=dc V` — DC level for sinusoidal waveforms.

28 `ampl=1 V` — amplitude of sinusoidal waveform.

29 `freq=0 Hz` — Frequency of sinusoidal waveform.

30 `sinephase=0 °` — Phase of sinusoid when `t=delay`.

31 `ampl2=1 V` — amplitude of second sinusoidal waveform.

32 `freq2=0 Hz` — Frequency of second sinusoidal waveform.

33 `sinephase2=0 °` — Phase of second sinusoid when `t=delay`.

34 `fundname2` — Name of the fundamental frequency associated with freq2. Must be specified if freq2 is used in a pdisto analysis.

35 `iqmodfiles=[...]` — Two file names which containing pwl I/Q source waveform.

36 `fmmodindex=0` — FM index of modulation for sinusoidal waveform.

37 `fmmodfreq=0 Hz` — FM modulation frequency for sinusoidal waveform.

38 `fmmodfiles=[...]`	One or two file names: containing FM waveform for one file case, and FM I/Q signals for two files with I file first.
39 `ammodindex=0`	AM index of modulation for sinusoidal waveform.
40 `ammodoffset=1`	AM offset of modulation for sinusoidal waveform.
41 `ammodfreq=0 Hz`	AM modulation frequency for sinusoidal waveform.
42 `ammodphase=0 °`	AM phase of modulation for sinusoidal waveform.
43 `damp=0 1/s`	Damping factor for sinusoidal waveform.
44 `freqvec=[...] Hz`	Vector of support frequency of sinusoidal channel source.
45 `amplvec=[...] V`	Vector of amplitude of sinusoidal channel source.
46 `phasevec=[...] °`	Vector of phase of sinusoidal channel source.
47 `maxharms=[...]`	Array of number of harmonics of each frequency.

Exponential waveform parameters

48 `td1=0 s`	Rise start time for exponential wave.
49 `tau1 (s)`	Rise time constant for exponential wave.
50 `td2 (s)`	Fall start time for exponential wave.
51 `tau2 (s)`	Fall time constant for exponential wave.
52 `expperiod (s)`	Period of the periodic EXP waveform.

Pattern parameters

53 `data`	The bit string. A string that contains a series of the four states, 1 0 m z. For prbs, it can contain only 0 and 1, and m, z is not supported.
54 `rptstart=1`	The starting bit when repeating. The data repeats from the specified bit to the end of the bit string. The parameter should be an integer from 1 to the length of the bit string.

55 `rpttimes=0` — The repeat times. The output will maintain the state of the last bit after the last repeat. If its value is negative, the string repeats forever.

Prbs parameters

56 `ref (V)` — Sets the crossing reference for the control node. This parameter applies only when the Prbs source operates as a 3 or 4 terminal device. When the voltage across terminals 3 and 4 drops below ref, the output of the source is set to 0. If terminal 4 is not specified, it is assumed to be connected to ground.

57 `jitter (s)` — The parameter jitter is obsolete. It has no effect on the output.

58 `rjseed=1` — The seed for random number generator, used in generating random jitter for PRBS sources. The default value is 1.

59 `rjrms (s)` — When set for PRBS source or Bit source, the source has a normally distributed random jitter, whose mean is zero and whose standard deviation is rjrms.

60 `pjamp=[...] s` — When set for PRBS source or Bit source, the source has multiple periodic jitters, whose amplitudes are defined by pjamp and frequencies are defined by pjfreq.

61 `pjfreq=[...] Hz` — When set for PRBS source or Bit source, the source has multiple periodic jitters, whose amplitudes are defined by pjamp and whose frequency are defined by pjfreq.

62 `pjtype="sine"` — For PRBS source or Bit source, pjtype defines the types of periodic jitters. Possible valudes are 'sine', 'sawtooth', or 'square'.

63 `seed` — This parameter is obsolete but retained for backward compatability. Set registerlength=[2 ... 32] to choose a Maximum Length Sequence or define a custom PRBS by use of the parameters, lfsrtaps and lfsrseed.

64 `taps=[...]` — The use of taps is discouraged. For PRBS, taps is an integer array which sets the locations of the LFSR taps. Please use lfsrtaps instead. Please see the section, 'PRBS Type Waveform' below for details of the PRBS operation.

65 `lfsrtaps=[...]` For PRBS source, lfsrtaps is an integer array which sets the location of LFSR taps. Locations are 1-based and ordered form MSB to LSB of the LFSR. The largest element of the taps array is equal to the width of the LFSR. Please see the section, 'PRBS Type Waveform' for details of PRBS source operation.

66 `lfsrseed=[...]` For PRBS source, lfsrseed is an integer array which sets the initial state of the LFSR. Array elements sets the locations of non-zero bits. Locations are 1-based and ordered from MSB to LSB of the LFSR. For example, assume lfsrtaps=[6] and lfsrseed=[1 3 5]. The width of the register is then 6 bits and the initial state is '101010'.

67 `registerlength` When set for PRBS, the registerlength defines the width of the LFSR and the LFSR works in Maximum Length Sequence mode. Please see the section 'PRBS Type Waveform' below for details of MLS setting.

68 `triggerthreshold (V)`
For PRBS, when triggerthreshold is set and the source is instantiated with optional control terminals (terminals 3 and optionally 4; if terminal 4 is unspecified it is assumed to be connected to ground), triggerthreshold defines the crossing threshold for the trigger event. The event causes the emission of the next PRBS pulse.

69 `triggerdelthresh (V)`
For PRBS in external triggering mode, triggerdelthresh is used with triggerthreshold to define the crossing threshold. For rising edge triggering, the actual threshold is (triggerthreshold + triggerdelthresh); for falling edge triggering, the threshold is (triggerthreshold - triggerdelthresh). The default value is zero.

70 `triggerdirection="both"`
For PRBS in external triggering mode, trigger direction defines the direction of the control signal at the crossing event. Possible valudes are 'rise', 'fall', or 'both'.

71 `transitionreference`
Defines the voltage swing for the duration of rise and fall time, as a percentage of val1 - val0. For example, transitionreference =100 means that the output voltage transitions from val0 to val1 in rise seconds. 90 means that it transitions from 0.1*(val1-val0)

to 0.9*(val1-val0) in rise seconds, 80 means from 0.2*(val1-val0) to 0.8*(val1-val0), etc. Possible values are 100, 90, 80, 70 and 60.

Noise Parameters

72 `noisefile` — Name of file containing excess spot noise data in the form of frequency-noise pairs. The noise can be specified as the spectral density in V^2/Hz, or as single-sideband phase noise in dBc. The parameter noisetype determines how Spectre interprets the noise data..

73 `noisevec=[...] V`^{2}`/Hz` — Excess spot noise as a function of frequency in the form of frequency-noise pairs. The parameter noisetype determines how Spectre interprets the noise data..

74 `noisetype=noisevoltage`

When set to noisevoltage, the noise data represents the noise spectral density in V^2/Hz. When set to ssbphasenoise, the noise data represresnets single-sideband phase noise in dBc. When set to noisevoltage, the frequencies are absolute. For ssbphasenoise, the frequencies are offset from carrier..
Possible values are `noisevoltage` and `ssbphasenoise`.

75 `noiseinterp=linear`

Determine how the specified noise data is interpolated. This parameter only applies to noisetype=noisevoltage. When set to linear, interpolation is linear over both axes. When set to loglog, Spectre uses log interpolation over both axes..
Possible values are `linear` and `loglog`.

76 `isnoisy=yes` — Should vsource generate noise.
Possible values are `no` and `yes`.

Small signal parameters

77 `mag=0 V` — Small signal voltage.

78 `phase=0 ·` — Small signal phase.

79 `xfmag=1 V/V` — Transfer function analysis magnitude.

80 `pacmag=0 V` Periodic AC analysis magnitude.

81 `pacphase=0 ·` Periodic AC analysis phase.

Multiplication factor parameters

82 `m=1` Multiplicity factor.

Temperature effects parameters

83 `tc1=0 1/C` First order temperature coefficient.

84 `tc2=0` C^{-2} Second order temperature coefficient.

85 `tnom=27 C` Parameter measurement temperature. Default set by options.

86 `trise=0.0 C` Temperature rise from ambient.

If you do not specify the DC value, it is assumed to be the `time`=0 value of the waveform.

Sinusoidal waveform in the time interval `0<t<delay` has constant value equal to that at `t=delay`.

In DC analyses, the only active parameters are `dc`, `m`, and the temperature coefficient parameters. In AC analyses, the only active parameters are `m`, `mag` and `phase`. In transient analyses, all parameters are active except the small signal parameters and the noise parameters. The `type` parameter selects which type of waveform is generated. You may specify parameters for more than one waveform type, and use the alter statement to change the waveform type between analyses. There is one exception for type `bit`. You cannot change `bit` type to other types or other types to `bit`.

PWL Type Waveform

A vector of time-value pairs describes the piecewise linear waveform. As an alternative, you can read the waveform from a file. In this case, you give time-value pairs one pair per line with a space or tab between the time and the value.

If you set `allbrkpts` to `yes`, you force the simulator to place time points at each point specified in a PWL waveform during a transient analysis. This can be very expensive for waveforms with many points. If you set `allbrkpts` to `no`, Spectre inspects the waveform, looking for abrupt changes, and forces time points only at those changes.

The PWL waveform is periodic if you specify `pwlperiod` and/or `pwlperiodstart`. If both `pwlperiod` and `pwlperiodstart` are specified, `pwlperiod` should be longer than (wavelength - pwlperiodstart), where wavelength means the last time point. If only `pwlperiod` is specified and `pwlperiodstart` is undefined, then the period will start at first time point or (wavelength - pwlperiod), whichever is greater. If only `pwlperiodstart` is specified and `pwlperiod` is undefined, then the period will end at the last time point in the waveform vector. If the value of the waveform specified is not exactly the same at both the period beginning and the period end, then you must provide a nonzero value `twidth`. Before repeating, the waveform changes linearly in an interval of `twidth` from its value at (`period` - `twidth`) to its value at the beginning of the waveform. Thus `twidth` must always be less than `period`.

Bit Type Waveform

Bit type waveform is the analog waveform of a series of digital logic state. It uses the pattern parameters to provide the digital state sequence, and some pulse waveform parameters to define the waveform characteristics.

To define the waveform characteristics, use parameters: val1, val0, rise, fall, and period. Note that parameter period here defines the length of a bit and it must be given. The general parameter delay can also be used for bit type to define the delay time from the beginning of the transient interval to the beginning of the first bit. The state during the delay time is the same as the first state specified in data.

Pattern parameters are used to specify the digital bit string. The pattern parameters of sources are the same as those of a pattern, except that you can specify rpttimes to a negative number for sources but not for patterns. Please do "spectre -h pattern" for details on how to use pattern parameters.

Noise of the source

You can give the excess noise of the source as a file or specify it with a vector of frequency-noise pairs. For a file, give the frequency-noise pairs one pair per line with a space or tab between the frequency and noise values.

Operating-Point Parameters

1	`v (V)`	Voltage across the source.
2	`i (A)`	Current through the source.
3	`pwr (W)`	Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

z-Domain Current Controlled Voltage Source (zccvs)

The output is defined with a transfer function given as the ratio of two polynomials in the complex variable z. Each polynomial can be specified using either its coefficients or its roots. The roots of the numerator are the zeros of the transfer function and the roots of the denominator are the poles.

You may specify polynomials either in the complex variable z or 1/z by setting optional parameter `polyarg` to `z` or `inversez` respectively. By default, it is set to `inversez`. If you choose to provide the coefficients of a polynomial, enter them as a vector in ascending order of the power of the variable z or 1/z, starting from the constant term. For example, to specify a denominator of 3z^-2 + 4z^-1 + 1, use `denom=[1 4 3]`. Or to specify a denominator of 4z^2 + 3z - 2, use `polyarg=z denom=[2 3 4]`.

To specify transfer function in terms of its zeros and poles in z-plane, give them as vectors of complex numbers. You must always give the real and imaginary portions of the root, even when the root is real. You may give either both roots of a complex-conjugate pair or only one. In the latter case the conjugate complex root will be generated automatically. The order of the roots is not important. For example, to specify poles of z = 1, z = 4j, z = -4j, z = 2 + 2j, and z = 2 - 2j, use `poles=[1 0 0 4 0 -4 2 2 2 -2]` or, omitting conjugate poles, `poles=[1 0 0 4 2 2 ]`.

Either the numerator or the denominator specification can be omitted. An omitted denominator or numerator is taken to be 1.

Transition time (`tt`) is an optional parameter that at each sampling point forces linear transition of the output to a new value within the specified time range. By default, it is set to one percent of the sampling period.

The sampling delay (`td`) is another optional parameter, with the default value of 0, that lets you set asynchronous sampling rates.

To use the `s` to `z` transformation, set the optional `sxz` parameter to one of the transformation methods - forward differences, backward differences, or bilinear. When the `sxz` parameter is specified, the transfer function specification is assumed to be given in the complex variable s and it will be transformed to the complex variable z using the indicated method.

Notes on gain and gainfactor

The parameter `gain` is interpreted either as the DC gain or, if the function has zeros or poles at the origin, as a constant factor. Note that `gain` has a default value of 1, so if you do not want to specify the DC gain, you should always use parameter `gainfactor` to disable parameter `gain`. When `gainfactor` is specified, `gain` is not valid any more. For example, if the instant statement is:

s1 (1 0 control 0) svcvs numer=[1 2] denom=[3 4]

the transfer function will be 2*(2s+1)/(4s+3). Factor 2 is applied to make the DC gain of the transfer function to be 1. If you just want the transfer function to be (2s+1)/(4s+3), specify `gainfactor=1` to disable the default value of `gain`. In this example, the statement will be:

s1 (1 0 control 0) svcvs numer=[1 2] denom=[3 4] gainfactor=1

where the transfer function is 1*(2s+1)/(4s+3). 1 is the gainfactor.

This device is not supported within altergroup.

Sample Instance Statement

```
va (1 0) vsource type=sine freq=10K
z2 2 0 zccvs probe=va gain=-2 ts=5e-5 tt=1.1e-5 numer=[1 -1]
```

Instance Definition

```
Name  p  n zccvs parameter=value ...
```

Instance Parameters

1 `probe` Device through which the controlling current flows.

2 `mprobe`	The mprobe functions the same as probe except that it will divide the input current by the mfactor.
3 `port=0`	Index of the probe port through which the controlling current flows.
4 `ts=1 s`	Sampling period.
5 `td=0 s`	Sampling delay.
6 `tt=0.01 ts s`	Transition time.
7 `gain=1`	DC gain or constant transfer function factor. See `notes on gain and gainfactor` for details.
8 `gainfactor`	Factor applied to transfer function. It overwrites the parameter gain.
9 `polyarg=inversez`	Polynomial argument. Possible values are `z` or `inversez`.
10 `sxz=none`	s to z transformation. Possible values are `none`, `backward`, `forward`, or `bilinear`.
11 `numer=[...]`	Vector of numerator coefficients.
12 `denom=[...]`	Vector of denominator coefficients.
13 `zeros=[...]`	Vector of complex zeros.
14 `poles=[...]`	Vector of complex poles.
15 `m=1`	Multiplicity factor.
16 `tc1=0 1/C`	Linear temperature coefficient.
17 `tc2=0 C`$^{-2}$	Quadratic temperature coefficient.

Operating-Point Parameters

1 `i (A)`	Output current.
2 `v (V)`	Output voltage.

3 `pwr (W)` Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

denom I-12	mprobe I-2	probe I-1	td I-5
gain I-7	numer I-11	pwr OP-3	ts I-4
gainfactor I-8	poles I-14	sxz I-10	tt I-6
i OP-1	polyarg I-9	tc1 I-16	v OP-2
m I-15	port I-3	tc2 I-17	zeros I-13

z-Domain Voltage Controlled Voltage Source (zvcvs)

The output is defined with a transfer function given as the ratio of two polynomials in the complex variable z. Each polynomial can be specified using either its coefficients or its roots. The roots of the numerator are the zeros of the transfer function and the roots of the denominator are the poles.

You may specify polynomials either in the complex variable z or 1/z by setting optional parameter `polyarg` to `z` or `inversez` respectively. By default, it is set to `inversez`. If you choose to provide the coefficients of a polynomial, enter them as a vector in ascending order of the power of the variable z or 1/z, starting from the constant term. For example, to specify a denominator of 3z^-2 + 4z^-1 + 1, use `denom=[1 4 3]`. Or to specify a denominator of 4z^2 + 3z - 2, use `polyarg=z denom=[2 3 4]`.

To specify transfer function in terms of its zeros and poles in z-plane, give them as vectors of complex numbers. You must always give the real and imaginary portions of the root, even when the root is real. You may give either both roots of a complex-conjugate pair or only one. In the latter case the conjugate complex root will be generated automatically. The order of the roots is not important. For example, to specify poles of z = 1, z = 4j, z = -4j, z = 2 + 2j, and z

= 2 - 2j, use `poles=[1 0 0 4 0 -4 2 2 2 -2]` or, omitting conjugate poles, `poles=[1 0 0 4 2 2 ]`.

Either the numerator or the denominator specification can be omitted. An omitted denominator or numerator is taken to be 1.

Transition time (`tt`) is an optional parameter that at each sampling point forces linear transition of the output to a new value within the specified time range. By default, it is set to one percent of the sampling period.

The sampling delay (`td`) is another optional parameter, with the default value of 0, that lets you set asynchronous sampling rates.

To use the `s` to `z` transformation, set the optional `sxz` parameter to one of the transformation methods - forward differences, backward differences, or bilinear. When the `sxz` parameter is specified, the transfer function specification is assumed to be given in the complex variable s and it will be transformed to the complex variable z using the indicated method.

Notes on gain and gainfactor

The parameter `gain` is interpreted either as the DC gain or, if the function has zeros or poles at the origin, as a constant factor. Note that `gain` has a default value of 1, so if you do not want to specify the DC gain, you should always use parameter `gainfactor` to disable parameter `gain`. When `gainfactor` is specified, `gain` is not valid any more. For example, if the instant statement is:

s1 (1 0 control 0) svcvs numer=[1 2] denom=[3 4]

the transfer function will be 2*(2s+1)/(4s+3). Factor 2 is applied to make the DC gain of the transfer function to be 1. If you just want the transfer function to be (2s+1)/(4s+3), specify `gainfactor=1` to disable the default value of `gain`. In this example, the statement will be:

s1 (1 0 control 0) svcvs numer=[1 2] denom=[3 4] gainfactor=1

where the transfer function is 1*(2s+1)/(4s+3). 1 is the gainfactor.

This device is not supported within altergroup.

Sample Instance Statement:

va (1 0) vsource type=sine freq=10K

z3 (3 0 1 0) zvcvs gain=-1 ts=4e-5 tt=1e-5 numer=[-1 -1]

Instance Definition

Name p n ps ns zvcvs parameter=value ...

Instance Parameters

1 `ts=1 s`	Sampling period.
2 `td=0 s`	Sampling delay.
3 `tt=0.01 ts s`	Transition time.
4 `gain=1`	DC gain or constant transfer function factor. See `notes on gain and gainfactor` for details.
5 `gainfactor`	Factor applied to transfer function. It overwrites the parameter gain.
6 `polyarg=inversez`	Polynomial argument. Possible values are `z` or `inversez`.
7 `sxz=none`	s to z transformation. Possible values are `none`, `backward`, `forward`, or `bilinear`.
8 `numer=[...]`	Vector of numerator coefficients.
9 `denom=[...]`	Vector of denominator coefficients.
10 `zeros=[...]`	Vector of complex zeros.
11 `poles=[...]`	Vector of complex poles.
12 `m=1`	Multiplicity factor.
13 `tc1=0 1/C`	Linear temperature coefficient.
14 `tc2=0` C^{-2}	Quadratic temperature coefficient.

Operating-Point Parameters

1 `i (A)` Output current.

2 `v (V)` Output voltage.

3 `pwr (W)` Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Behavioral Source (bsource)

Behavioral source enables you to model a resistor, inductor, capacitor, voltage or current source as a behavioral component. Using bsource, you can express the value of a resistance, capacitance, voltage or current as a combination of device operating points, node voltages, branch currents, and built in Virtuoso® Spectre® circuit simulator expressions. `bsource` simulation performance has now been improved by compiling the bsource devices.

Bsource simulation performance has been improved by compiling the bsource devices. This is explained in more detail in the bsource compilation section below.

Sample Instance Statement

```
name (node1 node2) bsource behav_param param_list
```

where behav_param can be

`c=simple_expr`	Capacitance between the nodes
`g=simple_expr`	Conductance between the nodes
`i=generic_expr`	Current through bsource
`l=simple_expr`	Inductance between the nodes
`phi=simple_expr`	Flux in the bsource device
`q=simple_expr`	Charge in bsource device
`r=simple_expr`	Resistance between the nodes
`v=generic_expr`	Voltage across the nodes

A simple_expr is defined as a spectre expression containing,

1. netlist parameters
2. current simulation time, $time
3. node voltages, v(a,b), where a and b are nodes in the spectre netlist or v(a), which is voltage between node a and ground
4. branch currents, i("inst_id:index"), where inst_id is an instance name given in the netlist and index is the port index. The default value for index is 0.

A generic_expr is defined as a simple_expr or ddt() or idt() of simple_expr. The param_list is param_name=value.

Multiplicity factor

`m`	The value of m will be default to1.

Temperature Parameters

`1 tc1`	Linear temperature co-efficient. Valid for all behavioral elements. Default value is 0 1/C.

2 `tc2`	Quadratic temperature co-efficient. Valid for all behavioral elements. Default value is 0 C^-2
3 `tnom`	Parameters measurement temperature. Valid for all behavioral elements. Default value is 27.0.
4 `trise`	Temperature rise for ambient. Valid for all behavioral elements. Default value is 0.0.

Clipping Parameters

1 `max_val`	Maximum value of bsource expression. Valid for all behavioral elements, but generally used with i and v elements for clipping the current or voltage between the specified values.
2 `min_val`	Minimum value of bsource expression. Valid for all behavioral elements, but generally used with i and v elements for clipping the current or voltage between the specified values.

Noise Parameters

1 `af`	Flicker noise exponent, Valid for r and g elements Default value is 2.
2 `fexp`	Flicker noise frequency exponent. Valid for r, g, v, and i elements. Default value is 1.
3 `isnoisy`	Specifies whether to generate noise. Valid for r, g, i, and v elements Valid values are yes and no. Default value is yes.
4 `kf`	Flicker noise co-efficient. Valid for r and g elements.
5 `white_noise`	White noise expression. Valid for v and i elements.
6 `flicker_noise`	Flicker noise expression. Valid for v and i elements.

DC Mismatch Parameters

`mr`	DC-Mismatch parameter. Valid for r only. For algorithm in detail, Refer to "Affirma Spectre DC Device Matching Analysis Tutorial."

Note: All the parameters in the param_name table are instance parameters. `white_noise` and `flicker_noise` may be assigned behavioral expressions; the other parameters must be assigned constant or parametric expressions.

Instance Parameters

`bsource` supports the following instance parameters for the Spectre primitives.

`1 Resistor`	isnoisy, m, r, tc1, tc2, trise, kf, af, fexp, ldexp, wdexp, l, w, mr.
`2 Capacitor`	c, m, tc1, tc2, trise, ic.
`3 Inductor`	l, m, tc1, tc2, trise.

Mathematical Definitions

The i and v elements are current and voltage sources respectively with the current and voltage values specified by the generic_expression.

The `q` and `phi` elements are defined as:

(1-1)

$$i = ddt(q)) = ddt(simple\_\mathrm{expr})$$

(1-2)

$$v = ddt(phi) = ddt(simple\_\mathrm{expr})$$

The `r`, `g`, `c`, and `l` elements are defined as:

(1-3)

$$v = i \times r = i \times (simple\_\mathrm{expr})$$

(1-4)

$$i = g \times v = (simple\_\mathrm{expr}) \times v$$

(1-5)

$$i = c \times ddt(v) = (simple\_\mathrm{expr}) \times ddt(v)$$

(1-6)

$$v = l \times ddt(i) = (simple\_\text{expr}) \times ddt(i)$$

The elements `r`, `g`, `c`, and `l` are provided for compatibility reasons. The actual resistance, conductance, capacitance, and inductance are different from the expressions you specify. For example, a non-linear conductance is defined as:

(1-7)

$$g(v) = \frac{di}{dv}$$

where i and v are the conductance branch current and voltage respectively. If we use the conductance element (equation 5-4), and specify the conductance as a function of the branch voltage:

(1-8)

$$g = g_s(v)$$

then the true conductance is given by:

(1-9)

$$g(v) = \frac{d}{dv}(g_s(v) \times v)$$

(1-10)

$$g(v) = g_s(v) + v\left(\frac{d}{dv}g_s v\right)$$

Note that the true conductance is different from the specified conductance. The correct way to implement a conductance $g_S(v)$ is to use the `i` element and specify the current expression as:

(1-11)

$$i = \int g_s(v)dv$$

Noise Model for bsource

Noise sources are implemented for the elements i, v, r, and g.

Noise for Elements i and v

You need to specify the expression for Power Spectrel Density (PSD) using the *white_noise* and *flicker_noise* parameters.

(1-12)

$$white\_\mathrm{noise} = simple\_\mathrm{expr}$$

(1-13)

$$flicker\_\mathrm{noise} = simple\_\mathrm{expr} \qquad \mathrm{fexp} = constant\_\mathrm{expr}$$

where *simple_expr* is the power of the flicker noise (or white noise) source at 1Hz and *fexp* is the exponent of the frequency.

(1-14)

$$noisePSD = \frac{simple\_\mathrm{expr}}{f^{fexp}}$$

The noise source unit is A^2/Hz for `i` and V^2/Hz for `v`. The following is an example of a noise parameter specification for a current source:

(1-15)

$$white\_\mathrm{noise} = 4 \times k \times T \times g$$

where k is the Boltzman constant (1.380626e-23) and

T is the temperature.

(1-16)

$$flicker\_\mathrm{noise} = kf \times pow((g \times V(p, n)), af)\ fexp = 2$$

where $V(p,n)$ is the voltage across the `i` element.

The following is an example of a noise parameter specification for a voltage source:

(1-17)

$$white\_\text{noise} = 4 \times k \times T \times r$$

(1-18)

$$flicker\_\text{noise} = kf \times (r \times pow(i(""\texttt{inst\_name:0}), af))fexp = 2$$

Noise for elements g and r

The syntax is:

```
name (node1 node2) bsource { r | g }=simple_expr kf=value af=value fexp=value
     isnoisy={ yes | no }
```

The white_noise and flicker_noise values are calculated from the above expression. When `isnoisy=no`, noise contributions are turned off. By default the white noise source is on and the flicker noise source is off (default is `kf=0`).

The noise source for g is a current source in parallel with the g element and the noise power is in units of A^2/Hz. If x is the expression for the g element,

(1-19)

$$white\_\text{noise} = 4 \times k \times T \times x$$

(1-20)

$$flicker\_\text{noise} = \frac{kf \times (x \times v(p, n))^{af}}{freq^{fexp}}$$

where *kf*, *af*, and *fexp* are the values specified for these parameters

k is the Boltzman constant (1.380626e-23)

T is the temperature and

v(p,n) is the voltage across the `g` element.

The noise source for r is a current source in parallel with the r element and the noise power is in units of V^2/Hz. If x is the expression for the r element,

(1-21)

$$white\_\text{noise} = 4 \times k \times T \times x$$

(1-22)

$$flicker\_\text{noise} = \frac{kf \times (x \times I(relement))^{af}}{freq^{fexp}}$$

where kf, af, and $fexp$ are the values specified for these parameters

k is the Boltzman constant (1.380626e-23)

T is the temperature and

I(relement) is the current through r element.

Temperature Effect on bsource

The equation for calculating temperature effect is:

(1-23)

$$tempFactor = [1 + tc1 \times (temp + trise - tnom) + tc1 \times (temp + trise - tnom)^2]$$

Independent Resistive Source (port)

In time-domain, a port is a resistive source that is tied between `pos` and `neg`. It is equivalent to a voltage source in series with a resistor, and the reference resistance of the port is the value of the resistor. The DC value given for the port voltage specifies the DC voltage across the port when it is terminated in its reference resistance (in other words, the DC voltage of the internal voltage source is double the user specified DC value, `dc`). The same is true for the values for the transient, and PAC signals of the port. However, the amplitude of the sine wave in the transient and PAC analyses can alternatively be specified as the power in dBm delivered by the port when terminated with the reference resistance. In frequency-domain, a port can have complex reference impedance. The value of AC signal of the port specifies the voltage across the port when it is terminated in its complex conjugate reference impedance. The reactance part of the impedance is ignored when the port is used in time-domain analyses.

While generally useful as a stimulus in high frequency circuits, the port has three unique capabilities. First, it acts to define the ports of the circuit to the S-parameter analysis. Second, it has an intrinsic noise source, and so allows the noise analysis to directly compute the noise figure of the circuit. And finally, it is the only source for which the amplitude can be specified in terms of power.

You can define 2 or 3 terminal port. if you define 2-terminal port it operates like was described above. In case of 3-terminal port it also includes internal ideal choke inductor and ideal blocking capacitor. They are work like switches to terminate or connect appropriate branch dependent on type of analysis

This device is not supported within altergroup.

The value of the DC voltage as a function of the temperature is given by:

V(T) = V * [1 + tc1 * (T - tnom) + tc2 * (T - tnom)^2].

Sample Instance Statement

```
p20 (2 0) port num=2 r=50 type=pulse period=1e-9 rise=1e-10 fall=1e-10 val1=1
width=0.5n mag=1
 p30 (2 0 choke) port num=1 r=50 lchoke=0.1 cblock=0.00001 type=pulse period=1e-9
rise=1e-10 fall=1e-10
```

Instance Definition

```
Name  p  n ... port parameter=value ...
```

Instance Parameters

1 `dc=0 V` — DC value.

General waveform parameters

2 `type=dc` — Waveform type.
Possible values are `dc`, `pulse`, `pwl`, `sine`, `exp`, or `bit`.

3 `fundname` — Name of the fundamental frequency. Must be specified if the source is active during a pdisto analysis or it is the active clock during an envlp analysis.

4 `delay=0 s` — Waveform delay time.

5 `edgetype=linear` — Type of the rising and falling edges. This is for pulse waveform and pulse-like piecewise linear waveform.
Possible values are `linear` or `halfsine`.

Pulse waveform parameters

6 `val0=0 V`	Zero value used in pulse and exponential waveforms.
7 `val1=1 V`	One value used in pulse and exponential waveforms.
8 `period=∞ s`	Period of waveform.
9 `rise (s)`	Rise time for pulse waveform (time for transition from `val0` to `val1`). If parameter rise is not given, then the rise time will be the same as fall time; if fall time is not given either, then the rise time will be 1/100 of the waveform period; if the waveform is not periodic, then the rise time will be 1/100 of the simulation interval.
10 `fall (s)`	Fall time for pulse waveform (time for transition from `val1` to `val0`). If parameter fall is not given, then the fall time will be the same as rise time; if rise time is not given either, then the fall time will be 1/100 of the waveform period; if the waveform is not periodic, then the fall time will be 1/100 of the simulation interval.
11 `width=∞ s`	Pulse width (duration of `val1`).

PWL waveform parameters

12 `file`	Name of file containing waveform.
13 `wave=[...]`	Vector of time/value pairs that defines waveform.
14 `offset=0 V`	DC offset for the PWL waveform.
15 `scale=1`	Scale factor for the PWL waveform.
16 `pwldbm (dBm)`	Power of PWL waveform in dBm (alternative to `scale`).
17 `stretch=1`	Scale factor for time given for the PWL waveform.
18 `rms`	Desired rms(root of mean squre) value of the PWL waveform.
19 `pwlfilter=none`	Add filter to pwl source, where the pwl data should be equal space sampled. Possible values are 'nrc'(normal raised cosine filter) and 'none'. Possible values are `none` and `nrc`.

20 `rolloff` Desired rolloff factor for the raised cosine filter, default value is 0.2. Only valid when 'pwlfilter' is set to nrc.

21 `pwlbandwidth` Bandwidth of the pwl input signal. Be used when 'pwlfilter' is set to nrc.

22 `allbrkpts` All the points in the PWL waveform are breakpoints if set to yes. Default is yes if the number of points is less than 20.
Possible values are `no` and `yes`.

23 `pwlperiod (s)` Period of the periodic PWL waveform.

24 `pwlperiodstart (s)` Period start time of the periodic PWL waveform.

25 `twidth=pwlperiod/1000 s`
Transition width used when making PWL waveforms periodic.

26 `highz=1e12` The impedance of high z state.

27 `min_z_transition_width=10e-12 s`
Minimum width of transition from z-state to non z-state. The width of transition is set as 1e-3*(z-sate duration). .

Sinusoidal waveform parameters

28 `sinedc=dc V` DC level for sinusoidal waveforms.

29 `ampl=1 V` amplitude of sinusoidal waveform.

30 `dbm (dBm)` Amplitude of sinusoidal waveform in dBm (alternative to `ampl`).

31 `freq=0 Hz` Frequency of sinusoidal waveform.

32 `sinephase=0 ·` Phase of sinusoid when `t=delay`.

33 `ampl2=1 V` amplitude of second sinusoidal waveform.

34 `dbm2 (dBm)` Amplitude of second sinusoidal waveform in dBm (alternative to `ampl2`).

35 `freq2=0 Hz` Frequency of second sinusoidal waveform.

36 `sinephase2=0 ·` Phase of second sinusoid when `t=delay`.

37 `fundname2`	Name of the fundamental frequency associated with freq2. Must be specified if freq2 is used in a pdisto analysis.
38 `iqmodfiles=[...]`	Two file names which containing pwl I/Q source waveform.
39 `fmmodindex=0`	FM index of modulation for sinusoidal waveform.
40 `fmmodfreq=0 Hz`	FM modulation frequency for sinusoidal waveform.
41 `fmmodfiles=[...]`	One or two file names: containing FM waveform for one file case, and FM I/Q signals for two files with I file first.
42 `ammodindex=0`	AM index of modulation for sinusoidal waveform.
43 `ammodoffset=1`	AM offset of modulation for sinusoidal waveform.
44 `ammodfreq=0 Hz`	AM modulation frequency for sinusoidal waveform.
45 `ammodphase=0 ·`	AM phase of modulation for sinusoidal waveform.
46 `damp=0 1/s`	Damping factor for sinusoidal waveform.
47 `freqvec=[...] Hz`	Vector of support frequency of sinusoidal channel source.
48 `amplvec=[...] V`	Vector of amplitude of sinusoidal channel source.
49 `dbmvec=[...] dBm`	Vector of amplitude of sinusoidal waveform in dBm (alternative to `amplvec`).
50 `phasevec=[...] ·`	Vector of phase of sinusoidal channel source.
51 `maxharms=[...]`	Array of number of harmonics of each frequency.

Exponential waveform parameters

52 `td1=0 s`	Rise start time for exponential wave.
53 `tau1 (s)`	Rise time constant for exponential wave.
54 `td2 (s)`	Fall start time for exponential wave.
55 `tau2 (s)`	Fall time constant for exponential wave.

56 `expperiod (s)`	Period of the periodic EXP waveform.

Pattern parameters

57 `data`	The bit string. A string that contains a series of the four states, 1 0 m z. For prbs, it can contain only 0 and 1, and m, z is not supported.
58 `rptstart=1`	The starting bit when repeating. The data repeats from the specified bit to the end of the bit string. The parameter should be an integer from 1 to the length of the bit string.
59 `rpttimes=0`	The repeat times. The output will maintain the state of the last bit after the last repeat. If its value is negative, the string repeats forever.

Prbs parameters

60 `ref (V)`	Sets the crossing reference for the control node. This parameter applies only when the Prbs source operates as a 3 or 4 terminal device. When the voltage across terminals 3 and 4 drops below ref, the output of the source is set to 0. If terminal 4 is not specified, it is assumed to be connected to ground.
61 `jitter (s)`	The parameter jitter is obsolete. It has no effect on the output.
62 `rjseed=1`	The seed for random number generator, used in generating random jitter for PRBS sources. The default value is 1.
63 `rjrms (s)`	When set for PRBS source or Bit source, the source has a normally distributed random jitter, whose mean is zero and whose standard deviation is rjrms.
64 `pjamp=[...] s`	When set for PRBS source or Bit source, the source has multiple periodic jitters, whose amplitudes are defined by pjamp and frequencies are defined by pjfreq.
65 `pjfreq=[...] Hz`	When set for PRBS source or Bit source, the source has multiple periodic jitters, whose amplitudes are defined by pjamp and whose frequency are defined by pjfreq.

66 `pjtype="sine"` For PRBS source or Bit source, pjtype defines the types of periodic jitters. Possible valudes are 'sine', 'sawtooth', or 'square'.

67 `seed` This parameter is obsolete but retained for backward compatability. Set registerlength=[2 ... 32] to choose a Maximum Length Sequence or define a custom PRBS by use of the parameters, lfsrtaps and lfsrseed.

68 `taps=[...]` The use of taps is discouraged. For PRBS, taps is an integer array which sets the locations of the LFSR taps. Please use lfsrtaps instead. Please see the section, 'PRBS Type Waveform' below for details of the PRBS operation.

69 `lfsrtaps=[...]` For PRBS source, lfsrtaps is an integer array which sets the location of LFSR taps. Locations are 1-based and ordered form MSB to LSB of the LFSR. The largest element of the taps array is equal to the width of the LFSR. Please see the section, 'PRBS Type Waveform' for details of PRBS source operation.

70 `lfsrseed=[...]` For PRBS source, lfsrseed is an integer array which sets the initial state of the LFSR. Array elements sets the locations of non-zero bits. Locations are 1-based and ordered from MSB to LSB of the LFSR. For example, assume lfsrtaps=[6] and lfsrseed=[1 3 5]. The width of the register is then 6 bits and the initial state is '101010'.

71 `registerlength` When set for PRBS, the registerlength defines the width of the LFSR and the LFSR works in Maximum Length Sequence mode. Please see the section 'PRBS Type Waveform' below for details of MLS setting.

72 `triggerthreshold (V)`
For PRBS, when triggerthreshold is set and the source is instantiated with optional control terminals (terminals 3 and optionally 4; if terminal 4 is unspecified it is assumed to be connected to ground), triggerthreshold defines the crossing threshold for the trigger event. The event causes the emission of the next PRBS pulse.

73 `triggerdelthresh (V)`
For PRBS in external triggering mode, triggerdelthresh is used with triggerthreshold to define the crossing threshold. For rising edge triggering, the actual threshold is (triggerthreshold +

triggerdelthresh); for falling edge triggering, the threshold is (triggerthreshold - triggerdelthresh). The default value is zero.

74 `triggerdirection="both"`

For PRBS in external triggering mode, trigger direction defines the direction of the control signal at the crossing event. Possible valudes are 'rise', 'fall', or 'both'.

75 `transitionreference`

Defines the voltage swing for the duration of rise and fall time, as a percentage of val1 - val0. For example, transitionreference =100 means that the output voltage transitions from val0 to val1 in rise seconds. 90 means that it transitions from 0.1*(val1-val0) to 0.9*(val1-val0) in rise seconds, 80 means from 0.2*(val1-val0) to 0.8*(val1-val0), etc. Possible values are 100, 90, 80, 70 and 60. .

Noise Parameters

76 `noisefile` Name of file containing excess spot noise data in the form of frequency-noise pairs. The noise can be specified as the spectral density in V^2/Hz, or as single-sideband phase noise in dBc. The parameter noisetype determines how Spectre interprets the noise data..

77 `noisevec=[...]` V^2/Hz Excess spot noise as a function of frequency in the form of frequency-noise pairs. The parameter noisetype determines how Spectre interprets the noise data..

78 `noisetype=noisevoltage`

When set to noisevoltage, the noise data represents the noise spectral density in V^2/Hz. When set to ssbphasenoise, the noise data represesnets single-sideband phase noise in dBc. When set to noisevoltage, the frequencies are absolute. For ssbphasenoise, the frequencies are offset from carrier..
Possible values are `noisevoltage` and `ssbphasenoise`.

79 `noiseinterp=linear`

Determine how the specified noise data is interpolated. This parameter only applies to noisetype=noisevoltage. When set to linear, interpolation is linear over both axes. When set to loglog, Spectre uses log interpolation over both axes..
Possible values are `linear` and `loglog`.

80 `noisetemp (C)`	Noise temperature of port. If not specified, the noise temperature is taken to be 290 K.
81 `isnoisy=yes`	Should port generate noise. Possible values are `no` and `yes`.

Port parameters

82 `r=50 Ω`	Reference resistance.
83 `x=0 Ω`	Reference reactance, ignored for time domain analyses.
84 `lchock=0.1 H`	Choke inductor for network analyser.
85 `lchoke=0.1 H`	Choke inductor for network analyser.
86 `cblock=0.0001 F`	Blocking capacitance for network analyser.
87 `num`	Port number.
88 `m=1`	Multiplicity factor.

Small signal parameters

89 `mag=0 V`	Small signal voltage.
90 `phase=0 ·`	Small signal phase.
91 `xfmag=1 V/V`	Transfer function analysis magnitude.
92 `pacmag=0 V`	Periodic AC analysis magnitude.
93 `pacdbm (dBm)`	Periodic AC analysis magnitude in dBm (alternative to `pacmag`).
94 `pacphase=0 ·`	Periodic AC analysis phase.

Temperature effects parameters

95 `tc1=0 1/C`	First order temperature coefficient.
96 `tc2=0` C^{-2}	Second order temperature coefficient.

97 `tnom (C)` Parameters measurement temperature. Default set by options.

Harmonic balance parameters

98 `harmvec=[...]` Harmvec, rvec, and xvec are considered together, and are only applied in harmonic balance large-signal analyses. Harmvec is a list of harmonics to have impedances set manually. If the input to the circuit has a single frequency, then this is a list of harmonics like [1 3] which would set the first and third harmonic. When there are two inputs, then each harmonic has two indices. An example would be [2 -1 -1 2] which would set the harmonics 2, -1, and 1, -2 manually. When there are three inputs, then each harmonic has three indices, and so on.

99 `rvec=[...]` Ω Rvec is the list of series resistance values that go with the list of harmonics to be set manually. If there are three harmonics in the harmvec, for example [1 4 5] in a single tone analysis, then there must be three resistance values in rvec, like [60 70 80]. The order in the list corresponds to the order of harmvec. In this example, harmonic 5 gets set to 80 Ohms. All values must be specified. There is no default.

100 `xvec=[...]` Ω Xvec is the list of series reactance values that go with the list of harmonics to be set manually. If there are two harmonics in the harmvec, for example [2 -1 1 -2] in a two tone circuit, then xvec must have two values, like [0 25]. The order in the list corresponds to the order of harmvec. In this example, harmonic 1, -2 gets set to 25 Ohms. All values must be specified. There is no default.

101 `ro=50` Ω Series resistance for all the harmonics that are not set manually. This is also the value used in time-domain (transient and shooting PSS) and AC analyses.

102 `xo=0` Ω This is used for the frequency-domain analyses only. This specifies the series reactance for all the harmonics that are not set manually. This value is ignored in time-domain analyses. It is used to represent the port impedance at all frequencies in AC analysis.

If you do not specify the DC value, it is assumed to be the `time`=0 value of the waveform.

Sinusoidal waveform in the time interval `0<t<delay` has constant value equal to that at `t=delay`.

In DC analyses, the only active parameters are `dc`, `m`, and the temperature coefficient parameters. In AC analyses, the only active parameters are `m`, `mag` and `phase`. In transient analyses, all parameters are active except the small signal parameters and the noise parameters. The `type` parameter selects which type of waveform is generated. You may specify parameters for more than one waveform type, and use the alter statement to change the waveform type between analyses. There is one exception for type `bit`. You cannot change `bit` type to other types or other types to `bit`.

PWL Type Waveform

A vector of time-value pairs describes the piecewise linear waveform. As an alternative, you can read the waveform from a file. In this case, you give time-value pairs one pair per line with a space or tab between the time and the value.

If you set `allbrkpts` to `yes`, you force the simulator to place time points at each point specified in a PWL waveform during a transient analysis. This can be very expensive for waveforms with many points. If you set `allbrkpts` to `no`, Spectre inspects the waveform, looking for abrupt changes, and forces time points only at those changes.

The PWL waveform is periodic if you specify `pwlperiod` and/or `pwlperiodstart`. If both `pwlperiod` and `pwlperiodstart` are specified, `pwlperiod` should be longer than (wavelength - pwlperiodstart), where wavelength means the last time point. If only `pwlperiod` is specified and `pwlperiodstart` is undefined, then the period will start at first time point or (wavelength - pwlperiod), whichever is greater. If only `pwlperiodstart` is specified and `pwlperiod` is undefined, then the period will end at the last time point in the waveform vector. If the value of the waveform specified is not exactly the same at both the period beginning and the period end, then you must provide a nonzero value `twidth`. Before repeating, the waveform changes linearly in an interval of `twidth` from its value at (`period` - `twidth`) to its value at the beginning of the waveform. Thus `twidth` must always be less than `period`.

Bit Type Waveform

Bit type waveform is the analog waveform of a series of digital logic state. It uses the pattern parameters to provide the digital state sequence, and some pulse waveform parameters to define the waveform characteristics.

To define the waveform characteristics, use parameters: val1, val0, rise, fall, and period. Note that parameter period here defines the length of a bit and it must be given. The general parameter delay can also be used for bit type to define the delay time from the beginning of the transient interval to the beginning of the first bit. The state during the delay time is the same as the first state specified in data.

Pattern parameters are used to specify the digital bit string. The pattern parameters of sources are the same as those of a pattern, except that you can specify rpttimes to a negative number for sources but not for patterns. Type `spectre -h pattern` for details on how to use pattern parameters.

Noise of the source

You can give the excess noise of the source as a file or specify it with a vector of frequency-noise pairs. For a file, give the frequency-noise pairs one pair per line with a space or tab between the frequency and noise values.

When computing the noise figure of a circuit driven at its input by a port, the noise temperature (noisetemp) of the port should be set to 16.85C (290K) in order to match the standard IEEE definition of noise figure. In addition, all other sources of noise in the port (noisefile and noisevec) should be disabled. If a noiseless port is desired, set the noise temperature to absolute zero or below, and do not specify a noise file or noise vector.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

`allbrkpts I-22`	`fundname I-3`	`phase I-90`	`sinephase2 I-36`
`ammodfreq I-44`	`fundname2 I-37`	`phasevec I-50`	`stretch I-17`

Linear N Port (nport)

An N-port takes its characteristics from an S, Y or Z-parameter data file. An N-port can have as many ports as there are in the N-port described in the data file. Each pair of terminals in the `nport' instance statement represents one port. Because there is no limit to the number of ports, there is no limit to the number of terminals. However, the terminals must be given in pairs and there must be at least one pair. The order of the pairs is the same as the order of the ports in the data file. Any missing ports should be skipped.

The S, Y or Z-parameter data file specifies the characteristics of the N-port. You can scale the frequency axis with the `scale' parameter. The frequencies in the data file are then multiplied by 'scale' before the simulator uses them. The default scale factor is unity. In addition to Spectre's native format, the S, Y, or Z-parameters can be in Touchstone or CITIfile format, and the data can be given as: real-imag, mag-deg, mag-rad, db-deg, or db-rad.

An internal thermal noise model is used in noise analysis. However, if the user provides frequency-dependent noise data then this data is used to build a noise model. Currently Touchstone format accepts the two-port noise parameters (NFmin, Gamma (Gopt, Bopt) and Rn), while Spectre's native format accepts both two-port noise parameters and noise correlation matrix.

If interp=linear or spline is specified, then impulse response is calculated, and convolution method is used for simulation in time domain. It is assumed that the S, Y or Z-parameter data is complete and smooth enough to be safely interpolated or extrapolated in the frequency range from fdelta to fmax, and to DC. Be aware that N-port can be used to model many different kind of systems, the default setting of the impulse response and convolution algorithm is made for typical N-port applications. See the important notes below on when and how to set some of the controlling parameters.

Linear interpolation or cubic spline is used on the data in polar form. A simple algorithm removes 2 pi jumps in the phase data. Frequency points where the data is measured must therefore be close enough to avoid an excessive number of jumps. Unfortunately, noisy phase data can cause unnecessary warning messages. Number of frequency domain samples used for FFT is fmax/fdelta with upper limit of maxn. It might be necessary to increase maxn in the case of extremely large average group delay. When usewindow is set to yes, the data in frequency domain is multiplied by Kaiser-Bessel window function with smoothing parameter equal to one.

If interp=rational is specified, the data is interpolated and extrapolated using a rational function fit to the data. The degree of rational interpolation is automatically selected based on the values of abserr and relerr, unless ratorder is given, in which case relerr and abserr are ignored in selecting the order of the rational function interpolation. It is usually better to allow the simulator to automatically select the rational interpolation order.

If the S, Y or Z-parameter data contains noise, abserr and relerr should be set so that the fitting procedure can ignore the noise, for example, by setting abserr above the noise floor and/or relaxing relerr as necessary.

Because the fitting procedure can take a long time for complicated data, the reduced order model (ROM) file option is available to store and re-use the rational interpolation function in subsequent simulations.

It is not practical to rely on extrapolated data.

If `matrixform' parameter is set to `yes', then the nport becomes a state-space model. A state-space model is a set of state space equations in matrix form describing a linear system. The equations are in the following form:

E(dx/dt) = Ax + Bu

y = Cx + K(du/dt) + Du

where u is the input vector, y is the output vector, x is the internal-state vector. A, B, C, D, E and K are coefficient matrices.

Please see notes on state-space models for detailed information on how to use the parameters.

Sample Instance Statement

```
x1 (a1 0 b1 0 b3 0) ndata file="sparam2.data"
```

Sample Model Statement

```
model ndata nport file="sparam.data" scale=1
```

This device is not supported within altergroup.

Synopsis

```
Name  t1  b1  [t2]  [b2] ... ModelName <parameter=value> ...
Name  t1  b1  [t2]  [b2] ... nport <parameter=value> ...
```

Terminals must be given in pairs.

Model Synopsis

```
model ModelName nport <parameter=value> ...
```

Instance Parameters

1 `m=1`	Multiplicity factor.
2 `file`	S-parameter data file name.
3 `datafmt`	The format of the S-parameter data file. If this parameter is not given, Spectre will try to detect the format by itself. Possible values are `spectre`, `touchstone`, `citi`, and `rfm`.
4 `scale=1`	Frequency scale factor.
5 `interp=linear`	Method to interpolate s-parameter data. Possible values are `spline`, `rational`, `linear`, and `bbspice`.
6 `matrixform=no`	Flag for matrix form input. Possible values are `no` and `yes`.
7 `isnoisy=yes`	Should nport generate noise. Possible values are `no` and `yes`.

Spline/Linear interpolation parameters

8 `fmax (Hz)`	Maximum frequency of interest. Default is 3 times the highest frequency found in s-parameter file.
9 `fdelta (Hz)`	Frequency sampling interval, auto calculated by simulator. If user specified the parameter explicitly, the adaptive sampling is disable.

10 `maxn=131072`	Maximal order of impulse response. Cannot exceed 262144.
11 `imptrunc=1.0e-4`	Impulse response truncation threschold relative to the main maximum. The tail of the impulse response below imptrunc will be removed. Set imptrunc=0 to keep the tail.
12 `datatrunc=1.0e-4`	Relative truncation threshold for the S-parameter data.
13 `usewindow=no`	Use smooth data windowing function. Possible values are `no` and `yes`.
14 `dcextrap=constant`	Long delay DC extrapolation method. Possible values are `constant`, `unwrap`, and `hpunwrap`.
15 `hfextrap=constant`	Long delay high-frequency extrapolation method. Possible values are `constant` and `linear`.

Passivity checking and enforcement parameters

16 `passivity=check`	Check and enforce passivity of s parameters. Possible values are `no`, `check`, and `enforce`.
17 `pabstol=-1.0e-6`	Absolute tolerance of passivity criteria.

Causality correction parameters

18 `causality=fmax`	Correct s parameter data to ensure system is causal. Possible options are no, fmax and auto. The default is 'fmax'. 'auto' will take long time to perform causality correction. Possible values are `no`, `fmax`, and `auto`.

Rational interpolation parameters

19 `relerr=0.01`	Maximum relative allowed tolerance for rational interpolation errors. Deviations of the nport model from supplied s-parameter data of relative magnitude less than relerr are generally ignored.
20 `abserr=1e-4`	Maximum absolute allowed tolerance for rational interpolation errors. Deviations of the nport model from supplied s-parameter

data of absolute magnitude less than abserr are generally ignored.

21 `romdatfile` File used for storing time-domain reduced order model (ROM).

22 `ratorder` Order of rational function to use in fitting the s-parameter data. If this argument is given, relerr and abserr are ignored in selecting the order of the rational function interpolation. If ratorder is not specified then the program will attempt to select an order of rational interpolation that satisfies the criteria implied by abserr and relerr.

Noise parameters

23 `trise (C)` Temperature rise from ambient.

24 `thermalnoise=yes` Should nport generate noise.
Possible values are `no` and `yes`.

25 `noisemodel` To use the internal thermal noise model, or the externally supplied noise data in the S-parameter data file. The default behavior is to use external data whenever it is available. When interp=bbspice, externally supplied noise data will be ignored, default will use the broadbandspice rational fitting model to get noise model.
Possible values are `internal` and `external`.

26 `noisecorr=complex`
Setting noisecorr to real forces the nport noise correlation matrix to be real-valued. The parameter is used for backward compatibility only. Its value is now determined automatically and its use is no longer recommended because it can lead to incorrect answer. The simulator will issue a warning if the noise correlation matrix is complex while the value of noisecorr is set to real.
Possible values are `real` and `complex`.

Matrixform state-space model parameter

27 `porttypes=[...]` A vector of integers that defines types of the ports. Use 0 for input port, 1 for output port and 2 if the port is both input and output.

28 `portquantities=[...]` A vector of integers that defines quantities of the ports. Use 0 for voltage and 1 for current.

29 `matrixfile` Matrix entry data file name.

30 `matrixA=[...]` Nonzero entries in coefficient matrix A. Its format is [... row_i col_j value_ij ...].

31 `matrixB=[...]` Nonzero entries in coefficient matrix B. Its format is [... row_i col_j value_ij ...].

32 `matrixC=[...]` Nonzero entries in coefficient matrix C. Its format is [... row_i col_j value_ij ...].

33 `matrixD=[...]` Nonzero entries in coefficient matrix D. Its format is [... row_i col_j value_ij ...].

34 `matrixE=[...]` Nonzero entries in coefficient matrix E. Its format is [... row_i col_j value_ij ...].

35 `matrixK=[...]` Nonzero entries in coefficient matrix K. Its format is [... row_i col_j value_ij ...].

36 `acmodel=freqdomain`
Alters nport behaviour in small signal analyses: sp, ac and xf. The default value is freqdomain.
Possible values are `freqdomain` and `timedomain`.

37 `outfile` File used for storing the equivalent s-parameter data based on corresponding time-domain model. The file format is touchstone. The instance name is added as a suffix and the file extension is added automatically.

Model Definition

model modelName nport parameter=value ...

Model Parameters

1 `file` S-parameter data file name.

2 `datafmt` — The format of the S-parameter data file. If this parameter is not given, Spectre will try to detect the format by itself.
Possible values are `spectre`, `touchstone`, `citi`, and `rfm`.

3 `scale=1` — Frequency scale factor.

4 `dcextrap=constant` — Long delay DC extrapolation method.
Possible values are `constant`, `unwrap`, and `hpunwrap`.

5 `matrixform=no` — Flag for matrix form input.
Possible values are `no` and `yes`.

Spline/Linear interpolation parameters

6 `interp=linear` — Method to interpolate s-parameter data.
Possible values are `spline`, `rational`, `linear`, and `bbspice`.

7 `fmax (Hz)` — Maximum frequency of interest. Default is 3 times the highest frequency provided in the s-parameter file.

8 `fdelta (Hz)` — Frequency sampling interval, auto calculated by simulator. If user specified the parameter explicitly, the adaptive sampling is disable.

9 `maxn=131072` — Maximal order of impulse response. Cannot exceed 262144.

10 `imptrunc=1.0e-4` — Relative truncation threschold for the impulse response.

11 `datatrunc=1.0e-4` — Relative truncation threshold for the S-parameter data.

12 `usewindow=no` — Use smooth data windowing function.
Possible values are `no` and `yes`.

13 `hfextrap=constant` — Long delay high-frequency extrapolation method.
Possible values are `constant` and `linear`.

Passivity checking and enforcement parameters

14 `passivity=check` Check and enforce passivity of s parameters.
Possible values are `no`, `check`, and `enforce`.

15 `pabstol=-1.0e-6` Absolute tolerance of passivity criteria.

Causality correction parameters

16 `causality=fmax` Correct s parameter data to ensure system is causal. The default value is 'fmax'. 'auto' will take long time to perform causality correction.
Possible values are `no`, `fmax`, and `auto`.

Noise parameters

17 `trise=0 C` Default temperature rise from ambient.

18 `thermalnoise=yes` Should nport generate noise.
Possible values are `no` and `yes`.

19 `isnoisy=yes` Should nport generate noise.
Possible values are `no` and `yes`.

20 `noisemodel` To use the internal thermal noise model, or the externally supplied noise data in the S-parameter data file. The default behavior is to use external data whenever it is available. When interp=bbspice, externally supplied noise data will be ignored, default will use the broadbandspice rational fitting model to get noise model.
Possible values are `internal` and `external`.

21 `noisecorr=complex`

Setting noisecorr to real forces the nport noise correlation matrix to be real-valued. The parameter is used for backward compatibility only. Its value is now determined automatically and its use is no longer recommended because it can lead to incorrect answer. The simulator will issue a warning if the noise correlation matrix is complex while the value of noisecorr is set to real.
Possible values are `real` and `complex`.

Matrixform state-space model parameter

22 `porttypes=[...]` A vector of integers that defines types of the ports. Use 0 for input port, 1 for output port and 2 if the port is both input and output.

23 `portquantities=[...]` A vector of integers that defines quantities of the ports. Use 0 for voltage and 1 for current.

24 `matrixfile` Matrix entry data file name.

25 `matrixA=[...]` Nonzero entries in coefficient matrix A. Its format is [... row_i col_j value_ij ...].

26 `matrixB=[...]` Nonzero entries in coefficient matrix B. Its format is [... row_i col_j value_ij ...].

27 `matrixC=[...]` Nonzero entries in coefficient matrix C. Its format is [... row_i col_j value_ij ...].

28 `matrixD=[...]` Nonzero entries in coefficient matrix D. Its format is [... row_i col_j value_ij ...].

29 `matrixE=[...]` Nonzero entries in coefficient matrix E. Its format is [... row_i col_j value_ij ...].

30 `matrixK=[...]` Nonzero entries in coefficient matrix K. Its format is [... row_i col_j value_ij ...].

Important note about spline and linear interpolation parameters:

interp

To calculate impulse response, either linear or spline interpolation is used to sample data points in the frequency domain, based on the S-parameter data file. When the input data points are sufficient, linear and spline interpolation produce comparable model accuracy. However, when the input data points are scarce, linear interpolation is preferred to bound jumps between data points. Interpolation/extrapolation can be avoided all together if s-parameter data is provided from zero frequency to fmax with uniform step fdelta, and number of samples is a power of 2.

fmax

The default of fmax is three times the highest frequency in the S-parameter data file. Impulse response is calculated by sampling frequency points between DC and `fmax'. The purpose of this extrapolation is to preserve high-frequency model accuracy. However, if user has enough bandwidth in the S-parameter data file, `fmax' needs to be set to the original highest frequency in the S-parameter data file. In general, fmax must be larger than expected signal bandwidth.

fdelta

Frequency sampling interval, with default of `fmax'/1024, or 1/tstop, whichever is smaller. Note that fdelta will be further reduced, so that fmax/fdelta is a power of 2. This is required by FFT algorithm.

maxn

Maximal order of impulse response, or the maximum number of sampling points in the frequency domain. User should only increase this value when modeling a system with large average group delay, such as transmission line. The given value of `maxn' will be reduced to the nearest power of 2. Setting this value unnecessarily large slows down time-domain simulation. Absolute upper limit for maxn is 16384.

imptrunc

Relative truncation threshold for impulse response. The tail of the impulse response with absolute values below `imptrunc' is removed to speed up simulation.

usewindow

Kaiser-Bessel window with smoothing parameter 1 is used to better regulate the stability of S-parameter data. This parameter trades off model accuracy with model stability, particular useful for S-parameter data with insufficient bandwidth. Window must be used for all-pass type systems, where s-parameters are nonzero for the frequencies beyond fmax.

dcextrap

For long delay, the DC extrapolation method can be set to constant, unwrap or hpunwrap. The default is 'constant', where without a dc point, the low-frequency magnitude is held at the lowest data point, the dc phase is set to the real axis near the lowest-frequency data point and interpolated elsewhere. For the 'unwrap' case and without a dc point, the DC magnitude is set based on a regression of some low-frequency data, and the DC phase is set by unwrapping the phase, then setting it onto the real axis. If the dc point is provided, the magnitude is interpolated while the phase is still determined using the unwrapped estimate. 'hpunwrap' is similar to 'unwrap' for DC phase extrapolation but provides an alternative approach for DC magnitude extrapolation which may be preferred for high-pass characteristics.

Important note about parameters for state-space models:

porttype and portquantities

Both parameters have the same number of entries as the number of ports, and each entry corresponds to a port. The entries are in the same order as the port order in terminal specification of the instance. `porttype' specifies the type of each port of the nport. A port can be of type input, output or both. `portquantities' specifies whether each input/output is a voltage or current. Each entry of `portquantities' corresponds to one entry in `porttypes'. It specifies the quantity of input for input and both ports and the quantity of output for output port.

matrixfile

==========

Matrix entry data file name.

File format:

Any line beginning with ";", "#", or "%" is treated as a comment and discarded.

Remaining lines should have a first character of A, B, C, D, E, or K, two integers, and a floating-point number. Such a line denotes an entry in the appropriate matrix with given row column indices and matrix element.

For example, a file may look like this:

;matrix A, 3x3

A 1 1 1234.5678

...

;

;matrix E, 3x3

E 1 1 1.0

...

;

;matrix B, 3x1

B 2 1 4.28

...

;

;matrix C, 2x3

C 2 1 3.14

...

If a matrix is not specified in the file, it will be treated as zero matrix for A, B, C, D, and K. Matrix E will be treated as identity matrix if it is not specified in the file.

matrixA matrixB matrixC matrixD matrixE matrixK

Coefficient matrices of the state-space model. The syntax of the vector is in sparse form, i.e.

[Row_1, Column_1, Value_11,

...

Row_i, Column_j, Value_ij,

...]

If a matrix is not specified, it will be treated as a zero matrix for A, B, C, D, and K. Matrix E will be treated as identity matrix if it is not specified.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Current Probe (iprobe)

Current through the probe is computed and is defined to be positive if it flows from the input node, through the probe, to the output node. The current variable is given the name of the `iprobe` instance, so you cannot create an `iprobe` with the same name as a circuit node.

This device is not supported within altergroup.

Sample Instance Statement

ip (1 0) iprobe

Instance Definition

```
Name  in  out iprobe
```

Operating-Point Parameters

1 `i (A)` current through iprobe.

Circuit Reduced Order Model (cktrom)

The circuit reduced order model is described by a set of partial differential equations in the form of:

$$\dot{x} = Ax + Bu \qquad (1)$$

$$y = Cx + Du \qquad (2)$$

where Eqn.(1) is the state equation, Eqn.(2) is the output equation, A is nxn matrix, B is nxm, C is mxn, and D is an mxm matrix. x is a vector of state variables. Input u is a vector of voltages at all the ports and output y is a vector of electric current at all the ports. The number of inputs is always equal to the number of outputs. The order of the terminals in the input must be consistent with the matrix equations. In the input file, the matrices A, B, C and D are in the form of long vectors with row order.

This device is not supported within altergroup.

Sample Instance Statement

rom3 (net11 0) cktrom a=[-2.022852e+14 2.583012e+13 9.553125e+13 9.627727e+13 1.533971e+13 9.987851e+13 4.592012e+13 -1.671024e+14 2.296589e+13 -2.719915e+14 7.668472e+12 -1.564519e+14 8.543123e+13 3.395689e+13 -3.863150e+14 -1.101618e+14 -5.415116e+14 -2.303841e+14 9.627728e+13 -1.711915e+14 -1.001818e+14 -8.123120e+14 -2.272715e+14 -9.965181e+14 1.514961e+14 7.668372e+12 -6.415116e+14 -3.272715e+14 -2.852751e+15 -3.564466e+14 9.999851e+13 -1.761619e+14 -1.312841e+14 -8.967181e+14 -4.563456e+14 -4.068747e+15]

b=[3.366776e+06 5.932470e+05 -1.508475e+06 4.349182e+06 -3.128869e+06 -2.995677e+06 -2.831481e+06 2.708942e+06 -4.968876e+06 -3.338945e+06 -3.278564e+06 3.925648e+06]

c=[-3.111296e+06 1.593292e+06 3.324594e+06 3.083731e+06 5.887179e+06 3.766094e+06 -5.049263e+05 -4.275158e+06 3.035578e+06 -3.666385e+06 3.424639e+06 -3.832285e+06] d=[1.254627e-01 0.000000e+00 0.000000e+00 1.236790e-01]

Instance Definition

```
Name sink0 src0 [sink1] [src1] [sink2] [src2] [sink3] [src3] ... cktrom
parameter=value ...
```

Instance Parameters

1 `m=1`	Multiplicity factor.
2 `a=[...]`	Coefficient matrix A of state equations.
3 `b=[...]`	Coefficient Matrix B of state equations.
4 `c=[...]`	Coefficient matrix C of output equations.
5 `d=[...]`	Coefficient matrix D of output equations.

Operating-Point Parameters

1 `i=[...] A`	Port currents.
2 `v=[...] V`	Port voltages.
3 `pwr (W)`	Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Analog-to-Logic Converter (a2d)

The analog-to-logic converter transfers analog waveforms to a logic simulator.

This device is not supported within altergroup.

Sample Instance Statement

da99 (cmp_out 0) a2d dest=”99991” vl=0 vh=5 timex=200u

// 99991 is a digital net in the Verilog netlist.

Instance Definition

```
Name  p  n a2d parameter=value ...
```

Instance Parameters

1	`dest`	The foreign simulator name for the destination of the signal.
2	`nestlev=0`	Number of nesting levels to ignore in the hierarchical name. This should be used to skip over extra levels that do not exist in the co-simulator.
3	`vl=0 V`	Voltages below this will be logical 0.
4	`vh=5 V`	Voltages above this will be logical 1.
5	`timex=1 s`	Time signal can linger between `vl` and `vh` before the state becomes X.

device checker (assert)

The assert statement cannot be altered using the alter statement.

This device is supported within altergroups.

Instance Definition

```
Name assert parameter=value ...
```

Instance Parameters

1 `max=∞`	Upper bound of the parameter to be checked.
2 `min=∞`	Lower bound of the parameter to be checked.
3 `duration=0 s`	Time period over which the check has been in violation before a message is flagged.
4 `mod`	Model to be checked.
5 `dev`	Device or Subcircuit instance to be checked.
6 `primitive`	Primitive to be checked.
7 `sub`	Subcircuit master to be checked.
8 `param`	Any one of input, output, operating point or subcircuit instance parameter to be checked.
9 `modelparam`	Model parameter to be checked.
10 `message`	Message to be printed when assertion fails.
11 `level=warning`	Severity used when assertion fails. Possible values are `none`, `notice`, `warning`, `error`, or `fatal`.
12 `info=no`	When info=yes, parameter will not be checked against min/max, only its value will be printed out. Possible values are `no` or `yes`.
13 `expr`	Expression to be checked for violation (in MDL syntax).
14 `values=[...]`	List of values for a parameter of the enumerated type. If the parameter has a value outside of the listed ones, a message will be flagged.
15 `m=1`	Multiplicity factor.
16 `boolean=true`	Choose behavior and report style for boolean violations. If boolean = true, asserts are issued when boolean is true and reported in old style; If boolean = false, asserts are issued when

boolean is false and reported in new style.
Possible values are `false` or `true`.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

boolean I-16	info I-12	message I-10	param I-8
dev I-5	level I-11	min I-2	primitive I-6
duration I-3	m I-15	mod I-4	sub I-7
expr I-13	max I-1	modelparam I-9	values I-14

Logic-to-Analog Converter (d2a)

The logic-to-analog converter converts a binary signal from a logic simulator to an analog waveform.

This device is not supported within altergroup.

Sample Instance Statement

```
d2a_1 (net1 net2) d2a src="99991" val0=0 val1=2.5 valx=1.25 rise=200p fall=200p m=2
//99991 is an analog net
```

Instance Definition

```
Name  p  n d2a parameter=value ...
```

Instance Parameters

1 `src` The foreign simulators name for the source of the analog signal.

2 `nestlev=0`	Number of nesting levels to ignore in the hierarchical name. This should be used skip over extra levels that do not exist in the co-simulator.
3 `val0=0 V`	Final value for logical 0.
4 `val1=5 V`	Final value for logical 1.
5 `valx (V)`	Final value for logical X.
6 `valz (V)`	Final value for logical Z.
7 `rise=1ns s`	Time for transition from `val0` to `val1`.
8 `fall=1ns s`	Time for transition from `val1` to `val0`.
9 `ron=100 Ω`	Output resistance when in active state.
10 `m=1`	Multiplicity factor.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Ideal Switch (switch)

Ideal switch is a single-pole multiple-throw switch with infinite `off` resistance and zero `on` resistance. The switch is provided to allow you to reconfigure your circuit between analyses.

You can only change the switch state between analyses (using the alter statement), not during an analysis.

When the switch is set to position 0 it is open. In other words, no terminal is connected to any other. When the switch is set to position 1, terminal 1 is connected to terminal 0, and all others are unconnected. When the position is set to 2, terminal 2 is connected to terminal 0, etc.

An offset voltage is supported. It is placed in series with the common terminal. The negative side of the source is connected to the common terminal.

The switch can change its position based on which analysis type is being performed using the `xxx_position` parameters. This feature should be used carefully. Careless use can generate discontinuities that result in convergence problems. Once an analysis specific position has been specified using `xxx_position`, it will always dominate over a position given with the `position` parameter. To disable an analysis specific position, alter it to its default value of unspecified.

This device is not supported within altergroup.

Sample Instance Statement

```
sw1 (t1 t2 t3) switch dc_position=0 ac_position=1 tran_position=2
```

Instance Definition

```
Name  t0  t1 ... switch parameter=value ...
```

Instance Parameters

1	`position=0`	Switch position (0, 1, 2, ...).
2	`dc_position`	Position to which switch is set at start of DC analysis.
3	`ac_position`	Position to which switch is set at start of AC analysis.
4	`tran_position`	Position to which switch is set at start of transient analysis.
5	`ic_position`	Position to which switch is set at start of IC analysis (precedes transient analysis).
6	`offset=0`	Offset voltage in series with common terminal.
7	`m=1.0`	Multiplicity factor.

Output Parameters

1 `present_position`

Current switch position.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

ac_position I-3	ic_position I-5	offset I-6	present_position O-1
dc_position I-2	m I-7	position I-1	tran_position I-4

Ratiometric Fourier Analyzer (fourier)

The ratiometric Fourier analyzer measures the Fourier coefficients of two different signals at a specified fundamental frequency without loading the circuit. The algorithm used is based on the Fourier integral rather than the discrete Fourier transform and therefore is not subject to aliasing. Even on broad-band signals, it computes a small number of Fourier coefficients accurately and efficiently. Therefore, this Fourier analyzer is suitable on clocked sinusoids generated by sigma-delta converters, pulse-width modulators, digital-to-analog converters, sample-and-holds, and switched-capacitor filters as well as on the traditional low-distortion sinusoids produced by amplifiers or filters.

The analyzer is active only during a transient analysis. For each signal, the analyzer prints the magnitude and phase of the harmonics along with the total harmonic distortion at the end of the transient analysis. The total harmonic distortion is found by summing the power in all of the computed harmonics except DC and the fundamental. Consequently, the distortion is not accurate if you request an insufficient number of harmonics The Fourier analyzer also prints the ratio the spectrum of the first signal to the fundamental of the second, so you can use the analyzer to compute large signal gains and immittances directly.

If you are concerned about accuracy, perform an additional Fourier transform on a pure sinusoid generated by an independent source. Because both transforms use the same time points, the relative errors measured with the known pure sinusoid are representative of the errors in the other transforms. In practice, this second Fourier transform is performed on the reference signal. To increase the accuracy of the Fourier transform, use the `points` parameter to increase the number of points. Tightening `reltol` and setting `errpreset=conservative` are two other measures to consider.

The accuracy of the magnitude and phase for each harmonic is independent of the number of harmonics computed. Thus, increasing the number of harmonics (while keeping `points` constant) does not change the magnitude and phase of the low order harmonics, but it does improve the accuracy of the total harmonic distortion computation. However, if you do not specify `points`, you can increase accuracy by requesting more harmonics, which creates more points.

The large number of points required for accurate results is not a result of aliasing. Many points are needed because a quadratic polynomial interpolates the waveform between the time-points. If you use too few time-points the polynomials deviate slightly from the true waveform between time-points and all of the computed Fourier coefficients are slightly in error. The algorithm that computes the Fourier integral does accept unevenly spaced time-points, but because it uses quadratic interpolation, it is usually more accurate using time-steps that are small and nearly evenly spaced.

This device is not supported within altergroup.

Sample Instance Statement

```
four1 (1 0) fourmod harms=50
```

Sample Model Statement

```
model fourmod fourier fund=900M points=2500 order=2
```

Instance Definition

```
Name  [p]  [n]  [pr]  [nr] ModelName parameter=value ...
Name  [p]  [n]  [pr]  [nr] fourier parameter=value ...
```

The signal between terminals `p` and `n` is the test or numerator signal. The signal between terminals `pr` and `nr` is the reference or denominator signal. Fourier analysis is performed on terminal currents by specifying the `term` or `refterm` parameters. If both `term` and `p` or `n` are specified, then the terminal current becomes the numerator and the node voltages become the denominator. By mixing voltages and currents, it is possible to compute large signal immittances.

Instance Parameters

1 `fund (Hz)`	Fundamental frequency.
2 `points=20 maxharm`	Minimum number of time points.
3 `active=yes`	Whether Fourier analysis should be performed or skipped. Possible values are `no` or `yes`.
4 `order=2`	Order of interpolation.
5 `term`	Terminal used to measure current for test (numerator) channel.
6 `refterm`	Terminal used to measure current for reference (denominator) channel.
7 `harmsvec=[...]`	Array of desired harmonics for test (numerator) channel.
8 `harms=9`	Number of harmonics for test (numerator) channel, if an array is not given. The harmonics start from `firstharm` and go up to `firstharm` + `harms` - 1.
9 `refharmsvec=[...]`	Array of desired harmonics for reference (denominator) channel.
10 `refharms=9`	Number of harmonics for reference (denominator) channel, if an array is not given. The harmonics start from `reffirstharm` and go up to `reffirstharm` + `harms` - 1.
11 `scale=1`	Scale factor for ratio results.
12 `firstharm=1`	First harmonic computed for test (numerator) channel.
13 `reffirstharm=1`	First harmonic computed for reference (denominator) channel.
14 `normharm=1`	Normalizing harmonic for test (numerator) channel.
15 `refnormharm=1`	Normalizing harmonic for reference (denominator) channel.
16 `where=logfile`	Where Fourier results should be printed. Possible values are `screen`, `logfile` or `both`.

Model Definition

```
model modelName fourier parameter=value ...
```

Model Parameters

1 `fund (Hz)` Fundamental frequency.

2 `points=20 maxharm`
Minimum number of time points.

3 `harms=9` Desired number of harmonics.

4 `active=yes` Whether Fourier analysis should be performed or skipped. Possible values are `no` or `yes`.

5 `order=2` Order of interpolation.

6 `firstharm=1` First harmonic computed for test (numerator) channel.

7 `reffirstharm=1` First harmonic computed for reference (denominator) channel.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

`fund  M-1          order  M-5          refharmsvec  I-9`

IBIS I/O buffer (ibis_buffer)

IBIS buffer model is based on IBIS (I/O Buffer Information Specification) standard, version 3.2. Package and board models, are not included in the buffer, and have to be added as separate subcircuits.

This device is not supported within altergroup.

Driver equations

Current at the `die` terminal is a function of time and voltage:

I(die) = Ipd(V(die)-V(gnd))*Wd(t) + Icd(V(die)-V(gnd_c))

+ Ipu(V(die)-V(pwr))*Wu(t) + Icu(V(die)-V(pwr_c))

Ipd(V), Ipu(V), Icd(V), and Icu(V) are peace-wise linear transfer functions of pull-down, pull-up, ground clamp, and power clamp voltage controlled current sources. Wd(t) and Wu(t) are switching coefficient functions for pull-up and pull-down sources, defined as follows.

When the buffer is in the high state,

Wd(t)=0, Wu(t)=1.

When the state of the buffer is low,

Wd(t)=1, Wu(t)=0.

During a transition from low to high state

Wd(t)=Wdr(t-t0), Wu(t)=Wur(t-t0),

during a hi-lo transition

Wd(t)=Wdf(t-t0), Wu(t)=Wuf(t-t0),

where t0 - is a time when transition was initiated.

For the 3-state or I/O buffer types, driver can be disabled by `en` signal, then both Wu(t)=Wd(t)=0.

Wdr(t), Wur(t), Wdf(t), and Wuf(t) are pwl functions of time, derived from the rising and falling test waveforms and loads.

State of the buffer is defined by the voltage on the `out` terminal, and buffer polarity. During DC analysis buffer can be ether in high, or low state. For non-inverting buffer the state is high when V(out)>0.5, and low when V(out)>=0.5. For inverting buffer it is other way around. During transient analysis the buffer is turned into transition state at the time t0, when V(out) crosses the midpoint V(out)=0.5. When both Wd(t) and Wu(t) switching coefficient functions reach their final 1 or 0 values, the buffer returns to the static high or low state.

Receiver equations

Voltage at the `in` terminal is a controlled by voltage at the `die` node.

If V(die) > Vth_hi, then V(in) = 1, if V(die) < Vth_lo, then V(in) = 0.

In between Vth_hi >= V(die) >= Vth_lo, V(in) keeps previously assigned voltage.

For differential input buffers the voltage difference between non-inverting and inverting pins: V(die)-V(inv_die) is used instead of V(die)

Switching coefficients

Switching coefficients, if not given, are calculated from the test waveforms and loads. If two waveforms are available for rising transition (V1r, V2r) and two for falling (V1f, V2f), then linear system of equations is solved for pairs of switching coefficients (Wdr, Wur) and (Wdf, Wuf) at each time t:

Ipd(Vr1-Vgnd)*Wdr + Ipu(Vr1-Vpwr)*Wur = I0(Vr1)

Ipd(Vr2-Vgnd)*Wdr + Ipu(Vr2-Vpwr)*Wur = I0(Vr2)

Ipd(Vf1-Vgnd)*Wdf + Ipu(Vf1-Vpwr)*Wuf = I0(Vf1)

Ipd(Vf2-Vgnd)*Wdf + Ipu(Vf2-Vpwr)*Wuf = I0(Vf2)

Where Ipd(V), Ipu(V) are pull-down and pull-up current source fonctions. Load current I0(V) for each load resistance Rl, voltage Vl, and capacitance Cl is calculated as:

I0(V) = (Ccomp+Cl)*dV/dt - (V-Vl)/Rl - Igc(V-Vgndc) - Ipc(V-Vpwrc)

If only one waveform is available for each transition, additional equations are used:

Wdr + Wur = 1

Wdf + Wuf = 1

If no waveforms are given, then `ramp` parameters are used to determine the coefficients. In this case they will be linear functions of time with the slope equal to `ramp` value.

Sample Instance Statement

```
pin1 (die in out en gnd vdd gnd_c vdd_c) iobuff1
pin2 (die out en) ibis_buffer file="models.ibs" model="out2"
```

Sample Model Statement

```
model iobuff1 ibis_buffer type=io vrange=3 ccomp=1p polarity=noninv enable=high
    pullup=[-3 30m -2 25m -1 15m 0 0 1 -15m 2 -24m 3 -30m 4 -35m 5 -36m 6 -37m]
     pulldown=[6 40m 5 38m 4 35m 3 30m 2 25m 1 15m 0 0 -1 -15m -2 -24m -3 -30m]
      uprise=[0 0 3n 1]
      downrise=[0 1 3n 0]
      upfall=[0 1 3n 0]
      downfall=[0 0 3n 1]
      gndclamp=[-4 -40 -0.4 0 0 0]
```

Instance Definition

```
Name die [inp] [out] [en] [gnd] [pwr] [gnd_c] [pwr_c] [inv_die] ModelName
parameter=value ...
Name die [inp] [out] [en] [gnd] [pwr] [gnd_c] [pwr_c] [inv_die] ibis_buffer
parameter=value ...
```

Terminal comments

Number of terminals depend on the type of the buffer.

Only one terminal - `die` - is required for terminator.

Terminals `out` and `en` are required for output buffer. They connect to digital signals, which control pullup and pulldown current sources driving the `die`.

Input buffer must have `in` terminal, which is digital signal received from the `die`.

Terminals `gnd`, `pwr`, `gnd_c`, `pwr_c` provide optional ground and power connections for pull-down, pull-up, ground clamp, and power clamp current sources. Opendrain buffers do not require power connections. Opensource have no groun connections. Either none, or all possible reference voltage terminals have to be specified.

For differential input buffers `inv_die` terminal provides input voltage reference. It have to be connected to the die pad of the inverse pin.

buffer type	terminals (y-required, n-not, o-optional)								
	die	in	out	en	gnd	pwr	gnd_c	pwr_c	inv_die
terminator	y	n	n	n	n	n	o	o	n
input	y	y	n	n	n	n	o	o	o
output	y	n	y	n	o	o	o	o	n
tristate	y	n	y	y	o	o	o	o	n
io	y	y	y	y	o	o	o	o	o
opendrain	y	n	y	n	o	n	o	n	n
ioopendrain	y	y	y	y	o	n	o	n	o
opensource	y	n	y	n	n	o	n	o	n
ioopensource	y	y	y	y	n	o	n	o	o

Buffer type `opensink` is same as `opendrain`, and `ioopensink` is same as `ioopendrain`. Buffer types ending with ecl (inputecl, outputecl, ioecl, tristateecl) have same terminals as their normal counterparts (input, output, io, tristate).

Instance Parameters

1	`file`	Name of ibis file containing buffer model information.
2	`model`	Name of the model section in ibis file.
3	`corner=0`	IBIS model corner. Allowed values are: 0 or `typical`, 1 or `minimal`, 2 or `maximal`. Possible values are `typical`, `minimal` or `maximal`.

Differential buffer parameters

4	`polarity=inv`	Polarity of the buffer. Possible values are `inv` or `noninv`.
5	`delay (s)`	Relative delay for differential output buffer.
6	`vdiff (V)`	Threshold voltage for differential input buffer.

Multistage buffer parameters

7 `delay_schedule=[...] s` Delay schedule. Format: [rise_on_dly rise_off_dly fall_on_dly fall_off_dly].

HSPICE compatibility parameters. Ignored in spectre mode

8 `compatible=spectre`
Selects buffer format - terminal order, parameters. Possible values are `spectre` or `hspice`.

9 `buffer` IBIS model type. If given, must correspond to the buffer model type in the IBIS file. Allowed values are: 1 or `input`, 2 or `output`, 3 or `input_output`, 4 or `three_state`, 5 or `open_drain`, 6 or `io_open_drain`, 7 or `open_sink`, 8 or `io_open_sink`, 9 or `open_source`, 10 or `io_open_source`, 11 or `input_ecl`, 12 or `output_ecl`, 13 or `io_ecl`, 14 or `three_state_ecl`, 17 or `terminator`, .
Possible values are `none`, `input`, `output`, `input_output`, `three_state`, `open_drain`, `io_open_drain`, `open_sink`, `io_open_sink`, `open_source`, `io_open_source`, `input_ecl`, `output_ecl`, `io_ecl`, `three_state_ecl`, `series`, `series_switch`, or `terminator`.

10 `power` Selects internal (on) or external (off) power sources. Possible values are `on` or `off`.

11 `interpol` Interpolation method. Possible values: 1, 2.

12 `ramp_rwf` Use rising waveform, or ramp. Possible values: 0, 1, 2.

13 `ramp_fwf` Use falling waveform, or ramp. Possible values: 0, 1, 2.

14 `rwf_tune` Tune value for rising waveform.

15 `fwf_tune` Tune value for falling waveform.

16 `c_com_pu` Pull-up portion of die capacitance.

17 `c_com_pd` Pull-down portion of die capacitance.

18 `c_com_pc` Power-clamp portion of die capacitance.

19 `c_com_gc`	Ground-clamp portion of die capacitance.
20 `xv_pu`	
21 `xv_pd`	
22 `pu_scal`	Pull-up current scale factor.
23 `pd_scal`	Pull-down current scale factor.
24 `pc_scal`	Power-clamp current scale factor.
25 `gc_scal`	Ground-clamp current scale factor.
26 `rwf_scal`	Rising waveform scale factor.
27 `fwf_scal`	Falling waveform scale factor.
28 `spu_scal (V)`	High state voltage.
29 `spd_scal (V)`	Low state voltage.

Model Definition

```
model modelName ibis_buffer parameter=value ...
```

Model Parameters

1 `type=tristate`	Type of the buffer. Possible values are `input`, `output`, `io`, `tristate`, `opendrain`, `ioopendrain`, `opensource`, `ioopensource`, `terminator`, `inputecl`, `outputecl`, `ioecl`, `tristateecl`, `opensink`, or `ioopensink`.
2 `ccomp=0 F`	Node capacitance on the die pad.
3 `enable=high`	Polarity of the enable signal. Possible values are `low` or `high`.
4 `polarity=inv`	Polarity of the buffer. Possible values are `inv` or `noninv`.

Voltage reference parameters

5 `vrange=5.0 V` Reference voltage.

6 `vref=[...] V` Reference voltage, format [gnd pwr gnd_c pwr_c].

Voltage controlled current sources (I/V tables)

7 `pullup=[...]` Pull-up current source, format [v1 i1 ...].

8 `pulldown=[...]` Pull-down current source, format [v1 i1 ...].

9 `powerclamp=[...]` Power clamp current source, format [v1 i1 ...].

10 `gndclamp=[...]` Gnd clamp current source, format [v1 i1 ...].

Switching coefficients (W/T tables)

11 `uprise=[...]` Pull-up source, rising edge, format [t1 w1 ...].

12 `upfall=[...]` Pull-up source, falling edge, format [t1 w1 ...].

13 `downrise=[...]` Pull-down source, rising edge, format [t1 w1 ...].

14 `downfall=[...]` Pull-down source, falling edge, format [t1 w1 ...].

Test waveforms (V/T tables) and loads

15 `vtrise1=[...]` Rising waveform, format [t1 v1 ...].

16 `loadrise1=[...]` Load for the rising waveform, format [v r c l].

17 `vtfall1=[...]` Falling waveform, format [t1 v1 ...].

18 `loadfall1=[...]` Load for the falling waveform, format [v r c l].

19 `vtrise2=[...]` Rising waveform, format [t1 v1 ...].

20 `loadrise2=[...]` Test load for the rising waveform, format [v r c l].

21 `vtfall2=[...]` Falling waveform, format [t1 v1 ...].

22 `loadfall2=[...]` Test load for the falling waveform, format [v r c l].

23 `ramp=[...]` Rise and fall time, format [dv_rise dt_rise dv_fall dt_fall].

Input logic parameters

24 `vth=[...] V` Low and High switching threshold, format [vth_lo vth_hi].

When `file` and `model` parameters are given, buffer model information is read from the `model` section of the `file`. It is assumed that file has standard IBIS format if it has extension `.ibs`.

If `vref` is not given, reference voltages are set according to `vrange` value: vref=[0 vrange 0 vrange]. If reference voltage terminals are provided for the buffer instance, then both vref and vrange are ignored.

Multistaged buffers can modeled as multiple simple ibis buffers connected in parallel. Each stage may have different on and off switching delay relatively to the initial transition edge. Driver schedule have to be specified only for the instances, which are parts of multistaged buffer.

Differential buffer can be modeled by a pair of buffers, one for inverting pin, and another for noninverting pin. Instance parameter `polarity` is used to override the buffer model polarity. In the case of output buffer, `delay` sets transition delay for non-inverting pin relatively to the inverting one. For differential input buffer the inverse pin have to be specified, and `vdiff` instance parameter overrides threshold voltages defined in the model.

Parameter Index

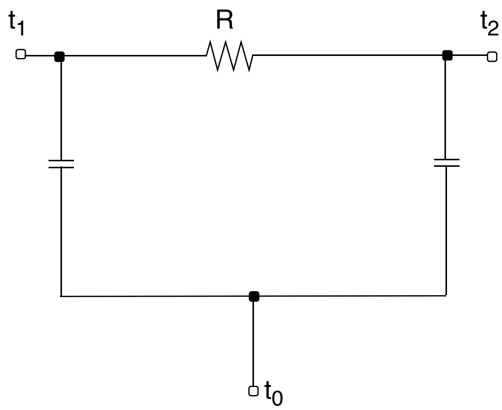
In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

2

Passive Components

This chapter contains information on

Two Terminal Resistor (resistor)



Two Terminal Resistor

If $R(inst)$ is not given and $R(model)$ is given,

$$R(inst) = R(model)$$

Otherwise,

$$R(inst) = Rsh \times \frac{(L - 2 \times etchl)}{(W - 2 \times etch)}$$

If the polynomial coefficients vector (*coeffs=[c1 c2 ...*`]`) is specified, the resistor is nonlinear. When `nonlinform` is set to `g`, the conductance is

$$G(V) = \frac{dI}{dV}$$

$$= \frac{(1 + c1 \times V + c2 \times V^2 + \ldots)}{R(inst)}$$

The branch current as a function of applied voltage is

$$I(V) = \left(\frac{V}{R(inst)}\right) \times \left(1 + \frac{1}{2} \times c1 \times V + \frac{1}{3} \times c2 \times V^2 + \ldots\right)$$

When `nonlinform` is set to `r`, the resistance is

$$R(V) = \frac{dV}{dI}$$
$$= R(inst) \times (1 + c1 \times V + c2 \times V^2 + \ldots)$$

where *ck* is the *k*th entry in the coefficient vector.

The value of the resistor as a function of the temperature is given by

$$R(T) = R(tnom) \times [1 + tc1 \times (T - tnom) + tc2 \times (T - tnom)^2]$$

where

$$T = trise(inst) + temp$$

if *trise(inst)* is given, and

$$T = trise(model) + temp$$

Rac is an instance or model parameter used in AC analysis.

If Rac(inst) is not given and Rac(model) is given,

$$Rac(inst) = Rac(model)$$

The final effective value of AC resistance is:

$$Rac\_\mathrm{eff} = Rac(inst) \times (1.0 + tc1 \times (T - tnom) + tc2 \times (T - tnom)^2)$$

If:

- *Rac* is not specified either in the instance or in the model, *Rac_eff* is the resistor value at operating point.
- *Rac_eff* is less than 1.0e-10 ohms, *Rac_eff*=1.0e-10 ohms.

Noise Model

Thermal Noise:

$$\overline{i_T} = \frac{4kT}{R} \cdot \Delta f$$

where

R is the resistor value and T is the temperature.

Flicker Noise:

$$\overline{i_f} = \frac{KF \cdot I^{AF}}{f^{FEXP}} \cdot \frac{1}{Weff^{WEEXP} \cdot Leff^{LEEXP} \cdot W^{WDEXP} \cdot L^{LDEXP}} \cdot \Delta f$$

where:

KF, AF, FEXP, WEEXP, LEEXP, WDEXP, and LDEXP are model parameters, I is the current, f is the frequency, and W and L are the device width and length.

`Weff=W-2ETCH` and `Leff=L-2ETCHL`.

Wire RC Model

If you specify the capacitance for a two terminal resistor, the model is a Wire RC model. If you do not specify the capacitance explicitly, it is computed from the physical length and width of the resistor using *Cj* and *Cjsw*. You can use the model parameter *cratio* to allocate the parasitic capacitance of the wire element between the model's input capacitor and output capacitor.

If *C(inst)* is not given and *C(model)* is given

$$C(inst) = C(model)$$

Otherwise,

$$C(inst) = Cj \times (L - 2 \times etch1) \times (W - 2 \times etch) + 2 \times Cjsw \times (W + L - 2 \times etch - 2 \times etch1)$$

The parasitic capacitance assigned to the input and output nodes is given by

$$C(1) = C(inst) \times cratio$$

$$C(2) = C(inst) \times (1 - cratio)$$

If Cj is not given, but thick is given and is nonzero, Cj is calculated as follows:

If di is given and is nonzero,

$$Cj = \frac{di \cdot \varepsilon o}{thick}$$

otherwise

$$Cj = \frac{\varepsilon ox}{thick}$$

where

εo = 8.8542149e-12 F/meter

εox = 3.453148e-11 F/meter

The value of each capacitor as a function of the temperature is given by

$$C(T) = C(tnom) \times [1 + tc1c \times (T - tnom) + tc2c \times (T - tnom)^2]$$

Scaling Effects

For scaling effects, see Scaling Factors (scale and scalem) on page 242.

The length and width of the Wire RC model are also scaled by the model parameter *shrink*.

Component Statements

You can give the resistance explicitly or allow it to be computed from the physical length and width of the resistor. In either case, the resistance can be a function of temperature or applied voltage.

This device is supported within altergroups.

If R(inst) is not given and R(model) is given

R(inst) = R(model)

otherwise,

R(inst) = Rsh * (L - 2 * etchl) / (W - 2 * etch)

If the polynomial coefficients vector (coeffs=[c1 c2 ...]) is specified, the resistor is nonlinear. When nonlinform is set to g, the conductance is

G(V) = dI / dV

= (1 + c1 * V + c2 * V^2 + ...) / R(inst).

The branch current as a function of applied voltage is

I(V) = (V / R(inst)) * (1 + 1/2 * c1 * V + 1/3 * c2 * V^2 + ...)

When nonlinform is set to r, the resistance is

R(V) = dV / dI

= R(inst) * (1 + c1 * V + c2 * V^2 + ...).

where ck is the kth entry in the coefficient vector.

For AC analysis, RAC(inst) AC resistance will be used.

If RAC(inst) is not given, and RAC(model) is given,

RAC(inst) = RAC(model)

otherwise,

RAC(inst) will use DC resistance.

The value of the resistor as a function of the temperature is given by:

R(T) = R(tnom) * [1 + tc1 * (T - tnom) + tc2 * (T - tnom)^2]

where

T = trise(inst) + temp

if trise(inst) is given, and

T = trise(model) + temp

otherwise.

If you specify capacitance the model is a wire RC model. You can give the capacitance explicitly or allow it to be computed from the physical length and width of the resistor. The model parameter `cratio` can be used to allocate the parasitic capacitance of the wire element between the models input capacitor and output capacitor.

If C(inst) is not given and C(model) is given,

C(inst) = C(model).

Otherwise,

C(inst) = Cj * (L - 2 * etchl) * (W - 2 * etch) + 2 * Cjsw * (W + L - 2 * etch - 2 * etchl).

The parasitic capacitance assigned to the input and output nodes is given by:

C(1) = C(inst) * cratio

C(2) = C(inst) * (1 - cratio).

The value of each capacitor as a function of the temperature is given by:

C(T) = C(tnom) * [1 + tc1c * (T - tnom) + tc2c * (T - tnom)^2].

Sample Instance Statement

without model:

```
r1 (1 2) resistor r=1.2K rac=100K m=2
```

with model:

```
r1 (1 2) resmod l=8u w=1u
```

Sample Model Statement

```
model resmod resistor rsh=150 l=2u w=2u etch=0.05u tc1=0.1 tnom=27 kf=1
```

This device support behavior expression

Sample behavior Statement

```
r1 (1 0) resistor r=rsh*(1 + v(1,2)*c1 + v(1,2)^2*c2)
r1 (1 0) resistor r= 100 + sqrt($freq)/1e6
```

Instance Definition

```
Name  1  2  [0] ModelName parameter=value ...
Name  1  2  [0] resistor parameter=value ...
```

Instance Parameters

1 `r (Ω)`	Resistance.
2 `l (m)`	Resistor length.
3 `w (m)`	Resistor width.
4 `m=1`	Multiplicity factor.
5 `scale=1`	Scale factor.
6 `resform`	Use the resistance form for this instance. Default is `yes` if `r < thresh`. Possible values are `no` or `yes`.
7 `tc1=0 1/C`	Linear temperature coefficient(alias=lv3,tc1r).
8 `tc1r=0 1/C`	Alias for tc1.
9 `tc2=0` C^{-2}	Quadratic temperature coefficient(alias=lv4,tc2r).
10 `tc2r=0` C^{-2}	Alias for tc2.
11 `trise (C)`	Temperature rise from ambient.
12 `isnoisy=yes`	Should resistor generate noise. Possible values are `no` or `yes`.
13 `c (F)`	Capacitance.
14 `tc1c=0 1/C`	Linear temperature coefficient of capacitor.
15 `tc2c=0` C^{-2}	Quadratic temperature coefficient of capacitor.
16 `rac (Ω)`	Default AC resistance, (alias=ac).
17 `scaler`	Resistance scaling factor.

18 `scalec` — Capacitance scaling factor.

19 `dtemp (C)` — Alias of Temperature rise from ambient.

20 `cap (F)` — Alias of capacitance.

The instance parameter scale, if specified, overrides the value given by the option parameter scale. The w and l parameters are scaled by the resulting scale, and the option parameter scalem. The parameters w and l are scaled also by the model parameter shrink.The values of w and l printed out by spectre are those given in the input, and these values might not have the correct units if the scaling factors are not unity. The actual effective resistor dimensions are stored in the output parameters. You can obtain these dimensions by using the info statement.

Model Definition

```
model modelName resistor parameter=value ...
```

Model Parameters

Resistance parameters

1 `r=0.0 Ω` — Default resistance.

2 `rsh=0.0 Ω/sqr` — Sheet resistance.

3 `thresh=1.0e-3 Ω` — Resistances smaller than this will use the resistance form, as opposed to the standard conductance form.

4 `rthresh=1.0e-3 Ω` — alias of thresh.

5 `rac=0.0 Ω` — Default AC resistance.

Resistor size parameters

6 `l=0.0 m` — Default resistor length.

7 `w=1e-6 m` — Default resistor width.

8 `etch=0 m` — Width narrowing due to etching per side.

9 `etchl=0 m` Length narrowing due to etching per side.

10 `scaler=1` Resistance scaling factor.

Temperature effects parameters

11 `tc1=0 1/C` Linear temperature coefficient.

12 `tc2=0` C^{-2} Quadratic temperature coefficient.

13 `tnom (C)` Parameters measurement temperature. Default set by `options`.

14 `trise=0 C` Default temperature rise from ambient.

Nonlinear resistance

15 `coeffs=[...]` Vector of polynomial conductance coefficients.

16 `nonlinform=g` The form of the nonlinear resistance.
Possible values are `g` or `r`.

17 `symmetric=none` Use symmetric resistor model.
Possible values are `none`, `absolute` or `smooth`.

Noise model parameters

18 `kf=0` Flicker (1/f) noise coefficient.

19 `af=2` Flicker (1/f) noise exponent.

20 `wdexp=1` Flicker (1/f) noise W exponent.

21 `ldexp=1` Flicker (1/f) noise L exponent.

22 `weexp=0` Flicker (1/f) noise W effective exponent.

23 `leexp=0` Flicker (1/f) noise L effective exponent.

24 `fexp=1` Flicker (1/f) noise frequency exponent.

DC-mismatch model parameters

25 `mr=0.0` Resistor mismatch dependence.

26 `mrl=0.0 1/m^mrlp` Resistor mismatch length dependence.

27 `mrlp=0.0` Resistor mismatch length power dependence.

28 `mrw=0.0 1/m^mrwp` Resistor mismatch width dependence.

29 `mrwp=0.0` Resistor mismatch width power dependence.

30 `mrlw1=0.0 1/m^(2 mrlw1p)`
Resistor mismatch area 1 dependence.

31 `mrlw1p=0.0` Resistor mismatch area 1 power dependence.

32 `mrlw2=0.0 1/m^(2 mrlw2p)`
Resistor mismatch area 2 dependence.

33 `mrlw2p=0.0` Resistor mismatch area 2 power dependence.

Wire RC parameters

34 `c=0 F` Default capacitance.

35 `cj=0 F/m`^{2} Bottomwall capacitance.

36 `cjsw=0 F/m` Sidewall fringing capacitance.

37 `thick=0 m` Dielectric thickness.

38 `di=0` Relative dielectric constant.

39 `cratio=0.5` Cratio.

40 `tc1c=0 C`$^{-2}$ Linear temperature coefficient of capacitor.

41 `tc2c=0 C`$^{-2}$ Quadratic temperature coefficient of capacitor.

42 `shrink=1` Shrink Factor.

43 `scalec=1` Capacitance scaling factor.

44 `dtemp=0 C` Alias of default temperature rise from ambient.

45 `cap=0 F` Alias of default capacitance.

46 `dw=0 m` Alias of width narrowing due to etching per side.

47 `dlr=0 m` Alias of length narrowing due to etching per side.

48 `cox=0` F/m^2 Alias of bottomwall capacitance.

49 `capsw=0 F/m` Alias of sidewall fringing capacitance.

50 `res=0` Ω Alias of default resistance.

The instance parameter resform and the model parameter thresh control whether a resistor is formulated in the standard conductance form, or in the resistance form. If the value of the resistor is smaller than thresh, Spectre uses the resistance form; otherwise it uses the conductance form. If resform is set on an instance, it overrides the thresh parameter. The resistance form is appropriate for very small resistances and the conductance form is intended for larger resistances. Using the conductance form for very small resistances or the resistance form for very large resistances can cause convergence problems.

With the resistance form, the resistance can be zero; with the conductance form, the resistance can be infinite. The resistance form is less efficient than the conductance form. You cannot change the formulation of a resistor once it has been determined. Spectre makes this choice by comparing the initial value of the resistance to thresh.

If the polynomial coefficients vector is specified and symmetric=absolute, the resistor model is symmetric. When nonlinform is set to g, the conductance is

G(V) = dI / dV

= (1 + c1 * |V| + c2 * |V|^2 + ...) / R(inst)

where |V| = ABS(V(1) - V(2)) and ck is the kth entry in the coefficient vector.

When nonlinform is set to r, the resistance is

R(V) = dV / dI

= R(inst) * (1 + c1 * |V| + c2 * |V|^2 + ...)

where |V| = ABS(V(1) - V(2)).

If symmetric=smooth the smoothing function f(V) is used:

f(V) = V * V / sqrt(V * V + 0.00001).

For nonlinform=g the conductance is

G(V) = dI / dV

= (1 + c1 * f(V) + c2 * f(V)^2 + ...) / R(inst).

Modeling AC resistance

In certain situations, a part of a circuit that is required to calculate the DC operating point needs to be removed during a subsequent AC analysis or visa versa. An example of a situation in which this occurs is when measuring the loop gain of a feedback amplifier. In this case the feedback loop must be removed when computing the AC response of the amplifier. In Spectre, the most accurate method of doing this is to use an ideal switch component (see `spectre -h switch`), e.g.

Vin (pin 0) vsource mag=1

OA1 (pin nin out) opamp

Sw1 (nin out 0) switch position=1 ac_position=2

LoopGain ac start=1 stop=1MHz

Another possibility is that the resistance of an instance changes from one analysis to another. The following subcircuit models a resistance whose value is given by the parameter `rac` during AC analyses, and `rdc` for all other analyses.

subckt ac_res (a b)

parameters rdc=1 rac=2

R1 (a i) resistor r=rdc

Rac (i b) resistor r=rac-rdc

Sw (i b) switch position=1 ac_position=0

ends ac_res

Output Parameters

1 `leff (m)` Effective resistor length.

2 `weff (m)` Effective resistor width.

3 `reff (Ω)` Effective resistance.

4 `ceff (F)` Effective capacitance.

Operating-Point Parameters

1 `v (V)` Voltage at operating point.

2 `i (A)` Current through the resistor.

3 `res (Ω)` Resistance at op point.

4 `pwr (W)` Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Physical Resistor (phy_res)

A physical resistor consists of a two terminal resistor (tied between `t1` and `t2`) and two diodes (tied between `t1`-`t0` and `t2`-`t0`). The diodes are junction diodes. Under normal operation, the two diodes are reverse biased, but the parameter `subtype` can reverse the direction of the diodes. If you do not specify `t0`, ground is assumed. The instance parameters always override model parameters. If you do not specify the instance resistance value, it is calculated from the model parameters.

This device is supported within altergroups.

If R(inst) is not given and R(model) is given,

R(inst) = R(model).

Otherwise,

R(inst) = Rsh * (L - 2 * etchl) / (W - 2 * etch).

If the polynomial coefficients vector (coeffs=[c1 c2 ...]) is specified, the resistor is nonlinear. When `nonlinform` is set to `g`, the conductance is

G(V) = dI / dV

= (1 + c1 * V + c2 * V^2 + ...) / R(inst)

where

V = V(t1) - V(t2)

Here V is the controlling voltage across the resistor. It is also the controlling voltage when the model parameter `polyarg` is set to `diff`. In this form, the physical resistor is symmetric with respect to V(t1) and V(t2). The branch current as a function of the applied voltage is given by

I(V) = (V / R(inst)) * (1 + 1/2 * c1 * V + 1/3 * c2 * V^2 + ...)

where ck is the kth entry in the coefficient vector.

If the model parameter `polyarg` is set to `sum`, then the controlling voltage is defined as

Vsum = ((V(t1) - V(t0)) + (V(t2) - V(t0)))/2

Here, Vsum is the controlling voltage between the resistor and the substrate, `t0`. In this case, the device becomes asymmetric with respect to V(t1) and V(t2). The branch current as a function of the applied voltage for this case is given by

I(Vsum) = (V / R(inst)) * (1 + c1 * Vsum + c2 * Vsum^2 + ...)

The large-signal conductance is given by

G(Vsum) = I/V = (1 + c1 * Vsum + c2 * Vsum^2 + ...) / R(inst)

Note, since the device is asymmetrical, the small-signal model is more complicated then a simple conductance.

When `nonlinform` is set to `r`, the resistance is

R(V) = dV / dI

= R(inst) * (1 + c1 * V + c2 * V^2 + ...).

The resistance as a function of temperature is given by:

R(T) = R(tnom) * [1 + tc1 * (T - tnom) + tc2 * (T - tnom)^2].

where

T = trise(inst) + temp

if trise(inst) is given, and

T = trise(model) + temp

otherwise.

If you do not specify the junction leakage current (`is`) and `js` is specified, the leakage current is calculated from `js` and the device dimensions.

is = js * 0.5 * (L - 2 * etchl) * (W - 2 * etch)

If you specify the instance capacitance or the linear model capacitance, linear capacitors are used between `t1`-`t0` and `t2`-`t0`. Otherwise, nonlinear junction capacitors are used and the zero-bias capacitance values are calculated from the model parameters.

If C(inst) is not given and C(model) is given,

C(inst) = C(model).

Otherwise,

C(inst) = 0.5 * Cj * (L - 2 * etchlc) * (W - 2 * etchc) + Cjsw * (W + L - 2 * etchc - 2 * etchlc).

If the capacitance is nonlinear, the temperature model for the junction capacitance is used. Otherwise, the following equation is used.

C(T) = C(tnom) * [1 + tc1c * (T - tnom) + tc2c * (T - tnom)^2].

Thermal Noise

$$\overline{i_T} = \frac{4kT}{R} \cdot \Delta f$$

where:

R is the resistor value and T is the temperature.

Shot Noise for the Junctions

$$\overline{i_S} = 2 \cdot q \cdot I \cdot \Delta f$$

Where I is the current flow through the junction.

Flicker Noise for the Resistor

$$\overline{i_f} = \frac{KF \cdot I^{AF}}{f^{FEXP}} \cdot \frac{1}{Weff^{WEEXP} \cdot Leff^{LEEXP} \cdot W^{WDEXP} \cdot L^{LDEXP}} \cdot \Delta f$$

Where KF, AF, FEXP, WEEXP, LEEXP, WDEXP and LDEXP are model parameters, I is the current, W and L are the device width and length, `Weff=W-2ETCH` and `Leff=L-2ETCHL`.

Flicker Noise for the Junctions

$$\overline{i_f} = \frac{KF \cdot I^{AF}}{f^{FEXP}} \cdot \Delta f$$

Where:

Where KF, AF and FEXP are model parameters, I is the current, and f is the frequency.

Sample Instance Statement

```
res1 (net9 vcc) resphy l=1e-3 w=2e-6
```

Sample Model Statement

```
model resphy phy_res rsh=85 tc1=1.53e-3 tc2=4.67e-7 etch=0 cj=1.33e-3 cjsw=3.15e-
10 tc1c=9.26e-4
```

Instance Definition

```
Name  1  2  [0] ModelName parameter=value ...
```

Instance Parameters

1 `r (Ω)`	Resistance.
2 `c (F)`	Linear capacitance.
3 `l (m)`	Line length.
4 `w (m)`	Line width.
5 `region=normal`	Estimated operating region. Spectre outputs number (0-1) in a rawfile. Possible values are `normal` or `breakdown`.
6 `tc1=0 1/C`	Linear temperature coefficient of resistor.
7 `tc2=0` C^{-2}	Quadratic temperature coefficient of resistor.
8 `tc1c=0 1/C`	Linear temperature coefficient of linear capacitor.
9 `tc2c=0` C^{-2}	Quadratic temperature coefficient of linear capacitor.
10 `trise (C)`	Temperature rise from ambient.
11 `isnoisy=yes`	Should resistor generate noise. Possible values are `no` or `yes`.
12 `m=1`	Multiplicity factor.

The `w` and `l` parameters are scaled by the option parameters `scale` and `scalem`. The values of `w` and `l` printed by Spectre are those given in the input file. These values may not have the correct units if the scaling factors are not unity. The actual effective resistor dimensions are stored in the output parameters. You can obtain these dimensions with the info statement. You can delete the diodes from the device by either setting `is`=0 or `subtype=poly`. You can also set both `mj` and `mjsw` to zero to make the capacitance linear but still calculated from the device geometry. If `subtype=poly`, the linear capacitors will always be used irrespective of the values of `mj` and `mjsw`.

Model Definition

```
model modelName phy_res parameter=value ...
```

Model Parameters

Substrate type parameters

1 `subtype=p` — Substrate type.
Possible values are `n`, `p` or `poly`.

Resistance parameters

2 `r=∞ Ω` — Default resistance.

3 `rsh=∞ Ω/sqr` — Sheet resistance.

4 `minr=0.1 Ω` — Minimum resistance.

5 `coeffs=[...]` — Vector of polynomial conductance or resistance coefficients.

6 `nonlinform=g` — The form of the nonlinear resistance.
Possible values are `g` or `r`.

7 `polyarg=diff` — Polynomial model argument type.
Possible values are `sum` or `diff`.

Temperature effects parameters

8 `tc1=0 1/C` — Linear temperature coefficient of resistor.

9 `tc2=0` C^{-2} — Quadratic temperature coefficient of resistor.

10 `tc1c=0` C^{-2} — Linear temperature coefficient of linear capacitor.

11 `tc2c=0` C^{-2} — Quadratic temperature coefficient of linear capacitor.

12 `tnom (C)` — Parameters measurement temperature. Default set by `options`.

13 `trise=0 C` — Temperature rise from ambient.

Junction diode model parameters

14 `is (A)` — Saturation current.

15 `js=0 A/m`^{2} Saturation current density.

16 `n=1` Emission coefficient.

17 `eg=1.11 V` Band gap.

18 `xti=3` Saturation current temperature exponent.

19 `imelt=`imax' A` Explosion current, diode is linearized beyond this current to aid convergence.

20 `jmelt=`jmelt' A/m`^{2}
Explosion current density, diode is linearized beyond this current to aid convergence.

21 `imax=1 A` Maximum current, currents above this limit generate a warning.

22 `jmax=1e8 A/m`^{2} Maximum current density, currents above this limit generate a warning.

23 `dskip=yes` Use simple piece-wise linear model for diode currents below 0.1*`iabstol`.
Possible values are `no` or `yes`.

24 `bvj=∞ V` Junction reverse breakdown voltage.

Junction capacitance model parameters

25 `c=0 F` Default linear capacitance.

26 `cj=0 F/m`^{2} Zero-bias junction bottom capacitance density.

27 `cjsw=0 F/m` Zero-bias junction sidewall capacitance density.

28 `mj=1/2` Junction bottom grading coefficient.

29 `mjsw=1/3` Junction sidewall grading coefficient.

30 `pb=0.8 V` Junction bottom built-in potential.

31 `pbsw=0.8 V` Junction sidewall built-in potential.

32 `fc=0.5` Junction bottom capacitor forward-bias threshold.

33 `fcsw=0.5` Junction sidewall capacitor forward-bias threshold.

34 `tt=0 s` Transit time.

Device size parameters

35 `l=∞ m` Default line length.

36 `w=1e-6 m` Default line width.

37 `etch=0 m` Narrowing due to etching.

38 `etchl=0 m` Length reduction due to etching.

39 `etchc=etch m` Narrowing due to etching for capacitances.

40 `etchlc=etchl m` Length reduction due to etching for capacitances.

41 `scaler=1` Resistance scaling factor.

42 `scalec=1` Capacitance scaling factor.

Noise model parameters

43 `kf=0` Flicker (1/f) noise coefficient.

44 `af=1` Flicker (1/f) noise exponent.

45 `wdexp=1` Flicker (1/f) noise W exponent.

46 `ldexp=1` Flicker (1/f) noise L exponent.

47 `weexp=0` Flicker (1/f) noise W effective exponent.

48 `leexp=0` Flicker (1/f) noise L effective exponent.

49 `fexp=1` Flicker (1/f) noise frequency exponent.

DC-mismatch model parameters

50 `mr=0.0` Ω^2 Resistor mismatch dependence.

51 `mrl=0.0` Ω^2`/m^mrlp`
Resistor mismatch length dependence.

52 `mrlp=0.0` Resistor mismatch length power dependence.

53 `mrw=0.0` Ω^2`/m^mrwp`
Resistor mismatch width dependence.

54 `mrwp=0.0` Resistor mismatch width power dependence.

55 `mrlw1=0.0` Ω^2`/m^(2 mrlw1p)`
Resistor mismatch area 1 dependence.

56 `mrlw1p=0.0` Resistor mismatch area 1 power dependence.

57 `mrlw2=0.0` Ω^2`/m^(2 mrlw2p)`
Resistor mismatch area 2 dependence.

58 `mrlw2p=0.0` Resistor mismatch area 2 power dependence.

Output Parameters

1 `leff (m)` Effective line length.

2 `weff (m)` Effective line width.

3 `iseff (A)` Effective saturation current.

4 `reff (`Ω`)` Effective resistance.

5 `ceff (F)` Effective zero-bias capacitance.

Operating-Point Parameters

1 `subtype=p` Substrate type.
Possible values are `n`, `p` or `poly`.

2 `region=normal` Estimated operating region. Spectre outputs number (0-1) in a rawfile.
Possible values are `normal` or `breakdown`.

3 `i (A)` Current through the resistor.

4 `capd1 (F)` Capacitance at the positive node.

5 `capd2 (F)` Capacitance at the negative node.

6 `id1 (A)` Current between nodes `t1` and `t0`.

7 `id2 (A)` Current between nodes `t2` and `t0`.

8 `res (Ω)` Resistance between nodes `t1` and `t2`.

9 `resd1 (Ω)` Resistance between nodes `t1` and `t0`.

10 `resd2 (Ω)` Resistance between nodes `t2` and `t0`.

11 `pwr (W)` Power at op point.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

R2 Model (r2)

The R2 model is a nonlinear 2-terminal resistor model. The model does not include parasitic capacitances. As an option, the model can include self-heating. The nonlinearity form is from Agere Systems, and effectively implements first and second order electric field coefficients of resistance. The R2 model does not have the numerical problems that can arise in polynomial models. Although empirical, the form of the nonlinearity can model data reasonably well, especially for velocity saturation effects which are important in short resistors.

Usage

With model card:

```
r<instanceName> (<node1> <node2>) <modelName> <instanceParameters> .model
<modelName> <modelParameters>
```

Without model card:

```
r<name> (<node1> <node2>) r=<resistanceValue> [tc1=<tc1Value>] [tc2=<tc2Value>]
```

Examples

```
r137 (n1 n2) rnpoly1 w=1u l=10u
.model rnpoly1 r2
+ rsh=100.0 xl=0.2u xw=-0.05u
+ p3=0.12 q3=1.63 p2=0.014 q2=3.79
```

Equivalent Circuit

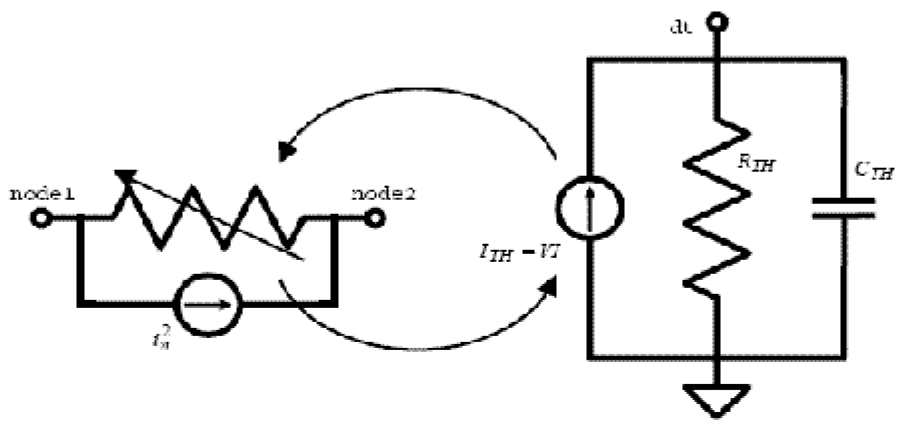


Figure 2-1 Model Equivalent Network (the thermal sub-network is optional)

Bias Dependence

If V is the voltage between the terminals node1 and node2, then the current flowing from node1 to node2 is

(2-1)

$$I = \frac{V}{r\_dc}$$

the DC bias dependent resistance is

(2-2)

$$r\_\mathrm{dc} = R_0(T) \cdot rFactor$$

where $R_0(T)$ is the zero-bias resistance at the device temperature (which includes self-heating for the electrothermal version of the model), and the bias-dependent resistance factor is

(2-3)

$$rFactor = 1 - p2 - p3 + p2\sqrt{1 + (q2\mathrm{E})^2} + p3\sqrt[3]{1 + |q3\mathrm{E}|^3}$$

The electric field E can be calculated based on either the design length or the effective electrical length, depending on the switch parameter `sw_efgeo`. This is because, depending upon how the model is used and the model parameters are characterized, there can be effects in the value of `xl` (the parameter that defines the difference between the design length and the effective electrical length) that are not related to velocity saturation (e.g. if end spreading and/or contact resistance are included in xl). If `sw_efgeo` is `1` (`true`), the electric field is calculated from the effective geometry.

(2-4)

$$\mathrm{E} = \frac{V}{leff\_\mathrm{um} + dxle}$$

otherwise it is calculated from the design geometry,

(2-5)

$$\mathrm{E} = \frac{V}{1\_\mathrm{um} + dxle}$$

In both cases, an additional length offset `dxle` is included to allow flexibility and optimization in fitting data by separating the lengths used for resistance and field nonlinearity calculation. Although there is a singularity at $V = E = 0$ because of the absolute value operation in Equation 2-3 on page 185, the derivative of Equation 2-1 on page 184 with respect to voltage is defined and continuous up to third order. The fourth order derivative does not exist at $V = 0$ and its left limit does not equal its right limit there.

For the electrothermal version of the model, the thermal power is calculated as

(2-6)

$$I_{TH} = V \cdot I$$

and the powers that flow through the thermal resistance and thermal capacitance are

(2-7)

$$T(dt)*g_{TH}$$

and

(2-8)

$$ddt(T(dt)*c_{TH})$$

respectively, where *T*(dt) is the local temperature rise due to self-heating and the thermal conductance and capacitance are g_{TH} and c_{TH}, respectively. The thermal admittance is $y_{TH} = g_{TH} + j\omega c_{TH}$.

Geometry Dependence

The basic calculation for the (zero bias) resistance of a resistor is R_0 = rsh*L/W*. Because of several physical effects, the length and width used in this calculation differ from the design (or mask) length and width that define the resistor layout.

The r2 model incorporates a simple, fixed offset between design and effective (electrical) length and width. Because subcircuit models for resistors can consist of multiple resistance sections connected in series, it is desirable to be able to switch on and off the end corrections for length to facilitate implementation of such multi-section models. This is the function of the c1 and c2 instance parameters of the r2 model. The effective length offset is

(2-9)

$$\mathrm{x}leff = xl(c1 + c2)/2$$

(which is zero if neither end is contacted, xl if both ends are contacted, and xl/2 if only one end is contacted).

The design length and width, in units of microns, are

(2-10)

$$l\_\mathrm{um} = l \cdot scale \cdot (1 - shrink/100) \cdot 10^6$$

(2-11)

$$w\_\mathrm{um} = l \cdot scale \cdot (1 - shrink / 100) \cdot 10^6$$

where conversions from optical shrinking and unit scale conversion are included. If `scale` is `1` then `l` and `w` should be specified on model instances in meters. If scale is `1.0e-6` then `l` and `w` should be specified in units if microns. The effective electrical dimensions are

(2-12)

$$leff\_\mathrm{um} = l\_\mathrm{um} + xleff$$

(2-13)

$$weff\_\mathrm{um} = w\_\mathrm{um} + xw$$

There are three modes of geometric calculation based on the instance parameters `w`, `l`, and `r`. All modes are based on resistance being specified (or calculated), at zero applied bias and at the nominal device temperature specified by the parameter `tnom`. The order of importance of considering the instance parameters is (in order of from most to least important) width, length, and resistance. If all are specified, the instance `r` value is ignored, and resistance is calculated from the specified length and width.

(2-14)

$$R_{0,\,nom} = r$$

and the effective width is calculated

(2-15)

$$weff\_\mathrm{um} = \frac{rsh}{R_{0,\,nom}} leff\_\mathrm{um}$$

and possibilities of zero resistance or length, and error conditions of negative length or width, are handled.

If resistance is specified, and length is not specified, then

(2-16)

$$R_{0,\,nom} = r$$

(2-17)

$$leff\_\mathrm{um} = \frac{R_{0,\,nom}}{rsh} weff\_\mathrm{um}$$

and again possibilities of zero resistance and error conditions of negative length or width are handled.

For any other combination of instance parameter specification (resistance is not specified, or if it is then both width and length, which override resistance specification, are also specified), then the resistance is calculated from the geometry,

(2-18)

$$R_{0,\,nom} = rsh\frac{leff\_\mathrm{um}}{weff\_\mathrm{um}}$$

and zero resistance or conductance, and negative length or width errors, are handled.

Although end effects, such as spreading resistance and contact resistance, are assumed to be modeled via the `xl` parameter, the temperature coefficients of the end effects may differ from those of the body of the resistor. Simple analysis shows that these different temperature coefficients can be accounted for by introducing inverse length dependence to the temperature coefficients. A width dependence of temperature coefficients of resistance is also included in the model. Therefore in the R2 model,

(2-19)

$$T_{C1}^{eff} = tc1 + \frac{0.5(c1 + c2)tc1l}{leff\_\mathrm{um}} + \frac{tc1w}{weff\_\mathrm{um}}$$

(2-20)

$$T_{C2}^{eff} = tc2 + \frac{0.5(c1 + c2)tc2l}{leff\_\mathrm{um}} + \frac{tc2w}{weff\_\mathrm{um}}$$

where the length dependence is switched on, off, or halved, depending on whether the resistor is contacted at both ends, not contacted, or contacted at only one end, respectively. The dependence of the temperature coefficients on whether a resistor is contacted or not enables consistent modeling of temperature coefficients for single or multiple section models.

The thermal conductance and capacitance include area, perimeter, and fixed components. Asymptotically for a large area device, the heat flow is perpendicular to the plane of heat generation in the resistor, and the heat energy stored in a device depends on its volume, hence the area dependent component. For a long resistor, as it becomes narrower, more of the heat flow is conducted by a fringe path at the edges of the device, hence the perimeter dependent component. As both length and width decrease, the thermal conditions in the device asymptotically approach that of a point source in an infinite medium, hence the fixed component. The thermal conductance and capacitance are therefore

(2-21)

$$g_{TH} = gth0 + gthp \cdot p\_\mathrm{um2} + gtha \cdot a\_\mathrm{um2}$$

(2-22)

$$c_{TH} = cth0 + cthp \cdot p\_\mathrm{um2} + ctha \cdot a\_\mathrm{um2}$$

where the area and perimeter are calculated as

(2-23)

$$a\_\mathrm{um2} = l\_\mathrm{um} \cdot w\_\mathrm{um}$$

(2-24)

$$p\_\mathrm{um} = 2l\_\mathrm{um} + (c1 + c2)w\_\mathrm{um}$$

The calculated perimeter therefore depends on whether the ends are contacted or not. Note that often the design dimensions of the body of a resistor differ from the overall dimensions of the device, for example if the design length is considered to be the unsolicited length of a poly resistor, the total resistor length will typically include silicided contact regions. So it is not readily apparent what dimension should be used in calculation of the thermal conductance and capacitance. That is why the design dimensions, rather than some effective dimensions (whose value is calculated to best fit DC electrical data), are used. This turns out to be fine (with the exception that differences between the perimeter components along length and width dimensions are ignored), because if there is some difference Δ between design and effective dimensions for thermal conductance modeling, then for a device contacted at both ends

(2-25)

$$g_{TH} = gth0 + gthp(2l\_\mathrm{um} + 2w\_\mathrm{um} + 4\Delta) + gtha(l\_\mathrm{um} + \Delta)(w\_\mathrm{um} + \Delta)$$
$$= (gth0 + 4gthp \cdot \Delta + gtha \cdot \Delta^2) + (gthp + 0.5gtha \cdot \Delta)p\_\mathrm{um} + gtha \cdot a\_\mathrm{um2}$$

therefore, any difference between design and effective dimensions can be taken into account by appropriate characterization of the fixed, perimeter, and area component parameters.

Because the local thermal conductance differs between the edge of a device and the center of a device, it is higher at the edge because of fringing conductance, the temperature of a resistor undergoing self-heating is not spatially uniform, but is lower at the edges than in the middle. This is not taken into account in the R2 model.

Temperature Dependence

The zero-bias resistance $R0$ varies with temperature as

(2-26)

$$R_0(T) = R_{0,now}(1 + T_{C1}^{eff}dT + T_{C2}^{eff}dT^2)$$

where $R_{0,nom}$ is the nominal value of the zero-bias resistance, at the nominal temperature `tnom`, dT is the temperature difference (including self-heating, if that form of the model is used) with respect to `tnom`, and

$$T_{c2}^{eff}$$

and

$$T_{c1}^{eff}$$

are first (linear) and second (quadratic) order temperature coefficients. These coefficients have both a width dependence and a length dependence, the latter to enable modeling of resistors that have different temperature coefficients for end resistance (which includes contacts and contact enhancement regions) compared to body resistance without having to implement a sectional (subcircuit) model with explicit end and body resistance components. The width and length dependency is detailed in the section on geometry dependence — see Equation 2-19 on page 188 and Equation 2-20 on page 188. Smooth limiting of the resistance temperature coefficient in (Equation 2-21 on page 189) is implemented to limit its lower value to 0.01.

For the isothermal version of the model the temperature difference dT is calculated statically based on the device temperature (which can vary from the circuit ambient temperature by setting the instance parameter `trise`, which is the local device temperature difference with respect to the circuit ambient temperature). For the electrothermal version of the model *dT* is calculated dynamically and self-consistently with the power dissipation of the device.

The flicker noise coefficient varies with temperature as

(2-27)

$$K_{FN}(T) = kfn(1 + tc1kfndT)$$

where kfn and tc1kfn are model parameters.

Noise

The noise model comprises two components, a thermal (white) noise component and a flicker ker ($1/f$) noise component. These components are noise current spectral density (in $A2/Hz$) that are implemented as a noise current sources in parallel with the resistance element.

The thermal noise component is based on the DC conductance of the device,

(2-28)

$$i^2_{thermal} = 4kT_K G_0(T)/rFactor$$

where k is Boltzmann's constant, T_K is the device temperature (in Kelvin, including the effect of self-heating), G_0 is the zero-bias conductance of the resistor (at the temperature T), and $rFactor$ is the bias-dependent (DC) resistance factor (Equation 2-3 on page 185).

The flicker noise component is DC current dependent (Equation 2-2 on page 185), and scales with geometry per the physical restrictions noted in Equation 2-3 on page 185.

(2-29)

$$i^2_{flicker} = K_{FN}(T)\left(\frac{I}{W}\right)^{afn}\frac{W}{L}\frac{1}{f^{bfn}}$$

where f is frequency (in Hz), afn and bfn are model parameters, $K_{FN}(T)$ is the temperature dependent flicker noise coefficient (Equation 2-27 on page 191), I is the DC current in the resistor, and W and L are the resistor width and length, respectively, in units of micron. If the switch parameter for flicker noise geometry calculation sw_fngeo is 0 (false) then W and L are design geometries, *w_um* and *l_um* respectively, else if it is 1 (true) then W and L are effective geometries, *weff_um* and *leff_um* respectively.

Note that if self-heating is included, then possibly there is a frequency dependence to the flicker noise because of the thermal time constant. There is no data to verify this at present so a frequency independent noise current spectral density is used.

Description and Details

The voltage nonlinearity of the device resistance is

(2-30)

$$R(E) = R_0\left((1 - p2 - p3) + p3\sqrt[3]{1 + |q3\mathrm{E}|^3} + p2\sqrt{1 + (q2\mathrm{E})^2}\right)$$

where R_0 is the zero bias resistance of the resistor, $E=V/L$ is the electric field across the device, p3 and q3 are parameters of the effective first order (linear) electric field coefficient, and p2 and q2 are parameters of the effective second order (quadratic) electric field coefficient. Because the nonlinearity is based on field, rather than voltage, it scales with geometry.

For q3E somewhat greater than 1, the cubic component of the model becomes

(2-31)

$$R(E) = R_0(1 + p3(|q3\mathrm{E}| - 1))$$

therefore this term approximates a linear (first order) field dependence of resistance with a coefficient of value p3.q3.

For q2E somewhat less than 1, the quadratic component of the model becomes

(2-32)

$$R(E) = R_0(1 + 0.5p2 \cdot q2^2E^2)$$

therefore this term approximates a quadratic (second order) field dependence of resistance with a coefficient of value $0.5p2^2q2^2$. For high fields this component becomes

(2-33)

$$R(E) = R_0(1 + p2(|q2\mathrm{E}| - 1))$$

and it turns out that the behavior embodied in Equation 2-32 on page 192 and Equation 2-33 on page 192 is quite accurate for modeling velocity saturation, which is a significant component of nonlinearity for shorter resistors.

To ensure that the resistance does not become negative,

(2-34)

$$0 \le p3 < 1$$

and

(2-35)

$$0 \le p2 < 1 - p3$$

are enforced. This also precludes the model exhibiting a negative differential resistance (NDR). NDR is observed in some devices, but this is from self-heating effects in resistors with positive temperature coefficients. This behavior should therefore be modeled using the electrothermal version of the model.

In SPICE-like simulators, which are based on modified nodal analysis (MNA), it is preferable to formulate models as voltage controlled current sources (VCCS's). This is the default for the R2 model. For small resistance values this can cause numerical problems, and the MNA formulation is not possible for zero valued resistors (which have infinite conductance). For small resistance values it is better to switch to a current controlled voltage source (CCVS) formulation. Implicitly, this increases the matrix size for MNA analysis, as the current through the CCVS becomes a system variable. The R2 model includes a parameter `rthresh`, and if the total (not per segment, but r/m) resistance at zero bias is less than `rthresh`, the model switches to a CCVS formulation for numerical stability and to be able to work properly for zero valued resistors. Note that this makes the model implicit as the formulation is effectively $V = I \cdot R(V)$.

Component Statements

Instance Definition

```
Name  1  2 ModelName parameter=value ...
Name  1  2 r2 parameter=value ...
```

Instance Parameters

1	`m=1`	Multiply factor.
2	`w=1e-6 m`	Default width.
3	`l=1e-6 m`	Resistor length.

4 `r=100.0 Ω` Resistance.

5 `c1=1` Contact terminal.

6 `c2=1` Contact terminal.

7 `trise=0.0 C` Temperature rise.

8 `isnoisy=yes` Should resistor generate noise.
Possible values are `no` or `yes`.

9 `sw_et=yes` switch for turning off self-heating.

10 `tc1=0.0 /K` resistance linear.

11 `tc2=0.0 /K` resistance linear.

Model Definition

```
model modelName r2 parameter=value ...
```

Model Parameters

1 `version=1.0` Model version selector. The available versions are 1.0.

2 `revision=0.0` Model sub-version selector. The available versions are 0.0.

3 `shrink=0.0 %` Shrink factor.

4 `tmin=-100 C` The minimal temperature.

5 `tmax=500.0 C` The maximal temperature.

6 `rthresh=1e-3 Ω` threshold.

7 `level=1002` r2 model selector. The available level are 1002.

8 `tnom=27.0 C` reference temperature.

9 `rsh=∞ Ω/sqr`
Sheet resistance.

10 `lmin=0.0 μm` Minimum channel length for which the model is valid.

11 `lmax=9.9e99 µm` Maximum channel length for which the model is valid.

12 `wmin=0.0 µm` Minimum channel width for which the model is valid.

13 `wmax=9.9e99 µm` Maximum channel width for which the model is valid.

14 `xw=0.0 µm` width offset.

15 `xl=0.0 µm` length offset.

16 `dxle=0.0 µm` length delta.

17 `sw_efgeo=no` Switch for electric field geometry calculation.

18 `q3=0.0 µm/V` threshold for the linear field coefficient activities.

19 `p3=0` coefficient for linear field.

20 `q2=0.0 µm/V` threshold for the quadratic field coefficient activities.

21 `p2=0` coefficient for quadratic field.

22 `kfn=0` coefficient for flicker noise.

23 `afn=2.0` flicker noise current exponent.

24 `bfn=1.0` coefficient for quadratic field.

25 `sw_fngeo=no` Switch for flicker noise geometry calculation.

26 `jmax=100.0 A/µm` Maximum allowable current density.

27 `tminclip=-100.0 C` clip minimum temperature.

28 `tmaxclip=500.0 C` clip maximum temperature.

29 `tc1=0.0 /K` resistance linear.

30 tc2=0.0 /K^2 resistance quadratic.

31 `tc1l=0.0 µm/K` tc length coefficient for resistance linear.

32 tc2l=0.0 µm/K^2 tc length coefficient for resistance quadratic.

33 `tc1w=0.0 μm/K` tc width coefficient for resistance linear.

34 `tc2w=0.0` $\mu m/K^2$ tc width coefficient for resistance quadratic.

35 `tc1kfn=0` coefficient for flicker noise linear tc1.

36 `gth0=1.0e6 W/K` thermal conductance fixed component.

37 `gthp=0.0 W/Kμm` thermal conductance perimeter component.

38 `gtha=0.0` $W/K\mu m^2$ thermal conductance area component.

39 `cth0=0.0 sW/K` thermal capacitance fixed component.

40 `cthp=0.0 sW/Kμm` thermal capacitance perimeter component.

41 `ctha=0.0` $sW/K\mu m^2$ thermal capacitance area component.

42 `c1=1` Resistance contact terminal.

43 `c2=1` Resistance contact terminal.

Operating-Point Parameters

1 `v (V)` Voltage at operating point.

2 `i (A)` Current through the resistor.

3 `power (W)` power dissipated.

4 `r0 (Ω)` zero bias resistance.

5 `leff_um (μm)` effective length in um.

6 `weff_um (μm)` effective width in um.

7 `r_dc (Ω)` DC Resistance.

8 `r_ac (Ω)` AC Resistance.

9 `rth (K/W)` thermal Resistance.

10 `cth (sW/K)` thermal capacitance.

11 `dt_et (C)` The self-heating temperature rise.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

afn M-23	jmax M-26	revision M-2	tmax M-5
bfn M-24	kfn M-22	rsh M-9	tmaxclip M-28
c1 I-5	l I-3	rth OP-9	tmin M-4
c1 M-42	leff_um OP-5	rthresh M-6	tminclip M-27
c2 I-6	level M-7	shrink M-3	tnom M-8
c2 M-43	lmax M-11	sw_efgeo M-17	trise I-7
cth OP-10	lmin M-10	sw_et I-9	v OP-1
cth0 M-39	m I-1	sw_fngeo M-25	version M-1
ctha M-41	p2 M-21	tc1 I-10	w I-2
cthp M-40	p3 M-19	tc1 M-29	weff_um OP-6
dt_et OP-11	power OP-3	tc1kfn M-35	wmax M-13
dxle M-16	q2 M-20	tc1l M-31	wmin M-12
gth0 M-36	q3 M-18	tc1w M-33	xl M-15
gtha M-38	r I-4	tc2 I-11	xw M-14
gthp M-37	r0 OP-4	tc2 M-30	

Fractional Impedance/Admittance Pole (fracpole)

Fractional Impedance Pole takes as input a start frequency, a stop frequency, a negative slope, the unity intercept point, and the number of lumps, and synthesizes a RC circuit that models a fractional impedance pole over the given frequency range. The circuit is a one-port that exhibits poles and zeros that are real and that are spaced evenly in a logarithmic sense over the frequency range. The impedance exhibited by the one port approximates a fractional pole slope between -1 and 0 in the frequency range. In other words, if the impedance is plotted on a log-log scale, it will have a negative slope equal to the fraction specified. The user requested half a pole, the slope will be -1/2, etc. Of course it is a lumped approximation, so the slope will not be exact, but it will slowly oscillate about the desired value.

```
o----+------+------+--...--+------+
     |      |      |       |      |
                                 |
     /      /      / ...   /      |
      R0     R1     R2      Rn    |
     |      |      |       |      |
     |     ---    --- ... ---    ---
     |     ---    ---     ---    ---
     |      | C1   | C2    | Cn   | Cinf
o----+------+------+--...--+------+
```

This model is converted to model a Fractional Admittance Pole by combining it with a gyrator.

```
o---+          +----+------+------+--...--+------+
    |          |    |      |      |       |      |
```

```
  |+---------+|                   |
  ||         ||  /    /    / ... /    |
  || Gyrator ||   R0   R1   R2    Rn  |
  ||         ||  |    |    |     |    |
  ||         ||  |   ---   --- ... ---   ---
  |+---------+|  |   ---   ---    ---   ---
  |          |   |   | C1  | C2   | Cn  | Cinf
o---+        +--+-+------+------+--...--+------+
             |
             |
             V
            GND
```

It can be used to model skin-effect loss in an inductor and dielectric absorption in a capacitor, and can be used to shape white noise into flicker noise.

Profile

In both fractional impedance/admittance pole cases, what happens outside the range of the approximation is specifies the parameter `profiles` of fracpole. It is a code that consists of a pair of letters. The first letter represents the low frequency behavior and the second represents the high frequency behavior. The letters are either `f` or `d`, `f` represents flat or a zero-pole slope, and `d` represents down or a one-pole slope. Depending on the profile chosen, either R0 or Cinf may or may not be present in the synthesized RC circuit.

Internal Nodes

Internal nodes are created for each RC pair in the synthesized RC circuit, and they are labeled as InstanceName:int_1, InstanceName:int_2, ... In the case of fractional admittance pole, one more additional internal node, InstanceName:int_gyr, is created on the opposite side of gyrator from the terminals of the device.

Current

The current reported by fracpole device is the static terminal current. In the case of fractional impedance pole, this current does not include the dynamic part. To find the total current of fractional impedance pole, either use current probe in series with it or use the option useprobes=yes.

This device is supported within altergroups.

Fractional Impedance Pole approximates

Z(s) = Coef*s^Slope

for s=2*pi*freq*j with f0 < freq < f1, and -1 < Slope < 0.

Fractional Admittance Pole approximates

Z(s) = Coef*s^Slope

(or Y(s) = s^(-Slope)/Coef)

for s=2*pi*freq*j with f0 < freq < f1, and 0 < Slope < 1.

Sample Instance Statement

without model:

fp (1 2) fracpole f0=1 f1=1M coef=1k dec=1.0 slope=-0.5 profile=ff

with model:

fp (1 2) fpModel f0=1 f1=1M coef=1.5k lumps=12 slope=-0.5 profile=dd

Sample Model Statement

model fpModel fracpole f0=1 f1=1M coef=1k dec=1.0 slope=-0.5 profile=ff

Instance Definition

```
Name  1  2 ModelName parameter=value ...
Name  1  2 fracpole parameter=value ...
```

Instance Parameters

1	`f0=1.0 Hz`	Low frequency limit for the approximation.
2	`f1=1.0e6 Hz`	High frequency limit for the approximation.

3 `coef=1.0 Ω` Unity intercept point for ideal impedance at 2*pi*freq=1.

4 `slope=-0.5` Slope of the impedance when plotted on a log-log scale.

5 `lumps` Number of lumps used in the approximation.

6 `dec=1.0` Number of lumps per decade used in the approximation.

7 `profile=dd if abs(slope)`

8 `m=1.0` Multiplicity factor.

9 `ic (V)` Initial condition for fractional impedance pole devices with `df` or `dd` profile.

10 `rforce=1.0 Ω` Resistance used when forcing initial conditions.

Model Definition

```
model modelName fracpole parameter=value ...
```

Model Parameters

1 `f0=1.0 Hz` Low frequency limit for the approximation.

2 `f1=1.0e6 Hz` High frequency limit for the approximation.

3 `coef=1.0 Ω` Unity intercept point for ideal impedance at 2*pi*freq=1.

4 `slope=-0.5` Slope of the impedance when plotted on a log-log scale.

5 `lumps` Number of lumps used in the approximation.

6 `dec=1.0` Number of lumps per decade used in the approximation.

7 `profile=dd if abs(slope)`

Operating-Point Parameters

1 `v (V)` Voltage at operating point.

2 `i (A)` Current. See comment on current above.

3 `pwr (W)` Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Two Terminal Capacitor (capacitor)

You can assign the capacitance or let Spectre compute it from the physical length and width of the capacitor. In either case, the capacitance can be a function of temperature or applied voltage.

This device is supported within altergroups.

If the C(inst) is not given,

C(inst) = C(model)

if C(model) is given,

and if Area(inst) or Perim(inst) is given

Area_eff = Area - (Perim)*etch + 4*etch^2

Perim_eff = Perim - 8*etch

else

Area_eff = (L - 2*etch)*(W - 2*etch)

Perim_eff = 2 *(W + L - 4*etch)

C(inst) = Cj*Area_eff + Cjsw*Perim_eff

if C(model) is not given.

If the polynomial coefficients vector (coeffs=[c1 c2 ...]) is specified, the capacitor is nonlinear and the capacitance is

C(V) = dQ(V) / dV

= C(inst)*(1 + c1*V + c2*V^2 + ...)

or

Q(V) = C(inst)*V*(1 + 1/2*c1*V + 1/3*c2*V^2 + ...)

where ck is the kth entry in the coefficient vector.

The value of the capacitor as a function of the temperature is given by:

C(T) = C(tnom)*[1 + tc1*(T - tnom) + tc2*(T - tnom)^2].

where

T = trise(inst) + temp

if trise(inst) is given, and

T = trise(model) + temp

if trise(inst) is not given.

Sample Instance Statement

without model:

```
c2 (1 0) capacitor c=2.5u tc1=1e-8
```

with model:

```
c2 (1 0) proc_cap c=2.5u tc1=1e-8
```

Sample Model Statement

```
model proc_cap capacitor c=2u tc1=1.2e-8 tnom=25
```

This device support behavior expression

Sample Behavior Statement

```
c1 (1 0) capacitor c=c0*(1 + tanh(v(1,2)*c2))
c1 (1 0) capacitor c=1e-12/(1+($freq)/1e9)
```

Instance Definition

```
Name  1  2 ModelName parameter=value ...
Name  1  2 capacitor parameter=value ...
```

Instance Parameters

1 `c (F)`	Capacitance.
2 `w (m)`	Capacitor width.
3 `l (m)`	Capacitor length.
4 `m=1`	Multiplicity factor.
5 `scale=1`	Scale factor.
6 `trise (C)`	Temperature rise from ambient.
7 `tc1 (1/C)`	Linear temperature coefficient.
8 tc2 (C^{-2})	Quadratic temperature coefficient.
9 `ic (V)`	Initial condition(alias=lv2).
10 area=1.0 m^2	Capacitor area.
11 `perim=0.0 m`	Capacitor perimeter.
12 `coeffs=[...]`	Vector of polynomial capacitance coefficients.
13 `symmetric=none`	Use symmetric capacitor model. Possible values are `none` and `absolute`.

14 `bv_max=∞ V` Maximum allowed voltage cross two terminals.

15 `scalec` Capacitance scaling factor.

The instance parameter scale, if specified, overrides the value given by the option parameter scale. The w and l parameters are scaled by the resulting scale, and the option parameter scalem. The values of w and l printed by Spectre are those given in the input file, and these values might not have the correct units if the scaling factors are not unity. The actual capacitor dimensions are stored in the output parameters. You can obtain these dimensions with the info statement.

Model Definition

```
model modelName capacitor parameter=value ...
```

Model Parameters

1 `c=0 F` Default capacitance.

2 `trise=0 C` Default `trise` value for instance.

3 `tnom (C)` Parameters measurement temperature. Default set by `options`.

4 `w=0 m` Default capacitor width.

5 `l=0 m` Default capacitor length.

6 `etch=0 m` Narrowing due to side etching.

7 `cj=0 F/m`^{2} Bottom capacitance density.

8 `cjsw=0 F/m` Sidewall capacitance.

9 `scalec=1` Capacitance scaling factor.

10 `rforce=1 Ω` Resistance used when forcing initial conditions.

11 `di=0` Relative dielectric constant.

12 `thick=0 m` Dielectric thickness.

Polynomial capacitor parameters

13 `coeffs=[...]` Vector of polynomial capacitance coefficients.

14 `symmetric=none` Use symmetric resistor model.
Possible values are `none` and `absolute`.

15 `min (F)` Minimum capacitance.

16 `max (F)` Maximum capacitance.

Temperature effects parameters

17 `tc1=0 1/C` Linear temperature coefficient.

18 `tc2=0` C^{-2} Quadratic temperature coefficient.

Shrink Parameters

19 `shrink=0.0` Linear shrink parameter.

20 `shrink2=0.0` Area shrink parameter.

Safe Operating Areas Parameters

21 `bv_max=∞ V` Maximum allowed voltage cross two terminals.

Output Parameters

1 `leff (m)` Effective capacitor length.

2 `weff (m)` Effective capacitor width.

3 `ceff (F)` Effective capacitance(alias=lv1).

Operating-Point Parameters

1 `cap (F)` Capacitance at operating point.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter

area I-10	coeffs M-13	perim I-11	tc1 M-17
bv_max I-14	di M-11	rforce M-10	tc2 I-8
bv_max M-21	etch M-6	scale I-5	tc2 M-18
c I-1	ic I-9	scalec I-15	thick M-12
c M-1	l I-3	scalec M-9	tnom M-3
cap OP-1	l M-5	shrink M-19	trise I-6
ceff O-3	leff O-1	shrink2 M-20	trise M-2
cj M-7	m I-4	symmetric I-13	w I-2
cjsw M-8	max M-16	symmetric M-14	w M-4
coeffs I-12	min M-15	tc1 I-7	weff O-2

Interconnect Capacitance (intcap)

Intcap is a model for the calculation of the interconnect capacitance, which takes into account the local layer composition and the tracks spacing width. It is described in the Phillips MOST Modelbook (Dec.96) as INTCAP model.

(c) Phillips Electronics N.V. 1993,1996

The model is extended by the device parameters `lxbelps`, `lxbelin` and `lxbelins`, according to a specification by H.Okel (I&A Hamburg).

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.sun4v/cmi/lib/5.0.doc/libphilips_sh.so

Sample Instance Statement:

intc (net9 net12) intconcap m=1 ael=2.5e-15 ain=2e-15 aps=1.8e-15

Sample Model Statement:

model intconcap intcap cbps=1.5e-13 cebpsm=0.9e-15 cebpsi=0.83e-15 cbin=1.45e-13 cbins=1.4e-13

Instance Definition

```
Name  n1  n2 ModelName parameter=value ...
```

Instance Parameters

1 `m=1`	Multiplicity factor.
2 `ael=0.0` m^2	The common area of `EL` track of the reference electrode.
3 `ain=0.0` m^2	The common area of `IN` track of the reference electrode.
4 `ains=0.0` m^2	The common area of `INS` track of the reference electrode.
5 `aps=0.0` m^2	The common area of `PS` track of the reference electrode.
6 `lbel=0.0 m`	The sum of periphery length of `EL`-segments common to node n2 downwards.
7 `lbin=0.0 m`	The sum of periphery length of `IN`-segments to node n2 downwards.
8 `lbins=0.0 m`	The sum of periphery length of `INS`-segments common to node n2 downwards.
9 `lbps=0.0 m`	The sum of periphery length of `PS`-segments common to node n2 downwards.
10 `lfbel=0.0 m`	The sum of periphery length-factor products `EL` downwards.
11 `lfbin=0.0 m`	The sum of periphery length-factor products `IN` downwards.

12 `lfbins=0.0 m`	The sum of periphery length-factor products `INS` downwards.
13 `lfbps=0.0 m`	The sum of periphery length-factor products `PS` downwards.
14 `lftel=0.0 m`	The sum of periphery length-factor products `EL` upwards.
15 `lftin=0.0 m`	The sum of periphery length-factor products `IN` upwards.
16 `lftins=0.0 m`	The sum of periphery length-factor products `INS` upwards.
17 `lftps=0.0 m`	The sum of periphery length-factor products `PS` upwards.
18 `ltel=0.0 m`	The sum of periphery length of `EL`-segments common to node n2 upwards.
19 `ltin=0.0 m`	The sum of periphery length of `IN`-segments common to node n2 upwards.
20 `ltins=0.0 m`	The sum of periphery length of `INS`-segments common to node n2 upwards.
21 `ltps=0.0 m`	The sum of periphery length of `PS`-segments common to node n2 upwards.
22 `ldsel=0.0 m`	The sum of Li/Si quotients for `EL` tracks.
23 `ldsin=0.0 m`	The sum of Li/Si quotients for `IN` tracks.
24 `ldsins=0.0 m`	The sum of Li/Si quotients for `INS` tracks.
25 `ldsps=0.0 m`	The sum of Li/Si quotients for `PS` tracks.
26 `lxbinps=0.0 m`	The sum of Li/Si quotients for an `IN` track in parallel with an `PS` track.
27 `lxbinsin=0.0 m`	The sum of Li/Si quotients for an `INS` track in parallel with an `IN` track.
28 `lxbinsps=0.0 m`	The sum of Li/Si quotients for an `INS` track in parallel with an `PS` track.
29 `lxbelps=0.0 m`	The sum of Li/Si quotients for an `EL` track in parallel with an `PS` track.

30 `lxbelin=0.0 m` The sum of Li/Si quotients for an `EL` track in parallel with an `IN` track.

31 `lxbelins=0.0 m` The sum of Li/Si quotients for an `EL` track in parallel with an `INS` track.

The Spectre option `scale`, default value is 1.0, scales the geometric

parameters. The actual areas (parameters starting with letter `a`) are equal

axxx * scale ^ 2

The actual lengths (parameters starting with letter `l`) are equal

lxxx * scale

Model Definition

```
model modelName intcap parameter=value ...
```

Model Parameters

1 `cbps=0.0` F/m^2 Bottom capacitance, `PS` to node n2.

2 `cebpsm=0.0 F/m` Edge to bottom capacitance (`PS`), 1.0um spacing.

3 `cebpsi=0.0 F/m` Edge to bottom capacitance (`PS`), single track.

4 `cetpsm=0.0 F/m` Edge to top capacitance (`PS`), 1.0um spacing.

5 `cetpsi=0.0 F/m` Edge to top capacitance (`PS`), single track.

6 `cbin=0.0` F/m^2 Bottom capacitance, `IN` to node n2.

7 `cebinm=0.0 F/m` Edge to bottom capacitance (`IN`), 1.0um spacing.

8 `cebini=0.0 F/m` Edge to bottom capacitance (`IN`), single track.

9 `cetinm=0.0 F/m` Edge to top capacitance (`IN`), 1.0um spacing.

10 `cetini=0.0 F/m` Edge to top capacitance (`IN`), single track.

11 `cbins=0.0` F/m^2 Bottom capacitance, `INS` to node n2.

12 `cebinsm=0.0 F/m` Edge to bottom capacitance (`INS`), 1.0um spacing.

13 `cebinsi=0.0 F/m` Edge to bottom capacitance (`INS`), single track.

14 `cetinsm=0.0 F/m` Edge to top capacitance (`INS`), 1.0um spacing.

15 `cetinsi=0.0 F/m` Edge to top capacitance (`INS`), single track.

16 `cbel=0.0` F/m^2 Bottom capacitance, `EL` to node n2.

17 `cebelm=0.0 F/m` Edge to bottom capacitance (`EL`), 1.0um spacing.

18 `cebeli=0.0 F/m` Edge to bottom capacitance (`EL`), single track.

19 `cetelm=0.0 F/m` Edge to top capacitance (`EL`), 1.0um spacing.

20 `ceteli=0.0 F/m` Edge to top capacitance (`EL`), single track.

21 `cecps=0.0 F/m` Lateral capacitance (`PS`), 1.0um spacing.

22 `cecin=0.0 F/m` Lateral capacitance (`IN`), 1.0um spacing.

23 `cecins=0.0 F/m` Lateral capacitance (`INS`), 1.0um spacing.

24 `cecel=0.0 F/m` Lateral capacitance (`EL`), 1.0um spacing.

Output Parameters

1 `cap (F)` Total Capacitance.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Junction Capacitor (juncap)

Instance Definition

```
Name  a  k ModelName parameter=value ...
```

Instance Parameters

1 `ab=1e-12` m^2 Diffusion area.

2 `ls=1e-06 m` Length of the side-wall of the diffusion area AB which is not under the gate.

3 `lg=1e-06 m` Length of the side-wall of the diffusion area AB which is under the gate.

4 `mult=1` Number of devices in parallel.

5 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `rev`, `fwd`, or `brk`.

6 `m=1` Multiplicity factor.

7 `area=1.0e-12` m^2 alias of ab.

8 `peri=0.0 m` alias of ls.

9 `pgate=0.0 m` alias of lg.

10 `pj=0.0 m` alias of peri.

Model Definition

```
model modelName juncap parameter=value ...
```

Model Parameters

1 `level=1` Level of this model.

2 `dta=0 K` Temperature offset of the juncap element with respect to TA.

3 `tr=25 C` Temperature at which the parameters have been determined.

4 `vr=0 V` Voltage at which the parameters have been determined.

5 `jsgbr=0.001` Am^{-2} Bottom saturation-current density due to electron-hole generation at V=VR.

6 `jsdbr=0.001` Am^{-2} Bottom saturation-current density due to diffusion from back contact.

7 `jsgsr=0.001 Am^-1` Sidewall saturation-current density due to electron-hole generation at V=VR.

8 `jsdsr=0.001 Am^-1` Sidewall saturation-current density due to diffusion from back contact.

9	`jsggr=0.001 Am^-1`	Gate edge saturation-current density due to diffusion from back contact.
10	`jsdgr=0.001 Am^-1`	Gate edge saturation-current density due to diffusion from back contact.
11	`nb=1`	Emission coefficient of the bottom forward current.
12	`ns=1`	Emission coefficient of the sidewall forward current.
13	`ng=1`	Emission coefficient of the gate edge forward current.
14	`vb=0.9 V`	Reverse breakdown voltage.
15	`cjbr=1e-12` Fm^{-2}	Bottom junction capacitance at V=VR.
16	`cjsr=1e-12 Fm^-1`	Sidewall junction capacitance at V=VR.
17	`cjgr=1e-12 Fm^-1`	Gate edge junction capacitance at V=VR.
18	`vdbr=1 V`	Diffusion voltage of the bottom junction at T=TR.
19	`vdsr=1 V`	Diffusion voltage of the sidewall junction at T=TR.
20	`vdgr=1 V`	Diffusion voltage of the gate edge junction at T=TR.
21	`pb=0.4`	Bottom junction grading coefficient.
22	`ps=0.4`	Sidewall junction grading coefficient.
23	`pg=0.4`	Gate edge junction grading coefficient.
24	`imax=1e+03 A`	Explosion current.
25	`shrink=0`	Linear shrink factor.
26	`shrink2=0`	Areal shrink factor.
27	`type=n`	Transistor gender. Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.
28	`tnom (C)`	alias of tnom.

29 `tref (C)` alias of tnom.

Output Parameters

1 `dta (K)`	Temperature offset of the juncap element with respect to TA.
2 `tr (C)`	Temperature at which the parameters have been determined.
3 `vr (V)`	Voltage at which the parameters have been determined.
4 `isgb` (Am^{-2})	Bottom saturation-current density due to electron-hole generation at V=VR.
5 `isdb` (Am^{-2})	Bottom saturation-current density due to diffusion from back contact.
6 `isgs (Am^-1)`	Sidewall saturation-current density due to electron-hole generation at V=VR.
7 `isds (Am^-1)`	Sidewall saturation-current density due to diffusion from back contact.
8 `isgg (Am^-1)`	Gate edge saturation-current density due to electron-hole generation at V=VR.
9 `isdg (Am^-1)`	Gate edge saturation-current density due to diffusion from back contact.
10 `nb`	Emission coefficient of the bottom forward current.
11 `ns`	Emission coefficient of the sidewall forward current.
12 `ng`	Emission coefficient of the gate edge forward current.
13 `cjb` (Fm^{-2})	Bottom junction capacitance at V=VR.
14 `cjs (Fm^-1)`	Sidewall junction capacitance at V=VR.
15 `cjg (Fm^-1)`	Gate edge junction capacitance at V=VR.
16 `vdb (V)`	Diffusion voltage of the bottom junction at T=TR.
17 `vds (V)`	Diffusion voltage of the sidewall junction at T=TR.

18 `vdg (V)` Diffusion voltage of the gate edge junction at T=TR.

19 `pb` Bottom junction grading coefficient.

20 `ps` Sidewall junction grading coefficient.

21 `imax (A)` Explosion current.

22 `vexpl (A)` Explosion voltage.

23 `pg` Gate edge junction grading coefficient.

Operating-Point Parameters

1 `g (S)` Total differential conductance.

2 `c (F)` Total capacitance.

3 `lx1 (A)` Total current.

4 `lx3 (Coul)` Total charge.

5 `lx5 (F)` Total capacitance, identical to OP output c.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

JUNCAP2 Model (juncap200)

This is SiMKit 3.0.2

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  a  k ModelName parameter=value ...
```

Instance Parameters

1 `ab=1e-12` m^2 Junction area.

2 `ls=1e-06 m` STI-edge part of junction perimeter.

3 `lg=1e-06 m` Gate-edge part of junction perimeter.

4 `mult=1` Number of devices in parallel.

5 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `rev`, `fwd`, or `brk`.

6 `m=1` Multiplicity factor.

7 `area=1` alias of mult.

Model Definition

```
model modelName juncap200 parameter=value ...
```

Model Parameters

1 `level=200` Model level must be 200.

2 `type=n` Type parameter, in output value 1 reflects n-type, -1 reflects p-type.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

3 `trj=21 C` Reference temperature.

4 `dta=0 C` Temperature offset with respect to ambient temperature.

5 `imax=1e+03 A` Maximum current up to which forward current behaves exponentially.

6 `cjorbot=0.001` Fm^{-2}
Zero-bias capacitance per unit-of-area of bottom component.

7 `cjorsti=1e-09 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component.

8 `cjorgat=1e-09 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component.

9 `vbirbot=1 V` Built-in voltage at the reference temperature of bottom component.

10 `vbirsti=1 V` Built-in voltage at the reference temperature of STI-edge component.

11 `vbirgat=1 V` Built-in voltage at the reference temperature of gate-edge component.

12 `pbot=0.5` Grading coefficient of bottom component.

13 `psti=0.5` Grading coefficient of STI-edge component.

14 `pgat=0.5` Grading coefficient of gate-edge component.

15 `phigbot=1.16 V` Zero-temperature bandgap voltage of bottom component.

16 `phigsti=1.16 V` Zero-temperature bandgap voltage of STI-edge component.

17 `phiggat=1.16 V` Zero-temperature bandgap voltage of gate-edge component.

18 `idsatrbot=1e-12` Am^{-2}
Saturation current density at the reference temperature of bottom component.

19 `idsatrsti=1e-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component.

20 `idsatrgat=1e-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component.

21 `csrhbot=100` Am^{-3} Shockley-Read-Hall prefactor of bottom component.

22 `csrhsti=0.0001` Am^{-2}
Shockley-Read-Hall prefactor of STI-edge component.

23 `csrhgat=0.0001 Am^-2`
Shockley-Read-Hall prefactor of gate-edge component.

24 `xjunsti=1e-07 m` Junction depth of STI-edge component.

25 `xjungat=1e-07 m` Junction depth of gate-edge component.

26 `ctatbot=100 Am^-3` Trap-assisted tunneling prefactor of bottom component.

27 `ctatsti=0.0001 Am^-2`
Trap-assisted tunneling prefactor of STI-edge component.

28 `ctatgat=0.0001 Am^-2`
Trap-assisted tunneling prefactor of gate-edge component.

29 `mefftatbot=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component.

30 `mefftatsti=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component.

31 `mefftatgat=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component.

32 `cbbtbot=1e-12 AV^-3`
Band-to-band tunneling prefactor of bottom component.

33 `cbbtsti=1e-18 AV^-3m`
Band-to-band tunneling prefactor of STI-edge component.

34 `cbbtgat=1e-18 AV^-3m`
Band-to-band tunneling prefactor of gate-edge component.

35 `fbbtrbot=1e+09 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component.

36 `fbbtrsti=1e+09 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component.

37 `fbbtrgat=1e+09 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component.

38 `stfbbtbot=-0.001 K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component.

39 `stfbbtsti=-0.001 K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component.

40 `stfbbtgat=-0.001 K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component.

41 `vbrbot=10 V` Breakdown voltage of bottom component.

42 `vbrsti=10 V` Breakdown voltage of STI-edge component.

43 `vbrgat=10 V` Breakdown voltage of gate-edge component.

44 `pbrbot=4 V` Breakdown onset tuning parameter of bottom component.

45 `pbrsti=4 V` Breakdown onset tuning parameter of STI-edge component.

46 `pbrgat=4 V` Breakdown onset tuning parameter of gate-edge component.

47 `swjunexp=0` Flag for JUNCAP-express; 0=full model, 1=express model.

48 `vjunref=2.5` Typical maximum junction voltage; usually about 2*VSUP.

49 `fjunq=0.03` Fraction below which junction capacitance components are considered negligible.

Operating-Point Parameters

1 `vak (V)` Voltage between anode and cathode.

2 `cj (F)` Total source junction capacitance.

3 `cjbot (F)` Junction capacitance (bottom component).

4 `cjgat (F)` Junction capacitance (gate-edge component).

5 `cjsti (F)` Junction capacitance (STI-edge component).

6 `ij (A)` Total source junction current.

7 `ijbot (A)` Junction current (bottom component).

8 `ijgat (A)` Junction current (gate-edge component).

9 `ijsti (A)` Junction current (STI-edge component).

10 `si` (A^2/Hz) Total junction current noise spectral density.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Junction Capacitor (juncap_eldo)

The juncap model is intended to describe the behavior of the juncaps that are formed by the source, drain or well-to-bulk junctions in MOS devices. It is described in the Phillips MOST Modelbook (Dec.93) as JUNCAP model. Information on how to obtain this document can be found on Source Link by searching for Phillips.

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In extension to the model book description a minimum conductance `gmin` is inserted between the juncap nodes, to aid convergence. The value of `gmin` is set by an options statement, default = 1e-12 S.

The `imax` parameter is used to aid convergence and to prevent numerical overflow. The junction characteristics of the junction capacitor are accurately modeled for currents up to `imax`. For currents above `imax`, the junction is modeled as a linear resistor and a warning is printed.

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Sample Instance Statement

```
c2 (1 2) capmod ab=7e-12 lg=5e-6 region=rev
```

Sample Model Statement

```
model capmod juncap type=n cjbr=0.2 cjgr=0.2 cjsr=0.2 tref=25 jsgbr=2e-3
jsdbr=0.28e-3 jsggr=1e-5 jsdgr=0.33e-6 vdsr=0.8 vdgr=0.8 vdbr=0.8
```

Instance Definition

```
Name  n  [b] ModelName parameter=value ...
```

Instance Parameters

1 `ab=1.0 scale`^{2} `m`^{2}	Diffusion area. Scale set by option scale.
2 `ls=1.0 scale m`	Length of the sidewall of the diffusion area ab which is not under the gate. Scale set by option scale.
3 `lg=1.0 scale m`	Length of the sidewall of the diffusion area ab which is under the gate. Scale set by option scale.
4 `m=1.0`	Multiplicity factor.
5 `region=rev`	Estimated DC operating region, used as a convergence aid. Possible values are `fwd` or `rev`.

Model Definition

```
model modelName juncap_eldo parameter=value ...
```

Model Parameters

Structural parameters

1 `type=n`	Type of the juncap device. Possible values are `n` or `p`.
2 `vb (V)`	Not used for juncap model.
3 `bv (V)`	Alias of `vb`.

4 `level` Not used for juncap model.

Current parameters

5 `jsgbr=1.0e-3 A/m`^{2}
Bottom saturation-current density due to electron-hole generation at reference voltage.

6 `jsdbr=1.0e-3 A/m`^{2}
Bottom saturation-current density due to diffusion from back contact.

7 `jsgsr=1.0e-3 A/m` Sidewall saturation-current density due to electron-hole generation at reference voltage.

8 `jsdsr=1.0e-3 A/m` Sidewall saturation-current density due to diffusion from back contact.

9 `jsggr=1.0e-3 A/m` Gate edge saturation-current density due to electron-hole generation at reference voltage.

10 `jsdgr=1.0e-3 A/m` Gate edge saturation-current density due to diffusion from back contact.

11 `imax=1.0 A` Explosion current.

Temperature effects parameters

12 `dta=0.0 K` Temperature offset of the juncap element with respect to ambient temperature.

13 `trise=0.0 K` Alias of `dta`.

14 `tr (C)` Temperature at which the parameters have been determined. Default set by option `tnom`.

15 `tref (C)` Alias of tr. Default set by option `tnom`.

16 `tnom (C)` Alias of tr. Default set by option `tnom`.

Junction capacitance parameters

17 `cjbr=1.0e-12 F/m`^{2}	Bottom junction capacitance at reference voltage.
18 `cjsr=1.0e-12 F/m`	Sidewall junction capacitance at reference voltage.
19 `cjgr=1.0e-12 F/m`	Gate edge junction capacitance at reference voltage.

Emission coefficient parameters

20 `nb=1.0`	Emission coefficient of the bottom forward current.
21 `ns=1.0`	Emission coefficient of the sidewall forward current.
22 `ng=1.0`	Emission coefficient of the gate-edge forward current.

Voltage parameters

23 `vr=0.0 V`	Voltage at which parameters have been determined.
24 `vdbr=1.0 V`	Diffusion voltage of the bottom junction at reference temperature.
25 `vdsr=1.0 V`	Diffusion voltage of the sidewall junction at reference temperature.
26 `vdgr=1.0 V`	Diffusion voltage of the gate edge junction at reference temperature.

Grading coefficient parameters

27 `pb=0.4`	Bottom-junction grading coefficient.
28 `ps=0.4`	Sidewall-junction grading coefficient.
29 `pg=0.4`	Gate edge-junction grading coefficient.

Compatibility model parameters

30 `compatible=spectre`

Encourage device equations to be compatible with a foreign simulator. This option does not affect input syntax.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, or `spiceplus`.

Output Parameters

1 `cjb (F)` Capacitance of bottom area `ab`.

2 `cjs (F)` Capacitance of locos-edge `ls`.

3 `cjg (F)` Capacitance of gate-edge `lg`.

4 `isdb (A)` Diffusion saturation-current of bottom area `ab`.

5 `isds (A)` Diffusion saturation-current of locos-edge `ls`.

6 `isdg (A)` Diffusion saturation-current of gate-edge `lg`.

7 `isgb (A)` Generation saturation-current of bottom area `ab`.

8 `isgs (A)` Generation saturation-current of locos-edge `ls`.

9 `isgg (A)` Generation saturation-current of gate-edge `lg`.

10 `vdb (V)` Diffusion voltage of bottom area `ab`.

11 `vds (V)` Diffusion voltage of locos-edge `ls`.

12 `vdg (V)` Diffusion voltage of gate-edge `lg`.

Operating-Point Parameters

1 `v (V)` juncap bias voltage (v = va - vk).

2 `i (A)` Total resistive current from anode to cathode (i = ia = -ik).

3 `gm (S)` Total differential conductance.

4 `q (Coul)` Total junction charge (q = qa = -qk).

5 `c (F)` Total capacitance.

6 `pwr (W)` Power.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

imax	M-11	lg	I-3	tref	M-15

Two Terminal Inductor (inductor)

The inductance of this component can be a function of temperature or branch current. If you do not specify the inductance in the instance statement, it is taken from the model.

This device is supported within altergroups.

If the polynomial coefficients vector (coeffs=[c1 c2 ...]) is specified, the inductor is nonlinear and the inductance is

L(I) = L(inst) * (1 + c1 * I + c2 * I^2 + ...).

The branch flux as a function of current is

Flux(I) = L(inst) * I * (1 + 1/2 * c1 * I + 1/3 * c2 * I^2 + ...)

where ck is the kth entry in the coefficient vector.

The value of the inductor as a function of the temperature is given by:

L(T) = L(tnom) * [1 + tc1 * (T - tnom) + tc2 * (T - tnom)^2].

where

T = trise(inst) + temp

if trise(inst) is given, and

T = trise(model) + temp

otherwise.

Sample Instance Statement

without model:

```
l33 (0 net29) inductor l=10e-9 r=1 m=1
```

with model:

```
l33 (0 net29) ind l=10e-9 r=1 m=1
```

Sample Model Statement

```
model ind inductor l=6e-9 r=1 tc1=1e-12 tc2=1e-12 tnom=25
```

This device support behavior expression

Sample Behavior Statement

```
l33 (0 net29) inductor l=l0*(1 + v(net27, net28)*c1)
l33 (0 net29) inductor l=1e-9+1e-9/(1+($freq)/1e9)
```

Instance Definition

```
Name  1  2 ModelName parameter=value ...
Name  1  2 inductor parameter=value ...
```

Instance Parameters

1	`l (H)`	Inductance.
2	`r (Ω)`	Resistance.
3	`m=1`	Multiplicity factor.
4	`trise`	Temperature rise from ambient.
5	`ic (A)`	Initial condition(alias=lv2).
6	`isnoisy=yes`	Should inductor resistance generate noise. Possible values are `no` or `yes`.
7	`coeffs=[...]`	Vector of polynomial inductance coefficients.
8	`tc1=0 1/C`	Linear temperature coefficient.
9	`tc2=0` C^{-2}	Quadratic temperature coefficient.
10	`scalei`	Inductance scaling factor.

Model Definition

```
model modelName inductor parameter=value ...
```

Model Parameters

1 `l=0 H` Default inductance.

2 `r=0` Ω Default resistance.

3 `tc1=0 1/C` Linear temperature coefficient.

4 `tc2=0` C^{-2} Quadratic temperature coefficient.

5 `trise=0 C` Default `trise` value for instance.

6 `tnom (C)` Parameters measurement temperature. Default set by `options`.

7 `rforce=1e9` Ω^2 Resistance used when forcing nodesets and initial conditions.

8 `coeffs=[...]` Vector of polynomial inductance coefficients.

9 `symmetric=none` Use symmetric inductor model.
Possible values are `none` and `absolute`.

10 `scalei=1` Inductance scaling factor.

Noise model parameters

10 `kf=0` Flicker (1/f) noise coefficient.

11 `af=2` Flicker (1/f) noise exponent.

Output Parameters

1 `indeff (H)` Effective inductance(alias=lv1).

Operating-Point Parameters

1 `ind (H)` Inductance at operating point.

2 `i (A)` Current at operating point(alias=lx2).

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Mutual Inductor (mutual_inductor)

The mutual inductor couples two previously specified inductors. There is no limit to the number of inductors that you can couple or to the number of couplings to a particular inductor, but you must specify separate mutual inductor statements for each coupling. Using the `dot` convention, place a `dot` on the first terminal of each inductor.

This device is supported within altergroups.

The mutual inductor modifies the constitutive equations of two isolated inductors to

v1 = L11*di1/dt + M*di2/dt

v2 = M*di1/dt + L22*di2/dt

where the mutual inductance, M, is computed from the coupling coefficient, k, using k = |M|/sqrt(L11*L22).

Sample Instance Statement with Two Inductors

```
l1 (1 0) inductor
l2 (2 0) inductor
```

```
ml1 mutual_inductor coupling=1 ind1=l1 ind2=l2
```

Instance Definition

```
Name mutual_inductor parameter=value ...
```

Instance Parameters

1	`coupling=0`	Coupling coefficient.
2	`k=0`	Alias to coupling.
3	`ind1`	Inductor to be coupled.
4	`ind2`	Inductor to be coupled.

Operating-Point Parameters

1	`mind (H)`	Mutual inductance between the inductors(alias=lv1).

Magnetic Core with Hysteresis (core)

This component models the magnetic hysteresis, with air gap, frequency, and temperature effects. The model is based on the AWB model for magnetic cores and windings. The user has to specify the cores material and geometric parameters to model the hysteresis.

The material parameters to specify are the `Br`, `Bm` and `Hc` of the core. The geometric parameters are the area, magnetic path length and the air gap of the core.

You can specify the magnetic path length in one of the following ways:

Give the length directly in cm.

Or give the outer and inner diameter of the core.

Cores without terminals represent complete magnetic loops. Cores with terminals are fragments that you can use as building blocks to build models of complicated core structures. For example, you can use the following set of core fragments to model an `E` core:

W1 e1p e1m winding turns=80 core=C1

W3a e2p e2c winding turns=80 core=C3

W3b e2c e2m winding turns=80 core=C3

C1 m1 0 permalloy area=1 len=2

C2 m1 0 permalloy area=2 len=2

C3 m1 0 permalloy area=1 len=2

model permalloy core ...

There are three parallel core fragments representing each of the three fingers on the `E`. One 80 turn winding is connected to core fragment `C1`. A center-tapped 160 turn winding (implemented as a pair of windings) are wrapped around core fragment `C3`. Node `m1` is a `magnetic` node whose value is in magnetomotive force and flow is flux.

You can calculate the frequency and temperature dependency of the core model by specifying the frequency loss parameters and the temperature effects parameters. You can make all the core parameters vary in temperature, including the permeability, saturation flux, and core loss. For frequency losses, a static model refers to a value that you type in for frequency. This model does not adjust the shape of the B-H loop in response to power dissipation or rate of rise of the applied currents and voltages during transient analysis.

This device is not supported within altergroup.

The hysteresis is modeled by different regions whose equations are:

phi = phir + (phis - phir) F/(F + Ha) for region number 1

phi = phis * (F - Fc)/(F - Hb) for region number 2

where phi = flux density

F = magnetomotive force

phir = residual flux density

phis = Saturated flux density

Fc = Coercive magnetic force

Ha and Hb are shape parameters.

Sample Instance Statement

```
c1 (1 0) core_mod area=1.2 len=8.1 id=0.55 gap=0.25
```

Sample Model Statement

```
model core_mod core len=7.7 area=0.85 br=1e3 bm=5e3 hc_t1=0.2 p1_f1=2.08 f1=10e3
p2_f2=50 f2=100K bflux=1e3 density=4.75
```

Instance Definition

```
Name  [1]  [2] ModelName parameter=value ...
```

Instance Parameters

1 `area (cm`^{2}`)`	Effective magnetic cross-sectional area of core.
2 `len (cm)`	Effective length of magnetic path.
3 `id (cm)`	Inner diameter of toroidal core.
4 `od (cm)`	Outer diameter of toroidal core.
5 `gap (cm)`	Gap length.
6 `m=1`	Multiplicity factor.

Model Definition

```
model modelName core parameter=value ...
```

Model Parameters

1 `br=1 gauss`	Residual flux density.
2 `bm=1 gauss`	Saturation flux density.
3 `hc=1 oersteds`	Coercive magnetizing force (value of H where B equals 0).
4 `area=1 cm`^{2}	Effective magnetic cross-sectional area of core.
5 `len=1 cm`	Effective length of magnetic path.
6 `id (cm)`	Inner diameter of toroidal core.
7 `od (cm)`	Outer diameter of toroidal core.

8 gap=0.0 cm — Gap length.

Initial Conditions

9 b0 (gauss) — Initial condition for core.

Frequency Loss Parameters

10 freq (Hz) — Core operating frequency.

11 p1_f1 (W/Kg) — Core power loss at frequency f1.

12 f1 (Hz) — Reference frequency for power loss.

13 p2_f2 (W/Kg) — Core power loss at frequency f2.

14 f2 (Hz) — Reference frequency for power loss.

15 bflux (gauss) — Reference flux density.

16 density (g/cm^3) — Core density.

Temperature Effects Parameters

17 temp (C) — Core operating temperature.

18 bm_t1 (gauss) — Saturated flux density Bm at T1.

19 br_t1 (gauss) — Residual flux density Br at T1.

20 hc_t1 (oersteds) — Coercive force Hc at T1.

21 t1 (C) — Reference temperature.

Operating-Point Parameters

1 b (gauss) — Flux density of the core.

2 h (oersteds) — Magnetic field strength.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Winding for Magnetic Core (winding)

This winding is used in conjunction with magnetic cores to model coils and transformers with hysteresis. Each winding must be associated with a single core, though a core may have any number of windings.

Winding connects terminals `t1` and `b1`. Current through the winding is computed.

This device is not supported within altergroup.

Sample Instance Statement

```
c1 (1 0) core_mod area=1.2 len=8.1 id=0.45 id=0.55 gap=0.25
y1 (2 0) winding turn=5 core=c1 resis=1m
```

Instance Definition

```
Name  t  b winding parameter=value ...
```

Instance Parameters

1 `turn=1` Number of turns on winding.

2 `resis (Ω)` Resistance of the winding.

3 `m=1` Multiplicity factor.

4 `core` Name of core around which winding is wrapped.

Initial Conditions

5 `ic=0.0 A` Initial condition on the winding.

Linear Inductance, Reluctance, Resistance, and Capacitance Matrix (rlck_matrix)

Matrix device allows to specify a set of coupled inductors, resistors and capacitors in a single device, as opposed to a netlist of individual two-terminal devices and pair couplings. Reluctance matrix can be given instead of inductance matrix.

This device is supported within altergroups.

Device equations can be formulated in terms of inductance matrix L, or reluctance matrix K, defined as inverse of L

Inductance form

Vp - Vn = R*I + L*ddt(I)

Reluctance form

K*Vp - K*Vn = K*R*I + ddt(I)

where R is resistance matrix, I - vector of branch currents, ddt - time differentiation operator, Vp and Vn are vectors of positive and negative terminal voltages.

Capacitance equations

Ip = I + Cp*ddt(Vp)

In = -I + Cn*ddt(Vn)

where Ip and In are vectors of terminal currents, Cp, Cn are capacitance matrices for positive and negative terminals.

Sample Instance Statement

```
l33 (p1 n1 p2 n2) rlck_matrix l=[1 1 10n 1 2 -1n 2 2 5n] r=[1 1 100m 2 2 50m]
```

Instance Definition

```
Name  1  2 ... rlck_matrix parameter=value ...
```

Number of terminals is two times dimension of matrix. When capacitance matrix is given, additional terminal can be specified to provide a reference for diagonal capacitors.

Sparse format is used for matrix input. Each matrix element is preceded by its row and column indices. All matrices should have the same dimensions. Matrices are symmetric, so that only upper or lower triangular elements should be specified. At least one of R, L, K matrices must be given. Either L, or K, but not both can be specified.

Instance Parameters

1 `l=[...] H` Inductance matrix.

2 `r=[...] Ω` Resistance matrix.

3 `k=[...] 1/H` Reluctance matrix.

4 `c1=[...] F` Capacitance matrix for positive terminals.

5 `c2=[...] F` Capacitance matrix for negative terminals.

6 `ignore_coupling=no`
Ignore coupling elements in r, l, k, and c matrices. Possible values are `no` or `yes`.

7 `file` rlck matrix data file name.

8 `m=1` Multiplicity factor.

Matrix data file may have several sections - one for each matrix. Each section starts with keyword: inductance (l), reluctance (k), resistance (r), capacitance1 (c1), capacitance2 (c2). If the keyword is not given, the data is assumed to be reluctance matrix. Matrix data is in sparse format, same as on the instance statement. Character + in the first column, as well as =, [, and] are treated as blank space.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

3

Parameters Common to All Devices

This chapter discusses the following topics:

Multiplication Factor (m)

The multiplication factor (`m`) puts `m` devices in parallel. `m` is an instance parameter and need not be an integer. All devices have the multiplication factor capability.

If you specify `m` in an instance statement, all currents and capacitances of that device are multiplied by `m`, and all resistances are divided by `m`. The multiplication factor, however, does not affect short-channel or narrow-gate effects in MOSFETs. For example, the following two statements might not give you the same simulation results:

```
m1 d g s b my_model w=10u l=1u m=10
m1 d g s b my_model w=100u l=1u m=1
```

You can also specify the multiplication factor on subcircuits. If a multiplication factor is specified in a subcircuit, it applies to all elements in that subcircuit. For example, if the multiplication factor of the subcircuit is 2 and the multiplication factor of an element in the subcircuit is 3, the effective multiplication factor for that element is 6.

Some devices—such as BJT, JFET, and diode—have an area factor parameter (`area`). The `area` parameter has identical effect on devices as the multiplication factor.

Scaling Factors (scale and scalem)

`scale` and `scalem` are options that set the scaling factors for instance and model parameters, respectively. You can specify the scaling factors in the `.options` statement. The following devices are affected by `scale` or `scalem`:

- Capacitors
- Diodes
- Resistors
- Physical resistors (`phy_res`)
- All levels of MOSFET models

These scaling factors affect capacitors, resistors, and physical resistors with specified device length (`l`) or width (`w`). `scale` and `scalem` are global options and apply to all instance and model statements for the preceding list of devices.

Parameters are scaled according to the following rules:

- Model (instance) parameters containing units of *m* (meters) are multiplied by `scalem` (`scale`).

- Model (instance) parameters containing units of m^n are multiplied by `scalem`^{n} (`scale`^{n}), where *n* can be a positive integer or a positive real number.
- Model (instance) parameters containing units of 1/*m* are divided by `scalem` (`scale`).
- Model (instance) parameters containing units of $1/m^n$ are divided by `scalem`^{n} (`scale`^{n}), where *n* can be a positive integer or a positive real number.
- Parameters that use the units *cm* (1/*cm*, cm^2, ...) and µ*m* (1/µ*m*, µm^2, ...) are not scaled. For example, `vmax`, which contains the unit *m*/*sec*, is scaled by `scalem`, but `ucrit`, which has the unit *V*/*cm*, is not scaled. Similarly, `nsub`, which has the unit 1/cm^3, is not scaled by `scalem`.
- Parameters with other units are not scaled.

Note: The `diode` model is not scaled by default. To scale the `diode` model, set `allow_scaling` in the model card to `yes`.

imelt and imax

`imelt` and `imax` are used on devices containing p-n junctions. These devices include

- JFETs
- GaAs FETs
- Physical resistors (`phy_res`)
- All MOSFET models
- Diodes
- All BJTs (G-P, VBIC, and HBT)

`imelt` is used to help convergence and to prevent numerical problems. The Virtuoso® Spectre® circuit simulator uses `imelt` to linearize the junction current. When the junction current is larger than `imelt` (a model parameter), the junction current is calculated as a linear function instead of an exponential function of the junction voltage. Therefore, if the junction current is larger than `imelt`, the current calculated by the Spectre circuit simulator is not what the original junction current model predicts, and the Spectre circuit simulator issues a warning.

`imax` is a warning control parameter. Normally, `imax` does not affect the simulation results. Whenever the junction current is larger than `imax`, the Spectre circuit simulator issues a warning. The default value of `imax` is `1A`, and the default value of `imelt` is `imax`. Therefore, `imax` can affect the simulation results only when `imelt` is not specified and takes its value from `imax`.

Typically, the junction current is much less than 1 A. When `imelt` is `1A`, the conductance of the junction at room temperature is about 40 siemens, which is much larger than those of typical semiconductor devices. The Spectre circuit simulator issues a warning message telling you the junction current is linearized when

- The `imelt` value is set too small
- The connection to devices is incorrect
- Temporary voltage overshoot due to capacitive coupling at fast transient transition

  If this happens, the warnings can be ignored in most cases unless the voltage overshoot is purposely designed to trigger some circuit functions.

In MOSFETs, you can use `jmelt` instead of `imelt`. The function of `jmelt` is identical to that of `imelt`, except that the junction current is linearized based on the current density specified by `jmelt`. If both `imelt` and `jmelt` are specified, `imelt` takes precedence.

For BJTs, `imelt` and `imax` are used to control the base-emitter and the substrate junctions. `imelt1` and `imax1` are used to control the base-collector junction.

SPICE Compatibility Flag (compatible)

The SPICE compatibility flag (`compatible`) is a parameter you can specify in an `.options` statement. This parameter solves some SPICE compatibility issues. The valid values for `compatible` are `spectre`, `spice2`, `spice3`, and `cdsspice`. This parameter affects two areas:

- Energy band gap

  If you set `compatible` to `spectre`, the Spectre simulator uses a more physics-based temperature equation to calculate the energy band gap. For all other values, the Spectre simulator uses the SPICE temperature equation. This different energy gap calculation affects only devices that use the common junction codes such as MOSFET, diode, JFET, and GaAs. BJT is not affected.

- MOSFET Level-2

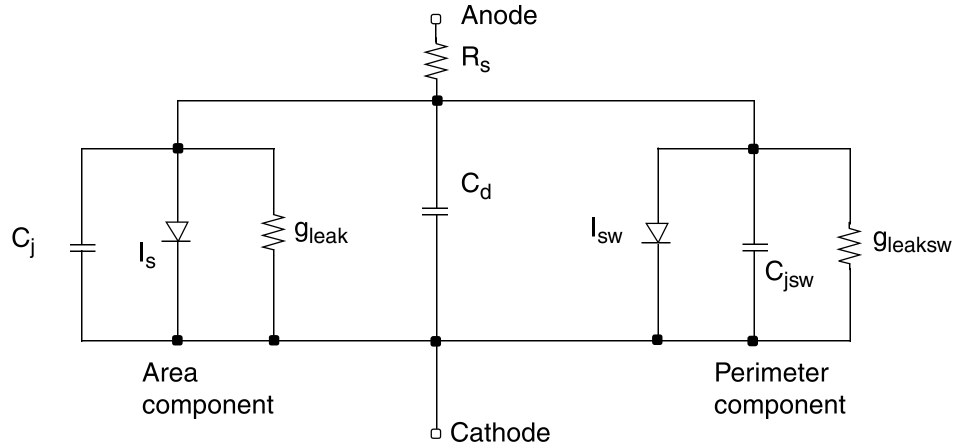
  The MOSFET Level-2 model includes a model parameter `smooth`, which chooses an improved (smoother and faster) model (`smooth = yes`) or the original SPICE Level-2 model (`smooth = no`). The default value of `smooth` is `yes`. If `compatible` is set to a value other than `spectre`, the Spectre simulator sets `smooth` to `no` regardless of the value you specify.

4

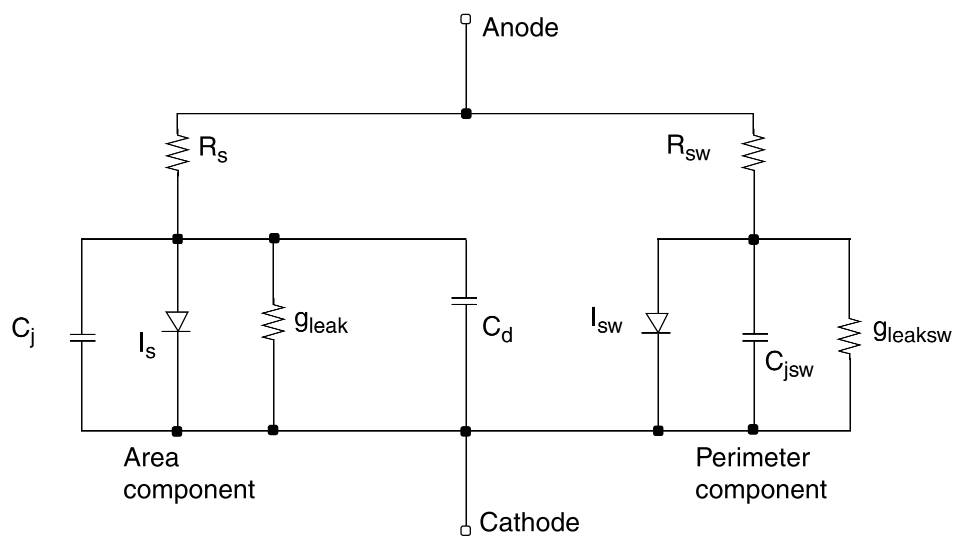
Diode Model (diode)

The DIODE level-1 model is based on the junction (Berkeley-spice) model and the level-2 model is based on the Fowler-Nordheim model. This chapter contains the following information about the DIODE model:

If R_{sw} is not given, the diode model schematic is given by



If R_{sw} is given, the diode model schematic is given by



Level-1 Model

The following effects are included in the junction diode model: forward characteristics, reverse leakage current, breakdown, parasitic resistance, diffusion capacitance, depletion capacitance, and overlap capacitance.

To achieve better scaling, a sidewall (peripheral) diode can also be specified. The peripheral diode shares most model parameters with the main diode except for the following parameters: `isw`, `ns`, `cjsw`, `mjsw`, `fcsw`, `rsw`, `gleaksw`, `ctp`, and `ptp`. If the sidewall parasitic resistance (`rsw`) is not specified, the peripheral diode shares the same parasitic resistance with the main diode. That is, both the main and the peripheral diodes are connected to the same internal nodes. If `rsw` is specified, the peripheral diode creates its own internal node. In this case, the peripheral and main diode are equivalent to connecting two diodes in parallel.

The leakage currents are modeled by putting two small conductances (`gleak` and `gleaksw`) in parallel with the intrinsic diodes.

DC Current

$$I_{jtot} = I_j + I_{jsw}$$

where V_t is the thermal voltage given by

$$V_t = \frac{kT}{q}$$

$$I_j = \begin{cases} is\left(e^{\frac{V}{nV_t}} - 1\right) & \text{if } V \le V_{Expl} \\ I_{offset} + G_{Expl}V & \text{otherwise} \end{cases}$$

$$V_{Expl} = nV_t \ln\left[1 + \frac{imelt}{is}\right]$$

is the forward explosion voltage,

$$G_{Expl} = \frac{(imelt + is)}{nV_t}$$

is the conductance at V_{Expl}, and

$$I_{offset} = imelt - V_{Expl}G_{Expl}$$

is the current linearly extrapolated to $V = 0$ from V_{Expl}.

$$Ij+ = -JTUNeff \times \left(e^{\frac{-vd}{NTUN \times vt}} - 1 \right)$$

If I_j>0 and I_k>0,

$$I_j = I_j / (1 + \sqrt{I_j / (I_k \times Area)})$$

$$I_{jsw} = \begin{cases} isw\left(e^{\frac{V}{n_s V_t}} - 1\right) & \text{if } V \le V_{Explsw} \\ I_{offsetsw} + G_{Explsw} V & \text{otherwise} \end{cases}$$

$$V_{Explsw} = n_s V_t \ln\left[1 + \frac{imelt}{is}\right]$$

$$G_{Explsw} = \frac{(imelt + isw)}{n_s V_t}$$

$$I_{offsetsw} = imelt - V_{Explsw} G_{Explsw}$$

If I_{jsw}>0 and I_{kp}>0,

$$I_{jsw} = I_{jsw} / (1 + \sqrt{I_{jsw} / (I_{kp} \times AreaSW)})$$

Junction Capacitance

$$C_j(V) = \begin{cases} \dfrac{cjo}{\left[1 - \dfrac{V}{vj}\right]^m} & \text{if } V \le fc * vj \\ \dfrac{cjo}{(1 - fc)^m}\left[1 + \dfrac{m(V - vj*fc)}{vj(1 - fc)}\right] & \text{otherwise} \end{cases}$$

Peripheral Junction Capacitance

$$C_{jsw}(V) = \begin{cases} \dfrac{cjsw}{\left[1 - \dfrac{V}{vjsw}\right]^{mjsw}} & \text{if } V \le fcsw * vjsw \\ \dfrac{cjsw}{(1-fcsw)^{mjsw}}\left[1 + \dfrac{mjsw(V - vjsw*fcsw)}{vjsw(1-fcsw)}\right] & \text{otherwise} \end{cases}$$

Diffusion Capacitance

$$C_{diff} = \frac{tt[I_j + is]}{nV_t} + \frac{tt[I_{jsw} + isw]}{n_s V_t}$$

Total Capacitance

$$C_{tot} = C_j + C_{jsw} + C_{diff} + C_d$$

Breakdown Current

$$I_{zener} = \begin{cases} -ibv\ \exp\left[-\dfrac{(V+bv)}{n_z V_t}\right] & \text{if } -(bv + V_{ZenerExpl}) \le V \\ -[I_{ZenerOffset} - G_{ZenerExpl}(V+bv)] & \text{otherwise} \end{cases}$$

where

$$V_{ZenerExpl} = n_z V_t \ln\left[\frac{imelt}{ibv}\right]$$

is the zener explosion voltage,

$$G_{ZenerExpl} = \frac{(imelt + ibv)}{n_z V_t}$$

is the conductance at $V_{ZenerExpl}$,

and

$$I_{ZenerOffset} = imelt - V_{ZenerExpl} G_{ZenerExpl}$$

is the current linearly extrapolated to $V = 0$ from $V_{ZenerExpl}$. The breakdown current is not modeled in the peripheral diode.

Temperature Effect

Energy Band Gap

$$E_g(T) = \begin{cases} eg - \dfrac{gap1 * T^2}{T + gap2} & \text{if } tlev = 2 \\ \left(1.17 - \dfrac{4.73 \times 10^{-4} T^2}{T + 636}\right) & \text{if } tlev = 0 \text{ or } 1 \text{ and } compatible{=}spectre \\ \left(1.16 - \dfrac{7.02 \times 10^{-4} T^2}{T + 1108}\right) & \text{otherwise} \end{cases}$$

Junction Currents

$$is = \begin{cases} is_{nom}\left(\dfrac{T}{Tnom}\right)^{\frac{xti}{n}} \exp\left[\dfrac{eg}{V_{t,nom}} - \dfrac{eg}{V_t}\right] & \text{if } tlev = 0 \text{ or } 1 \text{ and } eg \text{ is given, or } compatible \neq spectre \\ is_{nom}\left(\dfrac{T}{Tnom}\right)^{\frac{xti}{n}} \exp\left[\dfrac{E_g(Tnom)}{V_{t,nom}} - \dfrac{E_g(T)}{V_t}\right] & \text{if } tlev = 2 \text{ or } eg \text{ is not given} \end{cases}$$

Note: in the above equation, when eg is not specified, the default band gap is temperature dependent as specified by $E_g(T)$. The temperature dependence can be turned off by specifying eg in the model card or by setting the option *compatible* to something other than Virtuoso® Spectre® circuit simulator (for example *compatible = spice*).

$$isw = \begin{cases} isw_{nom}\left(\frac{T}{Tnom}\right)^{\frac{xti}{n_s}} \exp\left[\frac{eg}{V_{t,nom}} - \frac{eg}{V_t}\right] & \text{if } tlev = 0 \text{ or } 1 \\ isw_{nom}\left(\frac{T}{Tnom}\right)^{\frac{xti}{n_s}} \exp\left[\frac{E_g(Tnom)}{V_{t,nom}} - \frac{E_g(T)}{V_t}\right] & \text{if } tlev = 2 \end{cases}$$

Breakdown Voltage

$$bv = bv_{nom}(1 + tbv*\Delta T + tbv2*\Delta T^2)$$

Parasitic Resistance

$$rs = rs_{nom}(1 + trs*\Delta T + trs2*\Delta T^2)$$

$$rsw = rsw_{nom}(1 + trs*\Delta T + trs2*\Delta T^2)$$

Leakage Conductance

$$gleak = gleak_{nom}(1 + tgs*\Delta T + tgs2*\Delta T^2)$$

$$gleaksw = gleaksw_{nom}(1 + tgs*\Delta T + tgs2*\Delta T^2)$$

Junction Potential

$$vj = \begin{cases} vj_{nom}\left(\frac{T}{Tnom}\right) - \Delta V_j & \text{if } tlevc = 0 \\ vj_{nom} - pta\Delta T & \text{if } tlevc = 1 \text{ or } 2 \\ vj_{nom} - \frac{dV_j}{dT}\Delta T & \text{if } tlevc = 3 \end{cases}$$

$$vjsw = \begin{cases} vjsw_{nom}\left(\frac{T}{Tnom}\right) - \Delta V_j & \text{if } tlevc = 0 \\ vjsw_{nom} - ptp\Delta T & \text{if } tlevc = 1 \text{ or } 2 \\ vjsw_{nom} - \frac{dV_{jsw}}{dT}\Delta T & \text{if } tlevc = 3 \end{cases}$$

where

$$\Delta V_j = V_t\left[3\ln\left(\frac{T}{Tnom}\right) + \frac{E_g(Tnom)}{V_{t,nom}} - \frac{E_g(T)}{V_t}\right]$$

$$\frac{dV_j}{dT} = \begin{cases} \frac{\left[E_g(Tnom) + 3V_{t,nom} + (1.16 - E_g(Tnom))\left(2 - \frac{Tnom}{Tnom + 1108}\right) - vj\right]}{Tnom} \\ \frac{\left[E_g(Tnom) + 3V_{t,nom} + (eg - E_g(Tnom))\left(2 - \frac{Tnom}{Tnom + gap2}\right) - vj\right]}{Tnom} \end{cases}$$

$$\frac{dV_{jsw}}{dT} = \begin{cases} \frac{\left[E_g(Tnom) + 3V_{t,nom} + (1.16 - E_g(Tnom))\left(2 - \frac{Tnom}{Tnom + 1108}\right) - vjsw\right]}{Tnom} & \text{if } tlev = 0, 1 \\ \frac{\left[E_g(Tnom) + 3V_{t,nom} + (eg - E_g(Tnom))\left(2 - \frac{Tnom}{Tnom + gap2}\right) - vjsw\right]}{Tnom} & \text{if } tlev = 2 \end{cases}$$

Junction Capacitance

$$cjo = \begin{cases} cjo_{nom}\left[1 + m\left(0.0004\Delta T - \frac{vj}{vj_{nom}} + 1\right)\right] & \text{if } tlevc = 0 \\ cjo_{nom}(1 + cta\Delta T) & \text{if } tlevc = 1 \\ cjo_{nom}\left(\frac{vj_{nom}}{vj}\right)^{m} & \text{if } tlevc = 2 \\ cjo_{nom}\left(1 - 0.5\frac{dV_j}{dT}\frac{\Delta T}{vj_{nom}}\right) & \text{if } tlevc = 3 \end{cases}$$

$$cjsw = \begin{cases} cjsw_{nom}\left[1 + m\left(0.0004\Delta T - \frac{vjsw}{vjsw_{nom}} + 1\right)\right] & \text{if } tlevc = 0 \\ cjsw_{nom}(1 + ctp\Delta T) & \text{if } tlevc = 1 \\ cjsw_{nom}\left(\frac{vjsw_{nom}}{vjsw}\right)^{mjsw} & \text{if } tlevc = 2 \\ cjsw_{nom}\left(1 - 0.5\frac{dV_{jsw}}{dT}\frac{\Delta T}{vjsw_{nom}}\right) & \text{if } tlevc = 3 \end{cases}$$

Noise Model

Series Resistance Thermal Noise

$$\overline{i_{R_S}^2} = \frac{4kT}{rs}\Delta f$$

Diode Shot and Flicker Noise

$$\overline{i_D^2} = 2qI_D\Delta f + kf\frac{I_D^{af}}{f}\Delta f$$

where kf and af are constants for a given device. The Spectre® circuit simulator defaults for these constants are 0.0 and 1.0, respectively.

Scaling Effects

The following are the Spectre scaling effects:

- is, cjo, cd, and ibv are multiplied by $area$ and m.
- rs is divided by $area$ and m.
- All noises are multiplied by $area$ and m.
- isw and $cjsw$ are multiplied by $perim$ and m for the peripheral diode.
- rsw is divided by $perim$ and m.
- If $area$ is not specified and l and w are specified, $area$ is calculated from l and w as

  $$area = L_{eff} \times W_{eff}$$

  where

  $$W_{eff} = w - etch$$

  $$L_{eff} = l - etchl$$

  If $area$, w, and l are not specified on the instance line, and $area$ is specified on the model card, then $area = area_{model}$.

  Otherwise, $area$ defaults to 1.

- If $perim$ is not specified and l and w are specified, $perim$ is calculated from l and w as

  $$perim = 2 \times (L_{eff} + W_{eff})$$

  If $perim$, l, and w are not specified on the instance line, and $perim$ is specified on the model card, then $perim = perim_{model}$.

  Otherwise, $perim$ defaults to 0.

  The model parameter $allow\_scaling$ controls scaling of diode geometry parameters ($area$, $perim$, l, and w) by the scale option. If $allow\_scaling$ is set to yes, then the l, w, and $perim$ device parameters are multiplied by $scale$, while $area$ is multiplied by $scale^2$. By default, $allow\_scaling$ is no.

  If $scale$ is specified on the diode instance line, then this value overrides the value of the scale option for this particular instance, although it is still only used if $allow\_scaling$ is yes on the corresponding diode model card.

Level-2 Model

The level-2 diode model is used to model the Fowler-Nordheim tunneling current in very thin insulators, such as silicon dioxide, commonly seen in nonvolatile memory. The peripheral diode is not supported for the level-2 model. If $perim$ is specified, it is ignored.

DC Current

$$I_j = \begin{cases} if\left(\frac{V}{tox}\right)^{nf} e^{\frac{-ecrf \times tox}{V}} & \text{if } V \geq 0 \\ ir\left(\frac{V}{tox}\right)^{nr} e^{\frac{ecrr \times tox}{V}} & \text{otherwise} \end{cases}$$

Linear Capacitance

$$C_d = cd + \frac{\varepsilon_{ox}}{tox}$$

Scaling Effects

The following are the Spectre scaling effects:

- if, ir, and cd are multiplied by $area$ and m.
- rs is divided by $area$ and m.
- If $area$ is not specified and l and w are specified, $area$ is calculated from l and w as follows:

  $$area = L_{eff} \times W_{eff}$$

  where

  $$W_{eff} = w - etch$$

  $$L_{eff} = l - etchl$$

Otherwise, *area* defaults to 1.

Level-3 Model

The level-3 model shares the level-1 model parameters. In addition, the level-3 model supports the following parameters: LM, LP, WM, XM, XP, XOI and XOM.

The poly metal capacitor is calculated by:

If xoi is given:

$$C_{poly} = (oxide \text{ permittivity}|xoi \times 1.0E - 10) \times (wp + xp) \times (lp + xp)$$

otherwise,

$$C_{poly} = (oxide \text{ permittivity}|7.0E) \times (wp + xp) \times (lp + xp)$$

The metal capacitor is calculated by:

If xom is given:

$$C_{metal} = (oxide \text{ permittivity}|xoi \times 1.0E - 10) \times (wm + xm) \times (lm + xm)$$

otherwise,

$$C_{metal} = (oxide \text{ permittivity}|1.0E6) \times (wm + xm) \times (lm + xm)$$

Component Statements

The junction diode model includes nonlinear junction capacitance and reverse breakdown.

This device is supported within altergroups.

Sample Instance Statement

```
d0 (dp dn) pdiode l=3e-4 w=2.5e-4 area=1
```

Sample Model Statement

```
model pdiode diode is=1.8e-5 rs=1.43 n=1.22 nz=2.31 gleak=6.2e-5 rsw=10 isw=6.1e-10 ibv=0.95e-3 tgs=2 ik=1.2e7 fc=0.5 cj=1.43e-3 pb=0.967 mj=0.337 cjsw=2.76e-9 vjsw=0.94 jmax=1e20
```

Instance Definition

```
Name  a  c ModelName parameter=value ...
```

In forward operation, the voltage on the anode (`a`) is more positive than the voltage on the cathode (`c`).

Instance Parameters

1 `area`	Junction area factor (alias=lv1).
2 `perim`	Junction perimeter factor.
3 `l=1e-6 m`	Drawn length of junction.
4 `w=1e-6 m`	Drawn width of junction.
5 `m=1`	Multiplicity factor.
6 `scale=1`	Scale factor.
7 `region=on`	Estimated operating region. Spectre outputs number (0-2) in a rawfile. Possible values are `off`, `on`, and `breakdown`.
8 `trise (C)`	Temperature rise from ambient.
9 `lm=0.0 m`	Length of metal capacitor.
10 `lp=0.0 m`	Length of polysilicon capacitor.
11 `wm=0.0 m`	Width of metal capacitor.
12 `wp=0.0 m`	Width of polysilicon capacitor.
13 `isnoisy=yes`	Should device generate noise. Possible values are `no` and `yes`.

The instance parameter `scale`, if specified, overrides the value given by the `option` parameter `scale`. If the model parameter `allow_scaling` is set to `yes` then, the `area`, `perim`, `l` and `w` parameters are scaled by `scale`. By default `allow_scaling` is set to `no` and no scaling of geometry parameters will occur. The values of `area`, `perim`, `l` and `w` printed out by spectre are those given in the input, and these values might not have the correct units if the scaling factors are not unity.

Model Definition

```
model modelName diode parameter=value ...
```

Model Parameters

Model selector parameters

1 `level=1` Model selector. 1 = Junction ,2 = Fowler-Nordheim, 3 = Junction + additional metal and polysilicon capacitances.

2 `dcap=2` Depletion capacitance equations selector (hspice compatibility flag only).

3 `compatible=spectre`
Spice compatible flag.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, or `mica`.

Process parameters

4 `etch=0 m` Narrowing due to etching per side.

5 `etchl=0 m` Length reduction due to etching per side.

6 `l=1e-6 m` Drawn length of junction.

7 `w=1e-6 m` Drawn width of junction.

Junction diode parameters

8 `js=1e-14 A/Area` Saturation current.

9 `is=`jsA'` Alias to `js`.

10 `jsw=0 A/Perim`	Sidewall saturation current.
11 `isw=`jswA'`	Alias to `jsw`.
12 `isp=`jswA'`	Alias to `jsw`.
13 `n=1`	Emission coefficient.
14 `ns=1`	Sidewall emission coefficient.
15 `ik=0.0 A/Area`	High-level injection knee current.
16 `ikf=0.0 A/Area`	High-level injection knee current. For level=1/3, it is an alias to ik.
17 `ikp=`ikA/Area'`	High-level injection knee current for sidewall.
18 `ikr=ik A/Area`	Reverse high-level injection knee current (hspice compatibility flag only).
19 `area=1`	Junction area factor.
20 `perim=0`	Junction perimeter factor.
21 `allow_scaling=no`	Allow scale option and instance scale parameter to affect diode instance geometry parameters. Possible values are `no` and `yes`.

Capacitive parameters

22 `tt=0 s`	Transit time.
23 `cd=0 F/Area`	Linear capacitance.
24 `cjo=0 F/Area`	Zero-bias junction capacitance.
25 `vj=1 V`	Junction potential.(For HSPICE, its default value is 0.8).
26 `pb=`vjV'`	Alias to vj.
27 `m=0.5`	Grading coefficient.
28 `cjsw=0 F/Perim`	Zero-bias sidewall junction capacitance.

29 `cjp=`cjswF'`	Alias to `cjsw`.
30 `vjsw=1 V`	Sidewall junction potential.(For HSPICE, its default value is vj).
31 `php=`vjswV'`	Alias of `vjsw`.
32 `mjsw=0.33`	Sidewall grading coefficient.
33 `fc=0.5`	Forward-bias depletion capacitance threshold.
34 `fcs=`fc'`	Coefficient for forward-bias depletion sidewall capacitance.
35 `lm=0.0 m`	Length of metal capacitor (level=3 only).
36 `lp=0.0 m`	Length of polysilicon capacitor (level=3 only).
37 `wm=0.0 m`	Width of metal capacitor (level=3 only).
38 `wp=0.0 m`	Width of polysilicon capacitor (level=3 only).
39 `xm=0.0 m`	XM accounts for masking and etching effects (level=3 only).
40 `xp=0.0 m`	XP accounts for masking and etching effects (level=3 only).
41 `xoi=0.0 m`	Thickness of the polysilicon to bulk oxide. Units - nAngstram (level=3 only).
42 `xom=0.0 m`	Thickness of the metal to bulk oxide. Units - nAngstram (level=3 only).
43 `xw=0.0 m`	Accounts for masking and etching effects (level=3 only).
44 `vjmin=0.1`	Lowest value for build-in junction potential.

Breakdown parameters

45 `bv=∞ V`	Reverse breakdown voltage. Note: bv=0 is not the same as bv=infinity.
46 `vb=`bvV'`	Alias to `bv`.
47 `ibv=0.001 A/Area`	Current at breakdown voltage.

48 `nz=1` Emission coefficient for Zener diode.

49 `bvj=∞ V` Voltage at which junction breakdown warning is issued.

50 `isr=0 A/m`^{2} Recombination current parameter.

51 `ibvl=0 A/m`^{2} Low-level reverse breakdown current.

52 `nbv=1` Reverse breakdown ideality factor.

53 `nbvl=1` Reverse breakdown ideality factor.

Parasitic resistance parameters

54 `rs=0 Ω` Series resistance (/area).

55 `rsw=0 Ω` Sidewall series resistance (/perim).

56 `gleak=0 S` Bottom junction leakage conductance (*area).

57 `gleaksw=0 S` Sidewall junction leakage conductance (*perim).

58 `minr=0.1 Ω` Minimum series resistance.

Temperature effects parameters

59 `tlev=0` DC temperature selector.

60 `tlevc=0` AC temperature selector.

61 `eglev=0` DC temperature selector.

62 `eg=1.11 V` Band gap. Note: when not specified, the default value is temperature dependent. It is 1.11 at temp=27C.

63 `gap1=7.02e-4 V/C` Band gap temperature coefficient.

64 `gap2=1108 C` Band gap temperature offset.

65 `xti=3` Saturation current temperature exponent.

66 `tbv1=0 1/C` Linear temperature coefficient for `bv`.

67 `tcv=`tbv11/C'`	Linear temperature coefficient for `bv`.
68 `tbv2=0` C^{-2}	Quadratic temperature coefficient for `bv`.
69 `tikf=0 1/C`	IKF temperature coefficient (linear).
70 `tnom (C)`	Parameters measurement temperature. Default set by `options`.
71 `trise=0 C`	Temperature rise from ambient.
72 `trs=0 1/C`	Linear temperature coefficient for parasitic resistance.
73 `trs1=0 1/C`	Alias of trs.
74 `tmod=tnom C`	Model temperature.
75 `trs2=0` C^{-2}	Quadratic temperature coefficient for parasitic resistance.
76 `tgs=0 1/C`	Linear temperature coefficient for leakage conductance.
77 `tgs2=0` C^{-2}	Quadratic temperature coefficient for leakage conductance.
78 `cta=0 1/C`	Junction capacitance temperature coefficient.
79 `ctp=0 1/C`	Sidewall junction capacitance temperature coefficient.
80 `pta=0 V/C`	Junction potential temperature coefficient.
81 `ptp=0 V/C`	Sidewall junction potential temperature coefficient.
82 `ttt1=0.0 1/C`	1st order temp. coeff. for tt hspice.
83 `ttt2=0.0` C^{-2}	2st order temp. coeff. for tt hspice.
84 `tm1=0.0 1/C`	1st order temp. coeff. for Mj hspice.
85 `tm2=0.0` C^{-2}	2st order temp. coeff. for Mj hspice.

Junction diode model control parameters

86 `jmelt=`jmeltA/Area'`
Explosion current.

87 `imelt=`jmeltA'`	Alias to `jmelt`.
88 `expli=`jmeltA'`	Alias to `jmelt`.
89 `jmax=1 A/Area`	Maximum allowable current.
90 `imax=`jmaxA'`	Alias to `jmax`.
91 `dskip=yes`	Use simple piece-wise linear model for diode currents below 0.1*`iabstol`. Possible values are `no` or `yes`.

Fowler-Nordheim diode parameters

92 `if=1e-10 A/V^nf`	Forward Fowler-Nordheim current coefficient (*area).
93 `ir=`ifA/V^nr'`	Reverse Fowler-Nordheim current coefficient (*area).
94 `ecrf=2.55e10 V/m`	Forward critical field (For hspice compatible, the unit is V/cm, default value is 1.0e-8).
95 `ecrr=`ecrfV/m'`	Reverse critical field (For hspice compatible, the unit is V/cm).
96 `ef=`ecrfV/m'`	Alias of `ecrf`.
97 `er=`ecrrV/m'`	Alias of `ecrr`.
98 `nf=2`	Forward voltage power.
99 `nr=`nf'`	Reverse voltage power.
100 `tox=1e-8 m`	Thickness of insulating layer.

TSMC Stand Alone model parameters

101 `rod=`rs'`Ω	Alias for Rs (Ohmic series resistance).
102 `jts=0` A/m^2	Bottom trap-assisted saturation current density (with Level=1 and StAlone flag=1).
103 `jtssw=0` A/m^2	Sidewall trap-assisted saturation current density (with Level=1 and StAlone flag=1).

104 `mrs=0.4`	Fitting parameter for Rseff (with Level=1 and StAlone flag=1).
105 `njts=60`	Non-ideality factor for Jts (with Level=1 and StAlone flag=1).
106 `njtssw=60`	Non-ideality factor for Jtssw (with Level=1 and StAlone flag=1).
107 `xts=0.055`	Power dependence of Jts on temperature (with Level=1 and StAlone flag=1).
108 `xtssw=0.055`	Power dependence of Jtssw on temperature (with Level=1 and StAlone flag=1).
109 `tnjts=0.15`	Temperature coefficient for Njts (with Level=1 and StAlone flag=1).
110 `tnjtssw=0.15`	Temperature coefficient for Njtssw (with Level=1 and StAlone flag=1).
111 `trod=0`	Temperature coefficient for Rod(Rs) (with Level=1 and StAlone flag=1).

Noise model parameters

112 `kf=0`	Flicker noise (1/f) coefficient.
113 `af=1`	Flicker noise (1/f) exponent.

Shrink Parameters

114 `shrink=1.0`	Shrink factor.
115 `shrink2=0.0`	Area shrink parameter.

Trap-assisted tunneling current parameters

116 `jtun=0 A`	Tunneling saturation current per area.
117 `jtunsw=0 A`	Sidewall tunneling saturation current per unit junction periphery.
118 `ntun=30`	Tunneling emission coefficient.
119 `xtitun=3.0`	Exponent for the tunneling current temperature.

120 `egtun=eg V` Parameter for tunneling current at reverse region.

Safe Operating Areas Parameters

121 `bv_max=∞ V` Maximum allowed voltage cross two terminals.

122 `fv_max=∞ V` Maximum allowed forward voltage cross two terminals.

123 `keg=1.0 V` The factor that is multiplied by EG to calculate the tunneling bandgap.

Both of these parameters have current density counterparts, `jmax` and `jmelt`, that you can specify if you want the absolute current values to depend on the device area.

Output Parameters

1 `bveff (V)` Effective reverse breakdown voltage.

Operating-Point Parameters

1 `region=on` Estimated operating region. Spectre outputs number (0-2) in a rawfile.
Possible values are `off`, `on`, and `breakdown`.

2 `v (V)` Extrinsic diode voltage.

3 `i (A)` Resistive diode current (alias=lx1).

4 `pwr (W)` Power dissipation.

5 `res (Ω)` Resistance of intrinsic diode.

6 `resp (Ω)` Resistance of intrinsic sidewall diode.

7 `cap (F)` Junction capacitance.

8 `capp (F)` Sidewall junction capacitance.

9 `cd (F)` Total junction capacitance (alias=lx5).

10 `ctotal (F)` Total junction capacitance (alias=lx5).

11 `gd (S)`	Equivalent conductance (alias=lx2).
12 `qd (Coul)`	Charge of diode capacitor (alias=lx3).
13 `vdio (V)`	Voltage, across diode (VD), excluding RS (alias=lx0).

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

5

BJT Model (bjt)

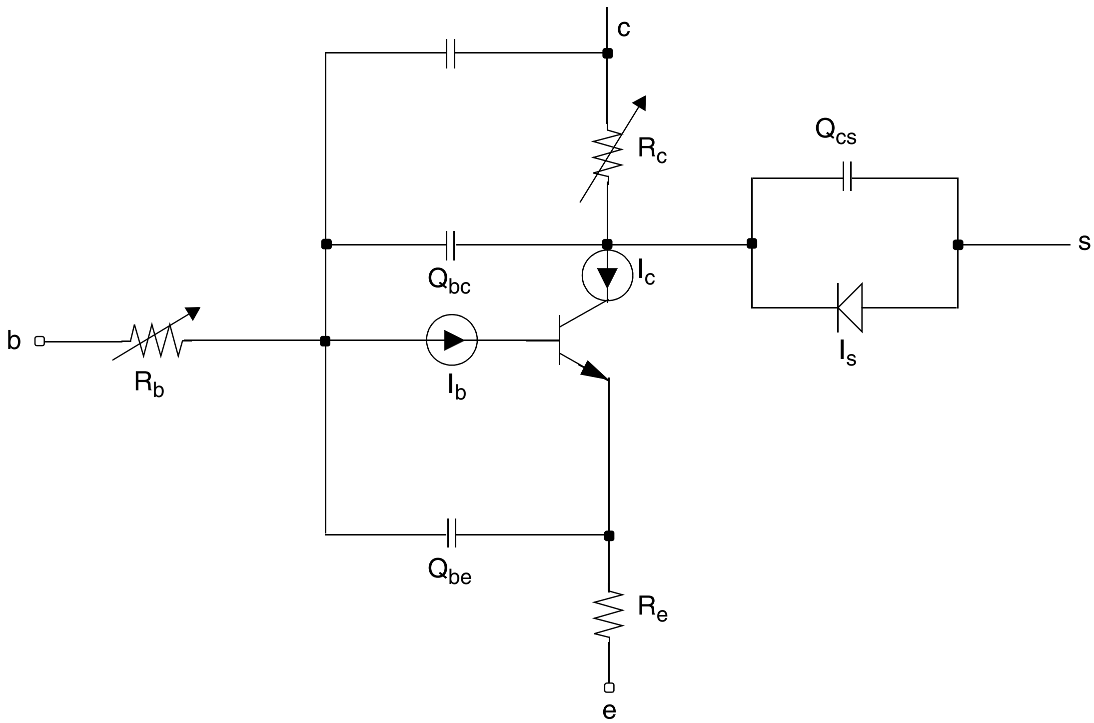
The BJT model is based on the Berkeley-Spice Gummel-Poon model. It defaults to the simpler Ebers-Moll model if certain parameters are left unspecified. This model also includes a substrate junction that connects either to the collector or to the base to model vertical and lateral structures.

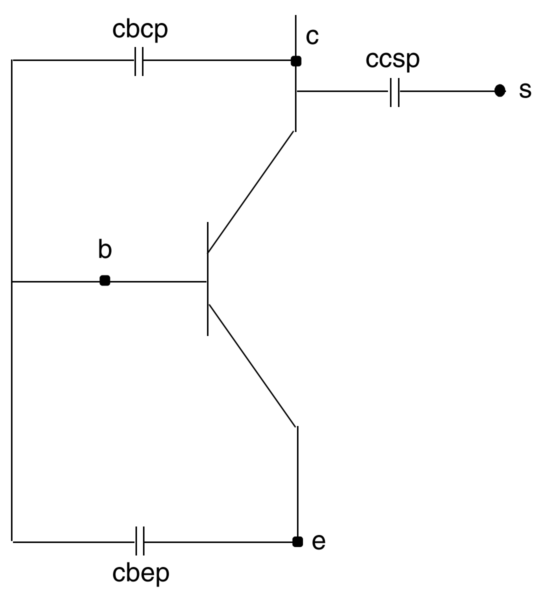
This chapter contains the following information for the BJT model:

Note: When the Virtuoso® Spectre® circuit simulator option `approx` is set to `yes`, `pow()` in the junction depletion capacitance calculation and `sqrt()` in the BJT and MOSFET level 1-5 models are replaced by a spline-function approximation. For more information, see `spectre -h options`.

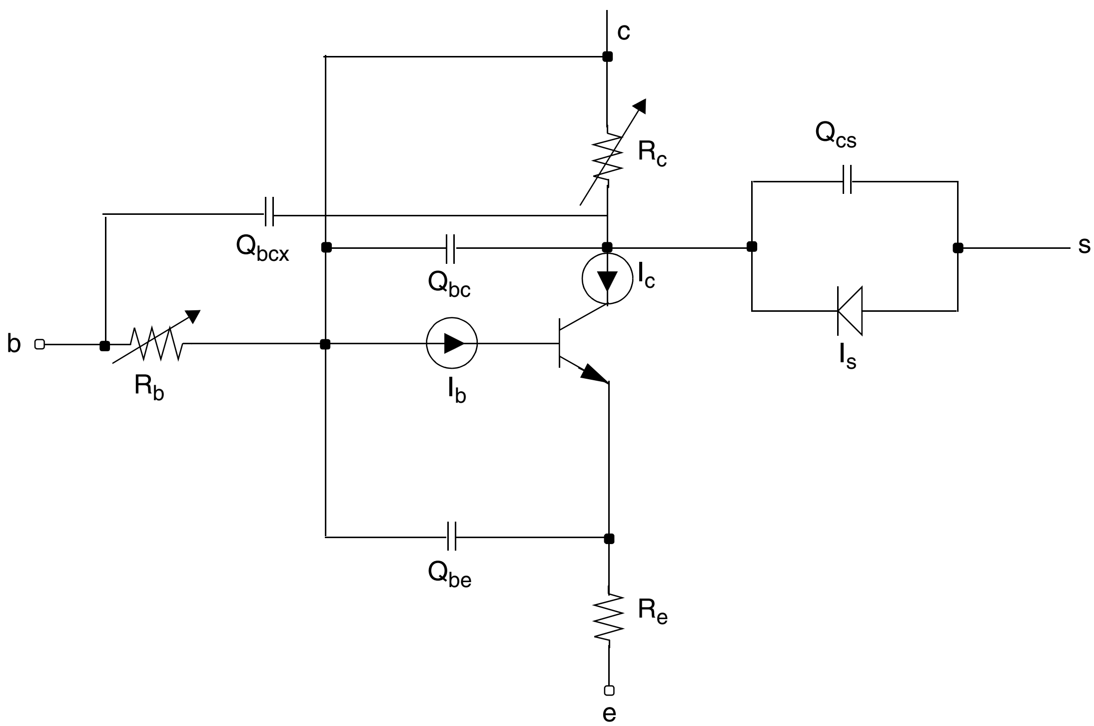
If `struct=vertical` (the default for NPN), the schematic of the model is given by one of the following figures:

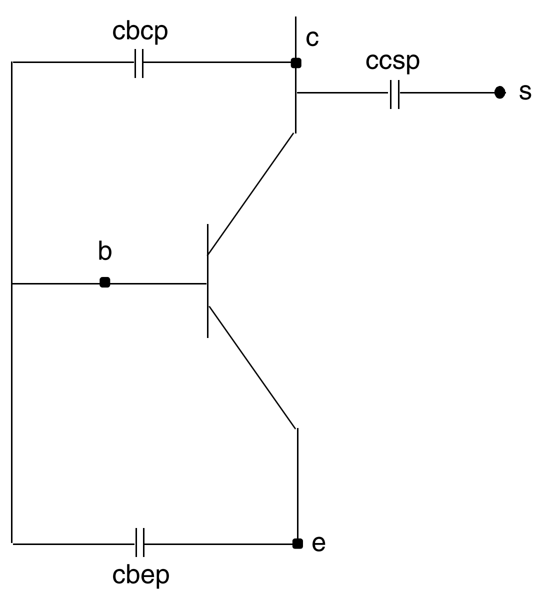
If Cbcsplit2 or Cbcsplit is not specified:



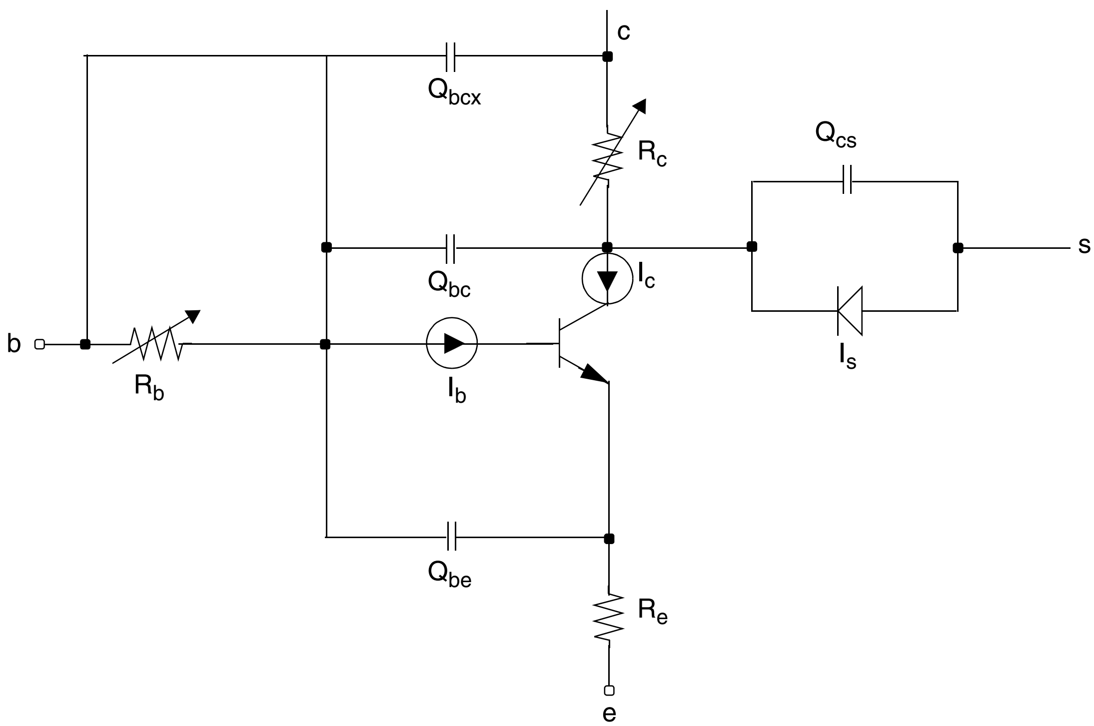


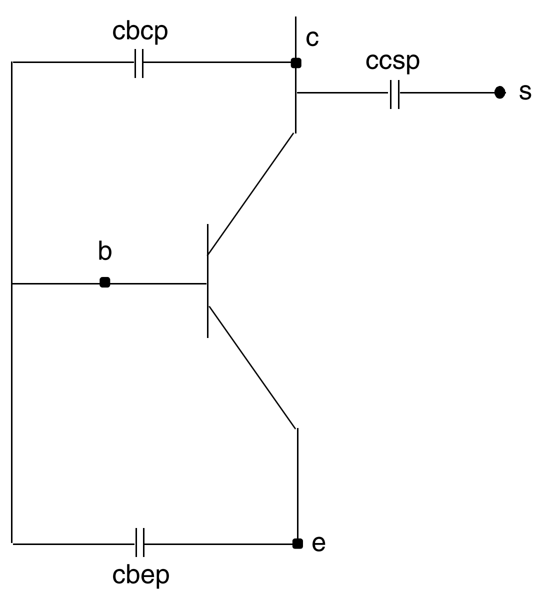
If Cbcsplit=xcjc:



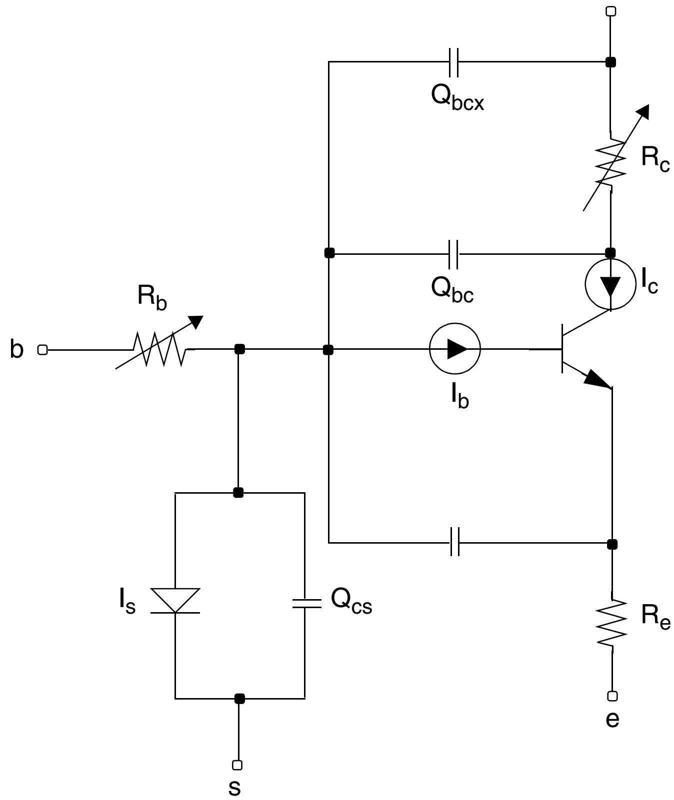


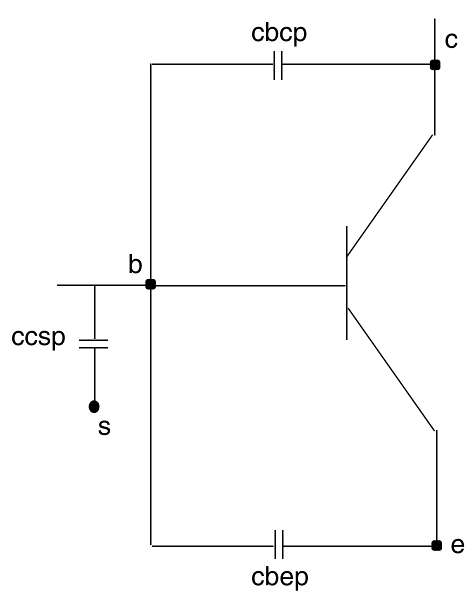
If Cbcsplit2=xcjc2





If `struct=lateral` (the default for PNP), the schematic of the model is given by





Device Regions

This section describes device regions for the BJT model.

The device region is	If
`breakdown`	■ bvsub is given and V_{CS} >= bvsub ■ bvbe is given and V_{BE} <= bvbe ■ bvce is given and V_{CE} >= bvce
`saturation`	V_{BE} > vbefwd and V_{BC} > vbcfwd
`reverse`	V_{BC} > vbcfwd and V_{BE} <= Vbefwd
`off`	none of the above conditions are true

DC Current

$$I_c = \frac{is}{Q_B}\left(e^{\frac{V_{BE}}{nfV_t}} - e^{\frac{V_{BC}}{nrV_t}}\right) - I_{CB}$$

$$I_b = \frac{is}{bf}\left(e^{\frac{V_{BE}}{nfV_t}} - 1\right) + ise\left(e^{\frac{V_{BE}}{neV_t}} - 1\right) + I_{CB}$$

where V_t is the thermal voltage given by

$$V_t = \frac{kT}{q}$$

$$I_{CB} = \frac{is}{br}\left(e^{\frac{V_{BC}}{nrV_t}} - 1\right) + isc\left(e^{\frac{V_{BC}}{ncV_t}} - 1\right)$$

The intact equation for QB and nkf is:

$$Q_B = \frac{Q_1}{2}(1 + (1 + 4Q_2)^{nkf})$$

When nkf=0.5, the QB equation is:

$$Q_B = \frac{Q_1}{2}(1 + \sqrt{1 + 4Q_2})$$

$$Q_1 = \begin{cases} \dfrac{1}{1 - \dfrac{V_{BC}}{vaf} - \dfrac{V_{BE}}{var}} & \text{if neither ke or kc is specified} \\ \left(1 + \displaystyle\int_0^{V_{BE}} f_{cj}(\text{ke, vje, mje})dv + \int_0^{V_{BC}} f_{cj}(\text{kc, vjc, mjc})dv\right) & \text{otherwise} \end{cases}$$

where f_{cj} is defined as follows:

$$f_{cj}(C, P, M) = \begin{cases} \dfrac{C}{\left(1 - \dfrac{v}{P}\right)^M} & \text{if v } \le \text{fc * P} \\ \dfrac{C}{(1 - fc)^{1 + M}}\left[1 - fc(1 + M) + \dfrac{M}{P}v\right] & \text{otherwise} \end{cases}$$

$$Q_2 = \frac{is}{ikf}\left(e^{\frac{V_{BE}}{nfV_t}} - 1\right) + \frac{is}{ikr}\left(e^{\frac{V_{BC}}{nrV_t}} - 1\right)$$

If ise (isc) is not given and $C2$ ($C4$) is specified, ise (isc) is calculated from

$$ise = C2 \times is$$

$$isc = C4 \times is$$

Nonlinear Base Resistance

$$R_B = rbm + \frac{rb - rbm}{Q_B} \qquad \text{if irb is not given}$$

If irb is given and `rbmod = spice` or SPICE compatibility is required,

$$R_B = rbm + 3(rb - rbm)\frac{\tan(z) - z}{z\tan^2(z)}$$

where

$$z = \frac{-1 + \sqrt{1 + \dfrac{144I_b}{irb\pi^2}}}{\dfrac{24}{\pi^2}\sqrt{\dfrac{I_b}{irb}}}$$

If irb is given and `rbmod = spectre`,

$$R_B = rbm + \frac{rb - rbm}{\sqrt{1 + 3\left(\dfrac{I_b}{irb}\right)^{0.852}}}$$

Nonlinear Collector Resistance (If rcv Is Specified)

$$R_C = rcv\left[1 + \left(\frac{n_i}{dope}\right)^2\left(e^{\frac{V_{BC}}{V_t}}\right)\right]^{-1}\left[1 + \left(\frac{I_c}{cco}\right)^{cex}\right] + rcm$$

Collector Leakage Current

If vbo is specified, the collector leakage current I_{CB} for $V_{BC} \leq 0$ is modeled by

$$I_{CB} = (-cbo + gboV_{BC})\left[1 - e^{\frac{V_{BC}}{vbo}}\right]$$

Note: To make the transition at $V_{BC} = 0$ smooth, vbo must satisfy

$$\frac{cbo}{vbo} = \frac{is}{br}\left(\frac{1}{nrV_t}\right) + \frac{isc}{ncV_t} \quad .$$

Substrate Leakage Current

$$I_S = iss\left(e^{\frac{V_{SC}}{nsV_t}} - 1\right)$$

where V_{SC} is the substrate-to-collector voltage if `struct=vertical` or the base-to-substrate voltage if `struct=lateral`.

Charge and Capacitance

$$Q_{be} = \frac{tfI_{Fwd}}{Q_B}\left\{1 + (xtf)e^{\frac{V_{BC}}{\sqrt{2}vtf}}\left[\frac{I_{Fwd}}{I_{Fwd} + itf}\right]^2\right\} + \int_0^{V_{BE}} f_{cj}(\text{cje, vje, mje})dv$$

where

$$I_{Fwd} = is\left(e^{\frac{V_{BE}}{nfV_t}} - 1\right)$$

Note: If `compatible()spectre`, the equation is as follows

$$Q_{be} = \frac{tfI_{Fwd}}{Q_B}\left\{1 + (xtf)e^{\frac{V_{BC}}{1.44vtf}}\left[\frac{I_{Fwd}}{I_{Fwd} + itf}\right]^2\right\} + \int_0^{V_{BE}} f_{cj}(\text{cje, vje, mje})dv$$

$$Q_{bc} = tr*is\left(e^{\frac{V_{BC}}{nrV_t}} - 1\right) + xcjc\int_0^{V_{BC}} f_{cj}\,(\text{cjc, vjc, mjc})dv$$

$$Q_{bcx} = (1 - xcjc)\int_0^{V_{BCX}} f_{cj}\,(\text{cjc, vjc, mjc})dv$$

$$Q_{cs} = \begin{cases} \int_0^{V_{CS}} f_{cj}\,(\text{cjs, vjs, mjs,})dv & \text{if } mjs \text{ is specified} \\ \text{cjs}V_{CS} & \text{otherwise} \end{cases}$$

Excess Phase

In an actual device, the measured phase shift is often larger than the shift predicted by the lumped model. The excess-phase parameter ptf accounts for this extra phase shift at high frequencies. An all-pass, second-order Bessel function filter creates this extra phase shift. The frequency response of this filter is

$$\phi(s) = \frac{3\omega_0^2}{s^2 + 3\omega_0 s + 3\omega_0^2}$$

where

$$\omega_0 = \frac{180}{ptf \times tf \times \pi}$$

and the phase shift due to this filter is

$$\theta = \tan^{-1}(H)$$

$$H = \frac{3\omega\omega_0}{3\omega_0^2 - \omega^2}$$

The value of ptf is usually the excess phase shift of transconductance measured at frequency f = 1(2πtf). The value of ptf should not be less than zero. SPICE does not implement the actual Bessel filter, which requires two more internal nodes for each BJT device. Instead, SPICE uses second-order numerical integration in the device code. This approach sometimes causes convergence problems. However, to remain compatible with SPICE, the Spectre® circuit simulator follows the SPICE method.

Temperature Effect

Energy Gap

For tlev=0, 1, or 3

$$E_{g,\,ref} = 1.16 - 7.02 \cdot 10^{-4} \cdot \frac{T_{nom}^2}{T_{nom} + 1108}$$

$$E_g = 1.16 - 7.02 \cdot 10^{-4} \cdot \frac{T_{nom}^2}{T + 1108}$$

$$dV_{je}dT = -\frac{E_{g,\,ref} + 3V_{T,\,nom} + (1.16 - E_{g,\,ref})\left(2 - \frac{T_{nom}}{T_{nom} + 1108}\right) - V_{je}}{T_{nom}}$$

$$dV_{jc}dT = -\frac{E_{g,\,ref} + 3V_{T,\,nom} + (1.16 - E_{g,\,ref})\left(2 - \frac{T_{nom}}{T_{nom} + 1108}\right) - V_{jc}}{T_{nom}}$$

$$dV_{js}dT = -\frac{E_{g,\,ref} + 3V_{T,\,nom} + (1.16 - E_{g,\,ref})\left(2 - \frac{T_{nom}}{T_{nom} + 1108}\right) - V_{js}}{T_{nom}}$$

For tlev=2

$$E_{g,ref} = E_g - Gap_1 \cdot \frac{T_{nom}^2}{T_{nom} + Gap_2}$$

$$E_g = E_g - Gap_1 \cdot \frac{T^2}{T + Gap_2}$$

$$dV_{je}dT = -\frac{E_{g,ref} + 3V_{T,nom} + (E_g - E_{g,ref})\left(2 - \frac{T_{nom}}{T_{nom} + Gap_2}\right) - V_{je}}{T_{nom}}$$

$$dV_{jc}dT = -\frac{E_{g,ref} + 3V_{T,nom} + (E_g - E_{g,ref})\left(2 - \frac{T_{nom}}{T_{nom} + Gap_2}\right) - V_{jc}}{T_{nom}}$$

$$dV_{js}dT = -\frac{E_{g,ref} + 3V_{T,nom} + (E_g - E_{g,ref})\left(2 - \frac{T_{nom}}{T_{nom} + Gap_2}\right) - V_{js}}{T_{nom}}$$

Saturation Current

For tlev=0 and tlev=2

$$I_{set} = \frac{I_{se}}{\left(\frac{T}{Tnom}\right)^{X_{TB}}} \cdot e^{LsT/Ne}$$

$$I_{sct} = \frac{I_{sc}}{\left(\frac{T}{Tnom}\right)^{X_{TB}}} \cdot e^{LsT/Nc}$$

$$I_{sst} = \frac{I_{ss}}{\left(\frac{T}{Tnom}\right)^{X_{TB}}} \cdot e^{LsT/Ns}$$

$$Ibet = Ibe \cdot e^{LsT/Nf}$$

$$Ibct = Ibc \cdot e^{LsT/Nr}$$

$$I_{sT} = I_s e^{L_{sT}}$$

For tlev=1

$$Iset = \frac{Ise}{1 + X_{TB} \cdot \Delta T} \cdot e^{LsT/Nc}$$

$$Isct = \frac{Isc}{1 + X_{TB} \cdot \Delta T} \cdot e^{LsT/N_c}$$

$$Isst = \frac{Iss}{1 + X_{TB} \cdot \Delta T} \cdot e^{LsT/Ns}$$

$$Ibet = Ibe \cdot e^{LsT/Nf}$$

$$Ibct = Ibc \cdot e^{LsT/Nr}$$

$$Ist = Is \cdot e^{LsT}$$

For tlev=3

$$Iset = Ise^{(1 + t_{ise1} \cdot \Delta T + t_{ise2} \cdot \Delta T^2)}$$

$$Isct = Isc^{(1 + t_{isc1} \cdot \Delta T + t_{isc2} \cdot \Delta T^2)}$$

$$Isst = Iss^{(1 + t_{iss1} \cdot \Delta T + t_{iss2} \cdot \Delta T^2)}$$

$$Ibet = Ibe^{(1 + t_{is1} \cdot \Delta T + t_{is2} \cdot \Delta T^2)}$$

$$Ibct = Ibc^{(1 + t_{is1} \cdot \Delta T + t_{is2} \cdot \Delta T^2)}$$

$$Ist = Is^{(1 + t_{is1} \cdot \Delta T + t_{is2} \cdot \Delta T^2)}$$

Parameters I_{kf}, I_{kr}, and I_{rb} are modified as follows.

For tlev=0, 1, or 2

$$I_{kfT} = I_{kf} \cdot (1 + t_{ikf1}\Delta T + t_{ikf2}\Delta T^2)$$

$$I_{krT} = I_{kr} \cdot (1 + t_{ikr1}\Delta T + t_{ikr2}\Delta T^2)$$

$$I_{rbT} = I_{rb} \cdot (1 + t_{irb1}\Delta T + t_{irb2}\Delta T^2)$$

For tlev=3

$$I_{kfT} = I_{kf}^{1 + t_{ikf1}\Delta T + t_{ikf2}\Delta T^2}$$

$$I_{krT} = I_{kr}^{1 + t_{ikr1}\Delta T + t_{ikr2}\Delta T^2}$$

$$I_{rbT} = I_{rb}^{1 + t_{irb1}\Delta T + t_{irb2}\Delta T^2}$$

Degree Factor

For tlev=0, 1, or 3

$$L_{sT} = \frac{Eg}{V_{Tnom}} - \frac{Eg}{V_T} + X_{TI} \cdot \ln\left(\frac{T}{Tnom}\right)$$

For tlev=2

$$LsT = \frac{Eg, ref}{V_{Tnom}} - \frac{Eg}{V_T} + X_{TI} \cdot \ln\left(\frac{T}{Tnom}\right)$$

Current Gains (B_f, B_r)

For tlev=0, 2, or 3

$$B_{fT} = B_f \cdot \left(\frac{T}{T_{nom}}\right)^{X_{TB}}$$

$$B_{rT} = B_r \cdot \left(\frac{T}{T_{nom}}\right)^{X_{TB}}$$

For tlev=1

$$B_{fT} = B_f \cdot (1 + X_{TB}\Delta T)$$

$$B_{rT} = B_r \cdot (1 + X_{TB}\Delta T)$$

If coefficients are specified,

$$B_f(T) = B_{fT} \cdot (1 + t_{Bf1}\Delta T + t_{Bf2}\Delta T^2)$$

$$B_r(T) = B_{rT} \cdot (1 + t_{Br1}\Delta T + t_{Br2}\Delta T^2)$$

$$V_{afT} = V_{af} \cdot (1 + t_{vaf1}\Delta T + t_{vaf2}\Delta T^2)$$

$$V_{arT} = V_{ar} \cdot (1 + t_{var1}\Delta T + t_{var2}\Delta T^2)$$

$$t_{fT} = t_f \cdot (1 + t_{tf1}\Delta T + t_{tf2}\Delta T^2)$$

$$t_{rT} = t_r \cdot (1 + t_{tr1}\Delta T + t_{tr2}\Delta T^2)$$

$$N_{fT} = N_f \cdot (1 + t_{nf1}\Delta T + t_{nf2}\Delta T^2)$$

$$N_{rT} = N_r \cdot (1 + t_{nr1}\Delta T + t_{nr2}\Delta T^2)$$

$$N_{eT} = N_e \cdot (1 + t_{ne1}\Delta T + t_{ne2}\Delta T^2)$$

$$N_{cT} = N_c \cdot (1 + t_{nc1}\Delta T + t_{nc2}\Delta T^2)$$

$$N_{sT} = N_s \cdot (1 + t_{ns1}\Delta T + t_{ns2}\Delta T^2)$$

$$M_{jeT} = M_{je} \cdot (1 + t_{mje1}\Delta T + t_{mje2}\Delta T^2)$$

$$M_{jcT} = M_{jc} \cdot (1 + t_{mjc1}\Delta T + t_{mjc2}\Delta T^2)$$

$$M_{jsT} = M_{js} \cdot (1 + t_{mjs1}\Delta T + t_{mjs2}\Delta T^2)$$

$$t_{dT} = t_d \cdot (1 + t_{tf1}\Delta T + t_{tf2}\Delta T^2)$$

$$I_{tfT} = I_{tf} \cdot (1 + t_{itf1}\Delta T + t_{itf2}\Delta T^2)$$

$$X_{tfT} = X_{tf} \cdot (1 + t_{xtf1}\Delta T + t_{xtf2}\Delta T^2)$$

$$V_{tfT} = V_{tf} \cdot (1 + t_{vtf1}\Delta T + t_{vtf2}\Delta T^2)$$

Junction Capacitors (cjc, cje, and cjs)

For tlevc=0

$$C_{jeT} = C_{je}\left[1 + M_{je} \cdot \left(400 \cdot 10^{-6}\Delta T + 1 - \frac{V_{jeT}}{V_{je}}\right)\right]$$

where

$$V_{jeT} = V_{je}\frac{T}{T_{nom}} - 3V_T \cdot \ln\frac{T}{T_{nom}} + E_{g,ref}\frac{T}{T_{nom}} - E_g$$

$$C_{jcT} = C_{jc}\left[1 + M_{jc} \cdot \left(400 \cdot 10^{-6}\Delta T + 1 - \frac{V_{jcT}}{V_{jc}}\right)\right]$$

where

$$V_{jcT} = V_{jc}\frac{T}{T_{nom}} - 3V_T \cdot \ln\frac{T}{T_{nom}} + E_{g,ref}\frac{T}{T_{nom}} - E_g$$

$$C_{jsT} = C_{js}\left[1 + M_{js} \cdot \left(400 \cdot 10^{-6}\Delta T + 1 - \frac{V_{jsT}}{V_{js}}\right)\right]$$

where

$$V_{jsT} = V_{js}\frac{T}{T_{nom}} - 3V_T \cdot \ln\frac{T}{T_{nom}} + E_{g,ref}\frac{T}{T_{nom}} - E_g$$

For tlevc=1

$$C_{jeT} = C_{je} \cdot (1 + C_{te}\Delta T)$$

where

$$V_{jeT} = V_{je} - t_{vje}\Delta T$$

$$C_{jcT} = C_{jc} \cdot (1 + C_{tc}\Delta T)$$

where

$$V_{jcT} = V_{jc} - t_{vjc}\Delta T$$

$$C_{jsT} = C_{js} \cdot (1 + C_{ts}\Delta T)$$

where

$$V_{jsT} = V_{js} - t_{vjs}\Delta T$$

For tlevc=2

$$C_{jeT} = C_{je} \cdot \left(\frac{V_{je}}{V_{jeT}}\right)^{M_{je}}$$

where

$$V_{jeT} = V_{je} - t_{vje}\Delta T$$

$$C_{jcT} = C_{jc} \cdot \left(\frac{V_{jc}}{V_{jcT}}\right)^{M_{jc}}$$

where

$$V_{jcT} = V_{jc} - t_{vjc}\Delta T$$

$$C_{jsT} = C_{js} \cdot \left(\frac{V_{js}}{V_{jsT}}\right)^{M_{js}}$$

where

$$V_{jsT} = V_{js} - t_{vjs}\Delta T$$

For tlevc=3

$$C_{jeT} = C_{je} \cdot \left(1 - 0.5 \cdot dV_{je}dT\frac{\Delta T}{V_{je}}\right)$$

where

$$V_{jeT} = V_{je} + dV_{je}dT\Delta T$$

$$C_{jcT} = C_{jc} \cdot \left(1 - 0.5 \cdot dV_{jc}dT\frac{\Delta T}{V_{jc}}\right)$$

where

$$V_{jcT} = V_{jc} + dV_{jc}dT\Delta T$$

$$C_{jsT} = C_{js} \cdot \left(1 - 0.5 \cdot dV_{js}dT\frac{\Delta T}{V_{js}}\right)$$

where

$$V_{jsT} = V_{js} + dV_{js}dT\Delta T$$

Parasitic Resistors (rb, rc, and re)

$$R_{eT} = R_e \cdot (1 + t_{re1}\Delta T + t_{re2}\Delta T^2)$$

$$R_{cT} = R_c \cdot (1 + t_{rc1}\Delta T + t_{rc2}\Delta T^2)$$

$$R_{sT} = R_s \cdot (1 + t_{rs1}\Delta T + t_{rs2}\Delta T^2)$$

$$R_{bmT} = R_{bm} \cdot (1 + t_{rm1}\Delta T + t_{rm2}\Delta T^2)$$

Noise Model

Base Resistance Thermal Noise

$$\overline{i_{R_B}^2} = \begin{cases} \frac{4kT}{R_B}\frac{rbnoi}{R_B}\Delta f & \text{if } rbnoi \text{ is specified} \\ \frac{4kt}{R_B}\Delta f & \text{otherwise} \end{cases}$$

Collector Resistance Thermal Noise

$$\overline{i_{R_C}^2} = \frac{4kT}{R_C}\Delta f$$

Emitter Resistance Thermal Noise

$$\overline{i_{R_E}^2} = \frac{4kT}{R_E}\Delta f$$

Collector Shot Noise Source

$$\overline{i_C^2} = 2qI_C\Delta f$$

Base Shot, Flicker, and Burst Noise Sources

$$\overline{i_B^2} = 2qI_B\Delta f + kf\frac{I_B^{af}}{f}\Delta f + kb\frac{I_B}{1 + (f/f_c)^2}\Delta f$$

where kf, af, kb, and fc are constants for a given device. The Spectre defaults for these constants are 0.0, 1.0, 0.0, and 1.0 respectively.

Scaling Effects

This model has the following enhancements over SPICE2G.6:

1. Two base resistance models are provided.

2. Nonlinear collector resistance is implemented.

3. The integral form of the Early voltage effect is available.

4. The substrate junction includes both the diode and the capacitor.

This device is supported within altergroups.

Sample Instance Statement:

```
q1 (vcc net3 minus) npn_mod region=fwd area=1 m=1
```

Sample Model Statement:

```
model npn_mod bjt type=npn is=10e-13 bf=200 va=58.8 ikf=5.63e-3 rb=700 rbm=86
re=3.2 cje=0.352e-12 pe=0.76 me=0.34 tf=249e-12 cjc=0.34e-12 pc=0.55
```

Instance Definition

```
Name  c  b  e  [s] ModelName parameter=value ...
```

You do not have to specify the substrate terminal. If you do not specify it, the substrate is connected to ground.

Instance Parameters

1	area=1	Transistor area factor (alias=lv1).
2	areab=1	Transistor areab factor.
3	areac=1	Transistor areac factor.
4	m=1	Multiplicity factor.
5	trise	Temperature rise from ambient.
6	region=fwd	Estimated operating region. Spectre outputs number (0-4) in a rawfile. Possible values are off, fwd, rev, sat, or breakdown.
7	isnoisy=yes	Should device generate noise. Possible values are no or yes.

Model Definition

```
model modelName bjt parameter=value ...
```

Model Parameters

Structural parameters

1	`type=npn`	Transistor type. Possible values are `npn` and `pnp`.

2 `struct=vertical` Transistor structure. For pnp, the default is `lateral`. Possible values are `vertical` and `lateral`.

3 `subs=1` Transistor structure. 1 for Vertical structure and 0 for lateral structure.

Saturation current parameters

4 `is=1e-16 A` Saturation current (*area).

5 `ise=0 A` B-E leakage saturation current. Set to `c2*is` if not given. (*area).

6 `isc=0 A` B-C leakage saturation current. Set to `c4*is` if not given. (*area).

7 `iss=0 A` Substrate leakage saturation current (*area).

8 `c2=0` Forward leakage saturation current coefficient.

9 `c4=0` Reverse leakage saturation current coefficient.

10 `nkf=0.5` Qb exponent parameter.

11 `nk=nkf` Qb exponent parameter, alias of nkf.

B-C leakage model parameters

12 `cbo=0 A` Extrapolated 0-volt B-C leakage current (*area).

13 `gbo=0 S` Slope of `Icbo` vs. `Vbc` above `Vbo` (*area).

14 `vbo=0 V` Slope of `Icbo` vs. `Vbc` at `Vbc`=0.

15 `tcbo=0 1/C` Temperature coefficient for cbo.

16 `tgbo=0 1/C` Temperature coefficient for gbo.

Emission coefficient parameters

17 `nf=1` Forward emission coefficient.

18 `nr=1` Reverse emission coefficient.

19 `ne=1.5` B-E leakage emission coefficient.

20 `nc=2` B-C leakage emission coefficient.

21 `ns=1` Substrate junction emission coefficient.

Current gain parameters

22 `bf=100 A/A` Forward current gain (`beta`).

23 `bfm (A/A)` Forward current gain (`beta`).

24 `br=1 A/A` Reverse current gain (`beta`).

25 `brm (A/A)` Reverse current gain (`beta`).

26 `ikf=∞ A` High current corner for forward `beta` (*area).

27 `ik=∞ A` High current corner for forward `beta` (*area).

28 `jbf=∞ A` High current corner for forward `beta` (*area).

29 `ikr=∞ A` High current corner for reverse `beta` (*area).

30 `jbr (A)` High current corner for reverse `beta` (*area).

Early voltage parameters

31 `vaf=∞ V` Forward Early voltage.

32 `va=∞ V` Forward Early voltage.

33 `var=∞ V` Reverse Early voltage.

34 `vb=∞ V` Reverse Early voltage.

35 `ke=0 1/V` B-E space-charge integral multiplier.

36 `kc=0 1/V` B-C space-charge integral multiplier.

Parasitic resistance parameters

37 `rb=0 Ω`	Zero-bias base resistance (/area).
38 `rbm=rb Ω`	Minimum base resistance for high currents (/area).
39 `irb=∞ A`	Current at base resistance midpoint (*area).
40 `jrb (A)`	Current at base resistance midpoint (*area).
41 `iob (A)`	Current at base resistance midpoint (*area).
42 `rbmod=spice`	Nonlinear `Rb` model. Possible values are `spectre` and `spice`.
43 `rc=0 Ω`	Collector resistance (/area).
44 `rcv=0 Ω`	Variable collector resistance (/area), only works when its value is given.
45 `rcm=0 Ω`	Minimum collector resistance (/area).
46 `dope=1e15` cm^{-3}	Collector background doping concentration.
47 `cex=1`	Current crowding exponent.
48 `cco=1 A`	Current crowding normalization constant (*area).
49 `re=0 Ω`	Emitter resistance (/area).
50 `minr=0.1 Ω`	Minimum parasitic resistance.

Junction capacitance parameters

51 `dcap=2`	Depletion capacitance model selector.
52 `cje=0 F`	B-E zero-bias junction capacitance (*area).
53 `vje=0.75 V`	B-E built-in junction potential.
54 `mje=1/3`	B-E junction exponent.
55 `pe=0.75 V`	B-E built-in junction potential.

56 `me=1/3`	B-E junction exponent.
57 `cjc=0 F`	B-C zero-bias junction capacitance (*area).
58 `vjc=0.75 V`	B-C built-in junction potential.
59 `mjc=1/3`	B-C junction exponent.
60 `pc=0.75 V`	B-C built-in junction potential.
61 `mc=1/3`	B-C junction exponent.
62 `xcjc=1`	Fraction of B-C capacitance tied to internal base node.
63 `xcjc2=1`	Fraction of B-C capacitance tied to collector and fraction of B-C tied to internal node.
64 `cjs=0 F`	B-S zero-bias junction capacitance (*area).
65 `ccs=0 F`	B-S zero-bias junction capacitance (*area).
66 `csub (F)`	B-S zero-bias junction capacitance (*area).
67 `vjs=0.75 V`	B-S built-in junction potential.
68 `mjs=0`	B-S junction exponent.
69 `ps=0.75 V`	B-S built-in junction potential.
70 `psub (V)`	B-S built-in junction potential.
71 `ms=0`	B-S junction exponent.
72 `esub`	B-S junction exponent.
73 `fc=0.5`	Junction capacitor forward-bias threshold.
74 `cbcp=0 F`	B-C parasitic capacitance.
75 `cbep=0 F`	B-E parasitic capacitance.
76 `ccsp=0 F`	C-S parasitic capacitance.

Transit time and excess phase parameters

77 `tf=0 s` Ideal forward transit time.

78 `td=0 s` Intrinsic base delay time.

79 `xtf=0` Coefficient for bias dependence of `tf`.

80 `vtf=∞ V` Voltage describing Vbc dependence of `tf`.

81 `itf=0 A` High current parameter for effect on `tf` (*area).

82 `jtf (A)` High current parameter for effect on `tf` (*area).

83 `tr=0 s` Ideal reverse transit time.

84 `ptf=0 °` Excess phase at freq = 1.0/(`tf`*2 pi) Hz.

Temperature effects parameters

85 `tnom (C)` Parameters measurement temperature. Default set by `options`.

86 `tref (C)` TNOMs alias.

87 `trise=0 C` Temperature rise from ambient.

88 `eg=1.11 V` Band-gap.

89 `xtb=0` `Beta` temperature exponent.

90 `xti=3` Temperature exponent for effect on `is`.

91 `pt` Temperature exponent for effect on `is`.

92 `trb1=0 1/C` Linear temperature coefficient for the base resistor.

93 `trb2=0` C^{-2} Quadratic temperature coefficient for the base resistor.

94 `trm1=0 1/C` Linear temperature coefficient for the minimum base resistor.

95 `trm2=0` C^{-2} Quadratic temperature coefficient for the minimum base resistor.

96 `trc1=0 1/C` Linear temperature coefficient for the collector resistor.

97 `trc2=0 C`$^{-2}$	Quadratic temperature coefficient for the collector resistor.
98 `tre1=0 1/C`	Linear temperature coefficient for the emitter resistor.
99 `tre2=0 C`$^{-2}$	Quadratic temperature coefficient for the emitter resistor.
100 `tlev=0`	DC temperature selector.
101 `tlevc=0`	AC temperature selector.
102 `eglev=0`	DC temperature selector.
103 `gap1=7.02e-4 V/C`	Band-gap temperature coefficient.
104 `gap2=1108 C`	Band-gap temperature offset.
105 `tikf1=0 1/C`	Linear temperature coefficient for `ikf`.
106 `tikf2=0 C`$^{-2}$	Quadratic temperature coefficient for `ikf`.
107 `tikr1=0 1/C`	Linear temperature coefficient for `ikr`.
108 `tikr2=0 C`$^{-2}$	Quadratic temperature coefficient for `ikr`.
109 `tirb1=0 1/C`	Linear temperature coefficient for `irb`.
110 `tirb2=0 C`$^{-2}$	Quadratic temperature coefficient for `irb`.
111 `tis1=0 1/C`	Linear temperature coefficient for `is`.
112 `tis2=0 C`$^{-2}$	Quadratic temperature coefficient for `is`.
113 `tise1=0 1/C`	Linear temperature coefficient for `ise`.
114 `tise2=0 C`$^{-2}$	Quadratic temperature coefficient for `ise`.
115 `tisc1=0 1/C`	Linear temperature coefficient for `isc`.
116 `tisc2=0 C`$^{-2}$	Quadratic temperature coefficient for `isc`.
117 `tiss1=0 1/C`	Linear temperature coefficient for `iss`.
118 `tiss2=0 C`$^{-2}$	Quadratic temperature coefficient for `iss`.

119 `tbf1=0 1/C`	Linear temperature coefficient for `bf`.
120 `tbf2=0 C`$^{-2}$	Quadratic temperature coefficient for `bf`.
121 `tbr1=0 1/C`	Linear temperature coefficient for `br`.
122 `tbr2=0 C`$^{-2}$	Quadratic temperature coefficient for `br`.
123 `tvaf1=0 1/C`	Linear temperature coefficient for `vaf`.
124 `tvaf2=0 C`$^{-2}$	Quadratic temperature coefficient for `vaf`.
125 `tvar1=0 1/C`	Linear temperature coefficient for `var`.
126 `tvar2=0 C`$^{-2}$	Quadratic temperature coefficient for `var`.
127 `titf1=0 1/C`	Linear temperature coefficient for `itf`.
128 `titf2=0 C`$^{-2}$	Quadratic temperature coefficient for `itf`.
129 `ttf1=0 1/C`	Linear temperature coefficient for `tf`.
130 `ttf2=0 C`$^{-2}$	Quadratic temperature coefficient for `tf`.
131 `ttr1=0 1/C`	Linear temperature coefficient for `tr`.
132 `ttr2=0 C`$^{-2}$	Quadratic temperature coefficient for `tr`.
133 `tnf1=0 1/C`	Linear temperature coefficient for `nf`.
134 `tnf2=0 C`$^{-2}$	Quadratic temperature coefficient for `nf`.
135 `tnr1=0 1/C`	Linear temperature coefficient for `nr`.
136 `tnr2=0 C`$^{-2}$	Quadratic temperature coefficient for `nr`.
137 `tne1=0 1/C`	Linear temperature coefficient for `ne`.
138 `tne2=0 C`$^{-2}$	Quadratic temperature coefficient for `ne`.
139 `tnc1=0 1/C`	Linear temperature coefficient for `nc`.
140 `tnc2=0 C`$^{-2}$	Quadratic temperature coefficient for `nc`.

141 `tns1=0 1/C`	Linear temperature coefficient for `ns`.
142 `tns2=0 C`$^{-2}$	Quadratic temperature coefficient for `ns`.
143 `tmje1=0 1/C`	Linear temperature coefficient for `mje`.
144 `tmje2=0 C`$^{-2}$	Quadratic temperature coefficient for `mje`.
145 `tmjc1=0 1/C`	Linear temperature coefficient for `mjc`.
146 `tmjc2=0 C`$^{-2}$	Quadratic temperature coefficient for `mjc`.
147 `tmjs1=0 1/C`	Linear temperature coefficient for `mjs`.
148 `tmjs2=0 C`$^{-2}$	Quadratic temperature coefficient for `mjs`.
149 `cte=0 1/C`	Temperature coefficient for `cje`.
150 `ctc=0 1/C`	Temperature coefficient for `cjc`.
151 `cts=0 1/C`	Temperature coefficient for `cjs`.
152 `tvje=0 V/C`	Temperature coefficient for `vje`.
153 `tvjc=0 V/C`	Temperature coefficient for `vjc`.
154 `tvjs=0 V/C`	Temperature coefficient for `vjs`.
155 `tvtf1=0 1/C`	Linear temperature coefficient for `vtf`.
156 `tvtf2=0 C`$^{-2}$	Quadratic temperature coefficient for `vtf`.
157 `txtf1=0 1/C`	Linear temperature coefficient for `xtf`.
158 `txtf2=0 C`$^{-2}$	Quadratic temperature coefficient for `xtf`.

Junction diode model control parameters

159 `dskip=yes`	Skip junction calculations if they are reverse-saturated. Possible values are `no` and `yes`.
160 `imelt=imax A`	Junction explosion current (*area).

Operating region warning control parameters

161 `bvbe=∞ V` B-E breakdown voltage.

162 `bvbc=∞ V` B-C breakdown voltage.

163 `bvce=∞ V` C-E breakdown voltage.

164 `bvsub=∞ V` Substrate junction breakdown voltage.

165 `vbefwd=0.2 V` B-E forward voltage.

166 `vbcfwd=0.2 V` B-C forward voltage.

167 `vsubfwd=0.2 V` Substrate junction forward voltage.

168 `imax=1e3 A` Maximum allowable base current (*area).

169 `imax1=imax A` Maximum allowable collector current (*area).

170 `alarm=none` Forbidden operating region.
Possible values are `none`, `off`, `fwd`, `rev`, and `sat`.

Noise model parameters

171 `kf=0` Flicker (1/f) noise coefficient.

172 `af=1` Flicker (1/f) noise exponent.

173 `kb=0` Burst noise coefficient.

174 `bnoisefc=1` Burst noise cutoff frequency.

175 `rbnoi=rb Ω` Effective base noise resistance.

DC-mismatch model parameters

176 `mvt0=0.0 V` Threshold mismatch intercept.

Compatibility model parameters

177 `compatible=spectre`
Encourage device equations to be compatible with a foreign simulator. This option does not affect input syntax.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, and `mica`.

178 `updatelevel=0` Model update selector. The available versions are 0, 1.

Shrink Parameters

Safe Operating Areas Parameters

179 `vbe_max=∞ V`
Maximum allowed voltage cross base and emitter.

180 `vbc_max=∞ V`
Maximum allowed voltage cross base and collector.

181 `vce_max=∞ V`
Maximum allowed voltage cross collector and emitter.

182 `vcs_max=∞ V`
Maximum allowed voltage cross collector and substrate.

Auto Model Selector parameters

183 `areamax=0` Maximum transistor area factor for which the model is valid.

184 `areamin=1`Minimum transistor area factor for which the model is valid.

Imax and Imelt

The `imax' parameter aids convergence and prevents numerical overflow. The junction characteristics of the device are accurately modeled for current up to `imax'. If `imax' is exceeded during iterations, the linear model is substituted until the current drops below 'imax' or until convergence is achieved. If convergence is achieved with the current exceeding `imax', the results are inaccurate, and a warning is printed out.

A separate model parameter, `imelt', is used as a limit warning for the junction current. This parameter can be set to the maximum current rating of the device. When any component of the junction current exceeds `imelt', note that base and collector currents are composed of many exponential terms, a warning will be issued and the results become inaccurate. The junction current is linearized above the value of `imelt' to prevent arithmetic exception, with the exponential term replaced by a linear equation at `imelt'.

Output Parameters

1	`ibeeff (Ohm)`	The effective reverse saturation current of BE.
2	`ibceff (Ohm)`	The effective reverse saturation current of BC.
3	`iseeff (Ohm)`	The effective leakage saturation current of BE.
4	`isceff (Ohm)`	The effective leakage saturation current of BC.
5	`isseff (Ohm)`	The effective reverse saturation current of bulk-collector or bulk-base.

Operating Point Parameters

1	`type=npn`	Transistor type. Possible values are `npn` and `pnp`.
2	`struct=vertical`	Transistor structure. For pnp, default is `lateral`. Possible values are `vertical` and `lateral`.
3	`region=fwd`	Estimated operating region. Spectre outputs number (0-4) in a rawfile. Possible values are `off`, `fwd`, `rev`, `sat`, and `breakdown`.
4	`vbe (V)`	Base-emitter voltage (alias=lx0).
5	`vbc (V)`	Base-collector voltage (alias=lx1).
6	`vce (V)`	Collector-emitter voltage.
7	`vsub (V)`	Substrate junction voltage (alias=lx24).
8	`ic (A)`	Resistive collector current (alias=lx2).

9 `ib (A)` Resistive base current (alias=lx3).

10 `isub (A)` Resistive substrate current (alias=lv6).

11 `pwr (W)` Power dissipation.

12 `betadc (A/A)` Ratio of resistive collector current to resistive base current (alias=lv10).

13 `betaac (A/A)` Small-signal common-emitter current gain.

14 `gm (S)` Common-emitter transconductance (alias=lx6).

15 `rpi (Ω)` Common-emitter input resistance.

16 `ro (Ω)` Common-emitter output resistance.

17 `rb (Ω)` Parasitic base resistance.

18 `rc (Ω)` Parasitic collector resistance.

19 `cpi (F)` Common-emitter input capacitance (alias=lx19).

20 `cmu (F)` Common-base output capacitance (alias=lx20).

21 `cmux (F)` External common-base output capacitance (alias=lx22).

22 `csub (F)` Substrate capacitance (alias=lx21).

23 `ft (Hz)` Unity small-signal current-gain frequency (alias=lv5).

24 `gpi (S)` Gpi=ib/vbe constant vbc (alias=lx4).

25 `gmu (S)` Gmu=ib/vbc constant vbe (alias=lx5).

26 `g0 (S)` G0=ic/vce constant vbe (alias=lx7).

27 `gb (S)` 1/Rbeff internal conductance (alias=lx16).

28 `qbe` Base emitter charge (alias=lx8).

29 `qbc` Base collector charge (alias=lx10).

30 `qsc` Collector substrate charge.

31 `grc (S)` Collector conductance (alias=lv16).

32 `rbb (Ω)` Base resistance (alias=lv14).

33 `log_ic (A)` Log(Ic) (alias=lv8).

34 `log_ib (A)` Log(Ib) (alias=lv9).

35 `gre (S)` Emitter conductance (alias=lv15).

36 `re (Ω)`

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

6

HiCUM Model (bht)

The HiCUM model was developed by Professor M. Schroter. This chapter contains the following information:

Spectre HICUM Model vs. Public HICUM Model

MMSIM supports HICUM model version = 1.0, 2.1, 2.20, 2.21, 2.22, 2.23, 2.24, 2.3, 2.31, and 2.32. Model parameter “updatelevel” is added by Cadence in order to include some enhancement. The detail information is in the below:

- **updatelevel = 0:** The model is compatible with the original HICUM Fortran code. Temperature dependence is ignored in the model. No fix or enhancement is added to updatelevel=0. The model may show convergence issue. It is not suggested to use it.
- **updatelevel = 1 / 2:** This level has better temperature dependence. It includes some fixes and enhancements. Version1.0, 2.1, 2.20, 2.21 and 2.22 supports this level.
- **updatelevel = 3:** This level has complete derivatives for current and charge model. And the simulation result is fully compatible with the result from HICUM Verilog-A model (released from TU Dresden, Germany). This level supports version = 2.1, 2.20, 2.21, 2.22, 2.23, 2.24, 2.3, 2.31, and 2.32. It is recommended to use this level. Further enhancement will be focusing on this level. Version = 2.23 and 2.24 support NQS effects.

Self-Heating

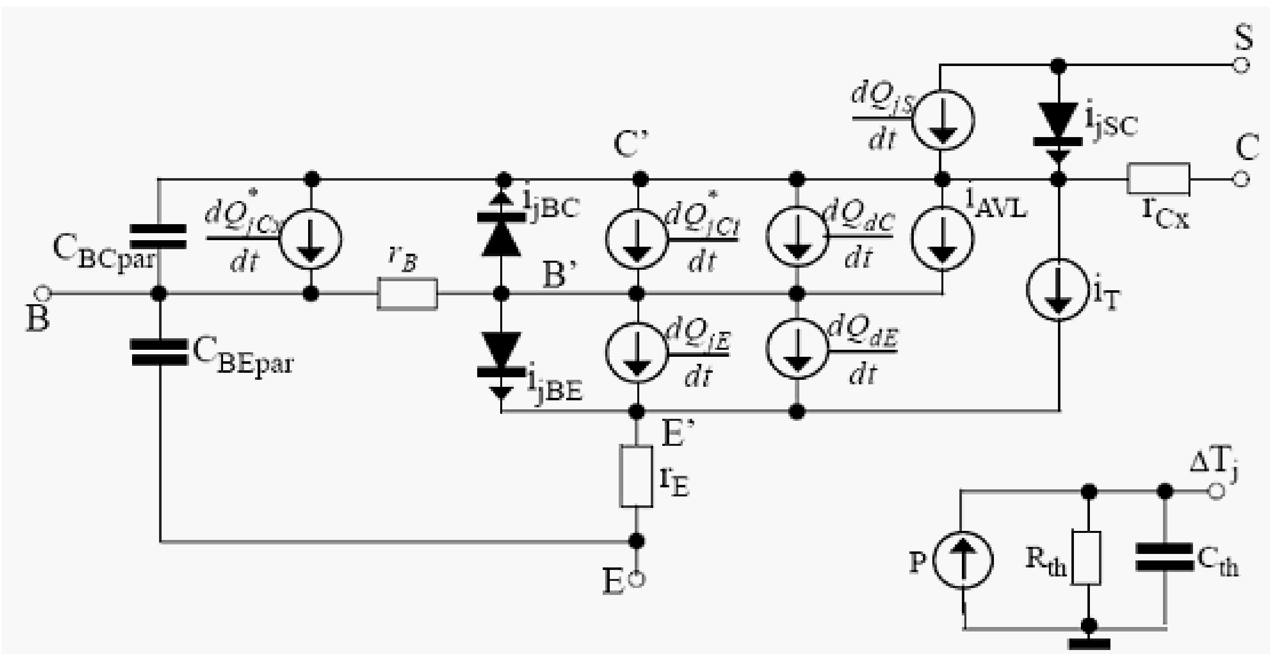
You can set `self_heating=fast` to enable the fast self-heating which has high performance. The result should be identical or very close to normal self-heating result.

Parameter flcomp

When updatelevel=3, if `flcomp`=0 or 2.1 the result is consistent with version2.1, irrespective of the version used in the netlist.

Model Description

The HICUM model is a semi-physical compact bipolar transistor model. Semi-physical means that for arbitrary transistor configurations, a complete set of model parameters can be calculated from a single set of technology specific electrical and technological data. This model was developed with special emphasis on modeling the operating region at high current densities. The modularity and physics-based approach of this model allows the construction of a model hierarchy without additional effort in parameter extraction.



Large-signal HICUM Equivalent Circuit

Thermal Network

DC Equations

$$i_T = i_{Tf} - i_{Tr}$$

$$i_{Tf1} = \frac{C_{10}}{Q_{p,T}} \exp\left(\frac{V_{B'E'}}{m_{cf} V_T}\right)$$

$$i_{Tf} = i_{Tf1}\left(1 + \frac{i_{Tf1}}{i_{ch}}\right)$$

$$i_{Tr} = \frac{C_{10}}{Q_{p,T}} \exp\left(\frac{V_{B'C'}}{V_T}\right)$$

$$Q_{p,T} = \frac{Q_{p,low}}{2} + \sqrt{\left(\frac{Q_{p,low}}{2}\right)^2 + \tau_{f0} C_{10} \exp\left(\frac{V_{B'E'}}{V_T}\right) + \tau_r C_{10} \exp\left(\frac{V_{B'C'}}{V_T}\right)}$$

$$Q_{p,1} = Q_{p0} + Q_{jEi} h_{jei} + h_{jci} Q_{jci}$$

$$I_{CK} = \frac{V_{ceff}}{r_{cio}} \frac{1}{\sqrt{1 + \left(\frac{V_{ceff}}{V_{lim}}\right)^2}} \left[1 + \frac{x + \sqrt{x^2 + 10^{-3}}}{2}\right]$$

$$X = (V_{ceff} - V_{lim}) / V_{PT}$$

$$r_{cio} = \frac{w_c}{q \mu_{nC0} N_{ci} A_E} \frac{1}{f_{cs}}$$

$$V_{lim} = \frac{V_{sn}}{\mu_{nc0}} w_c$$

$$V_{PT} = \frac{q N_{ci}}{2E} w_c^2$$

$$i_{jBEi} = I_{BEis}\left[\exp\left(\frac{V_{B'E'}}{m_{BEi}V_T}\right) - 1\right] + I_{REis}\left[\exp\left(\frac{V_{B'E'}}{m_{BEi}V_T}\right) - 1\right]$$

$$i_{jBEp} = I_{BEps}\left[\exp\left(\frac{V_{B'E'}}{m_{BEp}V_T}\right) - 1\right] + I_{REps}\left[\exp\left(\frac{V_{B'E'}}{m_{REp}V_T}\right) - 1\right]$$

$$i_{jBCi} = I_{BCis}\left[\exp\left(\frac{V_{B'C'}}{m_{BCi}V_T}\right) - 1\right]$$

$$i_{jBCx} = I_{BCxs}\left[\exp\left(\frac{V_{B'C'}}{M_{BCx}V_T}\right) - 1\right]$$

$$r_{Bi} = r_{Bi0}\frac{C_i}{C_i + C_{dEp}}$$

$$r_{Bi0} = r_{SBi0}\frac{b_E}{l_E n_E}g_i$$

$$C_i = C_{jEi} + C_{dEi} + C_{dci}$$

$$C_{dEp} = C_{dE}(1 - f_{Qi})$$

$$i_{AVL} = I_T\frac{f_{AVL}V_{DCi}}{C_c^{1/z_{ci}}}\exp\left(-\frac{q_{AVL}}{C_{jCi0}V_{DCi}}C_c^{(1/z_{ci} - 1)}\right)$$

$$C_c = \frac{C_{jci}(V_{B'C'})}{C_{jci}0}$$

*

$$i_{BEt} = I_{BEts}(-V_e)C_e^{1 - 1/z_E}\exp\left[-a_{BEt}C_e^{1/z_E - 1}\right]$$

$$I_{BEts} = 2\frac{\sqrt{2m^*/E_G}q^3V_{DE}^2}{h^2\varepsilon_{Si}}C_{jE0}$$

$$a_{BEt} = \frac{8\pi\sqrt{2m^*E_G}E_G}{3qh}\frac{W_{BE0}}{2V_{DE}}$$

$$C_e = \frac{C_{jE(V)}}{C_{jE0}}$$

$$i_{TS} = I_{TSf} - I_{TSr} = I_{TSS}\left[\exp\left(\frac{V_{B^*C'}}{m_{Sf}V_T}\right) - \exp\left(\frac{V_{S'C'}}{m_{Sr}V_T}\right)\right]$$

$$i_{SC} = I_{SCS}\left[\exp\left(\frac{V_{S'C'}}{m_{SC}V_T}\right) - 1\right]$$

Charge and Capacitance Equations

$$Q_{P,T} = Q_{p0} + h_{jEi}Q_{jEi} + h_{jCi}Q_{jCi} + Q_{f,T} + Q_{r,T}$$

$$Q_{f,T} = Q_{f0} + \Delta Q_{Ef} + \Delta Q_{fh}$$

$$Q_{f0} = \tau_{f0} i_{Tf}$$

$$\Delta Q_{Ef} = \Delta\tau_{Ef}\frac{i_{Tf}}{1 + g_{\tau E}}$$

$$\Delta\tau_{Ef} = \tau_{Ef0}\left(\frac{i_{Tf}}{I_{CK}}\right)^{g_{\tau E}}$$

$$\tau_{Ef0} = \frac{1}{\beta_0}\left(\frac{W_E}{V_{Ke}} + \frac{W_E^2}{2\mu_{PE}V_T}\right)$$

$$\Delta Q_{fh} = \Delta Q_{Bf} + Q_{cf} = \tau_{hcS} i_{Tf} W^2$$

$$Q_{r,T} = \tau_r i_{Tr}$$

$$C_{jEi} = \frac{C_{jEi0}}{(1 - V_j/V_{DEi})^{2_{Ei}}} \cdot \frac{e}{1 + e} + a_{jEi}C_{jEi0}\frac{1}{1 + e}$$

$$e = \exp\left(\frac{V_f - V_{B'E'}}{V_T}\right)$$

$$V_j = V_f - V_T\ln[1 + e] < V_f$$

$$V_f = V_{DEi}\left[1 - a_{jEi}^{-(1/(z_{Ei}))}\right]$$

$$Q_{jEi} = \frac{C_{jEi0}V_{DEi}}{1-Z_{Ei}}\left[1-\left(1-\frac{V_j}{V_{DEi}}\right)^{(1/(z_{Ei}))}\right]+a_{jEi}C_{jEi0}(V_{B'E'}-V_j)$$

$$C_{jci} = C_{jci,cl}+C_{jci,PT}+C_{jci,fb}$$

$$C_{jci,cl} = \frac{C_{jci0}}{(1-V_{j,m}/V_{DCi})^{z_{ci}}}\cdot\frac{Q_{j,r}}{1+e_{j,r}}\frac{e_{j,m}}{1+e_{j,m}}$$

$$C_{jci,fb} = a_{jci}C_{jci0}\frac{1}{e_{j,r}+1}$$

$$C_{jci,PT} = \frac{C_{jci0,r}}{(1-V_{j,r}/V_{DCi})^{Z_{ci,r}}}\cdot\frac{1}{1+e_{j,m}}$$

$$Q_{jCi} = Q_{jCi,m}+Q_{jci,r}+a_{jci}C_{jci0}(V_{B'C'}-V_{j,r})-Q_{jci,c}$$

$$Q_{jCi,m} = \frac{C_{jCi0}V_{DCi}}{1-z_{Ci}}\left[1-\left(1-\frac{V_{j,m}}{V_{DCi}}\right)^{1-z_{Ci}}\right]$$

$$Q_{jCi,r} = \frac{C_{jCi,r}V_{DCi}}{1-z_{Ci,r}}\left[1-\left(1-\frac{V_{j,r}}{V_{DCi}}\right)^{1-z_{Ci,r}}\right]$$

$$Q_{jCi,c} = \frac{C_{jCi,r}V_{DCi}}{1-z_{ci,r}}\left[1-\left(1-\frac{V_{j,m}}{V_{DCi}}\right)^{1-z_{Ci,r}}\right]$$

$$C_{jCi0,r} = C_{jCi0}\cdot\left(\frac{V_{DCi}}{V_{PTCi}}\right)^{(Z_{ci}-Z_{ci,r})}$$

$$C_i = C_{jEi}+C_{jCi}+C_{dE}+C_{dC}$$

$$Q_{dS} = \Upsilon_{Sf}i_{TSf}$$

$$C_{dE} = \tau_f S_{fb}$$

$$C_{dC} = \tau_r S_{rC} + \tau_f S_{fC}$$

$$C_{dS} = \tau_{Sf} S_{TSu,b}$$

$$S_{fb} = \left.\frac{dI_{Tf}}{dV_{B'E'}}\right|_{V_{B'C'}} = \frac{I_{Tf1}}{V_{Tf}} \cdot \frac{Q_{P,T} + \tau_r I_{Tr} - h_{jei} C_{jEi} V_{Tf}}{Q_{P,T} + \tau_r I_{Tr} + \tau_{fT} I_{Tf1} d_{ch}} d_{ch}$$

$$d_{Ch} = 1 + 2I_{Tf1}/I_{Ch}$$

$$S_{fC} = \left.\frac{dI_{Tf}}{dV_{C'E'}}\right|_{V_{B'E'}} = \frac{I_{Tf1}}{V_{Af}} \cdot \frac{d}{1 + d\tau_{f,T} I_{Tf1}/Q_{p,T}}$$

$$V_{Af} = \frac{Q_{P,T}}{h_{jci} C_{jCi} - \left.\frac{dQ_f}{dV_{C'E'}}\right|_{V_{B'E'}}}$$

$$d = d_{ch} \frac{e}{1 + e}$$

$$e = \exp\left(\frac{V_c}{V_T} - 1\right)$$

$$S_{rc} = \left.\frac{dI_{Tr}}{dV_{C'E'}}\right|_{V_{B'E'}} = -\frac{I_{Tr}}{V_T} \cdot \frac{Q_{P,T} + (\tau_{f,T} S_{fc} - h_{jci} C_{jci}) V_T}{Q_{p,T} + \tau_r I_{Tr}}$$

$$S_{Tsu,b} = \frac{I_{TsS}}{m_{sf} V_T} \exp\left(\frac{V_{B^*C'}}{m_{sf} V_T}\right)$$

Noise Model

$$\overline{i_{RE}^2} = \frac{4K_B T\Delta f}{r_E}$$

$$\overline{i_{Rcx}^2} = \frac{4K_B T\Delta f}{r_{cx}}$$

$$\overline{i_{Bx}^2} = \frac{4K_B T\Delta f}{r_{Bx}}$$

$$\overline{i_{Bin}^2} = \frac{4K_B T\Delta f}{r_{Bin}}$$

$$\overline{i_T^2} = 2qI_T\Delta f$$

$$\overline{i_{AVL}^2} = 2qI_{AVL}\Delta f$$

Diode currents I_{jdiode}={BEi, BCi, BEp, BCx, CS}:

$$\overline{i_{jdiode}^2} = 2qI_{jdiode}\Delta f$$

$$\overline{i_{BE}^2} = k_F(I_{jBEi} + I_{jBEp})^{\alpha_F}\frac{\Delta f}{f}$$

Correlation between base and collector noise spectral density S_{incinb}:

$$S_{incinb} \approx -2qI_T \times (j\omega\tau_{Bf} \times alit)$$

$$\tau_{Bf} = \frac{I_T}{I_{BEi}}$$

Temperature Effect

$$r_{ci}(T) = r_{ci}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{ci}}$$

$$V_{lim}(T) = V_{lim}(T_0)(1 - \alpha_{VS}\Delta T)\left(\frac{T}{T_0}\right)^{\zeta_{Ci}}$$

$$V_{C'E's}(T) = V_{C'E's}(T_0)[1 + \alpha_{CEs}\Delta T]$$

$$\tau_0(T) = \tau_0(T_0)[1 + \alpha_{\tau 0}\Delta T + K_{\tau 0}\Delta T^2]$$

$$\tau_{hcs}(T) = \tau_{hcs}(T_0)\left(\frac{T}{T_0}\right)^{(\tau_{ci} - 1)}$$

$$\tau_{Ef0}(T) = \tau_{Ef}(T_0)\frac{T/T_0}{1 + \alpha_B \Delta T}$$

$$V_D(T) = V_D(T_0)\frac{T}{T_0} - V_{Gj}\left(\frac{T}{T_0} - 1\right) - 3V_T \ln\left(\frac{T}{T_0}\right)$$

$$C_{j0}(T) = C_{j0}(T_0)\left(\frac{V_D(T_0)}{V_D(T)}\right)^2$$

$$\alpha_J(T) = \alpha_j(T_0)\frac{V_D(T)}{V_D(T_0)}$$

$$r_{Bi0}(T) = r_{Bi0}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{rBi}}$$

$$f_{AVL}(T) = f_{AVL}(T_0)\exp(\alpha_{fav}\Delta T)$$

$$q_{AVL}(T) = q_{AVL}(T_0)\exp(\alpha_{qav}\Delta T)$$

$$I_{BEtsS}(T) = I_{BEtS}(T_0)\sqrt{\frac{V_G(T_0)}{V_G(T)}}\left(\frac{V_{DEp}(T)}{V_{DEp}(T_0)}\right)^2\frac{C_{jEp0}(T)}{C_{jEp0}(T_0)}$$

$$a_{BEt}(T) = a_{BEt}(T_0)\left(\frac{V_G(T)}{V_G(T_0)}\right)^{3/2}\frac{V_{DEp}(T)}{V_{DEp}(T_0)}$$

When `updatelevel=0`,

$Itss(T) = Itss(T0)$ (No temperature dependence)

$$TEF0(T0) = TEF0(T0)\times(T/T0)/(0.5\times(A+\sqrt{A\times A+0.01}))$$

When `updatelevel=1`,

$$Itss(T) = Itss(T0)\times(T/T0)^{3/Msf}\times\exp(VGB/(Msf\times Vt)\times(T/T0-1))$$

$$TEF0(T0) = TEF0(T0)\times(T/T0)/(0.5\times(A+\sqrt{A\times A+le-6}))$$

$$Cdci = Tr\times Src$$

where

$$A = 1.0 + Alb\times DeltaT$$

The original HICUM model had simple derivatives for some currents and charges, which sometimes caused convergence issues. There have been some enhancements made to solve this problem, especially for AC analyses.

Self-Heating

You can set `self_heating=fast` to enable the fast self-heating, which is faster than the full self-heating but gives similar results in most cases.

Self-heating for parasitic resistor is given by the following equation:

$$Pwr = Vcei\times It - Vbci\times lavl$$

If updatelevel=2,

$$Pwr = Pwr + (Vbp - Vb) \times \frac{(Vbp - Vb)}{Rbi}$$ if Rbi0 is given

$$Pwr = Pwr + (Vbx - Vbp) \times \frac{(Vbx - Vbp)}{Rbx}$$ if Rbx is given

$$Pwr = Pwr + (Vcx - Vc) \times \frac{(Vcx - Vc)}{Rcx}$$ if Rcx is given

$$Pwr = Pwr + (Ve - Vex) \times \frac{(Ve - Vex)}{Re}$$ if Re is given

NQS effect

Lateral NQS

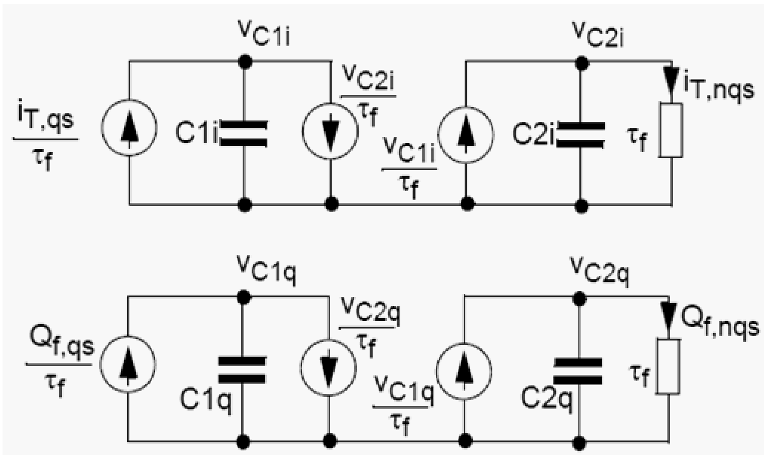
The lateral NQS effect is implemented by an adequate capacitance C_{rBi} in parallel to the resistance r_{Bi}.

$$C_{rBi} = f_{crBi} \times C_{jei} \times C_{jci} \times C_{dei} \times C_{dci}$$

$$Q_{rBi} = C_{rBi} \times V_{B \times B''''}$$

Vertical NQS

Vertical NQS effects are implemented through “additional delay times” for both minority charge Q_f and forward transfer current i_{Tf}. The figure below shows the adjunct NQS networks for Transfer Current i_T and Minority Charge Q_r.



$$\frac{I_{T,qs} - V_{C2i}}{\tau_f} = \frac{d \times (alit \times V_{C1i})}{dt}$$

$$\frac{V_{C1i} - V_{C2i}}{\tau_f} = \frac{d \times (alit \times V_{C2i}/3)}{dt}$$

$$I_{T,nqs} = \frac{V_{C2i}}{\tau_f}$$

$$\frac{Q_{T,qs} - V_{C2q}}{\tau_f} = \frac{d \times (alqf \times V_{C1i})}{dt}$$

$$\frac{V_{C1q} - V_{C2q}}{\tau_f} = \frac{d \times (alqf \times V_{C2q}/3)}{dt}$$

$$Q_{T,nqs} = \frac{V_{C2q}}{\tau_f}$$

HiCUM Model Version 2.2

Temperature Dependent Bandgap Voltage

$$V_g(T) = V_g(0) + K_1 T 1n(T) + K_2 T$$

$$V_g(T) = V_{g,cq}(0) - \frac{\alpha_g T^2}{T + T_g}$$

For compact model and application purposes, it is sometimes more convenient to re-write the above equation in terms of a reference temperature T_0 (e.g. for parameter extraction), which gives

$$V_g(T) = V_g(T_0) + k1\frac{T}{T_0}\ln\left(\frac{T}{T_0}\right) + k_2\left(\frac{T}{T_0} - 1\right)$$

with the definitions

$$k_1 = k_1 T_0$$

$$k_2 = k_2 T_0 + k_1 1n(T_0)$$

and the bandgap voltage at the measurement reference temperature,

$$V_g(T_0) = k_2 + V_g(0)$$

The choice of the bandgap description also influences the formulation of the effective intrinsic carrier density, which now reads

$$n_{ie}^2(T) = n_{ie}^2(T_0)\left(\frac{T}{T_0}\right)^{m_g}\exp\left[\frac{V_{geff}(0)}{V_T}\left(\frac{T}{T_0} - 1\right)\right]$$

with the constant

$$m_g = 3 - \frac{k_1}{V_{T0}} = 3 - \frac{qK_1}{K_B}$$

Transfer current

Base Region Reach-Through

$$Q_{pT,j} = Q_{p0} + h_{jEi}Q_{jEi} + h_{jCi}Q_{jCi}$$

$$Q_{pT,low} = Q_{B,rt}\left(1 + \frac{x + \sqrt{x^2 + a}}{2}\right)$$

and a = 1.921812.

$$x = \frac{Q_{pT,j}}{Q_{B,rt}} - 1$$

Temperature Dependence

Prefactor

$$c_{10}(T) = c_{10}(T_0)\left(\frac{T}{T_0}\right)^{\varsigma_{CT}} \exp\left[\frac{V_{gBeff}(0)}{V_T}\left(\frac{T}{T_0} - 1\right)\right]$$

$$\varsigma_{CT} = m_g + 1 - \zeta_{\mu mB}$$

Zero-Bias Hole Charge

$$Q_{p0}(T) = Q_{p0}(T_0)\left[2 - \left(\frac{V_{DEi}(T)}{V_{DEi}(T_0)}\right)^{Z_{Ei}}\right]$$

Base Currents

Excess Base Current from Recombination at the BC Barrier

$$i_{Bhrec} = \frac{\Delta Q_{Bf}}{\tau_{Bhrec}}$$

Temperature Dependent Junction Current Components

$$I_{BEiS}(T) = I_{BEiS}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{BET}} \exp\left[\frac{V_{gEeff}(0)}{V_T}\left(\frac{T}{T_0} - 1\right)\right]$$

$$V_{gEeff}(0) = V_{gBeff}(0) - \alpha_{Bf} T_0 V_{T0}$$

$$I_j = I_{jS} \exp\left(\frac{V}{mV_T}\right)$$

$$I_{jS}(T) = I_{jS}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_T} \exp\left[\frac{V_{geff}(0)}{V_T}\left(\frac{T}{T_0} - 1\right)\right]$$

$$V_{gBEeff} = \frac{V_{gBEeff} + V_{gEeff}}{2}$$

$$\mu_{Ci}(T) = \mu_{Ci}(T_0)\left(\frac{T}{T_0}\right)^{-\zeta_{Ci}}$$

$$\zeta_{BCiT} = m_g + 1 - \zeta_{Ci}$$

$$\zeta_{BCxT} = m_g + 1 - \zeta_{Cx}$$

$$\zeta_{SCT} = m_g + 1 - \zeta_{\mu pS}$$

Depletion Capacitances and Charges

Bias Dependence of Base-Emitter Component

$$v_j = V_f - V_T \frac{x + \sqrt{x^2 + a_{fj}}}{2} < V_f$$

$$x = \frac{V_f - v_{B'E'}}{V_T}$$

$$a_{fj} = 41n^2(2) = 1.921812$$

$$C_{jEi} = \frac{C_{jEi0}}{(1 - v_j / V_{DEi})^{z_{Ei}}} \cdot \frac{dv_j}{dv_{B'E'}} + a_{jEi} C_{jEi0}\left(1 - \frac{dv_j}{dv_{B'E'}}\right)$$

$$\frac{dv_j}{dv_{B'E'}} = \frac{x + \sqrt{x^2 + a_{fj}}}{2\sqrt{x^2 + a_{fj}}}$$

External Depletion Capacitances

The formulation for the depletion capacitances C_{jEp} also has been changed from exponential to hyperbolic smoothing functions.

Temperature Dependence of Built-in Voltages

$$V_{Dj}(T_0) = 2V_{T0}\ln\left[\exp\left(\frac{V_D(T_0)}{2V_{T0}}\right) - \exp\left(\frac{V_D(T_0)}{2V_{T0}}\right)\right]$$

$$V_{Dj}(T) = V_{Dj}(T_0)\frac{T}{T_0} - 3V_T\ln\left(\frac{T}{T_0}\right) + V_{geff}(T) - V_{geff}(T_0)\left(\frac{T}{T_0}\right)$$

For the bandgap voltage formulation, the above equation reads

$$V_{Dj}(T) = V_{Dj}(T_0)\frac{T}{T_0} - m_g V_T \ln\left(\frac{T}{T_0}\right) - V_{geff}(0)\left(\frac{T}{T_0} - 1\right)$$

which reduces to the classical equation (that assumes a linear temperature dependence of V_{geff}) if $m_g = 3$. Finally, the new built-in voltage is calculated as

$$V_D(T) = V_{Dj}(T) + 2V_T \ln\left(\frac{1}{2}\left[1 + \sqrt{1 + 4\exp\left(-\frac{V_{Dj}(T)}{V_T}\right)}\right]\right)$$

$$V_{geff} \rightarrow V_{g(x,y)eff} = \frac{V_{gxeff} + V_{gyeff}}{2}$$

$$\left.\frac{dV_D(T)}{dT}\right|_{T_0} \cong \left.\frac{dV_{Dj}(T)}{dT}\right|_{T_0}$$

$$\left.\frac{dV_{Dj}(T)}{dT}\right|_{T_0} = \frac{V_{Dj}(T_0) - V_{geff}(0) - m_g V_{T)}}{T_0}$$

Minority Charge

Effective Collector Voltage and Critical Current

$$v_{ceff} = V_T\left[1 + \frac{u + \sqrt{u^2 + a_{vceff}}}{2}\right]$$

$$u = \frac{v_c - V_T}{V_T}$$

$$x = \frac{v_{ceff} - V_{lim}}{V_{PT}}$$

Diffusion Capacitances

$$C_{dCi} = \tau_r S_{rc} + \tau_f S_{fc}$$

has been changed to

$$C_{dCi} = \tau_r S_{rc}$$

$$C_{dEi}^{C} = \tau_f S_{fc} + \left.\frac{dQ_f}{dV_{CE}}\right|_{T_{Tf},\,T}$$

$$C_{dEi}^{B} = \tau_r S_{rb}$$

Temperature Dependence

Critical Voltage Vlim

$$V_{lim}(T) = \frac{v_s(T)}{\mu_{nCi0}(T)}$$

$$v_s(T) = v_{s0}(T_0)\left(\frac{T}{T_0}\right)^{-a_{vs}}$$

$$a_{vs} = a_{vs}T_0$$

Inserting the temperature dependence of the collector electron mobility into the V_{lim}(T) equation gives the physics-based formulation

$$V_{lim}(T) = V_{lim}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{Cl} - a_{vs}}$$

The following equation replaces the formulation used in version 2.1:

$$V_{lim}(T) = V_{lim}(T_0)(1 - a_{vs}\Delta T)\left(\frac{T}{T_0}\right)^{\zeta_{Cl}}$$

Emitter Transit Time

$$\tau_{Ef0}(T) = \tau_{Ef0}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{\tau Cl}} \exp\left[-\frac{\Delta V_{geff}(0)}{V_T}\left(\frac{T}{T_0} - 1\right)\right]$$

$$\Delta V_{geff}(0) = V_{gBeff}(0) - V_{gEeff}(0)$$

$$\zeta_{\tau Ef} = \zeta_{BET} - \zeta_{CT} - 0.5$$

Collector Current Spreading

$$f_{ccs} = \frac{\tau_f(I_{CK})}{\tau_{f,ID}(I_{CK})}$$

$$\tau_{hcs} = f_{ccs}\tau_{pCs} + \tau_{Bfvs} = f_{ccs}\frac{w_C^2}{4\mu_{nC0}V_T} + \frac{w_{Bm}w_C}{2G_{\zeta i}\mu_{nC0}V_T}$$

The original model parameter τ_{hcs} is be extracted from measurements together with the partitioning factor

$$f_{thc} = \frac{\tau_{pCs}}{\tau_{hcs,x}}$$

Thus, during preprocessing for model card generation, the modified extracted time constant

$$\tau_{hcs} = (1 - f_{thc})\tau_{hcs,x} + f_{ccs}\tau_{pCs} = [(1 - f_{thc}) + f_{ccs}f_{thc}]\tau_{hcs,x}$$

is calculated and used as a model parameter.

Internal Base Resistance

In Version 2.1, the impact of the minority charge at the emitter periphery during large-signal switching on the lumped internal base resistance was taken into account by the equation

$$r^*_{Bi} = r_{Bi}\frac{\Delta Q_i}{\Delta Q_p} = r_{Bi}\frac{\Delta Q_i}{\Delta Q_i + \Delta Q_{fp}}$$

with

$$\Delta Q_i = Q_{jEi} + Q_{jCi} + Q_{fi}$$

For the case of a large negative BC voltage and a low forward BE voltage

$$\Delta Q_i = Q_{jEi} + Q_{jCi}$$

can become zero, causing a division by zero and a pole in the bias dependent r_{Bi} characteristic. Although this case is rare and is mostly likely caused by bad (non-physical) parameter combinations, it needs to be avoided under any circumstances. Therefore, to ensure numerical stability Q_{jCi} is dropped, leading to the modified formulation of the charge difference

$$\Delta Q_i = Q_{jEi} + Q_{fi}$$

In the corresponding small-signal equation,

$$r^*_{Bi} = r_{Bi}\frac{C_i}{C_i + C_{dEp}}$$

the internal capacitance has also to be modified to

$$C_i = C_{jEi} + C_{dEi}$$

Another change of the formulation for the internal base resistance is that the parameter KRBI is dropped. It was introduced about 10 years ago and intended to be used for changing during h.f. noise analysis due to the many uncertainties in bipolar transistor noise mechanisms and theory. With a better understanding of noise in bipolar transistors and many experimental investigations performed recently for advanced processes, this empirical parameter does not seem to be required anymore.

Base-emitter Tunnelling Component

Location of the Current Source

$$i_{BEt} = I_{BEtS}(-V_e)C_e^{1-1/z_g}\exp\left[-a_{BEt}C_e^{1/z_g-1}\right]$$

Temperature Dependence

$$I_{BEtS}(T) = I_{BEtS}(T_0)\sqrt{\frac{V_g(T_0)}{V_g(T)}}\left(\frac{V_{DE}(T)}{V_{DE}(T_0)}\right)^2\left(\frac{C_{jE0}(T)}{C_{jE0}(T_0)}\right)$$

$$a_{BEt}(T) = a_{BEt}(T_0)\left(\frac{V_g(T)}{V_g(T_0)}\right)^{3/2}\frac{V_{DE}(T_0)}{V_{DE}(T)}\frac{C_{jE0}(T_0)}{C_{jE0}(T)}$$

$$V_g(T) = V_{gBEeff}(T) = \frac{V_{gBeff}(0T) + V_{gEeff}(T)}{2}$$

Parasitic Base-Emitter Capacitance Partitioning

$$C_{BEpar} = C_{Eox} + C_{BE,\,metal}$$

$$f_{BEpar'} = \frac{C_{BEpar,\,2}}{C_{BEpar}} = \frac{C_{Eox,\,2} + C_{BE,\,metal}}{C_{Eox} + C_{BE,\,metal}}$$

Substrate Transistor

$$I_{TS}(T) = I_{TSS}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{BCxT}}\exp\left[\frac{V_{gCeff}(0)}{V_T}\left(\frac{T}{T_0}-1\right)\right]$$

$$\tau_{Sf}(T) = \tau_{Sf}(T_0)\left(\frac{T}{T_0}\right)^{(\zeta_{Cx}-1)}$$

HiCUM Model Version 2.3

HICUM/L2 version 2.30 has been developed to a large extent within the framework of the European DOTFIVE project. This HICUM/L2 version has been improved from its present official version (v2.24) in order to meet the requirements for emerging mm-wave applications. Following is a brief overview of the new improvements and additions in the new model.

Improvements in the model equations

Formulation for the critical current (ICK)

$$I_{ck} = \frac{V_{ceff}}{r_{ci0}} \frac{1}{\left(1 + \left(\frac{V_{ceff}}{V_{lim}}\right)^{\delta_{ck}}\right)^{1/\delta_{ck}}} \left[1 + \frac{\chi + \sqrt{\chi^2 - a_{ickpt}}}{2}\right]$$

where δ_{ck} is the new mode parameter.

Weight factors

Weight factor for low current transit time

A new weight factor hf0 for the low current minority charge has been introduced.

$$Q_{fT} = h_{f0} Q_{f0} + h_{fE} \Delta Q_{Ef} + \Delta Q_{Bf} + h_{fc} \Delta Q_{cf}$$

Note that the default value of hf0 (=1) makes it compatible with the previous version. The temperature dependence of hf0 is given by

$$h_{f0}(T) = h_{f0}(T_0) \exp\left[\frac{\Delta V_{gBE}}{V_T}\left(\frac{T}{T_0} - 1\right)\right]$$

where, Δ VgBE is the new model parameter and defined as the bandgap difference between base and BE-junction, used for hjEi0 and hf0.

Weight factor of BE depletion charge

In this version, the BE-depletion charge weight factor hjEi is modeled as bias dependent with the following equations:

$$h_{jEi} = h_{jEi0}\frac{\exp(u) - 1}{1}$$

With,

$$u = a_{hjEi}\left(1 - \left(1 - \frac{V_j}{V_{DEi}}\right)^{Z_{Ei}}\right)$$

Where, ahjEi is the new model parameter.

The junction voltage is limited to V_{DEi} and 0 by:

$$\chi_{upp} = \frac{V_{DEi} - V_{BEi}}{r_{h_{jEi}} V_t}$$

and

$$V_{j,\,upp} = V_{DEi} - r_{h_{jEi}} V_T \frac{\chi_{upp} + \sqrt{\chi^2{}_{upp} - a_{fi}}}{2}$$

where, rhjEi is the newly introduced model parameter.

The voltage has been further limited to values greater than zero using the following equations:

$$\chi_{low} = \frac{v_{j,\,upp} - V_T}{V_T}$$

$$v_j = V_T\left(1 + \frac{\chi_{low} + \sqrt{\chi^2{}_{low} + a_{fi}}}{2}\right)$$

The temperature dependence of h_{JEi} and r_{hjEi} is given by:

$$a_{hjEi}(T) = a_{hjEi}(T_0)\left(\frac{T}{T_0}\right)^{\xi_{h_{jEi}}}$$

$$h_{jEi0}(T) = h_{jEi}(T_0)\exp\left[\left(-\frac{\Delta V_{gBe}}{V_T}\right)\left(\left(\frac{T}{T_0}\right)^{\zeta_{VgBE}} - 1\right)\right]$$

Where,

ζ_{hjEi} and ζ_{VgBE} are the fitting parameters.

High current weight factors

Temperature dependences for hfE and hfC have been considered in the new model.

$$h_{fE}(T) = h_{fE}(T_0)\exp\left[\frac{V_{gb} - V_{ge}}{V_T}\left(\frac{T}{T_0} - 1\right)\right]$$

$$h_{fc}(T) = h_{fc}(T_0)\exp\left[\frac{V_{gb} - V_{gc}}{V_T}\left(\frac{T}{T_0} - 1\right)\right]$$

To enable full backward compatibility to previous versions of HICUM, the parameter `flcomp` needs to be set to 2.3, or more to turn on these models.

Transit Times

Barrier voltage

The barrier related term is calculated by the bias dependent barrier voltage:

$$\Delta V_{cBar} = V_{cBar}\exp\left(-\frac{2}{i_{Bar} + \sqrt{i^2_{Bar} + a_{cBar}}}\right)$$

$$i_{Bar} = \frac{i_{Tf} - I_{CK}}{i_{cBar}}$$

Barrier related minority charge

The high current minority charge expression has been extended by adding the barrier related part:

$$Q_{f,h} = \Delta Q_{Ef} + \Delta Q_{Bf,b} + \Delta Q_{Bf,c} + \Delta Q_{cf,c}$$

The new formulation for the barrier related minority charge reads as follows:

$$\Delta Q_{Bf,b} = \tau_{Bfvs} i_{Tf}\left[\exp\left(\frac{\Delta V_{cBar}}{V_T}\right) - 1\right]$$

With the already existing parameter:

$$\tau_{Bfvs} = (1 - f_{\tau hc})\tau_{hCs}$$

High current charges

Considering the “Kirk effect” the following expression can be obtained:

$$\Delta Q_{f_{h,c}} = \tau_{hCs} i_{Tf} w^2 \exp\left(\frac{\Delta V_{cBar} - V_{cBar}}{V_T}\right)$$

The high current collector charge including current spreading can be expressed as:

$$\Delta Q_{Cf,c} = \tau_{pCs} i_{Tf} \exp\left(\frac{\Delta V_{cBar} - V_{cBar}}{V_T}\right) \begin{cases} 2\dfrac{f_{Ci} 1n\left(\dfrac{1+\zeta_b w}{1+\zeta_l w}\right) - f_{Cb} + f_{Cl}}{\zeta_b - \zeta_l} & l_{E0} > b_{E0} \\ \dfrac{1+\zeta_{bw/3}}{1+\zeta_b w} w^2 & l_{E0} = b_{E0} \end{cases}$$

Emitter transit time

The temperature dependence of the emitter transit time has been removed. However, by setting `flcomp` to 2.2 or lower, the former existing equation will still be available.

Lateral non-quasi-static (NQS) effect

The formulation has been switched back to that of HICUM/L2 version 2.23.

Temperature dependence of thermal resistance

In this version, the thermal resistance (Rth) has been modeled as temperature dependent.

$$R_{th}(T) = R_{th}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{rth}}$$

where, ζ_{rth} is the temperature coefficient of Rth and a new model parameter.

Temperature dependence of internal BE recombination current

The current equation has been modified, within the existing simplifying assumptions, by replacing “1/2” with “1/m_{REi}”

$$I_{REiS}(T) = I_{REiS}(T0)\left(\frac{T}{T_0}\right)^{\frac{m_g}{m_{REi}}} \exp\left[\frac{1}{m_{REi}} \cdot \frac{V_{gBEeff}}{V_T}\left(\frac{T}{T_0} - 1\right)\right]$$

Temperature dependence of peripheral BE recombination current

In the same way the with peripheral BE recombination current has been modified:

$$I_{REpS}(T) = I_{REpS}(T0)\left(\frac{T}{T_0}\right)^{\frac{m_g}{m_{REp}}}\exp\left[\frac{1}{m_{REp}} \cdot \frac{V_{gBEeff}}{V_T}\left(\frac{T}{T_0} - 1\right)\right]$$

Note: Setting mREi =2 and mREp=2 yields the formulation of previous model versions.

Noise source of the emitter resistance

Based on measurements presented in an additional flicker noise contribution has been introduced for the series emitter resistance RE. The total noise contribution becomes:

$$\overline{I^2_{rE}} = \frac{Kf_{rE} \cdot T_E^{Af_{rE}}}{f} + \frac{4KT}{r_E}$$

where, the first component represents the flicker noise and second the thermal noise.

HiCUM Model Version 2.31

Improvements in Model Equations

Temperature Dependence of Thermal Resistance

In this version, the temperature dependence of thermal resistance (R_{th}) has been changed as follows:

$$R_{th}(T) = R_{th}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{rth}}(1 + alrth \cdot \Delta t)$$

Lateral Non-Quasi-Static (NQS) Effect

In this version, the lateral NQS modeling has been simplified to reduce the number of calculated derivatives.

$$Cdei = T(f0) \cdot itf/V_t$$

$$Cdci = tr \cdot itr/V_t$$

Vertical NQS Effect Parameters

The default value of the vertical NQS effect parameters has been changed as follows:

$$alqf = 0.167$$

$$alit = 0.333$$

Noise Correlation

A new noise correlation model has been introduced, which is valid at all frequencies.

HiCUM Model Version 2.32

Improvements in Model Equations

The conditional statement for the barrier term has been changed to transistor-specific values. The original conditional statement `if(icbar<1e-10)` has been changed to `if(icbar<0.05*(vlim/rci0))` where `vlim/rci0` is a rough bias and temperature-independent estimation of `ICK`.

Scaling Effects

For scaling effects, see Scaling Factors (scale and scalem) on page 242.

Component Statements

Instance Definition

```
Name  c  b  e  [s]  [t] ModelName parameter=value ...
```

Specifying the substrate terminal is optional. If not provided, the substrate is connected to ground.

Specifying the thermal node (`t`) is optional. However, if it is specified then:

- When it is connected, it is parallel with the internal Rth/Cth
- When it is shorted to ground, it disables the self heating effect
- When it is kept floated, it uses the internal Rth/Cth and is equivalent to not being specified.

Instance Parameters

Parameters valid for both modes

1	`region=fwd`	Estimated operating region. Possible values are `off`, `fwd`, `rev`, and `sat`.
2	`trise (C)`	Temperature rise from ambient.
3	`self_heating=yes`	Control switch for self-heating.Possible values are no, yes or fast.Fast is Cadence's proprietary approach that is significant faster than the full self-heating yet gives very similar results in most cases. Possible values are `no`, `yes`, and `fast`.
4	`m=1`	Multiplicity factor (number of devices in parallel).

Parameters for structure mode

5	`isnoisy=yes`	Should device generate noise. Possible values are `no` and `yes`.

Structural parameters

6 `area=1` Transistor area factor.

Model Definition

model modelName bht parameter=value ...

Model Parameters

Major mode of operation

1 `mode=internal` Mode for model parameter determination. Possible values are `internal`.

Parameters for internal mode

Structural parameters

2 `type=npn` Transistor type. Possible values are `pnp` and `npn`.

3 `latb=0.0` Parameter for lateral scaling (Zeta_b).

4 `latl=0.0` Parameter for lateral scaling (Zeta_l).

Internal transistor

5 `c10=2.0e-30` A^2s Constant for ICCR.

6 `qp0=2.0e-14 Coul` Zero-bias hole charge.

7 `ich=∞ A` High current correction (multidimensional ICCR).

8 `hjci=1.0` B-C depletion charge weighting factor.

9 `hf0=1.0` Weight factor for the low current minority charge.

10 `ahjei=0.0` Parameter describing the slope of hjEi(VBE).

11 `rhjei=1.0`	Smoothing parameter for hjEi(VBE) at high voltage.
12 `hjei=1.0`	B-E depletion charge weighting factor.
13 `mcf=1.0`	Forward non-ideality factor of Su transfer current.
14 `tsf=0.0 s`	Transit time (forward operation).
15 `hfc=1.0`	Collector minority charge weighting factor.
16 `hfe=1.0`	Emitter minority charge weighting factor.
17 `alit=0.0`	Factor for additional delay time of iT.
18 `cjei0=0.0 F`	Internal zero-bias BE depletion capacitance.
19 `vdei=0.9 V`	Internal BE built-in voltage.
20 `zei=0.5`	Internal BE depletion coefficient.
21 `aljei=2.5`	Maximum int. depl. cap. divided by Cjei0.
22 `cjci0=0.0 F`	Internal zero-bias BC depletion capacitance.
23 `vdci=0.7 V`	Internal BC built-in voltage.
24 `zci=0.4`	Internal BC depletion coefficient.
25 `vptci=∞ V`	Punch-through voltage of internal BC junction.
26 `t0=0.0 s`	Time constant (low current densities).
27 `dt0h=0.0 s`	Time constant for base and BC space charge layer width modulation.
28 `tbvl=0.0 s`	Time constant for modeling carrier jam.
29 `tef0=0.0 s`	Neutral emitter storage time.
30 `gtfe=1.0`	Current dependence factor for TEF0.
31 `thcs=0.0 s`	Saturation time constant.

32 `alhc=0.1`	Smoothing factor for base and collector transit time.
33 `fthc=0.0`	Partitioning factor for base and collector portion.
34 `vces=0.1 V`	Internal CE saturation voltage.
35 `rci0=150.0 Ω`	Low-field resistance of epitaxial collector.
36 `vlim=0.5 V`	Limitation voltage.
37 `vpt=∞ V`	Punch-through voltage. The default value is 100V since version 2.24.
38 `tr=0.0 s`	Ideal reverse transit time.
39 `vcbar=0.0 V`	Barrier voltage.
40 `icbar=0.0 A`	Normalization parameter.
41 `acbar=0.01`	Smoothing parameter for barrier voltage.
42 `delck=2.0`	fitting factor for critical current.
43 `alqf=0.0`	Factor for additional delay time of minority charge.
44 `ibeis=1.0e-18 A`	Internal BE saturation current.
45 `mbei=1.0`	Internal BE non-ideality factor.
46 `ireis=0.0 A`	Internal BE saturation current (recombination).
47 `mrei=2.0`	Internal BE non-ideality factor (recombination).
48 `ibcis=1.0e-16 A`	Internal BC saturation current.
49 `mbci=1.0`	Internal BC non-ideality factor.
50 `favl=0.0 1/V`	Avalanche current factor.
51 `qavl=0.0 Coul`	Exponent factor for Avalanche current.
52 `rbi0=0.0 Ω`	Internal base resistance at zero-bias.

53 `fdqr0=0.0` Correction factor for modulation.

54 `fgeo=0.6557` Geometry factor for current crowding.

55 `fqi=1.0` Ratio of internal to total minority charge.

56 `fcrbi=0.0` Ratio of high frequency shunt to total internal capacitance.

57 `dvgbe=0.0 V` Bandgap difference between B and B-E junction used for hjEi0 and hf0.

58 `zetahjei=1.0` Temperature coefficient for ahjEi.

59 `zetavgbe=1.0` Temperature coefficient for hjEi0.

60 `zetarth=0.0 K/W` Temperature coefficient for Rth.

61 `flcono=no` Flag for turning on and off of correlated noise implementation. Possible values are `no` and `yes`.

62 `alrth=0.0 1/K` First order relative TC of parameter Rth.

Peripheral elements

63 `cjep0=0.0 F` Peripheral zero-bias BE depletion capacitance.

64 `vdep=0.9 V` Peripheral BE built-in voltage.

65 `zep=0.5` Peripheral BE depletion coefficient.

66 `aljep=2.5` Maximum per. depl. cap. divided by Cjep0.

67 `ibeps=0.0 A` Peripheral BE saturation current.

68 `mbep=1.0` Peripheral BE non-ideality factor.

69 `ireps=0.0 A` Periph. BE saturation current (recomb.).

70 `mrep=2.0` Periph. BE non-ideality factor (recomb.).

External elements

71 `cjcx0=0.0 F` External zero-bias BC depletion capacitance.

72 `vdcx=0.7 V` External BC built-in voltage.

73 `zcx=0.4` External BC depletion coefficient.

74 `vptcx=∞ V` Punch-through voltage of external BC junction.

75 `ccox=0.0 F` BC overlap capacitance.

76 `fbc=0.0` Partitioning factor for Cjcx and Ccox over rBx.

77 `ibcxs=0.0 A` External BC saturation current.

78 `mbcx=1.0` External BC non-ideality factor.

79 `ceox=0.0 F` Emitter oxide (overlap) capacitance.

80 `rbx=0.0 Ω` External base series resistance.

81 `re=0.0 Ω` Emitter series resistance.

82 `rcx=0.0 Ω` External collector series resistance.

Substrate transistor

83 `cjs0=0.0 F` Zero-bias CS depletion capacitance.

84 `vds=0.6 V` CS built-in voltage.

85 `zs=0.5` CS depletion coefficient.

86 `vpts=∞ V` Punch-through voltage of CS junction.

87 `rsu=0.0 Ω` Substrate resistance.

88 `csu=0.0 F` Substrate coupling capacitance.

89 `iscs=0.0 A` CS diode saturation current.

90 `msc=1.0` CS diode non-ideality factor.

91 `itss=0.0 A` Transfer saturation current of Su transistor.

92 `msf=1.0` Forward non-ideality factor of Su transfer current.

93 `msr=1.0` Reverse non-ideality factor of Su transfer current.

94 `ibets=0.0 A` BE tunneling saturation current.

95 `abet=40.0` BE tunneling factor.

Noise parameters

96 `kf=0.0` Flicker noise factor.

97 `af=2.0` Flicker noise exponent factor.

98 `krbi=1.0` Noise factor for internal base resistance.

99 `kfre=0.0` Emitter resistance flicker noise coefficient.

100 `afre=2.0` Emitter resistance flicker noise exponent facto.

Temperature effect parameters

101 `tnom (C)` Parameters measurement temperature. Default set by options.

102 `vgb=1.17 V` Bandgap-voltage.

103 `alb=5.0e-3 1/K` Rel. temperature coeff. of current gain.

104 `alfav=0.0 1/K` Temperature coefficient for FAVL.

105 `alqav=0.0 1/K` Temperature coefficient for QAVL.

106 `zetaci=0.0` Temper. coeff. (mobility) for epi-collector.

107 `alvs=0.0 1/K` Relative temperature coefficient of saturation-drift velocity.

108 `alces=0.0 1/K` Relative temperature coefficient of VCEs.

109 `zetarbi=0.0` Temperature coefficient. (mobility) for int. base res.

110 `zetarbx=0.0` Temper. coeff. (mobility) for ext. base res.

111 `zetarcx=0.0` Temper. coeff. (mobility) for ext. collector res.

112 `zetare=0.0` Temper. coeff. (mobility) for emitter res.

113 `alt0=0.0 1/K` First-order temper. coeff. of temperature T0.

114 `kt0=0.0` Second-order temper. coeff. of temperature T0.

115 `rth=0.0 K/W` Thermal resistance for self-heating.

116 `cth=0.0 J/K` Thermal capacitance for self-heating.

117 `debug=0.0` Debug.

118 `version=2.1` The available versions are 1.0, 2.1, 2.20, 2.21, 2.22, 2.23, 2.24, 2.30, 2.31, and 2.32.

Operating region warning control parameters

119 `updatelevel=2.0` Model update selector. The available versions are 0, 1, 2, and 3. updatelevel = 0 : This level is compatible with the original HICUM Fortran code. Temperature dependence is ignored. It is not recommended to use this level for convergence issue; updatelevel = 1 OR 2 : This level has better temperature dependence. It includes some fixes and enhancements. Version 1.0, 2.1, 2.21, and 2.22 support this level; updatelevel = 3 : This level has complete derivatives for current and charge model. The simulation result is fully compatible with HICUM Verilog-A model. Version 2.1, 2.20, 2.22, 2.23, and 2.32 support this level.

120 `minr=0.001 Ω` Minimum resistance.

121 `imax=1e3` Maximum current.

122 `tmax=500 C` Maximum device temperature.

123 `tmin=200 C` Minimum resistance.

124 `alarm=none` Forbidden operating region.
Possible values are `none`, `off`, `fwd`, `rev`, and `sat`.

DC-mismatch model parameters

125 `mvt0=0.0 V` Threshold mismatch intercept.

Formally released Hicum 2.2 new parameters

126 `vgc=1.17 V` eff. collector bandgap voltage.

127 `vge=1.17 V` eff. emitter bandgap voltage.

128 `vgs=1.17 V` eff. substrate bandgap voltage.

129 `zetact=3.0` Exponent coefficient in transfer current temperature dependence.

130 `zetabet=3.5` Exponent coefficient in B-E junction current temperature dependence.

131 `tbhrec=0.0 s` Base current recombination time constant at B-C barrier for high forward injection.

132 `tunode=1` Specifies the base node connection for the tunneling current. Possible values are 0 and 1, where 1 signifies perimeter node.

133 `cbepar=0.0 F` Total parasitic B-E capacitance.

134 `fbepar=1.0` Partitioning factor of parasitic B-E cap.

135 `f1vg=-1.02377e-4` Coefficient K1 in T-dependent band-gap equation.

136 `f2vg=4.3215e-4` Coefficient K2 in T-dependent band-gap equation.

137 `cfbe=-1` Flag for determining where to tag the flicker noise source, possible values are -1 and -2.

138 `zetacx=1.0` Temperature exponent of mobility in substrate transistor transit time.

139 `cbcpar=0.0 F` Total parasitic B-C capacitance.

140 `fbcpar=0.0` Partitioning factor of parasitic B-C cap.

141 `ajei=2.5` Ratio of maximum to zero-bias value of internal B-E capacitance.

142 `ajep=2.5`	Ratio of maximum to zero-bias value of peripheral B-E capacitance.
143 `ahc=0.1`	Smoothing factor for current dependence of base and collector transit time.
144 `flsh=1`	Flag for turning on and off self-heating effect. Possible values are 0,1 and 2, 0 refer to turn off, 2 refer to full selfheating.
145 `flcomp=0.0`	Flag for compatibility with v2.1 model (0=v2.1).
146 `flnqs=1`	Flag for allowing to turn on(1) or off(0) NQS effect in a given model parameter set, that included non-zero values for alit and alqf.
147 `cornoise_flag=no`	Flag for turning on and off of correlated noise implementation. Alias of flcono. Possible values are `no` and `yes`.
148 `compatible=spectre`	Compatible parameters. Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, and `mica`.

Output Parameters

1 `tempeff (C)`	Effective temperature for a single device.
2 `meff`	Effective multiplicity factor (m-factor).
3 `debug`	Debug variable.

Operating-Point Parameters

1 `temp (C)`	Temperature.
2 `ic (A)`	Collector current.
3 `ib (A)`	Base current.
4 `vbei (V)`	Internal base-emitter voltage.

5 `qjei (Coul)`	Internal base-emitter space charge.
6 `cjei (F)`	Internal base-emitter depletion capacitance.
7 `vbep (V)`	Peripheral base-emitter voltage.
8 `qjep (Coul)`	Peripheral base-emitter space charge.
9 `cjep (F)`	Peripheral base-emitter depletion capacitance.
10 `vbci (V)`	Internal base-collector voltage.
11 `qjci (Coul)`	Internal base-collector space charge.
12 `cjci (F)`	Internal base-collector depletion capacitance.
13 `vbcp (V)`	Vbcp.
14 `qjcp (Coul)`	Qjcp.
15 `cjcp (F)`	Cjcp.
16 `vbcx (V)`	Vbcx.
17 `qjcx (Coul)`	Qjcx.
18 `cjcx (F)`	Cjcx.
19 `vsc (V)`	Vsc.
20 `qjs (Coul)`	Substrate space charge.
21 `cjs (F)`	Substrate capacitance.
22 `qdsu (Coul)`	Substrate diffusion charge.
23 `cdsu (F)`	Substrate diffusion capacitance.
24 `vcei (V)`	Internal collector emitter voltage.
25 `tf (s)`	Transit Time.
26 `qf (Coul)`	Minority charge.

27 `qdei (Coul)` Internal base-emitter diffusion charge.

28 `cdei (F)` Internal base-emitter diffusion capacitance.

29 `qdci (Coul)` Internal base-collector diffusion charge.

30 `cdci (F)` Internal base-collector diffusion capacitance.

31 `qp (Coul)` Hole charge.

32 `it (A)` Transfer current.

33 `itf (A)` Transfer current.

34 `itr (A)` Transfer current.

35 `ibet (A)` Tunneling current.

36 `gm (S)` Common-emitter transconductance.

37 `si (S)` Common emitter output conductance.

38 `sfb` Sfb variable.

39 `srb` Srb variable.

40 `sfc` Sfc variable.

41 `src` Src variable.

42 `rbi (Ω)` Internal base resistance.

43 `rbx (Ω)` External base resistance.

44 `rcx (Ω)` External collector resistance.

45 `re (Ω)` Re variable.

46 `rsu (Ω)` External collector resistance.

47 `is (A)` Substrate current.

48 `ft (Hz)` Unity small-signal current-gain frequency.

49 `pwr (W)` Power dissipation.

50 `iavl (A)` Iavl.

51 `ibei (A)` Ibei.

52 `ibci (A)` Ibci.

53 `ibep (A)` Ibep.

54 `ijbcx (A)` Ijbcx.

55 `ijsc (A)` Ijsc.

56 `ieei (A)` Ieei.

57 `ie (A)` Ie.

58 `cbe (F)` Cbe.

59 `cbc (F)` Cbc.

60 `betar (A/A)` betar.

61 `beta (A/A)` beta.

62 `betadc (A/A)` betadc, the alias is beta.

63 `betaac` Small signal current gain.

64 `gmavl (S)` Transconductance for avalanche current.

65 `gms (S)` Transconductance of the parasitic substrate PNP.

66 `rpii (Ω)` Intrinsic input resistance.

67 `rpix (Ω)` Extrinsic input resistance.

68 `rmui (Ω)` Intrinsic feedback resistance.

69 `rmux (Ω)` Extrinsic feedback resistance.

70 `rmus (Ω)` Intrinsic substrate feedback resistance.

71 `ro (Ω)` Output resistance.

72 `ros (Ω)` Output resistance for the parasitic substrate PNP.

73 `cpii (F)` Total intrinsic BE capacitance.

74 `cpix (F)` Total extrinsic BE capacitance.

75 `cmui (F)` Total intrinsic BC capacitance.

76 `cmux (F)` Total extrinsic BC capacitance.

77 `ccs (F)` CS junction capacitance.

78 `crbi (F)` Shunt capacitance across RBI.

79 `vef (V)` Effective Forward Early voltage.

80 `ver (V)` Effective Inverse Early voltage.

81 `vbe (V)` External BE voltage.

82 `vbc (V)` External BC voltage.

83 `vce (V)` External CE voltage.

84 `gmi (S)` Internal transconductance, alias of gm.

85 `roi (Ω)` Output resistance.

86 `rb (Ω)` Total base resistance as calculated in the model.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

7

HiCUM Level-0 Model (bht0)

The HiCUM Level0 model was developed by Professor M. Schroter. It combines the simplicity of the Spice Gummel Poon Model (SGPM) in terms of equivalent circuit and some of its model equations with several important features of HiCUM Level2. As a result, BHT0 is a more physics-based and accurate model than the SGPM and also reduces parameter extraction efforts, especially for single transistor sizes, compared to HiCUM Level2 and SGPM. The latest version of this model is 1.31, and all of previous versions are supported with setting model parameter VERSION.

This chapter contains the following information about the BHT0 model:

Model Version Updates

Version 1.2:

- Upper limit of the model parameter FGEO is now infinity.
- Four or five terminals can be used with the latest version model, corresponding "tnode" is set as internal or external.
- Flag FLSH introduced for controlling self-heating calculation.
- All series resistors and RTH are limited to a minimum value.
- ddx() operator used with QJMOD and QJMODF wherever required.
- Substrate transistor transfer current has been added.
- Hyperbolic smoothing is used in rbi computation to a void divide-by-zero.

Version 1.3

- Modification done at TUD: Third order polynomial is solved for transfer current. It can be turned on by setting `IT_MOD=1`.
- Added voltage dependent Reverse Early voltage. Parameter `aver` describes voltage dependence.
- Parameters `ZETAVER`, `ZETAVGBE`, `VGBE` describe temperature dependence of `VER` and `IQF`.
- Added temperature dependence for `IQFH` and `TFH`. `ALIQFH` and `KIQFH` are used to model a second order temperature model. Parameter `TEF_TEMP=0` turns off the temperature dependence for `TEF0`.
- Corrected SPICE name for `AHQ` and `ZETAIQF`. The original name is `AHQX` and `ZETIQF`, which are also valid aliases.
- Implemented a `gmin` between nodes `CI` and `EI`.
- `qj` is now limited to positive values to improve convergence at negative bias.
- Resolved a convergence issue for cc a calculation of voltage dependence of t0

Version 1.3.1

- NQS effects have been added and can be activated by using the flag FLNQS=1.

- Some operating point outputs have been added to the Va code.

Equivalent Circuit

Figure 7-1 Large signal equivalent circuit of the simplified HICUM version, HICUM/L0

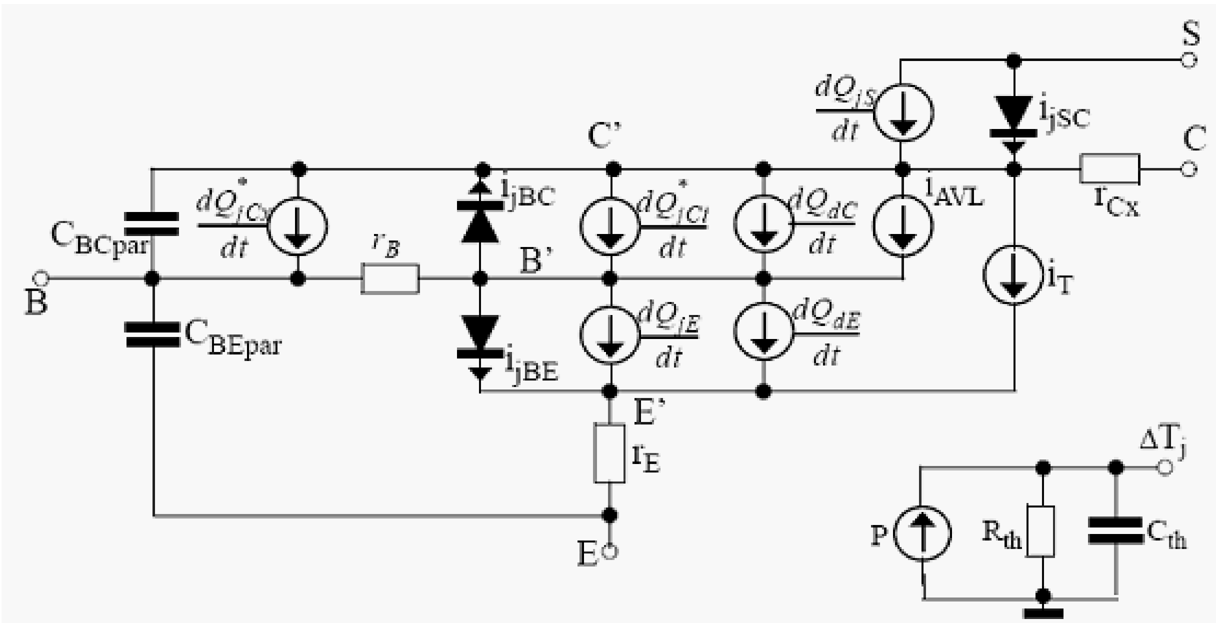


Figure 7-2 Small signal equivalent circuit of HICUM/L0

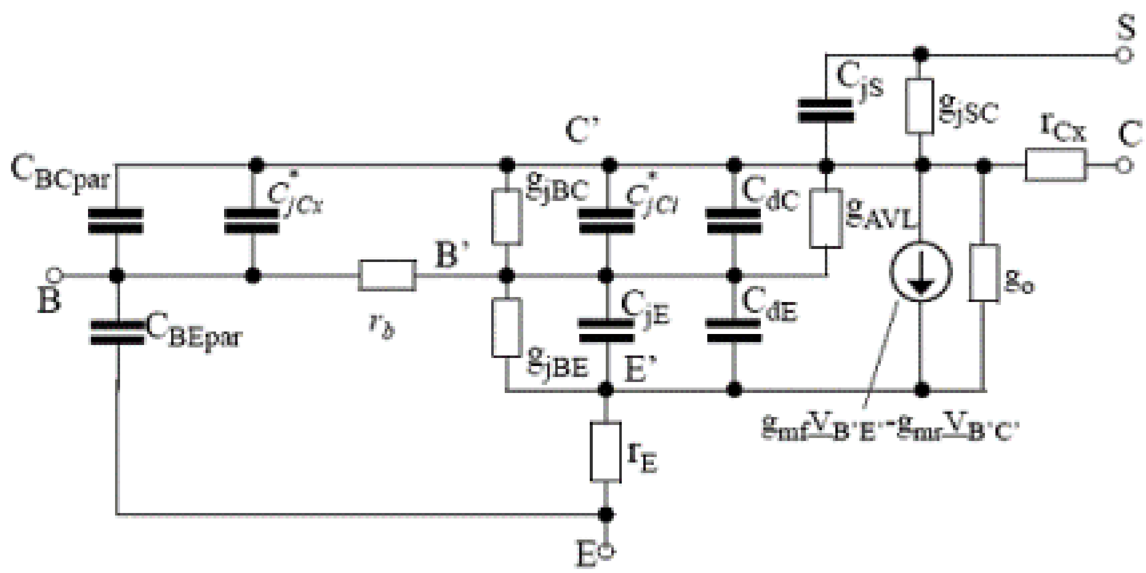
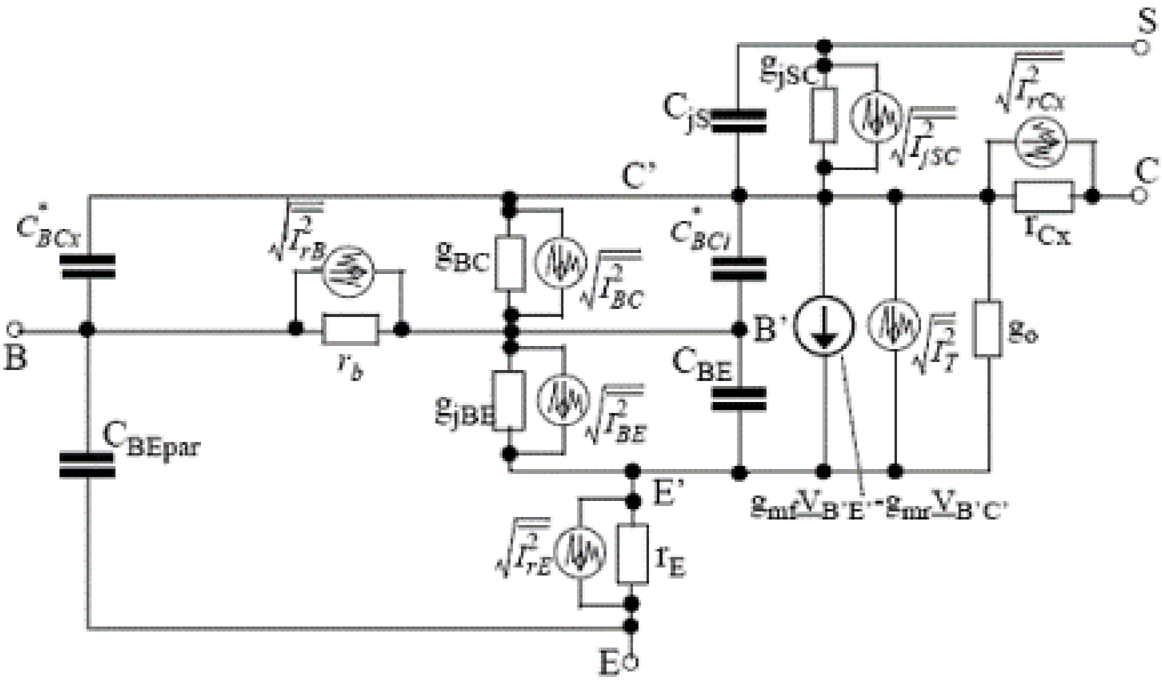


Figure 7-3 Small signal noise equivalent circuit of HICUM/L0 showing the noise sources with their RMS values used in a circuit simulator



Charge formulation of the internal transistor

All depletion charges and capacitances are described with the same equations as HICUM/L2. The formulation of forward minority charge Q_f is strongly based on the accurate description of the transit time τ_f. Like in HICUM/L2, the bias dependent of τ_f is modelled as

$$\tau = \tau_{f0}(v_{B'C'}) + \Delta\tau_{f0}(i_{Tf}, v_{C'E'})$$

with the low current component τ_{f0} , the high-current component $\Delta\tau_f$ and the i_{tf} as the forward transfer current. The formulation of τ_{f0} is same as in HICUM/L2.

$$\Delta\tau_f = \left(\tau_{hcs} w^2 \left(1 + \frac{2I_{CK}}{i_{Tf}\sqrt{\left(1 - \frac{I_{CK}}{i_{Tf}}\right)^2 + a_{hc}}} \right) + \tau_{fE0}\left(\frac{i_{Tf}}{I_{CK}}\right)^{g\tau E} \right) .$$

The minority charge Q_f used for dynamic transistor operation is then obtained analytically by integrating τ_f over i_{tf} .

$$Q_f = (\tau_{f0} i_{Tf} + \Delta Q_f) ,$$

Derivation of the simplified transfer current equation

$$i_T = \frac{c_{10}}{Q_{p,T}}\left[\exp\left(\frac{v_{B'E'}}{V_T}\right) - \exp\left(\frac{v_{B'C'}}{V_T}\right)\right] ,$$

The derivation starts with the transport related charge for low bias:

$$Q_{p,T} = Q_{p0} + h_{jei} Q_{jEi} + h_{jci} Q_{jCi} = Q_{p0} + h_{jei}(Q_{jEi,op} + \Delta Q_{jEi}) + h_{jci} Q_{jCi} .$$

$$Q_{p0}^{*} = Q_{p0} + h_{jei} Q_{jEi,op} .$$

$$\frac{Q_{p,T}}{Q_{p0}^{*}} = 1 + \frac{h_{jei}\Delta Q_{jEi}}{Q_{p0}^{*}} + \frac{h_{jci} Q_{jCi}}{Q_{p0}^{*}} + \frac{Q_{f,T}}{Q_{p0}^{*}} + \frac{Q_{r,T}}{Q_{p0}^{*}}$$

The resulting transfer current expression reads

$$i_{Tf} = \frac{I_S^*}{Q_{p,T}/Q_{p0}^*}\exp\left(\frac{v_{B'E'}}{V_T}\right) ,$$

with a modified saturation current

$$I_S^* = c_{10}/Q_{p0}^* .$$

The forward transfer current equation can be written in a more familiar form:

$$i_{Tf} = \frac{I_S^*}{1 + \frac{h_{jCi}Q_{jCi}}{Q_{p0}^*} + \frac{Q_{f,T}}{Q_{p0}^*} + \frac{Q_{r,T}}{Q_{p0}^*}} \exp\left(\frac{v_{B'E'}}{m_{Cf}V_T}\right) .$$

Where

$$m_{Cf} = \frac{i_{Tf}/V_T}{g_m} \cong \left(1 - \frac{h_{jEi}C_{jEi,op}V_T}{Q_{p0}^*}\right)^{-1} \cong 1 + \frac{h_{jEi}C_{jEi,op}V_T}{Q_{p0}^*} ,$$

the low-current transconductance at the selected bias point $V_{B'E',op}$ is given by

$$g_m = \frac{di_{Tf}}{dv_{B'E'}} \cong i_{Tf}\left(\frac{1}{V_T} - \frac{h_{jEi}C_{jEi,op}}{Q_{p0}^*}\right) = \frac{i_{Tf}}{V_T}\left(1 - \frac{h_{jEi}C_{jEi,op}V_T}{Q_{p0}^*}\right) .$$

The artificial Early Voltage is defined as:

$$V_{Ef} = \frac{Q_{p0}^{*}}{h_{jci} C_{jCi0}} \quad .$$

The critical (or knee) current of the D.C. forward transfer curve is defined as:

$$I_{Qf} = Q^{*}_{p0} / \tau_{f0}(V_{B'C'} = 0)$$

$$I_{Qr} = Q^{*}_{p0} / \tau_{f}$$

Quadratic equation for normalized charge:

$$q_{p,T} = \underbrace{1 + \frac{q_{jCi}}{V_{Ef}}}_{q_j} + \underbrace{\left(\frac{i_{Tfi}}{I_{Qf}} + \frac{i_{Tri}}{I_{Qr}}\right)}_{q_m} \cdot \frac{1}{q_{p,T}} \quad .$$

The final formulation for the HICUM/L0 transfer current components:

$$\boxed{i_{Tf} = \frac{i_{Tfl}}{1 + \frac{\Delta q_{fh}}{q_{p,T}}}} \quad \text{and} \quad \boxed{i_{Tr} = \frac{i_{Trl}}{1 + \frac{\Delta q_{fh}}{q_{p,T}}}}$$

The total transfer current in HICUM/L0 reads:

$$i_T = i_{Tf} - i_{Tr} \, .$$

Static base current components

$$i_{jBE} = I_{BES}\left[\exp\left(\frac{v_{B'E'}}{m_{BE}V_T}\right)-1\right] + I_{RES}\left[\exp\left(\frac{v_{B'E'}}{m_{RE}V_T}\right)-1\right],$$

$$i_{jBC} = I_{jBCS}\left[\exp\left(\frac{v_{B'C'}}{m_{BC}V_T}\right)-1\right]$$

$$i_{AVL} = k_{AVL}\frac{i_{Tf}}{C_c^{1/z_{Ci}}}\exp\left(-e_{AVL}\,C_c^{\left(\frac{1}{z_{Ci}}-1\right)}\right)$$

$$i_{jSC} = I_{SCS}\left[\exp\left(\frac{v_{SC}}{m_{SC}V_T}\right)-1\right]$$

Depletion charges and capacitances

$$C_{jE} = \frac{C_{jE0}}{(1-v_j/V_{DE})^{z_E}}\frac{dv_j}{dv_{B'E'}} + a_{jE}C_{jE0}\left(1-\frac{dv_j}{dv_{B'E'}}\right)$$

$$Q_{jE} = \frac{C_{jE0}V_{DE}}{1-z_E}\left[1-\left(1-\frac{v_j}{V_{DE}}\right)^{(1-z_E)}\right] + a_{jE}C_{jE0}(v_{B'E'}-v_j)$$

Minority charges and capacitances

The transit time consists of two components:

$$\tau_f(v_{C'E'}, i_{Tf}) = \tau_f(v_{B'C'}) + \Delta\tau_f(v_{C'E'}, i_{Tf})$$

Low current densities

The transit time reads:

$$\tau_{f0}(v_{B'C'}) = \tau_0 + \Delta\tau_{0h}(c-1) + \tau_{Bfvl}\left(\frac{1}{c}-1\right)$$

The respective forward minority charge is given by:

$$Q_{f0} = \tau_{f0}\, i_{Tf}$$

Medium and high current densities

The total increase in the (forward) transit time is given by:

$$\Delta\tau_f(v_{C'E'}, i_{Tf}) = \Delta\tau_{Ef} + \Delta\tau_{fh}$$

$$\Delta\tau_{fh} = \tau_{hcs}\cdot w^2\left[1 + \frac{2I_{CK}}{i_{Tf}\sqrt{i^2 + a_{hc}}}\right]$$

$$w = \frac{w_i}{w_C} = \frac{i + \sqrt{i^2 + a_{hc}}}{1 + \sqrt{1 + a_{hc}}}$$

$$i = 1 - \frac{I_{CK}}{I_{Tf}}$$

The critical current I_{CK} is described by the same voltage dependence as for HICUM/L2.:

$$I_{CK} = \frac{v_{ceff}}{r^*_{Ci0}} \frac{1}{\sqrt{1+\left(\frac{v_{ceff}}{V_{lim}}\right)^2}} \left[1 + \frac{x + \sqrt{x^2 + 10^{-3}}}{2}\right]$$

$$v_{ceff} = V_T\left[1 + \frac{1}{2}\left\{u_{vc} + \sqrt{u_{vc}^2 + 1.921812}\right\}\right]$$

$$\Delta Q_{fh} = \tau_{hcs} i_{Tf} w^2$$

Series Resistance

Internal base resistance

$$r_{Bi} = r_i \; \psi(\eta)$$

$$\psi(\eta) = \frac{\ln(1+\eta)}{\eta}$$

$$\eta = f_{geo} \frac{r_i I_{BE}}{V_T}$$

$$r_i = \frac{r_{Bi0}}{f_{Qz}}$$

$$f_{Qz} = \frac{1}{2}\left\{Q_z + \sqrt{Q_z^{\;2} + 0.01}\right\}$$

$$Q_z = \left(1 + \frac{q_{jE}}{V_{r0E}} + \frac{q^*_{jCi}}{V_{r0C}} + \frac{I_{Tf}}{I_{Qf}} + \frac{I_{Tr}}{I_{Qr}}\right)$$

External series resistances

$$r_B = r_{Bi} + r_{Bx}$$

Temperature Dependence

$$V_g(T) = V_g(T_0) + k_1 \frac{T}{T_0} \ln\left(\frac{T}{T_0}\right) + k_2\left(\frac{T}{T_0} - 1\right)$$

with the definitions

$$k_1 = K_1 T_0 \quad , \quad k_2 = K_2 T_0 + k_1 \ln(T_0)$$

and the bandgap voltage at the measurement reference temperature

$$V_g(T_0) = k_2 + V_g(0)$$

$$\overset{*}{I_S}(T) = \overset{*}{I_S}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{CT}} \exp\left[\frac{V_{Gb}}{V_T(T)}\left(\frac{T}{T_0} - 1\right)\right]$$

$$I_{BES}(T) = I_{BES}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{BET}} \exp\left[\frac{V_{Gb}}{V_T(T)}\left(\frac{T}{T_0} - 1\right)\right]$$

$$I_{RES}(T) = I_{RES}(T_0)\left(\frac{T}{T_0}\right)^{m_g/2} \exp\left[\frac{V_{Gb}}{V_T(T)}\left(\frac{T}{T_0} - 1\right)\right]$$

$$I_{BCS}(T) = I_{BCS}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{BCT}} \exp\left[\frac{V_{Gbx}}{V_T(T)}\left(\frac{T}{T_0} - 1\right)\right]$$

with $\zeta_{BET} = m_g + 1 - \zeta_{CT}$ and

$$I_{SCS}(T) = I_{SCS}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{SCT}} \exp\left[\frac{V_{Gsc}}{V_T(T)}\left(\frac{T}{T_0} - 1\right)\right]$$

$$I_{TSS}(T) = I_{TSS}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{SCT}} \exp\left[\frac{V_{Gc}}{V_T(T)}\left(\frac{T}{T_0} - 1\right)\right]$$

with $\zeta_{SCT} = m_g - 1.5$

$$C_{j0}(T) = C_{j0}(T_0)\left(\frac{V_D(T_0)}{V_D(T)}\right)^z$$

$$V_{Dj}(T_0) = 2V_{T0}\ln\left[\exp\left(\frac{V_D(T_0)}{2V_{T0}}\right) - \exp\left(-\frac{V_D(T_0)}{2V_{T0}}\right)\right]$$

$$V_{Dj}(T) = V_{Dj}(T_0)\left(\frac{T}{T_0}\right) + V_g\left(1 - \frac{T}{T_0}\right) - m_g V_{T0}\ln\left(\frac{T}{T_0}\right)$$

$$V_D(T) = V_{Dj}(T) + 2V_T \ln\left(\frac{1 + \sqrt{1 + 4\exp\left(-\frac{V_{Dj}(T)}{V_T}\right)}}{2}\right)$$

$$\tau_0(T) = \tau_0(T_0)[1 + alt0(T - T_0) + kt0(T - T_0)^2]$$

$$r_{Ci0}(T) = r_{Ci0}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{CI}}$$

$$V_{CEs}(T) = V_{CEs}(T_0)[1 + (T - T_0)\alpha_{CES}]$$

$$r_{Cx}(T) = r_{Cx}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{RCX}}$$

$$r_{Bx}(T) = r_{Bx}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{RBX}}$$

$$r_{Bi0}(T) = r_{Bi0}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{RBI}}$$

$$r_E(T) = r_E(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{RE}}$$

Noise Model

The equivalent noise current source is used for thermal noise in ohmic resistance:

$$\overline{I_r^2} = \frac{4kT\Delta f}{r}$$

For the transfer current, shot noise is assumes as:

$$\overline{I_T^2} = 2qI_T\,\Delta f$$

The noise resulting from the current injected across the BE junction into the emitter

$$\overline{I_{BE}^2} = 2qI_{jBE}\Delta f + k_F\,I_{jBE}^{a_F}\,\frac{\Delta f}{f}$$

The currents across the other junctions are assumed to have a shot noise component only

$$\overline{I_{jdiode}^2} = 2qI_{jdiode}\,\Delta f$$

Noise from avalanche generation within the internal BC depletion region is modelled as shot noise

$$\overline{I_{AVL}^2} = 2qI_{AVL}\,\Delta f$$

giving for the total noise contribution within the BC junction

$$\overline{I_{BC}^2} = \overline{I_{jBC}^2} + \overline{I_{AVL}^2}$$

DC Characteristics

$$i_T = c_{10} \cdot \frac{\exp(V_{B'E'}/V_T) - \exp(V_{B'C'}/V_T)}{Q_{p0} + h_{jei}Q_{jei} + h_{jci}Q_{jCi} + Q_{fT} + Q_{rT}}$$

$$i_{Tf} = \frac{I^*_S}{1 + \frac{h_{jci}Q_{jCi}}{Q_{p0}} + \frac{Q_{fT}}{Q_{p0}} + \frac{Q_{rT}}{Q_{p0}}} \cdot \exp\left(\frac{v_{B'E'}}{m_{Cf}V_T}\right)$$

$$I^*_S = (c_{10}/Q^*_{p0})\exp((h_{jei}C_{jei,\,op}v_{B'E',\,op})/Q^*_{p0})$$

$$V_{Ef} = \frac{Q^*_{p0}}{h_{jci}C_{jCi0}}$$

$$I_{Qf} = Q^*_{p0}/\tau_{f0}(v_{B'C'} = 0)$$

$$I_{Qr} = Q^*_{p0}/\tau_f$$

$$q_{pT} = \underbrace{1 + q_{jCi}/V_{Ef}}_{q_j} + \underbrace{i_{Tfl}/I_{Qf} + i_{Trl}/I_{Qr}}_{q_m/q_{pT}}$$

$$i_{Trl} = \frac{I^*_s}{q_{pT}}\exp\left(\frac{v_{B'C'}}{m_{Cr}V_T}\right)$$

$$\frac{Q_{fT} - \tau_{f0}i_{Tfl}}{Q^*_{p0}} \cong \Delta q_{fh} = \left(w^2 + t_{fh}\frac{i_{Tfl}}{I_{CK}}\right)\frac{i_{Tfl}}{I_{Qfh}}$$

$$i_T = \frac{i_{Tfl} - i_{Trl}}{1 + \Delta q_{fh}/q_{pT}}$$

Charge Storage Elements

$$\tau_f = \tau_{f0}(V_{B'C'}) + \Delta\tau_f(i_{Tf}, V_{C'E'})$$

The current dependence of $\Delta\tau_f$ is simplified by neglecting the bias dependent collector current spreading formulation. However, the bias independent collector current spreading factor *fcs* remains included in the critical current ICK, resulting in a more physical geometry dependence of the low-field internal (epi-)collector resistance.

$$\Delta\tau_f = \tau_{hcs}w^2\left(1 + \frac{2l_{CK}}{i_{Tf}\sqrt{(1 - l_{CK}/i_{Tf})^2 + a_{hc}}}\right) + \tau_{fE0}\left(\frac{i_{Tf}}{l_{CK}}\right)^{g_{\tau fE}}$$

$$Qf = ((Qf0 + dQef) + dQfh)$$

$$Q_r = \tau_r i_{Tr}$$

Series Resistance

The internal base resistance can be strongly bias dependent and is modeled as

$$r_i = \frac{r_{Bi0}}{1 + \frac{q_{jE}}{V_{r0E}} + \frac{q_{jCi}}{V_{r0C}} + \frac{i_{Tf}}{I_{Qf}} + \frac{i_{Tf}}{I_{Qr}}}$$

where *rBi0* is the geometry dependent zero-bias value, and the denominator represents the conductivity modulation. The above equation has been derived from HICUM level-2 by introducing certain simplifications. Note, that *VroC* is close to the Early voltage V_{Ef} for BJTs but generally differs from V_{Ef} for HBTs.

Temperature Effects

$$qtt0 = Tdev/Tnom$$

$$Is(t) = IS*\exp(ZETACT*\ln(qtt0) + VGB/VT*(qtt0-1))$$

$$Ibes(t) = IBES*\exp(ZETABET*\ln(qtt0) + VGE/VT*(qtt0-1))$$

$$Ires(t) = IRES*\exp(ZETABET*\ln(qtt0) + vgbe/VT*(qtt0-1))$$

$$Ibcs(t) = IBCS*\exp(ZETABCI*\ln(qtt0) + VGC/VT*(qtt0-1))$$

$$Iscs(t) = ISCS*\exp(ZETASCT*\ln(qtt0) + VGS/VT*(qtt0-1))$$

$$vdj0 = 2*VT0*\ln(\exp(0.5*vd/VT0) - \exp(-0.5*vd/VT0))$$

$$vdjt = vdj0*qtt0 + vg*(1-qtt0) - mg*VT*\ln(qtt0)$$

$$vd\_t = vdjt + 2*VT*\ln(0.5*(1 + sqrt(1 + 4*\exp(-vdjt/VT))))$$

where *vg* can be replaced with *vgbe*, *vgbc*, or *vgsc*

$$Cje0(t) = CJE0*\exp(ZE*\ln(VDE/vd\_t))$$

$$Cjci0(t) = CJCI0*\exp(ZCI*\ln(VDCI/vd\_t))$$

$$Cjcx0(t) = CJCX0*\exp(ZCX*\ln(VDCX/vd\_t))$$

$$Cjs0(t) = CJS0*\exp(ZS*\ln(VDS/vd\_t))$$

$$Rci0(t) = RCI0*\exp(ZETACI*\ln(qtt0))$$

$$Vlim(t) = VLIM*\exp((ZETACI - avs)*\ln(qtt0))$$

$$Vces(t) = VCES*(1 + ALCES*dt)$$

$$T0(t) = T0*(1 + ALT0*dt + KT0*dT*dT)$$

$$Thcs(t) = THCS*\exp((ZETACI - 1)*\ln\_qtto)$$

$$zetatef = ZETABET - ZETACT - 0.5$$

$$dvg = VGB - VGE$$

$$Tef0(t) = TEF0*\exp(ZETATEF*\ln(qtt0) - dvg/VT*(qtt0 - 1))$$

$$Rbx(t) = RBX*\exp(ZETARBX*\ln(qtt0))$$

$$Rcx(t) = RCX*\exp(ZETARCX*\ln(qtt0))$$

$$rbi0(t) = RBI0*\exp(ZETARBI*\ln(qtt0))$$

$$Re(t) = RE*\exp(ZETARE*\ln(qtt0))$$

$$Eavl(t) = EAVL*\exp(ALEAV*dT)$$ /

$$Kavl(t) = KAVL*\exp(ALKAV*dT)$$

Noise Model

The equivalent noise current source is used for thermal noise in ohmic resistance:

$$\overline{I_r^2} = \frac{4k_B T\Delta f}{r}, with \ \mathrm{r} \rightarrow r_E, r_{Cx}, r_B = r_{Bx} + R_{Bi}$$

Shot noise is assumed for transfer current

$$\overline{I_T^2} = 2qI_T\Delta f$$

Shot noise for current across BE junction is taken into account in the following equation

$$\overline{I_{jBE}^2} = 2qI_{jBE}\Delta f$$

A flicker noise source is implemented for the BE junction

$$\overline{I_{BE}^2} = k_f I_{jBE}^{a_f} \frac{\Delta f}{f}$$

Other Effects

Self-heating is included to overcome one of the most significant deficiencies of the SGPM for advanced processes including III-V HBTs.

Models and Equations in Version 1.30

Improved model formulations for the HICUM/L0 transfer current

The improvements can be categorized by:

- Bias Dependence
- Temperature Dependence

Bias Dependence

Low and Medium Current Range

The equation for reverse Early voltage is:

$$V_{Er} = \frac{V_{Er0}}{\left(\frac{\exp(u) - 1}{u}\right)}$$

where

$$u = a_{VEr}\left(1 - \left(1 - \frac{v_j}{V_{DE}}\right)^{Z_E}\right)$$

Here, V_{Er0} is the Early voltage for zero volt and aV_{Er} the parameter describing the change of the Early voltage. The junction voltage is limited to the range (0, VDEi) as follows:

$$\chi_{upp} = \frac{V_{DE} - V_{BEi}}{r_{VEr}V_t}$$

$$v_{j,upp} = V_{DE} - r_{VEr}V_T\frac{\chi_{upp} - \sqrt{\chi^2{}_{upp} + a_{fi}}}{2}$$

$r_{VEr}V_T$ is used rather than V_T since it allows a smooth transition to voltages larger than V_{DE}.

The limitation to values larger zero is realized by:

$$\chi_{low} = \frac{v_{j,upp} - V_T}{V_T} \qquad \text{and} \qquad v_j = V_T\left(1 + \frac{\chi_{low} + \sqrt{\chi^2{}_{low} + a_{fi}}}{2}\right)$$

The parameters V_{DE} and j used here are the same as for the electrostatic capacitance. For simplification, the parameter r_{VEr} is set to a fixed value of two, which is sufficient for all verifications. However, to allow full backward compatibility the parameter set for the DC charge VDEDC, zEDC and ajEDC is still kept separately from that of the AC charge, although the values may be the same. Therefore, the DC-charge formulation can still be used in the new version and the bias dependence of V_{Er} can be turned off by settings a_{VEr} to zero.

High Current

The transfer current equation for high current effects has been changed. In earlier versions, a second order polynomial (with bias dependent coefficients) was used for the whole range. However, a more physical description results in a third order polynomial function (resulting from $g_{\tau fE}$=1 in HICUM/L2). The third order polynomial reads:

$$q_{pT}^{3} - q_j q_{pT}^{2} - \left(\frac{I_{Tf0}}{I_{CKf}} + \frac{I_{Tr0}}{I_{CKr}} + \frac{I_{Tf0}}{I_{Qfh}} w^2\right) q_{pT} - \frac{I^2_{Tf0} t_{fh}}{I_{CK} I_{Qfh}} = 0$$

The above equation can be solved with respect to q_{pT}.

The following is the transfer current equation for modeling the high current effects:

$$i_{Tf} = \frac{I_s}{q_j + \frac{i_{Tf}}{I_{CKf}} + \frac{i_{Tr}}{I_{CKr}} + w^2 \frac{i_{Tf}}{I_{Qfh}} + \left(\frac{i_{Tf}}{I_{CK}}\right) \frac{i_{Tf}}{I_{QfE}}}$$

tfh can be simply calculated by:

$$t_{fh} = \frac{I_{Qfh}}{I_{QfE}}$$

Temperature Dependence

Medium Bias Range

The medium bias range is dominated by the temperature dependence of the saturation current and reverse Early voltage. The temperature dependence of the saturation current is kept untouched. The reverse Early voltage itself becomes temperature dependent. Two effects need to be taken into account.

First, the Early voltage at zero volt changes due to the different bandgap in the base and the BESCR. This bandgap difference is used as a parameter along with a non-idealitiy parameter. The equation itself reads:

$$V_{Er0}(T) = V_{Er0}(T_0) \exp\left[\frac{-\Delta V_{gBE}}{V_T}\left(\left(\frac{T}{T_o}\right)^{\zeta_{vgBE}} - 1\right)\right]$$

Additional, the parameter describing the Early voltage change also changes due to the temperature voltage VT and the temperature induced moving of the SCR-boundary. Both effects are modelled using one temperature coefficient.

$$a_{VEr}(T) = a_{VEr}(T_0)\left(\frac{T}{T_0}\right)^{\zeta_{VEr}}$$

High Current Effects

The temperature dependence of I_{Qf} is given by:

$$I_{Qf}(T) = I_{Qf}(T0)\left(\frac{T}{T0}\right)^{\zeta_{IQf}}\exp\left(\frac{-\Delta V_{gBE}}{V_T}\left(\frac{T}{T0}-1\right)\right)$$

Due to different bandgap voltages in the transistor, high current effects may become also temperature dependent. Since for IQfh, minorities in different regions of the transistor are taken into account, a simple second order polynomial fit is applied, as follows:

$$I_{Qfh}(T) = I_{Qfh}(T0)\left(1 + \alpha_{IQfh}\Delta T + k_{IQfh}\Delta T^2\right)$$

$$I_{Qfh} = \frac{Q_{p0}}{((1 - f_{\tau hC}) + f_{\tau hC}h_{fC})\tau_{hCs}}$$

The temperature dependence of t_{fh} is given by:

$$t_{fh}(T) = t_{fh}(T_0)\frac{I_{Qfh}(T)}{I_{Qfh}(T_0)}\exp\left(\frac{V_{gb} - V_{ge}}{V_T}\left(\frac{T}{T_0} - 1\right)\right)$$

Component Statements

The device is supported within altergroups.

Instance Definition

```
Name  c  b  e  s  [tnode] ModelName parameter=value ...
```

Instance Parameters

1 `dt=0.0 K`	Temperature change for particular transistor.
2 `m=1`	Instance parameter Mfactor.
3 `exp_cr=80`	Instance parameter exp_cr for limitexp.
4 `isnoisy=yes`	Should device generate noise. Possible values are `no` and `yes`.

Model Definition

```
model modelName bht0 parameter=value ...
```

Model Parameters

1 `is=1.0e-16 A`	(Modified) saturation current.
2 `it_mod=0`	Flag for using third order solution for transfer current.
3 `mcf=1.00`	Non-ideality coefficient of forward collector current.
4 `mcr=1.00`	Non-ideality coefficient of reverse collector current.
5 `vef=1.0e6 V`	forward Early voltage (normalization volt.).
6 `ver=1.0e6 V`	reverse Early voltage (normalization volt.).
7 `aver=0.0`	bias dependence for reverse Early voltage.
8 `iqf=1.0e6 A`	forward d.c. high-injection toll-off current.
9 `fiqf=0`	flag for turning on base related critical current.
10 `iqr=1.0e6 A`	inverse d.c. high-injection roll-off current.
11 `iqfh=1.0e6 A`	high-injection correction current.
12 `tfh=0.0`	high-injection correction factor.
13 `ahq=0`	Smoothing factor for the d.c. injection width.

14	`ibes=1e-18 A`	BE saturation current.
15	`mbe=1.0`	BE non-ideality factor.
16	`ires=0.0 A`	BE recombination saturation current.
17	`mre=2.0`	BE recombination non-ideality factor.
18	`ibcs=0.0 A`	BC saturation current.
19	`mbc=1.0`	BC non-ideality factor.
20	`cje0=1.0e-20 F`	Zero-bias BE depletion capacitance.
21	`vde=0.9 V`	BE built-in voltage.
22	`ze=0.5`	BE exponent factor.
23	`aje=2.5`	Ratio of maximum to zero-bias value.
24	`vdedc=0.9 V`	BE charge built-in voltage for d.c. transfer current.
25	`zedc=0.5`	charge BE exponent factor for d.c. transfer current.
26	`ajedc=2.5`	BE capacitance ratio Ratio maximum to zero-bias value for d.c. transfer current.
27	`t0=0.0 s`	low current transit time at Vbici=0.
28	`dt0h=0.0`	model parameter: no description.
29	`tbvl=0.0 s`	SCR width modulation contribution.
30	`tef0=0.0 s`	Storage time in neutral emitter.
31	`gte=1.0`	Exponent factor for emitter transit time.
32	`thcs=0.0 s`	Saturation time at high current densities.
33	`ahc=0.1`	Smoothing factor for current dependence.
34	`tr=0.0 s`	Storage time at inverse operation.

35 `rci0=150 Ω`	Low-field collector resistance under emitter.
36 `vlim=0.5 V`	Voltage dividing ohmic and satur.region.
37 `vpt=100 V`	Punch-through voltage.
38 `vces=0.1 V`	Saturation voltage.
39 `cjci0=1.0e-20 F`	Total zero-bias BC depletion capacitance.
40 `vdci=0.7 V`	BC built-in voltage.
41 `zci=0.333`	BC exponent factor.
42 `vptci=100 V`	Punch-through voltage of BC junction.
43 `cjcx0=1.0e-20 F`	Zero-bias external BC depletion capacitance.
44 `vdcx=0.7 V`	External BC built-in voltage.
45 `zcx=0.333`	External BC exponent factor.
46 `vptcx=100 V`	Punch-through voltage.
47 `fbc=1.0`	Split factor = Cjci0/Cjc0.
48 `rbi0=0.0 Ω`	Internal base resistance at zero-bias.
49 `vr0e=2.5 V`	forward Early voltage (normalization volt.).
50 `vr0c=1.0e6 V`	forward Early voltage (normalization volt.).
51 `fgeo=0.656`	Geometry factor.
52 `rbx=0.0 Ω`	External base series resistance.
53 `rcx=0.0 Ω`	Emitter series resistance.
54 `re=0.0 Ω`	External collector series resistance.
55 `itss=0.0 A`	Substrate transistor transfer saturation current.
56 `msf=1.0`	Substrate transistor transfer current non-ideality factor.

57 `iscs=0.0 A` SC saturation current.

58 `msc=1.0` SC non-ideality factor.

59 `cjs0=1.0e-20 F` Zero-bias SC depletion capacitance.

60 `vds=0.3 V` SC built-in voltage.

61 `zs=0.3` External SC exponent factor.

62 `vpts=100 V` SC punch-through voltage.

63 `cbcpar=0.0 F` Collector-base isolation (overlap) capacitance.

64 `cbepar=0.0 F` Emitter-base oxide capacitance.

65 `eavl=0.0` Exponent factor.

66 `kavl=0.0` Prefactor.

67 `kf=0.0 M^(1-AF)` flicker noise coefficient.

68 `af=2.0` flicker noise exponent factor.

69 `alqf=0.167` Factor for additional delay time of minority charge.

70 `alit=0.333` Factor for additional delay time of transfer current.

71 `flnqs=0` Flag for turning on and off of vertical NQS effect.

72 `vgb=1.2 V` Bandgap-voltage.

73 `vge=1.17 V` Effective emitter bandgap-voltage.

74 `vgc=1.17 V` Effective collector bandgap-voltage.

75 `vgs=1.17 V` Effective substrate bandgap-voltage.

76 `f1vg=(-1.02377e-4) V/K`
Coefficient K1 in T-dependent bandgap equation.

77 `f2vg=4.3215e-4 V/K`
Coefficient K2 in T-dependent bandgap equation.

78	`alt0=0.0 1/K`	First-order TC of tf0.
79	`kt0=0.0` $1/K^2$	Second-order TC of tf0.
80	`zetact=3.0`	Exponent coefficient in transfer current temperature dependence.
81	`zetabet=3.5`	Exponent coefficient in BE junction current temperature dependence.
82	`zetaci=0.0`	TC of epi-collector diffusivity.
83	`alvs=0.0 1/K`	Relative TC of satur.drift velocity.
84	`alces=0.0 1/K`	Relative TC of vces.
85	`zetarbi=0.0`	TC of internal base resistance.
86	`zetarbx=0.0`	TC of external base resistance.
87	`zetarcx=0.0`	TC of external collector resistance.
88	`zetare=0.0`	TC of emitter resistances.
89	`zetaiqf=0.0`	TC of iqf.
90	`alkav=0.0 1/K`	TC of avalanche prefactor.
91	`aleav=0.0 1/K`	TC of avalanche exponential factor.
92	`zetarth=0.0`	Exponent factor for temperature dependent thermal resistance.
93	`tef_temp=1`	Flag for turning temperature dependence of tef0 on and off.
94	`zetaver=(-1.0)`	TC of Reverse Early voltage.
95	`zetavgbe=1.0`	TC of AVER.
96	`dvgbe=0.0`	Bandgap difference between base and BE-junction.
97	`aliqfh=0 1/K`	First-order TC of iqfh.
98	`kiqfh=0` $1/K^2$	Second-order TC of iqfh.

99 `flsh=0` — Flag for self-heating calculation.

100 `rth=0.0 K/W` — Thermal resistance.

101 `cth=0.0 Ws/K` — Thermal capacitance.

102 `pnp=0` — model type flag for pnp.

103 `npn=1` — model type flag for npn.

104 `tnom=27 C` — Temperature for which parameters are valid.

105 `version=1.2` — The available versions are 1.0, 1.11, 1.12, 1.2, 1.3 and 1.31.

Output Parameters

1 `meff` — Effective multiplicity factor (m-factor).

Operating Point Parameters

1 `qjci (C)` — B-C internal junction charge.

2 `qjei (C)` — B-E internal junction charge.

3 `cjei (F)` — B-E internal junction capacitance.

4 `it (A)` — Transfer Current.

5 `ijbc (A)` — Base-collector diode current.

6 `iavl (A)` — Avalanche current.

7 `ijsc (A)` — Substrate-collector diode current.

8 `ieei (A)` — Current through external to internal emitter node.

9 `icci (A)` — Current through external to internal collector node.

10 `ibbi (A)` — Current through external to internal base node.

11 `ibici (A)` — Base-collector diode current minus the avalanche current.

12 `ijbe (A)`	Base-emitter diode current.
13 `vef (V)`	Effective forward Early-voltage.
14 `ver (V)`	Effective inverse Early-voltage.
15 `tempeff (C)`	Effective temperature for a single device.
16 `ib`	Base terminal current.
17 `ic`	Collector terminal current.
18 `is`	Substrate current.
19 `vbe`	External BE voltage.
20 `vbc`	External BC voltage.
21 `vce`	External CE voltage.
22 `vsc`	External SC voltage.
23 `betadc`	Common emitter forward current gain.
24 `gmi`	Internal transconductance.
25 `rpii`	Internal input resistance.
26 `rmui`	Internal feedback resistance.
27 `roi`	Internal Output resistance.
28 `cpii`	Total BE capacitance.
29 `cmui`	Total internal BC capacitance.
30 `cbcx`	Total external BC capacitance.
31 `ccs`	CS junction capacitance.
32 `rbi`	Internal base resistance.
33 `rb`	Total base resistance.

34 `rcx` External (saturated) collector series resistance.

35 `re` Emitter series resistance.

36 `betaac` Small signal current gain.

37 `tf` Total forward transit time.

38 `ft` Transit frequency.

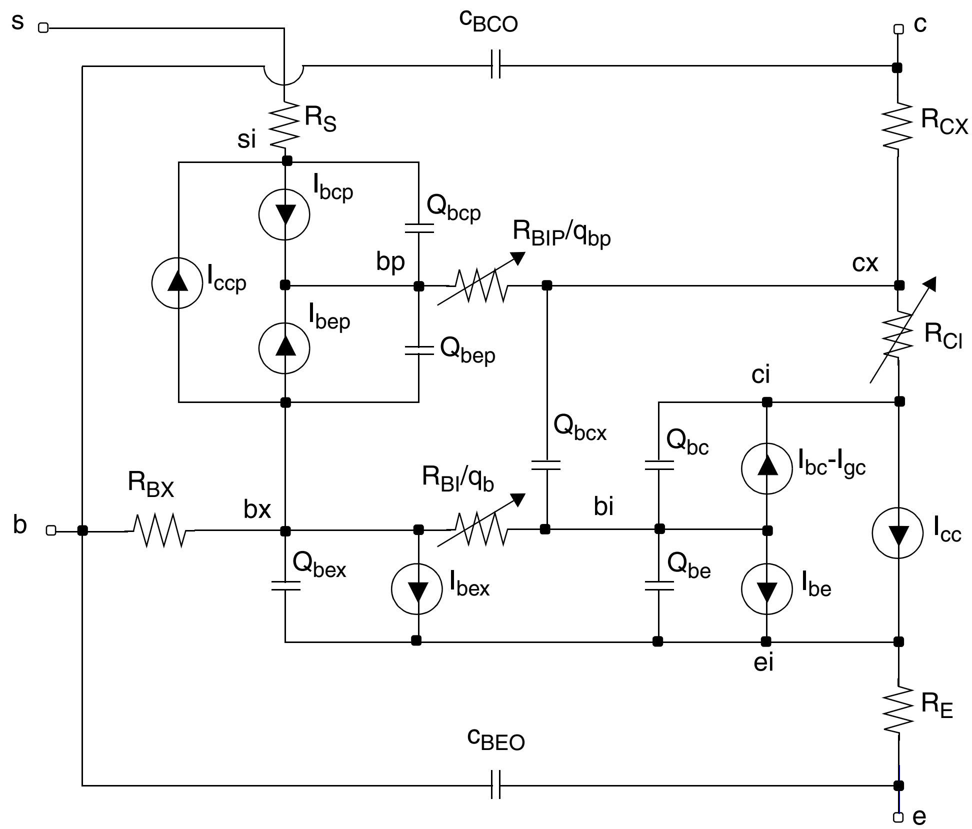
Parameter Index

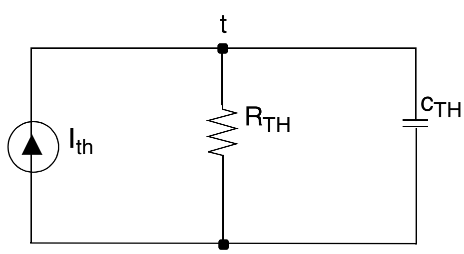
In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

8

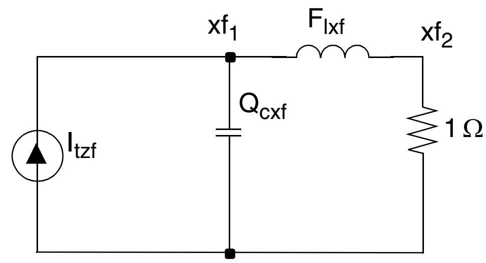
VBIC Model (vbic)

The VBIC model was developed by the Colin McAndrew team at Motorola as a replacement of the Gummel-Poon model. This chapter contains the following information for the VBIC model:





Thermal network



Excess phase network

VBIC 1.1

DC Current

$$I_{cc} = \frac{I_{tf} - I_{tr}}{Q_b}$$

$$I_{tf} = I_s \ (e^{V_{bei}/N_f V_{tm}} - 1)$$

$$I_{tr} = I_s \ (e^{V_{bci}/N_r V_{tm}} - 1)$$

$$Q_b = \frac{1}{2}\left(Q_1 + \sqrt{Q_1^2 + 4Q_2}\right)$$

$$Q_1 = \frac{1}{2}\sqrt{\left(0.9999 + \frac{Q'_{je}}{V_{er}} + \frac{Q'_{jc}}{V_{ef}}\right)^2 + 10^{-8}} + \frac{1}{2}\left(0.9999 + \frac{Q'_{je}}{V_{er}} + \frac{Q'_{jc}}{V_{ef}}\right) + 10^{-4}$$

$$Q'_{je} = \frac{Q_{je}}{C_{je}}$$

$$Q'_{jc} = \frac{Q_{jc}}{C_{jc}}$$

$$Q_2 = \frac{I_{tf}}{I_{kf}} + \frac{I_{tr}}{I_{kr}}$$

$$I_{be} = W_{be} \ \left[I_{bei}(e^{V_{bei}/N_{ei} V_{tm}} - 1) + I_{ben} \ (e^{V_{bei}/N_{en} V_{tm}} - 1)\right]$$

$$I_{bex} = (1 - W_{be}) \ \left[I_{bei} \ (e^{V_{bex}/N_{ei} V_{tm}} - 1) + I_{ben} \ (e^{V_{bex}/N_{en} V_{tm}} - 1)\right]$$

$$I_{bc} = I_{bci}\ (e^{V_{bci}/N_{ci}V_{tm}} - 1) + I_{bcn}\ (e^{V_{bci}/N_{cn}V_{tm}} - 1)$$

$$I_{gc} = (I_{cc} - I_{bc})\ A_{vc1}\ \ 1V_l\ \ e^{-A_{vc2}\ \ V_{lm}}$$

$$V_l = \frac{1}{2}\left[\sqrt{(P_c - V_{bc})^2 + 0.01} + (P_c - V_{bc})\right]$$

$$V_{lm} = V_l^{(M_c - 1)}$$

$$I_{bep} = I_{beip}\ (e^{V_{bep}/N_{ci}V_{tm}} - 1) + I_{benp}\ (e^{V_{bep}/(N_{cn}V_{tm})} - 1)$$

$$I_{bcp} = I_{bcip}\ (e^{V_{bcp}/(N_{cip}V_{tm})} - 1) + I_{bcnp}\ (e^{V_{bcp}/(N_{cnp}V_{tm})} - 1)$$

$$I_{ccp} = \frac{I_{tfp} - I_{trp}}{Q_{bp}}$$

$$I_{tfp} = W_{sp}\ I_{sp}\ (e^{V_{bep}/N_{fp}\ \ V_{tm}} - 1) + (1 - W_{sp})\ I_{sp}\ (e^{V_{bci}/N_{fp}\ \ V_{tm}} - 1)$$

$$I_{trp} = I_{sp}\ (e^{V_{bcp}/N_{fp}\ \ V_{tm}} - 1)$$

$$Q_{bp} = \frac{1}{2}(1 + \sqrt{1 + 4Q_{2p}})$$

$$Q_{2p} = \frac{I_{tfp}}{I_{kp}}$$

$$R_{bi} = \frac{R_{bi}}{Q_b}$$

$$R_{bp} = \frac{R_{bp}}{Qbp}$$

$$I_{rci} = \frac{V_{rci} + Vtm[Kbci - Kbcx - ln(Rxpi)]}{R_{ci}\sqrt{1 + (Derf)^2}}$$

$$D_{erf} = \frac{V_{rci} + V_{tm}\ [K_{bci} - K_{bcx} - \ln(R_{kp1})]}{V_o + \frac{\sqrt{V_{rci}^2 + 0.01}}{2H_{rcf}}}$$

If the backward compatibility flag imeltrci=no (the default value), K_{bci} and K_{bcx} are calculated as follows:

$$K_{bci} = \sqrt{1 + G_{amm}\ e^{V_{bc}/V_{tm}}}$$

$$K_{bcx} = \sqrt{1 + G_{amm}\ e^{V_{bcx}/V_{tm}}}$$

If imeltrci=yes, K_{bci} and K_{bcx} are limited.

$$R_{kp1} = \frac{K_{bci} + 1}{K_{bcx} + 1}$$

$$V_{bcx} = V_{bci} - V_{rci}$$

Charge Equations

$$Q_{be} = W_{be}\ Q_{je} + T_{ff}\ I_{tf}$$

$$T_{ff} = \begin{cases} T_f\ (1 + Q_{tf}\ Q_1)\left[1 + X_{tf}\ e^{V_{bci}/(1.44\ V_{tf})}\ \frac{\left(\frac{I_{tf}(current)}{I_{tf}(modelparameter)}\right)^2}{\left(1 + \frac{I_{tf}}{I_{tf}}\right)^2}\right] & \text{If } I_{tf} \text{ (model parameter)} > 0 \\ T_f\ (1 + Q_{tf}\ Q_1) & \text{otherwise} \end{cases}$$

Note: In the above equation, I_{tf} is the current calculated from the equation given under the section DC Current on page 391.

$$Q_{bc} = T_r \ I_{tr} + Q_{jc} + Q_{co} \ K_{bci}$$

$$Q_{bex} = (1 - W_{be}) \ Q_{jex}$$

$$Q_{bcx} = Q_{co} \ K_{bcx}$$

$$Q_{bep} = T_r \ I_{tfp} + Q_{jep}$$

$$Q_{bcp} = Q_{jcp}$$

$$Q_{je} = Q_j(C_{je}, P_e, M_e, A_{je}, V_{bei})$$

$$Q_{jc} = Q_j(C_{jc}, P_c, M_c, A_{jc}, V_{bci})$$

$$Q_{jex} = Q_j(C_{je}, P_e, M_e, A_{je}, V_{bex})$$

$$Q_{jep} = Q_j(C_{jep}, P_c, M_c, A_{jc}, V_{bep})$$

$$Q_{jcp} = Q_j(C_{jcp}, P_s, M_s, A_{js}, V_{bcp})$$

If $A_j > 0$, $Q_j(C_j, P, M, A_j, V)$ is calculated as

$$Q_j = \frac{C_j}{2}\left(1 - \frac{D_v}{M_v}\right)\left(1 - \frac{V_l}{P}\right)^{-M} + \frac{C_j}{(1 - F_c)^M}\left[1 - \frac{1}{2}\left(1 - \frac{D_v}{M_v}\right)\right]$$

$$D_v = V - P \ F_c$$

$$M_v = \sqrt{D_v^2 + A_j}$$

$$V_l = \frac{1}{2}(D_v - M_v) + P \ F_c$$

$$Q_j = -\frac{C_j \; P \; \left(1-\frac{V_l}{P}\right)\left(1-\frac{V_l}{P}\right)^{-M}}{1-M} - Q_0 + \frac{C_j \; (V - V_l + V_{l0})}{(1-F_c)^M}$$

$$Q_0 = -\frac{C_j \; P \; \left(1-\frac{V_{l0}}{P}\right)^{1-M}}{1-M}$$

$$V_{l0} = \frac{1}{2}(D_{v0} - M_{v0}) + P \; F_c$$

$$D_{v0} = -P \; F_c$$

$$M_{v0} = \sqrt{D_{v0}^2 + A_j}$$

If $A_j \le 0$, $Q_j(C_j, P, M, A_j, V)$ is calculated as

$$Q_j = \begin{cases} C_j P\left[\dfrac{1-\left(1-\frac{V}{P}\right)^{1-M}}{1-M}\right] & \text{If } V \le F_c P \\ \dfrac{[1-F_c \; (1+M)] \; (V - F_c \; P) + \dfrac{M \; (V^2 - F_c^2 \; P^2)}{2P}}{(1-F_c)^{M+1}} + \dfrac{P}{1-M}\left[1 - \dfrac{1}{(1-F_c)^{M-1}}\right] & \text{otherwise} \end{cases}$$

otherwise

$$C_j = \begin{cases} \dfrac{C_j}{\left(1-\frac{V}{P}\right)^M} & \text{If } V \le F_c P \\ \dfrac{1}{(1-F_c)^M\left[1 + \dfrac{M \; (V - F_c \; P)}{P - F_c \; P}\right]} & \text{otherwise} \end{cases}$$

Excess Phase

In an actual device, the measured phase shift is often larger than the shift predicted by the lumped model. The excess-phase parameter *td* accounts for this extra phase shift at high frequencies. An all-pass, second-order Bessel function filter creates this extra phase shift. The frequency response of this filter is

$$\phi(s) = \frac{3\omega_0^2}{s^2 + 3\omega_0 s + 3\omega_0^2}$$

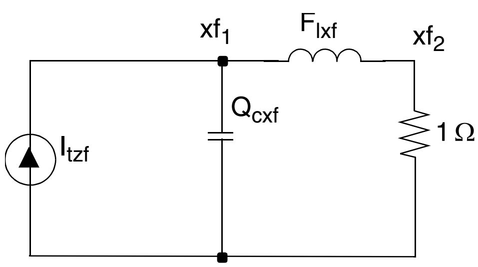
where

$$\omega_0 = \frac{1}{td}$$

and the phase shift due to this filter is

$$\theta = tan^{-1}\frac{3\omega\omega_0}{3\omega_0^2 - \omega^2}$$

The Bessel filter is implemented with the excess phase network shown below.



Excess phase network

where $L_{xf} = \frac{td}{3}$ and $C_{xf} = td$.

Small Signal Parameters

$$g_m = \frac{dI_{cc}}{dV_{be}} + \frac{dI_{cc}}{dV_{bc}}$$

$$g_{pi} = \frac{dI_{be}}{dV_{be}}$$

$$g_o = -\frac{dI_{cc}}{dV_{bc}}$$

$$g_{mu} = \frac{dI_{bc}}{dV_{bc}}$$

$$betaAC = \frac{g_m}{g_{pi}}$$

$$c_{pi} = \frac{dQ_{be}}{dV_{be}}$$

$$c_{mu} = \frac{dQ_{bc}}{dV_{bc}}$$

$$C_{bcx} = \frac{dQ_{bcx}}{dV_{bcx}}$$

If R_{ci} is given,

$$F_t = \frac{g_m}{2\pi(c_{pi} + g_m \cdot tf + cb_{cx} + cmu(g_m R_{ci} + 1))}$$

where

$$R_{ci} = \frac{dI_{rci}}{dV_{rci}}$$

and `tf` is the model parameter.

If R_{ci} is not given,

$$F_t = \frac{g_m}{2\pi(c_{pi} + c_{bcx} + c_{mu})}$$

Temperature Equations

$$\Delta T = T - Tnom$$

$$R_t = \frac{T}{Tnom}$$

$$R_{cx} = R_{cxnom} \ R_t^{X_{rc}}$$

$$R_{ci} = R_{cinom} \ R_t^{X_{rc}}$$

$$R_{bp} = R_{bpnom} \ R_t^{X_{rc}}$$

$$R_{bx} = R_{bxnom} \ R_t^{X_{rb}}$$

$$R_{bi} = R_{binom} R_t^{X_{rb}}$$

$$R_e = R_{enom} \ R_t^{X_{re}}$$

$$R_s = R_{snom} \ R_t^{X_{rs}}$$

$$I_s = I_{snom} \ R_t^{X_{is}/NF_{nom}} \ e^{-E_a(1 - R_t)/NF_{nom} \ V_{tm}}$$

$$I_{sp} = I_{spnom} \ R_t^{X_{is}/N_{fp}} \ e^{-E_a(1 - R_t)/N_{fp} \ V_{tm}}$$

$$I_{bei} = I_{beinom} \ R_t^{X_{ii}/N_{ei}} \ e^{-E_{aie}(1 - R_t)/N_{ei} \ V_{tm}}$$

$$I_{ben} = I_{bennom} \; R_t^{X_{in}/N_{en}} \; e^{-E_{ane}(1-R_t)/N_{en} \; V_{tm}}$$

$$I_{bci} = I_{bcinom} \; R_t^{X_{ii}/N_{ci}} \; e^{-E_{aic}(1-R_t)/N_{ci} \; V_{tm}}$$

$$I_{bcn} = I_{bcnnom} \; R_t^{X_{in}/N_{cn}} \; e^{-E_{anc}(1-R_t)/N_{cn} \; V_{tm}}$$

$$I_{beip} = I_{beipnom} \; R_t^{X_{ii}/N_{ci}V_{tm}} \; e^{-E_{aic}(1-R_t)/N_{ci} \; V_{tm}}$$

$$I_{benp} = I_{benpnom} \; R_t^{X_{in}/N_{cn}} \; e^{-E_{anc}(1-R_t)/N_{cn} \; V_{tm}}$$

$$I_{bcip} = I_{bcipnom} \; R_t^{X_{ii}/N_{cip}} \; e^{-E_{ais}(1-R_t)/N_{cip} \; V_{tm}}$$

$$I_{bcnp} = I_{bcnpnom} \; R_t^{X_{in}/N_{cnp}} \; e^{-E_{ans}(1-R_t)/N_{cnp} \; V_{tm}}$$

$$N_f = N_{fnom}(1 + T_{nf} \; \Delta T)$$

$$N_r = N_{rnom}(1 + T_{nf} \; \Delta T)$$

$$A_{vc2} = A_{vc2nom}(1 + T_{avc} \; \Delta T)$$

$$G_{amm} = G_{ammnom} \; R_t^{X_{is}} \; e^{-E_a\left(1 - \frac{T}{Tnom}\right)/V_{tm}}$$

$$V_o = V_{onom} \; R_t^{X_{vo}}$$

$$C_{je} = C_{jenom}\left(\frac{P_{enom}}{P_e}\right)^{M_e}$$

$$C_{jc} = C_{jcnom}\left(\frac{P_{cnom}}{P_c}\right)^{M_c}$$

$$C_{jep} = C_{jepnom}\left(\frac{P_{cnom}}{P_c}\right)^{M_c}$$

$$C_{jcp} = C_{jcpnom}\left(\frac{P_{snom}}{P_s}\right)^{M_s}$$

$$P_e = A_e + 2V_{tm}\ln\left[\frac{1}{2}\left(1 + \sqrt{1 + 4e^{-A_e/V_{tm}}}\right)\right]$$

$$A_e = 2V_{tm}\ln(e^{PE_{nom}/2V_{tm}} - e^{-PE_{nom}/2V_{tm}})\ R_t - 3V_{tm}\ln(R_t) - E_{aie}(R_t - 1)$$

$$P_c = A_c + 2V_{tm}\ln\left[\frac{1}{2}\left(1 + \sqrt{1 + 4e^{-A_c/V_{tm}}}\right)\right]$$

$$A_c = 2V_{tm}\ln(e^{PC_{nom}/2V_{tm}} - e^{-PC_{nom}/2V_{tm}})\ R_t - 3V_{tm}\ln(R_t) - E_{aic}(R_t - 1)$$

$$P_s = A_s + 2V_{tm}\ln\left[\frac{1}{2}\left(1 + \sqrt{1 + 4e^{-A_s/V_{tm}}}\right)\right]$$

$$A_s = 2V_{tm}\ln(e^{PS_{nom}/2V_{tm}} - e^{-PS_{nom}/2V_{tm}})\ R_t - 3V_{tm}\ln(R_t) - E_{ais}(R_t - 1)$$

Noise Equations

$$\overline{i_{Icc}^2} = 2\ q\ I_{cc}\Delta f$$

I_{be} shot and flicker noises:

$$\overline{i_{Ibe}^{2}} = 2\ q\ I_{be} + \frac{K_{fn}\ I_{be}^{A_{fn}}}{f^{B_{fn}}}\Delta f$$

R_{cx} thermal noise:

$$\overline{i_{Rcx}^{2}} = \frac{4K_t}{R_{cx}}$$

R_{ci} thermal noise:

$$\overline{i_{Rci}^{2}} = \frac{4K_t}{dI_{rci}}/(dV_{rci})$$

R_{bx} thermal noise:

$$\overline{i_{Rbx}^{2}} = \frac{4K_t}{R_{bx}}$$

R_{bi} thermal noise:

$$\overline{i_{Rbi}^{2}} = \frac{4K_t}{dI_{rbi}}/(dV_{rbi})$$

R_e thermal noise:

$$\overline{i_{RE}^{2}} = \frac{4K_t}{R_e}$$

R_s thermal noise:

$$\overline{i_{RS}^{2}} = \frac{4K_t}{R_e}$$

I_{ccp} shot noise:

$$\overline{i_{Rccp}^{2}} = 2\ q\ I_{ccp}$$

I_{bep} shot and flicker noises:

$$\overline{i_{Rbep}^2} = 2\ q\ I_{bep} + \frac{K_{fn}\ I_{bep}^{A_{fn}}}{f_{B_{fn}}}$$

R_{bp} thermal noise:

$$\overline{i_{Rbp}^2} = \frac{4K_t}{dI_{rbp}} / (dV_{rbp})$$

VBIC 1.2

This section lists equations new for VBIC 1.2. The rest of the equations remain the same as VBIC 1.15 (previous section).

DC Current

$$I_{tr} = I_s(T) \cdot I_{srr}(T) \cdot \left(e^{V_{bci}/(N_r \cdot V_{tm})} - 1\right)$$

If $Q_{bm} < \frac{1}{2}$

then

$$Q_b = \frac{1}{2} \cdot \left(Q_1 + \left(Q_1^{1/N_{kf}} + 4 \cdot Q_2\right)^{N_{kf}}\right)$$

otherwise

$$Q_b = \frac{1}{2} \cdot Q_1 \cdot \left(1 + (1 + 4 \cdot Q_2)^{N_{kf}}\right)$$

If $(V_{be} > 0)$

$$I_{bei} = I_{bei(T)}\left(e^{V_{bei}/(N_{en} \cdot V_{tm})} - 1\right)$$

$$I_{ben} = I_{ben(T)}\left(e^{V_{bei}/(N_{en} \cdot V_{tm})} - 1\right)$$

$$I_{bbe} = I_{bbe(T)_{nom}} \cdot \left(e^{(-V_{bbe}(T) - V_{bei})/(N_{bbe}(T) \cdot V_{tm})} - E_{bbe}(T)\right)$$

then

$$I_{be} = W_{be} \cdot I_{bei(T)} + I_{ben(T)} - I_{bbe(T)}$$

If $V_{bex} > 0$

$$I_{bexi} = I_{bexi(T)}\left(e^{V_{bex}/(N_{en} \cdot V_{tm})} - 1\right)$$

$$I_{bexn} = I_{bexn(T)}\left(e^{V_{bex}/(N_{en} \cdot V_{tm})} - 1\right)$$

$$I_{bbex} = I_{bbex(T)_{nom}} \cdot \left(e^{(-V_{bbe}(T) - V_{bex})/(N_{bbe}(T) \cdot V_{tm})} - E_{bbe}(T)\right)$$

then

$$I_{bex} = (1 - W_{be}) \cdot (I_{bexi(T)} + I_{bexn(T)} - I_{bbex(T)})$$

If $V_{be} \leq 0$

```
{
    Ibei = - Ibei(T);
    Iben = - Iben(T);
    Ibbe =  0;
}
```

If $V_{bex} \leq 0$

```
{
    Ibexi = - Ibexi(T);
    Ibexn = - Ibexn(T);
```

```
    Ibbex =  0;
}
```

Charge Equations

If $(A_{je} \le 0)$

{

If $V \le F_c P$

$$Q_j = \frac{P}{1-M}\left[1-\left(1-\frac{V}{P}\right)^{1-M}\right]$$

Else

$$Q_j = \frac{[1-Fc(1+M)]\cdot(V-FcP)+\dfrac{M\cdot(V^2-Fc^2p^2)}{2P}}{(1-Fc)^{M+1}} + \frac{P}{1-M}\left[1-\frac{1}{(1-Fc)^{M-1}}\right]$$

}

Else

{

$$Q_j = -\frac{P}{1-M}\cdot\left[\left(1-\frac{T1}{P}\right)^{1-M} - \left(1+\frac{1}{2P}\cdot\left(-FcP+\sqrt{Fc^2P^2+4Aj^2}\right)\right)^{1-M}\right] + \frac{Vbe-T1-\frac{1}{2}\cdot\left(-FcP+\sqrt{Fc^2P^2+4Aj^2}\right)}{(1-Fc)^M}$$

and

$$T1 = \frac{1}{2}\left(V-FcP-\sqrt{(V-FcP)^2+4Aj^2}\right)+FcP$$

}

If $(A_{jc} > 0)$

If $(V_{rt}>0) \wedge (A_{rt}>0)$

then

$$dv0 = -(F_c \cdot P)$$

$$vn0 = \frac{V_{rt} + dv0}{V_{rt} - dv0}$$

$$v_{nl0} = \frac{2 \cdot vn0}{\sqrt{(vn0-1)^2 + 4 \cdot A_j^2} + \sqrt{(vn0+1)^2 + 4 \cdot A_{rt}^2}}$$

$$v_{l0} = \frac{1}{2} \cdot (v_{nl0} \cdot (V_{rt-dv0}) - V_{rt} - dv0)$$

$$Q_{l0} = P \cdot \frac{\left(1 - \left(1 - \frac{V_{l0}}{P}\right)^{1-M}\right)}{1-M}$$

$$vn = \frac{2 \cdot V + V_{rt} + dv0}{V_{rt} - dv0}$$

$$vnl = \frac{2 \cdot vn}{\sqrt{(vn-1)^2 + 4 \cdot A \cdot A} + \sqrt{(vn+1)^2 + 4 \cdot A_{rt} \cdot A_{rt}}}$$

$$vl = \frac{1}{2} \cdot (vnl \cdot (V_{rt} - dv0) - V_{rt} - dv0)$$

$$Q_{jc0} = P \cdot \frac{\left(1 - \left(1 - \frac{vl}{P}\right)^{1-M}\right)}{1-M}$$

$$sel = \frac{1}{2} \cdot (vnl + 1)$$

$$crt = \left(1 + \frac{V_{rt}}{P}\right)^{-M}$$

$$cl = (1 - sel) \cdot crt + sel \cdot cmx$$

$$Q_l = (V - vl + vl0) \cdot cl$$

$$Q_{jc} = Q_l + Q_{jc0} - Q_{l0}$$

else

$$vl = \frac{1}{2} \cdot \left(V - F_c \cdot P - \sqrt{(V - (F_c \cdot P))^2 + 4 \cdot A \cdot A}\right) + F_c \cdot P$$

$$vl0 = -\frac{1}{2} \cdot \left(-Fc \cdot P + \sqrt{(F_c \cdot P)^2 + 4 \cdot A \cdot A}\right)$$

$$Q_{j0} = -P \cdot \frac{\left(1 - \frac{vl0}{P}\right)^{1-M}}{1-M}$$

$$Q_{lo} = -P \cdot \frac{\left(1 - \frac{vl}{P}\right)^{1-M}}{1-M}$$

$$Q_{jc} = Q_{lo} + (1 - F_c)^{-M} \cdot (V - vl + vlo) - Q_{jo}$$

Temperature Equations

If self-heating is on, the device temperature is calculated by

$$T = T_{op} + DTEMP + V(rth)$$

If self-heating is off, the device temperature is calculated by

$$T = T_{op} + DTEMP$$

The model parameter extraction temperature is calculated by

$$T_{nom} = TNOM$$

$$R_t = \frac{T}{T_{nom}}$$

$$V_{tm} = \frac{K_B \cdot T}{Q_e}$$

$$\Delta T = T - T_{nom}$$

$$R_{cx}(T) = R_{cx} \cdot R_t^{X_{rcx}}$$

$$R_{bx}(T) = R_{bx} \cdot R_t^{X_{rbx}}$$

$$R_{bp}(T) = R_{bp} \cdot R_t^{X_{rbp}}$$

$$I_{sp}(T) = I_{sp} \cdot R_t^{X_{is}/N_{fp}} \cdot e^{-E_{ap}/N_{fp} \cdot (1 - R_t)/(V_{tm} \cdot N_{fp})}$$

Scaling Effects

For scaling effects, Scaling Factors (scale and scalem) on page 242.

Component Statements

The VBIC model was developed as a replacement for the SPICE G-P model. The model has four electrical terminals, two thermal terminals, and up to nine internal nodes, depending on the model parameters that the user specifies. VBIC 1.1.5 and VBIC 1.2 are implemented and controlled by model parameter version. Default is version=1.1.5. Detailed description of the model and equations are given in the Virtuoso Spectre Circuit Simulator Device Model Equations manual.

This device is supported within altergroups.

Sample Instance Statement

```
q1 (1 2 0 0 0) vbjt area=1
```

Sample Model Statement

```
model vbjt vbic type=npn is=2e-16 iben=4.5e-15 isp=1e-15 gamm=1.55e-11 ikf=0.0021
ikr=0.0021 vef=15 ver=7 rbi=35 rbx=7 re=3 rs=15 cje=1.5e-14 tf=15e-12 selft=yes
rth=1K
```

Instance Definition

```
Name  c  b  e  [s]  [dt]  [tl] ModelName parameter=value ...
```

`tl` node is the local temperature and the `dt` node is the rise above the local temperature caused by the thermal power dissipated by the device being modeled by VBIC. Consequently, the `tl` node can be connected to a thermal network that models heat flow through the substrate and/or between devices. It is not necessary to specify the substrate and the two thermal terminals. If left unspecified, the substrate and the `tl` thermal terminal are connected to ground. But if the self-heating flag is turned on and `dt` is not given, an internal node is created for self-heating. You must specify the substrate terminal if you specify `dt` and both substrate and `dt` must be given if `tl` needs to be specified.

It is strongly recommended to avoid using the `tl` node. It is not fully supported and using it will degrade convergence properties. This node is removed in the VBIC 1.2 version. All thermal effects can be modeled with just the `dt` node.

Instance Parameters

1	`area=1`	Transistor area factor.
2	`m=1`	Multiplicity factor.
3	`region=fwd`	Estimated operating region. Spectre outputs number (0-4) in a rawfile. Possible values are `off`, `fwd`, `rev`, `sat`, or `breakdown`.
4	`trise`	Temperature rise from ambient.
5	`dtmp`	Alias to trise.
6	`dtemp`	Alias to trise.
7	`isnoisy=yes`	Should resistor generate noise. Possible values are `no` or `yes`.

small-signal model parameters

Model Definition

```
model modelName vbic parameter=value ...
```

Model Parameters

Structural parameters

1 `type=npn` Transistor type.
Possible values are `npn` or `pnp`.

2 `compatible=spectre`
Encourage device equations to be compatible with a foreign simulator. This option does not affect input syntax.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, or `mica`.

Saturation current parameters

3 `is=1e-16 A` Transport saturation current (*area).

4 `ibei=1e-18 A` Ideal B-E saturation current. (*area).

5 `iben=0 A` Nonideal B-E saturation current (*area).

6 `ibci=1e-16 A` Ideal B-C saturation current. (*area).

7 `ibcn=0 A` Nonideal B-C saturation current (*area).

8 `isp=0 A` Parasitic transport saturation current. (*area).

9 `ibeip=0 A` Ideal parasitic B-E saturation current (*area).

10 `ibenp=0 A` Nonideal parasitic B-E saturation current (*area).

11 `ibcip=0 A` Ideal parasitic B-C saturation current (*area).

12 `ibcnp=0 A` Nonideal parasitic B-C saturation current (*area).

13 `vo=0 V` Epi drift saturation voltage.

14 `gamm=0 V` Epi doping parameter.

15 `hrcf=1` High current RC factor.

16 `wbe=1` Portion of Ibei from Vbei.

17 `wsp=1` Portion of Iccp from Vbep.

Emission coefficient parameters

18 `nf=1` Forward emission coefficient.

19 `nr=1` Reverse emission coefficient.

20 `nei=1` Ideal B-E emission coefficient.

21 `nen=2` Nonideal B-E emission coefficient.

22 `nci=1` Ideal B-C emission coefficient.

23 `ncn=2` Nonideal B-C emission coefficient.

24 `nfp=1` Parasitic forward emission coefficient.

25 `ncip=1` Ideal parasitic B-C emission coefficient.

26 `ncnp=2` Nonideal parasitic B-C emission coefficient.

Current gain parameters

27 `ikf=∞ A` Forward knee current (*area).

28 `ikr=∞ A` Reverse knee current (*area).

29 `ikp=∞ A` Parasitic knee current (*area).

Early voltage parameters

30 `vef=∞ V` Forward Early voltage.

31 `ver=∞ V` Reverse Early voltage.

Breakdown voltage parameters

32 `avc1=0` B-C weak avalanche parameter.

33 `avc2=0` B-C weak avalanche parameter.

Parasitic resistance parameters

34 `rbi=0 Ω` Intrinsic base resistance (/area).

35 `rbx=0 Ω` Extrinsic base resistance (/area).

36 `re=0 Ω` Emitter resistance (/area).

37 `rs=0 Ω` Substrate resistance (/area).

38 `rbp=0 Ω` Parasitic base resistance (/area).

39 `rcx=0 Ω` Extrinsic collector resistance (/area).

40 `rci=0 Ω` Intrinsic collector resistance (/area).

41 `minr=0.01 Ω` Minimum parasitic resistance.

Junction capacitance parameters

42 `cje=0 F` B-E zero-bias capacitance (*area).

43 `pe=0.75 V` B-E built-in potential.

44 `me=0.33` B-E grading coefficient.

45 `aje=-0.5` B-E capacitance smoothing factor.

46 `fc=0.9` Forward-bias depletion capacitance limit.

47 `cbeo=0 F` Extrinsic B-E overlap capacitance (*area).

48 `cjc=0 F` B-C zero-bias capacitance (*area).

49 `cjep=0 F` B-C extrinsic zero-bias capacitance (*area).

50 `pc=0.75 V`	B-C built-in potential.
51 `mc=0.33`	B-C grading coefficient.
52 `ajc=-0.5`	B-C capacitance smoothing factor.
53 `cbco=0 F`	Extrinsic B-C overlap capacitance (*area).
54 `qco=0 Coul`	Epi charge parameter.
55 `cjcp=0 F`	S-C zero-bias capacitance (*area).
56 `ps=0.75 V`	S-C built-in potential.
57 `ms=0.33`	S-C grading coefficient.
58 `ajs=-0.5`	S-C capacitance smoothing factor.

Transit time and excess phase parameters

59 `tf=0 s`	Forward transit time.
60 `tr=0 s`	Reverse transit time.
61 `td=0 s`	Forward excess-phase delay time.
62 `qtf=0`	Variation of `tf` with base width modulation.
63 `xtf=0`	Coefficient of `tf` with bias dependence.
64 `vtf=0`	Coefficient of `tf` dependence on Vbc.
65 `itf=0`	Coefficient of `tf` dependence on Ic.

Temperature effects parameters

66 `selft=no`	Flag denoting self-heating. Possible values are `no` or `yes`.
67 `tnom (C)`	Parameters measurement temperature. Default set by options.
68 `trise=0 C`	Temperature rise from ambient.

69 `rth=0 Ω` Thermal resistance, must be given for self-heating.

70 `cth=0 F` Thermal capacitance.

71 `xis=3 V` Temperature exponent of Is.

72 `xii=3 V` Temperature exponent of Ibei, Ibci, Ibeip, and Ibcip.

73 `xin=3 V` Temperature exponent of Iben, Ibcn, Ibenp, and Ibcnp.

74 `tnf=0 V` Temperature coefficient of Nf.

75 `tavc=0 V` Temperature coefficient of Avc2.

76 `ea=1.12 V` Activation energy for `is`.

77 `eaie=1.12 V` Activation energy for Ibei.

78 `eaic=1.12 V` Activation energy for Ibci/Ibeip.

79 `eais=1.12 V` Activation energy for Ibcip.

80 `eane=1.12 V` Activation energy for Iben.

81 `eanc=1.12 V` Activation energy for Ibcn/Ibenp.

82 `eans=1.12 V` Activation energy for Ibcnp.

83 `xre=0` Temperature exponent of `re`.

84 `xrb=0` Temperature exponent of `rb`.

85 `xrc=0` Temperature exponent of `rc`.

86 `xrs=0` Temperature exponent of `rs`.

87 `xvo=0` Temperature exponent of `vo`.

88 `dtmax=226.85 C` Maximum expected device temperature. (500 K).

Noise model parameters

89 `kfn=0` B-E flicker (1/f) noise coefficient.

90 `afn=1` B-E flicker (1/f) noise exponent.

91 `bfn=1` B-E flicker (1/f) noise dependence.

Junction diode model control parameters

92 `dskip=yes` Skip junction calculations if they are reverse-saturated. Possible values are `no` or `yes`.

93 `imelt=10 A` Explosion current (*area).

Operating region warning control parameters

94 `bvbe=∞ V` B-E breakdown voltage.

95 `bvbc=∞ V` B-C breakdown voltage.

96 `bvce=∞ V` C-E breakdown voltage.

97 `bvsub=∞ V` Substrate junction breakdown voltage.

98 `vbefwd=0.2 V` B-E forward voltage.

99 `vbcfwd=0.2 V` B-C forward voltage.

100 `vsubfwd=0.2 V` Substrate junction forward voltage.

101 `imax=1 A` Maximum allowable base current (*area).

102 `imax1=`imax' A` Maximum allowable collector current (*area).

103 `alarm=none` Forbidden operating region. Possible values are `none`, `off`, `fwd`, `rev`, or `sat`.

DC-mismatch model parameters

104 `mvt0=0.0 V` Threshold mismatch intercept.

New model parameter for Vbic 1.2

105 `vrt=0 V` B-C reach-through limiting voltage.

106 `art=0.1 V`	B-C reach-through limiting smoothing factor .
107 `ccso=0 F`	Fixed collector-substrate capacitance.
108 `qbm=0`	Parameter to select SGP qb formulation.
109 `nkf=0.5`	High current beta rolloff parameter.
110 `xikf=0`	Parameter of temperature dependence to `ikf`.
111 `xrcx=0`	Parameter of temperature dependence to `rcx`.
112 `xrbx=0`	Parameter of temperature dependence to `rbx`.
113 `xrbp=0`	Parameter of temperature dependence to `rbp`.
114 `isrr=1`	Parameter to separate `is` for forward and reversed parts.
115 `xisr=0`	Temperature exponent coefficient of `isrr`.
116 `dear=0 V`	Activation energy for `isrr`.
117 `eap=1.12 V`	Activation energy for `isp`.
118 `vbbe=0 V`	B-E breakdown voltage.
119 `nbbe=1.0`	B-E breakdown emission coefficient.
120 `ibbe=1.0e-6 A`	B-E breakdown current.
121 `tvbbe1=0`	First temperature coefficient of `vbbe`.
122 `tvbbe2=0`	Second temperature coefficient of `vbbe`.
123 `tnbbe=0`	Temperature coefficient for `nbbe`.
124 `vers=1.15`	Version control parameter.
125 `vrev=0`	Revision control parameter.
126 `dtmp (C)`	Alias to trise.
127 `dtemp (C)`	Alias to trise.

128 `version` Alias to vers.

129 `rev` Alias to vrev.

130 `xrbi` Alias to xrb.

131 `xrci` Alias to xrc.

132 `ebbe=0.0` exp(-VBBE/(NBBE*Vtv))t.

Shrink Parameters

Imax and Imelt:

The `imax` parameter aids convergence and prevents numerical overflow. The junction characteristics of the device are accurately modeled for current up to `imax`. If `imax` is exceeded during iterations, the linear model is substituted until the current drops below imax or until convergence is achieved. If convergence is achieved with the current exceeding `imax`, the results are inaccurate, and Spectre prints a warning.

A separate model parameter, `imelt`, is used as a limit warning for the junction current. This parameter can be set to the maximum current rating of the device. When any component of the junction current exceeds `imelt`, note that base and collector currents are composed of many exponential terms, Spectre issues a warning and the results become inaccurate. The junction current is linearized above the value of `imelt` to prevent arithmetic exception, with the exponential term replaced by a linear equation at `imelt`.

Operating-Point Parameters

1 `type=npn` Transistor type.
Possible values are `npn` or `pnp`.

2 `region=fwd` Estimated operating region. Spectre outputs number (0-4) in a rawfile.
Possible values are `off`, `fwd`, `rev`, `sat`, or `breakdown`.

3 `vbe (V)` Base-emitter voltage.

4 `vbc (V)` Base-collector voltage.

5 `vce (V)`	Collector-emitter voltage.
6 `vcs (V)`	Collector-substrate voltage.
7 `temp (C)`	Device temperature.
8 `ith (A)`	Thermal source.
9 `ic (A)`	Intrinsic DC collector current. (Icc - Ibc + Igc).
10 `ib (A)`	Intrinsic DC base current. (Ibe + Ibc - Igc).
11 `icc (A)`	C-E current.
12 `ibe (A)`	Intrinsic B-E junction current.
13 `ibc (A)`	Intrinsic B-C junction current.
14 `ibex (A)`	BX-E junction current.
15 `igc (A)`	Breakdown current.
16 `iccp (A)`	Parasitic transport C-E current.
17 `ibep (A)`	Parasitic transport B-E current.
18 `ibcp (A)`	Parasitic transport B-C current.
19 `betadc (A/A)`	Ratio of external collector current to external base current. (ic_ext/ib_ext).
20 `gm (S)`	Intrinsic small-signal transconductance. (gm = dIcc_dVbe + dIcc_dVbc).
21 `gpi (S)`	Intrinsic small-signal input conductance. (gpi = dIbe_dVbe).
22 `go (S)`	Intrinsic small-signal output conductance. (go = -dIcc_dVbc).
23 `gmu (S)`	Intrinsic small-signal Collector-Base conductance. (gmu = dIbc_dVbc).
24 `cpi (F)`	Intrinsic small-signal B-E capacitance. Same as cje.

25 `cmu (F)` Intrinsic small signal B-C capacitance. Same as cjc.

26 `betaac (A/A)` Small-signal common-emitter current gain. (gm/gpi).

27 `ft (Hz)` Unity small-signal current-gain frequency.

28 `dic_dvbe (S)` Intrinsic dIc/dVbe.

29 `dic_dvbc (S)` Intrinsic dIc_dVbc.

30 `dib_dvbe (S)` Intrinsic dIb_dVbe.

31 `dib_dvbc (S)` Intrinsic dIb_dVbc.

32 `rbi (Ω)` Intrinsic base resistance.

33 `rci (Ω)` Intrinsic collector resistance.

34 `rbp (Ω)` Parasitic transistor base resistance.

35 `cje (F)` Intrinsic B-E capacitance.

36 `cjc (F)` Intrinsic B-C capacitance.

37 `cbex (F)` BX-E junction capacitance.

38 `cbcx (F)` B-CX junction capacitance.

39 `cbep (F)` Parasitic B-E junction capacitance.

40 `cbcp (F)` Parasitic B-C junction capacitance.

41 `pwr (W)` Power dissipation.

Parameter Index

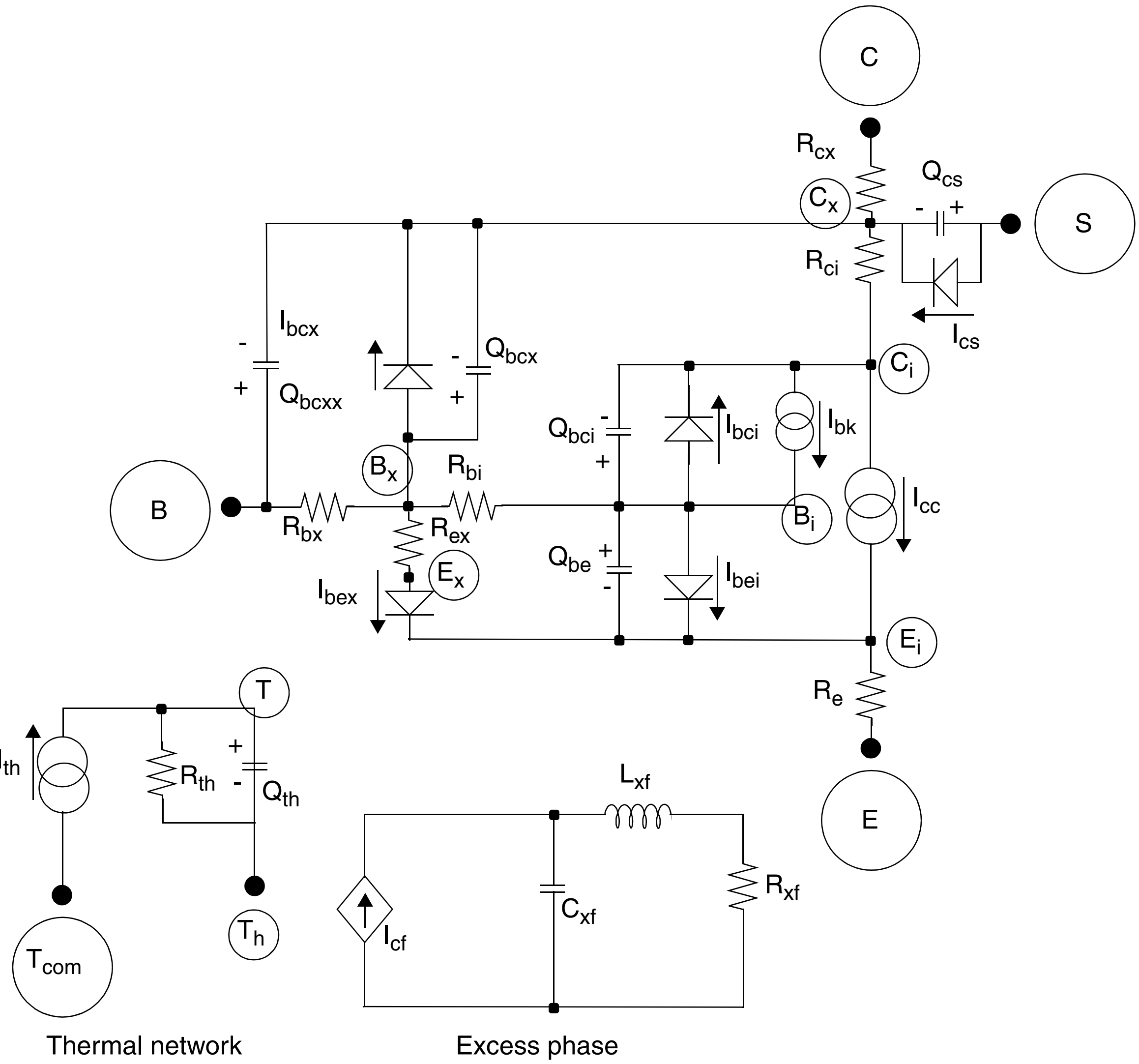
In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

9

HBT Model (hbt)

The Hetero-junction Bipolar Transistor (HBT) model was developed by UCSD as part of the ARPA High Speed Circuit Design Program. The model has four external electrical nodes, one thermal node, and up to nine internals depending on the version of the model you specify.

This chapter contains the following information for the HBT model:



DC Current

$$I_{cc} = I_{cf} - I_{cr}$$

$$I_{cf} = \frac{I_s}{\Delta}(e^{V_{be}/N_r(V_{tm})} - 1)$$

$$I_{cr} = \frac{I_s}{\Delta}(e^{V_{bc}/N_r(V_{tm})} - 1)$$

$$\Delta = Q_b + \frac{I_s}{I_{sa}}e^{V_{be}/N_a(V_{tm})} + \frac{I_s}{I_{sb}}e^{V_{bc}/N_b(V_{tm})}$$

$$Q_b = \frac{Q_1}{2}(1 + \sqrt{1 + 4Q_2})$$

$$Q_1 = \frac{1}{1 - \frac{V_{bc}}{V_{af}} - \frac{V_{be}}{V_{ar}}}$$

$$Q_2 = \frac{I_s}{I_k}(e^{V_{be}/N_f(V_{tm})} - 1)$$

$$I_{be} = \frac{I_{cf}}{B_f} + I_{se}(e^{V_{be}/N_e(V_{tm})} - 1)$$

$$I_{bex} = I_{sex}(e^{V_{bex}/N_{ex}(V_{tm})} - 1)$$

$$I_{bc} = \frac{I_{cr}}{B_r} + I_{sc}(e^{V_{be}/N_c(V_{tm})} - 1)$$

$$I_{bcx} = I_{scx}(e^{V_{bcx}/N_{cx}(V_{tmop})} - 1)$$

$$I_{cs} = I_{cs}(e^{-V_{cs}/N_{cs}(V_{tmop})} - 1)$$

$$I_{bk} = \begin{cases} 0 & \text{if } B_{kdn} = 0 \\ (M_f - 1)I_{cf} & \text{otherwise} \end{cases}$$

$$M_f = \begin{cases} \dfrac{1}{1 - \left(\dfrac{-V_{bc}}{B_{vc}}\right)^{N_{bc}}} & \text{if } V_{tm} < -V_{bc} < F_a(B_{vc}) \\ 1 & \text{if } -V_{bc} < V_{tm} \\ M_{f1} + g_1(-V_{bc} - F_a(B_{vc})) & -V_{bc} < F_a(B_{vc}) \end{cases}$$

$$M_{f1} = \frac{1}{1 - F_a^{\;N_{bc}}}$$

$$g_1 = M_{f1}(M_{f1} - 1)\frac{N_{bc}}{F_a(B_{vc})}$$

Junction Capacitance

Define

$$V_{min} = V_j\left[1 - \left(\frac{C_j}{C_{min}}\right)^{1/M_j}\right]$$

If $V < V_{min}$,

$$C_j = C_{min}$$

$$Q_j = C_{min}(V - V_j) + C_{min}(V_j)\left(\frac{M_j}{M_j - 1}\right)\left(\frac{C_j}{C_{min}}\right)^{1/M_j}$$

If $V < F_c(V_j)$,

$$C_j = \frac{C_j}{\left(1 - \frac{V}{V_j}\right)^{M_j}}$$

If $V > F_c(V_j)$ and $C_j \geq C_{min}(1 - F_c)^{Mj}$,

$$C_j = \frac{C_j}{(1-F_c)^{M_j}}[1 + M_j(V_R)]$$

$$Q_j = \frac{-C_j}{(1-F_c)^{M_j}}\left[\frac{1}{1-M_j} - V_r - \frac{M_j(V_R^2)}{2}\right]$$

where

$$V_R = \frac{V - F_c(V_j)}{V_j - F_c(V_j)}$$

If $V > F_c(V_j)$ and $C_j < C_{min}(1 - F_c)^{Mj}$,

$$C_j = C_{min} + \frac{C_j(M_j)(V_R)}{(1-F_c)^{M_j}}$$

$$Q_j = C_{min}\left(V - V_{min} - \frac{V_j - V_{min}}{1-M_j}\right) + \frac{C_j(M_j)(V - F_c(V_j))(V_R)}{2(1-F_c)^{M_j}}$$

Total Charge

$$Q_{be} = Q_{je} + (1 - F_{ex})Q_{fdiff}$$

where Q_{je} is the junction charge Q_j with $V = V_{be}$.

$$Q_{bc} = Q_{jc} + T_r(I_{cr}) + F_{ex}(Q_{fdiff})$$

$$Q_{bcx} = T_{rx}(I_{bcx}) + X_{cjc}(Q_{jcx})$$

$$Q_{bcxx} = (1 - X_{cjc})Q_{jcxx}$$

$$Q_{cs} = Q_{js}$$

$$Q_{fdiff} = I_{cf}(F_{tt})\left(T_{fbt} + \frac{T_{fco}}{Q_{cc}} + Q_{bcm} + Q_{krk}\right)$$

where

$$F_{tt} = R_{td}^{X_{ttf}}$$

$$T_{fbt} = T_{fb}\left(1 + \frac{V_{bc}}{V_{af}} + \frac{V_{be}}{V_{ar}}\right) + T_{bexs}(e^{-(V_{be} - V_{je})/N_a(V_{tm})}) + T_{bcxs}(e^{-(V_{bc} - V_{jc})/N_b(V_{tm})})$$

$$Q_{cc} = \frac{1 + (I_{cf})^2}{1 + \left(\frac{I_{cf}}{I_{tc2}}\right)^3 + \left(\frac{V_{jc} - V_{bc}}{V_{tc}}\right)}$$

$$Q_{krk} = T_{krk}(I_{cj})e^{(V_{bc}/V_{krk} + I_{cf}/I_{krk})}$$

$$Q_{bcm} = Q_{bcf} - Q_{jc}$$

where Q_{bcf} is calculated according to the following rules:

Define

$$I_o = \frac{I_{cf}}{I_{crit}}$$

where

$$I_{crit} = I_{crito}\left(\frac{Q_{cc}}{F_{tt}}\right)$$

$$C_{jch} = \begin{cases} C_{jc}\left((1 - I_o)^{M_{jc}}\right) & \text{If } I_o < 1 \\ -C_{jc}\left((I_o - 1)^{M_{jc}}\right) & \text{otherwise} \end{cases}$$

If $C_{jch} < 0$,

$$Q_{bcf} = C_{cmin}(V_{bc} - V_{jc}) - \frac{C_{cmin}(V_{jc})(M_{jc})}{M_{jc} - 1}\left(-\frac{C_{jch}}{C_{cmin}}\right)^{1/M_{jc}}$$

If $C_{jch} \geq 0$, define

$$V_{min1} = V_{jc}\left[1 - \left(\frac{C_{jch}}{C_{cmin}}\right)^{1/M_{jc}}\right]$$

If $V_{bc} < F_c(V_{jc})$ and $V_{bc} < V_{min1}$,

$$Q_{bcf} = C_{cmin}(V_{bc} - V_{jc}) + \frac{C_{cmin}(V_{jc})(M_{jc})}{M_{jc} - 1}\left(\frac{C_{jch}}{C_{cmin}}\right)^{1/M_{jc}}$$

If $V_{bc} < F_c(V_{jc})$ and $V_{bc} \geq V_{min1}$,

$$Q_{bcf} = -\frac{C_{jch}(V_{jc})}{1 - M_{jc}}\left(1 - \frac{V_{bc}}{V_{jc}}\right)^{1 - M_{jc}}$$

If $V_{bc} \geq F_c(V_{jc})$ and $C_{jch} > C_{min}(1 - F_c)^{Mjc}$,

$$Q_{bcf} = \frac{-C_{jch}(V_{jc} - F_c(V_{jc}))}{(1 - F_c)^{M_{jc}}}\left[\frac{1}{1 - M_{jc}} - V_{RC} - \frac{M_{jc}(V_{RC}^2)}{2}\right]$$

where

$$V_{RC} = \frac{V_{bc} - F_c(V_j)}{V_j - F_c(V_j)}$$

If $V_{bc} \geq F_c(V_{jc})$ and $C_{jch} \leq C_{min}(1 - F_c)^{Mjc}$,

$$Q_{bcf} = C_{cmin}\left(V_{bc} - V_{min1} - \frac{V_{jc} - V_{min1}}{1 - M_{jc}}\right) + \frac{C_{jch}(M_{jc})(V_{bc} - F_c(V_{jc}))V_{R_c}}{2(1 - F_c)^{M_{jc}}}$$

Thermal Current Equations

$$I_{th} = I_{cc}(V_{ce}) + I_{be}(V_{be}) + I_{bex}(V_{bex}) + I_{bcx}(V_{bcx}) + (I_{bc} - I_{bk})(V_{bc} - I_{cs})(V_{cs}) + \frac{V_{bbx}^2}{R_{bx}} + \frac{V_{bxex}^2}{R_{ex}} + \frac{V_{bxbi}^2}{R_{bi}} + \frac{V_{eei}^2}{R_e} + \frac{V_{ccx}^2}{R_{cx}} + \frac{V_{cxci}^2}{R_{ci}}$$

Temperature Equations

$$\Delta T = T - Tnom$$

$$V_{tm} = \frac{kT}{q}$$

$$V_{tmop} = \frac{kT_{op}}{q}$$

$$V_{tmnom} = \frac{kTnom}{q}$$

$$R_{td} = \frac{T}{Tnom}$$

$$R_{top} = \frac{T_{op}}{Tnom}$$

$$R_{th} = R_{thnom}\left(R_{td}^{X_{rt}}\right)$$

$$R_{cx} = R_{cxnom}\left(R_{t_op}^{X_{rc}}\right)$$

$$R_{ci} = R_{cinom}\left(R_{t_op}^{X_{rc}}\right)$$

$$R_{bx} = R_{bxnom}\left(R_{t_op}^{X_{rb}}\right)$$

$$R_{bi} = R_{binom}\left(R_{t_op}^{X_{rb}}\right)$$

$$R_{e} = R_{enom}\left(R_{t_op}^{X_{re}}\right)$$

$$R_{ex} = R_{exnom}\left(R_{t_op}^{X_{rex}}\right)$$

$$I_{s} = I_{snom}\left(R_{td}^{X_{ti}}\right)(e^{E_g(R_{td}-1)/V_{tm}})$$

$$I_{sa} = I_{sanom}\left(R_{td}^{X_{ti}}\right)(e^{(E_g+E_{aa})(R_{td}-1)/V_{tm}})$$

$$I_{sb} = I_{sbnom}\left(R_{td}^{X_{ti}}\right)(e^{(E_g+E_{ab})(R_{td}-1)/V_{tm}})$$

$$B_{f} = B_{fnom}\left(R_{td}^{X_{tb}}\right)$$

$$B_{r} = B_{rnom}\left(R_{td}^{X_{tb}}\right)$$

$$I_{se} = I_{senom}\left(R_{td}^{(X_{ti}/N_e-X_{tb})}\right)(e^{(E_g+E_{ae})/N_e(V_{tm})-(E_g+E_{ae})/N_{enom}(V_{tmnom})})$$

$$N_e = N_{enom} + T_{ne}(\Delta T)$$

$$I_{sc} = I_{scnom}\left(R_{td}^{(X_{ti}/N_c - X_{tb})}\right)\left(e^{(E_g + E_{ac})/N_c(V_{tm}) - (E_g + E_{ac})/N_{cnom}(V_{tmnom})}\right)$$

$$N_c = N_{cnom} + T_{nc}(\Delta T)$$

$$I_{sex} = I_{sexnom}\left(R_{td}^{X_{ti}/N_{ex} - X_{tb}}\right)\left(e^{(E_g + E_{ax})/N_{ex}(V_{tm}) - (E_g + E_{ax})/N_{exnom}(V_{tmnom})}\right)$$

$$N_{ex} = N_{exnom} + T_{nex}(\Delta T)$$

$$V_j = V_{jnom} - T_{vj}(T_{op} - Tnom)$$

$$C_j = C_{jnom}\left(\frac{V_{jnom}}{V_j}\right)^{M_j}$$

$$I_{tc} = I_{tcnom}\left(R_{td}^{X_{titc}}\right)$$

$$I_{tc2} = I_{tc2nom}\left(R_{td}^{X_{titc2}}\right)$$

$$T_{krk} = T_{krknom}\left(R_{top}^{X_{ttkrk}}\right)$$

$$V_{krk} = V_{krknom}\left(R_{top}^{X_{tvkrk}}\right)$$

$$I_{krk} = I_{krknom}\left(R_{top}^{X_{tikrk}}\right)$$

Scaling Effects

For scaling effects, see Scaling Factors (scale and scalem) on page 242.

Component Statements

Sample Instance Statement

```
q7 (net5 net2 0) hbtmod m=1 top=25
```

Sample Model Statement

```
model hbtmod hbt type=npn bf=500 br=1000 xtb=-2.4 xti=0 xcjc=0.83 mje=0.34 fc=0.5
eg=1.2 ise=5.5e-15 vjc=0.84 vaf=40 cjc=5.1e-15
```

Instance Definition

```
Name  c  b  e  [t]  [s] ModelName parameter=value ...
```

It is not necessary to specify the substrate and thermal terminal. If left unspecified, the substrate node is connected to ground while the thermal node is fixed to the ambient temperature. However, you must specify the thermal node if you specify the substrate node.

Instance Parameters

1	`area=1`	Transistor area factor.
2	`m=1`	Multiplicity factor.
3	`top (C)`	Average device operating temperature.
4	`region=fwd`	Estimated operating region. Spectre outputs number (0-3) in a rawfile. Possible values are `off`, `fwd`, `rev`, or `sat`.
5	`isnoisy=yes`	Should resistor generate noise. Possible values are `no` or `yes`.

Model Definition

```
model modelName hbt parameter=value ...
```

Model Parameters

Structural parameters

1 `type=npn` — Transistor type.
Possible values are `npn` or `pnp`.

Saturation current parameters

2 `is=1e-25 A` — Saturation value for forward collector current (*area).

3 `ise=1e-25 A` — Saturation value for nonideal base current. (*area).

4 `isex=1e-25 A` — Saturation current for emitter leakage diode (*area).

5 `isc=1e-20 A` — Saturation value for intrinsic BC junction current. (*area).

6 `iscx=1e-20 A` — Saturation value for extrinsic B-C junction current (*area).

7 `ics=1e-30 A` — Saturation value for C-S junction current (*area).

Emission coefficient parameters

8 `nf=1` — Forward collector current ideality factor.

9 `nr=1` — Reverse ideality factor.

10 `ne=2` — Nonideal base forward current ideality factor.

11 `nex=2` — Ideality factor for emitter leakage diode.

12 `nc=2` — Intrinsic B-C junction ideality factor.

13 `ncx=2` — Ideality factor for extrinsic B-C junction.

14 `ncs=2` — Ideality factor for C-S junction.

Current gain parameters

15 `bf=1000 A/A` — Forward ideal current gain (beta).

16 `br=1000 A/A`	Reverse ideal current gain.
17 `isa=1e10 A`	Collector E-B barrier limiting current (*area).
18 `na=2`	Collector E-B barrier ideality factor.
19 `isb=1e10 A`	Collector B-C barrier limiting current (*area).
20 `nb=2`	Collector B-C barrier ideality factor.
21 `ik=1e10 A`	Knee current for dc high-level injection effect (*area).

Early voltage parameters

22 `vaf=500 V`	Forward Early voltage.
23 `var=500 V`	Reverse Early voltage.

Breakdown voltage parameters

24 `bkdn=no`	Flag denoting B-C breakdown should be included. Possible values are `no` or `yes`.
25 `bvc=50 A`	Collector-base breakdown voltage BVcbo.
26 `nbc=8`	Exponent for B-C multiplication factor versus voltage.
27 `fa=0.9`	Factor for specification of avalanche voltage.
28 `imax=1 A`	Maximum allowable base current (*area).
29 `imelt=10 A`	Explosion current (*area).

Parasitic resistance parameters

30 `rbi=0 Ω`	Intrinsic base resistance (/area).
31 `rbx=0 Ω`	Extrinsic base resistance (/area).
32 `rci=0 Ω`	Intrinsic collector resistance (/area).

33 `rcx=0 Ω`	Extrinsic collector resistance (/area).
34 `re=0 Ω`	Emitter resistance (/area).
35 `rex=0 Ω`	Extrinsic emitter leakage diode series resistance (/area).

Junction capacitance parameters

36 `cje=0 F`	B-E depletion capacitance at zero bias (*area).
37 `vje=1.6 V`	B-E built-in potential for Cj.
38 `mje=0.5`	Exponent for voltage variation of B-E Cj.
39 `cemin=0 F`	Minimum B-E capacitance (*area).
40 `fce=0.8`	Factor for start of high bias B-E Cj approximation.
41 `cjc=0 F`	Intrinsic B-C depletion capacitance at zero bias (*area).
42 `vjc=1.4 V`	Intrinsic B-C built-in potential for Cj.
43 `mjc=0.33`	Exponent for voltage variation of Intrinsic B-C Cj.
44 `ccmin=0 F`	Minimum B-C capacitance (*area).
45 `fc=0.8`	Factor for start of high bias B-C Cj approximation.
46 `cjcx=0 F`	Extrinsic B-C depletion capacitance at zero bias (*area).
47 `vjcx=1.4 V`	Extrinsic B-C built-in potential for Cj.
48 `mjcx=0.33`	B-C junction exponent.
49 `cxmin=0 F`	Minimum extrinsic B-C capacitance (*area).
50 `xcjc=0`	Fraction of B-C capacitance tied to external base node.
51 `cjs=0 F`	B-S depletion capacitance at zero bias (*area).
52 `vjs=1.4 V`	B-S built-in potential for Cj.
53 `mjs=0.5`	Exponent for voltage variation of C-S Cj.

Transit time and excess phase parameters

54 `tfb=0 s` Base transit time.

55 `tbexs=0` Excess B-E heterojunction transit time.

56 `tbcxs=0` Excess B-C heterojunction transit time.

57 `tfc0=0 s` Collector forward transit time.

58 `icrit0=1e3 A` Critical current for intrinsic Cj variation.

59 `itc=0 A` Characteristic current for Tfc.

60 `itc2=0 A` Characteristic current for Tfc.

61 `vtc=1e3 V` Characteristic voltage for Tfc.

62 `tkrk=0 s` Forward transit time for Kirk effect.

63 `vkrk=1e3 V` Characteristic voltage for Kirk effect.

64 `ikrk=1e3 A` Characteristic voltage for Kirk effect.

65 `tr=0 s` Reverse charge storage time for intrinsic B-C junction.

66 `trx=0 s` Reverse charge storage time for extrinsic B-C junction.

67 `fex=0 s` Factor to determine excess phase.

Temperature effects parameters

68 `selft=no` Flag denoting self-heating.
Possible values are `no` or `yes`.

69 `tnom (C)` Parameters measurement temperature. Default set by options.

70 `top=27 C` Average device operating temperature.

71 `rth=0 Ω` Thermal resistance of device.

72 `cth=0 F` Thermal capacitance of device.

73 `xti=2`	Exponent for `is` temperature dependence.
74 `xtb=2`	Exponent for beta temperature dependence.
75 `tne=0`	Coefficient for `ne` temperature dependence.
76 `tnc=0`	Coefficient for `nc` temperature dependence.
77 `tnex=0`	Coefficient for `nex` temperature dependence.
78 `eae=0 V`	Activation energy for `isa` temperature dependence.
79 `eac=0 V`	Activation energy for `isb` temperature dependence.
80 `eaa=0 V`	Activation energy for `ise` temperature dependence.
81 `eab=0 V`	Activation energy for `isc` temperature dependence.
82 `eax=0 V`	Activation energy for `isex` temperature dependence.
83 `xre=0`	Exponent for `re` temperature dependence.
84 `xrex=0`	Exponent for `rex` temperature dependence.
85 `xrb=0`	Exponent for `rb` temperature dependence.
86 `xrc=0`	Exponent for `rc` temperature dependence.
87 `tvje=0 V/C`	Coefficient for `vje` temperature dependence.
88 `tvjc=0 V/C`	Coefficient for `vjc` temperature dependence.
89 `tvjcx=0 V/C`	Coefficient for `vjcx` temperature dependence.
90 `tvjs=0 V/C`	Coefficient for `vjs` temperature dependence.
91 `xtitc=0`	Exponent for `itc` temperature dependence.
92 `xtitc2=0`	Exponent for `itc2` temperature dependence.
93 `xttf=0`	Exponent for `tf` temperature dependence.
94 `xttkrk=0`	Exponent for `tkrk` temperature exponent.

95 `xtvkrk=0` Exponent for `vkrk` temperature dependence.

96 `xtikrk=0` Exponent for `ikrk` temperature dependence.

97 `xrt=0` Exponent for `rth` temperature dependence.

98 `eg=1.5 V` Activation energy for `is` temperature dependence.

99 `dtmax=1000 C` Maximum expected temperature rise above heat sink.

Noise model parameters

100 `kfn=0` Flicker (1/f) noise coefficient.

101 `afn=1` Flicker (1/f) noise exponent.

102 `bfn=1` Flicker noise frequency exponent.

Imax and Imelt

The `imax` parameter aids convergence and prevents numerical overflow. The junction characteristics of the device are accurately modeled for current up to `imax`. If `imax` is exceeded during iterations, the linear model is substituted until the current drops below imax or until convergence is achieved. If convergence is achieved with the current exceeding `imax`, the results are inaccurate, and Spectre prints a warning.

A separate model parameter, `imelt`, is used as a limit warning for the junction current. This parameter can be set to the maximum current rating of the device. When any component of the junction current exceeds `imelt`, note that base and collector currents are composed of many exponential terms, Spectre issues a warning and the results become inaccurate. The junction current is linearized above the value of `imelt` to prevent arithmetic exception, with the exponential term replaced by a linear equation at `imelt`.

Operating-Point Parameters

1 `type=npn` Transistor type.
Possible values are `npn` or `pnp`.

2 `region=fwd` Estimated operating region. Spectre outputs number (0-3) in a rawfile.
Possible values are `off`, `fwd`, `rev`, or `sat`.

3 `vbe (V)` Base-emitter voltage.

4 `vbc (V)` Base-collector voltage.

5 `vce (V)` Collector-emitter voltage.

6 `vcs (V)` XC-substrate voltage.

7 `temp (C)` Device temperature.

8 `ith (A)` Thermal source.

9 `ice (A)` Intrinsic B-C current.

10 `ibe (A)` Intrinsic B-E current.

11 `ics (A)` C-S junction current.

12 `ibei (A)` B-E junction current.

13 `ibci (A)` B-C junction current.

14 `ibex (A)` XB-E junction current.

15 `ibcx (A)` XB-C junction current.

16 `ibk (A)` Breakdown current.

17 `dice_dvbe (S)` Intrinsic dIce/dVbe.

18 `dice_dvbc (S)` Intrinsic dIce_dVbc.

19 `dibe_dvbe (S)` Intrinsic dIbe_dVbe.

20 `dibe_dvbc (S)` Intrinsic dIbe_dVbc.

21 `dqbe_dvbe (F)` Intrinsic dQbe_dVbe.

22 `dqbe_dvbc (F)` Intrinsic dQbe_dVbc.

23 `dqbc_dvbe (F)` Intrinsic dQbc_dVbe.

24 `dqbc_dvbc (F)` Intrinsic dQbc_dVbc.

25 `cbcx (F)` XB-C junction capacitance.

26 `cbcxx (F)` EXTB-C junction capacitance.

27 `ccs (F)` Substrate junction capacitance.

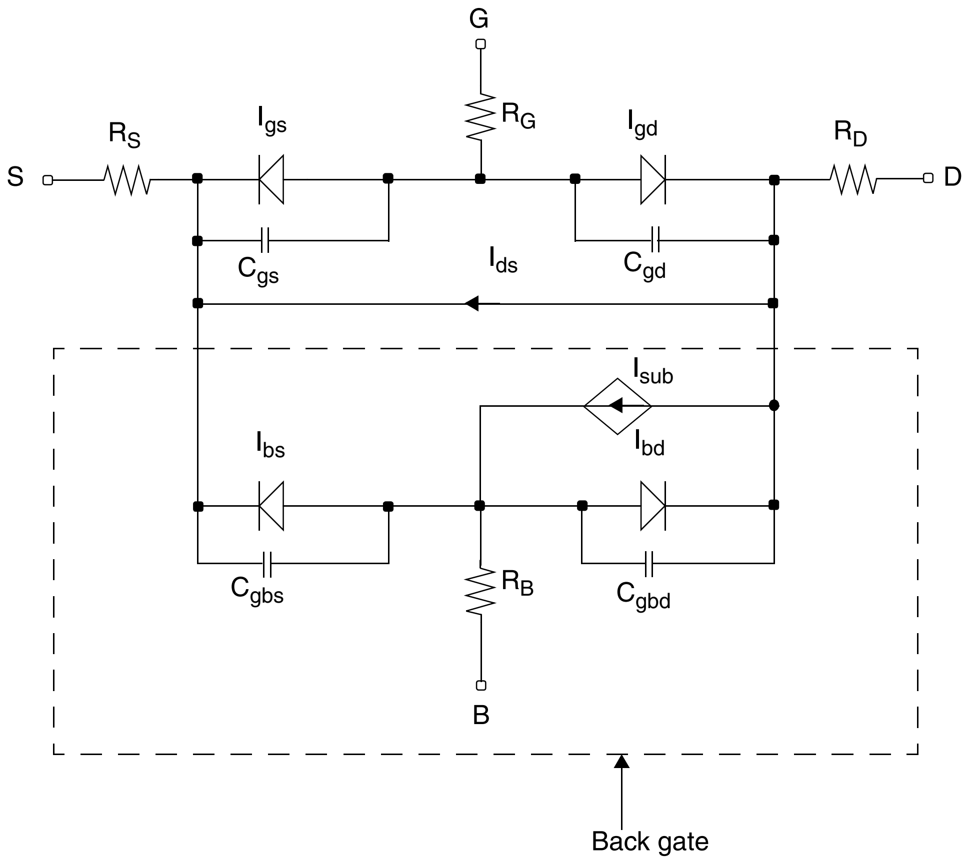
Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

10

JFET Model (jfet)

The JFET model is derived from the FET model of Shichman and Hodges. This chapter contains the following information for the JFET model:



Note: The back gate (enclosed by dotted lines) is available for $level$ = 3 only.

$$V_{GST} = V_{GS} - V_{TH}$$

where

$$V_{TH} = \begin{cases} vto & \text{if } level = 1, 2, \text{ or } 4 \\ V_{to4} & \text{if } level = 3 \end{cases}$$

$$V_{to4} = vtos(vtop - V_{BS})^{vtoe} + vtoc$$

Drain Current for the Subthreshold Region

Note: These equations apply when $V_{GST} \leq 0$.

$$I_{DS} = \begin{cases} 0 & \text{if } level = 1 \text{ or } 4 \\ \dfrac{I_{EXP} I_{LIMIT}}{I_{EXP} + I_{LIMIT}} & \text{otherwise} \end{cases}$$

where

$$I_{LIMIT} = 2 beta V_t^2$$

$$I_{EXP} = (io) e^{V_{GST}/nsV_t}(1 - e^{-V_{DS}/V_t})$$

Drain Current for the Triode Region

Note: These equations apply when $V_{GST} \geq 0$ and $V_{DS} \leq V_{GST}$.

$$I_{DS} = \begin{cases} beta(2V_{GST} - V_{DS})V_{DS}(1 + \lambda V_{DS}) & level = 1 \\ beta V_{GST}^{np} \tanh\left(\dfrac{alpha V_{DS}}{V_{GST}}\right)(1 + \lambda V_{DS}) & level = 2 \\ \beta_4 V_{GST}^{np} \tanh\left(\dfrac{alpha V_{DS}}{V_{GST}}\right)(1 + \lambda V_{DS}) & level = 3 \end{cases}$$

where

$$\beta_4 = beta\left(\frac{vto + vtop}{V_{to4} + vtop}\right)$$

$$\lambda = lambda(1 + lambda1 V_{GST})$$

Drain Current for the Saturation Region

Note: These equations apply when $V_{GST} \geq 0$ and $V_{DS} \geq V_{GST}$.

$$I_{DS} = \begin{cases} betaV_{GST}^{2}(1+\lambda V_{DS}) & level = 1 \\ betaV_{GST}^{np}\tanh\left(\frac{alphaV_{DS}}{V_{GST}}\right)(1+\lambda V_{DS}) & level = 2 \\ \beta_4 V_{GST}^{np}\tanh\left(\frac{alphaV_{DS}}{V_{GST}}\right)(1+\lambda V_{DS}) & level = 3 \end{cases}$$

where

$$Clm = \begin{cases} \frac{V_{GST}}{vto} & \text{if } V_{GS} \le 0 \\ 1 + lambda1 V_{GS} & \text{if } V_{GS} \ge 0 \end{cases}$$

Substrate Leakage Currents

If `ai` and `bi` are both greater than 0, and $V_{DS}>V_{DSAT}$,

$$I_{sub} = I_{DS} \times (V_{DS} - V_{DSAT}) \times exp\left[\frac{-b}{V_{DS} - V_{DSAT}}\right]$$

For information on bulk junction models I_{BS}, I_{BD}, C_{GBS}, and C_{GBD}, see Chapter 12, "Common MOSFET Equations."

Gate Junction Currents

$$I_{GS(GD)} = \begin{cases} is\left(e^{\frac{V_{gs(gd)}}{nV_t}} - 1\right) & \text{if Vgs(gd)} \le \text{VExpl} \\ I_{offset} + G_{Expl}V_{gs(gd)} & \text{otherwise} \end{cases}$$

where V_t is the thermal voltage given by

$$V_t = \frac{kT}{q} \ ,$$

$$V_{Expl} = nV_t \ln\left[1 + \frac{imelt}{is}\right]$$

is the forward explosion voltage,

$$G_{Expl} = \frac{(imelt + is)}{nV_t}$$

is the conductance at V_{Expl}, and

$$I_{offset} = imelt - V_{Expl} G_{Expl}$$

is the current linearly extrapolated to $V = 0$ from V_{Expl}.

Gate Junction Capacitance

$$C_{GS(GD)}(V_{GS(GD)}) = \begin{cases} \dfrac{cgs(cgd)}{\left[1 - \dfrac{V_{gsgd}}{pb}\right]^{mj}} & \text{if } V_{GS(GD)} \le fc*\text{pb} \\ \dfrac{cgs(cgd)}{(1-fc)^{mj}}\left[1 + \dfrac{mj(V_{gs(gd)} - pb*fc)}{pb(1-fc)}\right] & \text{otherwise} \end{cases}$$

Temperature Effect

Gate-Source and Gate-Drain Capacitance

$$C_{gs} = cgs_{nom}\left\{1 + mj\left[0.0004(T - Tnom) + \frac{(pb_{nom} - pb)}{pb_{nom}}\right]\right\}$$

$$C_{gd} = cgd_{nom}\left\{1 + mj\left[0.0004(T - Tnom) + \frac{(pb_{nom} - pb)}{pb_{nom}}\right]\right\}$$

Junction Potential

$$pb = pb_{nom}\left(\frac{T}{Tnom}\right) - 3V_t \ln\left[\frac{T}{Tnom}\right] - E_{g,\,nom}\left(\frac{T}{Tnom}\right) + E_g$$

Transconductance Temperature

$$Beta = Beta \times \left(\frac{T}{Tnom + bto}\right)^{bte}$$

$$Lambda = Lambda \times \left(\frac{T}{Tnom + lto}\right)^{lte}$$

$$Lambda1 = Lambda1 \times \left(\frac{T}{Tnom + lto}\right)^{lte}$$

Gate Junction Current

$$is = is_{nom}\left(\frac{T}{Tnom}\right)^{xti} \exp\left[\frac{E_{g,\,nom}}{V_{t,\,nom}} - \frac{E_g}{V_t}\right]$$

where, if SPICE-compatibility is required (set by the options),

$$E_g = 1.16 - \frac{7.02 \times 10^{-4} T^2}{1108 + T}$$

$$E_{g,\,nom} = 1.16 - \frac{7.02 \times 10^{-4} Tnom^2}{1108 + Tnom}$$

otherwise,

$$E_g = 1.17 - \frac{4.73 \times 10^{-4} T^2}{636 + T}$$

$$E_{g,nom} = 1.17 - \frac{4.73 \times 10^{-4} Tnom^2}{636 + Tnom}$$

For equations on parameters `tlev`, `tlevc`, `gap1`, and `gap2`, see Chapter 12, "Common MOSFET Equations."

Threshold Voltage

For *`tcv`*,

$$V_{TO} = V_{TO}(model) - tcv \times deltaT$$

$$V_{TOC} = V_{TOC}(model) - tcv \times deltaT$$

Parasitic Resistors

$$tempfactor = 1.0 + deltaT \times (tc1 \times deltaT + tc2)$$

$$R_{geff} = tempfactor \times R_g$$

$$R_{deff} = tempfactor \times R_d$$

$$R_{seff} = tempfactor \times R_s$$

$$R_{beff} = tempfactor \times R_b$$

Noise Model

Source Series Resistance Thermal Noise

$$\overline{i_{Rs}^2} = \frac{4kT}{rs}\Delta f$$

Drain Series Resistance Thermal Noise

$$\overline{i_{RD}^2} = \frac{4kT}{rd}\Delta f$$

Channel Thermal and Flicker Noise

$$\overline{i_{DS}^2} = \frac{8kT(g_m + g_{ds})}{3}\left(\frac{3}{2} - \frac{V'_{DS}}{2V_{DSAT}}\right) + kf\frac{(I_{DS})^{af}}{f}\Delta f$$

where

$$V'_{DS} = MIN(V_{DS}, V_{DSAT})$$

g_m is the transconductance, g_{ds} is the channel conductance, kf and af are constants for a given device. The Virtuoso® Spectre® circuit simulator defaults for kf and af are 0.0 and 1.0, respectively.

Gate Junction Noise

$$\overline{i_{gs}^2} = 2qI_{GS}\Delta f + kfd\frac{I_{GS}^{afg}}{f}\Delta f$$

$$\overline{i_{gd}^2} = 2qI_{GD}\Delta f + kfd\frac{I_{GD}^{afg}}{f}\Delta f$$

Scaling Effects

The following are the Spectre scaling effects:

- *is*, *cgs*, *cgd*, and *beta* are multiplied by *area*.
- *rs* and *rd* are divided by *area*.
- All noises are multiplied by *area*.

Component Statements

Sample Instance Statement:

```
jf1 (net1 net2 0) jmod area=1
```

Sample Model Statement

```
model jmod jfet beta=9e-5 lambda=0 type=n vt0=-18.7 rd=10 rs=10 cgs=1.3e-13 pb=0.65
```

Instance Definition

```
Name  d  g  s  [b] ModelName parameter=value ...
```

You do not have to specify the back gate terminal when you use the four-terminal model. If left unspecified, the substrate is connected to ground.

Instance Parameters

1	`area=1`	Junction area factor.
2	`m=1`	Multiplicity factor.
3	`region=triode`	Estimated operating region. Spectre outputs number (0-4) in a rawfile. Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.
4	`isnoisy=yes`	Should resistor generate noise. Possible values are `no` or `yes`.
5	`trise=0`	Temperature rise from ambient.

Model Definition

```
model modelName jfet parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n`	Transistor type. Possible values are `n` or `p`.

Drain current model parameters

2 `level=1`	Drain current model level selector.
3 `vto=-2 V`	Pinchoff voltage.
4 `beta=0.0001` A/V^2	Transconductance parameter.
5 `lambda=0 1/V`	Channel length modulation parameter.
6 `lambda1=0 1/V`	Gate dependence of channel length modulation parameter.
7 `np=2`	Power-law exponent.
8 `alpha=2`	Triode-to-saturation transition parameter.
9 `io=0 A`	Subthreshold current parameter.
10 `ns=1`	Subthreshold swing parameter.
11 `ai=0 1/V`	Impact ionization current coefficient.
12 `bi=0 V`	Impact ionization current exponent.

Four terminal threshold voltage parameters

13 `vtop=0.6 V`	Back gate to channel junction potential.
14 `vtos=1.2 V`	Threshold voltage slope.

15 `vtoe=0.33`	Threshold voltage exponent.
16 `vtoc=-3.3 V`	Threshold voltage constant.

Parasitic resistance parameters

17 `rd=0 Ω`	Drain resistance (/area).
18 `rs=0 Ω`	Source resistance (/area).
19 `rg=0 Ω`	Gate resistance (/area).
20 `rb=0 Ω`	Back gate resistance (/area).
21 `minr=0.1 Ω`	Minimum source/drain/gate resistance.

Junction diode model parameters

22 `is=1e-14 A`	Gate saturation current (*area).
23 `n=1`	Emission coefficient for G-D and G-S junctions.
24 `imelt=`imax' A`	Explosion current (*area).
25 `dskip=yes`	Use simple piece-wise linear model for diode currents below 0.1*`iabstol`. Possible values are `no` or `yes`.

Junction capacitance model parameters

26 `tt=0 s`	Transit time.
27 `cgs=0 F`	Gate-source zero-bias junction capacitance (*area).
28 `cgd=0 F`	Gate-drain zero-bias junction capacitance (*area).
29 `mj=1/2`	Junction grading coefficient.
30 `pb=1 V`	Gate-junction potential.
31 `fc=0.5`	Junction capacitor forward-bias threshold.

Four terminal junction parameters

32 `isb=1e-14 A` Back gate-saturation current (*area).

33 `nb=1` Emission coefficient for back gate-junctions.

34 `cgbs=0 F` Back gate-source zero-bias junction capacitance (*area).

35 `cgbd=0 F` Back gate-drain zero-bias junction capacitance (*area).

36 `mjb=1/2` Back gate-junction grading coefficient.

37 `pbb=1 V` Back gate-junction potential.

Temperature effect parameters

38 `tnom (C)` Parameters measurement temperature. Default set by `options`.

39 `trise=0 C` Temperature rise from ambient.

40 `xti=3` Temperature exponent for effect on `is`.

41 `tlev=0` DC temperature selector.

42 `tlevc=0` AC temperature selector.

43 `eg=1.12452 V` Energy band gap.

44 `gap1=7.02e-4 V/C` Band gap temperature coefficient.

45 `gap2=1108 C` Band gap temperature offset.

46 `eglev=0` DC temperature selector.

47 `tcv=0 1/C` Threshold voltage temperature coefficient.

48 `bto=0 C` Transconductance parameter temperature offset.

49 `bte=0` Transconductance parameter temperature exponent.

50 `lto=0 C` Channel length modulation parameters temperature offset.

51 `lte=0` Channel length modulation parameters temperature exponent.

52 `tc1=0 1/C` Linear temperature coefficient for parasitic resistors.

53 `tc2=0` C^{-2} Quadratic temperature coefficient for parasitic resistors.

54 `pta=0 V/C` Junction potential temperature coefficient.

Operating region warning control parameters

55 `alarm=none` Forbidden operating region.
Possible values are `none`, `off`, `triode`, `sat`, `subth`, or `rev`.

56 `imax=1 A` Maximum allowable current (*area).

57 `bvj=∞ V` Junction reverse breakdown voltage.

Noise parameters

58 `kf=0` Flicker noise (1/f) coefficient.

59 `af=1` Flicker noise (1/f) exponent.

60 `kfd=0` Flicker noise (1/f) coefficient for gate diodes.

61 `afg=1` Flicker noise (1/f) exponent for gate diodes.

Compatibility model parameters

62 `ldel=0 m` Difference between drawn and actual or optical device length.

63 `wdel=0 m` Difference between drawn and actual or optical device Width.

64 `rsh=0 Ω` heavily doped region, sheet resistance (ohm/sq).

65 `rshg=0 Ω` Gate sheet resistance (ohm/sq).

66 `rshl=0 Ω` lightly doped region, sheet resistance (ohm/sq).

67 `hdif=0 m` distance of the heavily diffused or low resistance region from source or drain contact to lightly doped region.

68 `ldif=0 m` distance of the lightly doped region from heavily doped region to transistor edge.

69 `trd=0 1/C` temperature coefficient for drain resistance.

70 `trs=0 1/C` temperature coefficient for source resistance.

71 `acm=0` area calculation method. acm=0 area=w/l, acm=1 area=w.l.

Imax and Imelt

The `imax` parameter aids convergence and prevents numerical overflow. The junction characteristics of the device are accurately modeled for current up to `imax`. If `imax` is exceeded during iterations, the linear model is substituted until the current drops below imax or until convergence is achieved. If convergence is achieved with the current exceeding `imax`, the results are inaccurate, and Spectre prints a warning.

A separate model parameter, `imelt`, is used as a limit warning for the junction current. This parameter can be set to the maximum current rating of the device. When any component of the junction current exceeds `imelt`, note that base and collector currents are composed of many exponential terms, Spectre issues a warning and the results become inaccurate. The junction current is linearized above the value of `imelt` to prevent arithmetic exception, with the exponential term replaced by a linear equation at `imelt`.

The `bv` parameter is used to detect the junction breakdown only. The breakdown currents of the junctions are not modeled.

Operating-Point Parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

2 `region=triode` Estimated operating region. Spectre outputs number (0-4) in a rawfile.
Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.

3 `ids (A)` Resistive drain current.

4 `id (A)` Id drain current.

5 `vgs (V)` Gate-source voltage.

6 `vds (V)` Drain-source voltage.

7 `vth (V)` Threshold at op point.

8 `vdsat (V)` Drain saturation voltage.

9 `gm (S)` Common-source transconductance.

10 `gds (S)` Common-source output conductance.

11 `cgs (F)` Gate-source capacitance.

12 `cgd (F)` Gate-drain capacitance.

13 `ig (A)` Resistive gate current.

14 `pwr (W)` Power at op point.

15 `qd (V)` Threshold at op point.

16 `qg (V)` Threshold at op point.

17 `qs (V)` Threshold at op point.

18 `qb (V)` Threshold at op point.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

11

Philips Models

This chapter describes the component statements for the following models:

Diode Level 500 (dio500)

The `dio500` model provides a detailed description of the diode currents in forward and reverse biased Si-diodes. It is described in the Philips Bipolar Modelbook (Dec.93) as `Diode level 500`. Information on how to obtain this document can be found on Source Link by searching for Philips.

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In extension to the model book description a minimum conductance `gmin` is inserted between the diode nodes to aid convergence. The value of `gmin` is set by an options statement, default is gmin = 1.0e-12 S.

The `imax` parameter is used to aid convergence and to prevent numerical overflow. The junction characteristics of the diode are accurately modeled for currents up to `imax`. For currents above `imax`, the junction is modeled as a linear resistor, and a warning is printed.

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Sample Instance Statement

```
d1 (pnode 0) phdiode area=2
```

Sample Model Statement

```
model phdiode dio500 is=3.5e-12 rs=26.3 n=2.7 imax=1e20 vlc=1.8 vbr=9.63 cj=2.65e-11 dta=12.88 tau=7.5e-10 tnom=25
```

Instance Definition

```
Name  a  k ModelName parameter=value ...
```

Instance Parameters

1 `area=1.0` Multiplication factor.

2 `mult` Alias of area factor.

3 `m=1.0` Multiplicity factor.

4 `region=fwd` Estimated DC operating region, used as a convergence aid. Possible values are `fwd`, `rev` or `brk`.

Model Definition

```
model modelName dio500 parameter=value ...
```

Model Parameters

1 `is=7.13e-13 A` Saturation current.

2 `n=1.044` Junction emission coefficient.

3 `vlc=0.0 V` Voltage dependence at low forward currents.

4 `vbr=7.459 V` Breakdown voltage.

5 `emvbr=1.36e+06 V/cm`
Electric field at breakdown.

6 `csrh=7.44e-07 A/cm`
Shockley-Read-Hall generation.

7 `cbbt=3.255 A/V` Band to band tunneling.

8 `ctat=3.31e-06 A/cm`
Trap assisted tunneling.

9 `rs=0.0 Ω` Series resistance.

10 `tau=500.0e-12 s` Transit time.

11 `cj=7.0e-12 F` Zero-bias depletion capacitance.

12 `vd=0.9 V` Diffusion voltage.

13 `p=0.4` Grading coefficient.

14 `tref (C)` Reference temperature. Default set by option `tnom`.

15 `tnom (C)` Alias of `tref`.

16 `tr (C)` Alias of `tref`.

17 `vg=1.206 V`	Bandgap voltage.
18 `ptrs=0.0`	Power for temperature dependence of `rs`.
19 `kf=0.0`	Flickernoise coefficient.
20 `af=1.0`	Flickernoise exponent.
21 `dta=0.0 K`	Difference between device temperature and ambient temperature.
22 `trise (K)`	Alias of `dta`.
23 `imax=1.0 A`	Explosion current.

Operating-Point Parameters

1 `vak (V)`	Diode voltage, measured from anode to cathode (including `rs`).
2 `id (A)`	Total resistive diode current.
3 `qd (Coul)`	Diffusion charge.
4 `qt (Coul)`	Depletion charge.
5 `rst (Ω)`	Series resistance (temperature updated).
6 `rl (Ω)`	AC linearized resistance.
7 `cl (F)`	AC linearized capacitance.
8 `pwr (W)`	Power dissipation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Lateral PNP Transistor (bjt301)

The bjt301 model provides an extensive description of a lateral integrated circuit junction-isolated PNP transistor. It is described in the Philips Bipolar Modelbook (Dec.93) as TPL level 301.

In extension to the model book description a minimum conductance `gmin` is inserted between the internal base and internal collector node, between the internal base and the internal emitter node, and between the external base and the substrate node to aid convergence. The value of `gmin` is set by an options statement, default = 1e-12 S.

The `imax` parameter is used to aid convergence and to prevent numerical overflow. The junction characteristics of the transistor are accurately modeled for currents up to `imax`. For currents above `imax`, the junction is modeled as a linear resistor and a warning is printed.

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Sample Instance Statement:

```
q2 (minus net3 vcc) pnp_mod region=fwd area=1 m=1
```

Sample Model Statement:

```
model pnp_mod bjt301 type=pnp struct=lateral is=1e-14 bf=85 ilf=11e-9 ikf=95e-6
re=3.2 cje=0.352e-12
```

Instance Definition

```
Name  c  b  e  [s] ModelName parameter=value ...
```

Instance Parameters

1	`area=1`	Area factor.
2	`mult=1`	Alias of area factor.
3	`m=1`	Multiplicity factor.
4	`region=fwd`	Estimated DC operating region, used as a convergence aid. Possible values are `off`, `fwd`, `rev`, or `sat`.

Model Definition

model modelName bjt301 parameter=value ...

Model Parameters

Structural parameters

1	`type=pnp`	Transistor type. Possible values are `pnp` or `pnpl`.
2	`struct=lateral`	Transistor structure. Possible values are `lateral`.

Current parameters

3 `is=1.0e-15 A`	Saturation current.
4 `imax=1.0 A`	Explosion current.
5 `bf=100.0 A/A`	Ideal forward common-emitter current gain (beta).
6 `ilf=10.0e-9 A`	Low-level knee-current of forward beta.
7 `nlf=2.0`	Emission coefficient of non-ideal forward base current.
8 `ikf=100.0e-6 A`	High-injection knee-current of forward beta.
9 `nhf=1.0`	Basewidening exponent.
10 `veaf=50.0 V`	Early voltage related to collector junction.
11 `br=10.0 A/A`	Ideal reverse common-collector current gain (beta).
12 `ilr=10.0e-9 A`	Low-level knee-current of reverse beta.
13 `nlr=2.0`	Emission coefficient of non-ideal reverse base current.
14 `ikr=100.0e-6 A`	High-injection knee-current of reverse beta.
15 `iks=100.0e-6 A`	High-injection current of substrate effect.
16 `xcs=1.0`	Current fraction of c-b-s transistor.
17 `xes=0.01`	Current fraction of e-b-s transistor.

Parasitic resistance parameters

18 `rc=1.0` Ω	Collector resistance.
19 `rbc=10.0` Ω	Constant part of base resistance.
20 `rbv=10.0` Ω	Variable part of base resistance.
21 `re=1.0` Ω	Emitter series resistance.

Junction capacitance parameters

22 `taub=25.0e-9 s` Forward transit time related to neutral base.

23 `taune=1.0e-9 s` Forward transit time related to neutral emitter in neutral e-b region.

24 `mtau=1.0` Coefficient of current dependence of taune.

25 `cje=100.0e-15 F` Zero bias emitter-base depletion capacitance.

26 `vde=0.55 V` Emitter-base diffusion voltage.

27 `pe=0.333` Emitter-base grading coefficient.

28 `taur=100.0e-9 s` Ideal reverse transit time.

29 `cjc=200.0e-15 F` Zero bias collector-base depletion capacitance.

30 `vdc=0.55 V` Collector-base diffusion voltage.

31 `pc=0.333` Collector-base grading coefficient.

32 `cjs=1.0e-12 F` Zero bias substrate junction depletion capacitance.

33 `vds=0.55 V` Substrate junction diffusion voltage.

34 `ps=0.333` Substrate junction grading coefficient.

35 `exphi=0.3` Excess phase shift.

36 `fc=0.95` Coefficient for forward bias capacitance.

Temperature effects parameters

37 `tref (C)` Reference temperature. Default set by option `tnom`.

38 `tnom (C)` Alias of tref. Default set by option `tnom`.

39 `dta=0.0 K` Difference between device temperature and ambient temperature.

40 `trise=0.0 K` Alias of dta.

41 `ptbf=0.0` Power for temperature dependence of `bf`.

42 `ptbr=0.0` Power for temperature dependence of `br`.

43 `ptrc=0.0` Power for temperature dependence of `rc`.

44 `ptrb=0.0` Power for temperature dependence of `rbc` and `rbv`.

45 `vg=1.2 V` Band-gap voltage.

46 `pt=1.2` Power for temperature dependence of diffusion coefficient.

Noise model parameters

47 `kf=0.0` Flickernoise coefficient.

48 `af=1.0` Flickernoise exponent.

Output Parameters

1 `ist (A)` Saturation current.

2 `iole (A)` Non-ideal forward base saturation current.

3 `iolc (A)` Non-ideal reverse base saturation current.

4 `bft (A/A)` Ideal forward common-emitter current gain (beta).

5 `brt (A/A)` Ideal reverse common-collector current gain (beta).

6 `rct (Ω)` Collector resistance.

7 `rbct (Ω)` Constant part of base resistance.

8 `rbvt (Ω)` Variable part of base resistance.

9 `taubt (s)` Forward transit time related to neutral base.

10 `cjet (F)` Zero bias emitter-base depletion capacitance.

11 `vdet (V)` Emitter-base diffusion voltage.

12 `taurt (s)` Ideal reverse transit time.

13 `cjct (F)` Zero bias collector-base depletion capacitance.

14 `vdct (V)` Collector-base diffusion voltage.

15 `cjst (F)` Zero bias substrate junction depletion capacitance.

16 `vdst (V)` Substrate junction diffusion voltage.

Operating-Point Parameters

1 `ib (A)` Base current.

2 `ic (A)` Collector current.

3 `ie (A)` Emitter current.

4 `isub (A)` Substrate current.

5 `vbe (V)` Base-emitter voltage.

6 `vbc (V)` Base-collector voltage.

7 `vce (V)` Collector-emitter voltage.

8 `vsubj (V)` Substrate voltage.

9 `betadc (A/A)` Ratio of DC collector current to DC Base current.

10 `rb` (Ω) Base resistance at operating point.

11 `rc` (Ω) Collector resistance at operating point.

12 `re` (Ω) Emitter resistance at operating point.

13 `icb (A)` Collector-Base current.

14 `ieb (A)` Emitter-Base current.

15 `icsub (A)` Collector-Substrate current.

16 `iesub (A)` Emitter-Substrate current.

17 `pwr (W)` Power.

18 `gpi (S)` Conductance emitter-base junction.

19 `gmu (S)` Conductance collector-base junction.

20 `gf (S)` Forward transconductance.

21 `gr (S)` Reverse transconductance.

22 `gs (S)` Conductance substrate-base junction.

23 `g3 (S)` Transconductance (parasitic PNP) c-b-s transistor.

24 `g4 (S)` Transconductance (parasitic PNP) e-b-s transistor.

25 `ced (F)` Emitter diffusion capacitance.

26 `ccd (F)` Collector diffusion capacitance.

27 `cet (F)` Emitter junction depletion capacitance.

28 `cct (F)` Collector junction depletion capacitance.

29 `cst (F)` Substrate junction depletion capacitance.

30 `betaac (A/A)` Small-signal common-emitter current gain.

31 `ft (Hz)` Unity small-signal current-gain frequency.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

g3	OP-23	kf	M-47	re	OP-12	xes	M-17
g4	OP-24	m	I-3	region	I-4		

Lateral PNP Transistor (bjt500)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  c  b  e  s ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Area factor.

2 `region=fwd` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `sat`, `rev`, or `fwd`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName bjt500 parameter=value ...
```

Model Parameters

1 `level=500` Bipolar Level.

2 `is=1.8e-16 A` Collector-emitter saturation current.

3 `bf=131 A` Ideal forward common-emitter current gain.

4 `ibf=2.6e-14 A`	Saturation current of non-ideal forward base current.
5 `vlf=0.54 V`	Cross-over voltage of non-ideal forward base current.
6 `ik=0.00011 A`	High injection knee current.
7 `xifv=0.43`	Vertical fraction of forward current.
8 `eafl=20.5 V`	Early voltage of the lateral forward current component.
9 `eafv=75 V`	Early voltage of the vertical forward current component.
10 `br=25 A`	Ideal reverse common-emitter current gain.
11 `ibr=1.2e-13 A`	Saturation current of non-ideal reverse base current.
12 `vlr=0.48 V`	Cross-over voltage of non-ideal reverse base current.
13 `xirv=0.43`	Vertical fraction of reverse current.
14 `earl=13.1 V`	Early voltage of the lateral reverse current component.
15 `earv=104 V`	Early voltage of the vertical reverse current component.
16 `xes=0.0027`	Ratio between saturation current of e-b-s transistor and e-b-c transistor.
17 `xhes=0.7`	Fraction of substrate current of e-b-s transistor subject to high injection.
18 `xcs=3`	Ratio between saturation current of c-b-s transistor and c-b-e transistor.
19 `xhcs=1`	Fraction of substrate current of c-b-s transistor subject to high injection.
20 `iss=4e-13 A`	Saturation current of substrate-base diode.
21 `rcex=5 Ω`	External part of the collector resistance.
22 `rcin=47 Ω`	Internal part of the collector resistance.
23 `rbcc=10 Ω`	Constant part of the base resistance `rbc`.

24 `rbcv=10 Ω`	Variable part of the base resistance `rbc`.
25 `rbec=10 Ω`	Constant part of the base resistance `rbe`.
26 `rbev=50 Ω`	Variable part of the base resistance `rbe`.
27 `reex=27 Ω`	External part of the emitter resistance.
28 `rein=66 Ω`	Internal part of the emitter resistance.
29 `rsb=1e+15 Ω`	Substrate-base leakage resistance.
30 `tlat=2.4e-09 s`	Low injection (forward and reverse) transit time of charge stored in the epilayer between emitter and collector.
31 `tfvr=3e-08 s`	Low injection forward transit time due to charge stored in the epilayer under the emitter.
32 `tfn=2e-10 s`	Low injection forward transit time due to charge stored in the emitter and the buried layer under the emitter.
33 `cje=6.1e-14 F`	Zero-bias emitter-base depletion capacitance.
34 `vde=0.52 V`	Emitter-base diffusion voltage.
35 `pe=0.3`	Emitter-base grading coefficient.
36 `trvr=1e-09 s`	Low injection reverse transit time due to charge stored in the epilayer under the collector.
37 `trn=3e-09 s`	Low injection reverse transit time due to charge stored in the collector and the buried layer under the collector.
38 `cjc=3.9e-13 F`	Zero-bias collector-base depletion capacitance.
39 `vdc=0.57 V`	Collector-base diffusion voltage.
40 `pc=0.36`	Collector-base grading coefficient.
41 `cjs=1.3e-12 F`	Zero-bias substrate-base depletion capacitance.
42 `vds=0.52 V`	Substrate-base diffusion voltage.

43 `ps=0.35`	Substrate-base grading coefficient.
44 `tref=25 C`	Reference temperature. Default set by option `tnom`.
45 `dta=0 K`	Difference between the device temperature and the ambient analysis temperature.
46 `vgeb=1.21 V`	Bandgap voltage of the emitter-base depletion region.
47 `vgcb=1.21 V`	Bandgap voltage of the collector-base depletion region.
48 `vgsb=1.21 V`	Bandgap voltage of the substrate-base depletion region.
49 `vgb=1.21 V`	Bandgap voltage of the base between emitter and collector.
50 `vge=1.21 V`	Bandgap voltage of the emitter.
51 `vgje=1.12 V`	Bandgap voltage recombination emitter-base junction.
52 `ae=4.48`	Temperature coefficient of `bf`.
53 `spb=2.85`	SC.
54 `snb=2.6`	Temperature coefficient of the epitaxial base electron mobility.
55 `snbn=0.3`	Temperature coefficient of buried layer electron mobility.
56 `spe=0.73`	Temperature coefficient of emitter hole mobility.
57 `spc=0.73`	Temperature coefficient of collector hole mobility.
58 `sx=1`	Temperature coefficient of combined minority carrier mobility in emitter and buried layer.
59 `kf=0`	Flickernoise coefficient.
60 `af=1`	Flickernoise exponent.
61 `exphi=0`	Not used in model bjt500.
62 `type=n`	Transistor gender. Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

63 `imax=1.0 A` Explosion current.

64 `tnom (C)` alias of tnom.

65 `tr (C)` alias of tnom.

Output Parameters

1 `is (A)` Collector-emitter saturation current.

2 `bf (A)` Ideal forward common-emitter current gain .

3 `ibf (A)` Saturation current of non-ideal forward base current.

4 `vlf (V)` Cross-over voltage of non-ideal forward base current.

5 `ik (A)` High injection knee current.

6 `xifv` Vertical fraction of forward current.

7 `eafl (V)` Early voltage of the lateral forward current component.

8 `eafv (V)` Early voltage of the vertical forward current component.

9 `br (A)` Ideal reverse common-emitter current gain.

10 `ibr (A)` Saturation current of non-ideal reverse base current.

11 `vlr (V)` Cross-over voltage of non-ideal reverse base current.

12 `xirv` Vertical fraction of reverse current.

13 `earl (V)` Early voltage of the lateral reverse current component.

14 `earv (V)` Early voltage of the vertical reverse current component.

15 `xes` Ratio between saturation current of e-b-s transistor and e-b-c transistor.

16 `xhes` Fraction of substrate current of e-b-s transistor subject to high injection.

17 `xcs`	Ratio between saturation current of c-b-s transistor and c-b-e transistor.
18 `xhcs`	Fraction of substrate current of c-b-s transistor subject to high injection.
19 `iss (A)`	Saturation current of substrate-base diode.
20 `rcex (Ω)`	External part of the collector resistance.
21 `rcin (Ω)`	Internal part of the collector resistance.
22 `rbcc (Ω)`	Constant part of the base resistance `rbc`.
23 `rbcv (Ω)`	Variable part of the base resistance `rbc`.
24 `rbec (Ω)`	Constant part of the base resistance `rbe`.
25 `rbev (Ω)`	Variable part of the base resistance `rbe`.
26 `reex (Ω)`	External part of the emitter resistance.
27 `rein (Ω)`	Internal part of the emitter resistance.
28 `rsb (Ω)`	Substrate-base leakage resistance.
29 `tlat (s)`	Low injection .
30 `tfvr (s)`	Low injection forward transit time due to charge stored in the epilayer under the emitter.
31 `tfn (s)`	Low injection forward transit time due to charge stored in the emitter and the buried layer under the emitter.
32 `cje (F)`	Zero-bias emitter-base depletion capacitance.
33 `vde (V)`	Emitter-base diffusion voltage.
34 `pe`	Emitter-base grading coefficient.
35 `trvr (s)`	Low injection reverse transit time due to charge stored in the epilayer under the collector.

36 `trn (s)`	Low injection reverse transit time due to charge stored in the collector and the buried layer under the collector.
37 `cjc (F)`	Zero-bias collector-base depletion capacitance.
38 `vdc (V)`	Collector-base diffusion voltage.
39 `pc`	Collector-base grading coefficient.
40 `cjs (F)`	Zero-bias substrate-base depletion capacitance.
41 `vds (V)`	Substrate-base diffusion voltage.
42 `ps`	Substrate-base grading coefficient.
43 `vgeb (V)`	Bandgap voltage of the emitter-base depletion region.
44 `vgcb (V)`	Bandgap voltage of the collector-base depletion region.
45 `vgsb (V)`	Bandgap voltage of the substrate-base depletion region.
46 `vgb (V)`	Bandgap voltage of the base between emitter and collector.
47 `vge (V)`	Bandgap voltage of the emitter.
48 `vgje (V)`	Bandgap voltage recombination emitter-base junction.
49 `ae`	Temperature coefficient of `bf`.
50 `spb`	SC.
51 `snb`	Temperature coefficient of the epitaxial base electron mobility.
52 `snbn`	Temperature coefficient of buried layer electron mobility.
53 `spe`	Temperature coefficient of emitter hole mobility.
54 `spc`	Temperature coefficient of collector hole mobility.
55 `sx`	Temperature coefficient of combined minority carrier mobility in emitter and buried layer.
56 `kf`	Flickernoise coefficient.

57 `af` Flickernoise exponent.

58 `exphi` Not used in model bjt500.

Operating-Point Parameters

1 `ic (A)` External DC collector current.

2 `ib (A)` External DC base current.

3 `ie (A)` Resistive emitter current.

4 `isub (A)` Resistive substrate current.

5 `iflat (A)` Lateral forward current.

6 `irlat (A)` Lateral reverse current.

7 `ifver (A)` Vertical forward current.

8 `irver (A)` Vertical reverse current.

9 `ire (A)` ideal forward base current.

10 `ile (A)` Non-ideal forward base current.

11 `ise (A)` Forward substrate current.

12 `irc (A)` Ideal reverse base current.

13 `ilc (A)` Non-ideal reverse base current.

14 `isc (A)` Reverse substrate current.

15 `isf (A)` Reverse leakage current of the substrate-base junction.

16 `ip (A)` Main current.

17 `betadc` External DC current gain Ic/Ib.

18 `vbc (V)` Base-collector voltage.

19 `vbe (V)` Base-emitter voltage.

20 `vce (V)`	Collector-emitter voltage.
21 `vsb (V)`	Substrate-base voltage.
22 `rcex (Ω)`	External part of the collector resistance.
23 `rcin (Ω)`	Internal part of the collector resistance.
24 `reex (Ω)`	External part of the emitter resistance.
25 `rein (Ω)`	Internal part of the emitter resistance.
26 `rbc (Ω)`	Base resistance under the collector.
27 `rbe (Ω)`	Base resistance under the emitter.
28 `rsb (Ω)`	Ohmic leakage across the substrate-base junction.
29 `pwr (W)`	Power.
30 `gfl (S)`	Forward conductance, lateral path.
31 `grl (S)`	Reverse conductance, lateral path.
32 `g11 (S)`	Forward conductance, vertical path.
33 `g12 (S)`	Collector Early-effect on Ifver.
34 `g21 (S)`	Emitter Early-effect on Irver.
35 `g22 (S)`	Reverse conductance, vertical path.
36 `gpiv (S)`	Conductance emitter-base junction.
37 `gmuv (S)`	Conductance collector-base junction.
38 `gbe (S)`	Emitter-side: base conductance B1-B.
39 `gibe (S)`	Emitter Early-effect on Ib1b.
40 `gbc (S)`	Collector-side: base conductance B2-B.
41 `gibc (S)`	Collector Early-effect on Ib2b.

42 gise (S)	Transconductance (parasitic PNP) e-b-s transistor.
43 gisc (S)	Transconductance (parasitic PNP) c-b-s transistor.
44 gsb (S)	Conductance substrate-base junction.
45 cpil (F)	Forward diffusion capacitance, lateral path.
46 cipil (F)	Collector Early-effect on Qflat.
47 cpiv (F)	Forward total capacitance, vertical path.
48 cmul (F)	Reverse diffusion capacitance, lateral path.
49 cimul (F)	Emitter Early-effect on Qrlat.
50 cmuv (F)	Reverse total capacitance, vertical path.
51 csb (F)	Total capacitance substrate-base junction.
52 irbe (A)	Ideal total forward base current.
53 irbc (A)	Ideal total reverse base current.
54 irsb (A)	Substrate base leakage resistance current.

Parameter Index

In the following index, I refers to instance parameters, M refers to the model parameters section, O refers to the output parameters section, and OP refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of M-35 means the 35th model parameter.

Lateral PNP Transistor (bjt500t)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  c  b  e  s  dt ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Area factor.

2 `region=fwd` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `sat`, `rev`, or `fwd`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName bjt500t parameter=value ...
```

Model Parameters

1 `level=500` Bipolar Level.

2 `is=1.8e-16 A` Collector-emitter saturation current.

3 `bf=131 A` Ideal forward common-emitter current gain .

4 `ibf=2.6e-14 A` Saturation current of non-ideal forward base current.

5 `vlf=0.54 V` Cross-over voltage of non-ideal forward base current.

6 `ik=0.00011 A` High injection knee current.

7 `xifv=0.43` Vertical fraction of forward current.

8 `eafl=20.5 V` Early voltage of the lateral forward current component.

9 `eafv=75 V` Early voltage of the vertical forward current component.

10 `br=25 A` Ideal reverse common-emitter current gain.

11 `ibr=1.2e-13 A` Saturation current of non-ideal reverse base current.

12 `vlr=0.48 V` Cross-over voltage of non-ideal reverse base current.

13 `xirv=0.43` Vertical fraction of reverse current.

14 `earl=13.1 V` Early voltage of the lateral reverse current component.

15 `earv=104 V` Early voltage of the vertical reverse current component.

16 `xes=0.0027` Ratio between saturation current of e-b-s transistor and e-b-c transistor.

17 `xhes=0.7` Fraction of substrate current of e-b-s transistor subject to high injection.

18 `xcs=3` Ratio between saturation current of c-b-s transistor and c-b-e transistor.

19 `xhcs=1` Fraction of substrate current of c-b-s transistor subject to high injection.

20 `iss=4e-13 A` Saturation current of substrate-base diode.

21 `rcex=5 Ω` External part of the collector resistance.

22 `rcin=47 Ω` Internal part of the collector resistance.

23 `rbcc=10 Ω` Constant part of the base resistance `rbc`.

24 `rbcv=10 Ω` Variable part of the base resistance `rbc`.

25 `rbec=10 Ω` Constant part of the base resistance `rbe`.

26 `rbev=50 Ω` Variable part of the base resistance `rbe`.

27 `reex=27 Ω`	External part of the emitter resistance.
28 `rein=66 Ω`	Internal part of the emitter resistance.
29 `rsb=1e+15 Ω`	Substrate-base leakage resistance.
30 `tlat=2.4e-09 s`	Low injection (forward and reverse) transit time of charge stored in the epilayer between emitter and collector.
31 `tfvr=3e-08 s`	Low injection forward transit time due to charge stored in the epilayer under the emitter.
32 `tfn=2e-10 s`	Low injection forward transit time due to charge stored in the emitter and the buried layer under the emitter.
33 `cje=6.1e-14 F`	Zero-bias emitter-base depletion capacitance.
34 `vde=0.52 V`	Emitter-base diffusion voltage.
35 `pe=0.3`	Emitter-base grading coefficient.
36 `trvr=1e-09 s`	Low injection reverse transit time due to charge stored in the epilayer under the collector.
37 `trn=3e-09 s`	Low injection reverse transit time due to charge stored in the collector and the buried layer under the collector.
38 `cjc=3.9e-13 F`	Zero-bias collector-base depletion capacitance.
39 `vdc=0.57 V`	Collector-base diffusion voltage.
40 `pc=0.36`	Collector-base grading coefficient.
41 `cjs=1.3e-12 F`	Zero-bias substrate-base depletion capacitance.
42 `vds=0.52 V`	Substrate-base diffusion voltage.
43 `ps=0.35`	Substrate-base grading coefficient.
44 `tref=25 C`	Reference temperature. Default set by option `tnom`.
45 `dta=0 K`	Difference between the device temperature and the ambient analysis temperature.

46 `vgeb=1.21 V` Bandgap voltage of the emitter-base depletion region.

47 `vgcb=1.21 V` Bandgap voltage of the collector-base depletion region.

48 `vgsb=1.21 V` Bandgap voltage of the substrate-base depletion region.

49 `vgb=1.21 V` Bandgap voltage of the base between emitter and collector.

50 `vge=1.21 V` Bandgap voltage of the emitter.

51 `vgje=1.12 V` Bandgap voltage recombination emitter-base junction.

52 `ae=4.48` Temperature coefficient of `bf`.

53 `spb=2.85` SC.

54 `snb=2.6` Temperature coefficient of the epitaxial base electron mobility.

55 `snbn=0.3` Temperature coefficient of buried layer electron mobility.

56 `spe=0.73` Temperature coefficient of emitter hole mobility.

57 `spc=0.73` Temperature coefficient of collector hole mobility.

58 `sx=1` Temperature coefficient of combined minority carrier mobility in emitter and buried layer.

59 `kf=0` Flickernoise coefficient.

60 `af=1` Flickernoise exponent.

61 `exphi=0` Not used in model bjt500.

62 `rth=300 K/W` Thermal resistance.

63 `cth=3e-09 J/K` Thermal capacitance.

64 `ath=0` Temperature coefficient of the thermal resistance.

65 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

66 `imax=1.0 A` Explosion current.

67 `tnom (C)` alias of tnom.

68 `tr (C)` alias of tnom.

Output Parameters

1 `is (A)` Collector-emitter saturation current.

2 `bf (A)` Ideal forward common-emitter current gain .

3 `ibf (A)` Saturation current of non-ideal forward base current.

4 `vlf (V)` Cross-over voltage of non-ideal forward base current.

5 `ik (A)` High injection knee current.

6 `xifv` Vertical fraction of forward current.

7 `eafl (V)` Early voltage of the lateral forward current component.

8 `eafv (V)` Early voltage of the vertical forward current component.

9 `br (A)` Ideal reverse common-emitter current gain.

10 `ibr (A)` Saturation current of non-ideal reverse base current.

11 `vlr (V)` Cross-over voltage of non-ideal reverse base current.

12 `xirv` Vertical fraction of reverse current.

13 `earl (V)` Early voltage of the lateral reverse current component.

14 `earv (V)` Early voltage of the vertical reverse current component.

15 `xes` Ratio between saturation current of e-b-s transistor and e-b-c transistor.

16 `xhes` Fraction of substrate current of e-b-s transistor subject to high injection.

17 `xcs` Ratio between saturation current of c-b-s transistor and c-b-e transistor.

18 `xhcs`	Fraction of substrate current of c-b-s transistor subject to high injection.
19 `iss (A)`	Saturation current of substrate-base diode.
20 `rcex (Ω)`	External part of the collector resistance.
21 `rcin (Ω)`	Internal part of the collector resistance.
22 `rbcc (Ω)`	Constant part of the base resistance `rbc`.
23 `rbcv (Ω)`	Variable part of the base resistance `rbc`.
24 `rbec (Ω)`	Constant part of the base resistance `rbe`.
25 `rbev (Ω)`	Variable part of the base resistance `rbe`.
26 `reex (Ω)`	External part of the emitter resistance.
27 `rein (Ω)`	Internal part of the emitter resistance.
28 `rsb (Ω)`	Substrate-base leakage resistance.
29 `tlat (s)`	Low injection .
30 `tfvr (s)`	Low injection forward transit time due to charge stored in the epilayer under the emitter.
31 `tfn (s)`	Low injection forward transit time due to charge stored in the emitter and the buried layer under the emitter.
32 `cje (F)`	Zero-bias emitter-base depletion capacitance.
33 `vde (V)`	Emitter-base diffusion voltage.
34 `pe`	Emitter-base grading coefficient.
35 `trvr (s)`	Low injection reverse transit time due to charge stored in the epilayer under the collector.
36 `trn (s)`	Low injection reverse transit time due to charge stored in the collector and the buried layer under the collector.

37 `cjc (F)`	Zero-bias collector-base depletion capacitance.
38 `vdc (V)`	Collector-base diffusion voltage.
39 `pc`	Collector-base grading coefficient.
40 `cjs (F)`	Zero-bias substrate-base depletion capacitance.
41 `vds (V)`	Substrate-base diffusion voltage.
42 `ps`	Substrate-base grading coefficient.
43 `vgeb (V)`	Bandgap voltage of the emitter-base depletion region.
44 `vgcb (V)`	Bandgap voltage of the collector-base depletion region.
45 `vgsb (V)`	Bandgap voltage of the substrate-base depletion region.
46 `vgb (V)`	Bandgap voltage of the base between emitter and collector.
47 `vge (V)`	Bandgap voltage of the emitter.
48 `vgje (V)`	Bandgap voltage recombination emitter-base junction.
49 `ae`	Temperature coefficient of `bf`.
50 `spb`	SC.
51 `snb`	Temperature coefficient of the epitaxial base electron mobility.
52 `snbn`	Temperature coefficient of buried layer electron mobility.
53 `spe`	Temperature coefficient of emitter hole mobility.
54 `spc`	Temperature coefficient of collector hole mobility.
55 `sx`	Temperature coefficient of combined minority carrier mobility in emitter and buried layer.
56 `kf`	Flickernoise coefficient.
57 `af`	Flickernoise exponent.

58 `exphi` Not used in model bjt500.

59 `rth (K/W)` Thermal resistance.

60 `cth (J/K)` Thermal capacitance.

Operating-Point Parameters

1 `ic (A)` External DC collector current.

2 `ib (A)` External DC base current.

3 `ie (A)` Resistive emitter current.

4 `isub (A)` Resistive substrate current.

5 `iflat (A)` Lateral forward current.

6 `irlat (A)` Lateral reverse current.

7 `ifver (A)` Vertical forward current.

8 `irver (A)` Vertical reverse current.

9 `ire (A)` ideal forward base current.

10 `ile (A)` Non-ideal forward base current.

11 `ise (A)` Forward substrate current.

12 `irc (A)` Ideal reverse base current.

13 `ilc (A)` Non-ideal reverse base current.

14 `isc (A)` Reverse substrate current.

15 `isf (A)` Reverse leakage current of the substrate-base junction.

16 `ip (A)` Main current.

17 `betadc` External DC current gain Ic/Ib.

18 `vbc (V)` Base-collector voltage.

19 `vbe (V)`	Base-emitter voltage.
20 `vce (V)`	Collector-emitter voltage.
21 `vsb (V)`	Substrate-base voltage.
22 `rcex (Ω)`	External part of the collector resistance.
23 `rcin (Ω)`	Internal part of the collector resistance.
24 `reex (Ω)`	External part of the emitter resistance.
25 `rein (Ω)`	Internal part of the emitter resistance.
26 `rbc (Ω)`	Base resistance under the collector.
27 `rbe (Ω)`	Base resistance under the emitter.
28 `rsb (Ω)`	Ohmic leakage across the substrate-base junction.
29 `pwr (W)`	Power.
30 `gfl (S)`	Forward conductance, lateral path.
31 `grl (S)`	Reverse conductance, lateral path.
32 `g11 (S)`	Forward conductance, vertical path.
33 `g12 (S)`	Collector Early-effect on Ifver.
34 `g21 (S)`	Emitter Early-effect on Irver.
35 `g22 (S)`	Reverse conductance, vertical path.
36 `gpiv (S)`	Conductance emitter-base junction.
37 `gmuv (S)`	Conductance collector-base junction.
38 `gbe (S)`	Emitter-side: base conductance B1-B.
39 `gibe (S)`	Emitter Early-effect on Ib1b.
40 `gbc (S)`	Collector-side: base conductance B2-B.

41 `gibc (S)` Collector Early-effect on Ib2b.

42 `gise (S)` Transconductance (parasitic PNP) e-b-s transistor.

43 `gisc (S)` Transconductance (parasitic PNP) c-b-s transistor.

44 `gsb (S)` Conductance substrate-base junction.

45 `cpil (F)` Forward diffusion capacitance, lateral path.

46 `cipil (F)` Collector Early-effect on Qflat.

47 `cpiv (F)` Forward total capacitance, vertical path.

48 `cmul (F)` Reverse diffusion capacitance, lateral path.

49 `cimul (F)` Emitter Early-effect on Qrlat.

50 `cmuv (F)` Reverse total capacitance, vertical path.

51 `csb (F)` Total capacitance substrate-base junction.

52 `irbe (A)` Ideal total forward base current.

53 `irbc (A)` Ideal total reverse base current.

54 `irsb (A)` Substrate base leakage resistance current.

55 `Pdiss (W)` Dissipation.

56 `TK (K)` Actual device temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Vertical NPN/PNP Transistor (bjt503)

The bjt503 model provides a detailed description of a vertical integrated NPN and PNP transistor. It is described in the Philips Bipolar Modelbook (Dec.95) as TN/TNS and TP/TPS level 503.

The NPN is also described in Nat.Lab. Unclassified Report Nr. 006/94 as Mextram Bipolar Transistor Model. Information on how to obtain this document can be found on Source Link by searching for Philips.

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In addition to the model description a `level` parameter is added. Via the `level` parameter the user can switch between Philips Bipolar Modelbook (Dec.95) and Philips Bipolar Modelbook (Dec.94).

The `imax` parameter is used to aid convergence and to prevent numerical overflow. The junction characteristics of the transistor are accurately modeled for currents up to `imax`. For currents above `imax`, the junction is modeled as a linear resistor and a warning is printed.

The descriptions of the operating point derivatives are given for the NPN type. For the PNP type the terminal voltage in the descriptions has to be exchanged. E.g.:

NPN: gx = dIn/dVb2e1

PNP: gx = dIn/dVe1b2

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Sample Instance Statement

```
q4 (vcc net3 minus) npn_mod region=fwd m=1 mult=1
```

Sample Model Statement:

```
model npn_mod bjt503 type=npn level=2 exmod=1 is=1e-14 bf=85 ik=95e-6 rbc=50
cje=0.352e-12
```

Instance Definition

```
Name  c  b  e  [s] ModelName parameter=value ...
```

Instance Parameters

1 `area=1` Area factor.

2 `mult=1` Alias of area factor.

3 `m=1` Multiplication factor.

4 `region=fwd` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `fwd`, `rev`, or `sat`.

Model Definition

```
model modelName bjt503 parameter=value ...
```

Model Parameters

1 `type=npn` Transistor type.
Possible values are `npn`, `npnv`, `pnp`, or `pnpv`.

2 `level=2.0` Transistor Level. Possible values are `1` (Philips Bipolar Modelbook Dec.94) or `2` (Philips Bipolar Modelbook Dec.95).

3 `exmod=0` Flag for extended modeling of the reverse current gain.

4 `exphi=0` Flag for distributed high frequency effects.

5 `exavl=1` Flag for extended modeling of avalanche currents.

6 `is=5.0e-17 A` Collector-emitter saturation current.

7 `bf=140.0 A/A`	Ideal forward current gain.
8 `xibi=0.0`	Fraction of ideal base current that belongs to the sidewall.
9 `ibf=2.0e-14 A`	Saturation current of the non-ideal forward base current.
10 `vlf=0.5 V`	Cross-over voltage of the non-ideal forward base current.
11 `ik=15.0e-3 A`	High-injection knee current.
12 `bri=16.0 A/A`	Ideal reverse current gain.
13 `ibr=8.0e-15 A`	Saturation current of the non-ideal reverse base current.
14 `vlr=0.5 V`	Cross-over voltage of the non-ideal reverse base current.
15 `xext=0.5`	Part of `Iex`, `Qex`, `Qtex` and `Isub` that depends on `Vbc1`.
16 `qbo=1.2e-12 Coul`	Base charge at zero bias.
17 `eta=4.0`	Factor of the built-in field of the base.
18 `avl=50.0`	Weak avalanche parameter.
19 `efi=0.7`	Electric field intercept (with `exavl`=1.
20 `ihc=3.0e-3 A`	Critical current for hot carriers.
21 `rcc=25.0 Ω`	Constant part of the collector resistance.
22 `rcv=750.0 Ω`	Resistance of the unmodulated epilayer.
23 `scrcv=1000.0 Ω`	Space charge resistance of the epilayer.
24 `sfh=0.6`	Current spreading factor epilayer.
25 `rbc=50.0 Ω`	Constant part of the base resistance.
26 `rbv=100.0 Ω`	Variable part of the base resistance at zero bias.
27 `re=2.0 Ω`	Emitter series resistance.
28 `taune=3.0e-10 s`	Minimum delay time of neutral and emitter charge.

29 `mtau=1.18` Non-ideality factor of the neutral and emitter charge.

30 `cje=2.5e-13 F` Zero bias emitter-base depletion capacitance.

31 `vde=0.9 V` Emitter-base diffusion voltage.

32 `pe=0.33` Emitter-base grading coefficient.

33 `xcje=0.5` Fraction of the e-b depletion cap. that belongs to the sidewall.

34 `cjc=1.3e-13 F` Zero bias collector-base depletion capacitance.

35 `vdc=0.6 V` Collector-base diffusion voltage.

36 `pc=0.4` Collector-base grading coefficient variable part.

37 `xp=0.2` Constant part of `cjc`.

38 `mc=0.5` Collector current modulation coefficient.

39 `xcjc=0.1` Fraction of the collector-base depletion cap. under the emitter area.

40 `tref (C)` Reference temperature. Default set by option `tnom`.

41 `tnom (C)` Alias of tref. Default set by option `tnom`.

42 `tr (C)` Alias of tref. Default set by option `tnom`.

43 `dta=0.0 K` Difference of the device temperature to the ambient temperature.

44 `trise=0.0 K` Alias of `dta`.

45 `vge=1.01 V` Band-gap voltage of the emitter.

46 `vgb=1.18 V` Band-gap voltage of the base.

47 `vgc=1.205 V` Band-gap voltage of the collector.

48 `vgj=1.1 V` Band-gap voltage recombination emitter-base junction.

49 `vi=0.04 V` Ionization voltage base dope.

50 `na=3.0e17 cm`$^{-3}$ Maximum base dope concentration.

51 `er=2.0e-3` Temperature coefficient of `vlf` and `vlr`.

52 `ab=1.35` Temperature coefficient resistivity base.

53 `aepi=2.15` Temperature coefficient resistivity of the epilayer.

54 `aex=1.0` Temperature coefficient resistivity of the extrinsic base.

55 `ac=0.4` Temperature coefficient resistivity of the buried layer.

56 `kf=2.0e-16` Flickernoise coefficient ideal base current.

57 `kfn=2.0e-16` Flickernoise coefficient non-ideal base current.

58 `af=1.0` Flickernoise exponent.

59 `iss=6.0e-16 A` Base-substrate saturation current.

60 `iks=5.0e-6 A` Knee current of the substrate.

61 `cjs=1.0e-12 F` Zero bias collector-substrate depletion capacitance.

62 `vds=0.5 V` Collector-substrate diffusion voltage.

63 `ps=0.33` Collector-substrate grading coefficient.

64 `vgs=1.15 V` Band-gap voltage of the substrate.

65 `as=2.15` For a closed buried layer: `as=ac`. For an open buried layer: `as=aepi`.

66 `imax=1.0 A` Explosion current.

67 `vers=503` Version number.

68 `compatible=spectre`

Encourage device equations to be compatible with a foreign simulator. This option does not affect input syntax.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, or `spiceplus`.

Output Parameters

1 `ist (A)` Collector-Emitter saturation current.

2 `bft (A/A)` Ideal forward current gain.

3 `ibft (A)` Saturation current of the non-ideal forward base current.

4 `vlft (V)` Cross-over voltage of the non-ideal forward base current.

5 `ikt (A)` High-injection knee current.

6 `ibrt (A)` Saturation current of the non-ideal reverse base current.

7 `vlrt (V)` Cross-over voltage of the non-ideal reverse base current.

8 `qbot (Coul)` Base charge at zero bias.

9 `avlt` Weak avalanche parameter.

10 `rcct (Ω)` Constant part of the collector resistance.

11 `rcvt (Ω)` Resistance of the unmodulated epilayer.

12 `rbct (Ω)` Constant part of the base resistance.

13 `rbvt (Ω)` Variable part of the base resistance at zero bias.

14 `taunet (s)` Minimum delay time of neutral and emitter charge.

15 `mtaut` Non-ideality factor of the neutral and emitter charge.

16 `cjet (F)` Zero bias emitter-base depletion capacitance.

17 `vdet (V)` Emitter-base diffusion voltage.

18 `cjct (F)` Zero bias collector-base depletion capacitance.

19 `vdct (V)` Collector-base diffusion voltage.

20 `xpt` Constant part of `cjc`.

21 `isst (A)` Base-substrate saturation current.

22 `ikst (A)` Knee current of the substrate.

23 `cjst (F)` Zero bias collector-substrate depletion capacitance.

24 `vdst (V)` Collector-substrate diffusion voltage.

Operating-Point Parameters

1 `ib (A)` Base current.

2 `ic (A)` Collector current.

3 `ie (A)` Emitter current.

4 `is (A)` Substrate current.

5 `vbe (V)` Base-emitter voltage.

6 `vbc (V)` Base-collector voltage.

7 `vce (V)` Collector-emitter voltage.

8 `vsc (V)` Substrate voltage.

9 `re (Ω)` Constant emitter resistance.

10 `rcc (Ω)` Constant collector resistance.

11 `rbc (Ω)` Constant part of base resistance.

12 `betadc (A/A)` DC current gain.

13 `pwr (W)` Power.

14 `Vb1e1 (V)` Internal voltage.

15 `Vb2e1 (V)` Internal voltage.

16 `Vb2c1 (V)` Internal voltage.

17 `Vb2c2 (V)` Internal voltage.

18 `Vb1b2 (V)` Internal voltage.

19 `Vb1c1 (V)` Internal voltage.

20 `Vbc1 (V)` Internal voltage.

21 `in (A)` Main current.

22 `ic1c2 (A)` Variable collector resistance current.

23 `ib1 (A)` Bulk component of ideal base current.

24 `ib1s (A)` Sidewall component of ideal base current.

25 `ib2 (A)` Non-ideal base current.

26 `iavl (A)` Weak avalanche current.

27 `ib1b2 (A)` Variable base resistance current.

28 `ib3 (A)` Non-ideal reverse base current.

29 `iex (A)` Internal extrinsic base current.

30 `isub (A)` Internal base-substrate current.

31 `isf (A)` Substrate-collector current.

32 `xiex (A)` External extrinsic base current.

33 `Xisub (A)` External base-substrate current.

34 `gx (S)` dIn/dVb2e1.

35 `gy (S)` dIn/dVb2c2.

36 `gz (S)` dIn/dVb2c1.

37 `grcvy (S)` dIc1c2/dVb2c2.

38 `grcvz (S)` dIc1c2/dVb2c1.

39 `gpi (S)` Conductance floor base-emitter junction: dIb1/dVb2e1 + dIb2/dVb2e1.

40 `sgpi (S)`	Conductance sidewall base-emitter junction: dIb1S/dVb1e1.
41 `gmux (S)`	Dependence avalanche multiplication on internal b-e junction: -dIavl/dVb2e1.
42 `gmu (S)`	Dependence avalanche multiplication on internal b-c junction: -dIavl/dVb2c2.
43 `gmuz (S)`	Dependence avalanche multiplication on external b-c junction:-dIavl/dVb2c1.
44 `grbv (S)`	dIb1b2/dVb1b2.
45 `grbvx (S)`	Emitter Early-effect on Ib1b2: dIb1b2/dVb2e1.
46 `grbvy (S)`	Internal collector Early-effect on Ib1b2: dIb1b2/dVb2c2.
47 `grbvz (S)`	External collector Early effect on Ib1b2: dIb1b2/dVb2c1.
48 `gmuex (S)`	Conductance floor extrinsic b-c junction: dIex/dVb1c1 + dIsub/dVb1c1 + dIb3/dVb1c1.
49 `xgmuex (S)`	Conductance sidewall extrinsic b-c junction: dXIex/dVbc1 + dXIsub/dVbc1.
50 `gsub (S)`	Conductance s-c junction: dIsf/dVsc1.
51 `gpnp (S)`	Transconductance floor extrinsic PNP transistor: dIsub/dVb1c1.
52 `xgpnp (S)`	Transconductance sidewall extrinsic PNP transistor: dXIsub/dVbc1.
53 `cbex (F)`	Capacitance floor b-e junction: dQte/dVb2e1 + dQbe/dVb2e1 + dQn/dVb2e1.
54 `cbey (F)`	Internal collector Early-effect on Qbe: dQbe/dVb2c2.
55 `cbez (F)`	External collector Early-effect on Qbe: dQbe/dVb2c1.
56 `scte (F)`	Dependence of QteS on internal b-e junction: dQteS/dVb2e1.
57 `cbcx (F)`	Emitter Early-effect on Qbc: dQbc/dVb2e1.

58 `cbcy (F)` Capacitance intrinsic b-c junction: dQtc/dVb2c2 + dQbc/dVb2c2 + dQepi/dVb2c2.

59 `cbcz (F)` Collector Early-effect on Qtc: dQtc/dVb2c1 + dQbc/dVb2c1 + dQepi/dVb2c1.

60 `cb1b2 (F)` Capacitance AC current crowding: dQb1b2/dVb1b2 = Cb.

61 `cb1b2x (F)` Dependence of Qb1b2 on internal b-e junction voltage: dQb1b2/dVb2e1.

62 `cbcex (F)` Capacitance floor extrinsic b-c junction: dQtex/dVb1c1 + dQex/dVb1c1.

63 `xcbcex (F)` Capacitance sidewall extrinsic b-c junction: dXQtex/dVbc1 + dXQex/dVbc1.

64 `cts (F)` Capacitance s-c junction: dQtex/dVb1c1 + dQex/dVb1c1.

65 `cbe (F)` Cbe.

66 `cbc (F)` Cbc.

67 `csc (F)` Csc.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Compact Bipolar-Transistor Model (bjt504)

Instance Definition

```
Name  c  b  e  s ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `region=fwd` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `sat`, `rev`, or `fwd`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName bjt504 parameter=value ...
```

Model Parameters

1 `level=504` Bipolar Level.

2 `tref=25 deg. C` Reference temperature.

3 `dta=0 K` Difference between the local ambient and global ambient temperature.

4 `exmod=1` Flag for extended modeling of reverse current gain.

5 `exphi=1` Flag for the distributed high-frequency effeCts in transient.

6 `exavl=0` Flag for extended modeling of avalanche currents.

7 `is=2.2e-17 A` Collector-emitter saturation current.

8 `ik=0.1 A` Collector-emitter high injection knee current.

9 `ver=2.5 V` Reverse Early voltage.

10 `vef=44 V` Forward Early voltage.

11 `bf=215` Ideal forward current gain.

12 `ibf=2.7e-15 A` Saturation current of the non-ideal forward base current.

13 `mlf=2` Non ideality factor of the non-ideal forward base current.

14 `xibi=0`	Part of ideal base current that belongs to the sidewall.
15 `bri=7`	Ideal reverse current gain.
16 `ibr=1e-15 A`	Saturation current of the non-ideal reverse base current.
17 `vlr=0.2 V`	Cross-over voltage of the non-ideal reverse base current.
18 `xext=0.63`	Part of Iex, Qtex, Qex and Isub that depends on Vbc1 instead of Vb1c1.
19 `wavl=1.1e-06 m`	Epilayer thickness used in weak-avalanche model.
20 `vavl=3 V`	Voltage determining curvature of avalanche current.
21 `sfh=0.3`	Current spreading factor of avalanche model (when EXAVL=1).
22 `re=5` Ω	Emitter resistance.
23 `rbc=23` Ω	Constant part of the base resistance.
24 `rbv=18` Ω	Zero-bias value of the variable part of the base resistance.
25 `rcc=12` Ω	Constant part of collector resistance.
26 `rcv=150` Ω	Resistance of the un-modulated epilayer.
27 `scrcv=1.25e+03` Ω	Space charge resistance of the epilayer.
28 `ihc=0.004 A`	Critical current for velocity saturation in the epilayer.
29 `axi=0.3`	Smoothness parameter for the onset of quasi-saturation.
30 `cje=7.3e-14 F`	Zero-bias emitter-base depletion capacitance.
31 `vde=0.95 V`	Emitter-base diffusion voltage.
32 `pe=0.4`	Emitter-base grading coefficient.
33 `xcje=0.4`	Fraction of the emitter-base depletion capacitance that belongs to the sidewall.

34 `cbeo=0`	Emitter-base overlap capacitance.
35 `cjc=7.8e-14 F`	Zero-bias collector-base depletion capacitance.
36 `vdc=0.68 V`	Collector-base diffusion voltage.
37 `pc=0.5`	Collector-base grading coefficient.
38 `xp=0.35`	Constant part of Cjc.
39 `mc=0.5`	Coefficient for the current modulation of the collector-base depletion capacitance.
40 `xcjc=0.032`	Fraction of the collector-base depletion capacitance under the emitter.
41 `cbco=0`	Collector-base overlap capacitance.
42 `mtau=1`	Non-ideality factor of the emitter stored charge.
43 `taue=2e-12 s`	Minimum transit time of stored emitter charge.
44 `taub=4.2e-12 s`	Transit time of stored base charge.
45 `tepi=4.1e-11 s`	Transit time of stored epilayer charge.
46 `taur=5.2e-10 s`	Transit time of reverse extrinsic base charge.
47 `deg=0 eV`	Bandgap difference over the base.
48 `xrec=0`	Pre-factor of the recombination part of Ib1.
49 `aqbo=0.3`	Temperature coefficient of the zero-bias base charge.
50 `ae=0`	Temperature coefficient of the resistivity of the emitter.
51 `ab=1`	Temperature coefficient of the resistivity of the base.
52 `dais=0`	Parameter for fine tuning of temperature dependence of collector-emitter saturation current.
53 `aepi=2.5`	Temperature coefficient of the resistivity of the epilayer.

54 `aex=0.62`	Temperature coefficient of the resistivity of the extrinsic base.
55 `ac=2`	Temperature coefficient of the resistivity of the buried layer.
56 `dvgbf=0.05 V`	Bandgap voltage difference of forward current gain.
57 `dvgbr=0.045 V`	Bandgap voltage difference of reverse current gain.
58 `vgb=1.17 V`	Bandgap voltage of the base.
59 `vgc=1.18 V`	Bandgap voltage of the collector.
60 `vgj=1.15 V`	Bandgap voltage recombination emitter-base junction.
61 `dvgte=0.05 V`	Bandgap voltage difference of emitter stored charge.
62 `af=2`	Exponent of the Flicker-noise.
63 `kf=2e-11`	Flicker-noise coefficient of the ideal base current.
64 `kfn=2e-11`	Flicker-noise coefficient of the non-ideal base current.
65 `kavl=0`	Switch for white noise contribution due to avalanche.
66 `iss=4.8e-17 A`	Base-substrate saturation current.
67 `iks=0.00025 A`	Base-substrate high injection knee current.
68 `cjs=3.15e-13 F`	Zero-bias collector-substrate depletion capacitance.
69 `vds=0.62 V`	Collector-substrate diffusion voltage.
70 `ps=0.34`	Collector-substrate grading coefficient.
71 `vgs=1.2 V`	Band-gap voltage of the substrate.
72 `as=1.58`	For a closed buried layer: As=Ac: for an open buried layer: As=Aepi.
73 `type=n`	Transistor gender. Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.
74 `imax=1.0 A`	Explosion current.

75 `tnom (deg. C)` alias of tnom.

76 `tr (deg. C)` alias of tnom.

Output Parameters

1 `tref (deg. C)` Reference temperature.

2 `dta (K)` Difference between the local ambient and global ambient temperatures.

3 `exmod` Flag for extended modeling of reverse current gain.

4 `exphi` Flag for the distributed high-frequency effeCts in transient.

5 `exavl` Flag for extended modeling of avalanche currents.

6 `is (A)` Collector-emitter saturation current.

7 `ik (A)` Collector-emitter high injection knee current.

8 `ver (V)` Reverse Early voltage.

9 `vef (V)` Forward Early voltage.

10 `bf` Ideal forward current gain.

11 `ibf (A)` Saturation current of the non-ideal forward base current.

12 `mlf` Non ideality factor of the non-ideal forward base current.

13 `xibi` Part of ideal base current that belongs to the sidewall.

14 `bri` Ideal reverse current gain.

15 `ibr (A)` Saturation current of the non-ideal reverse base current.

16 `vlr (V)` Cross-over voltage of the non-ideal reverse base current.

17 `xext` Part of Iex, Qtex, Qex and Isub that depends on Vbc1 instead of Vb1c1.

18 `wavl (M)` Epilayer thickness used in weak-avalanche model.

19 `vavl (V)`	Voltage determining curvature of avalanche current.
20 `sfh`	Current spreading factor of avalanche model (when EXAVL=1).
21 `re (Ω)`	Emitter resistance.
22 `rbc (Ω)`	Constant part of the base resistance.
23 `rbv (Ω)`	Zero-bias value of the variable part of the base resistance.
24 `rcc (Ω)`	Constant part of collector resistance.
25 `rcv (Ω)`	Resistance of the un-modulated epilayer.
26 `scrcv (Ω)`	Space charge resistance of the epilayer.
27 `ihc (A)`	Critical current for velocity saturation in the epilayer.
28 `axi`	Smoothness parameter for the onset of quasi-saturation.
29 `cje (F)`	Zero-bias emitter-base depletion capacitance.
30 `vde (V)`	Emitter-base diffusion voltage.
31 `pe`	Emitter-base grading coefficient.
32 `xcje`	Fraction of the emitter-base depletion capacitance that belongs to the sidewall.
33 `cbeo`	Emitter-base overlap capacitance.
34 `cjc (F)`	Zero-bias collector-base depletion capacitance.
35 `vdc (V)`	Collector-base diffusion voltage.
36 `pc`	Collector-base grading coefficient.
37 `xp`	Constant part of Cjc.
38 `mc`	Coefficient for the current modulation of the collector-base depletion capacitance.

39 `xcjc`	Fraction of the collector-base depletion capacitance under the emitter.
40 `cbco`	Collector-base overlap capacitance.
41 `mtau`	Non-ideality factor of the emitter stored charge.
42 `taue (s)`	Minimum transit time of stored emitter charge.
43 `taub (s)`	Transit time of stored base charge.
44 `tepi (s)`	Transit time of stored epilayer charge.
45 `taur (s)`	Transit time of reverse extrinsic stored base charge.
46 `deg (eV)`	Bandgap difference over the base.
47 `xrec`	Pre-factor of the recombination part of Ib1.
48 `aqbo`	Temperature coefficient of the zero-bias base charge.
49 `ae`	Temperature coefficient of the resistivity of the emitter.
50 `ab`	Temperature coefficient of the resistivity of the base.
51 `dais`	Parameter for fine tuning of temperature dependence of collector-emitter saturation current.
52 `aepi`	Temperature coefficient of the resistivity of the epilayer.
53 `aex`	Temperature coefficient of the resistivity of the extrinsic base.
54 `ac`	Temperature coefficient of the resistivity of the buried layer.
55 `dvgbf (V)`	Bandgap voltage diffrence of forward current gain.
56 `dvgbr (V)`	Bandgap voltage diffrence of reverse current gain.
57 `vgb (V)`	Bandgap voltage of the base.
58 `vgc (V)`	Bandgap voltage of the collector.
59 `vgj (V)`	Bandgap voltage recombination emitter-base junction.

60 `dvgte (V)`	Bandgap voltage difference of emitter stored charge.
61 `af`	Exponent of the Flicker-noise.
62 `kf`	Flicker-noise coefficient of the ideal base current.
63 `kfn`	Flicker-noise coefficient of the non-ideal base current.
64 `kavl`	Switch for white noise contribution due to avalanche.
65 `iss (A)`	Base-substrate saturation current.
66 `iks (A)`	Base-substrate high injection knee current.
67 `cjs (F)`	Zero-bias collector-substrate depletion capacitance.
68 `vds (V)`	Collector-substrate diffusion voltage.
69 `ps`	Collector-substrate grading coefficient.
70 `vgs (V)`	Band-gap voltage of the substrate.
71 `as`	For a closed buried layer: As=Ac, for an open buried layer: As=Aepi.

Operating-Point Parameters

1 `Ic (A)`	External DC collector current.
2 `Ib (A)`	External DC base current.
3 `BetaDC`	External DC current gain Ic/Ib.
4 `Vb2e1 (V)`	Internal base-emitter bias.
5 `Vb2c2 (V)`	Internal base-collector bias.
6 `Vb2c1 (V)`	Internal base-collector bias including epilayer.
7 `Vb1c1 (V)`	External base-collector bias without contact resistances.
8 `Ve1e (V)`	Bias over emitter resistance.

9 `In (A)`	Main current.
10 `Ic1c2 (A)`	Epilayer current.
11 `Ib1b2 (A)`	Pinched-base current.
12 `Ib1 (A)`	Ideal forward base current.
13 `SIb1 (A)`	Ideal side-wall base current.
14 `Ib2 (A)`	Non-ideal forward base current.
15 `Ib3 (A)`	Non-ideal reverse base current.
16 `Iex (A)`	Extrinsic reverse base current.
17 `XIex (A)`	Extrinsic reverse base current.
18 `Iavl (A)`	Avalanche current.
19 `IRE (A)`	Current through emitter resistance.
20 `IRBC (A)`	Current through constant base resistance.
21 `IRCC (A)`	Current through constant collector resistance.
22 `Qe (C)`	Emitter charge or emitter neutral charge.
23 `Qte (C)`	Base-emitter depletion charge.
24 `SQte (C)`	Sidewall base-emitter depletion charge.
25 `Qbe (C)`	Base-emitter diffusion charge.
26 `Qbc (C)`	Base-collector diffusion charge.
27 `Qtc (C)`	Base-collector depletion charge.
28 `Qepi (C)`	Epilayer diffusion charge.
29 `Qb1b2 (C)`	AC current crowding charge.
30 `Qtex (C)`	Extrinsic base-collector depletion charge.

31 `XQtex (C)`	Extrinsic base-collector depletion charge.
32 `Qex (C)`	Extrinsic base-collector diffusion charge.
33 `XQex (C)`	Extrinsic base-collector diffusion charge.
34 `gx (1/Ω)`	Forward transconductance.
35 `gy (1/Ω)`	Reverse transconductance.
36 `gz (1/Ω)`	Reverse transconductance.
37 `Sgpi (1/Ω)`	Conductance sidewall b-e junction.
38 `gpix (1/Ω)`	Conductance floor b-e junction.
39 `gpiy (1/Ω)`	Early effect on recombination base current.
40 `gpiz (1/Ω)`	Early effect on recombination base current.
41 `gmux (1/Ω)`	Early effect on avalanche current limiting.
42 `gmuy (1/Ω)`	Conductance of avalanche current.
43 `gmuz (1/Ω)`	Conductance of avalanche current.
44 `gmuex (1/Ω)`	Conductance extrinsic b-c junction.
45 `Xgmuex (1/Ω)`	Conductance extrinsic b-c junction.
46 `grcvy (1/Ω)`	Conductance of the epilayer current.
47 `grcvz (1/Ω)`	Conductance of the epilayer current.
48 `Rbv (Ω)`	Conductance of the epilayer current.
49 `grbvx (1/Ω)`	Early-effect on base resistance.
50 `grbvy (1/Ω)`	Early-effect on base resistance.
51 `grbvz (1/Ω)`	Early-effect on base resistance:.
52 `RE (Ω)`	Early-effect on base resistance:.

53 `RBC (Ω)`	Early-effect on base resistance:.
54 `RCC (Ω)`	Early-effect on base resistance:.
55 `SCbe (F)`	Capacitance sidewall b-e junction.
56 `Cbex (F)`	Capacitance floor b-e junction.
57 `Cbey (F)`	Early effect on b-e diffusion charge.
58 `Cbez (F)`	Early effect on b-e diffusion charge.
59 `Cbcx (F)`	Early effect on b-c diffusion charge.
60 `Cbcy (F)`	Capacitance floor b-c junction.
61 `Cbcz (F)`	Capacitance floor b-c junction.
62 `Cbcex (F)`	Capacitance extrinsic b-c junction.
63 `XCbcex (F)`	Capacitance extrinsic b-c junction.
64 `Cb1b2 (F)`	Capacitance AC current crowding.
65 `Cb1b2x (F)`	Cross-capacitance AC current crowding .
66 `Cb1b2y (F)`	Cross-capacitance AC current crowding.
67 `Cb1b2z (F)`	Cross-capacitance AC current crowding.
68 `gm (1/Ω)`	Transconductance.
69 `beta`	Current amplification.
70 `gout (1/Ω)`	Output conductance.
71 `gmu (1/Ω)`	Feedback transconductance.
72 `RB (Ω)`	Base resistance.
73 `Cbe (F)`	Base-emitter capacitance.
74 `Cbc (F)`	Base-collector capacitance.

75 `fT (Hz)` Good approximation for cut-off frequency.

76 `Iqs (A)` Current at onset of quasi-saturation.

77 `XiWepi (M)` Thickness of injection layer.

78 `Vb2c2star (V)` Physical value of internal base-collector bias.

79 `Pdiss (W)` Dissipation.

80 `TK (K)` Actual temperature.

81 `Isub (A)` Substrate current.

82 `XIsub (A)` Substrate current.

83 `Isf (A)` Substrate failure current.

84 `Qts (C)` Collector-substrate depletion charge.

85 `gS (1/Ω)` Conductance parasitic PNP transistor.

86 `XgS (1/Ω)` Conductance parasitic PNP transistor.

87 `gSf (1/Ω)`

88 `Cts (C)` Capacitance s-c junction:.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Compact Bipolar-Transistor Model (bjt504t)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  c  b  e  s  dt ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `region=fwd` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `sat`, `rev`, or `fwd`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName bjt504t parameter=value ...
```

Model Parameters

1 `level=504` Bipolar Level.

2 `tref=25 deg. C` Reference temperature.

3 `dta=0 K` Difference between the local ambient and global ambient temperature.

4 `exmod=1` Flag for extended modeling of reverse current gain.

5 `exphi=1` Flag for the distributed high-frequency effeCts in transient.

6 `exavl=0` Flag for extended modeling of avalanche currents.

7 `is=2.2e-17 A` Collector-emitter saturation current.

8 `ik=0.1 A` Collector-emitter high injection knee current.

9 `ver=2.5 V` Reverse Early voltage.

10 `vef=44 V` Forward Early voltage.

11 `bf=215` Ideal forward current gain.

12 `ibf=2.7e-15 A`	Saturation current of the non-ideal forward base current.
13 `mlf=2`	Non ideality factor of the non-ideal forward base current.
14 `xibi=0`	Part of ideal base current that belongs to the sidewall.
15 `bri=7`	Ideal reverse current gain.
16 `ibr=1e-15 A`	Saturation current of the non-ideal reverse base current.
17 `vlr=0.2 V`	Cross-over voltage of the non-ideal reverse base current.
18 `xext=0.63`	Part of Iex, Qtex, Qex and Isub that depends on Vbc1 instead of Vb1c1.
19 `wavl=1.1e-06 m`	Epilayer thickness used in weak-avalanche model.
20 `vavl=3 V`	Voltage determining curvature of avalanche current.
21 `sfh=0.3`	Current spreading factor of avalanche model (when EXAVL=1).
22 `re=5` Ω	Emitter resistance.
23 `rbc=23` Ω	Constant part of the base resistance.
24 `rbv=18` Ω	Zero-bias value of the variable part of the base resistance.
25 `rcc=12` Ω	Constant part of collector resistance.
26 `rcv=150` Ω	Resistance of the un-modulated epilayer.
27 `scrcv=1.25e+03` Ω	Space charge resistance of the epilayer.
28 `ihc=0.004 A`	Critical current for velocity saturation in the epilayer.
29 `axi=0.3`	Smoothness parameter for the onset of quasi-saturation.
30 `cje=7.3e-14 F`	Zero-bias emitter-base depletion capacitance.
31 `vde=0.95 V`	Emitter-base diffusion voltage.
32 `pe=0.4`	Emitter-base grading coefficient.

33 `xcje=0.4`	Fraction of the emitter-base depletion capacitance that belongs to the sidewall.
34 `cbeo=0`	Emitter-base overlap capacitance.
35 `cjc=7.8e-14 F`	Zero-bias collector-base depletion capacitance.
36 `vdc=0.68 V`	Collector-base diffusion voltage.
37 `pc=0.5`	Collector-base grading coefficient.
38 `xp=0.35`	Constant part of Cjc.
39 `mc=0.5`	Coefficient for the current modulation of the collector-base depletion capacitance.
40 `xcjc=0.032`	Fraction of the collector-base depletion capacitance under the emitter.
41 `cbco=0`	Collector-base overlap capacitance.
42 `mtau=1`	Non-ideality factor of the emitter stored charge.
43 `taue=2e-12 s`	Minimum transit time of stored emitter charge.
44 `taub=4.2e-12 s`	Transit time of stored base charge.
45 `tepi=4.1e-11 s`	Transit time of stored epilayer charge.
46 `taur=5.2e-10 s`	Transit time of reverse extrinsic base charge.
47 `deg=0 eV`	Bandgap difference over the base.
48 `xrec=0`	Pre-factor of the recombination part of Ib1.
49 `aqbo=0.3`	Temperature coefficient of the zero-bias base charge.
50 `ae=0`	Temperature coefficient of the resistivity of the emitter.
51 `ab=1`	Temperature coefficient of the resistivity of the base.
52 `dais=0`	Parameter for fine tuning of temperature dependence of collector-emitter saturation current.

53 `aepi=2.5`	Temperature coefficient of the resistivity of the epilayer.
54 `aex=0.62`	Temperature coefficient of the resistivity of the extrinsic base.
55 `ac=2`	Temperature coefficient of the resistivity of the buried layer.
56 `dvgbf=0.05 V`	Bandgap voltage difference of forward current gain.
57 `dvgbr=0.045 V`	Bandgap voltage difference of reverse current gain.
58 `vgb=1.17 V`	Bandgap voltage of the base.
59 `vgc=1.18 V`	Bandgap voltage of the collector.
60 `vgj=1.15 V`	Bandgap voltage recombination emitter-base junction.
61 `dvgte=0.05 V`	Bandgap voltage difference of emitter stored charge.
62 `af=2`	Exponent of the Flicker-noise.
63 `kf=2e-11`	Flicker-noise coefficient of the ideal base current.
64 `kfn=2e-11`	Flicker-noise coefficient of the non-ideal base current.
65 `kavl=0`	Switch for white noise contribution due to avalanche.
66 `iss=4.8e-17 A`	Base-substrate saturation current.
67 `iks=0.00025 A`	Base-substrate high injection knee current.
68 `cjs=3.15e-13 F`	Zero-bias collector-substrate depletion capacitance.
69 `vds=0.62 V`	Collector-substrate diffusion voltage.
70 `ps=0.34`	Collector-substrate grading coefficient.
71 `vgs=1.2 V`	Band-gap voltage of the substrate.
72 `as=1.58`	For a closed buried layer: As=Ac: for an open buried layer: As=Aepi.
73 `rth=300 K/W`	Thermal resistance.

74 `cth=3e-09 J/K` Thermal capacitance.

75 `ath=0` Temperature coefficient of the thermal resistance.

76 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

77 `imax=1.0 A` Explosion current.

78 `tnom (deg. C)` alias of tnom.

79 `tr (deg. C)` alias of tnom.

Output Parameters

1 `tref (deg. C)` Reference temperature.

2 `dta (K)` Difference between the local ambient and global ambient temperatures.

3 `exmod` Flag for extended modeling of reverse current gain.

4 `exphi` Flag for the distributed high-frequency effeCts in transient.

5 `exavl` Flag for extended modeling of avalanche currents.

6 `is (A)` Collector-emitter saturation current.

7 `ik (A)` Collector-emitter high injection knee current.

8 `ver (V)` Reverse Early voltage.

9 `vef (V)` Forward Early voltage.

10 `bf` Ideal forward current gain.

11 `ibf (A)` Saturation current of the non-ideal forward base current.

12 `mlf` Non ideality factor of the non-ideal forward base current.

13 `xibi` Part of ideal base current that belongs to the sidewall.

14 `bri` Ideal reverse current gain.

15 `ibr (A)`	Saturation current of the non-ideal reverse base current.
16 `vlr (V)`	Cross-over voltage of the non-ideal reverse base current.
17 `xext`	Part of Iex, Qtex, Qex and Isub that depends on Vbc1 instead of Vb1c1.
18 `wavl (M)`	Epilayer thickness used in weak-avalanche model.
19 `vavl (V)`	Voltage determining curvature of avalanche current.
20 `sfh`	Current spreading factor of avalanche model (when EXAVL=1).
21 `re (Ω)`	Emitter resistance.
22 `rbc (Ω)`	Constant part of the base resistance.
23 `rbv (Ω)`	Zero-bias value of the variable part of the base resistance.
24 `rcc (Ω)`	Constant part of collector resistance.
25 `rcv (Ω)`	Resistance of the un-modulated epilayer.
26 `scrcv (Ω)`	Space charge resistance of the epilayer.
27 `ihc (A)`	Critical current for velocity saturation in the epilayer.
28 `axi`	Smoothness parameter for the onset of quasi-saturation.
29 `cje (F)`	Zero-bias emitter-base depletion capacitance.
30 `vde (V)`	Emitter-base diffusion voltage.
31 `pe`	Emitter-base grading coefficient.
32 `xcje`	Fraction of the emitter-base depletion capacitance that belongs to the sidewall.
33 `cbeo`	Emitter-base overlap capacitance.
34 `cjc (F)`	Zero-bias collector-base depletion capacitance.
35 `vdc (V)`	Collector-base diffusion voltage.

36 `pc`	Collector-base grading coefficient.
37 `xp`	Constant part of Cjc.
38 `mc`	Coefficient for the current modulation of the collector-base depletion capacitance.
39 `xcjc`	Fraction of the collector-base depletion capacitance under the emitter.
40 `cbco`	Collector-base overlap capacitance.
41 `mtau`	Non-ideality factor of the emitter stored charge.
42 `taue (s)`	Minimum transit time of stored emitter charge.
43 `taub (s)`	Transit time of stored base charge.
44 `tepi (s)`	Transit time of stored epilayer charge.
45 `taur (s)`	Transit time of reverse extrinsic stored base charge.
46 `deg (eV)`	Bandgap difference over the base.
47 `xrec`	Pre-factor of the recombination part of Ib1.
48 `aqbo`	Temperature coefficient of the zero-bias base charge.
49 `ae`	Temperature coefficient of the resistivity of the emitter.
50 `ab`	Temperature coefficient of the resistivity of the base.
51 `dais`	Parameter for fine tuning of temperature dependence of collector-emitter saturation current.
52 `aepi`	Temperature coefficient of the resistivity of the epilayer.
53 `aex`	Temperature coefficient of the resistivity of the extrinsic base.
54 `ac`	Temperature coefficient of the resistivity of the buried layer.
55 `dvgbf (V)`	Bandgap voltage diffrence of forward current gain.

56 `dvgbr (V)`	Bandgap voltage diffrence of reverse current gain.
57 `vgb (V)`	Bandgap voltage of the base.
58 `vgc (V)`	Bandgap voltage of the collector.
59 `vgj (V)`	Bandgap voltage recombination emitter-base junction.
60 `dvgte (V)`	Bandgap voltage difference of emitter stored charge.
61 `af`	Exponent of the Flicker-noise.
62 `kf`	Flicker-noise coefficient of the ideal base current.
63 `kfn`	Flicker-noise coefficient of the non-ideal base current.
64 `kavl`	Switch for white noise contribution due to avalanche.
65 `iss (A)`	Base-substrate saturation current.
66 `iks (A)`	Base-substrate high injection knee current.
67 `cjs (F)`	Zero-bias collector-substrate depletion capacitance.
68 `vds (V)`	Collector-substrate diffusion voltage.
69 `ps`	Collector-substrate grading coefficient.
70 `vgs (V)`	Band-gap voltage of the substrate.
71 `as`	For a closed buried layer: As=Ac, for an open buried layer: As=Aepi.
72 `rth (K/W)`	Thermal resistance.
73 `cth (J/K)`	Thermal capacitance.
74 `ath`	Temperature coefficient of the thermal resistance.

Operating-Point Parameters

1 `Ic (A)`	External DC collector current.

2 `Ib (A)`	External DC base current.
3 `BetaDC`	External DC current gain Ic/Ib.
4 `Vb2e1 (V)`	Internal base-emitter bias.
5 `Vb2c2 (V)`	Internal base-collector bias.
6 `Vb2c1 (V)`	Internal base-collector bias including epilayer.
7 `Vb1c1 (V)`	External base-collector bias without contact resistances.
8 `Ve1e (V)`	Bias over emitter resistance.
9 `In (A)`	Main current.
10 `Ic1c2 (A)`	Epilayer current.
11 `Ib1b2 (A)`	Pinched-base current.
12 `Ib1 (A)`	Ideal forward base current.
13 `SIb1 (A)`	Ideal side-wall base current.
14 `Ib2 (A)`	Non-ideal forward base current.
15 `Ib3 (A)`	Non-ideal reverse base current.
16 `Iex (A)`	Extrinsic reverse base current.
17 `XIex (A)`	Extrinsic reverse base current.
18 `Iavl (A)`	Avalanche current.
19 `IRE (A)`	Current through emitter resistance.
20 `IRBC (A)`	Current through constant base resistance.
21 `IRCC (A)`	Current through constant collector resistance.
22 `Qe (C)`	Emitter charge or emitter neutral charge.
23 `Qte (C)`	Base-emitter depletion charge.

24 `SQte (C)`	Sidewall base-emitter depletion charge.
25 `Qbe (C)`	Base-emitter diffusion charge.
26 `Qbc (C)`	Base-collector diffusion charge.
27 `Qtc (C)`	Base-collector depletion charge.
28 `Qepi (C)`	Epilayer diffusion charge.
29 `Qb1b2 (C)`	AC current crowding charge.
30 `Qtex (C)`	Extrinsic base-collector depletion charge.
31 `XQtex (C)`	Extrinsic base-collector depletion charge.
32 `Qex (C)`	Extrinsic base-collector diffusion charge.
33 `XQex (C)`	Extrinsic base-collector diffusion charge.
34 `gx (1/Ω)`	Forward transconductance.
35 `gy (1/Ω)`	Reverse transconductance.
36 `gz (1/Ω)`	Reverse transconductance.
37 `Sgpi (1/Ω)`	Conductance sidewall b-e junction.
38 `gpix (1/Ω)`	Conductance floor b-e junction.
39 `gpiy (1/Ω)`	Early effect on recombination base current.
40 `gpiz (1/Ω)`	Early effect on recombination base current.
41 `gmux (1/Ω)`	Early effect on avalanche current limiting.
42 `gmuy (1/Ω)`	Conductance of avalanche current.
43 `gmuz (1/Ω)`	Conductance of avalanche current.
44 `gmuex (1/Ω)`	Conductance extrinsic b-c junction.
45 `Xgmuex (1/Ω)`	Conductance extrinsic b-c junction.

46 `grcvy (1/Ω)` Conductance of the epilayer current.

47 `grcvz (1/Ω)` Conductance of the epilayer current.

48 `Rbv (Ω)` Conductance of the epilayer current.

49 `grbvx (1/Ω)` Early-effect on base resistance.

50 `grbvy (1/Ω)` Early-effect on base resistance.

51 `grbvz (1/Ω)` Early-effect on base resistance:.

52 `RE (Ω)` Early-effect on base resistance:.

53 `RBC (Ω)` Early-effect on base resistance:.

54 `RCC (Ω)` Early-effect on base resistance:.

55 `SCbe (F)` Capacitance sidewall b-e junction.

56 `Cbex (F)` Capacitance floor b-e junction.

57 `Cbey (F)` Early effect on b-e diffusion charge.

58 `Cbez (F)` Early effect on b-e diffusion charge.

59 `Cbcx (F)` Early effect on b-c diffusion charge.

60 `Cbcy (F)` Capacitance floor b-c junction.

61 `Cbcz (F)` Capacitance floor b-c junction.

62 `Cbcex (F)` Capacitance extrinsic b-c junction.

63 `XCbcex (F)` Capacitance extrinsic b-c junction.

64 `Cb1b2 (F)` Capacitance AC current crowding.

65 `Cb1b2x (F)` Cross-capacitance AC current crowding .

66 `Cb1b2y (F)` Cross-capacitance AC current crowding.

67 `Cb1b2z (F)` Cross-capacitance AC current crowding.

68 `gm (1/Ω)`	Transconductance.
69 `beta`	Current amplification.
70 `gout (1/Ω)`	Output conductance.
71 `gmu (1/Ω)`	Feedback transconductance.
72 `RB (Ω)`	Base resistance.
73 `Cbe (F)`	Base-emitter capacitance.
74 `Cbc (F)`	Base-collector capacitance.
75 `fT (Hz)`	Good approximation for cut-off frequency.
76 `Iqs (A)`	Current at onset of quasi-saturation.
77 `XiWepi (M)`	Thickness of injection layer.
78 `Vb2c2star (V)`	Physical value of internal base-collector bias.
79 `Pdiss (W)`	Dissipation.
80 `TK (K)`	Actual temperature.
81 `Isub (A)`	Substrate current.
82 `XIsub (A)`	Substrate current.
83 `Isf (A)`	Substrate failure current.
84 `Qts (C)`	Collector-substrate depletion charge.
85 `gS (1/Ω)`	Conductance parasitic PNP transistor.
86 `XgS (1/Ω)`	Conductance parasitic PNP transistor.
87 `gSf (1/Ω)`	
88 `Cts (C)`	Capacitance s-c junction:.

Parameter Index

In the following index, I refers to instance parameters, M refers to the model parameters section, O refers to the output parameters section, and OP refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of M-35 means the 35th model parameter.

Compact Bipolar-Transistor Model (bjtd504)

Instance Definition

```
Name  c  b  e ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `region=fwd` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `sat`, `rev`, or `fwd`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName bjtd504 parameter=value ...
```

Model Parameters

1 `level=504` Bipolar Level.

2 `tref=25 deg. C` Reference temperature.

3 `dta=0 K` Difference between the local ambient and global ambient temperature.

4 `exmod=1` Flag for extended modeling of reverse current gain.

5 `exphi=1`	Flag for the distributed high-frequency effeCts in transient.
6 `exavl=0`	Flag for extended modeling of avalanche currents.
7 `is=2.2e-17 A`	Collector-emitter saturation current.
8 `ik=0.1 A`	Collector-emitter high injection knee current.
9 `ver=2.5 V`	Reverse Early voltage.
10 `vef=44 V`	Forward Early voltage.
11 `bf=215`	Ideal forward current gain.
12 `ibf=2.7e-15 A`	Saturation current of the non-ideal forward base current.
13 `mlf=2`	Non ideality factor of the non-ideal forward base current.
14 `xibi=0`	Part of ideal base current that belongs to the sidewall.
15 `bri=7`	Ideal reverse current gain.
16 `ibr=1e-15 A`	Saturation current of the non-ideal reverse base current.
17 `vlr=0.2 V`	Cross-over voltage of the non-ideal reverse base current.
18 `xext=0.63`	Part of Iex, Qtex, Qex and Isub that depends on Vbc1 instead of Vb1c1.
19 `wavl=1.1e-06 m`	Epilayer thickness used in weak-avalanche model.
20 `vavl=3 V`	Voltage determining curvature of avalanche current.
21 `sfh=0.3`	Current spreading factor of avalanche model (when EXAVL=1).
22 `re=5 Ω`	Emitter resistance.
23 `rbc=23 Ω`	Constant part of the base resistance.
24 `rbv=18 Ω`	Zero-bias value of the variable part of the base resistance.
25 `rcc=12 Ω`	Constant part of collector resistance.

26 `rcv=150 Ω`	Resistance of the un-modulated epilayer.
27 `scrcv=1.25e+03 Ω`	Space charge resistance of the epilayer.
28 `ihc=0.004 A`	Critical current for velocity saturation in the epilayer.
29 `axi=0.3`	Smoothness parameter for the onset of quasi-saturation.
30 `cje=7.3e-14 F`	Zero-bias emitter-base depletion capacitance.
31 `vde=0.95 V`	Emitter-base diffusion voltage.
32 `pe=0.4`	Emitter-base grading coefficient.
33 `xcje=0.4`	Fraction of the emitter-base depletion capacitance that belongs to the sidewall.
34 `cbeo=0`	Emitter-base overlap capacitance.
35 `cjc=7.8e-14 F`	Zero-bias collector-base depletion capacitance.
36 `vdc=0.68 V`	Collector-base diffusion voltage.
37 `pc=0.5`	Collector-base grading coefficient.
38 `xp=0.35`	Constant part of Cjc.
39 `mc=0.5`	Coefficient for the current modulation of the collector-base depletion capacitance.
40 `xcjc=0.032`	Fraction of the collector-base depletion capacitance under the emitter.
41 `cbco=0`	Collector-base overlap capacitance.
42 `mtau=1`	Non-ideality factor of the emitter stored charge.
43 `taue=2e-12 s`	Minimum transit time of stored emitter charge.
44 `taub=4.2e-12 s`	Transit time of stored base charge.
45 `tepi=4.1e-11 s`	Transit time of stored epilayer charge.

46 `taur=5.2e-10 s`	Transit time of reverse extrinsic base charge.
47 `deg=0 eV`	Bandgap difference over the base.
48 `xrec=0`	Pre-factor of the recombination part of Ib1.
49 `aqbo=0.3`	Temperature coefficient of the zero-bias base charge.
50 `ae=0`	Temperature coefficient of the resistivity of the emitter.
51 `ab=1`	Temperature coefficient of the resistivity of the base.
52 `dais=0`	Parameter for fine tuning of temperature dependence of collector-emitter saturation current.
53 `aepi=2.5`	Temperature coefficient of the resistivity of the epilayer.
54 `aex=0.62`	Temperature coefficient of the resistivity of the extrinsic base.
55 `ac=2`	Temperature coefficient of the resistivity of the buried layer.
56 `dvgbf=0.05 V`	Bandgap voltage difference of forward current gain.
57 `dvgbr=0.045 V`	Bandgap voltage difference of reverse current gain.
58 `vgb=1.17 V`	Bandgap voltage of the base.
59 `vgc=1.18 V`	Bandgap voltage of the collector.
60 `vgj=1.15 V`	Bandgap voltage recombination emitter-base junction.
61 `dvgte=0.05 V`	Bandgap voltage difference of emitter stored charge.
62 `af=2`	Exponent of the Flicker-noise.
63 `kf=2e-11`	Flicker-noise coefficient of the ideal base current.
64 `kfn=2e-11`	Flicker-noise coefficient of the non-ideal base current.
65 `kavl=0`	Switch for white noise contribution due to avalanche.
66 `type=n`	Transistor gender. Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

67 `imax=1.0 A` Explosion current.

68 `tnom (deg. C)` alias of tnom.

69 `tr (deg. C)` alias of tnom.

Output Parameters

1 `tref (deg. C)` Reference temperature.

2 `dta (K)` Difference between the local ambient and global ambient temperatures.

3 `exmod` Flag for extended modeling of reverse current gain.

4 `exphi` Flag for the distributed high-frequency effeCts in transient.

5 `exavl` Flag for extended modeling of avalanche currents.

6 `is (A)` Collector-emitter saturation current.

7 `ik (A)` Collector-emitter high injection knee current.

8 `ver (V)` Reverse Early voltage.

9 `vef (V)` Forward Early voltage.

10 `bf` Ideal forward current gain.

11 `ibf (A)` Saturation current of the non-ideal forward base current.

12 `mlf` Non ideality factor of the non-ideal forward base current.

13 `xibi` Part of ideal base current that belongs to the sidewall.

14 `bri` Ideal reverse current gain.

15 `ibr (A)` Saturation current of the non-ideal reverse base current.

16 `vlr (V)` Cross-over voltage of the non-ideal reverse base current.

17 `xext` Part of Iex, Qtex, Qex and Isub that depends on Vbc1 instead of Vb1c1.

18 `wavl (M)`	Epilayer thickness used in weak-avalanche model.
19 `vavl (V)`	Voltage determining curvature of avalanche current.
20 `sfh`	Current spreading factor of avalanche model (when EXAVL=1).
21 `re (Ω)`	Emitter resistance.
22 `rbc (Ω)`	Constant part of the base resistance.
23 `rbv (Ω)`	Zero-bias value of the variable part of the base resistance.
24 `rcc (Ω)`	Constant part of collector resistance.
25 `rcv (Ω)`	Resistance of the un-modulated epilayer.
26 `scrcv (Ω)`	Space charge resistance of the epilayer.
27 `ihc (A)`	Critical current for velocity saturation in the epilayer.
28 `axi`	Smoothness parameter for the onset of quasi-saturation.
29 `cje (F)`	Zero-bias emitter-base depletion capacitance.
30 `vde (V)`	Emitter-base diffusion voltage.
31 `pe`	Emitter-base grading coefficient.
32 `xcje`	Fraction of the emitter-base depletion capacitance that belongs to the sidewall.
33 `cbeo`	Emitter-base overlap capacitance.
34 `cjc (F)`	Zero-bias collector-base depletion capacitance.
35 `vdc (V)`	Collector-base diffusion voltage.
36 `pc`	Collector-base grading coefficient.
37 `xp`	Constant part of Cjc.
38 `mc`	Coefficient for the current modulation of the collector-base depletion capacitance.

39 `xcjc`	Fraction of the collector-base depletion capacitance under the emitter.
40 `cbco`	Collector-base overlap capacitance.
41 `mtau`	Non-ideality factor of the emitter stored charge.
42 `taue (s)`	Minimum transit time of stored emitter charge.
43 `taub (s)`	Transit time of stored base charge.
44 `tepi (s)`	Transit time of stored epilayer charge.
45 `taur (s)`	Transit time of reverse extrinsic stored base charge.
46 `deg (eV)`	Bandgap difference over the base.
47 `xrec`	Pre-factor of the recombination part of Ib1.
48 `aqbo`	Temperature coefficient of the zero-bias base charge.
49 `ae`	Temperature coefficient of the resistivity of the emitter.
50 `ab`	Temperature coefficient of the resistivity of the base.
51 `dais`	Parameter for fine tuning of temperature dependence of collector-emitter saturation current.
52 `aepi`	Temperature coefficient of the resistivity of the epilayer.
53 `aex`	Temperature coefficient of the resistivity of the extrinsic base.
54 `ac`	Temperature coefficient of the resistivity of the buried layer.
55 `dvgbf (V)`	Bandgap voltage diffrence of forward current gain.
56 `dvgbr (V)`	Bandgap voltage diffrence of reverse current gain.
57 `vgb (V)`	Bandgap voltage of the base.
58 `vgc (V)`	Bandgap voltage of the collector.
59 `vgj (V)`	Bandgap voltage recombination emitter-base junction.

60 `dvgte (V)` Bandgap voltage difference of emitter stored charge.

61 `af` Exponent of the Flicker-noise.

62 `kf` Flicker-noise coefficient of the ideal base current.

63 `kfn` Flicker-noise coefficient of the non-ideal base current.

64 `kavl` Switch for white noise contribution due to avalanche.

Operating-Point Parameters

1 `Ic (A)` External DC collector current.

2 `Ib (A)` External DC base current.

3 `BetaDC` External DC current gain Ic/Ib.

4 `Vb2e1 (V)` Internal base-emitter bias.

5 `Vb2c2 (V)` Internal base-collector bias.

6 `Vb2c1 (V)` Internal base-collector bias including epilayer.

7 `Vb1c1 (V)` External base-collector bias without contact resistances.

8 `Ve1e (V)` Bias over emitter resistance.

9 `In (A)` Main current.

10 `Ic1c2 (A)` Epilayer current.

11 `Ib1b2 (A)` Pinched-base current.

12 `Ib1 (A)` Ideal forward base current.

13 `SIb1 (A)` Ideal side-wall base current.

14 `Ib2 (A)` Non-ideal forward base current.

15 `Ib3 (A)` Non-ideal reverse base current.

16 `Iex (A)` Extrinsic reverse base current.

17 `XIex (A)`	Extrinsic reverse base current.
18 `Iavl (A)`	Avalanche current.
19 `IRE (A)`	Current through emitter resistance.
20 `IRBC (A)`	Current through constant base resistance.
21 `IRCC (A)`	Current through constant collector resistance.
22 `Qe (C)`	Emitter charge or emitter neutral charge.
23 `Qte (C)`	Base-emitter depletion charge.
24 `SQte (C)`	Sidewall base-emitter depletion charge.
25 `Qbe (C)`	Base-emitter diffusion charge.
26 `Qbc (C)`	Base-collector diffusion charge.
27 `Qtc (C)`	Base-collector depletion charge.
28 `Qepi (C)`	Epilayer diffusion charge.
29 `Qb1b2 (C)`	AC current crowding charge.
30 `Qtex (C)`	Extrinsic base-collector depletion charge.
31 `XQtex (C)`	Extrinsic base-collector depletion charge.
32 `Qex (C)`	Extrinsic base-collector diffusion charge.
33 `XQex (C)`	Extrinsic base-collector diffusion charge.
34 gx (1/Ω)	Forward transconductance.
35 gy (1/Ω)	Reverse transconductance.
36 gz (1/Ω)	Reverse transconductance.
37 Sgpi (1/Ω)	Conductance sidewall b-e junction.
38 gpix (1/Ω)	Conductance floor b-e junction.

39 `gpiy (1/Ω)`	Early effect on recombination base current.
40 `gpiz (1/Ω)`	Early effect on recombination base current.
41 `gmux (1/Ω)`	Early effect on avalanche current limiting.
42 `gmuy (1/Ω)`	Conductance of avalanche current.
43 `gmuz (1/Ω)`	Conductance of avalanche current.
44 `gmuex (1/Ω)`	Conductance extrinsic b-c junction.
45 `Xgmuex (1/Ω)`	Conductance extrinsic b-c junction.
46 `grcvy (1/Ω)`	Conductance of the epilayer current.
47 `grcvz (1/Ω)`	Conductance of the epilayer current.
48 `Rbv (Ω)`	Conductance of the epilayer current.
49 `grbvx (1/Ω)`	Early-effect on base resistance.
50 `grbvy (1/Ω)`	Early-effect on base resistance.
51 `grbvz (1/Ω)`	Early-effect on base resistance:.
52 `RE (Ω)`	Early-effect on base resistance:.
53 `RBC (Ω)`	Early-effect on base resistance:.
54 `RCC (Ω)`	Early-effect on base resistance:.
55 `SCbe (F)`	Capacitance sidewall b-e junction.
56 `Cbex (F)`	Capacitance floor b-e junction.
57 `Cbey (F)`	Early effect on b-e diffusion charge.
58 `Cbez (F)`	Early effect on b-e diffusion charge.
59 `Cbcx (F)`	Early effect on b-c diffusion charge.
60 `Cbcy (F)`	Capacitance floor b-c junction.

61 `Cbcz (F)` Capacitance floor b-c junction.

62 `Cbcex (F)` Capacitance extrinsic b-c junction.

63 `XCbcex (F)` Capacitance extrinsic b-c junction.

64 `Cb1b2 (F)` Capacitance AC current crowding.

65 `Cb1b2x (F)` Cross-capacitance AC current crowding .

66 `Cb1b2y (F)` Cross-capacitance AC current crowding.

67 `Cb1b2z (F)` Cross-capacitance AC current crowding.

68 `gm (1/Ω)` Transconductance.

69 `beta` Current amplification.

70 `gout (1/Ω)` Output conductance.

71 `gmu (1/Ω)` Feedback transconductance.

72 `RB (Ω)` Base resistance.

73 `Cbe (F)` Base-emitter capacitance.

74 `Cbc (F)` Base-collector capacitance.

75 `fT (Hz)` Good approximation for cut-off frequency.

76 `Iqs (A)` Current at onset of quasi-saturation.

77 `XiWepi (M)` Thickness of injection layer.

78 `Vb2c2star (V)` Physical value of internal base-collector bias.

79 `Pdiss (W)` Dissipation.

80 `TK (K)` Actual temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Compact Bipolar-Transistor Model (bjtd504t)

his is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  c  b  e  dt ModelName parameter=value ...
```

Instance Parameters

1 `mult=1`	Number of devices in parallel.
2 `region=fwd`	Estimated DC operating region, used as a convergence aid. Possible values are `off`, `sat`, `rev`, or `fwd`.
3 `m=1`	Multiplicity factor.
4 `area=1`	alias of mult.

Model Definition

```
model modelName bjtd504t parameter=value ...
```

Model Parameters

1 `level=504`	Bipolar Level.
2 `tref=25 deg. C`	Reference temperature.
3 `dta=0 K`	Difference between the local ambient and global ambient temperature.
4 `exmod=1`	Flag for extended modeling of reverse current gain.
5 `exphi=1`	Flag for the distributed high-frequency effeCts in transient.
6 `exavl=0`	Flag for extended modeling of avalanche currents.
7 `is=2.2e-17 A`	Collector-emitter saturation current.
8 `ik=0.1 A`	Collector-emitter high injection knee current.

9 `ver=2.5 V`	Reverse Early voltage.
10 `vef=44 V`	Forward Early voltage.
11 `bf=215`	Ideal forward current gain.
12 `ibf=2.7e-15 A`	Saturation current of the non-ideal forward base current.
13 `mlf=2`	Non ideality factor of the non-ideal forward base current.
14 `xibi=0`	Part of ideal base current that belongsbelongs to the sidewall.
15 `bri=7`	Ideal reverse current gain.
16 `ibr=1e-15 A`	Saturation current of the non-ideal reverse base current.
17 `vlr=0.2 V`	Cross-over voltage of the non-ideal reverse base current.
18 `xext=0.63`	Part of Iex, Qtex, Qex and Isub that depends on Vbc1 instead of Vb1c1.
19 `wavl=1.1e-06 m`	Epilayer thickness used in weak-avalanche model.
20 `vavl=3 V`	Voltage determining curvature of avalanche current.
21 `sfh=0.3`	Current spreading factor of avalanche model (when EXAVL=1).
22 `re=5` Ω	Emitter resistance.
23 `rbc=23` Ω	Constant part of the base resistance.
24 `rbv=18` Ω	Zero-bias value of the variable part of the base resistance.
25 `rcc=12` Ω	Constant part of collector resistance.
26 `rcv=150` Ω	Resistance of the un-modulated epilayer.
27 `scrcv=1.25e+03` Ω	Space charge resistance of the epilayer.
28 `ihc=0.004 A`	Critical current for velocity saturation in the epilayer.
29 `axi=0.3`	Smoothness parameter for the onset of quasi-saturation.

30 `cje=7.3e-14 F`	Zero-bias emitter-base depletion capacitance.
31 `vde=0.95 V`	Emitter-base diffusion voltage.
32 `pe=0.4`	Emitter-base grading coefficient.
33 `xcje=0.4`	Fraction of the emitter-base depletion capacitance that belongs to the sidewall.
34 `cbeo=0`	Emitter-base overlap capacitance.
35 `cjc=7.8e-14 F`	Zero-bias collector-base depletion capacitance.
36 `vdc=0.68 V`	Collector-base diffusion voltage.
37 `pc=0.5`	Collector-base grading coefficient.
38 `xp=0.35`	Constant part of Cjc.
39 `mc=0.5`	Coefficient for the current modulation of the collector-base depletion capacitance.
40 `xcjc=0.032`	Fraction of the collector-base depletion capacitance under the emitter.
41 `cbco=0`	Collector-base overlap capacitance.
42 `mtau=1`	Non-ideality factor of the emitter stored charge.
43 `taue=2e-12 s`	Minimum transit time of stored emitter charge.
44 `taub=4.2e-12 s`	Transit time of stored base charge.
45 `tepi=4.1e-11 s`	Transit time of stored epilayer charge.
46 `taur=5.2e-10 s`	Transit time of reverse extrinsic base charge.
47 `deg=0 eV`	Bandgap difference over the base.
48 `xrec=0`	Pre-factor of the recombination part of Ib1.
49 `aqbo=0.3`	Temperature coefficient of the zero-bias base charge.

50 `ae=0`	Temperature coefficient of the resistivity of the emitter.
51 `ab=1`	Temperature coefficient of the resistivity of the base.
52 `dais=0`	Parameter for fine tuning of temperature dependence of collector-emitter saturation current.
53 `aepi=2.5`	Temperature coefficient of the resistivity of the epilayer.
54 `aex=0.62`	Temperature coefficient of the resistivity of the extrinsic base.
55 `ac=2`	Temperature coefficient of the resistivity of the buried layer.
56 `dvgbf=0.05 V`	Bandgap voltage difference of forward current gain.
57 `dvgbr=0.045 V`	Bandgap voltage difference of reverse current gain.
58 `vgb=1.17 V`	Bandgap voltage of the base.
59 `vgc=1.18 V`	Bandgap voltage of the collector.
60 `vgj=1.15 V`	Bandgap voltage recombination emitter-base junction.
61 `dvgte=0.05 V`	Bandgap voltage difference of emitter stored charge.
62 `af=2`	Exponent of the Flicker-noise.
63 `kf=2e-11`	Flicker-noise coefficient of the ideal base current.
64 `kfn=2e-11`	Flicker-noise coefficient of the non-ideal base current.
65 `kavl=0`	Switch for white noise contribution due to avalanche.
66 `rth=300 K/W`	Thermal resistance.
67 `cth=3e-09 J/K`	Thermal capacitance.
68 `ath=0`	Temperature coefficient of the thermal resistance.
69 `type=n`	Transistor gender. Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.
70 `imax=1.0 A`	Explosion current.

71 `tnom (deg. C)` alias of tnom.

72 `tr (deg. C)` alias of tnom.

Output Parameters

1 `tref (deg. C)` Reference temperature.

2 `dta (K)` Difference between the local ambient and global ambient temperatures.

3 `exmod` Flag for extended modeling of reverse current gain.

4 `exphi` Flag for the distributed high-frequency effeCts in transient.

5 `exavl` Flag for extended modeling of avalanche currents.

6 `is (A)` Collector-emitter saturation current.

7 `ik (A)` Collector-emitter high injection knee current.

8 `ver (V)` Reverse Early voltage.

9 `vef (V)` Forward Early voltage.

10 `bf` Ideal forward current gain.

11 `ibf (A)` Saturation current of the non-ideal forward base current.

12 `mlf` Non ideality factor of the non-ideal forward base current.

13 `xibi` Part of ideal base current that belongs to the sidewall.

14 `bri` Ideal reverse current gain.

15 `ibr (A)` Saturation current of the non-ideal reverse base current.

16 `vlr (V)` Cross-over voltage of the non-ideal reverse base current.

17 `xext` Part of Iex, Qtex, Qex and Isub that depends on Vbc1 instead of Vb1c1.

18 `wavl (M)` Epilayer thickness used in weak-avalanche model.

19 `vavl (V)`	Voltage determining curvature of avalanche current.
20 `sfh`	Current spreading factor of avalanche model (when EXAVL=1).
21 `re (Ω)`	Emitter resistance.
22 `rbc (Ω)`	Constant part of the base resistance.
23 `rbv (Ω)`	Zero-bias value of the variable part of the base resistance.
24 `rcc (Ω)`	Constant part of collector resistance.
25 `rcv (Ω)`	Resistance of the un-modulated epilayer.
26 `scrcv (Ω)`	Space charge resistance of the epilayer.
27 `ihc (A)`	Critical current for velocity saturation in the epilayer.
28 `axi`	Smoothness parameter for the onset of quasi-saturation.
29 `cje (F)`	Zero-bias emitter-base depletion capacitance.
30 `vde (V)`	Emitter-base diffusion voltage.
31 `pe`	Emitter-base grading coefficient.
32 `xcje`	Fraction of the emitter-base depletion capacitance that belongs to the sidewall.
33 `cbeo`	Emitter-base overlap capacitance.
34 `cjc (F)`	Zero-bias collector-base depletion capacitance.
35 `vdc (V)`	Collector-base diffusion voltage.
36 `pc`	Collector-base grading coefficient.
37 `xp`	Constant part of Cjc.
38 `mc`	Coefficient for the current modulation of the collector-base depletion capacitance.

39 `xcjc`	Fraction of the collector-base depletion capacitance under the emitter.
40 `cbco`	Collector-base overlap capacitance.
41 `mtau`	Non-ideality factor of the emitter stored charge.
42 `taue (s)`	Minimum transit time of stored emitter charge.
43 `taub (s)`	Transit time of stored base charge.
44 `tepi (s)`	Transit time of stored epilayer charge.
45 `taur (s)`	Transit time of reverse extrinsic stored base charge.
46 `deg (eV)`	Bandgap difference over the base.
47 `xrec`	Pre-factor of the recombination part of Ib1.
48 `aqbo`	Temperature coefficient of the zero-bias base charge.
49 `ae`	Temperature coefficient of the resistivity of the emitter.
50 `ab`	Temperature coefficient of the resistivity of the base.
51 `dais`	Parameter for fine tuning of temperature dependence of collector-emitter saturation current.
52 `aepi`	Temperature coefficient of the resistivity of the epilayer.
53 `aex`	Temperature coefficient of the resistivity of the extrinsic base.
54 `ac`	Temperature coefficient of the resistivity of the buried layer.
55 `dvgbf (V)`	Bandgap voltage diffrence of forward current gain.
56 `dvgbr (V)`	Bandgap voltage diffrence of reverse current gain.
57 `vgb (V)`	Bandgap voltage of the base.
58 `vgc (V)`	Bandgap voltage of the collector.
59 `vgj (V)`	Bandgap voltage recombination emitter-base junction.

60 `dvgte (V)` Bandgap voltage difference of emitter stored charge.

61 `af` Exponent of the Flicker-noise.

62 `kf` Flicker-noise coefficient of the ideal base current.

63 `kfn` Flicker-noise coefficient of the non-ideal base current.

64 `kavl` Switch for white noise contribution due to avalanche.

65 `rth (K/W)` Thermal resistance.

66 `cth (J/K)` Thermal capacitance.

67 `ath` Temperature coefficient of the thermal resistance.

Operating-Point Parameters

1 `Ic (A)` External DC collector current.

2 `Ib (A)` External DC base current.

3 `BetaDC` External DC current gain Ic/Ib.

4 `Vb2e1 (V)` Internal base-emitter bias.

5 `Vb2c2 (V)` Internal base-collector bias.

6 `Vb2c1 (V)` Internal base-collector bias including epilayer.

7 `Vb1c1 (V)` External base-collector bias without contact resistances.

8 `Ve1e (V)` Bias over emitter resistance.

9 `In (A)` Main current.

10 `Ic1c2 (A)` Epilayer current.

11 `Ib1b2 (A)` Pinched-base current.

12 `Ib1 (A)` Ideal forward base current.

13 `SIb1 (A)` Ideal side-wall base current.

14 `Ib2 (A)` Non-ideal forward base current.

15 `Ib3 (A)` Non-ideal reverse base current.

16 `Iex (A)` Extrinsic reverse base current.

17 `XIex (A)` Extrinsic reverse base current.

18 `Iavl (A)` Avalanche current.

19 `IRE (A)` Current through emitter resistance.

20 `IRBC (A)` Current through constant base resistance.

21 `IRCC (A)` Current through constant collector resistance.

22 `Qe (C)` Emitter charge or emitter neutral charge.

23 `Qte (C)` Base-emitter depletion charge.

24 `SQte (C)` Sidewall base-emitter depletion charge.

25 `Qbe (C)` Base-emitter diffusion charge.

26 `Qbc (C)` Base-collector diffusion charge.

27 `Qtc (C)` Base-collector depletion charge.

28 `Qepi (C)` Epilayer diffusion charge.

29 `Qb1b2 (C)` AC current crowding charge.

30 `Qtex (C)` Extrinsic base-collector depletion charge.

31 `XQtex (C)` Extrinsic base-collector depletion charge.

32 `Qex (C)` Extrinsic base-collector diffusion charge.

33 `XQex (C)` Extrinsic base-collector diffusion charge.

34 gx (1/Ω) Forward transconductance.

35 gy (1/Ω) Reverse transconductance.

36 `gz (1/Ω)` Reverse transconductance.

37 `Sgpi (1/Ω)` Conductance sidewall b-e junction.

38 `gpix (1/Ω)` Conductance floor b-e junction.

39 `gpiy (1/Ω)` Early effect on recombination base current.

40 `gpiz (1/Ω)` Early effect on recombination base current.

41 `gmux (1/Ω)` Early effect on avalanche current limiting.

42 `gmuy (1/Ω)` Conductance of avalanche current.

43 `gmuz (1/Ω)` Conductance of avalanche current.

44 `gmuex (1/Ω)` Conductance extrinsic b-c junction.

45 `Xgmuex (1/Ω)` Conductance extrinsic b-c junction.

46 `grcvy (1/Ω)` Conductance of the epilayer current.

47 `grcvz (1/Ω)` Conductance of the epilayer current.

48 `Rbv (Ω)` Conductance of the epilayer current.

49 `grbvx (1/Ω)` Early-effect on base resistance.

50 `grbvy (1/Ω)` Early-effect on base resistance.

51 `grbvz (1/Ω)` Early-effect on base resistance:.

52 `RE (Ω)` Early-effect on base resistance:.

53 `RBC (Ω)` Early-effect on base resistance:.

54 `RCC (Ω)` Early-effect on base resistance:.

55 `SCbe (F)` Capacitance sidewall b-e junction.

56 `Cbex (F)` Capacitance floor b-e junction.

57 `Cbey (F)` Early effect on b-e diffusion charge.

58 `Cbez (F)`	Early effect on b-e diffusion charge.
59 `Cbcx (F)`	Early effect on b-c diffusion charge.
60 `Cbcy (F)`	Capacitance floor b-c junction.
61 `Cbcz (F)`	Capacitance floor b-c junction.
62 `Cbcex (F)`	Capacitance extrinsic b-c junction.
63 `XCbcex (F)`	Capacitance extrinsic b-c junction.
64 `Cb1b2 (F)`	Capacitance AC current crowding.
65 `Cb1b2x (F)`	Cross-capacitance AC current crowding .
66 `Cb1b2y (F)`	Cross-capacitance AC current crowding.
67 `Cb1b2z (F)`	Cross-capacitance AC current crowding.
68 `gm (1/Ω)`	Transconductance.
69 `beta`	Current amplification.
70 `gout (1/Ω)`	Output conductance.
71 `gmu (1/Ω)`	Feedback transconductance.
72 `RB (Ω)`	Base resistance.
73 `Cbe (F)`	Base-emitter capacitance.
74 `Cbc (F)`	Base-collector capacitance.
75 `fT (Hz)`	Good approximation for cut-off frequency.
76 `Iqs (A)`	Current at onset of quasi-saturation.
77 `XiWepi (M)`	Thickness of injection layer.
78 `Vb2c2star (V)`	Physical value of internal base-collector bias.
79 `Pdiss (W)`	Dissipation.

80 `TK (K)` Actual temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Compact Bipolar-Transistor Model (bjtd3500)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  c  b  e ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `region=fwd` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `sat`, `rev`, or `fwd`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName bjtd3500 parameter=value ...
```

Model Parameters

1 `level=3.5e+03` Bipolar Level.

2 `tref=25 deg. C` Reference temperature.

3 `dta=0 K` Difference between the local ambient and global ambient temperature.

4 `exmod=1` Flag for extended modeling of reverse current gain.

5 `exphi=1` Flag for the distributed high-frequency effeCts in transient.

6 `exavl=0` Flag for extended modeling of avalanche currents.

7 `is=2.2e-17 A`	Collector-emitter saturation current.
8 `ik=0.1 A`	Collector-emitter high injection knee current.
9 `ver=2.5 V`	Reverse Early voltage.
10 `vef=44 V`	Forward Early voltage.
11 `bf=215`	Ideal forward current gain.
12 `ibf=2.7e-15 A`	Saturation current of the non-ideal forward base current.
13 `mlf=2`	Non ideality factor of the non-ideal forward base current.
14 `mhf=1`	Non ideality factor of the non-ideal forward base current.
15 `mlr=2`	Non ideality factor of the non-ideal reverse base current.
16 `mhr=1`	Non ideality factor of the ideal reverse base current.
17 `mf=1`	Non ideality factor of main current.
18 `xibi=0`	Part of ideal base current that belongs to the sidewall.
19 `bri=7`	Ideal reverse current gain.
20 `ibr=1e-15 A`	Saturation current of the non-ideal reverse base current.
21 `vlr=0.2 V`	Cross-over voltage of the non-ideal reverse base current.
22 `xext=0.63`	Part of Iex, Qtex, Qex and Isub that depends on Vbc1 instead of Vb1c1.
23 `wavl=1.1e-06 m`	Epilayer thickness used in weak-avalanche model.
24 `vavl=3 V`	Voltage determining curvature of avalanche current.
25 `sfh=0.3`	Current spreading factor of avalanche model (when EXAVL=1).
26 `re=5 Ω`	Emitter resistance.
27 `rbc=23 Ω`	Constant part of the base resistance.

28 `rbv=18 Ω` Zero-bias value of the variable part of the base resistance.

29 `rcc=12 Ω` Constant part of collector resistance.

30 `rcv=150 Ω` Resistance of the un-modulated epilayer.

31 `scrcv=1.25e+03 Ω`
Space charge resistance of the epilayer.

32 `ihc=0.004 A` Critical current for velocity saturation in the epilayer.

33 `axi=0.3` Smoothness parameter for the onset of quasi-saturation.

34 `cje=7.3e-14 F` Zero-bias emitter-base depletion capacitance.

35 `vde=0.95 V` Emitter-base diffusion voltage.

36 `pe=0.4` Emitter-base grading coefficient.

37 `xcje=0.4` Fraction of the emitter-base depletion capacitance that belongs to the sidewall.

38 `cbeo=0` Emitter-base overlap capacitance.

39 `cjc=7.8e-14 F` Zero-bias collector-base depletion capacitance.

40 `vdc=0.68 V` Collector-base diffusion voltage.

41 `pc=0.5` Collector-base grading coefficient.

42 `xp=0.35` Constant part of Cjc.

43 `mc=0.5` Coefficient for the current modulation of the collector-base depletion capacitance.

44 `xcjc=0.032` Fraction of the collector-base depletion capacitance under the emitter.

45 `cbco=0` Collector-base overlap capacitance.

46 `vos=0.04 V` Voltage describing overshoot.

47 `isat=0.067 A` Saturation current.

48 `repi=6 Ω`	Ohmic resistance epilayer.
49 `rdmin=0`	Minimum relative collector doping.
50 `sbjn=0.1`	Smoothness parameter Qtc model.
51 `sbeb=0.1`	Smoothness parameter Qtc model.
52 `etavdr=0.23`	Slope-parameter of Vdrift at high electric field.
53 `nvdr=4`	Power describing saturation behavior of Qtc.
54 `alfaw=0`	Smooth switch for reach through modeling.
55 `sw=0.1`	Smoothness parameter for reach through modeling.
56 `mtau=1`	Non-ideality factor of the emitter stored charge.
57 `taue=2e-12 s`	Minimum transit time of stored emitter charge.
58 `taub=4.2e-12 s`	Transit time of stored base charge.
59 `tepi=4.1e-11 s`	Transit time of stored epilayer charge.
60 `taur=5.2e-10 s`	Transit time of reverse extrinsic base charge.
61 `deg=0 eV`	Bandgap difference over the base.
62 `xrec=0`	Pre-factor of the recombination part of Ib1.
63 `aqbo=0.3`	Temperature coefficient of the zero-bias base charge.
64 `ae=0`	Temperature coefficient of the resistivity of the emitter.
65 `ab=1`	Temperature coefficient of the resistivity of the base.
66 `dais=0`	Parameter for fine tuning of temperature dependence of collector-emitter saturation current.
67 `aepi=2.5`	Temperature coefficient of the resistivity of the epilayer.
68 `aex=0.62`	Temperature coefficient of the resistivity of the extrinsic base.

69 `ac=2` Temperature coefficient of the resistivity of the buried layer.

70 `aisat=-0.37` Temperature coefficient of the saturation current.

71 `dvgbf=0.05 V` Bandgap voltage difference of forward current gain.

72 `dvgbr=0.045 V` Bandgap voltage difference of reverse current gain.

73 `vgb=1.17 V` Bandgap voltage of the base.

74 `vgc=1.18 V` Bandgap voltage of the collector.

75 `vgj=1.15 V` Bandgap voltage recombination emitter-base junction.

76 `dvgte=0.05 V` Bandgap voltage difference of emitter stored charge.

77 `af=2` Exponent of the Flicker-noise.

78 `kf=2e-11` Flicker-noise coefficient of the ideal base current.

79 `kfn=2e-11` Flicker-noise coefficient of the non-ideal base current.

80 `kavl=0` Switch for white noise contribution due to avalanche.

81 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

82 `imax=1.0 A` Explosion current.

83 `tnom (deg. C)` alias of tnom.

84 `tr (deg. C)` alias of tnom.

Output Parameters

1 `tref (deg. C)` Reference temperature.

2 `dta (K)` Difference between the local ambient and global ambient temperatures.

3 `exmod` Flag for extended modeling of reverse current gain.

4 `exphi` Flag for the distributed high-frequency effeCts in transient.

5 `exavl`	Flag for extended modeling of avalanche currents.
6 `is (A)`	Collector-emitter saturation current.
7 `ik (A)`	Collector-emitter high injection knee current.
8 `ver (V)`	Reverse Early voltage.
9 `vef (V)`	Forward Early voltage.
10 `bf`	Ideal forward current gain.
11 `ibf (A)`	Saturation current of the non-ideal forward base current.
12 `mlf`	Non ideality factor of the non-ideal forward base current.
13 `mhf`	Non ideality factor of the ideal forward base current.
14 `mlr`	Non ideality factor of the non-ideal reverse base current.
15 `mhr`	Non ideality factor of the ideal reverse base current.
16 `mf`	Non ideality factor of main current.
17 `xibi`	Part of ideal base current that belongs to the sidewall.
18 `bri`	Ideal reverse current gain.
19 `ibr (A)`	Saturation current of the non-ideal reverse base current.
20 `vlr (V)`	Cross-over voltage of the non-ideal reverse base current.
21 `xext`	Part of Iex, Qtex, Qex and Isub that depends on Vbc1 instead of Vb1c1.
22 `wavl (M)`	Epilayer thickness used in weak-avalanche model.
23 `vavl (V)`	Voltage determining curvature of avalanche current.
24 `sfh`	Current spreading factor of avalanche model (when EXAVL=1).
25 `re (Ω)`	Emitter resistance.

26 `rbc (Ω)`	Constant part of the base resistance.
27 `rbv (Ω)`	Zero-bias value of the variable part of the base resistance.
28 `rcc (Ω)`	Constant part of collector resistance.
29 `rcv (Ω)`	Resistance of the un-modulated epilayer.
30 `scrcv (Ω)`	Space charge resistance of the epilayer.
31 `ihc (A)`	Critical current for velocity saturation in the epilayer.
32 `axi`	Smoothness parameter for the onset of quasi-saturation.
33 `cje (F)`	Zero-bias emitter-base depletion capacitance.
34 `vde (V)`	Emitter-base diffusion voltage.
35 `pe`	Emitter-base grading coefficient.
36 `xcje`	Fraction of the emitter-base depletion capacitance that belongs to the sidewall.
37 `cbeo`	Emitter-base overlap capacitance.
38 `cjc (F)`	Zero-bias collector-base depletion capacitance.
39 `vdc (V)`	Collector-base diffusion voltage.
40 `pc`	Collector-base grading coefficient.
41 `xp`	Constant part of Cjc.
42 `mc`	Coefficient for the current modulation of the collector-base depletion capacitance.
43 `xcjc`	Fraction of the collector-base depletion capacitance under the emitter.
44 `cbco`	Collector-base overlap capacitance.
45 `vos (V)`	Voltage describing overshoot.

46 `isat (A)`	Saturation current.
47 `repi (Ω)`	Ohmic resistance epilayer.
48 `rdmin`	Minimum relative collector doping.
49 `sbjn`	Smoothness parameter Qtc model.
50 `sbeb`	Smoothness parameter Qtc model.
51 `etavdr`	Slope-parameter of Vdrift at high electric field.
52 `nvdr`	Power describing saturation behavior of Qtc.
53 `alfaw`	Smooth switch for reach through modeling.
54 `sw`	Smoothness parameter for reach through modeling.
55 `mtau`	Non-ideality factor of the emitter stored charge.
56 `taue (s)`	Minimum transit time of stored emitter charge.
57 `taub (s)`	Transit time of stored base charge.
58 `tepi (s)`	Transit time of stored epilayer charge.
59 `taur (s)`	Transit time of reverse extrinsic stored base charge.
60 `deg (eV)`	Bandgap difference over the base.
61 `xrec`	Pre-factor of the recombination part of Ib1.
62 `aqbo`	Temperature coefficient of the zero-bias base charge.
63 `ae`	Temperature coefficient of the resistivity of the emitter.
64 `ab`	Temperature coefficient of the resistivity of the base.
65 `dais`	Parameter for fine tuning of temperature dependence of collector-emitter saturation current.
66 `aepi`	Temperature coefficient of the resistivity of the epilayer.

67 `aex`	Temperature coefficient of the resistivity of the extrinsic base.
68 `ac`	Temperature coefficient of the resistivity of the buried layer.
69 `aisat`	Temperature coefficient of the saturation current.
70 `dvgbf (V)`	Bandgap voltage diffrence of forward current gain.
71 `dvgbr (V)`	Bandgap voltage diffrence of reverse current gain.
72 `vgb (V)`	Bandgap voltage of the base.
73 `vgc (V)`	Bandgap voltage of the collector.
74 `vgj (V)`	Bandgap voltage recombination emitter-base junction.
75 `dvgte (V)`	Bandgap voltage difference of emitter stored charge.
76 `af`	Exponent of the Flicker-noise.
77 `kf`	Flicker-noise coefficient of the ideal base current.
78 `kfn`	Flicker-noise coefficient of the non-ideal base current.
79 `kavl`	Switch for white noise contribution due to avalanche.

Operating-Point Parameters

1 `Ic (A)`	External DC collector current.
2 `Ib (A)`	External DC base current.
3 `BetaDC`	External DC current gain Ic/Ib.
4 `Vb2e1 (V)`	Internal base-emitter bias.
5 `Vb2c2 (V)`	Internal base-collector bias.
6 `Vb2c1 (V)`	Internal base-collector bias including epilayer.
7 `Vb1c1 (V)`	External base-collector bias without contact resistances.
8 `Ve1e (V)`	Bias over emitter resistance.

9 `In (A)` Main current.

10 `Ic1c2 (A)` Epilayer current.

11 `Ib1b2 (A)` Pinched-base current.

12 `Ib1 (A)` Ideal forward base current.

13 `SIb1 (A)` Ideal side-wall base current.

14 `Ib2 (A)` Non-ideal forward base current.

15 `Ib3 (A)` Non-ideal reverse base current.

16 `Iex (A)` Extrinsic reverse base current.

17 `XIex (A)` Extrinsic reverse base current.

18 `Iavl (A)` Avalanche current.

19 `IRE (A)` Current through emitter resistance.

20 `IRBC (A)` Current through constant base resistance.

21 `IRCC (A)` Current through constant collector resistance.

22 `Qe (C)` Emitter charge or emitter neutral charge.

23 `Qte (C)` Base-emitter depletion charge.

24 `SQte (C)` Sidewall base-emitter depletion charge.

25 `Qbe (C)` Base-emitter diffusion charge.

26 `Qbc (C)` Base-collector diffusion charge.

27 `Qtc (C)` Base-collector depletion charge.

28 `Qepi (C)` Epilayer diffusion charge.

29 `Qb1b2 (C)` AC current crowding charge.

30 `Qtex (C)` Extrinsic base-collector depletion charge.

31 `XQtex (C)` Extrinsic base-collector depletion charge.

32 `Qex (C)` Extrinsic base-collector diffusion charge.

33 `XQex (C)` Extrinsic base-collector diffusion charge.

34 `gx (1/Ω)` Forward transconductance.

35 `gy (1/Ω)` Reverse transconductance.

36 `gz (1/Ω)` Reverse transconductance.

37 `Sgpi (1/Ω)` Conductance sidewall b-e junction.

38 `gpix (1/Ω)` Conductance floor b-e junction.

39 `gpiy (1/Ω)` Early effect on recombination base current.

40 `gpiz (1/Ω)` Early effect on recombination base current.

41 `gmux (1/Ω)` Early effect on avalanche current limiting.

42 `gmuy (1/Ω)` Conductance of avalanche current.

43 `gmuz (1/Ω)` Conductance of avalanche current.

44 `gmuex (1/Ω)` Conductance extrinsic b-c junction.

45 `Xgmuex (1/Ω)` Conductance extrinsic b-c junction.

46 `grcvy (1/Ω)` Conductance of the epilayer current.

47 `grcvz (1/Ω)` Conductance of the epilayer current.

48 `Rbv (Ω)` Conductance of the epilayer current.

49 `grbvx (1/Ω)` Early-effect on base resistance.

50 `grbvy (1/Ω)` Early-effect on base resistance.

51 `grbvz (1/Ω)` Early-effect on base resistance:.

52 `RE (Ω)` Early-effect on base resistance:.

53 `RBC (Ω)`	Early-effect on base resistance:.
54 `RCC (Ω)`	Early-effect on base resistance:.
55 `SCbe (F)`	Capacitance sidewall b-e junction.
56 `Cbex (F)`	Capacitance floor b-e junction.
57 `Cbey (F)`	Early effect on b-e diffusion charge.
58 `Cbez (F)`	Early effect on b-e diffusion charge.
59 `Cbcx (F)`	Early effect on b-c diffusion charge.
60 `Cbcy (F)`	Capacitance floor b-c junction.
61 `Cbcz (F)`	Capacitance floor b-c junction.
62 `Cbcex (F)`	Capacitance extrinsic b-c junction.
63 `XCbcex (F)`	Capacitance extrinsic b-c junction.
64 `Cb1b2 (F)`	Capacitance AC current crowding.
65 `Cb1b2x (F)`	Cross-capacitance AC current crowding .
66 `Cb1b2y (F)`	Cross-capacitance AC current crowding.
67 `Cb1b2z (F)`	Cross-capacitance AC current crowding.
68 `gm (1/Ω)`	Transconductance.
69 `beta`	Current amplification.
70 `gout (1/Ω)`	Output conductance.
71 `gmu (1/Ω)`	Feedback transconductance.
72 `RB (Ω)`	Base resistance.
73 `Cbe (F)`	Base-emitter capacitance.
74 `Cbc (F)`	Base-collector capacitance.

75 `fT (Hz)`	Good approximation for cut-off frequency.
76 `Iqs (A)`	Current at onset of quasi-saturation.
77 `XiWepi (M)`	Thickness of injection layer.
78 `Vb2c2star (V)`	Physical value of internal base-collector bias.
79 `Pdiss (W)`	Dissipation.
80 `TK (K)`	Actual temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Compact Bipolar-Transistor Model (bjtd3500t)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  c  b  e  dt ModelName parameter=value ...
```

Instance Parameters

1	`mult=1`	Number of devices in parallel.
2	`region=fwd`	Estimated DC operating region, used as a convergence aid. Possible values are `off`, `sat`, `rev`, or `fwd`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName bjtd3500t parameter=value ...
```

Model Parameters

1 `level=3.5e+03` Bipolar Level.

2 `tref=25 deg. C` Reference temperature.

3 `dta=0 K` Difference between the local ambient and global ambient temperature.

4 `exmod=1` Flag for extended modeling of reverse current gain.

5 `exphi=1` Flag for the distributed high-frequency effeCts in transient.

6 `exavl=0` Flag for extended modeling of avalanche currents.

7 `is=2.2e-17 A` Collector-emitter saturation current.

8 `ik=0.1 A` Collector-emitter high injection knee current.

9 `ver=2.5 V` Reverse Early voltage.

10 `vef=44 V` Forward Early voltage.

11 `bf=215` Ideal forward current gain.

12 `ibf=2.7e-15 A` Saturation current of the non-ideal forward base current.

13 `mlf=2` Non ideality factor of the non-ideal forward base current.

14 `mhf=1` Non ideality factor of the non-ideal forward base current.

15 `mlr=2` Non ideality factor of the non-ideal reverse base current.

16 `mhr=1` Non ideality factor of the ideal reverse base current.

17 `mf=1`	Non ideality factor of main current.
18 `xibi=0`	Part of ideal base current that belongs to the sidewall.
19 `bri=7`	Ideal reverse current gain.
20 `ibr=1e-15 A`	Saturation current of the non-ideal reverse base current.
21 `vlr=0.2 V`	Cross-over voltage of the non-ideal reverse base current.
22 `xext=0.63`	Part of Iex, Qtex, Qex and Isub that depends on Vbc1 instead of Vb1c1.
23 `wavl=1.1e-06 m`	Epilayer thickness used in weak-avalanche model.
24 `vavl=3 V`	Voltage determining curvature of avalanche current.
25 `sfh=0.3`	Current spreading factor of avalanche model (when EXAVL=1).
26 `re=5 Ω`	Emitter resistance.
27 `rbc=23 Ω`	Constant part of the base resistance.
28 `rbv=18 Ω`	Zero-bias value of the variable part of the base resistance.
29 `rcc=12 Ω`	Constant part of collector resistance.
30 `rcv=150 Ω`	Resistance of the un-modulated epilayer.
31 `scrcv=1.25e+03 Ω`	Space charge resistance of the epilayer.
32 `ihc=0.004 A`	Critical current for velocity saturation in the epilayer.
33 `axi=0.3`	Smoothness parameter for the onset of quasi-saturation.
34 `cje=7.3e-14 F`	Zero-bias emitter-base depletion capacitance.
35 `vde=0.95 V`	Emitter-base diffusion voltage.
36 `pe=0.4`	Emitter-base grading coefficient.

37 `xcje=0.4`	Fraction of the emitter-base depletion capacitance that belongs to the sidewall.
38 `cbeo=0`	Emitter-base overlap capacitance.
39 `cjc=7.8e-14 F`	Zero-bias collector-base depletion capacitance.
40 `vdc=0.68 V`	Collector-base diffusion voltage.
41 `pc=0.5`	Collector-base grading coefficient.
42 `xp=0.35`	Constant part of Cjc.
43 `mc=0.5`	Coefficient for the current modulation of the collector-base depletion capacitance.
44 `xcjc=0.032`	Fraction of the collector-base depletion capacitance under the emitter.
45 `cbco=0`	Collector-base overlap capacitance.
46 `vos=0.04 V`	Voltage describing overshoot.
47 `isat=0.067 A`	Saturation current.
48 `repi=6 Ω`	Ohmic resistance epilayer.
49 `rdmin=0`	Minimum relative collector doping.
50 `sbjn=0.1`	Smoothness parameter Qtc model.
51 `sbeb=0.1`	Smoothness parameter Qtc model.
52 `etavdr=0.23`	Slope-parameter of Vdrift at high electric field.
53 `nvdr=4`	Power describing saturation behavior of Qtc.
54 `alfaw=0`	Smooth switch for reach through modeling.
55 `sw=0.1`	Smoothness parameter for reach through modeling.
56 `mtau=1`	Non-ideality factor of the emitter stored charge.

57 `taue=2e-12 s`	Minimum transit time of stored emitter charge.
58 `taub=4.2e-12 s`	Transit time of stored base charge.
59 `tepi=4.1e-11 s`	Transit time of stored epilayer charge.
60 `taur=5.2e-10 s`	Transit time of reverse extrinsic base charge.
61 `deg=0 eV`	Bandgap difference over the base.
62 `xrec=0`	Pre-factor of the recombination part of Ib1.
63 `aqbo=0.3`	Temperature coefficient of the zero-bias base charge.
64 `ae=0`	Temperature coefficient of the resistivity of the emitter.
65 `ab=1`	Temperature coefficient of the resistivity of the base.
66 `dais=0`	Parameter for fine tuning of temperature dependence of collector-emitter saturation current.
67 `aepi=2.5`	Temperature coefficient of the resistivity of the epilayer.
68 `aex=0.62`	Temperature coefficient of the resistivity of the extrinsic base.
69 `ac=2`	Temperature coefficient of the resistivity of the buried layer.
70 `aisat=-0.37`	Temperature coefficient of the saturation current.
71 `dvgbf=0.05 V`	Bandgap voltage difference of forward current gain.
72 `dvgbr=0.045 V`	Bandgap voltage difference of reverse current gain.
73 `vgb=1.17 V`	Bandgap voltage of the base.
74 `vgc=1.18 V`	Bandgap voltage of the collector.
75 `vgj=1.15 V`	Bandgap voltage recombination emitter-base junction.
76 `dvgte=0.05 V`	Bandgap voltage difference of emitter stored charge.
77 `af=2`	Exponent of the Flicker-noise.

78 `kf=2e-11` Flicker-noise coefficient of the ideal base current.

79 `kfn=2e-11` Flicker-noise coefficient of the non-ideal base current.

80 `kavl=0` Switch for white noise contribution due to avalanche.

81 `rth=300 K/W` Thermal resistance.

82 `cth=3e-09 J/K` Thermal capacitance.

83 `ath=0` Temperature coefficient of the thermal resistance.

84 `dtmax=1e+03 K` Maximal dynamic temperature increase.

85 `exrth=0` Flag for extended modeling of non-linear thermal resistance.

86 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

87 `imax=1.0 A` Explosion current.

88 `tnom (deg. C)` alias of tnom.

89 `tr (deg. C)` alias of tnom.

Output Parameters

1 `tref (deg. C)` Reference temperature.

2 `dta (K)` Difference between the local ambient and global ambient temperatures.

3 `exmod` Flag for extended modeling of reverse current gain.

4 `exphi` Flag for the distributed high-frequency effeCts in transient.

5 `exavl` Flag for extended modeling of avalanche currents.

6 `is (A)` Collector-emitter saturation current.

7 `ik (A)` Collector-emitter high injection knee current.

8 `ver (V)` Reverse Early voltage.

9 `vef (V)`	Forward Early voltage.
10 `bf`	Ideal forward current gain.
11 `ibf (A)`	Saturation current of the non-ideal forward base current.
12 `mlf`	Non ideality factor of the non-ideal forward base current.
13 `mhf`	Non ideality factor of the ideal forward base current.
14 `mlr`	Non ideality factor of the non-ideal reverse base current.
15 `mhr`	Non ideality factor of the ideal reverse base current.
16 `mf`	Non ideality factor of main current.
17 `xibi`	Part of ideal base current that belongs to the sidewall.
18 `bri`	Ideal reverse current gain.
19 `ibr (A)`	Saturation current of the non-ideal reverse base current.
20 `vlr (V)`	Cross-over voltage of the non-ideal reverse base current.
21 `xext`	Part of Iex, Qtex, Qex and Isub that depends on Vbc1 instead of Vb1c1.
22 `wavl (M)`	Epilayer thickness used in weak-avalanche model.
23 `vavl (V)`	Voltage determining curvature of avalanche current.
24 `sfh`	Current spreading factor of avalanche model (when EXAVL=1).
25 `re` (Ω)	Emitter resistance.
26 `rbc` (Ω)	Constant part of the base resistance.
27 `rbv` (Ω)	Zero-bias value of the variable part of the base resistance.
28 `rcc` (Ω)	Constant part of collector resistance.
29 `rcv` (Ω)	Resistance of the un-modulated epilayer.

30 `scrcv (Ω)`	Space charge resistance of the epilayer.
31 `ihc (A)`	Critical current for velocity saturation in the epilayer.
32 `axi`	Smoothness parameter for the onset of quasi-saturation.
33 `cje (F)`	Zero-bias emitter-base depletion capacitance.
34 `vde (V)`	Emitter-base diffusion voltage.
35 `pe`	Emitter-base grading coefficient.
36 `xcje`	Fraction of the emitter-base depletion capacitance that belongs to the sidewall.
37 `cbeo`	Emitter-base overlap capacitance.
38 `cjc (F)`	Zero-bias collector-base depletion capacitance.
39 `vdc (V)`	Collector-base diffusion voltage.
40 `pc`	Collector-base grading coefficient.
41 `xp`	Constant part of Cjc.
42 `mc`	Coefficient for the current modulation of the collector-base depletion capacitance.
43 `xcjc`	Fraction of the collector-base depletion capacitance under the emitter.
44 `cbco`	Collector-base overlap capacitance.
45 `vos (V)`	Voltage describing overshoot.
46 `isat (A)`	Saturation current.
47 `repi (Ω)`	Ohmic resistance epilayer.
48 `rdmin`	Minimum relative collector doping.
49 `sbjn`	Smoothness parameter Qtc model.

50 `sbeb`	Smoothness parameter Qtc model.
51 `etavdr`	Slope-parameter of Vdrift at high electric field.
52 `nvdr`	Power describing saturation behavior of Qtc.
53 `alfaw`	Smooth switch for reach through modeling.
54 `sw`	Smoothness parameter for reach through modeling.
55 `mtau`	Non-ideality factor of the emitter stored charge.
56 `taue (s)`	Minimum transit time of stored emitter charge.
57 `taub (s)`	Transit time of stored base charge.
58 `tepi (s)`	Transit time of stored epilayer charge.
59 `taur (s)`	Transit time of reverse extrinsic stored base charge.
60 `deg (eV)`	Bandgap difference over the base.
61 `xrec`	Pre-factor of the recombination part of Ib1.
62 `aqbo`	Temperature coefficient of the zero-bias base charge.
63 `ae`	Temperature coefficient of the resistivity of the emitter.
64 `ab`	Temperature coefficient of the resistivity of the base.
65 `dais`	Parameter for fine tuning of temperature dependence of collector-emitter saturation current.
66 `aepi`	Temperature coefficient of the resistivity of the epilayer.
67 `aex`	Temperature coefficient of the resistivity of the extrinsic base.
68 `ac`	Temperature coefficient of the resistivity of the buried layer.
69 `aisat`	Temperature coefficient of the saturation current.
70 `dvgbf (V)`	Bandgap voltage diffrence of forward current gain.

71 `dvgbr (V)` Bandgap voltage diffrence of reverse current gain.

72 `vgb (V)` Bandgap voltage of the base.

73 `vgc (V)` Bandgap voltage of the collector.

74 `vgj (V)` Bandgap voltage recombination emitter-base junction.

75 `dvgte (V)` Bandgap voltage difference of emitter stored charge.

76 `af` Exponent of the Flicker-noise.

77 `kf` Flicker-noise coefficient of the ideal base current.

78 `kfn` Flicker-noise coefficient of the non-ideal base current.

79 `kavl` Switch for white noise contribution due to avalanche.

80 `rth (K/W)` Thermal resistance.

81 `cth (J/K)` Thermal capacitance.

82 `ath` Temperature coefficient of the thermal resistance.

83 `dtmax (K)` Maximal dynamic temperature increase.

84 `exrth` Flag for extended modeling of non-linear thermal resistance.

Operating-Point Parameters

1 `Ic (A)` External DC collector current.

2 `Ib (A)` External DC base current.

3 `BetaDC` External DC current gain Ic/Ib.

4 `Vb2e1 (V)` Internal base-emitter bias.

5 `Vb2c2 (V)` Internal base-collector bias.

6 `Vb2c1 (V)` Internal base-collector bias including epilayer.

7 `Vb1c1 (V)` External base-collector bias without contact resistances.

8 `Ve1e (V)`	Bias over emitter resistance.
9 `In (A)`	Main current.
10 `Ic1c2 (A)`	Epilayer current.
11 `Ib1b2 (A)`	Pinched-base current.
12 `Ib1 (A)`	Ideal forward base current.
13 `SIb1 (A)`	Ideal side-wall base current.
14 `Ib2 (A)`	Non-ideal forward base current.
15 `Ib3 (A)`	Non-ideal reverse base current.
16 `Iex (A)`	Extrinsic reverse base current.
17 `XIex (A)`	Extrinsic reverse base current.
18 `Iavl (A)`	Avalanche current.
19 `IRE (A)`	Current through emitter resistance.
20 `IRBC (A)`	Current through constant base resistance.
21 `IRCC (A)`	Current through constant collector resistance.
22 `Qe (C)`	Emitter charge or emitter neutral charge.
23 `Qte (C)`	Base-emitter depletion charge.
24 `SQte (C)`	Sidewall base-emitter depletion charge.
25 `Qbe (C)`	Base-emitter diffusion charge.
26 `Qbc (C)`	Base-collector diffusion charge.
27 `Qtc (C)`	Base-collector depletion charge.
28 `Qepi (C)`	Epilayer diffusion charge.
29 `Qb1b2 (C)`	AC current crowding charge.

30 `Qtex (C)`	Extrinsic base-collector depletion charge.
31 `XQtex (C)`	Extrinsic base-collector depletion charge.
32 `Qex (C)`	Extrinsic base-collector diffusion charge.
33 `XQex (C)`	Extrinsic base-collector diffusion charge.
34 `gx (1/Ω)`	Forward transconductance.
35 `gy (1/Ω)`	Reverse transconductance.
36 `gz (1/Ω)`	Reverse transconductance.
37 `Sgpi (1/Ω)`	Conductance sidewall b-e junction.
38 `gpix (1/Ω)`	Conductance floor b-e junction.
39 `gpiy (1/Ω)`	Early effect on recombination base current.
40 `gpiz (1/Ω)`	Early effect on recombination base current.
41 `gmux (1/Ω)`	Early effect on avalanche current limiting.
42 `gmuy (1/Ω)`	Conductance of avalanche current.
43 `gmuz (1/Ω)`	Conductance of avalanche current.
44 `gmuex (1/Ω)`	Conductance extrinsic b-c junction.
45 `Xgmuex (1/Ω)`	Conductance extrinsic b-c junction.
46 `grcvy (1/Ω)`	Conductance of the epilayer current.
47 `grcvz (1/Ω)`	Conductance of the epilayer current.
48 `Rbv (Ω)`	Conductance of the epilayer current.
49 `grbvx (1/Ω)`	Early-effect on base resistance.
50 `grbvy (1/Ω)`	Early-effect on base resistance.
51 `grbvz (1/Ω)`	Early-effect on base resistance:.

52 `RE (Ω)`	Early-effect on base resistance:.
53 `RBC (Ω)`	Early-effect on base resistance:.
54 `RCC (Ω)`	Early-effect on base resistance:.
55 `SCbe (F)`	Capacitance sidewall b-e junction.
56 `Cbex (F)`	Capacitance floor b-e junction.
57 `Cbey (F)`	Early effect on b-e diffusion charge.
58 `Cbez (F)`	Early effect on b-e diffusion charge.
59 `Cbcx (F)`	Early effect on b-c diffusion charge.
60 `Cbcy (F)`	Capacitance floor b-c junction.
61 `Cbcz (F)`	Capacitance floor b-c junction.
62 `Cbcex (F)`	Capacitance extrinsic b-c junction.
63 `XCbcex (F)`	Capacitance extrinsic b-c junction.
64 `Cb1b2 (F)`	Capacitance AC current crowding.
65 `Cb1b2x (F)`	Cross-capacitance AC current crowding .
66 `Cb1b2y (F)`	Cross-capacitance AC current crowding.
67 `Cb1b2z (F)`	Cross-capacitance AC current crowding.
68 `gm (1/Ω)`	Transconductance.
69 `beta`	Current amplification.
70 `gout (1/Ω)`	Output conductance.
71 `gmu (1/Ω)`	Feedback transconductance.
72 `RB (Ω)`	Base resistance.
73 `Cbe (F)`	Base-emitter capacitance.

74 `Cbc (F)` Base-collector capacitance.

75 `fT (Hz)` Good approximation for cut-off frequency.

76 `Iqs (A)` Current at onset of quasi-saturation.

77 `XiWepi (M)` Thickness of injection layer.

78 `Vb2c2star (V)` Physical value of internal base-collector bias.

79 `Pdiss (W)` Dissipation.

80 `TK (K)` Actual temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Long Channel JFET/MOSFET Model (mos30)

This long channel JFET/MOSFET model is specially developed to describe the drift region of LDMOS, EPMOS and VDMOS devices. It is described in the Philips MOST Modelbook (Dec.95) as MOS model, level 30 (Used for DMOS). Information on how to obtain this document can be found on Source Link by searching for Philips.

Note: In noise analysis, mos30 instances will not generate any contribution, since there are no noise sources included in the mos30 model.

Warning: Dont use this model. It is obsolete.

Mos30 will be removed from spectre in the next release.

(c) Philips Electronics N.V. 1993, 1994, 1996

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Sample Instance Statement

```
mn30 (1 2 0 0) nchmod area=2 mult=1
```

Sample Model Statement

```
model nchmod mos30 type=n tox=1.1e-5 ron=150 rsat=500 psat=2 vsat=1 vsub=0.59
cgate=1.65e-12 csub=1.1e-9 tref=25
```

Instance Definition

```
Name  d  g  s  [b] ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `area=1` Alias of mult.

3 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

4 `m=1` Multiplicity factor.

Model Definition

```
model modelName mos30 parameter=value ...
```

Model Parameters

1 `type=n` Transistor gender. Possible values are `n` or `p`.

2 `ron=1.0 Ω` Ohmic resistance at zero bias.

3 `rsat=1.0 Ω` Space charge resistance at zero bias.

4 `vsat=10.0 V` Critical drain-source voltage for hot carriers.

5 `psat=1.0` Velocity saturation coefficient.

6 `vp=-1.0 V` Pinch off voltage at zero gate and substrate voltages.

7 `tox=-1.0 cm` Gate oxide thickness.

8 `dch=1.0e15` cm^{-3} Doping level channel.

9 `dsub=1.0e15` cm^{-3} Doping level substrate.

10 `vsub=0.6 V` Substrate diffusion voltage.

11 `vgap=1.2 V` Bandgap voltage channel.

12 `cgate=0.0 F` Gate capacitance at zero bias.

13 `csub=0.0 F` Substrate capacitance at zero bias.

14 `tausc=0.0 s` Space charge transit time of the channel.

15 `ach=0.0` Temperature coefficient resistivity of the channel.

16 `kf=0.0` Flickernoise coefficient.

17 `af=1.0` Flickernoise exponent.

18 `tr (C)` Reference temperature. Default set by option `tnom`.

19 `tref (C)` Alias of tr. Default set by option `tnom`.

20 `tnom (C)` Alias of tr. Default set by option `tnom`.

21 `dta=0.0 K` Temperature offset of the device.

22 `trise=0.0 K` Alias of `dta`.

Output Parameters

1 `ront (Ω)` Ohmic resistance at zero bias.

2 `rsat (Ω)` Space charge resistance at zero bias.

3 `vsatt (V)` Critical drain-source voltage for hot carriers.

4 `vsubt (V)` Substrate diffusion voltage.

5 `cgate (F)` Gate capacitance at zero bias.

6 `csubt (F)` Substrate capacitance at zero bias.

Operating-Point Parameters

1 `pwr (W)` Power.

2 `ids (A)` Total current including velocity saturation.

3 `qb (Coul)` Substrate charge.

4 `qg (Coul)` Gate charge.

5 `qds (Coul)` Space charge in the channel.

6 `gdsd (S)` Conductance (d ids / d vd).

7 `gdsg (S)` Conductance (d ids / d vg).

8 `gdss (S)` Conductance (d ids / d vs).

9 `gdsb (S)` Conductance (d ids / d vb).

10 `cbd (F)` Capacitance (d qb / d vd).

11 `cbg (F)` Capacitance (d qb / d vg).

12 `cbs (F)` Capacitance (d qb / d vs).

13 `cbb (F)` Capacitance (d qb / d vb).

14 `cgd (F)` Capacitance (d qg / d vd).

15 `cgg (F)` Capacitance (d qg / d vg).

16 `cgs (F)` Capacitance (d qg / d vs).

17 `cgb (F)` Capacitance (d qg / d vb).

18 `cdsd (F)` Capacitance (d qds / d vd).

19 `cdsg (F)` Capacitance (d qds / d vg).

20 `cdss (F)` Capacitance (d qds / d vs).

21 `cdsb (F)` Capacitance (d qds / d vb).

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

MOS Model 40, Level 40 (mos40t)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b  dt ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName mos40t parameter=value ...
```

Model Parameters

1 `level=40` Level of this model.

2 `ron=1` Ω Ohmic resistance at zero bias.

3 `rsat=1 Ω`	Space charge resistance at zero bias.
4 `vsat=10 V`	Critical drain-source voltage for hot carriers.
5 `psat=1`	Velocity saturation coefficient.
6 `vp=-1 V`	Pinch off voltage at zero gate and substrate voltages.
7 `tox=-1 m`	Gate oxide thickness.
8 `dch=1e+21` m^{-3}	Doping level channel.
9 `tbox=-1` m^{-3}	Box oxide thickness.
10 `cgate=0 F`	Gate capacitance at zero bias.
11 `cbox=0 F`	Wafer capacitance.
12 `tausc=0 s`	Space charge transit time of the channel.
13 `ach=0`	Temperature coefficient resistivity of the channel.
14 `achmod=0`	Parameter to switch to extended temperature scaling.
15 `achron=0`	Temperature coefficient of ohmic resistance at zero bias.
16 `achvsat=0`	Temperature coefficient of critical drain-source voltage for hot carriers.
17 `achrsat=0`	Temperature coefficient of space charge resistance at zero bias.
18 `tref=25 C`	Reference temperature.
19 `dta=0 K`	Temperature offset of the device.
20 `rth=300 K/W`	Thermal resistance.
21 `cth=3e-09 J/K`	Thermal capacitance.
22 `ath=0`	Temperature coefficient of the thermal resistance.
23 `type=n`	Transistor gender. Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

24 `imax=1.0 A` Explosion current.

25 `tnom (C)` alias of tnom.

26 `tr (C)` alias of tnom.

Output Parameters

1 `ront (Ω)` Ohmic resistance at zero bias.

2 `rsatt (Ω)` Space charge resistance at zero bias.

3 `vsatt (V)` Critical drain-source voltage for hot carriers.

4 `psat` Velocity saturation coefficient.

5 `vp (V)` Pinch off voltage at zero gate and substrate voltages.

6 `tox (m)` Gate oxide thickness.

7 `dch` (m^{-3}) Doping level channel.

8 `tbox` (m^{-3}) Box oxide thickness.

9 `cgate (F)` Gate capacitance at zero bias.

10 `cbox (F)` Wafer capacitance.

11 `tausc (s)` Space charge transit time of the channel.

12 `rth (K/W)` Thermal resistance.

13 `cth (J/K)` Thermal capacitance.

14 `ath` Temperature coefficient of the thermal resistance.

Operating-Point Parameters

1 `ids (A)` Drain source current.

2 `vds (V)` Drain source voltage.

3 `vgs (V)`	Gate source voltage.
4 `vbs (V)`	Bulk source voltage.
5 `vp (V)`	Channel pinch-off voltage.
6 `gm (A/V)`	Transconductance.
7 `gmb (A/V)`	Bulk transconductance.
8 `gds (A/V)`	Output conductance.
9 `qg (C)`	Gate charge.
10 `cgd (F)`	Gate charge dependence on drain voltage.
11 `cgg (F)`	Gate charge dependence on gate voltage.
12 `cgs (F)`	Gate charge dependence on substrate voltage.
13 `cgb (F)`	Gate charge dependence on bulk voltage.
14 `qb (C)`	Bulk charge.
15 `cbd (F)`	Bulk charge dependence on drain voltage.
16 `cbg (F)`	Bulk charge dependence on gate voltage.
17 `cbs (F)`	Bulk charge dependence on substrate voltage.
18 `cbb (F)`	Bulk charge dependence on bulk voltage.
19 `qd (C)`	Drain charge.
20 `cdd (F)`	Drain charge dependence on drain voltage (dQd/dVd).
21 `cdg (F)`	Drain charge dependence on gate voltage (-dQd/dVg).
22 `cds (F)`	Drain charge dependence on source voltage (-dQd/dVs).
23 `cdb (F)`	Drain charge dependence on bulk voltage (-dQd/dVb).
24 `qs (C)`	Source charge.

25 `csd (F)`	Source charge dependence on drain voltage (-dQs/dVd).
26 `csg (F)`	Source charge dependence on gate voltage (-dQs/dVg).
27 `css (F)`	Source charge dependence on source voltage (dQs/dVs).
28 `csb (F)`	Source charge dependence on bulk voltage (-dQs/dVb).
29 `u`	Transistor gain.
30 `rout (Ω)`	Small-signal output resistance.
31 `vearly (V)`	Equivalent early voltage.
32 `iohm (A)`	Drain source current excluding velocity saturation.
33 `ihc (A)`	Critical current for velocity saturation.
34 `Pdiss (W)`	Dissipation.
35 `TK (K)`	Actual temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Long Channel JFET/MOSFET Model (mos3002)

This long channel JFET/MOSFET model is specially developed to describe the drift region of LDMOS, EPMOS and VDMOS devices. It is described in the Philips MOST Modelbook (Dec.98) as MOS model, level 3002 (Used for DMOS). Information on how to obtain this document can be found on Source Link by searching for Philips.

Note: In noise analysis, mos3002 instances will not generate any contribution, since there are no noise sources included in the mos3002 model.

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Sample Instance Statement

```
mn3 (1 2 0 0) nch3002 area=1 m=2
```

Sample Model Statement

```
model nch3002 mos3002 ron=20 rsat=150 vsat=1 tox=1.23e-5 dch=1.1e16 vsub=0.58
csub=5.43e-13 tausc=1.2e-12 kf=1 tref=27 psat=1 dta=0
```

Instance Definition

```
Name  d  g  s  [b] ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `area=1` Alias of mult.

3 `region=triode` Estimated DC operating region, used as a convergence aid.
Possible values are `off`, `triode`, `sat`, or `subth`.

4 `m=1` Multiplicity factor.

Model Definition

```
model modelName mos3002 parameter=value ...
```

Model Parameters

1 `type=n` Transistor gender.
Possible values are `n` or `p`.

2 `ron=1.0 Ω` Ohmic resistance at zero bias.

3 `rsat=1.0 Ω` Space charge resistance at zero bias.

4 `vsat=10.0 V` Critical drain-source voltage for hot carriers.

5 `psat=1.0` Velocity saturation coefficient.

6 `vp=-1.0 V` Pinch off voltage at zero gate and substrate voltages.

7 `tox=-1.0 cm` Gate oxide thickness.

8 `dch=1.0e15` cm^{-3} Doping level channel.

9 `dsub=1.0e15` cm^{-3} Doping level substrate.

10 `vsub=0.6 V` Substrate diffusion voltage.

11 `vgap=1.2 V` Bandgap voltage channel.

12 `cgate=0.0 F` Gate capacitance at zero bias.

13 `csub=0.0 F` Substrate capacitance at zero bias.

14 `tausc=0.0 s` Space charge transit time of the channel.

15 `ach=0.0` Temperature coefficient resistivity of the channel.

16 `kf=0.0` Flickernoise coefficient.

17 `af=1.0` Flickernoise exponent.

18 `tr (C)` Reference temperature. Default set by option `tnom`.

19 `tref (C)` Alias of tr. Default set by option `tnom`.

20 `tnom (C)` Alias of tr. Default set by option `tnom`.

21 `dta=0.0 K` Temperature offset of the device.

22 `trise=0.0 K` Alias of `dta`.

Output Parameters

1 `ront` (Ω) Ohmic resistance at zero bias.

2 `rsat` (Ω) Space charge resistance at zero bias.

3 `vsatt (V)` Critical drain-source voltage for hot carriers.

4 `vsubt (V)` Substrate diffusion voltage.

5 `cgate (F)` Gate capacitance at zero bias.

6 `csubt (F)` Substrate capacitance at zero bias.

Operating-Point Parameters

1 `pwr (W)` Power.

2 `ids (A)` Total current including velocity saturation.

3 `qb (Coul)` Substrate charge.

4 `qg (Coul)` Gate charge.

5 `qds (Coul)` Space charge in the channel.

6 `gdsd (S)` Conductance (d ids / d vd).

7 `gdsg (S)` Conductance (d ids / d vg).

8 `gdss (S)` Conductance (d ids / d vs).

9 `gdsb (S)` Conductance (d ids / d vb).

10 `cbd (F)` Capacitance (d qb / d vd).

11 `cbg (F)` Capacitance (d qb / d vg).

12 `cbs (F)` Capacitance (d qb / d vs).

13 `cbb (F)` Capacitance (d qb / d vb).

14 `cgd (F)` Capacitance (d qg / d vd).

15 `cgg (F)` Capacitance (d qg / d vg).

16 `cgs (F)` Capacitance (d qg / d vs).

17 `cgb (F)` Capacitance (d qg / d vb).

18 `cdsd (F)` Capacitance (d qds / d vd).

19 `cdsg (F)` Capacitance (d qds / d vg).

20 `cdss (F)` Capacitance (d qds / d vs).

21 `cdsb (F)` Capacitance (d qds / d vb).

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

cgate O-5	ids OP-2	tausc M-14
cgb OP-17	kf M-16	tnom M-20

Compact MOS-Transistor Model (mos705)

The mos705 model is a compact MOS-transistor model, intended for the simulation of circuit behavior with emphasis on analog applications. It is described in the Philips MOST Modelbook (Dec.93) as MOS model, level 705.

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In extension to the model book description a minimum conductance `gmin` is inserted between the drain and source node, to aid convergence. The value of `gmin` is set by an options statement, default = 1e-12 S.

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Sample Instance Statement:

```
mn1 (1 2 0 0) mna7 ln=120e-6 wn=12e-6
```

Sample Model Statement:

```
model mna7 mos705 type=n vtn=0.853 betan=77e-6 tox=15e-9 vfb=-850e-3 tref=25
subthn=3 phi=0.645 lap=100e-9 gkn=-350e-9 th1n=0.15 th2n=0.046 th3n=0.1 fnoise=1e-
10
```

Instance Definition

```
Name  d  g  s  [b] ModelName parameter=value ...
```

Instance Parameters

1 `wn=1.0 scale m` Drawn channel width in the lay-out of the actual transistor. Scale set by option scale.

2 `ln=1.0 scale m` Drawn channel length in the lay-out of the actual transistor. Scale set by option scale.

3 `w=1.0 scale m` Alias for `wn`.

4 `l=1.0 scale m` Alias for `ln`.

5 `mult=1` Number of devices in parallel.

6 `area=1` Alias of `mult`.

7 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

8 `m=1` Multiplicity factor.

Model Definition

```
model modelName mos705 parameter=value ...
```

Model Parameters

1 `type=n` Transistor gender.
Possible values are `n` or `p`.

2 `vtn=0 V` Threshold voltage of the reference transistor at the reference temperature.

3 `kon=0 √V` `Ko` of the reference transistor.

4 `kn=100m √V` `K` of the reference transistor.

5 `vsbxn=0 V` `Vsbx` of the reference transistor.

6 `delvx=0 V` `Dvsbx` of the reference transistor.

7 `th1n=0 1/V` `The1` of the reference transistor.

8 `th2n=0 1/√V` `The2` of the reference transistor.

9 `th3n=0 1/V` `The3` of the reference transistor at the reference temperature.

10 `gamman=0` `Gam` of the reference transistor.

11	`shiftn=0 V^(1-n)`	`Sh` of the reference transistor.
12	`nn=0`	`N` of the reference transistor.
13	`pn=0 1/V`	`P` of the reference transistor.
14	`ava=0`	`A` of the reference transistor.
15	`avb=1 V`	`B` of the reference transistor.
16	`avc=0`	`C` of the reference transistor.
17	`wref=100u m`	Effective width of the reference transistor.
18	`wtol=0 m`	Difference between drawn and effective gate width.
19	`dvtn=0 V m`	Narrow-width factor of the threshold voltage at `vsbref`.
20	`dkon=0` $\sqrt{v}$ `m`	Narrow-width factor of `ko`.
21	`dkn=0` $\sqrt{v}$ `m`	Narrow-width factor of `k`.
22	`dvsbxn=0 V m`	Narrow-width factor of `vsbx`.
23	`ddelvx=0 Vm`	Narrow-width factor of `dvsbx`.
24	`betan=20u` A/V^2	Gain factor of a infinite-square transistor at the reference temperature.
25	`dth1n=0 m/V`	Narrow-width factor of `the1`.
26	`dth2n=0 m/`$\sqrt{V}$	Narrow-width factor of `the2`.
27	`dth3n=0 m/V`	Narrow-width factor of `the3`.
28	`dgamn=0 m`	Narrow-width factor of `gam`.
29	`dava=0 m`	Narrow-width factor of `a`.
30	`davb=0 V m`	Narrow-width factor of `b`.
31	`davc=0 m`	Narrow-width factor of `c`.

32 `lref=100u m` Effective length of the reference transistor.

33 `ltol=0 m` Difference between drawn and actual gate polysilicon length.

34 `gvtn=0 V m` Short-channel factor of the threshold voltage at `vsbref`.

35 `gkon=0 √V m` Short-channel factor of `ko`.

36 `gkn=0 √V m` Short-channel factor of `k`.

37 `gvsbxn=0 V m` Short-channel factor of `vsbx`.

38 `gdelvx=0 V m` Short-channel factor of `dvsbx`.

39 `gth1n=0 m/V` Short-channel factor of `the1`.

40 `gth2n=0 m/√V` Short-channel factor of `the2`.

41 `gth3n=0 m/V` Short-channel factor of `the3`.

42 `ggamn=0 m` Short-channel factor of `gam`.

43 `gshift=0 V^(1-n)` m^2
Short-channel factor of `sh`.

44 `gnn=0 m` Short-channel factor of `n`.

45 `gpn=0 m/V` Short-channel factor of `p`.

46 `gava=0 m` Short-channel factor of `a`.

47 `gavb=0 V m` Short-channel factor of `b`.

48 `gavc=0 m` Short-channel factor of `c`.

49 `lap=0 m` Half of the effective channel-length reduction due to lateral diffusion.

50 `vsbref=0 V` Source to bulk reference voltage for parameter determination.

51 `phi=600m V` Diffusion potential at the reference temperature.

52 `tcvt=-1m V/K` Temperature coefficient of `vto`.

53 `tbetan=1.5` Power temperature coefficient of `bet`.

54 `tth3n=0 1/(V K)` Temperature coefficient of `the3`.

55 `tgth3n=0 m/(V K)` Temperature coefficient of the length dependence of `the3`.

56 `m=1.0` Subthreshold-slope factor at reference back bias and at the reference temperature.

57 `subthn=0` Weak-inversion factor.

58 `vtr=0 V` Depletion-MOS-transistor-transition voltage.

59 `ratio=0` Depletion-MOS-transistor-gain ratio.

60 `vfb=0 V` Flat-band voltage.

61 `tox=100n m` Gate-oxide thickness.

62 `col=0 F/m` Gate/drain or gate/source overlap capacitance per unit length.

63 `fnoise=0` m^2 V^2 Flicker-noise factor.

64 `tnoise=0` Thermal-noise factor.

Temperature parameters

65 `tr (C)` Reference temperature. Default set by option `tnom`.

66 `tref (C)` Alias of `tr`. Default set by option `tnom`.

67 `tnom (C)` Alias of `tr`. Default set by option `tnom`.

68 `dta=0 K` Deviation between the temperature of the transistor and the temperature of the circuit.

69 `trise=0 K` Alias of `dta`.

Output Parameters

1 `weff (V)` Effective channel width of the actual transistor.

2 `leff (V)`	Effective channel length of the actual transistor.
3 `twophif (V)`	Diffusion potential.
4 `bet` (A/V^2)	Gain factor of the transistor.
5 `k` $(\sqrt{V})$	Body-effect factor.
6 `ko` $(\sqrt{V})$	Initial body-effect factor for dual `k` approach.
7 `vsbx (V)`	Transition voltage for dual `k` approach.
8 `dvsbx (V)`	Transition-voltage range for dual `K` approach.
9 `vto (V)`	Threshold voltage.
10 `von (V)`	Onset voltage of the superthreshold region.
11 `the1 (1/V)`	Gate-bias-controlled transverse-field mobility reduction factor.
12 `the2` $(1/\sqrt{V})$	Back-bias-controlled transverse-field mobility reduction factor.
13 `the3 (1/V)`	Lateral-field mobility reduction factor (velocity saturation).
14 `gam`	Static-drain-feedback factor.
15 `sh (V^(1-n))`	Threshold-voltage-shift factor.
16 `n`	Threshold-voltage-shift exponent.
17 `p (1/V)`	Back-bias-shift factor.
18 `me` $(\sqrt{V})$	Auxiliary parameter for subthreshold-slope factor.
19 `a`	Weak-avalanche multiplier.
20 `b (V)`	Weak-avalanche exponent factor.
21 `c`	Saturation-voltage reduction factor.
22 `cox (F)`	Gate capacitance.
23 `cgso (F)`	Gate/source-overlap capacitance.

24 `cgdo (F)` Gate/drain-overlap capacitance.

25 `vtre (V)` Depletion MOS transistor transition voltage.

26 `ratio` Depletion MOS transistor gain ratio.

27 `vfbe (V)` Flat band voltage.

28 `vtemp (V)` kT/q at actual device temperature.

29 `gnoise` (V^2) Coefficient of the flicker noise for the actual transistor.

30 `unoise (J)` Coefficient of the thermal noise for the actual transistor.

Operating-Point Parameters

1 `ide (A)` Drain current.

2 `ige (A)` Gate current.

3 `ise (A)` Source current.

4 `ibe (A)` Bulk current.

5 `vds (V)` Drain-source voltage.

6 `vgs (V)` Gate-source voltage.

7 `vsb (V)` Source-bulk voltage.

8 `ids (A)` Drain-source current.

9 `idb (A)` Drain-bulk current.

10 `isb (A)` Source-bulk current.

11 `pwr (W)` Power.

12 `vts (V)` Vto including back-bias effects.

13 `vgt (V)` Effective gate drive including back-bias and drain effects.

14 `vdss (V)` Saturation voltage at actual bias.

15 `gm (S)`	Transconductance (d ids / d vgs).
16 `gmb (S)`	Bulk transconductance (d ids / d vbs).
17 `gds (S)`	Output conductance (d ids / d vds).
18 `cdd (F)`	Capacitance (d qd / d vd).
19 `cdg (F)`	Capacitance (- d qd / d vg).
20 `cds (F)`	Capacitance (- d qd / d vs).
21 `cdb (F)`	Capacitance (- d qd / d vb).
22 `cgd (F)`	Capacitance (- d qg / d vd).
23 `cgg (F)`	Capacitance (d qg / d vg).
24 `cgs (F)`	Capacitance (- d qg / d vs).
25 `cgb (F)`	Capacitance (- d qg / d vb).
26 `csd (F)`	Capacitance (- d qs / d vd).
27 `csg (F)`	Capacitance (- d qs / d vg).
28 `css (F)`	Capacitance (d qs / d vs).
29 `csb (F)`	Capacitance (- d qs / d vb).
30 `cbd (F)`	Capacitance (- d qb / d vd).
31 `cbg (F)`	Capacitance (- d qb / d vg).
32 `cbs (F)`	Capacitance (- d qb / d vs).
33 `cbb (F)`	Capacitance (d qb / d vb).
34 `u`	Transistor gain (gm/gds).
35 `rout (Ω)`	Small signal output resistance (1/gds).
36 `vearly (V)`	Equivalent Early voltage (|Id|/gds).

37 `keff (√V )` Describes body effect at actual bias.

38 `beff (S/V)` Effective beta at actual bias in the simple MOS model.

39 `fug (Hz)` Unity gain frequency at actual bias (gm/(2*pi*cox)).

40 `sqrtsfw (V/√Hz )`

Input-referred RMS white noise voltage (sqrt(sth)/gm).

41 `sqrtsff (V/√Hz )`

Input-referred RMS 1/f noise voltage at 1kHz (sqrt(gnoise/1000)).

42 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Compact MOS-Transistor Model (mos902)

The mos902 model is a compact MOS-transistor model, intended for the simulation of circuit behavior with emphasis on analog applications. It is described in the Philips MOST Modelbook (Feb.98) as MOS model, level 902. Information on how to obtain this document can be found on Source Link by searching for Philips.

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In extension to the model book description a minimum conductance `gmin` is inserted between the drain and source node, to aid convergence. The value of `gmin` is set by an options statement, default = 1e-12 S.

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Sample Instance Statement:

```
mp1 (0 1 2 2) mos9pch w=10u l=2u area=1.5
```

Sample Model Statement:

```
model mos9pch mos902 ler=0.93e-6 wer=20e-6 tref=27 vtor=1.11 kr=0.54 phibr=0.66
vsbxr=100 the1r=0.19 slk=-0.215e-6 swk=98e-9 swthe3=7.8e-9
```

Instance Definition

```
Name  d  g  s  [b] ModelName parameter=value ...
```

Instance Parameters

1 `w=1.0 scale m` Drawn channel width in the lay-out. Scale set by option scale.

2 `l=1.0 scale m` Drawn channel length in the lay-out. Scale set by option scale.

3 `mult=1` Number of devices in parallel.

4 `area=1` Alias of `mult`.

5 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

6 `m=1` Multiplicity factor.

Model Definition

```
model modelName mos902 parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n` Transistor gender. Possible values are `n` or `p`.

Geometry parameters

2 `ler=2.5e-6 m` Effective channel length of the reference transistor.

3 `wer=25e-6 m` Effective channel width of the reference transistor.

4 `lvar=0.3e-6 m`	Difference between the actual and the programmed poly-silicon gate length.
5 `lap=0.1e-6 m`	Effective channel length reduction per side.
6 `wvar=3e-6 m`	Difference between the actual and the programmed field-oxide opening.
7 `wot=1e-6 m`	Effective channel width reduction per side.
8 `wdog=0 m`	Characteristic drawn gate width, below which dogboning appears.

Threshold-voltage parameters

9 `vtor=0.8 V`	Threshold voltage at zero back-bias.
10 `stvto=0.01 V/K`	Coefficient of the temperature dependence of `vto`.
11 `slvto=0.5e-6 V m`	Coefficient of the length dependence of `vto`.
12 `sl2vto=0 V` m^2	Second coefficient of the length dependence of `vto`.
13 `swvto=5e-6 V m`	Coefficient of the width dependence of `vto`.
14 `kor=0.5` √V	Low-backbias body factor.
15 `slko=1e-6` √V m	Coefficient of the length dependence of `ko`.
16 `swko=10e-6` √V m	Coefficient of the width dependence of `ko`.
17 `kr=0.1` √V	High-backbias body factor.
18 `slk=0.5e-6` √V m	Coefficient of the length dependence of `k`.
19 `swk=5e-6` √V m	Coefficient of the width dependence of `k`.
20 `phibr=0.65 V`	Surface potential at strong inversion.

21 `vsbxr=0.9 V` Transition voltage for the dual-`k`-factor model.

22 `slvsbx=0.5e-6 V m` Coefficient of the length dependence of `vsbx`.

23 `swvsbx=5e-6 V m` Coefficient of the width dependence of `vsbx`.

Channel-current parameters

24 `betsq=0.1e-3 A/V`^{2}
Gain factor for an infinite square transistor.

25 `etabet=0.5` Exponent of the temperature dependence of the gain factor.

26 `the1r=0.05 1/V` Coefficient of the mobility reduction due to the gate-induced field.

27 `stthe1r=3e-3 1/(V K)`
Coefficient of the temperature dependence of `the1`.

28 `slthe1r=50e-9 m/V` Coefficient of the length dependence of `the1`.

29 `stlthe1=5e-9 m/(V K)`
Coefficient of the temperature dependence of `slthe1`.

30 `swthe1=1e-6 m/V` Coefficient of the width dependence of `the1`.

31 `fthe1=0` Coefficient describing the width dependence of `the1` for `w` < `wdog`.

32 `the2r=17e-3 1/√V`
Coefficient of the mobility reduction due to the back-bias.

33 `stthe2r=0.1e-3 1/(√V K)`
Coefficient of the temperature dependence of `the2`.

34 `slthe2r=5e-9 m/√V`
Coefficient of the length dependence of `the2`.

35 `stlthe2=0.5e-9 m/(√V K)`
Coefficient of the temperature dependence of `slthe2`.

36 `swthe2=0.1e-6 m/√V`
Coefficient of the width dependence of `the2`.

37 `the3r=37e-3 1/V` Coefficient of the mobility reduction due to the lateral field.

38 `stthe3r=0.1e-3 1/(V K)`
Coefficient of the temperature dependence of `the3`.

39 `slthe3r=5e-9 m/V` Coefficient of the length dependence of `the3`.

40 `stlthe3=0.5e-9 m/(V K)`
Coefficient of the temperature dependence of `slthe3`.

41 `swthe3=0.1e-6 m/V` Coefficient of the width dependence of `the3`.

Drain-feedback parameters

42 `gam1r=40e-3 V^(1-etads)`
Coefficient for the drain induced threshold shift for large gate drive.

43 `slgam1=0.1e-6 V^(1-etads) m`
Coefficient of the length dependence of `gam1`.

44 `swgam1=1e-6 V^(1-etads) m`
Coefficient of the width dependence of `gam1`.

45 `etadsr=0.6` Exponent of the vds dependence of `gam1`.

46 `alpr=4e-3` Factor of the channel-length modulation.

47 `etaalp=0.5` Exponent of the length dependence of `alp`.

48 `slalp=0.14e-3 m^etaalp`
Coefficient of the length dependence of `alp`.

49 `swalp=0.1e-6 m` Coefficient of the width dependence of `alp`.

50 `vpr=0.25 V` Characteristic voltage of the channel-length modulation.

Sub-threshold parameters

51 `gamoor=1.1e-3` Coefficient for the drain induced threshold shift at zero gate drive.

52 `slgamoo=10e-15 m`^{2}
Coefficient of the length dependence of `gamoo`.

53 `etagamr=2` Exponent of the back-bias dependence of `gamo`.

54 `mor=0.3` Factor for the subthreshold slope.

55 `stmo=0.01 1/K` Coefficient of the temperature dependence of `mo`.

56 `slmo=1.4e-3 √m`
Coefficient of the length dependence of `mo`.

57 `etamr=2` Exponent of the back-bias dependence of m.

58 `zet1r=0.7` Weak-inversion correction factor.

59 `etazet=0.5` Exponent of the length dependence of `zet1`.

60 `slzet1=0.14e-6 m^etazet`
Coefficient of the length dependence of `zet1`.

61 `vsbtr=99 V` Limiting voltage of the vsb dependence of m and `gamo`.

62 `slvsbt=10e-6 V m` Coefficient of the length dependence of `vsbt`.

Weak-avalanche parameters

63 `a1r=22` Factor of the weak-avalanche current.

64 `sta1=0.1 1/K` Coefficient of the temperature dependence of `a1`.

65 `sla1=10e-6 m` Coefficient of the length dependence of `a1`.

66 `swa1=0.1e-3 m` Coefficient of the width dependence of `a1`.

67 `a2r=33 V` Exponent of the weak-avalanche current.

68 `sla2=10e-6 V m` Coefficient of the length dependence of `a2`.

69 `swa2=0.1e-3 V m` Coefficient of the width dependence of `a2`.

70 `a3r=0.6` Factor of the drain-source voltage above which weak-avalanche occurs.

71 `sla3=1e-6 m` Coefficient of the length dependence of `a3`.

72 `swa3=10e-6 m` Coefficient of the width dependence of `a3`.

Charge parameters

73 `tox=20e-9 m` Thickness of the oxide layer.

74 `col=50e-12 F/m` Gate overlap capacitance per unit channel width.

Noise parameters

75 `ntr=21e-21 J` Coefficient of the thermal noise.

76 `nfr=16e-12` V^2 Coefficient of the flicker noise.

Temperature parameters

77 `tr (C)` Reference temperature. Default set by option `tnom`.

78 `tref (C)` Alias of `tr`. Default set by option `tnom`.

79 `tnom (C)` Alias of `tr`. Default set by option `tnom`.

80 `dta=0 K` Temperature offset of the device.

81 `trise=0 K` Alias of `dta`.

Output Parameters

1 `le (m)` Effective channel length.

2 `we (m)` Effective channel width.

3 `vto (V)` Threshold voltage at zero back-bias.

4 `ko` ($\sqrt{V}$) Low-backbias body factor.

5 `k` ($\sqrt{V}$) High-backbias body factor.

6 `phib (V)`	Surface potential at strong inversion.
7 `vsbx (V)`	Transition voltage for the dual-`k`-factor model.
8 `bet (A/V`^{2}`)`	Gain factor (* mult).
9 `the1 (1/V)`	Coefficient of the mobility reduction due to the gate-induced field.
10 `the2 (1/`$\sqrt{V}$`)`	Coefficient of the mobility reduction due to the back-bias.
11 `the3 (1/V)`	Coefficient of the mobility reduction due to the lateral field.
12 `gam1 (V^(1-etads))`	Coefficient for the drain induced threshold shift for large gate drive.
13 `etads`	Exponent of the vds dependence of `gam1`.
14 `alp`	Factor of the channel-length modulation.
15 `vp (V)`	Characteristic voltage of the channel-length modulation.
16 `gamoo`	Coefficient for the drain induced threshold shift at zero gate drive.
17 `etagam`	Exponent of the back-bias dependence of `gamo`.
18 `mo`	Factor for the subthreshold slope.
19 `etam`	Exponent of the back-bias dependence of `m`.
20 `phit (V)`	Thermal voltage.
21 `zet1`	Weak-inversion correction factor.
22 `vsbt (V)`	Limiting voltage of the vsb dependence of `m` and `gamo`.
23 `a1`	Factor of the weak-avalanche current.
24 `a2 (V)`	Exponent of the weak-avalanche current.
25 `a3`	Factor of the drain-source voltage above which weak-avalanche occurs.
26 `cox (F)`	Gate-to-channel capacitance (* mult).

27 `cgdo (F)` Gate-drain overlap capacitance (* mult).

28 `cgso (F)` Gate-source overlap capacitance (* mult).

29 `nt (J)` Coefficient of the thermal noise.

30 `nf` (V^2) Coefficient of the flicker noise (/ mult).

Operating-Point Parameters

1 `ide (A)` Resistive drain current.

2 `ige (A)` Resistive gate current.

3 `ise (A)` Resistive source current.

4 `ibe (A)` Resistive bulk current.

5 `vds (V)` Drain-source voltage.

6 `vgs (V)` Gate-source voltage.

7 `vsb (V)` Source-bulk voltage.

8 `ids (A)` Resistive drain-source current.

9 `idb (A)` Resistive drain-bulk current.

10 `isb (A)` Resistive source-bulk current.

11 `iavl (A)` Substrate current.

12 `pwr (W)` Power.

13 `vt1 (V)` `Vto` including backbias effects.

14 `vgt2 (V)` Effective gate drive including backbias and drain effects.

15 `vdss1 (V)` Saturation voltage at actual bias.

16 `vsat (V)` Saturation limit.

17 `gm (S)` Transconductance (d ids / d vgs).

18 `gmb (S)` Bulk transconductance (d ids / d vbs).

19 `gds (S)` Output conductance (d ids / d vds).

20 `cdd (F)` Capacitance (d qd / d vd).

21 `cdg (F)` Capacitance (- d qd / d vg).

22 `cds (F)` Capacitance (- d qd / d vs).

23 `cdb (F)` Capacitance (- d qd / d vb).

24 `cgd (F)` Capacitance (- d qg / d vd).

25 `cgg (F)` Capacitance (d qg / d vg).

26 `cgs (F)` Capacitance (- d qg / d vs).

27 `cgb (F)` Capacitance (- d qg / d vb).

28 `csd (F)` Capacitance (- d qs / d vd).

29 `csg (F)` Capacitance (- d qs / d vg).

30 `css (F)` Capacitance (d qs / d vs).

31 `csb (F)` Capacitance (- d qs / d vb).

32 `cbd (F)` Capacitance (- d qb / d vd).

33 `cbg (F)` Capacitance (- d qb / d vg).

34 `cbs (F)` Capacitance (- d qb / d vs).

35 `cbb (F)` Capacitance (d qb / d vb).

36 `u` Transistor gain (gm/gds).

37 `rout (Ω)` Small signal output resistance (1/gds).

38 `vearly (V)` Equivalent Early voltage (|id|/gds).

39 `keff (√V )` Describes body effect at actual bias.

40 `beff (S/V)`	Effective beta at actual bias in the simple MOS model (2*|ids|/vgt2^2).
41 `fug (Hz)`	Unity gain frequency at actual bias (gm/(2*pi*cin)).
42 `sqrtsfw (V/√Hz )`	Input-referred RMS white noise voltage (sqrt(sth)/gm).
43 `sqrtsff (V/√Hz )`	Input-referred RMS 1/f noise voltage at 1kHz (sqrt(nf/1000)).
44 `fknee (Hz)`	Cross-over frequency above which white noise is dominant.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Compact MOS-Transistor Model (mos903)

The mos903 model is a compact MOS-transistor model, intended for the simulation of circuit behavior with emphasis on analog applications. It is described in the Philips MOST Modelbook (Jun.98) as MOS model, level 903. Information on how to obtain this document can be found on Source Link by searching for Philips.

In extension to the model book description a minimum conductance `gmin` is inserted between the drain and source node, to aid convergence. The value of `gmin` is set by an options statement, default = 1e-12 S.

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Sample Instance Statement

```
m_1 (1 2 0 0) mos9nch w=0.35e-6 l=0.35e-6
```

Sample Model Statement

```
model mos9nch mos903 ler=3.5e-7 wer=1e-5 lvar=0 lap=2.2e-8 wvar=0 wot=3e-8
vtor=0.76 the1r=0.67 stthe1r=-1.76e-3 etaalp=0 slalp=0 alpr=0.01
```

Instance Definition

```
Name  d  g  s  [b] ModelName parameter=value ...
```

Instance Parameters

1 l=1.5e-06 m — Drawn channel length in the lay-out. Scale set by option scale.

2 w=2e-05 m — Drawn channel width in the lay-out. Scale set by option scale.

3 mult=1 — Number of devices in parallel.

4 region=triode — Estimated DC operating region, used as a convergence aid. Possible values are off, triode, sat, or subth.

5 m=1 — Multiplicity factor.

6 trise=0 — Temperature rise from ambient.

7 area=1 — alias of mult.

Model Definition

```
model modelName mos903 parameter=value ...
```

Model Parameters

1 level=903 — MOS Level.

2 ler=1.1e-06(n)/1.25e-06(p) m

Effective channel length of the reference transistor.

3 wer=2e-05 m — Effective channel width of the reference transistor.

4 lvar=-2.2e-07(n)/-4.6e-07(p) m

Difference between the actual and the programmed poly-silicon gate length.

5 lap=1e-07(n)/2.5e-08(p) m

Effective channel length reduction per side.

6 wvar=-2.5e-08(n)/-1.3e-07(p) m

Difference between the actual and the programmed field-oxide opening.

7 wot=0 m Effective channel width reduction per side.

8 tr=21 unitCELSIUS

Reference temperature. Default set by option `tnom'.

9 vtor=0.73(n)/1.1(p) V

Threshold voltage at zero back-bias.

10 stvto=-0.0012(n)/-0.0017(p) V/K

Coefficient of the temperature dependence of `vto'.

11 slvto=-1.35e-07(n)/3.5e-08(p) V*m

Coefficient of the length dependence of `vto'.

12 sl2vto=0 V*m^2 Second coefficient of the length dependence of `vto'.

13 sl3vto=0 V Third coefficient of the length dependence of `vto'.

14 swvto=1.3e-07(n)/5e-08(p) V*m

Coefficient of the width dependence of `vto'.

15 kor=0.65(n)/0.47(p) sqrt(V)

Low-backbias body factor.

16 slko=-1.3e-07(n)/-2e-07(p) sqrt(V)*m

Coefficient of the length dependence of `ko'.

17 sl2ko=0 V1/2m2 Second coefficient of the length dependence of `ko'.

18 swko=2e-09(n)/1.15e-07(p) sqrt(V)*m

Coefficient of the width dependence of `ko'.

19 kr=0.11(n)/0.47(p) sqrt(V)

High-backbias body factor.

20 slk=-2.8e-07(n)/-2e-07(p) sqrt(V)*m

Coefficient of the length dependence of `k'.

21 sl2k=0 V1/2m2 Second coefficient of the length dependence of `k'.

22 swk=2.75e-07(n)/1.15e-07(p) sqrt(V)*m

Coefficient of the width dependence of `k'.

23 phibr=0.65 V Surface potential at strong inversion.

24 vsbxr=0.66(n)/1e-12(p) V

Transition voltage for the dual-`k'-factor model.

25 slvsbx=0 V*m Coefficient of the length dependence of `vsbx'.

26 swvsbx=-6.75e-07(n)/0(p) V*m

Coefficient of the width dependence of `vsbx'.

27 betsq=8.3e-05(n)/2.61e-05(p) A/V^2

Gain factor for an infinite square transistor.

28 etabet=1.6 Exponent of the temperature dependence of the gain factor.

29 lp1=1e-06 m Characteristic length of first profile.

30 fbet1=0 Relative mobility decrease due to first profile.

31 lp2=1e-08 m Characteristic length of second profile.

32 fbet2=0 Relative mobility decrease due to second profile.

33 the1r=0.19 1/V Coefficient of the mobility reduction due to the gate-induced field.

34 stthe1r=0 1/(V*K)

Coefficient of the temperature dependence of `the1'.

35 slthe1r=1.4e-07(n)/7e-08(p) m/V

Coefficient of the length dependence of `the1'.

36 stlthe1=0 m/(V*K)

Coefficient of the temperature dependence of `slthe1'.

37 gthe1=0 Parameter that selects either the old (gthe1=0) or the new (gthe1=1) scaling rule of the1.

38 swthe1=-5.8e-08(n)/-8e-08(p) m/V

Coefficient of the width dependence of `the1'.

39 wdog=0 m Characteristic drawn gate width, below which dogboning appears.

40 fthe1=0 Coefficient describing the width dependence of `the1' for `w' < `wdog'.

41 the2r=0.012(n)/0.165(p) 1/sqrt(V)

Coefficient of the mobility reduction due to the back-bias.

42 stthe2r=0 1/(sqrt(V)*K)

Coefficient of the temperature dependence of `the2'.

43 slthe2r=-3.3e-08(n)/-7.5e-08(p) m/sqrt(V)

Coefficient of the length dependence of `the2'.

44 stlthe2=0 m/(sqrt(V)*K)

Coefficient of the temperature dependence of `slthe2'.

45 swthe2=3e-08(n)/2e-08(p) m/sqrt(V)

Coefficient of the width dependence of `the2'.

46 the3r=0.145(n)/0.027(p) 1/V

Coefficient of the mobility reduction due to the lateral field.

47 stthe3r=-0.00066(n)/0(p) 1/(V*K)

Coefficient of the temperature dependence of `the3'.

48 slthe3r=1.85e-07(n)/2.7e-08(p) m/V

Coefficient of the length dependence of `the3'.

49 stlthe3=-6.2e-10(n)/0(p) m/(V*K)

Coefficient of the temperature dependence of `slthe3'.

50 swthe3=2e-08(n)/1.1e-08(p) m/V

Coefficient of the width dependence of `the3'.

51 gam1r=0.145(n)/0.077(p) V^(1-etads)

Coefficient for the drain induced threshold shift for large gate drive.

52 slgam1=1.6e-07(n)/1.05e-07(p) V^(1-etads)*m

Coefficient of the length dependence of `gam1'.

53 swgam1=-1e-08(n)/-1.1e-08(p) V^(1-etads)*m

Coefficient of the width dependence of `gam1'.

54 etadsr=0.6 Exponent of the vds dependence of `gam1'.

55 alpr=0.003(n)/0.044(p)

Factor of the channel-length modulation.

56 etaalp=0.15(n)/0.17(p)

Exponent of the length dependence of `alp'.

57 slalp=-0.00565(n)/0.009(p) m^etaalp

Coefficient of the length dependence of `alp'.

58 swalp=1.67e-09(n)/1.8e-10(p) m

Coefficient of the width dependence of `alp'.

59 vpr=0.34(n)/0.235(p) V

Characteristic voltage of the channel-length modulation.

60 gamoor=0.018(n)/0.007(p)

Coefficient for the drain induced threshold shift at zero gate drive.

61 slgamoo=2e-14(n)/1.1e-14(p) m^2

Coefficient of the length dependence of `gamoo'.

62 sl2gamoo=0 Second coefficient of the length dependence of `gamoo'.

63 etagamr=2(n)/1(p)

Exponent of the back-bias dependence of `gamo'.

64 mor=0.5(n)/0.375(p)

Factor for the subthreshold slope.

65 stmo=0 1/K Coefficient of the temperature dependence of `mo'.

66 slmo=0.00028(n)/4.7e-05(p) sqrt(m)

Coefficient of the length dependence of `mo'.

67 etamr=2(n)/1(p) Exponent of the back-bias dependence of m.

68 zet1r=0.42(n)/1.3(p)

Weak-inversion correction factor.

69 etazet=0.17(n)/0.03(p)

Exponent of the length dependence of `zet1'.

70 slzet1=-0.39(n)/-2.8(p) m^etazet

Coefficient of the length dependence of `zet1'.

71 vsbtr=2.1(n)/100(p) V

Limiting voltage of the vsb dependence of m and `gamo'.

72 slvsbt=-4.4e-06(n)/0(p) V*m

Coefficient of the length dependence of `vsbt'.

73 a1r=6(n)/10(p) Factor of the weak-avalanche current.

74 sta1=0 1/K Coefficient of the temperature dependence of `a1'.

75 sla1=1.3e-06(n)/-1.5e-05(p) m

Coefficient of the length dependence of `a1'.

76 swa1=3e-06(n)/3e-05(p) m

Coefficient of the width dependence of `a1'.

77 a2r=38(n)/59(p) V

Exponent of the weak-avalanche current.

78 sla2=1e-06(n)/-8e-06(p) V*m

Coefficient of the length dependence of `a2'.

79 swa2=2e-06(n)/1.5e-05(p) V*m

Coefficient of the width dependence of `a2'.

80 a3r=0.65(n)/0.52(p) Factor of the drain-source voltage above which weak-avalanche occurs.

81 sla3=-5.5e-07(n)/-4.5e-07(p) m

Coefficient of the length dependence of `a3'.

82 swa3=0(n)/-1.4e-07(p) m

Coefficient of the width dependence of `a3'.

83 tox=2.5e-08 m Thickness of the oxide layer.

84 col=3.2e-10 F/m Gate overlap capacitance per unit channel width.

85 ntr=2.44e-20(n)/2.11e-20(p) J

Coefficient of the thermal noise.

86 nfmod=0 Switch that selects either old or new flicker noise model.

87 nfr=7e-11(n)/2.14e-11(p) V^2

Flicker noise coefficient of the reference transistor (for nfmod=0).

88 nfar=7.15e+22(n)/1.53e+22(p) 1/(V*m^4)

First coefficient of the flicker noise coefficient of the reference transistor (for nfmod=1).

89 nfbr=2.16e+07(n)/4.06e+06(p) 1/(V*m^2)

Second coefficient of the flicker noise coefficient of the reference transistor (for nfmod=1).

90 nfcr=0(n)/2.92e-10(p) 1/V

Third coefficient of the flicker noise coefficient of the reference transistor (for nfmod=1).

91	th3mod=1	Flag for theta3 clipping.
92	dta=0 K	Temperature offset of the device.
93	type=n	Transistor gender. Possible values are n, p, npn, pnp, npnv, pnpv, npnl, or pnpl.
94	imax=1.0 A	Explosion current.
95	vbox=0.0 V	Oxide breakdown voltage.
96	vbds=0.0 V	Drain-source breakdown voltage.
97	tnom (unitCELSIUS)	alias of tnom.
98	tref (unitCELSIUS)	alias of tnom.

Output Parameters

1	vto ()	Threshold voltage at zero back-bias.
2	ko ()	Low-backbias body factor.
3	k ()	High-backbias body factor.
4	phib ()	Surface potential at strong inversion.
5	vsbx ()	Transition voltage for the dual-k-factor model.
6	bet ()	Gain factor (* mult).
7	the1 ()	Coefficient of the mobility reduction due to the gate-induced field.
8	the2 ()	Coefficient of the mobility reduction due to the back-bias.
9	the3 ()	Coefficient of the mobility reduction due to the lateral field.
10	gam1 ()	Coefficient for the drain induced threshold shift for large gate drive.
11	etads	Exponent of the vds dependence of gam1.

12 alp	Factor of the channel-length modulation.
13 vp ()	Characteristic voltage of the channel-length modulation.
14 gamoo	Coefficient of the drain induced threshold shift at zero gate drive for the actual transistor.
15 etagam	Exponent of the back-bias dependence of gamo.
16 mo	Factor for the subthreshold slope.
17 etam	Exponent of the back-bias dependence of m.
18 phit ()	Thermal voltage.
19 zet1	Weak-inversion correction factor.
20 vsbt ()	Limiting voltage of the vsb dependence of m and gamo.
21 a1	Factor of the weak-avalanche current.
22 a2 ()	Exponent of the weak-avalanche current.
23 a3	Factor of the drain-source voltage above which weak-avalanche occurs.
24 cox ()	Gate-to-channel capacitance (* mult).
25 cgdo ()	Gate-drain overlap capacitance (* mult).
26 cgso ()	Gate-source overlap capacitance (* mult).
27 nt ()	Coefficient of the thermal noise.
28 nfmod	Switch that selects either old or new flicker noise model.
29 nf ()	Coefficient of the flicker noise (/ mult) (nfmod = 0).
30 nfa ()	First coefficient of the flickernoise of the actual transistor (nfmod = 1).
31 nfb ()	Second coefficient of the flickernoise of the actual transistor (nfmod = 1).

32 nfc ()	Second coefficient of the flickernoise of the actual transistor (nfmod = 1).
33 th3mod	Flag for theta3 clipping.
34 tox ()	Thickness of the oxide layer.

Operating-Point Parameters

1 ids ()	Resistive drain-source current.
2 iavl ()	Substrate current.
3 vds ()	Drain-source voltage.
4 vgs ()	Gate-source voltage.
5 vsb ()	Source-bulk voltage.
6 vto ()	Threshold voltage at zero back-bias.
7 vts ()	VT0 including backbias effects.
8 vgt ()	Effective gate drive including backbias and drain effects.
9 vdss ()	Saturation voltage at actual bias.
10 vsat ()	Saturation limit.
11 gm ()	Transconductance (d ids / d vgs).
12 gmb ()	Bulk transconductance (d ids / d vbs).
13 gds ()	Output conductance (d ids / d vds).
14 cdd ()	Capacitance (d qd / d vd).
15 cdg ()	Capacitance (- d qd / d vg).
16 cds ()	Capacitance (- d qd / d vs).
17 cdb ()	Capacitance (- d qd / d vb).

18 cgd ()	Capacitance (- d qg / d vd).
19 cgg ()	Capacitance (d qg / d vg).
20 cgs ()	Capacitance (- d qg / d vs).
21 cgb ()	Capacitance (- d qg / d vb).
22 csd ()	Capacitance (- d qs / d vd).
23 csg ()	Capacitance (- d qs / d vg).
24 css ()	Capacitance (d qs / d vs).
25 csb ()	Capacitance (- d qs / d vb).
26 cbd ()	Capacitance (- d qb / d vd).
27 cbg ()	Capacitance (- d qb / d vg).
28 cbs ()	Capacitance (- d qb / d vs).
29 cbb ()	Capacitance (d qb / d vb).
30 cgdol ()	Drain overlap capacitance of the actual transistor.
31 cgsol ()	Gate overlap capacitance of the actual transistor.
32 weff ()	Effective channel width for geometrical models.
33 leff ()	Effective channel length for geometrical models.
34 u	Transistor gain (gm/gds).
35 rout ()	Small signal output resistance (1/gds).
36 vearly ()	Equivalent Early voltage (lidl/gds).
37 keff ()	Describes body effect at actual bias.
38 beff ()	Effective beta at actual bias in the simple MOS model (2*lidsl/ vgt2^2).

39 fug () Unity gain frequency at actual bias (gm/(2*pi*cin)).

40 sqrtsfw () Input-referred RMS white noise voltage (sqrt(sth)/gm).

41 sqrtsff () Input-referred RMS 1/f noise voltage at 1kHz (sqrt(nf/1000)).

42 fknee () Cross-over frequency above which white noise is dominant.

43 table_ids () Channel current.

44 table_isub () Substrate current.

45 table_vth () Threshold voltage including back-bias and drain-bias effects.

46 table_vdsat () Saturation voltage at actual bias.

47 table_qg () Charge at g node.

48 table_qd () Charge at d node.

49 table_qb () Charge at b node.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

The mos10.00 model is an experimental model based on the thesis of Ronald van Langevelde: "A compact MOSFET Model for Distortion Analysis in Analog Circuit Design", Technische Universiteit Eindhoven, 1998.

Note: In noise analysis, mos10.00 instances will not generate any contribution, since there are no noise sources included (yet) in the mos10.00 model.

In extension to the description a minimum conductance `gmin` is inserted between the drain and source node, to aid convergence. The value of `gmin` is set by an options statement, default = 1e-12 S.

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.sun4v/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  [b] ModelName parameter=value ...
```

Instance Parameters

1	`w=1.0 scale m`	Drawn channel width in the lay-out. Scale set by option scale.
2	`l=1.0 scale m`	Drawn channel length in the lay-out. Scale set by option scale.
3	`mult=1`	Number of devices in parallel.
4	`area=1`	Alias of `mult`.
5	`region=triode`	Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.
6	`m=1`	Multiplicity factor.

Model Definition

```
model modelName mos1000 parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n` Transistor gender.
Possible values are `n` or `p`.

Geometry parameters

2 `ler=1.0e-6 m` Effective channel length of the reference transistor.

3 `wer=1e-6 m` Effective channel width of the reference transistor.

4 `lvar=0.0 m` Difference between the actual and the programmed poly-silicon gate length.

5 `lap=45.0e-9 m` Effective channel length reduction per side.

6 `wvar=-5.0e-9 m` Difference between the actual and the programmed field-oxide opening.

7 `wot=50.0e-9 m` Effective channel width reduction per side.

Threshold-voltage parameters

8 `vfbr=-518.9e-03 V` Flat-band voltage for reference transistor.

9 `stvfb=-1.2e-03 V/K`
Coefficient of temperature dependence of `vfb`.

10 `slvfb=24.0e-09 V m`
Coefficient of length dependence of `vfb`.

11 `sl2vfb=-1.1e-15 V` m^2
Second coefficient of length dependence of `vfb`.

12 `swvfb=4.400e-09 V m`
Coefficient of the width dependency of `vfb`.

13 `kor=368.0e-03 √V`
Body effect coefficient for the reference transistor.

14 `slko=-8.240e-09 √V m`
Coefficient of the length dependence of `ko`.

15 `sl2ko=-2.260e-15 √V` m^2
Second coefficient of the length dependence of `ko`.

16 `swko=5.86e-09 √V m`
Coefficient of the width dependence of `ko`.

17 `phibr=0.6 V` Surface potential at strong inversion.

Channel-current parameters

18 `betsq=370.9e-06 A/V`^{2}
Gain factor for an infinite square transistor.

19 `etabet=1.6` Exponent of the temperature dependence of the gain factor.

20 `thesrr=16.10e-3 1/V`^{2}
Mobility degradation parameter due to surface roughness scattering.

21 `stthesr=0.0 1/(V`^{2} `K)`
Coefficient of the temperature dependence of `thesr`.

22 `swthesr=0.0 1/(V`^{2} `m)`
Coefficient of the width dependence of `thesr`.

23 `thephr=0.055 1/V` Mobility degradation parameter due to phonon scattering.

24 `sttheph=0.0 1/(V K)`
Coefficient of the temperature dependence of `theph`.

25 `swtheph=0.0 1/(V m)`
Coefficient of the width dependence of `theph`.

26 `etamobr=1.6` Effective field parameter for dependence on depletion charge.

27 `swetamob=0.0 1/m` Coefficient of the width dependence of `etamobr`.

28 `thersq=0.155 1/V` Coefficient of gate voltage independent part of series resistance.

29 `swther=0.0 1/(V m)`
Coefficient of the width dependence of `ther`.

30 `ther1=0.0 V` Numerator of gate voltage independent part of series resistance.

31 `ther2=1.0 V` Denominator of gate voltage independent part of series resistance.

32 `thenr=0.480 1/V` Velocity saturation parameter due to optical phonon scattering.

33 `stthen=0.0 1/(V K)`
Coefficient of the temperature dependence of `then`.

34 `swthen=0.0 1/(V m)`
Coefficient of the width dependence of `then`.

35 `thepr=0.0 1/V` Velocity saturation parameter due to acoustic phonon scattering.

36 `stthep=0.0 1/(V K)`
Coefficient of the temperature dependence of `thep`.

37 `swthep=0.0 1/(V m)`
Coefficient of the width dependence of `thep`.

38 `gthep=1.0` Velocity saturation factor due to acoustic phonon scattering.

39 `thethr=3.227e-3` $1/V^3$
Coefficient of self-heating.

40 `sltheth=2.460e-9` $1/(V^3\ m)$
Coefficient of the length dependence of `theth`.

41 `swtheth=0.0` $1/(V^3\ m)$
Coefficient of the width dependence of `theth`.

Sub-threshold parameters

42 `sdiblo=2.030e-03 1/√V`
Drain-induced barrier lowering parameter.

43 `sdiblexp=1.340` Exponent of the length dependence of `sdibl`.

44 `dphi=0.800 V` Parameter for short-channel subthreshold behavior.

Saturation parameters

45 `ssfsq=6.250e-03 1/√V`
Static feedback parameter.

46 `swssf=0.0 1/(√V  m)`
Coefficient of the width dependence of `ssf`.

47 `alpsq=0.010 m` Characteristic length parameter for channel length modulation.

48 `swalp=0.0 m` Coefficient of the width dependence of `alp`.

49 `vp=0.075 V` Characteristic voltage of channel-length modulation.

Smoothing parameters

50 `mexpo=0.093` Smoothing factor.

51 `mexpl=0.065` Coefficient of the length dependence of `mexp`.

Weak-avalanche parameters

52 `a1r=6` Factor of the weak-avalanche current.

53 `sta1=0.0 1/K` Coefficient of the temperature dependence of `a1`.

54 `sla1=1.30e-6 m` Coefficient of the length dependence of `a1`.

55 `swa1=3.0e-06 m` Coefficient of the width dependence of `a1`.

56 `a2r=38.0 V` Exponent of the weak-avalanche current.

57 `sla2=1.00e-06 V m` Coefficient of the length dependence of `a2`.

58 `swa2=2.00e-06 V m` Coefficient of the width dependence of `a2`.

59 `a3r=0.650` Factor of the drain-source voltage above which weak-avalanche occurs.

60 `sla3=-550.0e-06 m` Coefficient of the length dependence of `a3`.

61 `swa3=0.0 m` Coefficient of the width dependence of `a3`.

Charge parameters

62 `tox=4.5e-09 m` Thickness of the oxide layer.

63 `col=320e-12 F/m` Gate overlap capacitance per unit channel width.

Temperature parameters

64 `tr (C)` Reference temperature. Default set by option `tnom`.

65 `tref (C)` Alias of `tr`. Default set by option `tnom`.

66 `tnom (C)` Alias of `tr`. Default set by option `tnom`.

67 `dta=0.0 K` Temperature offset of the device.

68 `trise=0.0 K` Alias of `dta`.

Output Parameters

1 `le (m)` Effective channel length.

2 `we (m)` Effective channel width.

3 `vfb (V)` Flat-band voltage.

4 `ko (√V )` Body effect coefficient.

5 `phib (V)` Surface potential at strong inversion.

6 `bet` (A/V^2)	Gain factor.
7 `thesr` (1/V^2)	Mobility degradation parameter due to surface roughness scattering.
8 `theph` (1/V)	Mobility degradation parameter due to phonon scattering.
9 `etamob`	Effective field parameter for dependence on depletion charge.
10 `ther` (1/V)	Coefficient of gate voltage independent part of series resistance.
11 `ther1` (V)	Numerator of gate voltage independent part of series resistance.
12 `ther2` (V)	Denominator of gate voltage independent part of series resistance.
13 `then` (1/V)	Velocity saturation parameter due to optical phonon scattering.
14 `thep` (1/V)	Velocity saturation parameter due to acoustic phonon scattering.
15 `gthep`	Velocity saturation factor due to acoustic phonon scattering.
16 `theth` (1/V^3)	Coefficient of self-heating.
17 `sdibl` (1/$\sqrt{V}$)	Drain-induced barrier lowering parameter.
18 `dphi` (V)	Parameter for short-channel subthreshold behavior.
19 `ssf` (1/$\sqrt{V}$)	Static feedback parameter.
20 `alp` (m)	Characteristic length parameter for channel length modulation.
21 `vp` (V)	Characteristic voltage of channel-length modulation.
22 `mexp`	Smoothing factor.
23 `phit` (V)	Thermal voltage.
24 `a1`	Factor of the weak-avalanche current.
25 `a2` (V)	Exponent of the weak-avalanche current.

26 `a3` Factor of the drain-source voltage above which weak-avalanche occurs.

27 `cox (F)` Gate-to-channel capacitance (* mult).

28 `cgdo (F)` Gate-drain overlap capacitance (* mult).

29 `cgso (F)` Gate-source overlap capacitance (* mult).

Operating-Point Parameters

1 `ide (A)` Resistive drain current.

2 `ige (A)` Resistive gate current.

3 `ise (A)` Resistive source current.

4 `ibe (A)` Resistive bulk current.

5 `vds (V)` Drain-source voltage.

6 `vgs (V)` Gate-source voltage.

7 `vsb (V)` Source-bulk voltage.

8 `ids (A)` Resistive drain current.

9 `idb (A)` Resistive drain-bulk current.

10 `isb (A)` Resistive source-bulk current.

11 `iavl (A)` Substrate current.

12 `pwr (W)` Power.

13 `vto (V)` Threshold voltage at zero back-bias.

14 `vts (V)` `Vts`.

15 `vgt (V)` Effective gate drive including backbias and drain effects.

16 `vdss (V)` Saturation voltage at actual bias.

17 `vsat (V)`	Saturation limit.
18 `gm (S)`	Transconductance (d ids / d vgs).
19 `gmb (S)`	Bulk transconductance (d ids / d vbs).
20 `gds (S)`	Output conductance (d ids / d vds).
21 `cdd (F)`	Capacitance (d qd / d vd).
22 `cdg (F)`	Capacitance (- d qd / d vg).
23 `cds (F)`	Capacitance (- d qd / d vs).
24 `cdb (F)`	Capacitance (- d qd / d vb).
25 `cgd (F)`	Capacitance (- d qg / d vd).
26 `cgg (F)`	Capacitance (d qg / d vg).
27 `cgs (F)`	Capacitance (- d qg / d vs).
28 `cgb (F)`	Capacitance (- d qg / d vb).
29 `csd (F)`	Capacitance (- d qs / d vd).
30 `csg (F)`	Capacitance (- d qs / d vg).
31 `css (F)`	Capacitance (d qs / d vs).
32 `csb (F)`	Capacitance (- d qs / d vb).
33 `cbd (F)`	Capacitance (- d qb / d vd).
34 `cbg (F)`	Capacitance (- d qb / d vg).
35 `cbs (F)`	Capacitance (- d qb / d vs).
36 `cbb (F)`	Capacitance (d qb / d vb).
37 `u`	Transistor gain (gm/gds).
38 `rout (Ω)`	Small signal output resistance (1/gds).

39 `vearly (V)` Equivalent Early voltage (|id|/gds).

40 `keff (√V )` Describes body effect at actual bias.

41 `beff (S/V)` Effective beta at actual bias in the simple MOS model (2*|ids|/vgt2^2).

42 `fug (Hz)` Unity gain frequency at actual bias (gm/(2*pi*cin)).

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Compact MOS-Transistor Distortion Model (mos1100)

Instance Definition

`Name d g s b ModelName parameter=value ...`

Instance Parameters

1	`l=2e-06 m`	Drawn channel length in the layout. Scale set by option scale..
2	`w=1e-05 m`	Drawn channel width in the layout. Scale set by option scale..
3	`mult=1`	Number of devices in parallel.
4	`region=triode`	Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.
5	`m=1`	Multiplicity factor.
6	`area=1`	alias of mult.

Model Definition

model modelName mos1100 parameter=value ...

Model Parameters

1	`level=1.1e+03`	MOS Level.

2 `ler=1e-06 m` Effective channel length of the reference transistor.

3 `wer=1e-05 m` Effective channel width of the reference transistor.

4 `lvar=0 m` Difference between the actual and the programmed poly-silicon gate length.

5 `lap=4e-08 m` Effective channel length reduction per side.

6 `wvar=0 m` Difference between the actual and the programmed field-oxide opening.

7 `wot=0 m` Effective channel width reduction per side.

8 `tr=21 C` Reference temperature. Default set by option `tnom`.

9 `vfbr=-1.05 V` Flat-band voltage for reference transistor.

10 `stvfb=0.0005 V/K` Coefficient of temperature dependence of `vfb`.

11 `kor=0.5 √V` Body effect coefficient for the reference transistor.

12 `slko=0 √V m` Coefficient of the length dependence of `ko`.

13 `sl2ko=0 √V` m^2

Second coefficient of the length dependence of `ko`.

14 `swko=0 √V m` Coefficient of the width dependence of `ko`.

15 `kpinv=0 1/√V` Inverse of body-effect factor of the poly-silicon gate.

16 `phibr=0.95 V` Surface potential at strong inversion.

17 `slphib=0 Vm` Coefficient of the length dependence of phib.

18 `sl2phib=0` Vm^2 Second coefficient of the length dependence of phib.

19 `swphib=0 Vm` Coefficient of the width dependence of phib.

20 `betsq=0.000371(n)/0.000115(p)` A/V^2

Gain factor for an infinite square transistor.

21 `etabet=1.3(n)/0.5(p)`
Exponent of the temperature dependence of the gain factor.

22 `fbet1=0` Relative mobility decrease due to first lateral profile.

23 `lp1=8e-07 m` Characteristic length of first lateral profile.

24 `fbet2=0` Relative mobility decrease due to second lateral profile.

25 `lp2=8e-07 m` Characteristic length of second lateral profile.

26 `thesrr=0.4(n)/0.73(p) 1/V`
Coefficient of the mobility reduction due to surface roughness scattering.

27 `swthesr=0 m` Coefficient of the width dependence of thesr.

28 `thephr=0.0129(n)/0.001(p) 1/V`
Coefficient of the mobility reduction due to phonon scattering.

29 `etaph=1.75` Exponent of the temperature dependence of theph.

30 `swtheph=0 m` Coefficient of the width dependence of theph.

31 `etamobr=1.4(n)/3(p)`
Effective field parameter for dependence on depletion/inversion charge.

32 `stetamob=0 1/K` Coefficient of the temperature dependence of etamob.

33 `swetamob=0 m` Coefficient of the width dependence of etamob.

34 `nur=1` Exponent of the field dependence of the mobility model minus 1.

35 `nuexp=5.25(n)/3.23(p)`
Exponent of the temperature dependence of parameter nu.

36 `therr=0.155(n)/0.08(p) 1/V`
Coefficient of the series resistance.

37 `etar=0.95(n)/0.4(p)`
Exponent of the temperature dependence of ther.

38 `swther=0 m` Coefficient of the width dependence of ther.

39 `ther1=0 V` Numerator of gate voltage dependent part of series resistance.

40 `ther2=1 V` Denominator of gate voltage dependent part of series resistance.

41 `thesatr=0.5(n)/0.2(p) 1/V`
Velocity saturation parameter due to optical/acoustic phonon scattering.

42 `slthesat=1` Coefficient of length dependence of thesat.

43 `thesatexp=1` Exponent of length dependence of thesat.

44 `etasat=1.04(n)/0.86(p)`
Exponent of the temperature dependence of thesat.

45 `swthesat=0 m` Coefficient of the width dependence of thesat.

46 `thethr=0.001(n)/0.0005(p) 1/V`^{3}
Coefficient of self-heating.

47 `thethexp=1` Exponent of the length dependence of theth.

48 `swtheth=0 m` Coefficient of the width dependence of Theth.

49 `sdiblo=0.002(n)/0.001(p) 1/√V`
Drain-induced barrier lowering parameter.

50 `sdiblexp=1.35` Exponent of the length dependence of sdibl.

51 `mor=0` Parameter for short-channel subthreshold slope.

52 `moexp=1.34` Exponent of the length dependence of mo.

53 `ssfr=0.00625 1/√V`
Static feedback parameter.

54 `slssf=1e-06 m` Coefficient of the length dependence of ssf.

55 `swssf=0 m` Coefficient of the width dependence of ssf.

56 `alpr=0.01` Factor of the channel length modulation.

57 `slalp=1` Coefficient of the length dependence of alp.

58 `alpexp=1` Exponent of the length dependence of alp.

59 `swalp=0 m` Coefficient of the width dependence of `alp`.

60 `vp=0.05 V` Characteristic voltage of channel-length modulation.

61 `lmin=1.5e-07 m` Minimum effective channel length in technology, used for calculation of smoothing factor m.

62 `a1r=6` Factor of the weak-avalanche current.

63 `sta1=0 1/K` Coefficient of the temperature dependence of a1.

64 `sla1=0 m` Coefficient of the length dependence of a1.

65 `swa1=0 m` Coefficient of the width dependence of a1.

66 `a2r=38 V` Exponent of the weak-avalanche current.

67 `sla2=0 V m` Coefficient of the length dependence of a2.

68 `swa2=0 V m` Coefficient of the width dependence of a2.

69 `a3r=1` Factor of the drain-source voltage above which weak-avalanche occurs.

70 `sla3=0 m` Coefficient of the length dependence of a3.

71 `swa3=0 m` Coefficient of the width dependence of `a3`.

72 `iginvr=0` A/V^2 Gain factor for intrinsic gate tunnelling current in inversion.

73 `binv=48(n)/87.5(p)` A/V^2
Probability factor for intrinsic gate tunnelling current in inversion.

74 `igaccr=0` A/V^2 Gain factor for intrinsic gate tunnelling current in accumulation.

75 `bacc=48 V` Probability factor for intrinsic gate tunnelling current in accumulation.

76 `vfbov=0 V` Flat-band voltage for the Source/Drain overlap extensions.

77 `kov=2.5 √V` Body-effect factor for the Source/Drain overlap extensions.

78 `igovr=0 A/V`^{2} Gain factor for Source/Drain overlap gate tunnelling current.

79 `tox=3.2e-09 m` Thickness of gate oxide layer.

80 `col=3.2e-10 F/m` Gate overlap capacitance per unit channel width.

81 `gatenoise=0` Flag for in/exclusion of induced gate thermal noise.

82 `ntr=1.66e-20 J` Coefficient of the thermal noise.

83 `nfar=1.57e+22(n)/3.83e+23(p) 1/(Vm`^{4}`)`
First coefficient of the flicker noise.

84 `nfbr=4.75e+08(n)/1.02e+08(p) 1/(Vm`^{2}`)`
Second coefficient of the flicker noise.

85 `nfcr=0(n)/7.3e-09(p) 1/V`
Third coefficient of the flicker noise.

86 `dta=0 K` Temperature offset of the device.

87 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

88 `imax=1.0 A` Explosion current.

89 `tnom (C)` alias of tnom.

90 `tref (C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flat-band voltage for the actual transistor.

2 `ko (√V )` Body-effect factor.

3 `kpinv (1/√V )` Inverse of body-effect factor of the poly-silicon gate.

4 `phib (V)` Surface potential at the onset of strong inversion.

5 `bet` (A/V^2)	Gain factor.
6 `thesr` (1/V)	Mobility degradation parameter due to surface roughness scattering.
7 `theph` (1/V)	Mobility degradation parameter due to phonon scattering.
8 `etamob`	Effective field parameter for dependence on depletion charge.
9 `nu`	Exponent of field dependence of mobility model.
10 `ther` (1/V)	Coefficient of series resistance.
11 `ther1` (V)	Numerator of gate voltage dependent part of series resistance.
12 `ther2` (V)	Denominator of gate voltage dependent part of series resistance.
13 `thesat` (1/V)	Velocity saturation parameter due to optical/acoustic phonon scattering.
14 `theth` (1/V^3)	Coefficient of self-heating.
15 `sdibl` (1/$\sqrt{V}$)	Drain-induced barrier lowering parameter.
16 `mo` (V)	Parameter for (short-channel) subthreshold slope.
17 `ssf` (1/$\sqrt{V}$)	Static-feedback parameter.
18 `alp`	Factor of channel length modulation.
19 `vp` (V)	Characteristic voltage of channel-length modulation.
20 `mexp`	Smoothing factor.
21 `phit` (V)	Thermal voltage at the actual temperature.
22 `a1`	Factor of the weak-avalanche current.
23 `a2` (V)	Exponent of the weak-avalanche current.
24 `a3`	Factor of the drain-source voltage above which weak-avalanche occurs.

25 `iginv (A/V`^{2}`)`	Gain factor for intrinsic gate tunnelling current in inversion.
26 `binv (A/V`^{2}`)`	Probability factor for intrinsic gate tunnelling current in inversion.
27 `igacc (A/V`^{2}`)`	Gain factor for intrinsic gate tunnelling current in accumulation.
28 `bacc (V)`	Probability factor for intrinsic gate tunnelling current in accumulation.
29 `vfbov (V)`	Flat-band voltage for the Source/Drain overlap extensions.
30 `kov (`$\sqrt{V}$` )`	Body-effect factor for the Source/Drain overlap extensions.
31 `igov (A/V`^{2}`)`	Gain factor for Source/Drain overlap tunnelling current.
32 `cox (F)`	Oxide capacitance for the intrinsic channel (* mult).
33 `cgdo (F)`	Oxide capacitance for the gate-drain overlap (* mult).
34 `cgso (F)`	Oxide capacitance for the gate-source overlap (* mult).
35 `gatenoise`	Flag for in/exclusion of induced gate thermal noise.
36 `nt (J)`	Thermal noise coefficient.
37 `nfa (1/(Vm`^{4}`))`	First coefficient of the flicker noise.
38 `nfb (1/(Vm`^{2}`))`	Second coefficient of the flicker noise.
39 `nfc (1/V)`	Third coefficient of the flicker noise.
40 `tox (m)`	Thickness of gate oxide layer.

Operating-Point Parameters

1 `ids (A)`	Drain current, excl. avalanche and tunnel currents.
2 `iavl (A)`	Substrate current due to weak-avalanche.
3 `igs (A)`	Gate-to-source current due to direct tunnelling.
4 `igd (A)`	Gate-to-drain current due to direct tunnelling.

5 `igb (A)`	Gate-to-bulk current due to direct tunnelling.
6 `vds (V)`	Drain-source voltage.
7 `vgs (V)`	Gate-source voltage.
8 `vsb (V)`	Source-bulk voltage.
9 `vto (V)`	Zero-bias threshold voltage.
10 `vts (V)`	Threshold voltage including back-bias effects.
11 `vth (V)`	Threshold voltage including back-bias and drain-bias effects.
12 `vgt (V)`	Effective gate drive voltage including back-bias and drain voltage effects.
13 `vdss (V)`	Drain saturation voltage at actual bias.
14 `vsat (V)`	Saturation limit.
15 `gm (A/V)`	Transconductance (d ids / d vgs).
16 `gmb (A/V)`	Substrate-transconductance (d ids / d vbs).
17 `gds (A/V)`	Output conductance (d ids / d vds).
18 `cdd (F)`	Capacitance (d qd / d vd).
19 `cdg (F)`	Capacitance (- d qd / d vg).
20 `cds (F)`	Capacitance (- d qd / d vs).
21 `cdb (F)`	Capacitance (- d qd / d vb).
22 `cgd (F)`	Capacitance (- d qg / d vd).
23 `cgg (F)`	Capacitance (d qg / d vg).
24 `cgs (F)`	Capacitance (- d qg / d vs).
25 `cgb (F)`	Capacitance (- d qg / d vb).

26 `csd (F)`	Capacitance (- d qs / d vd).
27 `csg (F)`	Capacitance (- d qs / d vg).
28 `css (F)`	Capacitance (d qs / d vs).
29 `csb (F)`	Capacitance (- d qs / d vb).
30 `cbd (F)`	Capacitance (- d qb / d vd).
31 `cbg (F)`	Capacitance (- d qb / d vg).
32 `cbs (F)`	Capacitance (- d qb / d vs).
33 `cbb (F)`	Capacitance (d qb / d vb).
34 `cgdol (F)`	Gate-drain overlap capacitance of the actual transistor.
35 `cgsol (F)`	Gate-source overlap capacitance of the actual transistor.
36 `weff (m)`	Effective channel width for geometrical models.
37 `leff (m)`	Effective channel length for geometrical models.
38 `u`	Transistor gain (gm/gds).
39 `rout` (Ω)	Small-signal output resistance (1/gds).
40 `vearly (V)`	Equivalent Early voltage (lidl/gds).
41 `keff` ($\sqrt{V}$)	Body effect parameter.
42 `beff` (A/V^2)	Gain factor.
43 `fug (Hz)`	Unity gain frequency at actual bias (gm/(2*pi*cin)).
44 `sqrtsfw` ($V/\sqrt{Hz}$)	Input-referred RMS white noise voltage density.
45 `sqrtsff` ($V/\sqrt{Hz}$)	Input-referred RMS white noise voltage density at 1 kHz.
46 `fknee (Hz)`	Cross-over frequency above which white noise is dominant.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Compact MOS-Transistor Distortion Model (mos1100e)

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.sun4v/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName mos1100e parameter=value ...
```

Model Parameters

1 `level=1.1e+03` MOS Level.

2 `vfb=-1.05 V` Flat-band voltage for the actual transistor.

3 `ko=0.5 √V` Body-effect factor.

4 `kpinv=0 1/√V` Inverse of body-effect factor of the poly-silicon gate.

5 `phib=0.95 V` Surface potential at the onset of strong inversion.

6 `bet=0.00192(n)/0.000381(p) A/V^2`
Gain factor.

7 `thesr=0.356(n)/0.73(p) 1/V`
Mobility degradation parameter due to surface roughness scattering.

8 `theph=0.0129(n)/0.001(p) 1/V`
Mobility degradation parameter due to phonon scattering.

9 `etamob=1.4(n)/3(p)`
Effective field parameter for dependence on depletion charge.

10 `nu=2` Exponent of field dependence of mobility model.

11 `ther=0.0812(n)/0.079(p) 1/V`
Coefficient of series resistance.

12 `ther1=0 V` Numerator of gate voltage dependent part of series resistance.

13 `ther2=1 V` Denominator of gate voltage dependent part of series resistance.

14 `thesat=0.251(n)/0.173(p) 1/V`
Velocity saturation parameter due to optical/acoustic phonon scattering.

15 `theth=1e-05(n)/0(p) 1/V`^{3}
Coefficient of self-heating.

16 `sdibl=0.000853(n)/3.55e-05(p) 1/√V`
Drain-induced barrier lowering parameter.

17 `mo=0 V` Parameter for (short-channel) subthreshold slope.

18 `ssf=0.012(n)/0.01(p) 1/√V`
Static-feedback parameter.

19 `alp=0.025` Factor of channel length modulation.

20 `vp=0.05 V` Characteristic voltage of channel-length modulation.

21 `mexp=5` Smoothing factor.

22 `phit=0.0266 V` Thermal voltage at the actual temperature.

23 `a1=6.02(n)/6.86(p)`
Factor of the weak-avalanche current.

24 `a2=38(n)/57.3(p) V`
Exponent of the weak-avalanche current.

25 `a3=0.641(n)/0.425(p)`
Factor of the drain-source voltage above which weak-avalanche occurs.

26 `iginv=0 A/V`^{2} Gain factor for intrinsic gate tunnelling current in inversion.

27 `binv=48(n)/87.5(p) A/V`^{2}
Probability factor for intrinsic gate tunnelling current in inversion.

28 `igacc=0 A/V`^{2} Gain factor for intrinsic gate tunnelling current in accumulation.

29 `bacc=48 V` Probability factor for intrinsic gate tunnelling current in accumulation.

30 `vfbov=0 V` Flat-band voltage for the Source/Drain overlap extensions.

31 `kov=2.5 √V` Body-effect factor for the Source/Drain overlap extensions.

32 `igov=0 A/V`^{2} Gain factor for Source/Drain overlap tunnelling current.

33 `cox=2.98e-14(n)/2.72e-14(p) F`
Oxide capacitance for the intrinsic channel (* mult).

34 `cgdo=6.39e-15(n)/6.36e-15(p) F`
Oxide capacitance for the gate-drain overlap (* mult).

35 `cgso=6.39e-15(n)/6.36e-15(p) F`
Oxide capacitance for the gate-source overlap (* mult).

36 `gatenoise=0` Flag for in/exclusion of induced gate thermal noise.

37 `nt=1.66e-20 J` Thermal noise coefficient.

38 `nfa=8.32e+22(n)/1.9e+22(p) 1/(Vm`^{4}`)`
First coefficient of the flicker noise.

39 `nfb=2.51e+07(n)/5.04e+06(p) 1/(Vm`^{2}`)`
Second coefficient of the flicker noise.

40 `nfc=0(n)/3.63e-10(p) 1/V`
Third coefficient of the flicker noise.

41 `tox=3.2e-09 m` Thickness of gate oxide layer.

42 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

43 `imax=1.0 A` Explosion current.

Output Parameters

1 `vfb (V)` Flat-band voltage for the actual transistor.

2 `ko (√V )` Body-effect factor.

3 `kpinv (1/√V )` Inverse of body-effect factor of the poly-silicon gate.

4 `phib (V)` Surface potential at the onset of strong inversion.

5 `bet (A/V`^{2}`)` Gain factor.

6 `thesr (1/V)`	Mobility degradation parameter due to surface roughness scattering.
7 `theph (1/V)`	Mobility degradation parameter due to phonon scattering.
8 `etamob`	Effective field parameter for dependence on depletion charge.
9 `nu`	Exponent of field dependence of mobility model.
10 `ther (1/V)`	Coefficient of series resistance.
11 `ther1 (V)`	Numerator of gate voltage dependent part of series resistance.
12 `ther2 (V)`	Denominator of gate voltage dependent part of series resistance.
13 `thesat (1/V)`	Velocity saturation parameter due to optical/acoustic phonon scattering.
14 `theth` $(1/V^3)$	Coefficient of self-heating.
15 `sdibl` $(1/\sqrt{V})$	Drain-induced barrier lowering parameter.
16 `mo (V)`	Parameter for (short-channel) subthreshold slope.
17 `ssf` $(1/\sqrt{V})$	Static-feedback parameter.
18 `alp`	Factor of channel length modulation.
19 `vp (V)`	Characteristic voltage of channel-length modulation.
20 `mexp`	Smoothing factor.
21 `phit (V)`	Thermal voltage at the actual temperature.
22 `a1`	Factor of the weak-avalanche current.
23 `a2 (V)`	Exponent of the weak-avalanche current.
24 `a3`	Factor of the drain-source voltage above which weak-avalanche occurs.
25 `iginv` (A/V^2)	Gain factor for intrinsic gate tunnelling current in inversion.

26 `binv` (A/V^2)	Probability factor for intrinsic gate tunnelling current in inversion.
27 `igacc` (A/V^2)	Gain factor for intrinsic gate tunnelling current in accumulation.
28 `bacc` (V)	Probability factor for intrinsic gate tunnelling current in accumulation.
29 `vfbov` (V)	Flat-band voltage for the Source/Drain overlap extensions.
30 `kov` ($\sqrt{V}$)	Body-effect factor for the Source/Drain overlap extensions.
31 `igov` (A/V^2)	Gain factor for Source/Drain overlap tunnelling current.
32 `cox` (F)	Oxide capacitance for the intrinsic channel (* mult).
33 `cgdo` (F)	Oxide capacitance for the gate-drain overlap (* mult).
34 `cgso` (F)	Oxide capacitance for the gate-source overlap (* mult).
35 `gatenoise`	Flag for in/exclusion of induced gate thermal noise.
36 `nt` (J)	Thermal noise coefficient.
37 `nfa` (1/(Vm^4))	First coefficient of the flicker noise.
38 `nfb` (1/(Vm^2))	Second coefficient of the flicker noise.
39 `nfc` (1/V)	Third coefficient of the flicker noise.
40 `tox` (m)	Thickness of gate oxide layer.

Operating-Point Parameters

1 `ids` (A)	Drain current, excl. avalanche and tunnel currents.
2 `iavl` (A)	Substrate current due to weak-avalanche.
3 `igs` (A)	Gate-to-source current due to direct tunnelling.
4 `igd` (A)	Gate-to-drain current due to direct tunnelling.
5 `igb` (A)	Gate-to-bulk current due to direct tunnelling.

6 `vds (V)` Drain-source voltage.

7 `vgs (V)` Gate-source voltage.

8 `vsb (V)` Source-bulk voltage.

9 `vto (V)` Zero-bias threshold voltage.

10 `vts (V)` Threshold voltage including back-bias effects.

11 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

12 `vgt (V)` Effective gate drive voltage including back-bias and drain voltage effects.

13 `vdss (V)` Drain saturation voltage at actual bias.

14 `vsat (V)` Saturation limit.

15 `gm (A/V)` Transconductance (d ids / d vgs).

16 `gmb (A/V)` Substrate-transconductance (d ids / d vbs).

17 `gds (A/V)` Output conductance (d ids / d vds).

18 `cdd (F)` Capacitance (d qd / d vd).

19 `cdg (F)` Capacitance (- d qd / d vg).

20 `cds (F)` Capacitance (- d qd / d vs).

21 `cdb (F)` Capacitance (- d qd / d vb).

22 `cgd (F)` Capacitance (- d qg / d vd).

23 `cgg (F)` Capacitance (d qg / d vg).

24 `cgs (F)` Capacitance (- d qg / d vs).

25 `cgb (F)` Capacitance (- d qg / d vb).

26 `csd (F)` Capacitance (- d qs / d vd).

27 `csg (F)` Capacitance (- d qs / d vg).

28 `css (F)` Capacitance (d qs / d vs).

29 `csb (F)` Capacitance (- d qs / d vb).

30 `cbd (F)` Capacitance (- d qb / d vd).

31 `cbg (F)` Capacitance (- d qb / d vg).

32 `cbs (F)` Capacitance (- d qb / d vs).

33 `cbb (F)` Capacitance (d qb / d vb).

34 `cgdol (F)` Gate-drain overlap capacitance of the actual transistor.

35 `cgsol (F)` Gate-source overlap capacitance of the actual transistor.

36 `u` Transistor gain (gm/gds).

37 `rout (Ω)` Small-signal output resistance (1/gds).

38 `vearly (V)` Equivalent Early voltage (|id|/gds).

39 `keff (√V )` Body effect parameter.

40 `beff` (A/V^2) Gain factor.

41 `fug (Hz)` Unity gain frequency at actual bias (gm/(2*pi*cin)).

42 `sqrtsfw (V/√Hz )`
Input-referred RMS white noise voltage density.

43 `sqrtsff (V/√Hz )`
Input-referred RMS white noise voltage density at 1 kHz.

44 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the

description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

```
a1  M-23
a1  O-22
a2  M-24
a2  O-23
a3  M-25
a3  O-24
alp  M-19
alp  O-18
area  I-4
bacc  M-29
bacc  O-28
beff  OP-40
bet  M-6
bet  O-5
binv  M-27
binv  O-26
cbb  OP-33
cbd  OP-30
cbg  OP-31
cgsol  OP-35
cox  M-33
cox  O-32
csb  OP-29
csd  OP-26
csg  OP-27
css  OP-28
etamob  M-9
etamob  O-8
fknee  OP-44
fug  OP-41
gatenoise  M-36
gatenoise  O-35
gds  OP-17
gm  OP-15
gmb  OP-16
iavl  OP-2
ids  OP-1
igacc  M-28
kpinv  M-4
kpinv  O-3
level  M-1
m  I-3
mexp  M-21
mexp  O-20
mo  M-17
mo  O-16
mult  I-1
nfa  M-38
nfa  O-37
nfb  M-39
nfb  O-38
nfc  M-40
nfc  O-39
nt  M-37
nt  O-36
nu  M-10
nu  O-9
ther  M-11
ther  O-10
ther1  M-12
ther1  O-11
ther2  M-13
ther2  O-12
thesat  M-14
thesat  O-13
thesr  M-7
thesr  O-6
theth  M-15
theth  O-14
tox  M-41
tox  O-40
type  M-42
u  OP-36
vds  OP-6
vdss  OP-13
vearly  OP-38
```

MOS Model 11, Level 1101 (mos11010)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `l=2e-06 m` Drawn channel length in the layout. Scale set by option scale..

2 `w=1e-05 m` Drawn channel width in the layout. Scale set by option scale..

3 `mult=1` Number of devices in parallel.

4 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

5 `m=1` Multiplicity factor.

6 `area=1` alias of mult.

Model Definition

```
model modelName mos11010 parameter=value ...
```

Model Parameters

1 `level=1.1e+04` Transistor Level.

2 `lvar=0 m` Difference between the actual and the programmed poly-silicon gate length.

3 `lap=4e-08 m` Effective channel length reduction per side.

4 `wvar=0 m` Difference between the actual and the programmed field-oxide opening.

5 `wot=0 m` Effective channel width reduction per side.

6 `tr=21 C` Reference temperature.

7 `vfb=-1.05 V` Flat-band voltage at reference temperature.

8 `stvfb=0.0005 V/K` Coefficient of temperature dependence of VFB.

9 `kor=0.5 √V` Body effect coefficient for the reference transistor.

10 `slko=0` Coefficient of the length dependence of KO.

11 `sl2ko=0` Second coefficient of the length dependence of KO.

12 `swko=0` Coefficient of the width dependence of KO.

13 `kpinv=0 1/√V` Inverse of body-effect factor of the poly-silicon gate.

14 `phibr=0.95 V` Surface potential at strong inversion.

15 `stphib=-0.00085 V/K`
Coefficient of the temperature dependency of PHIB.

16 `slphib=0` Coefficient of the length dependence of PHIB.

17 `sl2phib=0` Second coefficient of the length dependence of PHIB.

18 `swphib=0` Coefficient of the width dependence of PHIB.

19 `betsq=0.000371(n)/0.000115(p)` A/V^2
Gain factor for an infinite square transistor.

20 `etabetr=1.3(n)/0.5(p)`
Exponent of the temperature dependence of the gain factor.

21 `sletabet=0` Coefficient of lenght dependence of ETABETR.

22 `fbet1=0` Relative mobility decrease due to first lateral profile.

23 `lp1=8e-07 m` Characteristic length of first lateral profile.

24 `fbet2=0` Relative mobility decrease due to second lateral profile.

25 `lp2=8e-07 m` Characteristic length of second lateral profile.

26 `thesrr=0.4(n)/0.73(p) 1/V`
Coefficient of the mobility reduction due to surface roughness scattering.

27 `etasr=0.65(n)/0.5(p)`
Exponent of the temperatue dependence of THESR.

28 `swthesr=0` Coefficient of the width dependence of THESR.

29 `thephr=0.0129(n)/0.001(p) 1/V`
Coefficient of the mobility reduction due to phonon scattering.

30 `etaph=1.35(n)/3.75(p)`
Exponent of the temperature dependence of THEPH.

31 `swtheph=0` Coefficient of the width dependence of THEPH.

32 `etamobr=1.4(n)/3(p)`
Effective field parameter for dependence on depletion/inversion charge.

33 `stetamob=0 1/K` Coefficient of the temperature dependence of ETAMOB.

34 `swetamob=0` Coefficient of the width dependence of ETAMOB.

35 `nu=2` Exponent of field dependence of mobility model.

36 `nuexp=5.25(n)/3.23(p)`
Exponent of the temperature dependence of parameter NU.

37 `therr=0.155(n)/0.08(p) 1/V`
Coefficient of the series resistance.

38 `etar=0.95(n)/0.4(p)`
Exponent of the temperature dependence of THER.

39 `swther=0` Coefficient of the width dependence of THER.

40 `ther1=0 V` Numerator of gate voltage dependent part of series resistance.

41 `ther2=1 V` Denominator of gate voltage dependent part of series resistance.

42 `thesatr=0.5(n)/0.2(p) 1/V`
Velocity saturation parameter due to optical/acoustic phonon scattering.

43 `etasat=1.04(n)/0.86(p)`
Exponent of the temperature dependence of THESAT.

44 `slthesat=1` Coefficient of length dependence of THESAT.

45 `thesatexp=1` Exponent of length dependence of THESAT.

46 `swthesat=0` Coefficient of the width dependence of THESAT.

47 `thethr=0.001(n)/0.0005(p) 1/V`^{3}
Coefficient of self-heating.

48 `thethexp=1` Exponent of the length dependence of THETH.

49 `swtheth=0` Coefficient of the width dependence of THETH.

50 `sdiblo=0.0001 1/√V`
Drain-induced barrier lowering parameter.

51 `sdiblexp=1.35` Exponent of the length dependence of SDIBL.

52 `moo=0` Parameter for short-channel subthreshold slope.

53 `mor=0` Parameter for short-channel subthreshold slope per unit length.

54 `moexp=1.34` Exponent of the length dependence of MO.

55 `ssfr=0.00625 1/√V`
Static feedback parameter.

56 `slssf=1` Coefficient of the length dependence of SSF.

57 `swssf=0` Coefficient of the width dependence of SSF.

58 `alpr=0.01` Factor of the channel length modulation.

59 `slalp=1` Coefficient of the length dependence of ALP.

60 `alpexp=1` Exponent of the length dependence of ALP.

61 `swalp=0` Coefficient of the width dependence of ALP.

62 `vp=0.05 V` Characteristic voltage of channel-length modulation.

63 `lmin=1.5e-07 m` Minimum effective channel length in technology, used for calculation of smoothing factor m.

64 `a1r=6` Factor of the weak-avalanche current.

65 `sta1=0 1/K` Coefficient of the temperature dependence of A1.

66 `sla1=0` Coefficient of the length dependence of A1.

67 `swa1=0` Coefficient of the width dependence of A1.

68 `a2r=38 V` Exponent of the weak-avalanche current.

69 `sla2=0` Coefficient of the length dependence of A2.

70 `swa2=0` Coefficient of the width dependence of A2.

71 `a3r=1` Factor of the drain-source voltage above which weak-avalanche occurs.

72 `sla3=0` Coefficient of the length dependence of A3.

73 `swa3=0` Coefficient of the width dependence of A3.

74 `iginvr=0 A/V`^{2} Gain factor for intrinsic gate tunnelling current in inversion.

75 `binv=48(n)/87.5(p) V`
Probability factor for intrinsic gate tunnelling current in inversion.

76 `igaccr=0 A/V`^{2} Gain factor for intrinsic gate tunnelling current in accumulation.

77 `bacc=48 V` Probability factor for intrinsic gate tunnelling current in accumulation.

78 `vfbov=0 V` Flat-band voltage for the Source/Drain overlap extensions.

79 `kov=2.5 √V` Body-effect factor for the Source/Drain overlap extensions.

80 `igovr=0 A/V`^{2} Gain factor for Source/Drain overlap gate tunnelling current.

81 `agidlr=0 A/V`^{3} Gain factor for gate-induced leakage current.

82 `bgidl=41 V` Probability factor for gate-induced drain leakage current at reference temperature.

83 `stbgidl=-0.000364 V/K`
Coefficient of the temperature dependence of BGIDL.

84 `cgidl=0` Factor for the lateral field dependence of the gate-induced leakage current.

85 `tox=3.2e-09 m` Thickness of gate oxide layer.

86 `col=3.2e-16 F` Gate overlap capacitance for a channel width of 1 um.

87 `gatenoise=0` Flag for in/exclusion of induced gate thermal noise.

88 `nt=1.62e-20 J` Thermal noise coefficient.

89 `nfar=1.57e+23(n)/3.83e+24(p) 1/(Vm`^{4}`)`
First coefficient of the flicker noise for a channel area of 1 um^2.

90 `nfbr=4.75e+09(n)/1.02e+09(p) 1/(Vm`^{2}`)`
Second coefficient of the flicker noise for a channel area of 1 um^2.

91 `nfcr=0(n)/7.3e-08(p) 1/V`
Third coefficient of the flicker noise for a channel area of 1 um^2.

92 `dta=0 K` Temperature offset of the device.

93 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

94 `imax=1.0 A` Explosion current.

95 `tnom (C)` alias of tnom.

96 `tref (C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flat-band voltage at reference temperature.

2 `ko (`$\sqrt{V}$`)` Body-effect factor.

3 `kpinv (1/`$\sqrt{V}$`)` Inverse of body-effect factor of the poly-silicon gate.

4 `phib (V)` Surface potential at the onset of strong inversion.

5 `bet (A/V`^{2}`)` Gain factor.

6 `thesr (1/V)`	Mobility degradation parameter due to surface roughness scattering.
7 `theph (1/V)`	Mobility degradation parameter due to phonon scattering.
8 `etamob`	Effective field parameter for dependence on depletion charge.
9 `nu`	Exponent of field dependence of mobility model.
10 `ther (1/V)`	Coefficient of series resistance.
11 `ther1 (V)`	Numerator of gate voltage dependent part of series resistance.
12 `ther2 (V)`	Denominator of gate voltage dependent part of series resistance.
13 `thesat (1/V)`	Velocity saturation parameter due to optical/acoustic phonon scattering.
14 `theth` $(1/V^3)$	Coefficient of self-heating.
15 `sdibl` $(1/\sqrt{V})$	Drain-induced barrier lowering parameter.
16 `mo`	Parameter for (short-channel) subthreshold slope.
17 `ssf` $(1/\sqrt{V})$	Static-feedback parameter.
18 `alp`	Factor of channel length modulation.
19 `vp (V)`	Characteristic voltage of channel-length modulation.
20 `mexp`	Smoothing factor.
21 `a1`	Factor of the weak-avalanche current.
22 `a2 (V)`	Exponent of the weak-avalanche current.
23 `a3`	Factor of the drain-source voltage above which weak-avalanche occurs.
24 `iginv` (A/V^2)	Gain factor for intrinsic gate tunnelling current in inversion.
25 `binv (V)`	Probability factor for intrinsic gate tunnelling current in inversion.

26 `igacc` (A/V^2)	Gain factor for intrinsic gate tunnelling current in accumulation.
27 `bacc` (V)	Probability factor for intrinsic gate tunnelling current in accumulation.
28 `vfbov` (V)	Flat-band voltage for the Source/Drain overlap extensions.
29 `kov` ($\sqrt{V}$)	Body-effect factor for the Source/Drain overlap extensions.
30 `igov` (A/V^2)	Gain factor for Source/Drain overlap tunnelling current.
31 `agidl` (A/V^3)	Gain factor for gate-induced leakage current.
32 `bgidl` (V)	Probability factor for gate-induced drain leakage current at reference temperature.
33 `cgidl`	Factor for the lateral field dependence of the gate-induced leakage current.
34 `cox` (F)	Oxide capacitance for the intrinsic channel (* mult).
35 `cgdo` (F)	Oxide capacitance for the gate-drain overlap (* mult).
36 `cgso` (F)	Oxide capacitance for the gate-source overlap (* mult).
37 `gatenoise`	Flag for in/exclusion of induced gate thermal noise.
38 `nt` (J)	Thermal noise coefficient.
39 `nfa` ($1/(Vm^4)$)	First coefficient of the flicker noise.
40 `nfb` ($1/(Vm^2)$)	Second coefficient of the flicker noise.
41 `nfc` (1/V)	Third coefficient of the flicker noise.
42 `tox` (m)	Thickness of gate oxide layer.

Operating-Point Parameters

1 `ids` (A)	Drain current, excl. avalanche and tunnel currents.
2 `iavl` (A)	Substrate current due to weak-avalanche.

3 `igs (A)`	Gate-to-source current due to direct tunnelling.
4 `igd (A)`	Gate-to-drain current due to direct tunnelling.
5 `igb (A)`	Gate-to-bulk current due to direct tunnelling.
6 `vds (V)`	Drain-source voltage.
7 `vgs (V)`	Gate-source voltage.
8 `vsb (V)`	Source-bulk voltage.
9 `vto (V)`	Zero-bias threshold voltage.
10 `vts (V)`	Threshold voltage including back-bias effects.
11 `vth (V)`	Threshold voltage including back-bias and drain-bias effects.
12 `vgt (V)`	Effective gate drive voltage including back-bias and drain voltage effects.
13 `vdss (V)`	Drain saturation voltage at actual bias.
14 `vsat (V)`	Saturation limit.
15 `gm (A/V)`	Transconductance (d ids / d vgs).
16 `gmb (A/V)`	Substrate-transconductance (d ids / d vbs).
17 `gds (A/V)`	Output conductance (d ids / d vds).
18 `cdd (F)`	Capacitance (d qd / d vd).
19 `cdg (F)`	Capacitance (- d qd / d vg).
20 `cds (F)`	Capacitance (- d qd / d vs).
21 `cdb (F)`	Capacitance (- d qd / d vb).
22 `cgd (F)`	Capacitance (- d qg / d vd).
23 `cgg (F)`	Capacitance (d qg / d vg).

24 `cgs (F)`	Capacitance (- d qg / d vs).
25 `cgb (F)`	Capacitance (- d qg / d vb).
26 `csd (F)`	Capacitance (- d qs / d vd).
27 `csg (F)`	Capacitance (- d qs / d vg).
28 `css (F)`	Capacitance (d qs / d vs).
29 `csb (F)`	Capacitance (- d qs / d vb).
30 `cbd (F)`	Capacitance (- d qb / d vd).
31 `cbg (F)`	Capacitance (- d qb / d vg).
32 `cbs (F)`	Capacitance (- d qb / d vs).
33 `cbb (F)`	Capacitance (d qb / d vb).
34 `cgdol (F)`	Gate-drain overlap capacitance of the actual transistor.
35 `cgsol (F)`	Gate-source overlap capacitance of the actual transistor.
36 `weff (m)`	Effective channel width for geometrical models.
37 `leff (m)`	Effective channel length for geometrical models.
38 `u`	Transistor gain (gm/gds).
39 `rout (Ω)`	Small-signal output resistance (1/gds).
40 `vearly (V)`	Equivalent Early voltage (lidl/gds).
41 `keff (√V )`	Body effect parameter.
42 `beff` (A/V^2)	Gain factor.
43 `fug (Hz)`	Unity gain frequency at actual bias (gm/(2*pi*cin)).
44 `sqrtsfw (V/√Hz )`	Input-referred RMS white noise voltage density.

45 `sqrtsff (V/√Hz )`
Input-referred RMS white noise voltage density at 1 kHz.

46 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

MOS Model 11, Level 1101 (mos11010t)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b  dt ModelName parameter=value ...
```

Instance Parameters

1 `l=2e-06 m` Drawn channel length in the layout. Scale set by option scale..

2 `w=1e-05 m` Drawn channel width in the layout. Scale set by option scale..

3 `mult=1` Number of devices in parallel.

4 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

5 `m=1` Multiplicity factor.

6 `area=1` alias of mult.

Model Definition

```
model modelName mos11010t parameter=value ...
```

Model Parameters

1 `level=1.1e+04` Transistor Level.

2 `lvar=0 m` Difference between the actual and the programmed poly-silicon gate length.

3 `lap=4e-08 m` Effective channel length reduction per side.

4 `wvar=0 m` Difference between the actual and the programmed field-oxide opening.

5 `wot=0 m` Effective channel width reduction per side.

6 `tr=21 C` Reference temperature.

7 `vfb=-1.05 V` Flat-band voltage at reference temperature.

8 `stvfb=0.0005 V/K` Coefficient of temperature dependence of VFB.

9 `kor=0.5 √V` Body effect coefficient for the reference transistor.

10 `slko=0` Coefficient of the length dependence of KO.

11 `sl2ko=0` Second coefficient of the length dependence of KO.

12 `swko=0` Coefficient of the width dependence of KO.

13 `kpinv=0 1/√V` Inverse of body-effect factor of the poly-silicon gate.

14 `phibr=0.95 V` Surface potential at strong inversion.

15 `stphib=-0.00085 V/K`
Coefficient of the temperature dependency of PHIB.

16 `slphib=0` Coefficient of the length dependence of PHIB.

17 `sl2phib=0` Second coefficient of the length dependence of PHIB.

18 `swphib=0` Coefficient of the width dependence of PHIB.

19 `betsq=0.000371(n)/0.000115(p)` A/V^2
Gain factor for an infinite square transistor.

20 `etabetr=1.3(n)/0.5(p)`
Exponent of the temperature dependence of the gain factor.

21 `sletabet=0` Coefficient of lenght dependence of ETABETR.

22 `fbet1=0` Relative mobility decrease due to first lateral profile.

23 `lp1=8e-07 m` Characteristic length of first lateral profile.

24 `fbet2=0` Relative mobility decrease due to second lateral profile.

25 `lp2=8e-07 m` Characteristic length of second lateral profile.

26 `thesrr=0.4(n)/0.73(p) 1/V`
Coefficient of the mobility reduction due to surface roughness scattering.

27 `etasr=0.65(n)/0.5(p)`
Exponent of the temperatue dependence of THESR.

28 `swthesr=0` Coefficient of the width dependence of THESR.

29 `thephr=0.0129(n)/0.001(p) 1/V`
Coefficient of the mobility reduction due to phonon scattering.

30 `etaph=1.35(n)/3.75(p)`
Exponent of the temperature dependence of THEPH.

31 `swtheph=0` Coefficient of the width dependence of THEPH.

32 `etamobr=1.4(n)/3(p)`
Effective field parameter for dependence on depletion/inversion charge.

33 `stetamob=0 1/K` Coefficient of the temperature dependence of ETAMOB.

34 `swetamob=0` Coefficient of the width dependence of ETAMOB.

35 `nu=2` Exponent of field dependence of mobility model.

36 `nuexp=5.25(n)/3.23(p)`
Exponent of the temperature dependence of parameter NU.

37 `therr=0.155(n)/0.08(p) 1/V`
Coefficient of the series resistance.

38 `etar=0.95(n)/0.4(p)`
Exponent of the temperature dependence of THER.

39 `swther=0` Coefficient of the width dependence of THER.

40 `ther1=0 V` Numerator of gate voltage dependent part of series resistance.

41 `ther2=1 V` Denominator of gate voltage dependent part of series resistance.

42 `thesatr=0.5(n)/0.2(p) 1/V`
Velocity saturation parameter due to optical/acoustic phonon scattering.

43 `etasat=1.04(n)/0.86(p)`
Exponent of the temperature dependence of THESAT.

44 `slthesat=1` Coefficient of length dependence of THESAT.

45 `thesatexp=1` Exponent of length dependence of THESAT.

46 `swthesat=0` Coefficient of the width dependence of THESAT.

47 `thethr=0.001(n)/0.0005(p) 1/V`^{3}
Coefficient of self-heating.

48 `thethexp=1` Exponent of the length dependence of THETH.

49 `swtheth=0` Coefficient of the width dependence of THETH.

50 `sdiblo=0.0001 1/√V`
Drain-induced barrier lowering parameter.

51 `sdiblexp=1.35` Exponent of the length dependence of SDIBL.

52 `moo=0` Parameter for short-channel subthreshold slope.

53 `mor=0` Parameter for short-channel subthreshold slope per unit length.

54 `moexp=1.34` Exponent of the length dependence of MO.

55 `ssfr=0.00625 1/√V`
Static feedback parameter.

56 `slssf=1` Coefficient of the length dependence of SSF.

57 `swssf=0` Coefficient of the width dependence of SSF.

58 `alpr=0.01` Factor of the channel length modulation.

59 `slalp=1` Coefficient of the length dependence of ALP.

60 `alpexp=1` Exponent of the length dependence of ALP.

61 `swalp=0` Coefficient of the width dependence of ALP.

62 `vp=0.05 V` Characteristic voltage of channel-length modulation.

63 `lmin=1.5e-07 m` Minimum effective channel length in technology, used for calculation of smoothing factor m.

64 `a1r=6` Factor of the weak-avalanche current.

65 `sta1=0 1/K` Coefficient of the temperature dependence of A1.

66 `sla1=0` Coefficient of the length dependence of A1.

67 `swa1=0` Coefficient of the width dependence of A1.

68 `a2r=38 V` Exponent of the weak-avalanche current.

69 `sla2=0` Coefficient of the length dependence of A2.

70 `swa2=0` Coefficient of the width dependence of A2.

71 `a3r=1` Factor of the drain-source voltage above which weak-avalanche occurs.

72 `sla3=0` Coefficient of the length dependence of A3.

73 `swa3=0` Coefficient of the width dependence of A3.

74 `iginvr=0` A/V^2 Gain factor for intrinsic gate tunnelling current in inversion.

75 `binv=48(n)/87.5(p) V`
Probability factor for intrinsic gate tunnelling current in inversion.

76 `igaccr=0` A/V^2 Gain factor for intrinsic gate tunnelling current in accumulation.

77 `bacc=48 V` Probability factor for intrinsic gate tunnelling current in accumulation.

78 `vfbov=0 V` Flat-band voltage for the Source/Drain overlap extensions.

79 `kov=2.5` $\sqrt{V}$ Body-effect factor for the Source/Drain overlap extensions.

80 `igovr=0` A/V^2 Gain factor for Source/Drain overlap gate tunnelling current.

81 `agidlr=0` A/V^3 Gain factor for gate-induced leakage current.

82 `bgidl=41 V` Probability factor for gate-induced drain leakage current at reference temperature.

83 `stbgidl=-0.000364 V/K`
Coefficient of the temperature dependence of BGIDL.

84 `cgidl=0` Factor for the lateral field dependence of the gate-induced leakage current.

85 `tox=3.2e-09 m` Thickness of gate oxide layer.

86 `col=3.2e-16 F` Gate overlap capacitance for a channel width of 1 um.

87 `gatenoise=0` Flag for in/exclusion of induced gate thermal noise.

88 `nt=1.62e-20 J` Thermal noise coefficient.

89 `nfar=1.57e+23(n)/3.83e+24(p) 1/(Vm`^{4}`)`
First coefficient of the flicker noise for a channel area of 1 um^2.

90 `nfbr=4.75e+09(n)/1.02e+09(p) 1/(Vm`^{2}`)`
Second coefficient of the flicker noise for a channel area of 1 um^2.

91 `nfcr=0(n)/7.3e-08(p) 1/V`
Third coefficient of the flicker noise for a channel area of 1 um^2.

92 `dta=0 K` Temperature offset of the device.

93 `rth=300 K/W` Thermal resistance.

94 `cth=3e-09 J/K` Thermal capacitance.

95 `ath=0` Temperature coefficient of the thermal resistance.

96 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

97 `imax=1.0 A` Explosion current.

98 `tnom (C)` alias of tnom.

99 `tref (C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flat-band voltage at reference temperature.

2 `ko (`$\sqrt{V}$` )` Body-effect factor.

3 `kpinv` $(1/\sqrt{V})$	Inverse of body-effect factor of the poly-silicon gate.
4 `phib` (V)	Surface potential at the onset of strong inversion.
5 `bet` (A/V^2)	Gain factor.
6 `thesr` (1/V)	Mobility degradation parameter due to surface roughness scattering.
7 `theph` (1/V)	Mobility degradation parameter due to phonon scattering.
8 `etamob`	Effective field parameter for dependence on depletion charge.
9 `nu`	Exponent of field dependence of mobility model.
10 `ther` (1/V)	Coefficient of series resistance.
11 `ther1` (V)	Numerator of gate voltage dependent part of series resistance.
12 `ther2` (V)	Denominator of gate voltage dependent part of series resistance.
13 `thesat` (1/V)	Velocity saturation parameter due to optical/acoustic phonon scattering.
14 `theth` $(1/V^3)$	Coefficient of self-heating.
15 `sdibl` $(1/\sqrt{V})$	Drain-induced barrier lowering parameter.
16 `mo`	Parameter for (short-channel) subthreshold slope.
17 `ssf` $(1/\sqrt{V})$	Static-feedback parameter.
18 `alp`	Factor of channel length modulation.
19 `vp` (V)	Characteristic voltage of channel-length modulation.
20 `mexp`	Smoothing factor.
21 `a1`	Factor of the weak-avalanche current.
22 `a2` (V)	Exponent of the weak-avalanche current.

23	`a3`	Factor of the drain-source voltage above which weak-avalanche occurs.
24	`iginv` (A/V^2)	Gain factor for intrinsic gate tunnelling current in inversion.
25	`binv` (V)	Probability factor for intrinsic gate tunnelling current in inversion.
26	`igacc` (A/V^2)	Gain factor for intrinsic gate tunnelling current in accumulation.
27	`bacc` (V)	Probability factor for intrinsic gate tunnelling current in accumulation.
28	`vfbov` (V)	Flat-band voltage for the Source/Drain overlap extensions.
29	`kov` ($\sqrt{V}$)	Body-effect factor for the Source/Drain overlap extensions.
30	`igov` (A/V^2)	Gain factor for Source/Drain overlap tunnelling current.
31	`agidl` (A/V^3)	Gain factor for gate-induced leakage current.
32	`bgidl` (V)	Probability factor for gate-induced drain leakage current at reference temperature.
33	`cgidl`	Factor for the lateral field dependence of the gate-induced leakage current.
34	`cox` (F)	Oxide capacitance for the intrinsic channel (* mult).
35	`cgdo` (F)	Oxide capacitance for the gate-drain overlap (* mult).
36	`cgso` (F)	Oxide capacitance for the gate-source overlap (* mult).
37	`gatenoise`	Flag for in/exclusion of induced gate thermal noise.
38	`nt` (J)	Thermal noise coefficient.
39	`nfa` ($1/(Vm^4)$)	First coefficient of the flicker noise.
40	`nfb` ($1/(Vm^2)$)	Second coefficient of the flicker noise.
41	`nfc` (1/V)	Third coefficient of the flicker noise.
42	`tox` (m)	Thickness of gate oxide layer.

43 `rth (K/W)` Thermal resistance.

44 `cth (J/K)` Thermal capacitance.

Operating-Point Parameters

1 `ids (A)` Drain current, excl. avalanche and tunnel currents.

2 `iavl (A)` Substrate current due to weak-avalanche.

3 `igs (A)` Gate-to-source current due to direct tunnelling.

4 `igd (A)` Gate-to-drain current due to direct tunnelling.

5 `igb (A)` Gate-to-bulk current due to direct tunnelling.

6 `vds (V)` Drain-source voltage.

7 `vgs (V)` Gate-source voltage.

8 `vsb (V)` Source-bulk voltage.

9 `vto (V)` Zero-bias threshold voltage.

10 `vts (V)` Threshold voltage including back-bias effects.

11 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

12 `vgt (V)` Effective gate drive voltage including back-bias and drain voltage effects.

13 `vdss (V)` Drain saturation voltage at actual bias.

14 `vsat (V)` Saturation limit.

15 `gm (A/V)` Transconductance (d ids / d vgs).

16 `gmb (A/V)` Substrate-transconductance (d ids / d vbs).

17 `gds (A/V)` Output conductance (d ids / d vds).

18 `cdd (F)` Capacitance (d qd / d vd).

19 `cdg (F)`	Capacitance (- d qd / d vg).
20 `cds (F)`	Capacitance (- d qd / d vs).
21 `cdb (F)`	Capacitance (- d qd / d vb).
22 `cgd (F)`	Capacitance (- d qg / d vd).
23 `cgg (F)`	Capacitance (d qg / d vg).
24 `cgs (F)`	Capacitance (- d qg / d vs).
25 `cgb (F)`	Capacitance (- d qg / d vb).
26 `csd (F)`	Capacitance (- d qs / d vd).
27 `csg (F)`	Capacitance (- d qs / d vg).
28 `css (F)`	Capacitance (d qs / d vs).
29 `csb (F)`	Capacitance (- d qs / d vb).
30 `cbd (F)`	Capacitance (- d qb / d vd).
31 `cbg (F)`	Capacitance (- d qb / d vg).
32 `cbs (F)`	Capacitance (- d qb / d vs).
33 `cbb (F)`	Capacitance (d qb / d vb).
34 `cgdol (F)`	Gate-drain overlap capacitance of the actual transistor.
35 `cgsol (F)`	Gate-source overlap capacitance of the actual transistor.
36 `weff (m)`	Effective channel width for geometrical models.
37 `leff (m)`	Effective channel length for geometrical models.
38 `u`	Transistor gain (gm/gds).
39 `rout (Ω)`	Small-signal output resistance (1/gds).
40 `vearly (V)`	Equivalent Early voltage (lidl/gds).

41 `keff (√V )` Body effect parameter.

42 `beff (A/V`^{2}`)` Gain factor.

43 `fug (Hz)` Unity gain frequency at actual bias (gm/(2*pi*cin)).

44 `sqrtsfw (V/√Hz )`
Input-referred RMS white noise voltage density.

45 `sqrtsff (V/√Hz )`
Input-referred RMS white noise voltage density at 1 kHz.

46 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

47 `Pdiss (W)` Dissipation.

48 `TK (K)` Actual device temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

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MOS Model 11, Level 1101 (mos11011)

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `l=2e-06 m` Drawn channel length in the layout. Scale set by option scale..

2 `w=1e-05 m` Drawn channel width in the layout. Scale set by option scale..

3 `mult=1` Number of devices in parallel.

4 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

5 `m=1` Multiplicity factor.

6 `area=1` alias of mult.

Model Definition

```
model modelName mos11011 parameter=value ...
```

Model Parameters

1 `level=1.1e+04` Transistor Level.

2 `lvar=0 m` Difference between the actual and the programmed poly-silicon gate length.

3 `lap=4e-08 m` Effective channel length reduction per side.

4 `wvar=0 m` Difference between the actual and the programmed field-oxide opening.

5 `wot=0 m`	Effective channel width reduction per side.
6 `tr=21 C`	Reference temperature.
7 `lmin=0 m`	Device length low limit for binning selection.
8 `lmax=1 m`	Device length high limit for binning selection.
9 `wmin=0 m`	Device width low limit for binning selection.
10 `wmax=1 m`	Device width high limit for binning selection.
11 `vfb=-1.05 V`	Flat-band voltage at reference temperature.
12 `poko=0.5 √V`	Coefficient for the geometry independent part of KO.
13 `plko=0 √V`	Coefficient for the length dependence of KO.
14 `pwko=0 √V`	Coefficient for the width dependence of KO.
15 `plwko=0 √V`	Coefficient for the length times width dependence of KO.
16 `kpinv=0 1/√V`	Inverse of body-effect factor of the poly-silicon gate.
17 `pophib=0.95 V`	Coefficient for the geometric independent part of PHIB.
18 `plphib=0 V`	Coefficient for the length dependence of PHIB.
19 `pwphib=0 V`	Coefficient for the width dependence of PHIB.
20 `plwphib=0 V`	Coefficient for the length times width dependence of PHIB.
21 `pobet=0.00192(n)/0.000381(p) A/V`^{2}	Coefficient for the geometry independent part of BET.
22 `plbet=0 A/V`^{2}	Coefficient for the length dependence of BET.
23 `pwbet=0 A/V`^{2}	Coefficient for the width dependence of BET.
24 `plwbet=0 A/V`^{2}	Coefficient for the width over length dependence of BET.
25 `pothesr=0.356(n)/0.73(p) 1/V`	Coefficient of the geometry independent part of THESR.

26 `plthesr=0 1/V` Coefficient of the length dependence of THESR.

27 `pwthesr=0 1/V` Coefficient of the width dependence of THESR.

28 `plwthesr=0 1/V` Coefficient of the length times width dependence of THESR.

29 `potheph=0.0129(n)/0.001(p) 1/V`
Coefficient of the geometry independent part of THEPH.

30 `pltheph=0 1/V` Coefficient of the length dependence of THEPH.

31 `pwtheph=0 1/V` Coefficient of the width dependence of THEPH.

32 `plwtheph=0 1/V` Coefficient of the length times width dependence of THEPH.

33 `poetamob=1.4(n)/3(p)`
Coefficient of the geometry independent part of ETAMOB.

34 `pletamob=0` Coefficient of the length dependence of ETAMOB.

35 `pwetamob=0` Coefficient of the width dependence of ETAMOB.

36 `plwetamob=0` Coefficient of the length times width dependence of ETAMOB.

37 `pother=0.0812(n)/0.079(p) 1/V`
Coefficient of the geometry independent part of THER.

38 `plther=0 1/V` Coefficient of the length dependence of THER.

39 `pwther=0 1/V` Coefficient of the width dependence of THER.

40 `plwther=0 1/V` Coefficient of the length times width dependence of THER.

41 `ther1=0 V` Numerator of gate voltage dependent part of series resistance.

42 `ther2=1 V` Denominator of gate voltage dependent part of series resistance.

43 `pothesat=0.251(n)/0.173(p) 1/V`
Coefficient of the geometry independent part of THESAT.

44 `plthesat=0 1/V` Coefficient of the length dependence of THESAT.

45 `pwthesat=0 1/V` Coefficient of the width dependence of THESAT.

46 `plwthesat=0 1/V` Coefficient of the length times width dependence of THESAT.

47 `potheth=1e-05(n)/0(p)` $1/V^3$
Coefficient of the geometry independent part of THETH.

48 `pltheth=0` $1/V^3$ Coefficient of the length dependence of THETH.

49 `pwtheth=0` $1/V^3$ Coefficient of the width dependence of THETH.

50 `plwtheth=0` $1/V^3$ Coefficient of the length times width dependence of THETH.

51 `posdibl=0.000853(n)/3.55e-05(p)` $1/\sqrt{V}$
Coefficient of the geometry independent part of SDIBL.

52 `plsdibl=0` $1/\sqrt{V}$
Coefficient of the length dependence of SDIBL.

53 `pwsdibl=0` $1/\sqrt{V}$
Coefficient of the width dependence of SDIBL.

54 `plwsdibl=0` $1/\sqrt{V}$
Coefficient of the length times width dependence of SDIBL.

55 `pomo=0` Coefficient of the geometry independent part of MO.

56 `plmo=0` Coefficient of the length dependence of MO.

57 `pwmo=0` Coefficient of the width dependence of MO.

58 `plwmo=0` Coefficient of the length times width dependence of MO.

59 `possf=0.012(n)/0.01(p)` $1/\sqrt{V}$
Coefficient of the geometry independent part of SSF.

60 `plssf=0` $1/\sqrt{V}$ Coefficient of the length dependence of SSF.

61 `pwssf=0` $1/\sqrt{V}$ Coefficient of the width dependence of SSF.

62 `plwssf=0` $1/\sqrt{V}$
Coefficient of the length times width dependence of SSF.

63 `poalp=0.025` Coefficient of the geometry independent part of ALP.

64 `plalp=0` Coefficient of the length dependence of ALP.

65 `pwalp=0` Coefficient of the width dependence of ALP.

66 `plwalp=0` Coefficient of the length times width dependence of ALP.

67 `vp=0.05 V` Characteristic voltage of channel-length modulation.

68 `pomexp=0.2` Coefficient of the geometry independent part of MEXP.

69 `plmexp=0` Coefficient of the length dependence of MEXP.

70 `pwmexp=0` Coefficient of the width dependence of MEXP.

71 `plwmexp=0` Coefficient of the length times width dependence of MEXP.

72 `poa1=6.02(n)/6.86(p)`
Coefficient of the geometry independent part of A1.

73 `pla1=0` Coefficient of the length dependence of A1.

74 `pwa1=0` Coefficient of the width dependence of A1.

75 `plwa1=0` Coefficient of the length times width dependence of A1.

76 `poa2=38(n)/57.3(p) V`
Coefficient of the geometry independent part of A2.

77 `pla2=0 V` Coefficient of the length dependence of A2.

78 `pwa2=0 V` Coefficient of the width dependence of A2.

79 `plwa2=0 V` Coefficient of the length times width dependence of A2.

80 `poa3=0.641(n)/0.425(p)`
Coefficient of the geometry independent part of A3.

81 `pla3=0` Coefficient of the length dependence of A3.

82 `pwa3=0` Coefficient of the width dependence of A3.

83 `plwa3=0` Coefficient of the length times width dependence of A3.

84 `poiginv=0 A/V`^{2} Coefficient of the geometry independent part of IGINV.

85 `pliginv=0 A/V`^{2} Coefficient of the length dependence of IGINV.

86 `pwiginv=0 A/V`^{2} Coefficient of the width dependence of IGINV.

87 `plwiginv=0 A/V`^{2} Coefficient of the length times width dependence of IGINV.

88 `pobinv=48(n)/87.5(p) V`
Coefficient of the geometry independent part of BINV.

89 `plbinv=0 V` Coefficient of the length dependence of BINV.

90 `pwbinv=0 V` Coefficient of the width dependence of BINV.

91 `plwbinv=0 V` Coefficient of the length times width dependence of BINV.

92 `poigacc=0 A/V`^{2} Coefficient of the geometry independent part of IGACC.

93 `pligacc=0 A/V`^{2} Coefficient of the length dependence of IGACC.

94 `pwigacc=0 A/V`^{2} Coefficient of the width dependence of IGACC.

95 `plwigacc=0 A/V`^{2} Coefficient of the length times width dependence of IGACC.

96 `pobacc=48 V` Coefficient of the geometry independent part of BACC.

97 `plbacc=0 V` Coefficient of the length dependence of BACC.

98 `pwbacc=0 V` Coefficient of the width dependence of BACC.

99 `plwbacc=0 V` Coefficient of the length times width dependence of BACC.

100 `vfbov=0 V` Flat-band voltage for the Source/Drain overlap extensions.

101 `kov=2.5` $\sqrt{V}$ Body-effect factor for the Source/Drain overlap extensions.

102 `poigov=0 A/V`^{2} Coefficient of the geometry independent part of IGOV.

103 `pligov=0 A/V`^{2} Coefficient of the length dependence of IGOV.

104 `pwigov=0 A/V`^{2} Coefficient of the width dependence of IGOV.

105 `plwigov=0 A/V`^{2} Coefficient of the length times width dependence of IGOV.

106 `poagidl=0 A/V`^{3} Coefficient of the geometry independent part of AGIDL.

107 `plagidl=0 A/V`^{3} Coefficient of the length dependence of AGIDL.

108 `pwagidl=0 A/V`^{3} Coefficient of the width dependence of AGIDL.

109 `plwagidl=0 A/V`^{3} Coefficient of the length times width dependence of AGIDL.

110 `pobgidl=41 V` Coefficient of the geometry independent part of BGIDL.

111 `plbgidl=0 V` Coefficient of the length dependence of BGIDL.

112 `pwbgidl=0 V` Coefficient of the width dependence of BGIDL.

113 `plwbgidl=0 V` Coefficient of the length times width dependence of BGIDL.

114 `pocgidl=0` Coefficient of the geometry independent part of CGIDL.

115 `plcgidl=0` Coefficient of the length dependence of CGIDL.

116 `pwcgidl=0` Coefficient of the width dependence of CGIDL.

117 `plwcgidl=0` Coefficient of the length times width dependence of CGIDL.

118 `tox=3.2e-09 m` Thickness of gate oxide layer.

119 `pocox=2.98e-14(n)/2.72e-14(p) F`
Coefficient of the geometry independent part of COX.

120 `plcox=0 F` Coefficient of the length dependence of COX.

121 `pwcox=0 F` Coefficient of the width dependence of COX.

122 `plwcox=0 F` Coefficient of the length times width dependence of COX.

123 `pocgdo=6.39e-15(n)/6.36e-15(p) F`
Coefficient of the geometry independent part of CGDO.

124 `plcgdo=0 F` Coefficient of the length dependence of CGDO.

125 `pwcgdo=0 F` Coefficient of the width dependence of CGDO.

126 `plwcgdo=0 F` Coefficient of the length time width dependence of CGDO.

127 `pocgso=6.39e-15(n)/6.36e-15(p) F`
Coefficient of the geometry independent part of CGSO.

128 `plcgso=0 F` Coefficient of the length dependence of CGSO.

129 `pwcgso=0 F` Coefficient of the width dependence of CGSO.

130 `plwcgso=0 F` Coefficient of the length times width dependence of CGSO.

131 `gatenoise=0` Flag for in/exclusion of induced gate thermal noise.

132 `nt=1.62e-20 J` Thermal noise coefficient.

133 `ponfa=8.32e+22(n)/1.9e+22(p) 1/V` m^4
Coefficient of the geometry independent part of NFA.

134 `plnfa=0 1/V` m^4 Coefficient of the length dependence of NFA.

135 `pwnfa=0 1/V` m^4 Coefficient of the width dependence of NFA.

136 `plwnfa=0 1/V` m^4 Coefficient of the length times width dependence of NFA.

137 `ponfb=2.51e+07(n)/5.04e+06(p) 1/V` m^2
Coefficient of the geometry independent part of NFB.

138 `plnfb=0 1/V` m^2 Coefficient of the length dependence of NFB.

139 `pwnfb=0 1/V` m^2 Coefficient of the width dependence of NFB.

140 `plwnfb=0 1/V` m^2 Coefficient of the length times width dependence of NFB.

141 `ponfc=0(n)/3.63e-10(p) 1/V`
Coefficient of the geometry independent part of NFC.

142 `plnfc=0 1/V` Coefficient of the length dependence of NFC.

143 `pwnfc=0 1/V` Coefficient of the width dependence of NFC.

144 `plwnfc=0 1/V` Coefficient of the length times width dependence of NFC.

145 `potvfb=0.0005 V/K` Coefficient of the geometry independent part of STVFB.

146 `pltvfb=0 V/K` Coefficient of the length dependence of STVFB.

147 `pwtvfb=0 V/K` Coefficient of the width dependence of STVFB.

148 `plwtvfb=0 V/K` Coefficient of the length times width dependence of STVFB.

149 `potphib=-0.00085 V/K`
Coefficient of the geometry independent part of STPHIB.

150 `pltphib=0 V/K` Coefficient of the length dependence of STPHIB.

151 `pwtphib=0 V/K` Coefficient of the width dependence of STPHIB.

152 `plwtphib=0 V/K` Coefficient of the length times width dependence of STPHIB.

153 `potetabet=1.3(n)/0.5(p)`
Coefficient of the geometry independent part of ETABET.

154 `pltetabet=0` Coefficient of the length dependence of ETABET.

155 `pwtetabet=0` Coefficient of the width dependence of ETABET.

156 `plwtetabet=0` Coefficient of the length times width dependence of ETABET.

157 `potetasr=0.65(n)/0.5(p)`
Coefficient of the geometry independent part of ETASR.

158 `pltetasr=0` Coefficient of the length dependence of ETASR.

159 `pwtetasr=0` Coefficient of the width dependence of ETASR.

160 `plwtetasr=0` Coefficient of the length times width dependence of ETASR.

161 `potetaph=1.35(n)/3.75(p)`
Coefficient of the geometry independent part of ETAPH.

162 `pltetaph=0` Coefficient of the length dependence of ETAPH.

163 `pwtetaph=0` Coefficient of the width dependence of ETAPH.

164 `plwtetaph=0` Coefficient of the length times width dependence of ETAPH.

165 `potetamob=0 1/K` Coefficient of the geometry independent part of STETAMOB.

166 `pltetamob=0 1/K` Coefficient of the length dependence of STETAMOB.

167 `pwtetamob=0 1/K` Coefficient of the width dependence of STETAMOB.

168 `plwtetamob=0 1/K` Coefficient of the length times width dependence of STETAMOB.

169 `nu=2` Exponent of field dependence of mobility model.

170 `potnuexp=5.25(n)/3.23(p)`
Coefficient of the geometry independent part of NUEXP.

171 `pltnuexp=0` Coefficient of the length dependence of NUEXP.

172 `pwtnuexp=0` Coefficient of the width dependence of NUEXP.

173 `plwtnuexp=0` Coefficient of the length times width dependence of NUEXP.

174 `potetar=0.95(n)/0.4(p)`
Coefficient of the geometry independent part of ETAR.

175 `pltetar=0` Coefficient of the length dependence of ETAR.

176 `pwtetar=0` Coefficient of the width dependence of ETAR.

177 `plwtetar=0` Coefficient of the length times width dependence of ETAR.

178 `potetasat=1.04(n)/0.86(p)`
Coefficient of the geometry independent part of ETASAT.

179 `pltetasat=0` Coefficient of the length dependence of ETASAT.

180 `pwtetasat=0` Coefficient of the width dependence of ETASAT.

181 `plwtetasat=0` Coefficient of the length times width dependence of ETASAT.

182 `pota1=0 1/K` Coefficient of the geometry independent part of STA1.

183 `plta1=0 1/K` Coefficient of the length dependence of STA1.

184 `pwta1=0 1/K` Coefficient of the width dependence of STA1.

185 `plwta1=0 1/K` Coefficient of the length times width dependence of STA1.

186 `potbgidl=-0.000364 V/K`
Coefficient of the geometry independent part of STBGIDL.

187 `pltbgidl=0 V/K` Coefficient of the length dependence of STBGIDL.

188 `pwtbgidl=0 V/K` Coefficient of the width dependence of STBGIDL.

189 `plwtbgidl=0 V/K` Coefficient of the length times width dependence of STBGIDL.

190 `dta=0 K` Temperature offset of the device.

191 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

192 `imax=1.0 A` Explosion current.

193 `tnom (C)` alias of tnom.

194 `tref (C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flat-band voltage at reference temperature.

2 `ko (√V )` Body-effect factor.

3 `kpinv (1/√V )` Inverse of body-effect factor of the poly-silicon gate.

4 `phib (V)` Surface potential at the onset of strong inversion.

5 `bet` (A/V^2) Gain factor.

6 `thesr (1/V)` Mobility degradation parameter due to surface roughness scattering.

7 `theph (1/V)` Mobility degradation parameter due to phonon scattering.

8 `etamob` Effective field parameter for dependence on depletion charge.

9 `nu` Exponent of field dependence of mobility model.

10 `ther (1/V)`	Coefficient of series resistance.
11 `ther1 (V)`	Numerator of gate voltage dependent part of series resistance.
12 `ther2 (V)`	Denominator of gate voltage dependent part of series resistance.
13 `thesat (1/V)`	Velocity saturation parameter due to optical/acoustic phonon scattering.
14 `theth` $(1/V^3)$	Coefficient of self-heating.
15 `sdibl` $(1/\sqrt{V})$	Drain-induced barrier lowering parameter.
16 `mo`	Parameter for (short-channel) subthreshold slope.
17 `ssf` $(1/\sqrt{V})$	Static-feedback parameter.
18 `alp`	Factor of channel length modulation.
19 `vp (V)`	Characteristic voltage of channel-length modulation.
20 `mexp`	Smoothing factor.
21 `a1`	Factor of the weak-avalanche current.
22 `a2 (V)`	Exponent of the weak-avalanche current.
23 `a3`	Factor of the drain-source voltage above which weak-avalanche occurs.
24 `iginv` (A/V^2)	Gain factor for intrinsic gate tunnelling current in inversion.
25 `binv (V)`	Probability factor for intrinsic gate tunnelling current in inversion.
26 `igacc` (A/V^2)	Gain factor for intrinsic gate tunnelling current in accumulation.
27 `bacc (V)`	Probability factor for intrinsic gate tunnelling current in accumulation.
28 `vfbov (V)`	Flat-band voltage for the Source/Drain overlap extensions.
29 `kov` $(\sqrt{V})$	Body-effect factor for the Source/Drain overlap extensions.

30 `igov` (A/V^2)	Gain factor for Source/Drain overlap tunnelling current.
31 `agidl` (A/V^3)	Gain factor for gate-induced leakage current.
32 `bgidl (V)`	Probability factor for gate-induced drain leakage current at reference temperature.
33 `cgidl`	Factor for the lateral field dependence of the gate-induced leakage current.
34 `cox (F)`	Oxide capacitance for the intrinsic channel (* mult).
35 `cgdo (F)`	Oxide capacitance for the gate-drain overlap (* mult).
36 `cgso (F)`	Oxide capacitance for the gate-source overlap (* mult).
37 `gatenoise`	Flag for in/exclusion of induced gate thermal noise.
38 `nt (J)`	Thermal noise coefficient.
39 `nfa` $(1/(Vm^4))$	First coefficient of the flicker noise.
40 `nfb` $(1/(Vm^2))$	Second coefficient of the flicker noise.
41 `nfc (1/V)`	Third coefficient of the flicker noise.
42 `tox (m)`	Thickness of gate oxide layer.

Operating-Point Parameters

1 `ids (A)`	Drain current, excl. avalanche and tunnel currents.
2 `iavl (A)`	Substrate current due to weak-avalanche.
3 `igs (A)`	Gate-to-source current due to direct tunnelling.
4 `igd (A)`	Gate-to-drain current due to direct tunnelling.
5 `igb (A)`	Gate-to-bulk current due to direct tunnelling.
6 `vds (V)`	Drain-source voltage.
7 `vgs (V)`	Gate-source voltage.

8 `vsb (V)` Source-bulk voltage.

9 `vto (V)` Zero-bias threshold voltage.

10 `vts (V)` Threshold voltage including back-bias effects.

11 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

12 `vgt (V)` Effective gate drive voltage including back-bias and drain voltage effects.

13 `vdss (V)` Drain saturation voltage at actual bias.

14 `vsat (V)` Saturation limit.

15 `gm (A/V)` Transconductance (d ids / d vgs).

16 `gmb (A/V)` Substrate-transconductance (d ids / d vbs).

17 `gds (A/V)` Output conductance (d ids / d vds).

18 `cdd (F)` Capacitance (d qd / d vd).

19 `cdg (F)` Capacitance (- d qd / d vg).

20 `cds (F)` Capacitance (- d qd / d vs).

21 `cdb (F)` Capacitance (- d qd / d vb).

22 `cgd (F)` Capacitance (- d qg / d vd).

23 `cgg (F)` Capacitance (d qg / d vg).

24 `cgs (F)` Capacitance (- d qg / d vs).

25 `cgb (F)` Capacitance (- d qg / d vb).

26 `csd (F)` Capacitance (- d qs / d vd).

27 `csg (F)` Capacitance (- d qs / d vg).

28 `css (F)` Capacitance (d qs / d vs).

29 `csb (F)`	Capacitance (- d qs / d vb).
30 `cbd (F)`	Capacitance (- d qb / d vd).
31 `cbg (F)`	Capacitance (- d qb / d vg).
32 `cbs (F)`	Capacitance (- d qb / d vs).
33 `cbb (F)`	Capacitance (d qb / d vb).
34 `cgdol (F)`	Gate-drain overlap capacitance of the actual transistor.
35 `cgsol (F)`	Gate-source overlap capacitance of the actual transistor.
36 `weff (m)`	Effective channel width for geometrical models.
37 `leff (m)`	Effective channel length for geometrical models.
38 `u`	Transistor gain (gm/gds).
39 `rout` (Ω)	Small-signal output resistance (1/gds).
40 `vearly (V)`	Equivalent Early voltage (lidl/gds).
41 `keff` ($\sqrt{V}$)	Body effect parameter.
42 `beff` (A/V^2)	Gain factor.
43 `fug (Hz)`	Unity gain frequency at actual bias (gm/(2*pi*cin)).
44 `sqrtsfw` ($V/\sqrt{Hz}$)	Input-referred RMS white noise voltage density.
45 `sqrtsff` ($V/\sqrt{Hz}$)	Input-referred RMS white noise voltage density at 1 kHz.
46 `fknee (Hz)`	Cross-over frequency above which white noise is dominant.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the

description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

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cbs OP-32	plcgidl M-115	plwtphib M-152	pwtetabet M-155
cdb OP-21	plcgso M-128	plwtvfb M-148	pwtetamob M-167
cdd OP-18	plcox M-120	poa1 M-72	pwtetaph M-163
cdg OP-19	pletamob M-34	poa2 M-76	pwtetar M-176
cds OP-20	pligacc M-93	poa3 M-80	pwtetasat M-180

MOS Model 11, Level 1101 (mos11011t)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b  dt ModelName parameter=value ...
```

Instance Parameters

1 `l=2e-06 m`	Drawn channel length in the layout. Scale set by option scale..
2 `w=1e-05 m`	Drawn channel width in the layout. Scale set by option scale..

3 `mult=1` Number of devices in parallel.

4 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

5 `m=1` Multiplicity factor.

6 `area=1` alias of mult.

Model Definition

```
model modelName mos11011t parameter=value ...
```

Model Parameters

1 `level=1.1e+04` Transistor Level.

2 `lvar=0 m` Difference between the actual and the programmed poly-silicon gate length.

3 `lap=4e-08 m` Effective channel length reduction per side.

4 `wvar=0 m` Difference between the actual and the programmed field-oxide opening.

5 `wot=0 m` Effective channel width reduction per side.

6 `tr=21 C` Reference temperature.

7 `lmin=0 m` Device length low limit for binning selection.

8 `lmax=1 m` Device length high limit for binning selection.

9 `wmin=0 m` Device width low limit for binning selection.

10 `wmax=1 m` Device width high limit for binning selection.

11 `vfb=-1.05 V` Flat-band voltage at reference temperature.

12 `poko=0.5 √V` Coefficient for the geometry independent part of KO.

13 `plko=0 √V` Coefficient for the length dependence of KO.

14 `pwko=0 √V` Coefficient for the width dependence of KO.

15 `plwko=0 √V` Coefficient for the length times width dependence of KO.

16 `kpinv=0 1/√V` Inverse of body-effect factor of the poly-silicon gate.

17 `pophib=0.95 V` Coefficient for the geometric independent part of PHIB.

18 `plphib=0 V` Coefficient for the length dependence of PHIB.

19 `pwphib=0 V` Coefficient for the width dependence of PHIB.

20 `plwphib=0 V` Coefficient for the length times width dependence of PHIB.

21 `pobet=0.00192(n)/0.000381(p)` A/V^2
Coefficient for the geometry independent part of BET.

22 `plbet=0` A/V^2 Coefficient for the length dependence of BET.

23 `pwbet=0` A/V^2 Coefficient for the width dependence of BET.

24 `plwbet=0` A/V^2 Coefficient for the width over length dependence of BET.

25 `pothesr=0.356(n)/0.73(p) 1/V`
Coefficient of the geometry independent part of THESR.

26 `plthesr=0 1/V` Coefficient of the length dependence of THESR.

27 `pwthesr=0 1/V` Coefficient of the width dependence of THESR.

28 `plwthesr=0 1/V` Coefficient of the length times width dependence of THESR.

29 `potheph=0.0129(n)/0.001(p) 1/V`
Coefficient of the geometry independent part of THEPH.

30 `pltheph=0 1/V` Coefficient of the length dependence of THEPH.

31 `pwtheph=0 1/V` Coefficient of the width dependence of THEPH.

32 `plwtheph=0 1/V` Coefficient of the length times width dependence of THEPH.

33 `poetamob=1.4(n)/3(p)`
Coefficient of the geometry independent part of ETAMOB.

34 `pletamob=0` Coefficient of the length dependence of ETAMOB.

35 `pwetamob=0` Coefficient of the width dependence of ETAMOB.

36 `plwetamob=0` Coefficient of the length times width dependence of ETAMOB.

37 `pother=0.0812(n)/0.079(p) 1/V`
Coefficient of the geometry independent part of THER.

38 `plther=0 1/V` Coefficient of the length dependence of THER.

39 `pwther=0 1/V` Coefficient of the width dependence of THER.

40 `plwther=0 1/V` Coefficient of the length times width dependence of THER.

41 `ther1=0 V` Numerator of gate voltage dependent part of series resistance.

42 `ther2=1 V` Denominator of gate voltage dependent part of series resistance.

43 `pothesat=0.251(n)/0.173(p) 1/V`
Coefficient of the geometry independent part of THESAT.

44 `plthesat=0 1/V` Coefficient of the length dependence of THESAT.

45 `pwthesat=0 1/V` Coefficient of the width dependence of THESAT.

46 `plwthesat=0 1/V` Coefficient of the length times width dependence of THESAT.

47 `potheth=1e-05(n)/0(p)` $1/V^3$
Coefficient of the geometry independent part of THETH.

48 `pltheth=0` $1/V^3$ Coefficient of the length dependence of THETH.

49 `pwtheth=0` $1/V^3$ Coefficient of the width dependence of THETH.

50 `plwtheth=0` $1/V^3$ Coefficient of the length times width dependence of THETH.

51 `posdibl=0.000853(n)/3.55e-05(p)` $1/\sqrt{V}$
Coefficient of the geometry independent part of SDIBL.

52 `plsdibl=0` $1/\sqrt{V}$
Coefficient of the length dependence of SDIBL.

53 `pwsdibl=0 1/√V`
Coefficient of the width dependence of SDIBL.

54 `plwsdibl=0 1/√V`
Coefficient of the length times width dependence of SDIBL.

55 `pomo=0` Coefficient of the geometry independent part of MO.

56 `plmo=0` Coefficient of the length dependence of MO.

57 `pwmo=0` Coefficient of the width dependence of MO.

58 `plwmo=0` Coefficient of the length times width dependence of MO.

59 `possf=0.012(n)/0.01(p) 1/√V`
Coefficient of the geometry independent part of SSF.

60 `plssf=0 1/√V` Coefficient of the length dependence of SSF.

61 `pwssf=0 1/√V` Coefficient of the width dependence of SSF.

62 `plwssf=0 1/√V`
Coefficient of the length times width dependence of SSF.

63 `poalp=0.025` Coefficient of the geometry independent part of ALP.

64 `plalp=0` Coefficient of the length dependence of ALP.

65 `pwalp=0` Coefficient of the width dependence of ALP.

66 `plwalp=0` Coefficient of the length times width dependence of ALP.

67 `vp=0.05 V` Characteristic voltage of channel-length modulation.

68 `pomexp=0.2` Coefficient of the geometry independent part of MEXP.

69 `plmexp=0` Coefficient of the length dependence of MEXP.

70 `pwmexp=0` Coefficient of the width dependence of MEXP.

71 `plwmexp=0` Coefficient of the length times width dependence of MEXP.

72 `poa1=6.02(n)/6.86(p)`
Coefficient of the geometry independent part of A1.

73 `pla1=0` Coefficient of the length dependence of A1.

74 `pwa1=0` Coefficient of the width dependence of A1.

75 `plwa1=0` Coefficient of the length times width dependence of A1.

76 `poa2=38(n)/57.3(p) V`
Coefficient of the geometry independent part of A2.

77 `pla2=0 V` Coefficient of the length dependence of A2.

78 `pwa2=0 V` Coefficient of the width dependence of A2.

79 `plwa2=0 V` Coefficient of the length times width dependence of A2.

80 `poa3=0.641(n)/0.425(p)`
Coefficient of the geometry independent part of A3.

81 `pla3=0` Coefficient of the length dependence of A3.

82 `pwa3=0` Coefficient of the width dependence of A3.

83 `plwa3=0` Coefficient of the length times width dependence of A3.

84 `poiginv=0` A/V^2 Coefficient of the geometry independent part of IGINV.

85 `pliginv=0` A/V^2 Coefficient of the length dependence of IGINV.

86 `pwiginv=0` A/V^2 Coefficient of the width dependence of IGINV.

87 `plwiginv=0` A/V^2 Coefficient of the length times width dependence of IGINV.

88 `pobinv=48(n)/87.5(p) V`
Coefficient of the geometry independent part of BINV.

89 `plbinv=0 V` Coefficient of the length dependence of BINV.

90 `pwbinv=0 V` Coefficient of the width dependence of BINV.

91 `plwbinv=0 V` Coefficient of the length times width dependence of BINV.

92 `poigacc=0 A/V`^{2} Coefficient of the geometry independent part of IGACC.

93 `pligacc=0 A/V`^{2} Coefficient of the length dependence of IGACC.

94 `pwigacc=0 A/V`^{2} Coefficient of the width dependence of IGACC.

95 `plwigacc=0 A/V`^{2} Coefficient of the length times width dependence of IGACC.

96 `pobacc=48 V` Coefficient of the geometry independent part of BACC.

97 `plbacc=0 V` Coefficient of the length dependence of BACC.

98 `pwbacc=0 V` Coefficient of the width dependence of BACC.

99 `plwbacc=0 V` Coefficient of the length times width dependence of BACC.

100 `vfbov=0 V` Flat-band voltage for the Source/Drain overlap extensions.

101 `kov=2.5` $\sqrt{V}$ Body-effect factor for the Source/Drain overlap extensions.

102 `poigov=0 A/V`^{2} Coefficient of the geometry independent part of IGOV.

103 `pligov=0 A/V`^{2} Coefficient of the length dependence of IGOV.

104 `pwigov=0 A/V`^{2} Coefficient of the width dependence of IGOV.

105 `plwigov=0 A/V`^{2} Coefficient of the length times width dependence of IGOV.

106 `poagidl=0 A/V`^{3} Coefficient of the geometry independent part of AGIDL.

107 `plagidl=0 A/V`^{3} Coefficient of the length dependence of AGIDL.

108 `pwagidl=0 A/V`^{3} Coefficient of the width dependence of AGIDL.

109 `plwagidl=0 A/V`^{3} Coefficient of the length times width dependence of AGIDL.

110 `pobgidl=41 V` Coefficient of the geometry independent part of BGIDL.

111 `plbgidl=0 V` Coefficient of the length dependence of BGIDL.

112 `pwbgidl=0 V` Coefficient of the width dependence of BGIDL.

113 `plwbgidl=0 V` Coefficient of the length times width dependence of BGIDL.

114 `pocgidl=0` Coefficient of the geometry independent part of CGIDL.

115 `plcgidl=0` Coefficient of the length dependence of CGIDL.

116 `pwcgidl=0` Coefficient of the width dependence of CGIDL.

117 `plwcgidl=0` Coefficient of the length times width dependence of CGIDL.

118 `tox=3.2e-09 m` Thickness of gate oxide layer.

119 `pocox=2.98e-14(n)/2.72e-14(p) F`
Coefficient of the geometry independent part of COX.

120 `plcox=0 F` Coefficient of the length dependence of COX.

121 `pwcox=0 F` Coefficient of the width dependence of COX.

122 `plwcox=0 F` Coefficient of the length times width dependence of COX.

123 `pocgdo=6.39e-15(n)/6.36e-15(p) F`
Coefficient of the geometry independent part of CGDO.

124 `plcgdo=0 F` Coefficient of the length dependence of CGDO.

125 `pwcgdo=0 F` Coefficient of the width dependence of CGDO.

126 `plwcgdo=0 F` Coefficient of the length time width dependence of CGDO.

127 `pocgso=6.39e-15(n)/6.36e-15(p) F`
Coefficient of the geometry independent part of CGSO.

128 `plcgso=0 F` Coefficient of the length dependence of CGSO.

129 `pwcgso=0 F` Coefficient of the width dependence of CGSO.

130 `plwcgso=0 F` Coefficient of the length times width dependence of CGSO.

131 `gatenoise=0` Flag for in/exclusion of induced gate thermal noise.

132 `nt=1.62e-20 J` Thermal noise coefficient.

133 `ponfa=8.32e+22(n)/1.9e+22(p) 1/V` m^4
Coefficient of the geometry independent part of NFA.

134 `plnfa=0 1/V m`^{4} Coefficient of the length dependence of NFA.

135 `pwnfa=0 1/V m`^{4} Coefficient of the width dependence of NFA.

136 `plwnfa=0 1/V m`^{4} Coefficient of the length times width dependence of NFA.

137 `ponfb=2.51e+07(n)/5.04e+06(p) 1/V m`^{2}
Coefficient of the geometry independent part of NFB.

138 `plnfb=0 1/V m`^{2} Coefficient of the length dependence of NFB.

139 `pwnfb=0 1/V m`^{2} Coefficient of the width dependence of NFB.

140 `plwnfb=0 1/V m`^{2} Coefficient of the length times width dependence of NFB.

141 `ponfc=0(n)/3.63e-10(p) 1/V`
Coefficient of the geometry independent part of NFC.

142 `plnfc=0 1/V` Coefficient of the length dependence of NFC.

143 `pwnfc=0 1/V` Coefficient of the width dependence of NFC.

144 `plwnfc=0 1/V` Coefficient of the length times width dependence of NFC.

145 `potvfb=0.0005 V/K` Coefficient of the geometry independent part of STVFB.

146 `pltvfb=0 V/K` Coefficient of the length dependence of STVFB.

147 `pwtvfb=0 V/K` Coefficient of the width dependence of STVFB.

148 `plwtvfb=0 V/K` Coefficient of the length times width dependence of STVFB.

149 `potphib=-0.00085 V/K`
Coefficient of the geometry independent part of STPHIB.

150 `pltphib=0 V/K` Coefficient of the length dependence of STPHIB.

151 `pwtphib=0 V/K` Coefficient of the width dependence of STPHIB.

152 `plwtphib=0 V/K` Coefficient of the length times width dependence of STPHIB.

153 `potetabet=1.3(n)/0.5(p)`
Coefficient of the geometry independent part of ETABET.

154 `pltetabet=0` Coefficient of the length dependence of ETABET.

155 `pwtetabet=0` Coefficient of the width dependence of ETABET.

156 `plwtetabet=0` Coefficient of the length times width dependence of ETABET.

157 `potetasr=0.65(n)/0.5(p)`
Coefficient of the geometry independent part of ETASR.

158 `pltetasr=0` Coefficient of the length dependence of ETASR.

159 `pwtetasr=0` Coefficient of the width dependence of ETASR.

160 `plwtetasr=0` Coefficient of the length times width dependence of ETASR.

161 `potetaph=1.35(n)/3.75(p)`
Coefficient of the geometry independent part of ETAPH.

162 `pltetaph=0` Coefficient of the length dependence of ETAPH.

163 `pwtetaph=0` Coefficient of the width dependence of ETAPH.

164 `plwtetaph=0` Coefficient of the length times width dependence of ETAPH.

165 `potetamob=0 1/K` Coefficient of the geometry independent part of STETAMOB.

166 `pltetamob=0 1/K` Coefficient of the length dependence of STETAMOB.

167 `pwtetamob=0 1/K` Coefficient of the width dependence of STETAMOB.

168 `plwtetamob=0 1/K` Coefficient of the length times width dependence of STETAMOB.

169 `nu=2` Exponent of field dependence of mobility model.

170 `potnuexp=5.25(n)/3.23(p)`
Coefficient of the geometry independent part of NUEXP.

171 `pltnuexp=0` Coefficient of the length dependence of NUEXP.

172 `pwtnuexp=0` Coefficient of the width dependence of NUEXP.

173 `plwtnuexp=0` Coefficient of the length times width dependence of NUEXP.

174 `potetar=0.95(n)/0.4(p)`
Coefficient of the geometry independent part of ETAR.

175 `pltetar=0` Coefficient of the length dependence of ETAR.

176 `pwtetar=0` Coefficient of the width dependence of ETAR.

177 `plwtetar=0` Coefficient of the length times width dependence of ETAR.

178 `potetasat=1.04(n)/0.86(p)`
Coefficient of the geometry independent part of ETASAT.

179 `pltetasat=0` Coefficient of the length dependence of ETASAT.

180 `pwtetasat=0` Coefficient of the width dependence of ETASAT.

181 `plwtetasat=0` Coefficient of the length times width dependence of ETASAT.

182 `pota1=0 1/K` Coefficient of the geometry independent part of STA1.

183 `plta1=0 1/K` Coefficient of the length dependence of STA1.

184 `pwta1=0 1/K` Coefficient of the width dependence of STA1.

185 `plwta1=0 1/K` Coefficient of the length times width dependence of STA1.

186 `potbgidl=-0.000364 V/K`
Coefficient of the geometry independent part of STBGIDL.

187 `pltbgidl=0 V/K` Coefficient of the length dependence of STBGIDL.

188 `pwtbgidl=0 V/K` Coefficient of the width dependence of STBGIDL.

189 `plwtbgidl=0 V/K` Coefficient of the length times width dependence of STBGIDL.

190 `dta=0 K` Temperature offset of the device.

191 `rth=300 K/W` Thermal resistance.

192 `cth=3e-09 J/K` Thermal capacitance.

193 `ath=0` Temperature coefficient of the thermal resistance.

194 `type=n`	Transistor gender. Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.
195 `imax=1.0 A`	Explosion current.
196 `tnom (C)`	alias of tnom.
197 `tref (C)`	alias of tnom.

Output Parameters

1 `vfb (V)`	Flat-band voltage at reference temperature.
2 `ko (√V )`	Body-effect factor.
3 `kpinv (1/√V )`	Inverse of body-effect factor of the poly-silicon gate.
4 `phib (V)`	Surface potential at the onset of strong inversion.
5 `bet` (A/V^2)	Gain factor.
6 `thesr (1/V)`	Mobility degradation parameter due to surface roughness scattering.
7 `theph (1/V)`	Mobility degradation parameter due to phonon scattering.
8 `etamob`	Effective field parameter for dependence on depletion charge.
9 `nu`	Exponent of field dependence of mobility model.
10 `ther (1/V)`	Coefficient of series resistance.
11 `ther1 (V)`	Numerator of gate voltage dependent part of series resistance.
12 `ther2 (V)`	Denominator of gate voltage dependent part of series resistance.
13 `thesat (1/V)`	Velocity saturation parameter due to optical/acoustic phonon scattering.
14 `theth` $(1/V^3)$	Coefficient of self-heating.
15 `sdibl (1/√V )`	Drain-induced barrier lowering parameter.

16 `mo`	Parameter for (short-channel) subthreshold slope.
17 `ssf (1/√V )`	Static-feedback parameter.
18 `alp`	Factor of channel length modulation.
19 `vp (V)`	Characteristic voltage of channel-length modulation.
20 `mexp`	Smoothing factor.
21 `a1`	Factor of the weak-avalanche current.
22 `a2 (V)`	Exponent of the weak-avalanche current.
23 `a3`	Factor of the drain-source voltage above which weak-avalanche occurs.
24 `iginv` (A/V^2)	Gain factor for intrinsic gate tunnelling current in inversion.
25 `binv (V)`	Probability factor for intrinsic gate tunnelling current in inversion.
26 `igacc` (A/V^2)	Gain factor for intrinsic gate tunnelling current in accumulation.
27 `bacc (V)`	Probability factor for intrinsic gate tunnelling current in accumulation.
28 `vfbov (V)`	Flat-band voltage for the Source/Drain overlap extensions.
29 `kov (√V )`	Body-effect factor for the Source/Drain overlap extensions.
30 `igov` (A/V^2)	Gain factor for Source/Drain overlap tunnelling current.
31 `agidl` (A/V^3)	Gain factor for gate-induced leakage current.
32 `bgidl (V)`	Probability factor for gate-induced drain leakage current at reference temperature.
33 `cgidl`	Factor for the lateral field dependence of the gate-induced leakage current.
34 `cox (F)`	Oxide capacitance for the intrinsic channel (* mult).
35 `cgdo (F)`	Oxide capacitance for the gate-drain overlap (* mult).

36 `cgso (F)` Oxide capacitance for the gate-source overlap (* mult).

37 `gatenoise` Flag for in/exclusion of induced gate thermal noise.

38 `nt (J)` Thermal noise coefficient.

39 `nfa` $(1/(Vm^4))$ First coefficient of the flicker noise.

40 `nfb` $(1/(Vm^2))$ Second coefficient of the flicker noise.

41 `nfc (1/V)` Third coefficient of the flicker noise.

42 `tox (m)` Thickness of gate oxide layer.

43 `rth (K/W)` Thermal resistance.

44 `cth (J/K)` Thermal capacitance.

Operating-Point Parameters

1 `ids (A)` Drain current, excl. avalanche and tunnel currents.

2 `iavl (A)` Substrate current due to weak-avalanche.

3 `igs (A)` Gate-to-source current due to direct tunnelling.

4 `igd (A)` Gate-to-drain current due to direct tunnelling.

5 `igb (A)` Gate-to-bulk current due to direct tunnelling.

6 `vds (V)` Drain-source voltage.

7 `vgs (V)` Gate-source voltage.

8 `vsb (V)` Source-bulk voltage.

9 `vto (V)` Zero-bias threshold voltage.

10 `vts (V)` Threshold voltage including back-bias effects.

11 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

12 `vgt (V)`	Effective gate drive voltage including back-bias and drain voltage effects.
13 `vdss (V)`	Drain saturation voltage at actual bias.
14 `vsat (V)`	Saturation limit.
15 `gm (A/V)`	Transconductance (d ids / d vgs).
16 `gmb (A/V)`	Substrate-transconductance (d ids / d vbs).
17 `gds (A/V)`	Output conductance (d ids / d vds).
18 `cdd (F)`	Capacitance (d qd / d vd).
19 `cdg (F)`	Capacitance (- d qd / d vg).
20 `cds (F)`	Capacitance (- d qd / d vs).
21 `cdb (F)`	Capacitance (- d qd / d vb).
22 `cgd (F)`	Capacitance (- d qg / d vd).
23 `cgg (F)`	Capacitance (d qg / d vg).
24 `cgs (F)`	Capacitance (- d qg / d vs).
25 `cgb (F)`	Capacitance (- d qg / d vb).
26 `csd (F)`	Capacitance (- d qs / d vd).
27 `csg (F)`	Capacitance (- d qs / d vg).
28 `css (F)`	Capacitance (d qs / d vs).
29 `csb (F)`	Capacitance (- d qs / d vb).
30 `cbd (F)`	Capacitance (- d qb / d vd).
31 `cbg (F)`	Capacitance (- d qb / d vg).
32 `cbs (F)`	Capacitance (- d qb / d vs).

33 `cbb (F)` Capacitance (d qb / d vb).

34 `cgdol (F)` Gate-drain overlap capacitance of the actual transistor.

35 `cgsol (F)` Gate-source overlap capacitance of the actual transistor.

36 `weff (m)` Effective channel width for geometrical models.

37 `leff (m)` Effective channel length for geometrical models.

38 `u` Transistor gain (gm/gds).

39 `rout` (Ω) Small-signal output resistance (1/gds).

40 `vearly (V)` Equivalent Early voltage (|id|/gds).

41 `keff` ($\sqrt{V}$) Body effect parameter.

42 `beff` (A/V^2) Gain factor.

43 `fug (Hz)` Unity gain frequency at actual bias (gm/(2*pi*cin)).

44 `sqrtsfw` ($V/\sqrt{Hz}$) Input-referred RMS white noise voltage density.

45 `sqrtsff` ($V/\sqrt{Hz}$) Input-referred RMS white noise voltage density at 1 kHz.

46 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

47 `Pdiss (W)` Dissipation.

48 `TK (K)` Actual device temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

MOS Model 11, Level 1101 (mos1101e)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

model modelName mos1101e parameter=value ...

Model Parameters

1 `level=1.1e+03` Transistor Level.

2 `tr=21 C` Reference temperature.

3 `vfb=-1.05 V` Flat-band voltage at reference temperature.

4 `stvfb=0.0005 V/K` Coefficient of temperature dependence of VFB.

5 `ko=0.5 √V` Body-effect factor.

6 `kpinv=0 1/√V` Inverse of body-effect factor of the poly-silicon gate.

7 `phib=0.95 V` Surface potential at the onset of strong inversion.

8 `stphib=-0.00085 V/K`
Coefficient of the temperature dependency of PHIB.

9 `bet=0.00192(n)/0.000381(p) A/V`^{2}
Gain factor.

10 `etabet=1.3(n)/0.5(p)`
Exponent of the temperature dependence of the gain factor.

11 `thesr=0.356(n)/0.73(p) 1/V`
Mobility degradation parameter due to surface roughness scattering.

12 `etasr=0.65(n)/0.5(p)`
Exponent of the temperatue dependence of THESR.

13 `theph=0.0129(n)/0.001(p) 1/V`
Mobility degradation parameter due to phonon scattering.

14 `etaph=1.35(n)/3.75(p)`
Exponent of the temperature dependence of THEPH.

15 `etamob=1.4(n)/3(p)`
Effective field parameter for dependence on depletion charge.

16 `stetamob=0 1/K` Coefficient of the temperature dependence of ETAMOB.

17 `nu=2` Exponent of field dependence of mobility model.

18 `nuexp=5.25(n)/3.23(p)`
Exponent of the temperature dependence of parameter NU.

19 `ther=0.0812(n)/0.079(p) 1/V`
Coefficient of series resistance.

20 `etar=0.95(n)/0.4(p)`
Exponent of the temperature dependence of THER.

21 `ther1=0 V` Numerator of gate voltage dependent part of series resistance.

22 `ther2=1 V` Denominator of gate voltage dependent part of series resistance.

23 `thesat=0.251(n)/0.173(p) 1/V`
Velocity saturation parameter due to optical/acoustic phonon scattering.

24 `etasat=1.04(n)/0.86(p)`
Exponent of the temperature dependence of THESAT.

25 `theth=1e-05(n)/0(p)` $1/V^3$
Coefficient of self-heating.

26 `sdibl=0.000853(n)/3.55e-05(p)` $1/\sqrt{V}$
Drain-induced barrier lowering parameter.

27 `mo=0` Parameter for (short-channel) subthreshold slope.

28 `ssf=0.012(n)/0.01(p) 1/√V`
Static-feedback parameter.

29 `alp=0.025` Factor of channel length modulation.

30 `vp=0.05 V` Characteristic voltage of channel-length modulation.

31 `mexp=5` Smoothing factor.

32 `a1=6.02(n)/6.86(p)`
Factor of the weak-avalanche current.

33 `sta1=0 1/K` Coefficient of the temperature dependence of A1.

34 `a2=38(n)/57.3(p) V`
Exponent of the weak-avalanche current.

35 `a3=0.641(n)/0.425(p)`
Factor of the drain-source voltage above which weak-avalanche occurs.

36 `iginv=0` A/V^2 Gain factor for intrinsic gate tunnelling current in inversion.

37 `binv=48(n)/87.5(p) V`
Probability factor for intrinsic gate tunnelling current in inversion.

38 `igacc=0` A/V^2 Gain factor for intrinsic gate tunnelling current in accumulation.

39 `bacc=48 V` Probability factor for intrinsic gate tunnelling current in accumulation.

40 `vfbov=0 V` Flat-band voltage for the Source/Drain overlap extensions.

41 `kov=2.5 √V` Body-effect factor for the Source/Drain overlap extensions.

42 `igov=0` A/V^2 Gain factor for Source/Drain overlap tunnelling current.

43 `agidl=0` A/V^3 Gain factor for gate-induced leakage current.

44 `bgidl=41 V` Probability factor for gate-induced drain leakage current at reference temperature.

45 `stbgidl=-0.000364 V/K`
Coefficient of the temperature dependence of BGIDL.

46 `cgidl=0` Factor for the lateral field dependence of the gate-induced leakage current.

47 `cox=2.98e-14(n)/2.72e-14(p) F`
Oxide capacitance for the intrinsic channel (* mult).

48 `cgdo=6.39e-15(n)/6.36e-15(p) F`
Oxide capacitance for the gate-drain overlap (* mult).

49 `cgso=6.39e-15(n)/6.36e-15(p) F`
Oxide capacitance for the gate-source overlap (* mult).

50 `gatenoise=0` Flag for in/exclusion of induced gate thermal noise.

51 `nt=1.62e-20 J` Thermal noise coefficient.

52 `nfa=8.32e+22(n)/1.9e+22(p) 1/(Vm`^{4}`)`
First coefficient of the flicker noise.

53 `nfb=2.51e+07(n)/5.04e+06(p) 1/(Vm`^{2}`)`
Second coefficient of the flicker noise.

54 `nfc=0(n)/3.63e-10(p) 1/V`
Third coefficient of the flicker noise.

55 `tox=3.2e-09 m` Thickness of gate oxide layer.

56 `dta=0 K` Temperature offset of the device.

57 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

58 `imax=1.0 A` Explosion current.

59 `tnom (C)` alias of tnom.

60 `tref (C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flat-band voltage at reference temperature.

2 `ko (√V )` Body-effect factor.

3 `kpinv (1/√V )` Inverse of body-effect factor of the poly-silicon gate.

4 `phib (V)` Surface potential at the onset of strong inversion.

5 `bet (A/V`^{2}`)` Gain factor.

6 `thesr (1/V)` Mobility degradation parameter due to surface roughness scattering.

7 `theph (1/V)` Mobility degradation parameter due to phonon scattering.

8 `etamob` Effective field parameter for dependence on depletion charge.

9 `nu` Exponent of field dependence of mobility model.

10 `ther (1/V)` Coefficient of series resistance.

11 `ther1 (V)` Numerator of gate voltage dependent part of series resistance.

12 `ther2 (V)` Denominator of gate voltage dependent part of series resistance.

13 `thesat (1/V)` Velocity saturation parameter due to optical/acoustic phonon scattering.

14 `theth (1/V`^{3}`)` Coefficient of self-heating.

15 `sdibl (1/√V )` Drain-induced barrier lowering parameter.

16 `mo` Parameter for (short-channel) subthreshold slope.

17 `ssf (1/√V )` Static-feedback parameter.

18 `alp` Factor of channel length modulation.

19 `vp (V)` Characteristic voltage of channel-length modulation.

20 `mexp`	Smoothing factor.
21 `a1`	Factor of the weak-avalanche current.
22 `a2 (V)`	Exponent of the weak-avalanche current.
23 `a3`	Factor of the drain-source voltage above which weak-avalanche occurs.
24 `iginv` (A/V^2)	Gain factor for intrinsic gate tunnelling current in inversion.
25 `binv (V)`	Probability factor for intrinsic gate tunnelling current in inversion.
26 `igacc` (A/V^2)	Gain factor for intrinsic gate tunnelling current in accumulation.
27 `bacc (V)`	Probability factor for intrinsic gate tunnelling current in accumulation.
28 `vfbov (V)`	Flat-band voltage for the Source/Drain overlap extensions.
29 `kov` $(\sqrt{V})$	Body-effect factor for the Source/Drain overlap extensions.
30 `igov` (A/V^2)	Gain factor for Source/Drain overlap tunnelling current.
31 `agidl` (A/V^3)	Gain factor for gate-induced leakage current.
32 `bgidl (V)`	Probability factor for gate-induced drain leakage current at reference temperature.
33 `cgidl`	Factor for the lateral field dependence of the gate-induced leakage current.
34 `cox (F)`	Oxide capacitance for the intrinsic channel (* mult).
35 `cgdo (F)`	Oxide capacitance for the gate-drain overlap (* mult).
36 `cgso (F)`	Oxide capacitance for the gate-source overlap (* mult).
37 `gatenoise`	Flag for in/exclusion of induced gate thermal noise.
38 `nt (J)`	Thermal noise coefficient.
39 `nfa` $(1/(Vm^4))$	First coefficient of the flicker noise.

40 `nfb (1/(Vm`^{2}`))` Second coefficient of the flicker noise.

41 `nfc (1/V)` Third coefficient of the flicker noise.

42 `tox (m)` Thickness of gate oxide layer.

Operating-Point Parameters

1 `ids (A)` Drain current, excl. avalanche and tunnel currents.

2 `iavl (A)` Substrate current due to weak-avalanche.

3 `igs (A)` Gate-to-source current due to direct tunnelling.

4 `igd (A)` Gate-to-drain current due to direct tunnelling.

5 `igb (A)` Gate-to-bulk current due to direct tunnelling.

6 `vds (V)` Drain-source voltage.

7 `vgs (V)` Gate-source voltage.

8 `vsb (V)` Source-bulk voltage.

9 `vto (V)` Zero-bias threshold voltage.

10 `vts (V)` Threshold voltage including back-bias effects.

11 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

12 `vgt (V)` Effective gate drive voltage including back-bias and drain voltage effects.

13 `vdss (V)` Drain saturation voltage at actual bias.

14 `vsat (V)` Saturation limit.

15 `gm (A/V)` Transconductance (d ids / d vgs).

16 `gmb (A/V)` Substrate-transconductance (d ids / d vbs).

17 `gds (A/V)` Output conductance (d ids / d vds).

18 `cdd (F)`	Capacitance (d qd / d vd).
19 `cdg (F)`	Capacitance (- d qd / d vg).
20 `cds (F)`	Capacitance (- d qd / d vs).
21 `cdb (F)`	Capacitance (- d qd / d vb).
22 `cgd (F)`	Capacitance (- d qg / d vd).
23 `cgg (F)`	Capacitance (d qg / d vg).
24 `cgs (F)`	Capacitance (- d qg / d vs).
25 `cgb (F)`	Capacitance (- d qg / d vb).
26 `csd (F)`	Capacitance (- d qs / d vd).
27 `csg (F)`	Capacitance (- d qs / d vg).
28 `css (F)`	Capacitance (d qs / d vs).
29 `csb (F)`	Capacitance (- d qs / d vb).
30 `cbd (F)`	Capacitance (- d qb / d vd).
31 `cbg (F)`	Capacitance (- d qb / d vg).
32 `cbs (F)`	Capacitance (- d qb / d vs).
33 `cbb (F)`	Capacitance (d qb / d vb).
34 `cgdol (F)`	Gate-drain overlap capacitance of the actual transistor.
35 `cgsol (F)`	Gate-source overlap capacitance of the actual transistor.
36 `u`	Transistor gain (gm/gds).
37 `rout (Ω)`	Small-signal output resistance (1/gds).
38 `vearly (V)`	Equivalent Early voltage (lidl/gds).
39 `keff (√V )`	Body effect parameter.

40 `beff` (A/V^2) Gain factor.

41 `fug (Hz)` Unity gain frequency at actual bias (gm/(2*pi*cin)).

42 `sqrtsfw (V/√Hz )`
Input-referred RMS white noise voltage density.

43 `sqrtsff (V/√Hz )`
Input-referred RMS white noise voltage density at 1 kHz.

44 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

MOS Model 11, Level 1101 (mos1101et)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b  dt ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName mos1101et parameter=value ...
```

Model Parameters

1 `level=1.1e+03` Transistor Level.

2 `tr=21 C` Reference temperature.

3 `vfb=-1.05 V` Flat-band voltage at reference temperature.

4 `stvfb=0.0005 V/K` Coefficient of temperature dependence of VFB.

5 `ko=0.5 √V` Body-effect factor.

6 `kpinv=0 1/√V` Inverse of body-effect factor of the poly-silicon gate.

7 `phib=0.95 V` Surface potential at the onset of strong inversion.

8 `stphib=-0.00085 V/K`
Coefficient of the temperature dependency of PHIB.

9 `bet=0.00192(n)/0.000381(p)` A/V^2
Gain factor.

10 `etabet=1.3(n)/0.5(p)`
Exponent of the temperature dependence of the gain factor.

11 `thesr=0.356(n)/0.73(p) 1/V`
Mobility degradation parameter due to surface roughness scattering.

12 `etasr=0.65(n)/0.5(p)`
Exponent of the temperatue dependence of THESR.

13 `theph=0.0129(n)/0.001(p) 1/V`
Mobility degradation parameter due to phonon scattering.

14 `etaph=1.35(n)/3.75(p)`
Exponent of the temperature dependence of THEPH.

15 `etamob=1.4(n)/3(p)`
Effective field parameter for dependence on depletion charge.

16 `stetamob=0 1/K` Coefficient of the temperature dependence of ETAMOB.

17 `nu=2` Exponent of field dependence of mobility model.

18 `nuexp=5.25(n)/3.23(p)`
Exponent of the temperature dependence of parameter NU.

19 `ther=0.0812(n)/0.079(p) 1/V`
Coefficient of series resistance.

20 `etar=0.95(n)/0.4(p)`
Exponent of the temperature dependence of THER.

21 `ther1=0 V` Numerator of gate voltage dependent part of series resistance.

22 `ther2=1 V` Denominator of gate voltage dependent part of series resistance.

23 `thesat=0.251(n)/0.173(p) 1/V`
Velocity saturation parameter due to optical/acoustic phonon scattering.

24 `etasat=1.04(n)/0.86(p)`
Exponent of the temperature dependence of THESAT.

25 `theth=1e-05(n)/0(p)` $1/V^3$
Coefficient of self-heating.

26 `sdibl=0.000853(n)/3.55e-05(p)` $1/\sqrt{V}$
Drain-induced barrier lowering parameter.

27 `mo=0` Parameter for (short-channel) subthreshold slope.

28 `ssf=0.012(n)/0.01(p)` $1/\sqrt{V}$
Static-feedback parameter.

29 `alp=0.025` Factor of channel length modulation.

30 `vp=0.05 V` Characteristic voltage of channel-length modulation.

31 `mexp=5` Smoothing factor.

32 `a1=6.02(n)/6.86(p)`
Factor of the weak-avalanche current.

33 `sta1=0 1/K` Coefficient of the temperature dependence of A1.

34 `a2=38(n)/57.3(p) V`
Exponent of the weak-avalanche current.

35 `a3=0.641(n)/0.425(p)`
Factor of the drain-source voltage above which weak-avalanche occurs.

36 `iginv=0` A/V^2 Gain factor for intrinsic gate tunnelling current in inversion.

37 `binv=48(n)/87.5(p) V`
Probability factor for intrinsic gate tunnelling current in inversion.

38 `igacc=0` A/V^2 Gain factor for intrinsic gate tunnelling current in accumulation.

39 `bacc=48 V` Probability factor for intrinsic gate tunnelling current in accumulation.

40 `vfbov=0 V` Flat-band voltage for the Source/Drain overlap extensions.

41 `kov=2.5` $\sqrt{V}$ Body-effect factor for the Source/Drain overlap extensions.

42 `igov=0` A/V^2 Gain factor for Source/Drain overlap tunnelling current.

43 `agidl=0` A/V^3 Gain factor for gate-induced leakage current.

44 `bgidl=41 V` Probability factor for gate-induced drain leakage current at reference temperature.

45 `stbgidl=-0.000364 V/K`
Coefficient of the temperature dependence of BGIDL.

46 `cgidl=0` Factor for the lateral field dependence of the gate-induced leakage current.

47 `cox=2.98e-14(n)/2.72e-14(p) F`
Oxide capacitance for the intrinsic channel (* mult).

48 `cgdo=6.39e-15(n)/6.36e-15(p) F`
Oxide capacitance for the gate-drain overlap (* mult).

49 `cgso=6.39e-15(n)/6.36e-15(p) F`
Oxide capacitance for the gate-source overlap (* mult).

50 `gatenoise=0` Flag for in/exclusion of induced gate thermal noise.

51 `nt=1.62e-20 J` Thermal noise coefficient.

52 `nfa=8.32e+22(n)/1.9e+22(p) 1/(Vm`^{4}`)`
First coefficient of the flicker noise.

53 `nfb=2.51e+07(n)/5.04e+06(p) 1/(Vm`^{2}`)`
Second coefficient of the flicker noise.

54 `nfc=0(n)/3.63e-10(p) 1/V`
Third coefficient of the flicker noise.

55 `tox=3.2e-09 m` Thickness of gate oxide layer.

56 `dta=0 K` Temperature offset of the device.

57 `rth=300 K/W` Thermal resistance.

58 `cth=3e-09 J/K` Thermal capacitance.

59 `ath=0` Temperature coefficient of the thermal resistance.

60 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

61 `imax=1.0 A` Explosion current.

62 `tnom (C)` alias of tnom.

63 `tref (C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flat-band voltage at reference temperature.

2 `ko (√V )` Body-effect factor.

3 `kpinv` $(1/\sqrt{V})$	Inverse of body-effect factor of the poly-silicon gate.
4 `phib (V)`	Surface potential at the onset of strong inversion.
5 `bet` (A/V^2)	Gain factor.
6 `thesr (1/V)`	Mobility degradation parameter due to surface roughness scattering.
7 `theph (1/V)`	Mobility degradation parameter due to phonon scattering.
8 `etamob`	Effective field parameter for dependence on depletion charge.
9 `nu`	Exponent of field dependence of mobility model.
10 `ther (1/V)`	Coefficient of series resistance.
11 `ther1 (V)`	Numerator of gate voltage dependent part of series resistance.
12 `ther2 (V)`	Denominator of gate voltage dependent part of series resistance.
13 `thesat (1/V)`	Velocity saturation parameter due to optical/acoustic phonon scattering.
14 `theth` $(1/V^3)$	Coefficient of self-heating.
15 `sdibl` $(1/\sqrt{V})$	Drain-induced barrier lowering parameter.
16 `mo`	Parameter for (short-channel) subthreshold slope.
17 `ssf` $(1/\sqrt{V})$	Static-feedback parameter.
18 `alp`	Factor of channel length modulation.
19 `vp (V)`	Characteristic voltage of channel-length modulation.
20 `mexp`	Smoothing factor.
21 `a1`	Factor of the weak-avalanche current.
22 `a2 (V)`	Exponent of the weak-avalanche current.

23 a3	Factor of the drain-source voltage above which weak-avalanche occurs.
24 iginv (A/V^2)	Gain factor for intrinsic gate tunnelling current in inversion.
25 binv (V)	Probability factor for intrinsic gate tunnelling current in inversion.
26 igacc (A/V^2)	Gain factor for intrinsic gate tunnelling current in accumulation.
27 bacc (V)	Probability factor for intrinsic gate tunnelling current in accumulation.
28 vfbov (V)	Flat-band voltage for the Source/Drain overlap extensions.
29 kov ($\sqrt{V}$)	Body-effect factor for the Source/Drain overlap extensions.
30 igov (A/V^2)	Gain factor for Source/Drain overlap tunnelling current.
31 agidl (A/V^3)	Gain factor for gate-induced leakage current.
32 bgidl (V)	Probability factor for gate-induced drain leakage current at reference temperature.
33 cgidl	Factor for the lateral field dependence of the gate-induced leakage current.
34 cox (F)	Oxide capacitance for the intrinsic channel (* mult).
35 cgdo (F)	Oxide capacitance for the gate-drain overlap (* mult).
36 cgso (F)	Oxide capacitance for the gate-source overlap (* mult).
37 gatenoise	Flag for in/exclusion of induced gate thermal noise.
38 nt (J)	Thermal noise coefficient.
39 nfa ($1/(Vm^4)$)	First coefficient of the flicker noise.
40 nfb ($1/(Vm^2)$)	Second coefficient of the flicker noise.
41 nfc (1/V)	Third coefficient of the flicker noise.
42 tox (m)	Thickness of gate oxide layer.

43 `rth (K/W)` Thermal resistance.

44 `cth (J/K)` Thermal capacitance.

Operating-Point Parameters

1 `ids (A)` Drain current, excl. avalanche and tunnel currents.

2 `iavl (A)` Substrate current due to weak-avalanche.

3 `igs (A)` Gate-to-source current due to direct tunnelling.

4 `igd (A)` Gate-to-drain current due to direct tunnelling.

5 `igb (A)` Gate-to-bulk current due to direct tunnelling.

6 `vds (V)` Drain-source voltage.

7 `vgs (V)` Gate-source voltage.

8 `vsb (V)` Source-bulk voltage.

9 `vto (V)` Zero-bias threshold voltage.

10 `vts (V)` Threshold voltage including back-bias effects.

11 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

12 `vgt (V)` Effective gate drive voltage including back-bias and drain voltage effects.

13 `vdss (V)` Drain saturation voltage at actual bias.

14 `vsat (V)` Saturation limit.

15 `gm (A/V)` Transconductance (d ids / d vgs).

16 `gmb (A/V)` Substrate-transconductance (d ids / d vbs).

17 `gds (A/V)` Output conductance (d ids / d vds).

18 `cdd (F)` Capacitance (d qd / d vd).

19 `cdg (F)` Capacitance (- d qd / d vg).

20 `cds (F)` Capacitance (- d qd / d vs).

21 `cdb (F)` Capacitance (- d qd / d vb).

22 `cgd (F)` Capacitance (- d qg / d vd).

23 `cgg (F)` Capacitance (d qg / d vg).

24 `cgs (F)` Capacitance (- d qg / d vs).

25 `cgb (F)` Capacitance (- d qg / d vb).

26 `csd (F)` Capacitance (- d qs / d vd).

27 `csg (F)` Capacitance (- d qs / d vg).

28 `css (F)` Capacitance (d qs / d vs).

29 `csb (F)` Capacitance (- d qs / d vb).

30 `cbd (F)` Capacitance (- d qb / d vd).

31 `cbg (F)` Capacitance (- d qb / d vg).

32 `cbs (F)` Capacitance (- d qb / d vs).

33 `cbb (F)` Capacitance (d qb / d vb).

34 `cgdol (F)` Gate-drain overlap capacitance of the actual transistor.

35 `cgsol (F)` Gate-source overlap capacitance of the actual transistor.

36 `u` Transistor gain (gm/gds).

37 `rout` (Ω) Small-signal output resistance (1/gds).

38 `vearly (V)` Equivalent Early voltage (|id|/gds).

39 `keff` ($\sqrt{V}$) Body effect parameter.

40 `beff` (A/V^2) Gain factor.

41 `fug (Hz)` Unity gain frequency at actual bias (gm/(2*pi*cin)).

42 `sqrtsfw (V/√Hz )`
Input-referred RMS white noise voltage density.

43 `sqrtsff (V/√Hz )`
Input-referred RMS white noise voltage density at 1 kHz.

44 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

45 `Pdiss (W)` Dissipation.

46 `TK (K)` Actual device temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

MOS Model 11, Level 1102 (mos11020)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1	`l=2e-06 m`	Drawn channel length in the layout. Scale set by option scale..
2	`w=1e-05 m`	Drawn channel width in the layout. Scale set by option scale..
3	`mult=1`	Number of devices in parallel.

4 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

5 `m=1` Multiplicity factor.

6 `area=1` alias of mult.

Model Definition

```
model modelName mos11020 parameter=value ...
```

Model Parameters

1 `level=1.1e+04` Transistor Level.

2 `lvar=0 m` Difference between the actual and the programmed poly-silicon gate length.

3 `lap=4e-08 m` Effective channel length reduction per side.

4 `wvar=0 m` Difference between the actual and the programmed field-oxide opening.

5 `wot=0 m` Effective channel width reduction per side.

6 `tr=21 C` Reference temperature.

7 `vfb=-1.05 V` Flat-band voltage at reference temperature.

8 `stvfb=0.0005 V/K` Coefficient of temperature dependence of VFB.

9 `kor=0.5 √V` Body effect coefficient for the reference transistor.

10 `slko=0` Coefficient of the length dependence of KO.

11 `sl2ko=0` Second coefficient of the length dependence of KO.

12 `swko=0` Coefficient of the width dependence of KO.

13 `kpinv=0 1/√V` Inverse of body-effect factor of the poly-silicon gate.

14 `phibr=0.95 V` Surface potential at strong inversion.

15 `stphib=-0.00085 V/K`
Coefficient of the temperature dependency of PHIB.

16 `slphib=0` Coefficient of the length dependence of PHIB.

17 `sl2phib=0` Second coefficient of the length dependence of PHIB.

18 `swphib=0` Coefficient of the width dependence of PHIB.

19 `betsq=0.000371(n)/0.000115(p)` A/V^2
Gain factor for an infinite square transistor.

20 `etabetr=1.3(n)/0.5(p)`
Exponent of the temperature dependence of the gain factor.

21 `sletabet=0` Coefficient of lenght dependence of ETABETR.

22 `fbet1=0` Relative mobility decrease due to first lateral profile.

23 `lp1=8e-07 m` Characteristic length of first lateral profile.

24 `fbet2=0` Relative mobility decrease due to second lateral profile.

25 `lp2=8e-07 m` Characteristic length of second lateral profile.

26 `thesrr=0.4(n)/0.73(p) 1/V`
Coefficient of the mobility reduction due to surface roughness scattering.

27 `etasr=0.65(n)/0.5(p)`
Exponent of the temperature dependence of THESR.

28 `swthesr=0` Coefficient of the width dependence of THESR.

29 `thephr=0.0129(n)/0.001(p) 1/V`
Coefficient of the mobility reduction due to phonon scattering.

30 `etaph=1.35(n)/3.75(p)`
Exponent of the temperature dependence of THEPH.

31 `swtheph=0` Coefficient of the width dependence of THEPH.

32 `etamobr=1.4(n)/3(p)`
Effective field parameter for dependence on depletion/inversion charge.

33 `stetamob=0 1/K` Coefficient of the temperature dependence of ETAMOB.

34 `swetamob=0` Coefficient of the width dependence of ETAMOB.

35 `nu=2` Exponent of field dependence of mobility model.

36 `nuexp=5.25(n)/3.23(p)`
Exponent of the temperature dependence of parameter NU.

37 `therr=0.155(n)/0.08(p) 1/V`
Coefficient of the series resistance.

38 `etar=0.95(n)/0.4(p)`
Exponent of the temperature dependence of THER.

39 `swther=0` Coefficient of the width dependence of THER.

40 `ther1=0 V` Numerator of gate voltage dependent part of series resistance.

41 `ther2=1 V` Denominator of gate voltage dependent part of series resistance.

42 `thesatr=0.5(n)/0.2(p) 1/V`
Velocity saturation parameter due to optical/acoustic phonon scattering.

43 `etasat=1.04(n)/0.86(p)`
Exponent of the temperature dependence of THESAT.

44 `slthesat=1` Coefficient of length dependence of THESAT.

45 `thesatexp=1` Exponent of length dependence of THESAT.

46 `swthesat=0` Coefficient of the width dependence of THESAT.

47 `thethr=0.001(n)/0.0005(p)` $1/V^3$
Coefficient of self-heating.

48 `thethexp=1` Exponent of the length dependence of THETH.

49 `swtheth=0` Coefficient of the width dependence of THETH.

50 `sdiblo=0.0001 1/√V`
Drain-induced barrier lowering parameter.

51 `sdiblexp=1.35` Exponent of the length dependence of SDIBL.

52 `moo=0` Parameter for short-channel subthreshold slope.

53 `mor=0` Parameter for short-channel subthreshold slope per unit length.

54 `moexp=1.34` Exponent of the length dependence of MO.

55 `ssfr=0.00625 1/√V`
Static feedback parameter.

56 `slssf=1` Coefficient of the length dependence of SSF.

57 `swssf=0` Coefficient of the width dependence of SSF.

58 `alpr=0.01` Factor of the channel length modulation.

59 `slalp=1` Coefficient of the length dependence of ALP.

60 `alpexp=1` Exponent of the length dependence of ALP.

61 `swalp=0` Coefficient of the width dependence of ALP.

62 `vp=0.05 V` Characteristic voltage of channel-length modulation.

63 `lmin=1.5e-07 m` Minimum effective channel length in technology, used for calculation of smoothing factor m.

64 `a1r=6` Factor of the weak-avalanche current.

65 `sta1=0 1/K` Coefficient of the temperature dependence of A1.

66 `sla1=0` Coefficient of the length dependence of A1.

67 `swa1=0` Coefficient of the width dependence of A1.

68 `a2r=38 V` Exponent of the weak-avalanche current.

69 `sla2=0` Coefficient of the length dependence of A2.

70 `swa2=0` Coefficient of the width dependence of A2.

71 `a3r=1` Factor of the drain-source voltage above which weak-avalanche occurs.

72 `sla3=0` Coefficient of the length dependence of A3.

73 `swa3=0` Coefficient of the width dependence of A3.

74 `iginvr=0` A/V^2 Gain factor for intrinsic gate tunnelling current in inversion.

75 `binv=48(n)/87.5(p) V`
Probability factor for intrinsic gate tunnelling current in inversion.

76 `igaccr=0` A/V^2 Gain factor for intrinsic gate tunnelling current in accumulation.

77 `bacc=48 V` Probability factor for intrinsic gate tunnelling current in accumulation.

78 `vfbov=0 V` Flat-band voltage for the Source/Drain overlap extensions.

79 `kov=2.5` $\sqrt{V}$ Body-effect factor for the Source/Drain overlap extensions.

80 `igovr=0` A/V^2 Gain factor for Source/Drain overlap gate tunnelling current.

81 `agidlr=0` A/V^3 Gain factor for gate-induced leakage current.

82 `bgidl=41 V` Probability factor for gate-induced drain leakage current at reference temperature.

83 `stbgidl=-0.000364 V/K`
Coefficient of the temperature dependence of BGIDL.

84 `cgidl=0` Factor for the lateral field dependence of the gate-induced leakage current.

85 `tox=3.2e-09 m` Thickness of gate oxide layer.

86 `col=3.2e-16 F` Gate overlap capacitance for a channel width of 1 um.

87 `gatenoise=0` Flag for in/exclusion of induced gate thermal noise.

88 `nt=1.62e-20 J` Thermal noise coefficient.

89 `nfar=1.57e+23(n)/3.83e+24(p) 1/(Vm`^{4}`)`
First coefficient of the flicker noise for a channel area of 1 um^2.

90 `nfbr=4.75e+09(n)/1.02e+09(p) 1/(Vm`^{2}`)`
Second coefficient of the flicker noise for a channel area of 1 um^2.

91 `nfcr=0(n)/7.3e-08(p) 1/V`
Third coefficient of the flicker noise for a channel area of 1 um^2.

92 `dta=0 K` Temperature offset of the device.

93 `csr=0` Factor of the Coulomb scattering.

94 `slcs=0` Coefficient of the length dependence of CS.

95 `csexp=1` Exponent of the length dependence of CS.

96 `swcs=0` Coefficient of the width dependence of CS.

97 `etacs=0` Exponent of the temperature dependence of CS.

98 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

99 `imax=1.0 A` Explosion current.

100 `mbeo=0.0` DCmatch parameter.

101 `mvto=0.0` DCmatch parameter.

102 `tnom (C)` alias of tnom.

103 `tref (C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flat-band voltage at reference temperature.

2 `ko (`$\sqrt{V}$` )` Body-effect factor.

3 `kpinv` (1/√V)	Inverse of body-effect factor of the poly-silicon gate.
4 `phib` (V)	Surface potential at the onset of strong inversion.
5 `bet` (A/V^2)	Gain factor.
6 `thesr` (1/V)	Mobility degradation parameter due to surface roughness scattering.
7 `theph` (1/V)	Mobility degradation parameter due to phonon scattering.
8 `etamob`	Effective field parameter for dependence on depletion charge.
9 `nu`	Exponent of field dependence of mobility model.
10 `cs`	Coefficient of Coulomb scattering.
11 `ther` (1/V)	Coefficient of series resistance.
12 `ther1` (V)	Numerator of gate voltage dependent part of series resistance.
13 `ther2` (V)	Denominator of gate voltage dependent part of series resistance.
14 `thesat` (1/V)	Velocity saturation parameter due to optical/acoustic phonon scattering.
15 `theth` (1/V^3)	Coefficient of self-heating.
16 `sdibl` (1/√V)	Drain-induced barrier lowering parameter.
17 `mo`	Parameter for (short-channel) subthreshold slope.
18 `ssf` (1/√V)	Static-feedback parameter.
19 `alp`	Factor of channel length modulation.
20 `vp` (V)	Characteristic voltage of channel-length modulation.
21 `mexp`	Smoothing factor.
22 `a1`	Factor of the weak-avalanche current.

23 `a2 (V)`	Exponent of the weak-avalanche current.
24 `a3`	Factor of the drain-source voltage above which weak-avalanche occurs.
25 `iginv` (A/V^2)	Gain factor for intrinsic gate tunnelling current in inversion.
26 `binv (V)`	Probability factor for intrinsic gate tunnelling current in inversion.
27 `igacc` (A/V^2)	Gain factor for intrinsic gate tunnelling current in accumulation.
28 `bacc (V)`	Probability factor for intrinsic gate tunnelling current in accumulation.
29 `vfbov (V)`	Flat-band voltage for the Source/Drain overlap extensions.
30 `kov` ($\sqrt{V}$)	Body-effect factor for the Source/Drain overlap extensions.
31 `igov` (A/V^2)	Gain factor for Source/Drain overlap tunnelling current.
32 `agidl` (A/V^3)	Gain factor for gate-induced leakage current.
33 `bgidl (V)`	Probability factor for gate-induced drain leakage current at reference temperature.
34 `cgidl`	Factor for the lateral field dependence of the gate-induced leakage current.
35 `cox (F)`	Oxide capacitance for the intrinsic channel (* mult).
36 `cgdo (F)`	Oxide capacitance for the gate-drain overlap (* mult).
37 `cgso (F)`	Oxide capacitance for the gate-source overlap (* mult).
38 `gatenoise`	Flag for in/exclusion of induced gate thermal noise.
39 `nt (J)`	Thermal noise coefficient.
40 `nfa` ($1/(Vm^4)$)	First coefficient of the flicker noise.
41 `nfb` ($1/(Vm^2)$)	Second coefficient of the flicker noise.
42 `nfc (1/V)`	Third coefficient of the flicker noise.

43 `tox (m)` Thickness of gate oxide layer.

Operating-Point Parameters

1 `ids (A)` Drain current, excl. avalanche and tunnel currents.

2 `iavl (A)` Substrate current due to weak-avalanche.

3 `igs (A)` Gate-to-source current due to direct tunnelling.

4 `igd (A)` Gate-to-drain current due to direct tunnelling.

5 `igb (A)` Gate-to-bulk current due to direct tunnelling.

6 `vds (V)` Drain-source voltage.

7 `vgs (V)` Gate-source voltage.

8 `vsb (V)` Source-bulk voltage.

9 `vto (V)` Zero-bias threshold voltage.

10 `vts (V)` Threshold voltage including back-bias effects.

11 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

12 `vgt (V)` Effective gate drive voltage including back-bias and drain voltage effects.

13 `vdss (V)` Drain saturation voltage at actual bias.

14 `vsat (V)` Saturation limit.

15 `gm (A/V)` Transconductance (d ids / d vgs).

16 `gmb (A/V)` Substrate-transconductance (d ids / d vbs).

17 `gds (A/V)` Output conductance (d ids / d vds).

18 `cdd (F)` Capacitance (d qd / d vd).

19 `cdg (F)` Capacitance (- d qd / d vg).

20 `cds (F)` Capacitance (- d qd / d vs).

21 `cdb (F)` Capacitance (- d qd / d vb).

22 `cgd (F)` Capacitance (- d qg / d vd).

23 `cgg (F)` Capacitance (d qg / d vg).

24 `cgs (F)` Capacitance (- d qg / d vs).

25 `cgb (F)` Capacitance (- d qg / d vb).

26 `csd (F)` Capacitance (- d qs / d vd).

27 `csg (F)` Capacitance (- d qs / d vg).

28 `css (F)` Capacitance (d qs / d vs).

29 `csb (F)` Capacitance (- d qs / d vb).

30 `cbd (F)` Capacitance (- d qb / d vd).

31 `cbg (F)` Capacitance (- d qb / d vg).

32 `cbs (F)` Capacitance (- d qb / d vs).

33 `cbb (F)` Capacitance (d qb / d vb).

34 `cgdol (F)` Gate-drain overlap capacitance of the actual transistor.

35 `cgsol (F)` Gate-source overlap capacitance of the actual transistor.

36 `weff (m)` Effective channel width for geometrical models.

37 `leff (m)` Effective channel length for geometrical models.

38 `u` Transistor gain (gm/gds).

39 `rout (Ω)` Small-signal output resistance (1/gds).

40 `vearly (V)` Equivalent Early voltage (lidl/gds).

41 `keff (√V )` Body effect parameter.

42 `beff` (A/V^2) Gain factor.

43 `fug (Hz)` Unity gain frequency at actual bias (gm/(2*pi*cin)).

44 `sqrtsfw (V/√Hz )`
Input-referred RMS white noise voltage density.

45 `sqrtsff (V/√Hz )`
Input-referred RMS white noise voltage density at 1 kHz.

46 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

MOS Model 11, Level 1102 (mos11020t)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b  dt ModelName parameter=value ...
```

Instance Parameters

1	`l=2e-06 m`	Drawn channel length in the layout. Scale set by option scale..
2	`w=1e-05 m`	Drawn channel width in the layout. Scale set by option scale..
3	`mult=1`	Number of devices in parallel.
4	`region=triode`	Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.
5	`m=1`	Multiplicity factor.
6	`area=1`	alias of mult.

Model Definition

```
model modelName mos11020t parameter=value ...
```

Model Parameters

1	`level=1.1e+04`	Transistor Level.
2	`lvar=0 m`	Difference between the actual and the programmed poly-silicon gate length.
3	`lap=4e-08 m`	Effective channel length reduction per side.

4 `wvar=0 m` Difference between the actual and the programmed field-oxide opening.

5 `wot=0 m` Effective channel width reduction per side.

6 `tr=21 C` Reference temperature.

7 `vfb=-1.05 V` Flat-band voltage at reference temperature.

8 `stvfb=0.0005 V/K` Coefficient of temperature dependence of VFB.

9 `kor=0.5 √V` Body effect coefficient for the reference transistor.

10 `slko=0` Coefficient of the length dependence of KO.

11 `sl2ko=0` Second coefficient of the length dependence of KO.

12 `swko=0` Coefficient of the width dependence of KO.

13 `kpinv=0 1/√V` Inverse of body-effect factor of the poly-silicon gate.

14 `phibr=0.95 V` Surface potential at strong inversion.

15 `stphib=-0.00085 V/K`
Coefficient of the temperature dependency of PHIB.

16 `slphib=0` Coefficient of the length dependence of PHIB.

17 `sl2phib=0` Second coefficient of the length dependence of PHIB.

18 `swphib=0` Coefficient of the width dependence of PHIB.

19 `betsq=0.000371(n)/0.000115(p)` A/V^2
Gain factor for an infinite square transistor.

20 `etabetr=1.3(n)/0.5(p)`
Exponent of the temperature dependence of the gain factor.

21 `sletabet=0` Coefficient of lenght dependence of ETABETR.

22 `fbet1=0` Relative mobility decrease due to first lateral profile.

23 `lp1=8e-07 m` Characteristic length of first lateral profile.

24 `fbet2=0` Relative mobility decrease due to second lateral profile.

25 `lp2=8e-07 m` Characteristic length of second lateral profile.

26 `thesrr=0.4(n)/0.73(p) 1/V`
Coefficient of the mobility reduction due to surface roughness scattering.

27 `etasr=0.65(n)/0.5(p)`
Exponent of the temperature dependence of THESR.

28 `swthesr=0` Coefficient of the width dependence of THESR.

29 `thephr=0.0129(n)/0.001(p) 1/V`
Coefficient of the mobility reduction due to phonon scattering.

30 `etaph=1.35(n)/3.75(p)`
Exponent of the temperature dependence of THEPH.

31 `swtheph=0` Coefficient of the width dependence of THEPH.

32 `etamobr=1.4(n)/3(p)`
Effective field parameter for dependence on depletion/inversion charge.

33 `stetamob=0 1/K` Coefficient of the temperature dependence of ETAMOB.

34 `swetamob=0` Coefficient of the width dependence of ETAMOB.

35 `nu=2` Exponent of field dependence of mobility model.

36 `nuexp=5.25(n)/3.23(p)`
Exponent of the temperature dependence of parameter NU.

37 `therr=0.155(n)/0.08(p) 1/V`
Coefficient of the series resistance.

38 `etar=0.95(n)/0.4(p)`
Exponent of the temperature dependence of THER.

39 `swther=0` Coefficient of the width dependence of THER.

40 `ther1=0 V` Numerator of gate voltage dependent part of series resistance.

41 `ther2=1 V` Denominator of gate voltage dependent part of series resistance.

42 `thesatr=0.5(n)/0.2(p) 1/V`
Velocity saturation parameter due to optical/acoustic phonon scattering.

43 `etasat=1.04(n)/0.86(p)`
Exponent of the temperature dependence of THESAT.

44 `slthesat=1` Coefficient of length dependence of THESAT.

45 `thesatexp=1` Exponent of length dependence of THESAT.

46 `swthesat=0` Coefficient of the width dependence of THESAT.

47 `thethr=0.001(n)/0.0005(p)` $1/V^3$
Coefficient of self-heating.

48 `thethexp=1` Exponent of the length dependence of THETH.

49 `swtheth=0` Coefficient of the width dependence of THETH.

50 `sdiblo=0.0001` $1/\sqrt{V}$
Drain-induced barrier lowering parameter.

51 `sdiblexp=1.35` Exponent of the length dependence of SDIBL.

52 `moo=0` Parameter for short-channel subthreshold slope.

53 `mor=0` Parameter for short-channel subthreshold slope per unit length.

54 `moexp=1.34` Exponent of the length dependence of MO.

55 `ssfr=0.00625` $1/\sqrt{V}$
Static feedback parameter.

56 `slssf=1` Coefficient of the length dependence of SSF.

57 `swssf=0` Coefficient of the width dependence of SSF.

58 `alpr=0.01` Factor of the channel length modulation.

59 `slalp=1` Coefficient of the length dependence of ALP.

60 `alpexp=1` Exponent of the length dependence of ALP.

61 `swalp=0` Coefficient of the width dependence of ALP.

62 `vp=0.05 V` Characteristic voltage of channel-length modulation.

63 `lmin=1.5e-07 m` Minimum effective channel length in technology, used for calculation of smoothing factor m.

64 `a1r=6` Factor of the weak-avalanche current.

65 `sta1=0 1/K` Coefficient of the temperature dependence of A1.

66 `sla1=0` Coefficient of the length dependence of A1.

67 `swa1=0` Coefficient of the width dependence of A1.

68 `a2r=38 V` Exponent of the weak-avalanche current.

69 `sla2=0` Coefficient of the length dependence of A2.

70 `swa2=0` Coefficient of the width dependence of A2.

71 `a3r=1` Factor of the drain-source voltage above which weak-avalanche occurs.

72 `sla3=0` Coefficient of the length dependence of A3.

73 `swa3=0` Coefficient of the width dependence of A3.

74 `iginvr=0` A/V^2 Gain factor for intrinsic gate tunnelling current in inversion.

75 `binv=48(n)/87.5(p) V`
Probability factor for intrinsic gate tunnelling current in inversion.

76 `igaccr=0` A/V^2 Gain factor for intrinsic gate tunnelling current in accumulation.

77 `bacc=48 V` Probability factor for intrinsic gate tunnelling current in accumulation.

78 `vfbov=0 V` Flat-band voltage for the Source/Drain overlap extensions.

79 `kov=2.5 √V` Body-effect factor for the Source/Drain overlap extensions.

80 `igovr=0` A/V^2 Gain factor for Source/Drain overlap gate tunnelling current.

81 `agidlr=0` A/V^3 Gain factor for gate-induced leakage current.

82 `bgidl=41 V` Probability factor for gate-induced drain leakage current at reference temperature.

83 `stbgidl=-0.000364 V/K`
Coefficient of the temperature dependence of BGIDL.

84 `cgidl=0` Factor for the lateral field dependence of the gate-induced leakage current.

85 `tox=3.2e-09 m` Thickness of gate oxide layer.

86 `col=3.2e-16 F` Gate overlap capacitance for a channel width of 1 um.

87 `gatenoise=0` Flag for in/exclusion of induced gate thermal noise.

88 `nt=1.62e-20 J` Thermal noise coefficient.

89 `nfar=1.57e+23(n)/3.83e+24(p)` $1/(Vm^4)$
First coefficient of the flicker noise for a channel area of 1 um^2.

90 `nfbr=4.75e+09(n)/1.02e+09(p)` $1/(Vm^2)$
Second coefficient of the flicker noise for a channel area of 1 um^2.

91 `nfcr=0(n)/7.3e-08(p) 1/V`
Third coefficient of the flicker noise for a channel area of 1 um^2.

92 `dta=0 K` Temperature offset of the device.

93 `csr=0` Factor of the Coulomb scattering.

94 `slcs=0` Coefficient of the length dependence of CS.

95 `csexp=1` Exponent of the length dependence of CS.

96 `swcs=0` Coefficient of the width dependence of CS.

97 `etacs=0` Exponent of the temperature dependence of CS.

98 `rth=300 K/W` Thermal resistance.

99 `cth=3e-09 J/K` Thermal capacitance.

100 `ath=0` Temperature coefficient of the thermal resistance.

101 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

102 `imax=1.0 A` Explosion current.

103 `mbeo=0.0` DCmatch parameter.

104 `mvto=0.0` DCmatch parameter.

105 `tnom (C)` alias of tnom.

106 `tref (C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flat-band voltage at reference temperature.

2 `ko (√V )` Body-effect factor.

3 `kpinv (1/√V )` Inverse of body-effect factor of the poly-silicon gate.

4 `phib (V)` Surface potential at the onset of strong inversion.

5 `bet` (A/V^2) Gain factor.

6 `thesr (1/V)` Mobility degradation parameter due to surface roughness scattering.

7 `theph (1/V)` Mobility degradation parameter due to phonon scattering.

8 `etamob` Effective field parameter for dependence on depletion charge.

9 `nu` Exponent of field dependence of mobility model.

10 `cs` Coefficient of Coulomb scattering.

11 `ther (1/V)`	Coefficient of series resistance.
12 `ther1 (V)`	Numerator of gate voltage dependent part of series resistance.
13 `ther2 (V)`	Denominator of gate voltage dependent part of series resistance.
14 `thesat (1/V)`	Velocity saturation parameter due to optical/acoustic phonon scattering.
15 `theth` $(1/V^3)$	Coefficient of self-heating.
16 `sdibl` $(1/\sqrt{V})$	Drain-induced barrier lowering parameter.
17 `mo`	Parameter for (short-channel) subthreshold slope.
18 `ssf` $(1/\sqrt{V})$	Static-feedback parameter.
19 `alp`	Factor of channel length modulation.
20 `vp (V)`	Characteristic voltage of channel-length modulation.
21 `mexp`	Smoothing factor.
22 `a1`	Factor of the weak-avalanche current.
23 `a2 (V)`	Exponent of the weak-avalanche current.
24 `a3`	Factor of the drain-source voltage above which weak-avalanche occurs.
25 `iginv` (A/V^2)	Gain factor for intrinsic gate tunnelling current in inversion.
26 `binv (V)`	Probability factor for intrinsic gate tunnelling current in inversion.
27 `igacc` (A/V^2)	Gain factor for intrinsic gate tunnelling current in accumulation.
28 `bacc (V)`	Probability factor for intrinsic gate tunnelling current in accumulation.
29 `vfbov (V)`	Flat-band voltage for the Source/Drain overlap extensions.
30 `kov` $(\sqrt{V})$	Body-effect factor for the Source/Drain overlap extensions.

31 `igov (A/V`^{2}`)`	Gain factor for Source/Drain overlap tunnelling current.
32 `agidl (A/V`^{3}`)`	Gain factor for gate-induced leakage current.
33 `bgidl (V)`	Probability factor for gate-induced drain leakage current at reference temperature.
34 `cgidl`	Factor for the lateral field dependence of the gate-induced leakage current.
35 `cox (F)`	Oxide capacitance for the intrinsic channel (* mult).
36 `cgdo (F)`	Oxide capacitance for the gate-drain overlap (* mult).
37 `cgso (F)`	Oxide capacitance for the gate-source overlap (* mult).
38 `gatenoise`	Flag for in/exclusion of induced gate thermal noise.
39 `nt (J)`	Thermal noise coefficient.
40 `nfa (1/(Vm`^{4}`))`	First coefficient of the flicker noise.
41 `nfb (1/(Vm`^{2}`))`	Second coefficient of the flicker noise.
42 `nfc (1/V)`	Third coefficient of the flicker noise.
43 `tox (m)`	Thickness of gate oxide layer.
44 `rth (K/W)`	Thermal resistance.
45 `cth (J/K)`	Thermal capacitance.

Operating-Point Parameters

1 `ids (A)`	Drain current, excl. avalanche and tunnel currents.
2 `iavl (A)`	Substrate current due to weak-avalanche.
3 `igs (A)`	Gate-to-source current due to direct tunnelling.
4 `igd (A)`	Gate-to-drain current due to direct tunnelling.
5 `igb (A)`	Gate-to-bulk current due to direct tunnelling.

6 `vds (V)`	Drain-source voltage.
7 `vgs (V)`	Gate-source voltage.
8 `vsb (V)`	Source-bulk voltage.
9 `vto (V)`	Zero-bias threshold voltage.
10 `vts (V)`	Threshold voltage including back-bias effects.
11 `vth (V)`	Threshold voltage including back-bias and drain-bias effects.
12 `vgt (V)`	Effective gate drive voltage including back-bias and drain voltage effects.
13 `vdss (V)`	Drain saturation voltage at actual bias.
14 `vsat (V)`	Saturation limit.
15 `gm (A/V)`	Transconductance (d ids / d vgs).
16 `gmb (A/V)`	Substrate-transconductance (d ids / d vbs).
17 `gds (A/V)`	Output conductance (d ids / d vds).
18 `cdd (F)`	Capacitance (d qd / d vd).
19 `cdg (F)`	Capacitance (- d qd / d vg).
20 `cds (F)`	Capacitance (- d qd / d vs).
21 `cdb (F)`	Capacitance (- d qd / d vb).
22 `cgd (F)`	Capacitance (- d qg / d vd).
23 `cgg (F)`	Capacitance (d qg / d vg).
24 `cgs (F)`	Capacitance (- d qg / d vs).
25 `cgb (F)`	Capacitance (- d qg / d vb).
26 `csd (F)`	Capacitance (- d qs / d vd).

27 `csg (F)`	Capacitance (- d qs / d vg).
28 `css (F)`	Capacitance (d qs / d vs).
29 `csb (F)`	Capacitance (- d qs / d vb).
30 `cbd (F)`	Capacitance (- d qb / d vd).
31 `cbg (F)`	Capacitance (- d qb / d vg).
32 `cbs (F)`	Capacitance (- d qb / d vs).
33 `cbb (F)`	Capacitance (d qb / d vb).
34 `cgdol (F)`	Gate-drain overlap capacitance of the actual transistor.
35 `cgsol (F)`	Gate-source overlap capacitance of the actual transistor.
36 `weff (m)`	Effective channel width for geometrical models.
37 `leff (m)`	Effective channel length for geometrical models.
38 `u`	Transistor gain (gm/gds).
39 `rout (Ω)`	Small-signal output resistance (1/gds).
40 `vearly (V)`	Equivalent Early voltage (lidl/gds).
41 `keff (√V )`	Body effect parameter.
42 `beff` (A/V^2)	Gain factor.
43 `fug (Hz)`	Unity gain frequency at actual bias (gm/(2*pi*cin)).
44 `sqrtsfw (V/√Hz )`	Input-referred RMS white noise voltage density.
45 `sqrtsff (V/√Hz )`	Input-referred RMS white noise voltage density at 1 kHz.
46 `fknee (Hz)`	Cross-over frequency above which white noise is dominant.
47 `Pdiss (W)`	Dissipation.

48 `TK (K)` Actual device temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

MOS Model 11, Level 1102 (mos11021)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `l=2e-06 m` Drawn channel length in the layout. Scale set by option scale..

2 `w=1e-05 m` Drawn channel width in the layout. Scale set by option scale..

3 `mult=1` Number of devices in parallel.

4 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

5 `m=1` Multiplicity factor.

6 `area=1` alias of mult.

Model Definition

```
model modelName mos11021 parameter=value ...
```

Model Parameters

1 `level=1.1e+04` Transistor Level.

2 `lvar=0 m` Difference between the actual and the programmed poly-silicon gate length.

3 `lap=4e-08 m` Effective channel length reduction per side.

4 `wvar=0 m` Difference between the actual and the programmed field-oxide opening.

5 `wot=0 m` Effective channel width reduction per side.

6 `tr=21 C` Reference temperature.

7 `lmin=0 m` Device length low limit for binning selection.

8 `lmax=1 m` Device length high limit for binning selection.

9 `wmin=0 m` Device width low limit for binning selection.

10 `wmax=1 m` Device width high limit for binning selection.

11 `vfb=-1.05 V` Flat-band voltage at reference temperature.

12 `poko=0.5 √V` Coefficient for the geometry independent part of KO.

13 `plko=0 √V` Coefficient for the length dependence of KO.

14 `pwko=0 √V` Coefficient for the width dependence of KO.

15 `plwko=0 √V` Coefficient for the length times width dependence of KO.

16 `kpinv=0 1/√V` Inverse of body-effect factor of the poly-silicon gate.

17 `pophib=0.95 V` Coefficient for the geometric independent part of PHIB.

18 `plphib=0 V` Coefficient for the length dependence of PHIB.

19 `pwphib=0 V` Coefficient for the width dependence of PHIB.

20 `plwphib=0 V` Coefficient for the length times width dependence of PHIB.

21 `pobet=0.00192(n)/0.000381(p)` A/V^2
Coefficient for the geometry independent part of BET.

22 `plbet=0` A/V^2 Coefficient for the length dependence of BET.

23 `pwbet=0` A/V^2 Coefficient for the width dependence of BET.

24 `plwbet=0` A/V^2 Coefficient for the width over length dependence of BET.

25 `pothesr=0.356(n)/0.73(p) 1/V`
Coefficient of the geometry independent part of THESR.

26 `plthesr=0 1/V` Coefficient of the length dependence of THESR.

27 `pwthesr=0 1/V` Coefficient of the width dependence of THESR.

28 `plwthesr=0 1/V` Coefficient of the length times width dependence of THESR.

29 `potheph=0.0129(n)/0.001(p) 1/V`
Coefficient of the geometry independent part of THEPH.

30 `pltheph=0 1/V` Coefficient of the length dependence of THEPH.

31 `pwtheph=0 1/V` Coefficient of the width dependence of THEPH.

32 `plwtheph=0 1/V` Coefficient of the length times width dependence of THEPH.

33 `poetamob=1.4(n)/3(p)`
Coefficient of the geometry independent part of ETAMOB.

34 `pletamob=0` Coefficient of the length dependence of ETAMOB.

35 `pwetamob=0` Coefficient of the width dependence of ETAMOB.

36 `plwetamob=0` Coefficient of the length times width dependence of ETAMOB.

37 `pother=0.0812(n)/0.079(p) 1/V`
Coefficient of the geometry independent part of THER.

38 `plther=0 1/V` Coefficient of the length dependence of THER.

39 `pwther=0 1/V` Coefficient of the width dependence of THER.

40 `plwther=0 1/V` Coefficient of the length times width dependence of THER.

41 `ther1=0 V` Numerator of gate voltage dependent part of series resistance.

42 `ther2=1 V` Denominator of gate voltage dependent part of series resistance.

43 `pothesat=0.251(n)/0.173(p) 1/V`
Coefficient of the geometry independent part of THESAT.

44 `plthesat=0 1/V` Coefficient of the length dependence of THESAT.

45 `pwthesat=0 1/V` Coefficient of the width dependence of THESAT.

46 `plwthesat=0 1/V` Coefficient of the length times width dependence of THESAT.

47 `potheth=1e-05(n)/0(p)` $1/V^3$
Coefficient of the geometry independent part of THETH.

48 `pltheth=0 1/V`^{3} Coefficient of the length dependence of THETH.

49 `pwtheth=0 1/V`^{3} Coefficient of the width dependence of THETH.

50 `plwtheth=0 1/V`^{3} Coefficient of the length times width dependence of THETH.

51 `posdibl=0.000853(n)/3.55e-05(p) 1/√V`
Coefficient of the geometry independent part of SDIBL.

52 `plsdibl=0 1/√V`
Coefficient of the length dependence of SDIBL.

53 `pwsdibl=0 1/√V`
Coefficient of the width dependence of SDIBL.

54 `plwsdibl=0 1/√V`
Coefficient of the length times width dependence of SDIBL.

55 `pomo=0` Coefficient of the geometry independent part of MO.

56 `plmo=0` Coefficient of the length dependence of MO.

57 `pwmo=0` Coefficient of the width dependence of MO.

58 `plwmo=0` Coefficient of the length times width dependence of MO.

59 `possf=0.012(n)/0.01(p) 1/√V`
Coefficient of the geometry independent part of SSF.

60 `plssf=0 1/√V` Coefficient of the length dependence of SSF.

61 `pwssf=0 1/√V` Coefficient of the width dependence of SSF.

62 `plwssf=0 1/√V`
Coefficient of the length times width dependence of SSF.

63 `poalp=0.025` Coefficient of the geometry independent part of ALP.

64 `plalp=0` Coefficient of the length dependence of ALP.

65 `pwalp=0` Coefficient of the width dependence of ALP.

66 `plwalp=0` Coefficient of the length times width dependence of ALP.

67 `vp=0.05 V` Characteristic voltage of channel-length modulation.

68 `pomexp=0.2` Coefficient of the geometry independent part of MEXP.

69 `plmexp=0` Coefficient of the length dependence of MEXP.

70 `pwmexp=0` Coefficient of the width dependence of MEXP.

71 `plwmexp=0` Coefficient of the length times width dependence of MEXP.

72 `poa1=6.02(n)/6.86(p)`
Coefficient of the geometry independent part of A1.

73 `pla1=0` Coefficient of the length dependence of A1.

74 `pwa1=0` Coefficient of the width dependence of A1.

75 `plwa1=0` Coefficient of the length times width dependence of A1.

76 `poa2=38(n)/57.3(p) V`
Coefficient of the geometry independent part of A2.

77 `pla2=0 V` Coefficient of the length dependence of A2.

78 `pwa2=0 V` Coefficient of the width dependence of A2.

79 `plwa2=0 V` Coefficient of the length times width dependence of A2.

80 `poa3=0.641(n)/0.425(p)`
Coefficient of the geometry independent part of A3.

81 `pla3=0` Coefficient of the length dependence of A3.

82 `pwa3=0` Coefficient of the width dependence of A3.

83 `plwa3=0` Coefficient of the length times width dependence of A3.

84 poiginv=0 A/V^2 Coefficient of the geometry independent part of IGINV.

85 pliginv=0 A/V^2 Coefficient of the length dependence of IGINV.

86 pwiginv=0 A/V^2 Coefficient of the width dependence of IGINV.

87 `plwiginv=0 A/V`^{2} Coefficient of the length times width dependence of IGINV.

88 `pobinv=48(n)/87.5(p) V`
Coefficient of the geometry independent part of BINV.

89 `plbinv=0 V` Coefficient of the length dependence of BINV.

90 `pwbinv=0 V` Coefficient of the width dependence of BINV.

91 `plwbinv=0 V` Coefficient of the length times width dependence of BINV.

92 `poigacc=0 A/V`^{2} Coefficient of the geometry independent part of IGACC.

93 `pligacc=0 A/V`^{2} Coefficient of the length dependence of IGACC.

94 `pwigacc=0 A/V`^{2} Coefficient of the width dependence of IGACC.

95 `plwigacc=0 A/V`^{2} Coefficient of the length times width dependence of IGACC.

96 `pobacc=48 V` Coefficient of the geometry independent part of BACC.

97 `plbacc=0 V` Coefficient of the length dependence of BACC.

98 `pwbacc=0 V` Coefficient of the width dependence of BACC.

99 `plwbacc=0 V` Coefficient of the length times width dependence of BACC.

100 `vfbov=0 V` Flat-band voltage for the Source/Drain overlap extensions.

101 `kov=2.5` $\sqrt{V}$ Body-effect factor for the Source/Drain overlap extensions.

102 `poigov=0 A/V`^{2} Coefficient of the geometry independent part of IGOV.

103 `pligov=0 A/V`^{2} Coefficient of the length dependence of IGOV.

104 `pwigov=0 A/V`^{2} Coefficient of the width dependence of IGOV.

105 `plwigov=0 A/V`^{2} Coefficient of the length times width dependence of IGOV.

106 `poagidl=0 A/V`^{3} Coefficient of the geometry independent part of AGIDL.

107 `plagidl=0 A/V`^{3} Coefficient of the length dependence of AGIDL.

108 `pwagidl=0 A/V`^{3} Coefficient of the width dependence of AGIDL.

109 `plwagidl=0 A/V`^{3} Coefficient of the length times width dependence of AGIDL.

110 `pobgidl=41 V` Coefficient of the geometry independent part of BGIDL.

111 `plbgidl=0 V` Coefficient of the length dependence of BGIDL.

112 `pwbgidl=0 V` Coefficient of the width dependence of BGIDL.

113 `plwbgidl=0 V` Coefficient of the length times width dependence of BGIDL.

114 `pocgidl=0` Coefficient of the geometry independent part of CGIDL.

115 `plcgidl=0` Coefficient of the length dependence of CGIDL.

116 `pwcgidl=0` Coefficient of the width dependence of CGIDL.

117 `plwcgidl=0` Coefficient of the length times width dependence of CGIDL.

118 `tox=3.2e-09 m` Thickness of gate oxide layer.

119 `pocox=2.98e-14(n)/2.72e-14(p) F`
Coefficient of the geometry independent part of COX.

120 `plcox=0 F` Coefficient of the length dependence of COX.

121 `pwcox=0 F` Coefficient of the width dependence of COX.

122 `plwcox=0 F` Coefficient of the length times width dependence of COX.

123 `pocgdo=6.39e-15(n)/6.36e-15(p) F`
Coefficient of the geometry independent part of CGDO.

124 `plcgdo=0 F` Coefficient of the length dependence of CGDO.

125 `pwcgdo=0 F` Coefficient of the width dependence of CGDO.

126 `plwcgdo=0 F` Coefficient of the length time width dependence of CGDO.

127 `pocgso=6.39e-15(n)/6.36e-15(p) F`
Coefficient of the geometry independent part of CGSO.

128 `plcgso=0 F` Coefficient of the length dependence of CGSO.

129 `pwcgso=0 F` Coefficient of the width dependence of CGSO.

130 `plwcgso=0 F` Coefficient of the length times width dependence of CGSO.

131 `gatenoise=0` Flag for in/exclusion of induced gate thermal noise.

132 `nt=1.62e-20 J` Thermal noise coefficient.

133 `ponfa=8.32e+22(n)/1.9e+22(p) 1/V` m^4
Coefficient of the geometry independent part of NFA.

134 `plnfa=0 1/V` m^4 Coefficient of the length dependence of NFA.

135 `pwnfa=0 1/V` m^4 Coefficient of the width dependence of NFA.

136 `plwnfa=0 1/V` m^4 Coefficient of the length times width dependence of NFA.

137 `ponfb=2.51e+07(n)/5.04e+06(p) 1/V` m^2
Coefficient of the geometry independent part of NFB.

138 `plnfb=0 1/V` m^2 Coefficient of the length dependence of NFB.

139 `pwnfb=0 1/V` m^2 Coefficient of the width dependence of NFB.

140 `plwnfb=0 1/V` m^2 Coefficient of the length times width dependence of NFB.

141 `ponfc=0(n)/3.63e-10(p) 1/V`
Coefficient of the geometry independent part of NFC.

142 `plnfc=0 1/V` Coefficient of the length dependence of NFC.

143 `pwnfc=0 1/V` Coefficient of the width dependence of NFC.

144 `plwnfc=0 1/V` Coefficient of the length times width dependence of NFC.

145 `potvfb=0.0005 V/K` Coefficient of the geometry independent part of STVFB.

146 `pltvfb=0 V/K` Coefficient of the length dependence of STVFB.

147 `pwtvfb=0 V/K` Coefficient of the width dependence of STVFB.

148 `plwtvfb=0 V/K` Coefficient of the length times width dependence of STVFB.

149 `potphib=-0.00085 V/K`
Coefficient of the geometry independent part of STPHIB.

150 `pltphib=0 V/K` Coefficient of the length dependence of STPHIB.

151 `pwtphib=0 V/K` Coefficient of the width dependence of STPHIB.

152 `plwtphib=0 V/K` Coefficient of the length times width dependence of STPHIB.

153 `potetabet=1.3(n)/0.5(p)`
Coefficient of the geometry independent part of ETABET.

154 `pltetabet=0` Coefficient of the length dependence of ETABET.

155 `pwtetabet=0` Coefficient of the width dependence of ETABET.

156 `plwtetabet=0` Coefficient of the length times width dependence of ETABET.

157 `potetasr=0.65(n)/0.5(p)`
Coefficient of the geometry independent part of ETASR.

158 `pltetasr=0` Coefficient of the length dependence of ETASR.

159 `pwtetasr=0` Coefficient of the width dependence of ETASR.

160 `plwtetasr=0` Coefficient of the length times width dependence of ETASR.

161 `potetaph=1.35(n)/3.75(p)`
Coefficient of the geometry independent part of ETAPH.

162 `pltetaph=0` Coefficient of the length dependence of ETAPH.

163 `pwtetaph=0` Coefficient of the width dependence of ETAPH.

164 `plwtetaph=0` Coefficient of the length times width dependence of ETAPH.

165 `potetamob=0 1/K` Coefficient of the geometry independent part of STETAMOB.

166 `pltetamob=0 1/K` Coefficient of the length dependence of STETAMOB.

167 `pwtetamob=0 1/K` Coefficient of the width dependence of STETAMOB.

168 `plwtetamob=0 1/K` Coefficient of the length times width dependence of STETAMOB.

169 `nu=2` Exponent of field dependence of mobility model.

170 `potnuexp=5.25(n)/3.23(p)`
Coefficient of the geometry independent part of NUEXP.

171 `pltnuexp=0` Coefficient of the length dependence of NUEXP.

172 `pwtnuexp=0` Coefficient of the width dependence of NUEXP.

173 `plwtnuexp=0` Coefficient of the length times width dependence of NUEXP.

174 `potetar=0.95(n)/0.4(p)`
Coefficient of the geometry independent part of ETAR.

175 `pltetar=0` Coefficient of the length dependence of ETAR.

176 `pwtetar=0` Coefficient of the width dependence of ETAR.

177 `plwtetar=0` Coefficient of the length times width dependence of ETAR.

178 `potetasat=1.04(n)/0.86(p)`
Coefficient of the geometry independent part of ETASAT.

179 `pltetasat=0` Coefficient of the length dependence of ETASAT.

180 `pwtetasat=0` Coefficient of the width dependence of ETASAT.

181 `plwtetasat=0` Coefficient of the length times width dependence of ETASAT.

182 `pota1=0 1/K` Coefficient of the geometry independent part of STA1.

183 `plta1=0 1/K` Coefficient of the length dependence of STA1.

184 `pwta1=0 1/K` Coefficient of the width dependence of STA1.

185 `plwta1=0 1/K` Coefficient of the length times width dependence of STA1.

186 `potbgidl=-0.000364 V/K`
Coefficient of the geometry independent part of STBGIDL.

187 `pltbgidl=0 V/K` Coefficient of the length dependence of STBGIDL.

188 `pwtbgidl=0 V/K` Coefficient of the width dependence of STBGIDL.

189 `plwtbgidl=0 V/K` Coefficient of the length times width dependence of STBGIDL.

190 `dta=0 K` Temperature offset of the device.

191 `pocs=0` Coefficient of the geometry independent part of CS.

192 `plcs=0` Coefficient of the length dependence of CS.

193 `pwcs=0` Coefficient of the width dependence of CS.

194 `plwcs=0` Coefficient of the length times width dependence of CS.

195 `potetacs=0` Coefficient of the geometry independent part of ETACS.

196 `pltetacs=0` Coefficient of the length dependence of ETACS.

197 `pwtetacs=0` Coefficient of the width dependence of ETACS.

198 `plwtetacs=0` Coefficient of the length times width dependence of ETACS.

199 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

200 `imax=1.0 A` Explosion current.

201 `mbeo=0.0` DCmatch parameter.

202 `mvto=0.0` DCmatch parameter.

203 `tnom (C)` alias of tnom.

204 `tref (C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flat-band voltage at reference temperature.

2 `ko (√V )` Body-effect factor.

3 `kpinv (1/√V )` Inverse of body-effect factor of the poly-silicon gate.

4 `phib (V)`	Surface potential at the onset of strong inversion.
5 `bet` (A/V^2)	Gain factor.
6 `thesr (1/V)`	Mobility degradation parameter due to surface roughness scattering.
7 `theph (1/V)`	Mobility degradation parameter due to phonon scattering.
8 `etamob`	Effective field parameter for dependence on depletion charge.
9 `nu`	Exponent of field dependence of mobility model.
10 `cs`	Coefficient of Coulomb scattering.
11 `ther (1/V)`	Coefficient of series resistance.
12 `ther1 (V)`	Numerator of gate voltage dependent part of series resistance.
13 `ther2 (V)`	Denominator of gate voltage dependent part of series resistance.
14 `thesat (1/V)`	Velocity saturation parameter due to optical/acoustic phonon scattering.
15 `theth` $(1/V^3)$	Coefficient of self-heating.
16 `sdibl` $(1/\sqrt{V})$	Drain-induced barrier lowering parameter.
17 `mo`	Parameter for (short-channel) subthreshold slope.
18 `ssf` $(1/\sqrt{V})$	Static-feedback parameter.
19 `alp`	Factor of channel length modulation.
20 `vp (V)`	Characteristic voltage of channel-length modulation.
21 `mexp`	Smoothing factor.
22 `a1`	Factor of the weak-avalanche current.
23 `a2 (V)`	Exponent of the weak-avalanche current.

24 `a3`	Factor of the drain-source voltage above which weak-avalanche occurs.
25 `iginv (A/V`^{2}`)`	Gain factor for intrinsic gate tunnelling current in inversion.
26 `binv (V)`	Probability factor for intrinsic gate tunnelling current in inversion.
27 `igacc (A/V`^{2}`)`	Gain factor for intrinsic gate tunnelling current in accumulation.
28 `bacc (V)`	Probability factor for intrinsic gate tunnelling current in accumulation.
29 `vfbov (V)`	Flat-band voltage for the Source/Drain overlap extensions.
30 `kov (`$\sqrt{V}$` )`	Body-effect factor for the Source/Drain overlap extensions.
31 `igov (A/V`^{2}`)`	Gain factor for Source/Drain overlap tunnelling current.
32 `agidl (A/V`^{3}`)`	Gain factor for gate-induced leakage current.
33 `bgidl (V)`	Probability factor for gate-induced drain leakage current at reference temperature.
34 `cgidl`	Factor for the lateral field dependence of the gate-induced leakage current.
35 `cox (F)`	Oxide capacitance for the intrinsic channel (* mult).
36 `cgdo (F)`	Oxide capacitance for the gate-drain overlap (* mult).
37 `cgso (F)`	Oxide capacitance for the gate-source overlap (* mult).
38 `gatenoise`	Flag for in/exclusion of induced gate thermal noise.
39 `nt (J)`	Thermal noise coefficient.
40 `nfa (1/(Vm`^{4}`))`	First coefficient of the flicker noise.
41 `nfb (1/(Vm`^{2}`))`	Second coefficient of the flicker noise.
42 `nfc (1/V)`	Third coefficient of the flicker noise.
43 `tox (m)`	Thickness of gate oxide layer.

Operating-Point Parameters

1 `ids (A)` Drain current, excl. avalanche and tunnel currents.

2 `iavl (A)` Substrate current due to weak-avalanche.

3 `igs (A)` Gate-to-source current due to direct tunnelling.

4 `igd (A)` Gate-to-drain current due to direct tunnelling.

5 `igb (A)` Gate-to-bulk current due to direct tunnelling.

6 `vds (V)` Drain-source voltage.

7 `vgs (V)` Gate-source voltage.

8 `vsb (V)` Source-bulk voltage.

9 `vto (V)` Zero-bias threshold voltage.

10 `vts (V)` Threshold voltage including back-bias effects.

11 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

12 `vgt (V)` Effective gate drive voltage including back-bias and drain voltage effects.

13 `vdss (V)` Drain saturation voltage at actual bias.

14 `vsat (V)` Saturation limit.

15 `gm (A/V)` Transconductance (d ids / d vgs).

16 `gmb (A/V)` Substrate-transconductance (d ids / d vbs).

17 `gds (A/V)` Output conductance (d ids / d vds).

18 `cdd (F)` Capacitance (d qd / d vd).

19 `cdg (F)` Capacitance (- d qd / d vg).

20 `cds (F)` Capacitance (- d qd / d vs).

21 `cdb (F)` Capacitance (- d qd / d vb).

22 `cgd (F)` Capacitance (- d qg / d vd).

23 `cgg (F)` Capacitance (d qg / d vg).

24 `cgs (F)` Capacitance (- d qg / d vs).

25 `cgb (F)` Capacitance (- d qg / d vb).

26 `csd (F)` Capacitance (- d qs / d vd).

27 `csg (F)` Capacitance (- d qs / d vg).

28 `css (F)` Capacitance (d qs / d vs).

29 `csb (F)` Capacitance (- d qs / d vb).

30 `cbd (F)` Capacitance (- d qb / d vd).

31 `cbg (F)` Capacitance (- d qb / d vg).

32 `cbs (F)` Capacitance (- d qb / d vs).

33 `cbb (F)` Capacitance (d qb / d vb).

34 `cgdol (F)` Gate-drain overlap capacitance of the actual transistor.

35 `cgsol (F)` Gate-source overlap capacitance of the actual transistor.

36 `weff (m)` Effective channel width for geometrical models.

37 `leff (m)` Effective channel length for geometrical models.

38 `u` Transistor gain (gm/gds).

39 `rout (Ω)` Small-signal output resistance (1/gds).

40 `vearly (V)` Equivalent Early voltage (|id|/gds).

41 `keff` ($\sqrt{V}$) Body effect parameter.

42 `beff` (A/V^2) Gain factor.

43 `fug (Hz)` Unity gain frequency at actual bias (gm/(2*pi*cin)).

44 `sqrtsfw (V/√Hz )`
Input-referred RMS white noise voltage density.

45 `sqrtsff (V/√Hz )`
Input-referred RMS white noise voltage density at 1 kHz.

46 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

MOS Model 11, Level 1102 (mos11021t)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name   d  g  s  b  dt ModelName parameter=value ...
```

Instance Parameters

1	`l=2e-06 m`	Drawn channel length in the layout. Scale set by option scale..
2	`w=1e-05 m`	Drawn channel width in the layout. Scale set by option scale..
3	`mult=1`	Number of devices in parallel.
4	`region=triode`	Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.
5	`m=1`	Multiplicity factor.
6	`area=1`	alias of mult.

Model Definition

model modelName mos11021t parameter=value ...

Model Parameters

1	`level=1.1e+04`	Transistor Level.

2 `lvar=0 m` — Difference between the actual and the programmed poly-silicon gate length.

3 `lap=4e-08 m` — Effective channel length reduction per side.

4 `wvar=0 m` — Difference between the actual and the programmed field-oxide opening.

5 `wot=0 m` — Effective channel width reduction per side.

6 `tr=21 C` — Reference temperature.

7 `lmin=0 m` — Device length low limit for binning selection.

8 `lmax=1 m` — Device length high limit for binning selection.

9 `wmin=0 m` — Device width low limit for binning selection.

10 `wmax=1 m` — Device width high limit for binning selection.

11 `vfb=-1.05 V` — Flat-band voltage at reference temperature.

12 `poko=0.5 √V` — Coefficient for the geometry independent part of KO.

13 `plko=0 √V` — Coefficient for the length dependence of KO.

14 `pwko=0 √V` — Coefficient for the width dependence of KO.

15 `plwko=0 √V` — Coefficient for the length times width dependence of KO.

16 `kpinv=0 1/√V` — Inverse of body-effect factor of the poly-silicon gate.

17 `pophib=0.95 V` — Coefficient for the geometric independent part of PHIB.

18 `plphib=0 V` — Coefficient for the length dependence of PHIB.

19 `pwphib=0 V` — Coefficient for the width dependence of PHIB.

20 `plwphib=0 V` — Coefficient for the length times width dependence of PHIB.

21 `pobet=0.00192(n)/0.000381(p)` A/V^2
Coefficient for the geometry independent part of BET.

22 `plbet=0 A/V`^{2} Coefficient for the length dependence of BET.

23 `pwbet=0 A/V`^{2} Coefficient for the width dependence of BET.

24 `plwbet=0 A/V`^{2} Coefficient for the width over length dependence of BET.

25 `pothesr=0.356(n)/0.73(p) 1/V`
Coefficient of the geometry independent part of THESR.

26 `plthesr=0 1/V` Coefficient of the length dependence of THESR.

27 `pwthesr=0 1/V` Coefficient of the width dependence of THESR.

28 `plwthesr=0 1/V` Coefficient of the length times width dependence of THESR.

29 `potheph=0.0129(n)/0.001(p) 1/V`
Coefficient of the geometry independent part of THEPH.

30 `pltheph=0 1/V` Coefficient of the length dependence of THEPH.

31 `pwtheph=0 1/V` Coefficient of the width dependence of THEPH.

32 `plwtheph=0 1/V` Coefficient of the length times width dependence of THEPH.

33 `poetamob=1.4(n)/3(p)`
Coefficient of the geometry independent part of ETAMOB.

34 `pletamob=0` Coefficient of the length dependence of ETAMOB.

35 `pwetamob=0` Coefficient of the width dependence of ETAMOB.

36 `plwetamob=0` Coefficient of the length times width dependence of ETAMOB.

37 `pother=0.0812(n)/0.079(p) 1/V`
Coefficient of the geometry independent part of THER.

38 `plther=0 1/V` Coefficient of the length dependence of THER.

39 `pwther=0 1/V` Coefficient of the width dependence of THER.

40 `plwther=0 1/V` Coefficient of the length times width dependence of THER.

41 `ther1=0 V` Numerator of gate voltage dependent part of series resistance.

42 `ther2=1 V` Denominator of gate voltage dependent part of series resistance.

43 `pothesat=0.251(n)/0.173(p) 1/V`
Coefficient of the geometry independent part of THESAT.

44 `plthesat=0 1/V` Coefficient of the length dependence of THESAT.

45 `pwthesat=0 1/V` Coefficient of the width dependence of THESAT.

46 `plwthesat=0 1/V` Coefficient of the length times width dependence of THESAT.

47 `potheth=1e-05(n)/0(p)` $1/V^3$
Coefficient of the geometry independent part of THETH.

48 `pltheth=0` $1/V^3$ Coefficient of the length dependence of THETH.

49 `pwtheth=0` $1/V^3$ Coefficient of the width dependence of THETH.

50 `plwtheth=0` $1/V^3$ Coefficient of the length times width dependence of THETH.

51 `posdibl=0.000853(n)/3.55e-05(p)` $1/\sqrt{V}$
Coefficient of the geometry independent part of SDIBL.

52 `plsdibl=0` $1/\sqrt{V}$
Coefficient of the length dependence of SDIBL.

53 `pwsdibl=0` $1/\sqrt{V}$
Coefficient of the width dependence of SDIBL.

54 `plwsdibl=0` $1/\sqrt{V}$
Coefficient of the length times width dependence of SDIBL.

55 `pomo=0` Coefficient of the geometry independent part of MO.

56 `plmo=0` Coefficient of the length dependence of MO.

57 `pwmo=0` Coefficient of the width dependence of MO.

58 `plwmo=0` Coefficient of the length times width dependence of MO.

59 `possf=0.012(n)/0.01(p)` $1/\sqrt{V}$
Coefficient of the geometry independent part of SSF.

60 `plssf=0 1/√V` Coefficient of the length dependence of SSF.

61 `pwssf=0 1/√V` Coefficient of the width dependence of SSF.

62 `plwssf=0 1/√V`
Coefficient of the length times width dependence of SSF.

63 `poalp=0.025` Coefficient of the geometry independent part of ALP.

64 `plalp=0` Coefficient of the length dependence of ALP.

65 `pwalp=0` Coefficient of the width dependence of ALP.

66 `plwalp=0` Coefficient of the length times width dependence of ALP.

67 `vp=0.05 V` Characteristic voltage of channel-length modulation.

68 `pomexp=0.2` Coefficient of the geometry independent part of MEXP.

69 `plmexp=0` Coefficient of the length dependence of MEXP.

70 `pwmexp=0` Coefficient of the width dependence of MEXP.

71 `plwmexp=0` Coefficient of the length times width dependence of MEXP.

72 `poa1=6.02(n)/6.86(p)`
Coefficient of the geometry independent part of A1.

73 `pla1=0` Coefficient of the length dependence of A1.

74 `pwa1=0` Coefficient of the width dependence of A1.

75 `plwa1=0` Coefficient of the length times width dependence of A1.

76 `poa2=38(n)/57.3(p) V`
Coefficient of the geometry independent part of A2.

77 `pla2=0 V` Coefficient of the length dependence of A2.

78 `pwa2=0 V` Coefficient of the width dependence of A2.

79 `plwa2=0 V` Coefficient of the length times width dependence of A2.

80 `poa3=0.641(n)/0.425(p)`
Coefficient of the geometry independent part of A3.

81 `pla3=0` Coefficient of the length dependence of A3.

82 `pwa3=0` Coefficient of the width dependence of A3.

83 `plwa3=0` Coefficient of the length times width dependence of A3.

84 `poiginv=0 A/V`^{2} Coefficient of the geometry independent part of IGINV.

85 `pliginv=0 A/V`^{2} Coefficient of the length dependence of IGINV.

86 `pwiginv=0 A/V`^{2} Coefficient of the width dependence of IGINV.

87 `plwiginv=0 A/V`^{2} Coefficient of the length times width dependence of IGINV.

88 `pobinv=48(n)/87.5(p) V`
Coefficient of the geometry independent part of BINV.

89 `plbinv=0 V` Coefficient of the length dependence of BINV.

90 `pwbinv=0 V` Coefficient of the width dependence of BINV.

91 `plwbinv=0 V` Coefficient of the length times width dependence of BINV.

92 `poigacc=0 A/V`^{2} Coefficient of the geometry independent part of IGACC.

93 `pligacc=0 A/V`^{2} Coefficient of the length dependence of IGACC.

94 `pwigacc=0 A/V`^{2} Coefficient of the width dependence of IGACC.

95 `plwigacc=0 A/V`^{2} Coefficient of the length times width dependence of IGACC.

96 `pobacc=48 V` Coefficient of the geometry independent part of BACC.

97 `plbacc=0 V` Coefficient of the length dependence of BACC.

98 `pwbacc=0 V` Coefficient of the width dependence of BACC.

99 `plwbacc=0 V` Coefficient of the length times width dependence of BACC.

100 `vfbov=0 V` Flat-band voltage for the Source/Drain overlap extensions.

101 `kov=2.5 √V` Body-effect factor for the Source/Drain overlap extensions.

102 `poigov=0 A/V`^{2} Coefficient of the geometry independent part of IGOV.

103 `pligov=0 A/V`^{2} Coefficient of the length dependence of IGOV.

104 `pwigov=0 A/V`^{2} Coefficient of the width dependence of IGOV.

105 `plwigov=0 A/V`^{2} Coefficient of the length times width dependence of IGOV.

106 `poagidl=0 A/V`^{3} Coefficient of the geometry independent part of AGIDL.

107 `plagidl=0 A/V`^{3} Coefficient of the length dependence of AGIDL.

108 `pwagidl=0 A/V`^{3} Coefficient of the width dependence of AGIDL.

109 `plwagidl=0 A/V`^{3} Coefficient of the length times width dependence of AGIDL.

110 `pobgidl=41 V` Coefficient of the geometry independent part of BGIDL.

111 `plbgidl=0 V` Coefficient of the length dependence of BGIDL.

112 `pwbgidl=0 V` Coefficient of the width dependence of BGIDL.

113 `plwbgidl=0 V` Coefficient of the length times width dependence of BGIDL.

114 `pocgidl=0` Coefficient of the geometry independent part of CGIDL.

115 `plcgidl=0` Coefficient of the length dependence of CGIDL.

116 `pwcgidl=0` Coefficient of the width dependence of CGIDL.

117 `plwcgidl=0` Coefficient of the length times width dependence of CGIDL.

118 `tox=3.2e-09 m` Thickness of gate oxide layer.

119 `pocox=2.98e-14(n)/2.72e-14(p) F`
Coefficient of the geometry independent part of COX.

120 `plcox=0 F` Coefficient of the length dependence of COX.

121 `pwcox=0 F` Coefficient of the width dependence of COX.

122 `plwcox=0 F` Coefficient of the length times width dependence of COX.

123 `pocgdo=6.39e-15(n)/6.36e-15(p) F`
Coefficient of the geometry independent part of CGDO.

124 `plcgdo=0 F` Coefficient of the length dependence of CGDO.

125 `pwcgdo=0 F` Coefficient of the width dependence of CGDO.

126 `plwcgdo=0 F` Coefficient of the length time width dependence of CGDO.

127 `pocgso=6.39e-15(n)/6.36e-15(p) F`
Coefficient of the geometry independent part of CGSO.

128 `plcgso=0 F` Coefficient of the length dependence of CGSO.

129 `pwcgso=0 F` Coefficient of the width dependence of CGSO.

130 `plwcgso=0 F` Coefficient of the length times width dependence of CGSO.

131 `gatenoise=0` Flag for in/exclusion of induced gate thermal noise.

132 `nt=1.62e-20 J` Thermal noise coefficient.

133 `ponfa=8.32e+22(n)/1.9e+22(p) 1/V` m^4
Coefficient of the geometry independent part of NFA.

134 `plnfa=0 1/V` m^4 Coefficient of the length dependence of NFA.

135 `pwnfa=0 1/V` m^4 Coefficient of the width dependence of NFA.

136 `plwnfa=0 1/V` m^4 Coefficient of the length times width dependence of NFA.

137 `ponfb=2.51e+07(n)/5.04e+06(p) 1/V` m^2
Coefficient of the geometry independent part of NFB.

138 `plnfb=0 1/V` m^2 Coefficient of the length dependence of NFB.

139 `pwnfb=0 1/V` m^2 Coefficient of the width dependence of NFB.

140 `plwnfb=0 1/V` m^2 Coefficient of the length times width dependence of NFB.

141 `ponfc=0(n)/3.63e-10(p) 1/V`
Coefficient of the geometry independent part of NFC.

142 `plnfc=0 1/V` Coefficient of the length dependence of NFC.

143 `pwnfc=0 1/V` Coefficient of the width dependence of NFC.

144 `plwnfc=0 1/V` Coefficient of the length times width dependence of NFC.

145 `potvfb=0.0005 V/K` Coefficient of the geometry independent part of STVFB.

146 `pltvfb=0 V/K` Coefficient of the length dependence of STVFB.

147 `pwtvfb=0 V/K` Coefficient of the width dependence of STVFB.

148 `plwtvfb=0 V/K` Coefficient of the length times width dependence of STVFB.

149 `potphib=-0.00085 V/K`
Coefficient of the geometry independent part of STPHIB.

150 `pltphib=0 V/K` Coefficient of the length dependence of STPHIB.

151 `pwtphib=0 V/K` Coefficient of the width dependence of STPHIB.

152 `plwtphib=0 V/K` Coefficient of the length times width dependence of STPHIB.

153 `potetabet=1.3(n)/0.5(p)`
Coefficient of the geometry independent part of ETABET.

154 `pltetabet=0` Coefficient of the length dependence of ETABET.

155 `pwtetabet=0` Coefficient of the width dependence of ETABET.

156 `plwtetabet=0` Coefficient of the length times width dependence of ETABET.

157 `potetasr=0.65(n)/0.5(p)`
Coefficient of the geometry independent part of ETASR.

158 `pltetasr=0` Coefficient of the length dependence of ETASR.

159 `pwtetasr=0` Coefficient of the width dependence of ETASR.

160 `plwtetasr=0` Coefficient of the length times width dependence of ETASR.

161 `potetaph=1.35(n)/3.75(p)`
Coefficient of the geometry independent part of ETAPH.

162 `pltetaph=0` Coefficient of the length dependence of ETAPH.

163 `pwtetaph=0` Coefficient of the width dependence of ETAPH.

164 `plwtetaph=0` Coefficient of the length times width dependence of ETAPH.

165 `potetamob=0 1/K` Coefficient of the geometry independent part of STETAMOB.

166 `pltetamob=0 1/K` Coefficient of the length dependence of STETAMOB.

167 `pwtetamob=0 1/K` Coefficient of the width dependence of STETAMOB.

168 `plwtetamob=0 1/K` Coefficient of the length times width dependence of STETAMOB.

169 `nu=2` Exponent of field dependence of mobility model.

170 `potnuexp=5.25(n)/3.23(p)`
Coefficient of the geometry independent part of NUEXP.

171 `pltnuexp=0` Coefficient of the length dependence of NUEXP.

172 `pwtnuexp=0` Coefficient of the width dependence of NUEXP.

173 `plwtnuexp=0` Coefficient of the length times width dependence of NUEXP.

174 `potetar=0.95(n)/0.4(p)`
Coefficient of the geometry independent part of ETAR.

175 `pltetar=0` Coefficient of the length dependence of ETAR.

176 `pwtetar=0` Coefficient of the width dependence of ETAR.

177 `plwtetar=0` Coefficient of the length times width dependence of ETAR.

178 `potetasat=1.04(n)/0.86(p)`
Coefficient of the geometry independent part of ETASAT.

179 `pltetasat=0` Coefficient of the length dependence of ETASAT.

180 `pwtetasat=0` Coefficient of the width dependence of ETASAT.

181 `plwtetasat=0` Coefficient of the length times width dependence of ETASAT.

182 `pota1=0 1/K` Coefficient of the geometry independent part of STA1.

183 `plta1=0 1/K` Coefficient of the length dependence of STA1.

184 `pwta1=0 1/K` Coefficient of the width dependence of STA1.

185 `plwta1=0 1/K` Coefficient of the length times width dependence of STA1.

186 `potbgidl=-0.000364 V/K`
Coefficient of the geometry independent part of STBGIDL.

187 `pltbgidl=0 V/K` Coefficient of the length dependence of STBGIDL.

188 `pwtbgidl=0 V/K` Coefficient of the width dependence of STBGIDL.

189 `plwtbgidl=0 V/K` Coefficient of the length times width dependence of STBGIDL.

190 `dta=0 K` Temperature offset of the device.

191 `pocs=0` Coefficient of the geometry independent part of CS.

192 `plcs=0` Coefficient of the length dependence of CS.

193 `pwcs=0` Coefficient of the width dependence of CS.

194 `plwcs=0` Coefficient of the length times width dependence of CS.

195 `potetacs=0` Coefficient of the geometry independent part of ETACS.

196 `pltetacs=0` Coefficient of the length dependence of ETACS.

197 `pwtetacs=0` Coefficient of the width dependence of ETACS.

198 `plwtetacs=0` Coefficient of the length times width dependence of ETACS.

199 `rth=300 K/W` Thermal resistance.

200 `cth=3e-09 J/K` Thermal capacitance.

201 `ath=0` Temperature coefficient of the thermal resistance.

202 `type=n` — Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

203 `imax=1.0 A` — Explosion current.

204 `mbeo=0.0` — DCmatch parameter.

205 `mvto=0.0` — DCmatch parameter.

206 `tnom (C)` — alias of tnom.

207 `tref (C)` — alias of tnom.

Output Parameters

1 `vfb (V)` — Flat-band voltage at reference temperature.

2 `ko (√V )` — Body-effect factor.

3 `kpinv (1/√V )` — Inverse of body-effect factor of the poly-silicon gate.

4 `phib (V)` — Surface potential at the onset of strong inversion.

5 `bet` (A/V^2) — Gain factor.

6 `thesr (1/V)` — Mobility degradation parameter due to surface roughness scattering.

7 `theph (1/V)` — Mobility degradation parameter due to phonon scattering.

8 `etamob` — Effective field parameter for dependence on depletion charge.

9 `nu` — Exponent of field dependence of mobility model.

10 `cs` — Coefficient of Coulomb scattering.

11 `ther (1/V)` — Coefficient of series resistance.

12 `ther1 (V)` — Numerator of gate voltage dependent part of series resistance.

13 `ther2 (V)` — Denominator of gate voltage dependent part of series resistance.

14 `thesat (1/V)`	Velocity saturation parameter due to optical/acoustic phonon scattering.
15 `theth` $(1/V^3)$	Coefficient of self-heating.
16 `sdibl` $(1/\sqrt{V})$	Drain-induced barrier lowering parameter.
17 `mo`	Parameter for (short-channel) subthreshold slope.
18 `ssf` $(1/\sqrt{V})$	Static-feedback parameter.
19 `alp`	Factor of channel length modulation.
20 `vp (V)`	Characteristic voltage of channel-length modulation.
21 `mexp`	Smoothing factor.
22 `a1`	Factor of the weak-avalanche current.
23 `a2 (V)`	Exponent of the weak-avalanche current.
24 `a3`	Factor of the drain-source voltage above which weak-avalanche occurs.
25 `iginv` (A/V^2)	Gain factor for intrinsic gate tunnelling current in inversion.
26 `binv (V)`	Probability factor for intrinsic gate tunnelling current in inversion.
27 `igacc` (A/V^2)	Gain factor for intrinsic gate tunnelling current in accumulation.
28 `bacc (V)`	Probability factor for intrinsic gate tunnelling current in accumulation.
29 `vfbov (V)`	Flat-band voltage for the Source/Drain overlap extensions.
30 `kov` $(\sqrt{V})$	Body-effect factor for the Source/Drain overlap extensions.
31 `igov` (A/V^2)	Gain factor for Source/Drain overlap tunnelling current.
32 `agidl` (A/V^3)	Gain factor for gate-induced leakage current.
33 `bgidl (V)`	Probability factor for gate-induced drain leakage current at reference temperature.

34 `cgidl`	Factor for the lateral field dependence of the gate-induced leakage current.
35 `cox (F)`	Oxide capacitance for the intrinsic channel (* mult).
36 `cgdo (F)`	Oxide capacitance for the gate-drain overlap (* mult).
37 `cgso (F)`	Oxide capacitance for the gate-source overlap (* mult).
38 `gatenoise`	Flag for in/exclusion of induced gate thermal noise.
39 `nt (J)`	Thermal noise coefficient.
40 nfa $(1/(Vm^4))$	First coefficient of the flicker noise.
41 nfb $(1/(Vm^2))$	Second coefficient of the flicker noise.
42 `nfc (1/V)`	Third coefficient of the flicker noise.
43 `tox (m)`	Thickness of gate oxide layer.
44 `rth (K/W)`	Thermal resistance.
45 `cth (J/K)`	Thermal capacitance.

Operating-Point Parameters

1 `ids (A)`	Drain current, excl. avalanche and tunnel currents.
2 `iavl (A)`	Substrate current due to weak-avalanche.
3 `igs (A)`	Gate-to-source current due to direct tunnelling.
4 `igd (A)`	Gate-to-drain current due to direct tunnelling.
5 `igb (A)`	Gate-to-bulk current due to direct tunnelling.
6 `vds (V)`	Drain-source voltage.
7 `vgs (V)`	Gate-source voltage.
8 `vsb (V)`	Source-bulk voltage.

9 `vto (V)`	Zero-bias threshold voltage.
10 `vts (V)`	Threshold voltage including back-bias effects.
11 `vth (V)`	Threshold voltage including back-bias and drain-bias effects.
12 `vgt (V)`	Effective gate drive voltage including back-bias and drain voltage effects.
13 `vdss (V)`	Drain saturation voltage at actual bias.
14 `vsat (V)`	Saturation limit.
15 `gm (A/V)`	Transconductance (d ids / d vgs).
16 `gmb (A/V)`	Substrate-transconductance (d ids / d vbs).
17 `gds (A/V)`	Output conductance (d ids / d vds).
18 `cdd (F)`	Capacitance (d qd / d vd).
19 `cdg (F)`	Capacitance (- d qd / d vg).
20 `cds (F)`	Capacitance (- d qd / d vs).
21 `cdb (F)`	Capacitance (- d qd / d vb).
22 `cgd (F)`	Capacitance (- d qg / d vd).
23 `cgg (F)`	Capacitance (d qg / d vg).
24 `cgs (F)`	Capacitance (- d qg / d vs).
25 `cgb (F)`	Capacitance (- d qg / d vb).
26 `csd (F)`	Capacitance (- d qs / d vd).
27 `csg (F)`	Capacitance (- d qs / d vg).
28 `css (F)`	Capacitance (d qs / d vs).
29 `csb (F)`	Capacitance (- d qs / d vb).

30 `cbd (F)`	Capacitance (- d qb / d vd).
31 `cbg (F)`	Capacitance (- d qb / d vg).
32 `cbs (F)`	Capacitance (- d qb / d vs).
33 `cbb (F)`	Capacitance (d qb / d vb).
34 `cgdol (F)`	Gate-drain overlap capacitance of the actual transistor.
35 `cgsol (F)`	Gate-source overlap capacitance of the actual transistor.
36 `weff (m)`	Effective channel width for geometrical models.
37 `leff (m)`	Effective channel length for geometrical models.
38 `u`	Transistor gain (gm/gds).
39 `rout` (Ω)	Small-signal output resistance (1/gds).
40 `vearly (V)`	Equivalent Early voltage (|id|/gds).
41 `keff` ($\sqrt{V}$)	Body effect parameter.
42 `beff` (A/V^2)	Gain factor.
43 `fug (Hz)`	Unity gain frequency at actual bias (gm/(2*pi*cin)).
44 `sqrtsfw` ($V/\sqrt{Hz}$)	Input-referred RMS white noise voltage density.
45 `sqrtsff` ($V/\sqrt{Hz}$)	Input-referred RMS white noise voltage density at 1 kHz.
46 `fknee (Hz)`	Cross-over frequency above which white noise is dominant.
47 `Pdiss (W)`	Dissipation.
48 `TK (K)`	Actual device temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

MOS Model 11, Level 1102 (mos1102e)

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1	`mult=1`	Number of devices in parallel.
2	`region=triode`	Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.
3	`m=1`	Multiplicity factor.
4	`area=1`	alias of mult.

Model Definition

```
model modelName mos1102e parameter=value ...
```

Model Parameters

1	`level=1.1e+03`	Transistor Level.
2	`tr=21 C`	Reference temperature.
3	`vfb=-1.05 V`	Flat-band voltage at reference temperature.
4	`stvfb=0.0005 V/K`	Coefficient of temperature dependence of VFB.
5	`ko=0.5 √V`	Body-effect factor.
6	`kpinv=0 1/√V`	Inverse of body-effect factor of the poly-silicon gate.
7	`phib=0.95 V`	Surface potential at the onset of strong inversion.

8 `stphib=-0.00085 V/K`
Coefficient of the temperature dependency of PHIB.

9 `bet=0.00192(n)/0.000381(p)` A/V^2
Gain factor.

10 `etabet=1.3(n)/0.5(p)`
Exponent of the temperature dependence of the gain factor.

11 `thesr=0.356(n)/0.73(p) 1/V`
Mobility degradation parameter due to surface roughness scattering.

12 `etasr=0.65(n)/0.5(p)`
Exponent of the temperatue dependence of THESR.

13 `theph=0.0129(n)/0.001(p) 1/V`
Mobility degradation parameter due to phonon scattering.

14 `etaph=1.35(n)/3.75(p)`
Exponent of the temperature dependence of THEPH.

15 `etamob=1.4(n)/3(p)`
Effective field parameter for dependence on depletion charge.

16 `stetamob=0 1/K` Coefficient of the temperature dependence of ETAMOB.

17 `nu=2` Exponent of field dependence of mobility model.

18 `nuexp=5.25(n)/3.23(p)`
Exponent of the temperature dependence of parameter NU.

19 `ther=0.0812(n)/0.079(p) 1/V`
Coefficient of series resistance.

20 `etar=0.95(n)/0.4(p)`
Exponent of the temperature dependence of THER.

21 `ther1=0 V` Numerator of gate voltage dependent part of series resistance.

22 `ther2=1 V` Denominator of gate voltage dependent part of series resistance.

23 `thesat=0.251(n)/0.173(p) 1/V`
Velocity saturation parameter due to optical/acoustic phonon scattering.

24 `etasat=1.04(n)/0.86(p)`
Exponent of the temperature dependence of THESAT.

25 `theth=1e-05(n)/0(p)` $1/V^3$
Coefficient of self-heating.

26 `sdibl=0.000853(n)/3.55e-05(p)` $1/\sqrt{V}$
Drain-induced barrier lowering parameter.

27 `mo=0` Parameter for (short-channel) subthreshold slope.

28 `ssf=0.012(n)/0.01(p)` $1/\sqrt{V}$
Static-feedback parameter.

29 `alp=0.025` Factor of channel length modulation.

30 `vp=0.05 V` Characteristic voltage of channel-length modulation.

31 `mexp=5` Smoothing factor.

32 `a1=6.02(n)/6.86(p)`
Factor of the weak-avalanche current.

33 `sta1=0 1/K` Coefficient of the temperature dependence of A1.

34 `a2=38(n)/57.3(p) V`
Exponent of the weak-avalanche current.

35 `a3=0.641(n)/0.425(p)`
Factor of the drain-source voltage above which weak-avalanche occurs.

36 `iginv=0` A/V^2 Gain factor for intrinsic gate tunnelling current in inversion.

37 `binv=48(n)/87.5(p) V`
Probability factor for intrinsic gate tunnelling current in inversion.

38 `igacc=0` A/V^2 Gain factor for intrinsic gate tunnelling current in accumulation.

39 `bacc=48 V` Probability factor for intrinsic gate tunnelling current in accumulation.

40 `vfbov=0 V` Flat-band voltage for the Source/Drain overlap extensions.

41 `kov=2.5 √V` Body-effect factor for the Source/Drain overlap extensions.

42 `igov=0` A/V^2 Gain factor for Source/Drain overlap tunnelling current.

43 `agidl=0` A/V^3 Gain factor for gate-induced leakage current.

44 `bgidl=41 V` Probability factor for gate-induced drain leakage current at reference temperature.

45 `stbgidl=-0.000364 V/K`
Coefficient of the temperature dependence of BGIDL.

46 `cgidl=0` Factor for the lateral field dependence of the gate-induced leakage current.

47 `cox=2.98e-14(n)/2.72e-14(p) F`
Oxide capacitance for the intrinsic channel (* mult).

48 `cgdo=6.39e-15(n)/6.36e-15(p) F`
Oxide capacitance for the gate-drain overlap (* mult).

49 `cgso=6.39e-15(n)/6.36e-15(p) F`
Oxide capacitance for the gate-source overlap (* mult).

50 `gatenoise=0` Flag for in/exclusion of induced gate thermal noise.

51 `nt=1.62e-20 J` Thermal noise coefficient.

52 `nfa=8.32e+22(n)/1.9e+22(p)` $1/(Vm^4)$
First coefficient of the flicker noise.

53 `nfb=2.51e+07(n)/5.04e+06(p)` $1/(Vm^2)$
Second coefficient of the flicker noise.

54 `nfc=0(n)/3.63e-10(p) 1/V`
Third coefficient of the flicker noise.

55 `tox=3.2e-09 m` Thickness of gate oxide layer.

56 `dta=0 K` Temperature offset of the device.

57 `cs=0` Coefficient of Coulomb scattering.

58 `etacs=0` Exponent of the temperatue dependence of CS.

59 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

60 `imax=1.0 A` Explosion current.

61 `mbe=0.0` DCmatch parameter.

62 `mvt=0.0` DCmatch parameter.

63 `tnom (C)` alias of tnom.

64 `tref (C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flat-band voltage at reference temperature.

2 `ko` ($\sqrt{V}$) Body-effect factor.

3 `kpinv` ($1/\sqrt{V}$) Inverse of body-effect factor of the poly-silicon gate.

4 `phib (V)` Surface potential at the onset of strong inversion.

5 `bet` (A/V^2) Gain factor.

6 `thesr (1/V)` Mobility degradation parameter due to surface roughness scattering.

7 `theph (1/V)` Mobility degradation parameter due to phonon scattering.

8 `etamob` Effective field parameter for dependence on depletion charge.

9 `nu` Exponent of field dependence of mobility model.

10 `cs` Coefficient of Coulomb scattering.

11 `ther (1/V)` Coefficient of series resistance.

12 `ther1 (V)`	Numerator of gate voltage dependent part of series resistance.
13 `ther2 (V)`	Denominator of gate voltage dependent part of series resistance.
14 `thesat (1/V)`	Velocity saturation parameter due to optical/acoustic phonon scattering.
15 `theth` $(1/V^3)$	Coefficient of self-heating.
16 `sdibl` $(1/\sqrt{V})$	Drain-induced barrier lowering parameter.
17 `mo`	Parameter for (short-channel) subthreshold slope.
18 `ssf` $(1/\sqrt{V})$	Static-feedback parameter.
19 `alp`	Factor of channel length modulation.
20 `vp (V)`	Characteristic voltage of channel-length modulation.
21 `mexp`	Smoothing factor.
22 `a1`	Factor of the weak-avalanche current.
23 `a2 (V)`	Exponent of the weak-avalanche current.
24 `a3`	Factor of the drain-source voltage above which weak-avalanche occurs.
25 `iginv` (A/V^2)	Gain factor for intrinsic gate tunnelling current in inversion.
26 `binv (V)`	Probability factor for intrinsic gate tunnelling current in inversion.
27 `igacc` (A/V^2)	Gain factor for intrinsic gate tunnelling current in accumulation.
28 `bacc (V)`	Probability factor for intrinsic gate tunnelling current in accumulation.
29 `vfbov (V)`	Flat-band voltage for the Source/Drain overlap extensions.
30 `kov` $(\sqrt{V})$	Body-effect factor for the Source/Drain overlap extensions.
31 `igov` (A/V^2)	Gain factor for Source/Drain overlap tunnelling current.

32 `agidl (A/V`^{3}`)`	Gain factor for gate-induced leakage current.
33 `bgidl (V)`	Probability factor for gate-induced drain leakage current at reference temperature.
34 `cgidl`	Factor for the lateral field dependence of the gate-induced leakage current.
35 `cox (F)`	Oxide capacitance for the intrinsic channel (* mult).
36 `cgdo (F)`	Oxide capacitance for the gate-drain overlap (* mult).
37 `cgso (F)`	Oxide capacitance for the gate-source overlap (* mult).
38 `gatenoise`	Flag for in/exclusion of induced gate thermal noise.
39 `nt (J)`	Thermal noise coefficient.
40 `nfa (1/(Vm`^{4}`))`	First coefficient of the flicker noise.
41 `nfb (1/(Vm`^{2}`))`	Second coefficient of the flicker noise.
42 `nfc (1/V)`	Third coefficient of the flicker noise.
43 `tox (m)`	Thickness of gate oxide layer.

Operating-Point Parameters

1 `ids (A)`	Drain current, excl. avalanche and tunnel currents.
2 `iavl (A)`	Substrate current due to weak-avalanche.
3 `igs (A)`	Gate-to-source current due to direct tunnelling.
4 `igd (A)`	Gate-to-drain current due to direct tunnelling.
5 `igb (A)`	Gate-to-bulk current due to direct tunnelling.
6 `vds (V)`	Drain-source voltage.
7 `vgs (V)`	Gate-source voltage.
8 `vsb (V)`	Source-bulk voltage.

9 `vto (V)`	Zero-bias threshold voltage.
10 `vts (V)`	Threshold voltage including back-bias effects.
11 `vth (V)`	Threshold voltage including back-bias and drain-bias effects.
12 `vgt (V)`	Effective gate drive voltage including back-bias and drain voltage effects.
13 `vdss (V)`	Drain saturation voltage at actual bias.
14 `vsat (V)`	Saturation limit.
15 `gm (A/V)`	Transconductance (d ids / d vgs).
16 `gmb (A/V)`	Substrate-transconductance (d ids / d vbs).
17 `gds (A/V)`	Output conductance (d ids / d vds).
18 `cdd (F)`	Capacitance (d qd / d vd).
19 `cdg (F)`	Capacitance (- d qd / d vg).
20 `cds (F)`	Capacitance (- d qd / d vs).
21 `cdb (F)`	Capacitance (- d qd / d vb).
22 `cgd (F)`	Capacitance (- d qg / d vd).
23 `cgg (F)`	Capacitance (d qg / d vg).
24 `cgs (F)`	Capacitance (- d qg / d vs).
25 `cgb (F)`	Capacitance (- d qg / d vb).
26 `csd (F)`	Capacitance (- d qs / d vd).
27 `csg (F)`	Capacitance (- d qs / d vg).
28 `css (F)`	Capacitance (d qs / d vs).
29 `csb (F)`	Capacitance (- d qs / d vb).

30 `cbd (F)` Capacitance (- d qb / d vd).

31 `cbg (F)` Capacitance (- d qb / d vg).

32 `cbs (F)` Capacitance (- d qb / d vs).

33 `cbb (F)` Capacitance (d qb / d vb).

34 `cgdol (F)` Gate-drain overlap capacitance of the actual transistor.

35 `cgsol (F)` Gate-source overlap capacitance of the actual transistor.

36 `u` Transistor gain (gm/gds).

37 `rout (Ω)` Small-signal output resistance (1/gds).

38 `vearly (V)` Equivalent Early voltage (|id|/gds).

39 `keff (√V )` Body effect parameter.

40 `beff` (A/V^2) Gain factor.

41 `fug (Hz)` Unity gain frequency at actual bias (gm/(2*pi*cin)).

42 `sqrtsfw (V/√Hz )`
Input-referred RMS white noise voltage density.

43 `sqrtsff (V/√Hz )`
Input-referred RMS white noise voltage density at 1 kHz.

44 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

MOS Model 11, Level 1102 (mos1102et)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b  dt ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName mos1102et parameter=value ...
```

Model Parameters

1 `level=1.1e+03` Transistor Level.

2 `tr=21 C` Reference temperature.

3 `vfb=-1.05 V` Flat-band voltage at reference temperature.

4 `stvfb=0.0005 V/K` Coefficient of temperature dependence of VFB.

5 `ko=0.5 √V` Body-effect factor.

6 `kpinv=0 1/√V` Inverse of body-effect factor of the poly-silicon gate.

7 `phib=0.95 V` Surface potential at the onset of strong inversion.

8 `stphib=-0.00085 V/K`
Coefficient of the temperature dependency of PHIB.

9 `bet=0.00192(n)/0.000381(p) A/V`^{2}
Gain factor.

10 `etabet=1.3(n)/0.5(p)`
Exponent of the temperature dependence of the gain factor.

11 `thesr=0.356(n)/0.73(p) 1/V`
Mobility degradation parameter due to surface roughness scattering.

12 `etasr=0.65(n)/0.5(p)`
Exponent of the temperatue dependence of THESR.

13 `theph=0.0129(n)/0.001(p) 1/V`
Mobility degradation parameter due to phonon scattering.

14 `etaph=1.35(n)/3.75(p)`
Exponent of the temperature dependence of THEPH.

15 `etamob=1.4(n)/3(p)`
Effective field parameter for dependence on depletion charge.

16 `stetamob=0 1/K` Coefficient of the temperature dependence of ETAMOB.

17 `nu=2` Exponent of field dependence of mobility model.

18 `nuexp=5.25(n)/3.23(p)`
Exponent of the temperature dependence of parameter NU.

19 `ther=0.0812(n)/0.079(p) 1/V`
Coefficient of series resistance.

20 `etar=0.95(n)/0.4(p)`
Exponent of the temperature dependence of THER.

21 `ther1=0 V` Numerator of gate voltage dependent part of series resistance.

22 `ther2=1 V` Denominator of gate voltage dependent part of series resistance.

23 `thesat=0.251(n)/0.173(p) 1/V`
Velocity saturation parameter due to optical/acoustic phonon scattering.

24 `etasat=1.04(n)/0.86(p)`
Exponent of the temperature dependence of THESAT.

25 `theth=1e-05(n)/0(p)` $1/V^3$
Coefficient of self-heating.

26 `sdibl=0.000853(n)/3.55e-05(p)` $1/\sqrt{V}$
Drain-induced barrier lowering parameter.

27 `mo=0` Parameter for (short-channel) subthreshold slope.

28 `ssf=0.012(n)/0.01(p)` $1/\sqrt{V}$
Static-feedback parameter.

29 `alp=0.025` Factor of channel length modulation.

30 `vp=0.05 V` Characteristic voltage of channel-length modulation.

31 `mexp=5` Smoothing factor.

32 `a1=6.02(n)/6.86(p)`
Factor of the weak-avalanche current.

33 `sta1=0 1/K` Coefficient of the temperature dependence of A1.

34 `a2=38(n)/57.3(p) V`
Exponent of the weak-avalanche current.

35 `a3=0.641(n)/0.425(p)`
Factor of the drain-source voltage above which weak-avalanche occurs.

36 `iginv=0` A/V^2 Gain factor for intrinsic gate tunnelling current in inversion.

37 `binv=48(n)/87.5(p) V`
Probability factor for intrinsic gate tunnelling current in inversion.

38 `igacc=0 A/V`^{2} Gain factor for intrinsic gate tunnelling current in accumulation.

39 `bacc=48 V` Probability factor for intrinsic gate tunnelling current in accumulation.

40 `vfbov=0 V` Flat-band voltage for the Source/Drain overlap extensions.

41 `kov=2.5 √V` Body-effect factor for the Source/Drain overlap extensions.

42 `igov=0 A/V`^{2} Gain factor for Source/Drain overlap tunnelling current.

43 `agidl=0 A/V`^{3} Gain factor for gate-induced leakage current.

44 `bgidl=41 V` Probability factor for gate-induced drain leakage current at reference temperature.

45 `stbgidl=-0.000364 V/K`
Coefficient of the temperature dependence of BGIDL.

46 `cgidl=0` Factor for the lateral field dependence of the gate-induced leakage current.

47 `cox=2.98e-14(n)/2.72e-14(p) F`
Oxide capacitance for the intrinsic channel (* mult).

48 `cgdo=6.39e-15(n)/6.36e-15(p) F`
Oxide capacitance for the gate-drain overlap (* mult).

49 `cgso=6.39e-15(n)/6.36e-15(p) F`
Oxide capacitance for the gate-source overlap (* mult).

50 `gatenoise=0` Flag for in/exclusion of induced gate thermal noise.

51 `nt=1.62e-20 J` Thermal noise coefficient.

52 `nfa=8.32e+22(n)/1.9e+22(p) 1/(Vm`^{4}`)`
First coefficient of the flicker noise.

53 `nfb=2.51e+07(n)/5.04e+06(p) 1/(Vm`^{2}`)`
Second coefficient of the flicker noise.

54 `nfc=0(n)/3.63e-10(p) 1/V`
Third coefficient of the flicker noise.

55 `tox=3.2e-09 m` Thickness of gate oxide layer.

56 `dta=0 K` Temperature offset of the device.

57 `cs=0` Coefficient of Coulomb scattering.

58 `etacs=0` Exponent of the temperatue dependence of CS.

59 `rth=300 K/W` Thermal resistance.

60 `cth=3e-09 J/K` Thermal capacitance.

61 `ath=0` Temperature coefficient of the thermal resistance.

62 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

63 `imax=1.0 A` Explosion current.

64 `mbe=0.0` DCmatch parameter.

65 `mvt=0.0` DCmatch parameter.

66 `tnom (C)` alias of tnom.

67 `tref (C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flat-band voltage at reference temperature.

2 `ko (√V )` Body-effect factor.

3 `kpinv (1/√V )` Inverse of body-effect factor of the poly-silicon gate.

4 `phib (V)` Surface potential at the onset of strong inversion.

5 `bet` (A/V^2) Gain factor.

6 `thesr (1/V)` Mobility degradation parameter due to surface roughness scattering.

7 `theph (1/V)` Mobility degradation parameter due to phonon scattering.

8 `etamob`	Effective field parameter for dependence on depletion charge.
9 `nu`	Exponent of field dependence of mobility model.
10 `cs`	Coefficient of Coulomb scattering.
11 `ther (1/V)`	Coefficient of series resistance.
12 `ther1 (V)`	Numerator of gate voltage dependent part of series resistance.
13 `ther2 (V)`	Denominator of gate voltage dependent part of series resistance.
14 `thesat (1/V)`	Velocity saturation parameter due to optical/acoustic phonon scattering.
15 `theth` $(1/V^3)$	Coefficient of self-heating.
16 `sdibl` $(1/\sqrt{V})$	Drain-induced barrier lowering parameter.
17 `mo`	Parameter for (short-channel) subthreshold slope.
18 `ssf` $(1/\sqrt{V})$	Static-feedback parameter.
19 `alp`	Factor of channel length modulation.
20 `vp (V)`	Characteristic voltage of channel-length modulation.
21 `mexp`	Smoothing factor.
22 `a1`	Factor of the weak-avalanche current.
23 `a2 (V)`	Exponent of the weak-avalanche current.
24 `a3`	Factor of the drain-source voltage above which weak-avalanche occurs.
25 `iginv` (A/V^2)	Gain factor for intrinsic gate tunnelling current in inversion.
26 `binv (V)`	Probability factor for intrinsic gate tunnelling current in inversion.
27 `igacc` (A/V^2)	Gain factor for intrinsic gate tunnelling current in accumulation.

28 `bacc (V)` Probability factor for intrinsic gate tunnelling current in accumulation.

29 `vfbov (V)` Flat-band voltage for the Source/Drain overlap extensions.

30 `kov` ($\sqrt{V}$) Body-effect factor for the Source/Drain overlap extensions.

31 `igov` (A/V^2) Gain factor for Source/Drain overlap tunnelling current.

32 `agidl` (A/V^3) Gain factor for gate-induced leakage current.

33 `bgidl (V)` Probability factor for gate-induced drain leakage current at reference temperature.

34 `cgidl` Factor for the lateral field dependence of the gate-induced leakage current.

35 `cox (F)` Oxide capacitance for the intrinsic channel (* mult).

36 `cgdo (F)` Oxide capacitance for the gate-drain overlap (* mult).

37 `cgso (F)` Oxide capacitance for the gate-source overlap (* mult).

38 `gatenoise` Flag for in/exclusion of induced gate thermal noise.

39 `nt (J)` Thermal noise coefficient.

40 `nfa` ($1/(Vm^4)$) First coefficient of the flicker noise.

41 `nfb` ($1/(Vm^2)$) Second coefficient of the flicker noise.

42 `nfc (1/V)` Third coefficient of the flicker noise.

43 `tox (m)` Thickness of gate oxide layer.

44 `rth (K/W)` Thermal resistance.

45 `cth (J/K)` Thermal capacitance.

Operating-Point Parameters

1 `ids (A)` Drain current, excl. avalanche and tunnel currents.

2 `iavl (A)` Substrate current due to weak-avalanche.

3 `igs (A)` Gate-to-source current due to direct tunnelling.

4 `igd (A)` Gate-to-drain current due to direct tunnelling.

5 `igb (A)` Gate-to-bulk current due to direct tunnelling.

6 `vds (V)` Drain-source voltage.

7 `vgs (V)` Gate-source voltage.

8 `vsb (V)` Source-bulk voltage.

9 `vto (V)` Zero-bias threshold voltage.

10 `vts (V)` Threshold voltage including back-bias effects.

11 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

12 `vgt (V)` Effective gate drive voltage including back-bias and drain voltage effects.

13 `vdss (V)` Drain saturation voltage at actual bias.

14 `vsat (V)` Saturation limit.

15 `gm (A/V)` Transconductance (d ids / d vgs).

16 `gmb (A/V)` Substrate-transconductance (d ids / d vbs).

17 `gds (A/V)` Output conductance (d ids / d vds).

18 `cdd (F)` Capacitance (d qd / d vd).

19 `cdg (F)` Capacitance (- d qd / d vg).

20 `cds (F)` Capacitance (- d qd / d vs).

21 `cdb (F)` Capacitance (- d qd / d vb).

22 `cgd (F)` Capacitance (- d qg / d vd).

23 `cgg (F)` Capacitance (d qg / d vg).

24 `cgs (F)` Capacitance (- d qg / d vs).

25 `cgb (F)` Capacitance (- d qg / d vb).

26 `csd (F)` Capacitance (- d qs / d vd).

27 `csg (F)` Capacitance (- d qs / d vg).

28 `css (F)` Capacitance (d qs / d vs).

29 `csb (F)` Capacitance (- d qs / d vb).

30 `cbd (F)` Capacitance (- d qb / d vd).

31 `cbg (F)` Capacitance (- d qb / d vg).

32 `cbs (F)` Capacitance (- d qb / d vs).

33 `cbb (F)` Capacitance (d qb / d vb).

34 `cgdol (F)` Gate-drain overlap capacitance of the actual transistor.

35 `cgsol (F)` Gate-source overlap capacitance of the actual transistor.

36 `u` Transistor gain (gm/gds).

37 `rout (Ω)` Small-signal output resistance (1/gds).

38 `vearly (V)` Equivalent Early voltage (|id|/gds).

39 `keff` ($\sqrt{V}$) Body effect parameter.

40 `beff` (A/V^2) Gain factor.

41 `fug (Hz)` Unity gain frequency at actual bias (gm/(2*pi*cin)).

42 `sqrtsfw` ($V/\sqrt{Hz}$)

Input-referred RMS white noise voltage density.

43 `sqrtsff` ($V/\sqrt{Hz}$)

Input-referred RMS white noise voltage density at 1 kHz.

44 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

45 `Pdiss (W)` Dissipation.

46 `TK (K)` Actual device temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Lateral Double-diffused MOS Model (MOS Model Level 2001) (mos2001)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `w=2e-05 m` Drawn width of the channel region.

2 `wd=2e-05 m` Drawn width of the drift region.

3 `mult=1` Number of devices in parallel.

4 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

5 `m=1` Multiplicity factor.

6 `area=1` alias of mult.

Model Definition

```
model modelName mos2001 parameter=value ...
```

Model Parameters

1 `level=2e+03` Must be 2001.

2 `wvar=0 m` Width offset of the channel region.

3 `wdvar=0 m` Width offset of the drift region.

4 `tref=25 deg. C` Reference temperature.

5 `vfb=-1 V` Flatband voltage of the channel region, at reference temperature.

6 `stvfb=0 V/K` Temperature scaling coefficient for VFB.

7 `vfbd=-0.1 V` Flatband voltage of the drift region, at reference temperature.

8 `stvfbd=0 V/K` Temperature scaling coefficient for the flatband voltage of the drift region.

9 `kor=1.6 V^(1/2)` Body factor of the channel region of an infinitely wide transistor.

10 `swko=0` Width scaling coefficient for KO.

11 `kodr=1 V^-1/2` Body factor of the drift region of an infinitely wide transistor.

12 `swkod=0` Width scaling coefficient for the body factor of the drift region.

13 `phib=0.86 V` Surface potential at the onset of strong inversion in the channel region, at reference temperature.

14 `stphib=-0.0012 V/K`
Temperature scaling coefficient for PHIB.

15 `phibd=0.78 V` Surface potential at the onset of strong inversion in the drift region, at reference temperature.

16 `stphibd=-0.0012 V/K`
Temperature scaling coefficient for PHIBD.

17 `betw=7e-05 A/V`^{2} Gain factor of a channel region of 1 um wide, at reference temperature.

18 `etabet=1.6` Temperature scaling exponent for BET.

19 `betaccw=7e-05 A/V`$^{-2}$
Gain factor of drift region of 1 um wide, at reference temperature.

20 `etabetacc=1.5` Temperature scaling exponent for BETACC.

21 `rdw=4e+03` Ω On-resistance of a drift region of 1 um wide, at reference temperature.

22 `etard=1.5` Temperature scaling exponent for RD.

23 `lamd=0.2` Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.

24 `the1r=0.09 V^-1` Mobility reduction coefficient of infinitely wide transistor, due to vertical strong-inversion field in a channel region.

25 `swthe1=0` Width scaling coefficient for THE1.

26 `the1acc=0.02 V^-1` Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.

27 `the2r=0.03 V^(-1/2)`
Mobility reduction coefficient for VSB > 0 of an infinitely wide transistor, due to vertical depletion field in channel region.

28 `swthe2=0` Width scaling coefficient for THE2.

29 `the3r=0.4 V^-1` Mobility reduction coefficient in a channel region of an infinitely wide transistor due to velocity saturation.

30 `etathe3=1` Temperature scaling exponent for THE3.

31 `swthe3=0` Width scaling coefficient for THE3.

32 `mexp=2` Smoothing factor for transition from linear to saturation regime.

33 `alp=0.002` Factor for channel length modulation.

34 `vp=0.05 V` Characteristic voltage of channel length modulation.

35 `sdibl=0.001 V^(-1/2)`
Factor for drain-induced barrier lowering.

36 `msdibl=3` Exponent for the drain-induced barrier lowering dependence on the backgate bias.

37 `mo=0 V` Parameter for the (short-channel) sub-threshold slope.

38 `ssf=1e-12 V^(-1/2)`
Factor for static feedback.

39 `a1r=15` Factor of weak avalanche current of an infinitely wide transistor, at reference temperature.

40 `sta1=0 K^-1` Temperature scaling coefficient for A1.

41 `swa1=0` Width scaling coefficient for A1.

42 `a2=73 V` Exponent of weak avalanche current.

43 `a3=0.8` Factor of the drain-source voltage above which weak avalanche occurs.

44 `coxw=7.5e-16 F` Oxide capacitance for an intrinsic channel region of 1um wide.

45 `coxdw=7.5e-16 F` Oxide capacitance for an intrinsic drift region of 1um wide.

46 `cgdow=0 F` Gate-to-drain overlap capacitance for a drift region of 1 um wide.

47 `cgsow=0 F` Gate-to-source overlap capacitance for a channel region of 1 um wide.

48 `nt=1.65e-20 J` Coefficient of thermal noise, at reference temperature.

49 `nfaw=1.4e+25 V^-1 m^-4`
First coefficient of flicker noise for a channel region of 1 um wide.

50 `nfbw=2e+08 V^-1` m^{-2}
Second coefficient of flicker noise for a channel region of 1 um wide.

51 `nfcw=0 V^-1` Third coefficient of flicker noise for a channel region of 1 um wide.

52 `tox=3.8e-08 m` Thickness of the oxide above the channel region.

53 `dta=0 K` Temperature offset to the ambient temperature.

54 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

55 `imax=1.0 A` Explosion current.

56 `tnom (deg. C)` alias of tnom.

57 `tr (deg. C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flatband voltage of the channel region, at reference temperature.

2 `vfbd (V)` Flatband voltage of the drift region.

3 `ko (V^1/2)` Body factor of the channel region.

4 `kod (V^-1/2)` Body factor of the drift region.

5 `phib (V)` Surface potential at the onset of strong inversion in the channel region, at reference temperature.

6 `phibd (V)` Surface potential at the onset of strong inversion in the drift region, at reference temperature.

7 `bet` (A/V^2) Gain factor of the channel region, at reference temperature.

8 `betacc` (A/V^2) Gain factor for accumulation in the drift region, at reference temperature.

9 `rd (Ω)`	On-resistance of the drift region, at reference temperature.
10 `lamd`	Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.
11 `the1 (V^-1)`	Mobility reduction coefficient in the channel region due to vertical electrical field caused by strong inversion.
12 `the1acc (V^-1)`	Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.
13 `the2 (V^-1/2)`	Mobility reduction coefficient for VSB > 0 in the channel region due to the vertical electrical field caused by depletion.
14 `the3 (V^-1)`	Mobility reduction coefficient in the channel region due to the horizontal electrical field caused by velocity saturation.
15 `mexp`	Smoothing factor for transition from linear to saturation regime.
16 `alp`	Factor for channel length modulation.
17 `vp (V)`	Characteristic voltage of channel length modulation.
18 `sdibl (V^-1/2)`	Factor for drain-induced barrier lowering.
19 `msdibl`	Exponent for the drain-induced barrier lowering dependence on the backgate bias.
20 `mo (V)`	Parameter for the (short-channel) sub-threshold slope.
21 `ssf (V^-1/2)`	Factor for static feedback.
22 `a1`	Factor of weak avalanche current, at reference temperature.
23 `a2 (V)`	Exponent of weak avalanche current.
24 `a3`	Factor of the drain-source voltage above which weak avalanche occurs.
25 `cox (F)`	Oxide capacitance for the intrinsic channel region.
26 `coxd (F)`	Oxide capacitance for the intrinsic drift region.

27 `cgdo (F)` Gate-to-drain overlap capacitance.

28 `cgso (F)` Gate-to-source overlap capacitance.

29 `nt (J)` Coefficient of thermal noise, at reference temperature.

30 `nfa (V^-1 m^-4)` First coefficient of flicker noise.

31 `nfb (V^-1 m`$^{-2}$`)` Second coefficient of flicker noise.

32 `nfc (V^-1)` Third coefficient of flicker noise.

33 `tox (m)` Thickness of the oxide above the channel region.

Operating-Point Parameters

1 `ids (A)` Drain current, excl. avalanche and tunnel currents.

2 `iavl (A)` Substrate current due to weak-avalanche.

3 `vds (V)` Drain-source voltage.

4 `vgs (V)` Gate-source voltage.

5 `vsb (V)` Source-bulk voltage.

6 `vto (V)` Zero-bias threshold voltage.

7 `vts (V)` Threshold voltage including back-bias effects.

8 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

9 `vgt (V)` Effective gate drive voltage including back-bias and drain voltage effects.

10 `vtod (V)` Threshold voltage of the drift region.

11 `vdiseff (V)` Effective internal drain-to-source voltage at actual bias.

12 `vdissat (V)` Internal drain saturation voltage at actual bias.

13 `vdssat (V)` Drain-source saturation voltage at actual bias.

14 `gm (A/V)`	Transconductance (d ids / d vgs).
15 `gmb (A/V)`	Substrate-transconductance (d ids / d vbs).
16 `gds (A/V)`	Output conductance (d ids / d vds).
17 `cdd (F)`	Capacitance (d qd / d vd).
18 `cdg (F)`	Capacitance (- d qd / d vg).
19 `cds (F)`	Capacitance (- d qd / d vs).
20 `cdb (F)`	Capacitance (- d qd / d vb).
21 `cgd (F)`	Capacitance (- d qg / d vd).
22 `cgg (F)`	Capacitance (d qg / d vg).
23 `cgs (F)`	Capacitance (- d qg / d vs).
24 `cgb (F)`	Capacitance (- d qg / d vb).
25 `csd (F)`	Capacitance (- d qs / d vd).
26 `csg (F)`	Capacitance (- d qs / d vg).
27 `css (F)`	Capacitance (d qs / d vs).
28 `csb (F)`	Capacitance (- d qs / d vb).
29 `cbd (F)`	Capacitance (- d qb / d vd).
30 `cbg (F)`	Capacitance (- d qb / d vg).
31 `cbs (F)`	Capacitance (- d qb / d vs).
32 `cbb (F)`	Capacitance (d qb / d vb).
33 `weff (m)`	Effective channel width for geometrical models.
34 `wdeff (m)`	Effective drift region width for geometrical model.
35 `u`	Transistor gain (gm/gds).

36 `rout (Ω)` Small-signal output resistance (1/gds).

37 `vearly (V)` Equivalent Early voltage (|id|/gds).

38 `beff (A/V^2)` Gain factor.

39 `fug (Hz)` Unity gain frequency at actual bias (gm/(2*pi*cin)).

40 `gmmos (A/V)` Transconductance of channel region.

41 `sqrtsfw (V/Hz^1/2)`
Input-referred RMS white noise voltage density.

42 `sqrtsff (V/Hz^1/2)`
Input-referred RMS white noise voltage density at 1 kHz.

43 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Lateral Double-diffused MOS Model (MOS Model Level 2001) (mos2001e)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName mos2001e parameter=value ...
```

Model Parameters

1 `level=2e+03` Must be 2001.

2 `tref=25 deg. C` Reference temperature.

3 `vfb=-1 V` Flatband voltage of the channel region, at reference temperature.

4 `stvfb=0 V/K` Temperature scaling coefficient for VFB.

5 `vfbd=-0.1 V` Flatband voltage of the drift region, at reference temperature.

6 `stvfbd=0 V/K` Temperature scaling coefficient for the flatband voltage of the drift region.

7 `ko=1.6 V^(1/2)` Body factor of the channel region.

8 `kod=1 V^-1/2` Body factor of the drift region.

9 `phib=0.86 V` Surface potential at the onset of strong inversion in the channel region, at reference temperature.

10 `stphib=-0.0012 V/K`
Temperature scaling coefficient for PHIB.

11 `phibd=0.78 V` Surface potential at the onset of strong inversion in the drift region, at reference temperature.

12 `stphibd=-0.0012 V/K`
Temperature scaling coefficient for PHIBD.

13 `bet=0.0014` A/V^2 Gain factor of the channel region, at reference temperature.

14 `etabet=1.6` Temperature scaling exponent for BET.

15 `betacc=0.0014` A/V^{-2}
Gain factor for accumulation in the drift region, at reference temperature.

16 `etabetacc=1.5` Temperature scaling exponent for BETACC.

17 `rd=200 Ω` On-resistance of the drift region, at reference temperature.

18 `etard=1.5` Temperature scaling exponent for RD.

19 `lamd=0.2` Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.

20 `the1=0.09 V^-1` Mobility reduction coefficient in the channel region due to vertical electrical field caused by strong inversion.

21 `the1acc=0.02 V^-1` Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.

22 `the2=0.03 V^(-1/2)`
Mobility reduction coefficient for VSB > 0 in the channel region due to the vertical electrical field caused by depletion.

23 `the3=0.4 V^-1` Mobility reduction coefficient in the channel region due to the horizontal electrical field caused by velocity saturation.

24 `etathe3=1` Temperature scaling exponent for THE3.

25 `mexp=2` Smoothing factor for transition from linear to saturation regime.

26 `alp=0.002` Factor for channel length modulation.

27 `vp=0.05 V` Characteristic voltage of channel length modulation.

28 `sdibl=0.001 V^(-1/2)`
Factor for drain-induced barrier lowering.

29 `msdibl=3` Exponent for the drain-induced barrier lowering dependence on the backgate bias.

30 `mo=0 V` Parameter for the (short-channel) sub-threshold slope.

31 `ssf=1e-12 V^(-1/2)`
Factor for static feedback.

32 `a1=15` Factor of weak avalanche current, at reference temperature.

33 `sta1=0 K^-1` Temperature scaling coefficient for A1.

34 `a2=73 V` Exponent of weak avalanche current.

35 `a3=0.8` Factor of the drain-source voltage above which weak avalanche occurs.

36 `cox=1.5e-14 F` Oxide capacitance for the intrinsic channel region.

37 `coxd=1.5e-14 F` Oxide capacitance for the intrinsic drift region.

38 `cgdo=0 F` Gate-to-drain overlap capacitance.

39 `cgso=0 F` Gate-to-source overlap capacitance.

40 `nt=1.65e-20 J` Coefficient of thermal noise, at reference temperature.

41 `nfa=7e+23 V^-1 m^-4`
First coefficient of flicker noise.

42 `nfb=1e+07 V^-1` m^{-2}
Second coefficient of flicker noise.

43 `nfc=0 V^-1` Third coefficient of flicker noise.

44 `tox=3.8e-08 m` Thickness of the oxide above the channel region.

45 `dta=0 K` Temperature offset to the ambient temperature.

46 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

47 `imax=1.0 A` Explosion current.

48 `tnom (deg. C)` alias of tnom.

49 `tr (deg. C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flatband voltage of the channel region, at reference temperature.

2 `vfbd (V)`	Flatband voltage of the drift region.
3 `ko (V^1/2)`	Body factor of the channel region.
4 `kod (V^-1/2)`	Body factor of the drift region.
5 `phib (V)`	Surface potential at the onset of strong inversion in the channel region, at reference temperature.
6 `phibd (V)`	Surface potential at the onset of strong inversion in the drift region, at reference temperature.
7 `bet` (A/V^2)	Gain factor of the channel region, at reference temperature.
8 `betacc` (A/V^2)	Gain factor for accumulation in the drift region, at reference temperature.
9 `rd` (Ω)	On-resistance of the drift region, at reference temperature.
10 `lamd`	Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.
11 `the1 (V^-1)`	Mobility reduction coefficient in the channel region due to vertical electrical field caused by strong inversion.
12 `the1acc (V^-1)`	Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.
13 `the2 (V^-1/2)`	Mobility reduction coefficient for VSB > 0 in the channel region due to the vertical electrical field caused by depletion.
14 `the3 (V^-1)`	Mobility reduction coefficient in the channel region due to the horizontal electrical field caused by velocity saturation.
15 `mexp`	Smoothing factor for transition from linear to saturation regime.
16 `alp`	Factor for channel length modulation.
17 `vp (V)`	Characteristic voltage of channel length modulation.
18 `sdibl (V^-1/2)`	Factor for drain-induced barrier lowering.

19 `msdibl`	Exponent for the drain-induced barrier lowering dependence on the backgate bias.
20 `mo (V)`	Parameter for the (short-channel) sub-threshold slope.
21 `ssf (V^-1/2)`	Factor for static feedback.
22 `a1`	Factor of weak avalanche current, at reference temperature.
23 `a2 (V)`	Exponent of weak avalanche current.
24 `a3`	Factor of the drain-source voltage above which weak avalanche occurs.
25 `cox (F)`	Oxide capacitance for the intrinsic channel region.
26 `coxd (F)`	Oxide capacitance for the intrinsic drift region.
27 `cgdo (F)`	Gate-to-drain overlap capacitance.
28 `cgso (F)`	Gate-to-source overlap capacitance.
29 `nt (J)`	Coefficient of thermal noise, at reference temperature.
30 `nfa (V^-1 m^-4)`	First coefficient of flicker noise.
31 nfb (V^-1 m^{-2})	Second coefficient of flicker noise.
32 `nfc (V^-1)`	Third coefficient of flicker noise.
33 `tox (m)`	Thickness of the oxide above the channel region.

Operating-Point Parameters

1 `ids (A)`	Drain current, excl. avalanche and tunnel currents.
2 `iavl (A)`	Substrate current due to weak-avalanche.
3 `vds (V)`	Drain-source voltage.
4 `vgs (V)`	Gate-source voltage.
5 `vsb (V)`	Source-bulk voltage.

6 `vto (V)` Zero-bias threshold voltage.

7 `vts (V)` Threshold voltage including back-bias effects.

8 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

9 `vgt (V)` Effective gate drive voltage including back-bias and drain voltage effects.

10 `vtod (V)` Threshold voltage of the drift region.

11 `vdiseff (V)` Effective internal drain-to-source voltage at actual bias.

12 `vdissat (V)` Internal drain saturation voltage at actual bias.

13 `vdssat (V)` Drain-source saturation voltage at actual bias.

14 `gm (A/V)` Transconductance (d ids / d vgs).

15 `gmb (A/V)` Substrate-transconductance (d ids / d vbs).

16 `gds (A/V)` Output conductance (d ids / d vds).

17 `cdd (F)` Capacitance (d qd / d vd).

18 `cdg (F)` Capacitance (- d qd / d vg).

19 `cds (F)` Capacitance (- d qd / d vs).

20 `cdb (F)` Capacitance (- d qd / d vb).

21 `cgd (F)` Capacitance (- d qg / d vd).

22 `cgg (F)` Capacitance (d qg / d vg).

23 `cgs (F)` Capacitance (- d qg / d vs).

24 `cgb (F)` Capacitance (- d qg / d vb).

25 `csd (F)` Capacitance (- d qs / d vd).

26 `csg (F)` Capacitance (- d qs / d vg).

27 `css (F)` Capacitance (d qs / d vs).

28 `csb (F)` Capacitance (- d qs / d vb).

29 `cbd (F)` Capacitance (- d qb / d vd).

30 `cbg (F)` Capacitance (- d qb / d vg).

31 `cbs (F)` Capacitance (- d qb / d vs).

32 `cbb (F)` Capacitance (d qb / d vb).

33 `u` Transistor gain (gm/gds).

34 `rout (Ω)` Small-signal output resistance (1/gds).

35 `vearly (V)` Equivalent Early voltage (|id|/gds).

36 `beff` (A/V^2) Gain factor.

37 `fug (Hz)` Unity gain frequency at actual bias (gm/(2*pi*cin)).

38 `gmmos (A/V)` Transconductance of channel region.

39 `sqrtsfw (V/Hz^1/2)`
Input-referred RMS white noise voltage density.

40 `sqrtsff (V/Hz^1/2)`
Input-referred RMS white noise voltage density at 1 kHz.

41 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Lateral Double-diffused MOS Model (MOS Model Level 2001) (mos2001et)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b  dt ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName mos2001et parameter=value ...
```

Model Parameters

1 `level=2e+03` Must be 2001.

2 `tref=25 deg. C` Reference temperature.

3 `vfb=-1 V` Flatband voltage of the channel region, at reference temperature.

4 `stvfb=0 V/K` Temperature scaling coefficient for VFB.

5 `vfbd=-0.1 V` Flatband voltage of the drift region, at reference temperature.

6 `stvfbd=0 V/K` Temperature scaling coefficient for the flatband voltage of the drift region.

7 `ko=1.6 V^(1/2)` Body factor of the channel region.

8 `kod=1 V^-1/2` Body factor of the drift region.

9 `phib=0.86 V` Surface potential at the onset of strong inversion in the channel region, at reference temperature.

10 `stphib=-0.0012 V/K`
Temperature scaling coefficient for PHIB.

11 `phibd=0.78 V` Surface potential at the onset of strong inversion in the drift region, at reference temperature.

12 `stphibd=-0.0012 V/K`
Temperature scaling coefficient for PHIBD.

13 `bet=0.0014 A/V`^{2} Gain factor of the channel region, at reference temperature.

14 `etabet=1.6` Temperature scaling exponent for BET.

15 `betacc=0.0014 A/V`$^{-2}$
Gain factor for accumulation in the drift region, at reference temperature.

16 `etabetacc=1.5` Temperature scaling exponent for BETACC.

17 `rd=200` Ω On-resistance of the drift region, at reference temperature.

18 `etard=1.5` Temperature scaling exponent for RD.

19 `lamd=0.2` Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.

20 `the1=0.09 V^-1` Mobility reduction coefficient in the channel region due to vertical electrical field caused by strong inversion.

21 `the1acc=0.02 V^-1` Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.

22 `the2=0.03 V^(-1/2)`
Mobility reduction coefficient for VSB > 0 in the channel region due to the vertical electrical field caused by depletion.

23 `the3=0.4 V^-1` Mobility reduction coefficient in the channel region due to the horizontal electrical field caused by velocity saturation.

24 `etathe3=1` Temperature scaling exponent for THE3.

25 `mexp=2` Smoothing factor for transition from linear to saturation regime.

26 `alp=0.002` Factor for channel length modulation.

27 `vp=0.05 V` Characteristic voltage of channel length modulation.

28 `sdibl=0.001 V^(-1/2)`
Factor for drain-induced barrier lowering.

29 `msdibl=3` Exponent for the drain-induced barrier lowering dependence on the backgate bias.

30 `mo=0 V` Parameter for the (short-channel) sub-threshold slope.

31 `ssf=1e-12 V^(-1/2)`
Factor for static feedback.

32 `a1=15` Factor of weak avalanche current, at reference temperature.

33 `sta1=0 K^-1` Temperature scaling coefficient for A1.

34 `a2=73 V` Exponent of weak avalanche current.

35 `a3=0.8` Factor of the drain-source voltage above which weak avalanche occurs.

36 `cox=1.5e-14 F` Oxide capacitance for the intrinsic channel region.

37 `coxd=1.5e-14 F` Oxide capacitance for the intrinsic drift region.

38 `cgdo=0 F` Gate-to-drain overlap capacitance.

39 `cgso=0 F` Gate-to-source overlap capacitance.

40 `nt=1.65e-20 J` Coefficient of thermal noise, at reference temperature.

41 `nfa=7e+23 V^-1 m^-4`
First coefficient of flicker noise.

42 nfb=1e+07 V^-1 m^{-2}
Second coefficient of flicker noise.

43 `nfc=0 V^-1` Third coefficient of flicker noise.

44 `tox=3.8e-08 m` Thickness of the oxide above the channel region.

45 `dta=0 K` Temperature offset to the ambient temperature.

46 `rth=300 K/W` Thermal resistance.

47 `cth=3e-09 J/K` Thermal capacitance.

48 `ath=0` — Temperature coefficient of the thermal resistance.

49 `type=n` — Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

50 `imax=1.0 A` — Explosion current.

51 `tnom (deg. C)` — alias of tnom.

52 `tr (deg. C)` — alias of tnom.

Output Parameters

1 `vfb (V)` — Flatband voltage of the channel region, at reference temperature.

2 `vfbd (V)` — Flatband voltage of the drift region.

3 `ko (V^1/2)` — Body factor of the channel region.

4 `kod (V^-1/2)` — Body factor of the drift region.

5 `phib (V)` — Surface potential at the onset of strong inversion in the channel region, at reference temperature.

6 `phibd (V)` — Surface potential at the onset of strong inversion in the drift region, at reference temperature.

7 `bet` (A/V^2) — Gain factor of the channel region, at reference temperature.

8 `betacc` (A/V^2) — Gain factor for accumulation in the drift region, at reference temperature.

9 `rd` (Ω) — On-resistance of the drift region, at reference temperature.

10 `lamd` — Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.

11 `the1 (V^-1)` — Mobility reduction coefficient in the channel region due to vertical electrical field caused by strong inversion.

12 `the1acc (V^-1)` — Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.

13 `the2 (V^-1/2)`	Mobility reduction coefficient for VSB > 0 in the channel region due to the vertical electrical field caused by depletion.
14 `the3 (V^-1)`	Mobility reduction coefficient in the channel region due to the horizontal electrical field caused by velocity saturation.
15 `mexp`	Smoothing factor for transition from linear to saturation regime.
16 `alp`	Factor for channel length modulation.
17 `vp (V)`	Characteristic voltage of channel length modulation.
18 `sdibl (V^-1/2)`	Factor for drain-induced barrier lowering.
19 `msdibl`	Exponent for the drain-induced barrier lowering dependence on the backgate bias.
20 `mo (V)`	Parameter for the (short-channel) sub-threshold slope.
21 `ssf (V^-1/2)`	Factor for static feedback.
22 `a1`	Factor of weak avalanche current, at reference temperature.
23 `a2 (V)`	Exponent of weak avalanche current.
24 `a3`	Factor of the drain-source voltage above which weak avalanche occurs.
25 `cox (F)`	Oxide capacitance for the intrinsic channel region.
26 `coxd (F)`	Oxide capacitance for the intrinsic drift region.
27 `cgdo (F)`	Gate-to-drain overlap capacitance.
28 `cgso (F)`	Gate-to-source overlap capacitance.
29 `nt (J)`	Coefficient of thermal noise, at reference temperature.
30 `nfa (V^-1 m^-4)`	First coefficient of flicker noise.
31 nfb (V^-1 m^{-2})	Second coefficient of flicker noise.
32 `nfc (V^-1)`	Third coefficient of flicker noise.

33 `tox (m)` Thickness of the oxide above the channel region.

34 `rth (K/W)` Thermal resistance.

35 `cth (J/K)` Thermal capacitance.

Operating-Point Parameters

1 `ids (A)` Drain current, excl. avalanche and tunnel currents.

2 `iavl (A)` Substrate current due to weak-avalanche.

3 `vds (V)` Drain-source voltage.

4 `vgs (V)` Gate-source voltage.

5 `vsb (V)` Source-bulk voltage.

6 `vto (V)` Zero-bias threshold voltage.

7 `vts (V)` Threshold voltage including back-bias effects.

8 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

9 `vgt (V)` Effective gate drive voltage including back-bias and drain voltage effects.

10 `vtod (V)` Threshold voltage of the drift region.

11 `vdiseff (V)` Effective internal drain-to-source voltage at actual bias.

12 `vdissat (V)` Internal drain saturation voltage at actual bias.

13 `vdssat (V)` Drain-source saturation voltage at actual bias.

14 `gm (A/V)` Transconductance (d ids / d vgs).

15 `gmb (A/V)` Substrate-transconductance (d ids / d vbs).

16 `gds (A/V)` Output conductance (d ids / d vds).

17 `cdd (F)` Capacitance (d qd / d vd).

18 `cdg (F)`	Capacitance (- d qd / d vg).
19 `cds (F)`	Capacitance (- d qd / d vs).
20 `cdb (F)`	Capacitance (- d qd / d vb).
21 `cgd (F)`	Capacitance (- d qg / d vd).
22 `cgg (F)`	Capacitance (d qg / d vg).
23 `cgs (F)`	Capacitance (- d qg / d vs).
24 `cgb (F)`	Capacitance (- d qg / d vb).
25 `csd (F)`	Capacitance (- d qs / d vd).
26 `csg (F)`	Capacitance (- d qs / d vg).
27 `css (F)`	Capacitance (d qs / d vs).
28 `csb (F)`	Capacitance (- d qs / d vb).
29 `cbd (F)`	Capacitance (- d qb / d vd).
30 `cbg (F)`	Capacitance (- d qb / d vg).
31 `cbs (F)`	Capacitance (- d qb / d vs).
32 `cbb (F)`	Capacitance (d qb / d vb).
33 `u`	Transistor gain (gm/gds).
34 `rout (Ω)`	Small-signal output resistance (1/gds).
35 `vearly (V)`	Equivalent Early voltage (lidl/gds).
36 beff (A/V^2)	Gain factor.
37 `fug (Hz)`	Unity gain frequency at actual bias (gm/(2*pi*cin)).
38 `gmmos (A/V)`	Transconductance of channel region.

39 `sqrtsfw (V/Hz^1/2)`
Input-referred RMS white noise voltage density.

40 `sqrtsff (V/Hz^1/2)`
Input-referred RMS white noise voltage density at 1 kHz.

41 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

42 `Pdiss (W)` Dissipation.

43 `TK (K)` Actual temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Lateral Double-diffused MOS Model (MOS Model Level 2001) (mos2001t)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b  dt ModelName parameter=value ...
```

Instance Parameters

1 `w=2e-05 m` Drawn width of the channel region.

2 `wd=2e-05 m` Drawn width of the drift region.

3 `mult=1` Number of devices in parallel.

4 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

5 `m=1` Multiplicity factor.

6 `area=1` alias of mult.

Model Definition

```
model modelName mos2001t parameter=value ...
```

Model Parameters

1 `level=2e+03` Must be 2001.

2 `wvar=0 m` Width offset of the channel region.

3 `wdvar=0 m` Width offset of the drift region.

4 `tref=25 deg. C` Reference temperature.

5 `vfb=-1 V` Flatband voltage of the channel region, at reference temperature.

6 `stvfb=0 V/K` Temperature scaling coefficient for VFB.

7 `vfbd=-0.1 V` Flatband voltage of the drift region, at reference temperature.

8 `stvfbd=0 V/K` Temperature scaling coefficient for the flatband voltage of the drift region.

9 `kor=1.6 V^(1/2)` Body factor of the channel region of an infinitely wide transistor.

10 `swko=0` Width scaling coefficient for KO.

11 `kodr=1 V^-1/2` Body factor of the drift region of an infinitely wide transistor.

12 `swkod=0` Width scaling coefficient for the body factor of the drift region.

13 `phib=0.86 V` Surface potential at the onset of strong inversion in the channel region, at reference temperature.

14 `stphib=-0.0012 V/K`
Temperature scaling coefficient for PHIB.

15 `phibd=0.78 V` Surface potential at the onset of strong inversion in the drift region, at reference temperature.

16 `stphibd=-0.0012 V/K`
Temperature scaling coefficient for PHIBD.

17 `betw=7e-05` A/V^2 Gain factor of a channel region of 1 um wide, at reference temperature.

18 `etabet=1.6` Temperature scaling exponent for BET.

19 `betaccw=7e-05 A/V`$^{-2}$
Gain factor of drift region of 1 um wide, at reference temperature.

20 `etabetacc=1.5` Temperature scaling exponent for BETACC.

21 `rdw=4e+03 Ω` On-resistance of a drift region of 1 um wide, at reference temperature.

22 `etard=1.5` Temperature scaling exponent for RD.

23 `lamd=0.2` Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.

24 `the1r=0.09 V^-1` Mobility reduction coefficient of infinitely wide transistor, due to vertical strong-inversion field in a channel region.

25 `swthe1=0` Width scaling coefficient for THE1.

26 `the1acc=0.02 V^-1` Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.

27 `the2r=0.03 V^(-1/2)`
Mobility reduction coefficient for VSB > 0 of an infinitely wide transistor, due to vertical depletion field in channel region.

28 `swthe2=0` Width scaling coefficient for THE2.

29 `the3r=0.4 V^-1` Mobility reduction coefficient in a channel region of an infinitely wide transistor due to velocity saturation.

30 `etathe3=1` Temperature scaling exponent for THE3.

31 `swthe3=0` Width scaling coefficient for THE3.

32 `mexp=2` Smoothing factor for transition from linear to saturation regime.

33 `alp=0.002` Factor for channel length modulation.

34 `vp=0.05 V` Characteristic voltage of channel length modulation.

35 `sdibl=0.001 V^(-1/2)`
Factor for drain-induced barrier lowering.

36 `msdibl=3` Exponent for the drain-induced barrier lowering dependence on the backgate bias.

37 `mo=0 V` Parameter for the (short-channel) sub-threshold slope.

38 `ssf=1e-12 V^(-1/2)`
Factor for static feedback.

39 `a1r=15` Factor of weak avalanche current of an infinitely wide transistor, at reference temperature.

40 `sta1=0 K^-1` Temperature scaling coefficient for A1.

41 `swa1=0` Width scaling coefficient for A1.

42 `a2=73 V` Exponent of weak avalanche current.

43 `a3=0.8` Factor of the drain-source voltage above which weak avalanche occurs.

44 `coxw=7.5e-16 F` Oxide capacitance for an intrinsic channel region of 1um wide.

45 `coxdw=7.5e-16 F` Oxide capacitance for an intrinsic drift region of 1um wide.

46 `cgdow=0 F` Gate-to-drain overlap capacitance for a drift region of 1 um wide.

47 `cgsow=0 F` Gate-to-source overlap capacitance for a channel region of 1 um wide.

48 `nt=1.65e-20 J` Coefficient of thermal noise, at reference temperature.

49 `nfaw=1.4e+25 V^-1 m^-4`
First coefficient of flicker noise for a channel region of 1 um wide.

50 `nfbw=2e+08 V^-1` m^{-2}
Second coefficient of flicker noise for a channel region of 1 um wide.

51 `nfcw=0 V^-1` Third coefficient of flicker noise for a channel region of 1 um wide.

52 `tox=3.8e-08 m` Thickness of the oxide above the channel region.

53 `dta=0 K` Temperature offset to the ambient temperature.

54 `rth=300 K/W` Thermal resistance.

55 `cth=3e-09 J/K` Thermal capacitance.

56 `ath=0` Temperature coefficient of the thermal resistance.

57 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

58 `imax=1.0 A` Explosion current.

59 `tnom (deg. C)` alias of tnom.

60 `tr (deg. C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flatband voltage of the channel region, at reference temperature.

2 `vfbd (V)` Flatband voltage of the drift region.

3 `ko (V^1/2)` Body factor of the channel region.

4 `kod (V^-1/2)` Body factor of the drift region.

5 `phib (V)` Surface potential at the onset of strong inversion in the channel region, at reference temperature.

6 `phibd (V)` Surface potential at the onset of strong inversion in the drift region, at reference temperature.

7 `bet` (A/V^2) Gain factor of the channel region, at reference temperature.

8 `betacc` (A/V^2) Gain factor for accumulation in the drift region, at reference temperature.

9 `rd` (Ω) On-resistance of the drift region, at reference temperature.

10 `lamd`	Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.
11 `the1 (V^-1)`	Mobility reduction coefficient in the channel region due to vertical electrical field caused by strong inversion.
12 `the1acc (V^-1)`	Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.
13 `the2 (V^-1/2)`	Mobility reduction coefficient for VSB > 0 in the channel region due to the vertical electrical field caused by depletion.
14 `the3 (V^-1)`	Mobility reduction coefficient in the channel region due to the horizontal electrical field caused by velocity saturation.
15 `mexp`	Smoothing factor for transition from linear to saturation regime.
16 `alp`	Factor for channel length modulation.
17 `vp (V)`	Characteristic voltage of channel length modulation.
18 `sdibl (V^-1/2)`	Factor for drain-induced barrier lowering.
19 `msdibl`	Exponent for the drain-induced barrier lowering dependence on the backgate bias.
20 `mo (V)`	Parameter for the (short-channel) sub-threshold slope.
21 `ssf (V^-1/2)`	Factor for static feedback.
22 `a1`	Factor of weak avalanche current, at reference temperature.
23 `a2 (V)`	Exponent of weak avalanche current.
24 `a3`	Factor of the drain-source voltage above which weak avalanche occurs.
25 `cox (F)`	Oxide capacitance for the intrinsic channel region.
26 `coxd (F)`	Oxide capacitance for the intrinsic drift region.
27 `cgdo (F)`	Gate-to-drain overlap capacitance.

28 `cgso (F)` Gate-to-source overlap capacitance.

29 `nt (J)` Coefficient of thermal noise, at reference temperature.

30 `nfa (V^-1 m^-4)` First coefficient of flicker noise.

31 `nfb (V^-1 m`$^{-2}$`)` Second coefficient of flicker noise.

32 `nfc (V^-1)` Third coefficient of flicker noise.

33 `tox (m)` Thickness of the oxide above the channel region.

34 `rth (K/W)` Thermal resistance.

35 `cth (J/K)` Thermal capacitance.

Operating-Point Parameters

1 `ids (A)` Drain current, excl. avalanche and tunnel currents.

2 `iavl (A)` Substrate current due to weak-avalanche.

3 `vds (V)` Drain-source voltage.

4 `vgs (V)` Gate-source voltage.

5 `vsb (V)` Source-bulk voltage.

6 `vto (V)` Zero-bias threshold voltage.

7 `vts (V)` Threshold voltage including back-bias effects.

8 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

9 `vgt (V)` Effective gate drive voltage including back-bias and drain voltage effects.

10 `vtod (V)` Threshold voltage of the drift region.

11 `vdiseff (V)` Effective internal drain-to-source voltage at actual bias.

12 `vdissat (V)` Internal drain saturation voltage at actual bias.

13 `vdssat (V)`	Drain-source saturation voltage at actual bias.
14 `gm (A/V)`	Transconductance (d ids / d vgs).
15 `gmb (A/V)`	Substrate-transconductance (d ids / d vbs).
16 `gds (A/V)`	Output conductance (d ids / d vds).
17 `cdd (F)`	Capacitance (d qd / d vd).
18 `cdg (F)`	Capacitance (- d qd / d vg).
19 `cds (F)`	Capacitance (- d qd / d vs).
20 `cdb (F)`	Capacitance (- d qd / d vb).
21 `cgd (F)`	Capacitance (- d qg / d vd).
22 `cgg (F)`	Capacitance (d qg / d vg).
23 `cgs (F)`	Capacitance (- d qg / d vs).
24 `cgb (F)`	Capacitance (- d qg / d vb).
25 `csd (F)`	Capacitance (- d qs / d vd).
26 `csg (F)`	Capacitance (- d qs / d vg).
27 `css (F)`	Capacitance (d qs / d vs).
28 `csb (F)`	Capacitance (- d qs / d vb).
29 `cbd (F)`	Capacitance (- d qb / d vd).
30 `cbg (F)`	Capacitance (- d qb / d vg).
31 `cbs (F)`	Capacitance (- d qb / d vs).
32 `cbb (F)`	Capacitance (d qb / d vb).
33 `weff (m)`	Effective channel width for geometrical models.
34 `wdeff (m)`	Effective drift region width for geometrical model.

35 `u` — Transistor gain (gm/gds).

36 `rout (Ω)` — Small-signal output resistance (1/gds).

37 `vearly (V)` — Equivalent Early voltage (|id|/gds).

38 `beff (A/V^2)` — Gain factor.

39 `fug (Hz)` — Unity gain frequency at actual bias (gm/(2*pi*cin)).

40 `gmmos (A/V)` — Transconductance of channel region.

41 `sqrtsfw (V/Hz^1/2)`
Input-referred RMS white noise voltage density.

42 `sqrtsff (V/Hz^1/2)`
Input-referred RMS white noise voltage density at 1 kHz.

43 `fknee (Hz)` — Cross-over frequency above which white noise is dominant.

44 `Pdiss (W)` — Dissipation.

45 `TK (K)` — Actual temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Lateral Double-diffused MOS Model (MOS Model Level 2002) (mos2002)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `w=2e-05 m` Drawn width of the channel region.

2 `wd=2e-05 m` Drawn width of the drift region.

3 `mult=1` Number of devices in parallel.

4 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

5 `m=1` Multiplicity factor.

6 `area=1` alias of mult.

Model Definition

```
model modelName mos2002 parameter=value ...
```

Model Parameters

1 `level=2e+03` Must be 2002.

2 `wvar=0 m` Width offset of the channel region.

3 `wdvar=0 m` Width offset of the drift region.

4 `tref=25 deg. C` Reference temperature.

5 `vfb=-1 V` Flatband voltage of the channel region, at reference temperature.

6 `stvfb=0 V/K` Temperature scaling coefficient for VFB.

7 `vfbd=-0.1 V` Flatband voltage of the drift region, at reference temperature.

8 `stvfbd=0 V/K` Temperature scaling coefficient for the flatband voltage of the drift region.

9 `kor=1.6 V^(1/2)` Body factor of the channel region of an infinitely wide transistor.

10 `swko=0` Width scaling coefficient for KO.

11 `kodr=1 V^(1/2)` Body factor of the drift region of an infinitely wide transistor.

12 `swkod=0` Width scaling coefficient for the body factor of the drift region.

13 `phib=0.86 V` Surface potential at the onset of strong inversion in the channel region, at reference temperature.

14 `stphib=-0.0012 V/K`
Temperature scaling coefficient for PHIB.

15 `phibd=0.78 V` Surface potential at the onset of strong inversion in the drift region, at reference temperature.

16 `stphibd=-0.0012 V/K`
Temperature scaling coefficient for PHIBD.

17 `betw=7e-05` A/V^2 Gain factor of a channel region of 1 um wide, at reference temperature.

18 `etabet=1.6` Temperature scaling exponent for BET.

19 `betaccw=7e-05` A/V^{-2}
Gain factor of drift region of 1 um wide, at reference temperature.

20 `etabetacc=1.5` Temperature scaling exponent for BETACC.

21 `rdw=4e+03` Ω On-resistance of a drift region of 1 um wide, at reference temperature.

22 `etard=1.5` Temperature scaling exponent for RD.

23 `lamd=0.2` Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.

24 `the1r=0.09 V^-1` Mobility reduction coefficient of infinitely wide transistor, due to vertical strong-inversion field in a channel region.

25 `swthe1=0` Width scaling coefficient for THE1.

26 `the1acc=0.02 V^-1` Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.

27 `the2r=0.03 V^(-1/2)`
Mobility reduction coefficient for VSB > 0 of an infinitely wide transistor, due to vertical depletion field in channel region.

28 `swthe2=0` Width scaling coefficient for THE2.

29 `the3r=0.4 V^-1` Mobility reduction coefficient in a channel region of an infinitely wide transistor due to velocity saturation.

30 `etathe3=1` Temperature scaling exponent for THE3.

31 `swthe3=0` Width scaling coefficient for THE3.

32 `mexp=2` Smoothing factor for transition from linear to saturation regime.

33 `the3dr=0 V^-1` Mobility reduction coefficient in a channel region of an infinitely wide transistor due to velocity saturation.

34 `etathe3d=1` Temperature scaling exponent for THE3D.

35 `swthe3d=0` Width scaling coefficient for THE3D.

36 `mexpd=2` Smoothing factor for transition from linear to quasi-saturation regime.

37 `alp=0.002` Factor for channel length modulation.

38 `vp=0.05 V` Characteristic voltage of channel length modulation.

39 `sdibl=0.001 V^(-1/2)`
Factor for drain-induced barrier lowering.

40 `msdibl=3` Exponent for the drain-induced barrier lowering dependence on the backgate bias.

41 `mo=0 V` Parameter for the (short-channel) sub-threshold slope.

42 `ssf=1e-12 V^(-1/2)`
Factor for static feedback.

43 `a1chr=15` Factor of channel weak avalanche current of an infinitely wide transistor, at reference temperature.

44 `sta1ch=0 K^-1` Temperature scaling coefficient for A1CH.

45 `swa1ch=0` Width scaling coefficient for A1CH.

46 `a2ch=73 V` Exponent of channel weak avalanche current.

47 `a3ch=0.8` Factor of the drain-source voltage above which channel weak avalanche occurs.

48 `a1drr=15` Factor of drift weak avalanche current of an infinitely wide transistor, at reference temperature.

49 `sta1dr=0 K^-1` Temperature scaling coefficient for A1DR.

50 `swa1dr=0` Width scaling coefficient for A1DR.

51 `a2dr=73 V` Exponent of drift weak avalanche current.

52 `a3dr=0.8` Factor of the drain-source voltage above which drift weak avalanche occurs.

53 `coxw=7.5e-16 F` Oxide capacitance for an intrinsic channel region of 1um wide.

54 `coxdw=7.5e-16 F` Oxide capacitance for an intrinsic drift region of 1um wide.

55 `cgdow=0 F` Gate-to-drain overlap capacitance for a drift region of 1 um wide.

56 `cgsow=0 F` Gate-to-source overlap capacitance for a channel region of 1 um wide.

57 `nt=1.65e-20 J` Coefficient of thermal noise, at reference temperature.

58 `nfaw=1.4e+25 V^-1 m^-4`
First coefficient of flicker noise for a channel region of 1 um wide.

59 `nfbw=2e+08 V^-1 m`$^{-2}$
Second coefficient of flicker noise for a channel region of 1 um wide.

60 `nfcw=0 V^-1` Third coefficient of flicker noise for a channel region of 1 um wide.

61 `tox=3.8e-08 m` Thickness of the oxide above the channel region.

62 `dta=0 K` Temperature offset to the ambient temperature.

63 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

64 `imax=1.0 A` Explosion current.

65 `tnom (deg. C)` alias of tnom.

66 `tr (deg. C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flatband voltage of the channel region, at reference temperature.

2 `vfbd (V)` Flatband voltage of the drift region.

3 `ko (V^1/2)` Body factor of the channel region.

4 `kod (V^1/2)` Body factor of the drift region.

5 `phib (V)` Surface potential at the onset of strong inversion in the channel region, at reference temperature.

6 `phibd (V)` Surface potential at the onset of strong inversion in the drift region, at reference temperature.

7 `bet` (A/V^2) Gain factor of the channel region, at reference temperature.

8 `betacc` (A/V^2) Gain factor for accumulation in the drift region, at reference temperature.

9 `rd (Ω)` On-resistance of the drift region, at reference temperature.

10 `lamd` Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.

11 `the1 (V^-1)` Mobility reduction coefficient in the channel region due to vertical electrical field caused by strong inversion.

12 `the1acc (V^-1)` Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.

13 `the2 (V^-1/2)`	Mobility reduction coefficient for VSB > 0 in the channel region due to the vertical electrical field caused by depletion.
14 `the3 (V^-1)`	Mobility reduction coefficient in the channel region due to the horizontal electrical field caused by velocity saturation.
15 `mexp`	Smoothing factor for transition from linear to saturation regime.
16 `the3d (V^-1)`	Mobility reduction coefficient in the drift region due to the horizontal electrical field caused by velocity saturation.
17 `etathe3d`	Temperature scaling exponent for THE3D.
18 `mexpd`	Smoothing factor for transition from linear to quasi-saturation regime.
19 `alp`	Factor for channel length modulation.
20 `vp (V)`	Characteristic voltage of channel length modulation.
21 `sdibl (V^-1/2)`	Factor for drain-induced barrier lowering.
22 `msdibl`	Exponent for the drain-induced barrier lowering dependence on the backgate bias.
23 `mo (V)`	Parameter for the (short-channel) sub-threshold slope.
24 `ssf (V^-1/2)`	Factor for static feedback.
25 `a1ch`	Factor of channel weak avalanche current, at reference temperature.
26 `a2ch (V)`	Exponent of channel weak avalanche current.
27 `a3ch`	Factor of the drain-source voltage above which channel weak avalanche occurs.
28 `a1dr`	Factor of drift weak avalanche current, at reference temperature.
29 `a2dr (V)`	Exponent of drift weak avalanche current.
30 `a3dr`	Factor of the drain-source voltage above which drift weak avalanche occurs.

31 `cox (F)`	Oxide capacitance for the intrinsic channel region.
32 `coxd (F)`	Oxide capacitance for the intrinsic drift region.
33 `cgdo (F)`	Gate-to-drain overlap capacitance.
34 `cgso (F)`	Gate-to-source overlap capacitance.
35 `nt (J)`	Coefficient of thermal noise, at reference temperature.
36 `nfa (V^-1 m^-4)`	First coefficient of flicker noise.
37 `nfb (V^-1` m^{-2}`)`	Second coefficient of flicker noise.
38 `nfc (V^-1)`	Third coefficient of flicker noise.
39 `tox (m)`	Thickness of the oxide above the channel region.

Operating-Point Parameters

1 `ids (A)`	Drain current, excl. avalanche and tunnel currents.
2 `iavl (A)`	Substrate current due to weak-avalanche.
3 `vds (V)`	Drain-source voltage.
4 `vgs (V)`	Gate-source voltage.
5 `vsb (V)`	Source-bulk voltage.
6 `vto (V)`	Zero-bias threshold voltage.
7 `vts (V)`	Threshold voltage including back-bias effects.
8 `vth (V)`	Threshold voltage including back-bias and drain-bias effects.
9 `vgt (V)`	Effective gate drive voltage including back-bias and drain voltage effects.
10 `vtod (V)`	Threshold voltage of the drift region.
11 `vdiseff (V)`	Effective internal drain-to-source voltage at actual bias.

12 `vdissat (V)` Saturation voltage of channel region at actual bias.

13 `vddisat (V)` Saturation voltage of drift region at actual bias.

14 `gm (A/V)` Transconductance (d ids / d vgs).

15 `gmb (A/V)` Substrate-transconductance (d ids / d vbs).

16 `gds (A/V)` Output conductance (d ids / d vds).

17 `cdd (F)` Capacitance (d qd / d vd).

18 `cdg (F)` Capacitance (- d qd / d vg).

19 `cds (F)` Capacitance (- d qd / d vs).

20 `cdb (F)` Capacitance (- d qd / d vb).

21 `cgd (F)` Capacitance (- d qg / d vd).

22 `cgg (F)` Capacitance (d qg / d vg).

23 `cgs (F)` Capacitance (- d qg / d vs).

24 `cgb (F)` Capacitance (- d qg / d vb).

25 `csd (F)` Capacitance (- d qs / d vd).

26 `csg (F)` Capacitance (- d qs / d vg).

27 `css (F)` Capacitance (d qs / d vs).

28 `csb (F)` Capacitance (- d qs / d vb).

29 `cbd (F)` Capacitance (- d qb / d vd).

30 `cbg (F)` Capacitance (- d qb / d vg).

31 `cbs (F)` Capacitance (- d qb / d vs).

32 `cbb (F)` Capacitance (d qb / d vb).

33 `weff (m)` Effective channel width for geometrical models.

34 `wdeff (m)` Effective drift region width for geometrical model.

35 `u` Transistor gain (gm/gds).

36 `rout (Ω)` Small-signal output resistance (1/gds).

37 `vearly (V)` Equivalent Early voltage (|id|/gds).

38 `beff (A/V^2)` Gain factor.

39 `fug (Hz)` Unity gain frequency at actual bias (gm/(2*pi*cin)).

40 `gmmos (A/V)` Transconductance of channel region.

41 `sqrtsfw (V/Hz^1/2)`
Input-referred RMS white noise voltage density.

42 `sqrtsff (V/Hz^1/2)`
Input-referred RMS white noise voltage density at 1 kHz.

43 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Lateral Double-diffused MOS Model (MOS Model Level 2002) (mos2002e)

This is SimKit 4.0.

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName mos2002e parameter=value ...
```

Model Parameters

1 `level=2e+03` Must be 2002.

2 `tref=25 deg. C` Reference temperature.

3 `vfb=-1 V` Flatband voltage of the channel region, at reference temperature.

4 `stvfb=0 V/K` Temperature scaling coefficient for VFB.

5 `vfbd=-0.1 V` Flatband voltage of the drift region, at reference temperature.

6 `stvfbd=0 V/K` Temperature scaling coefficient for the flatband voltage of the drift region.

7 `ko=1.6 V^(1/2)` Body factor of the channel region.

8 `kod=1 V^(1/2)` Body factor of the drift region.

9 `phib=0.86 V` Surface potential at the onset of strong inversion in the channel region, at reference temperature.

10 `stphib=-0.0012 V/K` Temperature scaling coefficient for PHIB.

11 `phibd=0.78 V` Surface potential at the onset of strong inversion in the drift region, at reference temperature.

12 `stphibd=-0.0012 V/K`
Temperature scaling coefficient for PHIBD.

13 `bet=0.0014 A/V`^{2} Gain factor of the channel region, at reference temperature.

14 `etabet=1.6` Temperature scaling exponent for BET.

15 `betacc=0.0014 A/V`$^{-2}$
Gain factor for accumulation in the drift region, at reference temperature.

16 `etabetacc=1.5` Temperature scaling exponent for BETACC.

17 `rd=200` Ω On-resistance of the drift region, at reference temperature.

18 `etard=1.5` Temperature scaling exponent for RD.

19 `lamd=0.2` Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.

20 `the1=0.09 V^-1` Mobility reduction coefficient in the channel region due to vertical electrical field caused by strong inversion.

21 `the1acc=0.02 V^-1` Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.

22 `the2=0.03 V^(-1/2)`
Mobility reduction coefficient for VSB > 0 in the channel region due to the vertical electrical field caused by depletion.

23 `the3=0.4 V^-1` Mobility reduction coefficient in the channel region due to the horizontal electrical field caused by velocity saturation.

24 `etathe3=1` Temperature scaling exponent for THE3.

25 `mexp=2` Smoothing factor for transition from linear to saturation regime.

26 `the3d=0 V^-1` Mobility reduction coefficient in the drift region due to the horizontal electrical field caused by velocity saturation.

27 `etathe3d=1` Temperature scaling exponent for THE3D.

28 `mexpd=2` Smoothing factor for transition from linear to quasi-saturation regime.

29 `alp=0.002` Factor for channel length modulation.

30 `vp=0.05 V` Characteristic voltage of channel length modulation.

31 `sdibl=0.001 V^(-1/2)`
Factor for drain-induced barrier lowering.

32 `msdibl=3` Exponent for the drain-induced barrier lowering dependence on the backgate bias.

33 `mo=0 V` Parameter for the (short-channel) sub-threshold slope.

34 `ssf=1e-12 V^(-1/2)`
Factor for static feedback.

35 `a1ch=15` Factor of channel weak avalanche current, at reference temperature.

36 `sta1ch=0 K^-1` Temperature scaling coefficient for A1CH.

37 `a2ch=73 V` Exponent of channel weak avalanche current.

38 `a3ch=0.8` Factor of the drain-source voltage above which channel weak avalanche occurs.

39 `a1dr=15` Factor of drift weak avalanche current, at reference temperature.

40 `sta1dr=0 K^-1` Temperature scaling coefficient for A1DR.

41 `a2dr=73 V` Exponent of drift weak avalanche current.

42 `a3dr=0.8` Factor of the drain-source voltage above which drift weak avalanche occurs.

43 `cox=1.5e-14 F` Oxide capacitance for the intrinsic channel region.

44 `coxd=1.5e-14 F` Oxide capacitance for the intrinsic drift region.

45 `cgdo=0 F` Gate-to-drain overlap capacitance.

46 `cgso=0 F` Gate-to-source overlap capacitance.

47 `nt=1.65e-20 J` Coefficient of thermal noise, at reference temperature.

48 `nfa=7e+23 V^-1 m^-4`
First coefficient of flicker noise.

49 `nfb=1e+07 V^-1` m^{-2}
Second coefficient of flicker noise.

50 `nfc=0 V^-1` Third coefficient of flicker noise.

51 `tox=3.8e-08 m` Thickness of the oxide above the channel region.

52 `dta=0 K` Temperature offset to the ambient temperature.

53 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

54 `imax=1.0 A` Explosion current.

55 `tnom (deg. C)` alias of tnom.

56 `tr (deg. C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flatband voltage of the channel region, at reference temperature.

2 `vfbd (V)` Flatband voltage of the drift region.

3 `ko (V^1/2)` Body factor of the channel region.

4 `kod (V^1/2)` Body factor of the drift region.

5 `phib (V)` Surface potential at the onset of strong inversion in the channel region, at reference temperature.

6 `phibd (V)` Surface potential at the onset of strong inversion in the drift region, at reference temperature.

7 `bet` (A/V^2) Gain factor of the channel region, at reference temperature.

8 `betacc (A/V`^{2}`)`	Gain factor for accumulation in the drift region, at reference temperature.
9 `rd (Ω)`	On-resistance of the drift region, at reference temperature.
10 `lamd`	Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.
11 `the1 (V^-1)`	Mobility reduction coefficient in the channel region due to vertical electrical field caused by strong inversion.
12 `the1acc (V^-1)`	Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.
13 `the2 (V^-1/2)`	Mobility reduction coefficient for VSB > 0 in the channel region due to the vertical electrical field caused by depletion.
14 `the3 (V^-1)`	Mobility reduction coefficient in the channel region due to the horizontal electrical field caused by velocity saturation.
15 `mexp`	Smoothing factor for transition from linear to saturation regime.
16 `the3d (V^-1)`	Mobility reduction coefficient in the drift region due to the horizontal electrical field caused by velocity saturation.
17 `etathe3d`	Temperature scaling exponent for THE3D.
18 `mexpd`	Smoothing factor for transition from linear to quasi-saturation regime.
19 `alp`	Factor for channel length modulation.
20 `vp (V)`	Characteristic voltage of channel length modulation.
21 `sdibl (V^-1/2)`	Factor for drain-induced barrier lowering.
22 `msdibl`	Exponent for the drain-induced barrier lowering dependence on the backgate bias.
23 `mo (V)`	Parameter for the (short-channel) sub-threshold slope.
24 `ssf (V^-1/2)`	Factor for static feedback.

25 `a1ch` Factor of channel weak avalanche current, at reference temperature.

26 `a2ch (V)` Exponent of channel weak avalanche current.

27 `a3ch` Factor of the drain-source voltage above which channel weak avalanche occurs.

28 `a1dr` Factor of drift weak avalanche current, at reference temperature.

29 `a2dr (V)` Exponent of drift weak avalanche current.

30 `a3dr` Factor of the drain-source voltage above which drift weak avalanche occurs.

31 `cox (F)` Oxide capacitance for the intrinsic channel region.

32 `coxd (F)` Oxide capacitance for the intrinsic drift region.

33 `cgdo (F)` Gate-to-drain overlap capacitance.

34 `cgso (F)` Gate-to-source overlap capacitance.

35 `nt (J)` Coefficient of thermal noise, at reference temperature.

36 `nfa (V^-1 m^-4)` First coefficient of flicker noise.

37 `nfb (V^-1 m`$^{-2}$`)` Second coefficient of flicker noise.

38 `nfc (V^-1)` Third coefficient of flicker noise.

39 `tox (m)` Thickness of the oxide above the channel region.

Operating-Point Parameters

1 `ids (A)` Drain current, excl. avalanche and tunnel currents.

2 `iavl (A)` Substrate current due to weak-avalanche.

3 `vds (V)` Drain-source voltage.

4 `vgs (V)` Gate-source voltage.

5 `vsb (V)` Source-bulk voltage.

6 `vto (V)` Zero-bias threshold voltage.

7 `vts (V)` Threshold voltage including back-bias effects.

8 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

9 `vgt (V)` Effective gate drive voltage including back-bias and drain voltage effects.

10 `vtod (V)` Threshold voltage of the drift region.

11 `vdiseff (V)` Effective internal drain-to-source voltage at actual bias.

12 `vdissat (V)` Saturation voltage of channel region at actual bias.

13 `vddisat (V)` Saturation voltage of drift region at actual bias.

14 `gm (A/V)` Transconductance (d ids / d vgs).

15 `gmb (A/V)` Substrate-transconductance (d ids / d vbs).

16 `gds (A/V)` Output conductance (d ids / d vds).

17 `cdd (F)` Capacitance (d qd / d vd).

18 `cdg (F)` Capacitance (- d qd / d vg).

19 `cds (F)` Capacitance (- d qd / d vs).

20 `cdb (F)` Capacitance (- d qd / d vb).

21 `cgd (F)` Capacitance (- d qg / d vd).

22 `cgg (F)` Capacitance (d qg / d vg).

23 `cgs (F)` Capacitance (- d qg / d vs).

24 `cgb (F)` Capacitance (- d qg / d vb).

25 `csd (F)` Capacitance (- d qs / d vd).

26 `csg (F)`	Capacitance (- d qs / d vg).
27 `css (F)`	Capacitance (d qs / d vs).
28 `csb (F)`	Capacitance (- d qs / d vb).
29 `cbd (F)`	Capacitance (- d qb / d vd).
30 `cbg (F)`	Capacitance (- d qb / d vg).
31 `cbs (F)`	Capacitance (- d qb / d vs).
32 `cbb (F)`	Capacitance (d qb / d vb).
33 `u`	Transistor gain (gm/gds).
34 `rout (Ω)`	Small-signal output resistance (1/gds).
35 `vearly (V)`	Equivalent Early voltage (lidl/gds).
36 beff (A/V^2)	Gain factor.
37 `fug (Hz)`	Unity gain frequency at actual bias (gm/(2*pi*cin)).
38 `gmmos (A/V)`	Transconductance of channel region.
39 `sqrtsfw (V/Hz^1/2)`	Input-referred RMS white noise voltage density.
40 `sqrtsff (V/Hz^1/2)`	Input-referred RMS white noise voltage density at 1 kHz.
41 `fknee (Hz)`	Cross-over frequency above which white noise is dominant.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Lateral Double-diffused MOS Model (MOS Model Level 2002) (mos2002et)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b  dt ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName mos2002et parameter=value ...
```

Model Parameters

1 `level=2e+03` Must be 2002.

2 `tref=25 deg. C` Reference temperature.

3 `vfb=-1 V` Flatband voltage of the channel region, at reference temperature.

4 `stvfb=0 V/K` Temperature scaling coefficient for VFB.

5 `vfbd=-0.1 V` Flatband voltage of the drift region, at reference temperature.

6 `stvfbd=0 V/K` Temperature scaling coefficient for the flatband voltage of the drift region.

7 `ko=1.6 V^(1/2)` Body factor of the channel region.

8 `kod=1 V^(1/2)` Body factor of the drift region.

9 `phib=0.86 V` Surface potential at the onset of strong inversion in the channel region, at reference temperature.

10 `stphib=-0.0012 V/K`
Temperature scaling coefficient for PHIB.

11 `phibd=0.78 V` Surface potential at the onset of strong inversion in the drift region, at reference temperature.

12 `stphibd=-0.0012 V/K`
Temperature scaling coefficient for PHIBD.

13 `bet=0.0014` A/V^2 Gain factor of the channel region, at reference temperature.

14 `etabet=1.6` Temperature scaling exponent for BET.

15 `betacc=0.0014` A/V^{-2}
Gain factor for accumulation in the drift region, at reference temperature.

16 `etabetacc=1.5` Temperature scaling exponent for BETACC.

17 `rd=200` Ω On-resistance of the drift region, at reference temperature.

18 `etard=1.5` Temperature scaling exponent for RD.

19 `lamd=0.2` Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.

20 `the1=0.09 V^-1` Mobility reduction coefficient in the channel region due to vertical electrical field caused by strong inversion.

21 `the1acc=0.02 V^-1` Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.

22 `the2=0.03 V^(-1/2)`
Mobility reduction coefficient for VSB > 0 in the channel region due to the vertical electrical field caused by depletion.

23 `the3=0.4 V^-1` Mobility reduction coefficient in the channel region due to the horizontal electrical field caused by velocity saturation.

24 `etathe3=1` Temperature scaling exponent for THE3.

25 `mexp=2` Smoothing factor for transition from linear to saturation regime.

26 `the3d=0 V^-1` Mobility reduction coefficient in the drift region due to the horizontal electrical field caused by velocity saturation.

27 `etathe3d=1` Temperature scaling exponent for THE3D.

28 `mexpd=2` Smoothing factor for transition from linear to quasi-saturation regime.

29 `alp=0.002` Factor for channel length modulation.

30 `vp=0.05 V` Characteristic voltage of channel length modulation.

31 `sdibl=0.001 V^(-1/2)`
Factor for drain-induced barrier lowering.

32 `msdibl=3` Exponent for the drain-induced barrier lowering dependence on the backgate bias.

33 `mo=0 V` Parameter for the (short-channel) sub-threshold slope.

34 `ssf=1e-12 V^(-1/2)`
Factor for static feedback.

35 `a1ch=15` Factor of channel weak avalanche current, at reference temperature.

36 `sta1ch=0 K^-1` Temperature scaling coefficient for A1CH.

37 `a2ch=73 V` Exponent of channel weak avalanche current.

38 `a3ch=0.8` Factor of the drain-source voltage above which channel weak avalanche occurs.

39 `a1dr=15` Factor of drift weak avalanche current, at reference temperature.

40 `sta1dr=0 K^-1` Temperature scaling coefficient for A1DR.

41 `a2dr=73 V` Exponent of drift weak avalanche current.

42 `a3dr=0.8` Factor of the drain-source voltage above which drift weak avalanche occurs.

43 `cox=1.5e-14 F` Oxide capacitance for the intrinsic channel region.

44 `coxd=1.5e-14 F` Oxide capacitance for the intrinsic drift region.

45 `cgdo=0 F` Gate-to-drain overlap capacitance.

46 `cgso=0 F` Gate-to-source overlap capacitance.

47 `nt=1.65e-20 J` Coefficient of thermal noise, at reference temperature.

48 `nfa=7e+23 V^-1 m^-4`
First coefficient of flicker noise.

49 `nfb=1e+07 V^-1` m^{-2}
Second coefficient of flicker noise.

50 `nfc=0 V^-1` Third coefficient of flicker noise.

51 `tox=3.8e-08 m` Thickness of the oxide above the channel region.

52 `dta=0 K` Temperature offset to the ambient temperature.

53 `rth=300 K/W` Thermal resistance.

54 `cth=3e-09 J/K` Thermal capacitance.

55 `ath=0` Temperature coefficient of the thermal resistance.

56 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

57 `imax=1.0 A` Explosion current.

58 `tnom (deg. C)` alias of tnom.

59 `tr (deg. C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flatband voltage of the channel region, at reference temperature.

2 `vfbd (V)` Flatband voltage of the drift region.

3 `ko (V^1/2)` Body factor of the channel region.

4 `kod (V^1/2)`	Body factor of the drift region.
5 `phib (V)`	Surface potential at the onset of strong inversion in the channel region, at reference temperature.
6 `phibd (V)`	Surface potential at the onset of strong inversion in the drift region, at reference temperature.
7 `bet` (A/V^2)	Gain factor of the channel region, at reference temperature.
8 `betacc` (A/V^2)	Gain factor for accumulation in the drift region, at reference temperature.
9 `rd` (Ω)	On-resistance of the drift region, at reference temperature.
10 `lamd`	Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.
11 `the1 (V^-1)`	Mobility reduction coefficient in the channel region due to vertical electrical field caused by strong inversion.
12 `the1acc (V^-1)`	Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.
13 `the2 (V^-1/2)`	Mobility reduction coefficient for VSB > 0 in the channel region due to the vertical electrical field caused by depletion.
14 `the3 (V^-1)`	Mobility reduction coefficient in the channel region due to the horizontal electrical field caused by velocity saturation.
15 `mexp`	Smoothing factor for transition from linear to saturation regime.
16 `the3d (V^-1)`	Mobility reduction coefficient in the drift region due to the horizontal electrical field caused by velocity saturation.
17 `etathe3d`	Temperature scaling exponent for THE3D.
18 `mexpd`	Smoothing factor for transition from linear to quasi-saturation regime.
19 `alp`	Factor for channel length modulation.
20 `vp (V)`	Characteristic voltage of channel length modulation.

21 `sdibl (V^-1/2)` Factor for drain-induced barrier lowering.

22 `msdibl` Exponent for the drain-induced barrier lowering dependence on the backgate bias.

23 `mo (V)` Parameter for the (short-channel) sub-threshold slope.

24 `ssf (V^-1/2)` Factor for static feedback.

25 `a1ch` Factor of channel weak avalanche current, at reference temperature.

26 `a2ch (V)` Exponent of channel weak avalanche current.

27 `a3ch` Factor of the drain-source voltage above which channel weak avalanche occurs.

28 `a1dr` Factor of drift weak avalanche current, at reference temperature.

29 `a2dr (V)` Exponent of drift weak avalanche current.

30 `a3dr` Factor of the drain-source voltage above which drift weak avalanche occurs.

31 `cox (F)` Oxide capacitance for the intrinsic channel region.

32 `coxd (F)` Oxide capacitance for the intrinsic drift region.

33 `cgdo (F)` Gate-to-drain overlap capacitance.

34 `cgso (F)` Gate-to-source overlap capacitance.

35 `nt (J)` Coefficient of thermal noise, at reference temperature.

36 `nfa (V^-1 m^-4)` First coefficient of flicker noise.

37 nfb (V^-1 m^{-2}) Second coefficient of flicker noise.

38 `nfc (V^-1)` Third coefficient of flicker noise.

39 `tox (m)` Thickness of the oxide above the channel region.

40 `rth (K/W)` Thermal resistance.

41 `cth (J/K)` Thermal capacitance.

Operating-Point Parameters

1 `ids (A)` Drain current, excl. avalanche and tunnel currents.

2 `iavl (A)` Substrate current due to weak-avalanche.

3 `vds (V)` Drain-source voltage.

4 `vgs (V)` Gate-source voltage.

5 `vsb (V)` Source-bulk voltage.

6 `vto (V)` Zero-bias threshold voltage.

7 `vts (V)` Threshold voltage including back-bias effects.

8 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

9 `vgt (V)` Effective gate drive voltage including back-bias and drain voltage effects.

10 `vtod (V)` Threshold voltage of the drift region.

11 `vdiseff (V)` Effective internal drain-to-source voltage at actual bias.

12 `vdissat (V)` Saturation voltage of channel region at actual bias.

13 `vddisat (V)` Saturation voltage of drift region at actual bias.

14 `gm (A/V)` Transconductance (d ids / d vgs).

15 `gmb (A/V)` Substrate-transconductance (d ids / d vbs).

16 `gds (A/V)` Output conductance (d ids / d vds).

17 `cdd (F)` Capacitance (d qd / d vd).

18 `cdg (F)` Capacitance (- d qd / d vg).

19 `cds (F)` Capacitance (- d qd / d vs).

20 `cdb (F)` Capacitance (- d qd / d vb).

21 `cgd (F)` Capacitance (- d qg / d vd).

22 `cgg (F)` Capacitance (d qg / d vg).

23 `cgs (F)` Capacitance (- d qg / d vs).

24 `cgb (F)` Capacitance (- d qg / d vb).

25 `csd (F)` Capacitance (- d qs / d vd).

26 `csg (F)` Capacitance (- d qs / d vg).

27 `css (F)` Capacitance (d qs / d vs).

28 `csb (F)` Capacitance (- d qs / d vb).

29 `cbd (F)` Capacitance (- d qb / d vd).

30 `cbg (F)` Capacitance (- d qb / d vg).

31 `cbs (F)` Capacitance (- d qb / d vs).

32 `cbb (F)` Capacitance (d qb / d vb).

33 `u` Transistor gain (gm/gds).

34 `rout (Ω)` Small-signal output resistance (1/gds).

35 `vearly (V)` Equivalent Early voltage (lidl/gds).

36 `beff` (A/V^2) Gain factor.

37 `fug (Hz)` Unity gain frequency at actual bias (gm/(2*pi*cin)).

38 `gmmos (A/V)` Transconductance of channel region.

39 `sqrtsfw (V/Hz^1/2)`
Input-referred RMS white noise voltage density.

40 `sqrtsff (V/Hz^1/2)`
Input-referred RMS white noise voltage density at 1 kHz.

41 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

42 `Pdiss (W)` Dissipation.

43 `TK (K)` Actual temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Lateral Double-diffused MOS Model (MOS Model Level 2002) (mos2002t)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b  dt ModelName parameter=value ...
```

Instance Parameters

1	`w=2e-05 m`	Drawn width of the channel region.
2	`wd=2e-05 m`	Drawn width of the drift region.
3	`mult=1`	Number of devices in parallel.
4	`region=triode`	Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.
5	`m=1`	Multiplicity factor.
6	`area=1`	alias of mult.

Model Definition

```
model modelName mos2002t parameter=value ...
```

Model Parameters

1 `level=2e+03`	Must be 2002.
2 `wvar=0 m`	Width offset of the channel region.
3 `wdvar=0 m`	Width offset of the drift region.
4 `tref=25 deg. C`	Reference temperature.
5 `vfb=-1 V`	Flatband voltage of the channel region, at reference temperature.
6 `stvfb=0 V/K`	Temperature scaling coefficient for VFB.
7 `vfbd=-0.1 V`	Flatband voltage of the drift region, at reference temperature.
8 `stvfbd=0 V/K`	Temperature scaling coefficient for the flatband voltage of the drift region.
9 `kor=1.6 V^(1/2)`	Body factor of the channel region of an infinitely wide transistor.
10 `swko=0`	Width scaling coefficient for KO.
11 `kodr=1 V^(1/2)`	Body factor of the drift region of an infinitely wide transistor.
12 `swkod=0`	Width scaling coefficient for the body factor of the drift region.
13 `phib=0.86 V`	Surface potential at the onset of strong inversion in the channel region, at reference temperature.
14 `stphib=-0.0012 V/K`	Temperature scaling coefficient for PHIB.
15 `phibd=0.78 V`	Surface potential at the onset of strong inversion in the drift region, at reference temperature.
16 `stphibd=-0.0012 V/K`	Temperature scaling coefficient for PHIBD.
17 `betw=7e-05` A/V^2	Gain factor of a channel region of 1 um wide, at reference temperature.

18 `etabet=1.6` Temperature scaling exponent for BET.

19 `betaccw=7e-05 A/V`$^{-2}$
Gain factor of drift region of 1 um wide, at reference temperature.

20 `etabetacc=1.5` Temperature scaling exponent for BETACC.

21 `rdw=4e+03` Ω On-resistance of a drift region of 1 um wide, at reference temperature.

22 `etard=1.5` Temperature scaling exponent for RD.

23 `lamd=0.2` Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.

24 `the1r=0.09 V^-1` Mobility reduction coefficient of infinitely wide transistor, due to vertical strong-inversion field in a channel region.

25 `swthe1=0` Width scaling coefficient for THE1.

26 `the1acc=0.02 V^-1` Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.

27 `the2r=0.03 V^(-1/2)`
Mobility reduction coefficient for VSB > 0 of an infinitely wide transistor, due to vertical depletion field in channel region.

28 `swthe2=0` Width scaling coefficient for THE2.

29 `the3r=0.4 V^-1` Mobility reduction coefficient in a channel region of an infinitely wide transistor due to velocity saturation.

30 `etathe3=1` Temperature scaling exponent for THE3.

31 `swthe3=0` Width scaling coefficient for THE3.

32 `mexp=2` Smoothing factor for transition from linear to saturation regime.

33 `the3dr=0 V^-1` Mobility reduction coefficient in a channel region of an infinitely wide transistor due to velocity saturation.

34 `etathe3d=1` Temperature scaling exponent for THE3D.

35 `swthe3d=0` Width scaling coefficient for THE3D.

36 `mexpd=2` Smoothing factor for transition from linear to quasi-saturation regime.

37 `alp=0.002` Factor for channel length modulation.

38 `vp=0.05 V` Characteristic voltage of channel length modulation.

39 `sdibl=0.001 V^(-1/2)`
Factor for drain-induced barrier lowering.

40 `msdibl=3` Exponent for the drain-induced barrier lowering dependence on the backgate bias.

41 `mo=0 V` Parameter for the (short-channel) sub-threshold slope.

42 `ssf=1e-12 V^(-1/2)`
Factor for static feedback.

43 `a1chr=15` Factor of channel weak avalanche current of an infinitely wide transistor, at reference temperature.

44 `sta1ch=0 K^-1` Temperature scaling coefficient for A1CH.

45 `swa1ch=0` Width scaling coefficient for A1CH.

46 `a2ch=73 V` Exponent of channel weak avalanche current.

47 `a3ch=0.8` Factor of the drain-source voltage above which channel weak avalanche occurs.

48 `a1drr=15` Factor of drift weak avalanche current of an infinitely wide transistor, at reference temperature.

49 `sta1dr=0 K^-1` Temperature scaling coefficient for A1DR.

50 `swa1dr=0` Width scaling coefficient for A1DR.

51 `a2dr=73 V` Exponent of drift weak avalanche current.

52 `a3dr=0.8` Factor of the drain-source voltage above which drift weak avalanche occurs.

53 `coxw=7.5e-16 F` Oxide capacitance for an intrinsic channel region of 1um wide.

54 `coxdw=7.5e-16 F` Oxide capacitance for an intrinsic drift region of 1um wide.

55 `cgdow=0 F` Gate-to-drain overlap capacitance for a drift region of 1 um wide.

56 `cgsow=0 F` Gate-to-source overlap capacitance for a channel region of 1 um wide.

57 `nt=1.65e-20 J` Coefficient of thermal noise, at reference temperature.

58 `nfaw=1.4e+25 V^-1 m^-4`
First coefficient of flicker noise for a channel region of 1 um wide.

59 `nfbw=2e+08 V^-1` m^{-2}
Second coefficient of flicker noise for a channel region of 1 um wide.

60 `nfcw=0 V^-1` Third coefficient of flicker noise for a channel region of 1 um wide.

61 `tox=3.8e-08 m` Thickness of the oxide above the channel region.

62 `dta=0 K` Temperature offset to the ambient temperature.

63 `rth=300 K/W` Thermal resistance.

64 `cth=3e-09 J/K` Thermal capacitance.

65 `ath=0` Temperature coefficient of the thermal resistance.

66 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

67 `imax=1.0 A` Explosion current.

68 `tnom (deg. C)` alias of tnom.

69 `tr (deg. C)` alias of tnom.

Output Parameters

1 `vfb (V)` Flatband voltage of the channel region, at reference temperature.

2 `vfbd (V)`	Flatband voltage of the drift region.
3 `ko (V^1/2)`	Body factor of the channel region.
4 `kod (V^1/2)`	Body factor of the drift region.
5 `phib (V)`	Surface potential at the onset of strong inversion in the channel region, at reference temperature.
6 `phibd (V)`	Surface potential at the onset of strong inversion in the drift region, at reference temperature.
7 `bet` (A/V^2)	Gain factor of the channel region, at reference temperature.
8 `betacc` (A/V^2)	Gain factor for accumulation in the drift region, at reference temperature.
9 `rd` (Ω)	On-resistance of the drift region, at reference temperature.
10 `lamd`	Quotient of the depletion layer thickness to the effective thickness of the drift region at VSB = 0 V.
11 `the1 (V^-1)`	Mobility reduction coefficient in the channel region due to vertical electrical field caused by strong inversion.
12 `the1acc (V^-1)`	Mobility reduction coefficient in the drift region due to the vertical electrical field caused by accumulation.
13 `the2 (V^-1/2)`	Mobility reduction coefficient for VSB > 0 in the channel region due to the vertical electrical field caused by depletion.
14 `the3 (V^-1)`	Mobility reduction coefficient in the channel region due to the horizontal electrical field caused by velocity saturation.
15 `mexp`	Smoothing factor for transition from linear to saturation regime.
16 `the3d (V^-1)`	Mobility reduction coefficient in the drift region due to the horizontal electrical field caused by velocity saturation.
17 `etathe3d`	Temperature scaling exponent for THE3D.
18 `mexpd`	Smoothing factor for transition from linear to quasi-saturation regime.

19 `alp` Factor for channel length modulation.

20 `vp (V)` Characteristic voltage of channel length modulation.

21 `sdibl (V^-1/2)` Factor for drain-induced barrier lowering.

22 `msdibl` Exponent for the drain-induced barrier lowering dependence on the backgate bias.

23 `mo (V)` Parameter for the (short-channel) sub-threshold slope.

24 `ssf (V^-1/2)` Factor for static feedback.

25 `a1ch` Factor of channel weak avalanche current, at reference temperature.

26 `a2ch (V)` Exponent of channel weak avalanche current.

27 `a3ch` Factor of the drain-source voltage above which channel weak avalanche occurs.

28 `a1dr` Factor of drift weak avalanche current, at reference temperature.

29 `a2dr (V)` Exponent of drift weak avalanche current.

30 `a3dr` Factor of the drain-source voltage above which drift weak avalanche occurs.

31 `cox (F)` Oxide capacitance for the intrinsic channel region.

32 `coxd (F)` Oxide capacitance for the intrinsic drift region.

33 `cgdo (F)` Gate-to-drain overlap capacitance.

34 `cgso (F)` Gate-to-source overlap capacitance.

35 `nt (J)` Coefficient of thermal noise, at reference temperature.

36 `nfa (V^-1 m^-4)` First coefficient of flicker noise.

37 nfb (V^{-1} m^{-2}) Second coefficient of flicker noise.

38 `nfc (V^-1)` Third coefficient of flicker noise.

39 `tox (m)` Thickness of the oxide above the channel region.

40 `rth (K/W)` Thermal resistance.

41 `cth (J/K)` Thermal capacitance.

Operating-Point Parameters

1 `ids (A)` Drain current, excl. avalanche and tunnel currents.

2 `iavl (A)` Substrate current due to weak-avalanche.

3 `vds (V)` Drain-source voltage.

4 `vgs (V)` Gate-source voltage.

5 `vsb (V)` Source-bulk voltage.

6 `vto (V)` Zero-bias threshold voltage.

7 `vts (V)` Threshold voltage including back-bias effects.

8 `vth (V)` Threshold voltage including back-bias and drain-bias effects.

9 `vgt (V)` Effective gate drive voltage including back-bias and drain voltage effects.

10 `vtod (V)` Threshold voltage of the drift region.

11 `vdiseff (V)` Effective internal drain-to-source voltage at actual bias.

12 `vdissat (V)` Saturation voltage of channel region at actual bias.

13 `vddisat (V)` Saturation voltage of drift region at actual bias.

14 `gm (A/V)` Transconductance (d ids / d vgs).

15 `gmb (A/V)` Substrate-transconductance (d ids / d vbs).

16 `gds (A/V)` Output conductance (d ids / d vds).

17 `cdd (F)` Capacitance (d qd / d vd).

18 `cdg (F)`	Capacitance (- d qd / d vg).
19 `cds (F)`	Capacitance (- d qd / d vs).
20 `cdb (F)`	Capacitance (- d qd / d vb).
21 `cgd (F)`	Capacitance (- d qg / d vd).
22 `cgg (F)`	Capacitance (d qg / d vg).
23 `cgs (F)`	Capacitance (- d qg / d vs).
24 `cgb (F)`	Capacitance (- d qg / d vb).
25 `csd (F)`	Capacitance (- d qs / d vd).
26 `csg (F)`	Capacitance (- d qs / d vg).
27 `css (F)`	Capacitance (d qs / d vs).
28 `csb (F)`	Capacitance (- d qs / d vb).
29 `cbd (F)`	Capacitance (- d qb / d vd).
30 `cbg (F)`	Capacitance (- d qb / d vg).
31 `cbs (F)`	Capacitance (- d qb / d vs).
32 `cbb (F)`	Capacitance (d qb / d vb).
33 `weff (m)`	Effective channel width for geometrical models.
34 `wdeff (m)`	Effective drift region width for geometrical model.
35 `u`	Transistor gain (gm/gds).
36 `rout (Ω)`	Small-signal output resistance (1/gds).
37 `vearly (V)`	Equivalent Early voltage (lidl/gds).
38 `beff` (A/V^2)	Gain factor.
39 `fug (Hz)`	Unity gain frequency at actual bias (gm/(2*pi*cin)).

40 `gmmos (A/V)` Transconductance of channel region.

41 `sqrtsfw (V/Hz^1/2)`
Input-referred RMS white noise voltage density.

42 `sqrtsff (V/Hz^1/2)`
Input-referred RMS white noise voltage density at 1 kHz.

43 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

44 `Pdiss (W)` Dissipation.

45 `TK (K)` Actual temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

MOS Model 31, Level 3100 (mos3100)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName mos3100 parameter=value ...
```

Model Parameters

1 `level=3.1e+03` Transistor level.

2 `ron=1` Ω Ohmic resistance at zero bias.

3 `rsat=1` Ω Space charge resistance at zero bias.

4 `vsat=10 V` Critical drain-source voltage for hot carriers.

5 `psat=1` Velocity saturation coefficient.

6 `vp=-1 V` Pinch off voltage at zero gate and substrate voltages.

7 `tox=-1 m` Gate oxide thickness.

8 `dch=1e+21` m^{-3} Doping level channel.

9 `dsub=1e+21` m^{-3} Doping level substrate.

10 `vsub=0.6 V` Substrate diffusion voltage.

11 `vgap=1.2 V` Bandgap voltage channel.

12 `cgate=0 F` Gate capacitance at zero bias.

13 `csub=0 F` Substrate capacitance at zero bias.

14 `tausc=0 s` Space charge transit time of the channel.

15 `ach=0` Temperature coefficient resistivity of the channel.

16 `achmod=0` Parameter to switch to extended temperature scaling.

17 `achron=0` Temperature coefficient of ohmic resistance at zero bias.

18 `achvsat=0` Temperature coefficient of critical drain-source voltage for hot carriers.

19 `achrsat=0` Temperature coefficient of space charge resistance at zero bias.

20 `tref=25 deg. C` Reference temperature.

21 `dta=0 deg. C` Temperature offset of the device.

22 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

23 `imax=1.0 A` Explosion current.

24 `tnom (deg. C)` alias of tnom.

25 `tr (deg. C)` alias of tnom.

Output Parameters

1 `ront (Ω)` Ohmic resistance at zero bias.

2 `rsatt (Ω)` Space charge resistance at zero bias.

3 `vsatt (V)` Critical drain-source voltage for hot carriers.

4 `psat` Velocity saturation coefficient.

5 `vp (V)` Pinch off voltage at zero gate and substrate voltages.

6 `tox (m)` Gate oxide thickness.

7 `dch` (m^{-3}) Doping level channel.

8 `dsub` (m^{-3}) Doping level substrate.

9 `vsubt (V)` Substrate diffusion voltage.

10 `cgate (F)` Gate capacitance at zero bias.

11 `csubt (F)` Substrate capacitance at zero bias.

12 `tausc (s)` Space charge transit time of the channel.

Operating-Point Parameters

1 `ids (A)` Drain source current (including velocity saturation).

2 `vds (V)` Drain source voltage.

3 `vgs (V)` Gate source voltage.

4 `vbs (V)` Bulk source voltage.

5 `vp (V)` Channel pinch off voltage.

6 `gm (A/V)` Transconductance (dIds/dVg).

7 `gmb (A/V)` Bulk transconductance (dIds/dVb).

8 `gds (A/V)` Output conductance (dIds/dVd).

9 `qg (C)` Gate charge.

10 `cgd (F)` Gate charge dependence on drain voltage (- dQg/dVd).

11 `cgg (F)` Gate charge dependence on gate voltage (dQg/dVg).

12 `cgs (F)` Gate charge dependence on source voltage (-dQg/dVs).

13 `cgb (F)` Gate charge dependence on bulk voltage (-dQg/dVb).

14 `qb (C)` Bulk charge.

15 `cbd (F)` Bulk charge dependence on drain voltage (-dQb/dVd).

16 `cbg (F)` Bulk charge dependence on gate voltage (-dQb/dVg).

17 `cbs (F)` Bulk charge dependence on source voltage (-dQb/dVs).

18 `cbb (F)` Bulk charge dependence on bulk voltage (dQb/dVb).

19 `qd (C)` Drain charge.

20 `cdd (F)` Drain charge dependence on drain voltage (dQd/dVd).

21 `cdg (F)` Drain charge dependence on gate voltage (-dQd/dVg).

22 `cds (F)` Drain charge dependence on source voltage (-dQd/dVs).

23 `cdb (F)` Drain charge dependence on bulk voltage (-dQd/dVb).

24 `qs (C)` Source charge.

25 `csd (F)` Source charge dependence on drain voltage (-dQs/dVd).

26 `csg (F)` Source charge dependence on gate voltage (-dQs/dVg).

27 `css (F)` Source charge dependence on source voltage (dQs/dVs).

28 `csb (F)` Source charge dependence on bulk voltage (-dQs/dVb).

29 `u` Transistor gain (gm/gds).

30 `rout (Ω)` Small signal output resistance (1/gds).

31 `vearly (V)` Equivalent early voltage (|Ids|/gds).

32 `iohm (A)` Drain source current excluding velocity saturation.

33 `ihc (A)` Critical current for velocity saturation.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

MOS Model 31, Level 3100 (mos3100t)

This is SimKit 4.0

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b  dt ModelName parameter=value ...
```

Instance Parameters

1 `mult=1` Number of devices in parallel.

2 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subth`.

3 `m=1` Multiplicity factor.

4 `area=1` alias of mult.

Model Definition

```
model modelName mos3100t parameter=value ...
```

Model Parameters

1 `level=3.1e+03` Transistor level.

2 `ron=1 Ω` Ohmic resistance at zero bias.

3 `rsat=1 Ω` Space charge resistance at zero bias.

4 `vsat=10 V` Critical drain-source voltage for hot carriers.

5 `psat=1` Velocity saturation coefficient.

6 `vp=-1 V` Pinch off voltage at zero gate and substrate voltages.

7 `tox=-1 m` Gate oxide thickness.

8 `dch=1e+21` m^{-3} Doping level channel.

9 `dsub=1e+21` m^{-3} Doping level substrate.

10 `vsub=0.6 V` Substrate diffusion voltage.

11 `vgap=1.2 V` Bandgap voltage channel.

12 `cgate=0 F` Gate capacitance at zero bias.

13 `csub=0 F` Substrate capacitance at zero bias.

14 `tausc=0 s` Space charge transit time of the channel.

15 `ach=0` Temperature coefficient resistivity of the channel.

16 `achmod=0` Parameter to switch to extended temperature scaling.

17 `achron=0` Temperature coefficient of ohmic resistance at zero bias.

18 `achvsat=0` Temperature coefficient of critical drain-source voltage for hot carriers.

19 `achrsat=0` Temperature coefficient of space charge resistance at zero bias.

20 `tref=25 deg. C` Reference temperature.

21 `dta=0 deg. C` Temperature offset of the device.

22 `rth=300 K/W` Thermal resistance.

23 `cth=3e-09 J/K` Thermal capacitance.

24 `ath=0` Temperature coefficient of the thermal resistance.

25 `type=n` Transistor gender.
Possible values are `n`, `p`, `npn`, `pnp`, `npnv`, `pnpv`, `npnl`, or `pnpl`.

26 `imax=1.0 A` Explosion current.

27 `tnom (deg. C)` alias of tnom.

28 `tr (deg. C)` alias of tnom.

Output Parameters

1 `ront (Ω)` Ohmic resistance at zero bias.

2 `rsatt (Ω)` Space charge resistance at zero bias.

3 `vsatt (V)` Critical drain-source voltage for hot carriers.

4 `psat` Velocity saturation coefficient.

5 `vp (V)` Pinch off voltage at zero gate and substrate voltages.

6 `tox (m)` Gate oxide thickness.

7 `dch` (m^{-3}) Doping level channel.

8 `dsub` (m^{-3}) Doping level substrate.

9 `vsubt (V)` Substrate diffusion voltage.

10 `cgate (F)` Gate capacitance at zero bias.

11 `csubt (F)` Substrate capacitance at zero bias.

12 `tausc (s)` Space charge transit time of the channel.

13 `rth (K/W)` Thermal resistance.

14 `cth (J/K)` Thermal capacitance.

Operating-Point Parameters

1 `ids (A)` Drain source current (including velocity saturation).

2 `vds (V)` Drain source voltage.

3 `vgs (V)` Gate source voltage.

4 `vbs (V)` Bulk source voltage.

5 `vp (V)` Channel pinch off voltage.

6 `gm (A/V)` Transconductance (dIds/dVg).

7 `gmb (A/V)` Bulk transconductance (dIds/dVb).

8 `gds (A/V)` Output conductance (dIds/dVd).

9 `qg (C)`	Gate charge.
10 `cgd (F)`	Gate charge dependence on drain voltage (- dQg/dVd).
11 `cgg (F)`	Gate charge dependence on gate voltage (dQg/dVg).
12 `cgs (F)`	Gate charge dependence on source voltage (-dQg/dVs).
13 `cgb (F)`	Gate charge dependence on bulk voltage (-dQg/dVb).
14 `qb (C)`	Bulk charge.
15 `cbd (F)`	Bulk charge dependence on drain voltage (-dQb/dVd).
16 `cbg (F)`	Bulk charge dependence on gate voltage (-dQb/dVg).
17 `cbs (F)`	Bulk charge dependence on source voltage (-dQb/dVs).
18 `cbb (F)`	Bulk charge dependence on bulk voltage (dQb/dVb).
19 `qd (C)`	Drain charge.
20 `cdd (F)`	Drain charge dependence on drain voltage (dQd/dVd).
21 `cdg (F)`	Drain charge dependence on gate voltage (-dQd/dVg).
22 `cds (F)`	Drain charge dependence on source voltage (-dQd/dVs).
23 `cdb (F)`	Drain charge dependence on bulk voltage (-dQd/dVb).
24 `qs (C)`	Source charge.
25 `csd (F)`	Source charge dependence on drain voltage (-dQs/dVd).
26 `csg (F)`	Source charge dependence on gate voltage (-dQs/dVg).
27 `css (F)`	Source charge dependence on source voltage (dQs/dVs).
28 `csb (F)`	Source charge dependence on bulk voltage (-dQs/dVb).
29 `u`	Transistor gain (gm/gds).
30 `rout` (Ω)	Small signal output resistance (1/gds).

31 `vearly (V)` Equivalent early voltage (|Ids|/gds).

32 `iohm (A)` Drain source current excluding velocity saturation.

33 `ihc (A)` Critical current for velocity saturation.

34 `Pdiss (W)` Dissipation.

35 `TK (K)` Actual temperature.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

12

Common MOSFET Equations

This chapter discusses the following topics:

Spectre® circuit simulator has the following public-domain MOSFET models: Level-1, Level-2, Level-3, EKV, BSIM1 (Level-4), BSIM2 (Level-5), BSIM3v2, and 7BSIM3v3.

When the Spectre option `approx` is set to `yes`, `pow()` in the junction depletion capacitance calculation and `sqrt()` in the BJT and MOSFET level 1-5 models are replaced by a spline-function approximation. For more information, see `spectre -h options`.

Parameters Common to BSIM1 and BSIM2 Models

Electrical parameters that you specify override electrical parameters calculated with process parameters. The Spectre circuit simulator selects the default parameter value if you do not specify an electrical or a process parameter.

Channel Width and Length

(12-1)

$$W_{scaled} = w \times scale + xw \times scalem$$

(12-2)

$$W_{eff} = \begin{cases} w \times scale + xw \times scalem - 2wd \times scalem & \text{Level 1-3} \\ w \times scale + xw \times scalem - dw \times scalem & \text{BSIM 1-2} \end{cases}$$

(12-3)

$$L_{eff} = \begin{cases} l \times scale + xl \times scalem - 2ld \times scalem & \text{Level 1-3} \\ l \times scale + xl \times scalem - ld \times scalem & \text{BSIM 1-2} \end{cases}$$

Parameters Common to Levels 1-3 Only

This section discusses parameters that are common to levels 1-3 only.

- If you do not give vto and $nsub$ is specified, vto is calculated from

(12-4)

$$vto = V_{FB} + phi + gamma\sqrt{phi}$$

where

(12-5)

$$V_{FB} = \phi_{MS} - \frac{q(nss)}{C_{ox}}$$

is the flat-band voltage and ϕ_{MS} is the work function difference between the gate material and the silicon substrate. With the following equations, the tpg (tps) parameter determines the value of ϕ_{MS}.

(12-6)

$$\phi_{MS} = \begin{cases} -0.5(E_g + phi) & \text{if } tpg = 1 \\ 0.5(E_g - phi) & \text{if } tpg = -1 \\ -0.05 - 0.5(E_g + phi) & \text{if } tpg = 0 \end{cases}$$

E_g is the energy gap whose equation is given later.

- If vto is specified, V_{FB} is calculated from

(12-7)

$$V_{FB} = vto - phi - gamma\sqrt{phi}$$

- If you do not give phi and $nsub$ is specified, phi is calculated from

(12-8)

$$phi = 2V_t \ln\left[\frac{nsub}{n_i}\right]$$

where n_i is the intrinsic carrier concentration of silicon and V_t is the thermal voltage given by kT/q.

- If you do not give $gamma$ and $nsub$ is specified, $gamma$ is calculated from

(12-9)

$$gamma = \frac{\sqrt{2q\varepsilon_{si}nsub}}{C_{ox}}$$

- The consistency between kp, uo, and C_{ox} $(kp = uoC_{ox})$ is checked according to the following rules:
    - If tox is not given, C_{ox} is calculated from the default value of tox.
    - If kp is given, uo is calculated from $uo = kp/C_{ox}$, whether uo is given or not. If this uo value is different from that specified in the model, a warning message tells you that the specified kp and uo values are inconsistent.

- If you do not give kp and uo is specified, kp is calculated from $kp = uo * C_{ox}$.
- If neither kp nor uo is given, their default values are used.

In SPICE, if you give kp but not uo, uo is not calculated from kp. The default value of uo (600) is used. If you specify both kp and uo, SPICE does not check the consistency between them. In the Spectre circuit simulator, kp and uo are always consistent. This can cause the simulation results of the Spectre and SPICE simulators to be different. SPICE uses kp to evaluate the drain current (through the b term) while it uses uo to evaluate the drain saturation voltage V_{DSAT} (if $vmax$ is also specified).

Often only kp is specified in the model. SPICE then assigns a default value (600) to uo, but Spectre calculates uo from kp. This usually causes drain currents to be smaller in the Spectre simulator than in SPICE. If you need SPICE compatibility, you can set `compatible` to any option other than `spectre` (for example, `spice2`, `spice3`, `cdsspice`, or `spiceplus`) in the `.options` card, and the Spectre simulator does not force uo to be consistent with kp. In SPICE, V_{DSAT} is a function of ($uo/vmax$) rather than uo alone. Therefore, you can still make uo consistent with kp by proportionally adjusting the $vmax$ value without changing the results. However, you should check the parameter extraction program to find out how uo and $vmax$ are extracted before comparing SPICE and Spectre results or changing any of the model parameters.

- If tox is not indicated in the Level-1 model, the intrinsic MOSFET gate capacitances are not calculated.

Source/Drain Bulk Junction Models

Junction Leakage Current

(12-10)

$$I_{BS(BD)} = \begin{cases} is\left(e^{\frac{V_{BS(BD)}}{V_t}} - 1\right) & \text{if } V_{BS(BD)} \le V_{Expl} \\ I_{offset} + G_{Expl}V_{BS(BD)} & \text{otherwise} \end{cases}$$

where

(12-11)

$$V_{Expl} = V_t \ln\left[1 + \frac{imax}{is}\right]$$

is the forward explosion voltage,

(12-12)

$$G_{Expl} = V_t(imax + is)$$

is the conductance at V_{Expl}, and

(12-13)

$$I_{offset} = imax - V_{Expl}G_{Expl}$$

is the linear extrapolated current at $V_{BS(BD)}$ = 0 from V_{Expl}.

Bulk-Junction Bottom (Sidewall) Capacitance

(12-14)

$$C_{BS(BD)} = \begin{cases} \dfrac{cbs(cbd)}{\left(1 - \dfrac{V_{BS(BD)}}{pb}\right)^{mj}} & \text{if } V_{BS(BD)} \le fc \times pb \\ \dfrac{cbs(cbd)}{(1 - fc)^{mj}}\left[1 + \dfrac{mj(V_{BS(BD)} - pb * fc)}{pb(1 - fc)}\right] & \text{otherwise} \end{cases}$$

These equations also apply to the sidewall capacitances with pb and fc replaced by $fcsw$ and $pbsw$. If $fcsw$ is not given, fc is used. If $pbsw$ is not given, pb is used.

Drain and Source Area

The drain and source areas are calculated in the order shown in the following equations:

(12-15)

$$\text{Drain area} = \begin{cases} ad & \text{if } ad \text{ is given} \\ 2hdif * scalem * W_{scaled} & \text{if } hdif \text{ is given} \\ W_{eff} * ld & \text{if } ld \text{ is given} \\ W_{eff} * ldd & \text{if } ldd \text{ is given} \\ 0 & \text{otherwise} \end{cases}$$

(12-16)

$$\text{Source area} = \begin{cases} as & \text{if } as \text{ is given} \\ 2hdif * scalem * W_{scaled} & \text{if } hdif \text{ is given} \\ W_{eff} * ls & \text{if } ls \text{ is given} \\ W_{eff} * lds & \text{if } lds \text{ is given} \\ 0 & \text{otherwise} \end{cases}$$

Note: The ld (length of drain) parameter is an instance parameter that is different from the model parameter ld (lateral diffusion) used in calculating L_{eff}.

Drain and Source Perimeters

The drain and source perimeters are calculated in the order shown in the following equations:

(12-17)

$$\text{Drain perimeter} = \begin{cases} pd & \text{if } pd \text{ is given} \\ 4hdif * scalem + 2W_{scaled} & \text{if } hdif \text{ is given} \\ W_{eff} + 2ld & \text{if } ld \text{ is given} \\ W_{eff} + 2ldd & \text{if } ldd \text{ is given} \\ 0 & \text{otherwise} \end{cases}$$

(12-18)

$$\text{Source perimeter} = \begin{cases} ps & \text{if } ps \text{ is given} \\ 4hdif * scalem + 2W_{scaled} & \text{if } hdif \text{ is given} \\ W_{eff} + 2ls & \text{if } ls \text{ is given} \\ W_{eff} + 2lds & \text{if } lds \text{ is given} \\ 0 & \text{otherwise} \end{cases}$$

Note: The ld (length of drain) parameter is an instance parameter that is different from the model parameter ld (lateral diffusion) used in calculating L_{eff}.

Drain and Source Squares

The number of drain and source squares is calculated in the order shown in the following equations:

(12-19)

$$\text{Number of drain squares} = \begin{cases} nrd & \text{if } nrd \text{ is given} \\ hdif / W_{scaled} & \text{if } hdif \text{ is given} \\ lgcd / W_{eff} & \text{if } lgcd \text{ is given} \\ 0 & \text{otherwise} \end{cases}$$

(12-20)

$$\text{Number of source squares} = \begin{cases} nrs & \text{if } nrs \text{ is given} \\ hdif / W_{scaled} & \text{if } hdif \text{ is given} \\ lgcs / W_{eff} & \text{if } lgcs \text{ is given} \\ 0 & \text{otherwise} \end{cases}$$

Junction Saturation Current

is always overrides js. If you give js but not is, the saturation currents are calculated from js and the source and drain areas.

(12-21)

$$\text{Drain saturation current} = \begin{cases} is & \text{if } is \text{ is given} \\ js*ad & \text{otherwise} \end{cases}$$

(12-22)

$$\text{Source saturation current} = \begin{cases} is & \text{if } is \text{ is given} \\ js*as & \text{otherwise} \end{cases}$$

Junction Capacitance

cbs (cbd) always overrides cj. If you do not give cbs (cbd) and cj is specified, cbs (cbd) is calculated from cj and the source (drain) area.

(12-23)

$$\text{Drain capacitance} = \begin{cases} cbd & \text{if } cbd \text{ is specified} \\ cj*ad & \text{otherwise} \end{cases}$$

(12-24)

$$\text{Source capacitance} = \begin{cases} cbs & \text{if } cbs \text{ is specified} \\ cj*as & \text{otherwise} \end{cases}$$

Drain and Source Parasitic Resistance

For MSOFET models except EKV,

(12-25)

$$\text{Drain Resistance } (R_{Deff}) = \begin{cases} nrd*rsh + \dfrac{rdc}{N_{SC}} + \dfrac{rd(ld + ldif)scalem}{W_{scaled}} & \text{if } ldif \text{ is given} \\ nrd*rsh + \dfrac{rdc}{N_{SC}} + rd + \dfrac{rdd}{W_{eff}} & \text{otherwise} \end{cases}$$

(12-26)

$$\text{Source Resistance } (R_{Seff}) = \begin{cases} nrs*rsh + \dfrac{rsc}{N_{SC}} + \dfrac{rs(ld + ldif)scalem}{W_{scaled}} & \text{if } ldif \text{ is given} \\ nrs*rsh + \dfrac{rsc}{N_{SC}} + rs + \dfrac{rss}{W_{eff}} & \text{otherwise} \end{cases}$$

z

(12-27)

$$N_{SC} = \begin{cases} 1 & \text{if } sc \text{ is infinity or negative (default)} \\ W_{eff} & \text{if } sc = 0 \\ MAX\left[INT\left(\dfrac{W_{eff}}{sc}\right), 1\right] & \text{otherwise} \end{cases}$$

For EKV,

(12-28)

$$\text{Drain Resistance (rdeff)} = \begin{cases} nrd*rsh + \dfrac{rdc}{W_{eff}} + \dfrac{rd(ld + ldif)scalem}{W_{scaled}} & \text{if } ldif \text{ is given} \\ nrd*rsh + \dfrac{rdc}{W_{eff}} + rd + \dfrac{rdd}{Width} & \text{otherwise} \end{cases}$$

(12-29)

$$\text{Source Resistance (rseff)} = \begin{cases} nrs*rsh + \dfrac{rsc}{W_{eff}} + \dfrac{rs(ld + ldif)scalem}{W_{scaled}} & \text{if } ldif \text{ is given} \\ nrs*rsh + \dfrac{rsc}{W_{eff}} + rs + \dfrac{rdd}{Width} & \text{otherwise} \end{cases}$$

Overlap Capacitance

(12-30)

$$C_{gd} = \begin{cases} \text{cgdo/scalem}*W_{eff} & \text{if } cgdo \text{ is given} \\ W_{scaled}(ld + meto)\text{scalem}*C_{ox} & \text{if } meto \text{ is given} \end{cases}$$

(12-31)

$$C_{gs} = \begin{cases} \text{cgso/scalem}*W_{eff} & \text{if } cgso \text{ is given} \\ W_{scaled}(ld + meto)\text{scalem}*C_{ox} & \text{if } meto \text{ is given} \end{cases}$$

(12-32)

$$C_{gb} = \begin{cases} cgbo/scalem*L_{eff} & \text{if } cgbo \text{ is given} \\ 2L_{eff}(ld + meto)\text{scalem}*C_{ox} & \text{if } meto \text{ is given} \end{cases}$$

where

(12-33)

$$C_{ox} = \frac{\varepsilon_{ox}}{tox*scalem}$$

Temperature Effect on Model Parameters

You can set both the model and the instance temperatures with the $trise$ parameter. If the instance $trise$ is specified, it overrides the model $trise$. The device temperature T is calculated by

(12-34)

$$T = trise + T_{ambient}$$

where $T_{ambient}$ is the global temperature set by the simulator.

Mobility and Transconductance Parameters

(12-35)

$$uo = uo_{nom}\left(\frac{T}{Tnom}\right)^{ute}$$

(12-36)

$$kp = kp_{nom}\left(\frac{T}{Tnom}\right)^{ute}$$

where ute is the exponent parameter. Default value of ute is `-1.5`.

Energy Band Gap

(12-37)

$$E_g(T) = \begin{cases} eg - \dfrac{gap1 * T^2}{T + gap2} & \text{if } tlev = 2 \\ \left(1.17 - \dfrac{4.73 \times 10^{-4} T^2}{T + 636}\right) & \text{if } tlev = 0 \text{ or } 1 \text{ and } compatible{=}spectre \\ \left(1.16 - \dfrac{7.02 \times 10^{-4} T^2}{T + 1108}\right) & \text{otherwise} \end{cases}$$

Surface Potential

(12-38)

$$phi(T) = \begin{cases} phi_{nom}\left(\frac{T}{Tnom}\right) - \Delta\phi & \text{if } tlevc = 0 \\ phi_{nom} - ptc\Delta T & \text{if } tlevc = 1 \text{ or } 2 \\ phi_{nom} - \frac{d\phi}{dT}\Delta T & \text{if } tlevc = 3 \end{cases}$$

where

(12-39)

$$\Delta\phi = V_t(T)\left\{3\ \ln\left[\frac{T}{Tnom}\right] + \frac{E_{g,\,nom}}{V_{t,\,nom}} - \frac{E_g(T)}{V_t(T)}\right\}$$

(12-40)

$$E_{g,\,nom} = E_g(Tnom)$$

(12-41)

$$V_{t,\,nom} = \frac{k(Tnom)}{q}$$

(12-42)

$$\Delta T = T - Tnom$$

(12-43)

$$n_i = 1.45 \times 10^{10}\left(\frac{T}{300}\right)^{1.5} \exp\left[\frac{1.12}{0.0516} - \frac{E_g(T)}{2V_t(T)}\right]$$

(12-44)

$$\frac{d\phi}{dT} = \begin{cases} \dfrac{-\left[\Delta E_{phi} + (1.16 - E_{g,\,nom}) * \left(2 - \dfrac{Tnom}{Tnom + 1108}\right)\right]}{Tnom} & \text{if } tlev = 0,\ 1 \\[2em] \dfrac{-\left[\Delta E_{phi} + (eg - E_{g,\,nom}) * \left(2 - \dfrac{Tnom}{Tnom + gap2}\right)\right]}{Tnom} & \text{if } tlev = 2 \end{cases}$$

where

(12-45) $$\Delta E_{phi} = E_{g,\,nom} + 3V_{t,\,nom} - phi_{nom}$$

Built-in Voltage of Source/Drain Junctions

If $tlevc$ = 0,

(12-46)

$$pb(T) = pb_{nom}\left(\frac{T}{Tnom}\right) - \Delta\phi$$

(12-47)

$$pbsw(T) = pbsw_{nom}\left(\frac{T}{Tnom}\right) - \Delta\phi$$

If $tlevc$ = 1,2,

(12-48)

$$pb(T) = pb_{nom} - pta\Delta T$$

(12-49)

$$pbsw(T) = pbsw_{nom} - ptp\Delta T$$

If $tlevc$ = 3,

(12-50)

$$pb(T) = pb_{nom} + \left(\frac{d\phi_B}{dT}\right)\Delta T$$

(12-51)

$$pbsw(T) = pbsw_{nom} + \left(\frac{d\phi_{sw}}{dT}\right)\Delta T$$

where

(12-52)

$$\frac{d\phi_B}{dT} = \begin{cases} \dfrac{-\left[\Delta E_{PB} + (1.16 - E_{g,\,nom}) * \left(2 - \dfrac{Tnom}{Tnom + 1108}\right)\right]}{Tnom} & \text{if } tlev = 0,\ 1 \\ \dfrac{-\left[\Delta E_{PB} + (eg - E_{g,\,nom}) * \left(2 - \dfrac{Tnom}{Tnom + gap2}\right)\right]}{Tnom} & \text{if } tlev = 2 \end{cases}$$

(12-53)

$$\frac{d\phi_{BSW}}{dT} = \begin{cases} \dfrac{-\left[\Delta E_{PBSW} + (1.16 - E_{g,\,nom}) * \left(2 - \dfrac{Tnom}{Tnom + 1108}\right)\right]}{Tnom} & \text{if } tlev = 0,\ 1 \\ \dfrac{-\left[\Delta E_{PBSW} + (eg - E_{g,\,nom}) * \left(2 - \dfrac{Tnom}{Tnom + gap2}\right)\right]}{Tnom} & \text{if } tlev = 2 \end{cases}$$

where

(12-54)

$$\Delta E_{PB} = E_{g,\,nom} + 3V_{t,\,nom} - pb_{nom}$$

(12-55)

$$\Delta E_{PBSW} = E_{g,\,nom} + 3V_{t,\,nom} - pbsw_{nom}$$

Junction Leakage Currents

(12-56)

$$is(T) = is_{nom}e^{Fact/n}$$

(12-57)

$$js(T) = js_{nom}e^{Fact/n}$$

where

(12-58)

$$Fact = \frac{E_{g,\,nom}}{V_{t,\,nom}} - \frac{E_g(T)}{V_t} + xti\ \ln\left[\frac{T}{Tnom}\right]$$

Junction Capacitances

If $tlevc = 0$

(12-59)

$$cbd(T) = cbd_{nom}\left[1 + mj\left(0.0004\Delta T - \frac{pb(T)}{pb_{nom}} + 1\right)\right]$$

(12-60)

$$cbs(T) = cbs_{nom}\left[1 + mj\left(0.0004\Delta T - \frac{pb(T)}{pb_{nom}} + 1\right)\right]$$

(12-61)

$$cj(T) = cj_{nom}\left[1 + mj\left(0.0004\Delta T - \frac{pb(T)}{pb_{nom}} + 1\right)\right]$$

(12-62)

$$cjsw(T) = cjsw_{nom}\left[1 + mjsw\left(0.0004\Delta T - \frac{pbsw(T)}{pbsw_{nom}} + 1\right)\right]$$

If $tlevc = 1$

(12-63)

$$cbd(T) = cbd_{nom}(1 + cta\Delta T)$$

(12-64)

$$cbs(T) = cbs_{nom}(1 + cta\Delta T)$$

(12-65)

$$cj(T) = cj_{nom}(1 + cta\Delta T)$$

(12-66)

$$cjsw(T) = cjsw_{nom}(1 + ctp\Delta T)$$

If $tlevc = 2$,

(12-67)

$$cbd(T) = cbd_{nom}\left(\frac{pb_{nom}}{pb(T)}\right)^{mj}$$

(12-68)

$$cbs(T) = cbs_{nom}\left(\frac{pb_{nom}}{pb(T)}\right)^{mj}$$

(12-69)

$$cj(T) = cj_{nom}\left(\frac{pb_{nom}}{pb(T)}\right)^{mj}$$

(12-70)

$$cjsw(T) = cjsw_{nom}\left(\frac{pbsw_{nom}}{pbsw(T)}\right)^{mjsw}$$

If $tlevc = 3$,

(12-71)

$$cbd(T) = cbd_{nom}\left[1 - 0.5\left(\frac{d\phi_B}{dT}\right)\left(\frac{\Delta T}{pb_{nom}}\right)\right]$$

(12-72)

$$cbs(T) = cbs_{nom}\left[1 - 0.5\left(\frac{d\phi_B}{dT}\right)\left(\frac{\Delta T}{pb_{nom}}\right)\right]$$

(12-73)

$$cj(T) = cj_{nom}\left[1 - 0.5\left(\frac{d\phi_B}{dT}\right)\left(\frac{\Delta T}{pb_{nom}}\right)\right]$$

(12-74)

$$cjsw(T) = cjsw_{nom}\left[1 - 0.5\left(\frac{d\phi_{SW}}{dT}\right)\left(\frac{\Delta T}{pbsw_{nom}}\right)\right]$$

Channel Length Modulation

(12-75)

$$lambda(T) = lambda_{nom}(1 + lamex\Delta T)$$

(12-76)

$$kappa(T) = kappa_{nom}(1 + lamex\Delta T)$$

Threshold Voltage

If $tlev = 0$,

(12-77)

$$V_{bi}(T) = vto_{nom} - gamma\sqrt{phi_{nom}} + \frac{phi(T) - phi_{nom}}{2} + \frac{E_{g,nom} - E_g(T)}{2}$$

(12-78)

$$vto(T) = V_{bi}(T) + gamma\sqrt{phi(T)}$$

If $tlev = 1$,

(12-79)

$$vto(T) = vto_{nom} - tcv\Delta T$$

Note: tcv is negative.

(12-80)

$$V_{bi}(T) = vto(T) - gamma\sqrt{phi(T)}$$

If $tlev = 2$,

(12-81)

$$vto(T) = vto_{nom} + \left(1 + \frac{gamma}{2\sqrt{phi_{nom}}}\right)\frac{d\phi}{dT}\Delta T$$

(12-82)

$$V_{bi}(T) = vto(T) - gamma\sqrt{phi(T)}$$

Drain and Source Parasitic Resistance

(12-83)

$$rd(T) = rd_{nom}(1 + trd\Delta T)$$

(12-84)

$$rs(T) = rs_{nom}(1 + trs\Delta T)$$

Critical Field

(12-85)

$$ucrit(T) = ucrit_{nom}\left(\frac{T}{Tnom}\right)^{f1ex}$$

Noise Model

This section contains model equations for the noise model.

Drain Resistance Thermal Noise

(12-86)

$$\overline{i^2_{Rd}} = \frac{4kT}{R_d}\Delta f$$

Source Resistance Thermal Noise

(12-87)

$$\overline{i^2_{Rs}} = \frac{4kT}{R_s}\Delta f$$

Channel Thermal and Flicker Noise

(12-88)

$$\overline{i^2_{DS}} = \overline{i^2_{n,\ thermal}} + \frac{kf I^{af}_{DS}\Delta f}{C_{ox} W_{eff} L_{eff} f^{ef}}$$

where

(12-89)

$$\overline{i^2_{n,\ thermal}} = \frac{8kT(g_m + g_{mb} + g_{ds})\Delta f}{3}\left[\frac{3}{2} - \frac{V'_{DS}}{2V_{DSAT}}\right]$$

(12-90)

$$V'_{DS} = MIN(V_{DS}, V_{DSAT})$$

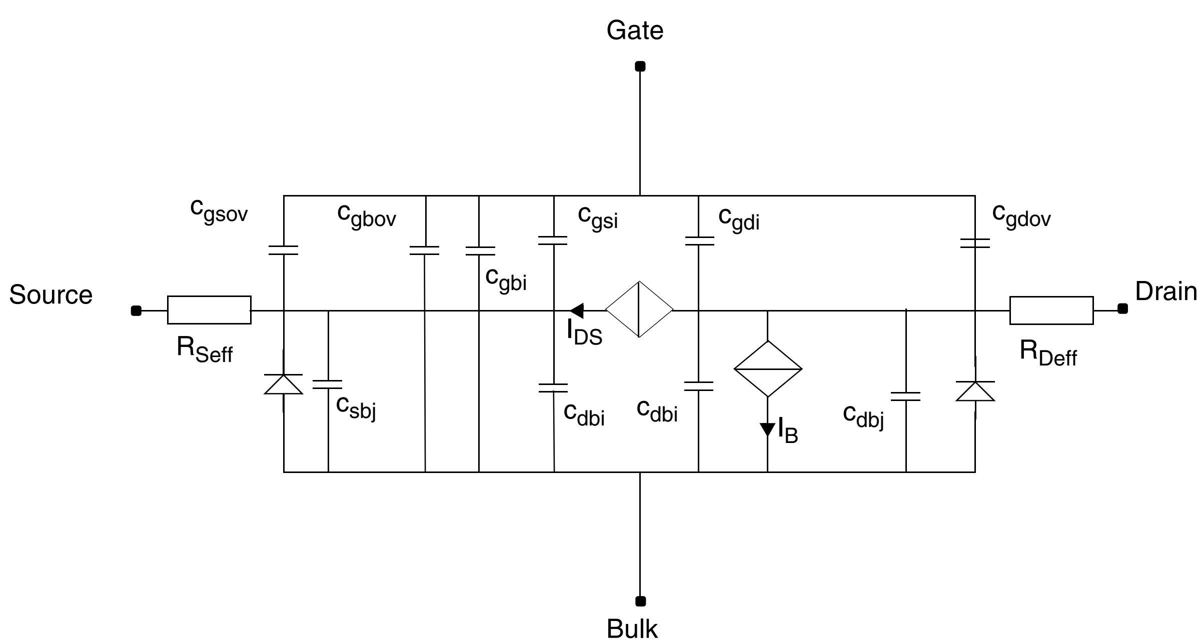
g_m is the transconductance, g_{ds} is the channel conductance, and g_{mb} is the body transconductance. The Spectre® circuit simulator default values for kf, af, and ef are 0.0, 1.0, and 1.0, respectively.

13

MOS Capacitance Model

This chapter contains model equations for the MOS capacitance model, including the following:

- Modified Meyer Model on page 976
- Yang-Chatterjee Model on page 980
- BSIM Charge Model with 0/100 Partitioning (xpart=1) on page 983
- BSIM Charge Model with 40/60 Partitioning (xpart=0) on page 983
- BSIM Charge Model with 50/50 Partitioning (xpart=0.5) on page 987
- Scaling Effects on page 990



The Virtuoso® Spectre® circuit simulator has three charge-based MOS capacitance models that you can select with the model parameter `capmod`:

- The modified Meyer model

  The modified Meyer model is a first-order model with 40/60 channel charge partitioning in the saturation region. This model does not include any short-channel effects.

- The Yang-Chatterjee model

  The Yang-Chatterjee model uses a 0/100 channel charge partitioning method and includes some short-channel effects.

- The BSIM charge model

  The BSIM charge model provides three methods for partitioning. You choose the method you want with the `xpart` parameter:

  - 40/60 for `xpart = 0` (or `xpart < 0.5`)

    For `xpart = 0`, the BSIM charge model is similar to the modified Meyer model, but it includes short-channel effects.

  - 50/50 for `xpart = 0.5`

  - 0/100 for `xpart = 1.0` (or `xpart > 0.5`)

    For `xpart = 1`, the BSIM charge model is identical to the Yang-Chatterjee model.

Modified Meyer Model

$$V_{TH} = V_{FB} + phi + gamma\sqrt{phi - V_{BS}}$$

$$V_{DSAT} = V_{GS} - V_{TH}$$

$$V_{GST} = V_{GS} - V_{TH}$$

$$V_{GDT} = V_{GS} - V_{TH} - V_{DS}$$

$$C_o = C_{ox} W_{eff} L_{eff}$$

$$C_{ij} \equiv \frac{dQ_i}{dV_j} \qquad i, j = g, d, s, b$$

Accumulation Region

Note: These equations apply when $V_{GS} - V_{BS} \le V_{FB}$.

$$C_{gg} = C_{bb} = C_o$$

$$C_{gb} = C_{bg} = -C_o$$

All other capacitances are zero.

Subthreshold Region

Note: These equations apply when $V_{GS} \le V_{TH}$.

$$C_{gg} = C_{bb} = \frac{C_o gamma}{2\sqrt{\left(\frac{gamma}{2}\right)^2 + V_{GS} - V_{BS} - V_{FB}}}$$

$$C_{gb} = C_{bg} = -C_{gg}$$

All other capacitances are zero.

Saturation Region

These equations apply when $V_{GS} \ge V_{TH}$ and $V_{DS} \ge V_{DSAT}$.

$$C_{gg} = \frac{2}{3}C_o$$

$$C_{gb} = \frac{1}{3}C_o\frac{dV_{TH}}{dV_{BS}}$$

$$C_{gs} = -(C_{gg} + C_{gb})$$

$$C_{bb} = -C_o \frac{dV_{TH}}{dV_{BS}}$$

$$C_{bs} = -C_{bb}$$

$$C_{dg} = -\frac{4}{15} C_o$$

$$C_{db} = \frac{4}{15} C_o \frac{dV_{TH}}{dV_{BS}}$$

$$C_{ds} = -(C_{dg} + C_{db})$$

$$C_{sg} = -\frac{6}{15} C_o$$

$$C_{sb} = \frac{6}{15} C_o \frac{dV_{TH}}{dV_{BS}}$$

$$C_{ss} = -(C_{sg} + C_{sb})$$

All other capacitances are zero.

Triode Region

Note: These equations apply when $V_{GS} \geq V_{TH}$ and $V_{DS} \leq V_{DSAT}$.

$$C_{gg} = \frac{2}{3} C_o \left[1 + \frac{2V_{GST}V_{GDT}}{(V_{GST} + V_{GDT})^2}\right]$$

$$C_{gd} = -\frac{2}{3} C_o \left[1 - \frac{V_{GST}^2}{(V_{GST} + V_{GDT})^2}\right]$$

$$C_{gb} = \frac{1}{3}C_o\left[1 - \frac{4V_{GST}V_{GDT}}{(V_{gst} + V_{GDT})^2}\right]$$

$$C_{gs} = -(C_{gg} + C_{gd} + C_{gb})$$

$$C_{bb} = -C_o\frac{dV_{TH}}{dV_{BS}}$$

$$C_{bs} = -C_{bb}$$

$$C_{dg} = -\frac{1}{3}C_o\left[1 + \frac{2V_{GST}V_{GDT}}{(V_{GST} + V_{GDT})^2} + \frac{1}{5}\frac{(V_{GDT} - V_{GST})^3}{(V_{GST} + V_{GDT})^3}\right]$$

$$C_{dd} = \frac{2}{15}C_o\left[3 - \left(\frac{V_{GST}^2}{(V_{GST} + V_{GDT})^2} - \frac{2V_{GST}^3}{(V_{GST} + V_{GDT})^3}\right)\right]$$

$$C_{db} = \frac{1}{3}C_o\frac{dV_{TH}}{dV_{BS}}\left[1 + 2V_{GST}V_{GDT}(V_{GST} + V_{GDT})^2 + \frac{1}{5}\frac{(V_{GDT} - V_{GST})^3}{(V_{GST} + V_{GDT})^3}\right]$$

$$C_{ds} = -(C_{dg} + C_{dd} + C_{ds})$$

$$C_{sg} = -(C_{gg} + C_{dg}) = -\frac{1}{3}C_o\left[1 + \frac{2V_{GST}V_{GDT}}{(V_{GST} + V_{GDT})^2} + \frac{1}{5}\frac{(V_{GST} - V_{GDT})^3}{(V_{GST} + V_{GDT})^3}\right]$$

$$C_{sg} = -(C_{gg} + C_{dg}) = \frac{4}{15}C_o\left(\frac{V_{GDT}}{(V_{GST} + V_{GDT})}\left[1 + \frac{V_{GST}V_{GDT}}{(V_{GST} + V_{GDT})^2}\right]\right)$$

$$C_{sb} = -(C_{gs} + C_{db} + C_{bb}) = \frac{1}{3}C_o\frac{dV_{TH}}{dV_{BS}}\left[1 + \frac{2V_{GST}V_{GDT}}{(V_{GST} + V_{GDT})^2} + \frac{1}{5}\frac{(V_{GST} - V_{GDT})^3}{(V_{GST} + V_{GDT})^3}\right]$$

$$C_{ss} = -(C_{gs} + C_{ds} + C_{bs}) = -(C_{sg} + C_{sd} + C_{sb})$$

Yang-Chatterjee Model

$$V_{TH} = V_{FB} + phi + gamma\sqrt{phi - V_{BS}}$$

$$V_{GST} = V_{GS} - V_{TH}$$

$$V_{GDT} = V_{GS} - V_{TH} - V_{DS}$$

$$C_o = C_{ox} W_{eff} L_{eff}$$

$$\alpha_x = \frac{V_{GST}}{V_{DSAT}}$$

$$C_{ij} \equiv \frac{dQ_i}{dV_j} \qquad i, j = g, d, s, b$$

Accumulation Region

Note: These equations apply when $V_{GS} - V_{BS} \le V_{FB}$.

$$C_{gg} = C_{bb} = C_o$$

$$C_{gb} = C_{bg} = -C_o$$

All other capacitances are zero.

Subthreshold Region

Note: These equations apply when $V_{GS} \le V_{TH}$.

$$C_{gg} = C_{bb} = \frac{C_o gamma}{2\sqrt{\left(\frac{gamma}{2}\right)^2 + V_{GS} - V_{BS} - V_{FB}}}$$

$$C_{gb} = C_{bg} = -C_{gg}$$

All other capacitances are zero.

Saturation Region

Note: These equations apply when $V_{GS} \geq V_{TH}$ and $V_{DS} \geq V_{DSAT}$.

$$C_{gg} = C_o\left[1 - \frac{1}{3\alpha_x} + \frac{V_{GST}}{3\alpha_x^2}\frac{d\alpha_x}{dV_{GS}}\right]$$

$$C_{gb} = C_o\left[\frac{1}{3\alpha_x}\frac{dV_{TH}}{dV_{BS}} + \frac{V_{GST}}{3\alpha_x^2}\frac{d\alpha_x}{dV_{BS}}\right]$$

$$C_{gs} = -(C_{gg} + C_{gb})$$

$$C_{bg} = C_o\left[\frac{V_{GST}}{3\alpha_x}\frac{d\alpha_x}{dV_{GS}} - \frac{(1-\alpha_x)}{3\alpha_x} + \frac{(1-\alpha_x)V_{GST}}{3\alpha_x^2}\frac{d\alpha_x}{dV_{GS}}\right]$$

$$C_{bb} = C_o\left[-\frac{dV_{TH}}{dV_{BS}} + \frac{V_{GST}}{3\alpha_x}\frac{d\alpha_x}{dV_{BS}} + \frac{(1-\alpha_x)}{3\alpha_x}\frac{d\alpha_x}{dV_{BS}} + \frac{(1-\alpha_x)V_{GST}}{3\alpha_x^2}\frac{d\alpha_x}{dV_{BS}}\right]$$

$$C_{bs} = -(C_{bg} + C_{bb})$$

$$C_{sg} = -\frac{2}{3}C_o$$

$$C_{sb} = \frac{2}{3}C_o\frac{dV_{TH}}{dV_{BS}}$$

$$C_{ss} = -(C_{sg} + C_{sb})$$

All other capacitances are zero.

Triode Region

Note: These equations apply when $V_{GS} \geq V_{TH}$ and $V_{DS} \leq V_{DSAT}$.

$$Fac \equiv \left(V_{GST} - \frac{1}{2}\alpha_x V_{DS}\right)$$

$$C_{gg} = C_o\left[1 + \frac{V_{DS}^2}{12Fac}\frac{d\alpha_x}{dV_{GS}} - \frac{\alpha_x V_{DS}^2}{12Fac^2}\left(1 - \frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{GS}}\right)\right]$$

$$C_{gd} = C_o\left[-\frac{1}{2} + \frac{V_{DS}^2}{12Fac}\frac{d\alpha_x}{dV_{DS}} + \frac{\alpha_x V_{DS}}{6Fac} + \frac{\alpha_x^2 V_{DS}^2}{24Fac^2}\right]$$

$$C_{gb} = Co\left[\frac{V_{DS}^2}{12Fac}\frac{d\alpha_x}{dV_{BS}} + \frac{\alpha_x V_{DS}^2}{12Fac^2}\left(\frac{dV_{TH}}{dV_{BS}} + \frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{BS}}\right)\right]$$

$$C_{gs} = -(C_{gg} + C_{gd} + C_{gb})$$

$$C_{bg} = C_o\left[-\frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{GS}} - \frac{(1-2\alpha_x)V_{DS}^2}{12Fac}\frac{d\alpha_x}{dV_{GS}} + \frac{(1-\alpha_x)\alpha_x V_{DS}^2}{12Fac^2}\left(1 - \frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{GS}}\right)\right]$$

$$C_{bb} = C_o\left[-\frac{dV_{TH}}{dV_{BS}} - \frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{BS}} - \frac{(1-2\alpha_x)V_{DS}^2}{12Fac}\frac{d\alpha_x}{dV_{BS}} - \frac{(1-\alpha_x)\alpha_x V_{DS}^2}{12Fac^2}\left(\frac{dV_{TH}}{dV_{BS}} + \frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{BS}}\right)\right]$$

$$C_{bd} = C_o\left[\frac{(1-\alpha_x)}{2} - \frac{(1-\alpha_x)\alpha_x V_{DS}}{6Fac} - \frac{(1-\alpha_x)\alpha_x^2 V_{DS}^2}{24Fac^2}\right]$$

$$C_{bs} = -(C_{bg} + C_{bd} + C_{bb})$$

$$C_{dg} = -C_o\left[\frac{1}{2} - \frac{V_{DS}}{4}\left(3 - \frac{\alpha_x V_{DS}}{Fac}\right)\frac{d\alpha_x}{dV_{GS}} - \frac{\alpha_x^2 V_{DS}^2}{8Fac}\left(1 - \frac{V_{DS}}{2}\right)d\alpha_x dV_{GS}\right]$$

$$C_{db} = -C_o\left[-\frac{1}{2}\frac{dV_{TH}}{dV_{BS}} - \frac{V_{DS}}{4}\left(3 - \frac{\alpha_x V_{DS}}{Fac}\right)\frac{d\alpha_x}{dV_{BS}} - \frac{\alpha_x^2 V_{DS}^2}{8Fac}\left(1 - \frac{V_{DS}}{2}\right)\frac{d\alpha_x}{dV_{BS}}\right]$$

$$C_{dd} = -C_o\left[-\frac{3}{4}\alpha_x + \frac{\alpha_x^2 V_{DS}}{4Fac} + \frac{\alpha_x^3 V_{DS}^2}{16Fac^2}\right]$$

$$C_{ds} = -(C_{dg} + C_{dd} + C_{ds})$$

$$C_{sg} = -(C_{gg} + C_{dg} + C_{bg})$$

$$C_{sd} = -(C_{gd} + C_{dd} + C_{bd})$$

$$C_{sb} = -(C_{gb} + C_{db} + C_{bb})$$

$$C_{ss} = -(C_{gs} + C_{ds} + C_{bs})$$

BSIM Charge Model with 0/100 Partitioning (xpart=1)

This model is the same as the Yang-Chatterjee model.

BSIM Charge Model with 40/60 Partitioning (xpart=0)

$$V_{TH} = V_{FB} + phi + gamma\sqrt{phi - V_{BS}}$$

$$V_{GST} = V_{GS} - V_{TH}$$

$$V_{GDT} = V_{GS} - V_{TH} - V_{DS}$$

$$C_o = C_{ox}W_{eff}L_{eff}$$

$$\alpha_x = \frac{V_{GST}}{V_{DSAT}}$$

$$C_{ij} \equiv \frac{dQ_i}{dV_j} \qquad i, j = g, d, s, b$$

Accumulation Region

Note: These equations apply when $V_{GS} - V_{BS} \le V_{FB}$.

$$C_{gg} = C_{bb} = C_o$$

$$C_{gb} = C_{bg} = -C_o$$

All other capacitances are zero.

Subthreshold Region

Note: These equations apply when $V_{GS} \le V_{TH}$.

$$C_{gg} = C_{bb} = \frac{C_o gamma}{2\sqrt{\left(\frac{gamma}{2}\right)^2 + V_{GS} - V_{BS} - V_{FB}}}$$

$$C_{gb} = C_{bg} = -C_{gg}$$

All other capacitances are zero.

Saturation Region

Note: These equations apply when $V_{GS} \ge V_{TH}$ and $V_{DS} \ge V_{DSAT}$.

$$C_{gg} = C_o\left[1 - \frac{1}{3\alpha_x} + \frac{V_{GST}}{3\alpha_x^2}\frac{d\alpha_x}{dV_{GS}}\right]$$

$$C_{gb} = C_o\left[\frac{1}{3\alpha_x}\frac{dV_{TH}}{dV_{BS}} + \frac{V_{GST}}{3\alpha_x^2}\frac{d\alpha_x}{dV_{BS}}\right]$$

$$C_{gs} = -(C_{gg} + C_{gb})$$

$$C_{bg} = C_o\left[\frac{V_{GST}}{3\alpha_x}\frac{d\alpha_x}{dV_{gs}} - \frac{(1-\alpha_x)}{3\alpha_x} + \frac{(1-\alpha_x)V_{GST}}{3\alpha_x^2}\frac{d\alpha_x}{dV_{GS}}\right]$$

$$C_{bb} = C_o\left[-\frac{dV_{TH}}{dV_{BS}} + \frac{V_{GST}}{3\alpha_x}\frac{d\alpha_x}{dV_{BS}} + \frac{(1-\alpha_x)}{3\alpha_x}\frac{d\alpha_x}{dV_{BS}} + \frac{(1-\alpha_x)V_{GST}}{3\alpha_x^2}\frac{d\alpha_x}{dV_{BS}}\right]$$

$$C_{bs} = -(C_{bg} + C_{bb})$$

$$C_{sg} = -\frac{6}{15}C_o$$

$$C_{sb} = \frac{6}{15}C_o\frac{dV_{TH}}{dV_{BS}}$$

$$C_{ss} = -(C_{sg} + C_{sb})$$

$$C_{dg} = -\frac{4}{15}C_o$$

$$C_{db} = \frac{4}{15}C_o\frac{dV_{TH}}{dV_{BS}}$$

$$C_{ds} = -(C_{dg} + C_{db})$$

All other capacitances are zero.

Triode Region

Note: These equations apply when $V_{GS} \geq V_{TH}$ and $V_{DS} \leq V_{DSAT}$.

$$Fac \equiv (2V_{DSAT} - V_{DS})$$

$$C_{gg} = C_o\left[1 + \frac{V_{DS}^2}{6\alpha_x Fac}\frac{d\alpha_x}{dV_{GS}} - \frac{V_{DS}^2}{3\alpha_x Fac^2}\left(1 - \frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{GS}}\right)\right]$$

$$C_{gd} = C_o\left[-\frac{1}{2} + \frac{V_{DS}^2}{6\alpha_x Fac}\frac{d\alpha_x}{dV_{DS}} + \frac{V_{DS}}{3Fac} + \frac{V_{DS}^2}{6Fac^2}\right]$$

$$C_{gb} = Co\left[\frac{V_{DS}^2}{6\alpha_x Fac}\frac{d\alpha_x}{dV_{BS}} + \frac{V_{DS}^2}{3\alpha_x Fac^2}\left(\frac{dV_{TH}}{dV_{BS}} + \frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{BS}}\right)\right]$$

$$C_{gs} = -(C_{gg} + C_{gd} + C_{gb})$$

$$C_{bg} = C_o\left[-\frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{GS}} - \frac{(1-2\alpha_x)V_{DS}^2}{6\alpha_x Fac}\frac{d\alpha_x}{dV_{GS}} + \frac{(1-\alpha_x)V_{DS}^2}{3\alpha_x Fac^2}\left(1 - \frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{GS}}\right)\right]$$

$$C_{bd} = C_o\left[\frac{(1-\alpha_x)}{2} - \frac{(1-\alpha_x)V_{DS}}{3Fac} - \frac{(1-\alpha_x)V_{DS}^2}{12Fac^2}\right]$$

$$C_{bs} = -(C_{bg} + C_{bd} + C_{bb})$$

$$C_{dg} = -\frac{C_o}{4}\left[2V_{DSAT} - 2V_{DS} + \frac{V_{DS}}{3Fac^2}\left(8V_{DSAT}^2 - 6V_{DSAT}V_{DS} + \frac{6}{5}V_{DS}^2\right)\right]\frac{d\alpha_x}{dV_{GS}}$$
$$-\frac{\alpha_x}{4}C_o\left[2 - \frac{4V_{DS}}{3Fac^3}\left(8V_{DSAT}^2 - 6V_{DSAT}V_{DS} + \frac{6}{5}V_{DS}^2\right) + \frac{V_{DS}(16V_{DSAT} - 6V_{DS})}{3Fac^2}\right]\frac{dV_{DSAT}}{dV_{GS}}$$

$$C_{db} = -\frac{C_o}{4}\left[2V_{DSAT} - 2V_{DS} + \frac{V_{DS}}{3Fac^2}\left(8V_{DSAT}^2 - 6V_{DSAT}V_{DS} + \frac{6}{5}V_{DS}^2\right)\right]\frac{d\alpha_x}{dV_{BS}}$$
$$-\frac{\alpha_x}{4}C_o\left[2 - \frac{4V_{DS}}{3Fac^3}\left(8V_{DSAT}^2 - 6V_{DSAT}V_{DS} + \frac{6}{5}V_{DS}^2\right) + \frac{V_{DS}(16V_{DSAT} - 6V_{DS})}{3Fac^2}\right]\frac{dV_{DSAT}}{dV_{BS}}$$

$$C_{dd} = \frac{\alpha_x}{4} C_o \left[\left(2 + \left(\frac{1}{3Fac^2} + \frac{2V_{DS}}{3Fac^3} \right) \left(8V_{DSAT}^2 - 6V_{DSAT}V_{DS} + \frac{6}{5}V_{DS}^2 \right) \right) + \frac{V_{DS}\left(\frac{12}{5}V_{DS} - 6V_{DSAT} \right)}{3Fac^2} \right]$$

$$C_{ds} = -(C_{dg} + C_{dd} + C_{ds})$$

$$C_{sg} = -(C_{gg} + C_{dg} + C_{bg})$$

$$C_{sd} = -(C_{gd} + C_{dd} + C_{bd})$$

$$C_{sb} = -(C_{gb} + C_{db} + C_{bb})$$

$$C_{ss} = -(C_{gs} + C_{ds} + C_{bs})$$

BSIM Charge Model with 50/50 Partitioning (xpart=0.5)

$$V_{TH} = V_{FB} + phi + gamma\sqrt{phi - V_{BS}}$$

$$V_{GST} = V_{GS} - V_{TH}$$

$$V_{GDT} = V_{GS} - V_{TH} - V_{DS}$$

$$C_o = C_{ox} W_{eff} L_{eff}$$

$$\alpha_x = \frac{V_{GST}}{V_{DSAT}}$$

$$C_{ij} \equiv \frac{dQ_i}{dV_j} \qquad i, j = g, d, s, b$$

Accumulation Region

Note: These equations apply when $V_{GS} - V_{BS} \le V_{FB}$.

$$C_{gg} = C_{bb} = C_o$$

$$C_{gb} = C_{bg} = -C_o$$

All other capacitances are zero.

Subthreshold Region

Note: These equations apply when $V_{GS} \le V_{TH}$.

$$C_{gg} = C_{bb} = \frac{C_o gamma}{2\sqrt{\left(\frac{gamma}{2}\right)^2 + V_{GS} - V_{BS} - V_{FB}}}$$

$$C_{gb} = C_{bg} = -C_{gg}$$

All other capacitances are zero.

Saturation Region

Note: These equations apply when $V_{GS} \ge V_{TH}$ and $V_{DS} \ge V_{DSAT}$.

$$C_{gg} = C_o\left[1 - \frac{1}{3\alpha_x} + \frac{V_{GST}}{3\alpha_x^2}\frac{d\alpha_x}{dV_{GS}}\right]$$

$$C_{gb} = C_o\left[\frac{1}{3\alpha_x}\frac{dV_{TH}}{dV_{BS}} + \frac{V_{GST}}{3\alpha_x^2}\frac{d\alpha_x}{dV_{BS}}\right]$$

$$C_{gs} = -(C_{gg} + C_{gb})$$

$$C_{bg} = C_o\left[\frac{V_{GST}}{3\alpha_x}\frac{d\alpha_x}{dV_{gs}} - \frac{(1-\alpha_x)}{3\alpha_x} + \frac{(1-\alpha_x)V_{GST}}{3\alpha_x^2}\frac{d\alpha_x}{dV_{GS}}\right]$$

$$C_{bb} = C_o\left[-\frac{dV_{TH}}{dV_{BS}} + \frac{V_{GST}}{3\alpha_x}\frac{d\alpha_x}{dV_{BS}} + \frac{(1-\alpha_x)}{3\alpha_x}\frac{d\alpha_x}{dV_{BS}} + \frac{(1-\alpha_x)V_{GST}}{3\alpha_x^2}\frac{d\alpha_x}{dV_{BS}}\right]$$

$$C_{bs} = -(C_{bg} + C_{bb})$$

$$C_{sg} = C_{dg} = -\frac{1}{3}C_o$$

$$C_{sb} = C_{db} = \frac{1}{3}C_o\frac{dV_{TH}}{dV_{BS}}$$

$$C_{ss} = C_{ds} = -(C_{sg} + C_{sb})$$

All other capacitances are zero.

Triode Region

Note: These equations apply when $V_{GS} \geq V_{TH}$ and $V_{DS} \leq V_{DSAT}$.

$$Fac \equiv (2V_{DSAT} - V_{DS})$$

$$C_{gg} = C_o\left[1 + \frac{V_{DS}^2}{6\alpha_x Fac}\frac{d\alpha_x}{dV_{GS}} - \frac{V_{DS}^2}{3\alpha_x Fac^2}\left(1 - \frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{GS}}\right)\right]$$

$$C_{gd} = C_o\left[-\frac{1}{2} + \frac{V_{DS}^2}{6\alpha_x Fac}\frac{d\alpha_x}{dV_{DS}} + \frac{V_{DS}}{3Fac} + \frac{V_{DS}^2}{6Fac^2}\right]$$

$$C_{gb} = C_o\left[\frac{V_{DS}^2}{6\alpha_x Fac}\frac{d\alpha_x}{dV_{BS}} + \frac{V_{DS}^2}{3\alpha_x Fac^2}\left(\frac{dV_{TH}}{dV_{BS}} + \frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{BS}}\right)\right]$$

$$C_{gs} = -(C_{gg} + C_{gd} + C_{gb})$$

$$C_{bg} = C_o\left[-\frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{GS}} - \frac{(1-2\alpha_x)V_{DS}^2}{6\alpha_x Fac}\frac{d\alpha_x}{dV_{GS}} + \frac{(1-\alpha_x)V_{DS}^2}{3\alpha_x Fac^2}\left(1 - \frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{GS}}\right)\right]$$

$$C_{bb} = C_o\left[-\frac{dV_{TH}}{dV_{BS}} - \frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{BS}} - \frac{(1-2\alpha_x)V_{DS}^2}{6\alpha_x Fac}\frac{d\alpha_x}{dV_{BS}} - \frac{(1-\alpha_x)V_{DS}^2}{3\alpha_x Fac^2}\left(\frac{dV_{TH}}{dV_{BS}} + \frac{V_{DS}}{2}\frac{d\alpha_x}{dV_{BS}}\right)\right]$$

$$C_{bd} = C_o\left[\frac{(1-\alpha_x)}{2} - \frac{(1-\alpha_x)V_{DS}}{3Fac} - \frac{(1-\alpha_x)V_{DS}^2}{12Fac^2}\right]$$

$$C_{bs} = -(C_{bg} + C_{bd} + C_{bb})$$

$$C_{sg} = C_{dg} = -\frac{1}{4}C_o\left(2V_{DSAT} - V_{DS} + \frac{V_{DS}}{3Fac}\right)\frac{d\alpha_x}{dV_{GS}} - \frac{\alpha_x}{4}C_o\left(2 - \frac{2V_{DS}^2}{3Fac^2}\right)\frac{dV_{DSAT}}{dV_{GS}}$$

$$C_{sb} = C_{db} = -\frac{1}{4}C_o\left(2V_{DSAT} - V_{DS} + \frac{V_{DS}}{3Fac}\right)\frac{d\alpha_x}{dV_{BS}} - \frac{\alpha_x}{4}C_o\left(2 - \frac{2V_{DS}^2}{3Fac^2}\right)\frac{dV_{DSAT}}{dV_{BS}}$$

$$C_{sd} = C_{dd} = \frac{\alpha_x}{4}C_o\left(1 - \frac{2V_{DS}}{3Fac} - \frac{V_{DS}^2}{3Fac^2}\right)$$

$$C_{ss} = C_{ds} = -(C_{sg} + C_{sd} + C_{sb})$$

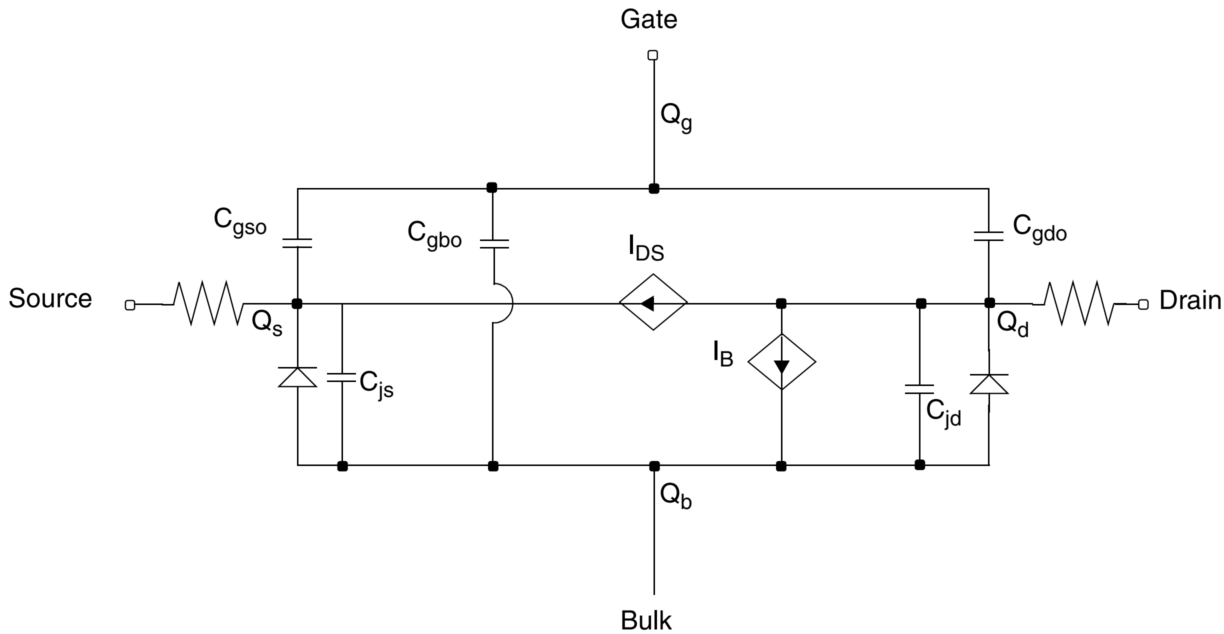
Scaling Effects

For scaling effects, see Scaling Factors (scale and scalem) on page 242.

14

MOS Level-1 Model (mos1)

The MOS1 model is derived from the FET model of Shichman and Hodges. Velocity saturation and the mobility variation effects can also be incorporated into this model. This chapter contains the following information about the MOS1 model:



Channel Width and Length

$$W_{scaled} = w*scale + xw*scalem$$

$$W_{eff} = \begin{cases} w*scale + xw*scalem - 2wd*scalem & \text{(Level 1-3)} \\ w*scale + xw*scalem - dw*scalem & \text{(BSIM 1-2)} \end{cases}$$

$$L_{eff} = \begin{cases} l*scale + xl*scalem - 2ld*scalem & \text{(Level 1-3)} \\ l*scale + xl*scalem - dl*scalem & \text{(BSIM 1-2)} \end{cases}$$

Threshold Voltage

$$V_{TH} = vto + gamma(\sqrt{phi - V_{BS}} - \sqrt{phi})$$

Drain Saturation Voltage

$$V_{DSAT} = V_{GS} - V_{TH} \equiv V_{GST}$$

Drain Current for the Subthreshold Region

Note: These equations apply when $V_{GS} - V_{ON} \leq 0$.

You cannot use the subthreshold current equations without nfs.

$$V_{ON} = \begin{cases} V_{TH} + nV_t & \text{if } nfs \text{ is specified} \\ V_{TH} & \text{otherwise} \end{cases}$$

where

$$n = 1 + \frac{C_{FS} + C_D}{C_{ox}}$$

$$C_{FS} = q \times (nfs)$$

$$C_D = \frac{gamma\ C_{ox}}{2\sqrt{phi - V_{BS}}}$$

$$I_{DS} = I_{DS,ON} e^{(V_{GS} - V_{ON})/nV_t}$$

where $I_{DS,ON}$ is the drain current evaluated at $V_{GS} = V_{ON}$.

Drain Current for the Triode Region

Note: These equations apply when V_{GS}ŠV_{ON} and $V_{DS} \leq V_{DSAT}$.

$$I_{DS} = \beta\left(V_{GST} - \frac{1}{2}V_{DS}\right)V_{DS}(1 + lambda * V_{DS})$$

where

$$\beta = \frac{kp * W_{eff}}{L_{eff}}$$

The mobility temperature offset parameter uto affects both u_{eff} and kp_{eff}, as shown below.

$$u_{eff} = uo*\mathrm{pow}(T/(Tnom + uto), ute)$$

$$kp_{eff} = kp*\mathrm{pow}(T/(Tnom + uto), ute)$$

Drain Current for the Saturation Region

Note: This equation applies when V_{GS}ŠV_{ON} and V_{DS}ŠV_{DSAT}.

$$I_{DS} = \frac{\beta V_{GST}^2}{2}(1 + lambda * V_{DS})$$

Because the standard SPICE Level-1 model does not include any of the short-channel phenomena, such as mobility modulation and velocity-saturation effects, the uses for this model are limited. To retain high computational efficiency and improve accuracy, the Virtuoso® Spectre® circuit simulator incorporates two parameters, $theta$ and $vmax$, into the Level-1 model. The meanings of $theta$ and $vmax$ are the same as those in the Level-3 model. The modified Level-1 model is like a simplified Level-3 model. Spectre uses the modified Level-1 model if $theta$ or $vmax$ (or both) is specified. The drain current equations for the modified Level-1 model are shown in the following section.

Drain Saturation Voltage (Modified Level-1 Model)

$$V_{DSAT} = \frac{V_{GST}}{\sqrt{K}}$$

where

$$K = \frac{1 + V_c + \sqrt{1 + 2V_c}}{2}$$

$$V_c = \frac{V_{GST}uo}{vmax * L_{eff}}$$

Drain Current for the Triode Region (Modified Level-1 Model)

$$I_{DS} = \frac{\beta\left(V_{GST} - \frac{1}{2}V_{DS}\right)V_{DS}[1 + lambda * V_{DS}]}{(1 + theta * V_{GST})(1 + V_{DS}/(E_c L_{eff}))}$$

where

$$E_c = \frac{vmax}{uo}$$

The mobility temperature offset parameter `uto` affects both $\mathtt{u_{eff}}$ and kp_{eff}, as shown below.

$$u_{eff} = u0 * \text{pow}(T/(Tnom + uto), ute)$$

$$kp_{eff} = kp * \text{pow}(T/(Tnom + uto), ute)$$

Drain Current for the Saturation Region (Modified Level-1 Model)

$$I_{DS} = \frac{\beta\left(V_{GST} - \frac{1}{2}V_{DSAT}\right)V_{DSAT}[1 + lambda * V_{DS}]}{(1 + theta * V_{GST})(1 + V_{DSAT}/E_c L_{eff})}$$

Substrate Current

The substrate current is the result of impact ionization in the velocity saturation region near the drain. This impact-ionization induced current (I_{DB}) flows between the drain and the substrate. You need both aio and bio to use the impact-ionization model.

$$I_{DB} = \begin{cases} I_{DS} A_i (V_{DS} - V_{DSAT}) e^{-B_i/(V_{DS} - V_{DSAT})} & \text{if } V_{DS} < V_{DSAT} \\ 0 & \text{otherwise} \end{cases}$$

where

$$A_i = aio + \frac{laio \times 10^{-6}}{L_{eff}} + \frac{waio \times 10^{-6}}{W_{eff}}$$

$$B_i = bio + \frac{lbio \times 10^{-6}}{L_{eff}} + \frac{wbio \times 10^{-6}}{W_{eff}}$$

Scaling Effects

For scaling effects, see Scaling Factors (scale and scalem) on page 242.

Component Statements

This device is supported within altergroups.

Sample Instance Statement

```
nch1 (1 2 0 0) nchmod1 l=2u w=15u ad=60p as=37.5p pd=23u ps=6u
```

Sample Model Statement

```
model nchmod1 mos1 vto=0.78 gamma=0.56 kp=0.8675e-4 tox=0.21e-7 nsub=0.21e17
ld=0.55e-6 capmod=yang vmax=4e5 theta=0.19 cbs=11e-15 cbd=10e-15 lambda=0.1
```

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `w (m)` Channel width.

2 `l (m)` Channel length.

3 `as` (m^2) — Area of source diffusion.

4 `ad` (m^2) — Area of drain diffusion.

5 `ps (m)` — Perimeter of source diffusion.

6 `pd (m)` — Perimeter of drain diffusion.

7 `nrd (m/m)` — Number of squares of drain diffusion.

8 `nrs (m/m)` — Number of squares of source diffusion.

9 `ld (m)` — Length of drain diffusion region.

10 `ls (m)` — Length of source diffusion region.

11 `m=1` — Multiplicity factor (number of MOSFETs in parallel).

12 `region=triode` — Estimated operating region. Spectre outputs number (0-4) in a rawfile.
Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.

13 `trise` — Temperature rise from ambient.

14 `isnoisy=yes` — Should resistor generate noise.
Possible values are `no` or `yes`.

15 `degradation=no` — Hot-electron degradation flag.
Possible values are `no` or `yes`.

Model Definition

```
model modelName mos1 parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n` — Transistor type.
Possible values are `n` or `p`.

Drain current model parameters

2 `vto=0 V` Threshold voltage at zero body bias.

3 `kp=2.0718e-5 A/V`^{2}
Transconductance parameter.

4 `lambda=0 1/V` Channel length modulation parameter.

5 `phi=0.7 V` Surface potential at strong inversion.

6 `gamma=0 √V` Body-effect parameter.

7 `uo=600 cm`^{2}`/V s` Carrier surface mobility.

8 `vmax=∞ m/s` Carrier saturation velocity.

9 `theta=0 1/V` Mobility modulation coefficient.

Process parameters

10 `nsub=1.13e16 cm`$^{-3}$
Channel doping concentration.

11 `nss=0 cm`$^{-2}$ Surface state density.

12 `nfs=0 cm`$^{-2}$ Fast surface state density.

13 `tpg=+1` Type of gate (+1 = opposite of substrate, -1 = same as substrate, 0 = aluminum).

14 `ld=0 m` Lateral diffusion.

15 `wd=0 m` Field-oxide encroachment.

16 `xw=0 m` Width variation due to masking and etching.

17 `xl=0 m` Length variation due to masking and etching.

18 `tox=1e-7 m` Gate oxide thickness.

Impact ionization parameters

19 `ai0=0 1/V` — Impact ionization current coefficient.

20 `lai0=0 µm/V` — Length sensitivity of `ai0`.

21 `wai0=0 µm/V` — Width sensitivity of `ai0`.

22 `bi0=0 V` — Impact ionization current exponent.

23 `lbi0=0 µm V` — Length sensitivity of `bi0`.

24 `wbi0=0 µm V` — Width sensitivity of `bi0`.

Overlap capacitance parameters

25 `cgso=0 F/m` — Gate-source overlap capacitance.

26 `cgdo=0 F/m` — Gate-drain overlap capacitance.

27 `cgbo=0 F/m` — Gate-bulk overlap capacitance.

28 `meto=0 m` — Metal overlap in fringing field.

Charge model selection parameters

29 `capmod=bsim` — Intrinsic charge model.
Possible values are `none`, `meyer`, `yang`, or `bsim`.

30 `xpart=1` — Drain/source channel charge partition in saturation for BSIM charge model, use 0.0 for 40/60, 0.5 for 50/50, or 1.0 for 0/100.

31 `xqc=0` — Drain/source channel charge partition in saturation for charge models, e.g. use 0.4 for 40/60, 0.5 for 50/50, 0 for 0/100.

Parasitic resistance parameters

32 `rs=0 Ω` — Source resistance.

33 `rd=0 Ω` — Drain resistance.

34 `rss=0 Ω m`	Scalable source resistance.
35 `rdd=0 Ω m`	Scalable drain resistance.
36 `rsh=0 Ω/sqr`	Source/drain diffusion sheet resistance.
37 `rsc=0 Ω`	Source contact resistance.
38 `rdc=0 Ω`	Drain contact resistance.
39 `minr=0.1 Ω`	Minimum source/drain resistance.
40 `ldif=0 m`	Lateral diffusion beyond the gate.
41 `hdif=0 m`	Length of heavily doped diffusion.
42 `lgcs=0 m`	Gate-to-contact length of source side.
43 `lgcd=0 m`	Gate-to-contact length of drain side.
44 `sc=∞ m`	Spacing between contacts.

Junction diode model parameters

45 `js` (A/m^2)	Bulk junction reverse saturation current density.
46 `is=1e-14 A`	Bulk junction reverse saturation current.
47 `n=1`	Junction emission coefficient.
48 `dskip=yes`	Use simple piece-wise linear model for diode currents below 0.1*`iabstol`. Possible values are `no` or `yes`.
49 ``imelt=`imax' A``	Explosion current, diode is linearized beyond this current to aid convergence.
50 ``jmelt=`jmax' A/m'``^{2}	Explosion current density, diode is linearized beyond this current to aid convergence.

Junction capacitance model parameters

51 `cbs=0 F` Bulk-source zero-bias junction capacitance.

52 `cbd=0 F` Bulk-drain zero-bias junction capacitance.

53 `cj=0 F/m`^{2} Zero-bias junction bottom capacitance density.

54 `mj=1/2` Bulk junction bottom grading coefficient.

55 `pb=0.8 V` Bulk junction built-in potential.

56 `fc=0.5` Forward-bias depletion capacitance threshold.

57 `cjsw=0 F/m` Zero-bias junction sidewall capacitance density.

58 `mjsw=1/3` Bulk junction sidewall grading coefficient.

59 `pbsw=0.8 V` Side-wall junction built-in potential.

60 `fcsw=0.5` Side-wall forward-bias depletion capacitance threshold.

Operating region warning control parameters

61 `alarm=none` Forbidden operating region.
Possible values are `none`, `off`, `triode`, `sat`, `subth`, or `rev`.

62 `imax=1 A` Maximum current, currents above this limit generate a warning.

63 `jmax=1e8 A/m`^{2} Maximum current density, currents above this limit generate a warning.

64 `bvj=∞ V` Junction reverse breakdown voltage.

65 `vbox=1e9 tox V` Oxide breakdown voltage.

Temperature effects parameters

66 `tnom (C)` Parameters measurement temperature. Default set by `options`.

67 `trise=0 C` Temperature rise from ambient.

68 `uto=0 C` Mobility temperature offset.

69 `ute=-1.5` Mobility temperature exponent.

70 `tlev=0` DC temperature selector.

71 `tlevc=0` AC temperature selector.

72 `eg=1.12452 V` Energy band gap.

73 `gap1=7.02e-4 V/C` Band gap temperature coefficient.

74 `gap2=1108 C` Band gap temperature offset.

75 `f1ex=0` Temperature exponent for `ucrit`.

76 `lamex=0 1/C` Temperature parameter for `lambda` and `kappa`.

77 `trs=0 1/C` Temperature parameter for source resistance.

78 `trd=0 1/C` Temperature parameter for drain resistance.

79 `xti=3` Saturation current temperature exponent.

80 `ptc=0 V/C` Surface potential temperature coefficient.

81 `tcv=0 V/C` Threshold voltage temperature coefficient.

82 `pta=0 V/C` Junction potential temperature coefficient.

83 `ptp=0 V/C` Sidewall junction potential temperature coefficient.

84 `cta=0 1/C` Junction capacitance temperature coefficient.

85 `ctp=0 1/C` Sidewall junction capacitance temperature coefficient.

Default instance parameters

86 `w=3e-6 m` Default channel width.

87 `l=3e-6 m` Default channel length.

88 `as=0` m^2 Default area of source diffusion.

89 `ad=0` m^2 — Default area of drain diffusion.

90 `ps=0 m` — Default perimeter of source diffusion.

91 `pd=0 m` — Default perimeter of drain diffusion.

92 `nrd=0 m/m` — Default number of squares of drain diffusion.

93 `nrs=0 m/m` — Default number of squares of source diffusion.

94 `ldd=0 m` — Default length of drain diffusion region.

95 `lds=0 m` — Default length of source diffusion region.

Noise model parameters

96 `noisemod=1` — Noise model selector.

97 `kf=0` — Flicker (1/f) noise coefficient.

98 `af=1` — Flicker (1/f) noise exponent.

99 `ef=1` — Flicker (1/f) noise frequency exponent.

100 `wnoi=1e-5 m` — Channel width at which noise parameters were extracted.

Auto Model Selector parameters

101 `wmax=1.0 m` — Maximum channel width for which the model is valid.

102 `wmin=0.0 m` — Minimum channel width for which the model is valid.

103 `lmax=1.0 m` — Maximum channel length for which the model is valid.

104 `lmin=0.0 m` — Minimum channel length for which the model is valid.

Degradation parameters

105 `degramod=spectre` — Degradation model selector.
Possible values are `spectre` or `bert`.

106 `degradation=no` Hot-electron degradation flag.
Possible values are `no` or `yes`.

107 `dvthc=1 V` Degradation coefficient for threshold voltage.

108 `dvthe=1` Degradation exponent for threshold voltage.

109 `duoc=1 S` Degradation coefficient for transconductance.

110 `duoe=1` Degradation exponent for transconductance.

111 `crivth=0.1 V` Maximum allowable threshold voltage shift.

112 `criuo=10%` Maximum allowable normalized mobility change.

113 `crigm=10%` Maximum allowable normalized transconductance change.

114 `criids=10%` Maximum allowable normalized drain current change.

115 `wnom=5e-6 m` Nominal device width in degradation calculation.

116 `lnom=1e-6 m` Nominal device length in degradation calculation.

117 `vbsn=0 V` Substrate voltage in degradation calculation.

118 `vdsni=0.1 V` Drain voltage in `Ids` degradation calculation.

119 `vgsni=5 V` Gate voltage in `Ids` degradation calculation.

120 `vdsng=0.1 V` Drain voltage in `Gm` degradation calculation.

121 `vgsng=5 V` Gate voltage in `Gm` degradation calculation.

Spectre stress parameters

122 `esat=1.1e7 V/m` Critical field in Vdsat calculation.

123 `esatg=2.5e6 1/m` Gate voltage dependence of `esat`.

124 `vpg=-0.25` Gate voltage modifier.

125 `vpb=-0.13` Gate voltage modifier.

126 `subc1=2.24e-5` Substrate current coefficient.

127 `subc2=-0.1e-5 1/V` Substrate current coefficient.

128 `sube=6.4` Substrate current exponent.

129 `strc=1` Stress coefficient.

130 `stre=1` Stress exponent.

BERT stress parameters

131 `h0=1` Aging coefficient.

132 `hgd=0 1/V` Bias dependence of `h0`.

133 `m0=1` Aging exponent.

134 `mgd=0 1/V` Bias dependence of `m0`.

135 `ecrit0=1.1e5 V/cm` Critical electric field.

136 `lecrit0=0 µm V/cm` Length dependence of `ecrit0`.

137 `wecrit0=0 µm V/cm` Width dependence of `ecrit0`.

138 `ecritg=0 1/cm` Gate voltage dependence of `ecrit0`.

139 `lecritg=0 µm/cm` Length dependence of `ecritg`.

140 `wecritg=0 µm/cm` Width dependence of `ecritg`.

141 `ecritb=0 1/cm` Substrate voltage dependence of `ecrit0`.

142 `lecritb=0 µm/cm` Length dependence of `ecritb`.

143 `wecritb=0 µm/cm` Width dependence of `ecritb`.

144 `lc0=1` Substrate current coefficient.

145 `llc0=0 µm` Length dependence of `lc0`.

146 `wlc0=0 µm` Width dependence of `lc0`.

147 lc1=1	Substrate current coefficient.
148 llc1=0 µm	Length dependence of lc1.
149 wlc1=0 µm	Width dependence of lc1.
150 lc2=1	Substrate current coefficient.
151 llc2=0 µm	Length dependence of lc2.
152 wlc2=0 µm	Width dependence of lc2.
153 lc3=1	Substrate current coefficient.
154 llc3=0 µm	Length dependence of lc3.
155 wlc3=0 µm	Width dependence of lc3.
156 lc4=1	Substrate current coefficient.
157 llc4=0 µm	Length dependence of lc4.
158 wlc4=0 µm	Width dependence of lc4.
159 lc5=1	Substrate current coefficient.
160 llc5=0 µm	Length dependence of lc5.
161 wlc5=0 µm	Width dependence of lc5.
162 lc6=1	Substrate current coefficient.
163 llc6=0 µm	Length dependence of lc6.
164 wlc6=0 µm	Width dependence of lc6.
165 lc7=1	Substrate current coefficient.
166 llc7=0 µm	Length dependence of lc7.
167 wlc7=0 µm	Width dependence of lc7.

Shrink Parameters

Imax and Imelt:

The `imax` parameter aids convergence and prevents numerical overflow. The junction characteristics of the device are accurately modeled for current up to `imax`. If `imax` is exceeded during iterations, the linear model is substituted until the current drops below imax or until convergence is achieved. If convergence is achieved with the current exceeding `imax`, the results are inaccurate, and Spectre prints a warning.

A separate model parameter, `imelt`, is used as a limit warning for the junction current. This parameter can be set to the maximum current rating of the device. When any component of the junction current exceeds `imelt`, note that base and collector currents are composed of many exponential terms, Spectre issues a warning and the results become inaccurate. The junction current is linearized above the value of `imelt` to prevent arithmetic exception, with the exponential term replaced by a linear equation at `imelt`.

Both of these parameters have current density counterparts, `jmax` and `jmelt`, that you can specify if you want the absolute current values to depend on the device area.

Auto Model Selection

Many models need to be characterized for different geometries in order to obtain accurate results for model development. The model selector program automatically searches for a model with the length and width range specified in the instance statement and uses this model in the simulations.

For the auto model selector program to find a specific model, the models to be searched should be grouped together within braces. Such a group is called a model group. An opening brace is required at the end of the line defining each model group. Every model in the group is given a name followed by a colon and the list of parameters. Also, the four geometric parameters `lmax`, `lmin`, `wmax`, and `wmin` should be given. The selection criteria to choose a model is as follows:

lmin <= inst_length < lmax and wmin <= inst_width < wmax

Example:

model ModelName ModelType {

1: <model parameters> lmin=2 lmax=4 wmin=1 wmax=2

2: <model parameters> lmin=1 lmax=2 wmin=2 wmax=4

3: <model parameters> lmin=2 lmax=4 wmin=4 wmax=6

}

Then for a given instance

M1 1 2 3 4 ModelName w=3 l=1.5

the program would search all the models in the model group with the name `ModelName` and then pick the first model whose geometric range satisfies the selection criteria. In the preceding example, the auto model selector program would choose ModelName.2.

You must specify both length (l) and width (w) on the device instance line to enable automatic model selection.

Output Parameters

1 `weff (m)`	Effective channel width.
2 `leff (m)`	Effective channel length.
3 `rseff (Ω)`	Effective source resistance.
4 `rdeff (Ω)`	Effective drain resistance.
5 `aseff` (m^2)	Effective area of source diffusion.
6 `adeff` (m^2)	Effective area of drain diffusion.
7 `pseff (m)`	Effective perimeter of source diffusion.
8 `pdeff (m)`	Effective perimeter of source diffusion.
9 `isseff (A)`	Effective source-bulk junction reverse saturation current.
10 `isdeff (A)`	Effective drain-bulk junction reverse saturation current.
11 `cbseff (F)`	Effective zero-bias source-bulk junction capacitance.
12 `cbdeff (F)`	Effective zero-bias drain-bulk junction capacitance.

Operating-Point Parameters

1 `type=n`	Transistor type. Possible values are `n` or `p`.
2 `region=triode`	Estimated operating region. Spectre outputs number (0-4) in a rawfile. Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.
3 `degradation=no`	Hot-electron degradation flag. Possible values are `no` or `yes`.
4 `reversed`	Reverse mode indicator. Possible values are `no` or `yes`.
5 `ids (A)`	Resistive drain-to-source current.
6 `vgs (V)`	Gate-source voltage.
7 `vds (V)`	Drain-source voltage.
8 `vbs (V)`	Bulk-source voltage.
9 `vth (V)`	Threshold voltage.
10 `vdsat (V)`	Drain-source saturation voltage.
11 `gm (S)`	Common-source transconductance.
12 `gds (S)`	Common-source output conductance.
13 `gmbs (S)`	Body-transconductance.
14 `gameff` ($\sqrt{V}$)	Effective body effect coefficient.
15 `betaeff` (A/V^2)	Effective `beta`.
16 `cbd (F)`	Drain-bulk junction capacitance.
17 `cbs (F)`	Source-bulk junction capacitance.
18 `cgs (F)`	Gate-source capacitance.

19 `cgd (F)` Gate-drain capacitance.

20 `cgb (F)` Gate-bulk capacitance.

21 `ron (Ω)` On-resistance.

22 `id (A)` Resistive drain current.

23 `ibulk (A)` Resistive bulk current.

24 `pwr (W)` Power at op point.

25 `gmoverid (1/V)` `Gm/Ids`.

26 `isub (A)` Substrate current.

27 `stress` Hot-electron stress.

28 `age (s)` Device age.

29 `he_vdsat (V)` Hot Electron `Vdsat`.

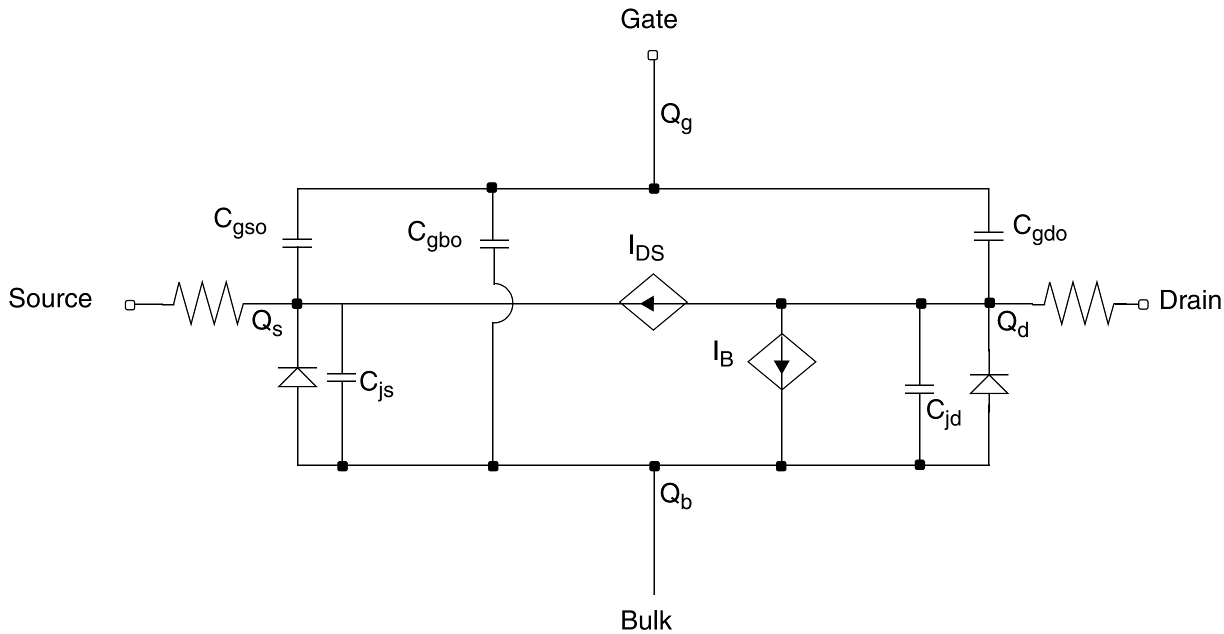
Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

15

MOS Level-2 Model (mos2)

The MOS2 model is the level-2 model from Berkeley SPICE. The MOS2 model is an analytical, one-dimensional model that incorporates most of the second-order small-size effects. A smoother version of the level-2 model (with continuous `Gds` at `Vdsat`) as well as three charge models are also available. This chapter contains the following information about the MOS2 model:



Channel Width and Length

$$W_{scaled} = w*scale + xw*scalem$$

$$W_{eff} = \begin{cases} w*scale + xw*scalem - 2wd*scalem & \text{(Level 1-3)} \\ w*scale + xw*scalem - dw*scalem & \text{(BSIM 1-2)} \end{cases}$$

$$L_{eff} = \begin{cases} l*scale + xl*scalem - 2ld*scalem & \text{(Level 1-3)} \\ l*scale + xl*scalem - dl*scalem & \text{(BSIM 1-2)} \end{cases}$$

Threshold Voltage

$$V_{TH} = V_{BI} + \gamma_s \sqrt{phi - V_{BS}} + (\eta - 1)(phi - V_{BS})$$

where

$$V_{BI} = vto - gamma\sqrt{phi}$$

$$\gamma_s = gamma(1 - \alpha_S - \alpha_D)$$

$$\alpha_S = \frac{xj}{2L_{eff}}\left[\sqrt{1 + \frac{2W_S}{xj}} - 1\right]$$

$$\alpha_D = \frac{xj}{2L_{eff}}\left[\sqrt{1 + \frac{2W_D}{xj}} - 1\right]$$

$$W_S = X_D\sqrt{phi - V_{BS}}$$

$$W_D = X_D\sqrt{phi - V_{BS} + V_{DS}}$$

$$X_D = \begin{cases} \sqrt{\dfrac{2\varepsilon_{si}}{q*(nsub)}} & \text{if } vmax \text{ is not specified} \\ \sqrt{\dfrac{2\varepsilon_{si}}{q*neff*nsub}} & \text{otherwise} \end{cases}$$

$$\eta = 1 + \frac{delta\pi\varepsilon_{si}}{4C_{ox}W_{eff}}$$

If xj or $nsub$ is zero, the short-channel effects on threshold voltage are not evaluated (that is, $\gamma_s = gamma$).

Drain Saturation Voltage

If $vmax$ is not specified, V_{DSAT} is determined by the pinchoff condition and is given by

$$V_{DSAT} = \frac{V_{GS} - V_{BIN}}{\eta} + \frac{1}{2}\left(\frac{\gamma_s}{\eta}\right)^2 (1 - Fac)$$

where

$$V_{BIN} = V_{BI} + \frac{delta\pi\varepsilon_{si}}{4C_{ox}W_{eff}}(phi - V_{BS})$$

$$Fac = \sqrt{1 + 4\left(\frac{\eta}{\gamma_s}\right)^2\left(\frac{V_{GS} - V_{BIN}}{\eta} + phi - V_{BS}\right)}$$

If $vmax$ is specified, V_{DSAT} is determined by the velocity saturation effect.

$$vmax = \frac{I_{DSAT}}{W_{eff}Q_{chan}}$$

where

$$Q_{chan} = W_{eff}\, C_{ox}[V_{GS} - V_{BIN} - \eta V_{DSAT} - \gamma_s\sqrt{phi - V_{BS} + V_{DSAT}}]$$

μ_{eff} is the effective mobility, defined later. V_{DSAT} can be calculated by solving the preceding equations.

Drain Current for the Subthreshold Region

Note: These equations apply when V_{GS} ?≤ V_{ON}.

You cannot use the subthreshold current equations without nfs.

$$V_{ON} = \begin{cases} V_{TH} + nV_t & \text{if } nfs \text{ is specified} \\ V_{TH} & \text{otherwise} \end{cases}$$

where

$$n = 1 + \frac{C_{FS} + C_D}{C_{ox}}$$

$$C_{FS} = q \times (nfs)$$

$$C_D = \left[\frac{\gamma_s}{2\sqrt{phi - V_{BS}}} - \frac{d\gamma_s}{dV_{BS}}\sqrt{phi - V_{BS}} + (\eta - 1)\right]C_{ox}$$

$$I_{DS} = I_{DS,ON}e^{(V_{GS} - V_{ON})/nV_t}$$

where $I_{DS,ON}$ is the drain current evaluated at $V_{GS} = V_{ON}$.

Drain Current for the Triode Region

Note: These equations apply when V_{GS} ?≥ V_{ON} and V_{DS} ?≤ V_{DSAT}.

$$I_{DS} = \beta\left\{\left(V_{GS} - V_{BIN} - \frac{\eta V_{DS}}{2}\right)V_{DS} - \frac{2}{3}\gamma_s[(phi - V_{BS} + V_{DS})^{3/2} - (phi - V_{BS})^{3/2}]\right\}$$

where

$$\beta = \frac{\mu_{eff} C_{ox} W_{eff}}{L_{eff} - \Delta L}$$

$$\mu_{eff} = uo\left[\frac{ucrit\ \varepsilon_{si}}{C_{ox}(V_{GS} - V_{TH} - utra * V_{DS})}\right]^{uexp}$$

SPICE does not implement the $utra$ effect. Also, if $(V_{GS} - V_{TH}) \leq (ucrit\varepsilon_{si}/C_{ox})$, μ_{eff} is clipped to uo. This creates a discontinuity in the first derivatives of the drain current. The Virtuoso® Spectre® circuit simulator does not have this clipping effect.

$$\Delta L = \begin{cases} lambda\ L_{eff} V_{DS} & \text{if } lambda \text{ is given} \\ 0 & \text{if } nsub \text{ is not given} \\ X_D \sqrt{\left(\frac{V_{DS} - V_{DSAT}}{4}\right) + \sqrt{1 + \left(\frac{V_{DS} - V_{DSAT}}{4}\right)^2}} & \text{if } vmax \text{ is not given} \\ X_D \left\{ \sqrt{\left(\frac{X_D vmax}{2\mu_{eff}}\right)^2 + V'_{DS} - V_{DSAT}} - \frac{X_D vmax}{2\mu_{eff}} \right\} & \text{if } V_{DS} \ge V_{DSAT} \end{cases}$$

If $\Delta L \geq (L_{eff} - W_B)$, β is calculated from the following equation to avoid device punchthrough:

$$\beta = \frac{\mu_{eff} C_{ox} W_{eff}}{L_{eff}} \left(\frac{L_{eff}}{W_B}\right)^2 \left(\frac{2 W_B}{L_{eff}} + \frac{\Delta L}{L_{eff}} - 1\right)$$

where

$$W_B = X_D \sqrt{\mathtt{pb}}$$

Drain Current for the Saturation Region

Note: This equation applies when V_{GS} ?≥ V_{ON} and V_{DS} ?≥ V_{DSAT}.

$$I_{DS} = \beta\left\{\left(V_{GS} - V_{BIN} - \frac{\eta V_{DSAT}}{2}\right) V_{DSAT} - \frac{2}{3}\gamma_s [(phi - V_{BS} + V_{DSAT})^{3/2} - (phi - V_{BS})^{3/2}]\right\}$$

Substrate Current

The substrate current results from impact ionization in the velocity saturation region near the drain. This impact-ionization induced current (I_{DB}) flows between the drain and the substrate. You need both *aio* and *bio* to use the impact-ionization model.

$$I_{DB} = \begin{cases} I_{DS}A_i(V_{DS} - V_{DSAT})e^{-B_i/(V_{DS} - V_{DSAT})} & \text{if } V_{DS} \le V_{DSAT} \\ 0 & \text{otherwise} \end{cases}$$

where

$$A_i = aio + \frac{laio \times 10^{-6}}{L_{eff}} + \frac{waio \times 10^{-6}}{W_{eff}}$$

$$B_i = bio + \frac{lbio \times 10^{-6}}{L_{eff}} + \frac{wbio \times 10^{-6}}{W_{eff}}$$

Scaling Effects

For scaling effects, see Scaling Factors (scale and scalem) on page 242.

Component Statements

This device is supported within altergroups.

Sample Instance Statement:

mn2 (1 2 0 0) nch2 w=10u ad=20p as=20p ps=24u pd=24u

Sample Model Statement:

model nch2 mos2 type=n vto=0.66 lambda=0.018 gamma=0.6 nsub=0.213e16 kp=0.978e-4 tpg=-1 vmax=6e4 ucrit=1e7 utra=0.1 uexp=0.2 is=0

Sample Instance Statement

```
mn2 (1 2 0 0) nch2 w=10u ad=20p as=20p ps=24u pd=24u
```

Sample Model Statement

```
model nch2 mos2 type=n vto=0.66 lambda=0.018 gamma=0.6 nsub=0.213e16 kp=0.978e-4
tpg=-1 vmax=6e4 ucrit=1e7 utra=0.1 uexp=0.2 is=0
```

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `w (m)`	Channel width.
2 `l (m)`	Channel length.
3 `as (m`^{2}`)`	Area of source diffusion.
4 `ad (m`^{2}`)`	Area of drain diffusion.
5 `ps (m)`	Perimeter of source diffusion.
6 `pd (m)`	Perimeter of drain diffusion.
7 `nrd (m/m)`	Number of squares of drain diffusion.
8 `nrs (m/m)`	Number of squares of source diffusion.
9 `ld (m)`	Length of drain diffusion region.
10 `ls (m)`	Length of source diffusion region.
11 `m=1`	Multiplicity factor (number of MOSFETs in parallel).
12 `region=triode`	Estimated operating region. Spectre outputs number (0-4) in a rawfile. Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.
13 `trise`	Temperature rise from ambient.
14 `isnoisy=yes`	Should resistor generate noise. Possible values are `no` or `yes`.
15 `degradation=no`	Hot-electron degradation flag. Possible values are `no` or `yes`.

Model Definition

```
model modelName mos2 parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

Drain current model parameters

2 `vto=0 V` Threshold voltage at zero body bias.

3 `kp=2.0718e-5 A/V`^{2}
Transconductance parameter.

4 `lambda=0 1/V` Channel length modulation parameter.

5 `phi=0.7 V` Surface potential at strong inversion.

6 `gamma=0` $\sqrt{V}$ Body-effect parameter.

7 `uo=600 cm`^{2}`/V s` Carrier surface mobility.

8 `vmax=∞ m/s` Carrier saturation velocity.

9 `ucrit=0 V/cm` Critical field for mobility degradation.

10 `uexp=0` Critical field exponent for mobility degradation.

11 `utra=0 1/V` Transverse field for mobility.

12 `neff=1` Total channel charge coefficient.

13 `delta=0` Width effect on threshold voltage.

14 `smooth=yes` Drain current smoothing flag.
Possible values are `no` or `yes`.

Process parameters

15 `nsub=1.13e16 cm`$^{-3}$
Channel doping concentration.

16 `nss=0` cm^{-2} Surface state density.

17 `nfs=0` cm^{-2} Fast surface state density.

18 `tpg=+1` Type of gate (+1 = opposite of substrate, -1 = same as substrate, 0 = aluminum).

19 `tox=1e-7 m` Gate oxide thickness.

20 `ld=0 m` Lateral diffusion.

21 `wd=0 m` Field-oxide encroachment.

22 `xw=0 m` Width variation due to masking and etching.

23 `xl=0 m` Length variation due to masking and etching.

24 `xj=0 m` Source/drain junction depth.

Impact ionization parameters

25 `ai0=0 1/V` Impact ionization current coefficient.

26 `lai0=0 µm/V` Length sensitivity of `ai0`.

27 `wai0=0 µm/V` Width sensitivity of `ai0`.

28 `bi0=0 V` Impact ionization current exponent.

29 `lbi0=0 µm V` Length sensitivity of `bi0`.

30 `wbi0=0 µm V` Width sensitivity of `bi0`.

Overlap capacitance parameters

31 `cgso=0 F/m` Gate-source overlap capacitance.

32 `cgdo=0 F/m` Gate-drain overlap capacitance.

33 `cgbo=0 F/m` Gate-bulk overlap capacitance.

34 `meto=0 m` Metal overlap in fringing field.

Charge model selection parameters

35 `capmod=bsim` Intrinsic charge model.
Possible values are `none`, `meyer`, `yang`, or `bsim`.

36 `xpart=1` Drain/source channel charge partition in saturation for BSIM charge model, use 0.0 for 40/60, 0.5 for 50/50, or 1.0 for 0/100.

37 `xqc=0` Drain/source channel charge partition in saturation for charge models, e.g. use 0.4 for 40/60, 0.5 for 50/50, 0 for 0/100.

Parasitic resistance parameters

38 `rs=0 Ω` Source resistance.

39 `rd=0 Ω` Drain resistance.

40 `rsh=0 Ω/sqr` Source/drain diffusion sheet resistance.

41 `rss=0 Ω m` Scalable source resistance.

42 `rdd=0 Ω m` Scalable drain resistance.

43 `rsc=0 Ω` Source contact resistance.

44 `rdc=0 Ω` Drain contact resistance.

45 `minr=0.1 Ω` Minimum source/drain resistance.

46 `ldif=0 m` Lateral diffusion beyond the gate.

47 `hdif=0 m` Length of heavily doped diffusion.

48 `lgcs=0 m` Gate-to-contact length of source side.

49 `lgcd=0 m` Gate-to-contact length of drain side.

50 `sc=∞ m` Spacing between contacts.

Junction diode model parameters

51 `js` (A/m^2) Bulk junction reverse saturation current density.

52 `is=1e-14 A` Bulk junction reverse saturation current.

53 `n=1` Junction emission coefficient.

54 `dskip=yes` Use simple piece-wise linear model for diode currents below 0.1*`iabstol`.
Possible values are `no` or `yes`.

55 `imelt=`imax' A` Explosion current, diode is linearized beyond this current to aid convergence.

56 `jmelt=`jmax' A/m'`^{2}
Explosion current density, diode is linearized beyond this current to aid convergence.

Junction capacitance model parameters

57 `cbs=0 F` Bulk-source zero-bias junction capacitance.

58 `cbd=0 F` Bulk-drain zero-bias junction capacitance.

59 `cj=0 F/m`^{2} Zero-bias junction bottom capacitance density.

60 `mj=1/2` Bulk junction bottom grading coefficient.

61 `pb=0.8 V` Bulk junction built-in potential.

62 `fc=0.5` Forward-bias depletion capacitance threshold.

63 `cjsw=0 F/m` Zero-bias junction sidewall capacitance density.

64 `mjsw=1/3` Bulk junction sidewall grading coefficient.

65 `pbsw=0.8 V` Side-wall junction built-in potential.

66 `fcsw=0.5` Side-wall forward-bias depletion capacitance threshold.

Operating region warning control parameters

67 `alarm=none` Forbidden operating region.
Possible values are `none`, `off`, `triode`, `sat`, `subth`, or `rev`.

68 `imax=1 A`	Maximum current, currents above this limit generate a warning.
69 `jmax=1e8 A/m`^{2}	Maximum current density, currents above this limit generate a warning.
70 `bvj=∞ V`	Junction reverse breakdown voltage.
71 `vbox=1e9 tox V`	Oxide breakdown voltage.

Temperature effects parameters

72 `tnom (C)`	Parameters measurement temperature. Default set by `options`.
73 `trise=0 C`	Temperature rise from ambient.
74 `uto=0 C`	Mobility temperature offset.
75 `ute=-1.5`	Mobility temperature exponent.
76 `tlev=0`	DC temperature selector.
77 `tlevc=0`	AC temperature selector.
78 `eg=1.12452 V`	Energy band gap.
79 `gap1=7.02e-4 V/C`	Band gap temperature coefficient.
80 `gap2=1108 C`	Band gap temperature offset.
81 `f1ex=0`	Temperature exponent for `ucrit`.
82 `lamex=0 1/C`	Temperature parameter for `lambda` and `kappa`.
83 `trs=0 1/C`	Temperature parameter for source resistance.
84 `trd=0 1/C`	Temperature parameter for drain resistance.
85 `xti=3`	Saturation current temperature exponent.
86 `ptc=0 V/C`	Surface potential temperature coefficient.
87 `tcv=0 V/C`	Threshold voltage temperature coefficient.

88 `pta=0 V/C` Junction potential temperature coefficient.

89 `ptp=0 V/C` Sidewall junction potential temperature coefficient.

90 `cta=0 1/C` Junction capacitance temperature coefficient.

91 `ctp=0 1/C` Sidewall junction capacitance temperature coefficient.

Default instance parameters

92 `w=3e-6 m` Default channel width.

93 `l=3e-6 m` Default channel length.

94 `as=0` m^2 Default area of source diffusion.

95 `ad=0` m^2 Default area of drain diffusion.

96 `ps=0 m` Default perimeter of source diffusion.

97 `pd=0 m` Default perimeter of drain diffusion.

98 `nrd=0 m/m` Default number of squares of drain diffusion.

99 `nrs=0 m/m` Default number of squares of source diffusion.

100 `ldd=0 m` Default length of drain diffusion region.

101 `lds=0 m` Default length of source diffusion region.

Noise model parameters

102 `noisemod=1` Noise model selector.

103 `kf=0` Flicker (1/f) noise coefficient.

104 `af=1` Flicker (1/f) noise exponent.

105 `ef=1` Flicker (1/f) noise frequency exponent.

106 `wnoi=1e-5 m` Channel width at which noise parameters were extracted.

Auto Model Selector parameters

107 `wmax=1.0 m` Maximum channel width for which the model is valid.

108 `wmin=0.0 m` Minimum channel width for which the model is valid.

109 `lmax=1.0 m` Maximum channel length for which the model is valid.

110 `lmin=0.0 m` Minimum channel length for which the model is valid.

Degradation parameters

111 `degramod=spectre` Degradation model selector.
Possible values are `spectre` or `bert`.

112 `degradation=no` Hot-electron degradation flag.
Possible values are `no` or `yes`.

113 `dvthc=1 V` Degradation coefficient for threshold voltage.

114 `dvthe=1` Degradation exponent for threshold voltage.

115 `duoc=1 S` Degradation coefficient for transconductance.

116 `duoe=1` Degradation exponent for transconductance.

117 `crivth=0.1 V` Maximum allowable threshold voltage shift.

118 `criuo=10%` Maximum allowable normalized mobility change.

119 `crigm=10%` Maximum allowable normalized transconductance change.

120 `criids=10%` Maximum allowable normalized drain current change.

121 `wnom=5e-6 m` Nominal device width in degradation calculation.

122 `lnom=1e-6 m` Nominal device length in degradation calculation.

123 `vbsn=0 V` Substrate voltage in degradation calculation.

124 `vdsni=0.1 V` Drain voltage in `Ids` degradation calculation.

125 `vgsni=5 V` Gate voltage in `Ids` degradation calculation.

126 `vdsng=0.1 V` Drain voltage in `Gm` degradation calculation.

127 `vgsng=5 V` Gate voltage in `Gm` degradation calculation.

Spectre stress parameters

128 `esat=1.1e7 V/m` Critical field in Vdsat calculation.

129 `esatg=2.5e6 1/m` Gate voltage dependence of `esat`.

130 `vpg=-0.25` Gate voltage modifier.

131 `vpb=-0.13` Gate voltage modifier.

132 `subc1=2.24e-5` Substrate current coefficient.

133 `subc2=-0.1e-5 1/V` Substrate current coefficient.

134 `sube=6.4` Substrate current exponent.

135 `strc=1` Stress coefficient.

136 `stre=1` Stress exponent.

BERT stress parameters

137 `h0=1` Aging coefficient.

138 `hgd=0 1/V` Bias dependence of `h0`.

139 `m0=1` Aging exponent.

140 `mgd=0 1/V` Bias dependence of `m0`.

141 `ecrit0=1.1e5 V/cm` Critical electric field.

142 `lecrit0=0 µm V/cm` Length dependence of `ecrit0`.

143 `wecrit0=0 µm V/cm` Width dependence of `ecrit0`.

144 `ecritg=0 1/cm` Gate voltage dependence of `ecrit0`.

145 `lecritg=0 µm/cm` Length dependence of `ecritg`.

146 `wecritg=0 µm/cm` Width dependence of `ecritg`.

147 `ecritb=0 1/cm` Substrate voltage dependence of `ecrit0`.

148 `lecritb=0 µm/cm` Length dependence of `ecritb`.

149 `wecritb=0 µm/cm` Width dependence of `ecritb`.

150 `lc0=1` Substrate current coefficient.

151 `llc0=0 µm` Length dependence of `lc0`.

152 `wlc0=0 µm` Width dependence of `lc0`.

153 `lc1=1` Substrate current coefficient.

154 `llc1=0 µm` Length dependence of `lc1`.

155 `wlc1=0 µm` Width dependence of `lc1`.

156 `lc2=1` Substrate current coefficient.

157 `llc2=0 µm` Length dependence of `lc2`.

158 `wlc2=0 µm` Width dependence of `lc2`.

159 `lc3=1` Substrate current coefficient.

160 `llc3=0 µm` Length dependence of `lc3`.

161 `wlc3=0 µm` Width dependence of `lc3`.

162 `lc4=1` Substrate current coefficient.

163 `llc4=0 µm` Length dependence of `lc4`.

164 `wlc4=0 µm` Width dependence of `lc4`.

165 `lc5=1` Substrate current coefficient.

166 `llc5=0 µm` Length dependence of `lc5`.

167 `wlc5=0 µm` Width dependence of `lc5`.

168 `lc6=1` Substrate current coefficient.

169 `llc6=0 µm` Length dependence of `lc6`.

170 `wlc6=0 µm` Width dependence of `lc6`.

171 `lc7=1` Substrate current coefficient.

172 `llc7=0 µm` Length dependence of `lc7`.

173 `wlc7=0 µm` Width dependence of `lc7`.

Shrink Parameters

Imax and Imelt

The `imax` parameter aids convergence and prevents numerical overflow. The junction characteristics of the device are accurately modeled for current up to `imax`. If `imax` is exceeded during iterations, the linear model is substituted until the current drops below imax or until convergence is achieved. If convergence is achieved with the current exceeding `imax`, the results are inaccurate, and Spectre prints a warning.

A separate model parameter, `imelt`, is used as a limit warning for the junction current. This parameter can be set to the maximum current rating of the device. When any component of the junction current exceeds `imelt`, note that base and collector currents are composed of many exponential terms, Spectre issues a warning and the results become inaccurate. The junction current is linearized above the value of `imelt` to prevent arithmetic exception, with the exponential term replaced by a linear equation at `imelt`.

Both of these parameters have current density counterparts, `jmax` and `jmelt`, that you can specify if you want the absolute current values to depend on the device area.

Auto Model Selection

Many models need to be characterized for different geometries in order to obtain accurate results for model development. The model selector program automatically searches for a model with the length and width range specified in the instance statement and uses this model in the simulations.

For the auto model selector program to find a specific model, the models to be searched should be grouped together within braces. Such a group is called a model group. An opening brace is required at the end of the line defining each model group. Every model in the group is given a name followed by a colon and the list of parameters. Also, the four geometric parameters `lmax`, `lmin`, `wmax`, and `wmin` should be given. The selection criteria to choose a model is as follows:

lmin <= inst_length < lmax and wmin <= inst_width < wmax

Example:

model ModelName ModelType {

1: <model parameters> lmin=2 lmax=4 wmin=1 wmax=2

2: <model parameters> lmin=1 lmax=2 wmin=2 wmax=4

3: <model parameters> lmin=2 lmax=4 wmin=4 wmax=6

}

Then for a given instance

M1 1 2 3 4 ModelName w=3 l=1.5

the program would search all the models in the model group with the name `ModelName` and then pick the first model whose geometric range satisfies the selection criteria. In the preceding example, the auto model selector program would choose ModelName.2.

You must specify both length (l) and width (w) on the device instance line to enable automatic model selection.

Output Parameters

1	`weff (m)`	Effective channel width.
2	`leff (m)`	Effective channel length.
3	`rseff` (Ω)	Effective source resistance.
4	`rdeff` (Ω)	Effective drain resistance.
5	`aseff` (m^2)	Effective area of source diffusion.
6	`adeff` (m^2)	Effective area of drain diffusion.

7 `pseff (m)`	Effective perimeter of source diffusion.
8 `pdeff (m)`	Effective perimeter of source diffusion.
9 `isseff (A)`	Effective source-bulk junction reverse saturation current.
10 `isdeff (A)`	Effective drain-bulk junction reverse saturation current.
11 `cbseff (F)`	Effective zero-bias source-bulk junction capacitance.
12 `cbdeff (F)`	Effective zero-bias drain-bulk junction capacitance.

Operating-Point Parameters

1 `type=n`	Transistor type. Possible values are `n` or `p`.
2 `region=triode`	Estimated operating region. Spectre outputs number (0-4) in a rawfile. Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.
3 `degradation=no`	Hot-electron degradation flag. Possible values are `no` or `yes`.
4 `reversed`	Reverse mode indicator. Possible values are `no` or `yes`.
5 `ids (A)`	Resistive drain-to-source current.
6 `vgs (V)`	Gate-source voltage.
7 `vds (V)`	Drain-source voltage.
8 `vbs (V)`	Bulk-source voltage.
9 `vth (V)`	Threshold voltage.
10 `vdsat (V)`	Drain-source saturation voltage.
11 `gm (S)`	Common-source transconductance.
12 `gds (S)`	Common-source output conductance.

13 `gmbs (S)`	Body-transconductance.
14 `gameff (√V )`	Effective body effect coefficient.
15 `betaeff (A/V`^{2}`)`	Effective `beta`.
16 `cbd (F)`	Drain-bulk junction capacitance.
17 `cbs (F)`	Source-bulk junction capacitance.
18 `cgs (F)`	Gate-source capacitance.
19 `cgd (F)`	Gate-drain capacitance.
20 `cgb (F)`	Gate-bulk capacitance.
21 `ron (Ω)`	On-resistance.
22 `id (A)`	Resistive drain current.
23 `ibulk (A)`	Resistive bulk current.
24 `pwr (W)`	Power at op point.
25 `gmoverid (1/V)`	`Gm/Ids`.
26 `isub (A)`	Substrate current.
27 `stress`	Hot-electron stress.
28 `age (s)`	Device age.
29 `he_vdsat (V)`	Hot Electron `Vdsat`.

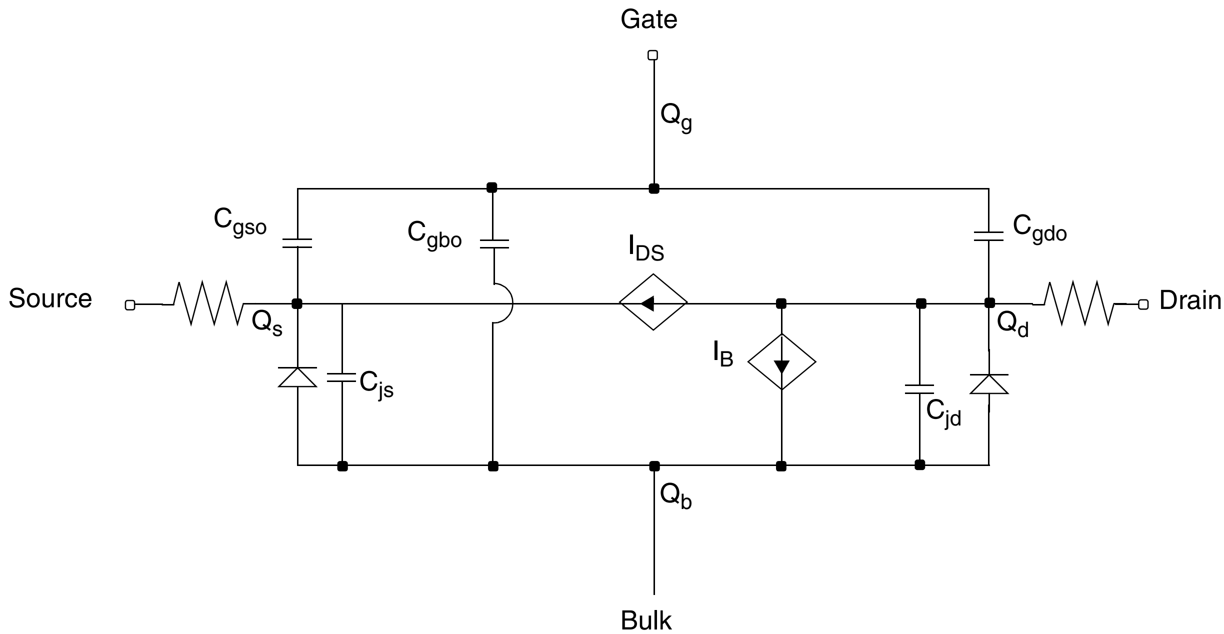
Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

16

MOS Level-3 Model (mos3)

The MOS3 model is the level-3 model from Berkeley SPICE, and is a semi-empirical model. Three charge models are available. This chapter contains the following information for the MOS3 model:



Channel Width and Length

$$W_{scaled} = w*scale + xw*scalem$$

$$W_{eff} = \begin{cases} w*scale + xw*scalem - 2wd*scalem & \text{(Level 1-3)} \\ w*scale + xw*scalem - dw*scalem & \text{(BSIM 1-2)} \end{cases}$$

$$L_{eff} = \begin{cases} l*scale + xl*scalem - 2ld*scalem & \text{(Level 1-3)} \\ l*scale + xl*scalem - dl*scalem & \text{(BSIM 1-2)} \end{cases}$$

Threshold Voltage

$$V_{TH} = V_{BI} + gamma\ F_S\sqrt{phi - V_{BS}} - \sigma V_{DS} + F_N(phi - V_{BS})$$

where

$$V_{BI} = vto - gamma\sqrt{phi}$$

$$\sigma = \frac{8.15 \times 10^{-22} eta}{C_{ox} L^3{}_{eff}}$$

$$F_S = 1 - \frac{xj}{L_{eff}}\left\{\left(\frac{ld}{xj} + \frac{W_C}{xj}\right)\sqrt{1 - \left(\frac{W_p}{1 + W_p}\right)^2} - \frac{ld}{xj}\right\}$$

$$W_p = \frac{X_D}{xj}\sqrt{phi - V_{BS}}$$

$$X_D = \sqrt{\frac{2\varepsilon_{si}}{q * nsub}}$$

$$\frac{W_c}{xj} = 0.0631353 + 0.8013292 W_p - 0.01110777 W_p^2$$

$$F_N = \frac{delta * \pi * \varepsilon_{si}}{2 C_{ox} W_{eff}}$$

If either xj or $nsub$ is zero, the short-channel effects on threshold voltage are not evaluated; that is, F_S = 1.

Drain Saturation Voltage

If $vmax$ is not input, V_{DSAT} is determined by the pinchoff condition and is given by

$$V_{DSAT} = \frac{V_{GST}}{1 + F_B}$$

where

$$V_{GST} = V_{GS} - V_{TH}$$

$$F_B = \frac{gamma\ F_S}{4\sqrt{phi - V_{BS}}} + F_N$$

If $vmax$ is specified, V_{DSAT} is determined by the velocity saturation effect.

$$V_{DSAT} = \frac{V_{GST}}{1 + F_B} + E_c L_{eff} - \sqrt{\left(\frac{V_{GST}}{1 + F_B}\right)^2 + (E_c L_{eff})^2}$$

where

$$E_c = \frac{vmax}{\mu_{eff}}$$

μ_{eff} is the effective mobility that is defined later.

Drain Current for the Subthreshold Region

Note: These equations apply when $V_{GS} \le V_{ON}$.

You cannot use the subthreshold current equations without nfs.

$$V_{ON} = \begin{cases} V_{TH} + nV_t & \text{if } nfs \text{ is specified} \\ V_{TH} & \text{otherwise} \end{cases}$$

where

$$n = 1 + \frac{C_{FS} + C_D}{C_{ox}}$$

$$C_{FS} = q(nfs)$$

$$C_D = \left[\frac{\gamma_s}{2\sqrt{phi - V_{BS}}} - \frac{d\gamma_s}{dV_{BS}}\sqrt{phi - V_{BS}} + F_N\right] C_{ox}$$

$$I_{DS} = I_{DS,\,ON} e^{(V_{GS} - V_{ON})/nV_t}$$

where $I_{DS,ON}$ is the drain current evaluated at $V_{GS} = V_{ON}$.

Drain Current for the Triode Region

Note: These equations apply when $V_{GS} \geq V_{ON}$ and $V_{DS} \leq V_{DSAT}$.

$$I_{DS} = \frac{\beta\left[V_{GS} - V_{TH} - \frac{(1 + F_B)}{2} V_{DS}\right] V_{DS}}{1 + \frac{\mu_{eff} V_{DS}}{vmax\ L_{eff}}} \quad \backslash$$

where

$$\beta = \frac{\mu_{eff} C_{ox} W_{eff}}{L_{eff}} \quad \backslash$$

$$\mu_{eff} = \frac{uo}{1 + theta(V_{GS} - V_{TH})}$$

Drain Current for the Saturation Region

Note: These equations apply when $V_{GS} \geq V_{ON}$ and $V_{DS} \geq V_{DSAT}$.

$$I_{DS} = \frac{\beta\left[V_{GS} - V_{TH} - \frac{(1 + F_B)}{2} V_{DSAT}\right] V_{DSAT}}{1 + \frac{\mu_{eff} V_{DSAT}}{vmax\ L_{eff}}}$$

where

$$\beta = \frac{\mu_{eff} C_{ox} W_{eff}}{L_{eff} - \Delta L}$$

$$\Delta L = \begin{cases} \sqrt{kappa\ X_D^2(V_{DS} - V_{DSAT})} & \text{if } vmax \text{ is not specified} \\ \sqrt{E_x^2 + kappa\ X_D^2(V_{DS} - V_{DSAT})} - E_x & \text{otherwise} \end{cases}$$

If ΔL Š $L_{eff}/2$, a new value of $\Delta L(\Delta L_{new})$ is calculated to avoid device punchthrough.

$$\Delta L_{new} = L_{eff} - \frac{L_{eff}^2}{4\Delta L}$$

Substrate Current

The substrate current results from impact ionization in the velocity saturation region near the drain. This impact-ionization induced current (I_{DB}) flows between the drain and the substrate. You need both aio and bio to use the impact-ionization model.

$$I_{DB} = \begin{cases} I_{DS}A_i(V_{DS} - V_{DSAT})e^{-B_i/(V_{DS} - V_{DSAT})} & \text{if } V_{DS} \le V_{DSAT} \\ 0 & \text{otherwise} \end{cases}$$

where

$$A_i = aio + \frac{laio \times 10^{-6}}{L_{eff}} + \frac{waio \times 10^{-6}}{W_{eff}}$$

$$B_i = bio + \frac{lbio \times 10^{-6}}{L_{eff}} + \frac{wbio \times 10^{-6}}{W_{eff}}$$

Scaling Effects

For scaling effects, see Scaling Factors (scale and scalem) on page 242.

Component Statements

This device is supported within altergroups.

Sample Instance Statement:

```
mp3 (0 1 2 2) pchmos3 l=2u w=30u ad=120p as=75p pd=36u ps=6u
```

Sample Model Statement:

```
model pchmos3 mos3 type=p vto=-0.83 gamma=0.4511 kappa=5 ld=0.45e-6 kp=0.334e-4
tox=0.3e-7 nsub=0.2e17 capmod=yang vmax=4.5e5 theta=0.25 cbs=10e-15 cbd=10e-15
```

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `w (m)`	Channel width.
2 `l (m)`	Channel length.
3 `as` (m^2)	Area of source diffusion.
4 `ad` (m^2)	Area of drain diffusion.
5 `ps (m)`	Perimeter of source diffusion.
6 `pd (m)`	Perimeter of drain diffusion.
7 `nrd (m/m)`	Number of squares of drain diffusion.
8 `nrs (m/m)`	Number of squares of source diffusion.
9 `ld (m)`	Length of drain diffusion region.
10 `ls (m)`	Length of source diffusion region.
11 `m=1`	Multiplicity factor (number of MOSFETs in parallel).
12 `region=triode`	Estimated operating region. Spectre outputs number (0-4) in a rawfile. Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.
13 `trise`	Temperature rise from ambient.

14 `isnoisy=yes` — Should resistor generate noise.
Possible values are `no` or `yes`.

15 `degradation=no` — Hot-electron degradation flag.
Possible values are `no` or `yes`.

Model Definition

```
model modelName mos3 parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n` — Transistor type.
Possible values are `n` or `p`.

Drain current model parameters

2 `vto=0 V` — Threshold voltage at zero body bias.

3 `kp=2.0718e-5 A/V`^{2} — Transconductance parameter.

4 `theta=0 1/V` — Mobility modulation coefficient.

5 `phi=0.7 V` — Surface potential at strong inversion.

6 `gamma=0 √V` — Body-effect parameter.

7 `uo=600 cm`^{2}`/V s` — Carrier surface mobility.

8 `vmax=∞ m/s` — Carrier saturation velocity.

9 `eta=0 1/V` — Static feedback coefficient.

10 `kappa=0.2` — Saturation field factor.

11 `delta=0` — Width effect on threshold voltage.

Process parameters

12 `nsub=1.13e16 cm`$^{-3}$	Channel doping concentration.
13 `nss=0 cm`$^{-2}$	Surface state density.
14 `nfs=0 cm`$^{-2}$	Fast surface state density.
15 `tpg=+1`	Type of gate (+1 = opposite of substrate, -1 = same as substrate, 0 = aluminum).
16 `tox=1e-7 m`	Gate oxide thickness.
17 `ld=0 m`	Lateral diffusion.
18 `wd=0 m`	Field-oxide encroachment.
19 `xw=0 m`	Width variation due to masking and etching.
20 `xl=0 m`	Length variation due to masking and etching.
21 `xj=0 m`	Source/drain junction depth.

Impact ionization parameters

22 `ai0=0 1/V`	Impact ionization current coefficient.
23 `lai0=0 µm/V`	Length sensitivity of `ai0`.
24 `wai0=0 µm/V`	Width sensitivity of `ai0`.
25 `bi0=0 V`	Impact ionization current exponent.
26 `lbi0=0 µm V`	Length sensitivity of `bi0`.
27 `wbi0=0 µm V`	Width sensitivity of `bi0`.

Overlap capacitance parameters

28 `cgso=0 F/m`	Gate-source overlap capacitance.

29 `cgdo=0 F/m`	Gate-drain overlap capacitance.
30 `cgbo=0 F/m`	Gate-bulk overlap capacitance.
31 `meto=0 m`	Metal overlap in fringing field.

Charge model selection parameters

32 `capmod=bsim`	Intrinsic charge model. Possible values are `none`, `meyer`, `yang`, or `bsim`.
33 `xpart=1`	Drain/source channel charge partition in saturation for BSIM charge model, use 0.0 for 40/60, 0.5 for 50/50, or 1.0 for 0/100.
34 `xqc=0`	Drain/source channel charge partition in saturation for charge models, for example, use 0.4 for 40/60, 0.5 for 50/50, 0 for 0/100.

Parasitic resistance parameters

35 `rs=0 Ω`	Source resistance.
36 `rd=0 Ω`	Drain resistance.
37 `rsh=0 Ω/sqr`	Source/drain diffusion sheet resistance.
38 `rss=0 Ω m`	Scalable source resistance.
39 `rdd=0 Ω m`	Scalable drain resistance.
40 `rsc=0 Ω`	Source contact resistance.
41 `rdc=0 Ω`	Drain contact resistance.
42 `minr=0.1 Ω`	Minimum source/drain resistance.
43 `ldif=0 m`	Lateral diffusion beyond the gate.
44 `hdif=0 m`	Length of heavily doped diffusion.
45 `lgcs=0 m`	Gate-to-contact length of source side.
46 `lgcd=0 m`	Gate-to-contact length of drain side.

47 `sc=∞ m` Spacing between contacts.

Junction diode model parameters

48 `js (A/m`^{2}`)` Bulk junction reverse saturation current density.

49 `is=1e-14 A` Bulk junction reverse saturation current.

50 `n=1` Junction emission coefficient.

51 `dskip=yes` Use simple piece-wise linear model for diode currents below 0.1*`iabstol`.
Possible values are `no` or `yes`.

52 `imelt=`imax' A` Explosion current, diode is linearized beyond this current to aid convergence.

53 `jmelt=`jmax' A/m'`^{2}
Explosion current density, diode is linearized beyond this current to aid convergence.

Junction capacitance model parameters

54 `cbs=0 F` Bulk-source zero-bias junction capacitance.

55 `cbd=0 F` Bulk-drain zero-bias junction capacitance.

56 `cj=0 F/m`^{2} Zero-bias junction bottom capacitance density.

57 `mj=1/2` Bulk junction bottom grading coefficient.

58 `pb=0.8 V` Bulk junction built-in potential.

59 `fc=0.5` Forward-bias depletion capacitance threshold.

60 `cjsw=0 F/m` Zero-bias junction sidewall capacitance density.

61 `mjsw=1/3` Bulk junction sidewall grading coefficient.

62 `pbsw=0.8 V` Side-wall junction built-in potential.

63 `fcsw=0.5` Side-wall forward-bias depletion capacitance threshold.

Operating region warning control parameters

64 `alarm=none` Forbidden operating region.
Possible values are `none`, `off`, `triode`, `sat`, `subth`, or `rev`.

65 `imax=1 A` Maximum current, currents above this limit generate a warning.

66 `jmax=1e8 A/m`^{2} Maximum current density, currents above this limit generate a warning.

67 `bvj=∞ V` Junction reverse breakdown voltage.

68 `vbox=1e9 tox V` Oxide breakdown voltage.

Temperature effects parameters

69 `tnom (C)` Parameters measurement temperature. Default set by `options`.

70 `trise=0 C` Temperature rise from ambient.

71 `uto=0 C` Mobility temperature offset.

72 `ute=-1.5` Mobility temperature exponent.

73 `tlev=0` DC temperature selector.

74 `tlevc=0` AC temperature selector.

75 `eg=1.12452 V` Energy band gap.

76 `gap1=7.02e-4 V/C` Band gap temperature coefficient.

77 `gap2=1108 C` Band gap temperature offset.

78 `f1ex=0` Temperature exponent for `ucrit`.

79 `lamex=0 1/C` Temperature parameter for `lambda` and `kappa`.

80 `trs=0 1/C` Temperature parameter for source resistance.

81 `trd=0 1/C` Temperature parameter for drain resistance.

82 `xti=3` Saturation current temperature exponent.

83 `ptc=0 V/C` Surface potential temperature coefficient.

84 `tcv=0 V/C` Threshold voltage temperature coefficient.

85 `pta=0 V/C` Junction potential temperature coefficient.

86 `ptp=0 V/C` Sidewall junction potential temperature coefficient.

87 `cta=0 1/C` Junction capacitance temperature coefficient.

88 `ctp=0 1/C` Sidewall junction capacitance temperature coefficient.

Default instance parameters

89 `w=3e-6 m` Default channel width.

90 `l=3e-6 m` Default channel length.

91 `as=0` m^2 Default area of source diffusion.

92 `ad=0` m^2 Default area of drain diffusion.

93 `ps=0 m` Default perimeter of source diffusion.

94 `pd=0 m` Default perimeter of drain diffusion.

95 `nrd=0 m/m` Default number of squares of drain diffusion.

96 `nrs=0 m/m` Default number of squares of source diffusion.

97 `ldd=0 m` Default length of drain diffusion region.

98 `lds=0 m` Default length of source diffusion region.

Noise model parameters

99 `noisemod=1` Noise model selector.

100 `kf=0` Flicker (1/f) noise coefficient.

101 `af=1` Flicker (1/f) noise exponent.

102 `ef=1`	Flicker (1/f) noise frequency exponent.
103 `wnoi=1e-5 m`	Channel width at which noise parameters were extracted.

Auto Model Selector parameters

104 `wmax=1.0 m`	Maximum channel width for which the model is valid.
105 `wmin=0.0 m`	Minimum channel width for which the model is valid.
106 `lmax=1.0 m`	Maximum channel length for which the model is valid.
107 `lmin=0.0 m`	Minimum channel length for which the model is valid.

Degradation parameters

108 `degramod=spectre`	Degradation model selector. Possible values are `spectre` or `bert`.
109 `degradation=no`	Hot-electron degradation flag. Possible values are `no` or `yes`.
110 `dvthc=1 V`	Degradation coefficient for threshold voltage.
111 `dvthe=1`	Degradation exponent for threshold voltage.
112 `duoc=1 S`	Degradation coefficient for transconductance.
113 `duoe=1`	Degradation exponent for transconductance.
114 `crivth=0.1 V`	Maximum allowable threshold voltage shift.
115 `criuo=10%`	Maximum allowable normalized mobility change.
116 `crigm=10%`	Maximum allowable normalized transconductance change.
117 `criids=10%`	Maximum allowable normalized drain current change.
118 `wnom=5e-6 m`	Nominal device width in degradation calculation.
119 `lnom=1e-6 m`	Nominal device length in degradation calculation.

120 `vbsn=0 V` Substrate voltage in degradation calculation.

121 `vdsni=0.1 V` Drain voltage in `Ids` degradation calculation.

122 `vgsni=5 V` Gate voltage in `Ids` degradation calculation.

123 `vdsng=0.1 V` Drain voltage in `Gm` degradation calculation.

124 `vgsng=5 V` Gate voltage in `Gm` degradation calculation.

Spectre stress parameters

125 `esat=1.1e7 V/m` Critical field in Vdsat calculation.

126 `esatg=2.5e6 1/m` Gate voltage dependence of `esat`.

127 `vpg=-0.25` Gate voltage modifier.

128 `vpb=-0.13` Gate voltage modifier.

129 `subc1=2.24e-5` Substrate current coefficient.

130 `subc2=-0.1e-5 1/V` Substrate current coefficient.

131 `sube=6.4` Substrate current exponent.

132 `strc=1` Stress coefficient.

133 `stre=1` Stress exponent.

BERT stress parameters

134 `h0=1` Aging coefficient.

135 `hgd=0 1/V` Bias dependence of `h0`.

136 `m0=1` Aging exponent.

137 `mgd=0 1/V` Bias dependence of `m0`.

138 `ecrit0=1.1e5 V/cm` Critical electric field.

139 `lecrit0=0 µm V/cm` Length dependence of `ecrit0`.

140 `wecrit0=0 µm V/cm` Width dependence of `ecrit0`.

141 `ecritg=0 1/cm` Gate voltage dependence of `ecrit0`.

142 `lecritg=0 µm/cm` Length dependence of `ecritg`.

143 `wecritg=0 µm/cm` Width dependence of `ecritg`.

144 `ecritb=0 1/cm` Substrate voltage dependence of `ecrit0`.

145 `lecritb=0 µm/cm` Length dependence of `ecritb`.

146 `wecritb=0 µm/cm` Width dependence of `ecritb`.

147 `lc0=1` Substrate current coefficient.

148 `llc0=0 µm` Length dependence of `lc0`.

149 `wlc0=0 µm` Width dependence of `lc0`.

150 `lc1=1` Substrate current coefficient.

151 `llc1=0 µm` Length dependence of `lc1`.

152 `wlc1=0 µm` Width dependence of `lc1`.

153 `lc2=1` Substrate current coefficient.

154 `llc2=0 µm` Length dependence of `lc2`.

155 `wlc2=0 µm` Width dependence of `lc2`.

156 `lc3=1` Substrate current coefficient.

157 `llc3=0 µm` Length dependence of `lc3`.

158 `wlc3=0 µm` Width dependence of `lc3`.

159 `lc4=1` Substrate current coefficient.

160 `llc4=0 µm` Length dependence of `lc4`.

161 `wlc4=0 µm` Width dependence of `lc4`.

162 `lc5=1` Substrate current coefficient.

163 `llc5=0 µm` Length dependence of `lc5`.

164 `wlc5=0 µm` Width dependence of `lc5`.

165 `lc6=1` Substrate current coefficient.

166 `llc6=0 µm` Length dependence of `lc6`.

167 `wlc6=0 µm` Width dependence of `lc6`.

168 `lc7=1` Substrate current coefficient.

169 `llc7=0 µm` Length dependence of `lc7`.

170 `wlc7=0 µm` Width dependence of `lc7`.

Shrink Parameters

Imax and Imelt

The `imax` parameter aids convergence and prevents numerical overflow. The junction characteristics of the device are accurately modeled for current up to `imax`. If `imax` is exceeded during iterations, the linear model is substituted until the current drops below imax or until convergence is achieved. If convergence is achieved with the current exceeding `imax`, the results are inaccurate, and Spectre prints a warning.

A separate model parameter, `imelt`, is used as a limit warning for the junction current. This parameter can be set to the maximum current rating of the device. When any component of the junction current exceeds `imelt`, note that base and collector currents are composed of many exponential terms, Spectre issues a warning and the results become inaccurate. The junction current is linearized above the value of `imelt` to prevent arithmetic exception, with the exponential term replaced by a linear equation at `imelt`.

Both of these parameters have current density counterparts, `jmax` and `jmelt`, that you can specify if you want the absolute current values to depend on the device area.

Auto Model Selection

Many models need to be characterized for different geometries in order to obtain accurate results for model development. The model selector program automatically searches for a model with the length and width range specified in the instance statement and uses this model in the simulations.

For the auto model selector program to find a specific model, the models to be searched should be grouped together within braces. Such a group is called a model group. An opening brace is required at the end of the line defining each model group. Every model in the group is given a name followed by a colon and the list of parameters. Also, the four geometric parameters `lmax`, `lmin`, `wmax`, and `wmin` should be given. The selection criteria to choose a model is as follows:

lmin <= inst_length < lmax and wmin <= inst_width < wmax

Example:

model ModelName ModelType {

1: <model parameters> lmin=2 lmax=4 wmin=1 wmax=2

2: <model parameters> lmin=1 lmax=2 wmin=2 wmax=4

3: <model parameters> lmin=2 lmax=4 wmin=4 wmax=6

}

Then for a given instance

M1 1 2 3 4 ModelName w=3 l=1.5

the program would search all the models in the model group with the name `ModelName` and then pick the first model whose geometric range satisfies the selection criteria. In the preceding example, the auto model selector program would choose ModelName.2.

You must specify both length (l) and width (w) on the device instance line to enable automatic model selection.

Output Parameters

1	`weff (m)`	Effective channel width.
2	`leff (m)`	Effective channel length.
3	`rseff (Ω)`	Effective source resistance.

4 `rdeff (Ω)` Effective drain resistance.

5 `aseff (m²)` Effective area of source diffusion.

6 `adeff (m²)` Effective area of drain diffusion.

7 `pseff (m)` Effective perimeter of source diffusion.

8 `pdeff (m)` Effective perimeter of source diffusion.

9 `isseff (A)` Effective source-bulk junction reverse saturation current.

10 `isdeff (A)` Effective drain-bulk junction reverse saturation current.

11 `cbseff (F)` Effective zero-bias source-bulk junction capacitance.

12 `cbdeff (F)` Effective zero-bias drain-bulk junction capacitance.

Operating-Point Parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

2 `region=triode` Estimated operating region. Spectre outputs number (0-4) in a rawfile.
Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.

3 `degradation=no` Hot-electron degradation flag.
Possible values are `no` or `yes`.

4 `reversed` Reverse mode indicator.
Possible values are `no` or `yes`.

5 `ids (A)` Resistive drain-to-source current.

6 `vgs (V)` Gate-source voltage.

7 `vds (V)` Drain-source voltage.

8 `vbs (V)` Bulk-source voltage.

9 `vth (V)` Threshold voltage.

10 `vdsat (V)`	Drain-source saturation voltage.
11 `gm (S)`	Common-source transconductance.
12 `gds (S)`	Common-source output conductance.
13 `gmbs (S)`	Body-transconductance.
14 `gameff` ($\sqrt{V}$)	Effective body effect coefficient.
15 `betaeff` (A/V^2)	Effective `beta`.
16 `cbd (F)`	Drain-bulk junction capacitance.
17 `cbs (F)`	Source-bulk junction capacitance.
18 `cgs (F)`	Gate-source capacitance.
19 `cgd (F)`	Gate-drain capacitance.
20 `cgb (F)`	Gate-bulk capacitance.
21 `ron` (Ω)	On-resistance.
22 `id (A)`	Resistive drain current.
23 `ibulk (A)`	Resistive bulk current.
24 `pwr (W)`	Power at op point.
25 `gmoverid (1/V)`	`Gm/Ids`.
26 `isub (A)`	Substrate current.
27 `stress`	Hot-electron stress.
28 `age (s)`	Device age.
29 `he_vdsat (V)`	Hot Electron `Vdsat`.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

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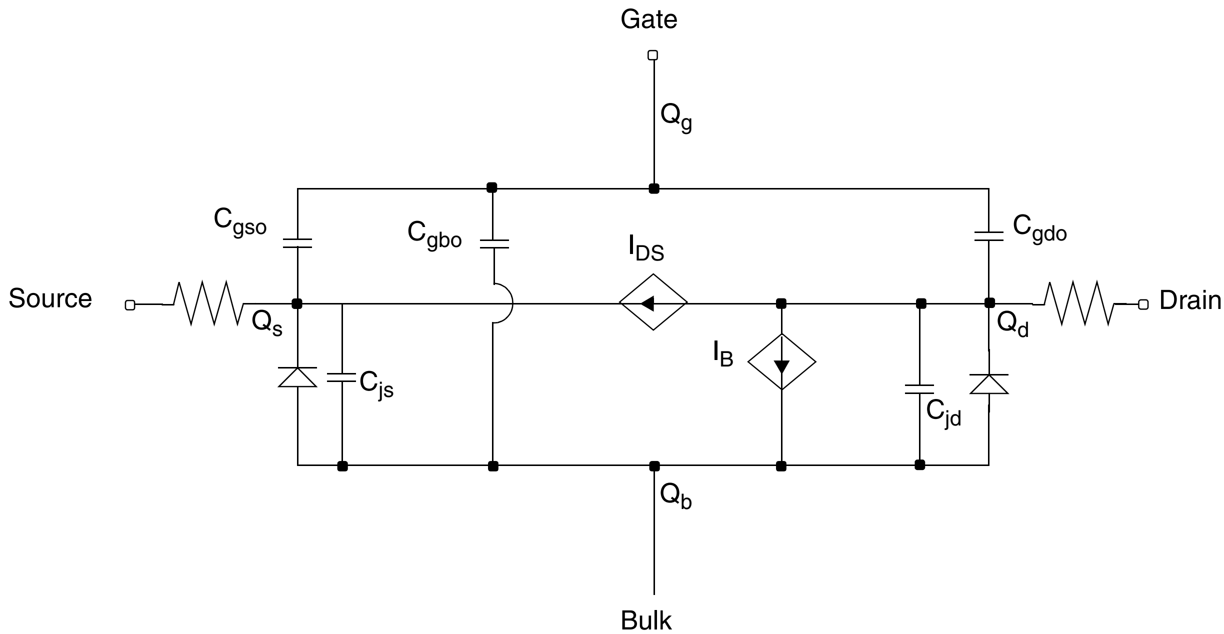
BSIM1 Level-4 Model (bsim1)

The BSIM1 model is based on the industry standard efforts of the Compact Modeling Counsel (CMC) and the BSIM modeling group at the University of California, Berkeley. This chapter contains the following information for the BSIM1 model:



BSIM1 stands for Berkeley Short-Channel IGFET Model version-1. The BSIM1 model is a semiempirical model suitable for devices with channel length from long channel to about 0.8 µm. This model extracts all model parameters directly from physical devices. You can obtain an automated parameter extraction program, based on the HP9836 and HP4145 systems, from the ILP office, Department of EECS, University of California, Berkeley. The following table shows the correspondence between the input parameter names and the equation symbols for the BSIM1 model.

Parameter	Symbol	Parameter	Symbol	Parameter	Symbol
vfb	$V_{FB,0}$	lvfb	$V_{FB,L}$	wvfb	$V_{FB,W}$
phi	ϕ_0	lphi	ϕ_L	wphi	ϕ_W
k1	K_1	lk1	$K_{1,L}$	wk1	$K_{1,W}$
k2	K_2	lk2	$K_{2,L}$	wk2	$K_{2,W}$
eta	η_0	leta	η_L	weta	η_W
muz	μ_0	dl	dl	dw	dw
u0	$U_{0,0}$	lu0	$U_{0,L}$	wu0	$U_{0,W}$
u1	$U_{1,0}$	lu1	$U_{1,L}$	wu1	$U_{1,W}$

Parameter	Symbol	Parameter	Symbol	Parameter	Symbol
x2mz	$\mu_{0B,0}$	lx2mz	$\mu_{0B,L}$	wx2mz	$\mu_{0B,W}$
x2e	$\eta_{B,0}$	lx2e	$\eta_{B,L}$	wx2e	$\eta_{B,W}$
x3e	$\eta_{D,0}$	lx3e	$\eta_{D,L}$	wx3e	$\eta_{D,W}$
x2u0	$U_{0B,0}$	lx2u0	$U_{0B,L}$	wx2u0	$U_{0B,W}$
x2u1	$U_{1B,0}$	lx2u1	$U_{1B,L}$	wx2u1	$U_{1,B,W}$
mus	μ_s	lmus	$\mu_{s,L}$	wmus	$\mu_{s,W}$
x2ms	$\mu_{sB,0}$	lx2ms	$\mu_{sB,L}$	wx2ms	$\mu_{sB,W}$
x3ms	$\mu_{sD,0}$	lx3ms	$\mu_{sD,L}$	wx3ms	$\mu_{sD,W}$
x3u1	$U_{1D,0}$	lx3u1	$U_{1D,L}$	wx3u1	$U_{1D,W}$
n0	$N_{0,0}$	ln0	$N_{0,L}$	wn0	$N_{0,W}$
nb	$N_{B,0}$	lnb	$N_{B,L}$	wnb	$N_{B,W}$
nd	$N_{D,0}$	lnd	$N_{D,L}$	wnd	$N_{D,W}$
aio	Ai_0	laio	$Ai_{0,L}$	waio	$Ai_{0,W}$
bio	Bi_0	lbio	$Bi_{0,L}$	wbio	$Bi_{0,W}$
vdd	V_{DD}				

Parameter Calculation

Except for muz, dl, and dw, all device parameters are calculated from the following equation:

$$P_i = P_{i,0} + \frac{P_{i,L}}{L_{eff}} + \frac{P_{i,W}}{W_{eff}}$$

where P_i is any device parameter, $P_{i,0}$ is the parameter value for very long channel length and width, and $P_{i,L}$ and $P_{i,W}$ are the channel length and width dependencies of the parameter, respectively. The following example shows how the flat-band voltage for a device with $l = 2$ µm and $w = 5$ µm is calculated from the model parameters:

$$V_{FB} = V_{FB,0} + \frac{V_{FB,L}}{2 - dl} + \frac{V_{FB,W}}{5 - dw}$$

Drain Current Model

Channel Width and Length

$$W_{scaled} = w*scale + xw*scalem$$

$$W_{eff} = \begin{cases} w*scale + xw*scalem - 2wd*scalem & \text{(Level 1-3)} \\ w*scale + xw*scalem - dw*scalem & \text{(BSIM 1-2)} \end{cases}$$

$$L_{eff} = \begin{cases} l*scale + xl*scalem - 2ld*scalem & \text{(Level 1-3)} \\ l*scale + xl*scalem - dl*scalem & \text{(BSIM 1-2)} \end{cases}$$

Threshold Voltage

$$V_{TH} = V_{FB} + \phi + K_1\sqrt{\phi - V_{BS}} - K_2(\phi - V_{BS}) - \eta V_{DS}$$

where

$$\eta = \eta_0 + \eta_B V_{BS} + \eta_D(V_{DS} - V_{DD})$$

Drain Saturation Voltage

$$V_{DSAT} = \frac{V_{GS} - V_{TH}}{a\sqrt{K}}$$

where

$$a = 1 + \frac{gK_1}{2\sqrt{\phi - V_{BS}}}$$

$$g = 1 - \frac{1}{1.744 + 0.8364(\phi - V_{BS})}$$

$$K = \frac{1 + V_c + \sqrt{1 + 2V_c}}{2}$$

$$V_c = \frac{U_{1S}(V_{GS} - V_{TH})}{a}$$

Drain Current for the Subthreshold Region

Note: These equations apply when V_{GS} Ý≤ V_{TH}.

If you specify that N_0 is less than 10, the subthreshold current is calculated and added to the drain current.

$$I_{subth} = \frac{I_{EXP} I_{LIMIT}}{I_{EXP} + I_{LIMIT}}$$

where

$$I_{EXP} = \beta_0 V_t^2 e^{1.8 + (V_{GS} - V_{TH})/nV_t}(1 - e^{-V_{DS}/V_t})$$

$$I_{LIMIT} = 4.5\beta_0 V_t^2$$

$$n = N_0 + N_B V_{BS} + N_D V_{DS}$$

The subthreshold current is added to the drain current.

$$I_{DS,tot} = I_{DS} + I_{subth}$$

Drain Current for the Triode Region

Note: These equations apply when $V_{GS} \geq V_{ON}$ and $V_{DS} \leq V_{DSAT}$.

$$I_{DS} = \frac{\beta_0\left(V_{GS} - V_{TH} - \frac{a}{2}V_{DS}\right)V_{DS}}{(1 + U_{1S}V_{DS})[1 + \theta(V_{GS} - V_{TH})]}$$

where

$$\theta = U_0 + U_{0B}V_{BS}$$

$$U_{1S} = \frac{U_1 + U_{1B}V_{BS} + U_{1D}(V_{DS} - V_{DD})}{L_{eff}}$$

$$\beta_0 = \beta_1\left(\frac{V_{DS}}{V_{DD}} - 1\right)^2 + \beta_2\left(2 - \frac{V_{DS}}{V_{DD}}\right)\frac{V_{DS}}{V_{DD}} + \beta_{sD}V_{DS}\left(\frac{V_{DS}}{V_{DD}} - 1\right)$$

$$\beta_1 = \frac{C_{ox}W_{eff}}{L_{eff}}(\mu_0 + \mu_{0B}V_{BS})$$

$$\beta_2 = \frac{C_{ox}W_{eff}}{L_{eff}}(\mu_s + \mu_{sB}V_{BS})$$

$$\beta_{sD} = \frac{C_{ox}W_{eff}}{L_{eff}}\mu_{sD}$$

Drain Current for the Saturation Region

Note: This equation applies when $V_{GS} \geq V_{ON}$ and $V_{DS} \geq V_{DSAT}$.

$$I_{DS} = \frac{\beta(V_{GS} - V_{TH})^2}{2aK}$$

Substrate Current

The substrate current results from impact ionization in the velocity saturation region near the drain. This impact-ionization induced current (I_{DB}) flows between the drain and the substrate. You need both A_i and B_i to use the impact-ionization model.

$$I_{DB} = \begin{cases} I_{DS}A_i(V_{DS} - V_{DSAT})e^{-B_i/(V_{DS} - V_{DSAT})} & \text{if } V_{DS} \leq V_{DSAT} \\ 0 & \text{otherwise} \end{cases}$$

where

$$A_i = A_{io} + \frac{A_{io,L} \times 10^{-6}}{L_{eff}} + \frac{A_{io,W} \times 10^{-6}}{W_{eff}}$$

$$B_i = B_{io} + \frac{B_{io,L} \times 10^{-6}}{L_{eff}} + \frac{B_{io,W} \times 10^{-6}}{W_{eff}}$$

Scaling Effects

For scaling effects, see Scaling Factors (scale and scalem) on page 242.

Component Statements

This device is supported within altergroups.

Sample Instance Statement

```
m1 (1 2 0 0) nchmod l=5u w=10u as=40u ad=40u pd=28u ps=28u m=1
```

Sample Model Statement

```
model nchmod bsim1 vfb0=-0.5 lvfb=0.5 wvfb=0.3 phi0=0.8 eta0=0.056 k1=0.5 muz=454
eg=0.99 gap1=5.5e-04 trs=1e-3 trd=1e-3 xpart=0.5 rs=10 rd=10
```

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1	`w (m)`	Channel width.
2	`l (m)`	Channel length.
3	`as` (m^2)	Area of source diffusion.
4	`ad` (m^2)	Area of drain diffusion.

5 `ps (m)` Perimeter of source diffusion.

6 `pd (m)` Perimeter of drain diffusion.

7 `nrd (m/m)` Number of squares of drain diffusion.

8 `nrs (m/m)` Number of squares of source diffusion.

9 `ld (m)` Drain diffusion length.

10 `ls (m)` Source diffusion length.

11 `m=1` Multiplicity factor (number of MOSFETs in parallel).

12 `region=triode` Estimated operating region. Spectre outputs number (0-4) in a rawfile.
Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.

13 `trise (C)` Temperature rise from ambient.

14 `degradation=no` Hot-electron degradation flag.
Possible values are `no` or `yes`.

15 `isnoisy=yes` Should resistor generate noise.
Possible values are `no` or `yes`.

Model Definition

```
model modelName bsim1 parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

Threshold voltage parameters

2 `vfb0=-0.8 V` Flat-band voltage.

3 `lvfb=0 V µm`	Length dependence of `vfb`.
4 `wvfb=0 V µm`	Width dependence of `vfb`.
5 `pvfb=0 V µm`	Width-length dependence of `vfb`.
6 `phi0=0.75 V`	Surface potential.
7 `lphi=0 V µm`	Length dependence of `phi`.
8 `wphi=0 V µm`	Width dependence of `phi`.
9 `pphi=0 V µm`	Width-length dependence of `phi`.
10 `k1=0.7 √V`	Body-effect coefficient.
11 `lk1=0 √V µm`	Length dependence of `k1`.
12 `wk1=0 √V µm`	Width dependence of `k1`.
13 `pk1=0 √V µm`	Width-length dependence of `k1`.
14 `k2=0`	Charge-sharing parameter.
15 `lk2=0 µm`	Length dependence of `k2`.
16 `wk2=0 µm`	Width dependence of `k2`.
17 `pk2=0 µm`	Width-length dependence of `k2`.
18 `eta0=0`	Drain-induced barrier-lowering coefficient.
19 `leta=0 µm`	Length dependence of eta.
20 `weta=0 µm`	Width dependence of `eta`.
21 `peta=0 µm`	Width-length dependence of `eta`.
22 `x2e=0 1/V`	Body-bias dependence of eta.
23 `lx2e=0 µm/V`	Length dependence of `x2e`.
24 `wx2e=0 µm/V`	Width dependence of `x2e`.

25 `px2e=0 µm/V` Width-length dependence of `x2e`.

26 `x3e=0 1/V` Drain-bias dependence of `eta`.

27 `lx3e=0 µm/V` Length dependence of `x3e`.

28 `wx3e=0 µm/V` Width dependence of `x3e`.

29 `px3e=0 µm/V` Width-length dependence of `x3e`.

Mobility parameters

30 `muz=400` $cm^2/V\ s$ Low-field mobility.

31 `lmuz=0` $cm^2/V\ s$ Length dependence of muz.

32 `wmuz=0` $cm^2/V\ s$ Width dependence of muz.

33 `pmuz=0` $cm^2/V\ s$ Width-length dependence of muz.

34 `x2mz=0` $cm^2/V^2\ s$ Body-bias dependence of `muz`.

35 `lx2mz=0` $cm^2\ \mu m/V^2\ s$
Length dependence of `x2mz`.

36 `wx2mz=0` $cm^2\ \mu m/V^2\ s$
Width dependence of `x2mz`.

37 `px2mz=0` $cm^2\ \mu m/V^2\ s$
Width-length dependence of `x2mz`.

38 `mus=450` $cm^2/V\ s$ Mobility in the saturation region.

39 `lmus=0` $cm^2\ \mu m/V\ s$
Length dependence of `mus`.

40 `wmus=0` $cm^2\ \mu m/V\ s$
Width dependence of `mus`.

41 `pmus=0` $cm^2\ \mu m/V\ s$
Width-length dependence of `mus`.

42 `x2ms=0` $cm^2/V^2\ s$ Body-bias dependence of `mus`.

43 `lx2ms=0` cm^2 µm/V^2 s
Length dependence of `x2ms`.

44 `wx2ms=0` cm^2 µm/V^2 s
Width dependence of `x2ms`.

45 `px2ms=0` cm^2 µm/V^2 s
Width-length dependence of `x2ms`.

46 `x3ms=0` cm^2/V^2 s — Drain-bias dependence of `mus`.

47 `lx3ms=0` cm^2 µm/V^2 s
Length dependence of `x3ms`.

48 `wx3ms=0` cm^2 µm/V^2 s
Width dependence of `x3ms`.

49 `px3ms=0` cm^2 µm/V^2 s
Width-length dependence of `x3ms`.

Mobility modulation parameters

50 `u00=0 1/V` — Gate voltage dependence of mobility.

51 `lu0=0 µm/V` — Length dependence of `u0`.

52 `wu0=0 µm/V` — Width dependence of `u0`.

53 `pu0=0 µm/V` — Width-length dependence of `u0`.

54 `x2u0=0` $1/V^2$ — Body-bias dependence of `u0`.

55 `lx2u0=0` µm/V^2 — Length dependence of `x2u0`.

56 `wx2u0=0` µm/V^2 — Width dependence of `x2u0`.

57 `px2u0=0` µm/V^2 — Width-length dependence of `x2u0`.

Velocity saturation parameters

58 `u10=0 1/V` — Velocity saturation coefficient.

59 `lu1=0` μm/V Length dependence of `u1`.

60 `wu1=0` μm/V Width dependence of `u1`.

61 `pu1=0` μm/V Width-length dependence of `u1`.

62 `x2u1=0` 1/V^2 Body-bias dependence of `u1`.

63 `lx2u1=0` μm/V^2 Length dependence of `x2u1`.

64 `wx2u1=0` μm/V^2 Width dependence of `x2u1`.

65 `px2u1=0` μm/V^2 Width-length dependence of `x2u1`.

66 `x3u1=0` 1/V^2 Drain-bias dependence of `u1`.

67 `lx3u1=0` μm/V^2 Length dependence of `x3u1`.

68 `wx3u1=0` μm/V^2 Width dependence of `x3u1`.

69 `px3u1=0` μm/V^2 Width-length dependence of `x3u1`.

Subthreshold parameters

70 `n0=0` Subthreshold swing parameter.

71 `ln0=0` μm Length dependence of subthreshold swing parameter.

72 `wn0=0` μm Width dependence of subthreshold swing parameter.

73 `pn0=0` μm Width-length dependence of subthreshold swing parameter.

74 `nb=0` √V Body-bias dependence of `n0`.

75 `lnb=0` √V μm Length dependence of `nb`.

76 `wnb=0` √V μm Width dependence of `nb`.

77 `pnb=0` √V μm Width-length dependence of `nb`.

78 `nd=0` 1/V Drain-bias dependence of `n0`.

79 `lnd=0` μm/V Length dependence of `nd`.

80 `wnd=0 µm/V` Width dependence of `nd`.

81 `pnd=0 µm/V` Width-length dependence of `nd`.

82 `subthmod=2` Subthreshold model selector.

Impact ionization parameters

83 `ai0=0 1/V` Hot-electron effect on `Rout` parameter.

84 `lai0=0 µm/V` Length dependence of `ai0`.

85 `wai0=0 µm/V` Width dependence of `ai0`.

86 `pai0=0 µm/V` Width-length dependence of `ai0`.

87 `bi0=0 V` Hot-electron effect on `Rout` exponent.

88 `lbi0=0 V µm` Length dependence of `bi0`.

89 `wbi0=0 V µm` Width dependence of `bi0`.

90 `pbi0=0 V µm` Width-length dependence of `bi0`.

Length and width modulation parameters

91 `dl0=0 µm` Lateral diffusion.

92 `dw0=0 µm` Field oxide encroachment.

93 `lref=∞ m` Reference channel length.

94 `wref=∞ m` Reference channel width.

95 `xw=0 m` Width variation due to masking and etching.

96 `xl=0 m` Length variation due to masking and etching.

Temperature effects parameters

97 `temp (C)` Parameters measurement temperature. Default set by options.

98 `trise=0 C` Temperature rise from ambient.

99 `tempmod=432` Temperature model selector.

100 `version=432` Version selector.

101 `uto=0 C` Mobility temperature offset.

102 `ute=-1.5` Mobility temperature exponent.

103 `tlev=0` DC temperature selector.

104 `tlevc=0` AC temperature selector.

105 `eg=1.12452 V` Energy band gap.

106 `gap1=7.02e-4 V/C`^{2} Band gap temperature coefficient.

107 `gap2=1108 K` Band gap temperature offset.

108 `trs=0 1/C` Temperature coefficient for source resistance.

109 `trd=0 1/C` Temperature coefficient for drain resistance.

110 `xti=3` Saturation current temperature exponent.

Overlap capacitance parameters

111 `cgso=0 F/m` Gate-source overlap capacitance.

112 `cgdo=0 F/m` Gate-drain overlap capacitance.

113 `cgbo=0 F/m` Gate-bulk overlap capacitance.

114 `meto=0 m` Metal overlap in fringing field.

Charge model selection parameters

115 `capmod=bsim` Intrinsic charge model.
Possible values are `none`, `meyer`, `yang`, or `bsim`.

116 `xpart=1` Drain/source channel charge partition in saturation for BSIM charge model, use 0.0 for 40/60, 0.5 for 50/50, or 1.0 for 0/100.

117 `xqc=0` Drain/source channel charge partition in saturation for charge models, e.g. use 0.4 for 40/60, 0.5 for 50/50, or 0 for 0/100.

Parasitic resistance parameters

118 `rs=0 Ω` Source resistance.

119 `rd=0 Ω` Drain resistance.

120 `rsh=0 Ω/sqr` Source/drain diffusion sheet resistance.

121 `rsc=0 Ω` Source contact resistance.

122 `rdc=0 Ω` Drain contact resistance.

123 `rss=0 Ω m` Scalable source resistance.

124 `rdd=0 Ω m` Scalable drain resistance.

125 `minr=0.1 Ω` Minimum source/drain resistance.

126 `hdif=0 m` Length of heavily doped diffusion.

127 `ldif=0 m` Lateral diffusion beyond the gate.

128 `lgcs=0 m` Gate-to-contact length of source side.

129 `lgcd=0 m` Gate-to-contact length of drain side.

130 `sc=∞ m` Spacing between contacts.

Junction diode parameters

131 `js` (A/m^2) Bulk junction reverse saturation current density.

132 `is=1e-14 A` Bulk junction reverse saturation current.

133 `n=1` Junction emission coefficient.

134 `imelt=`imax' A` Explosion current, diode is linearized beyond this current to aid convergence.

135 `jmelt=`jmax' A/m'`^{2}
Explosion current density, diode is linearized beyond this current to aid convergence.

136 `dskip=yes` Use simple piece-wise linear model for diode currents below 0.1*`iabstol`.
Possible values are `no` or `yes`.

Junction capacitance model parameters

137 `cbs=0 F` Bulk-source zero-bias junction capacitance.

138 `cbd=0 F` Bulk-drain zero-bias junction capacitance.

139 `cj=0 F/m`^{2} Zero-bias junction bottom capacitance density.

140 `mj=1/2` Bulk junction bottom grading coefficient.

141 `pb=0.8 V` Bulk junction potential.

142 `fc=0.5` Forward-bias depletion capacitance threshold.

143 `cjsw=0 F/m` Zero-bias junction sidewall capacitance density.

144 `mjsw=1/3` Bulk junction sidewall grading coefficient.

145 `pbsw=0.8 V` Side-wall junction potential.

146 `fcsw=0.5` Side-wall forward-bias depletion capacitance threshold.

Operating region warning control parameters

147 `alarm=none` Forbidden operating region.
Possible values are `none`, `off`, `triode`, `sat`, `subth`, or `rev`.

148 `imax=1 A` Maximum current, currents above this limit generate a warning.

149 `jmax=1e8 A/m`^{2} Maximum current density, currents above this limit generate a warning.

150 `bvj=∞ V` Junction reverse breakdown voltage.

151 `vbox=1e9 tox V` Oxide breakdown voltage.

Process and power supply parameters

152 `tox=4e-8 m` Gate oxide thickness.

153 `vdd=5 V` Drain voltage at which parameters are extracted.

Default device parameters

154 `w=3e-6 m` Channel width.

155 `l=3e-6 m` Channel length.

156 `as=0` m^2 Area of source diffusion.

157 `ad=0` m^2 Area of drain diffusion.

158 `ps=0 m` Perimeter of source diffusion.

159 `pd=0 m` Perimeter of drain diffusion.

160 `nrd=0 m/m` Number of squares of drain diffusion.

161 `nrs=0 m/m` Number of squares of source diffusion.

162 `ldd=0 m` Drain diffusion length.

163 `lds=0 m` Source diffusion length.

Noise model parameters

164 `noisemod=1` Noise model selector.

165 `kf=0` Flicker (1/f) noise coefficient.

166 `af=1` Flicker (1/f) noise exponent.

167 `ef=1` Flicker (1/f) noise frequency exponent.

168 `wnoi=1e-5 m` Channel width at which noise parameters were extracted.

Auto Model Selector parameters

169 `wmax=1.0 m` Maximum channel width for which the model is valid.

170 `wmin=0.0 m` Minimum channel width for which the model is valid.

171 `lmax=1.0 m` Maximum channel length for which the model is valid.

172 `lmin=0.0 m` Minimum channel length for which the model is valid.

Degradation parameters

173 `degramod=spectre` Degradation model selector.
Possible values are `spectre` or `bert`.

174 `degradation=no` Hot-electron degradation flag.
Possible values are `no` or `yes`.

175 `dvthc=1 V` Degradation coefficient for threshold voltage.

176 `dvthe=1` Degradation exponent for threshold voltage.

177 `duoc=1 S` Degradation coefficient for transconductance.

178 `duoe=1` Degradation exponent for transconductance.

179 `crivth=0.1 V` Maximum allowable threshold voltage shift.

180 `criuo=10%` Maximum allowable normalized mobility change.

181 `crigm=10%` Maximum allowable normalized transconductance change.

182 `criids=10%` Maximum allowable normalized drain current change.

183 `wnom=5e-6 m` Nominal device width in degradation calculation.

184 `lnom=1e-6 m` Nominal device length in degradation calculation.

185 `vbsn=0 V` Substrate voltage in degradation calculation.

186 `vdsni=0.1 V` Drain voltage in `Ids` degradation calculation.

187 `vgsni=5 V` Gate voltage in `Ids` degradation calculation.

188 `vdsng=0.1 V` Drain voltage in `Gm` degradation calculation.

189 `vgsng=5 V` Gate voltage in `Gm` degradation calculation.

Spectre stress parameters

190 `esat=1.1e7 V/m` Critical field in `Vdsat` calculation.

191 `esatg=2.5e6 1/m` Gate voltage dependence of `esat`.

192 `vpg=-0.25` Gate voltage modifier.

193 `vpb=-0.13` Gate voltage modifier.

194 `subc1=2.24e-5` Substrate current coefficient.

195 `subc2=-0.1e-5 1/V` Substrate current coefficient.

196 `sube=6.4` Substrate current exponent.

197 `strc=1` Stress coefficient.

198 `stre=1` Stress exponent.

BERT stress parameters

199 `h0=1` Aging coefficient.

200 `hgd=0 1/V` Bias dependence of `h0`.

201 `m0=1` Aging exponent.

202 `mgd=0 1/V` Bias dependence of `m0`.

203 `ecrit0=1.1e5 V/cm` Critical electric field.

204 `lecrit0=0 µm V/cm` Length dependence of `ecrit0`.

205 `wecrit0=0 µm V/cm` Width dependence of `ecrit0`.

206 `ecritg=0 1/cm` Gate voltage dependence of `ecrit0`.

207 `lecritg=0 µm/cm` Length dependence of `ecritg`.

208 `wecritg=0 µm/cm` Width dependence of `ecritg`.

209 `ecritb=0 1/cm` Substrate voltage dependence of `ecrit0`.

210 `lecritb=0 µm/cm` Length dependence of `ecritb`.

211 `wecritb=0 µm/cm` Width dependence of `ecritb`.

212 `lc0=1` Substrate current coefficient.

213 `llc0=0 µm` Length dependence of `lc0`.

214 `wlc0=0 µm` Width dependence of `lc0`.

215 `lc1=1` Substrate current coefficient.

216 `llc1=0 µm` Length dependence of `lc1`.

217 `wlc1=0 µm` Width dependence of `lc1`.

218 `lc2=1` Substrate current coefficient.

219 `llc2=0 µm` Length dependence of `lc2`.

220 `wlc2=0 µm` Width dependence of `lc2`.

221 `lc3=1` Substrate current coefficient.

222 `llc3=0 µm` Length dependence of `lc3`.

223 `wlc3=0 µm` Width dependence of `lc3`.

224 `lc4=1` Substrate current coefficient.

225 `llc4=0 µm` Length dependence of `lc4`.

226 `wlc4=0 µm` Width dependence of `lc4`.

227 `lc5=1`	Substrate current coefficient.
228 `llc5=0 µm`	Length dependence of `lc5`.
229 `wlc5=0 µm`	Width dependence of `lc5`.
230 `lc6=1`	Substrate current coefficient.
231 `llc6=0 µm`	Length dependence of `lc6`.
232 `wlc6=0 µm`	Width dependence of `lc6`.
233 `lc7=1`	Substrate current coefficient.
234 `llc7=0 µm`	Length dependence of `lc7`.
235 `wlc7=0 µm`	Width dependence of `lc7`.

Imax and Imelt:

The `imax` parameter aids convergence and prevents numerical overflow. The junction characteristics of the device are accurately modeled for current up to `imax`. If `imax` is exceeded during iterations, the linear model is substituted until the current drops below imax or until convergence is achieved. If convergence is achieved with the current exceeding `imax`, the results are inaccurate, and Spectre prints a warning.

A separate model parameter, `imelt`, is used as a limit warning for the junction current. This parameter can be set to the maximum current rating of the device. When any component of the junction current exceeds `imelt`, note that base and collector currents are composed of many exponential terms, Spectre issues a warning and the results become inaccurate. The junction current is linearized above the value of `imelt` to prevent arithmetic exception, with the exponential term replaced by a linear equation at `imelt`.

Both of these parameters have current density counterparts, `jmax` and `jmelt`, that you can specify if you want the absolute current values to depend on the device area.

Auto Model Selection:

Many models need to be characterized for different geometries in order to obtain accurate results for model development. The model selector program automatically searches for a model with the length and width range specified in the instance statement and uses this model in the simulations.

For the auto model selector program to find a specific model, the models to be searched should be grouped together within braces. Such a group is called a model group. An opening brace is required at the end of the line defining each model group. Every model in the group is given a name followed by a colon and the list of parameters. Also, the four geometric parameters `lmax`, `lmin`, `wmax`, and `wmin` should be given. The selection criteria to choose a model is as follows:

lmin <= inst_length < lmax and wmin <= inst_width < wmax

Example:

model ModelName ModelType {

1: <model parameters> lmin=2 lmax=4 wmin=1 wmax=2

2: <model parameters> lmin=1 lmax=2 wmin=2 wmax=4

3: <model parameters> lmin=2 lmax=4 wmin=4 wmax=6

}

Then for a given instance

M1 1 2 3 4 ModelName w=3 l=1.5

the program would search all the models in the model group with the name `ModelName` and then pick the first model whose geometric range satisfies the selection criteria. In the preceding example, the auto model selector program would choose ModelName.2.

You must specify both length (l) and width (w) on the device instance line to enable automatic model selection.

Output Parameters

1	`weff (m)`	Effective channel width.
2	`leff (m)`	Effective channel length.
3	`rseff (Ω)`	Effective source resistance.
4	`rdeff (Ω)`	Effective drain resistance.
5	`aseff` (m^2)	Effective area of source diffusion.

6 `adeff (m^2)`	Effective area of drain diffusion.
7 `pseff (m)`	Effective perimeter of source diffusion.
8 `pdeff (m)`	Effective perimeter of source diffusion.
9 `isseff (A)`	Effective source-bulk junction reverse saturation current.
10 `isdeff (A)`	Effective drain-bulk junction reverse saturation current.
11 `cbseff (F)`	Effective zero-bias source-bulk junction capacitance.
12 `cbdeff (F)`	Effective zero-bias drain-bulk junction capacitance.
13 `vto (V)`	Effective zero-bias threshold voltage.
14 `vfb (V)`	Effective flat-band voltage.
15 `phi (V)`	Effective surface potential.
16 `k1 (√V )`	Effective body-effect coefficient.
17 `k2`	Effective charge-sharing parameter.
18 `eta`	Effective DIBL coefficient.

Operating-Point Parameters

1 `type=n`	Transistor type. Possible values are `n` or `p`.
2 `region=triode`	Estimated operating region. Spectre outputs number (0-4) in a rawfile. Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.
3 `degradation=no`	Hot-electron degradation flag. Possible values are `no` or `yes`.
4 `reversed`	Reverse mode indicator. Possible values are `no` or `yes`.
5 `ids (A)`	Resistive drain-to-source current.

6 `vgs (V)`	Gate-source voltage.
7 `vds (V)`	Drain-source voltage.
8 `vbs (V)`	Bulk-source voltage.
9 `vth (V)`	Threshold voltage.
10 `vdsat (V)`	Drain-source saturation voltage.
11 `betaeff` (A/V^2)	Effective beta.
12 `gm (S)`	Common-source transconductance.
13 `gds (S)`	Common-source output conductance.
14 `gmbs (S)`	Body-transconductance.
15 `cbd (F)`	Drain-bulk junction capacitance.
16 `cbs (F)`	Source-bulk junction capacitance.
17 `cgs (F)`	Gate-source capacitance.
18 `cgd (F)`	Gate-drain capacitance.
19 `cgb (F)`	Gate-bulk capacitance.
20 `ron` (Ω)	ON-resistance.
21 `id (A)`	Resistive drain current.
22 `ibulk (A)`	Resistive bulk current.
23 `pwr (W)`	Power at op point.
24 `gmoverid (1/V)`	Gm/Ids.
25 `isub (A)`	Substrate current.
26 `stress`	Hot-electron stress.
27 `age (s)`	Device age.

28 `he_vdsat (V)` hot electron vdsat.

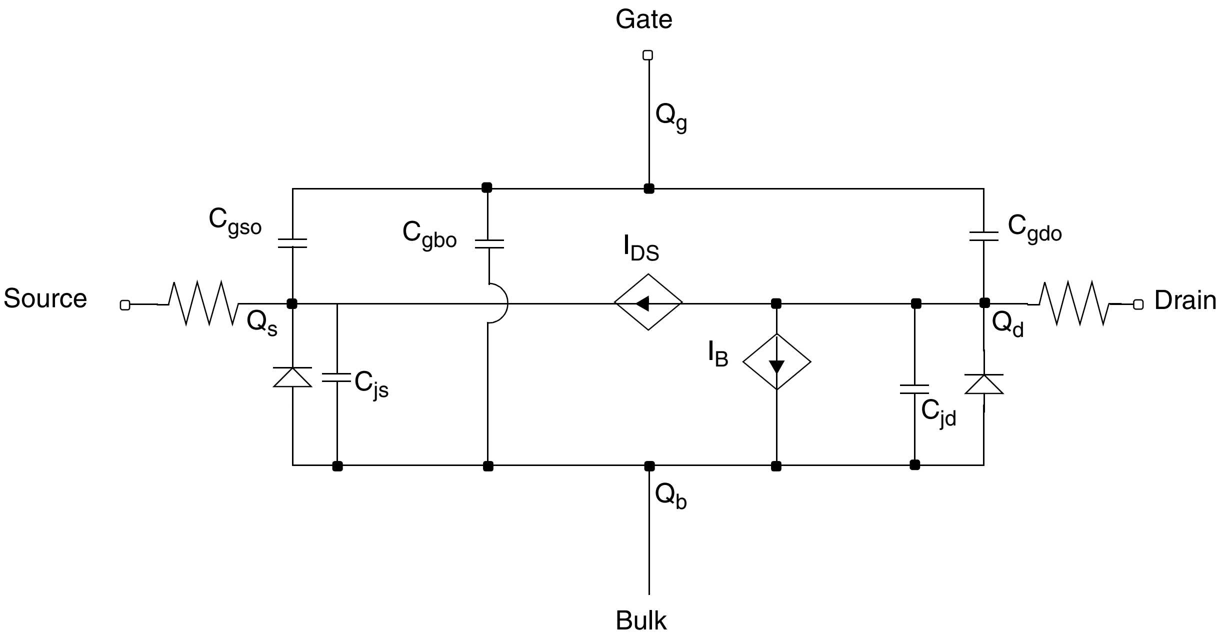
Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

18

BSIM2 Level-5 Model (bsim2)

The BSIM2 model is based on the industry standard efforts of the Compact Modeling Counsel (CMC) and the BSIM modeling group at the University of California, Berkeley. This chapter contains the following information about the BSIM2 model:



BSIM2 stands for Berkeley Short-Channel IGFET Model version-2. The BSIM2 is a semi empirical model suitable for devices with channel length from long channel to about 0.2 μm. Because it also models the output resistance, BSIM2 is suitable for both digital and analog applications. BSIM2 extracts all model parameters directly from physical devices. You can obtain an automated parameter extraction program, based on the IBM PC and HP4145 system, from the ILP office, Department of EECS, University of California, Berkeley. The following table shows the correspondence between the input parameter names and the equation symbols for the BSIM2 model.

Parameter	Symbol	Parameter	Symbol	Parameter	Symbol
vfb	$V_{FB,0}$	lvfb	$V_{FB,L}$	wvfb	$V_{FB,W}$
phi	ϕ_0	lphi	ϕ_L	wphi	ϕ_W
k1	K_1	lk1	$K_{1,L}$	wk1	$K_{1,W}$
k2	K_2	lk2	$K_{2,L}$	wk2	$K_{2,W}$
eta0	$\eta_{0,0}$	leta0	$\eta_{0,L}$	weta0	$\eta_{0,W}$
mu0	$\mu_{0,0}$	dl	dl	dw	dw
ua0	$U_{a0,0}$	lua0	$U_{a0,L}$	wua0	$U_{a0,W}$

Parameter	Symbol	Parameter	Symbol	Parameter	Symbol
uab	$U_{aB,0}$	luab	$U_{aB,L}$	wuab	$U_{aB,W}$
ub0	$U_{b0,0}$	lub0	$U_{b0,L}$	wub0	$U_{b0,W}$
ubb	$U_{bB,0}$	lubb	$U_{bB,L}$	wubb	$U_{bB,W}$
u10	$U_{10,0}$	lu10	$U_{10,L}$	wu10	$U_{10,W}$
u1b	$U_{1B,0}$	lu1b	$U_{1B,L}$	wu1b	$U_{1B,W}$
u1d	$U_{1D,0}$	lu1d	$U_{1D,L}$	wu1d	$U_{1D,W}$
mu0b	$\mu_{0B,0}$	lmu0b	$\mu_{0B,L}$	mu0b	$\mu_{0B,W}$
mus0	$\mu_{s0,0}$	lmus0	$\mu_{s0,L}$	wmus0	$\mu_{s0,W}$
musb	$\mu_{sB,0}$	lmusb	$\mu_{sB,L}$	wmusb	$\mu_{sB,W}$
mu20	$\mu_{20,0}$	lmu20	$\mu_{20,L}$	wmu20	$\mu_{20,W}$
mu2b	$\mu_{2B,0}$	lmu2b	$\mu_{2B,L}$	wmu2b	$\mu_{2B,W}$
mu2g	$\mu_{2G,0}$	lmu2g	$\mu_{2G,L}$	wmu2g	$\mu_{2G,W}$
mu30	$\mu_{30,0}$	lmu30	$\mu_{30,L}$	wmu30	$\mu_{30,W}$
mu3b	$\mu_{3B,0}$	lmu3b	$\mu_{3B,L}$	wmu3b	$\mu_{3B,W}$
mu3g	$\mu_{3G,0}$	lmu3g	$\mu_{3G,L}$	wmu3g	$\mu_{3G,W}$
mu40	$\mu_{40,0}$	lmu40	$\mu_{40,L}$	wmu40	$\mu_{40,W}$
mu4b	$\mu_{4B,0}$	lmu4b	$\mu_{4B,L}$	wmu4b	$\mu_{4B,W}$
mu4g	$\mu_{4G,0}$	lmu4g	$\mu_{4G,L}$	wmu4g	$\mu_{4G,W}$
etab	$\eta_{B,0}$	letab	$\eta_{B,L}$	wetab	$\eta_{B,W}$
n0	$N_{0,0}$	ln0	$N_{0,L}$	wn0	$N_{0,W}$
nb	$N_{B,0}$	lnb	$N_{B,L}$	wnb	$N_{B,W}$
nd	$N_{D,0}$	lnd	$N_{D,L}$	wnd	$N_{D,W}$
vof0	$V_{offset0,0}$	lvof0	$V_{offset0,L}$	wvof0	$V_{offset0,W}$
vofb	$V_{offsetB,0}$	lvofb	$V_{offsetB,L}$	wvofb	$V_{offsetB,W}$
vofd	$V_{offsetD,0}$	lvofd	$V_{offsetD,L}$	wvofd	$V_{offsetD,W}$
ai0	$A_{i0,0}$	lai0	$A_{i0,L}$	wai0	$A_{i0,W}$
aib	$A_{iB,0}$	laib	$A_{iB,L}$	waib	$A_{iB,W}$

Parameter	Symbol	Parameter	Symbol	Parameter	Symbol
bi0	$B_{i0,0}$	lbi0	$B_{i0,L}$	wbi0	$B_{i0,W}$
bib	$B_{iB,0}$	lbib	$B_{iB,L}$	wbib	$B_{iB,W}$
vdd	V_{DD}	vgg	V_{GG}	vbb	V_{BB}
vghigh	$V_{G,high}$	vglow	$V_{G,low}$		

Parameter Calculation

Except for mu0, dl, and dw, all device parameters are calculated from the following equation:

$$P_i = P_{i,0} + \frac{P_{i,L}}{L_{eff}} + \frac{P_{i,W}}{W_{eff}}$$

where P_i is any device parameter, $P_{i,0}$ is the parameter value for very long channel length and width, and $P_{i,L}$ and $P_{i,W}$ are the channel length and width dependencies of the parameter, respectively. The following is an example showing how the flat-band voltage for a device with l = 2µm and w = 5µm is calculated from the model parameters.

$$V_{FB} = V_{FB,0} + \frac{V_{FB,L}}{2.0 - dl} + \frac{V_{FB,W}}{5.0 - dw}$$

Drain Current Model

Channel Width and Length

$$W_{scaled} = w*scale + xw*scalem$$

$$W_{eff} = \begin{cases} w*scale + xw*scalem - 2wd*scalem & \text{(Level 1-3)} \\ w*scale + xw*scalem - dw*scalem & \text{(BSIM 1-2)} \end{cases}$$

$$L_{eff} = \begin{cases} l*scale + xl*scalem - 2ld*scalem & \text{(Level 1-3)} \\ l*scale + xl*scalem - dl*scalem & \text{(BSIM 1-2)} \end{cases}$$

Threshold Voltage

$$V_{TH} = V_{FB} + \phi + K_1\sqrt{\phi - V_{BS}}K_2(\phi - V_{BS}) - \eta V_{DS}$$

where

$$\eta = \eta_0 + \eta_B V_{BS}$$

Drain Saturation Voltage

$$V_{DSAT} = \frac{V_{GST}}{a\sqrt{K}}$$

where

$$V_{GST} = V_{GS} - V_{TH}$$

$$a = 1 + \frac{gK_1}{2\sqrt{\phi - V_{BS}}}$$

$$g = 1 - \frac{1}{1.744 + 0.8364(\phi - V_{BS})}$$

$$K = \frac{1 + V_c + \sqrt{1 + 2V_c}}{2}$$

$$V_c = \frac{U_{1S}V_{GST}}{a[1 + U_a V_{GST} + U_b V_{GST}^2]}$$

$$U_{1S} = \begin{cases} U_1\left[1 - \dfrac{U_{1D}(V_{DS} - V_{DSAT})^2}{V_{DSAT}^2}\right] & \text{if } V_{DS} \le V_{DSAT} \\ U_1 & \text{otherwise} \end{cases}$$

$$U_1 = U_{10} + U_{1B}V_{BS}$$

Drain Current for the Subthreshold Region

Note: These equations apply when $V_{GST} \le V_{glow}$.

$$I_{subth} = \beta V_t^2 e^{V_{offset} + V_{GST}/nV_t}\left[1 - e^{-V_{DS}/V_t}\right]$$

where

$$n = N_0 + \frac{N_B}{\sqrt{\phi - V_{BS}}} + N_D V_{DS}$$

$$V_{offset} = V_{offset0} + V_{offsetB}V_{BS} + V_{offsetD}V_{DS}$$

Drain Current for the Triode Region

Note: These equations apply when $V_{GST} \ge 0$ and $V_{DS} \le V_{SAT}$.

$$I_{DS} = \frac{\beta_0\left(V_{GST} - \frac{a}{2}V_{DS}\right)V_{DS}}{[1 + U_a V_{GST} + U_b V_{GST}^2 + U_{1S}V_{DS}]}$$

where

$$U_a = U_{a0} + U_{a0B}V_{BS}$$

$$U_b = U_{b0} + U_{b0B}V_{BS}$$

$$\beta_0 = \beta_{0lin} + \beta_1 \tanh\left[\frac{\beta_2 V_{DS}}{V_{DSAT}}\right] + \beta_3 V_{DS} - \beta_4 V_{DS}^2$$

$$\beta_{0lin} = \frac{C_{ox}W_{eff}}{L_{eff}}(\mu_0 + \mu_{0B}V_{BS})$$

$$\beta_1 = \beta_s - (\beta_{0lin} + \beta_3 V_{DD} - \beta_4 V_{DD}^2)$$

$$\beta_s = \frac{C_{ox} W_{eff}}{L_{eff}}(\mu_{s0} + \mu_{sB} V_{BS})$$

$$\beta_2 = \mu_{20} + \mu_{2B} V_{BS} + \mu_{2G} V_{GS}$$

$$\beta_3 = \frac{C_{ox} W_{eff}}{L_{eff}}(\mu_{30} + \mu_{3B} V_{BS} + \mu_{3G} V_{GS})$$

$$\beta_4 = \frac{C_{ox} W_{eff}}{L_{eff}}(\mu_{40} + \mu_{4b} V_{BS} + \mu_{4G} V_{GS})$$

Drain Current for the Saturation Region

Note: These equations apply when $V_{GST} \geq V_{ghigh}$ and $V_{DS} \geq V_{DSAT}$.

$$I_{DS} = \frac{\beta V_{GST}^2}{2aK}\left(1 + A_i e^{\frac{-B_i}{V_{DS} - V_{DSAT}}}\right)$$

where

$$\beta = \frac{\beta_0}{1 + U_a V_{GST} + U_b V_{GST}^2}$$

$$A_i = A_{i0} + A_{iB} V_{BS}$$

$$B_i = B_{i0} + B_{iB} V_{BS}$$

Drain Current for the Transition Region

Note: These equations apply when $V_{glow} \leq V_{GST} \leq V_{ghigh}$.

Drain current equations are the same as those for the strong-inversion region, except that V'_{GST} replaces all V_{GST} terms. V'_{GST} is calculated from a cubic spline function to match the drain current and its first derivative at the upper and lower bounds (V_{ghigh} and V_{glow}).

$$V'_{GST} = C_0 + C_1 V_{GST} + C_2 V^2_{GST} + C_3 V^3_{GST}$$

All the coefficients, C_is, are automatically calculated during

$$V_{glow} = V_{TH} + V_{offset} + nV_t \ln\left(\frac{C_{ox}}{10C_d}\right)$$

$$V_{ghigh} = V_{TH} + nV_t \ln\left(\frac{10C_{ox}}{C_d}\right)$$

$$C_d = \sqrt{\frac{q\varepsilon_{si}N_{sub}}{2\phi}}$$

Scaling Effects

For scaling effects, see Scaling Factors (scale and scalem) on page 242.

Component Statements

This device is supported within altergroups.

Sample Instance Statement:

```
m2 (0 2 1 1) pchmod l=5u w=10u as=40u ad=40u pd=28u ps=28u m=1
```

Sample Model Statement:

```
model pchmod bsim2 type=p vfb0=-0.5 lvfb=0.5 wvfb=0.3 phi0=0.8 eta0=0.056 k1=0.5
eg=0.99 gap1=5.5e-04 trs=1e-3 trd=1e-3 xpart=0.5 rs=10 rd=10
```

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `w (m)`	Channel width.
2 `l (m)`	Channel length.
3 `as (m`^{2}`)`	Area of source diffusion.
4 `ad (m`^{2}`)`	Area of drain diffusion.
5 `ps (m)`	Perimeter of source diffusion.
6 `pd (m)`	Perimeter of drain diffusion.
7 `nrd (m/m)`	Number of squares of drain diffusion.
8 `nrs (m/m)`	Number of squares of source diffusion.
9 `ld (m)`	Drain diffusion length.
10 `ls (m)`	Source diffusion length.
11 `m=1`	Multiplicity factor (number of MOSFETs in parallel).
12 `region=triode`	Estimated operating region. Spectre outputs number (0-4) in a rawfile. Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.
13 `trise (C)`	Temperature rise from ambient.
14 `degradation=no`	Hot-electron degradation flag. Possible values are `no` or `yes`.
15 `isnoisy=yes`	Should resistor generate noise. Possible values are `no` or `yes`.

Model Definition

```
model modelName bsim2 parameter=value ...
```

Model Parameters

Device type parameters

1	`type=n`	Transistor type. Possible values are `n` or `p`.

Threshold voltage parameters

2	`vfb0=-0.8 V`	Flat-band voltage.
3	`lvfb=0 V µm`	Length dependence of `vfb`.
4	`wvfb=0 V µm`	Width dependence of `vfb`.
5	`pvfb=0 V µm`	Width-length dependence of `vfb`.
6	`phi0=0.75 V`	Surface potential.
7	`lphi=0 V µm`	Length dependence of `phi`.
8	`wphi=0 V µm`	Width dependence of `phi`.
9	`pphi=0 V µm`	Width-length dependence of `phi`.
10	`k1=0.7 √V`	Body-effect coefficient.
11	`lk1=0 √V µm`	Length dependence of `k1`.
12	`wk1=0 √V µm`	Width dependence of `k1`.
13	`pk1=0 √V µm`	Width-length dependence of `k1`.
14	`k2=0`	Charge-sharing parameter.
15	`lk2=0 µm`	Length dependence of `k2`.
16	`wk2=0 µm`	Width dependence of `k2`.
17	`pk2=0 µm`	Width-length dependence of `k2`.
18	`eta0=0`	Drain-induced barrier-lowering coefficient.

19 `leta0=0 µm` Length dependence of `eta0`.

20 `weta0=0 µm` Width dependence of `eta0`.

21 `peta0=0 µm` Width-length dependence of `eta0`.

22 `etab=0 1/V` Body-bias dependence of `eta0`.

23 `letab=0 µm/V` Length dependence of etab.

24 `wetab=0 µm/V` Width dependence of `etab`.

25 `petab=0 µm/V` Width-length dependence of `etab`.

Mobility parameters

26 `mu0=400` $cm^2/V\ s$ Low-field mobility.

27 `lmu0=0` $cm^2/V\ s$ Length dependence of `mu0`.

28 `wmu0=0` $cm^2/V\ s$ Width dependence of `mu0`.

29 `pmu0=0` $cm^2/V\ s$ Width-length dependence of `mu0`.

30 `mu0b=0` $cm^2/V^2\ s$ Body-bias dependence of `muz`.

31 `lmu0b=0` $cm^2\ \mu m/V^2\ s$
Length dependence of `x2mz`.

32 `wmu0b=0` $cm^2\ \mu m/V^2\ s$
Width dependence of `x2mz`.

33 `pmu0b=0` $cm^2\ \mu m/V^2\ s$
Width-length dependence of `x2mz`.

34 `mus0=450` $cm^2/V\ s$ Mobility in the saturation region.

35 `lmus0=0` $cm^2\ \mu m/V\ s$
Length dependence of `mus0`.

36 `wmus0=0` $cm^2\ \mu m/V\ s$
Width dependence of `mus0`.

37 `pmus0=0 cm2 µm/V s`
Width-length dependence of `mus0`.

38 `musb=0 cm2/V2 s` Body-bias dependence of `mus0`.

39 `lmusb=0 cm2 µm/V2 s`
Length dependence of `mus0`.

40 `wmusb=0 cm2 µm/V2 s`
Length dependence of `mus0`.

41 `pmusb=0 cm2 µm/V2 s`
Length dependence of `mus0`.

42 `mu20=1` Empirical channel length modulation parameter.

43 `lmu20=0 µm` Length dependence of mu20.

44 `wmu20=0 µm` Width dependence of `mu20`.

45 `pmu20=0 µm` Width-length dependence of `mu20`.

46 `mu2b=0 1/V` Body-bias dependence of `mu20`.

47 `lmu2b=0 µm/V` Length dependence of `mu2b`.

48 `wmu2b=0 µm/V` Width dependence of `mu2b`.

49 `pmu2b=0 µm/V` Width-length dependence of `mu2b`.

50 `mu2g=0 1/V` Gate-bias dependence of `mu20`.

51 `lmu2g=0 µm/V` Length dependence of `mu2g`.

52 `wmu2g=0 µm/V` Width dependence of `mu2g`.

53 `pmu2g=0 µm/V` Width-length dependence of `mu2g`.

54 `mu30=5 cm2/V2 s` Empirical output resistance parameter.

55 `lmu30=0 cm2 µm/V2 s`
Length dependence of `mu30`.

56 `wmu30=0` cm^2 $\mu m/V^2$ s
Width dependence of `mu30`.

57 `pmu30=0` cm^2 $\mu m/V^2$ s
Width-length dependence of `mu30`.

58 `mu3b=0` cm^2/V^3 s
Body-bias dependence of `mu30`.

59 `lmu3b=0` cm^2 $\mu m/V^3$ s
Length dependence of `mu3b`.

60 `wmu3b=0` cm^2 $\mu m/V^3$ s
Width dependence of `mu3b`.

61 `pmu3b=0` cm^2 $\mu m/V^3$ s
Width-length dependence of `mu3b`.

62 `mu3g=0` cm^2/V^3 s
Gate-bias dependence of `mu30`.

63 `lmu3g=0` cm^2 $\mu m/V^3$ s
Length dependence of `mu3g`.

64 `wmu3g=0` cm^2 $\mu m/V^3$ s
Width dependence of `mu3g`.

65 `pmu3g=0` cm^2 $\mu m/V^3$ s
Width-length dependence of `mu3g`.

66 `mu40=0` cm^2/V^3 s
Empirical output resistance parameter.

67 `lmu40=0` cm^2 $\mu m/V^3$ s
Length dependence of `mu40`.

68 `wmu40=0` cm^2 $\mu m/V^3$ s
Width dependence of `mu40`.

69 `pmu40=0` cm^2 $\mu m/V^3$ s
Width-length dependence of `mu40`.

70 `mu4b=0` cm^2/V^3 s
Empirical output resistance parameter.

71 `lmu4b=0` cm^2 $\mu m/V^3$ s
Length dependence of `mu4b`.

72 wmu4b=0 cm^2 µm/V^3 s
Width dependence of mu4b.

73 pmu4b=0 cm^2 µm/V^3 s
Width-length dependence of mu4b.

74 mu4g=0 cm^2/V^3 s Gate-bias dependence of mu4g.

75 lmu4g=0 cm^2 µm/V^3 s
Length dependence of mu4g.

76 wmu4g=0 cm^2 µm/V^3 s
Width dependence of mu4g.

77 pmu4g=0 cm^2 µm/V^3 s
Width-length dependence of mu4g.

Mobility modulation parameters

78 ua0=0 1/V Gate voltage dependence of mobility.

79 lua0=0 µm/V Length dependence of ua0.

80 wua0=0 µm/V Width dependence of ua0.

81 pua0=0 µm/V Width-length dependence of ua0.

82 uab=0 $1/V^2$ Body-bias dependence of ua.

83 luab=0 µm/V^2 Length dependence of uab.

84 wuab=0 µm/V^2 Width dependence of uab.

85 puab=0 µm/V^2 Width-length dependence of uab.

86 ub0=0 $1/V^2$ Second-order effect of gate voltage dependence of mobility.

87 lub0=0 µm/V^2 Length dependence of ub0.

88 wub0=0 µm/V^2 Width dependence of ub0.

89 pub0=0 µm/V^2 Width-length dependence of ub0.

90 `ubb=0 1/V`^{3} Body-bias dependence of `ub`.

91 `lubb=0 µm/V`^{3} Length dependence of `ubb`.

92 `wubb=0 µm/V`^{3} Width dependence of `ubb`.

93 `pubb=0 µm/V`^{3} Width-length dependence of `ubb`.

Velocity saturation parameters

94 `u10=0 1/V` Velocity saturation coefficient.

95 `lu10=0 µm/V` Length dependence of `u1`.

96 `wu10=0 µm/V` Width dependence of `u1`.

97 `pu10=0 µm/V` Width-length dependence of `u1`.

98 `u1b=0 1/V`^{2} Body-bias dependence of `u1`.

99 `lu1b=0 µm/V`^{2} Length dependence of `u1b`.

100 `wu1b=0 µm/V`^{2} Width dependence of `u1b`.

101 `pu1b=0 µm/V`^{2} Width-length dependence of `u1b`.

102 `u1d=0 1/V`^{2} Drain-bias dependence of `u1`.

103 `lu1d=0 µm/V`^{2} Length dependence of `u1d`.

104 `wu1d=0 µm/V`^{2} Width dependence of `u1d`.

105 `pu1d=0 µm/V`^{2} Width-length dependence of `u1d`.

Subthreshold parameters

106 `n0=0` Subthreshold swing parameter.

107 `ln0=0 µm` Length dependence of subthreshold swing parameter.

108 `wn0=0 µm` Width dependence of subthreshold swing parameter.

109 pn0=0 µm — Width-length dependence of subthreshold swing parameter.

110 nb=0 √V — Body-bias dependence of n0.

111 lnb=0 √V µm — Length dependence of nb.

112 wnb=0 √V µm — Width dependence of nb.

113 pnb=0 √V µm — Width-length dependence of nb.

114 nd=0 1/V — Drain-bias dependence of n0.

115 lnd=0 µm/V — Length dependence of nd.

116 wnd=0 µm/V — Width dependence of nd.

117 pnd=0 µm/V — Width-length dependence of nd.

118 vof0=1 V — Threshold voltage offset in the subthreshold region.

119 lvof0=0 V µm — Length dependence of vof.

120 wvof0=0 V µm — Width dependence of vof.

121 pvof0=0 V µm — Width-length dependence of vof.

122 vofb=0 — Body-bias dependence of vof0.

123 lvofb=0 µm — Length dependence of vofb.

124 wvofb=0 µm — Width dependence of vofb.

125 pvofb=0 µm — Width-length dependence of vofb.

126 vofd=0 — Drain-bias dependence of vof0.

127 lvofd=0 µm — Length dependence of vofd.

128 wvofd=0 µm — Width dependence of vofd.

129 pvofd=0 µm — Width-length dependence of vofd.

130 subthmod=2 — Subthreshold model selector.

Impact ionization parameters

131 `ai0=0 1/V` Hot-electron effect on `Rout` parameter.

132 `lai0=0 µm/V` Length dependence of `ai0`.

133 `wai0=0 µm/V` Width dependence of `ai0`.

134 `pai0=0 µm/V` Width-length dependence of `ai0`.

135 `aib=0` $1/V^2$ Body-bias dependence of `ai0`.

136 `laib=0` $\mu m/V^2$ Length dependence of `aib`.

137 `waib=0` $\mu m/V^2$ Width dependence of `aib`.

138 `paib=0` $\mu m/V^2$ Width-length dependence of `aib`.

139 `bi0=0 V` Hot-electron effect on `Rout` exponent.

140 `lbi0=0 V µm` Length dependence of `bi0`.

141 `wbi0=0 V µm` Width dependence of `bi0`.

142 `pbi0=0 V µm` Width-length dependence of `bi0`.

143 `bib=0` Body-bias dependence of `bi0`.

144 `lbib=0 µm` Length dependence of `bib`.

145 `wbib=0 µm` Width dependence of `bib`.

146 `pbib=0 µm` Width-length dependence of `bib`.

Transition region bound parameters

147 `vghigh=0.2 V` Upper bound of the transition region.

148 `lvghigh=0 V µm` Length dependence of `Vghigh`.

149 `wvghigh=0 V µm` Width dependence of `Vghigh`.

150 `pvghigh=0 V µm` Width-length dependence of `Vghigh`.

151 `vglow=-0.15 V` Lower bound of the transition region.

152 `lvglow=0 V µm` Length dependence of `Vglow`.

153 `wvglow=0 V µm` Width dependence of `Vglow`.

154 `pvglow=0 V µm` Width-length dependence of `Vglow`.

Length and width modulation parameters

155 `dl0=0 µm` Lateral diffusion.

156 `dw0=0 µm` Field oxide encroachment.

157 `lref=∞ m` Reference channel length.

158 `wref=∞ m` Reference channel width.

159 `xw=0 m` Width variation due to masking and etching.

160 `xl=0 m` Length variation due to masking and etching.

Temperature effects parameters

161 `temp (C)` Parameters measurement temperature. Default set by options.

162 `trise=0 C` Temperature rise from ambient.

163 `tempmod=432` Temperature model selector.

164 `version=432` Version selector.

165 `uto=0 C` Mobility temperature offset.

166 `ute=-1.5` Mobility temperature exponent.

167 `tlev=0` DC temperature selector.

168 `tlevc=0` AC temperature selector.

169 `ptc=0 V/C` Surface potential temperature coefficient.

170 `eg=1.12452 V` Energy band gap.

171 `gap1=7.02e-4 V/C`^{2}
Band gap temperature coefficient.

172 `gap2=1108 K` Band gap temperature offset.

173 `trs=0 1/C` Temperature coefficient for source resistance.

174 `trd=0 1/C` Temperature coefficient for drain resistance.

175 `xti=3` Saturation current temperature exponent.

Overlap capacitance parameters

176 `cgso=0 F/m` Gate-source overlap capacitance.

177 `cgdo=0 F/m` Gate-drain overlap capacitance.

178 `cgbo=0 F/m` Gate-bulk overlap capacitance.

179 `meto=0 m` Metal overlap in fringing field.

Charge model selection parameters

180 `capmod=bsim` Intrinsic charge model.
Possible values are `none`, `meyer`, `yang`, or `bsim`.

181 `xpart=1` Drain/source channel charge partition in saturation for BSIM charge model, use 0.0 for 40/60, 0.5 for 50/50, or 1.0 for 0/100.

182 `xqc=0` Drain/source channel charge partition in saturation for charge models, e.g. use 0.4 for 40/60, 0.5 for 50/50, or 0 for 0/100.

Parasitic resistance parameters

183 `rs=0 Ω` Source resistance.

184 `rd=0 Ω` Drain resistance.

185 `rsh=0 Ω/sqr` Source/drain diffusion sheet resistance.

186 `rsc=0 Ω` Source contact resistance.

187 `rdc=0 Ω` Drain contact resistance.

188 `rss=0 Ω m` Scalable source resistance.

189 `rdd=0 Ω m` Scalable drain resistance.

190 `minr=0.1 Ω` Minimum source/drain resistance.

191 `hdif=0 m` Length of heavily doped diffusion.

192 `ldif=0 m` Lateral diffusion beyond the gate.

193 `lgcs=0 m` Gate-to-contact length of source side.

194 `lgcd=0 m` Gate-to-contact length of drain side.

195 `sc=∞ m` Spacing between contacts.

Junction diode parameters

196 `js` (A/m^2) Bulk junction reverse saturation current density.

197 `is=1e-14 A` Bulk junction reverse saturation current.

198 `n=1` Junction emission coefficient.

199 `dskip=yes` Use simple piece-wise linear model for diode currents below 0.1*`iabstol`.
Possible values are `no` or `yes`.

200 `imelt=`imax' A` Explosion current, diode is linearized beyond this current to aid convergence.

201 `jmelt=`jmax' A/m'`^{2}
Explosion current density, diode is linearized beyond this current to aid convergence.

Operating region warning control parameters

202 `alarm=none`	Forbidden operating region. Possible values are `none`, `off`, `triode`, `sat`, `subth`, or `rev`.
203 `imax=1 A`	Maximum current, currents above this limit generate a warning.
204 `jmax=1e8 A/m`^{2}	Maximum current density, currents above this limit generate a warning.
205 `bvj=∞ V`	Junction reverse breakdown voltage.
206 `vbox=1e9 tox V`	Oxide breakdown voltage.

Junction capacitance model parameters

207 `cbs=0 F`	Bulk-source zero-bias junction capacitance.
208 `cbd=0 F`	Bulk-drain zero-bias junction capacitance.
209 `cj=0 F/m`^{2}	Zero-bias junction bottom capacitance density.
210 `mj=1/2`	Bulk junction bottom grading coefficient.
211 `pb=0.8 V`	Bulk junction potential.
212 `fc=0.5`	Forward-bias depletion capacitance threshold.
213 `cjsw=0 F/m`	Zero-bias junction sidewall capacitance density.
214 `mjsw=1/3`	Bulk junction sidewall grading coefficient.
215 `pbsw=0.8 V`	Side-wall junction potential.
216 `fcsw=0.5`	Side-wall forward-bias depletion capacitance threshold.

Process and power supply parameters

217 `tox=4e-8 m`	Gate oxide thickness.
218 `vdd=5 V`	Drain voltage at which parameters are extracted.

219 `vgg=5 V` Gate voltage at which parameters are extracted.

220 `vbb=-5 V` Body voltage at which parameters are extracted.

Default device parameters

221 `w=3e-6 m` Channel width.

222 `l=3e-6 m` Channel length.

223 `as=0` m^2 Area of source diffusion.

224 `ad=0` m^2 Area of drain diffusion.

225 `ps=0 m` Perimeter of source diffusion.

226 `pd=0 m` Perimeter of drain diffusion.

227 `nrd=0 m/m` Number of squares of drain diffusion.

228 `nrs=0 m/m` Number of squares of source diffusion.

229 `ldd=0 m` Drain diffusion length.

230 `lds=0 m` Source diffusion length.

Noise model parameters

231 `noisemod=1` Noise model selector.

232 `kf=0` Flicker (1/f) noise coefficient.

233 `af=1` Flicker (1/f) noise exponent.

234 `ef=1` Flicker (1/f) noise frequency exponent.

235 `wnoi=1e-5 m` Channel width at which noise parameters were extracted.

Auto Model Selector parameters

236 `wmax=1.0 m` Maximum channel width for which the model is valid.

237 `wmin=0.0 m` Minimum channel width for which the model is valid.

238 `lmax=1.0 m` Maximum channel length for which the model is valid.

239 `lmin=0.0 m` Minimum channel length for which the model is valid.

Degradation parameters

240 `degramod=spectre` Degradation model selector.
Possible values are `spectre` or `bert`.

241 `degradation=no` Hot-electron degradation flag.
Possible values are `no` or `yes`.

242 `dvthc=1 V` Degradation coefficient for threshold voltage.

243 `dvthe=1` Degradation exponent for threshold voltage.

244 `duoc=1 S` Degradation coefficient for transconductance.

245 `duoe=1` Degradation exponent for transconductance.

246 `crivth=0.1 V` Maximum allowable threshold voltage shift.

247 `criuo=10%` Maximum allowable normalized mobility change.

248 `crigm=10%` Maximum allowable normalized transconductance change.

249 `criids=10%` Maximum allowable normalized drain current change.

250 `wnom=5e-6 m` Nominal device width in degradation calculation.

251 `lnom=1e-6 m` Nominal device length in degradation calculation.

252 `vbsn=0 V` Substrate voltage in degradation calculation.

253 `vdsni=0.1 V` Drain voltage in `Ids` degradation calculation.

254 `vgsni=5 V` Gate voltage in `Ids` degradation calculation.

255 `vdsng=0.1 V` Drain voltage in `Gm` degradation calculation.

256 `vgsng=5 V` Gate voltage in `Gm` degradation calculation.

Spectre stress parameters

257 `esat=1.1e7 V/m`	Critical field in `Vdsat` calculation.
258 `esatg=2.5e6 1/m`	Gate voltage dependence of `esat`.
259 `vpg=-0.25`	Gate voltage modifier.
260 `vpb=-0.13`	Gate voltage modifier.
261 `subc1=2.24e-5`	Substrate current coefficient.
262 `subc2=-0.1e-5 1/V`	Substrate current coefficient.
263 `sube=6.4`	Substrate current exponent.
264 `strc=1`	Stress coefficient.
265 `stre=1`	Stress exponent.

BERT stress parameters

266 `h0=1`	Aging coefficient.
267 `hgd=0 1/V`	Bias dependence of `h0`.
268 `m0=1`	Aging exponent.
269 `mgd=0 1/V`	Bias dependence of `m0`.
270 `ecrit0=1.1e5 V/cm`	Critical electric field.
271 `lecrit0=0 µm V/cm`	Length dependence of `ecrit0`.
272 `wecrit0=0 µm V/cm`	Width dependence of `ecrit0`.
273 `ecritg=0 1/cm`	Gate voltage dependence of `ecrit0`.
274 `lecritg=0 µm/cm`	Length dependence of `ecritg`.
275 `wecritg=0 µm/cm`	Width dependence of `ecritg`.
276 `ecritb=0 1/cm`	Substrate voltage dependence of `ecrit0`.

277 lecritb=0 µm/cm	Length dependence of ecritb.
278 wecritb=0 µm/cm	Width dependence of ecritb.
279 lc0=1	Substrate current coefficient.
280 llc0=0 µm	Length dependence of lc0.
281 wlc0=0 µm	Width dependence of lc0.
282 lc1=1	Substrate current coefficient.
283 llc1=0 µm	Length dependence of lc1.
284 wlc1=0 µm	Width dependence of lc1.
285 lc2=1	Substrate current coefficient.
286 llc2=0 µm	Length dependence of lc2.
287 wlc2=0 µm	Width dependence of lc2.
288 lc3=1	Substrate current coefficient.
289 llc3=0 µm	Length dependence of lc3.
290 wlc3=0 µm	Width dependence of lc3.
291 lc4=1	Substrate current coefficient.
292 llc4=0 µm	Length dependence of lc4.
293 wlc4=0 µm	Width dependence of lc4.
294 lc5=1	Substrate current coefficient.
295 llc5=0 µm	Length dependence of lc5.
296 wlc5=0 µm	Width dependence of lc5.
297 lc6=1	Substrate current coefficient.
298 llc6=0 µm	Length dependence of lc6.

299 `wlc6=0 μm` Width dependence of `lc6`.

300 `lc7=1` Substrate current coefficient.

301 `llc7=0 μm` Length dependence of `lc7`.

302 `wlc7=0 μm` Width dependence of `lc7`.

Imax and Imelt:

The `imax` parameter aids convergence and prevents numerical overflow. The junction characteristics of the device are accurately modeled for current up to `imax`. If `imax` is exceeded during iterations, the linear model is substituted until the current drops below imax or until convergence is achieved. If convergence is achieved with the current exceeding `imax`, the results are inaccurate, and Spectre prints a warning.

A separate model parameter, `imelt`, is used as a limit warning for the junction current. This parameter can be set to the maximum current rating of the device. When any component of the junction current exceeds `imelt`, note that base and collector currents are composed of many exponential terms, Spectre issues a warning and the results become inaccurate. The junction current is linearized above the value of `imelt` to prevent arithmetic exception, with the exponential term replaced by a linear equation at `imelt`.

Both of these parameters have current density counterparts, `jmax` and `jmelt`, that you can specify if you want the absolute current values to depend on the device area.

Auto Model Selection:

Many models need to be characterized for different geometries in order to obtain accurate results for model development. The model selector program automatically searches for a model with the length and width range specified in the instance statement and uses this model in the simulations.

For the auto model selector program to find a specific model, the models to be searched should be grouped together within braces. Such a group is called a model group. An opening brace is required at the end of the line defining each model group. Every model in the group is given a name followed by a colon and the list of parameters. Also, the four geometric parameters `lmax`, `lmin`, `wmax`, and `wmin` should be given. The selection criteria to choose a model is as follows:

lmin <= inst_length < lmax and wmin <= inst_width < wmax

Example:

model ModelName ModelType {

1: <model parameters> lmin=2 lmax=4 wmin=1 wmax=2

2: <model parameters> lmin=1 lmax=2 wmin=2 wmax=4

3: <model parameters> lmin=2 lmax=4 wmin=4 wmax=6

}

Then for a given instance

M1 1 2 3 4 ModelName w=3 l=1.5

the program would search all the models in the model group with the name `ModelName` and then pick the first model whose geometric range satisfies the selection criteria. In the preceding example, the auto model selector program would choose ModelName.2.

You must specify both length (l) and width (w) on the device instance line to enable automatic model selection.

Output Parameters

1 `weff (m)`	Effective channel width.
2 `leff (m)`	Effective channel length.
3 `rseff (Ω)`	Effective source resistance.
4 `rdeff (Ω)`	Effective drain resistance.
5 `aseff` (m^2)	Effective area of source diffusion.
6 `adeff` (m^2)	Effective area of drain diffusion.
7 `pseff (m)`	Effective perimeter of source diffusion.
8 `pdeff (m)`	Effective perimeter of source diffusion.
9 `isseff (A)`	Effective source-bulk junction reverse saturation current.
10 `isdeff (A)`	Effective drain-bulk junction reverse saturation current.
11 `cbseff (F)`	Effective zero-bias source-bulk junction capacitance.
12 `cbdeff (F)`	Effective zero-bias drain-bulk junction capacitance.

13 `vto (V)`	Effective zero-bias threshold voltage.
14 `vfb (V)`	Effective flat-band voltage.
15 `phi (V)`	Effective surface potential.
16 `k1 (√V )`	Effective body-effect coefficient.
17 `k2`	Effective charge-sharing parameter.
18 `eta`	Effective DIBL coefficient.

Operating-Point Parameters

1 `type=n`	Transistor type. Possible values are `n` or `p`.
2 `region=triode`	Estimated operating region. Spectre outputs number (0-4) in a rawfile. Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.
3 `degradation=no`	Hot-electron degradation flag. Possible values are `no` or `yes`.
4 `reversed`	Reverse mode indicator. Possible values are `no` or `yes`.
5 `ids (A)`	Resistive drain-to-source current.
6 `vgs (V)`	Gate-source voltage.
7 `vds (V)`	Drain-source voltage.
8 `vbs (V)`	Bulk-source voltage.
9 `vth (V)`	Threshold voltage.
10 `vdsat (V)`	Drain-source saturation voltage.
11 `betaeff` (A/V^2)	Effective beta.
12 `gm (S)`	Common-source transconductance.

13 `gds (S)`	Common-source output conductance.
14 `gmbs (S)`	Body-transconductance.
15 `cbd (F)`	Drain-bulk junction capacitance.
16 `cbs (F)`	Source-bulk junction capacitance.
17 `cgs (F)`	Gate-source capacitance.
18 `cgd (F)`	Gate-drain capacitance.
19 `cgb (F)`	Gate-bulk capacitance.
20 `ron (Ω)`	ON-resistance.
21 `id (A)`	Resistive drain current.
22 `ibulk (A)`	Resistive bulk current.
23 `pwr (W)`	Power at op point.
24 `gmoverid (1/V)`	Gm/Ids.
25 `isub (A)`	Substrate current.
26 `stress`	Hot-electron stress.
27 `age (s)`	Device age.
28 `he_vdsat (V)`	hot electron vdsat.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

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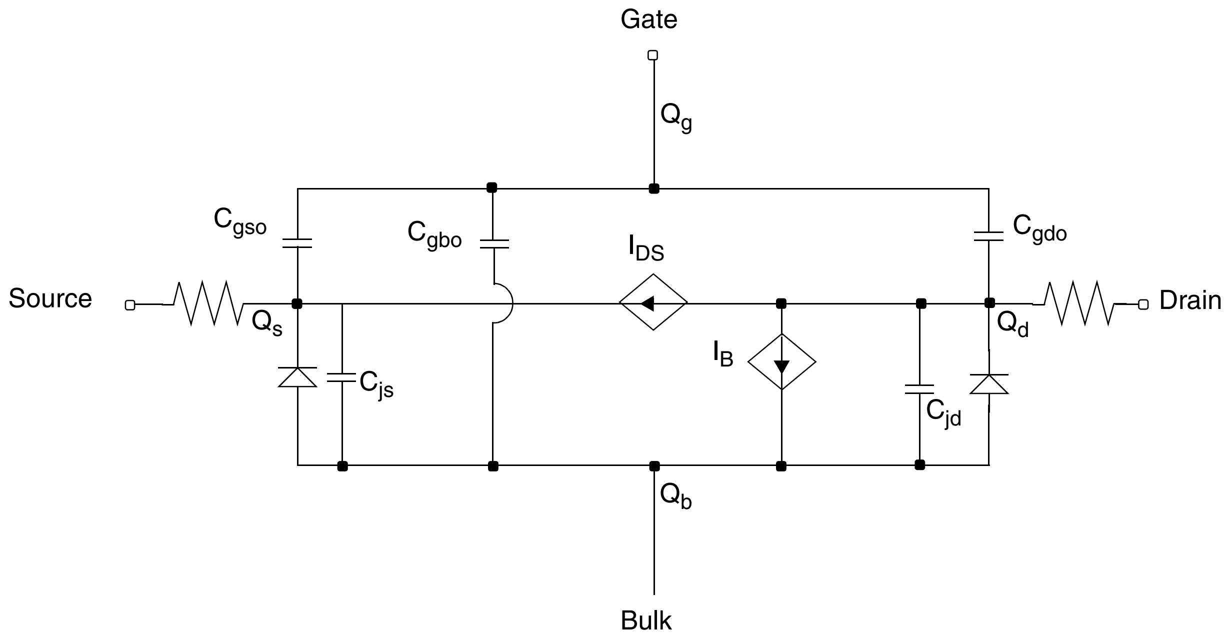
BSIM3v2 Level-10 Model (bsim3)

The BSIM3 model is based on the industry standard efforts of the Compact Modeling Counsel (CMC) and the BSIM modeling group at the University of California, Berkeley. It is suitable for both digital and analog applications. This chapter contains the following information for the BSIM3v2 model:



Threshold Voltage

$$V_{TH} = vtho + k1(\sqrt{phi - V_{BS}} - \sqrt{phi}) - k2 * V_{BS} - \Delta V_{TH} +$$

$$k1\left[\sqrt{1 + \frac{nlx}{L_{eff}}\sqrt{\frac{phi}{phi - V_{BS}}}} - 1\right]\sqrt{phi} + \frac{k3 * tox * phi}{W_{eff} + w0} + (kt1 + kt2V_{BS})\left(\frac{T}{tnom} - 1\right)$$

where

$$\Delta V_{TH} = \theta(vbi - phi)$$

$$\theta = dvt0 * \theta_0$$

$$\theta_0 = e^{-dvt1 * L_{eff}/2l_0} + 2e^{-dvt1 * L_{eff}/l_0}$$

L_{eff} is the effective channel length, and I_0 is given by

$$l_0 = \sqrt{\frac{\varepsilon_{si} tox X_{dep}}{\varepsilon_{ox}}}(1 + dvt2 * V_{BS})$$

and

$$X_{dep} = \sqrt{\frac{2\varepsilon_{si}(phi - V_{BS})}{q * npeak}}$$

Subthreshold Current

There are two subthreshold current models that you can select with the `subthmod` parameter. If you set `subthmod` to 0, none of the subthreshold current models are used. For example, the drain current is zero when the gate voltage is less than the threshold voltage. If you set `subthmod` to 1, the summation approach is used. For example, the subthreshold current is always calculated and added to the drain current for the strong-inversion region, regardless of the operating region.

If you set `subthmod` to 2, a transition region between the subthreshold regions and the strong-inversion regions is created. This transition region provides smooth switching between the subthreshold and the strong-inversion regions. The following equations are model equations for the subthreshold and transition regions.

subthmod = 1

$$I_{subth} = \frac{I_{exp} I_{limit}}{I_{exp} + I_{limit}}(1 - e^{-V_{DS}/V_{tm}})$$

where

$$I_{limit} = 4.5\beta_0 V_{tm}^2$$

$$I_{exp} = \beta_{subth} V_{tm}^2 e^{(V'_{GST}/nV_{tm})}$$

$$V'_{GST} = V_{GST} - voff + V_{dibl}$$

$$V_{dibl} = (eta0 + etab * V_{BS}) * \theta_d * V_{DS}$$

$$\theta_d = pdibl1[e^{-drout*L_{eff}/2l_{00}} + 2e^{-drout*L_{eff}/l_{00}}]$$

$$l_{00} = \sqrt{\frac{\varepsilon_{si} tox X_{dep0}}{\varepsilon_{ox}}}$$

$$X_{dep0} = \sqrt{\frac{2\varepsilon_{si} phi}{q*npeak}}$$

$$V_{GST} = V_{GS} - V_{TH}$$

$$\beta_{subth} = \frac{uoC_{d0}W_{eff}}{L_{eff}}$$

$$n = 1 + \frac{C_d}{C_{ox}} nfactor + \frac{(cdsc + cdsc1*V_{BS})}{C_{ox}}\theta_0 + \frac{C_{it}}{C_{ox}}$$

subthmod = 2

If $V_{GST} \le V_{glow} - V_{dibl}$, the drain current is given by current.

$$I_{DS} = I_{subth} = \beta_0 V_{tm}^2 e^{(V'_{GST}/nV_{tm})}(1 - e^{-V_{DS}/V_{tm}})$$

If $V_{glow} - V_{dibl} \le V_{GST} \le V_{ghigh} + V_{dibl}$, the device is operated in the transition region and the drain current is given by

$$I_{DS} = (1-t)^2 I_{dlow} + 2t(1-t)I_p + t^2 I_{dhigh}$$

where I_{dlow} is the subthreshold current evaluated at $V_{GST} = V_{glow} - V_{dibl}$, and I_{dhigh} is the strong-inversion drain current evaluated at $V_{GST} = V_{ghigh} + V_{dibl}$.

$$t = \left(\frac{V_p - V_{glow}}{Y}\right)\left[\sqrt{1 + \frac{Y(V_{GST} - V_{glow})}{(V_p - V_{glow})^2}} - 1\right]$$

$$Y = V_{glow} - 2V_p + V_{ghigh}$$

$$I_p = I_{dlow} + g_{mlow}(V_p - V_{glow})$$

$$V_p = \frac{(g_{mhigh}V_{ghigh} - g_{mlow}V_{glow}) - (I_{dhigh} - I_{dlow})}{g_{mhigh} - g_{mlow}}$$

g_{mhigh} and g_{mlow} are the transconductances evaluated at $V_{GST} = V_{ghigh} + V_{dibl}$.

Drain Saturation Voltage

If $R_{ds} = 0$,

$$V_{DSAT} = \frac{V_{GST}E_{SAT}L_{eff}}{V_{GST} + A_{bulk}E_{SAT}L_{eff}}$$

otherwise

$$V_{DSAT} = \frac{C_B - \sqrt{C_B^2 - 4C_AC_C}}{2C_A}$$

where

$$R_{ds} = rds0 + \frac{rdsw*10^{-6}}{W_{eff}}$$

$$E_{SAT} = \frac{2vsat}{\mu_{eff}}$$

$$\mu_{eff} = \frac{uo}{U_{vert}}$$

$$U_{vert} = 1 + ua\left(\frac{V_{GS} + V_{TH}}{tox}\right) + ub\left(\frac{V_{GS} + V_{TH}}{tox}\right)^2 + uc*V_{BS}$$

If $keta = 0$,

$$A_{bulk} = 1 + \frac{k1*a0*L_{eff}}{2(L_{eff} + 2\sqrt{xjX_{dep}})\sqrt{phi - V_{BS}}}$$

otherwise,

$$A_{bulk} = \left(1 + \frac{k1*a0*L_{eff}}{2(L_{eff} + 2\sqrt{xjX_{dep}})\sqrt{phi}}\right)\frac{1}{1 + keta*V_{BS}/L_{eff}}$$

$$C_A = A_{bulk}^2 R_{vcw}$$

$$C_B = V_{GST} + A_{bulk}E_{SAT}L_{eff} + 3A_{bulk}R_{vcw}V_{GST}$$

$$C_C = E_{SAT}L_{eff}V_{GST} + 2R_{vcw}V_{GST}^2$$

$$R_{vcw} = V_{SAT}*R_{ds}C_{ox}W_{eff}$$

Drain Current for the Triode Region

Note: These equations apply to $V_{GST} \geq 0$ and $V_{DS} \leq V_{DSAT}$.

$$I_{DS} = \frac{I_{dslin0}}{1 + R_{ds}*I_{dslin0}/V_{DS}} \qquad \backslash$$

where I_{dslin0} is the drain current in the triode region without the presence of source and drain parasitic resistance.

$$I_{dslin0} = \frac{\beta_{effs}\left(V_{GST} - \frac{1}{2}A_{bulk}V_{DS}\right)V_{DS}}{1 + V_{DS}/E_{SAT}L_{eff}}$$

$$\beta_{eff} = \frac{\mu_{eff}C_{ox}W_{eff}}{L_{eff}}$$

Drain Current for the Saturation Region

Note: These equations apply to V_{GST} > 0 and $V_{DS} \geq V_{DSAT}$.

$$I_{DSAT} = I_{DSAT0}\left(1 + \frac{V'_{DS}}{V_a}\right) * \left[1 + \frac{pscbe2}{L_{eff}} V'_{DS} e^{(-pscbe1 * litl / V'_{DS})}\right]$$

where

$$I_{DSAT0} = W_{eff} C_{ox} vsat(V_{GST} - A_{bulk} V_{DSAT})$$

$$V'_{DS} = V_{DS} - V_{DSAT}$$

satmod = 1

$$V_a = V_{aa} + \left(1 + \frac{eta * ldd}{litl}\right) * \left[\frac{(E_{SAT} L_{eff} + V_{GST}) V'_{DS}}{alpha * litl * E_{SAT}}\right]\left(1 - \frac{V'_{DS}}{2 litl * em}\right)$$

$$V_{aa} = \frac{E_{SAT} L_{eff} + V_{DSAT} + 2R_{vcw}(V_{GST} - 0.5 A_{bulk} V_{DSAT})}{1 + A_{bulk} R_{vcw}}$$

satmod = 2

$$V_a = V_{aa} + \left(1 + \frac{eta * ldd}{litl}\right)\left(\frac{V_{aclm} * V_{dibl}}{V_{aclm} + V_{adibl}}\right) * pvag$$

$$V_{aclm} = \frac{(E_{SAT} L_{eff} A_{bulk} + V_{GST}) V'_{DS}}{litl * pclm * E_{SAT} A_{bulk}}$$

$$V_{adibl} = \left(\frac{V_{GST} - \dfrac{V_{GST} A_{bulk} V_{DSAT}}{V_{GST} + A_{bulk} V_{DSAT}}}{\theta_{rout}} \right)$$

where

$$\theta_{rout} = pdibli[e^{-drout * L_{eff}/2l_0} + 2e^{-drout * L_{eff}/l_0}] + pdibl2$$

Default Model Parameter Value Calculation

The following are the calculation methods for default model parameter values under various conditions:

- If $vtho$ is not given, it is calculated from

$$vtho = vfb + phi + k1\sqrt{phi}$$

- If phi is not given, it is calculated from

$$phi = 2V_{tm}\ln\left(\frac{npeak}{n_i}\right)$$

where V_{tm} is the thermal voltage given by

$$V_{tm} = \frac{kT}{q}$$

$$n_i = 1.45 \times 10^{10}\left(\frac{T}{300}\right)^{1.5}\exp\left(\frac{1.12}{0.0516} - \frac{E_g(T)}{2V_{tm}}\right)$$

where $E_g(T)$ is the energy band gap at temperature T. The equation for E_g is shown in Chapter 12, “Common MOSFET Equations.”

- If $k1$ is not given, it is calculated from

$$k1 = gamma2 + 2k2\sqrt{phi - vbm}$$

- If $k2$ is not given, it is calculated from

$$k2 = \frac{(gamma2 - gamma1)(\sqrt{phi - vbx} - \sqrt{phi})}{2\sqrt{phi}(\sqrt{phi - vbm} - \sqrt{phi}) + vbm}$$

- If *gamma1* is not given, it is calculated from

$$gamma1 = \frac{\sqrt{2q\varepsilon_{si}npeak}}{C_{ox}}$$

- If *gamma2* is not given, it is calculated from

$$gamma2 = \frac{\sqrt{2q\varepsilon_{si}nsub}}{C_{ox}}$$

- If *litl* is not given, it is calculated from

$$litl = \sqrt{\frac{\varepsilon_{si}xj}{C_{ox}}}$$

- If *vtho* is not given, *vfb* is always calculated from

$$vfb = vtho - phi - k1\sqrt{phi} + k2*phi$$

regardless of any value you specify.

- If V_{bi} is not given, it is calculated from

$$V_{bi} = V_{tm}\ln\left(\frac{10^{22}npeak}{n_i^2}\right)$$

- If V_{bx} is not given, it is calculated from

$$V_{bx} = phi - \frac{q*npeak*xt^2}{2\varepsilon_{si}}$$

- If *gamma1* is given, *npeak* is calculated from

$$npeak = \frac{gamma1^2C_{ox}^2}{2q\varepsilon_{si}}$$

regardless of any value you specify.

If neither $gamma1$ nor $npeak$ is specified, $npeak$ defaults to 1.7e1.7, and $gamma1$ is calculated from $npeak$.

- The default value for uo is 670 cm^2/V sec for NMOS and 250 cm^2/V sec for PMOS.
- The temperature-dependent mobility is calculated as

$$U_o(T) = U_o\left(\frac{T}{Tnom}\right)^{ute}$$

- The temperature-dependent saturation velocity is calculated as

$$V_{sat}(T) = V_{sat} - at(T - Tnom)$$

- The temperature-dependent mobility degradation parameters are calculated as

$$U_a(T) = U_a - U_{a1}\left(\frac{T}{Tnom} - 1\right)$$

$$U_b(T) = U_b - U_{b1}\left(\frac{T}{Tnom} - 1\right)$$

$$U_c(T) = U_c - U_{c1}\left(\frac{T}{Tnom} - 1\right)$$

- If V_{ghigh} is not given, it is calculated from

$$V_{ghigh} = n0V_{tm}\left[ln\left(\frac{10C_{ox}}{C_d}\right) + 3\right]$$

where

$$C_d = \sqrt{\frac{q\varepsilon_{si}npeak}{2phi}}$$

- If V_{glow} is not given, it is calculated from

$$V_{glow} = voff + n0V_{tm}ln\left(\frac{C_{ox}}{10C_d}\right) - theta*vdd$$

- If $cgdo(cgso)$ is not given, it is calculated from

$$cgdo(cgso) = \begin{cases} (dl + meto)*C_{ox} & \text{if } dl \text{ is given} \\ 0.5xj*C_{ox} & \text{otherwise} \end{cases}$$

Also, if $cgdo(cgso)$ is zero, 10^{-7} x C_{ox} is used.

If $cgbo$ is not given, it is calculated from

$$cgbo = 2dw*C_{ox}$$

Scaling Effects

For more information about scaling effects, seeScaling Factors (scale and scalem) on page 242.

New Features in BSIM3 Version 3.2.4

The following features have been added to BSIM3v3.2.4:

1. A Spectre circuit simulator thermal noise model with the noise coefficient varying smoothly between 4 to 8/3 when the device moves from linear region to saturation region.
2. A BSIM4 ACNQS model that enables the NQS effect in AC simulations.
3. A new parameter *lintnoi* introducing an offset to the length reduction parameter (*lint*) to improve the accuracy of the flicker noise model

With the capacitance bug fix in this version, the transcapacitance CGG for capmod=3 is now smooth from the subthreshold region to strong inversion with no negative value.

BSIM3v3.2.4 is backward compatible with the previous versions of the model.

Component Statements

This device is supported within altergroups.

Sample Instance Statement:

```
m3 (1 2 0 0) nchmod l=1.5u w=100u as=450p ad=450p pd=209u ps=209u nrd=207m nrs=207m
m=1
```

Sample Model Statement:

```
model nchmod bsim3 vtho=5.94e-01 phi=0.69 k1=0.72 k2=0 w0=1.3e-07 tox=5.9e-09
rdsw=80 uo=499 xj=2e-07 vsat=600e+04 at=3.4e+04 a0=0.8 cdsc=1.4e-03 nfactor=1.03
```

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `w (m)`	Channel width.
2 `l (m)`	Channel length.
3 `as (m`^{2}`)`	Area of source diffusion.
4 `ad (m`^{2}`)`	Area of drain diffusion.
5 `ps (m)`	Perimeter of source diffusion.
6 `pd (m)`	Perimeter of drain diffusion.
7 `nrd (m/m)`	Number of squares of drain diffusion.
8 `nrs (m/m)`	Number of squares of source diffusion.
9 `isnoisy=yes`	Should resistor generate noise. Possible values are `no` or `yes`.
10 `m=1`	Multiplicity factor (number of MOSFETs in parallel).
11 `region=triode`	Estimated operating region. Spectre outputs number (0-4) in a rawfile. Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.
12 `trise`	Temperature rise from ambient.
13 `geo=0`	Geometry selector.

Model Definition

```
model modelName bsim3 parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

Threshold voltage parameters

2 `vtho=0 V` Threshold voltage at zero body bias.

3 `phi=0.7 V` Surface potential at strong inversion.

4 `k1=0.53 √V` Body-effect coefficient.

5 `k2=-0.0186` Charge-sharing parameter.

6 `k3=80` Narrow width coefficient.

7 `k3b=0 1/V` Narrow width coefficient.

8 `w0=2.5e-6 m` Narrow width coefficient.

9 `nlx=1.74e-7 m` Lateral nonuniform doping coefficient.

10 `gamma1=0 √V` Body-effect coefficient near the surface.

11 `gamma2=0 √V` Body-effect coefficient in the bulk.

12 `theta=0.02 1/V` Drain-induced barrier lowering coefficient.

13 `eta=0.3 1/V` Effective drain voltage coefficient.

14 `litl (m)` Depth of current path.

15 `vfb (V)` Flat-band voltage.

16 `vbx (V)` Threshold voltage transition body voltage.

17 `vbi (V)` Substrate junction built-in potential.

18 `vbm=-5 V` Maximum applied body voltage.

19 `dvt0=2.2` First coefficient of short-channel effects.

20 `dvt1=0.53` Second coefficient of short-channel effects.

21 `dvt2=-0.032 1/V` Body-bias coefficient of short-channel effects.

22 `a0=1 for nmos and 4.4 for pmos`
Nonuniform depletion width effect coefficient.

23 `a1=0 for nmos, 0.23 for pmos`
No-saturation coefficient.

24 `a2=1 for nmos, 0.08 for pmos`
No-saturation coefficient.

25 `keta=-0.047 1/V` Body-bias coefficient for non-uniform depletion width effect.

Process parameters

26 `nsub=2e15` cm^{-3} Substrate doping concentration.

27 `npeak=1.7e17` cm^{-3}
Peak channel doping concentration.

28 `ngate` (cm^{-3}) Poly-gate doping concentration.

29 `xj=0.15e-6 m` Source/drain junction depth.

30 `dl=0 m` Lateral diffusion for one side.

31 `dw=0 m` Width reduction for one side.

32 `tox=1.5e-8 m` Gate oxide thickness.

33 `vdd=5 V` Maximum drain voltage.

34 `xt=1.55e-7 m` Doping depth.

35 `ldd=0 m` Total length of lightly doped drain region.

36 `rds0=0` Ω Total drain-source resistance.

37 `rdsw=0` Ω μm Width dependence of drain-source resistance.

Mobility parameters

38 `uo=670 cm`^{2}`/V s` Low-field surface mobility at `tnom`. Default is 250 for PMOS.

39 `vsat=9.58e4 m/s` Carrier saturation velocity at `tnom`.

40 `ua=2.25e-9 m/v` First-order mobility reduction coefficient.

41 `ub=5.87e-19 m`^{2}`/v`^{2}
Second-order mobility reduction coefficient.

42 `uc=0.0465 1/V` Body-bias dependence of mobility.

43 `uc0=0` Mobility coefficient.

Output resistance parameters

44 `satmod=2` Saturation model selector.

45 `bulkmod=1` Bulk-charge effect model selector.

46 `drout=0.56` DIBL effect on output resistance coefficient.

47 `alpha=1.9` Reference voltage multiplication factor.

48 `em=4.1e7 V/m` Maximum electric field.

49 `pclm=1.3` Channel length modulation coefficient.

50 `pdibl1=0.39` First coefficient of drain-induced barrier lowering.

51 `pdibl2=8.6e-3` Second coefficient of drain-induced barrier lowering.

52 `pscbe1=4.24e8 V/m` First coefficient of substrate current body effect.

53 `pscbe2=1e-5 m/v` Second coefficient of substrate current body effect.

54 `pvag=0` Gate dependence of Early voltage.

Subthreshold parameters

55 `subthmod=2` Subthreshold model selector.

56 `vghigh=0.12 V`	Upper bound of transition region.
57 `vglow=-0.12 V`	Lower bound of transition region.
58 `cdsc=2.4e-4 F/m`^{2}	Source/drain and channel coupling capacitance.
59 `cdscb=0 F/m`^{2} `V`	Body-bias dependence of `cdsc`.
60 `nfactor=1`	Subthreshold swing coefficient.
61 `cit=0 F`	Interface trap parameter for subthreshold swing.
62 `voff=-0.11 V`	Threshold voltage offset.
63 `dsub=drout`	DIBL effect in subthreshold region.
64 `eta0=0.08`	DIBL coefficient subthreshold region.
65 `etab=-0.07 1/V`	Body-bias dependence of `et0`.

Parasitic resistance parameters

66 `rsh=0 Ω/sqr`	Source/drain diffusion sheet resistance.
67 `rs=0 Ω`	Source resistance.
68 `rd=0 Ω`	Drain resistance.
69 `lgcs=0 m`	Gate-to-contact length of source side.
70 `lgcd=0 m`	Gate-to-contact length of drain side.
71 `rsc=0 Ω`	Source contact resistance.
72 `rdc=0 Ω`	Drain contact resistance.
73 `rss=0 Ω m`	Scalable source resistance.
74 `rdd=0 Ω m`	Scalable drain resistance.
75 `sc=∞ m`	Spacing between contacts.
76 `ldif=0 m`	Lateral diffusion beyond the gate.

77 `hdif=0 m` Length of heavily doped diffusion.

78 `minr=0.1 Ω` Minimum source/drain resistance.

Junction diode model parameters

79 `js (A/m`^{2}`)` Bulk junction reverse saturation current density.

80 `is=1e-14 A` Bulk junction reverse saturation current.

81 `n=1` Junction emission coefficient.

82 `dskip=yes` Use simple piece-wise linear model for diode currents below 0.1*`iabstol`.
Possible values are `no` or `yes`.

83 `imelt=`imax' A` Explosion current.

84 `jmelt=`jmax' A/m'`^{2}
Explosion current density.

Overlap capacitance parameters

85 `cgso (F/m)` Gate-source overlap capacitance.

86 `cgdo (F/m)` Gate-drain overlap capacitance.

87 `cgbo (F/m)` Gate-bulk overlap capacitance.

88 `meto=0 m` Metal overlap in fringing field.

Junction capacitance model parameters

89 `cbs=0 F` Bulk-source zero-bias junction capacitance.

90 `cbd=0 F` Bulk-drain zero-bias junction capacitance.

91 `cj=5e-4 F/m`^{2} Zero-bias junction bottom capacitance density.

92 `mj=1/2` Bulk junction bottom grading coefficient.

93 `pb=0.8 V` Bulk junction built-in potential.

94 `fc=0.5` Forward-bias depletion capacitance threshold.

95 `cjsw=5e-10 F/m` Zero-bias junction sidewall capacitance density.

96 `mjsw=1/3` Bulk junction sidewall grading coefficient.

97 `pbsw=0.8 V` Side-wall junction built-in potential.

98 `fcsw=0.5` Side-wall forward-bias depletion capacitance threshold.

Charge model selection parameters

99 `capmod=yang` Intrinsic charge model.
Possible values are `none`, `meyer`, `yang`, or `bsim`.

100 `xpart=1` Drain/source channel charge partition in saturation for BSIM charge model, use 0.0 for 40/60, 0.5 for 50/50, or 1.0 for 0/100.

101 `xqc=0` Drain/source channel charge partition in saturation for charge models, e.g. use 0.4 for 40/60, 0.5 for 50/50, 0 for 0/100.

Default instance parameters

102 `w=5e-6 m` Default channel width.

103 `l=5e-6 m` Default channel length.

104 `as=0` m^2 Default area of source diffusion.

105 `ad=0` m^2 Default area of drain diffusion.

106 `ps=0 m` Default perimeter of source diffusion.

107 `pd=0 m` Default perimeter of drain diffusion.

108 `nrd=0 m/m` Default number of squares of drain diffusion.

109 `nrs=0 m/m` Default number of squares of source diffusion.

Temperature effects parameters

110 `tnom (C)` Parameters measurement temperature. Default set by `options`.

111 `trise=0 C` Temperature rise from ambient.

112 `tlev=0` DC temperature selector.

113 `tlevc=0` AC temperature selector.

114 `eg=1.12452 V` Energy band gap.

115 `gap1=7.02e-4 V/C` Band gap temperature coefficient.

116 `gap2=1108 C` Band gap temperature offset.

117 `kt1=-0.11 V` Temperature coefficient for threshold voltage.

118 `kt1l=-1.86e-7 v m` Temperature coefficient for threshold voltage.

119 `kt2=0.022` Temperature coefficient for threshold voltage.

120 `at=3.3e4 m/s` Temperature coefficient for `vsat`.

121 `ua1=4.31e-9 m/v` Temperature coefficient for `ua`.

122 `ub1=-7.61e-18` m^2/v^2 Temperature coefficient for `ub`.

123 `uc1=-0.056 1/V` Temperature coefficient for `uc`.

124 `trs=0 1/C` Temperature parameter for source resistance.

125 `trd=0 1/C` Temperature parameter for drain resistance.

126 `ute=-1.5` Mobility temperature exponent.

127 `xti=3` Saturation current temperature exponent.

128 `ptc=0 V/C` Surface potential temperature coefficient.

129 `tcv=0 V/C` Threshold voltage temperature coefficient.

130 `pta=0 V/C` Junction potential temperature coefficient.

131 `ptp=0 V/C` Sidewall junction potential temperature coefficient.

132 `cta=0 1/C` Junction capacitance temperature coefficient.

133 `ctp=0 1/C` Sidewall junction capacitance temperature coefficient.

Noise model parameters

134 `noisemod=1` Noise model selector.

135 `kf=0` Flicker (1/f) noise coefficient.

136 `af=1` Flicker (1/f) noise exponent.

137 `ef=1` Flicker (1/f) noise frequency exponent.

138 `wnoi=1e-5 m` Channel width at which noise parameters were extracted.

139 `a=1e16 for nmos and 9.9e14 for pmos`
Oxide trap density coefficient.

140 `b=5e4 for nmos and 2.4e3 for pmos`
Oxide trap density coefficient.

141 `c=-1.4e-8 for nmos and 1.4e-8 for pmos`
Oxide trap density coefficient.

Operating region warning control parameters

142 `alarm=none` Forbidden operating region.
Possible values are `none`, `off`, `triode`, `sat`, `subth`, or `rev`.

143 `imax=1 A` Maximum allowable current.

144 `jmax=1e8 A/m`^{2} Maximum allowable current density.

145 `bvj=∞ V` Junction reverse breakdown voltage.

146 `vbox=1e9 tox V` Oxide breakdown voltage.

147 `maxvp=1.12 V` Maximum allowable voltage across the gate poly layer.

Compatibility model parameters

148 `compatible=spectre`
Encourage device equations to be compatible with a foreign simulator. This option does not affect input syntax.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, or `mica`.

Auto Model Selector parameters

149 `wmax=1.0 m` Maximum channel width for which the model is valid.

150 `wmin=0.0 m` Minimum channel width for which the model is valid.

151 `lmax=1.0 m` Maximum channel length for which the model is valid.

152 `lmin=0.0 m` Minimum channel length for which the model is valid.

HSPICE junction model

153 `acm=12` HSPICE junction area calculation method selector.

154 `jsw=0.0 A/m` Sidewall bulk junction saturation current density.

155 `nds=1.0` Reverse bias slope coefficient.

156 `vnds=-1.0 V` Reverse diode current transition point.

157 `cjgate=`cjswF/m'` Zero bias gate-edge sidewall bulk junction capacitance density.

158 `php= pb  V` Bulk junction sidewall contact potential.

159 `tt=0.0 s` Transit time.

160 `ld (m)` Lateral diffusion into the channel from the source and drain diffusion.

161 `wmlt=1.0` Width diffusion layer shrink reduction factor.

162 `ijth=1.0 A` Explosion current.

Imax and Imelt:

The `imax` parameter aids convergence and prevents numerical overflow. The junction characteristics of the device are accurately modeled for current up to `imax`. If `imax` is exceeded during iterations, the linear model is substituted until the current drops below imax or until convergence is achieved. If convergence is achieved with the current exceeding `imax`, the results are inaccurate, and Spectre prints a warning.

A separate model parameter, `imelt`, is used as a limit warning for the junction current. This parameter can be set to the maximum current rating of the device. When any component of the junction current exceeds `imelt`, note that base and collector currents are composed of many exponential terms, Spectre issues a warning and the results become inaccurate. The junction current is linearized above the value of `imelt` to prevent arithmetic exception, with the exponential term replaced by a linear equation at `imelt`.

Both of these parameters have current density counterparts, `jmax` and `jmelt`, that you can specify if you want the absolute current values to depend on the device area.

Auto Model Selection:

Many models need to be characterized for different geometries in order to obtain accurate results for model development. The model selector program automatically searches for a model with the length and width range specified in the instance statement and uses this model in the simulations.

For the auto model selector program to find a specific model, the models to be searched should be grouped together within braces. Such a group is called a model group. An opening brace is required at the end of the line defining each model group. Every model in the group is given a name followed by a colon and the list of parameters. Also, the four geometric parameters `lmax`, `lmin`, `wmax`, and `wmin` should be given. The selection criteria to choose a model is as follows:

lmin <= inst_length < lmax and wmin <= inst_width < wmax

Example:

model ModelName ModelType {

1: <model parameters> lmin=2 lmax=4 wmin=1 wmax=2

2: <model parameters> lmin=1 lmax=2 wmin=2 wmax=4

3: <model parameters> lmin=2 lmax=4 wmin=4 wmax=6

}

Then for a given instance

M1 1 2 3 4 ModelName w=3 l=1.5

the program would search all the models in the model group with the name `ModelName` and then pick the first model whose geometric range satisfies the selection criteria. In the preceding example, the auto model selector program would choose ModelName.2.

You must specify both length (l) and width (w) on the device instance line to enable automatic model selection.

Output Parameters

1 `weff (m)`	Effective channel width.
2 `leff (m)`	Effective channel length.
3 `rseff (Ω)`	Effective source resistance.
4 `rdeff (Ω)`	Effective drain resistance.

Operating-Point Parameters

1 `type=n`	Transistor type. Possible values are `n` or `p`.
2 `region=triode`	Estimated operating region. Spectre outputs number (0-4) in a rawfile. Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.
3 `reversed`	Reverse mode indicator. Possible values are `no` or `yes`.
4 `ids (A)`	Resistive drain-to-source current.
5 `vgs (V)`	Gate-source voltage.
6 `vds (V)`	Drain-source voltage.
7 `vbs (V)`	Bulk-source voltage.
8 `vth (V)`	Threshold voltage.
9 `vdsat (V)`	Drain-source saturation voltage.

10 gm (S)	Common-source transconductance.
11 gds (S)	Common-source output conductance.
12 gmbs (S)	Body-transconductance.
13 betaeff (A/V^2)	Effective beta.
14 cbd (F)	Drain-bulk junction capacitance.
15 cbs (F)	Source-bulk junction capacitance.
16 cgs (F)	Gate-source capacitance.
17 cgd (F)	Gate-drain capacitance.
18 cgb (F)	Gate-bulk capacitance.
19 ron (Ω)	On-resistance.
20 id (A)	Resistive drain current.
21 ibulk (A)	Resistive bulk current.
22 pwr (W)	Power at op point.
23 gmoverid (1/V)	Gm/Ids.

Parameter Index

In the following index, I refers to instance parameters, M refers to the model parameters section, O refers to the output parameters section, and OP refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of M-35 means the 35th model parameter.

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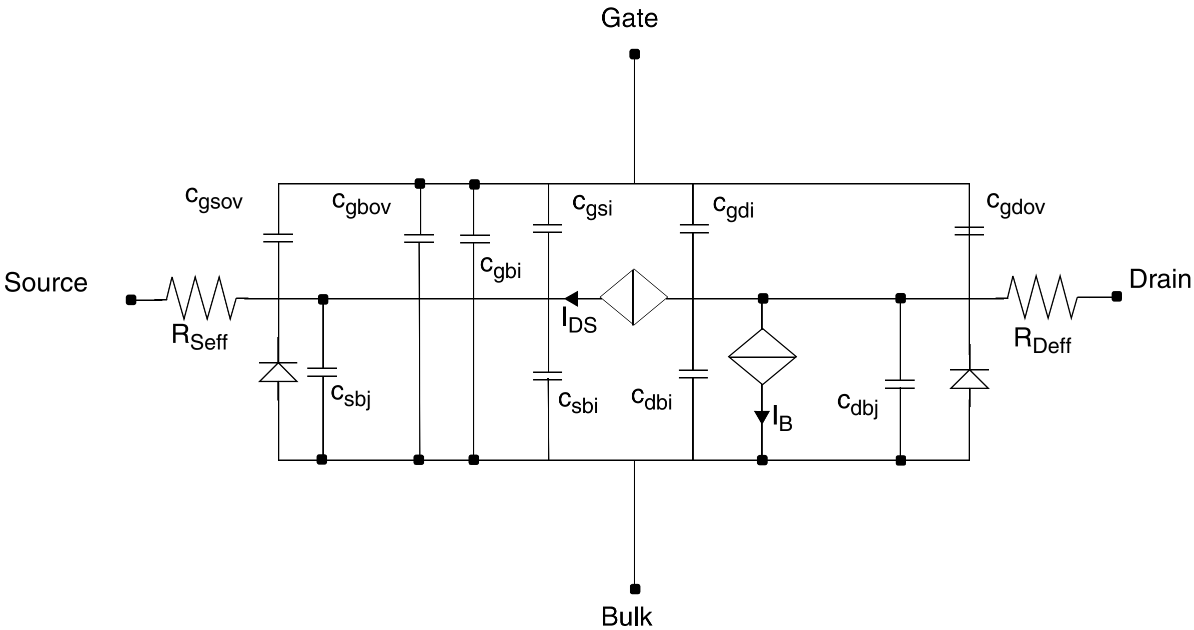
BSIM3v3 Level-11 Model (bsim3v3)

The BSIM3v3 model is based on the industry standard efforts of the Compact Modeling Counsel (CMC) and the BSIM modeling group at the University of California, Berkeley. The available versions for BSIM3v3 model are 3.1, 3.2, 3.21, 3.22, 3.23, 3.24, and 3.3. This chapter contains the following information:



Spectre-Specific Parameters

Some of the following parameters are left in the model for backward compatibility to other Virtuoso® Spectre® circuit simulator models.

Instance Parameters

The instance parameters mentioned in the table below help you in performing mismatch analyses. They represent the statistical variation of the threshold voltage (vth0), the mobility (u0), the body bias coefficient (k1) and the subthreshold swing factor (Nfactor). These parameters are implemented in the following manner:

Parameter	Unit	Description
`Delvto`	`v`	shift in zero-bias threshold voltage vth0. Default value is `0.0`.
`Nulmu0`		Mobility multiplier. Default value is `1.0`.
`Delk1`	$v^{1/2}$	shift in body bias coefficient k1. Default value is `0.0`.
`Delnfct`		Shift in subthreshold swing factor. Default value is `0.0`.

The checking of these parameters is as follows:

- If Mulu0 < 0.0 and Paramchk returns a warning message, reset Nulmu0 to 1.0.
- If Delk1 < -K1 (after binning) and Paramchk returns a warning message, reset Delk1 to 0.0.

The parameters are added whether Vto and K1 are given (specified by you or computed internally when not specified). Mulmu0 is multiplied after binning.

Model Parameters

Parameter	Description
`ad`	Area of drain diffusion. This is an instance parameter in Spice, but may be specified as a model parameter in Spectre.
`alarm`	Forbidden operating region. Can be set to `none`, `off`, `triode`, `sat`, `subth`, or `rev`. Spectre will issue a warning if your device's operating point enters this region.
`as`	Area of source diffusion. This is an instance parameter in Spice, but may be specified as a model parameter in Spectre.
`bvj`	The junction reverse breakdown voltage. Spectre checks this at the DC operating point, and also on each step of the transient simulation. Spectre issues a warning if the bulk-drain voltage exceeds this voltage.
`cbd`	Bulk-drain zero bias junction capacitance.
`cbs`	Bulk-drain zero bias junction capacitance.
`cta`	Junction capacitance temperature coefficient.
`ctp`	Sidewall junction capacitance temperature coefficient.
`diomod`	Controls the junction models. If `diomod=1` (default value), the Spectre junction model is used. The equations are described in *Chapter 12: Common MOSFET Equations*. If `diomod=0`, the Berkeley BSIM3v3 junction model is used.
`drout`	DIBL effect on rout coefficient.
`dskip`	Allows the substitution of a simple `pwl` model for the diode current if it falls below 0.1*iabstol.
`eg`	Energy band gap.

`fc`	Forward bias depletion capacitance threshold.
`fcsw`	Sidewall forward bias depletion capacitance threshold.
`gap1`	Band gap temperature coefficient.
`gap2`	Bandgap temp offset.
`hdif`	Length of heavily doped diffusion.
`imax`	Maximum current.
`imelt`	Explosion current. The junction current is linearized after this current is exceeded.
`jmax`	Maximum current density.
`jmelt`	Explosion current density.
`is`	Bulk-junction reverse saturation current.
`l`	Default channel length, if not specified on the instance.
`ldif`	Lateral diffusion beyond the gate.
`lgcs`	Gate to contact length of source.
`lgcd`	Gate to contact length of drain.
`meto`	Metal overlap in fringing field.
`minr`	Minimum resistance.
`nrd`	Default number of drain squares. This is an instance parameter also.
`nrs`	Default number of source squares. This is an instance parameter also.
`pd`	Drain perimeter. This is an instance parameter also.
`ps`	Source perimeter. This is an instance parameter also.
`pta`	Junction potential temperature coefficient.
`ptp`	Sidewall junction potential temperature coefficient.
`rd`	Drain resistance.
`rdc`	Drain contact resistance.
`rdd`	Scalable drain resistance.
`rs`	Source resistance.
`rsc`	Source contact resistance.

`rss`	Scalable source resistance.
`sc`	Contact spacing.
`tlev`	DC temperature selector.
`tlevc`	AC temperature selector.
`trd`	Temperature param for drain resistance.
`trise`	Temperature rise from ambient.
`trs`	Temperature param for source resistance.
`type`	Specifies `nmos` or `pmos`, since the primitive name is bsim3v3.
`xl`	Length variation from masking and etching.
`xw`	Width variation from masking and etching.
`w`	Default channel width, if not specified on the instance.
`warn`	Parameter to turn warnings off and on.
`wnoi`	Channel width at which noise parameters extracted.
`vbox`	Oxide breakdown voltage.

Note: `n` in the Spectre® circuit simulator is `nj` in Berkeley. `nqsmod` is an instance parameter for Berkeley, but both an instance and model parameter for the Spectre circuit simulator. `level=11` in the Spectre simulator, but `level=8` in Berkeley. The `ijth` parameter (diode-limiting current) is aliased to the Spectre simulator's `imelt` parameter. Some of the Spectre-specific parameters can affect the behavior of the model in such a way to make the model incompatible with other simulators. Cadence recommends that care be taken when using these parameters.

See `spectre -h bsim3v3` for more details about these parameters.

Drain and Source Area

The drain and source areas are calculated in the order shown in the following equations.

Drain and Source Perimeters

The drain and source perimeters are calculated in the order shown in the following equations:

$$\text{Drain perimeter} = \begin{cases} pd & \text{if } pd \text{ is given} \\ 4hidif * scalem + 2W_{scaled} & \text{if } hidif \text{ is given} \\ 2 \cdot (W_{eff} + ld) & \text{if } ld \text{ is given} \\ 0 & \text{otherwise} \end{cases}$$

$$\text{Source perimeter} = \begin{cases} ps & \text{if } ps \text{ is given} \\ 4hidif * scalem + 2W_{scaled} & \text{if } hidif \text{ is given} \\ 2 \cdot (W_{eff} + ls) & \text{if } ls \text{ is given} \\ 0 & \text{otherwise} \end{cases}$$

Note: The ld (length of drain) parameter is an instance parameter that is different from the model parameter ld (lateral diffusion) used in calculating L_{eff}.

Drain and Source Parasitic Resistance

$$\text{Drain area} = \begin{cases} ad & \text{if } ad \text{ is given} \\ 2hidif * scalem * W_{scaled} & \text{if } hidif \text{ is given} \\ W_{eff} * ld & \text{if } ld \text{ is given} \\ 0 & \text{otherwise} \end{cases}$$

$$\text{Source area} = \begin{cases} as & \text{if } as \text{ is given} \\ 2hidif{*}scalem{*}W_{scaled} & \text{if } hidif \text{ is given} \\ W_{eff}{*}ls & \text{if } ls \text{ is given} \\ 0 & \text{otherwise} \end{cases}$$

Note: The ld (length of drain) parameter is an instance parameter that is different from the model parameter ld (lateral diffusion) used in calculating L_{eff}.

I-V Model

Threshold Voltage

$$V_{TH} = V_{tho} + K_1(\sqrt{\Phi_s - V_{bseff}} - \sqrt{\Phi_s}) - K_2 V_{bseff}$$
$$+ K_1\left(\sqrt{1 + \frac{N_{lx}}{L_{eff}}} - 1\right)\sqrt{\Phi_s} + (K_3 + K_{3b}V_{bseff}) \times \frac{T_{ox}}{W'_{eff} + W_0}\Phi_s -$$
$$-D_{vtow}\left(\exp\left(-D_{vt1w}\frac{W_{eff}L_{eff}}{2l_{tw}}\right) + 2\exp\left(-D_{vt1w}\frac{W_{eff}L_{eff}}{l_{tw}}\right)\right)(V_{bi} - \Phi_s)$$
$$- D_{vto}\left(\exp\left(-D_{vt1}\frac{L_{eff}}{2l_t}\right) + 2\exp\left(-D_{vt1}\frac{L_{eff}}{l_t}\right)\right)(V_{bi} - \Phi_s)$$
$$-\left(\exp\left(-D_{sub}\frac{L_{eff}}{2l_{to}}\right) + 2\exp\left(-D_{sub}\frac{L_{eff}}{l_{to}}\right)\right)(E_{tao} + E_{tab}V_{bseff})V_{ds}$$

where

$$l_t = \sqrt{\varepsilon_{si}X_{dep}/C_{ox}}(1 + D_{vt2}V_{bseff})$$

$$l_{tw} = \sqrt{\varepsilon_{si}X_{dep}/C_{ox}}(1 + D_{vt2w}V_{bseff})$$

$$l_{to} = \sqrt{\varepsilon_{si} X_{dep0} / C_{ox}}$$

$$X_{dep} = \sqrt{\frac{2\varepsilon_{si}(\Phi_s - V_{bseff})}{qN_{ch}}}$$

$$X_{dep0} = \sqrt{\frac{2\varepsilon_{si}\Phi_s}{qN_{ch}}}$$

$$V_{bseff} = V_{bc} + 0.5\left[V_{bs} - V_{bc} - \delta_1 + \sqrt{\frac{(V_{bs} - V_{bc} - \delta_1)^2 - 4\delta_1 V_{bc}}{(\delta 1 = 0.001)}}\right]$$

$$V_{bc} = 0.9\left(\Phi_s - \frac{K_1^2}{4K_2^2}\right)$$

$$V_{bi} = V_t \times \ln\left[\frac{N_{ch} N_{DS}}{n_i^2}\right]$$

$$N_{DS} = 10^{20},\ V_t = \frac{kT}{q}, \text{ the thermal voltage}$$

Effective Vgs-Vthc

$$V_{gsteff} = \frac{2nv_t \ln\left[1 + \exp\left(\frac{V_{gs} - V_{th}}{2nv_t}\right)\right]}{1 + 2nC_{ox}\sqrt{\frac{2\Phi_s}{q\varepsilon_{si}N_{ch}}}\exp\left(-\frac{V_{gs} - V_{th} - 2V_{off}}{2nv_t}\right)}$$

$$n = 1 + N_{factor}\frac{C_d}{C_{ox}} + \frac{(C_{dsc} + C_{dscd}V_{ds} + C_{dscb}V_{bseff})\left(\exp\left(-D_{vt1}\frac{L_{eff}}{2l_t}\right) + 2\exp\left(-D_{vt1}\frac{L_{eff}}{l_t}\right)\right)}{C_{ox}} + \frac{C_{it}}{C_{ox}}$$

$$C_d = \frac{\varepsilon_{si}}{X_{dep}}$$

Mobility

For `Mobmod`=1,

$$\mu_{eff} = \frac{\mu_o}{1 + (U_a + U_c V_{bseff})\left(\frac{V_{gsteff} + 2V_{th}}{T_{ox}}\right) + U_b\left(\frac{V_{gsteff} + 2V_{th}}{T_{ox}}\right)^2}$$

For `Mobmod`=2,

$$\mu_{eff} = \frac{\mu_o}{1 + (U_a + U_c V_{bseff})\left(\frac{V_{gsteff}}{T_{ox}}\right) + U_b\left(\frac{V_{gsteff}}{T_{ox}}\right)^2}$$

For `Mobmod`=3,

$$\mu_{eff} = \frac{\mu_o}{1 + \left[U_a\left(\frac{V_{gsteff} + 2V_{th}}{T_{ox}}\right) + U_b\left(\frac{V_{gsteff} + 2V_{th}}{T_{ox}}\right)^2\right](1 + U_c V_{bseff})}$$

Drain Saturation Voltage

For $R_{ds} > 0$ or $\lambda \neq 1$,

$$V_{DSAT} = \frac{-b - \sqrt{b^2 - 4ac}}{2a}$$

$$a = A_{bulk}^2 W_{eff} v_{sat} C_{ox} R_{ds} + \left(\frac{1}{\lambda} - 1\right) A_{bulk}$$

$$b = -\left((V_{gsteff} + 2v_t)\left(\frac{2}{\lambda} - 1\right) + A_{bulk} E_{sat} L_{eff} + 3A_{bulk}(V_{gsteff} + 2v_t) W_{eff} v_{sat} C_{ox} R_{ds}\right)$$

$$c = (V_{gsteff} + 2v_t) E_{sat} L_{eff} + 2(V_{gsteff} + 2v_t)^2 W_{eff} v_{sat} C_{ox} R_{ds}$$

$$\lambda = A_1 V_{gsteff} + A_2$$

For $R_{ds} = 0$ and $\lambda = 1$,

$$V_{DSAT} = \frac{E_{sat} L_{eff} (V_{gsteff} + 2v_t)}{A_{bulk} E_{sat} L_{eff} + (V_{gsteff} + 2v_t)}$$

$$A_{bulk} = \left(1 + \frac{K_1}{2\sqrt{\Phi_s - V_{bseff}}}\left\{\frac{A_o L_{eff}}{L_{eff} + 2\sqrt{X_j X_{dep}}}\left[1 - A_{gs} V_{gsteff}\left(\frac{L_{eff}}{L_{eff} + 2\sqrt{X_j X_{dep}}}\right)^2\right] + \frac{B_o}{Weff + B_1}\right\}\right)\frac{1}{1 + K_{eta} V_{bseff}}$$

$$E_{sat} = \frac{2v_{sat}}{\mu_{eff}}$$

Effective Vds

$$V_{dseff} = V_{dsat} - \frac{1}{2}\left(V_{dsat} - V_{ds} - \delta + \sqrt{(V_{dsat} - V_{ds} - \delta)^2 + 4\delta V_{dsat}}\right)$$

Drain Current Expression

$$I_{DS} = \frac{I_{dso(Vdseff)}}{1 + \frac{R_{ds} I_{dso(Vdseff)}}{V_{dseff}}} \left(1 + \frac{V_{ds} - V_{dseff}}{V_a}\right) \left(1 + \frac{V_{ds} - V_{dseff}}{V_{ascbe}}\right)$$

$$I_{dso} = I_{dso} = \frac{W_{eff} \mu_{eff} C_{ox} V_{gsteff} \left(1 - A_{bulk} \frac{V_{dseff}}{2(V_{gsteff} + 2v_t)}\right) V_{dseff}}{L_{eff}[1 + V_{dseff} / (E_{sat} L_{eff})]}$$

$$V_a = V_{asat} + \left(1 + \frac{P_{vag} V_{gsteff}}{E_{sat} L_{eff}}\right) \left(\frac{1}{V_{aclm}} + \frac{1}{V_{adiblc}}\right)^{-1}$$

$$V_{aclm} = \frac{A_{bulk} E_{sat} L_{eff} + V_{gsteff}}{P_{clm} A_{bulk} E_{sat} L_{itl}} (V_{ds} - V_{dseff})$$

$$V_{adiblc} = \frac{(V_{gsteff} + 2v_t)}{\theta_{rout}(1 + P_{diblcb} V_{bseff})} \left(1 - \frac{A_{bulk} V_{dsat}}{A_{bulk} V_{dsat} + V_{gsteff} + 2v_t}\right)$$

$$\theta_{rout} = P_{diblc1} \left[\exp\left(-D_{rout} \frac{L_{eff}}{2l_{t0}}\right) + 2\exp\left(-D_{rout} \frac{L_{eff}}{l_{t0}}\right)\right] + P_{diblc2}$$

$$\frac{1}{V_{ascbe}} = \frac{p_{scbe2}}{L_{eff}} \exp\left(\frac{-P_{scbe1} L_{itl}}{V_{ds} - V_{dseff}}\right)$$

$$V_{asat} = \frac{E_{sat} L_{eff} + V_{dsat} + 2R_{ds} v_{sat} C_{ox} W_{eff} V_{gsteff} \left[1 - \frac{A_{bulk} V_{dsat}}{2(V_{gsteff} + 2v_t)}\right]}{2/\lambda - 1 + R_{ds} v_{sat} C_{ox} W_{eff} A_{bulk}}$$

$$L_{itl} = \sqrt{\frac{\varepsilon_{si} T_{ox} X_j}{\varepsilon_{ox}}}$$

Substrate Current

$$I_{sub} = \frac{\alpha}{L_{eff}}(V_{ds} - V_{dseff})\exp\left(-\frac{\beta_o}{V_{ds} - V_{dseff}}\right)\frac{I_{dso}}{1 + \frac{R_{ds}I_{dso}}{V_{dseff}}}\left(1 + \frac{V_{ds} - V_{dseff}}{V_a}\right)$$

$$\alpha = \alpha_0 + \alpha_1 L_{eff}$$

Junction Saturation Current

is always overrides js. If you give js but not is, the saturation currents are calculated from js and the source and drain areas.

$$\text{Drain saturation current} = \begin{cases} is & \text{if } is \text{ is given} \\ js*ad + jsw \times pd & \text{otherwise} \end{cases}$$

$$\text{Source saturation current} = \begin{cases} is & \text{if } is \text{ is given} \\ js*as + jsw \times ps & \text{otherwise} \end{cases}$$

Polysilicon Depletion Effect

$$V_{poly} = \frac{1}{2}X_{poly}E_{poly} = \frac{qN_{gate}X_{poly}^2}{2\varepsilon_{si}}$$

$$\varepsilon_{ox}E_{ox} = \varepsilon_{si}E_{poly} = \sqrt{2q\varepsilon_{si}N_{gate}V_{poly}}$$

$$V_{gs} - V_{fb} - \Phi_s = V_{poly} + V_{ox}$$

$$a(V_{gs} - V_{fb} - \Phi_s - V_{poly})^2 - V_{poly} = 0$$

$$a = \frac{\varepsilon_{ox}^2}{2q\varepsilon_{si}N_{gate}T_{ox}^2}$$

$$V_{gs\_eff} = V_{fb} + \Phi_s + \frac{q\varepsilon_{si}N_{gate}T_{ox}^2}{\varepsilon_{ox}^2}\left(\sqrt{1 + \frac{2\varepsilon_{ox}^2(V_{gs} - V_{FB} - \Phi_s)}{q\varepsilon_{si}N_{gate}T_{ox}^2}} - 1\right)$$

Effective Channel Length and Width

$$L_{eff} = L_{drawn} - 2dL$$

where

$$L_{drawn} = L(given) \times scale + xl \times scalem$$

$$W_{eff} = W_{drawn} - 2dW$$

$$W_{eff}' = W_{drawn} - 2dW'$$

$$dW = dW' + dW_g V_{gsteff} + dW_b(\sqrt{\Phi_s - V_{bseff}} - \sqrt{\Phi_s})$$

$$dW' = W_{\text{int}} + \frac{W_l}{L^{W_{\ln}}} + \frac{W_w}{W^{W_{wn}}} + \frac{W_{wl}}{L^{W_{\ln}}W^{W_{wn}}}$$

$$dL = L_{\text{int}} + \frac{L_l}{L^{L_{\ln}}} + \frac{L_w}{W^{L_{wn}}} + \frac{L_{wl}}{L^{L_{\ln}}W^{L_{wn}}}$$

$$W_{effc} = W_{drawn} - dWC$$

Drain/Source Resistance

$$R_{ds} = \frac{R_{dsw}[1 + P_{rwg}V_{gsteff} + P_{rwb}(\sqrt{\Phi_s - V_{bseff}} - \sqrt{\Phi_s})]}{(10^6 W_{eff}')^{Wr}}$$

Temperature Effects

$$V_{th(T)} = V_{th}(T_{nom}) + (K_{t1} + K_{t1l}/L_{eff} + K_{t2}V_{bseff})\left(\frac{T}{T_{nom}} - 1\right)$$

$$\mu_{o(T)} = \mu_o(T_{nom})\left(\frac{T}{T_{nom}}\right)^{U_{te}}$$

$$v_{sat(T)} = v_{sat}(T_{nom}) - A_t\left(\frac{T}{T_{nom}} - 1\right)$$

$$R_{dsw(T)} = R_{dsw}(T_{nom}) + P_{rt}\left(\frac{T}{T_{nom}} - 1\right)$$

$$U_{a(T)} = U_a(T_{nom}) + U_{a1}\left(\frac{T}{T_{nom}} - 1\right)$$

$$U_{b(T)} = U_b(T_{nom}) + U_{b1}\left(\frac{T}{T_{nom}} - 1\right)$$

$$U_{c(T)} = U_c(T_{nom}) + U_{c1}\left(\frac{T}{T_{nom}} - 1\right)$$

Capacitance Model

Dimension Dependence

$$L_{active} = L_{drawn} - 2\delta L_{eff}$$

$$\delta L_{eff} = D_{lc} + \frac{L_{lc}}{L^{L_{\ln}}} + \frac{L_{wc}}{W^{L_{wn}}} + \frac{L_{wlc}}{L^{L_{\ln}} W^{L_{wn}}}$$

$$W_{active} = W_{drawn} - 2\delta W_{eff}$$

$$\delta W_{eff} = D_{wc} + \frac{W_{lc}}{L^{W_{\ln}}} + \frac{W_{wc}}{W^{W_{wn}}} + \frac{W_{wlc}}{L^{W_{\ln}} W^{W_{wn}}}$$

Junction Capacitance

If pd > W_{eff},

$$cd = ad \times cjbs + pd \times cjbssw - W_{eff} \times cjbssw + W_{eff} \times cjbsswg$$

otherwise

$$cd = ad \times cjbs + pd \times cjbssw$$

where

cjbs is a function of cj, mj, and pb

cjbssw is a function of cjsw, mjsw, and pbsw

cjbsswg is a function of cjswg, mjswg, and pbswg

Overlap Capacitance (for NMOS)

$$OverlapCgs = \begin{cases} C_{gso} & \text{if } cgso \text{ is given} \\ (dlc + meto) \times C_{ox} - C_{gsl} & \text{if } dlc \text{ is given and dlc>0} \\ 0.6 \times X_j \times C_{ox} & \text{otherwise} \end{cases}$$

$$OverlapCgd = \begin{cases} C_{gdo} & \text{if } cgdo \text{ is given} \\ (dlc + meto) \times C_{ox} - C_{gdl} & \text{if } dlc \text{ is given and dlc>0} \\ 0.6 \times X_j \times C_{ox} & \text{otherwise} \end{cases}$$

$$OverlapCgb = \begin{cases} C_{gbo} & \text{if } cgso \text{ is given} \\ 2.0 \times dwc \times C_{ox} & \text{otherwise} \end{cases}$$

If OverlapCgs/OverlapCgd < 0, OverlapCgs/OverlapCgd=1.0e-7*Tox

OverlapCgb<0, OverlapCgb=0

Source Overlap Capacitance

For `capmod`=0,

$$Q_{overlap,\,s} = C_{gso}\mathrm{V}_{gs}W_{active}$$

For `capmod`=1,

if (V_{gs} < 0),

$$Q_{overlap,\,s} = \left[C_{gso}\mathrm{V}_{gs} + \frac{C_{kappa}C_{gsl}}{2}\left(-1 + \sqrt{1 - \frac{4V_{gs}}{C_{kappa}}}\right)\right]W_{active}$$

else

$$Q_{overlap,\,s} = [(\mathrm{C}_{gso} + C_{kappa}C_{gsl})V_{gs}]W_{active}$$

For `capmod`=2,

$$Q_{overlap,s} = \left[C_{gso}\mathrm{V}_{gs} + C_{gsl}\left\{V_{gs} - V_{gs,overlap} + \frac{\mathrm{C}_{kappa}}{2}\left(-1 + \sqrt{1 + \frac{4V_{gs,overlap}}{\mathrm{C}_{kappa}}}\right)\right\}\right]$$

$$W_{active}$$

$$V_{gs,overlap} = \frac{1}{2}\left\{(V_{gs} + \delta_1) - \sqrt{(V_{gs} + \delta_1)^2 + 4\delta_1}\right\} \qquad where \quad \delta_1 = 0.02$$

Drain Overlap Capacitance

For `capmod`=0,

$$Q_{overlap,d} = C_{gdo}\mathrm{V}_{gd}W_{active}$$

For `capmod`=1,

if ($V_{gd} < 0$),

$$Q_{overlap,d} = \left[C_{gdo}\mathrm{V}_{gd} + \frac{C_{kappa}C_{gdl}}{2}\left(-1 + \sqrt{1 - \frac{4V_{gd}}{C_{kappa}}}\right)\right]W_{active}$$

else

$$\frac{Q_{overlap,d}}{W_{active}} = (C_{gdo} + C_{kappa}C_{gdl})V_{gd}$$

For `capmod`=2 or 3,

$$QQ_{overlap,d} = \left[C_{gdo}V_{gd} + C_{gdl}\left\{V_{gd} - V_{gd,overlap} + \frac{C_{kappa}}{2}\left(-1 + \sqrt{1 + \frac{4V_{gd,overlap}}{C_{kappa}}}\right)\right\} W_{active}\right]$$

$$V_{gd,overlap} = \frac{1}{2}\left\{(V_{gd} + \delta_1) - \sqrt{(V_{gd} + \delta_1)^2 + 4\delta_1}\right\} \qquad where \quad \delta_1 = 0.02$$

Gate Overlap Charge

$$Q_{overlap,g} = -(Q_{overlap,s} + Q_{overlap,d})$$

Intrinsic Charges

For capmod=0

Accumulation region ($V_{gs} < V_{fb} + V_{bs}$)

$$Q_g = W_{active}L_{active}C_{ox}(V_{gs} - V_{bs} - V_{fbcv})$$

$$Q_{sub} = -Q_g$$

$$Q_{inv} = 0$$

Subthreshold region ($V_{gs} < V_{th}$)

$$Q_b = -W_{active}L_{active}C_{ox}\frac{K_1^2}{2}\left(-1+\sqrt{1+\frac{4(V_{gs}-V_{fbcv}-V_{bs})}{K_1^2}}\right)$$

$$Q_g = -Q_b$$

$$Q_{inv} = 0$$

Strong inversion ($V_{gs} > V_{th}$)

$$V_{dsat,cv} = \frac{V_{gs}-V_{th}}{A_{bulk}'}$$

$$A_{bulk}' = \begin{cases} A_{bulk0}\left(1+\left(\dfrac{C_{lc}}{L_{eff}}\right)^{C_{le}}\right) & \text{if version} <= 3.1 \\ A_{bulk0}\left(1+\left(\dfrac{C_{lc}}{L_{active}}\right)^{C_{le}}\right) & \text{if version} > 3.1 \end{cases}$$

$$A_{bulk0} = \left(1+\frac{K_1}{2\sqrt{\Phi_s-V_{bs}}}\left\{\frac{A_0L_{eff}}{L_{eff}+2\sqrt{X_jX_{dep}}}+\frac{B_o}{W_{eff}'+B_1}\right\}\right)\frac{1}{1+K_{eta}V_{bs}}$$

$$V_{TH} = V_{fbcv}+\Phi_s+K_1\sqrt{\Phi_s-V_{bs}}$$

50/50 Charge Partition

If $V_{ds} < V_{dsat'}$

$$Q_g = C_{ox}W_{active}L_{active}\left[V_{gs}-V_{fbcv}-\Phi_s-\frac{V_{ds}}{2}+\frac{A_{bulk}'\times V_{ds}^2}{12\left(V_{gs}-V_{th}-\dfrac{A_{bulk}'V_{ds}}{2}\right)}\right]$$

$$Q_{inv} = -W_{active}L_{active}C_{ox}\left(V_{gs} - V_{th} - \frac{A_{bulk}' \times V_{ds}}{2} + \frac{A_{bulk}^2{}'V_{ds}^2}{12\left(V_{gs} - V_{th} + -\frac{A_{bulk}'}{2}V_{ds}\right)}\right)$$

$$Q_b = W_{active}L_{active}C_{ox}\left[V_{fbcv} - V_{th} + \Phi_s + \frac{(1 - A_{bulk}')V_{ds}}{2} - \frac{(1-A_{bulk}')A_{bulk}'V_{ds}^2}{12\left(V_{gs}-V_{th}-\frac{A_{bulk}'}{2}V_{ds}\right)}\right]$$

$$Q_s = Q_d = 0.5Q_{inv}$$

$$0.5Q_{inv} = -W_{active}L_{active}C_{ox}\left[V_{gs} - V_{th} - \frac{A_{bulk}'}{2}V_{ds} + \frac{A_{bulk}^2{}'V_{ds}^2}{12\left(V_{gs} - V_{th} - \frac{A_{bulk}'}{2}V_{ds}\right)}\right]$$

otherwise,

$$Q_g = W_{active}L_{active}C_{ox}\left(V_{gs} - V_{fbcv} - \Phi_s - \frac{V_{dsat}}{3}\right)$$

$$Q_s = Q_d = -\frac{1}{3}W_{active}L_{active}C_{ox}(V_{gs} - V_{th})$$

$$Q_b = -W_{active}L_{active}C_{ox}\left(V_{fbcv} + \Phi_s - V_{th} + \frac{(1 - A_{bulk}')V_{dsat}}{3}\right)$$

40/60 Channel-Charge Partition

If $V_{ds} < V_{dsat}$,

$$Q_g = C_{ox}W_{active}L_{active}\left[V_{gs} - V_{fbcv} - \Phi_s - \frac{V_{ds}}{2} + \frac{A_{bulk}'V_{ds}^2}{12\left(V_{gs}-V_{th}-\frac{A_{bulk}'}{2}V_{ds}\right)}\right]$$

$$Q_{inv} = -W_{active}L_{active}C_{ox}\left[V_{gs} - V_{th} - \frac{A_{bulk}'V_{ds}}{2} + \frac{A_{bulk}'^2V_{ds}^2}{12\left(V_{gs}-V_{th}-\frac{A_{bulk}'}{2}V_{ds}\right)}\right]$$

$$Q_b = W_{active}L_{active}C_{ox}\left[V_{fbcv} - V_{th} + \Phi_s + \frac{(1 - A_{bulk}')V_{ds}}{2} - \frac{(1-A_{bulk}')A_{bulk}'V_{ds}^2}{12\left(V_{gs}-V_{th}-\frac{A_{bulk}'}{2}V_{ds}\right)}\right]$$

$$Q_d = -W_{active}L_{active}C_{ox} \times$$

$$\left[\frac{V_{gs} - V_{th}}{2} - \frac{A_{bulk}'V_{ds}}{2} + \frac{A_{bulk}'V_{ds} \times \left[\frac{(V_{gs} - V_{th})^2}{6} - \frac{A_{bulk}'V_{ds}(V_{gs} - V_{th})}{8} + \frac{A_{bulk}'V_{ds}{}^2}{40}\right]}{\left(V_{gs} - V_{th} - \frac{A_{bulk}'}{2}V_{ds}\right)^2}\right]$$

$$Q_s = -(Q_g + Q_b + Q_d)$$

otherwise,

$$Q_g = W_{active}L_{active}C_{ox}\left(V_{gs} - V_{fbcv} - \Phi_s - \frac{V_{dsat}}{3}\right)$$

$$Q_d = -\frac{4}{15}W_{active}L_{active}C_{ox}(V_{gs} - V_{th})$$

$$Q_s = -(Q_g + Q_b + Q_d)$$

$$Q_b = -W_{active}L_{active}C_{ox}\left(V_{fbcv} + \Phi_s - V_{th} + \frac{(1 - A_{bulk}')V_{dsat}}{3}\right)$$

0/100 Channel-Charge Partition

If $V_{ds} < V_{dsat}$,

$$Q_g = C_{ox} W_{active} L_{active} \left[V_{gs} - V_{fbcv} - \Phi_s - \frac{V_{ds}}{2} + \frac{A_{bulk}' V_{ds}^2}{12\Delta\left(V_{gs} - V_{th} - \frac{A_{bulk}'}{2} V_{ds}\right)} \right]$$

$$Q_{inv} = -W_{active} L_{active} C_{ox} \left[V_{gs} - V_{th} - \frac{A_{bulk}' V_{ds}}{2} + \frac{A_{bulk}'^2 V_{ds}^2}{12\left(V_{gs} - V_{th} - \frac{A_{bulk}'}{2} V_{ds}\right)} \right]$$

$$Q_b = W_{active} L_{active} C_{ox} \left[V_{fbcv} - V_{th} + \Phi_s + \frac{(1 - A_{bulk}') V_{ds}}{2} - \frac{(1 - A_{bulk}') A_{bulk}' V_{ds}^2}{12\left(V_{gs} - V_{th} - \frac{A_{bulk}'}{2} V_{ds}\right)} \right]$$

$$Q_d = -W_{active} L_{active} C_{ox} \left[\frac{V_{gs} - V_{th}}{2} + \frac{A_{bulk}' V_{ds}}{4} - \frac{(A_{bulk}' V_{ds})^2}{24\left(V_{gs} - V_{th} - \frac{A_{bulk}'}{2} V_{ds}\right)} \right]$$

$$Q_s = -(Q_g + Q_b + Q_d)$$

otherwise,

$$Q_g = W_{active} L_{active} C_{ox}\left(V_{gs} - V_{fbcv} - \Phi_s - \frac{V_{dsat}}{3}\right)$$

$$Q_b = -W_{active} L_{active} C_{ox}\left(V_{fbcv} + \Phi_s - V_{th} + \frac{(1 - A_{bulk}') V_{dsat}}{3}\right)$$

$$Q_d = 0$$

$$Q_s = -(Q_g + Q_b)$$

For capmod=1

if $V_{gs} < V_{fb} + V_{bs} + V_{gsteffcv}$,

$$Q_{g1} = -W_{active}L_{active}C_{ox}(V_{gs} - V_{fb} - V_{bs} - V_{gsteffcv})$$

else

$$Q_{g1} = W_{active}L_{active}C_{ox}\frac{K_1^2}{2}\left(-1 + \sqrt{1 + \frac{4(V_{gs} - V_{FB} - V_{gsteffcv} - V_{bs})}{K_1^2}}\right)$$

$$Q_{b1} = -Q_{g1}$$

$$V_{fb} = \begin{cases} V_{th} - \Phi_s - K_1\sqrt{\Phi_s} & \text{if version} \le 3.1 \text{ and version} = 3.2.1 \\ V_{th}(V_{bs} = 0) - \Phi_s - K_1\sqrt{\Phi_s} & \text{if version} = 3.2 \text{ and version} = 3.2.2 \end{cases}$$

$$V_{dsat,\,cv} = \frac{V_{gsteffcv}}{A_{bulk}'}$$

$$A_{bulk}' = \begin{cases} A_{bulk0}\left(1 + \left(\frac{C_{lc}}{L_{eff}}\right)^{C_{le}}\right) & \text{if version} <= 3.1 \\ A_{bulk0}\left(1 + \left(\frac{C_{lc}}{L_{active}}\right)^{C_{le}}\right) & \text{if version} > 3.1 \end{cases}$$

$$A_{bulk0} = \left(1 + \frac{K_1}{2\sqrt{\Phi_s - V_{bseff}}}\left\{\frac{A_0L_{eff}}{L_{eff} + 2\sqrt{X_jX_{dep}}} + \frac{B_o}{W_{eff}' + B_1}\right\}\right)\frac{1}{1 + K_{eta}V_{bseff}}$$

$$V_{gsteffcv} = n \times N_{off} \times V_t \ln\left[1 + \exp\left(\frac{V_{gs} - V_{th} - V_{offcv}}{n \times N_{off} \times V_t}\right)\right]$$

If $V_{ds} \le V_{dsat}$,

$$Q_g = Q_{g1} + W_{active}L_{active}C_{ox}\left(V_{gsteffcv} - \frac{V_{ds}}{2} + \frac{A_{bulk}'V_{ds}^2}{12\left(V_{gsteffcv} - \frac{A_{bulk}'}{2}V_{ds}\right)}\right)$$

$$Q_b = Q_{b1} + W_{active}L_{active}C_{ox}\left[\frac{(1 - A_{bulk}')V_{ds}}{2} - \frac{(1 - A_{bulk}')A_{bulk}'V_{ds}^2}{12\left(V_{gsteffcv} - \frac{A_{bulk}'}{2}V_{ds}\right)}\right]$$

50/50 Charge-Channel Partition

$$Q_s = Q_d = -\frac{W_{active}L_{active}C_{ox}}{2}\left(V_{gsteffcv} - \frac{A_{bulk}'}{2}V_{ds} + \frac{A_{bulk}'^2V_{ds}^2}{12\left(V_{gsteffcv} - \frac{A_{bulk}'}{2}V_{ds}\right)}\right)$$

40/60 Channel-Charge Partition

$$Q_s = -\frac{W_{active}L_{active}C_{ox}}{2\left(V_{gsteff^{cv}} - \frac{A_{bulk}'}{2} \times V_{ds}\right)^2}$$
$$\times \left(V_{gsteffcv}^3 - \frac{4}{3}V_{gstefcvf}^2(A_{bulk}'V_{ds}) + \frac{2}{3}V_{gsteffcv}(A_{bulk}'V_{ds})^2 - \frac{2}{15}(A_{bulk}'V_{ds})^3\right)$$

$$Q_d = -(Q_g + Q_b + Q_s)$$

0/100 Channel-Charge Partition

$$Q_s = -W_{active}L_{active}C_{ox}\left(\frac{V_{gstefcv}}{2} + \frac{A_{bulk}'V_{ds}}{4} - \frac{(A_{bulk}'V_{ds})^2}{24\left(V_{gsteffcv} - \frac{A_{bulk}'}{2}V_{ds}\right)}\right)$$

$$Q_d = -(Q_g + Q_b + Q_s)$$

If $V_{ds} > V_{dsat}$,

$$Q_g = Q_{g1} + W_{active} L_{active} C_{ox}\left(V_{gsteffcv} - \frac{V_{dsat}}{3}\right)$$

$$Q_b = Q_{b1} - W_{active} L_{active} C_{ox}\left[\frac{V_{gsteffcv} - V_{dsat}}{3}\right]$$

50/50 Channel-Charge Partition

$$Q_s = Q_d = -\frac{W_{active} L_{active} C_{ox}}{3}(V_{gsteffcv})$$

40/60 Channel-Charge Partition

$$Q_s = -\frac{2 W_{active} L_{active} C_{ox}}{5}(V_{gsteffcv})$$

$$Q_d = -(Q_g + Q_b + Q_s)$$

0/100 Channel-Charge Partition

$$Q_s = -W_{active} L_{active} C_{ox}\left(\frac{2 V_{gstefcv}}{3}\right)$$

$$Q_d = -(Q_g + Q_b + Q_s)$$

For capmod=2

$$Q_g = -(Q_{inv} + Q_{acc} + Q_{sub0} + \delta Q_{sub})$$

$$Q_b = Q_{acc} + Q_{sub0} + \delta Q_{sub}$$

$$Q_{inv} = Q_s + Q_d$$

$$V_{FBeff} = V_{fb} - 0.5\left\{V_3 + \sqrt{V_3^2 + 4\delta_3 V_{fb}}\right\} \quad where \quad V_3 = V_{fb} - V_{gb} - \delta_3 \; ; \; \delta_3 = 0.02$$

$$V_{fb} = \begin{cases} V_{th} - \Phi_s - K_1\sqrt{\Phi_s} & \text{if version} \le 3.1 \text{ or version} = \text{3v3.2.1} \\ V_{th}(V_{bs} = 0) - \Phi_s - K_1\sqrt{\Phi_s} & \text{otherwise} \end{cases}$$

$$Q_{acc} = -W_{active}L_{active}C_{ox}(V_{fbeff} - V_{fb})$$

$$Q_{sub0} = -W_{active}L_{active}C_{ox}\frac{K_1^2}{2}\left(-1 + \sqrt{1 + \frac{4(V_{gs} - V_{fbeff} - V_{gsteffcv} - V_{bseff})}{K_1^2}}\right)$$

$$V_{dsat,\,cv} = \frac{V_{gsteffcv}}{A_{bulk}'}$$

$$A_{bulk}' = \begin{cases} A_{bulk0}\left(1 + \left(\frac{C_{lc}}{L_{eff}}\right)^{C_{le}}\right) & \text{if version <= 3.1} \\ A_{bulk0}\left(1 + \left(\frac{C_{lc}}{L_{active}}\right)^{C_{le}}\right) & \text{if version > 3.1} \end{cases}$$

$$A_{bulk0} = \left(1 + \frac{K_1}{2\sqrt{\Phi_s - V_{bseff}}}\left\{\frac{A_0 L_{eff}}{L_{eff} + 2\sqrt{X_j X_{dep}}} + \frac{B_o}{W_{eff}' + B_1}\right\}\right)\frac{1}{1 + K_{eta}V_{bseff}}$$

$$V_{gsteffcv} = n \times N_{off} \times V_t \ln\left[1 + \exp\left(\frac{V_{gs} - V_{th} - V_{offcv}}{n \times N_{off} \times V_t}\right)\right]$$

$$V_{cveff} = V_{dsat,\,cv} - 0.5\left\{V_4 + \sqrt{V_4^2 + 4\delta_4 V_{dsat,\,cv}}\right\}$$

$$where V_4 = V_{dsat,\,cv} - V_{ds} - \delta_4; \quad \delta_4 = 0.02$$

$$Q_{inv} = -W_{active}L_{active}C_{ox}\left(\left(V_{gsteffcv} - \frac{A_{bulk}'}{2}V_{cveff}\right) + \frac{A_{bulk}'^2 V_{cveff}^2}{12\left(V_{gsteffcv} - \frac{A_{bulk}'}{2}V_{cveff}\right)}\right)$$

$$\delta Q_{sub} = W_{active}L_{active}C_{ox}\left(\frac{1 - A_{bulk}'}{2}V_{cveff} - \frac{(1 - A_{bulk}')A_{bulk}'V_{cveff}^2}{12\left(V_{gsteffcv} - \frac{A_{bulk}'}{2}V_{cveff}\right)}\right)$$

50/50 Charge Partition

$$Q_s = Q_d = 0.5Q_{inv} =$$

$$(-1)\frac{W_{active}L_{active}C_{ox}}{2}\left(V_{gsteffcv} - \frac{A_{bulk}'}{2}V_{cveff} + \frac{A_{bulk}^2{}'V_{cveff}^2}{12\left(V_{gsteffcv} - \frac{A_{bulk}}{2}V_{cveff}\right)}\right)$$

40/60 Channel-Charge Partition

$$Q_s = \left(-\frac{W_{active}L_{active}C_{ox}}{2\left(V_{gsteffcv} - \frac{A_{bulk}'}{2}V_{cveff}\right)^2}\right)\left(V_{gsteffcv}^3 - \frac{4}{3}V_{gsteffcv}^2(A_{bulk}'V_{cveff})\right.$$

$$\left. + \frac{2}{3}V_{gsteffcv}(A_{bulk}'V_{cveff})^2 - \frac{2}{15}(A_{bulk}'V_{cveff})^3\right)$$

$$Q_d = \left(-\frac{W_{active}L_{active}C_{ox}}{2\left(V_{gsteffcv}-\frac{A_{bulk}'}{2}V_{cveff}\right)^2}\right)\left(V_{gsteffcv}^3-\frac{5}{3}V_{gsteffcv}^2(A_{bulk}'V_{cveff})+\right.$$

$$\left.V_{gsteffcv}(A_{bulk}'V_{cveff})^2-\frac{1}{5}(A_{bulk}'V_{cveff})^3\right)$$

0/100 Charge Partition

$$Q_s = -W_{active}L_{active}C_{ox}\left(\frac{V_{gsteffcv}}{2}+\frac{A_{bulk}'V_{cveff}}{4}-\frac{(A_{bulk}'V_{cveff})^2}{24\left(V_{gsteffcv}-\frac{A_{bulk}'}{2}V_{cveff}\right)}\right)$$

$$Q_d = -W_{active}L_{active}C_{ox}\left(\frac{V_{gsteffcv}}{2}-\frac{3A_{bulk}'V_{cveff}}{4}+\frac{(A_{bulk}'V_{cveff})^2}{8\left(V_{gsteffcv}-\frac{A_{bulk}'}{2}V_{cveff}\right)}\right)$$

For capmod = 3

`capmod` = 3 supports only zero-bias V_{fp}; that is, V_{fb} is calculated from bias-independent V_{th}, regardless of the version number. This is different from `capmod` = 1 and 2.

$$Q_g = -(Q_{inv}+Q_{acc}+Q_{sub0}+\delta Q_{sub})$$

$$Q_b = Q_{acc}+Q_{sub0}+\delta Q_{sub}$$

$$Q_{inv} = Q_d+Q_s$$

$$V_{FBeff} = V_{fb}-0.5\left(V_3+\sqrt{V_3^2+4\delta_3V_{fb}}\right)$$

where

$$V_3 = V_{fb} - V_{gb} - \delta_3$$

$$\delta_3 = 0.02$$

$$V_{fb} = V_{th}(V_{bs} = 0) - \phi_s - K_1\sqrt{\phi_s}$$

$$Q_{acc} = -W_{active}L_{active}C_{oxeff}(V_{fbeff} - V_{fb})$$

$$C_{oxeff} = \frac{C_{ox}C_{cen}}{C_{ox} + C_{cen}}$$

$$C_{ox} = \frac{E_{ox}}{t_{ox} - dtoxcv}$$

$$C_{cen} = \frac{\varepsilon_{si}}{T_{cen}}$$

$$T_{cen} = L_{deb} - 0.5 \times \left(T_3 + \sqrt{T_3^2 + 4 \times 10^{-3}L_{deb}T_{ox}}\right)$$

$$T_3 = L_{deb}\left\{1 - \exp\left[\frac{A_{cde} \times (V_{gs} - V_{bseff} - V_{fb})}{10^8 T_{ox}}\right]\right\} - 10^{-3}T_{ox}$$

$$Q_{sub} = -W_{active}L_{active}C_{oxeff}K_1\left[\sqrt{\frac{K_1^2}{4} + V_{gs} - V_{fbeff} - V_{bseff} - V_{gsteffcv}} - \frac{K_1}{2}\right]$$

$$V_{gsteffcv} = nN_{off}V_t\ln\left[1 + \exp\left(\frac{V_{gs} - V_{th} - V_{offcv}}{nN_{off}V_t}\right)\right]$$

$$Q_{inv} = -W_{active}L_{active}C'_{oxeff}\left[V_{gsteffcv} - \delta\phi_s - \frac{A'_{bulk}}{2}V_{cveff} + \frac{A'^2_{bulk}V^2_{cveff}}{12\left(V_{gsteffcv} - \delta\phi_s - \frac{A'_{bulk}}{2}V_{cveff}\right)}\right]$$

$$\delta Q_{sub} = W_{active}L_{active}C'_{oxeff}\left[\frac{1 - A'_{bulk}}{2}V_{cveff} - \frac{(1 - A'_{bulk})A'_{bulk}V^2_{cveff}}{12\left(V_{gsteffcv} - \delta\phi_s - \frac{A'_{bulk}}{2}V_{cveff}\right)}\right]$$

$$C'_{oxeff} = \frac{C_{ox}C'_{cen}}{C_{ox} + C'_{cen}}$$

$$C'_{cen} = \frac{\varepsilon_{si}}{T_{cen}}$$

$$T_{cen} = \frac{1.9\times10^{-9}}{1 + \left[\frac{4(V_{th} - V_{fb} - \phi_s) + V_{gsteffcv}}{2\times10^8 T_{ox}}\right]^{0.7}}$$

$$\delta\phi_s = V_t\log\left(1 + \frac{2K_1\sqrt{\phi_s}V_{gsteffcv}}{M_{oin}V_tK_1^2}\right)$$

$$V_{dsat,cv} = \frac{V_{gsteffcv} - \delta\phi_s}{A'_{bulk}}$$

$$A_{bulk}' = \begin{cases} A_{bulk0}\left(1 + \left(\dfrac{C_{lc}}{L_{eff}}\right)^{C_{le}}\right) & \text{if version} <= 3.1 \\ A_{bulk0}\left(1 + \left(\dfrac{C_{lc}}{L_{active}}\right)^{C_{le}}\right) & \text{if version} > 3.1 \end{cases}$$

$$A_{bulk0} = \left[1 + \frac{K_1}{2\sqrt{\phi_s - V_{bseff}}}\left(\frac{A_0 L_{eff}}{L_{eff} + 2\sqrt{X_j X_{dep}}} + \frac{B_0}{W'_{eff} + B_1}\right)\right] \times \frac{1}{1 + K_{eta} V_{bseff}}$$

$$V_{cveff} = V_{dsat,\,cv} - 0.5\left(V_4 + \sqrt{V_4^2 + 4\delta_4 V_{dsat,\,cv}}\right)$$

$$V_4 = V_{dsat,\,cv} - V_{ds} - \delta_4$$

$$\delta_4 = 0.02$$

50/50 Charge Partition

$$Q_s = Q_d = 0.5 Q_{inv}$$

40/60 Charge Partition

$$Q_s = -\frac{W_{active} L_{active} C'_{oxeff}}{2\left(V_{gsteffcv} - \delta\phi_s - \dfrac{A'_{bulk}}{2} V_{cveff}\right)^2}[(V_{gsteffcv} - \delta\phi_s)^3$$
$$-\frac{4}{3}(V_{gsteffcv} - \delta\phi_s)^2 A'_{bulk} V_{cveff} + \frac{2}{3}(V_{gsteffcv} - \delta\phi_s)(A'_{bulk}\, V_{cveff})^2 - \frac{2}{15}(A'_{bulk}\, V_{cveff})^3]$$

$$Q_d = Q_{inv} - Q_s$$

0/100 Charge Partition

$$Q_s = -W_{active}L_{active}C'_{oxeff}\left[\frac{V_{gsteffcv} - \delta\phi_s}{2} + \frac{A'_{bulk}}{4}V_{cveff}\left(-\frac{(A'_{bulk}V_{cveff})^2}{24\left(V_{gsteffcv} - \delta\phi_s - \frac{A'_{bulk}}{2}V_{cveff}\right)}\right)\right]$$

$$Q_d = Q_{inv} - Q_s$$

Intrinsic Capacitances (with Body Bias and DIBL)

$$C_{(s,d,g,b),g} = \frac{\partial Q_{s,d,g,b}}{\partial V_{gsteffcv}}\frac{\partial V_{gsteffcv}}{\partial V_{gt}}$$

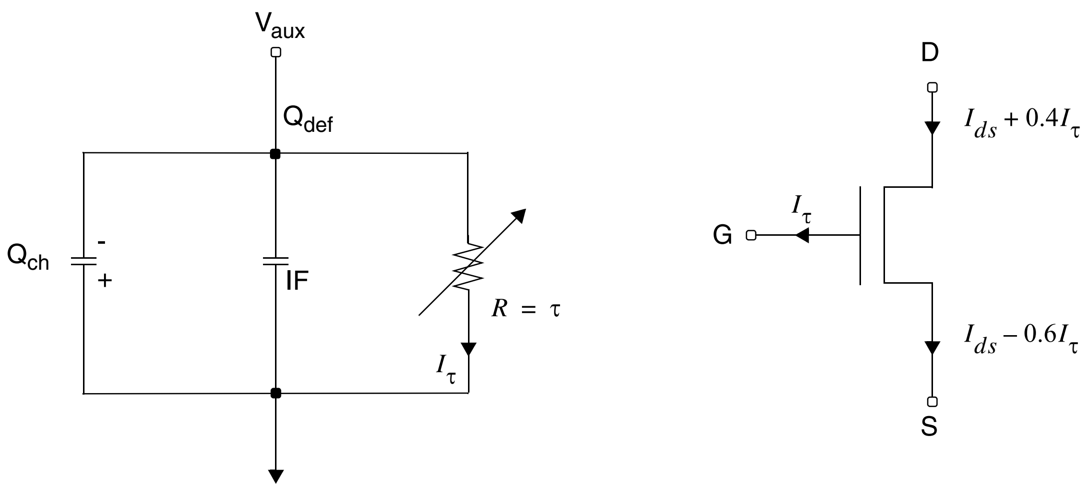
$$C_{(s,d,g,b),s} = -\frac{\partial Q_{s,d,g,b}}{\partial V_{ds}} + \frac{\partial Q_{s,d,g,b}}{\partial V_{gsteffcv}}\frac{\partial V_{gsteffcv}}{\partial V_{gt}}\left(\frac{\partial V_{th}}{\partial V_{ds}} + \frac{\partial V_{th}}{\partial V_{bs}}\right)$$

$$C_{(s,d,g,b),d} = \frac{\partial Q_{s,d,g,b}}{\partial V_{ds}} - \frac{\partial Q_{s,d,g,b}}{\partial (V_{gsteffcv})}\frac{\partial V_{gsteffcv}}{\partial V_{gt}}\frac{\partial V_{th}}{\partial V_{ds}}$$

$$C_{(s,d,g,b),b} = \frac{\partial Q_{s,d,g,b}}{\partial V_{bs}} - \frac{\partial Q_{s,d,g,b}}{\partial V_{gsteffcv}}\frac{\partial V_{gsteffcv}}{\partial V_{gt}}\frac{\partial V_{th}}{\partial V_{bs}}$$

Nonquasi-static (NQS) Model

The following equivalent circuit is used if `nqsmod` = 1. (Only the intrinsic transistor is affected by NQS. The extrinsic components remain the same).



Quasi-static equilibrium channel charge:

$$Q_{eq} = -(Q_g + Q_b)$$

Actual channel charge and `Qdef` obtained from subcircuit:

$$Q_{ch} = Q_{eq} - Q_{def}$$

$$g_\tau = \frac{1}{\tau} = \frac{1}{\tau_{drift}} + \frac{1}{\tau_{diff}}$$

$$\tau_{drift} = \frac{C_{ox} W_{eff} L_{eff}^3}{\mu_{eff} \varepsilon |Q_{eq} - \alpha Q_{def}|} \approx \frac{\zeta}{|Q_{eq}|}$$

where

$\varepsilon \equiv$ Elmore Constant (default = 5)

$0.0 \le \alpha \le 1.0$ (default = 0.5) and

$$\zeta = \frac{C_{ox} W_{eff} L_{eff}^3}{\mu_{eff} \varepsilon}$$

$$\tau_{diff} = \frac{L_{eff}^2}{16 \mu_{eff} V_{tm}}$$

SPICE3 Junction Diode Model

There are two junction models in the BSIM3v3 device model. The `diomod` parameter determines the model to be used in a given simulation:

- If `diomod=1` (default value), the model uses the equations described in the chapter *Common MOSFET Equations*.
- If `diomod=0`, the model uses the equations described in *Chapter 9* of the BSIM3v3.2.2 MOSFET Model-Users' Manual available at:

  http://www-device.EECS.Berkeley.EDU/~bsim3/get.html

  The BSIM3v3 device model uses the same equations when `tlev=1`.

Starting with MMSIM1211ISR17, bsim3v3 supports the trap-assisted tunneling current, if `diomod!=100`. For more information, refer to the equations described in the *Total Junction Source/Drain Diode Including Tunneling* section in chapter *BSIM4 Level-14 Model (bsim4)*.

Flicker Noise

Two models exist for flicker noise. Each of these can be toggled by the `noimod` flag.

For noimod = 1 and 4

If `wnoi` is given

$$FlickerNoise = \frac{K_f I_{ds}^{A_f}}{C_{ox} L_{eff}^2 f^{E_f}} \times (wnoi)/(weff)$$

otherwise

$$FlickerNo = \frac{K_f I_{ds}^{A_f}}{C_{ox} L_{eff}^2 f^{E_f}}$$

For noimod = 2 and 3

$V_{gs} > V_{th}$ + 0.1:

where V_{tm} is the thermal voltage, μ_{eff} is the effective mobility at the given bias condition, L_{eff} and W_{eff} are the effective channel length and width, respectively. The parameter N_0 is the charge density at the source given by

$$N_0 = \frac{C_{ox}(V_{gs} - V_{th})}{q}$$

$$FlickerNoise = \frac{V_{tm} q^2 I_{ds} \mu_{eff}}{f^{E_f} L_{eff}^2 C_{ox} \times 10^8}\left[N_{oia} \log\left(\frac{N_0 + 2 \times 10^{14}}{N_l + 2 \times 10^{14}}\right) + N_{oib} \times (N_0 - N_l) + 0.5 \times N_{oic}(N_0^2 - N_l^2)\right] + \frac{V_{tm} I_{ds}^2 \Delta L_{clm}}{f^{E_f} L_{eff}^2 W_{eff} 10^8} \times \frac{N_{oia} + N_{oib} N_l + N_{oic} N_l^2}{(N_l + N_{oid})^2}$$

The parameter N_l is the charge density at the drain given by

$$N_l = \begin{cases} C_{ox}\left(\dfrac{V_{gs} - V_{th} - V_{ds}}{q}\right) & \text{if version} < 3.2.4 \\ \left(C_{OX} \cdot V_{gsteff} \cdot \left(1 - \dfrac{A_{bulk} V_{dseff}}{V_{gsteff} + 2V_t}\right)\right)/q & \text{if version} >= 3.2.4 \end{cases}$$

$$V_{ds} = MIN(V_{ds}, V_{dsat})$$

ΔL_{CLM} refers to channel length reduction due to CLM and is given by

$$\Delta L_{clm} = \begin{bmatrix} L_{itl} \times \log\left(\dfrac{\dfrac{V_{ds} - V_{dsat}}{L_{itl}} + E_m}{E_{sat}}\right) & \text{if } V_{DS} > V_{DSAT} \\ 0 & \text{otherwise} \end{bmatrix}$$

$$E_{sat} = \frac{2 \times V_{sat}}{U_{eff}}$$

Otherwise,

$$\text{FlickerNoise} = \frac{S_{limit} \times S_{wi}}{S_{limit} + S_{wi}}$$

where S_{limit} is the flicker noise calculated at $V_{gs} = V_{th} + 0.1$ and S_{wi} is given by

$$S_{wi} = \frac{N_{oia} V_{tm} \times I_{ds}^2}{W_{eff} \times L_{eff} \times f^{E_f} \times 10^8 \times N_{oid}^{\;2}}$$

Channel Thermal Noise

Two models exist for channel thermal noise. Each of these can be toggled by the `noimod` flag.

For `noimod`=1 and 3,

$$\overline{i_D^2} = \frac{4kT}{3} \times gamma \times (g_m + g_{ds} + g_{mb})$$

where gamma is a new model parameter introduced to model short channel device thermal noise. The default value for gamma is 2/3.

The standard Berkeley BSIM3v3 equation is

$$\overline{i_D^2} = \frac{8kT}{3}(g_m + g_{ds} + g_{mb})$$

For `noimod`=2 and 4,

$$\overline{i_d^2} = \frac{4kTu_{eff}}{L^2_{eff} + u_{eff}|Q_{inv}| \cdot R_{ds}}|Q_{inv}| \qquad \text{if version = 3.2.4}$$

$$\overline{i_d^2} = \left(\frac{4kTu_{eff}}{L^2_{eff}} \cdot |Q_{inv}|\right) \qquad \text{if version > or < 3.2.4}$$

where Qinv is the channel inversion charge, and is calculated as follows:

- For version 3.1:

$$Q_{inv} = -W_{eff}L_{eff}C_{ox}V_{gsteff}\left(1 - \frac{A_{bulk}}{2(V_{gsteff} + 2V_{tm})}V_{dseff}\right)$$

- For version 3.2, the Qinv equations are described in Intrinsic Charges on page 1170.

Default Model Parameter Value Calculation

- If $vtho$ is not given, it is calculated from

$$vtho = vfb + phi + k1\sqrt{phi}$$

- If phi is not given, it is calculated from

$$phi = 2V_{tm}\ln\left(\frac{nch}{n_i}\right)$$

  where V_{tm} is the thermal voltage given by

$$V_{tm} = \frac{kT}{q}$$

$$n_i = 1.45 \times 10^{10}\left(\frac{T}{300}\right)^{1.5}\exp\left(21.5565981 - \frac{E_g(T)}{2V_{tm}}\right)$$

where $E_g(T)$ is the energy band gap at temperature T. The equation for E_g is shown in *Chapter 12 Common MOSFET Equations*.

- If $k1$ is not given, it is calculated from

$$k1 = gamma2 - 2k2\sqrt{phi - vbm}$$

- If $k2$ is not given, it is calculated from

$$k2 = \frac{(gamma1 - gamma2)(\sqrt{phi - vbx} - \sqrt{phi})}{2\sqrt{phi}(\sqrt{phi - vbm} - \sqrt{phi}) + vbm}$$

- If $gamma1$ is not given, it is calculated from

$$gamma1 = \frac{\sqrt{2q\varepsilon_{si}nch}}{C_{ox}}$$

- If $gamma2$ is not given, it is calculated from

$$gamma2 = \frac{\sqrt{2q\varepsilon_{si}nsub}}{C_{ox}}$$

- If Version <= 3.1 or version = 3.21, and capmod < 3

$$vfb = vth - phi - k1 \times \sqrt{phi - vbs}$$

otherwise

$$vfb = vth0z - phi - k1\sqrt{phi}$$

- If V_{bi} is not given, it is calculated from

$$V_{bi} = V_{tm}\ln\left(\frac{1.0e20 \times nch}{n_i^2}\right)$$

- If V_{bx} is not given, it is calculated from

$$V_{bx} = phi - \frac{q*nch*xt^2}{2\varepsilon_{si}}$$

- If *cgso* is not given, *dlc* is given, and *dlc* > 0

  $$cgso = (dlc + meto) \times cox - cgsl$$

  otherwise

  $$cgso = 0.6 \times xj \times cox$$

- If *cgdo* not given, *dlc* given, and *dlc* > 0

  $$cgdo = (dlc + meto) \times cox - cgdl$$

  otherwise

  $$cgdo = 0.6 \times xj \times cox$$

Gate Leak Currents

This section describes the parameters and equations for gate leak currents.

Instance Parameters

Parameter	Description
`Aforward`	Forward gate leakage current coefficient. Default value is `0.0`.
`Areverse`	Reverse gate leakage current coefficient. Default value is `0.0`.

If Aforward and Areverse are both 0.0, gate leak current is also 0.0.

Model Parameters

Parameter	Description
`Bforward`	Forward gate leakage current coefficient in `pow()`. Default value is `0.0`.

Parameter	Description
`Breverse`	Reverse gate leakage current coefficient in `pow()`. Default value is `0.0`.
`Cforward`	Forward gate leakage current coefficient in `exp()`. Default value is `0.0`.
`Creverse`	Reverse gate leakage current coefficient in `exp()`. Default value is `0.0`.
`Tcc`	Gate leakage current temperature coefficient. Default value is `0.0`.

Leak current between Gate and Drain

If Vgd>0

$$I_{gd} = Aforward \times (1.0 + Tcc \times (Temp - Tnom)) \times pow(Vgd, Bforward) \times \exp(Cforward \times Vgd)$$

If Vgd<0

$$I_{gd} = -Areverse \times (1.0 + Tcc \times (Temp - Tnom)) \times pow(-Vgd, Breverse) \times \exp(Creverse \times Vgd)$$

If Vgd=0

Igd=0.0

Leak current between Gate and Source

- If IgcModel=0 and Igbmodel=0,

  If Vgs>0

  $$I_{gs} = Aforward \times (1.0 + Tcc \times (Temp - Tnom)) \times pow(Vgs, Bforward) \times \exp(Cforward \times Vgs)$$

  If Vgs<0

  $$I_{gs} = -Areverse \times (1.0 + Tcc \times (Temp - Tnom)) \times pow(-Vgs, Breverse) \times \exp(Creverse \times Vgs)$$

  If Vgs=0

Igs=0.0

- Otherwise,

  Igc

  If IgcModel=0 and Igbmodel=0, the above equations apply.

  Otherwise, the following equations apply.

  Igc=Igcs+Igcd

$$Igc0 = W_{eff}L_{eff}A \cdot T_{oxratio}V_{gse}V_{aux} \cdot \exp(-B \cdot Toxe(Aigc - Bigc \cdot V_{oxdepinv})(1 + Cigc \cdot V_{oxdepinv}))$$

For Igcmod=1

$$V_{aux} = Nigc \cdot vt \cdot \log\left(1 + \exp\left(\frac{V_{gse} - Vth0}{Nigc \cdot vt}\right)\right)$$

For Igcmod=2

$$V_{aux} = Nigc \cdot vt \cdot \log\left(1 + \exp\left(\frac{V_{gse} - Vth}{Nigc \cdot vt}\right)\right)$$

$$T_{oxratio} = \left(\frac{Toxref}{Toxe}\right)^{Ntox}\frac{1}{Toxe^2}$$

$$V_{oxdepinv} = K1_{ox}\sqrt{\phi_s} + V_{gsteff}$$

Then

$$Igcs = Igc0\frac{Pigcd \cdot V_{dseff} + \exp(-Pigcd \cdot V_{dseff}) - 1 + 1.0e-4}{Pigcd^2 V_{dseff}^2 + 2.0e-4}$$

$$Igcd = Igc0\frac{1 - (Pigcd \cdot V_{dseff} + 1)\exp(-Pigcd \cdot V_{dseff}) + 1.0e-4}{Pigcd^2 V_{dseff}^2 + 2.0e-4}$$

Igs and Igd

Igs represents the gate tunneling current between the gate and source diffusion region, while Igd represents the gate tunneling current between the gate and the drain diffusion region.

$$Igs = W_{eff} Dlcig \cdot Aechvb \cdot T_{oxratioedge} V_{gs} V_{gs}' \exp(-Bechvb \cdot Toxe \cdot Poxedge \cdot (Aigsd - Bigsd \cdot V_{gs}'))$$

$$Igd = W_{eff} Dlcig \cdot Aechvb \cdot T_{oxratioedge} V_{gd} V_{gd}' \exp(-Bechvb \cdot Toxe \cdot Poxedge \cdot (Aigsd - Bigsd \cdot V_{gd}'))$$

where

$$T_{oxratioedge} = \left(\frac{T_{oxref}}{T_{oxe} P_{oxedge}}\right) \frac{1}{(T_{oxe} P_{oxedge})^2}$$

Igb

Igb=Igbacc+Igbinv

Igbacc is determined by ECB (Electronic tunneling from Conduction band) and is significant in accumulation and given by:

$$I_{gbacc} = W_{eff} L_{eff} Aechve \cdot T_{oxratio} V_{gb} V_{aux} \cdot \exp(-Bechvb \cdot Toxe(Aigbacc - Bigbacc \cdot V_{oxacc})(1 + Cigbac \cdot V_{oxacc}))$$

Where

$$V_{oxacc} = V_{fbsb} - V_{fbeff}$$

$$V_{fbsb} = V_{th}\big|_{Vbs = Vds = 0q} - \phi_s - K1\sqrt{\phi_s}$$

$$V_{aux} = Nigbacc \cdot vt \cdot \log\left(1 + \exp\left(\frac{V_{gb} - V_{fbsb}}{Nigbacc \cdot vt}\right)\right)$$

Igbinv is determined by EVB (Electron tunneling from valence band) and is significant in inversion and given by:

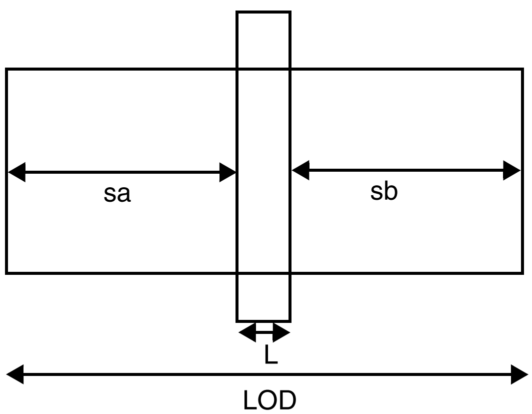
$$I_{gbinv} = W_{eff} L_{eff} Aechve \cdot T_{oxratio} V_{gb} V_{aux} \cdot \exp(-Bechvb \cdot Toxe(Aigbinv - Bigbinv \cdot V_{oxdepinv})(1 + Cigbinv \cdot V_{oxdepinv}))$$

Where

$$V_{aux} = Nigbinv \cdot vt \cdot \log\left(1 + \exp\left(\frac{V_{oxdepinv} - Eigbinv}{Nigbinv \cdot vt}\right)\right)$$

LOD Model

The following diagram displays the LOD instance geometry parameters `sa` and `sb`.



$$\rho_{\mu eff} = \frac{ku0}{Kstress\_u0} \cdot (Inv\_sa + Inv\_sb)$$

$$Inv\_sa = \frac{1}{SA + 0.5 \cdot L_{drawn}}$$

$$Inv\_sb = \frac{1}{SB + 0.5 \cdot L_{drawn}}$$

$$Kstress\_u0 = \left(1 + \frac{LKU0}{(L_{drawn} + XL)^{LLODKU0}} + \frac{WKU0}{(W_{drawn} + XW + WLOD)^{WLODKU0}} + \frac{PKU0}{(L_{drawn} + XL)^{LLODKU0} \cdot (W_{drawn} + XW + WLOD)^{WLODKU0}}\right) \times \left(1 + TKU0 \cdot \left(\frac{Temperature}{TNOM} - 1\right)\right)$$

For irregular LOD device,

$$\frac{1}{SA_{eff} + 0.5 \cdot L_{drawn}} = \sum_{i=1}^{n} \frac{SW_i}{W_{drawn}} \cdot \frac{1}{sa_i + 0.5 \cdot L_{drawn}}$$

$$\frac{1}{SB_{eff} + 0.5 \cdot L_{drawn}} = \sum_{i=1}^{n} \frac{SW_i}{W_{drawn}} \cdot \frac{1}{sb_i + 0.5 \cdot L_{drawn}}$$

Stress Effect

$$\mu_{eff} = \frac{1 + \rho_{\mu eff}(SA, SB)}{1 + \rho_{\mu eff}(SA_{ref}, SB_{ref})} \mu_{effo}$$

$$\upsilon_{sat} = \frac{1 + K \cdot \rho_{\mu eff}(SA, SB)}{1 + K \cdot \rho_{\mu eff}(SA_{ref}, SB_{ref})} \upsilon_{sato}$$

where μ_{effo}, υ_{sato} are low field mobility, saturation velocity at SA_{ref}, SB_{ref}.

$$Kstress\_vth0 = 1 + \frac{LKVTH0}{(L_{drawn} + XL)^{LLODKVTH}} + \frac{WKVTH0}{(W_{drawn} + XW + WLOD)^{WLODKVTH}} + \frac{PKVTH0}{(L_{drawn} + XL)^{LLODKVTH} \cdot (W_{drawn} + XW + WLOD)^{WLODKVTH}}$$

$$VTH0 = VTH0_{original} + \frac{KVTH0}{Kstress\_\mathrm{vth0}} \cdot (Inv\_\mathrm{sa} + Inv\_\mathrm{sb} - Inv\_\mathrm{sa}_{ref} - Inv\_\mathrm{sb}_{ref})$$

$$K2 = K2_{original} + \frac{STK2}{Kstress\_\mathrm{vth0}^{LODK2}} \cdot (Inv\_\mathrm{sa} + Inv\_\mathrm{sb} - Inv\_\mathrm{sa}_{ref} - Inv\_\mathrm{sb}_{ref})$$

$$ETA0 = ETA0_{original} + \frac{STETAO}{Kstress\_\mathrm{vth0}^{LODETO}} \cdot (Inv\_\mathrm{sa} + Inv\_\mathrm{sb} - Inv\_\mathrm{sa}_{ref} - Inv\_\mathrm{sb}_{ref})$$

Well Proximity Effect

$$Vth0 = Vth0_{org} + KVth0we \cdot (Sca + Web \cdot Scb + Wec \cdot Scc)$$

$$K2 = K2_{org} + K2we \cdot (Sca + Web \cdot Scb + Wec \cdot Scc)$$

$$\mu_{eff} = \mu_{eff,\,org} \cdot (1 + Ku0we \cdot (Sca + Web \cdot Scb + Wec \cdot Scc))$$

SC is defined as the distance to a single well edge used in calculations of SCA, SCB, and SCC when layout information is not available. If SCA, SCB, and SCC are not given, their estimation is as follows:

$$Sca = \frac{Scref^2}{W_{drawn}}\left(\frac{1}{Sc} - \frac{1}{Sc + W_{drawn}}\right)$$

$$Scb = \frac{1}{W_{drawn} Scref}\left(\begin{array}{l} \frac{Scref}{20} Sc \cdot \exp\left(-10\frac{Sc}{Scref}\right) + \frac{Scref^2}{400}\exp\left(-10\frac{Sc}{Scref}\right) \\ -\frac{Scref}{10}(Sc + W_{drawn})\exp\left(-10\frac{Sc + W_{drawn}}{Scref}\right) \\ -\frac{Scref^2}{400}\exp\left(-10\frac{Sc + W_{drawn}}{Scref}\right) \end{array}\right)$$

$$Scc = \frac{1}{W_{drawn}Scref}\begin{pmatrix} \frac{Scref}{20}Sc \cdot \exp\left(-20\frac{Sc}{Scref}\right) + \frac{Scref^2}{400}\exp\left(-20\frac{Sc}{Scref}\right) \\ -\frac{Scref}{20}(Sc + W_{drawn})\exp\left(-20\frac{Sc + W_{drawn}}{Scref}\right) \\ -\frac{Scref^2}{400}\exp\left(-20\frac{Sc + W_{drawn}}{Scref}\right) \end{pmatrix}$$

Differences between BSIM3v3 Subversions

1. Intrinsic Charges

When **The equations are**

capmod=0

$$A_{bulk}' = \begin{cases} A_{bulk0}\left(1 + \left(\frac{C_{lc}}{L_{eff}}\right)^{C_{le}}\right) & \text{if version} \le 3.1 \\ A_{bulk0}\left(1 + \left(\frac{C_{lc}}{L_{active}}\right)^{C_{le}}\right) & \text{if version} > 3.1 \end{cases}$$

capmod=1

$$V_{fb} = \begin{cases} V_{th} - \Phi_s - K_1\sqrt{\Phi_s} & \text{if version} \le 3.1 \text{ and version} = 3.2.1 \\ V_{th}(V_{bs} = 0) - \Phi_s - K_1\sqrt{\Phi_s} & \text{if version} = 3.2 \text{ and version} = 3.2.2 \end{cases}$$

$$A_{bulk}' = \begin{cases} A_{bulk0}\left(1 + \left(\frac{C_{lc}}{L_{eff}}\right)^{C_{le}}\right) & \text{if version} \le 3.1 \\ A_{bulk0}\left(1 + \left(\frac{C_{lc}}{L_{active}}\right)^{C_{le}}\right) & \text{if version} > 3.1 \end{cases}$$

When	**The equations are**
capmod=2	$$V_{fb} = \begin{cases} V_{th} - \Phi_s - K_1\sqrt{\Phi_s} & \text{if version} \le 3.1 \text{ or version} = 3.2.1 \\ V_{th}(V_{bs} = 0) - \Phi_s - K_1\sqrt{\Phi_s} & \text{otherwise} \end{cases}$$ $$A_{bulk}' = \begin{cases} A_{bulk0}\left(1 + \left(\frac{C_{lc}}{L_{eff}}\right)^{C_{le}}\right) & \text{if version} \le 3.1 \\ A_{bulk0}\left(1 + \left(\frac{C_{lc}}{L_{active}}\right)^{C_{le}}\right) & \text{if version} > 3.1 \end{cases}$$
capmod=3	$$A_{bulk}' = \begin{cases} A_{bulk0}\left(1 + \left(\frac{C_{lc}}{L_{eff}}\right)^{C_{le}}\right) & \text{if version} \le 3.1 \\ A_{bulk0}\left(1 + \left(\frac{C_{lc}}{L_{active}}\right)^{C_{le}}\right) & \text{if version} > 3.1 \end{cases}$$

2. Flicker noise

For noimod=2 and 3

$$N_l = \begin{cases} C_{ox}\left(\frac{V_{gs} - V_{th} - V_{ds}}{q}\right) & \text{if version} < 3.2.4 \\ \left(C_{OX} \cdot V_{gsteff} \cdot \left(1 - \frac{A_{bulk}V_{dseff}}{V_{gsteff} + 2V_t}\right)\right) / q0 & \text{if version Š } 3.2.4 \end{cases}$$

3. Channel Thermal Noise

$$\overline{i_d^2} = \frac{4kTu_{eff}}{L^2{}_{eff} + u_{eff}|Q_{inv}| \cdot R_{ds}}|Q_{inv}|$$ if version = 3.2.4

$$\overline{i_d^2} = \left(\frac{4kTu_{eff}}{L^2{}_{eff}} \cdot |Q_{inv}|\right)$$ if version < or > 3.2.4

4. If vto is not given

$$vto = \begin{cases} -1.0 + Phi + K1 \times SqrtPhi + Delvto & \text{if version} \le 3.1 \\ Vfb + Phi + K1 \times SqrtPhi + Delvto & \text{if version} > 3.1 \end{cases}$$

5. Overlap Capacitance

- If OverlapCgs < 0

  For BSIM3v3 version < 3.1

  $$OverlapCgs = 1.0e-7 \times T_{ox}$$

  For BSIM3v3 version ≥ 3.1

  $$OverlapCgs = 0$$

- If OverlapCgd < 0

  For BSIM3v3 version < 3.1

  $$OverlapCgd = 1.0e-7 \times T_{ox}$$

  For BSIM3v3 version ≥ 3.1

  $$OverlapCgs = 0$$

- If OverlapCgb is not given

  For BSIM3v3 version < 3.1

  $$OverlapCgb = 0$$

  For BSIM3v3 version ≥ 3.1

  $$OverlapCgb = 2.0 \times dwc \times C_{ox}$$

Parameter Differences between BSIM3v3 Levels

The following table lists the parameters whose default value depends on the level of the BSIM3v3 model.

Parameter Name	Default Value for each Level	Description
k1	0.53V^1/2 (LEVEL=49/53) 1.90923V^1/2 (LEVEL=11)	Body-effect coefficient
k2	0.0186 (LEVEL=49/53) -0.33 (LEVEL=11)	Charge-sharing parameter
vfbflag	0 (LEVEL=49/53)	Vfb selector
binflag	0 (LEVEL=49/53)	Binning factor
lref	1.0e20 (LEVEL=49/53)	Binning length factor
minr	0.1 Ohm (LEVEL=11) 1e-5 Ohm (LEVEL=49/53)	Minimum source/drain resistance
js	0A/m2 (LEVEL=49) 1e-4A/m2 (LEVEL=53)	Bulk junction reverse saturation current density
f	1.0e20 (LEVEL=49/53)	Binning width factor
is	1e-14 (LEVEL=11)	Bulk junction reverse saturation current
pb	1V (LEVEL=11/53) 0.8V (LEVEL=49)	Bulk junction built-in potential
cjsw	5e-10F/m (LEVEL=11/53) 0F/m (LEVEL=49)	Zero-bias junction sidewall capacitance density
capmod	2 (LEVEL=11) 3 (LEVEL=49/53)	Intrinsic charge model
xpart	0 (LEVEL=11/53) 1 (LEVEL=49)	Drain/source channel charge partition in saturation for BSIM charge model. Use 0.0 for 40/60, 0.5 for 50/50, or 1.0 for 0/100.
version	3.1(LEVEL=11) 3.2(LEVEL=49/53)	Model version selector. The available versions are 3.1, 3.2, 3.21,3.22, 3.23, 3.24 and 3.3.

Parameter Name	Default Value for each Level	Description
paramchk	1 (LEVEL=11)	Model parameter checking selector
	0 (LEVEL=49/53)	
acm	0 (LEVEL=11/49)	BSIM3v3 area calculation method selector
	10 (LEVEL=53)	
calcacm	0 (LEVEL=49/53)	geometry factor
eg	1.12452V (LEVEL=11)	Energy band gap
	1.16V (LEVEL=49/53)	
diomod	1 (LEVEL=11/49)	Flag to select junction model:
	0 (LEVEL=53)	When diomod=1, the junction model described in Common MOSFET Equations section is used.
		When diomod=0, the Berkeley junction model is used.
		When diomod=100, the TSMC special diode model is used.
xti	3 (LEVEL=11/53)	Saturation current temperature exponent
	0 (LEVEL=49)	
nlev	2.0 (LEVEL=49/53)	Noise selector
gdsnoi	1.0 (LEVEL=49/53)	Channel thermal noise coefficient for 49 noise

Scaling Effects

`scale` and `scalem` are options that set the scaling factors for instance and model parameters, respectively. You can specify the scaling factors in the `.options` statement.

The following sections describe the parameters that are scaled.

Instance Parameters

Channel Width

$$w = w \times scale$$

Channel length

$$l = l \times scale$$

Source area

$$as = as \times scale \times scale$$

Drain area

$$ad = ad \times scale \times scale$$

Source perimeter

$$ps = ps \times scale \times scale$$

Drain perimeter

$$pd = pd \times scale$$

Component Statements

This device is supported within altergroups.

Sample Instance Statement

```
m4 (0 2 1 1) pchmod w=2u l=0.8u as=250p ad=250p pd=168p ps=168p m=1
```

Sample Model Statement

```
model pchmod bsim3v3 type=p mobmod=1 capmod=2 version=3.1 tox=9e-5 cdsc=1e-3
cdscb=-4.36889e-4 cdscd=0 cit=0 nfactor=1.79 xj=1.5e-7 vsat=1.5737e5 at=1e5
a0=1.2522809 ags=0.2912413 a1=1.01222e-4 a2=0.996841 keta=0 nch=4.06263e17
ngate=7.6e19 k1=0.823562
```

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `w (m)`	Channel width.
2 `l (m)`	Channel length.
3 `as (m`^{2}`)`	Area of source diffusion.
4 `ad (m`^{2}`)`	Area of drain diffusion.
5 `ps (m)`	Perimeter of source diffusion.
6 `pd (m)`	Perimeter of drain diffusion.
7 `nrd (m/m)`	Number of squares of drain diffusion.
8 `nrs (m/m)`	Number of squares of source diffusion.
9 `m=1`	Multiplicity factor (number of MOSFETs in parallel).
10 `region=triode`	Estimated operating region. Spectre outputs number (0-4) in a rawfile. Possible values are `off`, `triode`, `sat`, `subth`, and `breakdown`.
11 `nqsmod`	NQS flag.
12 `acnqsmod`	AC NQS flag.
13 `isnoisy=yes`	Should device generate noise. Possible values are `no` and `yes`.
14 `trise (C)`	Temperature rise from ambient.
15 `aforward=0`	Forward gate leakage current coefficient.
16 `areverse=0`	Reverse gate leakage current coefficient.
17 `delvto=0 V`	shift in zer0-bias threshold voltage vth0.
18 `mulmu0=1`	mobility multiplier.
19 `mulu0=1`	mobility multiplier.

20 `delk1=0 V` shift in body bias coefficient k1.

21 `delnfct=0` shift in subthreshold swing factor nfactor.

22 `geo=0` Geometry selector.

23 `rdc=0` Drain contact resistance.

24 `rsc=0` Srouce contact resistance.

25 `sa=0 m` Distance between OD edge to poly of one side.

26 `sb=0 m` Distance between OD edge to poly of the other side.

27 `sa1=0 m` Distance between OD edge to poly of one side 1.

28 `sa2=0 m` Distance between OD edge to poly of one side 2.

29 `sa3=0 m` Distance between OD edge to poly of one side 3.

30 `sa4=0 m` Distance between OD edge to poly of one side 4.

31 `sa5=0 m` Distance between OD edge to poly of one side 5.

32 `sa6=0 m` Distance between OD edge to poly of one side 6.

33 `sa7=0 m` Distance between OD edge to poly of one side 7.

34 `sa8=0 m` Distance between OD edge to poly of one side 8.

35 `sa9=0 m` Distance between OD edge to poly of one side 9.

36 `sa10=0 m` Distance between OD edge to poly of one side 10.

37 `sb1=0 m` Distance between OD edge to poly of the other side 1.

38 `sb2=0 m` Distance between OD edge to poly of the other side 2.

39 `sb3=0 m` Distance between OD edge to poly of the other side 3.

40 `sb4=0 m` Distance between OD edge to poly of the other side 4.

41 `sb5=0 m` Distance between OD edge to poly of the other side 5.

42 `sb6=0 m`	Distance between OD edge to poly of the other side 6.
43 `sb7=0 m`	Distance between OD edge to poly of the other side 7.
44 `sb8=0 m`	Distance between OD edge to poly of the other side 8.
45 `sb9=0 m`	Distance between OD edge to poly of the other side 9.
46 `sb10=0 m`	Distance between OD edge to poly of the other side 10.
47 `sw1=0 m`	Width of SA1/SB1.
48 `sw2=0 m`	Width of SA2/SB2.
49 `sw3=0 m`	Width of SA3/SB3.
50 `sw4=0 m`	Width of SA4/SB4.
51 `sw5=0 m`	Width of SA5/SB5.
52 `sw6=0 m`	Width of SA6/SB6.
53 `sw7=0 m`	Width of SA7/SB7.
54 `sw8=0 m`	Width of SA8/SB8.
55 `sw9=0 m`	Width of SA9/SB9.
56 `sw10=0 m`	Width of SA10/SB10.
57 `stimod`	LOD stress effect model selector.
58 `sca=0.0`	Integral of the first distribution function for scattered well dopant.
59 `scb=0.0`	Integral of the second distribution function for scattered well dopant.
60 `scc=0.0 V`	Integral of the third distribution function for scattered well dopant.
61 `sc=0.0 m`	Distance to a single well edge .
62 `mulid0=1.0`	Ids multiplier.

Model Definition

```
model modelName bsim3v3 parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n` Transistor type.
Possible values are `n` and `p`.

Threshold voltage parameters

2 `vtho (V)` Threshold voltage at zero body bias for long-channel devices. For enhancement-mode devices, vtho > 0 for n-channel and vth < 0 for p-channel. Default value is calculated from other model parameters.

3 `vfb=-1 V` Flat-band voltage.

4 `k1=0.5 √V` Body-effect coefficient.

5 `k2=-0.0186` Charge-sharing parameter.

6 `k3=80` Narrow width coefficient.

7 `k3b=0 1/V` Narrow width coefficient.

8 `w0=2.5e-6 m` Narrow width coefficient.

9 `nlx=1.74e-7 m` Lateral nonuniform doping coefficient.

10 `gamma1 (√V )` Body-effect coefficient near the surface.

11 `gamma2 (√V )` Body-effect coefficient in the bulk.

12 `vbx (V)` Threshold voltage transition body voltage.

13 `vbm=-3 V` Maximum applied body voltage.

14 `dvt0=2.2` First coefficient of short-channel effects.

15 `dvt1=0.53`	Second coefficient of short-channel effects.
16 `dvt2=-0.032 1/V`	Body-bias coefficient of short-channel effects.
17 `dvt0w=0 1/m`	First coefficient of narrow-width effects.
18 `dvt1w=5.3e6 1/m`	Second coefficient of narrow-width effects.
19 `dvt2w=-0.032 1/V`	Body-bias coefficient of narrow-width effects.
20 `a0=1`	Nonuniform depletion width effect coefficient.
21 `b0=0 m`	Bulk charge coefficient due to narrow width effect.
22 `b1=0 m`	Bulk charge coefficient due to narrow width effect.
23 `a1=0 1/V`	No-saturation coefficient.
24 `a2=1`	No-saturation coefficient.
25 `ags=0 1/v`	Gate-bias dependence of Abulk.
26 `keta=-0.047 1/V`	Body-bias coefficient for non-uniform depletion width effect.
27 `vfbflag=0`	49 Vfb selector.
28 `vthmod`	Vth output selector. 'std' outputs model equation Vth. 'vthcc' outputs constant current Vth, and may impact simulation performance. The default value is taken from the options parameter 'vthmod'. Possible values are `std` and `vthcc`.
29 `ivth (A)`	Vth current parameter. The default value is taken from the options parameter 'ivthn' or 'ivthp', depending on the type of the model.
30 `ivthw (m)`	Width offset for constant current Vth. The default value is taken from the options parameter 'ivthw'.
31 `ivthl (m)`	Length offset for constant current Vth. The default value is taken from the options parameter 'ivthl'.

32 `ivth_vdsmin (V)`	Minimum Vds in constant current Vth calculating. The default value is taken from the options parameter 'ivth_vdsmin'.

Process parameters

33 `nsub=6e16` cm^{-3}	Substrate doping concentration.
34 `nch=1.7e17` cm^{-3}	Peak channel doping concentration.
35 `ngate=0` cm^{-3}	Poly-gate doping concentration.
36 `xj=0.15e-6 m`	Source/drain junction depth.
37 `lint=0 m`	Lateral diffusion for one side.
38 `wint=0 m`	Width reduction for one side.
39 `ll=0 m^lln`	Length dependence of delta L.
40 `lln=1`	Length exponent of delta L.
41 `lw=0 m^lwn`	Width dependence of delta L.
42 `lwn=1`	Width exponent of delta L.
43 `lwl=0 m^lwn+lln`	Area dependence of delta L.
44 `wl=0 m^wln`	Length dependence of delta W.
45 `wln=1`	Length exponent of delta W.
46 `ww=0 m^wwn`	Width dependence of delta W.
47 `wwn=1`	Width exponent of delta W.
48 `wwl=0 m^wwn+wln`	Area dependence of delta W.
49 `dwg=0 m/v`	Gate-bias dependence of channel width.
50 `dwb=0 m/ |v`	Body-bias dependence of channel width.
51 `tox=1.5e-8 m`	Gate oxide thickness.

52 `dtoxcv=0.0 m`	Delta oxide thickness.
53 `toxm=tox m`	Tox at which parameters were extracted.
54 `toxe=tox m`	Electrical gate equivalent oxide thickness.
55 `xt=1.55e-7 m`	Doping depth.
56 `rdsw=0 ohm µm^wr`	Width dependence of drain-source resistance.
57 `prwb=0 1/` $\sqrt{v}$	Body-effect coefficient for Rds.
58 `prwg=0 1/V`	Gate-effect coefficient for Rds.
59 `wr=1`	Width offset for parasitic resistance.
60 `binunit=1`	Bin parameter unit selector. 1 for microns and 2 for meters.
61 `binflag=0`	49 binning factor.
62 `lref=1.0e20`	49 binning length factor.
63 `wref=1.0e20`	49 binning width factor.

Mobility parameters

64 `mobmod=1`	Mobility model selector.
65 `u0=670`	Low-field surface mobility at `tnom`. Default is 250 for PMOS Mobility can also be specified in M2/Vs.
66 `vsat=8e4 m/s`	Carrier saturation velocity at `tnom`.
67 `ua=2.25e-9 m/v`	First-order mobility reduction coefficient.
68 `ub=5.87e-19` m^2/v^2	Second-order mobility reduction coefficient.
69 `uc=-4.65e-11` m/v^2	Body-bias dependence of mobility. Default is -0.046 and unit is 1/V for mobmod=3.

Output resistance parameters

70 `drout=0.56` DIBL effect on output resistance coefficient.

71 `pclm=1.3` Channel length modulation coefficient.

72 `pdiblc1=0.39` First coefficient of drain-induced barrier lowering.

73 `pdiblc2=8.6e-3` Second coefficient of drain-induced barrier lowering.

74 `pdiblcb=0 1/V` Body-effect coefficient for DIBL.

75 `pscbe1=4.24e8 V/m` First coefficient of substrate current body effect.

76 `pscbe2=1e-5 m/v` Second coefficient of substrate current body effect.

77 `pvag=0` Gate dependence of Early voltage.

78 `delta=0.01 V` Effective drain voltage smoothing parameter.

Subthreshold parameters

79 `cdsc=2.4e-4` F/m^2 Source/drain and channel coupling capacitance.

80 `cdscb=0` F/m^2 V Body-bias dependence of `cdsc`.

81 `cdscd=0` F/m^2 V Drain-bias dependence of `cdsc`.

82 `nfactor=1` Subthreshold swing coefficient.

83 `cit=0` F/m^2 Interface trap parameter for subthreshold swing.

84 `voff=-0.08 V` Threshold voltage offset.

85 `dsub=drout` DIBL effect in subthreshold region.

86 `eta0=0.08` DIBL coefficient subthreshold region.

87 `etab=-0.07 1/V` Body-bias dependence of `et0`.

Substrate current parameters

88 `alpha0=0 m/v` Substrate current impact ionization coefficient.

89 `alpha1=0 1/V` Substrate current impact ionization coefficient.

90 `beta0=30 V` Substrate current impact ionization exponent.

Parasitic resistance parameters

91 `rsh=0 Ω/sqr` Source/drain diffusion sheet resistance.

92 `rs=0 Ω` Source resistance.

93 `rd=0 Ω` Drain resistance.

94 `lgcs=0 m` Gate-to-contact length of source side.

95 `lgcd=0 m` Gate-to-contact length of drain side.

96 `rsc=0 Ω` Source contact resistance.

97 `rdc=0 Ω` Drain contact resistance.

98 `rss=0 Ω m` Scalable source resistance.

99 `rdd=0 Ω m` Scalable drain resistance.

100 `sc=infinity m` Spacing between contacts.

101 `ldif=0 m` Lateral diffusion beyond the gate.

102 `hdif=0 m` Length of heavily doped diffusion.

103 `minr=0.001 Ω` Minimum source/drain resistance.

Junction diode model parameters

104 `js` (A/m^2) Bulk junction reverse saturation current density.

105 `jsw=0 A/m` Sidewall junction reverse saturation current density.

106 `jssw=0 A/m`	Alias of jsw.
107 `is=1e-14 A`	Bulk junction reverse saturation current.
108 `n=1`	Junction emission coefficient.
109 `nj=1`	Junction emission coefficient.
110 `dskip=yes`	Use simple piece-wise linear model for diode currents below 0.1*`iabstol`. Possible values are `no` and `yes`.
111 `imelt=`imaxA'`	Explosion current.
112 `ijth (A)`	Alias to `imelt`.
113 `jmelt=`jmaxA/m'`^{2}	Explosion current density.
114 `vnds=-1`	Reverse diode current transition point.
115 `nds=1`	Reverse bias slope coefficient.
116 `tt=0.0 s`	Transit time, spice compatible parameter.

Overlap capacitance parameters

117 `cgso (F/m)`	Gate-source overlap capacitance.
118 `cgdo (F/m)`	Gate-drain overlap capacitance.
119 `cgbo=2 Dwc Cox F/m`	Gate-bulk overlap capacitance. The default value is 0 if version=3.0.
120 `meto=0 m`	Metal overlap in fringing field.
121 `cgsl=0 F/m`	Gate-source overlap capacitance in LDD region.
122 `cgdl=0 F/m`	Gate-drain overlap capacitance in LDD region.
123 `ckappa=0.6 V`	Overlap capacitance fitting parameter.

Junction capacitance model parameters

124 `cbs=0 F`	Bulk-source zero-bias junction capacitance.
125 `cbd=0 F`	Bulk-drain zero-bias junction capacitance.
126 `cj=5e-4 F/m`^{2}	Zero-bias junction bottom capacitance density.
127 `mj=1/2`	Bulk junction bottom grading coefficient.
128 `pb=1 V`	Bulk junction built-in potential.
129 `fc=0.5`	Forward-bias depletion capacitance threshold.
130 `cjsw=5e-10 F/m`	Zero-bias junction sidewall capacitance density.
131 `mjsw=0.33`	Bulk junction sidewall grading coefficient.
132 `pbsw=1 V`	Side-wall junction built-in potential.
133 `cjswg=cjsw F/m`	Zero-bias gate-side junction capacitance density.
134 `mjswg=mjsw`	Gate-side junction grading coefficient.
135 `pbswg=pbsw V`	Gate-side junction built-in potential.
136 `fcsw=0.5`	Side-wall forward-bias depletion capacitance threshold.

Charge model selection parameters

137 `capmod=2`	Intrinsic charge model.
138 `nqsmod=0`	Non-quasi static model selector. Set to 1 to turn on nqs.
139 `acnqsmod=0`	AC Non-quasi static model selector. Set to 1 to turn on nqs.
140 `dwc=wint m`	Delta W for capacitance model.
141 `dlc=lint m`	Delta L for capacitance model.
142 `clc=1e-7 m`	Intrinsic capacitance fitting parameter.
143 `cle=0.6`	Intrinsic capacitance fitting parameter.

144 `cf (F/m)`	Fringe capacitance parameter.
145 `elm=5`	Elmore constant of the channel.
146 `vfbcv=-1`	Flat-band voltage for capmod=0.
147 `acde=1 m/v`	CV parameter.
148 `moin=15`	CV parameter.
149 `noff=1`	Transition parameter.
150 `voffcv=0`	Transition parameter.
151 `xpart=0`	Drain/source channel charge partition in saturation for BSIM charge model, use 0.0 for 40/60, 0.5 for 50/50, or 1.0 for 0/100.
152 `llc=ll m^lln`	Length dependence of delta L for CV.
153 `lwc=lw m^lwn`	Width dependence of delta L for CV.
154 `lwlc=lwl m^lwn+lln`	Area dependence of delta L for CV.
155 `wlc=wl m^wln`	Length dependence of delta W for CV.
156 `wwc=ww m^wwn`	Width dependence of delta W for CV.
157 `wwlc=wwl m^wln+wwn`	Area dependence of delta W for CV.
158 `wmlt=1.0`	Width shrink reduction factor.
159 `lmlt=1.0`	Length shrink reduction factor.

Default for instance parameters

160 `w=5e-6 m`	Default channel width.
161 `l=5e-6 m`	Default channel length.
162 `as=0` m^2	Default area of source diffusion.

163 `ad=0 m`^{2}	Default area of drain diffusion.
164 `ps=0 m`	Default perimeter of source diffusion.
165 `pd=0 m`	Default perimeter of drain diffusion.
166 `nrd=0 m/m`	Default number of squares of drain diffusion.
167 `nrs=0 m/m`	Default number of squares of source diffusion.
168 `version=3.1`	Model parameter "version" only accepts real number value, like 3.21 for version=3.2.1. The available versions are 3.1(3.1.0), 3.2(3.2.0), 3.21(3.2.1), 3.22(3.2.2), 3.23(3.2.3), 3.24(3.2.4) and 3.3(3.3.0)..
169 `paramchk=1`	Model parameter checking selector.
170 `fullreinit=0`	Model parameter full reinit selector.
171 `level=11`	BSIM3v3 model selector. The available level are 11, 49 and 53.
172 `acm=0`	BSIM3v3 area calculation method selector.
173 `geo=0`	geometry selector.
174 `calcacm=0`	49 geometry factor.

Temperature effects parameters

175 `tnom (C)`	Parameters measurement temperature. Default set by `options`.
176 `trise=0 C`	Temperature rise from ambient.
177 `tlev=0`	DC temperature selector.
178 `tlevc=0`	AC temperature selector.
179 `eg=1.12452 V`	Energy band gap. Defaulted as 1.16 when spice compatible and 1.11 when tlev is 0 or 1 for spice.
180 `gap1=7.02e-4 V/C`	Band gap temperature coefficient.
181 `gap2=1108 C`	Band gap temperature offset.

182 `eglev=0` DC temperature selector.

183 `diomod=1` a flag to select junction model.diomod=1 junction model described in Common MOSFET Equations section will be used. diomod=0 Berkeley junction model is used.diomod=100 TSMC special diode model .

184 `kt1=-0.11 V` Temperature coefficient for threshold voltage.

185 `kt1l=0 v m` Temperature coefficient for threshold voltage.

186 `kt2=0.022` Temperature coefficient for threshold voltage.

187 `at=3.3e4 m/s` Temperature coefficient for `vsat`.

188 `ua1=4.31e-9 m/v` Temperature coefficient for `ua`.

189 `ub1=-7.61e-18` m^2/v^2
Temperature coefficient for `ub`.

190 `uc1=-5.5e-11` m/v^2
Temperature coefficient for `uc`. Default is -0.056 for mobmod=3.

191 `prt=0 Ω` Temperature coefficient for Rds.

192 `trs=0 1/C` Temperature parameter for source resistance.

193 `trd=0 1/C` Temperature parameter for drain resistance.

194 `ute=-1.5` Mobility temperature exponent.

195 `xti=3` Saturation current temperature exponent.

196 `pta=0 V/C` Junction potential temperature coefficient.

197 `tpb=0 V/C` Temperature coefficient for `pb`.

198 `ptp=0 V/C` Sidewall junction potential temperature coefficient.

199 `tpbsw=0 V/C` Temperature coefficient for `pbsw`.

200 `tpbswg=0 V/C` Temperature coefficient for `pbswg`.

201 `cta=0 1/C`	Junction capacitance temperature coefficient.
202 `tcj=0 1/C`	Temperature coefficient for `cj`.
203 `ctp=0 1/C`	Sidewall junction capacitance temperature coefficient.
204 `tcjsw=0 1/C`	Temperature coefficient for `cjsw`.
205 `tcjswg=0 1/C`	Temperature coefficient for `cjswg`.

Noise model parameters

206 `noimod=1`	Noise model selector.
207 `kf=0`	Flicker (1/f) noise coefficient.
208 `af=1`	Flicker (1/f) noise exponent.
209 `ef=1`	Flicker (1/f) noise frequency exponent.
210 `noia=1e20`	Oxide trap density coefficient. Default is 9.9e18 for pmos.
211 `noib=5e4`	Oxide trap density coefficient. Default is 2.4e3 for pmos.
212 `noic=-1.4e-12`	Oxide trap density coefficient. Default is 1.4e-12 for pmos.
213 `noid=2e14`	flicker noise subthreshold-above threshold transition coefficient.
214 `wnoi=1e-5 m`	Channel width at which noise parameters were extracted.
215 `em=4.1e7 V/m`	Maximum electric field.
216 `flkmod=0`	Flicker noise model (0 for Ids based model, 1 for gm based model).
217 `gamma=2.0/3.0`	Thermal noise coefficient.
218 `nlev=2.0`	49 noise selector.
219 `gdsnoi=1.0`	Channel thermal noise coefficient for 49 noise.
220 `lintnoi=0 m`	Lint offset for noise calculation.

Gate-Induced drain leakage parameters

221 `agidl=0.0 1/Ω` Pre-exponential coefficient for GIDL.

222 `bgidl=2.3e9 V/m` Exponential coefficient for GIDL.

223 `cgidl=0.5 V`^{3} Parameter for body-bias effect on GIDL.

224 `egidl=0.8 V` Fitting parameter for band bending for GIDL.

225 `agisl=agidl 1/Ω` Pre-exponential coefficient for GISL.

226 `bgisl=bgidl V/m` Exponential coefficient for GISL.

227 `cgisl=cgidl V`^{3} Parameter for body-bias effect on GISL.

228 `egisl=egidl V` Fitting parameter for band bending for GISL.

Gate leak current parameters

229 `bforward=0` Forward gate leakage current coefficient in pow().

230 `breverse=0` Reverse gate leakage current coefficient in pow().

231 `cforward=0` Forward gate leakage current coefficient in exp().

232 `creverse=0` Reverse gate leakage current coefficient in exp().

233 `tcc=0` Gate leakage current temperature coefficient.

234 `aigbinv=1.11e-2 F/g s/m`
Parameter for Igb in inversion.

235 `bigbinv=9.49e-4 F/g s/(m V)`
Parameter for Igb in inversion.

236 `cigbinv=0.006 1/V` Parameter for Igb in inversion.

237 `eigbinv=1.1 V` Parameter for Igb in inversion.

238 `nigbinv=3.0` Parameter for Igb in inversion.

239 `aigbacc=1.36e-2 F/g s/m`
Parameter for Igb in accumulation.

240 `bigbacc=1.71e-3 F/g s/(m V)`
Parameter for Igb in accumulation.

241 `cigbacc=0.075 1/V` Parameter for Igb in accumulation.

242 `nigbacc=1.0` Parameter for Igb in accumulation.

243 `aigsd=1.36e-2(nmos) / 9.80e-3(pmos) F/g s/m`
Parameter for Igs and Igd.

244 `bigsd=1.71e-3(nmos) / 7.59e-4(pmos) F/g s/(m V)`
Parameter for Igs and Igd.

245 `cigsd=0.075(nmos) / 0.03(pmos) 1/V`
Parameter for Igs and Igd.

246 `aigc=1.36e-2(nmos) / 9.80e-3(pmos) F/g s/m`
Parameter for Igcs and Igcd.

247 `bigc=1.71e-3(nmos) / 7.59e-4(pmos) F/g s/(m V)`
Parameter for Igcs and Igcd.

248 `cigc=0.075(nmos) / 0.03(pmos) 1/V`
Parameter for Igcs and Igcd.

249 `nigc=1.0` Parameter for Igcs, Igcd ,Igs and Igd.

250 `pigcd=1.0` Vds dependence of Igcs and Igcd.

251 `` dlcig=`Lintm' `` Source/drain overlap length for Igs and Igd.

252 `ntox=1.0` Exponent for the gate oxide ratio.

253 `toxref=3.0e-9 m` Nominal gate oxide thickness for gate dielectric tunneling current model only.

254 `poxedge=1.0` Factor for the gate oxide thickness in source/drain overlap regions.

255 `igcmod=0` Gate-to-channel and gate-to-source, gate-to-drain tunneling model selector.

256 `igbmod=0` Gate-to-substrate tunneling model selector.

Auto Model Selector parameters

257 `wmax=1 m` Maximum channel width for which the model is valid.

258 `wmin=0 m` Minimum channel width for which the model is valid.

259 `lmax=1 m` Maximum channel length for which the model is valid.

260 `lmin=0 m` Minimum channel length for which the model is valid.

Operating region warning control parameters

261 `alarm=none` Forbidden operating region.
Possible values are `none`, `off`, `triode`, `sat`, `subth`, and `rev`.

262 `imax=1 A` Maximum allowable current.

263 `jmax=1e8 A/m`^{2} Maximum allowable current density.

264 `bvj=infinity V` Junction reverse breakdown voltage.

265 `vbox=3e9 tox V` Oxide breakdown voltage.

266 `warn=on` Parameter to turn warnings on and off.
Possible values are `off` and `on`.

267 `apwarn=0` Warning message flag.

Safe Operating Areas Parameters

268 `vds_max=infinity V`
Maximum allowed voltage cross source and drain.

269 `vgd_max=infinity V`
Maximum allowed voltage cross gate and drain.

270 `vgs_max=infinity V`
Maximum allowed voltage cross gate and source/bulk.

271 `vbd_max=infinity V`
Maximum allowed voltage cross source/drain and bulk.

272 `vbs_max=vbd_max V` Maximum allowed voltage cross source and bulk.

273 `vgb_max=infinity V`
Maximum allowed voltage cross gate and bulk.

274 `vgdr_max=vgd_max V`
Maximum allowed reverse voltage cross gate and drain.

275 `vgsr_max=vgs_max V`
Maximum allowed reverse voltage cross gate and source.

276 `vgbr_max=vgb_max V`
Maximum allowed reverse voltage cross gate and bulk.

277 `vbsr_max=vbs_max V`
Maximum allowed reverse voltage cross bulk and source.

278 `vbdr_max=vbd_max V`
Maximum allowed reverse voltage cross bulk and drain.

Length dependent parameters

279 `lvtho=0` Length dependence of Vth0.

280 `lvth0` Alias of lvtho.

281 `lk1=0` Length dependence of k1.

282 `lk2=0` Length dependence of k2.

283 `lk3=0` Length dependence of k3.

284 `lk3b=0` Length dependence of k3b.

285 `lw0=0` Length dependence of w0.

286 `lnlx=0` Length dependence of nlx.

287 `lgamma1=0` Length dependence of gamma1.

288 `lgamma2=0` Length dependence of gamma2.

289 `lvbx=0` Length dependence of vbx.

290 `lvbm=0` Length dependence of vbm.

291 `ldvt0=0` Length dependence of dvt0.

292 `ldvt1=0` Length dependence of dvt1.

293 `ldvt2=0` Length dependence of dvt2.

294 `ldvt0w=0` Length dependence of dvt0w.

295 `ldvt1w=0` Length dependence of dvt1w.

296 `ldvt2w=0` Length dependence of dvt2w.

297 `la0=0` Length dependence of a0.

298 `lb0=0` Length dependence of b0.

299 `lb1=0` Length dependence of b1.

300 `la1=0` Length dependence of a1.

301 `la2=0` Length dependence of a2.

302 `lags=0` Length dependence of ags.

303 `lketa=0` Length dependence of keta.

304 `lnsub=0` Length dependence of nsub.

305 `lnch=0` Length dependence of nch.

306 `lngate=0` Length dependence of ngate.

307 `lxj=0` Length dependence of xj.

308 `ldwg=0` Length dependence of dwg.

309 `ldwb=0` Length dependence of dwb.

310 `lxt=0` Length dependence of xt.

311 `lrdsw=0` Length dependence of rdsw.

312 `lprwb=0` Length dependence of prwb.

313 `lprwg=0` Length dependence of prwg.

314 `lwr=0` Length dependence of wr.

315 `lu0=0` Length dependence of u0.

316 `lvsat=0` Length dependence of vsat.

317 `lua=0` Length dependence of ua.

318 `lub=0` Length dependence of ub.

319 `luc=0` Length dependence of uc.

320 `ldrout=0` Length dependence of drout.

321 `lpclm=0` Length dependence of pclm.

322 `lpdiblc1=0` Length dependence of pdiblc1.

323 `lpdiblc2=0` Length dependence of pdiblc2.

324 `lpdiblcb=0` Length dependence of pdiblcb.

325 `lpscbe1=0` Length dependence of pscbe1.

326 `lpscbe2=0` Length dependence of pscbe2.

327 `lpvag=0` Length dependence of pvag.

328 `ldelta=0` Length dependence of delta.

329 `lcdsc=0` Length dependence of cdsc.

330 `lcdscb=0` Length dependence of cdscb.

331 `lcdscd=0`	Length dependence of cdscd.
332 `lnfactor=0`	Length dependence of nfactor.
333 `lcit=0`	Length dependence of cit.
334 `lvoff=0`	Length dependence of voff.
335 `ldsub=0`	Length dependence of dsub.
336 `leta0=0`	Length dependence of eta0.
337 `letab=0`	Length dependence of etab.
338 `lalpha0=0`	Length dependence of alpha0.
339 `lalpha1=0`	Length dependence of alpha1.
340 `lbeta0=0`	Length dependence of beta0.
341 `lcgsl=0`	Length dependence of cgsl.
342 `lcgdl=0`	Length dependence of cgdl.
343 `lckappa=0`	Length dependence of ckappa.
344 `lclc=0`	Length dependence of clc.
345 `lcle=0`	Length dependence of cle.
346 `lcf=0`	Length dependence of cf.
347 `lelm=0`	Length dependence of elm.
348 `lvfbcv=0`	Length-dependence of vfbc.
349 `lvfb=0`	Length dependence of lvfb.
350 `lacde=0`	Length dependence of acde.
351 `lmoin=0`	Length dependence of moin.
352 `lnoff=0`	Length dependence of noff.

353 `lvoffcv=0` Length dependence of voffcv.

354 `lkt1=0` Length dependence of kt1.

355 `lkt1l=0` Length dependence of kt1l.

356 `lkt2=0` Length dependence of kt2.

357 `lat=0` Length dependence of at.

358 `lua1=0` Length dependence of ua1.

359 `lub1=0` Length dependence of ub1.

360 `luc1=0` Length dependence of uc1.

361 `lprt=0` Length dependence of prt.

362 `lute=0` Length dependence of ute.

363 `xl=0 m` Length variation due to masking and etching.

364 `xlref=0 m` Length variation due to masking and etching.

365 `lagidl=0.0` Length dependence of agidl.

366 `lbgidl=0.0` Length dependence of bgidl.

367 `lcgidl=0.0` Length dependence of cgidl.

368 `legidl=0.0` Length dependence of egidl.

Width dependent parameters

369 `wvtho=0` Width dependence of Vth0.

370 `wvth0` Alias of wvtho.

371 `wk1=0` Width dependence of k1.

372 `wk2=0` Width dependence of k2.

373 `wk3=0` Width dependence of k3.

374 `wk3b=0`	Width dependence of k3b.
375 `ww0=0`	Width dependence of w0.
376 `wnlx=0`	Width dependence of nlx.
377 `wgamma1=0`	Width dependence of gamma1.
378 `wgamma2=0`	Width dependence of gamma2.
379 `wvbx=0`	Width dependence of vbx.
380 `wvbm=0`	Width dependence of vbm.
381 `wdvt0=0`	Width dependence of dvt0.
382 `wdvt1=0`	Width dependence of dvt1.
383 `wdvt2=0`	Width dependence of dvt2.
384 `wdvt0w=0`	Width dependence of dvt0.
385 `wdvt1w=0`	Width dependence of dvt1w.
386 `wdvt2w=0`	Width dependence of dvt2w.
387 `wa0=0`	Width dependence of a0.
388 `wb0=0`	Width dependence of b0.
389 `wb1=0`	Width dependence of b1.
390 `wa1=0`	Width dependence of a1.
391 `wa2=0`	Width dependence of a2.
392 `wags=0`	Width dependence of ags.
393 `wketa=0`	Width dependence of keta.
394 `wnsub=0`	Width dependence of nsub.
395 `wnch=0`	Width dependence of nch.

396 `wngate=0`	Width dependence of ngate.
397 `wxj=0`	Width dependence of xj.
398 `wdwg=0`	Width dependence of dwg.
399 `wdwb=0`	Width dependence of dwb.
400 `wxt=0`	Width dependence of xt.
401 `wrdsw=0`	Width dependence of rdsw.
402 `wprwb=0`	Width dependence of prwb.
403 `wprwg=0`	Width dependence of prwg.
404 `wwr=0`	Width dependence of wr.
405 `wu0=0`	Width dependence of u0.
406 `wvsat=0`	Width dependence of vsat.
407 `wua=0`	Width dependence of ua.
408 `wub=0`	Width dependence of ub.
409 `wuc=0`	Width dependence of uc.
410 `wdrout=0`	Width dependence of drout.
411 `wpclm=0`	Width dependence of pclm.
412 `wpdiblc1=0`	Width dependence of pdiblc1.
413 `wpdiblc2=0`	Width dependence of pdiblc2.
414 `wpdiblcb=0`	Width dependence of pdiblcb.
415 `wpscbe1=0`	Width dependence of pscbe1.
416 `wpscbe2=0`	Width dependence of pscbe2.
417 `wpvag=0`	Width dependence of pvag.

418 `wdelta=0`	Width dependence of delta.
419 `wcdsc=0`	Width dependence of cdsc.
420 `wcdscb=0`	Width dependence of cdscb.
421 `wcdscd=0`	Width dependence of cdscd.
422 `wnfactor=0`	Width dependence of nfactor.
423 `wcit=0`	Width dependence of cit.
424 `wvoff=0`	Width dependence of voff.
425 `wdsub=0`	Width dependence of dsub.
426 `weta0=0`	Width dependence of eta0.
427 `wetab=0`	Width dependence of etab.
428 `walpha0=0`	Width dependence of alpha0.
429 `walpha1=0`	Width dependence of alpha1.
430 `wbeta0=0`	Width dependence of beta0.
431 `wcgsl=0`	Width dependence of cgsl.
432 `wcgdl=0`	Width dependence of cgdl.
433 `wckappa=0`	Width dependence of ckappa.
434 `wclc=0`	Width dependence of clc.
435 `wcle=0`	Width dependence of cle.
436 `wcf=0`	Width dependence of cf.
437 `welm=0`	Width dependence of el.
438 `wvfbcv=0`	Width-dependence of vfbcv.
439 `wvfb=0`	Width dependence of lvfb.

440 `wacde=0` Width dependence of acde.

441 `wmoin=0` Width dependence of moin.

442 `wnoff=0` Width dependence of noff.

443 `wvoffcv=0` Width dependence of voffcv.

444 `wkt1=0` Width dependence of kt1.

445 `wkt1l=0` Width dependence of kt1l.

446 `wkt2=0` Width dependence of kt2.

447 `wat=0` Width dependence of at.

448 `wua1=0` Width dependence of ua1.

449 `wub1=0` Width dependence of ub1.

450 `wuc1=0` Width dependence of uc1.

451 `wprt=0` Width dependence of prt.

452 `wute=0` Width dependence of ute.

453 `xw=0 m` Width variation due to masking and etching.

454 `xwref=0 m` Width variation due to masking and etching.

455 `wagidl=0.0` Width dependence of agidl.

456 `wbgidl=0.0` Width dependence of bgidl.

457 `wcgidl=0.0` Width dependence of cgidl.

458 `wegidl=0.0` Width dependence of egidl.

Cross-term dependent parameters (Not listed)

459 `pvtho=0` Product dependence of Vth0.

460 `pvth0` Alias of pvtho.

461 `pk1=0` Product dependence of k1.

462 `pk2=0` Product dependence of k2.

463 `pk3=0` Product dependence of k3.

464 `pk3b=0` Product dependence of k3b.

465 `pw0=0` Product dependence of w0.

466 `pnlx=0` Product dependence of nlx.

467 `pgamma1=0` Product dependence of gamma1.

468 `pgamma2=0` Product dependence of gamma2.

469 `pvbx=0` Product dependence of vbx.

470 `pvbm=0` Product dependence of vbm.

471 `pdvt0=0` Product dependence of dvt0.

472 `pdvt1=0` Product dependence of dvt1.

473 `pdvt2=0` Product dependence of dvt2.

474 `pdvt0w=0` Product dependence of dvt0w.

475 `pdvt1w=0` Product dependence of dvt1w.

476 `pdvt2w=0` Product dependence of dvt2w.

477 `pa0=0` Product dependence of a0.

478 `pb0=0` Product dependence of b0.

479 `pb1=0` Product dependence of b1.

480 `pa1=0` Product dependence of a1.

481 `pa2=0` Product dependence of a2.

482 `pags=0` Product dependence of ags.

483 `pketa=0`	Product dependence of keta.
484 `pnsub=0`	Product dependence of nsub.
485 `pnch=0`	Product dependence of nch.
486 `pngate=0`	Product dependence of ngate.
487 `pxj=0`	Product dependence of xj.
488 `pdwg=0`	Product dependence of dwg.
489 `pdwb=0`	Product dependence of dwb.
490 `pxt=0`	Product dependence of xt.
491 `prdsw=0`	Product dependence of rdsw.
492 `pprwb=0`	Product dependence of prwb.
493 `pprwg=0`	Product dependence of prwg.
494 `pwr=0`	Product dependence of wr.
495 `pu0=0`	Product dependence of u0.
496 `pvsat=0`	Product dependence of vsat.
497 `pua=0`	Product dependence of ua.
498 `pub=0`	Product dependence of ub.
499 `puc=0`	Product dependence of uc.
500 `pdrout=0`	Product dependence of drout.
501 `ppclm=0`	Product dependence of pclm.
502 `ppdiblc1=0`	Product dependence of pdiblc1.
503 `ppdiblc2=0`	Product dependence of pdiblc2.
504 `ppdiblcb=0`	Product dependence of pdiblcb.

505 `ppscbe1=0` Product dependence of pscbe1.

506 `ppscbe2=0` Product dependence of pscbe2.

507 `ppvag=0` Product dependence of pvag.

508 `pdelta=0` Product dependence of delta.

509 `pcdsc=0` Product dependence of cdsc.

510 `pcdscb=0` Product dependence of cdscb.

511 `pcdscd=0` Product dependence of cdscd.

512 `pnfactor=0` Product dependence of nfactor.

513 `pcit=0` Product dependence of cit.

514 `pvoff=0` Product dependence of voff.

515 `pdsub=0` Product dependence of dsub.

516 `peta0=0` Product dependence of eta0.

517 `petab=0` Product dependence of etab.

518 `palpha0=0` Product dependence of alpha0.

519 `palpha1=0` Product dependence of alpha1.

520 `pbeta0=0` Product dependence of beta0.

521 `pcgsl=0` Product dependence of cgsl.

522 `pcgdl=0` Product dependence of cgdl.

523 `pckappa=0` Product dependence of ckappa.

524 `pclc=0` Product dependence of clc.

525 `pcle=0` Product dependence of cle.

526 `pcf=0` Product dependence of cf.

527 `pelm=0` Product dependence of elm.

528 `pvfbcv=0` Product dependence of vfbcv.

529 `pvfb=0` Product dependence of lvfb.

530 `pacde=0` Product dependence of acde.

531 `pmoin=0` Product dependence of moin.

532 `pnoff=0` Product dependence of noff.

533 `pvoffcv=0` Product dependence of voffcv.

534 `pkt1=0` Product dependence of kt1.

535 `pkt1l=0` Product dependence of kt1l.

536 `pkt2=0` Product dependence of kt2.

537 `pat=0` Product dependence of at.

538 `pua1=0` Product dependence of ua1.

539 `pub1=0` Product dependence of ub1.

540 `puc1=0` Product dependence of uc1.

541 `pprt=0` Product dependence of prt.

542 `pute=0` Product dependence of ute.

543 `pagidl=0.0` Cross-term dependence of agidl.

544 `pbgidl=0.0` Cross-term dependence of bgidl.

545 `pcgidl=0.0` Cross-term dependence of cgidl.

546 `pegidl=0.0` Cross-term dependence of egidl.

DC-mismatch dependent parameters

547 `mvtwl=0.0 v m` Threshold mismatch area dependence.

548 `mvtwl2=0.0 v m^1.5`
Threshold mismatch area square dependence.

549 `mvt0=0.0 V` Threshold mismatch intercept.

550 `mbewl=0.0 m` Beta mismatch area dependence.

551 `mbe0=0.0` Beta mismatch intercept.

552 `mismatchmod=0` select Mismatch mode. The available modes are 0, 1, 2 and 3.

553 `mismatchdist=0 m` Mismatch Distance.

LOD model parameters

554 `stimod=1` LOD stress effect model selector. 0 for no LOD, 1 for UCB LOD, 2 for TSMC LOD.

555 `sa0=1e-6 m` reference distance between od edge to poly of one side.

556 `saref (m)` Alias to Sa0.

557 `sb0=1e-6 m` reference distance between od edge to poly of the other side.

558 `sbref (m)` Alias to sb0.

559 `wlod=0 m` length parameter for stress effect.

560 `ku0=0 m` mobility degradation/enhancement coefficient for stress effect.

561 `kvsat=0` saturation velocity degradation/enhancement parameter for stress effect.

562 `kvth0=0 v m` threshold shift parameter for stress effect.

563 `tku0=0` temperature coefficient of ku0.

564 `llodku0=0` length parameter for u0 stress effect.

565 `wlodku0=0` width parameter for u0 stress effect.

566 `llodvth=0` length parameter for vth stress effect.

567 `wlodvth=0` width parameter for vth stress effect.

568 `lku0=0 m^llodku0` length dependence of ku0.

569 `wku0=0 m^wlodku0` width dependence of ku0.

570 `pku0=0 m^(llodku0+wlodku0)`
cross-term dependence of ku0.

571 `lkvth0=0 v m^llodku0`
length dependence of kvth0.

572 `wkvth0=0 v m^wlodku0`
width dependence of kvth0.

573 `pkvth0=0 v m^(llodku0+wlodku0)`
cross-term dependence of kvth0.

574 `stk2=0 m` k2 shift factor related to vth0 change.

575 `lodk2=0` k2 shift modification factor for stress effect.

576 `steta0=0 m` eta0 shift factor related to vth0 change.

577 `lodeta0=0` eta0 shift modification factor for stress effect.

578 `wpemod=0` Flag for WPE model (WPEMOD=1 to activate this model) .

579 `web=0.0` Coefficient for SCB.

580 `wec=0.0` Coefficient for SCC.

581 `kvth0we=0.0 V` Threshold shift factor for well proximity effect .

582 `k2we=0.0` K2 shift factor for well proximity effect.

583 `lkvth0we=0.0 V` Length dependence of kvth0we.

584 `wkvth0we=0.0 V` Width dependence of kvth0we .

585 `pkvth0we=0.0 V` Cross-term dependence of kvth0we .

586 `lk2we=0.0` Length dependence of k2we.

587 `wk2we=0.0` Width dependence of k2we.

588 `pk2we=0.0` Cross-term dependence of k2we.

589 `ku0we=0.0` Mobility degradation factor for well proximity effect .

590 `lku0we=0.0` Length dependence of ku0we.

591 `wku0we=0.0` Width dependence of ku0we.

592 `pku0we=0.0` Cross-term dependence of ku0we.

593 `scref=1.0e-6 m` Reference distance to calculate SCA, SCB and SCC .

TSMC junction diode model parameters

594 `jtss=0 A/m`^{2} Source bottom trap-assisted saturation current density.

595 `jtsd=0 A/m`^{2} Drain bottom trap-assisted saturation current density.

596 `jtssws=0 A/m` Source isolation-edge sidewall trap-assisted saturation current density.

597 `jtsswd=0 A/m` Drain isolation-edge sidewall trap-assisted saturation current density.

598 `jtsswgs=0 A/m` Source Gate-edge isolation-edge sidewall trap-assisted saturation current density.

599 `jtsswgd=0 A/m` Drain isolation-edge sidewall trap-assisted saturation current density.

600 `njts=60` Non-ideality factor for Jtss and Jtsd.

601 `njtssw=60` Non-ideality factor for Jtssws and Jtsswd.

602 `njtsswg=60` Non-ideality factor for Jtsswgs and Jtsswgd.

603 `njtsd=njts` Non-ideality factor for jtsd.

604 `njtsswd=njtssw` Non-ideality factor for jtsswd.

605 `njtsswgd=njtsswg` Non-ideality factor for jtsswgd.

606 `mnr=21` Fitting parameter for resistance induced non-ideality factor.

607 `bnr=0` Fitting parameter for resistance induced non-ideality factor.

608 `cnr=0 1/v m` Fitting parameter for resistance induced non-ideality factor.

609 `dnr=0 1/v` Fitting parameter for resistance induced non-ideality factor.

610 `xtss=0.02` Power dependence of Jtss on temperature.

611 `xtsd=0.02` Power dependence of Jtsd on temperature.

612 `xtssws=0.02` Power dependence of Jtssws on temperature.

613 `xtsswd=0.02` Power dependence of Jtsswd on temperature.

614 `xtsswgs=0.02` Power dependence of Jtsswgs on temperature.

615 `xtsswgd=0.02` Power dependence of Jtsswgd on temperature.

616 `tnjts=0` Temperature coefficient for NJTS.

617 `tnjtssw=0` Temperature coefficient for njtssw.

618 `tnjtsswg=0` Temperature coefficient for njtsswg.

619 `tnjtsd=tnjts` Temperature coefficient for njtsd.

620 `tnjtsswd=tnjtsssw`
Temperature coefficient for njtsswd.

621 `tnjtsswgd=tnjtsswg`
Temperature coefficient for njtsswgd.

622 `tmnr=0` Temperature coefficient for mnr.

623 `tcnr=0` Temperature coefficient for cnr.

624 `tdnr=0` Temperature coefficient for dnr.

625 `jsswg=0` Sidewall-gate junction reverse saturation current density.

626 `xjbv=1.0` Fitting parameter for diodes breakdown.

627 `ijthrev=0.1` Reverse maximum allowable current.

628 `nrfwd=1.0` Nominal value of Nr for forward linearization.

629 `vtss=10.0 V` Source bottom trap-assisted voltage dependent parameter.

630 `vtsd=`vtssV'` Drain bottom trap-assisted voltage dependent parameter.

631 `vtssws=10.0 V` Source STI sidewall trap-assisted voltage dependent parameter.

632 `vtsswd=`vtsswsV'` Drain STI sidewall trap-assisted voltage dependent parameter.

633 `vtsswgs=10.0 V` Source gate-edge sidewall trap-assisted voltage dependent parameter.

634 `vtsswgd=`vtsswgsV'`
Drain gate-edge sidewall trap-assisted voltage dependent parameter.

Shrink Parameters

635 `shrink=0` linear shrink parameter.

636 `shrink2=0` area shrink parameter.

637 `msgskip=off` Skip some warning message customer requested.
Possible values are `off` and `on`.

638 `compatible=spectre`
Encourage device equations to be compatible with a foreign simulator. This option does not affect input syntax.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, `mica`, `tispice`, and `pspice`.

Imax and Imelt

The `imax` parameter aids convergence and prevents numerical overflow. The junction characteristics of the device are accurately modeled for current up to `imax`. If `imax` is exceeded during iterations, the linear model is substituted until the current drops below 'imax' or until convergence is achieved. If convergence is achieved with the current exceeding `imax`, the results are inaccurate, and a warning is printed out.

A separate model parameter, `imelt`, is used as a limit warning for the junction current. This parameter can be set to the maximum current rating of the device. When any component of the junction current exceeds `imelt`, note that base and collector currents are composed of many exponential terms, a warning will be issued and the results become inaccurate. The junction current is linearized above the value of `imelt` to prevent arithmetic exception, with the exponential term replaced by a linear equation at `imelt`.

Both of these parameters have current density counterparts, `jmax` and `jmelt`, that you can specify if you want the absolute current values to depend on the device area.

Auto Model Selection

Many models need to be characterized for different geometries in order to obtain accurate results for model development. The model selector program automatically searches for a model with the length and width range specified in the instance statement and uses this model in the simulations.

For the auto model selector program to find a specific model, the models to be searched should be grouped together within braces. Such a group is called a model group. An opening brace is required at the end of the line defining each model group. Every model in the group is given a name followed by a colon and the list of parameters. Also, the four geometric parameters `lmax`, `lmin`, `wmax`, and `wmin` should be given. The selection criteria to choose a model is as follows:

lmin <= inst_length < lmax and wmin <= inst_width < wmax

Example:

model ModelName ModelType {

1: <model parameters> lmin=2 lmax=4 wmin=1 wmax=2

2: <model parameters> lmin=1 lmax=2 wmin=2 wmax=4

3: <model parameters> lmin=2 lmax=4 wmin=4 wmax=6

}

Then for a given instance

M1 1 2 3 4 ModelName w=3 l=1.5

the program would search all the models in the model group with the name `ModelName` and then pick the first model whose geometric range satisfies the selection criteria. In the preceding example, the auto model selector program would choose ModelName.2.

You must specify both length (l) and width (w) on the device instance line to enable automatic model selection.

Output Parameters

1 `tempeff (C)`	Effective temperature for a single device.
2 `meff`	Effective multiplicity factor (m-factor).
3 `weff (m)`	Effective channel width (alias=lv2).
4 `leff (m)`	Effective channel length (alias=lv1).
5 `rseff (Ω)`	Effective source resistance (alias=lv17).
6 `rdeff (Ω)`	Effective drain resistance (alias=lv16).
7 `aseff (m`^{2}`)`	Effective source area (alias=lv4).
8 `adeff (m`^{2}`)`	Effective drain area (alias=lv3).
9 `pseff (m)`	Effective source perimeter (alias=lv12).
10 `pdeff (m)`	Effective drain perimeter (alias=lv11).

Operating-Point Parameters

1 `type=n`	Transistor type. Possible values are `n` and `p`.
2 `region=triode`	Estimated operating region. Spectre outputs number (0-4) in a rawfile. Possible values are `off`, `triode`, `sat`, `subth`, and `breakdown`.
3 `reversed`	Reverse mode indicator. Possible values are `no` and `yes`.

4 `ids (A)`	Resistive drain-to-source current (alias=lx4).
5 `isub (A)`	substrate current (alias=lx50).
6 `vgs (V)`	Gate-source voltage.
7 `vds (V)`	Drain-source voltage (alias=lx3).
8 `vbs (V)`	Bulk-source voltage.
9 `vgb (V)`	gate-bulk voltage.
10 `vdb (V)`	Drain-bulk voltage.
11 `vgd (V)`	Gate-Drain voltage.
12 `vth (V)`	Threshold voltage (alias=lv9).
13 `vdsat (V)`	Drain-source saturation voltage (alias=lv10).
14 `vfbeff (V)`	Vfb effective (alias=lv26).
15 `gm (S)`	Common-source transconductance (alias=lx7).
16 `gds (S)`	Common-source output conductance (alias=lx8).
17 `gmbs (S)`	Body-transconductance (alias=lx9).
18 `betaeff` (A/V^2)	Effective `beta`.
19 `cjd (F)`	Drain-bulk junction capacitance (alias=lx29).
20 `cjs (F)`	Source-bulk junction capacitance (alias=lx28).
21 `qb (Coul)`	total bulk charge (alias=lx12).
22 `qg (Coul)`	Total gate charge (alias=lx14).
23 `qd (Coul)`	Total drain charge (alias=lx16).
24 `qbd (Coul)`	Drain-bulk charge (alias=lx24).
25 `qbs (Coul)`	Source-bulk charge (alias=lx26).

26 `cgg (F)`	dQg_dVg (alias=lx18).
27 `cgd (F)`	dQg_dVd (alias=lx19).
28 `cgs (F)`	dQg_dVs (alias=lx20).
29 `cgb (F)`	dQg_dVbk.
30 `cdg (F)`	dQd_dVg (alias=lx32).
31 `cdd (F)`	Total drain capacitance (including intrinsic, overlap and fringing components, and junction capacitance) (alias=lx33).
32 `cds (F)`	dQd_dVs (alias=lx34).
33 `cdb (F)`	dQd_dVb.
34 `csg (F)`	dQs_dVg.
35 `csd (F)`	dQs_dVd.
36 `css (F)`	dQs_dVs.
37 `csb (F)`	dQs_dVb.
38 `cbg (F)`	dQb_dVg (alias=lx21).
39 `cbd (F)`	dQb_dVd (alias=lx22).
40 `cbs (F)`	dQb_dVs (alias=lx23).
41 `cbb (F)`	dQb_dVb.
42 `ron (Ω)`	On-resistance.
43 `id (A)`	Resistive drain current (alias=i1).
44 `is (A)`	Resistive source current (alias=i3).
45 `ibulk (A)`	Resistive bulk current (alias=i4).
46 `ibs (A)`	Source-bulk diode current (alias=lx5).

47 `ibd (A)`	Drain-bulk diode current (alias=lx6).
48 `pwr (W)`	Power at op point.
49 `gmoverid (1/V)`	Gm/Ids.
50 `ueff`	ueff.
51 `cgsovl (F)`	Gate-source overlap and fringing capacitance (alias=lv36).
52 `cgdovl (F)`	Gate-drain overlap and fringing capacitance (alias=lv37).
53 `cgbovl (F)`	Gate-bulk overlap capacitance (alias=lv38).
54 `i1 (A)`	Alias for id.
55 `i3 (A)`	Alias of Resistive source current.
56 `i4 (A)`	Alias of Resistive bulk current.
57 `gbd (S)`	Conductance of the drain diode (alias=lx10).
58 `gbs (S)`	Conductance of the source diode (alias=lx11).
59 `vgsteff (V)`	effective vgs.
60 `qinv (Coul)`	inversion charge.
61 `igd (A)`	Gate-to-drain leakage current.
62 `igs (A)`	Gate-to-source leakage current.
63 `igb (A)`	Gate-to-bulk tunneling current.
64 `igcs (A)`	Gate-to-channel (source side) tunneling current.
65 `igcd (A)`	Gate-to-channel (drain side) tunneling current.
66 `igidl (A)`	Gate-induced drain leakage current.
67 `igisl (A)`	Gate-induced source leakage current.
68 `qgi (Coul)`	Intrinsic Gate charge.

69 `qsi (Coul)`	Intrinsic Source charge.
70 `qdi (Coul)`	Intrinsic Drain charge.
71 `qbi (Coul)`	Intrinsic Bulk charge.
72 `cddbi (F)`	Intrinsic drain capacitance.
73 `cssbi (F)`	Intrinsic source capacitance.
74 `cggbi (F)`	Intrinsic gate capacitance.
75 `cgsbi (F)`	Intrinsic gate-to-source capacitance.
76 `cgdbi (F)`	Intrinsic gate-to-drain capacitance.
77 `cbdbi (F)`	Intrinsic bulk-to-drain capacitance.
78 `cbsbi (F)`	Intrinsic bulk-to-source capacitance.
79 `qsrco (Coul)`	Total Source charge (Charge Conservation: QS=-(QG+QD+QB)).
80 `ide (A)`	Total DC drain current .
81 `ige (A)`	Total DC gate current .
82 `ise (A)`	Total DC source current .
83 `ibe (A)`	Total DC bulk current .
84 `idb (A)`	DC drain-bulk current .
85 `isb (A)`	DC source-bulk current .
86 `vsb (V)`	Source-Bulk DC voltage .
87 `gmb (S)`	DC bulk transconductance .
88 `vgt (V)`	Effective gate drive voltage including back bias drain bias effects .
89 `vdss (V)`	Drain saturation voltage at actual bias .

90 `vsat_marg (V)` Vds margin .

91 `self_gain` Transistor self gain .

92 `rout (Ω)` AC output resistor .

93 `beff` (A/V^2) Gain factor in saturation .

94 `fug (Hz)` Unity current gain frequency at actual bias .

95 `vearly (V)` Equivalent early voltage .

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Binning Parameters

The table below lists geometry sensitivity factors.

The value of a parameter is calculated from the following equation:

If `binunit` =1,

P = p0 + 1e-6 * wp0 / Weff + 1e-6 * lp0 / Leff + 1e-12 * pp0 / (Weff * Leff)

else

P = p0 + wp0 / Weff + lp0 / Leff + pp0 / (Weff * Leff)

where P is the parameter name.

Table 20-1 Binning Parameters

Parameter Name	Description
LVTO	VTO length sensitivity
WVTO	VTO width sensitivity
PVTO	VTO length and width sensitivity
LK1	K1 length sensitivity
WK1	K1 width sensitivity
PK1	K1 length and width sensitivity
LK2	K2 length sensitivity
WK2	K2 width sensitivity

Parameter Name	Description
PK2	K2 length and width sensitivity
LDVT0	DVT0 length sensitivity
WDVT0	DVT0 width sensitivity
PDVT0	DVT0 length and width sensitivity
LDVT1	DVT1 length sensitivity
WDVT1	DVT1 width sensitivity
PDVT1	DVT1 length and width sensitivity
LDVT2	DVT2 length sensitivity
WDVT2	DVT2 width sensitivity
PDVT2	DVT2 length and width sensitivity
LDVT0W	DVT0W length sensitivity
WDVT0W	DVT0W width sensitivity
PDVT0W	DVT0W length and width sensitivity
LDVT1W	DVT1W length sensitivity
WDVT1W	DVT1W width sensitivity
PDVT1W	DVT1W length and width sensitivity
LDVT2W	DVT2W length sensitivity
WDVT2W	DVT2W width sensitivity
PDVT2W	VFB length and width sensitivity
LLETA0	LETA0 length sensitivity
WLETA0	LETA0 width sensitivity
PLETA0	LETA0 length and width sensitivity
LETAB	ETAB length sensitivity
WETAB	ETAB width sensitivity
PETAB	ETAB length and width sensitivity
LNSUB	NSUB length sensitivity
WNSUB	NSUB width sensitivity

Parameter Name	Description
PNSUB	NSUB length and width sensitivity
LNCH	NCH length sensitivity
WNCH	NCH width sensitivity
PNCH	NCH length and width sensitivity
LNGATE	NGATE length sensitivity
WNGATE	NGATE width sensitivity
PNGATE	NGATE length and width sensitivity
LXJ	XJ length sensitivity
WXJ	XJ width sensitivity
PXJ	XJ length and width sensitivity
LU0	U0 length sensitivity
WU0	U0 width sensitivity
PU0	U0 length and width sensitivity
LVSAT	VSAT length sensitivity
WVSAT	VSAT width sensitivity
PVSAT	VSAT length and width sensitivity
LUA	UA length sensitivity
WUA	UA width sensitivity
PUA	UA length and width sensitivity
LUB	UB length sensitivity
WUB	UB width sensitivity
PUB	UB length and width sensitivity
LUC	UC length sensitivity
WUC	UC width sensitivity
PUC	UC length and width sensitivity
LPCLM	PCLM length sensitivity
WPCLM	PCLM width sensitivity

Parameter Name	Description
PPCLM	PCLM length and width sensitivity
LPDIBLC1	PDIBLC1 length sensitivity
WPDIBLC1	PDIBLC1 width sensitivity
PPDIBLC1	PDIBLC1 length and width sensitivity
LPDIBLC2	PDIBLC2 length sensitivity
WPDIBLC2	PDIBLC2 width sensitivity
PPDIBLC2	PDIBLC2 length and width sensitivity
LPDIBLCB	PDIBLCB length sensitivity
WPDIBLCB	PDIBLCB width sensitivity
PPDIBLCB	PDIBLCB length and width sensitivity
LPSCBE2	PSCBE2 length sensitivity
WPSCBE2	PSCBE2 width sensitivity
PPSCBE2	PSCBE2 length and width sensitivity
LVOFF	VOFF length sensitivity
WVOFF	VOFF width sensitivity
PVOFF	VOFF length and width sensitivity
LRDSW	RDSW length sensitivity
WRDSW	RDSW width sensitivity
PRDSW	RDSW length and width sensitivity
LPRWB	PRWB length sensitivity
WPRWB	PRWB width sensitivity
PPRWB	PRWB length and width sensitivity
LPRWG	PRWG length sensitivity
WPRWG	PRWG width sensitivity
PPRWG	PRWG length and width sensitivity
LPRT	PRT length sensitivity
WPRT	PRT width sensitivity

Parameter Name	Description
PPRT	PRT length and width sensitivity
LAGS	AGS length sensitivity
WAGS	AGS width sensitivity
PAGS	AGS length and width sensitivity
LPVAG	PVAG length sensitivity
WPVAG	PVAG width sensitivity
PPVAG	PVAG length and width sensitivity
LKETA	KETA length sensitivity
WKETA	KETA width sensitivity
PKETA	KETA length and width sensitivity
LELM	ELM length sensitivity
WELM	ELM width sensitivity
PELM	ELM length and width sensitivity
LUTE	UTE length sensitivity
WUTE	UTE width sensitivity
PUTE	UTE length and width sensitivity
LCDSC	CDSC length sensitivity
WCDSC	CDSC width sensitivity
PCDSC	CDSC length and width sensitivity
LCDSCB	CDSCB length sensitivity
WCDSCB	CDSCB width sensitivity
PCDSCB	CDSCB length and width sensitivity
LCDSCD	CDSCD length sensitivity
WCDSCD	CDSCD width sensitivity
PCDSCD	CDSCD length and width sensitivity
LNFACTOR	NFACTOR length sensitivity
WNFACTOR	NFACTOR width sensitivity

Parameter Name	Description
PNFACTOR	NFACTOR length and width sensitivity
LCIT	CIT length sensitivity
WCIT	CIT width sensitivity
PCIT	CIT length and width sensitivity
LAT	AT length sensitivity
WAT	AT width sensitivity
PAT	AT length and width sensitivity
LA0	A0 length sensitivity
WA0	A0 width sensitivity
PA0	A0 length and width sensitivity
LA1	A1 length sensitivity
WA1	A1 width sensitivity
PA1	A1 length and width sensitivity
LA2	A2 length sensitivity
WA2	A2 width sensitivity
PA2	A2 length and width sensitivity
LKT1	KT1 length sensitivity
WKT1	KT1 width sensitivity
PKT1	KT1 length and width sensitivity
LKT1L	KT1L length sensitivity
WKT1L	KT1L width sensitivity
PKT1L	KT1L length and width sensitivity
LKT2	KT2 length sensitivity
WKT2	KT2 width sensitivity
PKT2	KT2 length and width sensitivity
LK3	K3 length sensitivity
WK3	K3 width sensitivity

Parameter Name	Description
PK3	K3 length and width sensitivity
LK3B	K3B length sensitivity
WK3B	K3B width sensitivity
PK3B	K3B length and width sensitivity
LW0	W0 length sensitivity
WW0	W0 width sensitivity
PW0	W0 length and width sensitivity
LNLX	NLX length sensitivity
WNLX	NLX width sensitivity
PNLX	NLX length and width sensitivity
LDROUT	DROUT length sensitivity
WDROUT	DROUT width sensitivity
PDROUT	DROUT length and width sensitivity
LDSUB	DSUB length sensitivity
WDSUB	DSUB width sensitivity
PDSUB	DSUB length and width sensitivity
LUA1	UA1 length sensitivity
WUA1	UA1 width sensitivity
PUA1	UA1 length and width sensitivity
LUB1	UB1 length sensitivity
WUB1	UB1 width sensitivity
PUB1	UB1 length and width sensitivity
LUC1	UC1 length sensitivity
WUC1	UC1 width sensitivity
PUC1	UC1 length and width sensitivity
LDELTA	DELTA length sensitivity
WDELTA	DELTA width sensitivity

Parameter Name	Description
PDELTA	DELTA length and width sensitivity
LB0	B0 length sensitivity
WB0	B0 width sensitivity
PB0	B0 length and width sensitivity
LB1	B1 length sensitivity
WB1	B1 width sensitivity
PB1	B1 length and width sensitivity
LWR	WR length sensitivity
WWR	WR width sensitivity
PWR	WR length and width sensitivity
LDWG	DWG length sensitivity
WDWG	DWG width sensitivity
PDWG	DWG length and width sensitivity
LDWB	DWB length sensitivity
WDWB	DWB width sensitivity
PDWB	DWB length and width sensitivity
LALPHA0	ALPHA0 length sensitivity
WALPHA0	ALPHA0 width sensitivity
PALPHA0	ALPHA0 length and width sensitivity
LALPHA1	ALPHA1 length sensitivity
WALPHA1	ALPHA1 width sensitivity
PALPHA1	ALPHA1 length and width sensitivity
LBETA0	BETA0 length sensitivity
WBETA0	BETA0 width sensitivity
PBETA0	BETA0 length and width sensitivity
LDWC	DWC length sensitivity
WDWC	DWC width sensitivity

Parameter Name	Description
PDWC	DWC length and width sensitivity
LDLC	DLC length sensitivity
WDLC	DLC width sensitivity
PDLC	DLC length and width sensitivity
LCGSL	CGSL length sensitivity
WCGSL	CGSL width sensitivity
PCGSL	CGSL length and width sensitivity
LCGDL	CGDL length sensitivity
WCGDL	CGDL width sensitivity
PCGDL	CGDL length and width sensitivity
LCKAPPA	CKAPPA length sensitivity
WCKAPPA	CKAPPA width sensitivity
PCKAPPA	CKAPPA length and width sensitivity
LCLC	CLC length sensitivity
WCLC	CLC width sensitivity
PCLC	CLC length and width sensitivity
LCLE	CLE length sensitivity
WCLE	CLE width sensitivity
PCLE	CLE length and width sensitivity
LCF	CF length sensitivity
WCF	CF width sensitivity
PCF	CF length and width sensitivity
LACDE	ACDE length sensitivity
WACDE	ACDE width sensitivity
PACDE	ACDE length and width sensitivity
LMOIN	MOIN length sensitivity
WMOIN	MOIN width sensitivity

Parameter Name	Description
PMOIN	MOIN length and width sensitivity
LNOFF	NOFF length sensitivity
WNOFF	NOFF width sensitivity
PNOFF	NOFF length and width sensitivity
LVOFFCV	VOFFCV length sensitivity
WVOFFCV	VOFFCV width sensitivity
PVOFFCV	VOFFCV length and width sensitivity
LGAMMA1	GAMMA1 length sensitivity
WGAMMA1	GAMMA1 width sensitivity
PGAMMA1	GAMMA1 length and width sensitivity
LGAMMA2	GAMMA2 length sensitivity
WGAMMA2	GAMMA2 width sensitivity
PGAMMA2	GAMMA2 length and width sensitivity
LVFB	VFB length sensitivity
WVFB	VFB width sensitivity
PVFB	VFB length and width sensitivity
LVFBCV	VFBCV length sensitivity
WVFBCV	VFBCV width sensitivity
PVFBCV	VFBCV length and width sensitivity
LVBX	VBX length sensitivity
WVBX	VBX width sensitivity
PVBX	VBX length and width sensitivity
LVBM	VBM length sensitivity
WVBM	VBM width sensitivity
PVBM	VBM length and width sensitivity
LXT	XT length sensitivity
WXT	XT width sensitivity

Parameter Name	Description
PXT	XT length and width sensitivity

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BSIM4 Level-14 Model (bsim4)

BSIM4 model, as the extention of BSIM3v3 model, addresses more physical effects for MOSFET device of 100 nm and beyond. Gate leakage, layout dependent effects, high-K, etc. are modeled in BSIM4.

This chapter contains the following information about the BSIM4 model:

Instance

Instance syntax

BSIM4 instance have 4 terminals. To specify BSIM4 instance element, the ModelName has to be associated with a BSIM4 model card.

```
InstanceName (d g s b) ModelName <parameter=value> ...
```

Sample Instance Statement

```
m4 (0 2 1 1) pchmod w=2u l=0.8u as=250p ad=250p pd=168p ps=168p m=1
```

Note: For detailed list of Instance Parameters, see section Component Statements on page 1357.

Model

Model syntax

The following syntax specifies BSIM4 model:

```
model ModelName bsim4 <parameter=value> ...
```

The third parameter, “bsim4”, is the master to indicate this model card is a BSIM4 model card.

Sample Model Statement

```
model pchmod bsim4 type=p mobmod=0 capmod=2 version=4.21 toxe=3e-9 cdsc=2.58e-4
cdscb=0 cdscd=6.1e-8 cit=0 nfactor=1.1 xj=9e-8 vfb=0.76vsat=9.2e4 at=3.3e4 a0=1.1
ags=1.0e-20 a1=0 ngate=9e19 vth0=-0.42a1=0 a2=1 delta=0.014 pvag=1e-20 pclm=6.28e-
4 pdits=0.2 pditsl=2.3e6pditsd=0.23 fprout=0.2 pdiblcb=3.4e-8 pdiblc1=0.81
drout=0.56pdiblc2=9.84e-6 pscbe1=8.14e8 pscbe2=9.58e-07 lint=5e-9 wint=5e-9
dmcg=5e-6 dmci=5e-6 dmdg=5e-6 dmcgt=6e-7 dwj=4.5e-8 rsh=6cgso=7.43e-10 cgdo=7.43e-
10 cgbo=2.56e-11 cgsl=1e-14 cgdl=1e-14ckappas=0.5 ckappad=0.5 noff=0.9 voffcv=0.02
acde=1 moin=15 xpart=0kt1l=0 kt2=2.2e-2 lpe0=5.75e-8 lpeb=2.3e-10 dvt0=2.89
dvt1=0.53dvt2=-3.2e-2 dvt0w=0 dvt1w=0 dvt2w=0 dvtp0=7.32e-7 dvtp1=0.12dsub=0.058
eta0=0.001 u0=4.19e-2 ua=8.7e-16 ub=3.06e-18 k1=0.33uc=4.6e-13 ute=-1.5 ua1=4.31e-
9 ub1=7.61e-18 uc1=-5.6e-11 k2=-1.87e-2 rdsw=369.4 rdw=184.7 rsw=184.7 prwg=3.22e-
8 prwb=6.8e-11 wr=1 rdswmin=0 rdwmin=0 rswmin=0 prt=0 b0=-1e-20 k3=80 k3b=0
w0=2.5e-6b1=0 keta=-0.047 alpha0=7.4e-2 alpha1=0.005 beta0=30
```

Note: For detailed list of Model Parameters, see section Component Statements on page 1357.

Auto Model Selection

BSIM4 supports dependent model parameters; users can tune these parameters to make a single model card to fit all sizes of devices. But with device geometry shrinks, device needs all kinds of optimization, there are very complicated physical effects. It is very hard to use a single model card to fit all devices. An alternative approach is binning option that uses interpolation to calculate model parameters covered by inside that bin. The binning equation is given by

```
P = P0 + Pl / Leff + Pw / Weff + Pp / (Leff * Weff)
```

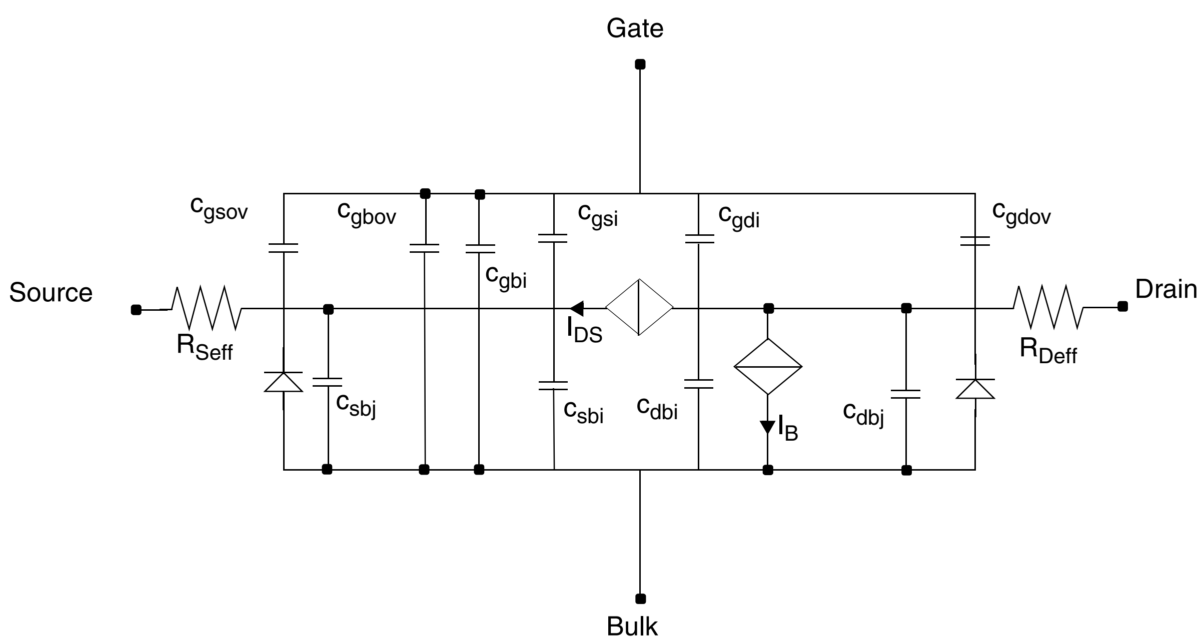
The names of P_l, P_w, and P_p are identical to that of P_0 but with a prefix of l, w, and p, respectively.

Bin selection criteria are as follows:

lmin <= inst_length < lmax and   wmin <= inst_width < wmax

Equivalent Circuit

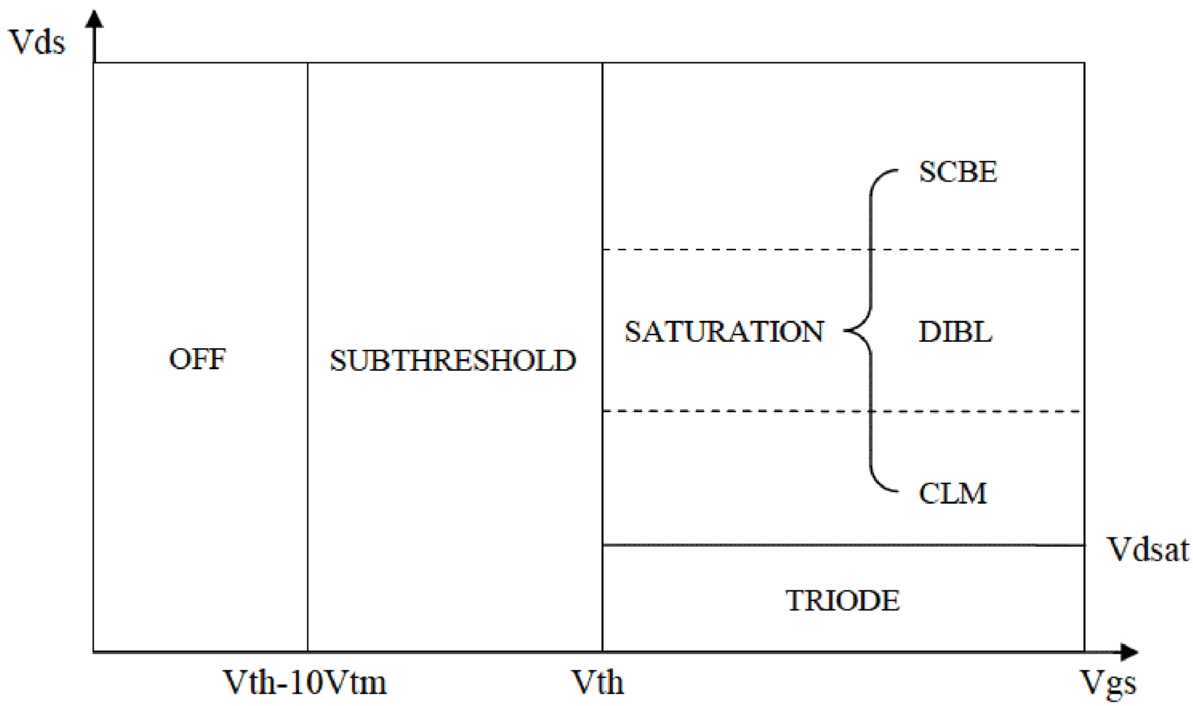
The followings show the equivalent circuits for BSIM4 devices:



Device Regions

Device region is determined by both Vds and Vgs. The following figure shows the region of N-type BSIM4 device. Saturation region can be splitted to three regions corresponding to different dominant physical mechanism: channel length modulation (CLM) effect, drain-induced barrier lowering (DIBL) effect, and the substrate current induced body effect (SCBE).

For P-type device, all the voltage in figure is negative. Vtm is the thermal voltage which is about 0.026V for 300K temperature.



Global Control Options

The following global options affect BSIM4 model.

1. GMIN: GMIN helps solver convergence. It places a conductance in parallel with both the channel and source junction. The default GMIN is 1.0e-12.
2. MINR: Source, drain and gate parasitic resistors inside devices less than minr will be removed. The order of checking inside devices is:
   - Check if resistors are smaller than local minr, if so then remove the parasitic resistors, give warning message.

- ❑ Check global minr, parasitic resistors less than global minr will be removed and warning message will be issued.

Note: Local minr is specified by model parameter minr. The default value is 0.1

3. COMPATIBLE: Encourage device equations to be compatible with a foreign simulator. This option does not affect input syntax.

TMI 1.0 Model

TMI, TSMC Model Interface, is supported in MMSIM7.1.0.

In order to support customized model equations for advanced technologies, TMI is proposed to provide an alternative approach for this request in addition to adding more macro models.

TMI provides both good flexibility as macro model and good simulation efficiency as build-in standard model at the same time.

TMI 2.0 Model

The TMI 2.0 model feature is released in MMSIM10.1, provides the following new capabilities:

Flexible device topology with customized model formulations

With MMSIM 10.1 release, additional component(s) and/or internal node(s) can be added on top of existing standard public domain model topology. This allows the simulator to evaluate (during runtime), the customized model as well as the standard core model formulations, gather/scatter device information and conduct matrix stamping for various type of circuit analysis.

Support for reliability aging modeling and analysis for simulators with and without aging capability

With this feature, the user can add customized aging algorithms for all age integration, extrapolation and mapping. The Safe Operating Areas (SOA) check is also supported.

Model Version Update

Version 4.30

1. Introduced a stress effect model for process induced stress effect;
2. Introduced a temperature model format to predict temperature effects on saturation velocity, mobility, and S/D resistances;
3. Introduced a unified current saturation model that includes all mechanisms of current saturation- velocity saturation, velocity overshoot and source end velocity limit and quasi-ballistic transport;
4. Enhanced holistic thermal noise model;
5. Enhanced forward body bias model;
6. Extended gate direct tunneling model to multiple-layer gate stacks.
7. Fixed minor bugs.

Version 4.40

1. Introduced a trap-assisted tunneling and recombination current model, which is applicable to gate-edge side-wall, STI-edge side-wall and bottom junction;
2. Introduced a flatband voltage offset parameter (vfbsdoff) to improve gate overlap tunneling current;
3. Introduced an offset parameter (lintnoi) to length reduction parameter (lint) to improve the accuracy of the flicker noise model;
4. Fixed minor bugs.

Version 4.50

1. Introduced a mobility model which accounts for Coulomb scattering and the channel length dependence of mobility due to heavy halo-doping;
2. Introduced a substrate resistance model (rbodymod = 2), which is scalable with channel length, channel width and number of fingers;
3. Specified gate resistance parameters xgw and ngcon as instance parameters;
4. Improved temperature dependence for model parameters voff and vfbsdoff;

5. Enhanced temperature model (tempmod = 2), where Vth (DITS) and gate tunneling models are functions of nominal temperature and the temperature dependence of flat-band voltage is added;
6. Introduced a new instance parameter delvto to represent threshold voltage variation;
7. Enhanced well-proximity effect model, enable some device parameters to vary with distance from the edge of well-implantation mask due to ion-scattering;
8. Implemented a full BSIM4 Vth model into the Igc equation which enables accurate prediction of the Vbs dependence of Igc.
9. Fixed minor bugs.

Version 4.60

1. Introduced separated model parameters for the GIDL and GISL leakage current modules.
2. Introduced separated parameters for the source and drain side junction diode current due to the trap-assisted tunneling current in space-charge region.
3. Introduced separated parameters for the gate tunneling current in the S/D overlap diffusion regions (Igs/Igd).
4. Modified the coulomb scattering term in mobility model to avoid the possibility of non-monoticity in drain current trend with respect to gate voltage.
5. Improved the accuracy for rgatemod = 2 by accounting correctly the contribution from Rgate to overall noise.
6. Set the default value of the parameter vfb to -1.0V.

Version 4.61

1. Introduced new material model (by setting mtrlmod=1) for predictive modeling of non-SiO2 insulator, non-poly Silicon gate and non-silicon channel. Add new parameters including new material model selector (mtrlmod), non-poly silicon gate parameters (phig and epsrgate), non-SiO2 gate dielectric (eot and vddeot), and non-silicon channel parameters (easub, epsrsub, ni0sub, bg0sub, tbgasub, tbgbsub, ados, and bdos).
2. Improved mobility model (mobmod = 0 and 1) through predictive modeling of vertical electric field. The improved mobility model is selected through mtrlmod = 1 for backward compatibility.

3. Improved GIDL/GISL models through an improved definition of flatband voltages at S/D ends. The improved GISL/GIDL model is selected through mtrlmod = 1 for backward compatibility.
4. Modified poly-depletion model to account for new gate and gate-insulator materials.
5. Introduced a new VgsteffCV definition into C-V model (by setting cvchargemod = 1) to improve sub-threshold fitting. Add six new parameters including cvchargemod, minvcv, lminvcv, wminvcv, pminvcv and voffcvl.
6. Fixed an error in the derivative calculation of dVdseffCV_dVb for capmod = 1 and 2.
7. Removed warning messages for the limits of noff and voffcv.

Version 4.62

1. Included the width dependence in trap assisted tunneling (TAT) model. Introduce a new model parameter jtweff and set it to zero to maintain the backward compatibility.
2. Introduced mobility model (mobmod =3) to enhance the modeling of Coulomb scattering in the high-k/metal gate transistors.
3. Fixed minor bugs in:
   - Output conductance model: vascbe;
   - Thermal noise model (tnoimod=0);
   - Negative thermal noise (tnoimod=1);
   - Source/drain bulk junction capacitance;
   - Derivative issue in capacitance model (capmod=0);
   - Toxp calculation (mtrlmod=1);
   - Source/drain resistance;
   - Drain/body breakdown voltage.

Version 4.63

Fixed minor bug in litl calculation.

Version 4.64

1. Fixed bug in thermal noise model when tnoimod=1.
2. Removed duplicate counting of temperature coefficient when mobmod=3.
3. Updated Esat after EsatL calculation.

Version 4.65

1. Set Pseff and Pdeff to zero when they are negative and give a warning message.
2. Turn off source side diode by setting sourceSaturationCurrent=0.0 when Aseff and Pseff are zero. Turn off drain side diode by setting DrainSaturationCurrent=0.0 when Adeff and Pdeff are zero.

Version 4.70

1. Improved GIDL/GISL model from BIMSOI.
   - Add new model with flag gidlmod=1.
   - New binnable parameters `rgidl (lrgidl, wrgidl, prgidl)/rgisl`, `kgidl/kgisl`, and `fgidl/fgisl` have been introduced.
   - The previous GIDL/GISL model is in gidlmod=0.
   - Impacts igidl and igisl.
2. Improved DIBL/Rout model from BIMSOI.
   - Existing DIBL/Rout model in BSIM is proposed to enhance with additional term DVTP5 (with parameters `DVTP2`, `DVTP3`, `DVTP4`, `DVTP5`), to better capture V_{ds} effect in long channel device.
   - Impacts Vth.
3. Improved sub-threshold temperature dependence.
   - Improve formulations to capture temperature dependence of Leakage Current with new parameters `tnfactor`, `teta0`, and `tvoffcv`.
4. Improved thermal noise model (`tnoimod=2`).
   - New noise models have been introduced as `tnoimod=2`. Added new parameters `tnoic` and `rnoic`. Correlated noise is considered.
5. Limiting of diode ideality factor (NJS,NJD).

6. New parameter `mtrlCompatMod` to ensure consistent results of `mtrlMod=0` versus `mtrlMod=1`.
7. BugFix of `Toxm`.
    - Corrected `Toxm` setting in `Initialize()`.
8. BugFix of `igc`.
    - Removed redundant `toxe` term appearing in the Igc formulation

Version 4.80

1. Three new mobility models mobmod=4, mobmod=5, and mobmod=6 have been introduced.
2. The derivative bugs in igcmod=2 have been fixed.
3. Some unused lines have been removed.
4. Parameter check on toxp has been adjusted.
5. The default value of fgidl has been changed to 1.0 for version 4.80.
6. Computational efficiency of rbsbx, rbsby, rbdby, rbpbx, rbpby, rbps0, and rbpd0 has been improved.

Model Equations

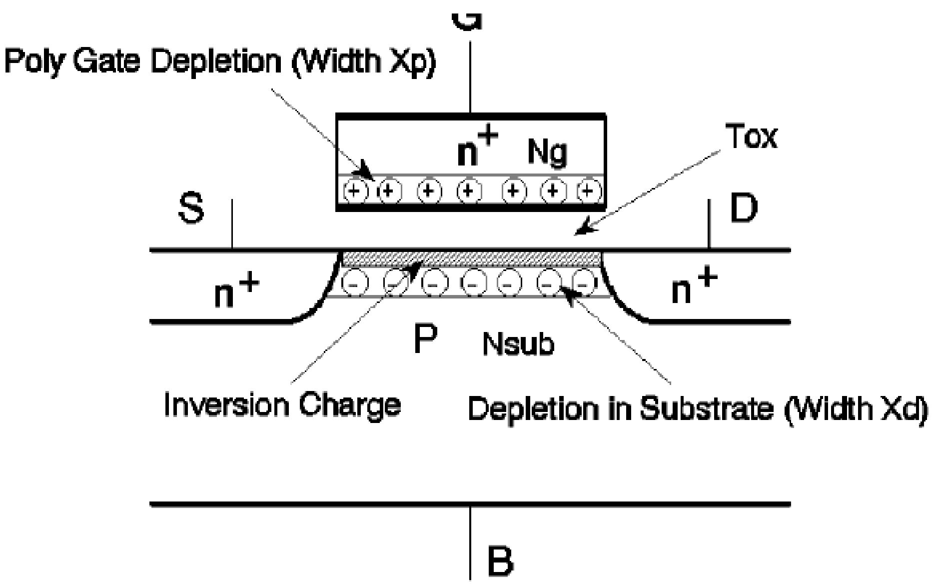
Effective Oxide Thickness, Channel Length and Channel Width

Gate Dielectric Model

The finite chargelayer thickness cannot be ignored when the gate oxide thickness is vigorously scaled down. There are two ways in BSIM4 for modeling this effect in both IV and CV, which can be selected by `mtrlmod`. When `mtrlmod=0` (for SiO2 gate) , the input parameters includes `toxe`, `toxp` and `dtox`. When `mtrlmod=1` (for high-k dielectric gate), the input parameters includes `eot`, `weffeot`, `leffeot`, `tempeot` and `vddeot`. `toxe` is equal to `eot`, and `toxp` could be calculated by the input parameters.

Poly-Silicon Gate Depletion

Charge distribution in a MOSFET with the poly gate depletion effect is shown in the following figure. The device is in the strong inversion region.



The effective gate voltage V_{gse} is

For mtrlmod=0

(21-1)

$$V_{gse} = VFB + \Phi_s + \frac{q\varepsilon_{si}NGATE \cdot T^2_{oxe}}{EPSROX^2}\left(\sqrt{1 + \frac{2EPSROX^2(V_{gs} - VFB - \Phi_s)}{q\varepsilon_{si}NGATE \cdot T^2_{oxe}}}\right)$$

For mtrlmod =1(the non-silicon channel or high -k gate insulator

(21-2)

$$V_{gse} = VFB + \Phi_s + \frac{q\varepsilon_{gate}NGATE}{C^2_{oxe}}\left(\sqrt{1 + \frac{2C^2_{oxe}(V_{gs} - VFB - \Phi_s)}{q\varepsilon_{gate}NGATE}} - 1\right)$$

Effective Channel Length and Width

(21-3)

$$L_{eff} = L_{drawn} + XL - 2dL$$

(21-4)

$$W_{eff} = \frac{W_{drawn}}{NF} + XW - 2dW$$

(21-5)

$$W_{eff}' = \frac{W_{drawn}}{NF} + XW - 2dW'$$

(21-6)

$$dW = dW' + DWG \cdot V_{gsteff} + DWB(\sqrt{\Phi_s - V_{bseff}} - \sqrt{\Phi_s})$$

(21-7)

$$dW' = WINT + \frac{WL}{L^{WLN}} + \frac{WW}{W^{WWN}} + \frac{WWL}{L^{WLN}W^{WWN}}$$

(21-8)

$$dL = LINT + \frac{LL}{L^{LLN}} + \frac{LW}{W^{LWN}} + \frac{LWL}{L^{LLN}W^{LWN}}$$

WINT represents the traditional manner from which "delta *W*" is extracted (from the intercept of straight lines on a $1/R_{ds}$~W_{drawn} plot). The parameters *DWG* and *DWB* are used to account for the contribution of both gate and substrate bias effects. For *dL*, *LINT* represents the traditional manner from which "delta *L*" is extracted from the intercept of lines on a R_{ds}~L_{drawn} plot.

The remaining terms in *dW* and *dL* are provided for your convenience. They are meant to allow you to model each parameter as a function of W_{drawn}, L_{drawn}, and their product term. By default, the above geometrical dependencies for *dW* and *dL* are turned off.

MOSFET capacitances can be divided into intrinsic and extrinsic components. The intrinsic capacitance is associated with the region between the metallurgical source and drain junction, which is defined by the effective length (L_{active}) and width (W_{active}) when the gate to source/drain regions are under flat-band condition. L_{active} and W_{active} are defined as

(21-9)

$$L_{active} = L_{drawn} + XL - 2dL$$

(21-10)

$$W_{active} = \frac{W_{drawn}}{NF} + XW - 2dW$$

(21-11)

$$dL = DLC + \frac{LLC}{L^{LLN}} + \frac{LWC}{W^{LWN}} + \frac{LWLC}{L^{LLN}W^{LWN}}$$

(21-12)

$$dW = DWC + \frac{WLC}{L^{WLN}} + \frac{WWC}{W^{WWN}} + \frac{WWLC}{L^{WLN}W^{WWN}}$$

The meanings of *DWC* and *DLC* are different from those of *WINT* and *LINT* in the I-V model. Unlike the case of I-V, these dimensions are bias-dependent. The parameter δL_{eff} is equal to the source/drain to gate overlap length plus the difference between drawn and actual POLY CD due to processing (gate patterning, etching, and oxidation) on one side.

The effective channel length L_{eff} for the I-V model does not necessarily carry a physical meaning. It is just a parameter used in the I-V formulation. This L_{eff} is therefore very sensitive to the I-V equations and also to the conduction characteristics of the LDD region relative to the channel region. A device with a large L_{eff} and a small parasitic resistance can have a similar current drive as another with a smaller L_{eff} but larger R_{ds}.

The L_{active} parameter extracted from capacitance is a closer representation of the metallurgical junction length (physical length). Due to the graded source/drain junction profile, the source to drain length can have a very strong bias dependence. L_{active} is measured at flat-band voltage between gate to source/drain. If *DWC*, *DLC* and the length/width dependence parameters (*LLC*, *LWC*, *LWLC*, *WLC*, *WWC* and *WWLC*) are not specified in technology files, BSIM4 assumes that the DC bias-independent L_{eff} and W_{eff} will be used for the capacitance models, and *DWC*, *DLC*, *LLC*, *LWC*, *LWLC*, *WLC*, *WWC*, and *WWLC* will be set to the values of their DC counterparts.

BSIM4 uses the effective source/drain diffusion width W_{effcj} for modeling parasitics, such as source/drain resistance, gate electrode resistance, and gate induced drain leakage (GIDL) current. W_{effcj} is defined as:

(21-13)

$$W_{effcj} = \frac{W_{drawn}}{NF} - 2 \cdot \left(DWJ + \frac{WLC}{L^{WLN}} + \frac{WWC}{W^{WWN}} + \frac{WWLC}{L^{WLN} W^{WWN}} \right)$$

Threshold Voltage Model

Considering non-uniform doping, short-channel effect, DIBL effect, and narrow-width effect, the complete V_{th} model is:

(21-14)

$$\begin{aligned} V_{th} = {} & VTH0 + (K_{10x} \cdot \sqrt{\Phi_s - V_{bseff}} - K1 \cdot \sqrt{\Phi_s}) \sqrt{1 + \frac{LPEB}{L_{eff}}} - K_{2ox} V_{bseff} \\ & + K_{1ox} \left(\sqrt{1 + \frac{LPE0}{L_{eff}}} - 1 \right) \sqrt{\Phi_s} + (K3 + K3B \cdot V_{bseff}) \frac{TOXE}{W_{eff}' + W0} \Phi_s \\ & -0.5 \cdot \left[\frac{DVT0W}{\cosh\left(DVT1W \frac{L_{eff} W_{eff}'}{l_{tw}} \right) - 1} + \frac{DVT0}{\cosh\left(DVT1 \frac{L_{eff}}{l_t} \right) - 1} \right] (V_{bi} - \Phi_s) \\ & - \frac{0.5}{\cosh\left(DSUB \frac{L_{eff}}{l_{t0}} \right) - 1} (ETA0 + ETAB \cdot V_{bseff}) \cdot V_{ds} \\ & - nv_t \cdot 1n \left(\frac{L_{eff}}{L_{eff} + DVTP0 \cdot \left(1 + e^{-DVTPI \cdot V_{DS}} \right)} \right) \end{aligned}$$

Channel Charge and Subthreshold Swing Models

A unified expression for channel charge from subthreshold to strong inversion regions is

(21-15)

$$Q_{ch}(y) = C_{oxeff} \cdot V_{gsteff} \cdot \left(1 - \frac{V_F(y)}{V_b}\right)$$

In the above equation, V_{gsteff} (the effective $V_{gst}(V_{gse}-V_{th})$) used to describe the channel charge densities from subthreshold to strong inversion is modeled by:

$$V_{gsteff} = \frac{n_{vt}\ln\left\{1 + \exp\left[\frac{m^*(V_{gse} - V_{th})}{nv_t}\right]\right\}}{m^* + nC_{oxe} \cdot \sqrt{\frac{2\Phi_s}{qNDEP\varepsilon_{si}}}\exp\left[-\frac{(1-m^*)(V_{gse} - V_{th}) - V'_{off}}{nv_t}\right]}$$

The drain current equation in the subthreshold region can be expressed as:

(21-16)

$$I_{ds} = I_0\left[1 - \exp\left(-\frac{V_{ds}}{v_t}\right)\right] \cdot \exp\left(\frac{V_{gs} - V_{th} - V'_{off}}{nv_t}\right)$$

(21-17)

$$I_0 = \mu\frac{W}{L}\sqrt{\frac{q\varepsilon_{si}NDEP}{2\Phi_s}}v_t^2$$

Gate Direct Tunneling Current Model

In BSIM4, the gate tunneling current components include the tunneling current between gate and substrate (I_{gb}), and the current between gate and channel (I_{gc}), which is partitioned between the source and drain terminals by $I_{gc} = I_{gcs} + I_{gcd}$. The third component happens between gate and source/drain diffusion regions (I_{gs} and I_{gd}). Following figure shows the schematic gate tunneling current flows.

I_{gc}, I_{gs}, and I_{gd} are turned on when `igcmod` = 1, 2; I_{gb} is turned on when `igbmod` = 1; no gate tunneling currents are modeled when `igcmod` = 0. V_t (= kT/q) is replaced by V_{tnom}(=kTnom/q) when `tempmod` = 2. The gate tunneling current components are expressed as following:

(21-18)

$$\begin{aligned} {}_{gb} &= I_{gbacc} + I_{gbinv} \\ &= W_{eff} L_{eff} \cdot A \cdot T_{oxRatio} \cdot V_{gb} \cdot V_{aux} \\ &\quad \begin{bmatrix} \exp(-B \cdot TOXE(AIGBACC - BIGBACC \cdot V_{oxacc}) \cdot (1 + CIGBACC \cdot V_{oxacc})) + \\ \exp(-B \cdot TOXE(AIGBINV - BIGBINV \cdot V_{oxdepinv}) \cdot (1 + CIGBINV \cdot V_{oxdepinv})) \end{bmatrix} \end{aligned}$$

(21-19)

$$I_{gs} = \begin{aligned} & W_{eff} \cdot DLCIG \cdot A \cdot T_{oxRatioEdge} \cdot V_{gs} \cdot V'_{gs} \\ & \cdot \exp[-B \cdot TOXE \cdot POXEDGE \cdot (AIGS - BIGS \cdot V'_{gs}) \cdot (1 + CIGS \cdot V'_{gs})] \end{aligned}$$

(21-20)

$$I_{gd} = \begin{aligned} & W_{eff} \cdot DLCIGD \cdot A \cdot T_{oxRatioEdge} \cdot V_{gd} \cdot V'_{gd} \\ & \cdot \exp[-B \cdot TOXE \cdot POXEDGE \cdot (AIGD - BIGD \cdot V'_{gd}) \cdot (1 + CIGD \cdot V'_{gd})] \end{aligned}$$

(21-21)

$$I_{gc} = I_{gcs} + I_{gcd}$$

(21-22)

$$Igcs = I_{gc0} \cdot \frac{PIGCD \cdot V_{dseff} + \exp(-PIGCD \cdot V_{dseff}) - 1 + 1.0e-4}{PIGCD^2 \cdot V^2{}_{dseff} + 2.0e-4}$$

(21-23)

$$Igcd = I_{gc0} \cdot \frac{1 + -(PIGCD \cdot V_{dseff} + 1) \cdot \exp(-PIGCD \cdot V_{dseff}) + 1.0e-4}{PIGCD^2 \cdot V^2_{dseff} + 2.0e-4}$$

(21-24)

$$I_{gc0} = \frac{W_{eff} L_{eff} \cdot A \cdot T_{oxRatio} \cdot V_{gse} \cdot V_{aux}}{\cdot \quad \exp[-B \cdot TOXE(AIGC - BIGC \cdot V_{oxdepinv}) \cdot (1 + CIGC \cdot V_{oxdepinv})]}$$

Drain Current Model

Bulk Charge Effect

The bulk charge effect caused by non-zero V_{ds} is modeled as

(21-25)

$$A_{bulk} = \left\{ 1 \pm F\ \ doping \cdot \left[\frac{A0\,L_{eff}}{L_{eff} + 2\sqrt{XJ \cdot X_{dep}}} \left(1 - AGSV_{gsteff} \left(\frac{L_{eff}}{L_{eff} + 2\sqrt{XJ \cdot X_{dep}}} \right)^2 \right) + \frac{B0}{W'_{eff} + B1} \right] \right\} \cdot \frac{1}{1 + KETA\,V_{bseff}}$$

(21-26)

$$F\_\text{doping} = \frac{\sqrt{1 + (LPEB)L_{eff}}\ K_{1ox}}{2\sqrt{\Phi_s - V_{bseff}}} + K_{2ox} - K3B\frac{TOXE}{W'_{eff} + W0}\Phi_s$$

Mobility Model

Several mobility models are provided in BSIM4. For `mtrlmod` = 0, `mobmod` = 0 and 1 models are from BSIM3v3.2.2, `mobmod` = 2 is a universal mobility model, which is more accurate and suitable. For `mtrlmod` = 1, a new expression of the vertical field in channel is adopted (introduced by BSIM4.6.1). The mobility model is modified as following:

mobmod=0

(21-27)

$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + (UA + UCV_{bseff})E_{eff} + UB \cdot E^2{}_{eff} + UD\left(\frac{V_{th} \cdot EOT}{V_{gsteff} + 2\sqrt{V^2{}_{th} + 0.0001}}\right)^2}$$

mobmod=1

(21-28)

$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + (UAE_{eff} + UBE^2{}_{eff})(1 + UCV_{bseff}) + UD\left(\frac{V_{th} \cdot EOT}{V_{gsteff} + 2\sqrt{V^2{}_{th} + 0.0001}}\right)^2}$$

mobmod=2

(21-29)

$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + (UA + UCV_{bseff}) + \left[\frac{V_{gsteff} + C_0 \cdot (VTHO - VFB - \Phi_s)}{TOXE}\right]^{EU} + UD\left(\frac{V_{th} \cdot TOXE}{V_{gsteff} + 2\sqrt{V^2{}_{th} + 0.0001}}\right)^2}$$

mobmod=3 for high k/metal gate structure (introduced by BSIM4..2):

(21-30)

$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + (UA + UCV_{bseff}) + \left[\frac{V_{gsteff} + C_0 \cdot (VTHO - VFB - \Phi_s)}{6 \cdot TOXE}\right]^{EU} + \frac{UD}{0.5[1 + V_{gsteff}/V_{gsteff} \cdot V_{th}]^{UCS}}}$$

BSIM4.80 introduces three new mobility models, mobmod=4, mobmod=5, and mobmod=6 as modified versions of mobmod=0, mobmod=1, and mobmod=2 respectively.

mobmod=4

(21-31)

$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + (UA + UCV_{bseff})\left[\frac{V_{gsteff} + C_0 \cdot (VTHO - VFB - \Phi_s)}{TOXE}\right] + UB\left(\frac{V_{gsteff} + C_0 \cdot (VTHO - VFB - \Phi_s)}{TOXE}\right)^2 + UD\left(\frac{C_0 \cdot (VTHO - VFB - \Phi_s) \cdot TOXE}{V_{gseff} + 2\sqrt{C_0^2 \cdot (VTHO - VFB - \Phi_s)^2 + 0.0001}}\right)^2}$$

mobmod=5

(21-32)

$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + \left[UA\left(\frac{V_{gsteff} + C_0 \cdot (VTHO - VFB - \Phi_s)}{TOXE}\right) + UB\left(\frac{V_{gsteff} + C_0 \cdot (VTHO - VFB - \Phi_s)}{TOXE}\right)^2\right] (1 + UC \cdot V_{eff}) + UD\left(\frac{C_0 \cdot (VTHO - VFB - \Phi_s) \cdot TOXE}{V_{gseff} + 2\sqrt{C_0^2 \cdot (VTHO - VFB - \Phi_s)^2 + 0.0001}}\right)^2}$$

mobmod=6

(21-33)

$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + (UA + UC \cdot V_{bseff})\left[\frac{V_{gsteff} + C_0 \cdot (VTHO - VFB - \Phi_s)}{TOXE}\right]^{EU} + UD\left(\frac{C_0 \cdot (VTHO - VFB - \Phi_s) \cdot TOXE}{V_{gseff} + 2\sqrt{C_0^2 \cdot (VTHO - VFB - \Phi_s)^2 + 0.0001}}\right)^2}$$

Bias-Dependant Source/Drain-Resistance Model

rdsMod=0 (Internal R_{ds} (V))

(21-34)

$$R_{ds}(V) = \left\{ \begin{array}{l} RDSWMIN + RDSW \cdot \\ \left[PRWB \cdot (\sqrt{\Phi_s - V_{bseff}} - \sqrt{\Phi_s}) + \frac{1}{1 + PRWG \cdot V_{gsteff}}\right] \end{array} \right\} / (1e6 \cdot W_{effcj})^{WR}$$

rdsMod=1 (External R_d(V) and R_s(V)

(21-35)

$$R_d(V) = \left\{ \begin{array}{l} RDWMIN + RDW \cdot \\ \left[-PRWB V_{bd} + \frac{1}{1 + PRWG \cdot (V_{gd} - V_{fbsd})}\right] \end{array} \right\} / (1e6 \cdot W_{effcj})^{WR} \cdot NF$$

(21-36)

$$R_s(V) = \left\{ \begin{array}{l} RSWMIN + RSW \cdot \\ \left[-PRWB V_{bs} + \frac{1}{1 + PRWG \cdot (V_{gs} - V_{fbsd})}\right] \end{array} \right\} / (1e6 \cdot W_{effcj})^{WR} \cdot NF$$

Saturation Voltage V_{dsat}

Intrinsic Case

(21-37)

$$V_{dsat} = \frac{E_{sat}L(V_{gsteff} + 2v_t)}{A_{bulk}E_{sat}L + V_{gsteff} + 2v_t}$$

Extrinsic Case

(21-38)

$$V_{dsat} = \frac{-b - \sqrt{b^2 - 4ac}}{2a}$$

where

(21-39)

$$a = A^2{}_{bulk} W_{eff} VSATC_{oxe} R_{ds} + A_{bulk}\left(\frac{1}{\lambda} - 1\right)$$

(21-40)

$$b = -\begin{bmatrix} (V_{gsteff} + 2v_t)\left(\frac{2}{\lambda} - 1\right) + A_{bulk} E_{sat} L_{eff} \\ +3\mathrm{A}_{bulk}(V_{gsteff} + 2v_t) W_{eff} VSATC_{oxe} R_{ds} \end{bmatrix}$$

(21-41)

$$c = (V_{gsteff} + 2v_t) E_{sat} L_{eff} + 2(V_{gsteff} + 2v_t)^2 W_{eff} VSATC_{oxe} R_{ds}$$

(21-42)

$$\lambda = A1 V_{gsteff} + A2$$

Drain Current

Considering only the channel current, the I-V curve can be divided into two parts: the linear region and the saturation region. In the linear region, carrier velocity is not saturated and the drain current has a strong dependence on the drain voltage. In the saturation region, several physical mechanisms affect the output resistance: channel length modulation (CLM), drain-induced barrier lowering (DIBL), and the substrate current induced body effect (SCBE). These mechanisms all affect the output resistance in the saturation range, but each of them dominates in a specific region. The channel current equation for both linear and saturation regions is:

(21-43)

$$I_{ds} = \frac{I_{ds0}NF}{1 + \frac{R_{ds}I_{ds0}}{V_{dseff}}}\left[1 + \frac{1}{C_{clm}}1n\left(\frac{V_A}{V_{Asat}}\right)\right]\left(1 + \frac{V_{ds} - V_{dseff}}{V_{ADIBL}}\right)\left(1 + \frac{V_{ds} - V_{dseff}}{V_{ASCBE}}\right)\left(1 + \frac{V_{ds} - V_{dseff}}{V_{ADITS}}\right)$$

where NF is the number of device fingers, and Early voltage.

(21-44)

$$V_A = V_{Asat} + V_{ACLM}$$

The Early voltage at $V_{ds} = V_{dsat}$ is

(21-45)

$$V_{Asat} = \frac{E_{sat}L_{eff} + V_{dsat} + 2R_{ds}vsatC_{oxe}W_{eff}V_{gsteff}}{R_{ds}vsatC_{oxe}W_{eff}A_{bulk} - 1 + \frac{2}{\lambda}}\left[1 - \frac{A_{bulk}V_{dsat}}{2(V_{gsteff} + 2v_t)}\right]$$

The Early voltage due to CLM effect is

(21-46)

$$V_{ACLIM} = C_{clm}(V_{ds} - V_{dsat})$$

where

(21-47)

The Early voltage due to DIBL effect is

$$C_{clm} = \frac{F}{PCLM}\left(1 + PVAG\frac{V_{gsteff}}{E_{sat}L_{eff}}\right)\left(1 + \frac{R_{ds}I_{ds0}}{V_{dseff}}\right)\left(L_{eff} + \frac{V_{sat}}{E_{sat}}\right)\frac{1}{litl}$$

(21-48)

$$V_{ADIBL} = \frac{V_{gsteff} + 2v_t}{\theta_{rout}(1 + PDIBLCB \cdot V_{bseff})}\left(1 - \frac{A_{bulk}V_{dsat}}{A_{bulk}V_{sat} + V_{gseff} + 2v_t}\right)\left(1 + PVAG\frac{V_{gsteff}}{E_{sat}L_{eff}}\right)$$

The Early voltage due to SCBE effect is

(21-49)

$$V_{ASCBE} = \frac{L_{eff}}{PSCBE2}\exp\left(\frac{PSCBE1 \cdot litl}{V_{ds} - V_{dsat}}\right)$$

The Early voltage due to Drain-Induced Threshold Shift (DITS) by pocket implant is

(21-50)

$$V_{ADITS} = \frac{F}{PDITS}[1 + (1 + PDITSL \cdot L_{eff})\exp(PDITSD \cdot V_{ds})]$$

Velocity Overshoot and Source End Velocity Limit Model

In the deep-submicron region, the velocity overshoot and source end velocity limit model should be used. The unified current expression with velocity saturation, velocity overshoot and source velocity limit is:

(21-51)

$$I_{DS} = \frac{I_{DS,HD}}{[1 + (v_{sHD}/v_{sBT})^{2MM}]^{1/(2MM)}}$$

where the current including the velocity overshoot effect is:

(21-52)

$$I_{DS,HD} = \frac{I_{DS}\left(1 + \frac{V_{dseff}}{L_{eff}E_{sat}}\right)}{1 + \frac{V_{dseff}}{L_{eff}E_{sat}^{OV}}}$$

Body Current Model

I_{sub} Model

When the electrical field near the drain is very large (> 0.1MV/cm), some electrons coming from the source (in the case of NMOSFETs) will be energetic (hot) enough to cause impact ionization. This will generate electron-hole pairs when these energetic electrons collide with silicon atoms. The substrate current Isub thus created during impact ionization will increase exponentially with the drain voltage. A well known Isub model is:

(21-53)

$$I_{sub} = \frac{A_i}{B_i} I_{ds}(V_{ds} - V_{dsat}) \exp\left(-\frac{B_i, litl}{V_{ds} - V_{dsat}}\right)$$

In addition to the junction diode current and gate-to-body tunneling current, the substrate terminal current consists of the substrate current due to impact ionization (Iii), and gate-induced drain leakage and source leakage currents (I_{GIDL} and I_{GISL}).

I_{ii} Model

(21-54)

$$I_{ii} = \frac{ALPHA0 + ALPHA1 \cdot L_{eff}}{L_{eff}}(V_{ds} - V_{dseff})\exp\left(\frac{BETA0}{V_{ds} - V_{dseff}}\right) \cdot \frac{I_{ds}}{1 + \frac{V_{ds} - V_{dseff}}{V_{ASCBE}}}$$

I_{GIDL} and I_{GISL} Model

mtrmod=0

(21-55)

$$I_{GIDL} = AGIDL \cdot W_{effCJ} \cdot NF \cdot \frac{V_{ds} - V_{gse} - EGIDL}{3T_{oxe}} \exp\left(-\frac{3T_{oxe} \cdot BGIDL}{V_{ds} - V_{gse} - EGIDL}\right)\frac{V^3{}_{db}}{CGIDL + V^3{}_{db}}$$

(21-56)

$$I_{GISL} = AGISL \cdot W_{effCJ} \cdot NF \cdot \frac{-V_{ds} - V_{gde} - EGISL}{3T_{oxe}} \cdot \exp(-\frac{3T_{oxe} \cdot BGISL}{-V_{ds} - V_{gde} - EGISL}) \cdot \frac{V_{sb}^3}{CGISL + V_{sb}^3}$$

(21-57)

mtrmod=1

$$I_{GIDL} = AGIDL \cdot W_{effCJ} \cdot NF \cdot \frac{V_{ds} - V_{gse} - EGIDL + V_{fbsd}}{EOT \cdot \frac{EPSRSUB}{3.9}} \cdot \exp(-\frac{EOT \cdot \frac{EPSRSUB}{3.9} \cdot BGIDL}{V_{ds} - V_{gse} - EGIDL + V_{fbsd}}) \cdot \frac{V_{db}^3}{CGIDL + V_{db}^3}$$

(21-58)

$$I_{GISL} = AGISL \cdot W_{effCJ} \cdot NF \cdot \frac{-V_{ds} - V_{gde} - EGISL + V_{fbsd}}{EOT \cdot \frac{EPSRSUB}{3.9}} \cdot \exp(-\frac{EOT \cdot \frac{EPSRSUB}{3.9} \cdot BGISL}{-V_{ds} - V_{gde} - EGISL + V_{fbsd}}) \cdot \frac{V_{sb}^3}{CGISL + V_{sb}^3}$$

(21-59)

where

$$V_{fbsd} = PHIG - (EASUB + \frac{Eg0}{2} - BSIM4type \cdot MIN(\frac{Eg0}{2}, v_t \ln(\frac{NSD}{n_i}))$$

Capacitance Model

The following table displays the BSIM4 capacitance model options:

BSIM4 Capacitance Models	Matched capmod in BSIM3v3.2.2
`capMod` = 0 (simple and piecewise model)	Intrinsic `capMod` = 0 + overlap/fringing `capMod`=0
`capMod` = 1 (single equation model)	Intrinsic `capMod` = 2 + overlap/fringing `capMod` = 2
`capMod` = 2 (default; single-equation and charge-thickness model)	Intrinsic `capMod` = 3 + overlap/fringing `capMod` = 2

Intrinsic Capacitance Modeling

The relationship of terminal charges (Q_g, Q_b, Q_s, and Q_d) and the channel charge Q_{inv}, accumulation charge Q_{acc} and substrate depletion charge Q_{sub} are:

(21-60)

$$Q_g = -(Q_{sub} + Q_{inv} + Q_{acc})$$

(21-61)

$$Q_b = Q_{acc} + Q_{sub}$$

(21-62)

$$Q_{inv} = Q_s + Q_d$$

All capacitances are derived from the charges to ensure charge conservation. Since there are four terminals, there are a total of 16 components. For each component:

(21-63)

$$C_{ij} = \frac{\partial Q_i}{\partial V_j}$$

where i and j denote the transistor terminals. C_{ij} satisfies

(21-64)

$$\sum_i C_{ij} = \sum_j C_{ij} = 0$$

A new threshold voltage definition is introduced to improve the fitting in subthreshold region. Setting `cvchargemod` = 1 activates the new V_{gsteff}, CV calculation which is similar to the V_{gsteff} formulation in the I-V model. Setting `cvchargemod` = 0 is corresponding to long-channel charge model which assumes a constant mobility with no velocity saturation.

Intrinsic capacitance model equations

For capmod=0

Accumulation region

(21-65)

$$Q_g = W_{active}L_{active}C_{oxe}(V_{gs} - V_{bs} - VFBCV)$$

(21-66)

$$Q_{sub} = -Q_g$$

(21-67)

$$Q_{inv} = 0$$

Subthreshold region

(21-68)

$$Q_{sub0} = -W_{active}L_{active}C_{oxe}\frac{{K_{1ox}}^2}{2}\left(-1 + \sqrt{1 + \frac{4(V_{gs} - VFBCV - V_{bs})}{{K_{1ox}}^2}}\right)$$

(21-69)

$$Q_g = -Q_{sub0}$$

(21-70)

$$Q_{inv} = 0$$

Strong inversion

(21-71)

$$V_{dsat, cv} = \frac{V_{gs} - V_{th}}{A_{bulk}'}$$

(21-72)

$$A_{bulk}' = A_{bulk}\left(1 + \left(\frac{CLC}{L_{eff}}\right)^{CLE}\right)$$

(21-73)

$$V_{TH} = VFBCV + \Phi_s + K_{1ox}\sqrt{\Phi_s - V_{bseff}}$$

Linear Region

(21-74)

$$Q_g = C_{oxe}W_{active}L_{active}\left[V_{gs} - VFBCV - \Phi_s - \frac{V_{ds}}{2} + \frac{A_{bulk}' \times V_{ds}^{\ 2}}{12\left(V_{gs} - V_{th} - \frac{A_{bulk}'V_{ds}}{2}\right)}\right]$$

(21-75)

$$Q_b = C_{oxe}W_{active}L_{active}\left[VFBCV - V_{th} - \Phi_s + \frac{(1 - A_{bulk}')V_{ds}}{2} - \frac{(1 - A_{bulk}')A_{bulk}'V_{ds}^{\ 2}}{12\left(V_{gs} - V_{th} - \frac{A_{bulk}'V_{ds}}{2}\right)}\right]$$

50/50 Charge Partition

(21-76)

$$Q_{inv} = -C_{oxe}W_{active}L_{active}\left(V_{gs} - V_{th} - \Phi_s - \frac{A_{bulk}'V_{ds}}{2} + \frac{A_{bulk}'^{2}V_{ds}^{\ 2}}{12\left(V_{gs} - V_{th} - \frac{A_{bulk}'V_{ds}}{2}\right)}\right)$$

(21-77)

$$Q_s = Q_d = 0.5Q_{inv}$$

40/60 Channel-Charge Partition

(21-78)

$$Q_d = -C_{oxe}W_{active}L_{active}$$

$$\left(\frac{V_{gs}-V_{th}}{2}-\frac{A_{bulk}'V_{ds}}{2}+\frac{A_{bulk}'V_{ds}\left[\frac{(V_{gs}-V_{th})^2}{6}-\frac{A_{bulk}'V_{ds}(V_{gs}-V_{th})}{8}+\frac{(A_{bulk}'V_{ds})^2}{40}\right]}{12\left(V_{gs}-V_{th}-\frac{A_{bulk}'V_{ds}}{2}\right)^2}\right)$$

(21-79)

$$Q_s = -(Q_g + Q_b + Q_d)$$

0/100 Partitioning

(21-80)

$$Q_d = -C_{oxe}W_{active}L_{active}\left(\frac{V_{gs}-V_{th}}{2}+\frac{A_{bulk}'V_{ds}}{4}-\frac{(A_{bulk}'V_{ds})^2}{24}\right)$$

(21-81)

$$Q_s = -(Q_g + Q_b + Q_d)$$

Saturation Region

(21-82)

$$Q_g = C_{oxe}W_{active}L_{active}\left(V_{gs}-VFBCV-\Phi_s-\frac{V_{dsat}}{3}\right)$$

(21-83)

$$Q_b = -C_{oxe}W_{active}L_{active}\left(VFBCV + \Phi_s - V_{th} + \frac{(1 - A_{bulk}')V_{dsat}}{3}\right)$$

50/50 Partitioning

(21-84)

$$Q_s = Q_d = -\frac{1}{3}C_{oxe}W_{active}L_{active}(V_{gs} - V_{th})$$

40/60 Partitioning

(21-85)

$$Q_d = -\frac{4}{15}C_{oxe}W_{active}L_{active}(V_{gs} - V_{th})$$

(21-86)

$$Q_s = -(Q_g + Q_b + Q_d)$$

0/100 Channel-Charge Partition

(21-87)

$$Q_d = 0$$

(21-88)

$$Q_s = -(Q_g + Q_b)$$

For capmod=1

(21-89)

$$Q_g = -(Q_{inv} + Q_{acc} + Q_{sub0} + \delta Q_{sub})$$

(21-90)

$$Q_b = -(Q_{acc} + Q_{sub0} + \delta Q_{sub})$$

(21-91)

$$Q_{inv} = Q_s + Q_d$$

(21-92)

$$Q_{acc} = -W_{active}L_{active}C_{oxe} \cdot (V_{FBeff} - V_{fbzb})$$

(21-93)

$$Q_{sub0} = -W_{active}L_{active}C_{oxe} \cdot \frac{K_{1ox}{}^2}{2} \cdot \left[-1 + \sqrt{1 + \frac{4(V_{gse} - V_{FBeff} - V_{gsteff} - V_{bseff})}{K_{1ox}{}^2}}\right]$$

(21-94)

$$V_{dsat,\,cv} = \frac{V_{gsteffcv}}{A_{bulk}'}$$

(21-95)

$$Q_{inv} = -W_{active}L_{active}C_{oxe} \cdot \left[V_{gsteff,\,cv} - \frac{1}{2}A_{bulk}'V_{cveff} + \frac{A_{bulk}'^2 V_{cveff}^2}{12 \cdot \left(V_{gsteff,\,cv} - \frac{A_{bulk}'V_{cveff}}{2}\right)}\right]$$

(21-96)

$$\delta Q_{sub} = W_{active}L_{active}C_{oxe} \cdot \left[\frac{1 - A_{bulk}'}{2}V_{cveff} - \frac{(1 - A_{bulk}') \cdot A_{bulk}'V_{cveff}^2}{12 \cdot \left(V_{gsteff,\,cv} - \frac{A_{bulk}'V_{cveff}}{2}\right)}\right]$$

50/50 Charge Partition

(21-97)

$$Q_S = Q_D = -\frac{W_{active}L_{active}C_{oxe}}{2}\left[V_{gsteff,\,cv} - \frac{1}{2}A_{bulk}'V_{cveff} + \frac{A_{bulk}'^{2}V_{cveff}^{2}}{12\cdot\left(V_{gsteff,\,cv} - \frac{A_{bulk}'V_{cveff}}{2}\right)}\right]$$

40/60 Channel-Charge Partition

(21-98)

$$Q_S = -\frac{W_{active}L_{active}C_{oxe}}{2\left(V_{gsteff,\,cv} - \frac{A_{bulk}'V_{cveff}}{2}\right)^2}\left[V_{gsteffcv}{}^3 - \frac{4}{3}V_{gsteffcv}{}^2A_{bulk}'V_{cveff} + \frac{2}{3}V_{gsteff,\,cv}(A_{bulk}'V_{cveff})^2 - \frac{2}{15}(A_{bulk}'V_{cveff})^3\right]$$

(21-99)

$$Q_D = -\frac{W_{active}L_{active}C_{oxe}}{2\left(V_{gsteff,\,cv} - \frac{A_{bulk}'V_{cveff}}{2}\right)^2}\left[V_{gsteff,\,cv}{}^3 - \frac{5}{3}V_{gsteff,\,cv}{}^2A_{bulk}'V_{cveff} + V_{gsteff,\,cv}(A_{bulk}'V_{cveff})^2 - \frac{1}{5}(A_{bulk}'V_{cveff})^3\right]$$

0/100 Charge Partition

(21-100)

$$Q_S = -\frac{W_{active}L_{active}C_{oxe}}{2}\cdot\left(V_{gsteff,\,cv} + \frac{1}{2}A_{bulk}'V_{cveff} - \frac{A_{bulk}'^{2}V_{cveff}^{2}}{12\cdot\left(V_{gsteff,\,cv} - \frac{A_{bulk}'V_{cveff}}{2}\right)}\right)$$

(21-101)

$$Q_D = -\frac{W_{active}L_{active}C_{oxe}}{2} \cdot \left[V_{gsteff,\,cv} - \frac{3}{2}A_{bulk}'V_{cveff} + \frac{A_{bulk}'^2 V_{cveff}^2}{4 \cdot \left(V_{gsteff,\,cv} - \frac{A_{bulk}'V_{cveff}}{2}\right)}\right]$$

For capmod = 2

(21-102)

$$Q_{acc} = W_{active}L_{active}C_{oxeff} \cdot V_{gbacc}$$

(21-103)

$$V_{gbacc} = \frac{1}{2} \cdot \left[V_0 + \sqrt{V_0^{\;2} + 0.08V_{fbzb}}\right]$$

(21-104)

$$V_0 = V_{fbzb} + V_{bseff} - V_{gs} - 0.02$$

(21-105)

$$V_{cveff} = V_{dsat} - \frac{1}{2} \cdot \left(V_1 + \sqrt{V_1^{\;2} + 0.08V_{dsat}}\right)$$

(21-106)

$$V_1 = V_{dsat} - V_{ds} - 0.02$$

(21-107)

$$V_{dsat} = \frac{\langle V_{gsteff,\,cv} - \varphi_\delta \rangle_{eff}}{A_{bulk}'}$$

When updatelevel=1, a smooth function is applied when calculating ($V_{gsteff,\ cv}$-psi_{delta})$_{eff}$ to improve convergence behavior of the model.

(21-108)

(21-109)

$$\varphi_\delta = \Phi_s - 2\Phi_B = v_t \ln\left(\frac{V_{gsteffCV} \cdot (V_{gsteffCV} + 2K_{1ox}\sqrt{2\Phi_B})}{MOIN \cdot K_{1ox}^{2} v_t}\right)$$

(21-110)

$$Q_{sub0} = -W_{active}L_{active}C_{oxeff} \cdot \frac{K_{1ox}^{2}}{2}\left[-1 + \sqrt{1 + \frac{4(V_{gse} - V_{FBeff} - V_{bseffs} - V_{gsteff,cv})}{K_{1ox}^{2}}}\right]$$

(21-111)

$$Q_{inv} = -W_{active}L_{active}C_{oxeff} \cdot \left[\langle V_{gsteff,cv} - \varphi_\delta\rangle_{eff} - \frac{1}{2}A_{bulk}'V_{cveff} + \frac{A_{bulk}'^{2}V_{cveff}^{2}}{12 \cdot \left((V_{gsteff,cv} - \varphi_\delta)_{eff} - \frac{A_{bulk}'V_{cveff}}{2}\right)}\right]$$

(21-112)

$$\delta Q_{sub} = -W_{active}L_{active}C_{oxeff} \cdot \left[\frac{1 - A_{bulk}'}{2}V_{cveff} - \frac{(1 - A_{bulk}') \cdot A_{bulk}'V_{cveff}^{2}}{12 \cdot \left(\langle V_{gsteff,cv} - \varphi_\delta\rangle_{eff} - \frac{A_{bulk}'V_{cveff}}{2}\right)}\right]$$

50/50 Partitioning

(21-113)

$$Q_S = Q_D = -\frac{W_{active}L_{active}C_{oxeff}}{2}$$

$$\left[\langle V_{gsteff,\,cv} - \varphi_\delta\rangle_{eff} - \frac{1}{2}A_{bulk}'V_{cveff} + \frac{A_{bulk}'^2 V_{cveff}^2}{12\cdot\left(\langle V_{gsteff,\,cv} - \varphi_\delta\rangle_{eff} - \frac{A_{bulk}'V_{cveff}}{2}\right)}\right]$$

40/60 Partitioning

(21-114)

$$Q_S = -\frac{W_{active}L_{active}C_{oxeff}}{2\left(\langle V_{gsteff,\,cv} - \varphi_\delta\rangle_{eff} - \frac{A_{bulk}'V_{cveff}}{2}\right)^2}$$

$$\left[\langle V_{gsteff,\,cv} - \varphi_\delta\rangle_{eff}^{\;3} - \frac{4}{3}\langle V_{gsteff,\,cv} - \varphi_\delta\rangle_{eff}^{\;2}A_{bulk}'V_{cveff} + \right.$$

$$\left.\frac{2}{3}\langle V_{gsteff,\,cv} - \varphi_\delta\rangle_{eff}(A_{bulk}'V_{cveff})^2 - \frac{2}{15}(A_{bulk}'V_{cveff})^3\right]$$

(21-115)

$$Q_D = -\frac{W_{active}L_{active}C_{oxeff}}{2\left(\langle V_{gsteff,\,cv} - \varphi_\delta\rangle_{eff} - \frac{A_{bulk}'V_{cveff}}{2}\right)^2}$$

$$\left[\langle V_{gsteff,\,cv} - \varphi_\delta\rangle_{eff}^{\;3} - \frac{5}{3}\langle V_{gsteff,\,cv} - \varphi_\delta\rangle_{eff}^{\;2}A_{bulk}'V_{cveff} + \langle V_{gsteff,\,cv} - \varphi_\delta\rangle_{eff}(A_{bulk}'V_{cveff})^2\right.$$

$$\left. - \frac{1}{5}(A_{bulk}'V_{cveff})^3\right]$$

0/100 Partitioning

(21-116)

$$Q_S = -\frac{W_{active}L_{active}C_{oxeff}}{2}\cdot\left[(V_{gsteff,cv}-\varphi_\delta)_{eff}+\frac{1}{2}A_{bulk}'V_{cveff}-\right.$$
$$\left.\frac{A_{bulk}'^2V_{cveff}^2}{12\cdot\left((V_{gsteff,cv}-\varphi_\delta)_{eff}-\frac{A_{bulk}'V_{cveff}}{2}\right)}\right]$$

(21-117)

$$Q_D = -\frac{W_{active}L_{active}C_{oxeff}}{2}\cdot\left[(V_{gsteff,cv}-\varphi_\delta)_{eff}-\frac{3}{2}A_{bulk}'V_{cveff}-\right.$$
$$\left.\frac{A_{bulk}'^2V_{cveff}^2}{4\cdot\left(\langle V_{gsteff,cv}-\varphi_\delta\rangle_{eff}-\frac{A_{bulk}'V_{dveff}}{2}\right)}\right]$$

When `updatelevel`=0,

(21-118)

$$\langle V_{gsteff,cv}-\varphi_\delta\rangle_{eff} = V_{gsteff,cv}-\varphi_\delta$$

When `updatelevel`=1, or version=4.5,

(21-119)

$$\langle V_{gsteff,cv}-\varphi_\delta\rangle_{eff} = 0.5\cdot\left[(V_{gsteff,cv}-\varphi_\delta-0.0001)+\right.$$
$$\left.\sqrt{(V_{gsteff,cv}-\varphi_\delta-0.0001)^2+V_{gsteff,cv}\cdot 0.0004}\right]$$

Intrinsic Capacitances (with Body Bias and DIBL)

(21-120)

$$C_{(s,\,d,\,g,\,b),\,g} = \frac{\partial Q_{s,\,d,\,g,\,b}}{\partial V_{gsteffcv}}\frac{\partial V_{gsteffcv}}{\partial V_{gt}}$$

(21-121)

$$C_{(s,\,d,\,g,\,b),\,s} = -\frac{\partial Q_{s,\,d,\,g,\,b}}{\partial V_{ds}} + \frac{\partial Q_{s,\,d,\,g,\,b}}{\partial V_{gsteffcv}}\frac{\partial V_{gsteffcv}}{\partial V_{gt}}\left(\frac{\partial V_{th}}{\partial V_{ds}} + \frac{\partial V_{th}}{\partial V_{bs}}\right)$$

(21-122)

$$C_{(s,\,d,\,g,\,b),\,d} = \frac{\partial Q_{s,\,d,\,g,\,b}}{\partial V_{ds}} - \frac{\partial Q_{s,\,d,\,g,\,b}}{\partial (V_{gsteffcv})}\frac{\partial V_{gsteffcv}}{\partial V_{gt}}\frac{\partial V_{th}}{\partial V_{ds}}$$

(21-123)

$$C_{(s,\,d,\,g,\,b),\,b} = \frac{\partial Q_{s,\,d,\,g,\,b}}{\partial V_{bs}} - \frac{\partial Q_{s,\,d,\,g,\,b}}{\partial V_{gsteffcv}}\frac{\partial V_{gsteffcv}}{\partial V_{gt}}\frac{\partial V_{th}}{\partial V_{bs}}$$

Overlap Capacitance Models

capmod=0, Bias-independent overlap capacitance model

(21-124)

$$Q_{overlap,s} = W_{active} \cdot CGSO \cdot V_{gs}$$

(21-125)

$$Q_{overlap,d} = W_{active} \cdot CGDO \cdot V_{gd}$$

(21-126)

$$Q_{overlap,b} = L_{active} \cdot CGBO \cdot V_{gb}$$

capmod 1 and 2, Bias dependent overlap capacitance model

(21-127)

$$\frac{Q_{overlap,s}}{W_{active}} = CGSO \cdot V_{gs} + CGSL\left(V_{gs} - V_{gs,overlap} - \frac{CKAPPAS}{2}\left(-1 + \sqrt{1 - \frac{4V_{gs,overlap}}{CKAPPAS}}\right)\right)$$

(21-128)

$$\frac{Q_{overlap,d}}{W_{active}} = CGDO \cdot V_{gd} + CGDL\left(V_{gd} - V_{gd,overlap} - \frac{CKAPPAD}{2}\left(-1 + \sqrt{1 - \frac{4V_{gd,overlap}}{CKAPPAD}}\right)\right)$$

(21-129)

$$Q_{overlap,g} = -(Q_{overlap.d} + Q_{overlap,s} + CGBO \cdot L_{active} \cdot V_{gb})$$

(21-130)

$$V_{gs.overlap} = \frac{V_{gs} + \delta_1 - \sqrt{(V_{gs} + \delta_1)^2 + 4\delta_1}}{2}$$

(21-131)

$$V_{gd.overlap} = \frac{V_{gd} + \delta_1 - \sqrt{(V_{gd} + \delta_1)^2 + 4\delta_1}}{2}, \delta_1 = 0.02V$$

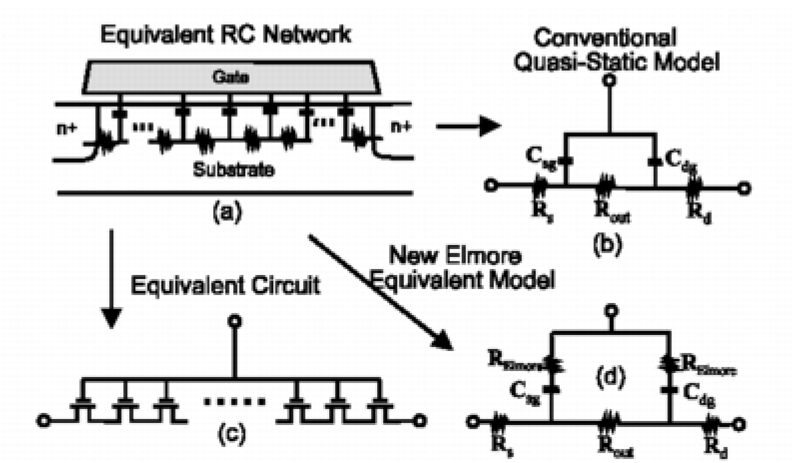
High Speed/RF Models

Charge-deficit Nonquasi-static (NQS) Model

BSIM4 uses two separate model selectors to turn on or off the charge-deficit NQS model in transient simulation (using ***trnqsMod***) and AC simulation (using ***acnqsMod***). The AC NQS model does not require the internal NQS charge node that is needed for the transient NQS model. The transient and AC NQS models are developed from the same fundamental physics: the channel/gate charge response to the external signal are relaxation-time (τ)

dependent and the transcapacitances and transconductances (such as G_m) for AC analysis can therefore be expressed as functions for $j\omega\tau$.

MOSGFET channel region is analogous to a bias-dependent RC distributed transmission line as shown section "a" of the figure below. In the Quasi-Static (QS) approach, the gate capacitor node is lumped with the external source and drain nodes as shown in section "b" of the figure below. This ignores the finite time for the channel charge to build-up. One way to capture the NQS effect is to represent the channel with *n* transistors in series as shown in section "c" of the figure below, but it comes at the expense of simulation time. The BSIM4 charge-deficit NQS model uses Elmore equivalent circuit to model channel charge build-up as shown in section "d" of the figure below.



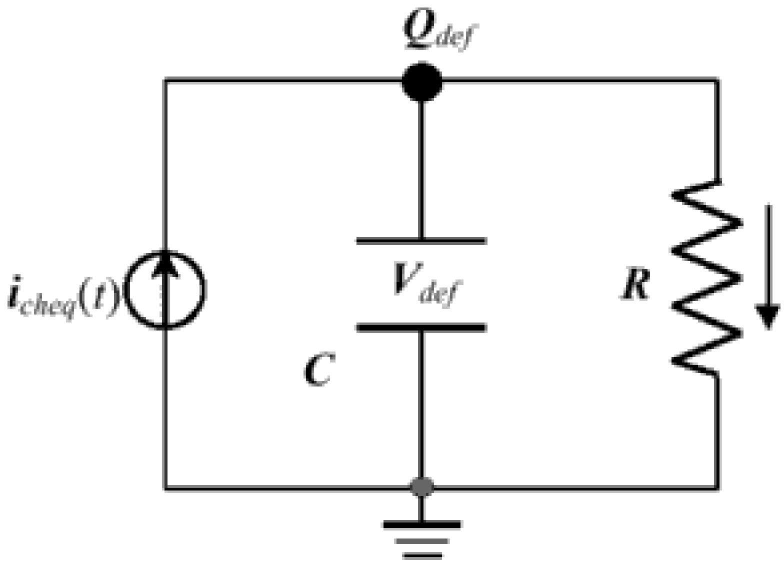
The Transient Model

The transient charge-deficit NQS model can be turned on by setting ***trnqsMod*** = 1 and off by setting ***trnqsMod*** = 0.

The figure below shows the RC subcircuit of charge deficit NQS model for transient simulation. An internal node, $Q_{def}(t)$, is created to keep track of the amount of deficit/surplus channel charge necessary to reach equilibrium. The resistance ***R*** is determined from the RC time constant (τ) . The current source $i_{cheq}(t)$ represents the equilibrium channel charging effect. The capacitor ***C*** is the value of C_{fact} (with a typical value of 1 x 10^{-9} Farad) to improve simulation accuracy. Q_{def} now becomes:

(21-132)

$$Q_{def}(t) = V_{def} \times C_{fact}$$



Considering both the transport and charging component, the total current related to the terminals D, G, and S can be written as:

(21-133)

$$i_{D,G,S}(t) = I_{D,G,S}(DC) + \frac{\partial Q_{d,g,s}(t)}{\partial t}$$

Based on the relaxation time approach, the terminal charge and corresponding charging current are modeled by

(21-134)

$$Q_{def}(t) = Q_{cheq}(t) - Q_{ch}(t)$$

and

(21-135)

$$\frac{\partial Q_{def}(t)}{\partial t} = \frac{\partial Q_{cheq}(t)}{\partial t} - \frac{Q_{def}(t)}{\tau}$$

(21-136)

$$\frac{\partial Q_{d,g,s}(t)}{\partial t} = D, G, S_{xpart}\frac{Q_{def}(t)}{\tau}$$

where D,G,S_{xpart} are charge deficit NQS channel charge partitioning numbers for terminals D, G, and S; $D_{xpart} + S_{xpart} = 1$ and $G_{xpart} = -1$.

The transit time τ is equal to the product of R_{ii} and $W_{eff}L_{eff}C_{oxe}$, where R_{ii} is the intrinsic-input resistance given by

(21-137)

$$\frac{1}{R_{ii}} = XRCRG1 \cdot \left(\frac{I_{ds}}{V_{dseff}} + XRCRG2 \cdot \frac{W_{eff}\mu_{eff}C_{oxeff}k_B T}{qL_{eff}}\right)$$

where C_{oxeff} is the effective gate dielectric capacitance calculated from the DC model.

Note: R_{ii} considers both the drift and diffusion components of the channel conduction, each of which dominates in inversion and subthreshold regions.

The AC Mode

The small-signal AC charge-deficit NQS model can be turned on by setting ***acnqsMod*** = 1 and off by setting ***acnqsMod*** = 0.

For small signals in the frequency domain, $Q_{ch}(t)$ can be transformed into:

(21-138)

$$\Delta Q_{ch}(t) = \frac{\Delta Q_{cheq}(t)}{1 + j\omega\tau}$$

where ω is the angular frequency. It can be shown that the transcapacitances C_{gi}, C_{si}, and C_{di} (*i* stands for any of the G, D, S, and B terminals of the device) and the channel transconductances G_m, G_{ds}, and G_{mbs} all become complex quantities. For example, now G_m has the form of:

(21-139)

$$G_m = \frac{G_{m0}}{1+\omega^2\tau^2} + j\left(-\frac{G_{m0}\cdot\omega\tau}{1+\omega^2\tau^2}\right)$$

and

(21-140)

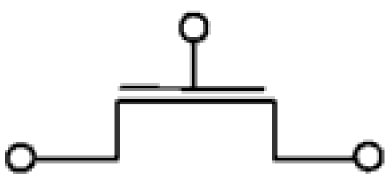
$$C_{dg} = \frac{C_{dg0}}{1+\omega^2\tau^2} + j\left(-\frac{C_{dg0}\cdot\omega\tau}{1+\omega^2\tau^2}\right)$$

The quantities above with sub "0" are known from OP (Operating Point) analysis.

Gate Electrode and Intrinsic-Input Resistance (IIR) Model

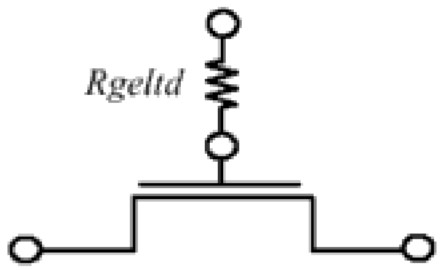
BSIM4 provides four options for modeling gate electrode resistance (bias-independent) and intrinsic-input resistance (IIR, bias-dependent). The IIR model considers the relaxation-time effect due to the distributive RC nature of the channel region, and therefore describes the first-order non-quasi-static effect. Thus, the IIR model should not be used together with the charge-deficit NQS model. The model selector ***rgateMod*** is used to choose different options.

rgateMod = 0 (zero-resistance)



In this case, no gate resistance is generated.

rgateMod = 1 (constant-resistance)

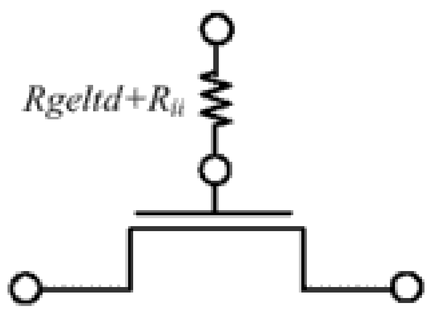


In this case, only the electrode gate resistance (bias-dependent) is generated by adding an internal gate node. Rgeltd is given by

(21-141)

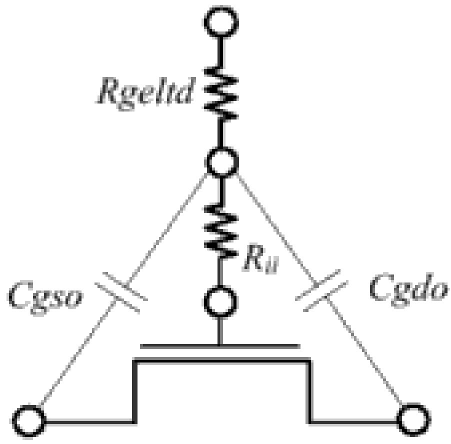
$$Rgeltd = \frac{RSHG \cdot \left(XGW + \frac{W_{effcj}}{3 \cdot NGCON}\right)}{NGCON \cdot (L_{drawn} - XGL) \cdot NF}$$

rgateMod = 2 (IIR model with variable resistance)



In this case, the gate resistance is the sum of the electrode gate resistance and the intrinsic-input resistance R_{ii}. An internal gate node will be generated. ***trnqsMod*** = 0 (default) and ***acnqsMod*** = 0 (default) should be selected for this case.

rgateMod = 3 (IIR model with two nodes)



In this case, the gate electrode resistance given is in series with the intrinsic-input resistance R_{ii} through two internal gate nodes, so that the overlap capacitance current will not pass through the intrinsic-input resistance. ***trnqsMod*** = 0 (default) and ***acnqsMod*** = 0 (default) should be selected for this case.

Substrate Resistance Network

For CMOS RF circuit simulation, it is essential to consider the high frequency coupling through the substrate. BSIM4 offers a flexible built-in substrate resistance network. This network is constructed so that little simulation efficiency penalty will result.

Model Selector and Topology

The model selector ***rbodyMod*** can be used to turn on or turn off the resistance network.

rbody = 0 (Off)

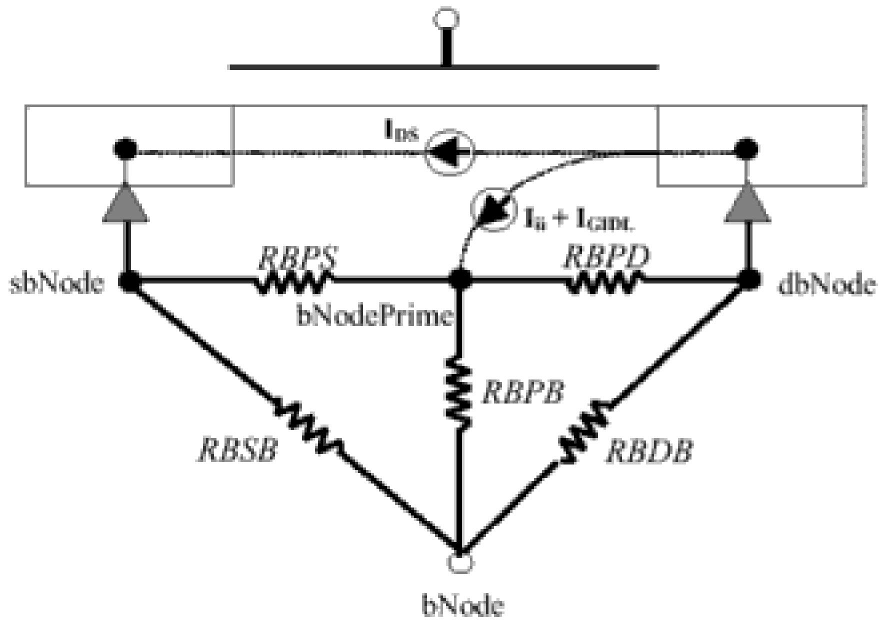
No substrate resistance network is generated at all.

rbody = 1 (On)

All five resistances in the substrate network as shown schematically below are present simultaneously.

A minimum conductance, *GBMIN*, is introduced in parallel with each resistance to prevent infinite resistance values which would otherwise cause poor convergence. In the following figure, *GBMIN* is merged into each resistance to simplify the representation of the model topology.

Note: The intrinsic model substrate reference point in this case is the internal body node **bNodePrime**, into which the impact ionization current I_{ii} and the GIDL current I_{GIDL} flow.



Noise Models

The following noise sources in MOSFETs are modeled in BSIM4 for noise analysis: flicker noise (also known as 1/f noise), channel thermal noise and induced gate noise and their correlation, thermal noise due to physical resistances such as the source/ drain, gate electrode, and substrate resistances, and shot noise due to the gate dielectric tunneling current.

Flicker Noise Models

BSIM4 provides two flicker noise models: simple model and unified physical model (default model). They can be selected by *fnoimod*. Both modes come from BSIM3v3, but there are many improvements in unified physical model.

fnoiMod = 0 (simple model)

The noise density is:

(21-142)

$$S_{id}(f) = \frac{KF \cdot I_{ds}^{AF}}{C_{oxe} L_{eff}^2 f^{EF}}$$

$$fnoimod = 1 \text{ (unified model)}$$

The total flicker noise density is:

(21-143)

$$S_{id}(f) = \frac{S_{id,inv}(f) \cdot S_{id,subvt}(f)}{S_{id,inv}(f) + S_{id,subvt}(f)}$$

The noise density in the inversion region is:

(21-144)

$$S_{id,inv}(f) = \frac{k_B T q^2 \mu_{eff} I_{ds}}{C_{ox}(L_{eff} - 2 \cdot LINTNOI)^2 A_{bulk} f^{EF} \cdot 10^{10}} \cdot \left(NOIA \cdot \log\left(\frac{N_0 + N^*}{N_l + N^*}\right) + NOIB \cdot (N_0 - N_l) + \frac{NOIC}{2}(N_0^2 - N_l^2) \right) + \frac{k_B T I_{ds}^2 \Delta L_{clm}}{W_{eff} \cdot (L_{eff} - 2 \cdot LINTNOI)^2 f^{EF} \cdot 10^{10}} \cdot \frac{NOIA + NOIB \cdot N_l + NOIC \cdot N_l^2}{(N_l + N^*)^2}$$

lintmoi is an offset to the length reduction parameter (*lint*) for flicker noise, which is introduced by BSIM4.4.

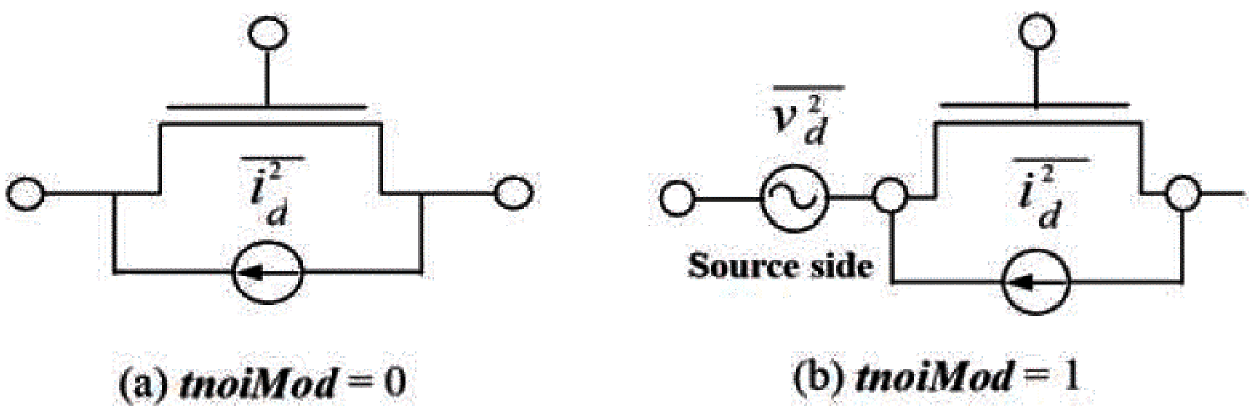
The noise density in the subthreshold region is:

(21-145)

$$S_{id,subVt}(f) = \frac{NOIA \cdot k_B T \cdot I_{ds}^2}{W_{eff} L_{eff} f^{EF} N^{*2} \cdot 10^{10}}$$

Channel Thermal Noise

BSIM4 provides two channel thermal noise models: charge-based model (default model) and the holistic model. They can be selected by *tnoimod*. The schematic for BSIM4 channel thermal noise modeling is shown as following:



tnoiMod = 0 (charge-based)

Charge-based model is similar to that used in BSIM3v3.2. The noise current is given by:

(21-146)

$$\overline{i_D^2} = \frac{4k_B T \Delta f}{R_{ds}(V) + \dfrac{L_{eff}^2}{\mu_{eff}|Q_{inv}|}} \cdot NTNOI$$

where

(21-147)

$$Q_{inv} = W_{active}L_{active}C_{oxeff} \cdot NF \cdot \left[V_{gsteff} - \frac{A_{bulk}V_{dseff}}{2} + \frac{A_{bulk}^{2}V_{dseff}^{2}}{12 \cdot \left(V_{gsteff} - \frac{A_{bulk}V_{dseff}}{2}\right)}\right]$$

tnoiMod = 1 (holistic)

In this thermal noise model, all the short-channel effects and velocity saturation effect incorporated in the IV model are automatically included, hence the name “holistic thermal noise model”. In addition, the amplification of the channel thermal noise through G_m and G_{mbs} as well as the induced-gate noise with partial correlation to the channel thermal noise are all captured in the new “noise partition” model.

The noise voltage source partitioned to the source side is given by

(21-148)

$$\overline{v_d^{2}} = 4k_BT \cdot \theta_{tnoi}^{2} \cdot \frac{V_{dseff}\Delta f}{I_{ds}}$$

The noise current source put in the channel region with gate and body amplification is given by:

(21-149)

$$\overline{i_d^{2}} = 4k_BT\frac{V_{dseff}\Delta f}{I_{ds}}[G_{ds} + \beta_{tnoi} \cdot (G_m + G_{mbs})]^2 - \overline{v_d^{2}} \cdot (G_m + G_{ds} + G_{mbs})^2 \qquad if Vds \geq Vdsat$$

where

(21-150)

$$\theta_{tnoi} = RNOIB \cdot \left[1 + TNOIB \cdot L_{eff} \cdot \left(\frac{V_{gsteff}}{E_{sat}L_{eff}}\right)^2\right]$$

$$\beta_{tnoi} = RNOIA \cdot \left[1 + TNOIA \cdot L_{eff} \cdot \left(\frac{V_{gsteff}}{E_{sat}L_{eff}}\right)^2\right]$$

Asymmetric MOS Junction Diode Models

Junction Diode IV Model

In BSIM4, there are three junction diode IV models. When the IV model selector ***dioMod*** is set to 0 ("resistance free"), the diode IV is modeled as resistance-free with or without breakdown depending on the parameter values of *XJBVS* or *XJBVD*. When ***dioMod*** is set to 1 ("breakdown-free"), the diode is modeled exactly the same way as in BSIM3v3 with current-limiting feature in the forward-bias region through the limiting current parameters *IJTHSFWD* or *IJTHDFWD*; diode breakdown is not modeled for ***dioMod*** = 1 and *XJBVS*, *XJBVD*, *BVS*, and *BVD* parameters all have no effect. When ***dioMod*** is set to 2 ("resistance-and-breakdown"), BSIM4 models the diode breakdown with current limiting in both forward and reverse operations. In general, setting ***dioMod*** to 1 produces fast convergence.

Source/Body Junction Diode

dioMod - 0 (resistance-free)

(21-151)

$$I_{bs} = I_{sbs}\left[\exp\left(\frac{qV_{bs}}{NJS \cdot k_B TNOM}\right) - 1\right] \cdot f_{breakdown} + V_{bs} \cdot G_{min}$$

where I_{sbs} is the total saturation current consisting of the components through the gate-edge (J_{sswgs}) and isolation-edge sidewalls (J_{ssws}) and the bottom junction (J_{ss}).

(21-152)

$$I_{sbs} = A_{seff} J_{ss}(T) + R_{seff} J_{ssws}(T) + W_{effcj} \cdot NF \cdot J_{sswgs}(T)$$

where

(21-153)

$$f_{breakdown} = 1 + XJBVS \cdot \exp\left(-\frac{q \cdot (BVS + V_{bs})}{NJS \cdot k_B TNOM}\right)$$

In the above equation, if *XJBVS* = 0, no breakdown will be modeled. If *XJBVS* < 0.0, it is reset to 1.0.

dioMod = 1 (breakdown-free)

The exponential IV term is linearized at the limiting current *IJTHSFWD* in the forward-bias model only.

(21-154)

$$I_{bs} = I_{sbs}\left[\exp\left(\frac{qV_{bs}}{NJS \cdot k_B TNOM}\right) - 1\right] + V_{bs} \cdot G_{min}$$

dioMod = 2 (resistance-and-breakdown)

Diode breakdown is always modeled. The exponential term is linearized at both the limiting current *IJTHSFWD* in the forward-bias mode and the limiting current *IJTHSREV* in the reverse-bias mode.

(21-155)

$$I_{bs} = I_{sbs}\left[\exp\left(\frac{qV_{bs}}{NJS \cdot k_B TNOM}\right) - 1\right] \cdot f_{breakdown} + V_{bs} \cdot G_{min}$$

for ***dioMod*** = 2, if *XJBVS* <= 0.0, it is reset to 1.0.

Drain/Body Junction Diode

The drain-side diode has the same system of equations as those for the source-side diode, but with a separate set of model parameters.

dioMod = 0 (resistance-free)

(21-156)

$$I_{bd} = I_{sbd}\left[\exp\left(\frac{qV_{bd}}{NJD \cdot k_B TNOM}\right) - 1\right] \cdot f_{breakdown} + V_{bd} \cdot G_{min}$$

where I_{sbd} is the total saturation current consisting of the components through the gate-edge (J_{sswgd}) and isolation-edge sidewalls (J_{sswd}) and the bottom junction (J_{sd}),

(21-157)

$$I_{sbd} = A_{deff} J_{sd}(T) + P_{deff} J_{sswd}(T) + W_{effcj} \cdot NF \cdot J_{sswgd}(T)$$

where

(21-158)

$$f_{breakdown} = 1 + XJBVD \cdot \exp\left(-\frac{q \cdot (BVD + V_{bd})}{NJD \cdot k_B TNOM}\right)$$

In the above equation, when *XJBVD* = 0, no breakdown is modeled. If *XJBVD* < 0.0, it is reset to 1.0.

dioMod = 1 (breakdown-free)

No breakdown is modeled. The exponential IV term is linearized at the limiting current *IJTHSFWD* in the forward-bias model only.

(21-159)

$$I_{bd} = I_{sbd}\left[\exp\left(\frac{qV_{bd}}{NJD \cdot k_B TNOM}\right) - 1\right] + V_{bd} \cdot G_{min}$$

dioMod = 2 (resistance-and-breakdown)

Diode breakdown is always modeled. The exponential term is linearized at both the limiting current *IJTHSFWD* in the forward-bias mode and the limiting current *IJTHSFWD* in the reverse-bias mode.

(21-160)

$$I_{bd} = I_{sbd}\left[\exp\left(\frac{qV_{bd}}{NJD \cdot k_B TNOM}\right) - 1\right] \cdot f_{breakdown} + V_{bd} \cdot G_{min}$$

For ***dioMod*** = 2, if *XJBVD* <= 0.0, it is reset to 1.0.

Total Junction Source/Drain Diode Including Tunneling

Total diode current including the carrier recombination and trap-assisted tunneling current in the space-charge region is modeled by:

(21-161)

$$I_{bs\_\text{total}} = I_{bs}$$
$$-W_{effcj} \cdot NF \cdot J_{tsswgs}(T) \cdot \left[\exp\left(\frac{-V_{bs}}{NJTSSWG(T) \cdot Vtm0} \cdot \frac{VTSSWGS}{VTSSWGS - V_{bs}}\right) - 1\right]$$
$$-P_{s,deff} J_{tssws}(T)\left[\exp\left(\frac{-V_{bs}}{NJTSSW(T) \cdot Vtm0} \cdot \frac{VTSSWS}{VTSSWS - V_{bs}}\right) - 1\right]$$
$$-A_{s,deff} J_{tss}(T)\left[\exp\left(\frac{-V_{bs}}{NJTS(T) \cdot Vtm0} \cdot \frac{VTSS}{VTSS - V_{bs}}\right) - 1\right] + g_{min} \cdot V_{bs}$$

(21-162)

$$I_{bd\_\text{total}} = I_{bd}$$
$$-W_{effcj} \cdot NF \cdot J_{tsswgd}(T) \cdot \left[\exp\left(\frac{-V_{bd}}{NJTSSWGD(T) \cdot Vtm0} \cdot \frac{VTSSWGD}{VTSSWGD - V_{bd}}\right) - 1\right]$$
$$-P_{s,deff} J_{tsswd}(T)\left[\exp\left(\frac{-V_{bd}}{NJTSSWD(T) \cdot Vtm0} \cdot \frac{VTSSWD}{VTSSWD - V_{bd}}\right) - 1\right]$$
$$-A_{d,deff} J_{tsd}(T)\left[\exp\left(\frac{-V_{bd}}{NJTSD(T) \cdot Vtm0} \cdot \frac{VTSD}{VTSD - V_{bd}}\right) - 1\right] + g_{min} \cdot V_{bd}$$

Junction Diode CV Model

Source and drain junction capacitances consist of three components: the bottom junction capacitance, sidewall junction capacitance along the isolation edge, and sidewall junction capacitance along the gate edge. An analogous set of equations are used for both sides but each side has a separate set of model parameters.

Source/Body Junction Diode

(21-163)

$$C_{bs} = A_{seff}C_{jbs} + P_{seff}C_{jbsws} + W_{effcj} \cdot NF \cdot C_{jbswgs}$$

where C_{jbs} is the unit-area bottom S/B junction capacitance, C_{jbsws} is the unit-length S/B junction sidewall capacitance along the isolation edge, and C_{jbswgs} is the unit-length S/B junction sidewall capacitance along the gate edge.

C_{jbs}

if $V_{bs} < 0$

(21-164)

$$C_{jbs} = CJS(T) \cdot \left(1 - \frac{V_{bs}}{PBS(T)}\right)^{-MJS}$$

otherwise

(21-165)

$$C_{jbs} = CJS(T) \cdot \left(1 + MJS \cdot \frac{V_{bs}}{PBS(T)}\right)$$

C_{jbsws}

if $V_{bs}< 0$

(21-166)

$$C_{jbsws} = CJSWS(T) \cdot \left(1 - \frac{V_{bs}}{PBSWS(T)}\right)^{-MJSWS}$$

otherwise

(21-167)

$$C_{jbsws} = CJSWS(T) \cdot \left(1 + MJSWS \cdot \frac{V_{bs}}{PBSWS(T)}\right)$$

C_{jbsws}

if $V_{bs}< 0$

(21-168)

$$C_{jbswgs} = CJSWGS(T) \cdot \left(1 - \frac{V_{bs}}{PBSWGS(T)}\right)^{-MJSWGS}$$

otherwise

(21-169)

$$C_{jbswgs} = CJSWGS(T) \cdot \left(1 + MJSWGS \cdot \frac{V_{bs}}{PBSWGS(T)}\right)$$

Drain/Body Junction Diode

(21-170)

$$C_{bd} = A_{deff}C_{jbd} + P_{deff}C_{jbswd} + W_{effcj} \cdot NF \cdot C_{jbswgd}$$

where C_{jbd} is the unit-area bottom D/B junction capacitance, C_{jbswd} is the unit-length D/B junction sidewall capacitance along the isolation edge, and C_{jbswgd} is the unit-length D/B junction sidewall capacitance along the gate edge.

C_{jbd}

if $V_{bd} < 0$

(21-171)

$$C_{jbd} = CJD(T) \cdot \left(1 - \frac{V_{bd}}{PBD(T)}\right)^{-MJD}$$

otherwise

(21-172)

$$C_{jbd} = CJD(T) \cdot \left(1 + MJD \cdot \frac{V_{bd}}{PBD(T)}\right)$$

C_{jbdsw}

f $V_{bd} < 0$

(21-173)

$$C_{jbswd} = CJSWD(T) \cdot \left(1 - \frac{V_{bd}}{PBSWD(T)}\right)^{-MJSWD}$$

otherwise

(21-174)

$$C_{jbswd} = CJSWD(T) \cdot \left(1 + MJSWD \cdot \frac{V_{bd}}{PBSWD(T)}\right)$$

C_{jbdswg}

f $V_{bd} < 0$

(21-175)

$$C_{jbswgd} = CJSWGD(T) \cdot \left(1 - \frac{V_{bd}}{PBSWGD(T)}\right)^{-MJSWD}$$

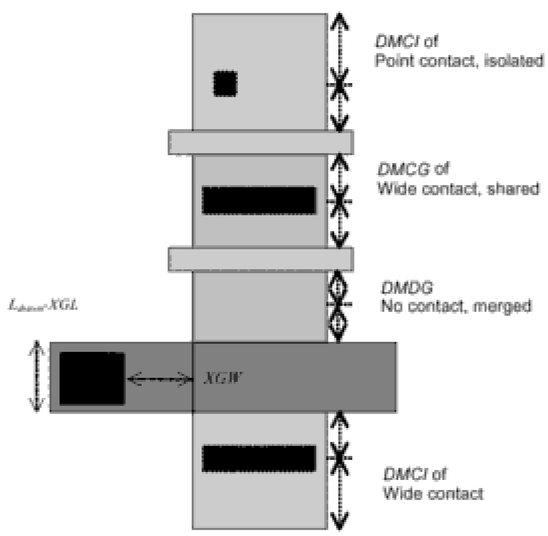
otherwise

(21-176)

$$C_{jbswgd} = CJSWGD(T) \cdot \left(1 + MJSWGD \cdot \frac{V_{bd}}{PBSWGD(T)}\right)$$

Layout Dependent Parasitics Models

The following figure shows the geometry definition for various source/drain connections and source/drain/gate contacts. The layout parameters shown in this figure will be used to calculate resistances and source/drain perimeters and areas.



Effective Junction Perimeter and Area

The source-side case is illustrated below. The same approach is used for the drain side. The effective junction perimeter is calculated by:

If (*PS* is given)

if (***perMod*** = 0)

$P_{seff} = PS$

else

(21-177)

$$P_{seff} = PS - W_{effcj} \cdot NF$$

Else

P_{seff} computed from *NF*, *DWJ*, ***geoMod***, *DMCG*, *DMCI*, *DMDG*, *DMCGT*, and *MIN*.

The effective junction area is calculated by:

If (*AS* is given)

$A_{seff} = AS$

Else

A_{seff} computed from *NF*, *DWJ*, ***geoMod***, *DMCG*, *DMCI*, *DMDG*, *DMCGT*, and *MIN*.

In the above, P_{seff} and A_{seff} will be used to calculate junction diode IV and CV. P_{seff} does not include the gate-edge perimeter.

geoMod	**End source**	**End drain**	**Note**
0	isolated	isolated	*NF=Odd*
1	isolated	shared	*NF=Odd, Even*
2	shared	isolated	*NF=Odd, Even*
3	shared	shared	*NF=Odd, Even*
4	isolated	merged	*NF=Odd*
5	shared	merged	*NF=Odd, Even*

geoMod	**End source**	**End drain**	**Note**
6	merged	isolated	*NF=Odd*
7	merged	shared	*NF=Odd, Even*
8	merged	merged	*NF=Odd*
9	sha/iso	shared	*NF=Even*
10	shared	sha/iso	*NF=Even*

Temperature Effects Models

Accurate modeling of the temperature effects on MOSFET characteristics is important to predict circuit behavior over a range of operating temperatures (*T*). The operating temperature might be different from the nominal temperature (*TNOM*) at which the BSIM4 model parameters are extracted.

Temperature Dependence of Threshold Voltage

The temperature dependence of V_{th} is modeled by:

(21-178)

$$V_{th}(T) = V_{th}(TNOM) + \left(KT1 + \frac{KT1L}{L_{eff}} + KT2 \cdot V_{bseff}\right) \cdot \left(\frac{T}{TNOM} - 1\right)$$

(21-179)

$$V_{fb}(T) = V_{fb}(TNOM) - KT1 \cdot \left(\frac{T}{TNOM} - 1\right)$$

(21-180)

$$VOFF(T) = VOFF(TNOM) \cdot [1 + TVOFF \cdot (T - TNOM)]$$

(21-181)

$$VFBSDOFF(T) = VFBSDOFF(TNOM) \cdot [1 + TVFBSDOFF \cdot (T - TNOM)]$$

Temperature Dependence of Mobility

(21-182)

$$U0(T) = U0(TNOM) \cdot (T/TNOM)^{UTE}$$

(21-183)

$$UA(T) = UA(TNOM) + UA1 \cdot (T/TNOM - 1)$$

(21-184)

$$UB(T) = UB(TNOM) + UB1 \cdot (T/TNOM - 1)$$

(21-185)

$$UC(T) = UC(TNOM) + UC1 \cdot (T/TNOM - 1)$$

Temperature Dependence of Saturation Velocity

(21-186)

$$v_{sat(T)} = VSAT(TNOM) - AT \cdot (T/TNOM - 1)$$

Temperature Dependence of LDD Resistance

rdsMod = 0 (internal source/drain LDD resistance)

(21-187)

$$RDSW(T) = RDSW(TNOM) + PRT \cdot \left(\frac{T}{TNOM} - 1\right)$$

(21-188)

$$RDSWMIN(T) = RDSWMIN(TNOM) + PRT \cdot \left(\frac{T}{TNOM} - 1\right)$$

rdsMod = 1 (external source/drain LDD resistance)

(21-189)

$$RDW(T) = RDW(TNOM) + PRT \cdot \left(\frac{T}{TNOM} - 1\right)$$

(21-190)

$$RDWMIN(T) = RDWMIN(TNOM) + PRT \cdot \left(\frac{T}{TNOM} - 1\right)$$

(21-191)

$$RSW(T) = RSW(TNOM) + PRT \cdot \left(\frac{T}{TNOM} - 1\right)$$

(21-192)

$$RSWMIN(T) = RSWMIN(TNOM) + PRT \cdot \left(\frac{T}{TNOM} - 1\right)$$

Temperature Dependence of Junction Diode IV

Side Source Diode 0

(21-193)

$$I_{sbs} = A_{seff}J_{ss}(T) + P_{seff}J_{ssws}(T) + W_{effcj} \cdot NF \cdot J_{sswgs}(T)$$

where

(21-194)

$$J_{ss}(T) = JSS(TNOM) \cdot \exp\left(\frac{\frac{E_g(TNOM)}{v_t(TNOM)} - \frac{E_g(T)}{v_t(T)} + XTIS \cdot \ln\left(\frac{T}{TNOM}\right)}{NJS}\right)$$

(21-195)

$$J_{ssws}(T) = JSSWS(TNOM) \cdot \exp\left(\frac{\frac{E_g(TNOM)}{v_t(TNOM)} - \frac{E_g(T)}{v_t(T)} + XTIS \cdot \ln\left(\frac{T}{TNOM}\right)}{NJS}\right)$$

(21-196)

$$J_{sswgs}(T) = JSSWGS(TNOM)x\left(\sqrt{\frac{JTWEFF}{W_{effci}}} + 1.0\right)\exp\left(\frac{\frac{E_g(Tnom)}{V_t(Tnom)} - \frac{E_g(T)}{V_t(T)} + XTIS \cdot \ln\left(\frac{T}{Tnom}\right)}{NJS}\right)$$

where

(21-197)

$$E_g(TNOM) = 1.16 - \frac{7.02 \times 10^{-4} TNOM^2}{TNOM + 1108}$$

(21-198)

$$E_g(T) = 1.16 - \frac{7.02 \times 10^{-4} T^2}{T + 1108}$$

(21-199)

$$n_i = 1.45e10 \cdot \frac{TNOM}{300.15} \cdot \sqrt{\frac{TNOM}{300.15}} \cdot \exp\left[21.5565981 - \frac{qE_g(TNOM)}{2 \cdot k_B T}\right]$$

Temperature Dependence of Junction Diode CV

Source-Side Diode

The temperature dependences of zero-bias unit-length/area junction capacitances on the source side are modeled by

(21-200)

$$CJS(T) = CJS(TNOM) \cdot [1 + TCJ \cdot (T - TNOM)]$$

(21-201)

$$CJSWS(T) = CJSWS(TNOM) + TCJSW \cdot (T - TNOM)$$

(21-202)

$$CJSWGS(T) = CJSWGS(TNOM) \cdot [1 + TCJSWG \cdot (T - TNOM)]$$

The temperature dependences of the built-in potentials on the source side are modeled by

(21-203)

$$PBS(T) = PBS(TNOM) - TPB \cdot (T - TNOM)$$

(21-204)

$$PBSWS(T) = PBSWS(TNOM) - TPBSW \cdot (T - TNOM)$$

(21-205)

$$PBSWGS(T) = PBSWGS(TNOM) - TPBSWG \cdot (T - TNOM)$$

Temperature Dependence of Junction Diode IV

(21-206)

$$J_{tsswgs,\,d}(T) = J_{tsswgs,\,d}(TNOM) \cdot \exp\left[\frac{-Eg(TNOM)}{k_B T} \cdot X_{tsswgs,\,d} \cdot \left(1 - \frac{T}{TNOM}\right)\right]$$

(21-207)

$$J_{tssws,d}(T) = J_{tssws,d}(TNOM) \cdot \exp\left[\frac{-Eg(TNOM)}{k_B T} \cdot X_{tssws,d} \cdot \left(1 - \frac{T}{TNOM}\right)\right]$$

(21-208)

$$J_{tss,d}(T) = J_{tss,d}(TNOM) \cdot \exp\left[\frac{-Eg(TNOM)}{k_B T} \cdot X_{tss,d} \cdot \left(1 - \frac{T}{TNOM}\right)\right]$$

(21-209)

$$NJTSSWG(T) = NJTSSWG(TNOM) \cdot \left[1 + TNJTSSWG\left(\frac{T}{TNOM} - 1\right)\right]$$

(21-210)

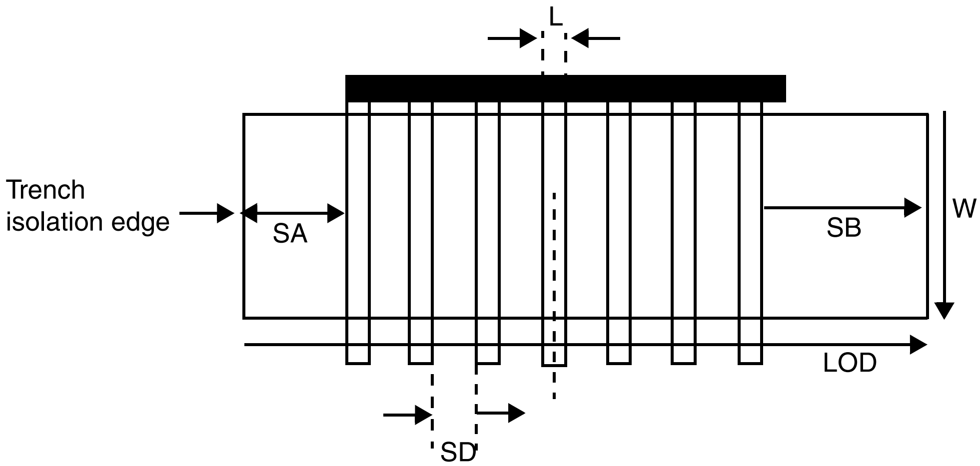
$$NJTSSW(T) = NJTSSW(TNOM) \cdot \left[1 + TNJTSSW\left(\frac{T}{TNOM} - 1\right)\right]$$

(21-211)

$$NJTS(T) = NJTS(TNOM) \cdot \left[1 + TNTJS\left(\frac{T}{TNOM} - 1\right)\right]$$

Stress Effects Models

BSIM4 considers the influence of stress on mobility, velocity saturation, threshold voltage, body effect, and DIBL effect. The following diagram displays the LOD instance geometry parameters SA and SB.



(21-212)

$$\mu_{eff} = \frac{1 + \rho_{\mu eff}(SA, SB)}{1 + \rho_{\mu eff}(SA_{ref}, SB_{ref})} \mu_{effo}$$

(21-213)

$$v_{sattemp} = \frac{1 + KVSAT \cdot \rho_{\mu eff}(SA, SB)}{1 + KVSAT \cdot \rho_{\mu eff}(SA_{ref}, SB_{ref})} v_{sattempo}$$

(21-214)

$$VTH0 = VTH0_{original} + \frac{KVTH0}{Kstress\_vth0} \cdot (Inv\_sa + Inv\_sb - Inv\_sa_{ref} - Inv\_sb_{ref})$$

(21-215)

$$K2 = K2_{original} + \frac{STK2}{Kstress\_vth0^{LODK2}} \cdot (Inv\_sa + Inv\_sb - Inv\_sa_{ref} - Inv\_sb_{ref})$$

(21-216)

$$ETA0 = ETA0_{original} + \frac{STETA0}{Kstress\_vth0^{LODETA0}} \cdot (Inv\_sa + Inv\_sb - Inv\_sa_{ref} - Inv\_sb_{ref})$$

where

(21-217)

$$\rho_{\mu eff} = \frac{KU_0}{Kstress\_\mu 0} \cdot (Inv\_sa + Inv\_sb)$$

(21-218)

$$K_{stress\_\mu 0} = \left(1 + \frac{LKU0}{(L_{drawn} + XL)^{LLODKU0}} + \frac{WKU0}{(W_{drawn} + XW + WLOD)^{WLODKU0}} + \frac{PKU0}{(L_{drawn} + XL)^{LLODKU0} \cdot (W_{drawn} + XW + WLOD)^{WLODKU0}}\right) \cdot \left(1 + TKU0 \cdot \left(\frac{Temperature}{TNOM} - 1\right)\right)$$

(21-219)

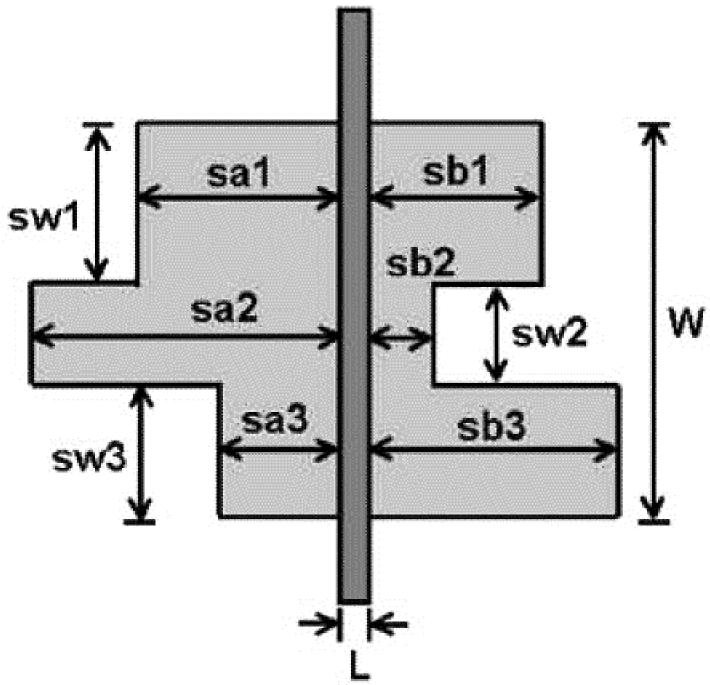
$$K_{stress\_vth0} = \left(1 + \frac{LKVTH0}{(L_{drawn} + XL)^{LLODKVTH}} + \frac{WKVTH0}{(W_{drawn} + XW + WLOD)^{WLODKVTH}} + \frac{PKVTH0}{(L_{drawn} + XL)^{LLODKVTH} \cdot (W_{drawn} + XW + WLOD)^{WLODKVTH}}\right) \cdot \left(1 + TKU0 \cdot \left(\frac{Temperature}{TNOM} - 1\right)\right)$$

(21-220)

$$Inv\_sa = \frac{1}{NF} \sum_{i=0}^{NF-1} \frac{1}{SA + 0.5 \cdot L_{drawn} + i \cdot (SD + L_{drawn})}$$

(21-221)

$$Inv\_sb = \frac{1}{NF}\sum_{i=0}^{NF-1}\frac{1}{SB+0.5\cdot L_{drawn}+i\cdot(SD+L_{drawn})}$$



For irregular LOD device like above figure, more instance parameters (swi, sai and sbi) are needed. Then,

(21-222)

$$Inv\_sa = \sum_{i=1}^{n}\frac{sw_i}{W_{drawn}}\cdot\frac{1}{sa_i+0.5\cdot L_{drawn}}$$

(21-223)

$$Inv\_sb = \sum_{i=1}^{n}\frac{sw_i}{W_{drawn}}\cdot\frac{1}{sb_i+0.5\cdot L_{drawn}}$$

Well Proximity Effect Model

Deep buried layers can affect devices located near the mask edge. Some of the ions scattered out of the edge of the photoresist are implanted in the silicon surface near the mask edge, altering the threshold voltage of those devices. BSIM4 considers the influence of well proximity effect on threshold voltage, mobility, and body effect as following:

(21-224)

$$Vth0 = Vth0_{org} + KVTH0WE \cdot (SCA + WEB \cdot SCB + WEC \cdot SCC)$$

(21-225)

$$\mu_{eff} = \mu_{eff,org} \cdot (1 + KU0WE \cdot (SCA + WEB \cdot SCB + WEC \cdot SCC))$$

(21-226)

$$K2 = K2_{org} + K2WE \cdot (SCA + WEB \cdot SCB + WEC \cdot SCC)$$

TMIBSIM4 Model (tmibsim4)

The TSMC Model Interface (TMI) implements a modified version of the BSIM4 model, known as TMIBSIM4. You can activate the `tmibsim4` model by specifying the `tmiflag` and `tmipath` parameters as follows:

```
.options tmiflag = 1
.option tmipath = TMI_shared-library_path
```

Models and Equations in Version Updates

This section briefly lists equations and information for various BSIM4 model versions. For more details, please refer to UC Berkeley’s BSIM4.64 Users’ Manual

http://www-device.eecs.berkeley.edu/~bsim3/BSIM4/BSIM464/BSIM464_Manual.pdf

BSIM4 Version 4

BSIM4.4 has the following updates.

Trap-Assisted-Tunneling Current

(21-227)

$$
\begin{aligned}
I_{bs,\,d} = {} & I_{sbs,\,d}\left[\exp\left(\frac{qV_{bs,\,d}}{NJS,\,D\cdot k_B T}\right)-1\right]\cdot f_{breakdown} \\
& -W_{effcj}\cdot NF\cdot J_{tsswgs,\,d}(T)\cdot\left[\exp\left(\frac{-V_{bs,\,d}}{NJTSSWG(T)\cdot Vtm0}\cdot\frac{VTSSWGS,\,D}{VTSSWGS,\,D-V_{bs,\,d}}\right)-1\right] \\
& -P_{s,\,deff}J_{tssws,\,d}(T)\left[\exp\left(\frac{-V_{bs,\,d}}{NJTSSW(T)\cdot Vtm0}\cdot\frac{VTSSWS,\,D}{VTSSWS,\,D-V_{bs,\,d}}\right)-1\right] \\
& -A_{s,\,deff}J_{tss,\,d}(T)\left[\exp\left(\frac{-V_{bs,\,d}}{NJTS(T)\cdot Vtm0}\cdot\frac{VTSS,\,D}{VTSS,\,D-V_{bs,\,d}}\right)-1\right] \\
& +V_{bs,\,d}\cdot G_{min}
\end{aligned}
$$

Flatband Voltage Offset Parameter

VFBSDOFF is an offset voltage added to the original source/drain flatband voltage which allows independent setting of V_{fbsd} to accurately model gate overlap tunneling current.

(21-228)

$$
V_{fbsd} = k_B T/q\log(NGATE/NSD) + VFBSDOFF
$$

Length Reduction Parameter Offset

BSIM4.4 has a new parameter LINTNOI which is an offset to the length reduction parameter (Lint) for flicker noise.

For fnoiMod=1 (unified model), the noise density in the inversion region is:

(21-229)

$$S_{id,\,inv}(f) = \frac{k_B T q^2 \mu_{eff} I_{ds}}{C_{oxe}(L_{eff} + LINTNOI)^2 A_{bulk} f^{ef}} \left(NOIA \cdot \log\left(\frac{N_0 + N^*}{N_l + N^*}\right) + NOIB \cdot (N_o - N_l) + \frac{NOIC}{2}(N_0^{\,2} - N_l^{\,2}) \right) + \frac{k_B (T I_{ds}^{\,2} \Delta L_{clm})}{W_{eff} \cdot (L_{eff} + LINTNOI)^2 f^{ef} \cdot 10^{10}} \cdot \frac{NOIA + NOIB \cdot N_l + NOIC \cdot N_l^{\,2}}{(N_l + N^*)^2}$$

New Temperature Model

(21-230)

$$J_{tsswgs,\,d}(T) = J_{tsswgs,\,d}(TNOM) \cdot \exp\left[\frac{-Eg(TNOM)}{k_B T} \cdot X_{tsswgs,\,d} \cdot \left(1 - \frac{T}{TNOM}\right)\right]$$

(21-231)

$$J_{tssws,\,d}(T) = J_{tssws,\,d}(TNOM) \cdot \exp\left[\frac{-Eg(TNOM)}{k_B T} \cdot X_{tssws,\,d} \cdot \left(1 - \frac{T}{TNOM}\right)\right]$$

(21-232)

$$J_{tss,\,d}(T) = J_{tss,\,d}(TNOM) \cdot \exp\left[\frac{-Eg(TNOM)}{k_B T} \cdot X_{tss,\,d} \cdot \left(1 - \frac{T}{TNOM}\right)\right]$$

(21-233)

$$NJTSSWG(T) = NJTSSWG(TNOM) \cdot \left[1 + TNJTSSWG\left(\frac{T}{TNOM} - 1\right)\right]$$

(21-234)

$$NJTSSW(T) = NJTSSW(TNOM) \cdot \left[1 + TNJTSSW\left(\frac{T}{TNOM} - 1\right)\right]$$

(21-235)

$$NJTS(T) = NJTS(TNOM) \cdot \left[1 + TNTJS\left(\frac{T}{TNOM} - 1\right)\right]$$

BSIM4 Version 5

BSIM4.5.0 has the following new features:

- A mobility model which accounts for Coulomb scattering effect as well as the channel length dependence of mobility due to heavy halo-doping
- A scalable substrate resistance model (rbodyMod = 2) that is scalable with channel length, channel width, and number of fingers
- Gate resistance parameters XGW, NGCON that can now be specified as instance parameters (XGL is still a model parameter)
- Additional temperature dependence of model parameters VOFF and VFBSDOFF
- Enhanced tempMod = 2, where Vth(DITS) and gate tunneling models are functions of nominal temperature and the temperature dependence of zero-bias flat-band voltage is added
- A new instance parameter DELVTO that may be used to represent threshold voltage variation
- A new well-proximity effect model developed by CMC companies
- Igc Vbs dependence improvement with the full BSIM4 Vth model implemented

Mobility Model

Mobility Coulomb Scattering Model and Leff dependence

(21-236)

mobMod=0

$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + (UA + UCV_{bseff})\left(\frac{V_{gsteff} + 2V_{th}}{TOXE}\right) + UB\left(\frac{V_{gsteff} + 2V_{th}}{TOXE}\right)^2 + UD\left(\frac{V_{th} \cdot TOXE}{V_{gsteff} + 2\sqrt{V_{th} + 0.0001}}\right)^2}$$

(21-237)

mobMod=1

$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + \left[UA\left(\frac{V_{gsteff} + 2V_{th}}{TOXE}\right) + UB\left(\frac{V_{gsteff} + 2V_{th}}{TOXE}\right)^2\right](1 + UC \cdot V_{bseff}) + UD\left(\frac{V_{th} \cdot TOXE}{V_{gsteff} + 2\sqrt{V_{th + 0.0001}}}\right)^2}$$

(21-238)

mobMod=2

$$\mu_{eff} = U0/1 + (UA + UC \cdot V_{bseff})\left[\frac{V_{gsteff} + C_0 \cdot (VTHO - VFB - \Phi_s)}{TOXE}\right]^{EU} +$$

$$UD\left(\frac{V_{th} \cdot TOXE}{V_{gsteff} + 2\sqrt{V_{th}^2 + 0.0001}}\right)^2$$

where the constant C0 = 2 for NMOS and 2.5 for PMOS.

(21-239)

$$f(L_{eff}) = 1 - UP \cdot e^{-L_{eff}/(LP)}$$

Scalable Substrate Resistance Model

(21-240)

$$R_X = R_{X\_\mathrm{HORT}} \parallel R_{X\_\mathrm{VERT}} \qquad where\ R_{X\_\mathrm{H(V)}} = R_0 L^{a} W^{\beta} NF$$

Temperature Dependence for VOFF, VFBSDOFF

(21-241)

$$VOFF(T) = VOFF(TNOM) \cdot [1 + TVOFF \cdot (T - TNOM)]$$

(21-242)

$$VFBSDOFF(T) = VFBSDOFF(TNOM) \cdot [1 + TVFBSDOFF \cdot (T - TNOM)]$$

New Temperature Mode (TempMod = 2)

Share the same temperature equations as for TempMod=1 with the following modifications:

From

(21-243)

$$\Delta V_{th}(DITS) = -nv_t \cdot \ln\left(\frac{L_{eff}}{L_{eff} + DVTP0 \cdot (1 + e^{-DVPT1 \cdot V_{ds}})}\right)$$

To

(21-244)

$$\Delta V_{th}(DITS) = -nv_{tnom} \cdot \ln\left(\frac{L_{eff}}{L_{eff} + DVTP0 \cdot (1 + e^{-DVPT1 \cdot V_{ds}})}\right)$$

Vfbzb(T)

(21-245)

$$V_{fbzb}(T) = V_{fbzb}(TNOM) - KT1 \cdot \left(\frac{T}{TNOM} - 1\right)$$

Igate(T)

T is replaced by TNOM

DELVTO: An Instance Parameter

if vth0 is given:

(21-246)

$$Vth0 = Vth0 + DELVTO$$

if vth0 is not given,

(21-247)

$$Vfb = Vfb + DELVTO$$

(21-248)

$$Vth0 = Vfb + \Phi + k1 \times \sqrt{k1}$$

Well-Proximity Effect Modeling

Instance parameters: SCA, SCB, SCC, SC

Model parameters: WEB, WEC, KVTH0WE, K2WE, KU0WE,SCREF,WPEMOD

Model equations:

(21-249)

$$Vth0 = Vth0_{org} + KVTH0WE \cdot (SCA + WEB \cdot SCB + WEC \cdot SCC)$$

(21-250)

$$K2 = K2_{ORG} + K2WE \cdot (SCA + WEB \cdot SCB + WEC \cdot SCC)$$

(21-251)

$$\mu_{eff} = \mu_{eff,\, org} \cdot (1 + KU0WE \cdot (SCA + WEB \cdot SCB + WEC \cdot SCC))$$

Gate Current Vbs Dependence

(21-252)

$$Igc0 = W_{eff}L_{eff} \cdot A \cdot T_{oxRatio} \cdot V_{gse} \cdot V_{aux} \cdot \exp[-B \cdot TOXE(AIGC - BIGC \cdot V_{OXDEPINV}) \cdot (1 + CIGC \cdot v_{oxdepinv})]$$

For IGCMOD=1

(21-253)

$$V_{aux} = NIGC \cdot v_t \cdot \log\left(1 + \exp\left(\frac{V_{gse} - VTH0}{NIGC \cdot v_t}\right)\right)$$

For IGCMOD=2

(21-254)

$$V_{aux} = NIGC \cdot v_t \cdot \log\left(1 + \exp\left(\frac{V_{gse} - VTH\_\mathrm{bsim4}}{NIGC \cdot v_t}\right)\right)$$

Implementing full BSIM4 Vth model into Igc enables the accurate prediction of Igc Vbs dependence.

BSIM4 Version 6

GISL and GIDL Leakage Module

Four new parameters have been added.

Junction Diode I-V

In BSIM4.5.0, the junction diode current due to the trap-assisted tunneling current in space-charge region has same set of parameters for both source and drain junctions.

Gate Tunneling Current

In BSIM4.5.0, the gate tunneling current in the overlapping S/D diffusion regions (IGS / IGD) share the same set of parameters for both source and drain (DLCIG, AIGSD, BIGSD, CIGSD).

In BSIM4.6.0, the parameters for IGS and IGD are separate.

- I_{GS} : DLCIG, AIGS, BIGS, CIGS
- I_{GD} : DLCIGD, AIGD, BIGD, CIGD

Mobility Model

The coulomb scattering term has been modified in BSIM4.6.0 release to avoid the possibility of non-monotonic drain current trend with respect to gate voltage.

mobMod=0

(21-255)

$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + (UA + UCV_{bseff})\left(\frac{V_{gsteff} + 2V_{th}}{TOXE}\right) + UB\left(\frac{V_{gsteff} + 2V_{th}}{TOXE}\right)^2 + UD\left(\frac{V_{th} \cdot TOXE}{V_{gsteff} + 2\sqrt{V_{th}^2 + 0.00001}}\right)^2}$$

mobMod=1

(21-256)

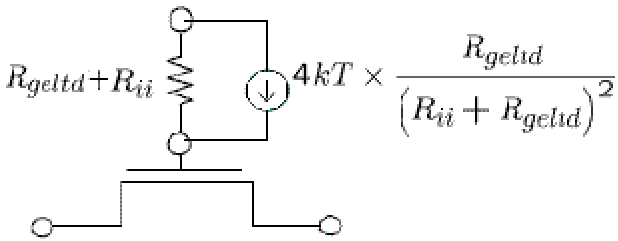
$$\mu_{eff} = \frac{U0 \cdot f(L_{eff})}{1 + \left[UA\left(\frac{V_{gsteff} + 2V_{th}}{TOXE}\right) + UB\left(\frac{V_{gsteff} + 2V_{th}}{TOXE}\right)^2\right](1 + UC \cdot V_{bseff}) + UD\left(\frac{V_{th} \cdot TOXE}{V_{gsteff} + 2\sqrt{V_{th}^2 + 0.00001}}\right)^2}$$

mobMod=2

(21-257)

$$\mu_{eff} = \frac{U0}{1 + (UA + UC \cdot V_{bseff})\left[\frac{V_{gsteff} + C_0 \cdot (VTHO - VFB - \Phi_s)}{TOXE}\right]^{EU} + UD\left(\frac{V_{th} \cdot TOXE}{V_{gsteff} + 2\sqrt{V_{th}^2 + 0.00001}}\right)^2}$$

Improvement to NOIMOD = 2



BSIM4 Version 6.1

C-V Model

A new VgsteffCV definition is introduced in the C-V model to improve threshold fitting. Six new parameters have been added: CVCHARGEMOD, MINVCV, LMINVCV, WMINVCV, WMINVCV, PMINVCV, and VOFFCVL.

New Material Model

A new materials model (activated by setting MTRLMOD=1) has been introduced with the following features:

- Predictive modeling of
  - Non-SiO2 insulator
  - Non-poly-Si gate
    New parameters
  - Non-silicon channel
- Improved predictive models for GIDL/GISL leakage current, mobility degradation, and short channel effects
- A model selector (MTRLMOD) is used to turn on/off all the new materials parameters and equations for backward compatibility.

New Materials Model Parameters

Model selector:

MTRLMOD : =1 activates the new-materials option and =0 (default) deactivates

For non-poly-silicon gate:

- PHIG : Gate work function
- EPSRGATE : Dielectric constant of gate relative to vacuum (= 0 deactivates poly depletion)

For non-SiO2 gate-dielectric:

- EOT : Equivalent SiO2 thickness
- VDDEOT : Gate voltage at which EOT is measured

For non-silicon channel material:

- EASUB : Electron affinity of substrate
- EPSRSUB : Dielectric constant of substrate relative to vacuum
- NI0SUB : Intrinsic carrier concentration at T=300.15K
- BG0SUB : Band-gap of substrate at T=0K
- TBGASUB : First parameter of band-gap change due to temperature
- TBGBSUB : Second parameter of band-gap change due to temperature
- ADOS : Density of states parameter to control charge centroid
- BDOS : Density of states parameter to control charge centroid

Non-Silicon Channel Material

Defines the temperature-dependent intrinsic carrier concentrations and the band gap with the new non-silicon parameters for MTRLMOD = 1.

(21-258)

$$Eg0 = BG0SUB - \frac{TBGASUB \times Tnom^2}{Tnom + TBGBSUB}$$

(21-259)

$$Eg(300.15) = BG0SUB - \frac{TBGASUB \times 300.15^2}{300.15 + TBGBSUB}$$

(21-260)

$$ni = NI0SUB \times \left(\frac{Tnom}{300.15}\right)^{3/2} \cdot e^{\frac{Eg(300.15K) - Eg0}{2V_t}}$$

(21-261)

$$Eg = BG0SUB - \frac{TBGASUB \times Temp^2}{Temp + TBGBSUB}$$

Introduces two new parameters for charge centroid for non-silicon channel materials in both I-V and C-V models.

(21-262)

$$X_{dc} = \frac{ADOS \times 1.9 \times 10^{-9}}{1 + \left(\frac{Vgsteff + (VTH0 - VFB - \phi_s)}{2toxp}\right)^{0.7 \times BDOS}}$$

Non-SiO2 Dielectric Material

For MTRLMOD = 1, use EOT (defined as the electrical oxide thickness at V_{gs} = VDDEOT) to calculate oxide thickness at flatband voltage.

(21-263)

$$Toxp = EOT - \frac{3.9}{EPSRSUB} \cdot X_{dc|Vgs = VDDEOT, V_{ds} = V_{bs} = 0}$$

Non-poly-Si gate Material

Poly depletion is calculated using the following equation:

(21-264)

$$V_{gse} = VFB + \Phi_s + \frac{q\varepsilon_{gate}NGATE}{coxe^2}\left(\sqrt{1 + \frac{2coxe^2(V_{gs} - VFB - \Phi_s)}{q\varepsilon_{gate}NGATE}} - 1\right)$$

where

(21-265)

$$\varepsilon_{gate} = EPSRGATE \cdot EPS0 \qquad for\ \text{MTRLMOD=1}$$
$$\varepsilon_{gate} = EPSSI \qquad for\ \text{MTRLMOD=0}$$

Setting EPSRGATE = 0 turns the poly depletion model off.

Improved Mobility Model

The new equations for the improved mobility model are given in the coming sections.

Improved GIDL/GISL Model

For MTRLMOD=1, the flat band voltage at source/drain is given in the coming sections. New equations for the GIDL and GISL model are also given.

BSIM4 Version 6.2

Width Dependent TAT Model

New Model Parameter

A new model parameter `JTWEFF` is added to describe the TAT current width dependence.

Change in Equation for Temperature Dependence of Junction Diode IV

Side Source Diode 0

(21-266)

$$I_{sbs} = A_{seff}J_{ss}(T) + P_{seff}J_{ssws}(T) + W_{effcj} \cdot NF \cdot J_{sswgs}(T)$$

where

(21-267)

$$J_{ss}(T) = JSS(TNOM) \cdot \exp\left(\frac{\frac{E_g(TNOM)}{v_t(TNOM)} - \frac{E_g(T)}{v_t(T)} + XTIS \cdot \ln\left(\frac{T}{TNOM}\right)}{NJS}\right)$$

(21-268)

$$J_{ssws}(T) = JSSWS(TNOM) \cdot \exp\left(\frac{\frac{E_g(TNOM)}{v_t(TNOM)} - \frac{E_g(T)}{v_t(T)} + XTIS \cdot \ln\left(\frac{T}{TNOM}\right)}{NJS}\right)$$

(21-269)

$$J_{sswgs}(T) = JSSWGS(TNOM)x\left(\sqrt{\frac{JTWEFF}{W_{effci}}} + 1.0\right)\exp\left(\frac{\frac{E_g(Tnom)}{V_t(Tnom)} - \frac{E_g(T)}{V_t(T)} + XTIS \cdot \ln\left(\frac{T}{Tnom}\right)}{NJS}\right)$$

where

(21-270)

$$E_g(TNOM) = 1.16 - \frac{7.02 \times 10^{-4} TNOM^2}{TNOM + 1108}$$

(21-271)

$$E_g(T) = 1.16 - \frac{7.02 \times 10^{-4} T^2}{T + 1108}$$

(21-272)

$$n_i = 1.45e10 \cdot \frac{TNOM}{300.15} \cdot \sqrt{\frac{TNOM}{300.15}} \cdot \exp\left[21.5565981 - \frac{qE_g(TNOM)}{2 \cdot k_B T}\right]$$

High K Mobility

New Model Parameters

The following new model parameters are added:

- LUCS
- LUCSTE
- PUCS
- PUCSTE
- UCS

- UCSTE
- WUCS
- WUCSTE

The UCS parameter is temperature dependent as given below:

(21-273)

$$UCS(T) = UCS(TNOM) \cdot \left(\frac{T}{TNOM}\right)^{UCSTE}$$

New Mobility Model for High K Material

A new mobility model `mobMod=3` is added to enhance the modeling of coulomb scattering in high-k and metal gate transistors.

New Temperature Mode (tempMod = 3) for Mobility

`tempMod=3` only affects the mobility. Other parameters, such as `Rs` and `Rd` are the same as in `tempMod=2`.

Note the following:

- For `tempMod=1`, `tempMod=2` and `tempMod=3`:

(21-274)

$$U0(T) = U0(TNOM) \cdot \left(\frac{T}{TNOM}\right)^{UTE}$$

and

(21-275)

$$UCS(T) = UCS(TNOM) \cdot \left(\frac{T}{TNOM}\right)^{UCSTE}$$

- However, when `tempMod=3`:

(21-276)

$$UA(T) = UA(TNOM) \cdot \left(\frac{T}{TNOM}\right)^{UA1}$$

(21-277)

$$UB(T) = UB(TNOM) \cdot \left(\frac{T}{TNOM}\right)^{UB1}$$

(21-278)

$$UC(T) = UC(TNOM) \cdot \left(\frac{T}{TNOM}\right)^{UC1}$$

(21-279)

$$UD(T) = UD(TNOM) \cdot \left(\frac{T}{TNOM}\right)^{UD1}$$

BSIM4 Version 7.0

GIDL/GISL Model

A new model selector GIDLMOD=1 is introduced to decouple V_d from V_g through new parameters RGIDL, KGIDL and FGIDL (same for GISL).

(21-280)

$$I_{GIDL} = AGIDL \cdot W_{diod} \cdot Nf \cdot \frac{V_{ds} - RGIDL \cdot V_{gse} - EGIDL + V_{fbsd}}{3 \cdot T_{oxe}} \cdot \exp\left(-\frac{3 \cdot T_{oxe} \cdot BGIDL}{V_{ds} - V_{gse} - EGIDL}\right) \cdot \exp\left(\frac{KGIDL}{V_{ds} - FGIDL}\right)$$

DIBL/Rout Model

A new function tanh() is introduced to capture the V_{ds} effect in long channel devices.

(21-281)

$$
\begin{aligned}
V_{th} = {} & VTH0 + \left(K_{10x}\cdot\sqrt{\Phi_s - V_{bseff}} - K1\cdot\sqrt{\Phi_s}\right)\sqrt{1+\frac{LPEB}{L_{eff}}} - K_{2ox}V_{bseff} \\
& + K_{1ox}\left(\sqrt{1+\frac{LPE0}{L_{eff}}}-1\right)\sqrt{\Phi_s} + (K3 + K3B\cdot V_{bseff})\frac{TOXE}{W_{eff}' + W0}\Phi_s \\
& -0.5\cdot\left[\frac{DVT0W}{\cosh\left(DVT1W\frac{L_{eff}W_{eff}'}{l_{tw}}\right)-1} + \frac{DVT0}{\cosh\left(DVT1\frac{L_{eff}}{l_t}\right)-1}\right](V_{bi}-\Phi_s) \\
& - \frac{0.5}{\cosh\left(DSUB\frac{L_{eff}}{l_{t0}}\right)-1}(ETA0 + ETAB\cdot V_{bseff})\cdot V_{ds} \\
& - nv_t\cdot 1n\left(\frac{L_{eff}}{L_{eff} + DVTP0\cdot\left(1+e^{-DVTPI\cdot V_{DS}}\right)}\right) \\
& - \left(DVTP5 + \frac{DVTP2}{L_{eff}^{DVTP3}}\right)\cdot\tanh(DVTP4\cdot V_{ds})
\end{aligned}
$$

where DVTP2, DVTP3, DVTP4, and DVTP5 are new model parameters.

Temperature Dependence of Subthreshold Leakage Current

The new temperature dependence of subthreshold leakage current is modeled by:

(21-282)

$$Nfactor(T) = nfactor(Tnom) + tnfactor\left(\frac{T}{Tnom}-1\right)$$

$$ETA0(T) = ETA0(Tnom) + TETA0*\left(\frac{T}{Tnom}-1\right)$$

$$voffCV(T) = voffCV*(1.0 + tvoffCV*(T - Tnom))$$

where tnfactor, TETA0, and tvoffCV are the new model parameters.

New Model Selector for MTRLMOD=0 and MTRLMOD=1 Compatibility

A new model selector MTRLCOMPATMOD=1 is introduced to make MTRLMOD=0 and MTRLMOD=1 consistent.

Physical Oxide Thickness

When MTRLMOD=1 and MTRLCOMPATMOD=1

(21-283)

$$T_{oxp} = EOT * \frac{EPSROX}{3.9} - DTOX$$

Effective Field for Mobility Calculation

(21-284)

$$E_{eff}(V_{gsteff} + 2V_{th} - 2(V_{fb} + \phi_{st})) \qquad \text{for mtrlMod} = 1$$
$$E_{eff}(V_{gsteff} + 2V_{th}) \qquad \text{for mtrlMod} = 0$$

With MTRLCOMPATMOD=1 and MTRLMOD=1

(21-285)

$$E_{eff}(V_{gsteff} + 2V_{th})$$

Enhanced Thermal Noise Model

A new thermal noise model tnoimod=2 has been implemented in SPICE3. Following new expressions have been added for drain noise (S_{id}), induced gate noise (S_{ig}) and correlation coefficient (c):

Drain Noise

(21-286)

$$S_{id} = 4kT \cdot \gamma \cdot g_{d0} \cdot (3 \cdot \beta_{noi}{}^2)$$

Induced Gate Noise

(21-287)

$$S_{ig0} = 4kT \cdot C_0^{\ 2} \cdot \omega^2 \cdot \frac{\delta}{g_{d0}} \cdot \left(\frac{15 \cdot \theta_{noi}^{\ 2}}{4}\right)$$

Correlation Coefficient

(21-288)

$$c = -j\sqrt{\frac{\varepsilon}{\gamma \cdot \delta}} \cdot \left(\frac{c_{tnoi}}{0.395}\right)$$

Where

(21-289)

$$\beta_{noi} = RNOIA \cdot \left[1 + TNOIA \cdot L_{eff} \cdot \left(\frac{V_{gsteff}}{E_{sat}L_{eff}}\right)^2\right] \qquad RNOIA = 0.577(\text{default})$$

$$\theta_{noi} = RNOIB \cdot \left[1 + TNOIB \cdot L_{eff} \cdot \left(\frac{V_{gsteff}}{E_{sat}L_{eff}}\right)^2\right] \qquad RNOIB = 0.5164(\text{default})$$

$$C_{tnoi} = RNOIC \cdot \left[1 + TNOIC \cdot L_{eff} \cdot \left(\frac{V_{gsteff}}{E_{sat}L_{eff}}\right)^2\right] \qquad RNOIC = 0.395(\text{default})$$

$$g_{d0} = NF \times \frac{\mu_{eff}C_{oxeff}\frac{W_{eff}}{L_{eff}}V_{gsteff}}{1 + gche \cdot R_{ds}}$$

$$C_0 = NF \times C_{oxeff}W_{eff,CV}L_{eff,CV}$$

BSIM4 Version 8.0

Mobility Models

BSIM4.80 introduces three new mobility models mobmod=4, mobmod=5, and mobmod=6. See equations 21-31, 21-32, and 21-33 for details.

Component Statements

This device is supported within altergroups.

Instance Definition

Name d g s b ModelName parameter=value ...

Instance Parameters

1 `w (m)`	Channel width.
2 `l (m)`	Channel length.
3 `as` (m^2)	Area of source diffusion.
4 `ad` (m^2)	Area of drain diffusion.
5 `ps (m)`	Perimeter of source diffusion.
6 `pd (m)`	Perimeter of drain diffusion.
7 `nrd`	Number of squares of drain diffusion.
8 `nrs`	Number of squares of source diffusion.
9 `rdc=0.0` Ω	Drain contact resistance.
10 `rsc=0.0` Ω	Source contact resistance.
11 `sa=0.0 m`	Distance between OD edge to poly from one side.
12 `sb=0.0 m`	Distance between OD edge to poly from the other side.
13 `sd=0.0 m`	Distance between neighbor fingers.
14 `sa1=0.0 m`	Distance between OD edge to poly from one side 1.

15 `sa2=0.0 m`	Distance between OD edge to poly from one side 2.
16 `sa3=0.0 m`	Distance between OD edge to poly from one side 3.
17 `sa4=0.0 m`	Distance between OD edge to poly from one side 4.
18 `sa5=0.0 m`	Distance between OD edge to poly from one side 5.
19 `sa6=0.0 m`	Distance between OD edge to poly from one side 6.
20 `sa7=0.0 m`	Distance between OD edge to poly from one side 7.
21 `sa8=0.0 m`	Distance between OD edge to poly from one side 8.
22 `sa9=0.0 m`	Distance between OD edge to poly from one side 9.
23 `sa10=0.0 m`	Distance between OD edge to poly from one side 10.
24 `sb1=0.0 m`	Distance between OD edge to poly from other side 1.
25 `sb2=0.0 m`	Distance between OD edge to poly from other side 2.
26 `sb3=0.0 m`	Distance between OD edge to poly from other side 3.
27 `sb4=0.0 m`	Distance between OD edge to poly from other side 4.
28 `sb5=0.0 m`	Distance between OD edge to poly from other side 5.
29 `sb6=0.0 m`	Distance between OD edge to poly from other side 6.
30 `sb7=0.0 m`	Distance between OD edge to poly from other side 7.
31 `sb8=0.0 m`	Distance between OD edge to poly from other side 8.
32 `sb9=0.0 m`	Distance between OD edge to poly from other side 9.
33 `sb10=0.0 m`	Distance between OD edge to poly from other side 10.
34 `sw1=0.0 m`	Width of SA1/SB1.
35 `sw2=0.0 m`	Width of SA2/SB2.
36 `sw3=0.0 m`	Width of SA3/SB3.

37	`sw4=0.0 m`	Width of SA4/SB4.
38	`sw5=0.0 m`	Width of SA5/SB5.
39	`sw6=0.0 m`	Width of SA6/SB6.
40	`sw7=0.0 m`	Width of SA7/SB7.
41	`sw8=0.0 m`	Width of SA8/SB8.
42	`sw9=0.0 m`	Width of SA9/SB9.
43	`sw10=0.0 m`	Width of SA10/SB10.
44	`isnoisy=yes`	Should device generate noise. Possible values are `no` and `yes`.
45	`m=1`	Multiplicity factor (number of MOSFETs in parallel).
46	`region=triode`	Estimated operating region. %Z outputs the number (0-4) in a rawfile. Possible values are `off`, `triode`, `sat`, `subth`, and `breakdown`.
47	`trnqsmod`	Transient NQS model selector.
48	`acnqsmod`	AC small-signal NQS model selector.
49	`trise (C)`	Temperature rise from ambient.
50	`dtemp (C)`	Alias for trise.
51	`deltox=0 m`	Shift in gate electrical/physical equivalent oxide thinkness (for both TOXE and TOXP.
52	`rgatemod`	Gate resistance model selector.
53	`rbodymod`	Substrate resistance network model selector.
54	`geomod`	Geometry dependent parasitics model selector.
55	`stimod`	LOD stress effect model selector.

56 `rgeomod`	Diffusion resistance and contact model selector.
57 `rbpb (Ω)`	Resistance connected between bNode' and bNode.
58 `rbpd (Ω)`	Resistance connected between bNode' and dbNode.
59 `rbps (Ω)`	Resistance connected between bNode' and sbNode.
60 `rbdb (Ω)`	Resistance connected between dbNode and bNode.
61 `rbsb (Ω)`	Resistance connected between sbNode and bNode.
62 `nf`	Number of device fingers.
63 `min`	Whether to minimize the number of drain or source diffusions for evennumber fingered device. Set to 0 to minimize.
64 `delvto=0.0 V`	Shift in zer0-bias threshold voltage vth0.
65 `mulmu0=1.0`	Mobility multiplier, alias of mulu0.
66 `mulvsat=1.0`	Vsat multiplier.
67 `mulu0=1.0`	Mobility multiplier.
68 `mulid0=1.0`	Ids multiplier.
69 `delk1=0.0 V`	Shift in body bias coefficient k1.
70 `delnfct=0.0`	Shift in subthreshold swing factor nfactor.
71 `deleta0=0.0`	Shift in DIBL coefficient subthreshold region.
72 `sca=0.0`	Integral of the first distribution function for scattered well dopant.
73 `scb=0.0`	Integral of the second distribution function for scattered well dopant.
74 `scc=0.0`	Integral of the third distribution function for scattered well dopant.
75 `sc=0.0 m`	Distance to a single well edge.
76 `xgw=0.0 m`	Distance from the gate contact to the channel edge.

77 `ngcon=1.0`	Number of gate contacts.

Model Definition

model modelName bsim4 parameter=value ...

Model Parameters

Device type parameters

1 `type=n`	Transistor type. Possible values are `n` and `p`.

Model Selectors & Controller

2 `level=14`	Model level selector for spice compatibility.
3 `version=4.21`	Model parameter "version" only accepts real number value, like 4.21 for version=4.2.1. The available versions are 4.21(4.2.1), 4.30(4.3.0), 4.40(4.4.0), 4.50(4.5.0), 4.60(4.6.0), 4.61(4.6.1), 4.62(4.6.2), 4.63(4.6.3), 4.64(4.6.4), 4.65(4.6.5), 4.70(4.7.0), and 4.80(4.8.0).
4 `binunit=1`	Bin parameter unit selector. 1 for microns and 2 for meters.
5 `paramchk=1`	Switch for parameter value check. Set to 1 to turn on.
6 `mobmod=0`	Mobility model selector.
7 `cvchargemod=0.0`	Capacitance Charge model selector.
8 `mtrlmod=0.0`	parameter for non-silicon substrate or metal gate selector.
9 `mtrlcompatmod=0`	New material mod backward compatibility selector.
10 `rdsmod=0`	Bias-dependent source/drain resistance model selector.
11 `igcmod=0`	Gate-to-channel tunneling model selector.
12 `igbmod=0`	Gate-to-substrate tunneling model selector.

13 `capmod=2`	Capacitance model selector.
14 `rgatemod=0`	Gate resistance model selector.
15 `rbodymod=0`	Substrate resistance network model selector.
16 `trnqsmod=0`	Transient Non-quasi static model selector. Set to 1 to turn on nqs.
17 `acnqsmod=0`	Ac Non-quasi static model selector. Set to 1 to turn on nqs.
18 `fnoimod=1`	Flicker noise model selector.
19 `tnoimod=0`	Thermal noise model selector.
20 `diomod=1`	Source/Drain junction diode IV model selector.
21 `tempmod=0`	Temperature model selector. 0 for original model and 1 for new format.
22 `permod=1`	Perimeter model selector.
23 `geomod=0`	Geometry dependent parasitics model selector.
24 `stimod=0`	LOD stress effect model selector. 0 for Berkeley LOD, 1 & 2 for TSMC LOD.
25 `wpemod=0`	Flag for WPE model (WPEMOD=1 to activate this model).
26 `rgeomod=0`	Diffusion resistance and contact model selector. It served as the default value of instance rgeomod.
27 `flkmod=0`	Flicker Noise Model.
28 `fullreinit=0`	Model parameter full reinit selector.
29 `updatelevel=0`	Model update selector. Available versions are 0, 1 and 2.
30 `eglev=0`	DC temperature selector.
31 `minr=0.001` Ω	Minimum source/drain resistance.

Process parameters

32	`epsrox=3.9`	Gate dielectric constant.
33	`epsrgate=11.7`	Dielectric constant of gate relative to vacuum.
34	`epsrsub=11.7`	Dielectric constant of substrate relative to vacuum.
35	`eot=1.5e-9 m`	Equivalent gate oxide thickness in meters.
36	`toxe=3.0e-9 m`	Electrical gate equivalent oxide thickness.
37	``toxp=`toxem'``	Physical gate equivalent oxide thickness.
38	``toxm=`toxem'``	Toxe at which parameters were extracted.
39	`dtox=0.0 m`	Difference between electrical and physical gate oxide thickness.
40	`xj=0.15e-6 m`	Source/drain junction depth.
41	gamma1 ($\sqrt{V}$)	Body-effect coefficient near the surface.
42	gamma2 ($\sqrt{V}$)	Body-effect coefficient in the bulk.
43	ndep=1.7e17 cm^{-3}	Channel doping concentration at depletion edge for zero body bias.
44	nsub=6.0e16 cm^{-3}	Substrate doping concentration.
45	ngate=0.0 cm^{-3}	Poly Si gate doping concentration.
46	nsd=1.0e20 cm^{-3}	Source-drain doping concentration.
47	`vbx (V)`	Vbs at which the depletion region width equals XT.
48	`xt=1.55e-7 m`	Doping depth.
49	rsh=0.0 Ω/sqr	Source/drain sheet resistance.
50	rshg=0.1 Ω/sqr	Gate electrode sheet resistance.
51	`lint=0.0 m`	Lateral diffusion for one side.

52 `wint=0.0 m` Width reduction for one side.

53 `wl=0.0 m^wln` Length dependence of delta W.

54 `wln=1.0` Length exponent of delta W.

55 `ww=0.0 m^wwn` Width dependence of delta W.

56 `wwn=1.0` Width exponent of delta W.

57 `wwl=0.0 m^(wwn+wln)`
Area dependence of delta W.

58 `ll=0.0 m^lln` Length dependence of delta L.

59 `lln=1.0` Length exponent of delta L.

60 `lw=0.0 m^lwn` Width dependence of delta L.

61 `lwn=1.0` Width exponent of delta L.

62 `lwl=0.0 m^(lln+lwn)`
Area dependence of delta L.

63 `dwg=0.0 m/V` Gate-bias dependence of channel width.

64 `dwb=0.0 m/V` Body-bias dependence of channel width.

65 `lmlt=1.0` Length shrink reduction factor.

66 `wmlt=1.0` Width shrink reduction factor.

Threshold voltage parameters

67 `vtho=0.7(nmos) / -0.7(pmos) V`
Threshold voltage at Vbs=0 for long-channel devices. Alias of vth0.

68 `vfb=-1.0 V` Flat-band voltage.

69 `vddeot=1.5(nmos) / -1.5(pmos) V`
Voltage for extraction of Equivalent gate oxide thickness.

70	`phin=0.0 V`	Non-uniform vertical doping effect on surface potential.
71	`k1=0.53 √V`	First-order body bias coefficient.
72	`k2=-0.0186`	Second-order body bias coefficient.
73	`k3=80.0`	Narrow width coefficient.
74	`k3b=0.0 1/V`	Body effect coefficient of K3.
75	`w0=2.5e-6 m`	Narrow width coefficient.
76	`lpe0=1.74e-7 m`	Lateral non-uniform doping at Vbs=0.
77	`lpeb=0.0 m`	Lateral non-uniform doping effect on K1.
78	`vbm=-3.0 V`	Maximum applied body voltage in VTH0 calculation.
79	`dvt0=2.2`	First coefficient of short-channel effects.
80	`dvt1=0.53`	Second coefficient of short-channel effects.
81	`dvt2=-0.032 1/V`	Body-bias coefficient of short-channel effects.
82	`dvtp0=0.0 m`	First coefficient of drain-induced Vth shift for long-channel pocket devices.
83	`dvtp1=0.0 1/V`	Second coefficient of drain-induced Vth shift for long-channel pocket devices.
84	`dvtp2=0.0`	3rd parameter for Vth shift due to pocket.
85	`dvtp3=0.0`	4th parameter for Vth shift due to pocket.
86	`dvtp4=0.0`	5th parameter for Vth shift due to pocket.
87	`dvtp5=0.0`	6th parameter for Vth shift due to pocket.
88	`dvt0w=0.0`	First coefficient of narrow-width effects.
89	`dvt1w=5.3e6 1/m`	Second coefficient of narrow-width effects.
90	`dvt2w=-0.032 1/V`	Body-bias coefficient of narrow-width effects.

91 `a0=1.0` Nonuniform depletion width effect coefficient.

92 `ags=0.0 1/V` Gate-bias dependence of Abulk.

93 `b0=0.0 m` Bulk charge coefficient due to narrow width effect.

94 `b1=0.0 m` Bulk charge coefficient due to narrow width effect.

95 `keta=-0.047 1/V` Body-bias coefficient for non-uniform depletion width effect.

96 `a1=0.0 1/V` First non-saturation effect parameter.

97 `a2=1.0` Second non-saturation factor.

98 `phig=4.05 eV` The gate work function.

99 `ni0sub=1.45e10 cm`$^{-3}$
Intrinsic carrier concentration at T=300.15K.

100 `bg0sub=1.16 eV` Band-gap of substrate at T=0K.

101 `tbgasub=7.02e-4 V/K`
First parameter of band-gap change due to temperature.

102 `tbgbsub=1108.0 K` Second parameter of bandgap change due to temperature.

103 `ados=1.0` Charge centroid parameter.

104 `bdos=1.0` Charge centroid parameter.

105 `tempeot=300.15 C` Temperature for extraction of EOT.

106 `leffeot=1 m` Effective length for extraction of EOT.

107 `weffeot=10 m` Effective width for extraction of EOT.

108 `vthmod` Vth output selector. 'std' outputs model equation Vth. 'vthcc' outputs constant current Vth, and may impact simulation performance. The default value is taken from the options parameter 'vthmod'.
Possible values are `std` and `vthcc`.

109 `ivth (A)`	Vth current parameter. The default value is taken from the options parameter 'ivthn' or 'ivthp', depending on the type of the model.
110 `ivthw (m)`	Width offset for constant current Vth. The default value is taken from the options parameter 'ivthw'.
111 `ivthl (m)`	Length offset for constant current Vth. The default value is taken from the options parameter 'ivthl'.
112 `ivth_vdsmin (V)`	Minimum Vds in constant current Vth calculating. The default value is taken from the options parameter 'ivth_vdsmin'.
113 `acm=12`	area calculation method selector.
114 `hdif=0 m`	Length of heavily doped diffusion.
115 `ldif=0 m`	Lateral diffusion beyond the gate.
116 `rs=12.5 Ω`	Source resistance.
117 `rd=12.5 Ω`	Drain resistance.
118 `ld (m)`	Lateral diffusion into the channel from the source and drain diffusion.
119 `trd=0 1/C`	Temperature parameter for drain resistance.
120 `trs=0 1/C`	Temperature parameter for source resistance.

Mobility parameters

121 `u0=670(nmos) / 250(pmos)`
Low-field surface mobility at tnom.

122 `ua=1.0e-9(mobmod=0,1) / 1.0e-15 (mobmod=2) m/V`
First-order mobility reduction coefficient.

123 `ub=1.0e-19` m^2/V^2
Second-order mobility reduction coefficient.

124 `uc=-0.0465 1/V (mobmod=1) / -0.0465e-9` m/V^2 `(mobmod=0,2)`
Body-bias dependence of mobility.

125 `ud=1.0e14 /m`^{2} Coulomb scattering factor of mobility.

126 `up=0.0` Channel length linear factor of mobility.

127 `lp=1.0e-8 m` Channel length exponential factor of mobility.

128 `eu=1.67(nmos) / 1.0(pmos)`
Exponent for mobility degradation of mobmod=2.

129 `vsat=8.0e4 m/s` Carrier saturation velocity at tnom.

130 `lambda=0.0` Velocity overshoot coefficient.

131 `vtl=2.0e5 m/s` Thermal velocity.

132 `lc=5.0e-9 m` Velocity back scattering coefficient.

133 `xn=3.0` Velocity back scattering coefficient.

134 `easub=4.05 eV` Electron affinity of substrate.

135 `ucs=1.67(nmos) / 1.0(pmos)`
Coulomb scattering exponent.

136 `ucste=-4.775e-3` Temperature coefficient of colombic mobility.

Subthreshold parameters

137 `voff=-0.08 V` Threshold voltage offset.

138 `tvoff=0.0 V` Temperature parameter for voff.

139 `ltvoff=0.0 V` Length dependence of tvoff.

140 `wtvoff=0.0 V` Width dependence of tvoff.

141 `ptvoff=0.0 V` Cross-term dependence of tvoff.

142 `voffl=0.0 mV` Channel-length dependence of Voff.

143 `minv=0.0` Vgsteff fitting parameter for moderate inversion condition.

144 `nfactor=1.0` Subthreshold swing coefficient.

145 `eta0=0.08` DIBL coefficient subthreshold region.

146 `etab=-0.07 1/V` Body-bias dependence of et0.

147 `dsub=`drout'` DIBL effect in subthreshold region.

148 `cit=0.0 F/m`^{2} Interface trap parameter for subthreshold swing.

149 `cdsc=2.4e-4 F/m`^{2} Source/drain and channel coupling capacitance.

150 `cdscb=0.0 F/m`^{2} `V` Body-bias dependence of cdsc.

151 `cdscd=0.0 F/m`^{2} `V` Drain-bias dependence of cdsc.

Output resistance parameters

152 `pclm=1.3` Channel length modulation coefficient.

153 `pdiblc1=0.39` First coefficient of drain-induced barrier lowering.

154 `pdiblc2=8.6e-3` Second coefficient of drain-induced barrier lowering.

155 `pdiblcb=0.0 1/V` Body-effect coefficient for DIBL.

156 `drout=0.56` DIBL effect on output resistance coefficient.

157 `pscbe1=4.24e8 V/m` First coefficient of substrate current body effect.

158 `pscbe2=1e-5 m/V` Second coefficient of substrate current body effect.

159 `fprout=0.0 V/ m`

Effect of pocket implant on Rout degradation.

160 `pvag=0.0` Gate dependence of Early voltage.

161 `delta=0.01 V` Effective drain voltage smoothing parameter.

162 `pdits=0.0 1/V` Effect of pocket implant on Rout degradation.

163 `pditsl=0.0 1/m` Channel-length dependence of drain-induced Vth shift on Rout.

164 `pditsd=0.0 1/V` Vds dependence of drain-induced Vth shift on Rout.

Bias-dependent Rds parameters

165 `rdsw=200.0 Ω µm^wr`
Zero bias LDD resistance per unit width for RDSMOD=0.

166 `rdswmin=0.0 Ω µm^wr`
LDD resistance per unit width at high Vgs and zero Vbs for RDSMOD=0.

167 `rdw=100.0 Ω µm^wr`
Zero bias LDD resistance per unit width for RDSMOD=1.

168 `rdwmin=0.0 Ω µm^wr`
LDD resistance per unit width at high Vgs and zero Vbs for RDSMOD=1.

169 `rsw=100.0 Ω µm^wr`
Zero bias LDD resistance per unit width for RDSMOD=1.

170 `rswmin=0.0 Ω µm^wr`
LDD resistance per unit width at high Vgs and zero Vbs for RDSMOD=1.

171 `prwg=1 1/V` Gate-effect coefficient for Rds.

172 `prwb=0.0 1/√V`
Body-effect coefficient for Rds.

173 `wr=1.0` Width offset for parasitic resistance.

Substrate current parameters

174 `alpha0=0.0 A m/V` Substrate current impact ionization coefficient.

175 `alpha1=0.0 A/V` Substrate current impact ionization coefficient.

176 `beta0=30.0 1/V` Substrate current impact ionization exponent.

Gate-Induced drain leakage parameters

177 `gidlmod=0` Parameter for GIDL selector.

178 `agidl=0.0 1/Ω` Pre-exponential coefficient for GIDL.

179 `bgidl=2.3e9 V/m` Exponential coefficient for GIDL.

180 `cgidl=0.5` V^3 Parameter for body-bias effect on GIDL.

181 `egidl=0.8 V` Fitting parameter for band bending for GIDL.

182 `fgidl=0.0 V` GIDL vb parameter.

183 `kgidl=0.0 V` GIDL vb parameter.

184 `rgidl=1.0` GIDL vg parameter.

185 `agisl=agidl 1/Ω` Pre-exponential coefficient for GISL (bsim4.6).

186 `bgisl=bgidl V/m` Exponential coefficient for GISL (bsim4.6).

187 `cgisl=cgidl` V^3 Parameter for body-bias effect on GISL (bsim4.6).

188 `egisl=egidl V` Fitting parameter for band bending for GISL (bsim4.6).

189 `fgisl=fgidl V` GISL vb parameter.

190 `kgisl=kgidl V` GISL vb parameter.

191 `rgisl=rgidl` GISL vg parameter.

Gate Tunneling parameters

192 `aigbacc=0.43 F/g s/m`
Parameter for Igb in accumulation.

193 `bigbacc=0.054 F/g s/(m V)`
Parameter for Igb in accumulation.

194 `cigbacc=0.075 1/V` Parameter for Igb in accumulation.

195 `nigbacc=1.0` Parameter for Igb in accumulation.

196 `aigbinv=0.35 F/g s/m`
Parameter for Igb in inversion.

197 `bigbinv=0.03 |F/g  s/(m V)`
Parameter for Igb in inversion.

198 `cigbinv=0.006 1/V` Parameter for Igb in inversion.

199 `eigbinv=1.1 V` Parameter for Igb in inversion.

200 `nigbinv=3.0` Parameter for Igb in inversion.

201 `aigc=0.43(nmos) / 0.31(pmos) |F/g  s/m`
Parameter for Igcs and Igcd.

202 `bigc=0.054(nmos) / 0.024(pmos) |F/g  s/(m V)`
Parameter for Igcs and Igcd.

203 `cigc=0.075(nmos) / 0.03(pmos) 1/V`
Parameter for Igcs and Igcd.

204 `aigsd=0.43(nmos) / 0.31(pmos) |F/g  s/m`
Parameter for Igs and Igd.

205 `bigsd=0.054(nmos) / 0.024(pmos) |F/g  s/(m V)`
Parameter for Igs and Igd.

206 `cigsd=0.075(nmos) / 0.03(pmos) 1/V`
Parameter for Igs and Igd.

207 `aigs=1.36e-2(nmos) / 9.80e-3(pmos) |F/g  s/m`
Parameter for Igs (bsim4.6).

208 `bigs=1.71e-3(nmos) / 7.59e-4(pmos) |F/g  s/(m V)`
Parameter for Igs (bsim4.6).

209 `cigs=0.075(nmos) / 0.03(pmos) 1/V`
Parameter for Igs (bsim4.6).

210 `aigd=1.36e-2(nmos) / 9.80e-3(pmos) |F/g  s/m`
Parameter for Igd (bsim4.6).

211 `bigd=1.71e-3(nmos) / 7.59e-4(pmos) |F/g  s/(m V)`
Parameter for Igd (bsim4.6).

212 `cigd=0.075(nmos) / 0.03(pmos) 1/V`
Parameter for Igd (bsim4.6).

213 `dlcig=`Lintm'` Source overlap length for Igs.

214 `dlcigd=dlcig m` drain overlap length for Igd (bsim4.6).

215 `nigc=1.0` Parameter for Igcs, Igcd ,Igs and Igd.

216 `poxedge=1.0` Factor for the gate oxide thickness in source/drain overlap regions.

217 `pigcd=1.0` Vds dependence of Igcs and Igcd.

218 `ntox=1.0` Exponent for the gate oxide ratio.

219 `toxref=3.0e-9 m` Nominal gate oxide thickness for gate dielectric tunneling current model only.

220 `vfbsdoff=0.0 V` S/D flatband voltage offset.

221 `tvfbsdoff=0.0 V` Temperature parameter for vfbsdoff.

222 `ltvfbsdoff=0.0 V` Length dependence of tvfbsdoff.

223 `wtvfbsdoff=0.0 V` Width dependence of tvfbsdoff.

224 `ptvfbsdoff=0.0 V` Cross-term dependence of tvfbsdoff.

Overlap capacitance parameters

225 `cgso (F/m)` Non LDD region source-gate overlap capacitance per unit channel width.

226 `cgdo (F/m)` Non LDD region drain-gate overlap capacitance per unit channel width.

227 `cgbo=2 Dwc Coxe F/m`
Non LDD region drain-gate overlap capacitance per unit channel width.

228 `meto=0.0 m` Metal overlap in fringing field.

229 `cgsl=0.0 F/m`	Overlap capacitance between gate and lightly-doped source region.
230 `cgdl=0.0 F/m`	Overlap capacitance between gate and lightly-doped drain region.
231 `ckappas=0.6 V`	Coefficient of bias-dependent overlap capacitance for the source side.
232 `` ckappad=`ckappasV' ``	Coefficient of bias-dependent overlap capacitance for the source side.

Charge model selection parameters

233 `xpart=0.0`	Charge partition number. Use 0.0 for 40/60, 0.5 for 50/50, and 1.0 for 0/100.
234 `cf (F/m)`	Fringing field capacitance (alias=lx91).
235 `clc=1e-7 m`	Constant term for the short channel model.
236 `cle=0.6`	Exponential term for the short channel model.
237 `` dlc=`lintm' ``	Delta L for capacitance model.
238 `` dwc=`wintm' ``	Delta W for capacitance model.
239 `vfbcv=-1.0`	Flat-band voltage for capmod=0.
240 `noff=1.0`	Transition parameter.
241 `voffcv=0.0 V`	CV parameter in VgsteffCV for weak to strong inversion.
242 `minvcv=0.0`	Fitting parameter for moderate inversion condition.
243 `voffcvl=0.0 V m`	Length dependence parameter for Vth offset in CV.
244 `acde=1.0 m/V`	Exponential coefficient for charge thickness in CAPMOD=2 for accumulation and depletion regions.
245 `moin=15.0`	Exponential coefficient for charge thickness for accumulation and depletion regions.

246 `llc=`llm^lln'` Length dependence of delta L for CV.

247 `lwc=`lwm^lwn'` Width dependence of delta L for CV.

248 `lwlc=`lwlm^(lln+lwn)'`
Area dependence of delta L for CV.

249 `wlc=`wlm^wln'` Length dependence of delta W for CV.

250 `wwc=`wwm^wwn'` Width dependence of delta W for CV.

251 `wwlc=`wwlm^(wwn+wln)'`
Area dependence of delta W for CV.

Parasitic resistance parameters

252 `dmcg=0.0 m` Distance from S/D contact center to the gate edge.

253 `dmci=`dmcgm'` Distance from S/D contact center to the isolation edge in the channel-length direction.

254 `dmdg=0.0 m` Distance from S/D contact center to the gate edge.

255 `dmcgt=0.0 m` DMCG of test structures.

256 `dwj=`dwcm'` Offset of the S/D junction width.

257 `xgw=0.0 m` Distance from the gate contact to the channel edge.

258 `xgl=0.0 m` Offset of gate length due to variations in patterning.

259 `xl=0.0 m` Length variation due to masking and etching.

260 `xw=0.0 m` Width variation due to masking and etching.

261 `ngcon=1.0` Number of gate contacts.

262 `nf=1` Number of device fingers. It served as the default value of instance nf.

263 `min=0` Whether to minimize the number of drain or source diffusions for evennumber fingered device. Set to 0 to minimize. It served as the default value of instance min.

Junction diode model parameters

264 `ijthsrev=0.1 A` Source diode limiting current in reverse bias region.

265 `ijthdrev=`ijthsrevA'` Drain diode limiting current in reverse bias region.

266 `ijthsfwd=0.1 A` Source diode limiting current in forward bias region.

267 `ijthdfwd=`ijthsfwdA'` Drain diode limiting current in forward bias region.

268 `xjbvs=1.0` Fitting parameter for bulk-source diode breakdown.

269 `xjbvd=`xjbvs'` Fitting parameter for bulk-drain diode breakdown.

270 `bv=10.0 V` Diode breakdown voltage. Alias of bvs.

271 `bvs=10.0 V` Source diode breakdown voltage.

272 `bvd=`bvsV'` Drain diode breakdown voltage.

273 `is=1.0e-14 A` Bulk junction reverse saturation current.

274 `js=1.0e-4 A/m`^{2} Bottom junction reverse saturation current density. Alias of jss.

275 `jss=1.0e-4 A/m`^{2} Source bottom junction reverse saturation current density.

276 `jsd=`jssA/m'`^{2} Drain bottom junction reverse saturation current density.

277 `jsws=0.0 A/m` Isolation-edge sidewall source junction reverse saturation current density.

278 `jswd=`jswsA/m'` Isolation-edge sidewall drain junction reverse saturation current density.

279 `jswgs=0.0 A/m` Gate-edge sidewall source junction reverse saturation current density.

280 `jswgd=`jswgsA/m'` Gate-edge sidewall drain junction reverse saturation current density.

281 `jtss=0.0 A/m`^{2} Source bottom trap-assisted saturation current density.

282 `jtsd=`jtssA/m'`[2] Drain bottom trap-assisted saturation current density.

283 `jtssws=0.0 A/m` Source isolation-edge sidewall trap-assisted saturation current density.

284 `jtsswd=`jtsswsA/m'`
Drain isolation-edge sidewall trap-assisted saturation current density.

285 `jtsswgs=0.0 A/m` Source Gate-edge isolation-edge sidewall trap-assisted saturation current density.

286 `jtsswgd=`jtsswgsA/m'`
Drain isolation-edge sidewall trap-assisted saturation current density.

287 `njts=20.0` Non-ideality factor for jtss. For TSMC diode model, default=60.0.

288 `njtssw=20.0` Non-ideality factor for jtssws. For TSMC diode model, default=60.0.

289 `njtsswg=20` Non-ideality factor for jtsswgs. For TSMC diode model, default=60.0.

290 `njtsd=njts` Non-ideality factor for jtsd (bsim4.6).

291 `njtsswd=njtssw` Non-ideality factor for jtsswd (bsim4.6).

292 `njtsswgd=njtsswg` Non-ideality factor for jtsswgd (bsim4.6).

293 `xtss=0.02` Power dependence of jtss on temperature.

294 `xtsd=`xtss'` Power dependence of jtsd on temperature.

295 `xtssws=0.02` Power dependence of jtssws on temperature.

296 `xtsswd=`xtssws'` Power dependence of jtsswd on temperature.

297 `xtsswgs=0.02` Power dependence of jtsswgs on temperature.

298 `xtsswgd=`xtsswgs'`
Power dependence of jtsswgd on temperature.

299 `vtss=10.0 V` Source bottom trap-assisted voltage dependent parameter.

300 `vtsd=`vtssV'` Drain bottom trap-assisted voltage dependent parameter.

301 `vtssws=10.0 V` Source STI sidewall trap-assisted voltage dependent parameter.

302 `vtsswd=`vtsswsV'` Drain STI sidewall trap-assisted voltage dependent parameter.

303 `vtsswgs=10.0 V` Source gate-edge sidewall trap-assisted voltage dependent parameter.

304 `vtsswgd=`vtsswgsV'`
Drain gate-edge sidewall trap-assisted voltage dependent parameter.

305 `tnjts=0.0` Temperature coefficient for njts.

306 `tnjtssw=0.0` Temperature coefficient for njtssw.

307 `tnjtsswg=0.0` Temperature coefficient for njtsswg.

308 `tnjtsd=tnjts` Temperature coefficient for njtsd (bsim4.6).

309 `tnjtsswd=tnjtsssw`
Temperature coefficient for njtsswd (bsim4.6).

310 `tnjtsswgd=tnjtsswg`
Temperature coefficient for njtsswgd (bsim4.6).

311 `dskip=yes` Use simple piece-wise linear model for diode currents below 0.1*iabstol.
Possible values are `no` and `yes`.

312 `imelt=`imaxA'` Explosion current.

313 `jmelt=`jmaxA/m'`^{2}
Explosion current density.

314 `jtweff=0.0 m` TAT current width dependence.

TSMC junction diode model parameters

315 `mnr=21.0` Fitting parameter for resistance induced non-ideality factor.

316 `bnr=0.0`	Fitting parameter for resistance induced non-ideality factor.
317 `cnr=0.0 1/V m`	Fitting parameter for resistance induced non-ideality factor.
318 `dnr=0.0 1/V`	Fitting parameter for resistance induced non-ideality factor.
319 `tmnr=0.0`	Temperature coefficient for mnr.
320 `tcnr=0.0`	Temperature coefficient for cnr.
321 `tdnr=0.0`	Temperature coefficient for dnr.
322 `nrfwd=1.0 A/m`^{2}	Source bottom trap-assisted saturation current density.
323 `jsswg=0.0`	Sidewall-gate junction reverse saturation current density.

Junction capacitance model parameters

324 `cj=5e-4 F/m`^{2}	Zero bias bottom junction capacitance per unit area. Alias of cjs.
325 `cjs=5.0e-4 F/m`^{2}	Zero bias source bottom junction capacitance per unit area.
326 `cjd=`cjsF/m'`^{2}	Zero bias drain bottom junction capacitance per unit area.
327 `mj=1/2`	Bottom junction capacitance grading coefficient. Alias of mjs.
328 `mjs=1/2`	Source bottom junction capacitance grading coefficient.
329 `mjd=`mjs'`	Drain bottom junction capacitance grading coefficient.
330 `pb=1.0 V`	Bottom junction built-in potential. Alias of pbs.
331 `pbs=1.0 V`	Source bottom junction built-in potential.
332 `pbd=`pbsV'`	Drain bottom junction built-in potential.
333 `fc=0.5`	Forward-bias depletion capacitance threshold.
334 `cjsw=5e-10 F/m`	Sidewall junction capacitance per unit periphery. Alias of cjsws.
335 `cjsws=5.0e-10 F/m`	Source sidewall junction capacitance per unit periphery.
336 `cjswd=`cjswsF/m'`	Drain sidewall junction capacitance per unit periphery.

337 `mjsw=0.33` Isolation-edge sidewall junction capacitance grading coefficient. Alias of mjsws.

338 `mjsws=0.33` Isolation-edge sidewall source junction capacitance grading coefficient.

339 `mjswd=`mjsws'` Isolation-edge sidewall drain junction capacitance grading coefficient.

340 `pbsw=1.0 V` Isolation-edge sidewall junction built-in potential. Alias of pbsws.

341 `pbsws=1.0 V` Isolation-edge sidewall source junction built-in potential.

342 `pbswd=`pbswsV'` Isolation-edge sidewall drain junction built-in potential.

343 `cjswg=`cjswF/m'` Gate-side junction capacitance per unit width. Alias of cjswgs.

344 `cjswgs=`cjswsF/m'`
Gate-side source junction capacitance per unit width.

345 `cjswgd=`cjswgsF/m'`
Gate-side source junction capacitance per unit width.

346 `mjswg=`mjsw'` Gate-edge sidewall junction grading coefficient. Alias of mjswgs.

347 `mjswgs=`mjsws'` Gate-edge sidewall source junction grading coefficient.

348 `mjswgd=`mjswgs'` Gate-edge sidewall junction grading coefficient.

349 `pbswg=`pbswV'` Gate-edge sidewall junction built-in potential. Alias of pbswgs.

350 `pbswgs=`pbswsV'` Gate-edge sidewall source junction built-in potential.

351 `pbswgd=`pbswgsV'` Gate-edge sidewall drain junction built-in potential.

352 `fcsw=0.5` Side-wall forward-bias depletion capacitance threshold.

Temperature effects parameters

353 `tnom (C)` Parameters measurement temperature. Default set by options.

354 `trise=0.0 C` Temperature rise from ambient, alias of dtemp. It served as the default value of instance trise.

355 `ute=-1.5` Mobility temperature exponent.

356 `kt1=-0.11 V` Temperature coefficient for threshold voltage.

357 `kt1l=0.0 V m` Channel length dependence of the temperature coefficient for threshold voltage.

358 `kt2=0.022` Body-bias coefficient of Vth temperature effect.

359 `ua1=1.0e-9 m/V` Temperature coefficient for ua. When tempmod=1, units should be 1/C.

360 `ub1=-1.0e-18` m^2/V^2
Temperature coefficient for ub. When tempmod=1, units should be 1/C.

361 `uc1=-0.056 1/V (mobmod=1) / -5.6e-11` m/V^2 `(modmod=0,2)`
Temperature coefficient for uc. When tempmod=1, units should be 1/C.

362 `ud1=0.0` $/m^2$ Temperature coefficient of ud.

363 `at=3.3e4 m/s` Temperature coefficient for vsat. When tempmod=1, units should be 1/C.

364 `prt=0.0 Ω m` Temperature coefficient for Rdsw. If tempmod=1, units of the parameter equals 1/C.

365 `tlev=0` DC temperature selector.

366 `tlevc=0` AC temperature selector.

367 `eg=1.124519231 V` Energy band gap.

368 `gap1=7.02e-4 V/C` Band gap temperature coefficient.

369 `gap2=1108 C` Band gap temperature offset.

370 `n=1.0` junction emission coefficient. Alias of njs.

371 `njs=1.0` Bulk-Source junction emission coefficient.

372 `njd=`njs'` Bulk-Drain junction emission coefficient.

373 `xti=3`	Saturation current temperature exponent. Alias of xtis.
374 `xtis=3.0`	Bulk-Source junction saturation current temperature exponent.
375 `` xtid=`xtis' ``	Bulk-Drain junction saturation current temperature exponent.
376 `pta=0.0 V/C`	Temperature coefficient for pb. Alias of tpb.
377 `tpb=0.0 V/C`	Temperature coefficient for pb.
378 `ptp=0.0 V/C`	Temperature coefficient for pbsw. Alias of tpbsw.
379 `tpbsw=0.0 V/C`	Temperature coefficient for pbsw.
380 `tpbswg=0.0 V/C`	Temperature coefficient for pbswg.
381 `cta=0.0 1/C`	Temperature coefficient for cj. Alias of tcj.
382 `tcj=0.0 1/C`	Temperature coefficient for cj.
383 `ctp=0.0 1/C`	Temperature coefficient for cjsw. Alias of tcjsw.
384 `tcjsw=0.0 1/C`	Temperature coefficient for cjsw.
385 `tcjswg=0.0 1/C`	Temperature coefficient for cjswg.
386 `tnfactor=0.0`	Temperature parameter for nfactor.
387 `teta0=0.0`	Temperature parameter for eta0.
388 `tvoffcv=0.0 1/C`	Temperature parameter for tvoffcv.

LOD model parameters

389 `saref=1.0e-6 m`	Reference distance between od edge to poly of one side.
390 `sbref=1.0e-6 m`	Reference distance between od edge to poly of the other side.
391 `sl=2.0e-6 m`	Character length along length for stress effect.
392 `lsl=0.0`	Length dependence of sl.
393 `wsl=0.0`	Width dependence of sl.

394 `psl=0.0` Cross-term dependence of sl.

395 `sw=2.0e-6 m` Character length along width for stress effect.

396 `lsw=0.0` Length dependence of sw.

397 `wsw=0.0` Width dependence of sw.

398 `psw=0.0` Cross-term dependence of sw.

399 `sk0=0.0` First coefficient of stress effect.

400 `lsk0=0.0` Length dependence of sk0.

401 `wsk0=0.0` Width dependence of sk0.

402 `psk0=0.0` Cross-term dependence of sk0.

403 `sk1=0.0 m` Length coefficient of stress effect.

404 `lsk1=0.0` Length dependence of sk1.

405 `wsk1=0.0` Width dependence of sk1.

406 `psk1=0.0` Cross-term dependence of sk1.

407 `sk2=0.0 m` Width coefficient of stress effect.

408 `lsk2=0.0` Length dependence of sk2.

409 `wsk2=0.0` Width dependence of sk2.

410 `psk2=0.0` Cross-term dependence of sk2.

411 `k=0.0` Ratio of velocity/mobility changes for stress.

412 `lk=0.0` Length dependence of k.

413 `wk=0.0` Width dependence of k.

414 `pk=0.0` Cross-term dependence of k.

415 `wlod=0.0 m` Length parameter for stress effect.

416 `ku0=0.0 m`	Mobility degradation/enhancement coefficient for stress effect.
417 `kvsat=0.0 m`	Saturation velocity degradation/enhancement parameter for stress effect.
418 `tku0=0.0`	Temperature coefficient of ku0.
419 `llodku0=0.0`	Length parameter for u0 stress effect.
420 `wlodku0=0.0`	Width parameter for u0 stress effect.
421 `kvth0=0.0 V m`	Threshold shift parameter for stress effect.
422 `llodvth=0.0`	Length parameter for vth stress effect.
423 `wlodvth=0.0`	Width parameter for vth stress effect.
424 `stk2=0.0 m`	k2 shift factor related to vth0 change.
425 `lodk2=1.0`	k2 shift modification factor for stress effect.
426 `steta0=0.0 m`	eta0 shift factor related to vth0 change.
427 `lodeta0=1.0`	eta0 shift modification factor for stress effect.

WPE model parameters

428 `web=0.0`	Coefficient for SCB.
429 `wec=0.0`	Coefficient for SCC.
430 `kvth0we=0.0 V`	Threshold shift factor for well proximity effect.
431 `k2we=0.0`	K2 shift factor for well proximity effect.
432 `ku0we=0.0`	Mobility degradation factor for well proximity effect.
433 `scref=1.0e-6 m`	Reference distance to calculate SCA, SCB and SCC.

Noise model parameters

434 `noia=6.25e41(nmos) / 6.188e40(pmos) s^(1-EF)/(eV m`^{2}`)`
Flicker noise parameter A.

435 `noib=3.125e26(nmos) / 1.5e25(pmos) s^(1-EF)/eV`
Flicker noise parameter C.

436 `noic=8.75e9 s^(1-EF) m`^{2}`/eV`
Flicker noise parameter C.

437 `em=4.1e7 V/m` Saturation field.

438 `af=1.0` Flicker noise exponent.

439 `ef=1.0` Flicker noise frequency exponent.

440 `kf=0.0 A^(2-EF) s^(1-EF) F`
Flicker noise coefficient.

441 `lintnoi=0.0 m` Lint offset for noise calculation.

442 `wnoi=1.0e-5 m` Channel width at which noise parameters were extracted.

443 `ntnoi=1.0` Noise factor for short-channel devices for TNOIMOD=0 only.

444 `tnoia=1.5` Coefficient of channel-length dependence of total channel thermal noise.

445 `tnoib=3.5` Coefficient of channel-length dependence of total channel thermal noise.

446 `tnoic=0.0` Thermal noise parameter.

447 `rnoia=0.577` Thermal noise coefficient.

448 `rnoib=0.5164` Thermal noise coefficient.

449 `rnoic=0.395` Thermal noise coefficient.

Substrate Network parameters

450 `xrcrg1=12.0`	Parameter for distributed channel-resistance effect for both intrinsic-input resistance and charge-deficit NQS models.
451 `xrcrg2=1.0`	Parameter to account for the excess channel diffusion resistance for both intrinsic-input resistance and charge-deficit NQS models.
452 `rbpb=50.0` Ω	Resistance connected between bNode' and bNode.
453 `rbpbx0=100.0` Ω	Body resistance RBPBX scaling.
454 `rbpbxl=0.0`	Body resistance RBPBX L scaling.
455 `rbpbxw=0.0`	Body resistance RBPBX W scaling.
456 `rbpbxnf=0.0`	Body resistance RBPBX NF scaling.
457 `rbpby0=100.0` Ω	Body resistance RBPBY scaling.
458 `rbpbyl=0.0`	Body resistance RBPBY L scaling.
459 `rbpbyw=0.0`	Body resistance RBPBY W scaling.
460 `rbpbynf=0.0`	Body resistance RBPBY NF scaling.
461 `rbpd=50.0` Ω	Resistance connected between bNode' and dbNode.
462 `rbpd0=50.0` Ω	Body resistance RBPD scaling.
463 `rbpdl=0.0`	Body resistance RBPD L scaling.
464 `rbpdw=0.0`	Body resistance RBPD W scaling.
465 `rbpdnf=0.0`	Body resistance RBPD NF scaling.
466 `rbps=50.0` Ω	Resistance connected between bNode' and sbNode.
467 `rbps0=50.0` Ω	Body resistance RBPS scaling.
468 `rbpsl=0.0`	Body resistance RBPS L scaling.

469 `rbpsw=0.0` Body resistance RBPS W scaling.

470 `rbpsnf=0.0` Body resistance RBPS NF scaling.

471 `rbdb=50.0` Ω Resistance connected between dbNode and bNode.

472 `rbsb=50.0` Ω Resistance connected between sbNode and bNode.

473 `rbsbx0=100.0` Ω Body resistance RBSBX scaling.

474 `rbsby0=100.0` Ω Body resistance RBSBY scaling.

475 `rbdbx0=100.0` Ω Body resistance RBDBX scaling.

476 `rbdby0=100.0` Ω Body resistance RBDBY scaling.

477 `rbsdbxl=0.0` Body resistance RBSDBX L scaling.

478 `rbsdbxw=0.0` Body resistance RBSDBX W scaling.

479 `rbsdbxnf=0.0` Body resistance RBSDBX NF scaling.

480 `rbsdbyl=0.0` Body resistance RBSDBY L scaling.

481 `rbsdbyw=0.0` Body resistance RBSDBY W scaling.

482 `rbsdbynf=0.0` Body resistance RBSDBY NF scaling.

483 `gbmin=1.0e-12` 1/Ω
Conductance in parallel with each of the five substrate resistances to avoid potential numerical instability due to an unreasonably large substrate resistance.

Default for instance parameters

484 `w=5e-6 m` Default channel width.

485 `l=5e-6 m` Default channel length.

486 `as` (m^2) Default area of source diffusion.

487 `ad` (m^2) Default area of drain diffusion.

488 `ps (m)` Default perimeter of source diffusion.

489 `pd (m)` Default perimeter of drain diffusion.

490 `nrd` Default number of squares of drain diffusion.

491 `nrs` Default number of squares of source diffusion.

492 `rdc=0.0 Ω` Default drain contact resistance.

493 `rsc=0.0 Ω` Default source contact resistance.

Auto Model Selector parameters

494 `wmax=1.0 m` Maximum channel width for which the model is valid.

495 `wmin=0.0 m` Minimum channel width for which the model is valid.

496 `lmax=1.0 m` Maximum channel length for which the model is valid.

497 `lmin=0.0 m` Minimum channel length for which the model is valid.

Operating region warning control parameters

498 `alarm=none` Forbidden operating region.
Possible values are `none`, `off`, `triode`, `sat`, `subth`, and `rev`.

499 `imax=1.0 A` Maximum allowable junction current.

500 `jmax=1.0e8 A/m`^{2} Maximum allowable junction current density.

501 `bvj=infinity V` Voltage at which junction breakdown warning is issued.

502 `vbox=3e9 toxe V` Oxide breakdown voltage.

503 `warn=on` Parameter to turn warnings on and off.
Possible values are `off` and `on`.

Safe Operating Areas Parameters

504 `vds_max=infinity V`
Maximum allowed voltage cross source and drain.

505 `vgd_max=infinity V`
Maximum allowed voltage cross drain and gate.

506 `vgs_max=infinity V`
Maximum allowed voltage cross source/bulk and gate.

507 `vbd_max=infinity V`
Maximum allowed voltage cross drain/source and bulk.

508 `vbs_max=vbd_max V` Maximum allowed voltage cross source and bulk.

509 `vgb_max=infinity V`
Maximum allowed voltage cross gate and bulk.

510 `vgdr_max=vgd_max V`
Maximum allowed reverse voltage cross gate and drain.

511 `vgsr_max=vgs_max V`
Maximum allowed reverse voltage cross gate and source.

512 `vgbr_max=vgb_max V`
Maximum allowed reverse voltage cross gate and bulk.

513 `vbsr_max=vbs_max V`
Maximum allowed reverse voltage cross bulk and source.

514 `vbdr_max=vbd_max V`
Maximum allowed reverse voltage cross bulk and drain.

Length dependent parameters

515 `lvtho=0.0 V` Length dependence of vtho.

516 `lvth0` Length dependence of vth0.

517 `lvfb=0.0` Length dependence of vfb.

518 `lk1=0.0 V` Length dependence of k1.

519 `lk2=0.0` Length dependence of k2.

520 `lk3=0.0` Length dependence of k3.

521 `lk3b=0.0 1/V` Length dependence of k3b.

522 `lw0=0.0 m` Length dependence of w0.

523 `lgamma1=0.0` $\sqrt{V}$
Length dependence of gamma1.

524 `lgamma2=0.0` $\sqrt{V}$
Length dependence of gamma2.

525 `lvbx=0.0 V` Length dependence of vbx.

526 `lvbm=0.0 V` Length dependence of vbm.

527 `ldvt0=0.0` Length dependence of dvt0.

528 `ldvt1=0.0` Length dependence of dvt1.

529 `ldvt2=0.0 1/V` Length dependence of dvt2.

530 `ldvt0w=0.0` Length dependence of dvt0w.

531 `ldvt1w=0.0` Length dependence of dvt1w.

532 `ldvt2w=0.0` Length dependence of dvt2w.

533 `la0=0.0` Length dependence of a0.

534 `lb0=0.0 m` Length dependence of b0.

535 `lb1=0.0 m` Length dependence of b1.

536 `la1=0.0` Length dependence of a1.

537 `la2=0.0` Length dependence of a2.

538 `lags=0.0` F/m^2 V Length dependence of ags.

539 `lketa=0.0 1/V` Length dependence of keta.

540 `lnsub=0.0 cm`$^{-3}$ Length dependence of nsub.

541 `lngate=0.0 cm`$^{-3}$ Length dependence of ngate.

542 `lxj=0.0 m` Length dependence of xj.

543 `ldwg=0.0 m/V` Length dependence of dwg.

544 `ldwb=0.0 m/` $\sqrt{V}$ Length dependence of dwb.

545 `lxt=0.0 m` Length dependence of xt.

546 `lrdsw=0.0` Ω µm Length dependence of rdsw.

547 `lprwb=0.0 1/` $\sqrt{V}$ Length dependence of prwb.

548 `lprwg=0.0 1/V` Length dependence of prwg.

549 `lwr=0.0` Length dependence of wr.

550 `lu0=0.0` Length dependence of u0.

551 `lvsat=0.0 m/s` Length dependence of vsat.

552 `lua=0.0 m/V` Length dependence of ua.

553 `lub=0.0` m^2/V^2 Length dependence of ub.

554 `luc=0.0` m/V^2 Length dependence of uc.

555 `lud=0.0` $/m^2$ Length dependence of ud.

556 `lup=0.0` Length dependence of up.

557 `llp=0.0 m` Length dependence of lp.

558 `ldrout=0.0` Length dependence of drout.

559 `lpclm=0.0` Length dependence of pclm.

560 `lpdiblc1=0.0` Length dependence of pdiblc1.

561 `lpdiblc2=0.0` Length dependence of pdiblc2.

562 `lpdiblcb=0.0 1/V` Length dependence of pdiblcd.

563 `lpscbe1=0.0 V/m` Length dependence of pscbe1.

564 `lpscbe2=0.0 m/V` Length dependence of pscbe2.

565 `lpvag=0.0` Length dependence of pvag.

566 `ldelta=0.0 V` Length dependence of delta.

567 `lcdsc=0.0 F/m`^{2} Length dependence of cdsc.

568 `lcdscb=0.0 F/m`^{2} `V`
Length dependence of cdscb.

569 `lcdscd=0.0 F/m`^{2} `V`
Length dependence of cdscd.

570 `lnfactor=0.0` Length dependence of nfactor.

571 `ltnfactor=0.0` Length dependence of tnfactor.

572 `lcit=0.0 F` Length dependence of cit.

573 `lvoff=0.0 V` Length dependence of voff.

574 `ldsub=0.0` Length dependence of dsub.

575 `leta0=0.0` Length dependence of eta0.

576 `lteta0=0.0` Length dependence of teta0.

577 `letab=0.0 1/V` Length dependence of etab.

578 `lalpha0=0.0 m/V` Length dependence of alpha0.

579 `lalpha1=0.0 m/V` Length dependence of alpha1.

580 `lbeta0=0.0 1/V` Length dependence of beta0.

581 `lcgsl=0.0 F/m` Length dependence of cgsl.

582 `lcgdl=0.0 F/m` Length dependence of cgdl.

583 `lclc=0.0 m` Length dependence of clc.

584 `lcle=0.0` Length dependence of cle.

585 `lcf=0.0 F/m` Length dependence of cf.

586 `lvfbcv=0.0` Length dependence of vfbcv.

587 `lacde=0.0` Length dependence of acde.

588 `lmoin=0.0` Length dependence of moin.

589 `lnoff=0.0` Length dependence of noff.

590 `lvoffcv=0.0` Length dependence of voffcv.

591 `ltvoffcv=0.0` Length dependence of tvoffcv.

592 `lminvcv=0.0` Length dependence of minvcv.

593 `lkt1=0.0 V` Length dependence of kt1.

594 `lkt1l=0 V m` Length dependence of kt1l.

595 `lkt2=0.0` Length dependence of kt2.

596 `lat=0.0 m/s` Length dependence of at.

597 `lua1=0.0 m/V` Length dependence of ua1.

598 `lub1=0.0` m^2/V^2 Length dependence of ub1.

599 `luc1=0.0` m/V^2 Length dependence of uc1.

600 `lud1=0.0` $/m^2$ Length dependence of ud1.

601 `lprt=0.0` Ω Length dependence of prt.

602 `lute=0.0` Length dependence of ute.

603 `lndep=0.0` Length dependence of ndep.

604 `lnsd=0.0` Length dependence of nsd.

605 `lphin=0.0` Length dependence of phin.

606 `llpe0=0.0` Length dependence of lpe0.

607 `llpeb=0.0` Length dependence of lpeb.

608 `ldvtp0=0.0` Length dependence of dvtp0.

609 `ldvtp1=0.0` Length dependence of dvtp1.

610 `ldvtp2=0.0` Length dependence of dvtp2.

611 `ldvtp3=0.0` Length dependence of dvtp3.

612 `ldvtp4=0.0` Length dependence of dvtp4.

613 `ldvtp5=0.0` Length dependence of dvtp5.

614 `leu=0.0` Length dependence of eu.

615 `lminv=0.0` Length dependence of minv.

616 `lfprout=0.0` Length dependence of fprout.

617 `lpdits=0.0` Length dependence of pdits.

618 `lpditsd=0.0` Length dependence of pditsd.

619 `lrdw=0.0` Length dependence of rdw.

620 `lrsw=0.0` Length dependence of rsw.

621 `lagidl=0.0` Length dependence of agidl.

622 `lbgidl=0.0` Length dependence of bgidl.

623 `lcgidl=0.0` Length dependence of cgidl.

624 `legidl=0.0` Length dependence of egidl.

625 `lfgidl=0.0` Length dependence of fgidl.

626 `lkgidl=0.0` Length dependence of kgidl.

627 `lrgidl=0.0` Length dependence of rgidl.

628 `lfgisl=lfgidl` Length dependence of fgisl.

629 `lkgisl=lkgidl` Length dependence of kgisl.

630 `lrgisl=lrgidl` Length dependence of rgisl.

631 `laigbacc=0.0` Length dependence of aigbacc.

632 `lbigbacc=0.0` Length dependence of bigbacc.

633 `lcigbacc=0.0` Length dependence of cigbacc.

634 `lnigbacc=0.0` Length dependence of nigbacc.

635 `laigbinv=0.0` Length dependence of aigbinv.

636 `lbigbinv=0.0` Length dependence of bigbinv.

637 `lcigbinv=0.0` Length dependence of cigbinv.

638 `leigbinv=0.0` Length dependence of eigbinv.

639 `lnigbinv=0.0` Length dependence of nigbinv.

640 `laigc=0.0` Length dependence of aigc.

641 `lbigc=0.0` Length dependence of bigc.

642 `lcigc=0.0` Length dependence of cigc.

643 `laigsd=0.0` Length dependence of aigsd.

644 `lbigsd=0.0` Length dependence of bigsd.

645 `lcigsd=0.0` Length dependence of cigsd.

646 `lnigc=0.0` Length dependence of nigc.

647 `lpoxedge=0.0` Length dependence of poxedge.

648 `lpigcd=0.0` Length dependence of pigcd.

649 `lntox=0.0` Length dependence of ntox.

650 `lckappas=0.0` Length dependence of ckappas.

651 `lckappad=0.0` Length dependence of ckappad.

652 `lxrcrg1=0.0` Length dependence of xrcrg1.

653 `lxrcrg2=0.0` Length dependence of xrcrg2.

654 `lvfbsdoff=0.0` Length dependence of vfbsdoff.

655 `llambda=0.0` Length dependence of lambda.

656 `lvtl=0.0` Length dependence of vtl.

657 `lxn=0.0` Length dependence of xn.

658 `lkvth0we=0.0 V` Length dependence of kvth0we.

659 `lk2we=0.0` Length dependence of k2we.

660 `lku0we=0.0` Length dependence of ku0we.

661 `lku0=0.0 m^llodku0`
Length dependence of ku0.

662 `lkvth0=0.0 V m^llodku0`
Length dependence of kvth0.

663 `lucs=0.0` Length dependence of ucs.

664 `lucste=0.0` Length dependence of ucste.

Width dependent parameters

665 `wvtho=0.0 V` Width dependence of vtho.

666 `wvth0` Width dependence of vth0.

667 `wvfb=0.0` Width dependence of vfb.

668 `wk1=0.0 √V` Width dependence of k1.

669 `wk2=0.0` Width dependence of k2.

670 `wk3=0.0` Width dependence of k3.

671 `wk3b=0.0 1/V` Width dependence of k3b.

672 `ww0=0.0 m` Width dependence of w0.

673 `wgamma1=0.0 √V`
Width dependence of gamma1.

674 `wgamma2=0.0 √V`
Width dependence of gamma2.

675 `wvbx=0.0 V` Width dependence of vbx.

676 `wvbm=0.0 V` Width dependence of vbm.

677 `wdvt0=0.0` Width dependence of dvt0.

678 `wdvt1=0.0` Width dependence of dvt1.

679 `wdvt2=0.0 1/V` Width dependence of dvt2.

680 `wdvt0w=0.0` Width dependence of dvt0w.

681 `wdvt1w=0.0` Width dependence of dvt1w.

682 `wdvt2w=0.0` Width dependence of dvt2w.

683 `wa0=0.0` Width dependence of a0.

684 `wb0=0.0 m` Width dependence of b0.

685 `wb1=0.0 m` Width dependence of b1.

686 `wa1=0.0` Width dependence of a1.

687 `wa2=0.0` Width dependence of a2.

688 `wags=0.0` F/m^2 `V` Width dependence of ags.

689 `wketa=0.0 1/V` Width dependence of keta.

690 `wnsub=0.0 cm`$^{-3}$ Width dependence of nsub.

691 `wngate=0.0 cm`$^{-3}$ Width dependence of ngate.

692 `wxj=0.0 m` Width dependence of xj.

693 `wdwg=0.0 m/V` Width dependence of dwg.

694 `wdwb=0.0 m/`$\sqrt{V}$ Width dependence of dwb.

695 `wxt=0.0 m` Width dependence of xt.

696 `wrdsw=0.0` Ω µm Width dependence of rdsw.

697 `wprwb=0.0 1/`$\sqrt{V}$ Width dependence of prwb.

698 `wprwg=0.0 1/V` Width dependence of prwg.

699 `wwr=0.0` Width dependence of wr.

700 `wu0=0.0` Width dependence of u0.

701 `wvsat=0.0 m/s` Width dependence of vsat.

702 `wua=0.0 m/V` Width dependence of ua.

703 `wub=0.0` m^2/V^2 Width dependence of ub.

704 `wuc=0.0` m/V^2 Width dependence of uc.

705 `wud=0.0` $/m^2$ Width dependence of ud.

706 `wup=0.0` Width dependence of up.

707 `wlp=0.0 m` Width dependence of lp.

708 `wdrout=0.0` Width dependence of drout.

709 `wpclm=0.0` Width dependence of pclm.

710 `wpdiblc1=0.0` Width dependence of pdiblc1.

711 `wpdiblc2=0.0` Width dependence of pdiblc2.

712 `wpdiblcb=0.0 1/V` Width dependence of pdiblcb.

713 `wpscbe1=0.0 V/m` Width dependence of pscbe1.

714 `wpscbe2=0.0 m/V` Width dependence of pscbe2.

715 `wpvag=0.0` Width dependence of pvag.

716 `wdelta=0.0 V` Width dependence of delta.

717 `wcdsc=0.0 F/m`^{2} Width dependence of cdsc.

718 `wcdscb=0.0 F/m`^{2} `V`
Width dependence of cdscb.

719 `wcdscd=0.0 F/m`^{2} `V`
Width dependence of cdscd.

720 `wnfactor=0.0` Width dependence of nfactor.

721 `wtnfactor=0.0` Width dependence of tnfactor.

722 `wcit=0.0 F` Width dependence of cit.

723 `wvoff=0.0 V` Width dependence of voff.

724 `wdsub=0.0` Width dependence of dsub.

725 `weta0=0.0` Width dependence of eta0.

726 `wteta0=0.0` Width dependence of teta0.

727 `wetab=0.0 1/V` Width dependence of etab.

728 `walpha0=0.0 m/V` Width dependence of alpha0.

729 `walpha1=0.0 m/V` Width dependence of alpha1.

730 `wbeta0=0.0 1/V` Width dependence of beta0.

731 `wcgsl=0.0 F/m`	Width dependence of cgsl.
732 `wcgdl=0.0 F/m`	Width dependence of cgdl.
733 `wclc=0.0 m`	Width dependence of clc.
734 `wcle=0.0`	Width dependence of cle.
735 `wcf=0.0 F/m`	Width dependence of cf.
736 `wvfbcv=0.0`	Width dependence of vfbcv.
737 `wacde=0.0`	Width dependence of acde.
738 `wmoin=0.0`	Width dependence of moin.
739 `wnoff=0.0`	Width dependence of noff.
740 `wvoffcv=0.0`	Width dependence of voffcv.
741 `wtvoffcv=0.0`	Width dependence of tvoffcv.
742 `wminvcv=0.0`	Width dependence of minvcv.
743 `wkt1=0.0 V`	Width dependence of kt1.
744 `wkt1l=0 V m`	Width dependence of kt1l.
745 `wkt2=0.0`	Width dependence of kt2.
746 `wat=0.0 m/s`	Width dependence of at.
747 `wua1=0.0 m/V`	Width dependence of ua1.
748 `wub1=0.0` m^2/V^2	Width dependence of ub1.
749 `wuc1=0.0` m/V^2	Width dependence of uc1.
750 `wud1=0.0` $/m^2$	Width dependence of ud1.
751 `wprt=0.0` Ω	Width dependence of prt.
752 `wute=0.0`	Width dependence of ute.

753 `wndep=0.0` Width dependence of ndep.

754 `wnsd=0.0` Width dependence of nsd.

755 `wphin=0.0` Width dependence of phin.

756 `wlpe0=0.0` Width dependence of lpe0.

757 `wlpeb=0.0` Width dependence of lpeb.

758 `wdvtp0=0.0` Width dependence of dvtp0.

759 `wdvtp1=0.0` Width dependence of dvtp1.

760 `wdvtp2=0.0` Width dependence of dvtp2.

761 `wdvtp3=0.0` Width dependence of dvtp3.

762 `wdvtp4=0.0` Width dependence of dvtp4.

763 `wdvtp5=0.0` Width dependence of dvtp5.

764 `weu=0.0` Width dependence of eu.

765 `wminv=0.0` Width dependence of minv.

766 `wfprout=0.0` Width dependence of fprout.

767 `wpdits=0.0` Width dependence of pdits.

768 `wpditsd=0.0` Width dependence of pditsd.

769 `wrdw=0.0` Width dependence of rdw.

770 `wrsw=0.0` Width dependence of rsw.

771 `wagidl=0.0` Width dependence of agidl.

772 `wbgidl=0.0` Width dependence of bgidl.

773 `wcgidl=0.0` Width dependence of cgidl.

774 `wegidl=0.0` Width dependence of egidl.

775 `wfgidl=0.0`	Width dependence of fgidl.
776 `wkgidl=0.0`	Width dependence of kgidl.
777 `wrgidl=0.0`	Width dependence of rgidl.
778 `wfgisl=wfgidl`	Width dependence of fgisl.
779 `wkgisl=wkgidl`	Width dependence of kgisl.
780 `wrgisl=wrgidl`	Width dependence of rgisl.
781 `waigbacc=0.0`	Width dependence of aigbacc.
782 `wbigbacc=0.0`	Width dependence of bigbacc.
783 `wcigbacc=0.0`	Width dependence of cigbacc.
784 `wnigbacc=0.0`	Width dependence of nigbacc.
785 `waigbinv=0.0`	Width dependence of aigbinv.
786 `wbigbinv=0.0`	Width dependence of bigbinv.
787 `wcigbinv=0.0`	Width dependence of cigbinv.
788 `weigbinv=0.0`	Width dependence of eigbinv.
789 `wnigbinv=0.0`	Width dependence of nigbinv.
790 `waigc=0.0`	Width dependence of aigc.
791 `wbigc=0.0`	Width dependence of bigc.
792 `wcigc=0.0`	Width dependence of cigc.
793 `waigsd=0.0`	Width dependence of aigsd.
794 `wbigsd=0.0`	Width dependence of bigsd.
795 `wcigsd=0.0`	Width dependence of cigsd.
796 `wnigc=0.0`	Width dependence of nigc.

797 `wpoxedge=0.0` Width dependence of poxedge.

798 `wpigcd=0.0` Width dependence of pigcd.

799 `wntox=0.0` Width dependence of ntox.

800 `wckappas=0.0` Width dependence of ckappas.

801 `wckappad=0.0` Width dependence of ckappad.

802 `wxrcrg1=0.0` Width dependence of xrcrg1.

803 `wxrcrg2=0.0` Width dependence of xrcrg2.

804 `wvfbsdoff=0.0` Width dependence of vfbsdoff.

805 `wlambda=0.0` Width dependence of lambda.

806 `wvtl=0.0` Width dependence of vtl.

807 `wxn=0.0` Width dependence of xn.

808 `wkvth0we=0.0 V` Width dependence of kvth0we.

809 `wk2we=0.0` Width dependence of k2we.

810 `wku0we=0.0` Width dependence of ku0we.

811 `wku0=0.0 m^wlodku0`
Width dependence of ku0.

812 `wkvth0=0.0 V m^wlodku0`
Width dependence of kvth0.

813 `wucs=0.0` Width dependence of ucs.

814 `wucste=0.0` Width dependence of ucste.

Cross-term dependent parameters

815 `pvtho=0.0 V` Cross-term dependence of vtho.

816 `pvth0` Cross-term dependence of vth0.

817 `pvfb=0.0` Cross-term dependence of vfb.

818 `pk1=0.0 √V` Cross-term dependence of k1.

819 `pk2=0.0` Cross-term dependence of k2.

820 `pk3=0.0` Cross-term dependence of k3.

821 `pk3b=0.0 1/V` Cross-term dependence of k3b.

822 `pw0=0.0 m` Cross-term dependence of w0.

823 `pgamma1=0.0 √V`
Cross-term dependence of gamma1.

824 `pgamma2=0.0 √V`
Cross-term dependence of gamma2.

825 `pvbx=0.0 V` Cross-term dependence of vbx.

826 `pvbm=0.0 V` Cross-term dependence of vbm.

827 `pdvt0=0.0` Cross-term dependence of dvt0.

828 `pdvt1=0.0` Cross-term dependence of dvt1.

829 `pdvt2=0.0 1/V` Cross-term dependence of dvt2.

830 `pdvt0w=0.0` Cross-term dependence of dvt0w.

831 `pdvt1w=0.0` Cross-term dependence of dvt1w.

832 `pdvt2w=0.0` Cross-term dependence of dvt2w.

833 `pa0=0.0` Cross-term dependence of a0.

834 `pb0=0.0 m` Cross-term dependence of b0.

835 `pb1=0.0 m` Cross-term dependence of b1.

836 `pa1=0.0` Cross-term dependence of a1.

837 `pa2=0.0` Cross-term dependence of a2.

838 `pags=0.0 F/m`^{2} `V` Cross-term dependence of ags.

839 `pketa=0.0 1/V` Cross-term dependence of keta.

840 `pnsub=0.0 cm`$^{-3}$ Cross-term dependence of nsub.

841 `pngate=0.0 cm`$^{-3}$ Cross-term dependence of ngate.

842 `pxj=0.0 m` Cross-term dependence of xj.

843 `pdwg=0.0 m/V` Cross-term dependence of dwg.

844 `pdwb=0.0 m/`$\sqrt{V}$ Cross-term dependence of dwb.

845 `pxt=0.0 m` Cross-term dependence of xt.

846 `prdsw=0.0` Ω μm Cross-term dependence of rdsw.

847 `pprwb=0.0 1/`$\sqrt{V}$ Cross-term dependence of prwb.

848 `pprwg=0.0 1/V` Cross-term dependence of prwg.

849 `pwr=0.0` Cross-term dependence of wr.

850 `pu0=0.0` Cross-term dependence of u0.

851 `pvsat=0.0 m/s` Cross-term dependence of vsat.

852 `pua=0.0 m/V` Cross-term dependence of ua.

853 `pub=0.0` m^2/V^2 Cross-term dependence of ub.

854 `puc=0.0` m/V^2 Cross-term dependence of uc.

855 `pud=0.0` $/m^2$ Cross-term dependence of ud.

856 `pup=0.0` Cross-term dependence of up.

857 `plp=0.0 m` Cross-term dependence of lp.

858 `pdrout=0.0` Cross-term dependence of drout.

859 `ppclm=0.0` Cross-term dependence of pclm.

860 `ppdiblc1=0.0` Cross-term dependence of pdiblc1.

861 `ppdiblc2=0.0` Cross-term dependence of pdiblc2.

862 `ppdiblcb=0.0 1/V` Cross-term dependence of pdiblcd.

863 `ppscbe1=0.0 V/m` Cross-term dependence of pscbe1.

864 `ppscbe2=0.0 m/V` Cross-term dependence of pscbe2.

865 `ppvag=0.0` Cross-term dependence of pvag.

866 `pdelta=0.0 V` Cross-term dependence of delta.

867 `pcdsc=0.0 F/m`^{2} Cross-term dependence of cdsc.

868 `pcdscb=0.0 F/m`^{2} `V`
Cross-term dependence of cdscb.

869 `pcdscd=0.0 F/m`^{2} `V`
Cross-term dependence of cdscd.

870 `pnfactor=0.0` Cross-term dependence of nfactor.

871 `ptnfactor=0.0` Cross-term dependence of tnfactor.

872 `pcit=0.0 F` Cross-term dependence of cit.

873 `pvoff=0.0 V` Cross-term dependence of voff.

874 `pdsub=0.0` Cross-term dependence of dsub.

875 `peta0=0.0` Cross-term dependence of eta0.

876 `pteta0=0.0` Cross-term dependence of teta0.

877 `petab=0.0 1/V` Cross-term dependence of etab.

878 `palpha0=0.0 m/V` Cross-term dependence of alpha0.

879 `palpha1=0.0 m/V` Cross-term dependence of alpha1.

880 `pbeta0=0.0 1/V`	Cross-term dependence of beta0.
881 `pcgsl=0.0 F/m`	Cross-term dependence of cgsl.
882 `pcgdl=0.0 F/m`	Cross-term dependence of cgdl.
883 `pclc=0.0 m`	Cross-term dependence of clc.
884 `pcle=0.0`	Cross-term dependence of cle.
885 `pcf=0.0 F/m`	Cross-term dependence of cf.
886 `pvfbcv=0.0`	Cross-term dependence of vfbcv.
887 `pacde=0.0`	Cross-term dependence of acde.
888 `pmoin=0.0`	Cross-term dependence of moin.
889 `pnoff=0.0`	Cross-term dependence of noff.
890 `pvoffcv=0.0`	Cross-term dependence of voffcv.
891 `ptvoffcv=0.0`	Cross-term dependence of tvoffcv.
892 `pminvcv=0.0`	Cross-term dependence of minvcv.
893 `pkt1=0.0 V`	Cross-term dependence of kt1.
894 `pkt1l=0 V m`	Cross-term dependence of kt1l.
895 `pkt2=0.0`	Cross-term dependence of kt2.
896 `pat=0.0 m/s`	Cross-term dependence of at.
897 `pua1=0.0 m/V`	Cross-term dependence of ua1.
898 `pub1=0.0` m^2/V^2	Cross-term dependence of ub1.
899 `puc1=0.0` m/V^2	Cross-term dependence of uc1.
900 `pud1=0.0` $/m^2$	Cross-term dependence of ud1.
901 `pprt=0.0` Ω	Cross-term dependence of prt.

902 `pute=0.0` Cross-term dependence of ute.

903 `pndep=0.0` Cross-term dependence of ndep.

904 `pnsd=0.0` Cross-term dependence of nsd.

905 `pphin=0.0` Cross-term dependence of phin.

906 `plpe0=0.0` Cross-term dependence of lpe0.

907 `plpeb=0.0` Cross-term dependence of lpeb.

908 `pdvtp0=0.0` Cross-term dependence of dvtp0.

909 `pdvtp1=0.0` Cross-term dependence of dvtp1.

910 `pdvtp2=0.0` Cross-term dependence of dvtp2.

911 `pdvtp3=0.0` Cross-term dependence of dvtp3.

912 `pdvtp4=0.0` Cross-term dependence of dvtp4.

913 `pdvtp5=0.0` Cross-term dependence of dvtp5.

914 `peu=0.0` Cross-term dependence of eu.

915 `pminv=0.0` Cross-term dependence of minv.

916 `pfprout=0.0` Cross-term dependence of fprout.

917 `ppdits=0.0` Cross-term dependence of pdits.

918 `ppditsd=0.0` Cross-term dependence of pditsd.

919 `prdw=0.0` Cross-term dependence of rdw.

920 `prsw=0.0` Cross-term dependence of rsw.

921 `pagidl=0.0` Cross-term dependence of agidl.

922 `pbgidl=0.0` Cross-term dependence of bgidl.

923 `pcgidl=0.0` Cross-term dependence of cgidl.

924 `pegidl=0.0`	Cross-term dependence of egidl.
925 `pfgidl=0.0`	Cross-term dependence of fgidl.
926 `pkgidl=0.0`	Cross-term dependence of kgidl.
927 `prgidl=0.0`	Cross-term dependence of rgidl.
928 `pfgisl=pfgidl`	Cross-term dependence of fgisl.
929 `pkgisl=pkgidl`	Cross-term dependence of kgisl.
930 `prgisl=prgidl`	Cross-term dependence of rgisl.
931 `paigbacc=0.0`	Cross-term dependence of aigbacc.
932 `pbigbacc=0.0`	Cross-term dependence of bigbacc.
933 `pcigbacc=0.0`	Cross-term dependence of cigbacc.
934 `pnigbacc=0.0`	Cross-term dependence of nigbacc.
935 `paigbinv=0.0`	Cross-term dependence of aigbinv.
936 `pbigbinv=0.0`	Cross-term dependence of bigbinv.
937 `pcigbinv=0.0`	Cross-term dependence of cigbinv.
938 `peigbinv=0.0`	Cross-term dependence of eigbinv.
939 `pnigbinv=0.0`	Cross-term dependence of nigbinv.
940 `paigc=0.0`	Cross-term dependence of aigc.
941 `pbigc=0.0`	Cross-term dependence of bigc.
942 `pcigc=0.0`	Cross-term dependence of cigc.
943 `paigsd=0.0`	Cross-term dependence of aigsd.
944 `pbigsd=0.0`	Cross-term dependence of bigsd.
945 `pcigsd=0.0`	Cross-term dependence of cigsd.

946 `pnigc=0.0` Cross-term dependence of nigc.

947 `ppoxedge=0.0` Cross-term dependence of poxedge.

948 `ppigcd=0.0` Cross-term dependence of pigcd.

949 `pntox=0.0` Cross-term dependence of ntox.

950 `pckappas=0.0` Cross-term dependence of ckappas.

951 `pckappad=0.0` Cross-term dependence of ckappad.

952 `pxrcrg1=0.0` Cross-term dependence of xrcrg1.

953 `pxrcrg2=0.0` Cross-term dependence of xrcrg2.

954 `pvfbsdoff=0.0` Cross-term dependence of Vfbsdoff.

955 `plambda=0.0` Cross-term dependence of lambda.

956 `pvtl=0.0` Cross-term dependence of vtl.

957 `pxn=0.0` Cross-term dependence of xn.

958 `pkvth0we=0.0 V` Cross-term dependence of kvth0we.

959 `pk2we=0.0` Cross-term dependence of k2we.

960 `pku0we=0.0` Cross-term dependence of ku0we.

961 `pku0=0.0 m^(llodku0+wlodku0)`
Cross-term dependence of ku0.

962 `pkvth0=0.0 V m^(llodku0+wlodku0)`
Cross-term dependence of kvth0.

963 `pucs=0.0` Cross-term dependence of ucs.

964 `pucste=0.0` Cross-term dependence of ucste.

DC-mismatch dependent parameters

965 `mvtwl=0.0 V m` Threshold mismatch area dependence.

966 `mvtwl2=0.0 V m^1.5`
Threshold mismatch area square dependence.

967 `mvt0=0.0 V` Threshold mismatch intercept.

968 `mbewl=0.0 m` Beta mismatch area dependence.

969 `mbe0=0.0` Beta mismatch intercept.

970 `mismatchmod=0` Select Mismatch mode.

971 `mismatchdist=0 m` Mismatch Distance.

Compatibility model parameters

972 `compatible=spectre`
Encourage device equations to be compatible with a foreign simulator. This option does not affect input syntax.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, `mica`, `tispice`, and `pspice`.

Shrink Parameters

973 `shrink=0` Linear shrink parameter.

974 `shrink2=0` Area shrink parameter.

Imax and Imelt

The `imax` parameter aids convergence and prevents numerical overflow. The junction characteristics of the device are accurately modeled for current up to `imax`. If `imax` is exceeded during iterations, the linear model is substituted until the current drops below `imax` or until convergence is achieved. If convergence is achieved with the current exceeding `imax`, the results are inaccurate, and a warning is printed out.

A separate model parameter, `imelt`, is used as a limit warning for the junction current. This parameter can be set to the maximum current rating of the device. When any component of the junction current exceeds `imelt`, note that base and collector currents are composed of many exponential terms, a warning will be issued and the results become inaccurate. The junction current is linearized above the value of `imelt` to prevent arithmetic exception, with the exponential term replaced by a linear equation at `imelt`.

Both of these parameters have current density counterparts, `jmax` and `jmelt`, that you can specify if you want the absolute current values to depend on the device area.

In BSIM4, `imax` (`jmax`) will take effect only when `diomod=3` (Spectre common diode model). Berkeley uses other model parameters, such as `ijthsfwd`, `ijthdfwd` to do limitation. For more information, see the Berkeley BSIM4 manual.

Auto Model Selection

Many models need to be characterized for different geometries in order to obtain accurate results for model development. The model selector program automatically searches for a model with the length and width range specified in the instance statement and uses this model in the simulations.

For the auto model selector program to find a specific model, the models to be searched should be grouped together within braces. Such a group is called a model group. An opening brace is required at the end of the line defining each model group. Every model in the group is given a name followed by a colon and the list of parameters. Also, the four geometric parameters `lmax`, `lmin`, `wmax`, and `wmin` should be given. The selection criteria to choose a model is as follows:

```
lmin <= inst_length < lmax  and   wmin <= inst_width  < wmax
```

Example:

```
model ModelName ModelType {
   1:     <model parameters> lmin=2 lmax=4 wmin=1 wmax=2
   2:     <model parameters> lmin=1 lmax=2 wmin=2 wmax=4
   3:     <model parameters> lmin=2 lmax=4 wmin=4 wmax=6
}
```

Then for a given instance

```
M1 1 2 3 4 ModelName w=3 l=1.5
```

the program would search all the models in the model group with the name `ModelName` and then pick the first model whose geometric range satisfies the selection criteria. In the preceding example, the auto model selector program would choose ModelName.2.

You must specify both length (l) and width (w) on the device instance line to enable automatic model selection.

Inst Default to Model

In BSIM4, for customer convenience, some model parameters are added to serve as default values for the corresponding instance parameters (they are not Berkeley model parameters. These include: `l`, `w`, `as`, `ad`, `ps`, `pd`, `nrs`, `nrd`, `rdc`, `rsc`, `rgeomod`, `nf`, `min`, and `trise`.

Output Parameters

1 `tempeff (C)`	Effective temperature for a single device.
2 `meff`	Effective multiplicity factor (m-factor).
3 `weff (m)`	Effective channel width (alias=lx62).
4 `leff (m)`	Effective channel length (alias=lx63).
5 `weffcv (m)`	Effective channel width for CV (alias=lx64).
6 `leffcv (m)`	Effective channel length for CV (alias=lx65).
7 `vfbsd (V)`	Flat band Voltage between the gate and Drain/source diffusions (alias=lx75).
8 `rgbi (Ω)`	Gate bias-independent resistance.
9 `adeff (m`^{2}`)`	Effective drain area.
10 `aseff (m`^{2}`)`	Effective source area.
11 `pdeff (m)`	Effective drain perimeter.
12 `pseff (m)`	Effective source perimeter.

Operating-Point Parameters

1 `region=triode`	Estimated operating region. %Z outputs the number (0-4) in a rawfile. Possible values are `off`, `triode`, `sat`, `subth`, and `breakdown`.
2 `reversed`	Reverse mode indicator. Possible values are `no` and `yes`.

3 `ids (A)`	Resistive drain-to-source current.
4 `vgs (V)`	Gate-source voltage.
5 `vds (V)`	Drain-source voltage.
6 `vbs (V)`	Bulk-source voltage.
7 `vgd (V)`	Gate-drain voltage.
8 `vdb (V)`	Drain-bulk voltage.
9 `vgb (V)`	Gate-bulk voltage.
10 `vth (V)`	Threshold voltage (alias=lv9).
11 `vdsat (V)`	Drain-source saturation voltage (alias=lv10).
12 `gm (S)`	Common-source transconductance (alias=lx7).
13 `gds (S)`	Common-source output conductance (alias=lx8).
14 `gmbs (S)`	Body-transconductance (alias=lx9).
15 `betaeff` (A/V^2)	Effective beta (alias LV21).
16 `cjd (F)`	Drain-bulk junction capacitance (alias=lx29).
17 `cjs (F)`	Source-bulk junction capacitance (alias=lx28).
18 `cgg (F)`	Total gate capacitance, including intrinsic, overlap and fringing components (alias=lx82).
19 `cgd (F)`	Total gate-to-drain capacitance, including intrinsic, overlap, and fringing components (alias=lx83).
20 `cgs (F)`	Total gate-to-source capacitance, including intrinsic, overlap, and fringing components (alias=lx84).
21 `cgb (F)`	Total gate-to-bulk capacitance, including intrinsic and overlap components.

22 `cdg (F)`	Total drain-to-gate capacitance, including intrinsic, overlap, and fringing components (alias=lx87).
23 `cdd (F)`	Drain capacitance, including intrinsic, overlap, and fringing components.
24 `cds (F)`	Total drain-to-source capacitance (alias=lx86).
25 `cdb (F)`	Intrinsic drain-to-bulk capacitance.
26 `csg (F)`	Total source-to-gate capacitance, including intrinsic, overlap, and fringing components.
27 `csd (F)`	Total source-to-drain capacitance.
28 `css (F)`	Source capacitance, including intrinsic, overlap, and fringing components.
29 `csb (F)`	Intrinsic source-to-bulk capacitance.
30 `cbg (F)`	Total bulk-to-gate capacitance, including intrinsic and overlap components (alias=lx88).
31 `cbd (F)`	Intrinsic bulk-to-drain capacitance.
32 `cbs (F)`	Intrinsic bulk-to-source capacitance.
33 `cbb (F)`	Bulk capacitance, including intrinsic and overlap components.
34 `covlgs (F/m)`	Gate-source overlap and fringing capacitances (alias=lv36).
35 `covlgd (F/m)`	Gate-drain overlap and fringing capacitances (alias=lv37).
36 `covlgb (F/m)`	Gate-bulk overlap capacitances (alias=lv38).
37 `cggbo (F)`	CGGBO = dQg/dVg intrinsic gate capacitance (alias=lx18).
38 `cgdbo (F)`	CGDBO = -dQg/dVd intrinsic gate-to-drain capacitance (alias=lx19).
39 `cgsbo (F)`	CGSBO = -dQg/dVs intrinsic gate-to-source capacitance (alias=lx20).

40 `cbgbo (F)`	CBGBO = -dQb/dVg intrinsic bulk-to-gate capacitance (alias=lx21).
41 `cbdbo (F)`	CBDBO = -dQb/dVd intrinsic bulk-to-drain capacitance (alias=lx22).
42 `cbsbo (F)`	CBSBO = -dQb/dVs intrinsic bulk-to-source capacitance (alias=lx23).
43 `cdgbo (F)`	CDGBO = -dQd/dVg intrinsic drain-to-gate capacitance (alias=lx32).
44 `cddbo (F)`	CDDBO = dQd/dVd intrinsic drain capacitance (alias=lx33).
45 `cdsbo (F)`	CDSBO = -dQd/dVs intrinsic drain-to-source capacitance (alias=lx34).
46 `ron (Ω)`	On-resistance.
47 `id (A)`	Resistive drain current.
48 `ibulk (A)`	Resistive bulk current.
49 `pwr (W)`	Power at op point.
50 `gmoverid (1/V)`	Gm/Ids.
51 `ueff`	ueff.
52 `rdeff (Ω)`	Effective drain resistance.
53 `rseff (Ω)`	Effective source resistance.
54 `rgbd (Ω)`	Gate bias-dependent resistance.
55 `igidl (A)`	Gate-induced drain leakage current (alias=lx70).
56 `igisl (A)`	Gate-induced source leakage current.
57 `igdt (A)`	Gate Dielectric tunneling current (alias=lx71).
58 `igd (A)`	Gate-to-drain tunneling current (alias=lx39).

59 `igs (A)`	Gate-to-source tunneling current (alias=lx38).
60 `igb (A)`	Gate-to-bulk tunneling current (alias=lx66).
61 `igbacc (A)`	Gate-to-bulk tunneling current determined by ECB (alias=lx73).
62 `igbinv (A)`	Gate-to-bulk tunneling current determined by EVB (alias=lx74).
63 `igcs (A)`	Gate-to-channel (source side) tunneling current (alias=lx67).
64 `igcd (A)`	Gate-to-channel (drain side) tunneling current (alias=lx68).
65 `isub (A)`	Substrate current (alias to LX69).
66 `gbs (S)`	Bulk-source diode conductance (alias=lx11).
67 `gbd (S)`	Bulk-drain diode conductance (alias=lx10).
68 `qg (Coul)`	Total gate charge, including intrinsic, overlap and fringing components.
69 `qd (Coul)`	Total drain charge, including intrinsic, overlap and fringing components.
70 `qs (Coul)`	Total source charge, including intrinsic, overlap and fringing components.
71 `qb (Coul)`	Total bulk charge, including intrinsic and overlap components.
72 `qjd (Coul)`	Drain-bulk junction charge.
73 `qjs (Coul)`	Source-bulk junction charge.
74 `qgdovl (Coul)`	Gate-drain overlap and fringing charge.
75 `qgsovl (Coul)`	Gate-source overlap and fringing charge.
76 `qgi (Coul)`	Intrinsic gate charge.
77 `qdi (Coul)`	Intrinsic drain charge.
78 `qsi (Coul)`	Intrinsic source charge.

79 `qbi (Coul)`	Intrinsic bulk charge.
80 `ide (A)`	Total DC drain current.
81 `ige (A)`	Total DC gate current.
82 `ise (A)`	Total DC source current.
83 `ibe (A)`	Total DC bulk current.
84 `idb (A)`	DC drain-bulk current.
85 `isb (A)`	DC source-bulk current.
86 `vsb (V)`	Source-bulk DC voltage.
87 `gmb (S)`	DC bulk transconductance.
88 `vgt (V)`	Wffective gate drive voltage including back bias and drain bias effects.
89 `vdss (V)`	Drain saturation voltage at actual bias.
90 `vsat_marg (V)`	Vds margin.
91 `self_gain`	Transistor self gain.
92 `rout (Ω)`	AC output resistor.
93 `beff` (A/V^2)	Gain factor in saturation.
94 `fug (Hz)`	Unity current gain frequency at actual bias.
95 `rgate (Ω)`	MOS gate resistance.
96 `vearly (V)`	Equivalent early voltage.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the

description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

22

BSIM6 Model (bsim6)

BSIM6 is the new Bulk MOSFET model from the BSIM Group. The model provides excellent accuracy compared to measured data in all regions of operation. It features model symmetry valued for analog and RF applications while maintaining the strong support and performance of the BSIM model valued for all applications. The available version is 6.0.0.

This chapter contains the following information about the BSIM6 model:

Instance

Instance syntax

BSIM6 instance have 4 terminals. To specify BSIM6 instance element, the ModelName has to be associated with a BSIM6 model card.

```
InstanceName (d g s b) ModelName <parameter=value> ...
```

Sample Instance Statement

```
m1 (0 2 1 1) pchmod w=2u l=0.8u as=250p ad=250p pd=168p ps=168p m=1
```

Note: For detailed list of Instance Parameters, see section Component Statements on page 1462.

Model

Model syntax

The following syntax specifies BSIM6 model:

```
model ModelName bsim6 <parameter=value> ...
```

The third parameter, "bsim6", is the master to indicate this model card is a BSIM6 model card.

Sample Model Statement

```
model pchmod bsim6 type=p version=6.00
```

Note: For detailed list of Model Parameters, see section Component Statements on page 1462.

Model Equations

Effective Channel Length and Width

(22-1)

$$\Delta L = LINT$$

(22-2)

$$\Delta W = WINT$$

(22-3)

$$\Delta L_{CV} = DLC$$

(22-4)

$$\Delta W_{CV} = DWC$$

(22-5)

$$L_{eff} = L + XL - 2\Delta L$$

(22-6)

$$W_{eff} = W + XW - 2\Delta W$$

(22-7)

$$L_{eff,\,CV} = L + XL - 2\Delta L_{CV}$$

(22-8)

$$W_{eff,\,CV} = W + XW - 2\Delta W_{CV}$$

Binning Calculations

For given L and W, each model parameter $PARAM_i$ is calculated as a function of PARAM, a length dependent term, LPARAM, width dependent term, WPARAM, and area dependent term PPARAM:

(22-9)

$$PARAM_i = PARAM + \frac{LPARAM}{L_{eff}} + \frac{WPARAM}{W_{eff}} + \frac{PPARAM}{L_{eff} \cdot W_{eff}}$$

For the list of binnable parameters, refer to the Components Statements section.

Global Geometrical Scaling

Following scaling formulation is used in global scaling:

(22-10)

$$PARAM[L] = PARAM \cdot \left[1 + PARAML \cdot \left(\frac{1}{L_{eff}{}^{PARAMLEXP}} - \frac{1}{LLONG^{PARAMLEXP}}\right) + PARAMW \cdot \left(\frac{1}{W_{eff}{}^{PARAMWEXP}} - \frac{1}{WWIDE^{PARAMWEXP}}\right) + PARAMWL \cdot \left(\frac{1}{(L_{eff} \cdot W_{eff})^{PARAMWLEXP}}\right)\right]$$

Terminal Voltages

(22-11)

$$V_t = \frac{K \cdot T}{q}$$

(22-12)

$$V_g = V_g - V_b$$

(22-13)

$$V_d = V_d - V_b$$

(22-14)

$$V_s = V_s - V_b$$

(22-15)

$$V_{gs} = V_g - V_s$$

(22-16)

$$V_{gd} = V_g - V_d$$

(22-17)

$$V_{gb} = V_g - V_b$$

(22-18)

$$V_{ds} = V_d - V_s$$

(22-19)

$$V_{dsx} = \sqrt{V_{ds}^2 + 0.01} - 0.1$$

(22-20)

$$V_{bsx} = -\left[V_s + \frac{1}{2}(V_{ds} - V_{dsx})\right]$$

Pinch-Off Potential and Normalized Charge Calculation

Pinch-Off Potential with Poly Depletion

(22-21)

$$\psi_p = \begin{cases} 1 + \left[\sqrt{\upsilon_g + \upsilon_{fb} - 1 + \left(\frac{\gamma}{2}\right)^2} - \frac{\gamma}{2}\right]^2 & \text{if } \upsilon_g - \upsilon_{fb} > \phi_b + \gamma\sqrt{\phi_b} \\ 1 + e^{-\psi_{p0}}\left[\sqrt{\upsilon_g - \upsilon_{fb} - 1 + e^{-\psi_{p0}} + \left(\frac{\gamma}{2}\right)^2} - \frac{\gamma}{2}\right]^2 & \text{if } \phi_b + \gamma\sqrt{\phi_b} \ge \upsilon_g - \upsilon_{fb} \ge 0 \\ -\ln\left[1 - \psi_{p0} + \left(\frac{\upsilon_g - \upsilon_{fb} - \psi_{p0}}{\gamma}\right)^2\right] & \text{if } \upsilon_g - \upsilon_{fb} < 0 \end{cases}$$

Note: Derivatives of ψ_p are continuous in all regions.

Normalized Charge Density

Inversion charge: Normalized inversion charge density at source/drain is newly derived for BSIM6, and can be obtained as follows:

(22-22)

$$\ln(q_i) = \ln\left(\frac{4n_q}{\gamma_0} \cdot \sqrt{\psi_p}\right) + 2q_i = \psi_p - 2\phi_f - \upsilon_{ch}$$

Short Channel Effects

Vt roll-off, DIBL, and Subthreshold Slope Degradation

(22-23)

$$\Delta V_{th,VDNUD} = -K2 \cdot V_{bsx}$$

(22-24)

$$\Delta V_{th,DIBL} = -(ETA0 + ETAB \cdot V_{bsx}) \cdot V_{dsx}$$

(22-25)

$$\Delta V_{th,DITS} = -n\frac{KT}{q} \cdot \ln\left(\frac{L_{eff}}{L_{eff} + DVTP0 \cdot (1 + \exp(-DVTP1 \cdot V_{ds}))}\right)$$
$$-\left(DVTP5 + \frac{DVTP2}{L_{eff}^{DVTP3}}\right) \cdot \tanh(DVTP4 \cdot V_{dsx})$$

(22-26)

$$\Delta V_{th,all} = \Delta V_{th,VDNUD} + \Delta V_{th,DIBL} + \Delta V_{th,DITS}$$

(22-27)

$$V_{gfb} = V_g - V_{fb} - \Delta V_{th,all}$$

Note: Short channel effect and reverse short channel effect are modeled using NDEPL1, NDELEXP1, NDEPL2, and NDEPLEXP2 parameters. Width scaling of Vth is modeled using NDEPW and NDEPWEXP parameters.

Drain Saturation Voltage

The drain saturation voltage model is calculated after the source-side charge (q_s) has been calculated. V_{dseff} is subsequently used to compute the drain-side charge (q_d).

Electric Field Calculations

(22-28)

$$E_{effs} = 10^{-8} \cdot \left(\frac{qbs + \eta \cdot qis}{\varepsilon_{ratio} \cdot Tox}\right)$$

Drain Saturation Voltage (V_{dsat}) Calculations

(22-29)

$$D_{mobs} = 1 + (UA + UC \cdot V_{bsx}) \cdot (E_{effs})^{EU} + \frac{UD}{\left[\frac{1}{2} \cdot \left(1 + \frac{q_{is}}{q_{bs}}\right)\right]^{UCS}}$$

(22-30)

$$T_0 = \begin{cases} \dfrac{1}{1 + PSATB \cdot V_{bsx}} & V_{bs} \geq 0 \\ 1 - PSATB \cdot V_{bsx} & V_{bs} < 0 \end{cases}$$

(22-31)

$$\lambda_C = \frac{2 \cdot U0 \cdot nV_t}{(D_{mobs})^{PSAT} \cdot VSAT \cdot L_{eff}} \cdot \left[1 + PTWG \cdot \frac{10 \cdot PSATX \cdot qs \cdot T0}{10 \cdot PSATX + qs \cdot T0}\right]$$

(22-32)

$$q_{dsat} = \frac{\lambda_C}{2} \cdot \frac{q_s^2 + q_s}{1 + \frac{\lambda_C}{2} \cdot (1 + q_s)}$$

(22-33)

$$\upsilon_{dsat} = \psi_p - \frac{2\phi b}{n} - 2q_{dsat} - \ln\left[\frac{2q_{dsat} \cdot n_q}{gam} \cdot \left(\frac{2q_{dsat} \cdot n_q}{gam} + \frac{gam}{n_q - 1}\right)\right]$$

(22-34)

$$V_{dsat} = \upsilon_{dsat} \cdot nV_t$$

(22-35)

$$V_{dssat} = \upsilon_{dsat} - V_s$$

Mobility Degradation with Vertical Field

(22-36)

$$D_{mob} = 1 + (UA + UC \cdot V_{bsx}) \cdot (E_{effm})^{EU} + \frac{UD}{\left[\frac{1}{2} \cdot \left(1 + \frac{q_{ia}}{q_{ba}}\right)\right]^{UCS}}$$

Parasitic Series Resistance

Bias-Dependent Internal Series Resistance (R_{ds}(V))

The internal source-drain resistance (Rds(V)) option can be invoked by setting the model selector RDSMOD=0 (internal). Following are the expressions for source/drain series resistance calculation:

(22-37)

$$T_0 = 1 + PRWG \cdot q_{ia}$$

(22-38)

$$T_1 = PRWB \cdot (\sqrt{\phi_s - V_{bs}} - \sqrt{\phi_s})$$

(22-39)

$$T_2 = \frac{1}{T0} + T_1$$

(22-40)

$$\frac{1}{2}\left[T_2 + \sqrt{T2^2 + 0.01}\right]$$

(22-41)

$$R_{ds}(V) = NF \cdot (R_{s,geo} + R_{d,geo} + W_{eff}^{WR}\ [RDSWMIN + RDSW \cdot T3]\ )$$

Bias-Dependent External Series Resistance (R_s(V) & (R_d(V))

The bias-dependent external series resistance model is adopted from BSIM4 and can be invoked by setting the model selector RDSMOD=1

(22-42)

$$R_{source} = \frac{1}{W_{eff}{}^{WR} \cdot NF} \cdot \left(RSWMIN + RSW \cdot \left[-PRWB \cdot V_{bs} + \frac{1}{1 + PRWG_i \cdot V_{gs,eff}}\right]\right) + R_{s,geo}$$

(22-43)

$$R_{drain} = \frac{1}{W_{eff}{}^{WR} \cdot NF} \cdot \left(RDWMIN + RDW \cdot \left[-PRWB \cdot V_{bd} + \frac{1}{1 + PRWG_i \cdot V_{gd,eff}}\right]\right) + R_{d,geo}$$

Sheet Resistance Model

(22-44)

$$R_{s,geo} = NRS \cdot RSHS$$

$$R_{d,geo} = NRD \cdot RSHD$$

Output Conductance

Channel Length Modulation (CLM)

(22-45)

$$M_{CLM} = 1 + C_{clm} \ln\left[1 + \frac{V_{ds} - V_{dseff}}{V_{asat}} \cdot \frac{1}{C_{clm}}\right]$$

Drain Induced Barrier Lowering (DIBL)

(22-46)

$$M_{DIBL} = \left(1 + \frac{V_{ds} - Vdseff}{VAIDBL}\right)$$

Drain Induced Threshold Shift (DITS)

(22-47)

$$M_{DITS} = \left(1 + \frac{V_{ds} - Vdseff}{VADITS}\right)$$

Substrate Current Induced Body Effect (SCBE)

(22-48)

$$M_{OC} = M_{DIBL} + M_{CLM} + M_{DITS} + M_{SCBE}$$

Velocity Saturation

Current Degradation Due to Velocity Saturation

(22-49)

$$D_{tot} = D_{mob} \cdot D_{vsat} \cdot D_r$$

Effective Mobility

(22-50)

$$\mu_{eff} = \frac{U0}{D_{tot}}$$

Drain Current Model

Without Velocity Saturation

(22-51)

$$I_{DS} = 2 \cdot n_q \cdot \mu_{eff} \cdot \frac{W_{eff}}{L_{eff}} \cdot C_{ox} \cdot nV^2{}_t \cdot [(q_s - q_{deff})(q_s + q_{deff} + 1)]$$

Including Velocity Saturation

(22-52)

$$I_{DS} = 2 \cdot n_q \cdot \mu_{eff} \cdot \frac{W_{eff}}{L_{eff}} \cdot C_{ox} \cdot nV^2{}_t \cdot [(q_s - q_{deff})(q_s + q_{deff} + 1)] \cdot M_{OC}$$

Impact Ionization Model

(22-53)

$$I_{ii} = ALPHA0 \cdot (V_{ds} - V_{dseff}) \cdot \exp\left(-\frac{BETA0}{V_{ds} - Vdseff}\right) \cdot \frac{I_{ds}}{M_{SCBE}}$$

GIDL/GISL Current Model

(22-54)

$$I_{GIDL} = AGIDL \cdot W_{eff} \cdot NF \cdot \frac{V_{ds} - V_{gse} - EGIDL}{3 \cdot Toxe} \cdot \exp\left(\frac{-3 \cdot Toxe \cdot BGIDL}{V_{ds} - V_{gse} - EGIDL}\right) \cdot \frac{V_{db}^3}{CGIDL + V_{db}^3}$$

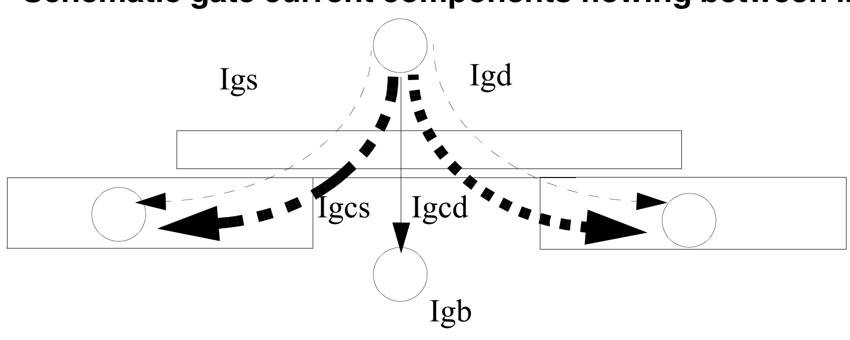
(22-55)

$$I_{GISL} = AGISL \cdot W_{eff} \cdot NF \cdot \frac{V_{ds} - V_{gde} - EGISL}{3 \cdot Toxe} \cdot \exp\left(\frac{-3 \cdot Toxe \cdot BGISL}{V_{ds} - V_{gde} - EGISL}\right) \cdot \frac{V_{sb}^3}{CGISL + V_{sb}^3}$$

I_{GIDL}/I_{GISL} can be switched off by setting GIDLMOD=0

Gate Tunneling Current Model

Figure 22-1 Schematic gate current components flowing between MOSFET terminals



Model Selectors

Two global selectors are provided to turn on or off the tunneling components. IGCMOD=1 turns on Igc, Igs, and Igd; IGBMOD=1 turns on Igb. When the selectors are set to 0, no gate tunneling currents are modeled.

Equations for Tunneling Currents

Gate-to-Substrate Current

(22-56)

$$I_{gbacc} = NF \cdot W_{eff} L_{eff} \cdot A \cdot T_{oxRatio} \cdot V_{gb} \cdot V_{aux} \cdot i_{gtemp}$$
$$\cdot \exp[-B \cdot TOXE(AIGBACC - BIGBACC \cdot V_{oxacc}) \cdot (1 + CIGBAC \cdot V_{oxacc})]$$

(22-57)

$$I_{gbinv} = NF \cdot W_{eff} L_{eff} \cdot A \cdot T_{oxRatio} \cdot V_{gb} \cdot V_{aux} \cdot i_{gtemp}$$
$$\cdot \exp[-B \cdot TOXE(AIGBINV - BIGBINV \cdot V_{oxdepinv}) \cdot (1 + CIGBINVV \cdot V_{oxdepinv})]$$

Gate-to-Channel Current (Igc0) and Gate-to-S/D (Igs and Igd)

(22-58)

$$I_{gc0} = NF \cdot W_{eff} L_{eff} \cdot A \cdot T_{oxRatio} \cdot V_{gse} \cdot V_{aux} \cdot i_{gtemp}$$
$$\cdot \exp[-B \cdot TOXE(AIGC - BIGC \cdot V_{oxdepinv}) \cdot (1 + CIGCV_{oxdepinv})]$$

Partition of Igc: Igc=Igcs+Igcd

(22-59)

$$I_{gcs} = I_{gc0} \cdot \frac{PIGCD \cdot V_{dseffx} + \exp(-PIGCD \cdot V_{dseffx}) - 1 + 10^{-4}}{PIGCD \cdot V^2{}_{dseffx} + 2 \cdot 10^{-4}}$$

(22-60)

$$I_{gcd} = I_{gc0} \cdot \frac{1 - (PIGCD \cdot V_{dseffx} + 1) \cdot \exp(-PIGCD \cdot V_{dseffx}) + 10^{-4}}{PIGCD \cdot V^2{}_{dseffx} + 2 \cdot 10^{-4}}$$

Igs and Igd

(22-61)

$$I_{gs} = \begin{array}{l} NF \cdot W_{eff} DLCIG \cdot A \cdot T_{oxRatioEdge} \cdot V_{gs} \cdot V_{gs}' \cdot i_{gtemp} \\ .\exp[-B \cdot TOXE \cdot POXEDGE \cdot (AIGS - BIGS \cdot V_{gs}') \cdot (1 + CIGSV_{gs}')] \end{array}$$

(22-62)

$$I_{gd} = \begin{array}{l} NF \cdot W_{eff} DLCIGD \cdot A \cdot T_{oxRatioEdge} \cdot V_{gd} \cdot V_{gd}' \cdot i_{gtemp} \\ .\exp[-B \cdot TOXE \cdot POXEDGE \cdot (AIGD - BIGD \cdot V_{gd}') \cdot (1 + CIGSV_{gd}')] \end{array}$$

Vfbsd is the flat-band voltage between gate and source/drain diffusions calculated as:

If NGATE>0

(22-63)

$$V_{fbsd} = \frac{k_B T}{q} \log\left(\frac{NGATE}{NSD}\right) + VFBSDOFF$$

Else V_{fbsd}=0.0.

Gate Resistance and Body Resistance Model

Gate Electrode and Intrinsic -Input Resistance (IIR) Model

BSIM6 provides four options for modeling gate electrode resistance (bias-dependent) and intrinsic-input resistance (IIR, bias-dependent). The IIR model considers relaxation-time effect due to distributive RC nature of the channel region, and therefore describes the first-order non-quasi static effect. Thus, the IIR model should not be used together with the charge-deficit NQS model at the same time. The model selector RGATEMOD is used to choose different options.

Model Option and Schematic

RGATEMOD=0 (zero resistance). In this case, no gate resistance is generated.

RGATEMOD=1 (constant resistance). Rgeltd is given by the following equation:

(22-64)

$$R_{geltd} = \frac{RSHG \cdot \left(XGW + \frac{W_{effci}}{3 \cdot NGCON}\right)}{NGCON \cdot (L_{drawn} - XGL) \cdot NF}$$

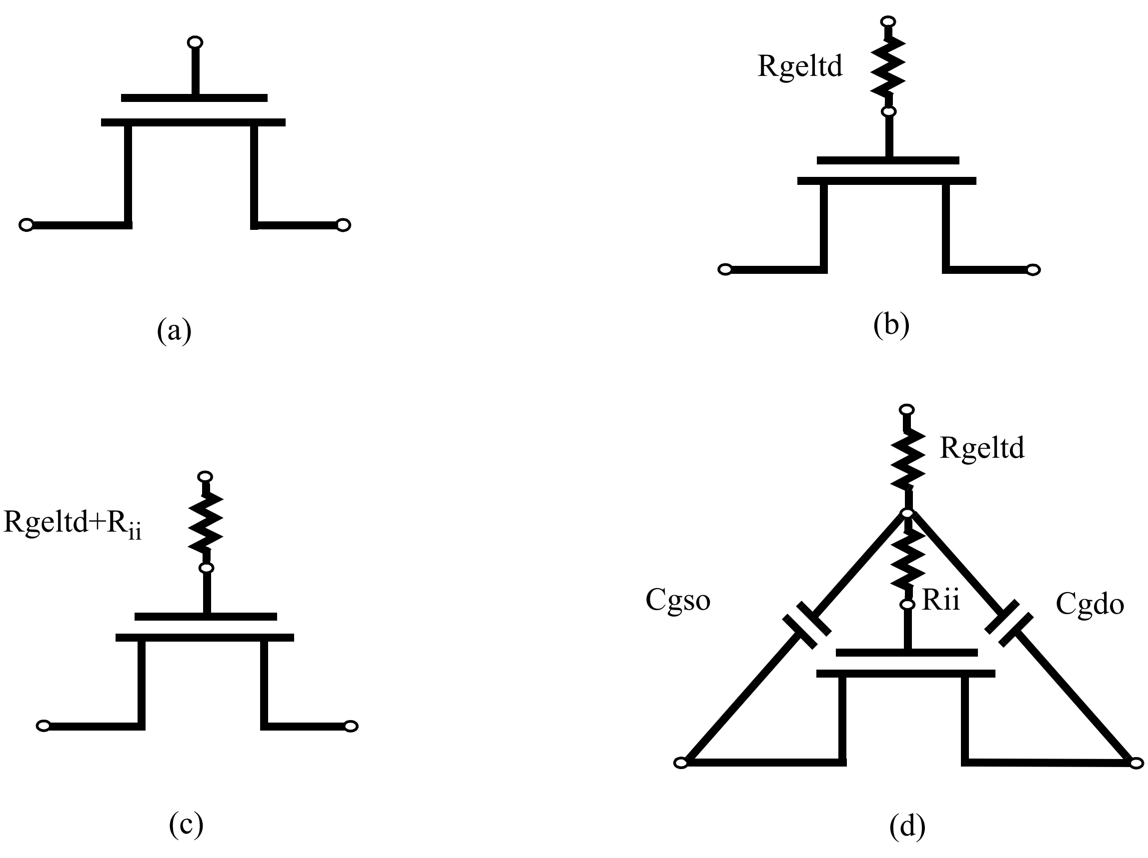
RGATEMOD=2 (IIR model with variable resistance):

(22-65)

$$\frac{1}{R_{ii}} \approx XRCRG1.NF \cdot \left(\mu_{eff}\left(\frac{W_{eff}}{L_{eff}}\right)Cox \cdot q_{ia} + XRCRG2 \cdot \frac{W_{eff}\mu_{eff}C_{oxeff}V_t}{L_{eff}}\right)$$

RGATEMOD=3 (IIR model with two nodes):

Figure 22-2 Gate resistance network for (a) RGATEMOD=0 (b) RGATEMOD=1 (c) RGATEMOD=2 and (d) RGATEMOD=3



Substrate Resistance Network

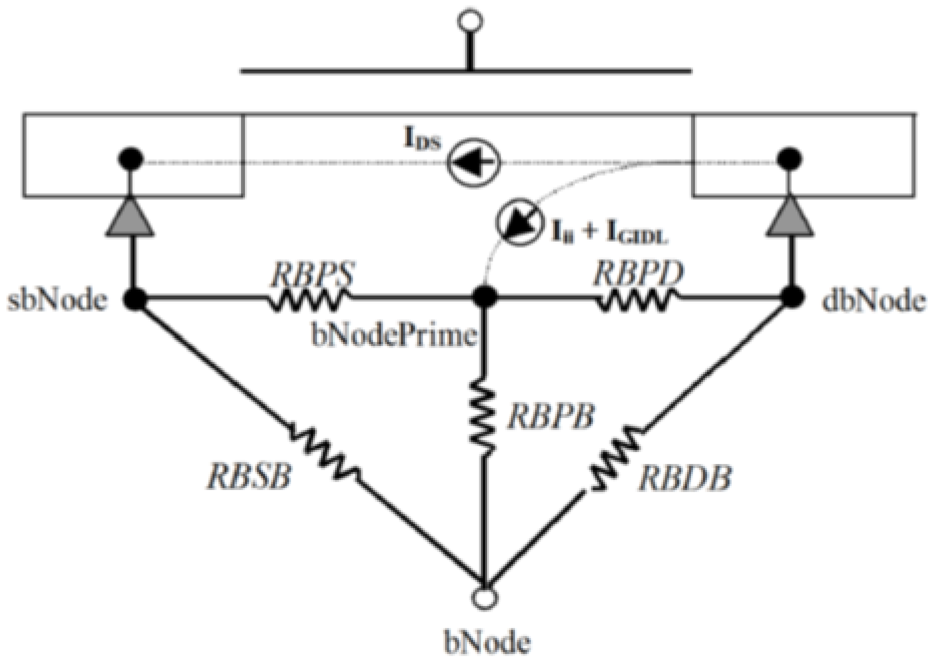
Model Selector and Topology

RBODYMOD=0 (Off)

RBODYMOD=1 (On)

RBODYMOD=2 (On: Scalable Substrate Network)

Figure 22-3 Topology with the substrate resistance network turned on



Noise Modeling

Noise Models in BSIM 6.0.0	Origin
Flicker noise model	BSIM4 Unified model (FNOIMOD=1)
Thermal noise (TNOIMOD=0)	BSIM4 (TNOIMOD=0)
Thermal noise (TNOIMOD=1)	BSIM4 (TNOIMOD=2)
Gate current shot noise	BSIM4 gate current noise

Noise Models in BSIM 6.0.0	Origin
Noise associated with parasitic resistance	BSIM4 parasitic resistance noise

Flicker Noise Models

The flicker noise model in BSIM6 is the same as FNOIMOD=1 in BSIM4. The unified physical flicker noise model is smooth over all bias regions.

(22-66)

$$S_{id,inv}(f) = \frac{kTq^2\mu_{eff}I_{ds}}{C_{oxe}L_{effNOI}^2 f^{EF}\cdot 10^{10}}\left(NOIA\cdot log\left(\frac{N_0+N^*}{N_l+N^*}\right)\right.$$
$$\left.NOIB\cdot(N_0-N_l)+\frac{NOIC}{2}(N_0^2-N_l^2)\right)$$
$$\frac{kTI_{ds}^2\Delta L_{clm}}{W_{eff}L_{effNOI}^2 f^{EF}\cdot 10^{10}}\left(\frac{NOIA+NOIB\cdot N_l+NOIC\cdot N_l^2}{(N_l+N^*)^2}\right)$$

(22-67)

$$S_{id,subVt}(f) = \frac{NOIA\cdot k\cdot T\cdot I^2{}_{ds}}{W_{eff}L_{eff}f^{EF}N^{*2}\cdot 10^{10}}$$

(22-68)

$$S_{id}(f) = \frac{S_{id,inv}\cdot S_{id,subVt}}{S_{id,inv}+S_{id,subVt}}$$

Channel Thermal Noise

There are two channel thermal noise models in BSIM6. One is a charge-based model (default model) similar to that used in BSIM3v3.2 and BSIM4.7.0 (TNOIMOD=0). The other is the holistic model similar to BSIM4.7.0 (TNOIMOD=2). These two models can be selected through the model selector TNOIMOD.

TNOIDMOD=0 (Charge based model): The noise current is given by:

(22-69)

$$Q_{inv} = |Q_{s,intrinsic}+Q_{s,intrinsic}|\times NFIN_{total}$$

(22-70)

$$\overline{i^2_d} = \begin{cases} NTNOI \cdot \dfrac{4kT\Delta f}{R_{ds} + \dfrac{L_{eff}^2}{\mu_{eff} Q_{inv}}} & \text{if RDSMOD=0} \\ NTNOI \cdot \dfrac{4kT\Delta f}{L_{eff}^2} \cdot \mu_{eff} Q_{inv} & \text{if RDSMOD=1} \end{cases}$$

TNOIMOD=1 (Holistic Model)

(22-71)

$$\beta_{tnoi} = RNOIA \cdot \left[1.0 + TNOIA \cdot L_{eff} \cdot \left(\frac{q_{ia}}{E_{sat,noi} L_{eff}}\right)^2\right]$$

(22-72)

$$\theta_{tnoi} = RNOIB \cdot \left[1.0 + TNOIB \cdot L_{eff} \cdot \left(\frac{q_{ia}}{E_{sat,noi} L_{eff}}\right)^2\right]$$

(22-73)

$$c_{tnoi} = RNOIC \cdot \left[1.0 + TNOIC \cdot L_{eff} \cdot \left(\frac{q_{ia}}{E_{sat,noi} L_{eff}}\right)^2\right]$$

(22-74)

$$S_{id} = 4KT \cdot \mu C_{ox} \frac{W_{eff}}{L_{vsat}} V_t D_{ptwg} M_{oc} \left[\frac{q_s + q_{deff}}{2} + \frac{(q_s - q_{deff})^2}{12\left(\frac{1+q_s+q_{deff}}{2}\right)}\right] \cdot (3 \cdot \beta_{tnoi}^2$$

(22-75)

$$S_{ig} = 4KT \cdot \frac{1}{12 \cdot NF \cdot W_{eff}\mu_{eff} \cdot D_{ptwg} M_{oc} C_{ox} \cdot V_t} \frac{L_{vsat}^3}{L_{eff}^2} \cdot \left[\frac{\frac{q_s+q_{deff}}{2}}{\left(\frac{1+q_s+q_{deff}}{2}\right)^2} - \frac{6\left(\frac{1+q_s+q_{deff}}{2}\right)(q_s - q_{deff})^2}{60\left(\frac{1+q_s+q_{deff}}{2}\right)^4} + \frac{(q_s - q_{deff})^4}{144\left(\frac{1+q_s+q_{deff}}{2}\right)^5}\right] \cdot (\frac{15}{4} \cdot \theta_{tnoi}^2)$$

(22-76)

$$S_{ig,id} = -j\omega \cdot 4KT \cdot \mu C_{ox} D_{ptwg} M_{oc} V_t (\frac{L_{vsat}}{L_{eff}}) \cdot \left[\frac{(q_s - q_{deff})}{12\left(\frac{1+q_s+q_{deff}}{2}\right)} - \frac{(q_s - q_{deff})^3}{144\left(\frac{1+q_s+q_{deff}}{2}\right)^3} \right] \cdot \frac{c_{tnoi}}{0.395}$$

(22-77)

$$c = \frac{S_{ig,id}}{\sqrt{S_{ig}} \cdot \sqrt{S_{id}}}$$

IGate Current Shot Noise

(22-78)

$$\overline{i^2}_{gs} = 2q(I_{gcs} + I_{gs})$$

(22-79)

$$\overline{i^2}_{gd} = 2q(I_{gcd} + I_{gd})$$

(22-80)

$$\overline{i^2}_{gb} = 2qI_{gbinv}$$

Resistor Noise

If RDSMOD=,1then

(22-81)

$$\frac{\overline{i_{RS}^2}}{\Delta f} = 4kT \cdot \frac{1}{R_{source}}$$

Figure 22-4

$$\frac{\overline{i_{RD}^2}}{\Delta f} = 4kT \cdot \frac{1}{R_{drain}}$$

If RGATGEMOD=1, then

(22-82)

$$\frac{\overline{i_{RG}^2}}{\Delta f} = 4kT \cdot \frac{1}{R_{geltd}}$$

Asymmetric MOS Junction Diode Models

Junction Diode IV Model

(22-83)

$$I_{bs} = I_{sbs}\left[\exp\left(\frac{V_{bs}}{NJS \cdot V_t}\right) - 1\right] \cdot f_{breakdown} + V_{bs} \cdot G_{min}$$

(22-84)

$$I_{bd} = I_{sbd}\left[\exp\left(\frac{V_{bd}}{NJD \cdot V_t}\right) - 1\right] \cdot f_{breakdown} + V_{bd} \cdot G_{min}$$

(22-85)

$$\begin{aligned} I_{bs\_totle} &= I_{bs} \\ &- W_{effcj} \cdot NF \cdot J_{tsswgs}(T) \cdot \left[exp\left(\frac{-V_{bs}}{NJTSSWG(T) \cdot Vtm0} \cdot \frac{VTSSWGS}{VTSSWGS - V_{bs}}\right)\right] \\ &- P_{s,deff} J_{tssws}(T)\left[exp\left(\frac{-V_{bs}}{NJTSSW(T) \cdot Vtm0} \cdot \frac{VTSSWS}{VTSSWS - V_{bs}}\right) - 1\right] \\ &- A_{s,deff} J_{tss}(T)\left[exp\left(\frac{-V_{bs}}{NJTS(T) \cdot Vtm0}\frac{VTSS}{VTSS - V_{bs}}\right) - 1\right] + g_{min} \cdot V_{bs} \end{aligned}$$

(22-86)

$$\begin{aligned} I_{bd\_totle} &= I_{bd} \\ &- W_{effcj} \cdot NF \cdot J_{tsswgd}(T) \cdot \left[exp\left(\frac{-V_{bd}}{NJTSSWGD(T) \cdot Vtm0} \cdot \frac{VTSSWGD}{VTSSWGD - V_{bd}}\right)\right] \\ &- P_{d,deff} J_{tsswd}(T)\left[exp\left(\frac{-V_{bd}}{NJTSSWD(T) \cdot Vtm0} \cdot \frac{VTSSWD}{VTSSWD - V_{bd}}\right) - 1\right] \\ &- A_{d,deff} J_{tsd}(T)\left[exp\left(\frac{-V_{bd}}{NJTD(T) \cdot Vtm0}\frac{VTSD}{VTSD - V_{bd}}\right) - 1\right] + g_{min} \cdot V_{bd} \end{aligned}$$

Junction Diode CV Model

(22-87)

$$C_{bs} = A_{seff}C_{jbs} + P_{seff}C_{jbssw} + W_{effcj} \cdot NF \cdot C_{jbsswg}$$

(22-88)

$$C_{jbs} = \begin{cases} CJS(T) \cdot \left(1 - \frac{V_{bs}}{PBS(T)}\right)^{-MJS} & \text{if } \frac{V_{bs}}{PBS(T)} \leq x_0 \\ CJS(T) \cdot \frac{1}{(1-x_0)^{MJS}} \cdot \left[1 + MJS\left(1 + \frac{\frac{V_{bs}}{PBS}-1}{1-x_0}\right)\right] & \text{otherwise} \end{cases}$$

(22-89)

$$C_{jbssw} = \begin{cases} CJSWS(T) \cdot \left(1 - \frac{V_{bs}}{PBSWS(T)}\right)^{-MJSWS} & \text{if } \frac{V_{bs}}{PBSWS(T)} \leq x_0 \\ CJSWS(T) \cdot \frac{1}{(1-x_0)^{MJSWS}} \cdot \left[1 + MJSWS\left(1 + \frac{\frac{V_{bs}}{PBSWS(T)}-1}{1-x_0}\right)\right] & \text{otherwise} \end{cases}$$

(22-90)

$$C_{jbsswg} = \begin{cases} CJSWGS(T) \cdot \left(1 - \frac{V_{bs}}{PBSWGS(T)}\right)^{-MJSWGS} & \text{if } \frac{V_{bs}}{PBSWGS(T)} \leq x_0 \\ CJSWGS(T) \cdot \frac{1}{(1-x_0)^{MJSWGS}} \cdot \left[1 + MJSWGS\left(1 + \frac{\frac{V_{bs}}{PBSWGS(T)}-1}{1-x_0}\right)\right] & \text{otherwise} \end{cases}$$

where the value of x0 is taken as 0.9.

(22-91)

$$C_{bd} = A_{deff}C_{jbd} + P_{deff}C_{jbdsw} + W_{effcj} \cdot NF \cdot C_{jbdswg}$$

(22-92)

$$C_{jbd} = \begin{cases} CJD(T) \cdot \left(1 - \frac{V_{bs}}{PBD(T)}\right)^{-MJD} & \text{if } \frac{V_{bs}}{PBD(T)} \leq x_0 \\ CJD(T) \cdot \frac{1}{(1-x_0)^{MJD}} \cdot \left[1 + MJD\left(1 + \frac{\frac{V_{bs}}{PBD}-1}{1-x_0}\right)\right] & \text{otherwise} \end{cases}$$

(22-93)

$$C_{jbdsw} = \begin{cases} CJSWD(T) \cdot \left(1 - \frac{V_{bs}}{PBSWD(T)}\right)^{-MJSWS} & \text{if } \frac{V_{bs}}{PBSWD(T)} \le x_0 \\ CJSWD(T) \cdot \frac{1}{(1-x_0)^{MJSWD}} \cdot \left[1 + MJSWD\left(1 + \frac{\frac{V_{bs}}{PBSWD(T)} - 1}{1 - x_0}\right)\right] & \text{otherwise} \end{cases}$$

(22-94)

$$C_{jbdswg} = \begin{cases} CJSWGD(T) \cdot \left(1 - \frac{V_{bs}}{PBSWGD(T)}\right)^{-MJSWGD} & \text{if } \frac{V_{bs}}{PBSWGD(T)} \le x_0 \\ CJSWGD(T) \cdot \frac{1}{(1-x_0)^{MJSWGD}} \cdot \left[1 + MJSWGD\left(1 + \frac{\frac{V_{bs}}{PBSWGD(T)} - 1}{1 - x_0}\right)\right] & \text{otherwise} \end{cases}$$

where the value of x0 is taken as 0.9.

Layout Dependent Parasitic Models

Effective Junction Perimeter and Area

If (PS is given)

if (**perMod**=0)

P_{seff}=PS

Else

P_{seff} computed from NF, DWJ, geoMod, DMCG, DMCI, DMDG, DMCGT, RSH, and MIN.

The effective junction area on the source side is calculated by:

If (AS is given)

A_{seff}=AS

Else

A_{seff} computed from NF, DWJ, geoMod, DMCG, DMCI, DMDG, DMCGT, RSH, and MIN.

Source/Drain Diffusion Resistance

If (number of sources NRS is given)

ELSE if (**rgeoMod**=0)

Source diffusion resistance Rsdiff is not generated.

Else

Rsdiff computed from NF, DWJ, geoMod, DMCG, DMCI, DMDG, DMCGT, RSH, and MIN.

where the number of source squares NRS is an instance parameter.

Similarly, the drain diffusion resistance is calculated by:

If (number of sources NRD is given)

ELSE if (rgeoMod=0)

Drain diffusion resistance Rddiff is not generated.

Else

Rddiff computed from NF, DWJ, geoMod, DMCG, DMCI, DMDG, DMCGT, RSH, and MIN.

Gate Electrode Resistance

(22-95)

$$R_{geltd} = \frac{RSHG \cdot \left(XGW + \frac{W_{effci}}{3NGCON}\right)}{NGCON \cdot (L_{drawn} - XGL) \cdot NF}$$

Options for Source/Drain Connections

Table 1: geoMod Options

geomod	End Source	End Drain	Note
0	isolated	isolated	NF=Odd
1	isolated	shared	NF=Odd, Even

2	shared	shared	NF=Odd, Even
3	shared	isolated	NF=Odd, Even
4	isolated	merged	NF=Odd
5	shared	merged	NF=Odd, Even
6	merged	isolated	NF=Odd
7	merged	shared	NF=Odd, Even
8	merged	merged	NF=Odd
9	sha/iso	shared	NF=Even
10	shared	sha/iso	NF=Even

Options for Source Drain Contacts

Table 2: rgeoMod Options

rgeomod	End Source contact	End Drain Contact
0	No R_{sdiff}	No R_{ddiff}
1	wide	wide
2	wide	point
3	point	wide
4	point	point
5	wide	merged
6	point	merged
7	merged	wide
8	merged	point

Temperature Dependence Models

Temperature Dependence Model

Temperature Dependence of Threshold Voltage

The temperature dependence of V_{th} is modeled by:

(22-96)

$$V_{th}(T) = V_{th}(TNOM) + \left(KT1 + \frac{KT1L}{L_{eff}} + KT2 \cdot V_{breff}\right) \cdot \left(\left(\frac{T}{TNOM}\right)^{KT1EXP} - 1\right)$$
$$V_{fb}(T) = V_{fb}(TNOM) - KT1 \cdot \left(\frac{T}{TNOM} - 1\right)$$

(22-97)

$$VFBSDOFF(T) = VFBSDOFF(TNOM) \cdot [1 + TVFBSDOFF \cdot (T - TNOM)]$$
$$NFACTOR(T) = NFACTOR(TNOM) + TFACTOR \cdot \left(\frac{T}{TNOM} - 1\right)$$

(22-98)

$$ETA0(T) = ETA0(TNOM) + TETA0\left(\frac{T}{TNOM} - 1\right)$$

Temperature Dependence of Mobility

(22-99)

$$U0(T) = U0(TNOM) \cdot (T/TNOM)^{UTE}$$

(22-100)

$$UA(T) = UA(TNOM)[1 + UA1 \cdot (T - TNOM)]$$

(22-101)

$$UC(T) = UC(TNOM)[1 + UC1 \cdot (T - TNOM)]$$

(22-102)

$$UD(T) = UD(TNOM) \cdot (T/TNOM)^{UD1}$$

(22-103)

$$UCS(T) = UCS(TNOM) \cdot (T/TNOM)^{UCSTE}$$

Temperature Dependence of Junction Diode IV

(22-104)

$$I_{sbs} = A_{seff}J_{ss}(T) + P_{seff}J_{ssws}(T) + W_{effcj} \cdot NF \cdot J_{sswgs}(T)$$

(22-105)

$$I_{sbd} = A_{deff}J_{sd}(T) + P_{deff}J_{sswd}(T) + W_{effcj} \cdot NF \cdot J_{sswgd}(T)$$

Temperature Dependence of Junction Diode CV

(22-106)

$$PBS(T) = PBS(TNOM) - TPB \cdot (T - TNOM)$$

(22-107)

$$PBSWS(T) = PBSWS(TNOM) - TPBSW \cdot (T - TNOM)$$

(22-108)

$$PBSWGS(T) = PBSWGS(TNOM) - TPBSWG \cdot (T - TNOM)$$

(22-109)

$$PBD(T) = PBD(TNOM) - TPB \cdot (T - TNOM)$$

(22-110)

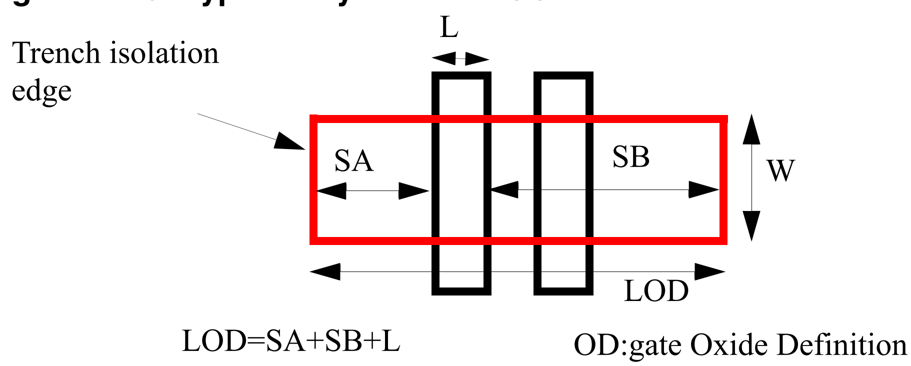
$$PBSWD(T) = PBSWD(TNOM) - TPBSW \cdot (T - TNOM)$$

(22-111)

$$PBSWGD(T) = PBSWGD(TNOM) - TPBSWG \cdot (T - TNOM)$$

Stress Effect Model Development

Figure 22-5 Typical Layout of a MOSFET



(22-112)

$$VTH0 = VTH0_{original} + \frac{KVTH0}{Kstress\_vth0} \cdot (Inv\_sa + Inv\_sb - Inv\_sa_{ref} - Inv\_sb_{ref})$$
$$K2 = K2_{original} + \frac{STK2}{Kstress\_vth0^{LODK2}} \cdot (Inv\_sa + Inv\_sb - Inv\_sa_{ref} - Inv\_sb_{ref})$$
$$ETA0 = ETA0_{original} + \frac{STETA0}{Kstress\_vth0^{LODETA0}} \cdot (Inv\_sa + Inv\_sb - Inv\_sa_{ref} - Inv\_sb_{ref})$$

Figure 22-6 Layout of multiple finger MOSFET

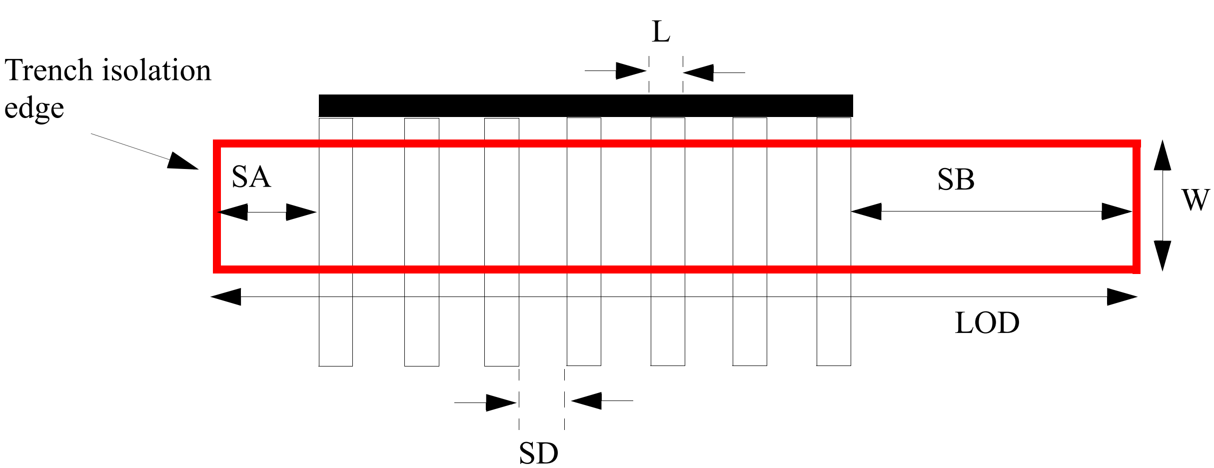
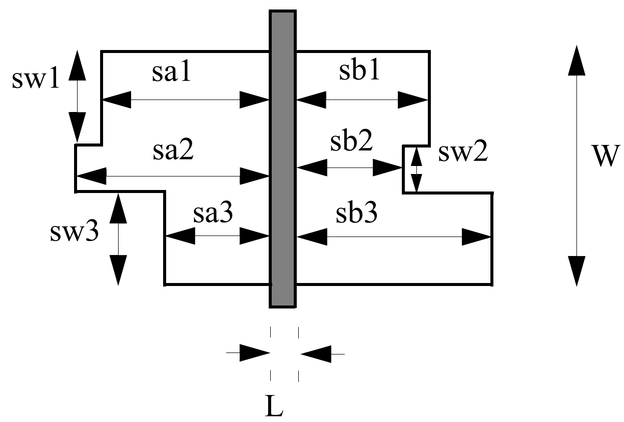


Figure 22-7 Typical layout of MOS devices with more instance parameters (swi, sai, and sbi) in addition to traditional L and W



Well Proximity Effect Model

(22-113)

$$
\begin{aligned}
Vth0 &= Vth0_{org} + KVTH0WE \cdot (SCA + WEB \cdot SCB + WEC \cdot SCC) \\
K2 &= K2_{org} + K2WE \cdot (SCA + WEB \cdot SCB + WEC \cdot SCC) \\
\mu_{eff} &= \mu_{eff,org} \cdot (1 + KU0WE \cdot (SCA + WEB \cdot SCB + WEB \cdot SCC))
\end{aligned}
$$

C-V Model

Inversion Charge

(22-114)

$$q_I = n_q \cdot \left[q_s + q_d + \frac{1}{3} \cdot \frac{(q_s - q_d)^2}{1 + q_s + q_d} \right]$$

Bulk Charge

(22-115)

$$q_B = A + B + \frac{1}{3} \cdot \frac{\Delta q^2}{C^3} \cdot \left[\frac{4}{8} \cdot \left(C^2 + P.Q \right) \cdot \frac{1}{1 + q_s + q_d} + \frac{2}{\gamma_g^2} \right] - n_q \cdot \left[q_s + q_d + \frac{1}{3} \cdot \frac{(q_s - q_d)^2}{1 + q_s + q_d} \right]$$

where

(22-116)

$$P = \sqrt{\frac{1}{4} + \frac{v_g - v_{fb} - \psi_p + 2.q_s}{\gamma_g^2}}$$

$$Q = \sqrt{\frac{1}{4} + \frac{v_g - v_{fb} - \psi_p + 2.q_d}{\gamma_g^2}}$$

$$A = \frac{v_g - v_{fb} - \psi_p + 2.q_s}{1 + 2.\sqrt{\frac{1}{4} + \frac{v_g - v_{fb} - \psi_p + 2.q_s}{\gamma_g^2}}}$$

$$B = \frac{v_g - v_{fb} - \psi_p + 2.q_d}{1 + 2.\sqrt{\frac{1}{4} + \frac{v_g - v_{fb} - \psi_p + 2.q_s}{\gamma_g^2}}}$$

$$C = \sqrt{\frac{1}{4} + \frac{v_g - v_{fb} - \psi_p + 2.q_s}{\gamma_g^2}} + \sqrt{\frac{1}{4} + \frac{v_g - v_{fb} - \psi_p + 2.q_d}{\gamma_g^2}}$$

Source and Drain Charges

(22-117)

$$Q_s = \frac{n_q}{3}\left[2 \cdot q_s + q_{deff} + \frac{1}{2} \cdot \left(1 + \frac{4}{5} \cdot q_s + \frac{6}{5} \cdot q_{deff}\right)\left(\frac{q_s - q_{deff}}{1 + q_s + q_{deff}}\right)^2\right]$$

$$Q_d = \frac{n_q}{3}\left[q_s + 2 \cdot q_{deff} + \frac{1}{2} \cdot \left(1 + \frac{6}{5} \cdot q_s + \frac{4}{5} \cdot q_{deff}\right)\left(\frac{q_s - q_{deff}}{1 + q_s + q_{deff}}\right)^2\right]$$

Bias Dependent Overlap Capacitance Model

(22-118)

$$\frac{Q_{gs,ov}}{NF \cdot W_{effCV}} = CGSO \cdot V_{gs} + CGSL \cdot \left[V_{gs} - V_{fbsd} - V_{gs,overlap} - \frac{CKAPPAS}{2}\left(\sqrt{1 - \frac{4V_{gs,overlap}}{CKAPPAS}} - 1\right)\right]$$

(22-119)

$$\frac{Q_{gd,ov}}{NF \cdot W_{effCV}} = CGDO \cdot V_{gd} + CGDL \cdot \left[V_{gd} - V_{fbsd} - V_{gd,overlap} - \frac{CKAPPAD}{2}\left(\sqrt{1 - \frac{4V_{gd,overlap}}{CKAPPAD}} - 1\right)\right]$$

Outer Fringing Capacitance

(22-120)

$$CF = \frac{2 \cdot EPSROX \cdot \epsilon_0}{\pi} \cdot ln[CFRCOEFF \cdot (1 + \frac{0.4e-6}{TOX})]$$

Component Statements

This device is supported within altergroups.

Instance Parameters

1 `m=1.0`	Multiplicity factor (number of MOSFETs in parallel).
2 `geomod`	Geo dependent parasitics model.
3 `rgeomod`	Geometry-dependent source/drain resistance. 0: RSH-based, 1: Holistic.
4 `rgatemod`	Gate resistance model selector.
5 `rbodymod`	Distributed body R model.
6 `l (m)`	Channel length.
7 `w (m)`	Total width including fingers.
8 `nf`	Number of fingers.
9 `as=0.0` m^2	Source to substrate junction area.
10 `ad=0.0` m^2	Drain to substrate junction area.
11 `ps=0.0 m`	Source to substrate junction perimeter.
12 `pd=0.0 m`	Drain to substrate junction perimeter.
13 `vfbsdoff`	S/D flatband voltage offset.
14 `nrs=1.0`	Number of squares in source.

15 `nrd=1.0`	Number of squares in drain.
16 `minz=0`	Minimize either D or S.
17 `xgw=0.0 m`	Dist from gate contact center to dev edge.
18 `ngcon`	Number of gate contacts.
19 `rbpb (Ω)`	Resistance between bNodePrime and bNode.
20 `rbdb (Ω)`	Resistance between bNode and dbNode.
21 `rbsb (Ω)`	Resistance between bNode and sbNode.
22 `rbps (Ω)`	Resistance between bNodePrime and sbNode.
23 `rbpd (Ω)`	Resistance between bNodePrime and bNode.
24 `dtemp=0.0 C`	Offset of device temperature.
25 `trise=0.0 C`	Alias of dtemp.
26 `sa=0.0 m`	Distance between OD edge from Poly from one side.
27 `sb=0.0 m`	Distance between OD edge from Poly from other side.
28 `sd=0.0 m`	Distance between neighboring fingers.
29 `sca=0.0`	Integration of first distribution function for scattered well dopant.
30 `scb=0.0`	Integration of second distribution function for scattered well dopant.
31 `scc=0.0`	Integration of second distribution function for scattered well dopant.
32 `sc=0.0 m`	Distance to a single well edge.
33 `isnoisy=1`	Should device generate noise.

Model Definition

```
model modelName bsim6 parameter=value ...
```

Model Parameters

1 `type=n` Transistor type.
Possible values are `p` and `n`.

2 `version=6.00` Model parameter "version" only accepts real number value, like 6.00 for version=6.0.0. The available version is 6.00 (6.0.0).

3 `cvmod=0` 0: Consistent IV-CV, 1: Different IV-CV.

4 `covmod=0` 0: Use Bias-independent Overlap Capacitances, 1: Use Bias-dependent Overlap Capacitances.

5 `rdsmod=0` 0: Internal bias dependent and external bias independent s/d resistance model, 1: External s/d resistance model, 2: Internal s/d resistance model.

6 `gidlmod=0` 0: Turn off GIDL Current, 1: Turn on GIDL Current.

7 `igcmod=0` 0: Turn off Igc, Igs and Igd, 1: Turn on Igc, Igs and Igd.

8 `igbmod=0` 0: Turn off Igb, 1: Turn on Igb.

9 `tnoimod=0` Thermal noise model selector.

10 `shmod=0` Self heating model selector, 1 : Turn on self heating model.

11 `llong=(10 1.0e-6) m`
L of extracted Long channel device.

12 `lmlt=1.0` Length Shrinking Parameter.

13 `wmlt=1.0` Width Shrinking Parameter.

14 `xl=0.0 m` L offset for channel length due to mask/etch effect.

15 `wwide=(10 1.0e-6) m`
W of extracted Wide channel device.

16 `xw=0.0 m` W offset for channel width due to mask/etch effect.

17 `lint=0.0 m` delta L for IV.

18 `ll=0.0 m^lln` Length dependence of delta L.

19 `lw=0.0 m^lwn` Width dependence of delta L.

20 `lwl=0.0 m^(lln+lwn)`
Area dependence of delta L.

21 `lln=1.0` Length exponent of delta L.

22 `lwn=1.0` Width exponent of delta L.

23 `wint=0.0 m` delta W for IV.

24 `wl=0.0 m^wln` Length dependence of delta W.

25 `ww=0.0 m^wwn` Width dependence of delta W.

26 `wwl=0.0 m^(wwn+wln)`
Area dependence of delta W.

27 `wln=1.0` Length exponent of delta W.

28 `wwn=1.0` Width exponent of delta W.

29 `dlc=0.0 m` delta L for CV.

30 `llc=0.0 m^lln` Length dependence of delta L for CV.

31 `lwc=0.0 m^lwn` Width dependence of delta L for CV.

32 `lwlc=0.0 m^(lln+lwn)`
Area dependence of delta L for CV.

33 `dwc=0.0 m` delta W for CV.

34 `wlc=0.0 m^wln` Length dependence of delta W for CV.

35 `wwc=0.0 m^wwn` Width dependence of delta W for CV.

36 `wwlc=0.0 m^(wwn+wln)`
Area dependence of delta W for CV.

37 `toxe=3.0e-9 m` Effective gate dielectric thickness relative to SiO2.

38 `toxp=3.0e-9 m`	Physical gate dielectric thickness. If not given, toxp is calculated from toxe and dtox.
39 `dtox=0.0 m`	Difference between effective dielectric thickness and physical thickness.
40 `ndep=1e24` m^{-3}	Channel Doping Concentration for IV.
41 `ndepl1=0.0`	Length dependence coefficient of ndep.
42 `ndeplexp1=1.0`	Length dependence exponent coefficient of ndep.
43 `ndepl2=0.0`	Length dependence of ndep - for short channel devices.
44 `ndeplexp2=2.0`	Length dependence exponent coefficient of ndep.
45 `ndepw=0.0`	Width dependence coefficient of ndep.
46 `ndepwexp=1.0`	Width dependence exponent coefficient of ndep.
47 `ndepwl=0.0`	Width-Length dependence coefficient of ndep.
48 `ndepwlexp=1.0`	Width-Length dependence exponent coefficient of ndep.
49 `lndep=0.0`	Length dependence of ndep.
50 `wndep=0.0`	Width dependence of ndep.
51 `pndep=0.0`	Cross-term dependence of ndep.
52 `ndepcv=1e24` m^{-3}	Channel Doping Concentration for CV.
53 `ndepcvl1=0.0`	Length dependence coefficient of ndepcv.
54 `ndepcvlexp1=1.0`	Length dependence exponent coefficient of ndepcv.
55 `ndepcvl2=0.0`	Length dependence coefficient of ndepcv - for short channel devices.
56 `ndepcvlexp2=2.0`	Length dependence exponent coefficient of ndepcv.
57 `ndepcvw=0.0`	Width dependence coefficient of ndepcv.

58 `ndepcvwexp=1.0` Width dependence exponent coefficient of ndepcv.

59 `ndepcvwl=0.0` Width-Length dependence coefficient of ndepcv.

60 `ndepcvwlexp=1.0` Width-Length dependence exponent coefficient of ndepcv.

61 `lndepcv=0.0` Length dependence of ndepcv.

62 `wndepcv=0.0` Width dependence of ndepcv.

63 `pndepcv=0.0` Cross-term dependence of ndepcv.

64 `ngate=5e25` m^{-3} Gate Doping Concentration.

65 `lngate=0.0` Length dependence of ngate.

66 `wngate=0.0` Width dependence of ngate.

67 `pngate=0.0` Cross-term dependence of ngate.

68 `easub=4.05 eV` Electron affinity of substrate.

69 `ni0sub=1.1e16` m^{-3}

Intrinsic carrier concentration of the substrate at 300.15K.

70 `bg0sub=1.17 eV` Band gap of substrate at 300.15K.

71 `epsrsub=11.9` Relative dielectric constant of the channel material.

72 `epsrox=3.9` Relative dielectric constant of the gate dielectric.

73 `xj=1.5e-7 m` S/D junction depth.

74 `lxj=0.0` Length dependence of xj.

75 `wxj=0.0` Width dependence of xj.

76 `pxj=0.0` Cross-term dependence of xj.

77 `vfb=(-1.0) V` Flat band voltage for IV.

78 `lvfb=0.0` Length dependence of vfb.

79	`wvfb=0.0`	Width dependence of vfb.
80	`pvfb=0.0`	Cross-term dependence vfb.
81	`vfbcv=(-1.0) V`	Flat band voltage for CV.
82	`lvfbcv=0.0`	Length dependence of vfbcv.
83	`wvfbcv=0.0`	Width dependence of vfbcv.
84	`pvfbcv=0.0`	Cross-term dependence vfbcv.
85	`vfbcvl=0.0`	Length dependence coefficient of vfbcv.
86	`vfbcvlexp=1.0`	Length dependence exponent coefficient of vfbcv.
87	`vfbcvw=0.0`	Width dependence coefficient of vfbcv.
88	`vfbcvwexp=1.0`	Width dependence exponent coefficient of vfbcv.
89	`vfbcvwl=0.0`	Width-Length dependence coefficient of vfbcv.
90	`vfbcvwlexp=1.0`	Width-Length dependence coefficient of vfbcv.
91	`permod=1`	Whether ps/pd (when given) include gate-edge perimeter.
92	`dwj=0.0`	delta W for S/D junctions.
93	`nsd=1e26` m^{-3}	S/D doping concentration.
94	`lnsd=0.0`	Length dependence of nsd.
95	`wnsd=0.0`	Width dependence of nsd.
96	`pnsd=0.0`	Cross-term dependence of nsd.
97	`dvtp0=0.0`	First coefficient of drain-induced vth shift for long-channel pocket devices.
98	`ldvtp0=0`	Length dependence of dvtp0.
99	`wdvtp0=0`	Width dependence of dvtp0.

100 `pdvtp0=0`	Cross-term dependence of dvtp0.
101 `dvtp1=0.0`	Second coefficient of drain-induced Vth shift for long-channel pocket devices.
102 `ldvtp1=0`	Length dependence of dvtp1.
103 `wdvtp1=0`	Width dependence of dvtp1.
104 `pdvtp1=0`	Cross-term dependence of dvtp1.
105 `dvtp2=0.0`	3rd parameter for vth shift due to pocket.
106 `ldvtp2=0`	Length dependence of dvtp2.
107 `wdvtp2=0`	Width dependence of dvtp2.
108 `pdvtp2=0`	Cross-term dependence of dvtp2.
109 `dvtp3=0.0`	4th parameter for vth shift due to pocket.
110 `ldvtp3=0`	Length dependence of dvtp3.
111 `wdvtp3=0`	Width dependence of dvtp3.
112 `pdvtp3=0`	Cross-term dependence of dvtp3.
113 `dvtp4=0.0`	5th parameter for vth shift due to pocket.
114 `ldvtp4=0`	Length dependence of dvtp4.
115 `wdvtp4=0`	Width dependence of dvtp4.
116 `pdvtp4=0`	Cross-term dependence of dvtp4.
117 `dvtp5=0.0`	6th parameter for vth shift due to pocket.
118 `ldvtp5=0`	Length dependence of dvtp5.
119 `wdvtp5=0`	Width dependence of dvtp5.
120 `pdvtp5=0`	Cross-term dependence of dvtp5.

121 `phin=0.045 V`	Nonuniform vertical doping effect on surface potential.
122 `lphin=0.0`	Length dependence of phin.
123 `wphin=0.0`	Width dependence of phin.
124 `pphin=0.0`	Cross-term dependence of phin.
125 `eta0=0.08`	DIBL coefficient.
126 `leta0=0.0`	Length dependence of eta0.
127 `weta0=0.0`	Width dependence of eta0.
128 `peta0=0.0`	Cross-term dependence of eta0.
129 `dsub=1.0`	Length scaling exponent for DIBL.
130 `etab=(-0.07)`	Body bias coefficient for subthreshold DIBL effect.
131 `etabexp=1.0`	Exponent coefficient of etab.
132 `letab=0.0`	Length dependence of etab.
133 `wetab=0.0`	Width dependence of etab.
134 `petab=0.0`	Cross-term dependence of etab.
135 `k2=0.0`	Vth shift due to vertical non-uniform doping.
136 `k2l=0.0`	Length dependence coefficient of k2.
137 `k2lexp=1.0`	Length dependence exponent coefficient of k2.
138 `k2w=0.0`	Width dependence coefficient of k2.
139 `k2wexp=1.0`	Width dependence exponent coefficient of k2.
140 `k2wl=0.0`	Width-Length dependence coefficient of k2.
141 `k2wlexp=1.0`	Width-Length dependence exponent coefficient of k2.
142 `lk2=0.0`	Length dependence of k2.

143 `wk2=0.0` Width dependence of k2.

144 `pk2=0.0` Cross-term dependence of k2.

145 `ados=0.0` Quantum mechanical effect prefactor cum switch in inversion.

146 `bdos=1.0` Charge centroid parameter - slope of CV curve under QME in inversion.

147 `qm0=1.0e-3` Charge centroid parameter - starting point for QME in inversion.

148 `etaqm=0.54` Bulk charge coefficient for charge centroid in inversion.

149 `cit=0.0 F/m`^{2} parameter for interface trap.

150 `lcit=0.0` Length dependence of cit.

151 `wcit=0.0` Width dependence of cit.

152 `pcit=0.0` Cross-term dependence of cit.

153 `nfactor=0.0` Sub-threshold slope factor.

154 `nfactorl=0.0` Length dependence coefficient of nfactor.

155 `nfactorlexp=1.0` Length dependence exponent coefficient of nfactor.

156 `nfactorw=0.0` Width dependence coefficient of nfactor.

157 `nfactorwexp=1.0` Width dependence exponent coefficient of nfactor.

158 `nfactorwl=0.0` Width-Length dependence coefficient of nfactor.

159 `nfactorwlexp=1.0` Width-Length dependence exponent coefficient of nfactor.

160 `lnfactor=0.0` Length dependence of nfactor.

161 `wnfactor=0.0` Width dependence of nfactor.

162 `pnfactor=0.0` Cross-term dependence of nfactor.

163 `cdscd=1e-9 F/m`^{2} `V`

drain-bias sensitivity of sub-threshold slope.

164 `cdscdl=0.0`	Length dependence coefficient of cdscd.
165 `cdscdlexp=1.0`	Length dependence exponent coefficient of cdscd.
166 `lcdscd=0.0`	Length dependence of cdscd.
167 `wcdscd=0.0`	Width dependence of cdscd.
168 `pcdscd=0.0`	Cross-term dependence of cdscd.
169 `cdscb=0.0` F/m^2 `V`	body-bias sensitivity of sub-threshold slope.
170 `cdscbl=0.0`	Length dependence coefficient of cdscb.
171 `cdscblexp=1.0`	Length dependence exponent coefficient of cdscb.
172 `lcdscb=0.0`	Length dependence of cdscb.
173 `wcdscb=0.0`	Width dependence of cdscb.
174 `pcdscb=0.0`	Cross-term dependence of cdscb.
175 `vsat=1e5 m/s`	Saturation velocity.
176 `lvsat=0.0`	Length dependence of vsat.
177 `wvsat=0.0`	Width dependence of vsat.
178 `pvsat=0.0`	Cross-term dependence of vsat.
179 `vsatl=0.0`	Length dependence coefficient of of vsat.
180 `vsatlexp=1.0`	Length dependence exponent coefficient of vsat.
181 `vsatw=0.0`	Width dependence coefficient of of vsat.
182 `vsatwexp=1.0`	Width dependence exponent coefficient of of vsat.
183 `vsatwl=0.0`	Width-Length dependence coefficient of of vsat.
184 `vsatwlexp=1.0`	Width-Length dependence exponent coefficient of of vsat.
185 `delta=0.125 V`	Smoothing function factor for Vdsat.

186 `ldelta=0.0`	Length dependence of delta.
187 `wdelta=0.0`	Width dependence of delta.
188 `pdelta=0.0`	Cross-term dependence of delta.
189 `deltal=0.0`	Length dependence coefficient of delta.
190 `deltalexp=1.0`	Length dependence exponent coefficient of delta.
191 `vsatcv=1e5 m/s`	vsat parameter for CV.
192 `lvsatcv=0.0`	Length dependence of vsatcv.
193 `wvsatcv=0.0`	Width dependence of vsatcv.
194 `pvsatcv=0.0`	Cross-term dependence of vsatcv.
195 `vsatcvl=0.0`	Length dependence coefficient of of vsatcv.
196 `vsatcvlexp=1.0`	Length dependence exponent coefficient of vsatcv.
197 `vsatcvw=0.0`	Width dependence coefficient of of vsatcv.
198 `vsatcvwexp=1.0`	Length dependence exponent coefficient of vsatcv.
199 `vsatcvwl=0.0`	Width-Length dependence coefficient of of vsatcv.
200 `vsatcvwlexp=1.0`	Width-Length dependence exponent coefficient of of vsatcv.
201 `u0=67.0e-3 m2/Vs`	Low-field surface mobility at tnom.
202 `u0l=0.0`	Length dependence coefficient of u0.
203 `u0lexp=1.0`	Length dependence exponent coefficient of u0.
204 `lu0=0.0`	Length dependence of u0.
205 `wu0=0.0`	Width dependence of u0.
206 `pu0=0.0`	Cross-term dependence of u0.
207 `etamob=1.0`	Effective field parameter (should be kept close to 1).

208 `ua=0.001 m/V` Mobility reduction coefficient.

209 `ual=0.0` Length dependence coefficient of ua.

210 `ualexp=1.0` Length dependence exponent coefficient of ua.

211 `uaw=0.0` Width dependence coefficient of ua.

212 `uawexp=1.0` Width dependence exponent coefficient of ua.

213 `uawl=0.0` Width-Length dependence coefficient of ua.

214 `uawlexp=1.0` Width-Length dependence coefficient of ua.

215 `lua=0.0` Length dependence of ua.

216 `wua=0.0` Width dependence of ua.

217 `pua=0.0` Cross-term dependence of ua.

218 `eu=1.5` Mobility reduction exponent.

219 `leu=0.0` Length dependence of eu.

220 `weu=0.0` Width dependence of eu.

221 `peu=0.0` Cross-term dependence of eu.

222 `eul=0.0` Length dependence coefficient of eu.

223 `eulexp=1.0` Length dependence exponent coefficient of eu.

224 `euw=0.0` Width dependence coefficient of eu.

225 `euwexp=1.0` Width dependence exponent coefficient of eu.

226 `euwl=0.0` Width-Length dependence coefficient of eu.

227 `euwlexp=1.0` Width-Length dependence coefficient of eu.

228 ud=0.001 $1/m^2$ Coulombic scattering parameter.

229 `udl=0.0` Length dependence coefficient of ud.

230 `udlexp=1.0` Length dependence exponent coefficient of ud.

231 `lud=0.0` Length dependence of ud.

232 `wud=0.0` Width dependence of ud.

233 `pud=0.0` Cross-term dependence of ud.

234 `ucs=2.0` Coulombic scattering parameter.

235 `lucs=0.0` Length dependence of ucs.

236 `wucs=0.0` Width dependence of ucs.

237 `pucs=0.0` Cross-term dependence of ucs.

238 `uc=0.0` Mobility reduction with body bias.

239 `ucl=0.0` Length dependence coefficient of uc.

240 `uclexp=1.0` Length dependence exponent coefficient of uc.

241 `ucw=0.0` Width dependence coefficient of uc.

242 `ucwexp=1.0` Width dependence exponent coefficient of uc.

243 `ucwl=0.0` Width-Length dependence coefficient of uc.

244 `ucwlexp=1.0` Width-Length dependence exponent coefficient.

245 `luc=0.0` Length dependence of uc.

246 `wuc=0.0` Width dependence of uc.

247 `puc=0.0` Cross-term dependence of uc.

248 `pclm=0.0` clm prefactor.

249 `pclml=0.0` Length dependence coefficient of pclm.

250 `pclmlexp=1.0` Length dependence exponent coefficient of pclm.

251 `lpclm=0.0` Length dependence of pclm.

252 `wpclm=0.0` Width dependence of pclm.

253 `ppclm=0.0` Cross-term dependence of pclm.

254 `pclmg=0.0` clm prefactor gate voltage dependence.

255 `pclmcv=0.0` clm parameter for CV.

256 `pclmcvl=0.0` Length dependence coefficient of pclmcv.

257 `pclmcvlexp=1.0` Length dependence exponent coefficient of pclmcv.

258 `lpclmcv=0.0` Length dependence of pclmcv.

259 `wpclmcv=0.0` Width dependence of pclmcv.

260 `ppclmcv=0.0` Cross-term dependence of pclmcv.

261 `pscbe1=4.24e8 V/m` Substrate current body-effect coeff.

262 `lpscbe1=0.0` Length dependence of pscbe1.

263 `wpscbe1=0.0` Width dependence of pscbe1.

264 `ppscbe1=0.0` Cross-term dependence of pscbe1.

265 `pscbe2=1.0e-8 V/m` Substrate current body-effect coeff.

266 `lpscbe2=0.0` Length dependence of pscbe2.

267 `wpscbe2=0.0` Width dependence of pscbe2.

268 `ppscbe2=0.0` Cross-term dependence of pscbe2.

269 `pdits=0.0 1/V` Coefficient for drain-induced vth shifts.

270 `lpdits=0.0` Length dependence of pdits.

271 `wpdits=0.0` Width dependence of pdits.

272 `ppdits=0.0` Cross-term dependence of pdits.

273 `pditsl=0.0 1/m` L dep of drain-induced vth shifts.

274 `pditsd=0.0 1/V` Vds dep of drain-induced vth shifts.

275 `lpditsd=0.0` Length dependence of pditsl.

276 `wpditsd=0.0` Width dependence of pditsl.

277 `ppditsd=0.0` Cross-term dependence of pditsl.

278 `rsh=0.0 Ω` Source-drain sheet resistance.

279 `prwg=1.0 1/V` gate bias dependence of S/D extension resistance.

280 `lprwg=0.0` Length dependence of prwg.

281 `wprwg=0.0` Width dependence of prwg.

282 `pprwg=0.0` Cross-term dependence of prwg.

283 `prwb=0.0 1/V`
Body bias dependence of resistance.

284 `lprwb=0.0` Length dependence of prwb.

285 `wprwb=0.0` Width dependence of prwb.

286 `pprwb=0.0` Cross-term dependence of prwb.

287 `prwbl=0.0` Length dependence coefficient of pprwb.

288 `prwblexp=1.0` Length dependence exponent coefficient of pprwb.

289 `wr=1.0` W dependence parameter of S/D extension resistance.

290 `lwr=0.0` Length dependence of wr.

291 `wwr=0.0` Width dependence of wr.

292 `pwr=0.0` Cross-term dependence of wr.

293 `rswmin=0.0 Ω μm^wr`
Source Resistance per unit width at high Vgs (rdsmod=1).

294 `lrswmin=0.0` Length dependence of rswmin.

295 `wrswmin=0.0` Width dependence of rswmin.

296 `prswmin=0.0` Cross-term dependence of rswmin.

297 `rsw=10.0 Ω µm^wr`
zero bias Source Resistance (rdsmod=1).

298 `lrsw=0.0` Length dependence of rsw.

299 `wrsw=0.0` Width dependence of rsw.

300 `prsw=0.0` Cross-term dependence of rsw.

301 `rswl=0.0` Geometrical scaling of rsw (rdsmod=1).

302 `rswlexp=1.0` Geometrical scaling of rsw (rdsmod=1).

303 `rdwmin=rswmin Ω µm^wr`
Drain Resistance per unit width at high Vgs (rdsmod=1).

304 `lrdwmin=lrswmin` Length dependence of rdwmin.

305 `wrdwmin=wrswmin` Width dependence of rdwmin.

306 `prdwmin=prswmin` Cross-term dependence of rdwmin.

307 `rdw=rsw Ω µm^wr` zero bias Drain Resistance (rdsmod=1).

308 `lrdw=lrsw` Length dependence of rdw.

309 `wrdw=wrsw` Width dependence of rdw.

310 `prdw=prsw` Cross-term dependence of rdw.

311 `rdwl=rswl` Geometrical scaling of rdw (rdsmod=1).

312 `rdwlexp=rswlexp` Geometrical scaling of rdw (rdsmod=1).

313 `rdswmin=0.0 Ω µm^wr`
S/D Resistance per unit width at high Vgs (rdsmod=0 and rdsmod=2).

314 `lrdswmin=0.0` Length dependence of rdswmin.

315 `wrdswmin=0.0` Width dependence of rdswmin.

316 `prdswmin=0.0` Cross-term dependence of rdswmin.

317 `rdsw=20.0 Ω µm^wr`
zero bias Resistance (rdsmod=0 and rdsmod=2).

318 `rdswl=0.0` Geometrical scaling of rdsw (rdsmod=0 and rdsmod=2).

319 `rdswlexp=1.0` Geometrical scaling of rdsw (rdsmod=0 and rdsmod=2).

320 `lrdsw=0.0` Length dependence of rdsw.

321 `wrdsw=0.0` Width dependence of rdsw.

322 `prdsw=0.0` Cross-term dependence of rdsw.

323 `psat=1.0` Gmsat variation with gate bias.

324 `lpsat=0.0` Length dependence of psat.

325 `wpsat=0.0` Width dependence of psat.

326 `ppsat=0.0` Cross-term dependence of psat.

327 `psatl=0.0` Geometrical scaling of psat.

328 `psatlexp=1.0` Geometrical scaling of psat.

329 `psatb=0.0` Body bias effect on Idsat.

330 `lpsatb=0.0` Length dependence of psatb.

331 `wpsatb=0.0` Width dependence of psatb.

332 `ppsatb=0.0` Cross-term dependence of psatb.

333 `psatx=1.0` Parameter for Idsat.

334 `ptwg=0.0` Idsat variation with gate bias.

335 `lptwg=0.0` Length dependence of ptwg.

336 `wptwg=0.0`	Width dependence of ptwg.
337 `pptwg=0.0`	Cross-term dependence of ptwg.
338 `ptwgl=0.0`	Length dependence coefficient of ptwg.
339 `ptwglexp=1.0`	Length dependence exponent coefficient of ptwg.
340 `pdiblc=0.0`	parameter for DIBL effect on rout.
341 `pdiblcl=0.0`	Length dependence coefficient of pdiblc.
342 `pdiblclexp=1.0`	Length dependence exponent coefficient of pdiblc.
343 `lpdiblc=0.0`	Length dependence of pdiblc.
344 `wpdiblc=0.0`	Width dependence of pdiblc.
345 `ppdiblc=0.0`	Cross-term dependence of pdiblc.
346 `pdiblcb=0.0 1/V`	parameter for DIBL effect on rout.
347 `lpdiblcb=0.0`	Length dependence of pdiblcb.
348 `wpdiblcb=0.0`	Width dependence of pdiblcb.
349 `ppdiblcb=0.0`	Cross-term dependence of pdiblcb.
350 `pvag=1.0`	Vg dependence of early voltage.
351 `lpvag=0.0`	Length dependence of pvag.
352 `wpvag=0.0`	Width dependence of pvag.
353 `ppvag=0.0`	Cross-term dependence of pvag.
354 `fprout=0.0 V/ m`	Effect of pocket implant on rout degradation.
355 `fproutl=0.0`	Length dependence coefficient of fprout.
356 `fproutlexp=1.0`	Length dependence exponent coefficient of fprout.

357 `lfprout=0.0` Length dependence of fprout.

358 `wfprout=0.0` Width dependence of fprout.

359 `pfprout=0.0` Cross-term dependence of fprout.

360 `alpha0=0.0 m/V` first parameter of Iii.

361 `alpha0l=0.0` Length dependence coefficient of alpha0.

362 `alpha0lexp=1.0` Length dependence exponent coefficient of alpha0.

363 `lalpha0=0.0` Length dependence of alpha0.

364 `walpha0=0.0` Width dependence of alpha0.

365 `palpha0=0.0` Cross-term dependence of alpha0.

366 `beta0=0.0 1/V` Vds dependent parameter of Iii.

367 `lbeta0=0.0` Length dependence of beta0.

368 `wbeta0=0.0` Width dependence of beta0.

369 `pbeta0=0.0` Cross-term dependence of beta0.

370 `aigbacc=1.36e-2 F/g s/m`
Parameter for Igb in accumulation.

371 `bigbacc=1.71e-3 F/g s/(m V)`
Parameter for Igb in accumulation.

372 `cigbacc=0.075 1/V` Parameter for Igb in accumulation.

373 `nigbacc=1.0` Parameter for Igbacc slope.

374 `aigbinv=1.11e-2 F/g s/m`
Parameter for Igb in inversion.

375 `bigbinv=9.49e-4 F/g s/(m V)`
Parameter for Igb in inversion.

376 `cigbinv=0.006 1/V` Parameter for Igb in inversion.

377 `eigbinv=1.1 V` Parm for the Si bandgap for Igbinv.

378 `nigbinv=3.0` Parameter for Igbinv slope.

379 `aigc=1.36e-2 |F/g s/m`
Parameter for Igc.

380 `bigc=1.71e-3 |F/g s/(m V)`
Parameter for Igc.

381 `cigc=0.075 1/V` Parameter for Igc.

382 `aigs=1.36e-2 |F/g s/m`
Parameter for Igs.

383 `bigs=1.71e-3 |F/g s/(m V)`
Parameter for Igs.

384 `cigs=0.075 1/V` Parameter for Igs.

385 `aigd=1.36e-2 |F/g s/m`
Parameter for Igd.

386 `bigd=1.71e-3 |F/g s/(m V)`
Parameter for Igd.

387 `cigd=0.075 1/V` Parameter for Igd.

388 `dlcig=0.0 m` Delta L for Ig model.

389 `dlcigd=0.0 m` Delta L for Ig model.

390 `poxedge=1.0` Factor for the gate edge tox.

391 `ntox=1.0` Exponent for tox ratio.

392 `toxref=3.0e-9 m` Target tox value.

393 `pigcd=1.0` Igc, S/D partition parameter.

394 `aigcl=0.0` Length dependence coefficient of aigc.

395 `aigcw=0.0` Width dependence coefficient of aigc.

396 `aigsl=0.0`	Length dependence coefficient of aigs.
397 `aigsw=0.0`	Width dependence coefficient of aigs.
398 `aigdl=0.0`	Length dependence coefficient of aigd.
399 `aigdw=0.0`	Width dependence coefficient of aigd.
400 `pigcdl=0.0`	Length dependence coefficient of pigcd.
401 `laigbinv=0.0`	Length dependence of aigbinv.
402 `waigbinv=0.0`	Width dependence of aigbinv.
403 `paigbinv=0.0`	Cross-term dependence of aigbinv.
404 `lbigbinv=0.0`	Length dependence of bigbinv.
405 `wbigbinv=0.0`	Width dependence of bigbinv.
406 `pbigbinv=0.0`	Cross-term dependence of bigbinv.
407 `lcigbinv=0.0`	Length dependence of cigbinv.
408 `wcigbinv=0.0`	Width dependence of cigbinv.
409 `pcigbinv=0.0`	Cross-term dependence of cigbinv.
410 `leigbinv=0.0`	Length dependence of eigbinv.
411 `weigbinv=0.0`	Width dependence of eigbinv.
412 `peigbinv=0.0`	Cross-term dependence of eigbinv.
413 `lnigbinv=0.0`	Length dependence of nigbinv.
414 `wnigbinv=0.0`	Width dependence of nigbinv.
415 `pnigbinv=0.0`	Cross-term dependence of nigbinv.
416 `laigbacc=0.0`	Length dependence of aigbacc.
417 `waigbacc=0.0`	Width dependence of aigbacc.

418 `paigbacc=0.0` Cross-term dependence of aigbacc.

419 `lbigbacc=0.0` Length dependence of bigbacc.

420 `wbigbacc=0.0` Width dependence of bigbacc.

421 `pbigbacc=0.0` Cross-term dependence of bigbacc.

422 `lcigbacc=0.0` Length dependence of cigbacc.

423 `wcigbacc=0.0` Width dependence of cigbacc.

424 `pcigbacc=0.0` Cross-term dependence of cigbacc.

425 `lnigbacc=0.0` Length dependence of nigbacc.

426 `wnigbacc=0.0` Width dependence of nigbacc.

427 `pnigbacc=0.0` Cross-term dependence of nigbacc.

428 `laigc=0.0` Length dependence of aigc.

429 `waigc=0.0` Width dependence of aigc.

430 `paigc=0.0` Cross-term dependence of aigc.

431 `lbigc=0.0` Length dependence of bigc.

432 `wbigc=0.0` Width dependence of bigc.

433 `pbigc=0.0` Cross-term dependence of bigc.

434 `lcigc=0.0` Length dependence of cigc.

435 `wcigc=0.0` Width dependence of cigc.

436 `pcigc=0.0` Cross-term dependence of cigc.

437 `laigs=0.0` Length dependence of aigs.

438 `waigs=0.0` Width dependence of aigs.

439 `paigs=0.0` Cross-term dependence of aigs.

440 `lbigs=0.0` Length dependence of bigs.

441 `wbigs=0.0` Width dependence of bigs.

442 `pbigs=0.0` Cross-term dependence of bigs.

443 `lcigs=0.0` Length dependence of cigs.

444 `wcigs=0.0` Width dependence of cigs.

445 `pcigs=0.0` Cross-term dependence of cigs.

446 `laigd=0.0` Length dependence of aigd.

447 `waigd=0.0` Width dependence of aigd.

448 `paigd=0.0` Cross-term dependence of aigd.

449 `lbigd=0.0` Length dependence of bigd.

450 `wbigd=0.0` Width dependence of bigd.

451 `pbigd=0.0` Cross-term dependence of bigd.

452 `lcigd=0.0` Length dependence of cigd.

453 `wcigd=0.0` Width dependence of cigd.

454 `pcigd=0.0` Cross-term dependence of cigd.

455 `lpoxedge=0.0` Length dependence of poxedge.

456 `wpoxedge=0.0` Width dependence of poxedge.

457 `ppoxedge=0.0` Cross-term dependence of poxedge.

458 `ldlcig=0.0` Length dependence of dlcig.

459 `wdlcig=0.0` Width dependence of dlcig.

460 `pdlcig=0.0` Cross-term dependence of dlcig.

461 `ldlcigd=0.0` Length dependence of dlcigd.

462 `wdlcigd=0.0`	Width dependence of dlcigd.
463 `pdlcigd=0.0`	Cross-term dependence of dlcigd.
464 `lntox=0.0`	Length dependence of ntox.
465 `wntox=0.0`	Width dependence of ntox.
466 `pntox=0.0`	Cross-term dependence of ntox.
467 `agidl=0.0 1/Ω`	Pre-exponential coefficient for GIDL.
468 `agidll=0.0`	Length dependence coefficient of agidl.
469 `agidlw=0.0`	Width dependence coefficient of agidl.
470 `lagidl=0.0`	Length dependence of agidl.
471 `wagidl=0.0`	Width dependence of agidl.
472 `pagidl=0.0`	Cross-term dependence of agidl.
473 `bgidl=2.3e9 V/m`	Exponential coefficient for GIDL.
474 `lbgidl=0.0`	Length dependence of bgidl.
475 `wbgidl=0.0`	Width dependence of bgidl.
476 `pbgidl=0.0`	Cross-term dependence of bgidl.
477 `cgidl=0.5` V^3	Parameter for body-bias effect on GIDL.
478 `lcgidl=0.0`	Length dependence of cgidl.
479 `wcgidl=0.0`	Width dependence of cgidl.
480 `pcgidl=0.0`	Cross-term dependence of cgidl.
481 `egidl=0.8 V`	Fitting parameter for band bending for GIDL.
482 `legidl=0.0`	Length dependence of egidl.
483 `wegidl=0.0`	Width dependence of egidl.

484 `pegidl=0.0`	Cross-term dependence of egidl.
485 `agisl=0.0 1/Ω`	Pre-exponential coefficient for GISL.
486 `agisll=0.0`	Length dependence coefficient of agisl.
487 `agislw=0.0`	Width dependence coefficient of agisl.
488 `lagisl=0.0`	Length dependence of agisl.
489 `wagisl=0.0`	Width dependence of agisl.
490 `pagisl=0.0`	Cross-term dependence of agisl.
491 `bgisl=2.3e9 V/m`	Exponential coefficient for GISL.
492 `lbgisl=0.0`	Length dependence of bgisl.
493 `wbgisl=0.0`	Width dependence of bgisl.
494 `pbgisl=0.0`	Cross-term dependence of bgisl.
495 `cgisl=0.5` V^3	Parameter for body-bias effect on GISL.
496 `lcgisl=0.0`	Length dependence of cgisl.
497 `wcgisl=0.0`	Width dependence of cgisl.
498 `pcgisl=0.0`	Cross-term dependence of cgisl.
499 `egisl=0.8 V`	Fitting parameter for band bending for GISL.
500 `legisl=0.0`	Length dependence of egisl.
501 `wegisl=0.0`	Width dependence of egisl.
502 `pegisl=0.0`	Cross-term dependence of egisl.
503 `cf=0.0 F`	Outer fringe cap.
504 `lcf=0.0`	Length dependence of cf.
505 `wcf=0.0`	Width dependence of cf.

506 `pcf=0.0` Cross-term dependence of cf.

507 `cfrcoeff=1.0 F` coefficient for outer fringe cap.

508 `cgso=0.0 F/m` Gate - source overlap capacitance.

509 `cgdo=0.0 F/m` Gate - drain overlap capacitance.

510 `cgbo=0.0 F/m` Gate - body overlap capacitance.

511 `cgsl=0.0 F/m` Overlap capacitance between gate and lightly-doped source region.

512 `lcgsl=0.0` Length dependence of cgsl.

513 `wcgsl=0.0` Width dependence of cgsl.

514 `pcgsl=0.0` Cross-term dependence of cgsl.

515 `cgdl=0.0 F/m` Overlap capacitance between gate and lightly-doped drain region.

516 `lcgdl=0.0` Length dependence of cgdl.

517 `wcgdl=0.0` Width dependence of cgdl.

518 `pcgdl=0.0` Cross-term dependence of cgdl.

519 `ckappas=0.6 V` Coefficient of bias-dependent overlap capacitance for the source side.

520 `lckappas=0.0` Length dependence of ckappas.

521 `wckappas=0.0` Width dependence of ckappas.

522 `pckappas=0.0` Cross-term dependence of ckappas.

523 `ckappad=0.6 V` Coefficient of bias-dependent overlap capacitance for the source side.

524 `lckappad=0.0` Length dependence of ckappad.

525 `wckappad=0.0` Width dependence of ckappad.

526 `pckappad=0.0`	Cross-term dependence of ckappad.
527 `dmcg=0.0 m`	Distance of mid-contact to gate edge.
528 `dmci=0.0 m`	Distance of mid-contact to isolation.
529 `dmdg=0.0 m`	Distance of mid-diffusion to gate edge.
530 `dmcgt=0.0 m`	Dist of mid-contact to gate edge in test.
531 `xgl=0.0 m`	Variation in Ldrawn.
532 `rshg=0.1 Ω`	Gate sheet resistance.
533 `cjs=5.0e-4 F/m`^{2}	Unit area source-side junction capacitance at zero bias.
534 `cjd=5.0e-4 F/m`^{2}	Unit area drain-side junction capacitance at zero bias.
535 `cjsws=5.0e-10 F/m`	Unit length source-side sidewall junction capacitance at zero bias.
536 `cjswd=5.0e-10 F/m`	Unit length drain-side sidewall junction capacitance at zero bias.
537 `cjswgs=0.0 F/m`	Unit length source-side gate sidewall junction capacitance at zero bias.
538 `cjswgd=0.0 F/m`	Unit length drain-side gate sidewall junction capacitance at zero bias.
539 `pbs=1.0 V`	Source-side bulk junction built-in potential.
540 `pbd=1.0 V`	Drain-side bulk junction built-in potential.
541 `pbsws=1.0 V`	Built-in potential for Source-side sidewall junction capacitance.
542 `pbswd=1.0 V`	Built-in potential for Drain-side sidewall junction capacitance.
543 `pbswgs=1.0 V`	Built-in potential for Source-side gate sidewall junction capacitance.
544 `pbswgd=1.0 V`	Built-in potential for Drain-side gate sidewall junction capacitance.

545 `mjs=0.5`	Source bottom junction capacitance grading coefficient.
546 `mjd=0.5`	Drain bottom junction capacitance grading coefficient.
547 `mjsws=0.33`	Source sidewall junction capacitance grading coefficient.
548 `mjswd=0.33`	Drain sidewall junction capacitance grading coefficient.
549 `mjswgs=0.33`	Source-side gate sidewall junction capacitance grading coefficient.
550 `mjswgd=0.33`	Drain-side gate sidewall junction capacitance grading coefficient.
551 `jss=1.0e-4 A/m`^{2}	Bottom source junction reverse saturation current density.
552 `jsd=1.0e-4 A/m`^{2}	Bottom drain junction reverse saturation current density.
553 `jsws=0.0 A/m`	Unit length reverse saturation current for sidewall source junction.
554 `jswd=0.0 A/m`	Unit length reverse saturation current for sidewall drain junction.
555 `jswgs=0.0 A/m`	Unit length reverse saturation current for gate-edge sidewall source junction.
556 `jswgd=0.0 A/m`	Unit length reverse saturation current for gate-edge sidewall drain junction.
557 `njs=1.0`	Source junction emission coefficient.
558 `njd=1.0`	Drain junction emission coefficient.
559 `ijthsfwd=0.1 A`	Forward source diode breakdown limiting current.
560 `ijthdfwd=0.1 A`	Forward drain diode breakdown limiting current.
561 `ijthsrev=0.1 A`	Reverse source diode breakdown limiting current.
562 `ijthdrev=0.1 A`	Reverse drain diode breakdown limiting current.
563 `bvs=10.0 V`	Source diode breakdown voltage.
564 `bvd=10.0 V`	Drain diode breakdown voltage.

565 `xjbvs=1.0`	Fitting parameter for source diode breakdown current.
566 `xjbvd=1.0`	Fitting parameter for drain diode breakdown current.
567 `jtss=0.0 A/m`^{2}	Bottom source junction trap-assisted saturation current density.
568 `jtsd=0.0 A/m`^{2}	Bottom drain junction trap-assisted saturation current density.
569 `jtssws=0.0 A/m`	Unit length trap-assisted saturation current for sidewall source junction.
570 `jtsswd=0.0 A/m`	Unit length trap-assisted saturation current for sidewall drain junction.
571 `jtsswgs=0.0 A/m`	Unit length trap-assisted saturation current for gate-edge sidewall source junction.
572 `jtsswgd=0.0 A/m`	Unit length trap-assisted saturation current for gate-edge sidewall drain junction.
573 `jtweff=0.0 m`	Trap assisted tunneling current width dependence.
574 `njts=20.0`	Non-ideality factor for jtss.
575 `njtsd=20.0`	Non-ideality factor for jtsd.
576 `njtssw=20.0`	Non-ideality factor for jtssws.
577 `njtsswd=20.0`	Non-ideality factor for jtsswd.
578 `njtsswg=20.0`	Non-ideality factor for jtsswgs.
579 `njtsswgd=20.0`	Non-ideality factor for jtsswgd.
580 `vtss=10.0 V`	Bottom source junction trap-assisted current voltage dependent parameter.
581 `vtsd=10.0 V`	Bottom drain junction trap-assisted current voltage dependent parameter.
582 `vtssws=10.0 V`	Unit length trap-assisted current voltage dependent parameter for sidewall source junction.

583 `vtsswd=10.0 V` Unit length trap-assisted current voltage dependent parameter for sidewall drain junction.

584 `vtsswgs=10.0 V` Unit length trap-assisted current voltage dependent parameter for gate-edge sidewall source junction.

585 `vtsswgd=10.0 V` Unit length trap-assisted current voltage dependent parameter for gate-edge sidewall drain junction.

586 `xrcrg1=12.0` 1st fitting parameter for the bias-dependent rg.

587 `xrcrg2=1.0` 2nd fitting parameter for the bias-dependent rg.

588 `gbmin=1.0e-12 1/Ω`
Minimum body conductance.

589 `rbps0=50.0 Ohms` Scaling prefactor for rbps.

590 `rbpsl=0.0` Length scaling parameter for rbps.

591 `rbpsw=0.0` Width scaling parameter for rbps.

592 `rbpsnf=0.0` Number of fingers scaling parameter for rbps.

593 `rbpd0=50.0 Ohms` Scaling prefactor for rbpd.

594 `rbpdl=0.0` Length scaling parameter for rbpd.

595 `rbpdw=0.0` Width scaling parameter for rbpd.

596 `rbpdnf=0.0` Number of fingers scaling parameter for rbpd.

597 `rbpbx0=100.0 Ohms` Scaling prefactor for rbpbx.

598 `rbpbxl=0.0` Length scaling parameter for rbpbx.

599 `rbpbxw=0.0` Width scaling parameter for rbpbx.

600 `rbpbxnf=0.0` Number of fingers scaling parameter for rbpbx.

601 `rbpby0=100.0 Ohms` Scaling prefactor for rbpby.

602 `rbpbyl=0.0` Length scaling parameter for rbpby.

603 `rbpbyw=0.0` Width scaling parameter for rbpby.

604 `rbpbynf=0.0` Number of fingers scaling parameter for rbpby.

605 `rbsbx0=100.0 Ohms` Scaling prefactor for rbsbx.

606 `rbsby0=100.0 Ohms` Scaling prefactor for rbsby.

607 `rbdbx0=100.0 Ohms` Scaling prefactor for rbdbx.

608 `rbdby0=100.0 Ohms` Scaling prefactor for rbdby.

609 `rbsdbxl=0.0` Length scaling parameter for rbsbx and rbdbx.

610 `rbsdbxw=0.0` Width scaling parameter for rbsbx and rbdbx.

611 `rbsdbxnf=0.0` Number of fingers Scaling parameter for rbsbx and rbdbx.

612 `rbsdbyl=0.0` Length scaling parameter for rbsby and rbdby.

613 `rbsdbyw=0.0` Width scaling parameter for rbsby and rbdby.

614 `rbsdbynf=0.0` Number of fingers scaling parameter for rbsby and rbdby.

615 `ef=1.0` Flicker Noise frequency exponent.

616 `em=4.1e7 V/m` Saturation field.

617 `noia=6.250e+40 s^(1-ef)/(eV m`^{2}`)`
Flicker noise parameter A.

618 `noib=3.125e+25 s^(1-EF)/eV`
Flicker noise parameter B.

619 `noic=8.750e+8 s^(1-EF) m`^{2}`/eV`
Flicker noise parameter C.

620 `lintnoi=0.0 m` Lint offset for noise calculation.

621 `ntnoi=1.0` Noise factor for short-channel devices for tnoimod=0 only.

622 `rnoia=0.577` Thermal noise coefficient for tnoimod=1.

623 `rnoib=0.5164` Thermal noise coefficient for tnoimod=1.

624 `rnoic=0.395` Thermal noise coefficient for tnoimod=1.

625 `tnoia=0.0` Coefficient of channel-length dependence of total channel thermal noise for tnoimod=1.

626 `tnoib=0.0` Coefficient of channel-length dependence of total channel thermal noise for tnoimod=1.

627 `tnoic=0.0` Correlation coefficient.

628 `binunit=1` Bin parameter unit selector. 1 for microns and 0 for meters.

629 `dlbin=0.0` Binning parameters.

630 `dwbin=0.0` Binning parameters.

631 `tnom=27.0 C` Temperature at which the model was extracted.

632 `tbgasub=4.73e-4 eV/C`
Bandgap Temperature Coefficient.

633 `tbgbsub=636.0 C` Bandgap Temperature Coefficient.

634 `tnfactor=0.0` Temperature exponent for nfactor.

635 `ute=(-1.5)` Mobility temperature exponent.

636 `lute=0.0` Length dependence of ute.

637 `wute=0.0` Width dependence of ute.

638 `pute=0.0` Cross-term dependence of ute.

639 `utel=0.0` Length Scaling parameter for ute.

640 `ua1=1.0e-3` Temperature coefficient for ua.

641 `lua1=0.0` Length dependence of ua1.

642 `wua1=0.0` Width dependence of ua1.

643 `pua1=0.0`	Cross-term dependence of ua1.
644 `ua1l=0.0`	Length Scaling parameter for ua1.
645 `uc1=0.056e-9`	Temperature coefficient for uc.
646 `luc1=0.0`	Length dependence of uc1.
647 `wuc1=0.0`	Width dependence of uc1.
648 `puc1=0.0`	Cross-term dependence of uc1.
649 `ud1=0.0`	Temperature coefficient for ud.
650 `lud1=0.0`	Length dependence of ud1.
651 `wud1=0.0`	Width dependence of ud1.
652 `pud1=0.0`	Cross-term dependence of ud1.
653 `ud1l=0.0`	Length Scaling parameter for ud1.
654 `ucste=(-4.775e-3)`	Temperature coefficient for ucs.
655 `lucste=0.0`	Length dependence of ucste.
656 `wucste=0.0`	Width dependence of ucste.
657 `pucste=0.0`	Cross-term dependence of ucste.
658 `teta0=0.0`	Temperature coefficient for eta0.
659 `prt=0.0 Ω m`	Temperature coefficient for resistance.
660 `lprt=0.0`	Length dependence of prt.
661 `wprt=0.0`	Width dependence of prt.
662 `pprt=0.0`	Cross-term dependence of prt.
663 `at=(-1.56e-3)`	Temperature coefficient for saturation velocity.

664 `lat=0.0` Length dependence of at.

665 `wat=0.0` Width dependence of at.

666 `pat=0.0` Cross-term dependence of at.

667 `atl=0.0` Length Scaling parameter for at.

668 `tdelta=0.0` Temperature coefficient for delta.

669 `ptwgt=0.0` Temperature coefficient for ptwg.

670 `lptwgt=0.0` Length dependence of ptwgt.

671 `wptwgt=0.0` Width dependence of ptwgt.

672 `pptwgt=0.0` Cross-term dependence of ptwgt.

673 `ptwgtl=0.0` Length Scaling parameter for ptwgt.

674 `kt1=(-0.11) V` Temperature coefficient for vth.

675 `kt1exp=1.0` Temperature coefficient for vth.

676 `kt1l=0.0` Temperature coefficient for vth.

677 `lkt1=0.0` Length dependence of kt1.

678 `wkt1=0.0` Width dependence of kt1.

679 `pkt1=0.0` Cross-term dependence of kt1.

680 `kt2=0.022` Temperature coefficient for vth.

681 `lkt2=0.0` Length dependence of kt2.

682 `wkt2=0.0` Width dependence of kt2.

683 `pkt2=0.0` Cross-term dependence of kt2.

684 `iit=0.0` Temperature coefficient for beta0.

685 `liit=0.0` Length dependence of iit.

686 `wiit=0.0` Width dependence of iit.

687 `piit=0.0` Cross-term dependence of iit.

688 `igt=2.5` Gate current temperature dependence.

689 `ligt=0.0` Length dependence of igt.

690 `wigt=0.0` Width dependence of igt.

691 `pigt=0.0` Cross-term dependence of igt.

692 `tgidl=0.0` Temperature coefficient for GIDL/GISL.

693 `ltgidl=0.0` Length dependence of tgidl.

694 `wtgidl=0.0` Width dependence of tgidl.

695 `ptgidl=0.0` Cross-term dependence of tgidl.

696 `tcj=0.0` Temperature coefficient for cjs/cjd.

697 `tcjsw=0.0` Temperature coefficient for cjsws/cjswd.

698 `tcjswg=0.0` Temperature coefficient for cjswgs/cjswgd.

699 `tpb=0.0` Temperature coefficient for pbs/pbd.

700 `tpbsw=0.0` Temperature coefficient for pbsws/pbswd.

701 `tpbswg=0.0` Temperature coefficient for pbswgs/pbswgd.

702 `xtis=3.0` Source junction current temperature exponent.

703 `xtid=3.0` Drain junction current temperature exponent.

704 `xtss=0.02` Power dependence of jtss on temperature.

705 `xtsd=0.02` Power dependence of jtsd on temperature.

706 `xtssws=0.02` Power dependence of jtssws on temperature.

707 `xtsswd=0.02` Power dependence of jtsswd on temperature.

708 `xtsswgs=0.02` Power dependence of jtsswgs on temperature.

709 `xtsswgd=0.02` Power dependence of jtsswgd on temperature.

710 `tnjts=0.0` Temperature coefficient for njts.

711 `tnjtsd=0.0` Temperature coefficient for njtsd.

712 `tnjtssw=0.0` Temperature coefficient for njtssw.

713 `tnjtsswd=0.0` Temperature coefficient for njtsswd.

714 `tnjtsswg=0.0` Temperature coefficient for njtsswg.

715 `tnjtsswgd=0.0` Temperature coefficient for njtsswgd.

716 `rth0=0.0` Thermal resistance.

717 `cth0=1.0e-05` Thermal capacitance.

718 `wth0=0.0` Width dependence coefficient for Rth and Cth.

719 `saref=1.0e-6 m` Reference distance between OD edge from Poly from one side.

720 `sbref=1.0e-6 m` Reference distance between OD edge from Poly from other side.

721 `wlod=0.0 m` Width Parameter for Stress Effect.

722 `ku0=0.0 m` Mobility degradation/enhancement parameter for stress effect.

723 `kvsat=0.0 m` Saturation velocity degradation/enhancement parameter for stress effect.

724 `tku0=0.0` Temperature coefficient for ku0.

725 `lku0=0.0 m^llodku0`
Length dependence of ku0.

726 `wku0=0.0 m^wlodku0`
Width dependence of ku0.

727 `pku0=0.0 m^(llodku0+wlodku0)`
Cross term dependence of ku0.

728 `llodku0=0.0`	Length Parameter for u0 stress effect.
729 `wlodku0=0.0`	Width Parameter for u0 stress effect.
730 `kvth0=0.0 V m`	Threshold shift parameter for stress effect.
731 `lkvth0=0.0`	Length dependence of kvth0.
732 `wkvth0=0.0`	Width dependence of kvth0.
733 `pkvth0=0.0`	Cross-term dependence of kvth0.
734 `llodvth=0.0`	Length parameter for vth stress effect.
735 `wlodvth=0.0`	Width parameter for vth stress effect.
736 `stk2=0.0 m`	K2 shift factor related to vth change.
737 `lodk2=0.0`	K2 shift modification factor for stress effect.
738 `steta0=0.0 m`	eta0 shift related to vth0 change.
739 `lodeta0=0.0`	eta0 modification foator for stress effect.
740 `web=0.0`	Coefficient for scb.
741 `wec=0.0`	Coefficient for scc.
742 `kvth0we=0.0 V`	Vth shift for well proximity effect.
743 `lkvth0we=0.0`	Length dependence of kvth0we.
744 `wkvth0we=0.0`	Width dependence of kvth0we.
745 `pkvth0we=0.0`	Cross term dependence of kvth0we.
746 `k2we=0.0`	K2 shift for well proximity effect.
747 `lk2we=0.0`	Length dependence of k2we.
748 `wk2we=0.0`	Width dependence of k2we.
749 `pk2we=0.0`	Cross term dependence of k2we.

750 `ku0we=0.0` Mobility degradation factor for well proximity effect.

751 `lku0we=0.0` Length dependence of ku0we.

752 `wku0we=0.0` Width dependence of ku0we.

753 `pku0we=0.0` Cross term dependence of ku0we.

754 `scref=1.0e-6 m` Reference distance to calculate sca,scb and scc.

755 `noisemethod=1` 1:Verilog-A method; 0:Simkit method.

756 `geomod=0` Geo dependent parasitics model.

757 `rgeomod=0` Geometry-dependent source/drain resistance. 0: RSH-based, 1: Holistic.

758 `rgatemod=0` Gate resistance model selector.

759 `rbodymod=0` Distributed body R model.

760 `l=1.0e-5 m` Default channel length.

761 `w=1.0e-5 m` Default total width including fingers.

762 `nf=1` Number of fingers. It served as the default value of instance nf.

763 `lmin=0.0 m` Minimum channel length for which the model is valid.

764 `lmax=1.0 m` Maximum channel length for which the model is valid.

765 `wmin=0.0 m` Minimum channel width for which the model is valid.

766 `wmax=1.0 m` Maximum channel width for which the model is valid.

767 `vds_max=infinity V`
Maximum allowed voltage cross source and drain.

768 `vgd_max=infinity V`
Maximum allowed voltage cross drain and gate.

769 `vgs_max=infinity V`
Maximum allowed voltage cross source/bulk and gate.

770 `vbd_max=infinity V`
Maximum allowed voltage cross drain/source and bulk.

771 `vbs_max=vbd_max V` Maximum allowed voltage cross source and bulk.

772 `vgb_max=infinity V`
Maximum allowed voltage cross gate and bulk.

773 `vgdr_max=vgd_max V`
Maximum allowed reverse voltage cross gate and drain.

774 `vgsr_max=vgs_max V`
Maximum allowed reverse voltage cross gate and source.

775 `vgbr_max=vgb_max V`
Maximum allowed reverse voltage cross gate and bulk.

776 `vbsr_max=vbs_max V`
Maximum allowed reverse voltage cross bulk and source.

777 `vbdr_max=vbd_max V`
Maximum allowed reverse voltage cross bulk and drain.

778 `vfbsdoff=0.0` S/D flatband voltage offset.

779 `rbpb=50.0` Ω Resistance between bNodePrime and bNode.

780 `rbdb=50.0` Ω Resistance between bNode and dbNode.

781 `rbsb=50.0` Ω Resistance between bNode and sbNode.

782 `rbps=50.0` Ω Resistance between bNodePrime and sbNode.

783 `rbpd=50.0` Ω Resistance between bNodePrime and bNode.

784 `ngcon=1` Number of gate contacts.

Output Parameters

1 `tempeff (C)` Effective temperature for a single device.

2 `meff` Effective multiplicity factor (m-factor).

Operating-Point Parameters

1	`qbi (Coul)`	Intrinsic bulk charge.
2	`qsi (Coul)`	Intrinsic source charge.
3	`qdi (Coul)`	Intrinsic drain charge.
4	`qgi (Coul)`	Intrinsic gate charge.
5	`cggi (F)`	Intrinsic gate capacitance.
6	`cgbi (F)`	Intrinsic gate-to-bulk capacitance.
7	`cgsi (F)`	Intrinsic gate-to-source capacitance.
8	`cgdi (F)`	Intrinsic gate-to-drain capacitance.
9	`csgi (F)`	Intrinsic source-to-gate capacitance.
10	`csbi (F)`	Intrinsic source-to-bulk capacitance.
11	`cssi (F)`	Intrinsic source capacitance.
12	`csdi (F)`	Intrinsic source-to-drain capacitance.
13	`cdgi (F)`	Intrinsic drain-to-gate capacitance.
14	`cdbi (F)`	Intrinsic drain-to-body capacitance.
15	`cdsi (F)`	Intrinsic drain-to-source capacitance.
16	`cddi (F)`	Intrinsic drain capacitance.
17	`cbgi (F)`	Intrinsic body-to-gate capacitance.
18	`cbbi (F)`	Intrinsic body capacitance.
19	`cbsi (F)`	Intrinsic body-to-source capacitance.
20	`cbdi (F)`	Intrinsic body-to-drain capacitance.
21	`qb (Coul)`	Total bulk charge.

22 `qs (Coul)`	Total source charge.
23 `qd (Coul)`	Total drain charge.
24 `qg (Coul)`	Total gate charge.
25 `cgg (F)`	Total gate capacitance.
26 `cgb (F)`	Total gate-to-bulk capacitance.
27 `cgs (F)`	Total gate-to-source capacitance.
28 `cgd (F)`	Total gate-to-drain capacitance.
29 `csg (F)`	Total source-to-gate capacitance.
30 `csb (F)`	Total source-to-bulk capacitance.
31 `css (F)`	Total source capacitance.
32 `csd (F)`	Total source-to-drain capacitance.
33 `cdg (F)`	Total drain-to-gate capacitance.
34 `cdb (F)`	Total drain-to-bulk capacitance.
35 `cds (F)`	Total drain-to-source capacitance.
36 `cdd (F)`	Total drain capacitance.
37 `cbg (F)`	Total bulk-to-gate capacitance.
38 `cbb (F)`	Total bulk capacitance.
39 `cbs (F)`	Total bulk-to-source capacitance.
40 `cbd (F)`	Total bulk-to-drain capacitance.
41 `iii (A)`	Alias of isub.
42 `isub (A)`	Impact ionization current.
43 `igidl (A)`	Gate-induced drain leakage current.

44 `igisl (A)`	Gate-induced source leakage current.
45 `igs (A)`	Gate-to-source tunneling current.
46 `igd (A)`	Gate-to-drain tunneling current.
47 `igcs (A)`	Gate-to-channel (source side) tunneling current.
48 `igcd (A)`	Gate-to-channel (drain side) tunneling current.
49 `igb (A)`	Gate-to-bulk tunneling current.
50 `cgsext (F)`	Gate-source overlap capacitance.
51 `cgdext (F)`	Gate-drain overlap capacitance.
52 `cgbov (F)`	Gate-bulk overlap capacitance.
53 `cjst (F)`	Alias of capbs.
54 `capbs (F)`	Source-bulk junction capacitance.
55 `cjdt (F)`	Alias of capbd.
56 `capbd (F)`	Drain-bulk junction capacitance.
57 `weff (m)`	Effective channel width.
58 `leff (m)`	Effective channel length.
59 `weffcv (m)`	Effective channel width for CV.
60 `leffcv (m)`	Effective channel length for CV.
61 `ids (A)`	Resistive drain-to-source current.
62 `ideff (A)`	Resistive drain current.
63 `iseff (A)`	Resistive source current.
64 `igeff (A)`	Resistive gate current.
65 `ijsb (A)`	Alias of ibs.

66 `ibs (A)`	Source-bulk junction current.
67 `ijdb (A)`	Alias of ibd.
68 `ibd (A)`	Drain-bulk junction current.
69 `vds (V)`	Internal drain-source voltage.
70 `vgs (V)`	Internal gate-source voltage.
71 `vsb (V)`	-vbs.
72 `vbs (V)`	Internal bulk-source voltage.
73 `vdst (V)`	External drain-source voltage.
74 `vgst (V)`	External gate-source voltage.
75 `vsbt (V)`	External source-bulk voltage.
76 `vdssat (V )`	Alias of vdsat.
77 `vdsat (V )`	Drain-source saturation voltage.
78 `gm (S)`	Common-source transconductance.
79 `gmbs (S)`	Body-transconductance.
80 `gds (S)`	Common-source output conductance.
81 `pwr (W)`	Power at op point.
82 `tk (K)`	TK.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the

description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

23

PSP102 Model

PSP102 is a compact MOSFET model intended for digital, analog and RFdesigns. It is jointly developed by NXP Semiconductors Research and Arizona State University, and is a surface-potential based MOS model containing all relevant physical effects (mobility reduction, velocity saturation, DIBL, gate current, lateral doping gradient effects, STI stress, and so forth), to model present-day and upcoming deep-submicron bulk CMOS technologies. The JUNCAP2 source/drain junction model is an integrated part of PSP102.

PSP102 not only gives an accurate description of currents, charges, and their first order derivatives (i.e. transconductance, conductance and capacitances), but also of the higher order derivatives, resulting in an accurate description of electrical distortion behavior. The latter is especially important for analog and RF circuit design. The model, furthermore, gives an accurate description of the noise behavior of MOSFETs.

For a full description of the PSP102 model, see http://pspmodel.asu.edu.

This chapter contains the following information about the PSP model:

Model Usage

Instance syntax

PSP102 instance has 4 terminals. The ModelName has to be associated with a PSP102 model card.

```
InstanceName (d g s b) PSP102ModelName <parameter=value>
```

Sample Instance Statement

```
q1 (v1 v2 v3 v4) psp102_mod w=1e-6 l=0.5e-6
```

Model syntax

The following syntax specifies PSP102 model:

```
model ModelName psp102 parameter=value ...
```

The third parameter, “psp102”, is the master to indicate this model card is a PSP102 model card.

Version and Master name

1. Versions 102.2, 102.2.1, 102.3, 102.3.2, 102.3.3, 102.3.4, and 102.4 are supported.
2. There are 7 master names - psp102, psp1020, psp1021, psp102e, pspnqs1020, pspnqs1021 and pspnqs102e
3. psp1020 is global model without NQS effect. psp1021 is bin model without NQS effect. psp102e is local model without NQS effect. pspnqs1020 is global model with NQS effect. pspnqs1021 is bin model with NQS effect. pspnqs102e is local model with NQS effect.
4. Master name "psp102" is a general name for PSP102, and it covers 6 psp102 masternames mentioned above. The relation between psp102 and other six masters is listed in the following table:

psp1020	psp102(binmod=0 geomod=1 swnqs=0)
psp1021	psp102(binmod=1 geomod=0/1 swnqs=0)
psp102e	psp102(binmod=0 geomod=0 swnqs=0)
pspnqs1020	psp102(binmod=0 geomod=1 swnqs=0)

pspnqs1021	psp102(binmod=1 geomod=0/1 swnqs=0)
pspnqs102e	psp102(binmod=0 geomod=0 swnqs=0)

Sample Model Statement

Example: PSP102.2

```
model psp102_mod psp102 type=n version=102.2
+tr = 25 swigate = 0
+binmod=0 geomod=1 swnqs=9 swgidl = 1 swjuncap = 3
```

Example: PSP102.3

```
model psp102_mod psp102 type=n version=102.3
+tr = 25 swigate = 0
+binmod=0 geomod=1 swnqs=9 swgidl = 1 swjuncap = 3
```

Model History and Development

PSP100

1. PSP100 is released by NXP in April 2005
2. PSP100 is supported in MMSIM 6.0.2 in Dec 2005

PSP101 (SiMKit2.3)

1. PSP101 is supported in MMISIM 6.1 in June 2006
2. PSP101 is not backward compatible with PSP100

Changes

- A complete set of binning scaling rules has been added as a phenomenological alternative to the physics-based geometrical scaling rules.
- BSIM-like instance parameters AS, AD, PS, and PD were added for the junction model.
- To avoid confusion between zeros and “O”s, zeros no longer occur in parameter names. They have all been replaced by “O”s.

- Some global parameter names have an additional “O” in their names in order to avoid duplicate names in the global and local model.

PSP102.0 (SiMKit2.3.2)

PSP102.0 is supported in MMSIM6.1.1 in Dec 2006

Changes

- The value for LG when SWJUNCAP = 2 was corrected.
- The clipping/limiting behavior of NP has been made more transparent.
- A minor numerical issue has been resolved.
- The scaling rule for DPHIB is now correctly implemented.
- A coding bug in JUNCAP has been corrected.
- A coding bug in the stress model (involving parameter PKVTHO) has been corrected.
- The parameters LVARW and WVARL have been removed from the binning model in order to ensure continuity of parameters across bin boundaries.

PSP102.1 (SiMKit2.4)

PSP102.1 is supported in MMSIM6.2 in June 2007

Changes

- Added clipping boundaries for SWNQS
- Several minor changes and improvements in model implementation
- Solved bug in stress model
- Solved bug in JUNCAP2
- Included preliminary implementation of PSP-NQS in SiMKit.

PSP102.1.1 (SiMKit 2.5)

PSP102.1.1 is released in MMSIM6.2.1 in Dec 2007

PSP102.2

VerilogA code for PSP102.2 is released in Oct 2007

Changes

- Add parameters EPSROX (electrical or local), EPSROXO (geometrical or global), POEPSROX (binning) representing relative dielectric constant of gate oxide.
- Added a "Well Proximity Effect" model
- Added instance parameters DELVTO (threshold voltage shift parameter) and FACTUO (zero-field mobility pre-factor) to the electrical (or local), geometrical (or global) and binning model.
- Added NF (number of fingers) support to geometrical (or global) and binning model.
- Extended the stress model to support NF.
- Added substrate resistance network and external gate resistance.
- Added geometry scaling for gate resistance in global and binning model.
- Integration of JUNCAP express into PSP. PSP is equipped with a switch-parameter SWJUNEXP.

PSP102.2.1 (SiMKit4.0.1)

Implemented in MMSIM7.0.1 in June 2008

Changes:

- Minor implementation change in juncap initInstance
- Fix issue in calculation of vfmin (juncap initInstance).
- Add clipping for fbbt-variables to nonnegative values (juncap initModel)
- Fix noise calculation for parasitic resistances
- Solved issue with Gmin for Vds<0
- Corrected error in expression for OP-variable cjssti

PSP102.3 (SiMKit3.1.2)

Implemented in MMSIM7.1.0 in Dec 2008

Changes

- Addition of asymmetric junction model. The new parameter SWJUNASYM is a flag.
- Addition of flicker noise frequency exponent parameter EF (local model), EFO (global model) and POEF (binning model).
- Addition of parameters LINTNOI and ALPNOI to the global model, to increase the flexibility of the length scaling of the flicker noise.
- Some minor bug-fixes and implementation changes.

PSP102.3.2 (SiMKit3.2)

Implemented in MMSIM7.1.1 in June 2009

Changes

- Fixed bug in JUNCAP2-model, involving FJUNQ-based selection-criterion in JUNCAPexpress charge model.
- Some minor implementation changes.

PSP102.3.3 (SiMKit3.3)

Implemented in MMSIM7.2 in Dec 2009. Since MMSIM7.2, version control and master name “psp102” are supported.

Changes

- Added value of gate resistance to OP-output
- Minor bug fix in conditional for SP-calculation of overlap areas.

PSP102.3.4 (SiMKit3.4)

Impemented in MMSIM10.1 in June 2010.

Changes

- Modified implementation of the asymmetrical junction model to improve simulation speed of the verilog-A code
- Modified scaliing of the MULT-scaling factor
- Minor bug fix for the output of sfl, sqrtsfw, and fknee

PSP102.4 (SiMKit4.01)

Implemented in MMSIM13.1 in September 2013.

Changes

The implementation of the thermal noise model has been improved in version 102.4. As a result, better convergence for some noise analysis could be expected in this version.

- A bug in the sign of the correlation coefficient for negative `Vds` has been resolved
- Gummel symmetry of `Sid` at very high frequency has been improved
- The number of `white_noise` sources has been reduced and the noise voltage values in the noise subcircuit have been scaled to more physical values

Reference

Structure of PSP102

The PSP model has a hierarchical structure, similar to that of MOS Model 11 and SP. This means that there is a strict separation of the geometry scaling in the global model and the model equations in the local model.

As a consequence, PSP can be used at either one of two levels.

- Global level One uses a global parameter set, which describes a whole geometry range. Combined with instance parameters (such as L and W), a local parameter set is internally generated and further processed at the local level in exactly the same way as a custom-made local parameter set.
- Local level One uses a custom-made local parameter set to simulate a transistor with a specific geometry. Temperature scaling is included at this level.

The set of parameters which occur in the equations for the various electrical quantities is called the local parameter set. In PSP, temperature scaling parameters are included in the local parameter set. Each of these parameters can be determined by purely electrical measurements. As a consequence, a local parameter set gives a complete description of the electrical properties of a device of one particular geometry.

Since most of these parameters scale with geometry, all transistors of a particular process can be described by a (larger) set of parameters, called the global parameter set. This set contains all local parameters for a long/wide device plus a number of sensitivity coefficients. From the global parameter set, you can obtain a local parameter set for a specific device by applying a set of scaling rules. For more information, see “Calculation of Transistor Geometry” on page 1528. The geometric properties of that specific device (such as its length and width) enter these scaling rules as instance parameters.

PSP is preferably used at the global level when designing a circuit in a specific technology for which a global parameter set is available. On the other hand, using PSP at local level can be helpful during parameter extraction.

As an option, it is possible to deal with the modification of transistor properties due to stress. In PSP, this is implemented by an additional set of transformation rules, which are optionally applied to the intermediate local parameter set generated at the global level. The parameters associated with the stress model are consequently part of the global parameter set.

The model structure described above is schematically depicted in the following figure.

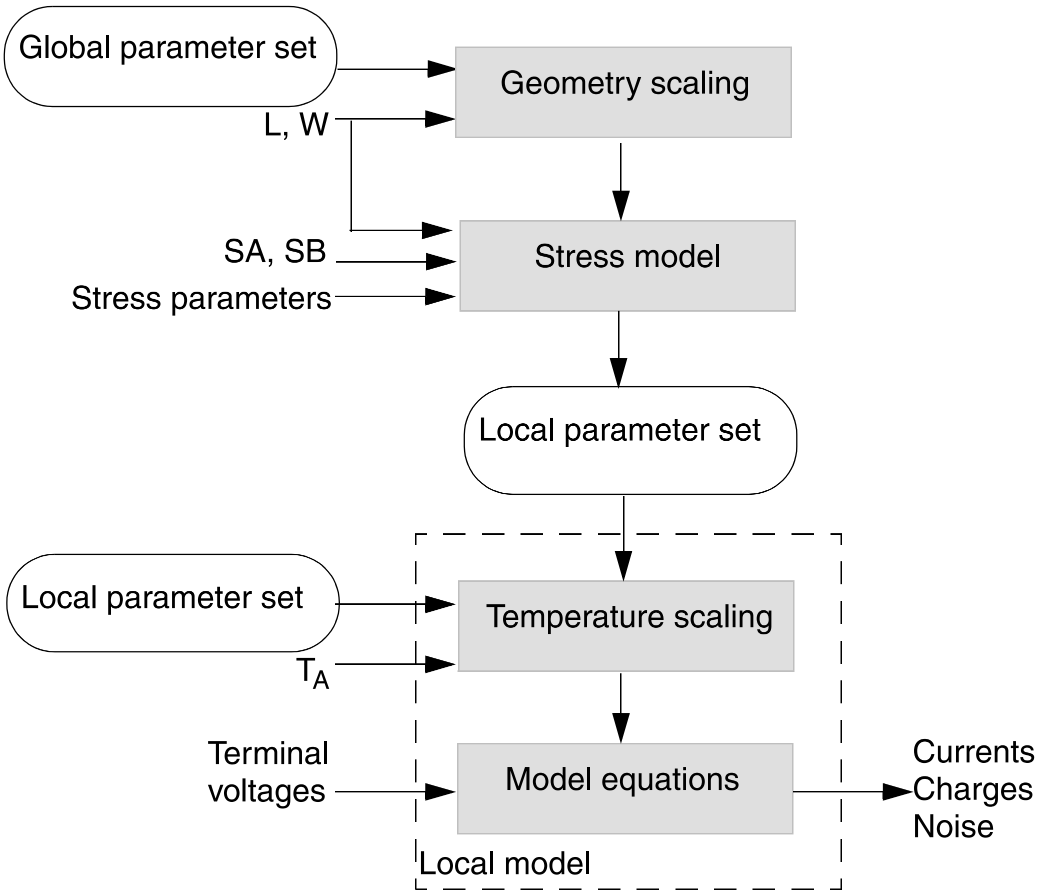


Figure 23-1 Schematic Overview of the PSP Model Structure

The JUNCAP2 model is implemented in such a way that the same set of JUNCAP2 parameters can be used at both the global and the local level.

Geometrical Scaling and Stress Model for Intrinsic MOSFET

The physical geometry scaling rules of PSP have been developed to give a good description over the whole geometry range of CMOS technologies. The parameters for which no scaling rules are specified, appear in both the list for the physical geometrical scaling rules and the list for the electrical model and can simply be copied. When the stress model is used, only the parameters for which shifts or multiplication factors are defined in “Parameter Modification due to Stress Effects” on page 1534 are affected.

Geometrical Scaling Rules

Calculation of Transistor Geometry

$$L_{EN} = 10^{-6}$$

$$W_{EN} = 10^{-6}$$

$$\Delta L_{PS} = LVAR0 \cdot \left(1 + LVARL \cdot \frac{L_{EN}}{L}\right) \cdot \left(1 + LVARW \cdot \frac{W_{EN}}{W}\right)$$

$$\Delta W_{OD} = WVAR0 \cdot \left(1 + WVARL \cdot \frac{L_{EN}}{L}\right) \cdot \left(1 + WVARW \cdot \frac{W_{EN}}{W}\right)$$

$$L_E = L - \Delta L = L + \Delta L_{PS} - 2 \cdot LAP$$

$$W_E = W - \Delta W = W + \Delta W_{OD} - 2 \cdot WOT$$

Note: L_E and W_E cannot be smaller than 10^{-9} after calculation.

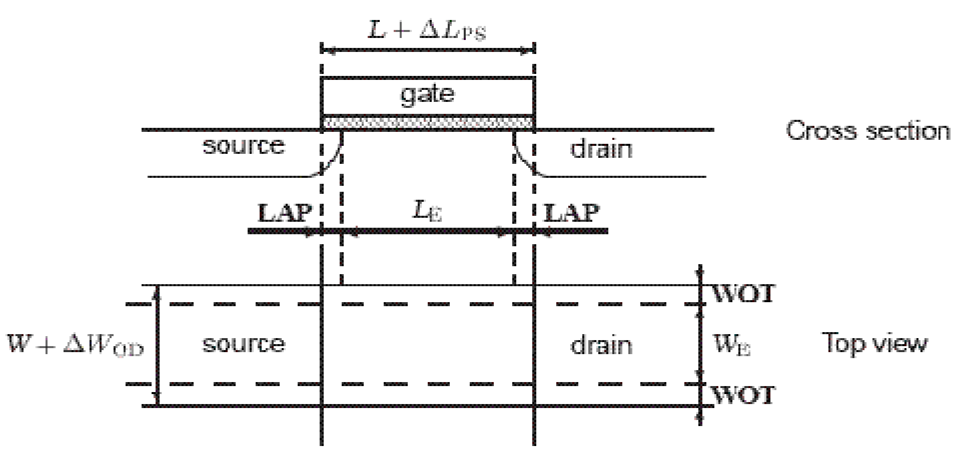


Figure 23-2 Dimensions of a MOS Transistor

Calculation of geometry-dependent parameters using physical scaling rules

Calculation of Process Parameters

$$VFB = VFB0 \cdot \left(1 + VFBL \cdot \frac{L_{EN}}{L_E}\right) \cdot \left(1 + VFBW \cdot \frac{W_{EN}}{W_E}\right) \cdot \left(1 + VFBLW \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}\right)$$

$$STVFB = STVFB0 \cdot \left(1 + STVFBL \cdot \frac{L_{EN}}{L_E}\right) \cdot \left(1 + STVFBW \cdot \frac{W_{EN}}{W_E}\right) \cdot \left(1 + STVFBLW \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}\right)$$

$$NSUB0e = NSUB0 \cdot MAX\left(\left[1 + NSUB0W \cdot \frac{W_{EN}}{W_E} \cdot \ln\left(1 + \frac{W_E}{WSEG}\right)\right], 10^{-3}\right)$$

$$NPCKe = NPCK \cdot MAX\left(\left[1 + NPCK \cdot \frac{W_{EN}}{W_E} \cdot \ln\left(1 + \frac{W_E}{WSEGP}\right)\right], 10^{-3}\right)$$

$$LPCKe = LPCK \cdot MAX\left(\left[1 + LPCKW \cdot \frac{W_{EN}}{W_E} \cdot \ln\left(1 + \frac{W_E}{WSEGP}\right)\right], 10^{-3}\right)$$

$$a = 7.5 \cdot 10^{10}$$

$$b = \sqrt{NSUB0e + 0.5 \cdot NPVCKe} - \sqrt{NSUB0e}$$

$$NP = NP0 \cdot \left(1 + NPL \cdot \frac{L_{EN}}{L_E}\right)$$

$$NSUB = \begin{cases} NSUB0e + NPCKe \cdot \left[2 - \dfrac{L_E}{LPCKe}\right] & \text{for } L_E < LPCKe \\ NSUB0e + NPCKe \cdot \dfrac{LPCKe}{L_E} & \text{for } LPCKe < L_E < LPCKe \\ \left[\sqrt{NSUB0e} + a \cdot \ln\left(1 + 2 \cdot \dfrac{LPCKe}{L_E} \cdot \left[\exp\left(\dfrac{b}{a}\right) - 1\right]\right)\right]^2 & \text{for } L_E > 2 * LPCKe \end{cases}$$

$$CT = \left(CT0 + CTL \cdot \left[\frac{L_{EN}}{L_E}\right]^{CTLEXP}\right) \cdot \left(1 + CTW \cdot \frac{W_{EN}}{W_E}\right)$$

Calculation of Lateral Gradient Factor Parameters

$$F0 = 1 - F0L1 \cdot \frac{L_{EN}}{L_E} - F0L2 \cdot \left[\frac{L_{EN}}{L_E}\right]^2$$

$$AF = \left(AF0 + AFL \cdot \left[\frac{L_{EN}}{L_E}\right]^{AFLEXP}\right) \cdot \left(1 + AFW \cdot \frac{W_{EN}}{W_E}\right)$$

$$BF = BFL \cdot \left[\frac{L_{EN}}{L_E}\right]^2$$

Calculation of Mobility Parameters

$$FBETIe = FBET1 \cdot \left(1 + FBET1W \cdot \frac{W_{EN}}{W_E}\right)$$

$$LPle = LP1 \cdot MAX\left(\left[1 + LP1W \cdot \frac{W_{EN}}{W_E}\right], 10^{-3}\right)$$

$$G_{P,E} = 1 + FBETIe \cdot \frac{LPle}{L_E} \cdot \left[1 - \exp\left(-\frac{L_E}{LPle}\right)\right] + FBET2 \cdot \frac{LP2}{L_E} \cdot \left[1 - \exp\left(-\frac{L_E}{LP2}\right)\right]$$

$$G_{W,E} = 1 + BETW1 \cdot \frac{W_{EN}}{W_E} + BETW2 \cdot \frac{W_{EN}}{W_E} \cdot \ln\left(1 + \frac{W_E}{WBET}\right)$$

$$BETN = \frac{U0}{G_{P,E}} \cdot \frac{W_E}{L_E} \cdot G_{W,E}$$

$$STBET = STBET0 \cdot \left(1 + STBETL \cdot \frac{L_{EN}}{L_E}\right) \cdot \left(1 + STBETW \cdot \frac{W_{EN}}{W_E}\right) \cdot 1 + STBETLW \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}$$

$$MUE = MUE0 \cdot \left[1 + MUEW \cdot \frac{W_{EN}}{W_E}\right]$$

$$XCOR = XCOR0 \cdot \left(1 + XCORL \cdot \frac{L_{EN}}{L_E}\right) \cdot \left(1 + XCORW \cdot \frac{W_{EN}}{LW_E}\right) \cdot \left(1 + XCORLW \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}\right)$$

$$CS = CS0 \cdot \left[1 + CSW \cdot \frac{W_{EN}}{W_E}\right]$$

Calculation of Series Resistance Parameters

$$RS = RSW1 \cdot \frac{W_{EN}}{W_E} \cdot \left[1 + RSW2 \cdot \frac{W_{EN}}{W_E}\right]$$

Calculation of Velocity Saturation Parameters

$$THESAT = \left(THESAT0 + THESATL \cdot \frac{G_{W,E}}{G_{P,E}} \cdot \left[\frac{L_{EN}}{L_E}\right]^{THESATLEXP}\right) \cdot \left(1 + THESATW \cdot \frac{w_{EN}}{w_E}\right)$$

$$STTHESAT = STTHESAT0 \cdot \left(1 + STTHESATL \cdot \frac{L_{EN}}{L_E}\right) \cdot \left(1 + STTHESATW \cdot \frac{W_{EN}}{W_E}\right) \cdot \left(1 + STTHESATLW \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}\right)$$

Calculation of Saturation Voltage Parameters

$$AX = \frac{AX0}{1 + AXL \cdot \frac{L_{EN}}{L_E}}$$

Calculation of Channel Length Modulation (CLM) Parameters

$$ALP = ALPL \cdot \left[\frac{L_{EN}}{L_E}\right]^{ALPLEXP} \cdot \left(1 + ALPW \cdot \frac{W_{EN}}{W_E}\right)$$

$$ALP1 = \frac{ALP1L1 \cdot \left[\frac{L_{EN}}{L_E}\right]^{ALP1LEXP}}{1 + ALP1L2 \cdot \left[\frac{L_{EN}}{L_E}\right]^{ALP1LEXP + 1}} \cdot \left(1 + ALP1W \cdot \frac{W_{EN}}{W_E}\right)$$

$$ALP2 = ALP20 \cdot \frac{1 + ALP2W \cdot \frac{W_{EN}}{W_E}}{1 + ALPL \cdot \frac{L_{EN}}{L_E}}$$

Calculation of Impact Ionization (II) Parameters

$$A1 = A10 \cdot \left(1 + A1L \cdot \frac{L_{EN}}{L_E}\right) \cdot \left(1 + A1W \cdot \frac{W_{EN}}{W_E}\right)$$

$$A3 = A30 \cdot \left(1 + A3L \cdot \frac{L_{EN}}{L_E}\right) \cdot \left(1 + A3W \cdot \frac{W_{EN}}{W_E}\right)$$

$$A4 = A40 \cdot \left(1 + A4W \cdot \frac{W_{EN}}{W_E}\right)$$

Calculation of Gate Current Parameters

$$IGINV = IGINVLW \cdot \frac{W_E \cdot L_E}{W_{EN} \cdot L_{EN}}$$

$$IGOV = IGOVW \cdot \frac{W_E \cdot LOV}{W_{EN} \cdot L_{EN}}$$

Calculation of Gate-Induced Drain Leakage (GIDL) Parameters

$$AGIDL = AGIDLLW \cdot \frac{W_E \cdot LOV}{W_{EN} \cdot L_{EN}}$$

Calculation of Charge Model Parameters

$$COX = \varepsilon_{OX} \cdot \frac{W_E \cdot L_E}{TOX}$$

$$CGOV = \varepsilon_{OX} \cdot \frac{W_E \cdot LOV}{TOXOV}$$

$$CGBOV = CGBOVL \cdot \frac{L + \Delta L_{PS}}{L_{EN}}$$

$$IFK = IFKW \cdot \frac{W_E}{W_{EN}}$$

$$CFR = CFRW \cdot \frac{W + \Delta W_{OD}}{W_{EN}}$$

Calculation of Noise Model Parameters

$$NFA = NFALW \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}$$

$$NFB = NFBLW \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}$$

$$NFC = NFCLW \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}$$

Parameter Modification due to Stress Effects

The stress model of BSIM4.4.0 has been adopted in PSP without any modifications. The PSP parameters affected are BETN, THESAT, VFB, AF, and CF.

Layout Effects for Regular Shapes

$$Inv\_sa = \frac{1}{SA + 0.5 \cdot L}$$

$$Inv\_sb = \frac{1}{SB + 0.5 \cdot L}$$

$$Inv\_sa_{ref} = \frac{1}{SAREF + 0.5 \cdot L}$$

$$Inv\_sb_{ref} = \frac{1}{SBREF + 0.5 \cdot L}$$

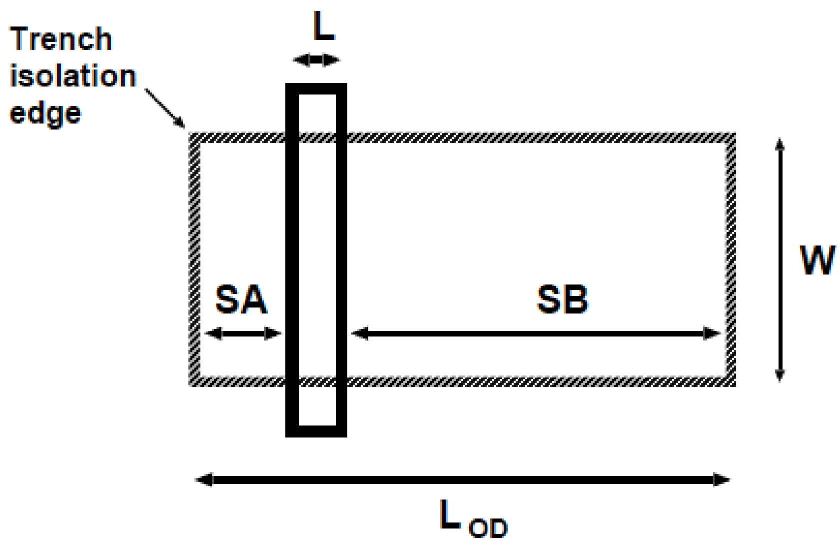


Figure 23-3 Typical layout of a MOSFET. Note that LOD = SA + SB + L, where OD is gate oxide definition

Layout effects for irregular shapes

For irregular shapes, the following effective values for **SA** and **SB** are to be used. You have to provide these values manually or by a layout extraction tool.

$$\frac{1}{SAEFF + 0.5 \cdot L} = \sum_{i=1}^{n} \frac{SWi}{W} \cdot \frac{1}{SAi + 0.5 \cdot L}$$

$$\frac{1}{SABFF + 0.5 \cdot L} = \sum_{i=1}^{n} \frac{SWi}{W} \cdot \frac{1}{SAB + 0.5 \cdot L}$$

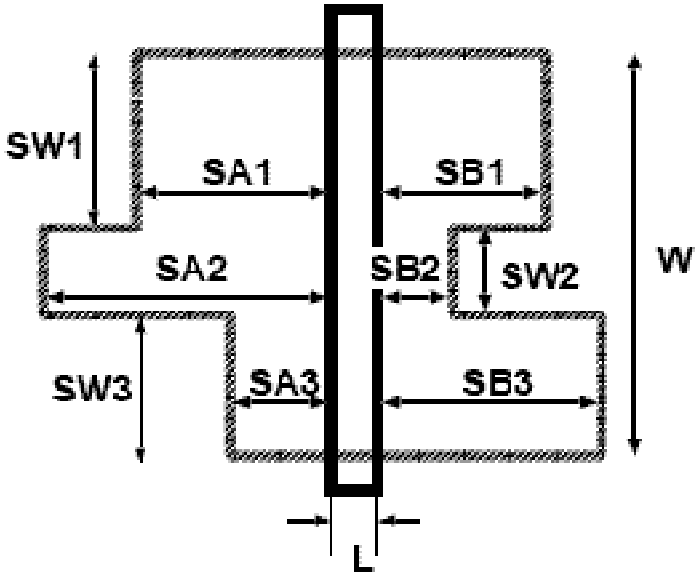


Figure 23-4 A typical layout of MOS devices with more instance parameters (SWi, SAi and SBi) in addition to the traditional L and W)

Calculation of Parameter Modifications

Mobility-Related Equations

$$Kstress\_u0 = \left(1 + \frac{LKU0}{(L + \Delta L_{PS})^{LLODKU0}} + \frac{WKU0}{(W + \Delta W_{OD} + WLOD)^{WLODKU0}} + \frac{PKU0}{(L + \Delta L_{PS})^{LLODKU0} \cdot (W + \Delta W_{OD} + WLOD)^{WLODKU0}}\right) \cdot \left(1 + TKU0 \cdot \left(\frac{T_{KD}}{T_{KR}} - 1\right)\right)$$

$$\rho\beta = \frac{KU0}{Kstress\_u0} \cdot (Inv\_sa + Inv\_sb)$$

$$\rho\beta, ref = \frac{KU0}{Kstress\_u0} \cdot (Inv\_sa_{ref} + Inv\_sb_{ref})$$

$$BETN = \frac{1 + \rho\beta}{1 + \rho\beta, ref} \cdot BETN_{ref}$$

$$THESAT = \frac{1 + \rho\beta}{1 + \rho\beta, ref} + \frac{1 + KVSAT \cdot \rho\beta, ref}{1 + KVSAT \cdot \rho\beta} \cdot THESAT_{ref}$$

Threshold-Voltage-Related Equations

$$Kstress\_vth0 = 1 + \frac{LKVTH0}{(L + \Delta L_{PS})^{LLODKVTH}} + \frac{WKVTH0}{(W + \Delta W_{OD} + WLOD)^{WLODKVTH}} + \frac{PKU0}{(L + \Delta L_{PS})^{LLODVTH} \cdot (W + \Delta W_{OD} + WLOD)^{WLODVTH}}$$

$$\Delta Inv\_s = Inv\_sa + Inv\_sb - Inv\_sa_{ref} - Inv\_sb_{ref}$$

$$VFB = VFB_{ref} + KVTH0 \cdot \frac{\Delta Inv\_s}{Kstress\_vth0}$$

$$AF = AF_{ref} + STK2 \cdot \frac{\Delta Inv\_s}{Kstress\_vth0^{LODK2}}$$

$$CF = CF_{ref} + STETA0 \cdot \frac{\Delta Inv\_s}{Kstress\_vth0^{LODETA0}}$$

PSP102 Model Equations

Calculation of Internal Parameters (including Temperature Scaling)

Calculation of Transistor Temperature

$$T_{KR} = T_0 + TR$$

$$T_{KD} = T_0 + T_A + DTA$$

$$\Delta T = T_{KD} - T_{KR}$$

$$\phi_T = \frac{k_B \cdot T_{KD}}{q}$$

Calculation of Local Process P arameters:

$$\phi^*{}_T = \phi_T \cdot \left(1 + CT \cdot \frac{T_{KR}}{T_{KD}}\right)$$

$$V_{FB} = VFB + STVFB \cdot \Delta T$$

$$E_g/q = 1.179 - 9.025 \cdot 10^{-5} \cdot T_{KD} - 3.05 \cdot 10^{-7} \cdot T_{KD}{}^2$$

$$r_T = (1.045 + 4.5 \cdot 10^{-4} \cdot T_{KD}) \cdot (0.523 + 1.4 \cdot 10^{-3} \cdot T_{KD} - 1.48 \cdot 10^{-6} \cdot T_{KD}{}^2)$$

$$n_i = 2.5 \cdot 10^{25} \cdot rT^{3/4} \cdot (T_{KD}/300)^{3/2} \cdot \exp\left(-\frac{E_g/q}{2 \cdot \phi_T}\right)$$

$$\phi_B^{cl} = MAX(2 \cdot \phi_T \cdot \ln[(NSUB)/n_i], 0.05)$$

$$C_{ox} = \varepsilon_{ox}/(TOX)$$

$$\gamma_0 = \sqrt{2 \cdot q \cdot \varepsilon_{si} \cdot NSUB/C_{ox}}$$

$$G_0^{cl} = \gamma_0/(\sqrt{\phi_T})$$

Calculation of Polysilicon Depletion Parameter

$$kp = \begin{cases} if\ NP \le 1 \text{ or } NP \ge 10^{28} & \{kp = 0 \\ if\ 1 < NP < 10^{28} & \begin{cases} NP_1 = MAX(NP, 8 \cdot 10^7/TOX^2) \\ NP_2 = MAX(NP_1, 3 \cdot 10^2) \\ kp = (2 \cdot \phi_T \cdot C_{ox}^2)/(q \cdot \varepsilon_{Si} \cdot NP^2) \end{cases} \end{cases}$$

Calculation of Quantum-Mechanical Correction Parameters

$$q_{lim} = 10 \cdot \phi_T$$

$$q_q = \begin{cases} 0.4 \cdot QMC \cdot QM_N \cdot C_{ox}^{2/3} & for\ NMOS \\ 0.4 \cdot QMC \cdot QM_p \cdot C_{ox}^{2/3} & for\ \text{PMOS} \end{cases}$$

$$q_{b0} = \gamma_0 \cdot \sqrt{\phi_B^{cl}}$$

$$\phi_B = \phi_B^{cl} + 0.75 \cdot q_q \cdot q_{b0}^{2/3}$$

$$G_0 = G_0^{cl} \cdot (1 + q_q \cdot q_{b0}^{-2/3})$$

$$\phi_X = 0.95 \cdot \phi_B$$

$$a_\phi = 2.5 \cdot 10^{-5} \cdot \phi_b^2$$

$$\phi^*_X = MAXA(\phi_X, 0, a_\phi) = 0.95000658 \cdot |\phi_B|$$

Calculation of Local Process Parameters in Gate Overlap Regions

$$\gamma_{ov} = \sqrt{2 \cdot q \cdot \varepsilon_{Si} \cdot NOV} \cdot (TOXOV)/\varepsilon_{ox}$$

$$G_{ov} = \gamma_{ov}/(\sqrt{\phi_T})$$

$$\xi_{ov} = 1 + G_{ov}/(\sqrt{2})$$

$$x_{mrgov} = 10^{-5} \cdot \xi_{ov}$$

Calculation of Lateral Gradient Factor Parameters

$$B_f = MIN\left(BF, \frac{1 - F0}{F0 + 0.01}\right)$$

Calculation of Mobility Parameters

$$\beta = BETN \cdot C_{ox} \cdot (T_{KR}/T_{KD})^{STBET}$$

$$\theta_{\mu} = THEMU \cdot (T_{KR}/T_{KD})^{STTHEMU}$$

$$\mu_E = MUE \cdot (T_{KR}/T_{KD})^{STMUE}$$

$$X_{cor} = XCOR \cdot (T_{KR}/T_{KD})^{STXCOR}$$

$$C_S = CS \cdot (T_{KR}/T_{KD})^{STCS}$$

$$E_{eff0} = 10^{-8} \cdot C_{ox}/\varepsilon_{Si}$$

$$\eta_{\mu} = \begin{cases} 1/2 & for \text{ NMOS} \\ 1/3 & for \text{ PMOS} \end{cases}$$

Calculation of Series Resistance Parameters

$$R_s = RS \cdot (T_{KR}/T_{KD})^{STRS}$$

$$\theta_R = 2 \cdot \beta \cdot R_s$$

Calculation of Velocity Saturation Parameter

$$\theta_{sat} = A2 \cdot (T_{KR}/T_{KD})^{STTHESAT}$$

Calculation of Impact-Ionization Parameter

$$\alpha_2 = A2 \cdot (T_{KD}/T_{KR})^{STA2}$$

Calculation of Gate Current Parameters

$$I_{GINV} = IGINV \cdot (T_{KD}/T_{KR})^{STIG}$$

$$I_{GOV} = A2IGOV \cdot (T_{KD}/T_{KR})^{STIG}$$

$$B = \frac{4}{3} \cdot \frac{TOX}{h} \cdot \sqrt{2 \cdot q \cdot m_0 \cdot CHIB} = 6.830909 \cdot 10^9 \cdot TOX \cdot \sqrt{CHIB}$$

$$B_{ov} = B \cdot (TOXOV)/(TOX)$$

$$GC_q = \begin{cases} -0.99 \cdot \dfrac{GC2}{2 \cdot GC3} & if\ GC3 < 0 \\ 0 & if\ GC3 \geq 0 \end{cases}$$

$$\alpha_b = \frac{E_g/q + \phi_B}{2}$$

$$D_{ch} = GC0 \cdot \phi^*{}_T$$

$$D_{ov} = GC0 \cdot \phi_T$$

Calculation of Gate–Induced Drain Leakage Parameters

$$A_{GIDL} = AGIDL \cdot \left(\frac{2 \cdot 10^{-9}}{TOXOV}\right)^2$$

$$B_{GIDL} = BGIDL \cdot MAX([1 + STBGIDL \cdot \Delta T], 0) \cdot \left(\frac{TOXOV}{2 \cdot 10^{-9}}\right)$$

Calculation of Noise Parameter

$$N_T = FNT \cdot 4 \cdot k_B \cdot T_{KD}$$

Calculation of Additional Internal Parameters

$$x_1 = 1.25$$

$$x_{g1} = \chi_1 + G_{ov} \cdot \sqrt{\exp(-\chi_1) + \chi_1 - 1}$$

PSP 102 Model Equations

Conditioning of Terminal Voltages

$$V^*_{GB} = V_{GS} + V_{SB} - V_{FB}$$

$$x_g = V^*_{GB} / \phi^*_T$$

$$V^*_{SB} = MAXA(V_{SB} + \phi_X, 0, a_\phi) - \phi^*_X$$

$$V^*_{DB} = V_{DS} + V^*_{SB}$$

Bias-Dependent Body Factor

$$D_{nsub} = DNSUB \cdot MAXA(0, V_{GS} + V_{SB} - VNSUB, NSLP)$$

$$G = G_0 \cdot \sqrt{1 + D_{nsub}}$$

Lateral Gradient Factor

$$V_{dsx} = \sqrt{V_{DS}^2 + 0.010.01}$$

$$V_{sbx} = V^*_{SB} + \frac{V_{DS} - V_{dsx}}{2}$$

$$V_{sbx1} = MAXA(V_{sbx}, 0, 10^{-4})$$

$$F_{DIBL} = CF \cdot V_{dsx} \cdot (1 + CF \cdot V_{dsx}) \cdot (1 + CFB \cdot V_{sbx})$$

$$f_0 = \frac{F0}{1 + AF \cdot V_{sbx} + B_f \cdot V_{sbx1} + F_{DIBL}} + 0.01$$

$$B_t = (f_0 - 0.01) \cdot B_f \cdot \phi^*_X$$

$$\tilde{x}_0 = \frac{\phi_B + V_{sbx}}{\phi^*_T}$$

$$x_{gc} = MAXA(\chi_g, 0, 50)$$

$$x_{subf} = \frac{\chi_{gc}^2}{\chi_{gc} + \frac{G^2 \times f_0}{2} + G \cdot \sqrt{B_t \cdot \chi_{gc}^2 + f_0 \cdot \chi_{gc} + \left(\frac{G \cdot f_0}{2}\right)^2}}$$

$$\eta f = MINA(\chi_{subf}, \tilde{\chi}_0 + 3, 5)$$

$$a_f = (\chi_{gc} - \eta_f)^2 - G^2 \cdot \eta_f \cdot (f_0 + B_t \cdot \eta_f)$$

$$c_f = 2 \cdot (\chi_{gc} - \eta_f) + G^2 \cdot (f_0 + 2 \cdot B_t \cdot \eta_f)$$

$$\tau = \tilde{\chi}_0 - \eta_f + \ln(a_f / G^2)$$

$$x_f = \sigma\left(\frac{a_f}{1 - B_t \cdot G^2}, \frac{c_f}{1 - B_t \cdot G^2}, \tau, \eta_f\right)$$

$$f = f_0 + B_t \cdot \chi_f$$

Surface Potential at Source Side and Related Variables

$$G_f = G \cdot \sqrt{f}$$

$$\xi = 1 + G_f/(\sqrt{2})$$

$$x_{ns} = \frac{\phi_B + V^*_{SB}}{\phi^*_T}$$

$$\Delta_{ns} = \exp(-\chi_{ns})/f$$

$$x_{mrg} = 10^{-5} \cdot \xi$$

$$\text{if } x_g < -x_{mrg} \quad \begin{cases} y_g = -x_g \\ z = 1.25 \cdot y_g/\xi \\ \eta = \left[z + 10 - \sqrt{(z-6)^2 + 64}\right]/2 \\ a = (y_g - \eta)^2 + G_f^2 \cdot (\eta + 1) \\ c = 2 \cdot (y_g - \eta) - G_f^2 \\ \tau = -\eta + \ln(a/G_f^2) \\ y_0 = \sigma_1(a, c, \tau, \eta) \\ \Delta_0 = EXP(y_0) \\ p = 2 \cdot (y_g - y_0) + G_f^2 \cdot [\Delta_0 - 1 + \Delta_{ns} \cdot (1 - \chi'(y_0) - 1/\Delta_0)] \\ q = (y_g - y_0)^2 + G_f^2 \cdot [y_0 - \Delta_0 + 1 + \Delta_{ns} \cdot (1 + \chi(y_0) - 1/\Delta_0 - 2 \cdot y_0)] \\ x_s = -y_0 - \dfrac{2 \cdot q}{p + \sqrt{p^2 - 2 \cdot q \cdot \left\{2 - G_f^2 \cdot [\Delta_0 + \Delta_{ns} \cdot (1/\Delta_0 - x^{n}(y_0))]\right\}}} \end{cases}$$

$$\text{if } |x_g| \le x_{mrg} \quad \left\{x_s = \frac{x_g}{\xi}, \left[1 + G_f \cdot x_g \cdot \frac{1 - \Delta_{ns}}{\xi^2 \cdot 6 \cdot \sqrt{2}}\right]\right.$$

$$
if\ x_g > x_{mrg} = \begin{cases}
\hat{x_{g1}} = x_1 + G_f \cdot \sqrt{\exp(-x_1) + x_1 - 1} \\
\bar{x} = \frac{x_g}{\xi} \cdot [1 + x_g \cdot (\xi \cdot x_1 - \hat{x}_{g1})/x_{g1}^2] \\
x_0 = x_g + G_f^2/2 - G_f \cdot \sqrt{x_g + G_f^2/4 - 1 + \exp(-\bar{x})} \\
b_x = x_{ns} + 0.5 + 2.5 \cdot f \\
\eta = MINA(x_0, b_x, 5) - \left(b_x - \sqrt{b_x^2 + 5}\right)/2 \\
a = (x_g - \eta)^2 - G_f^2 \cdot [\exp(-\eta) + \eta - 1 - \Delta_{ns} - (\eta + 1 + \chi(\eta))] \\
b = 1 - G_f^2 \cdot [\exp(-\eta) - \Delta_{ns} \cdot x^n(\eta)] \\
c = 2 \cdot (x_g - n) + G_f^2 \cdot [1 - \exp(-\eta) - \Delta_{ns} \cdot (1 + x'(\eta))] \\
\tau = x_{ns} - \eta + \ln(a/G^2) \\
y_0 = a_2(a, b, c, \tau, \eta) \\
\Delta_0 = \exp(y_0) \\
p = 2 \cdot (x_g - y_0) + G_f^2 \cdot [1 - 1/\Delta_0 + \Delta_{ns} \cdot (\Delta_0 - 1 - (y_0))] \\
x_s = \dfrac{2 \cdot q}{p + \sqrt{p^2 - 2 \cdot q \cdot \left\{2 - G_f^2 \cdot [1/\Delta_0 + \Delta_{ns} \cdot (\Delta_0 - x^n(y_0))]\right\}}}
\end{cases}
$$

The values of E_s, D_s, and P_s are calculated only for x_g>0.

$$E_s = \exp(-x_s)$$

$$D_s = [1/E_s - x_s - 1 - x(x_s)] \cdot \Delta_{ns}$$

$$P_s = x_s - 1 + E_s$$

$$
x_{gs} = \begin{cases}
x_g - x_s & for\ x_g \le 0 \\
G_f \cdot \sqrt{D_s + P_s} & for\ x_g > 0
\end{cases}
$$

$$\psi_{ss} = \phi^*{}_T \cdot x_s$$

Drain Saturation Voltage

All the equations in this sections have been calculated for x_g>0.

$$q_{is} = \frac{G_f^2 \cdot \phi^*_T \cdot D_s}{x_{gs} + G_f \cdot \sqrt{P_s}}$$

$$\alpha_s = 1 + \frac{G_f \cdot (1 - E_s)}{2 \cdot \sqrt{P_s}}$$

$$q_{bs} = \phi^*_T \cdot G_f \cdot \sqrt{P_s}$$

$$\rho_s = \theta_R \cdot \frac{1 + RSB \cdot V_{sbx}}{1 + RSG \cdot q_{is}} \cdot q_{is}$$

$$\mu_x = \frac{1 + X_{cor} \cdot V_{sbx}}{1 + 0.2 \cdot X_{cor} \cdot V_{sbx}}$$

$$E_{effs,s} = E_{eff0} \cdot (q_{bs} + \eta_\mu \cdot q_{is})$$

$$G_{mob,s} = \frac{1 + (\mu_E \cdot E_{eff,s})^{\theta_\mu} + C_S \cdot \left(\frac{q_{bs}}{q_{is} + q_{bs}}\right)^2 + \rho_s}{\mu_x}$$

$$w_{sat,s} = \frac{100 \cdot q_{is} \cdot (1 + THESATB \cdot V_{sbx})}{100 + q_{is} \cdot (1 + THESATB \cdot V_{sbx})}$$

$$\theta^*_{sat,s} = \frac{\theta_{sat,s}}{G_{mob,s}} \cdot (1 + THESATG \cdot w_{sat,s})$$

$$\phi_\infty = q_{is}/\alpha_s + \phi^*_T$$

$$y_{sat} = \begin{cases} \theta^*_{sat,s} \cdot \phi_\infty/(\sqrt{2}) & \textit{for}\ \text{NMOS} \\ \dfrac{\theta^*_{sat,s} \cdot \phi_\infty/(\sqrt{2})}{\sqrt{1 + \theta^*_{sat,s} \cdot \phi_\infty/(\sqrt{2})}} & \textit{for}\ \text{PMOS} \end{cases}$$

$$\phi_2 = \frac{\phi^*_T \cdot G_f^2 \cdot D_s \cdot SO}{a_{sat} + \sqrt{a_{sat}^2 - G_f^2 \cdot D_s \cdot SO}}$$

$$\phi_{sat} = \frac{2 \cdot \phi_0 \cdot \phi_2}{\phi_0 + \phi_2 + \sqrt{(\phi_0 + \phi_2)^2 - 3.96 \cdot \phi_0 \cdot \phi_2}}$$

$$V_{dsat} = \phi_{sat} - \phi^*_T \cdot \ln\left[1 + \frac{\phi_{sat} \cdot (\phi_{sat} - 2 \cdot a_{sat} \cdot \phi^*_T)}{G_f^2 \cdot D_s \cdot \phi_T^{*2}}\right]$$

$$V_{dse} = \frac{V_{DS}}{[1 + (V_{DS}/V_{dsat})^{AX}]^{1/(AX)}}$$

Surface Potential at Drain Side and Related Variables

$$x_{nd} = \frac{\phi_B + V^*_{SB} + V_{dse}}{\phi^*_T}$$

$$k_{ds} = \exp(-V_{dse}/\phi^*_T)$$

$$\textit{if}\ x_g \le x_{mrg} \qquad \left\{ x_d = \frac{x_g}{\xi} \cdot \left[1 + G_f \cdot x_g \cdot \frac{1 - \Delta_{nd}}{\xi^2 \cdot 6 \cdot \sqrt{2}}\right] \right.$$

$$
if\ x_g > x_{mrg} \quad \begin{cases} b_x = x_{nd} + 0.5 + 2.5 \cdot f \\ \eta = MINA(x_0, b_x, 5) - \left(b_x - \sqrt{b_x^2 + 5}\right)/2 \\ a = (x_g - \eta)^2 - G_f^2 \cdot [\exp(-\eta) + \eta - 1 - \Delta_{nd} \cdot (\eta + 1 + x(\eta))] \\ b = 1 - G_f^2/2 \cdot [\exp(-\eta) - \Delta_{nd} \cdot x''(\eta)] \\ c = 2 \cdot (x_g - \eta) + G_f^2 \cdot [1 - \exp(-\eta) - \Delta_{nd} \cdot (1 + x'(\eta))] \\ \tau = x_{nd} - \eta + \ln\langle a/G^2\rangle \\ y_0 = \sigma_2(a, b, c, \tau, \eta) \\ \Delta_0 = \exp(y_0) \\ p = 2 \cdot (x_g - y_0) + G_f^2 \cdot [1 - 1/\Delta_0 + \Delta_{nd} \cdot (\Delta_0 - 1 - x'(y_0))] \\ q = (x_g - y_0)^2 - G_f^2 \cdot [y_0 + 1/\Delta_0 - 1 + \Delta_{nd} \cdot (\Delta_0 - y_0 - 1 - x'(y_0))] \\ x_d = y_0 + \dfrac{2 \cdot q}{p + \sqrt{p^2 - 2 \cdot q \cdot \left\{2 - G_f^2 \cdot [1/\Delta_0 + \Delta_{nd} \cdot (\Delta_0 - x''(y_0))]\right\}}} \end{cases}
$$

$$x_{ds} = x_d - x_s$$

$$
if\ x_{ds} < 10^{-10} \quad \begin{cases} p = 2 \cdot x_{gs} + G_f^2 \cdot [1 - E_s + \Delta_{nd} \cdot (1/E_s - 1 - x'(x_s))] \\ q = G_f^2 \cdot (1 - k_{ds}) \cdot D_s \\ \xi = 1 - G_f^2 \cdot [E_s + \Delta_{nd}(1/E_s - x''(x_s))] \\ x_{ds} = \dfrac{2 \cdot q}{p + \sqrt{p^2 - 4 \cdot \xi \cdot q}} \\ x_d = x_s + x_{ds} \end{cases}
$$

$$E_d = \exp(-x_d)$$

$$D_d = (1/E_d - x_d - 1 - (x_d)) \cdot \Delta_{nd}$$

$$\Delta\psi = \phi_T^* \cdot x_{ds}$$

$$\psi_{sd} = \phi_T^* \cdot x_d$$

Mid-Point Surface Potential and Related Variables

$$\text{if } x_g > 0 \quad \begin{cases} x_m = (x_s + x_d)/2 \\ E_m = \sqrt{E_s \cdot E_d + 10^{-40}} \\ \bar{D} = (D_s + D_d)/2 \\ D_m = \bar{D} + x_{ds}^2/8 \cdot (E_m - 2/G_f^2) \\ P_m = x_m - 1 + E_m \\ x_{gm} = G_f \cdot \sqrt{D_m + P_m} \end{cases}$$

$$\text{if } x_g \le 0 \quad \begin{cases} x_m = x_s \\ x_{gm} = x_g - x_s \end{cases}$$

Polysilicon Depletion

The equations in this section are only calculated for $k_P > 0$ and $x_g > 0$ (otherwise $\eta_p = 1$).

$$x_m^{(0)} = x_m \quad , D_m^{(0)} = D_m \quad , E_m^{(0)} = E_m \quad , \Delta\psi^{(0)} = \Delta\psi$$

$$d_0 = 1 - E_m^{(0)} + 2 \cdot X_{gm}/G_f^2$$

$$\eta_p = 1/(\sqrt{1 + kp \cdot x_{gm}})$$

$$x_{pm} = kp \cdot \left[\frac{\eta_p \cdot x_{gm}}{1 + \eta_p}\right] \cdot \frac{D_m^{(0)}}{D_m^{(0)} + P_m}$$

$$p = 2 \cdot (x_{gm} - x_{pm}) + G_f^2 \cdot (1 - E_m^{(0)} + D_m^{(0)})$$

$$q = x_{pm} \cdot (x_{pm} - 2 \cdot x_{gm})$$

$$\xi_p = 1 - G_f^2/2 \cdot (E_m^{(0)} + D_m^{(0)})$$

$$u_p = \frac{p \cdot q}{p^2 - \xi_p \cdot q}$$

$$x_m = x_m^{(0)} + u_p$$

$$E_m = E_m^{(0)} \cdot \exp(-u_p)$$

$$D_m = D_m^{(0)} \cdot \exp(-u_p)$$

$$P_m = x_m - 1 + E_m$$

$$x_{gm} = G_f \cdot \sqrt{D_m + P_m}$$

$$\Delta\psi = \Delta\psi^{(0)} \cdot \frac{\exp(u_p) \cdot [\overline{D} + d_0]}{1 - E_m + 2 \cdot x_{gm} \cdot \eta_p / G_f^2 + \exp(u_p) \cdot \overline{D}}$$

Potential Mid-Point Inversion Charge and Related Variables

The equations in this section are only calculated for $x_g > 0$.

$$q_{im} = \frac{G_f^2 \cdot \phi_T^* \cdot D_m}{x_{gm} + G_f \cdot \sqrt{P_m}}$$

$$\alpha_m = \eta_p + \frac{G_f \cdot (1 - E_m)}{2 \cdot \sqrt{P_m}}$$

$$q_{im}^* = q_{im} + \phi_T^* \cdot \alpha_m$$

$$q_{bm} = \phi_T^* \cdot G_f \cdot \sqrt{P_m}$$

Series Resistance

$$\rho = \theta_R \cdot \frac{1 + RSB \cdot V_{sbx}}{1 + RSG \cdot q_{im}} \cdot q_{im}$$

Mobility Reduction

$$E_{eff} = E_{eff0} \cdot (q_{bm} + \eta_\mu \cdot q_{im})$$

$$G_{mob} = \frac{1 + (\mu_E \cdot E_{eff})^{\theta_\mu} + C_S \cdot \left(\frac{q_{bm}}{q_{im} + q_{bm}}\right) + \rho}{\mu_x}$$

Drain-Source Channel Current

Channel Length Modulation

$$R_1 = q_{im}/q_{im}^*$$

$$R_2 = \phi_T^* \cdot \alpha_m/q_{im}^*$$

$$\Delta L/L = ALP \cdot \frac{V_{DS}}{V_{DS} + \phi_T^*} \cdot \ln\left(1 + \frac{V_{DS} - \Delta\psi}{VP}\right)$$

$$G_{\Delta L} = \frac{1}{1 + \Delta L/L + (\Delta L/L)^2}$$

$$\Delta L_1/L = \left[ALP + \frac{ALP1}{q_m^*} \cdot R_1 + ALP2 \cdot q_{bm} \cdot R_2^2\right] \cdot \frac{V_{DS}}{V_{DS} + \phi_T^*} \cdot \ln\left(1 + \frac{V_{DS} - \Delta\psi}{VP}\right)$$

$$F_{\Delta L} = 1 + \Delta L_1/L + (\Delta L_1/L)^2$$

Velocity Saturation

$$w_{sat} = \frac{100 \cdot q_{im} \cdot (1 + THESATB \cdot V_{sbx})}{100 + q_{im} \cdot (1 + THESATB \cdot V_{sbx})}$$

$$\theta^*_{sat} = \frac{\theta_{sat}}{G_{mob} \cdot G_{\Delta L}} \cdot (1 + THESATG \cdot w_{sat})$$

$$z_{sat} = \begin{cases} (\theta^*_{sat} \cdot \Delta\psi)^2 & for\ \text{NMOS} \\ \dfrac{(\theta^*_{sat} \cdot \Delta\psi)^2}{1 + \theta^*_{sat} \cdot \Delta\psi} & for\ \text{PMOS} \end{cases}$$

$$G_{vsat} = \frac{G_{mob} \cdot G_{\Delta L}}{2} \cdot (1 + \sqrt{1 + 2 \cdot z_{sat}})$$

Drain-Source Channel Current

$$I_{DS} = \begin{cases} 0 & for\ x_g \le 0 \\ \beta \cdot F_{\Delta L} \cdot \dfrac{q^*_{im}}{G_{vsat}} \cdot \Delta\psi & for\ x_g > 0 \end{cases}$$

Variables for Calculation of Intrinsic Charges and Gate Current

The equations in this section are only calculated for $x_g > 0$.

$$V_{oxm} = \theta^*_T \cdot x_{gm}$$

$$\alpha'_m = \alpha_m \cdot \left[1 + \frac{z_{sat}}{2} \cdot \left(\frac{G_{mob} \cdot G_{\Delta L}}{G_{vsat}}\right)^2\right]$$

$$H = \frac{G_{mob} \cdot G_{\Delta L}}{G_{vsat}} \cdot \frac{q^*_{im}}{\alpha'_m}$$

Impact Ionization or Weak-Avalanche

The equations in this Section are calculated when SWIMPACT = 1 and only for $x_g > 0$.

$$a^*_2 = a_2 \cdot [1 + A4 \cdot (\sqrt{V^*_{SB} + \phi_B} - \sqrt{\phi_B})]$$

$$\Delta V_{sat} = V_{DS} - A3 \cdot \Delta\psi$$

$$M_{av1} = \begin{cases} 0 & for\ \Delta V_{sat} \le 0 \\ A1 \cdot \Delta V_{sat} \cdot \exp(\Delta\psi) & for\ \Delta V_{sat} > 0 \end{cases}$$

$$I_{av1} = M_{av1} \cdot I_{DS}$$

Surface Potential in Gate Overlap Regions

$$x_{ov}(x_g) = if\ x_g < -x_{mrgov} \quad \begin{cases} y_g = -x_g \\ z = x_1 \cdot y_g / \xi_{ov} \\ \eta = \left[z + 10 - \sqrt{(z-6)^2 + 64}\right]/2 \\ a = (y_g - \eta)^2 + G_{ov}^2 \cdot (\eta + 1) \\ c = 2 \cdot (y_g - \eta) - G_{ov}^2 \\ \tau = -\eta + \ln(a / G_{ov}^2) \\ y_0 = \sigma_1(a, c, \tau, \eta) \\ \Delta_0 = \exp(y_0) \\ p = 2 \cdot (y_g - y_0) + G_{ov}^2 \cdot (\Delta_0 - 1) \\ q = (y_g - y_0)^2 + G_{ov}^2 \cdot (y_0 - \Delta_0 + 1) \\ x_{ov} = \dfrac{2 \cdot q}{p + \sqrt{p^2 - 2 \cdot q \cdot (2 - G_{ov}^2 \cdot \Delta_0)}} \end{cases}$$

$$if\ |x_g| < x_{mrgov} \quad \{x_{ov} = x_g / \xi_{ov}$$

$$
x_{ov}(x_g) = \begin{cases}
if\ x_g < -x_{mrgov} & \begin{cases}
y_g = -x_g \\
z = x_1 \cdot y_g / \xi_{ov} \\
\eta = \left[z + 10 - \sqrt{(z-6)^2 + 64}\right] / 2 \\
a = (y_g - \eta)^2 + G_{ov}^2 \cdot (\eta + 1) \\
c = 2 \cdot (y_g - \eta) - G_{ov}^2 \\
\tau = -\eta + \ln(a / G_{ov}^2) \\
y_0 = \sigma_1(a, c, \tau, \eta) \\
\Delta_0 = \exp(y_0) \\
p = 2 \cdot (y_g - y_0) + G_{ov}^2 \cdot (\Delta_0 - 1) \\
q = (y_g - y_0)^2 + G_{ov}^2 \cdot (y_0 - \Delta_0 + 1) \\
x_{ov} = \dfrac{2 \cdot q}{p + \sqrt{p^2 - 2 \cdot q \cdot (2 - G_{ov}^2 \cdot \Delta_0)}}
\end{cases} \\
if\ |x_g| < x_{mrgov} & \{ x_{ov} = x_g / \xi_{ov} \\
if\ x_g > x_{mrgov} & \begin{cases}
\bar{x} = x_g / \xi_{ov} \cdot [1 + x_g \cdot (\xi_{ov} \cdot x_1 - x_{g1}) / x_{g1}^2] \\
w = 1 - \exp(-\bar{x}) \\
x_0 = x_g + G_{ov}^2 / 2 - G_{ov} \cdot \sqrt{x_g + G_{ov}^2 / 4 - w} \\
p = 2 \cdot (x_g - x_0) + G_{ov}^2 \cdot (1 + \Delta_0) \\
q = (x_g - x_0)^2 - G_{ov}^2 \cdot (x_0 + \Delta_0 - 1) \\
x_{ov} = x_0 + \dfrac{2 \cdot q}{p + \sqrt{p^2 - 2 \cdot q \cdot (2 - G_{ov}^2 \cdot \Delta_0)}}
\end{cases}
\end{cases}
$$

$$
\Psi_{sov} = -\phi_T \cdot x_{ov}\left(-\frac{V_{GS}}{\phi_T}\right)
$$

$$
\Psi_{dov} = -\phi_T \cdot x_{ov}\left(-\frac{V_{GS} - V_{DS}}{\phi_T}\right)
$$

$$V_{ov0} = V_{GS} - \Psi_{sov}$$

$$V_{ovL} = V_{GS} - V_{DS} - \Psi_{dov}$$

Gate Current

The equations in this section are calculated when SWIGATE = 1.

Source/Drain Gate Overlap Current

The gate tunnelling currents in both gate/source and gate/drain overlap are given by:

$$I_{Gov}(V_{GX}, \Psi_{ov}, V_{ov}) = \begin{cases} V^*_{ov} = \sqrt{V_{ov}^2 + 10^{-6}} \\ \Psi_{tov} = MINA(0, V_{ov} + D_{ov}, 0.01) \\ z_g = \begin{cases} MINA\left(\dfrac{V^*_{ov}}{CHIB}, GC_Q, 10^{-6}\right) & for\ GC3 < 0 \\ \dfrac{V^*_{ov}}{CHIB} & for\ GC3 \geq 0 \end{cases} \\ \Delta_{Siov} = \exp\left(\dfrac{3.0 \cdot \phi_T + \Psi_{ov} + \Psi_{tov}}{\phi_T}\right) \\ F_{Sov} = \ln\left[\dfrac{1 + \Delta_{Siov}}{1 + \Delta_{Siov} \cdot \exp(-V_{GX}/\phi_T)}\right] \\ I_{GOV} = I_{GOV} \cdot F_{Sov} \cdot \exp\left(B_{ov} \cdot \left[-\dfrac{3}{2} + z_g \cdot (GC2 + GC3 \cdot z_g)\right]\right) \end{cases}$$

$$I_{GSov} = I_{GOV}(V_{GS}, \Psi_{sov}, V_{ovo})$$

$$I_{GDov} = I_{GOV}(V_{GS} - V_{DS}, \Psi_{dov}, V_{ovL})$$

Gate-Channel Current

$$V_m = V^*_{SB} + \phi^*_T \cdot \left[x_m - x_s - \ln\left(\frac{1 + \exp(V_{dse}/\phi^*_T)}{2}\right)\right]$$

$$\psi_T = MINA(0, V_{oxm} + D_{ch}, 0.01)$$

$$V^*_{oxm} = \sqrt{V^2_{oxm} + 10^{-6}}$$

$$z_g = \begin{cases} MINA\left(\frac{V^*_{oxm}}{CHIB}, GC_Q, 10^{-6}\right) & for\ GC3 < 0 \\ \frac{V^*_{oxm}}{CHIB} & for\ GC3 \ge 0 \end{cases}$$

$$\Delta_{Si} = \exp\left(x_m - \frac{\alpha_b + V_m - \psi_t}{\phi^*_T}\right)$$

$$F_S = \ln\left[\frac{1 + \Delta_{Si}}{1 + \Delta_{Si} \cdot \exp\left(-\frac{V_{HS} + V_{SB} - V_m}{\phi^*_T}\right)}\right]$$

$$I_{GCO} = I_{GINV} \cdot F_S \cdot \exp\left(B \cdot \left[-\frac{3}{2} + z_g \cdot (GC2 + GC3 \cdot z_g)\right]\right)$$

$$if\ x_g > 0 \quad \begin{cases} u_0 = CHIB/[B \cdot (GC2 + 2 \cdot GC3 \cdot z_g)] \\ x = \Delta\psi/(2 \cdot u_0) \\ b = u_0/H \\ B_b = b \cdot (1 - b)/2 \\ A_g = 1/2 - 3 \cdot B_g \\ p_{gc} = (1 - b) \cdot \frac{\sinh(x)}{x} + b \cdot \cosh(x) \\ p_{gd} = \frac{p_{gc}}{2} - B_g \cdot \sinh(x) - A_g \cdot \frac{\sinh(x)}{x} \cdot \left[\cot h(x) - \frac{1}{x}\right] \end{cases}$$

$$if\ x_g \leq 0 \qquad \begin{cases} p_{gc} = 1 \\ p_{gd} = 1/2 \end{cases}$$

M $$S_g = \frac{1}{2} \cdot \left(1 + \frac{x_g}{\sqrt{x^2 + 10^{-6}}}\right)$$

$$I_{GC} = I_{GCO} \cdot p_{gc} \cdot S_g$$

$$I_{GCD} = I_{GCO} \cdot p_{gd} \cdot S_g$$

$$I_{GSD} = I_{GC} - I_{GCD}$$

— $$I_{GB} = I_{GCO} \cdot p_{gc} \cdot (1 - S_g)$$

Gate-Induced Drain/Source Leakage Current

The equations in this section are calculated when SWGIDL = 1.

$$I_{gixl(V_{ov}, V)} = \begin{cases} V_{tov} = \sqrt{V_{ov}^2 + CGIDL^2 \cdot V^2 + 10^{-6}} \\ t = V \cdot V_{tov} \cdot V_{ov} \\ I_{gixl} = \begin{cases} -A_{GIDL} \cdot t \cdot \exp\left(-\frac{B_{GIDL}}{V_{tov}}\right) & for\ V_{ov} > 0 \\ 0 & for\ V_{ov} \geq 0 \end{cases} \end{cases}$$

$$I_{gisl} = I_{gixl}(V_{ov0}, V_{SB})$$

$$I_{gidl} = I_{gixl}(V_{ovl}, V_{DS} + V_{SB})$$

Total Terminal Currents

$$I_D = I_{DS} + I_{avl} - I_{GDOV} - I_{GCD} + I_{gidl}$$

$$I_S = -I_{DS} - I_{GSov} - I_{GCS} + I_{gisl}$$

$$I_G = I_{GC} + I_{GB} + I_{GDov} + I_{GSov}$$

$$I_B = -I_{avl} - I_{GB} - I_{gidl} - I_{gisl}$$

Quantum-Mechanical Corrections

$$q_{eff} = \begin{cases} V_{oxm} & for\ x_g \le 0 \\ q_{bm} + \eta_\mu \cdot q_m & for\ x_g > 0 \end{cases}$$

$$C_{OX}^{qm} = \begin{cases} COX & for\ q_q = \\ \dfrac{COX}{1 + q_q/(qeff^2 + qlim^2)^{1/6}} & for\ q_q > 0 \end{cases}$$

Intrinsic Charge Model

$$
\text{if } x_g > 0 \quad \begin{cases} F_1 = \Delta\psi/(2 \cdot H) \\ q\Delta L = (1 - G_{\Delta L}) \cdot (q_{im} - \alpha_{am} \cdot \Delta\psi/2) \\ q^*{}_{\Delta L} = q\Delta L \cdot (1 + G_{\Delta L}) \\ Q_G^{(i)} = C_{OX}^{qm} \cdot \left[V_{oxm} + \dfrac{\eta_p \cdot \Delta\psi}{2} \cdot \left(\dfrac{G_{\Delta L}}{3} \cdot F_j + G_{\Delta L} - 1\right)\right] \\ Q_I^{(i)} = -C_{OX}^{qm} \cdot \left[G_{\Delta L} \cdot \left(q_{im} + \dfrac{\alpha \cdot \Delta\psi}{6} \cdot F_j\right) + q\Delta L\right] \\ Q_D^{(i)} = \dfrac{C_{OX}^{qm}}{2} \cdot \left[G_{\Delta L}^2 \cdot \left(q_{im} + \dfrac{\alpha \cdot \Delta\psi}{6} \cdot \left[\dfrac{F_j^2}{5} + F_j - 1\right]\right) + q^*{}_{\Delta L}\right] \end{cases}
$$

$$
\text{if } x_g \le 0 \quad \begin{cases} Q_G^{(i)} = C_{OX}^{qm} \cdot V_{oxm} \\ Q_I^{(i)} = 0 \\ Q_D^{(i)} = 0 \end{cases}
$$

$$
Q_S^{(i)} = Q_I^{(i)} - Q_D^{(i)}
$$

$$
Q_B^{(i)} = Q_I^{(i)} - Q_G^{(i)}
$$

Extrinsic Charge Model

The charges of the source and drain overlap regions

$$
Q_{sov} = CGOV \cdot (V_{GS} - \psi_{sov})
$$

$$
Q_{dov} = CGOV \cdot (V_{GS} - V_{DS} - \psi_{dov})
$$

The charge of the bulk overlap region

$$
Q_{bov} = CGBOV \cdot (V_{GS} - V_{SB})
$$

Inner fringe charge correction

$$\Delta Q_S = IFK \cdot (1 + IFC \cdot V^*{}_{SB}) \cdot \sqrt{MAXA(IFVBI + V^*{}_{SB} - \psi_{ss}, 0, 10^{-3})}$$

$$\Delta Q_D = IFK \cdot (1 + IFC \cdot V^*{}_{DB}) \cdot \sqrt{MAXA(IFVBI + V^*{}_{DB} - \psi_{sd}, 0, 10^{-3})}$$

$$\Delta Q_G = -\Delta Q_S - \Delta Q_D$$

Outer fringe charge

$$Q_{ofs} = CFR \cdot V_{GS}$$

$$Q_{ofd} = CFR \cdot (V_{GS} - V_{DS})$$

Total Terminal Charges

$$Q_G = Q_G^{(i)} + Q_{sov} + Q_{dov} + \Delta Q_G + Q_{ofs} + Q_{ofd} + Q_{bov}$$

$$Q_s = Q_S^{(i)} - Q_{sov} + \Delta Q_S - Q_{ofs}$$

$$Q_D = Q_D^{(i)} - Q_{dov} + \Delta Q_D - Q_{ofd}$$

$$Q_B = Q_B^{(i)} - Q_{bov}$$

Noise Model

The equations in this section are only calculated for $x_g > 0$. In these equations f_{op} represents the operation frequency of the transistor and $j = -1^{1/2}$.

$$N^* = \frac{C_{ox}}{q} \cdot \alpha_m \cdot \phi_T$$

$$N^*_m = \frac{C_{ox}}{q} \cdot q^*_m$$

$$\Delta N = \frac{C_{ox}}{q} \cdot \alpha_m \cdot \Delta\psi$$

$$S_{fl} = \frac{q \cdot \phi_T^2 \cdot \beta \cdot I_{DS}}{f_{op} \cdot C_{ox} \cdot G_{vsat} \cdot N^*} \cdot \left[(NFA - NFB \cdot N^* + NFC \cdot N^{*2}) \cdot \ln\left(\frac{N^*_m + \Delta N/2}{N^*_m - \Delta N/2}\right) + (NFB + NFC \cdot N^*_m - 2 \cdot N^*) \cdot \Delta N\right]$$

$$H_0 = \frac{q^*_{im}}{\alpha_m}$$

$$t_1 = \frac{q_{im}}{q^*_{im}}$$

$$t_2 = \left(\frac{\Delta\psi}{2 \cdot H_0}\right)^2$$

$$R = \frac{H_0}{H} - 1$$

$$l_c = 1 - 12 \cdot t_2 \cdot R$$

$$g_{ideal} = \frac{\beta \cdot q^*_{im}}{G_{vsat}} \cdot F_{\Delta L}$$

$$C_{Geff} = \left(\frac{G_{vsat}}{G_{mob} \cdot G_{\Delta L}}\right)^2 \cdot COX \cdot \eta_p$$

$$m_{id} = \frac{g_{ideal}}{l_c^2} \cdot [t_1 + 12 \cdot t_2 - 24 \cdot (1 + t_1) \cdot t_2 \cdot R]$$

$$S_{th} = N_T \cdot m_{id}$$

$$m_{ig} = \frac{1}{l_c^2 \cdot g_{ideal}} \cdot \left[\frac{t_1}{12} - t_2 \cdot \left(t_1 + \frac{1}{5} - 12 \cdot t_2\right) - \frac{8}{5} \cdot t_2 \cdot (t_1 + 1 - 12 \cdot t_2) \cdot R\right]$$

$$S_{ig} = N_T \cdot \frac{(2 \cdot \pi \cdot f_{op} \cdot C_{Geff})^2 \cdot m_{ig}}{1 + (2 \cdot \pi \cdot f_{op} \cdot C_{Geff} \cdot m_{ig})^2}$$

$$m_{igid} = \frac{\sqrt{t_2}}{l_c^2} \cdot \left[1 - 12 \cdot t_2 - \left(t_1 + \frac{96}{5} \cdot t_2 - 12 \cdot t_1 \cdot t_2\right) \cdot R\right]$$

$$S_{igth} = N_T \cdot \frac{2 \cdot \pi \cdot j \cdot f_{op} \cdot C_{Geff} \cdot m_{igid}}{1 + 2 \cdot \pi \cdot j \cdot f_{op} \cdot C_{Geff} \cdot m_{ig}}$$

Gate Current Shot Noise

$$S_{hotgs} = 2 \cdot q \cdot I_{js}$$

$$S_{hotgd} = 2 \cdot q \cdot (I_{GCD} + I_{GDov})$$

Avalanche Current Shot Noise

$$S_{jnoise} = 2 \cdot q \cdot (1 + M_{avl}) \cdot I_{avl}$$

$$D_{jnoise} = 2 \cdot q \cdot (1 + M_{avl}) \cdot I_{avl} + I_{jd}$$

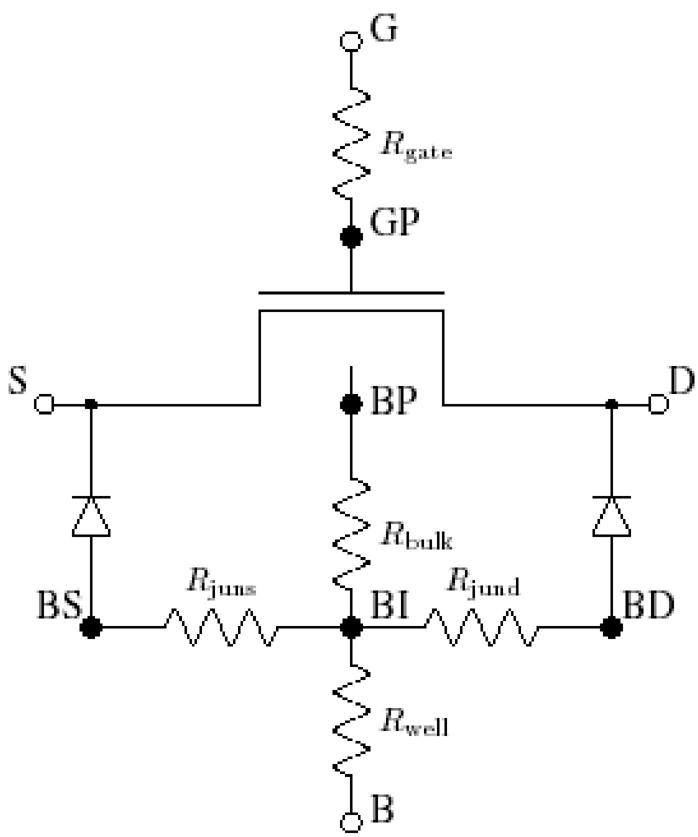
Non-Quasi-Static (NQS) RF Model

For high-frequency modeling and fast transient simulations, a special version of the PSP model is available, which enables the simulation of non-quasi-static (NQS) effects, and includes several parasitic resistances.

$$\begin{cases} \dfrac{dQ_1}{dt} = f_1(Q1, \ldots, Q_N) \\ \dfrac{dQ_N}{dt} = f_N(Q1, \ldots, Q_N) \end{cases}$$

Q_i is the charge density at the i-th collocation point and f_i are functions, which contain the complete PSP-charge model.

Parasitics Circuit



$$S_{R_G} = 4 \cdot k_B \cdot T_{KD} \cdot R_{gate}$$

$$S_{R_{BULK}} = 4 \cdot k_B \cdot T_{KD} \cdot R_{bulk}$$

$$S_{R_{WELL}} = 4 \cdot k_B \cdot T_{KD} \cdot R_{well}$$

$$S_{R_{JUNS}} = 4 \cdot k_B \cdot T_{KD} \cdot R_{juns}$$

$$S_{R_{JUND}} = 4 \cdot k_B \cdot T_{KD} \cdot R_{jund}$$

Additional NQS and RF Parameters

The PSP-NQS model has a few additional parameters, which are described in the tables below. The allowed values for the parameter SWNQS are 0, 1, 2, 3, 5, and 9. If $SWNQS = 0$, then NQS effects are switched off, i.e. the intrinsic MOS model is identical to the standard PSP-model (however, the parasitics-circuit is still in place). If SWNQS is nonzero, it indicates the number of collocation points to be used in the NQS-calculations. A higher value increases the accuracy, but leads to an increased computational burden.

Additional Parameters for Global NQS Model

Name	Unit	Default	Min	Max	Description
SWNQS	–	0	0	9	Switch for NQS effects / number of collocation points
MUNQSO	–	1	–	–	Relative mobility for NQS modeling
RGO	–	10^{-3}	–	–	Gate resistance R_{gate}
RBULKO	–	10^{-3}	–	–	Bulk resistance R_{bulk}
RWELLO	–	10^{-3}	–	–	Well resistance R_{well}
RJUNSO	–	10^{-3}	–	–	Source-side bulk resistance R_{juns}
RJUNDO	–	10^{-3}	–	–	Drain-side bulk resistance R_{jund}

Geometrical Scaling Rules

Although the parasitic resistances are (in general) dependent on geometry, the actual form of this dependency is be strongly influenced by the device layout. For this reason, L and W dependence of these resistances is currently not included in PSP; the correct values must be supplied manually for each geometry.

The following (trivial) scaling-rules are included for the NQS-model.

$$MUNQS = MUNQSO$$

$$RG = RGO$$

$$RBULK = RBULKO$$

$$RWELL = RWELLO$$

$RJUNS = RJUNSO$

$RJUND = RJUNDO$

Equations

In this section, y denotes the (normalized) position along the channel ($y = 0$ is source side, $y = 1$ is drain side), while x denotes the surface potential (normalized to ϕ*T) at a certain position.

In PSP 101.0 and before, only SWNQS=0,1,2,3,5,9 are allowed.

$n = SWNQS + 1$

$h = 1/n$

Initial Values

$$A_{i,j} = 0 \qquad for 0 \le i, j \le n$$

$$v_i = 0 \qquad for 0 \le i \le n$$

First Loop

$$\left.\begin{array}{l} p = 2 + v_{i-1}/2 \\ v_i = -1/(2 \cdot p) \\ A_{i,i-1} = 1/h \\ A_{i,i} = -2/h \\ A_{i,i+1} = 1/h \\ \left. A_{i,j} = \frac{1}{p} \cdot (3 \cdot A_{i,j}/h - A_{i-1,j}/2) \right\} for j = 0 \ldots n \end{array}\right\} for i = 1 \ldots (n-1)$$

Second Loop (Back Substitution)

$$A_{i,j} = v_i \cdot A_{i+1,j} + A_{i,j} \qquad for\ j = 0 \ldots n \} \qquad for\ i = (n-1) \ldots 0$$

Position Independent Quantities

$$If\ x_g > 0 \begin{cases} y_m = \frac{1}{2} \cdot \left(1 + \frac{\Delta\psi}{4 \cdot H}\right) \\ p_d = \frac{x_{gm}}{x_g - x_m} \\ G_P = G / p_d \end{cases}$$

$$If\ x_g \le 0 \begin{cases} y_m = \frac{1}{2} \\ p_d = 1 \\ G_P = G / p_d \end{cases}$$

$$a_p = 1 + G_p / \sqrt{2}$$

$$p_{mrg} = 10^{-5} \cdot a_p$$

Position Dependent Surface Potential and Charge

Interpolated (quasi-static) surface potential along the channel:

$$\psi(y) = x_m + \frac{H}{\phi_T^*} \cdot \left(1 - \sqrt{1 - \frac{2 \cdot \Delta\psi}{H} \cdot (y - y_m)}\right)$$

Normalized bulk-charge and its first two derivatives as functions of surface potential:

$$q_b(x) = -\mathrm{sgn}(x) \cdot G_p \cdot \sqrt{\exp(-x) + x - 1}$$

$$q'_b(x) = \frac{G_P^2 \cdot [1 - \exp(-x)]}{2 \cdot q_b(x)}$$

$$q''_b(x) = q'_b(x) - \frac{q'_b(x)^2 - G_P^2/2}{qb(x)}$$

$$
II_{(x_g)} = \begin{cases}
\text{if } x_g < -p_{mrg} & \begin{cases}
y_g = -x_g \\
z = 1.25 \cdot y_g / a_p \\
\eta = \left[z + 10 - \sqrt{(z-6)^2 + 64}\right]/2 \\
a = (y_g - \eta)^2 + G_P^2 \cdot (\eta + 1) \\
c = 2 \cdot (y_g - \eta) - G_P^2 \\
r = -\eta + \ln(a/G_P^2) \\
y_0 = \sigma_1(a, c, \tau, \eta) \\
\Delta_0 = \exp(y_0) \\
\xi = 1 - G_P^2 \cdot \Delta_0/2 \\
p = 2 \cdot (y_g - y_0) + G_P^2 \cdot (\Delta_0 - 1) \\
q = (y_g - y_0)^2 + G_P^2 \cdot (y_0 - \Delta_0 + 1) \\
II = -y_0 - \dfrac{2 \cdot q}{p + \sqrt{p^2 - 4 \cdot q \cdot \xi}}
\end{cases} \\
\text{if } |x_g| \le -p_{mrg} & \begin{cases} II = \dfrac{x_g}{a_p} \end{cases} \\
\text{if } x_g > x_{mrg} & \begin{cases}
\hat{x}_{g1} = x_1 + G \cdot \sqrt{\exp(-x_1) + x_1 - 1} \\
\bar{x} = \dfrac{x_g}{a_p} \cdot [1 + x_g \cdot (x_g + a_P/\hat{x}_{g1} - 1)/\hat{x}_{g1}] \\
x_0 = x_g + G_P^2/2 - G_P \cdot \sqrt{x_g + G_P^2/4 - 1 + \exp(-\bar{x})} \\
\Delta_0 = \exp(-x_0) \\
\xi = 1 - G_P^2 \cdot \Delta_0/2 \\
p = 2 \cdot (x_g - x_0) + G_P^2 \cdot (1 - \Delta_0) \\
q = (x_g - x_0)^2 - G_P^2 \cdot (x_0 + \Delta_0 - 1) \\
II = x_0 + \dfrac{2 \cdot q}{p + \sqrt{p^2 - 4 \cdot q \cdot \xi}}
\end{cases}
\end{cases}
$$

$$
X(x_g, q_{inv}) = II(x_g + q_{inv}/p_d)
$$

Auxiliary Functions

$$q(x) = -p_d \cdot (x_g - x) - q_b(x)$$

$$\psi(q, q_{x1}) = \frac{q}{q_{x1}} - 1$$

$$\phi(q, q_{x1}, q_{x2}) = \left(1 - \frac{q \cdot q_{x2}}{q_{x1}^2}\right) / q_{x1}$$

Normalized right-hand-side of continuity equation

$$f(x_g, q, q', q'') = \begin{cases} x_z = X(x_g, q) \\ q_{x1} = \frac{\partial q}{\partial x}(x_z) = p_d - q'_b(x_z) \\ q_{x2} = \frac{\partial^2 q}{\partial x^2}(x_z) = q''_b(x_z) \\ f_0 = \psi(q, q_{z1}) \cdot q'' + \phi(q, q_{z1}, q_{z2}) \cdot q'^2 \\ x_{y1} = \frac{\partial x_z}{\partial y} = (q')/q_{x1} \\ z_{sat} = \begin{cases} (\theta^*_{sat} \cdot \phi^*_T \cdot x_{y1})^2 \\ \frac{(\theta^*_{sat} \cdot \phi^*_T \cdot x_{y1})^2}{1 + \theta^*_{sat} \cdot \Delta\psi} \end{cases} \\ \varsigma = \sqrt{1 + 2 \cdot z_{sat}} \\ F_{vsat} = 2/(1 + \varsigma) \\ f = F_{vsat} \cdot \left[f_0 - F_{vsat} \cdot \frac{z_{sat}}{\varsigma} \cdot \psi(q, q_{x1}) \cdot (q'' + x_{y1}^2 \cdot q''_b(x_z))\right] \end{cases}$$

$$T_{norm} = \frac{MUNQS \cdot \phi^*_T \cdot \beta}{C_{OX}^{qm} \cdot G_{mob} \cdot G_{\Delta L}}$$

Cubic Spline Interpolation

$$q''_0 = 0$$

$$q''_n = 0$$

$$q''_i = \sum_{j=0}^{n} A_{i,j} \cdot q_i \qquad for\ 1 \le i \le n-1$$

$$q'_i = \frac{q_{i+1} - q_i}{h} - \frac{h}{6} \cdot (2 \cdot q''_i \cdot q''_{i+1}) \qquad for\ 1 \le i \le n-1$$

Continuity Equation

$$x_{i,0} = \psi(i \cdot h)$$

$$q_{i,0} = q(x_{i,0})$$

Note that $x_{0,0}$=x_s and $x_{n,0}$=x_d. Also, these values coincide with those in the quasi-static part of PSP.

The core of the NQS-model is the solution of q(y, t) from the charge continuity equation along the channel. By approximating the y-dependence by a cubic spline through a number of collocation points, the problem is reduced to solving the q_i(t) from the following set of coupled differential equations.

$$\begin{cases} \frac{\partial_{qi}}{\partial t}(t) + T_{norm} \cdot f\left(x_g, q_i(t), \frac{\partial_{qi}}{\partial y}(t), \frac{\partial^2 qi}{\partial y^2}(t)\right) = 0 \\ q_i(0) = q_{i,0} \end{cases} \qquad for\ 1 \le i \le n$$

Note that the boundary points q_0(t) = q(x_s) = q_{is} and q_n(t) = q(x_d) = q_{id} remain fixed to their quasi-static values; they are not solved from the equation above.

Non-Quasi-State Terminal Charges

$$S_0 = \sum_{i=1}^{n-1} q_i$$

$$S_2 = \sum_{i=1}^{n-1} q''_i$$

$$q_I^{NQS} = \int_0^1 q(y)dy = h \cdot S_0 + \frac{h}{2} \cdot (u_0 + u_n) - \frac{h^3}{12} \cdot S_2$$

$$U_0 = \sum_{i=1}^{n-1} i \cdot q_i$$

$$U_2 = \sum_{i=1}^{n-1} i \cdot q''_i$$

$$q_D^{NQS} = \int_0^1 q(y)dy = h^2 \cdot U_0 + \frac{h^2}{6} \cdot [q_0 + (3n-1)u_n] - \frac{h^4}{12} \cdot U_2$$

$$q_S^{NQS} = q_I^{NQS} - q_D^{NQS}$$

Currently, only SWNQS = 0; 1; 2; 3; 5; 9 are allowed. For odd values of SWNQS, the gate charge is integrated along the channel using Simpson's rule. If SWNQS = 2, Simpson's 3=8-rule is used.

- If SWNQS is odd (that is, n is even),

$$q_G^{NQS} = pd \cdot \left[x_g - \frac{h}{3} \cdot \left(X(x_g, q_0) + 4 \cdot \sum_{i=1}^{n/2} X(x_g, q2i-1) + 2 \cdot \sum_{i=1}^{n/2-1} X(x_g, q2i) + X(x_g, q_n)\right)\right]$$

- If SWNQS =2 (that is, n=3),

$$q_G^{NQS} = pd \cdot \left[x_g - \frac{3 \cdot h}{8} \cdot (X(x_{g,\,q0}) + 3 \cdot X(x_{g,\,q1}) + 3 \cdot X(x_{g,\,q2}) + X(x_{g,\,q3}))\right]$$

Converting back to conventional units:

$$Q_S^{NQS} = C_{OX}^{qm} \cdot \phi_T^* \cdot q_S^{NQS}$$

$$Q_D^{NQS} = C_{OX}^{qm} \cdot \phi_T^* \cdot q_D^{NQS}$$

$$Q_G^{NQS} = C_{OX}^{qm} \cdot \phi_T^* \cdot q_G^{NQS}$$

$$Q_B^{NQS} = -(Q_S^{NQS} + Q_D^{NQS} + Q_G^{NQS})$$

Component Statements

PSP MOSFET Model (psp102)

This is SiMKit 3.1.2

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0/libphilips_sh.so

Instance Definition

```
InstanceName (d g s b) PSP102ModelName <parameter=value> ...
```

Instance Parameters

1	`l=10e-6 m`	Design length.
2	`w=10e-6 m`	Design width.
3	`sa=0.0 m`	Distance between OD-edge and poly from one side.
4	`sb=0.0 m`	Distance between OD-edge and poly from other side.
5	`sd=0.0 m`	Distance between neighboring fingers.

6 `sca=0.0`	Integral of the first distribution function for scattered well dopants.
7 `scb=0.0`	Integral of the second distribution function for scattered well dopants.
8 `scc=0.0`	Integral of the third distribution function for scattered well dopants.
9 `sc=0.0 m`	Distance between OD-edge and nearest well edge.
10 `delvto=0.0 V`	Threshold voltage shift parameter.
11 `factuo=1.0`	Zero-field mobility pre-factor.
12 `absource=1E-12` m^2	Bottom area of source junction.
13 `lssource=1E-6 m`	STI-edge length of source junction.
14 `lgsource=1E-6 m`	Gate-edge length of source junction.
15 `abdrain=1E-12` m^2	Bottom area of drain junction.
16 `lsdrain=1E-6 m`	STI-edge length of drain junction.
17 `lgdrain=1E-6 m`	Gate-edge length of drain junction.
18 `as=1E-12` m^2	Bottom area of source junction.
19 `ps=1E-6 m`	Perimeter of source junction.
20 `ad=1E-12` m^2	Bottom area of drain junction.
21 `pd=1E-6 m`	Perimeter of drain junction.
22 `mulid0=1`	Ids multiplier.
23 `jw=1E-6 m`	Gate-edge length of source/drain junction.
24 `mult=1.0`	Number of devices in parallel.
25 `nf=1.0`	Number of fingers.

26 `ngcon=1.0` Number of gate contacts.

27 `xgw=1.0E-7 m` Distance from the gate contact to the channel edge.

28 `region=triode` Estimated operating region. %Z outputs the number (0-4) in a rawfile.
Possible values are `off`, `triode`, `sat`, `subth`, and `breakdown`.

29 `trise=0.0 K` Temperature rise from ambient.

30 `m=1.0` Multiplicity factor.

31 `isnoisy=yes` Should device generate noise.
Possible values are `no` and `yes`.

Model Definition

model modelName psp102 parameter=value ...

Model Parameters

1 `level=102` Model level.

2 `type=n` Channel type parameter, n,NMOS p,PMOS.
Possible values are `n` and `p`.

3 `tr=value of tnom C`
nominal (reference) temperature.

4 `swnqs=0` Flag for NQS, 0,off, 1, 2, 3, 5, or 9,number of collocation points.

5 `swigate=0` Flag for gate current, 0,turn off IG.

6 `swimpact=0` Flag for impact ionization current, 0,turn off II.

7 `swgidl=0` Flag for GIDL current, 0,turn off IGIDL.

8 `swjuncap=0` Flag for juncap, 0,turn off juncap.

9 `swjunasym=0` Flag for asymmetric junctions; 0,symmetric, 1,asymmetric.

10 `qmc=1.0` Quantum-mechanical correction factor.

11	`version=102.32`	The available versions are 102.2, 102.21, 102.3, 102.32, 102.33, 102.34 and 102.40.
12	`geomod=1`	1 for geometrical model and 0 for electrical model.
13	`binmod=0`	1 for bin model and 0 for non-bin model.
14	`scalelev=102`	102 for local, 1020 for global model and 1021 for bin model.
15	`compatible=spectre`	for compatible. Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, and `mica`.
16	`vfb=(-1.0) V`	Flatband voltage at TR.
17	`stvfb=5.0e-4 V/K`	Temperature dependence of VFB.
18	`tox=2.0e-09 m`	Gate oxide thickness.
19	`epsrox=3.9`	Relative permittivity of gate dielectric.
20	`neff=5.0e+23` m^{-3}	Effective substrate doping.
21	`vnsub=0.0 V`	Effective doping bias-dependence parameter.
22	`nslp=0.05 V`	Effective doping bias-dependence parameter.
23	`dnsub=0.0 V^-1`	Effective doping bias-dependence parameter.
24	`dphib=0.0 V`	Offset parameter for PHIB.
25	`np=1.0e+26` m^{-3}	Gate poly-silicon doping.
26	`ct=0.0`	Interface states factor.
27	`toxov=2.0e-09 m`	Overlap oxide thickness.
28	`toxovd=2.0e-09 m`	Overlap oxide thickness for drain side.
29	`nov=5.0e+25` m^{-3}	Effective doping of overlap region.
30	`novd=5.0e+25` m^{-3}	Effective doping of overlap region for drain side.

31 `cf=0.0`	DIBL-parameter.
32 `cfb=0.0 V^-1`	Back bias dependence of CF.
33 `betn=7e-2` m^2`/V/s`	Channel aspect ratio times zero-field mobility.
34 `stbet=1.0`	Temperature dependence of BETN.
35 `mue=0.5 m/V`	Mobility reduction coefficient at TR.
36 `stmue=0.0`	Temperature dependence of MUE.
37 `themu=1.5`	Mobility reduction exponent at TR.
38 `stthemu=1.5`	Temperature dependence of THEMU.
39 `cs=0.0`	Coulomb scattering parameter at TR.
40 `stcs=0.0`	Temperature dependence of CS.
41 `xcor=0.0 V^-1`	Non-universality factor.
42 `stxcor=0.0`	Temperature dependence of XCOR.
43 `feta=1.0`	Effective field parameter.
44 `rs=30 Ω`	Series resistance at TR.
45 `strs=1.0`	Temperature dependence of RS.
46 `rsb=0.0 V^-1`	Back-bias dependence of series resistance.
47 `rsg=0.0 V^-1`	Gate-bias dependence of series resistance.
48 `thesat=1.0 V^-1`	Velocity saturation parameter at TR.
49 `stthesat=1.0`	Temperature dependence of THESAT.
50 `thesatb=0.0 V^-1`	Back-bias dependence of velocity saturation.
51 `thesatg=0.0 V^-1`	Gate-bias dependence of velocity saturation.
52 `ax=3.0`	Linear/saturation transition factor.

53 `alp=0.01` CLM pre-factor.

54 `alp1=0.00 V` CLM enhancement factor above threshold.

55 `alp2=0.00 V^-1` CLM enhancement factor below threshold.

56 `vp=0.05 V` CLM logarithm dependence factor.

57 `a1=1.0` Impact-ionization pre-factor.

58 `a2=10.0 V` Impact-ionization exponent at TR.

59 `sta2=0.0 V` Temperature dependence of A2.

60 `a3=1.0` Saturation-voltage dependence of impact-ionization.

61 `a4=0.0 V^-0.5` Back-bias dependence of impact-ionization.

62 `gco=0.0` Gate tunnelling energy adjustment.

63 `iginv=0.0 A` Gate channel current pre-factor.

64 `igov=0.0 A` Gate overlap current pre-factor.

65 `igovd=0.0 A` Gate overlap current pre-factor for drain side.

66 `stig=2.0` Temperature dependence of IGINV and IGOV.

67 `gc2=0.375` Gate current slope factor.

68 `gc3=0.063` Gate current curvature factor.

69 `chib=3.1 V` Tunnelling barrier height.

70 `agidl=0.0` A/V^3 GIDL pre-factor.

71 `agidld=0.0` A/V^3 GIDL pre-factor for drain side.

72 `bgidl=41.0 V` GIDL probability factor at TR.

73 `bgidld=41.0 V` GIDL probability factor at TR for drain side.

74 `stbgidl=0.0 V/K` Temperature dependence of BGIDL.

75 `stbgidld=0.0 V/K` Temperature dependence of BGIDL for drain side.

76 `cgidl=0.0` Back-bias dependence of GIDL.

77 `cgidld=0.0` Back-bias dependence of GIDL for drain side.

78 `cox=1.0e-14 F` Oxide capacitance for intrinsic channel.

79 `cgov=1.0e-15 F` Oxide capacitance for gate-drain/source overlap.

80 `cgovd=1.0e-15 F` Oxide capacitance for gate-drain overlap.

81 `cgbov=0.0 F` Oxide capacitance for gate-bulk overlap.

82 `cfr=0.0 F` Outer fringe capacitance.

83 `cfrd=0.0 F` Outer fringe capacitance for drain side.

84 `fnt=1.0` Thermal noise coefficient.

85 `nfa=8.0e+22 V^-1/m`^{4}
First coefficient of flicker noise.

86 `nfb=3.0e+07 V^-1/m`^{2}
Second coefficient of flicker noise.

87 `nfc=0.0 V^-1` Third coefficient of flicker noise.

88 `ef=1.0` Flicker noise frequency exponent.

89 `munqs=1.0` Relative mobility for NQS modeling.

90 `rg=0.0 Ω` Gate resistance.

91 `rbulk=0.0 Ω` Bulk resistance between node BP and BI.

92 `rwell=0.0 Ω` Well resistance between node BI and B.

93 `rjuns=0.0 Ω` Source-side bulk resistance between node BI and BS.

94 `rjund=0.0 Ω` Drain-side bulk resistance between node BI and BD.

95 `lvaro=0.0 m`	Geom. independent difference between actual and programmed gate length.
96 `lvarl=0.0`	Length dependence of LVAR.
97 `lvarw=0.0`	Width dependence of LVAR.
98 `lap=0.0 m`	Effective channel length reduction per side.
99 `wvaro=0.0 m`	Geom. independent difference between actual and programmed field-oxide opening.
100 `wvarl=0.0`	Length dependence of WVAR.
101 `wvarw=0.0`	Width dependence of WVAR.
102 `wot=0.0 m`	Effective channel width reduction per side.
103 `dlq=0.0 m`	Effective channel length reduction for CV.
104 `dwq=0.0 m`	Effective channel width reduction for CV.
105 `vfbo=(-1.0) V`	Geometry-independent flat-band voltage at TR.
106 `vfbl=0.0`	Length dependence of flat-band voltage.
107 `vfbw=0.0`	Width dependence of flat-band voltage.
108 `vfblw=0.0`	Area dependence of flat-band voltage.
109 `stvfbo=5e-4 V/K`	Geometry-independent temperature dependence of VFB.
110 `stvfbl=0.0`	Length dependence of temperature dependence of VFB.
111 `stvfbw=0.0`	Width dependence of temperature dependence of VFB.
112 `stvfblw=0.0`	Area dependence of temperature dependence of VFB.
113 `toxo=2e-9 m`	Gate oxide thickness.
114 `epsroxo=3.9`	Relative permittivity of gate dielectric.
115 `nsubo=3e23` m^{-3}	Geometry independent substrate doping.

116 `nsubw=0.0`	Width dependence of background doping NSUBO due to segregation.
117 `wseg=1e-8 m`	Char. length of segregation of background doping NSUBO.
118 `npck=1e24 m`$^{-3}$	Pocket doping level.
119 `npckw=0.0`	Width dependence of pocket doping NPCK due to segregation.
120 `wsegp=1e-8 m`	Char. length of segregation of pocket doping NPCK.
121 `lpck=1e-8 m`	Char. length of lateral doping profile.
122 `lpckw=0.0`	Width dependence of char. length of lateral doping profile.
123 `fol1=0.0`	First length dependence coefficient for short channel body effect.
124 `fol2=0.0`	Second length dependence coefficient for short channel body effect.
125 `vnsubo=0.0 V`	Effective doping bias-dependence parameter.
126 `nslpo=0.05 V`	Effective doping bias-dependence parameter.
127 `dnsubo=0.0 V^-1`	Effective doping bias-dependence parameter.
128 `dphibo=0.0 V`	Geometry independent offset of PHIB.
129 `dphibl=0.0 V`	Length dependence offset of PHIB.
130 `dphiblexp=1.0`	Exponent for length dependence of offset of PHIB.
131 `dphibw=0.0`	Width dependence of offset of PHIB.
132 `dphiblw=0.0`	Area dependence of offset of PHIB.
133 `npo=1e26 m`$^{-3}$	Geometry-independent gate poly-silicon doping.
134 `npl=0.0`	Length dependence of gate poly-silicon doping.
135 `cto=0.0`	Geometry-independent interface states factor.
136 `ctl=0.0`	Length dependence of interface states factor.

137 `ctlexp=1.0`	Exponent for length dependence of interface states factor.
138 `ctw=0.0`	Width dependence of interface states factor.
139 `ctlw=0.0`	Area dependence of interface states factor.
140 `toxovo=2e-9 m`	Overlap oxide thickness.
141 `toxovdo=2e-9 m`	Overlap oxide thickness for drain side.
142 `lov=0 m`	Overlap length for gate/drain and gate/source overlap capacitance.
143 `lovd=0 m`	Overlap length for gate/drain overlap capacitance.
144 novo=5e25 m^{-3}	Effective doping of overlap region.
145 novdo=5e25 m^{-3}	Effective doping of overlap region for drain side.
146 `cfl=0.0`	Length dependence of DIBL-parameter.
147 `cflexp=2.0`	Exponent for length dependence of CF.
148 `cfw=0.0`	Width dependence of CF.
149 `cfbo=0.0 V^-1`	Back-bias dependence of CF.
150 uo=5e-2 m^2/V/s	Zero-field mobility at TR.
151 `fbet1=0.0`	Relative mobility decrease due to first lateral profile.
152 `fbet1w=0.0`	Width dependence of relative mobility decrease due to first lateral profile.
153 `lp1=1e-8 m`	Mobility-related characteristic length of first lateral profile.
154 `lp1w=0.0`	Width dependence of mobility-related characteristic length of first lateral profile.
155 `fbet2=0.0`	Relative mobility decrease due to second lateral profile.
156 `lp2=1e-8 m`	Mobility-related characteristic length of second lateral profile.

157 `betw1=0.0`	First higher-order width scaling coefficient of BETN.
158 `betw2=0.0`	Second higher-order width scaling coefficient of BETN.
159 `wbet=1e-9 m`	Characteristic width for width scaling of BETN.
160 `stbeto=1.0`	Geometry independent temperature dependence of BETN.
161 `stbetl=0.0`	Length dependence of temperature dependence of BETN.
162 `stbetw=0.0`	Width dependence of temperature dependence of BETN.
163 `stbetlw=0.0`	Area dependence of temperature dependence of BETN.
164 `mueo=0.5 m/V`	Geometry independent mobility reduction coefficient at TR.
165 `muew=0.0`	Width dependence of mobility reduction coefficient at TR.
166 `stmueo=0.0`	Temperature dependence of MUE.
167 `themuo=1.5`	Mobility reduction exponent at TR.
168 `stthemuo=1.5`	Temperature dependence of THEMU.
169 `cso=0.0`	Geometry independent coulomb scattering parameter at TR.
170 `csl=0.0`	Length dependence of CS.
171 `cslexp=0.0`	Exponent for length dependence of CS.
172 `csw=0.0`	Width dependence of CS.
173 `cslw=0.0`	Area dependence of CS.
174 `stcso=0.0`	Temperature dependence of CS.
175 `xcoro=0.0 V^-1`	Geometry independent non-universality parameter.
176 `xcorl=0.0`	Length dependence of non-universality parameter.
177 `xcorw=0.0`	Width dependence of non-universality parameter.
178 `xcorlw=0.0`	Area dependence of non-universality parameter.

179 `stxcoro=0.0`	Temperature dependence of XCOR.
180 `fetao=1.0`	Effective field parameter.
181 `rsw1=2.5e3` Ω	Source/drain series resistance for 1 um wide channel at TR.
182 `rsw2=0.0`	Higher-order width scaling of RS.
183 `strso=1.0`	Temperature dependence of RS.
184 `rsbo=0.0 V^-1`	Back-bias dependence of series resistance.
185 `rsgo=0.0 V^-1`	Gate-bias dependence of series resistance.
186 `thesato=0.0 V^-1`	Geometry independent velocity saturation parameter at TR.
187 `thesatl=0.05 V^-1`	Length dependence of THESAT.
188 `thesatlexp=1.0`	Exponent for length dependence of THESAT.
189 `thesatw=0.0`	Width dependence of velocity saturation parameter.
190 `thesatlw=0.0`	Area dependence of velocity saturation parameter.
191 `stthesato=1.0`	Geometry independent temperature dependence of THESAT.
192 `stthesatl=0.0`	Length dependence of temperature dependence of THESAT.
193 `stthesatw=0.0`	Width dependence of temperature dependence of THESAT.
194 `stthesatlw=0.0`	Area dependence of temperature dependence of THESAT.
195 `thesatbo=0.0 V^-1`	Back-bias dependence of velocity saturation.
196 `thesatgo=0.0 V^-1`	Gate-bias dependence of velocity saturation.
197 `axo=18`	Geometry independent linear/saturation transition factor.
198 `axl=0.4`	Length dependence of AX.
199 `alpl=5e-4`	Length dependence of ALP.
200 `alplexp=1.0`	Exponent for length dependence of ALP.

201 `alpw=0.0`	Width dependence of ALP.
202 `alp1l1=0.0 V`	Length dependence of CLM enhancement factor above threshold.
203 `alp1lexp=0.5`	Exponent for length dependence of ALP1.
204 `alp1l2=0.0`	Second_order length dependence of ALP1.
205 `alp1w=0.0`	Width dependence of ALP1.
206 `alp2l1=0.0 V^-1`	Length dependence of CLM enhancement factor below threshold.
207 `alp2lexp=0.5`	Exponent for length dependence of ALP2.
208 `alp2l2=0.0`	Second_order length dependence of ALP2.
209 `alp2w=0.0`	Width dependence of ALP2.
210 `vpo=0.05 V`	CLM logarithmic dependence parameter.
211 `a1o=1.0`	Geometry independent impact-ionization pre-factor.
212 `a1l=0.0`	Length dependence of A1.
213 `a1w=0.0`	Width dependence of A1.
214 `a2o=10 V`	Impact-ionization exponent at TR.
215 `sta2o=0.0 V`	Temperature dependence of A2.
216 `a3o=1.0`	Geometry independent saturation-voltage dependence of II.
217 `a3l=0.0`	Length dependence of A3.
218 `a3w=0.0`	Width dependence of A3.
219 `a4o=0.0 V^-0.5`	Geometry independent back-bias dependence of II.
220 `a4l=0.0`	Length dependence of A4.
221 `a4w=0.0`	Width dependence of A4.

222 `gcoo=0.0` Gate tunnelling energy adjustment.

223 `iginvlw=0.0 A` Gate channel current pre-factor for 1 um^2 channel area.

224 `igovw=0.0 A` Gate overlap current pre-factor for 1 um wide channel.

225 `igovdw=0.0 A` Gate overlap current pre-factor for 1 um wide channel for drain side.

226 `stigo=2.0` Temperature dependence of IGINV and IGOV.

227 `gc2o=0.375` Gate current slope factor.

228 `gc3o=0.063` Gate current curvature factor.

229 `chibo=3.1 V` Tunnelling barrier height.

230 `agidlw=0.0` A/V^3 Width dependence of GIDL pre-factor.

231 `agidldw=0.0` A/V^3 Width dependence of GIDL pre-factor for drain side.

232 `bgidlo=41 V` GIDL probability factor at TR.

233 `bgidldo=41 V` GIDL probability factor at TR for drain side.

234 `stbgidlo=0.0 V/K` Temperature dependence of BGIDL.

235 `stbgidldo=0.0 V/K` Temperature dependence of BGIDL for drain side.

236 `cgidlo=0.0` Back-bias dependence of GIDL.

237 `cgidldo=0.0` Back-bias dependence of GIDL for drain side.

238 `cgbovl=0.0 F` Oxide capacitance for gate-bulk overlap for 1 um long channel.

239 `cfrw=0.0 F` Outer fringe capacitance for 1 um wide channel.

240 `cfrdw=0.0 F` Outer fringe capacitance for 1 um wide channel for drain side.

241 `fnto=1.0` Thermal noise coefficient.

242 `nfalw=8e22` V^{-1}/m^4

First coefficient of flicker noise for 1 um^2 channel area.

243 `nfblw=3e7 V^-1/m`^{2}	Second coefficient of flicker noise for 1 um^2 channel area.
244 `nfclw=0.0 V^-1`	Third coefficient of flicker noise for 1 um^2 channel area.
245 `efo=1.0`	Flicker noise frequency exponent.
246 `lintnoi=0.0 m`	Length offset for flicker noise.
247 `alpnoi=2.0`	Exponent for length offset for flicker noise.
248 `dta=0 K`	Temperature offset w.r.t. ambient circuit temperature.
249 `kvthoweo=0`	Geometrical independent threshold shift parameter.
250 `kvthowel=0`	Length dependent threshold shift parameter.
251 `kvthowew=0`	Width dependent threshold shift parameter.
252 `kvthowelw=0`	Area dependent threshold shift parameter.
253 `kuoweo=0`	Geometrical independent mobility degradation factor.
254 `kuowel=0`	Length dependent mobility degradation factor.
255 `kuowew=0`	Width dependent mobility degradation factor.
256 `kuowelw=0`	Area dependent mobility degradation factor.
257 `vds_max=∞ V`	Maximum allowed voltage cross source and drain.
258 `vgd_max=∞ V`	Maximum allowed voltage cross gate and drain.
259 `vgs_max=∞ V`	Maximum allowed voltage cross gate and source/bulk.
260 `vbd_max=∞ V`	Maximum allowed voltage cross source/drain and bulk.
261 `vbs_max=∞ V`	Maximum allowed voltage cross source and bulk.

262 `vgb_max=∞ V`
Maximum allowed voltage cross gate and bulk.

263 `vgdr_max=∞ V`
Maximum allowed reverse voltage cross gate and drain.

264 `vgsr_max=∞ V`
Maximum allowed reverse voltage cross gate and source.

265 `vgbr_max=∞ V`
Maximum allowed reverse voltage cross gate and bulk.

266 `munqso=1.0` Relative mobility for NQS modeling.

267 `rgo=0.0 Ω` Gate resistance.

268 `rbulko=0.0 Ω` Bulk resistance between node BP and BI.

269 `rwello=0.0 Ω` Well resistance between node BI and B.

270 `rjunso=0.0 Ω` Source-side bulk resistance between node BI and BS.

271 `rjundo=0.0 Ω` Drain-side bulk resistance between node BI and BD.

272 `rint=0.0 Ω/Sqr` Contact resistance between silicide and ploy.

273 `rvpoly=0.0 Ω/Sqr`
Vertical poly resistance.

274 `rshg=0.0 Ω/Sqr` Gate electrode diffusion sheet resistance.

275 `dlsil=0.0 m` Silicide extension over the physical gate length.

276 `saref=1.0e-6 m` Reference distance between OD-edge and poly from one side.

277 `sbref=1.0e-6 m` Reference distance between OD-edge and poly from other side.

278 `wlod=0 m` Width parameter.

279 `kuo=0 m` Mobility degradation/enhancement coefficient.

280 `kvsat=0 m` Saturation velocity degradation/enhancement coefficient.

281 `tkuo=0` Temperature dependence of KUO.

282 `lkuo=0 m^LLODKUO` Length dependence of KUO.

283 `wkuo=0 m^WLODKUO` Width dependence of KUO.

284 `pkuo=0 m^(LLODKUO+WLODKUO)`
Cross-term dependence of KUO.

285 `llodkuo=0` Length parameter for UO stress effect.

286 `wlodkuo=0` Width parameter for UO stress effect.

287 `kvtho=0 Vm` Threshold shift parameter.

288 `lkvtho=0 m^LLODVTH`
Length dependence of KVTHO.

289 `wkvtho=0 m^WLODVTH`
Width dependence of KVTHO.

290 `pkvtho=0 m^(LLODVTH+WLODVTH)`
Cross-term dependence of KVTHO.

291 `llodvth=0` Length parameter for VTH-stress effect.

292 `wlodvth=0` Width parameter for VTH-stress effect.

293 `stetao=0 m` eta0 shift factor related to VTHO change.

294 `lodetao=1.0` eta0 shift modifaction factor for stress effect.

295 `scref=10e-6 m` Distance between OD-edge and well edge of a reference device.

296 `web=0` Coeffecient for SCB.

297 `wec=0` Coeffecient for SCC.

298 `imax=1000 A` Maximum current up to which forward current behaves exponentially.

299 `trj=21 C` reference temperature.

300 `cjorbot=1E-3 Fm`$^{-2}$
Zero-bias capacitance per unit-of-area of bottom component for source-bulk junction.

301 `cjorsti=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for source-bulk junction.

302 `cjorgat=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for source-bulk junction.

303 `vbirbot=1 V` Built-in voltage at the reference temperature of bottom component for source-bulk junction.

304 `vbirsti=1 V` Built-in voltage at the reference temperature of STI-edge component for source-bulk junction.

305 `vbirgat=1 V` Built-in voltage at the reference temperature of gate-edge component for source-bulk junction.

306 `pbot=0.5` Grading coefficient of bottom component for source-bulk junction.

307 `psti=0.5` Grading coefficient of STI-edge component for source-bulk junction.

308 `pgat=0.5` Grading coefficient of gate-edge component for source-bulk junction.

309 `phigbot=1.16 V` Zero-temperature bandgap voltage of bottom component for source-bulk junction.

310 `phigsti=1.16 V` Zero-temperature bandgap voltage of STI-edge component for source-bulk junction.

311 `phiggat=1.16 V` Zero-temperature bandgap voltage of gate-edge component for source-bulk junction.

312 `idsatrbot=1E-12 Am`$^{-2}$
Saturation current density at the reference temperature of bottom component for source-bulk junction.

313 `idsatrsti=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for source-bulk junction.

314 `idsatrgat=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for source-bulk junction.

315 `csrhbot=1E2 Am`$^{-3}$ Shockley-Read-Hall prefactor of bottom component for source-bulk junction.

316 `csrhsti=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of STI-edge component for source-bulk junction.

317 `csrhgat=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of gate-edge component for source-bulk junction.

318 `xjunsti=100E-9 m` Junction depth of STI-edge component for source-bulk junction.

319 `xjungat=100E-9 m` Junction depth of gate-edge component for source-bulk junction.

320 `ctatbot=1E2 Am`$^{-3}$ Trap-assisted tunneling prefactor of bottom component for source-bulk junction.

321 `ctatsti=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of STI-edge component for source-bulk junction.

322 `ctatgat=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of gate-edge component for source-bulk junction.

323 `mefftatbot=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component for source-bulk junction.

324 `mefftatsti=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for source-bulk junction.

325 `mefftatgat=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for source-bulk junction.

326 `cbbtbot=1E-12 AV`$^{-3}$

Band-to-band tunneling prefactor of bottom component for source-bulk junction.

327 `cbbtsti=1E-18 AV`$^{-3}$`m`

Band-to-band tunneling prefactor of STI-edge component for source-bulk junction.

328 `cbbtgat=1E-18 AV`$^{-3}$`m`

Band-to-band tunneling prefactor of gate-edge component for source-bulk junction.

329 `fbbtrbot=1E9 Vm^-1`

Normalization field at the reference temperature for band-to-band tunneling of bottom component for source-bulk junction.

330 `fbbtrsti=1E9 Vm^-1`

Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for source-bulk junction.

331 `fbbtrgat=1E9 Vm^-1`

Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for source-bulk junction.

332 `stfbbtbot=(-1E-3) K^-1`

Temperature scaling parameter for band-to-band tunneling of bottom component for source-bulk junction.

333 `stfbbtsti=(-1E-3) K^-1`

Temperature scaling parameter for band-to-band tunneling of STI-edge component for source-bulk junction.

334 `stfbbtgat=(-1E-3) K^-1`

Temperature scaling parameter for band-to-band tunneling of gate-edge component for source-bulk junction.

335 `vbrbot=10 V` Breakdown voltage of bottom component for source-bulk junction.

336 `vbrsti=10 V` Breakdown voltage of STI-edge component for source-bulk junction.

337 `vbrgat=10 V` Breakdown voltage of gate-edge component for source-bulk junction.

338 `pbrbot=4 V` Breakdown onset tuning parameter of bottom component for source-bulk junction.

339 `pbrsti=4 V` Breakdown onset tuning parameter of STI-edge component for source-bulk junction.

340 `pbrgat=4 V` Breakdown onset tuning parameter of gate-edge component for source-bulk junction.

341 `cjorbotd=1E-3 Fm`$^{-2}$
Zero-bias capacitance per unit-of-area of bottom component for drain-bulk junction.

342 `cjorstid=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for drain-bulk junction.

343 `cjorgatd=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for drain-bulk junction.

344 `vbirbotd=1 V` Built-in voltage at the reference temperature of bottom component for drain-bulk junction.

345 `vbirstid=1 V` Built-in voltage at the reference temperature of STI-edge component for drain-bulk junction.

346 `vbirgatd=1 V` Built-in voltage at the reference temperature of gate-edge component for drain-bulk junction.

347 `pbotd=0.5` Grading coefficient of bottom component for drain-bulk junction.

348 `pstid=0.5` Grading coefficient of STI-edge component for drain-bulk junction.

349 `pgatd=0.5` Grading coefficient of gate-edge component for drain-bulk junction.

350 `phigbotd=1.16 V` Zero-temperature bandgap voltage of bottom component for drain-bulk junction.

351 `phigstid=1.16 V` Zero-temperature bandgap voltage of STI-edge component for drain-bulk junction.

352 `phiggatd=1.16 V` Zero-temperature bandgap voltage of gate-edge component for drain-bulk junction.

353 `idsatrbotd=1E-12 Am`$^{-2}$
Saturation current density at the reference temperature of bottom component for drain-bulk junction.

354 `idsatrstid=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for drain-bulk junction.

355 `idsatrgatd=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for drain-bulk junction.

356 `csrhbotd=1E2 Am`$^{-3}$
Shockley-Read-Hall prefactor of bottom component for drain-bulk junction.

357 `csrhstid=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of STI-edge component for drain-bulk junction.

358 `csrhgatd=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of gate-edge component for drain-bulk junction.

359 `xjunstid=100E-9 m` Junction depth of STI-edge component for drain-bulk junction.

360 `xjungatd=100E-9 m` Junction depth of gate-edge component for drain-bulk junction.

361 `ctatbotd=1E2 Am`$^{-3}$
Trap-assisted tunneling prefactor of bottom component for drain-bulk junction.

362 `ctatstid=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of STI-edge component for drain-bulk junction.

363 `ctatgatd=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of gate-edge component for drain-bulk junction.

364 `mefftatbotd=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component for drain-bulk junction.

365 `mefftatstid=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for drain-bulk junction.

366 `mefftatgatd=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for drain-bulk junction.

367 `cbbtbotd=1E-12 AV`$^{-3}$
Band-to-band tunneling prefactor of bottom component for drain-bulk junction.

368 `cbbtstid=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of STI-edge component for drain-bulk junction.

369 `cbbtgatd=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of gate-edge component for drain-bulk junction.

370 `fbbtrbotd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component for drain-bulk junction.

371 `fbbtrstid=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for drain-bulk junction.

372 `fbbtrgatd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for drain-bulk junction.

373 `stfbbtbotd=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for drain-bulk junction.

374 `stfbbtstid=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for drain-bulk junction.

375 `stfbbtgatd=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for drain-bulk junction.

376 `vbrbotd=10 V` Breakdown voltage of bottom component for drain-bulk junction.

377 `vbrstid=10 V` Breakdown voltage of STI-edge component for drain-bulk junction.

378 `vbrgatd=10 V` Breakdown voltage of gate-edge component for drain-bulk junction.

379 `pbrbotd=4 V` Breakdown onset tuning parameter of bottom component for drain-bulk junction.

380 `pbrstid=4 V` Breakdown onset tuning parameter of STI-edge component for drain-bulk junction.

381 `pbrgatd=4 V` Breakdown onset tuning parameter of gate-edge component for drain-bulk junction.

382 `swjunexp=0.0` Flag for JUNCAP-express; 0,full model, 1,express model.

383 `vjunref=2.5` Typical maximum source-bulk junction voltage; usually about 2*VSUP.

384 `fjunq=0.03` Fraction below which source-bulk junction capacitance components are considered negligible.

385 `vjunrefd=2.5` Typical maximum drain-bulk junction voltage; usually about 2*VSUP.

386 `fjunqd=0.03` Fraction below which drain-bulk junction capacitance components are considered negligible.

387 `povfb=(-1) V` Coefficient for the geometry independent part of VFB.

388 `plvfb=0.0 V` Coefficient for the length dependence of VFB.

389 `pwvfb=0.0 V` Coefficient for the width dependence of VFB.

390 `plwvfb=0.0 V` Coefficient for the length times width dependence of VFB.

391 `postvfb=0.0005 V/K`
Coefficient for the geometry independent part of STVFB.

392 `plstvfb=0.0 V/K` Coefficient for the length dependence of STVFB.

393 `pwstvfb=0.0 V/K` Coefficient for the width dependence of STVFB.

394 `plwstvfb=0.0 V/K` Coefficient for the length times width dependence of STVFB.

395 `potox=2E-09 m` Coefficient for the geometry independent part of TOX.

396 `poepsrox=3.9` Coefficient for the geometry independent part of EPSOX.

397 `poneff=5E+23 m`$^{-3}$ Coefficient for the geometry independent part of NEFF.

398 `plneff=0.0 m`$^{-3}$ Coefficient for the length dependence of NEFF.

399 `pwneff=0.0 m`$^{-3}$ Coefficient for the width dependence of NEFF.

400 `plwneff=0.0 m`$^{-3}$ Coefficient for the length times width dependence of NEFF.

401 `povnsub=0 V` Coefficient for the geometry independent part of VNSUB.

402 `ponslp=0.05 V` Coefficient for the geometry independent part of NSLP.

403 `podnsub=0 V^-1` Coefficient for the geometry independent part of DNSUB.

404 `podphib=0 V` Coefficient for the geometry independent part of DPHIB.

405 `pldphib=0.0 V` Coefficient for the length dependence of DPHIB.

406 `pwdphib=0.0 V` Coefficient for the width dependence of DPHIB.

407 `plwdphib=0.0 V` Coefficient for the length times width dependence of DPHIB.

408 `ponp=1E+26 m`$^{-3}$ Coefficient for the geometry independent part of NP.

409 `plnp=0.0 m`$^{-3}$ Coefficient for the length dependence of NP.

410 `pwnp=0.0` m^{-3} Coefficient for the width dependence of NP.

411 `plwnp=0.0` m^{-3} Coefficient for the length times width dependence of NP.

412 `poct=0` Coefficient for the geometry independent part of CT.

413 `plct=0.0` Coefficient for the length dependence of CT.

414 `pwct=0.0` Coefficient for the width dependence of CT.

415 `plwct=0.0` Coefficient for the length times width dependence of CT.

416 `potoxov=2E-09 m` Coefficient for the geometry independent part of TOXOV.

417 `potoxovd=2E-09 m` Coefficient for the geometry independent part of TOXOV for drain side.

418 `ponov=5E+25` m^{-3} Coefficient for the geometry independent part of NOV.

419 `plnov=0.0` m^{-3} Coefficient for the length dependence of NOV.

420 `pwnov=0.0` m^{-3} Coefficient for the width dependence of NOV.

421 `plwnov=0.0` m^{-3} Coefficient for the length times width dependence of NOV.

422 `ponovd=5E+25` m^{-3} Coefficient for the geometry independent part of NOV for drain side.

423 `plnovd=0.0` m^{-3} Coefficient for the length dependence of NOV for drain side.

424 `pwnovd=0.0` m^{-3} Coefficient for the width dependence of NOV for drain side.

425 `plwnovd=0.0` m^{-3} Coefficient for the length times width dependence of NOV for drain side.

426 `pocf=0` Coefficient for the geometry independent part of CF.

427 `plcf=0.0` Coefficient for the length dependence of CF.

428 `pwcf=0.0` Coefficient for the width dependence of CF.

429 `plwcf=0.0` Coefficient for the length times width dependence of CF.

430 `pocfb=0 V^-1` Coefficient for the geometry independent part of CFB.

431 `pobetn=0.07` m^2`/V/s`
Coefficient for the geometry independent part of BETN.

432 `plbetn=0.0` m^2`/V/s`
Coefficient for the length dependence of BETN.

433 `pwbetn=0.0` m^2`/V/s`
Coefficient for the width dependence of BETN.

434 `plwbetn=0.0` m^2`/V/s`
Coefficient for the length times width dependence of BETN.

435 `postbet=1` Coefficient for the geometry independent part of STBET.

436 `plstbet=0.0` Coefficient for the length dependence of STBET.

437 `pwstbet=0.0` Coefficient for the width dependence of STBET.

438 `plwstbet=0.0` Coefficient for the length times width dependence of STBET.

439 `pomue=0.5 m/V` Coefficient for the geometry independent part of MUE.

440 `plmue=0.0 m/V` Coefficient for the length dependence of MUE.

441 `pwmue=0.0 m/V` Coefficient for the width dependence of MUE.

442 `plwmue=0.0 m/V` Coefficient for the length times width dependence of MUE.

443 `postmue=0` Coefficient for the geometry independent part of STMUE.

444 `pothemu=1.5` Coefficient for the geometry independent part of THEMU.

445 `postthemu=1.5` Coefficient for the geometry independent part of STTHEMU.

446 `pocs=0` Coefficient for the geometry independent part of CS.

447 `plcs=0.0` Coefficient for the length dependence of CS.

448 `pwcs=0.0` Coefficient for the width dependence of CS.

449 `plwcs=0.0` Coefficient for the length times width dependence of CS.

450 `postcs=0` Coefficient for the geometry independent part of STCS.

451 `poxcor=0 V^-1` Coefficient for the geometry independent part of XCOR.

452 `plxcor=0.0 V^-1` Coefficient for the length dependence of XCOR.

453 `pwxcor=0.0 V^-1` Coefficient for the width dependence of XCOR.

454 `plwxcor=0.0 V^-1` Coefficient for the length times width dependence of XCOR.

455 `postxcor=0` Coefficient for the geometry independent part of STXCOR.

456 `pofeta=1` Coefficient for the geometry independent part of FETA.

457 `pors=30 Ω` Coefficient for the geometry independent part of RS.

458 `plrs=0.0 Ω` Coefficient for the length dependence of RS.

459 `pwrs=0.0 Ω` Coefficient for the width dependence of RS.

460 `plwrs=0.0 Ω` Coefficient for the length times width dependence of RS.

461 `postrs=1` Coefficient for the geometry independent part of STRS.

462 `porsb=0 V^-1` Coefficient for the geometry independent part of RSB.

463 `porsg=0 V^-1` Coefficient for the geometry independent part of RSG.

464 `pothesat=1 V^-1` Coefficient for the geometry independent part of THESAT.

465 `plthesat=0.0 V^-1` Coefficient for the length dependence of THESAT.

466 `pwthesat=0.0 V^-1` Coefficient for the width dependence of THESAT.

467 `plwthesat=0.0 V^-1`
Coefficient for the length times width dependence of THESAT.

468 `postthesat=1` Coefficient for the geometry independent part of STTHESAT.

469 `plstthesat=0.0` Coefficient for the length dependence of STTHESAT.

470 `pwstthesat=0.0` Coefficient for the width dependence of STTHESAT.

471 `plwstthesat=0.0` Coefficient for the length times width dependence of STTHESAT.

472 `pothesatb=0 V^-1` Coefficient for the geometry independent part of THESATB.

473 `plthesatb=0.0 V^-1`
Coefficient for the length dependence of THESATB.

474 `pwthesatb=0.0 V^-1`
Coefficient for the width dependence of THESATB.

475 `plwthesatb=0.0 V^-1`
Coefficient for the length times width dependence of THESATB.

476 `pothesatg=0 V^-1` Coefficient for the geometry independent part of THESATG.

477 `plthesatg=0.0 V^-1`
Coefficient for the length dependence of THESATG.

478 `pwthesatg=0.0 V^-1`
Coefficient for the width dependence of THESATG.

479 `plwthesatg=0.0 V^-1`
Coefficient for the length times width dependence of THESATG.

480 `poax=3` Coefficient for the geometry independent part of AX.

481 `plax=0.0` Coefficient for the length dependence of AX.

482 `pwax=0.0` Coefficient for the width dependence of AX.

483 `plwax=0.0` Coefficient for the length times width dependence of AX.

484 `poalp=0.01` Coefficient for the geometry independent part of ALP.

485 `plalp=0.0` Coefficient for the length dependence of ALP.

486 `pwalp=0.0` Coefficient for the width dependence of ALP.

487 `plwalp=0.0` Coefficient for the length times width dependence of ALP.

488 `poalp1=0 V` Coefficient for the geometry independent part of ALP1.

489 `plalp1=0.0 V` Coefficient for the length dependence of ALP1.

490 `pwalp1=0.0 V`	Coefficient for the width dependence of ALP1.
491 `plwalp1=0.0 V`	Coefficient for the length times width dependence of ALP1.
492 `poalp2=0 V^-1`	Coefficient for the geometry independent part of ALP2.
493 `plalp2=0.0 V^-1`	Coefficient for the length dependence of ALP2.
494 `pwalp2=0.0 V^-1`	Coefficient for the width dependence of ALP2.
495 `plwalp2=0.0 V^-1`	Coefficient for the length times width dependence of ALP2.
496 `povp=0.05 V`	Coefficient for the geometry independent part of VP.
497 `poa1=1`	Coefficient for the geometry independent part of A1.
498 `pla1=0.0`	Coefficient for the length dependence of A1.
499 `pwa1=0.0`	Coefficient for the width dependence of A1.
500 `plwa1=0.0`	Coefficient for the length times width dependence of A1.
501 `poa2=10 V`	Coefficient for the geometry independent part of A2.
502 `posta2=0 V`	Coefficient for the geometry independent part of STA2.
503 `poa3=1`	Coefficient for the geometry independent part of A3.
504 `pla3=0.0`	Coefficient for the length dependence of A3.
505 `pwa3=0.0`	Coefficient for the width dependence of A3.
506 `plwa3=0.0`	Coefficient for the length times width dependence of A3.
507 `poa4=0 V^-0.5`	Coefficient for the geometry independent part of A4.
508 `pla4=0.0 V^-0.5`	Coefficient for the length dependence of A4.
509 `pwa4=0.0 V^-0.5`	Coefficient for the width dependence of A4.
510 `plwa4=0.0 V^-0.5`	Coefficient for the length times width dependence of A4.
511 `pogco=0`	Coefficient for the geometry independent part of GCO.

512 `poiginv=0 A`	Coefficient for the geometry independent part of IGINV.
513 `pliginv=0.0 A`	Coefficient for the length dependence of IGINV.
514 `pwiginv=0.0 A`	Coefficient for the width dependence of IGINV.
515 `plwiginv=0.0 A`	Coefficient for the length times width dependence of IGINV.
516 `poigov=0 A`	Coefficient for the geometry independent part of IGOV.
517 `pligov=0.0 A`	Coefficient for the length dependence of IGOV.
518 `pwigov=0.0 A`	Coefficient for the width dependence of IGOV.
519 `plwigov=0.0 A`	Coefficient for the length times width dependence of IGOV.
520 `poigovd=0 A`	Coefficient for the geometry independent part of IGOV for drain side.
521 `pligovd=0.0 A`	Coefficient for the length dependence of IGOV for drain side.
522 `pwigovd=0.0 A`	Coefficient for the width dependence of IGOV for drain side.
523 `plwigovd=0.0 A`	Coefficient for the length times width dependence of IGOV for drain side.
524 `postig=2`	Coefficient for the geometry independent part of STIG.
525 `pogc2=0.375`	Coefficient for the geometry independent part of GC2.
526 `pogc3=0.063`	Coefficient for the geometry independent part of GC3.
527 `pochib=3.1 V`	Coefficient for the geometry independent part of CHIB.
528 `poagidl=0` A/V^3	Coefficient for the geometry independent part of AGIDL.
529 `plagidl=0.0` A/V^3	Coefficient for the length dependence of AGIDL.
530 `pwagidl=0.0` A/V^3	Coefficient for the width dependence of AGIDL.
531 `plwagidl=0.0` A/V^3	Coefficient for the length times width dependence of AGIDL.

532 `poagidld=0 A/V`^{3} Coefficient for the geometry independent part of AGIDL for drain side.

533 `plagidld=0.0 A/V`^{3}
Coefficient for the length dependence of AGIDL for drain side.

534 `pwagidld=0.0 A/V`^{3}
Coefficient for the width dependence of AGIDL for drain side.

535 `plwagidld=0.0 A/V`^{3}
Coefficient for the length times width dependence of AGIDL for drain side.

536 `pobgidl=41 V` Coefficient for the geometry independent part of BGIDL.

537 `pobgidld=41 V` Coefficient for the geometry independent part of BGIDL for drain side.

538 `postbgidl=0 V/K` Coefficient for the geometry independent part of STBGIDL.

539 `postbgidld=0 V/K` Coefficient for the geometry independent part of STBGIDL for drain side.

540 `pocgidl=0` Coefficient for the geometry independent part of CGIDL.

541 `pocgidld=0` Coefficient for the geometry independent part of CGIDL for drain side.

542 `pocox=1E-14 F` Coefficient for the geometry independent part of COX.

543 `plcox=0.0 F` Coefficient for the length dependence of COX.

544 `pwcox=0.0 F` Coefficient for the width dependence of COX.

545 `plwcox=0.0 F` Coefficient for the length times width dependence of COX.

546 `pocgov=1E-15 F` Coefficient for the geometry independent part of CGOV.

547 `plcgov=0.0 F` Coefficient for the length dependence of CGOV.

548 `pwcgov=0.0 F` Coefficient for the width dependence of CGOV.

549 `plwcgov=0.0 F` Coefficient for the length times width dependence of CGOV.

550 `pocgovd=1E-15 F` Coefficient for the geometry independent part of CGOV for drain side.

551 `plcgovd=0.0 F` Coefficient for the length dependence of CGOV for drain side.

552 `pwcgovd=0.0 F` Coefficient for the width dependence of CGOV for drain side.

553 `plwcgovd=0.0 F` Coefficient for the length times width dependence of CGOV for drain side.

554 `pocgbov=0 F` Coefficient for the geometry independent part of CGBOV.

555 `plcgbov=0.0 F` Coefficient for the length dependence of CGBOV.

556 `pwcgbov=0.0 F` Coefficient for the width dependence of CGBOV.

557 `plwcgbov=0.0 F` Coefficient for the length times width dependence of CGBOV.

558 `pocfr=0 F` Coefficient for the geometry independent part of CFR.

559 `plcfr=0.0 F` Coefficient for the length dependence of CFR.

560 `pwcfr=0.0 F` Coefficient for the width dependence of CFR.

561 `plwcfr=0.0 F` Coefficient for the length times width dependence of CFR.

562 `pocfrd=0 F` Coefficient for the geometry independent part of CFR for drain side.

563 `plcfrd=0.0 F` Coefficient for the length dependence of CFR for drain side.

564 `pwcfrd=0.0 F` Coefficient for the width dependence of CFR for drain side.

565 `plwcfrd=0.0 F` Coefficient for the length times width dependence of CFR for drain side.

566 `pofnt=1` Coefficient for the geometry independent part of FNT.

567 `ponfa=8E+22 V^-1/m`^{4}
Coefficient for the geometry independent part of NFA.

568 `plnfa=0.0 V^-1/m`^{4}
Coefficient for the length dependence of NFA.

569 `pwnfa=0.0 V^-1/m`^{4}
Coefficient for the width dependence of NFA.

570 `plwnfa=0.0 V^-1/m`^{4}
Coefficient for the length times width dependence of NFA.

571 `ponfb=3E+07 V^-1/m`^{2}
Coefficient for the geometry independent part of NFB.

572 `plnfb=0.0 V^-1/m`^{2}
Coefficient for the length dependence of NFB.

573 `pwnfb=0.0 V^-1/m`^{2}
Coefficient for the width dependence of NFB.

574 `plwnfb=0.0 V^-1/m`^{2}
Coefficient for the length times width dependence of NFB.

575 `ponfc=0 V^-1` Coefficient for the geometry independent part of NFC.

576 `plnfc=0.0 V^-1` Coefficient for the length dependence of NFC.

577 `pwnfc=0.0 V^-1` Coefficient for the width dependence of NFC.

578 `plwnfc=0.0 V^-1` Coefficient for the length times width dependence of NFC.

579 `poef=1.0` Coefficient for the flicker noise frequency exponent.

580 `pokvthowe=0` Coefficient for the geometry independent part of KVTHOWE.

581 `plkvthowe=0` Coefficient for the length dependence part of KVTHOWE.

582 `pwkvthowe=0` Coefficient for the width dependence part of KVTHOWE.

583 `plwkvthowe=0` Coefficient for the length times width dependence part of KVTHOWE.

584 `pokuowe=0` Coefficient for the geometry independent part of KUOWE.

585 `plkuowe=0` Coefficient for the length dependence part of KUOWE.

586 `pwkuowe=0` Coefficient for the width dependence part of KUOWE.

587 `plwkuowe=0`	Coefficient for the length times width dependence part of KUOWE.
588 `lmin=0 m`	Dummy parameter to label binning set.
589 `lmax=1.0 m`	Dummy parameter to label binning set.
590 `wmin=0 m`	Dummy parameter to label binning set.
591 `wmax=1.0 m`	Dummy parameter to label binning set.
592 `w=10e-6 m`	Default width.
593 `l=10e-6 m`	Default length.
594 `nf=1`	Number of fingers, It served as the default value of instance nf.
595 `mvt=0.0`	DCmatch parameter.
596 `mvto=0.0`	DCmatch parameter.
597 `mbe=0.0`	DCmatch parameter.
598 `mbeo=0.0`	DCmatch parameter.
599 `vthmod`	Vth output selector. 'std' outputs model equation Vth. 'vthcc' outputs constant current Vth, and may impact simulation performance. The default value is taken from the options parameter 'vthmod'. Possible values are `std` and `vthcc`.
600 `ivth (A)`	Vth current parameter. The default value is taken from the options parameter 'ivthn' or 'ivthp', depending on the type of the model.
601 `ivthw (m)`	Width offset for constant current Vth. The default value is taken from the options parameter 'ivthw'.
602 `ivthl (m)`	Length offset for constant current Vth. The default value is taken from the options parameter 'ivthl'.
603 `ivth_vdsmin (V)`	Minimum Vds in constant current Vth calculating. The default value is taken from the options parameter 'ivth_vdsmin'.

604 noisemethod=oldcmi
Induced gate noise implementation .
Possible values are oldcmi, subckt, and newcmi.

Output Parameters

1 weff (m) Effective channel width for geometrical models.

2 leff (m) Effective channel length for geometrical models.

3 lp_vfb (V) Local parameter VFB after T-scaling and clipping.

4 lp_stvfb (V/K) Local parameter STVFB after clipping.

5 lp_tox (m) Local parameter TOX after clipping.

6 lp_epsrox Local parameter EPSROX after clipping.

7 lp_neff (m^{-3}) Local parameter NEFF after clipping.

8 lp_vnsub (V) Local parameter VNSUB after clipping.

9 lp_nslp (V) Local parameter NSLP after clipping.

10 lp_dnsub (V^-1)
Local parameter DNSUB after clipping.

11 lp_dphib (V) Local parameter DPHIB after clipping.

12 lp_np (m^{-3}) Local parameter NP after clipping.

13 lp_ct Local parameter CT after clipping.

14 lp_toxov (m) Local parameter TOXOV after clipping.

15 lp_toxovd (m) Local parameter TOXOVD after clipping.

16 lp_nov (m^{-3}) Local parameter NOV after clipping.

17 lp_novd (m^{-3}) Local parameter NOVD after clipping.

18 lp_cf Local parameter CF after clipping.

19 `lp_cfb (V^-1)` Local parameter CFB after clipping.

20 `lp_betn` (m^2/(V s))
Local parameter BETN after T-scaling and clipping.

21 `lp_stbet` Local parameter STBET after clipping.

22 `lp_mue (m/V)` Local parameter MUE after T-scaling and clipping.

23 `lp_stmue` Local parameter STMUE after clipping.

24 `lp_themu` Local parameter THEMU after T-scaling and clipping.

25 `lp_stthemu` Local parameter STTHEMU after clipping.

26 `lp_cs` Local parameter CS after T-scaling and clipping.

27 `lp_stcs` Local parameter STCS after clipping.

28 `lp_xcor (V^-1)` Local parameter XCOR after T-scaling and clipping.

29 `lp_stxcor` Local parameter STXCOR after clipping.

30 `lp_feta` Local parameter FETA after clipping.

31 `lp_rs` (Ω) Local parameter RS after T-scaling and clipping.

32 `lp_strs` Local parameter STRS after clipping.

33 `lp_rsb (V^-1)` Local parameter RSB after clipping.

34 `lp_rsg (V^-1)` Local parameter RSG after clipping.

35 `lp_thesat (V^-1)`
Local parameter THESAT after T-scaling and clipping.

36 `lp_stthesat` Local parameter STTHESAT after clipping.

37 `lp_thesatb (V^-1)`
Local parameter THESATB after clipping.

38 `lp_thesatg (V^-1)`
Local parameter THESATG after clipping.

39 `lp_ax`	Local parameter AX after clipping.
40 `lp_alp`	Local parameter ALP after clipping.
41 `lp_alp1 (V)`	Local parameter ALP1 after clipping.
42 `lp_alp2 (V^-1)`	Local parameter ALP2 after clipping.
43 `lp_vp (V)`	Local parameter VP after clipping.
44 `lp_a1`	Local parameter A1 after clipping.
45 `lp_a2 (V)`	Local parameter A2 after T-scaling and clipping.
46 `lp_sta2`	Local parameter STA2 after clipping.
47 `lp_a3`	Local parameter A3 after clipping.
48 `lp_a4` ($1/\sqrt{V}$)	Local parameter A4 after clipping.
49 `lp_gco`	Local parameter GCO after clipping.
50 `lp_iginv (A)`	Local parameter IGINV after T-scaling and clipping.
51 `lp_igov (A)`	Local parameter IGOV after T-scaling and clipping.
52 `lp_igovd (A)`	Local parameter IGOVD after T-scaling and clipping.
53 `lp_stig`	Local parameter STIG after clipping.
54 `lp_gc2`	Local parameter GC2 after clipping.
55 `lp_gc3`	Local parameter GC3 after clipping.
56 `lp_chib (V)`	Local parameter CHIB after clipping.
57 `lp_agidl` (A/V^3)	Local parameter AGIDL after clipping.
58 `lp_agidld` (A/V^3)	Local parameter AGIDLD after clipping.

59 `lp_bgidl (V)`	Local parameter BGIDL after T-scaling and clipping.
60 `lp_bgidld (V)`	Local parameter BGIDLD after T-scaling and clipping.
61 `lp_stbgidl (V/K)`	Local parameter STBGIDL after clipping.
62 `lp_stbgidld (V/K)`	Local parameter STBGIDLD after clipping.
63 `lp_cgidl`	Local parameter CGIDL after clipping.
64 `lp_cgidld`	Local parameter CGIDLD after clipping.
65 `lp_cox (F)`	Local parameter COX after clipping.
66 `lp_cgov (F)`	Local parameter CGOV after clipping.
67 `lp_cgovd (F)`	Local parameter CGOVD after clipping.
68 `lp_cgbov (F)`	Local parameter CGBOV after clipping.
69 `lp_cfr (F)`	Local parameter CFR after clipping.
70 `lp_cfrd (F)`	Local parameter CFRD after clipping.
71 `lp_fnt`	Local parameter FNT after clipping.
72 lp_nfa $(1/(V\ m^4))$	Local parameter NFA after clipping.
73 lp_nfb $(1/(V\ m^2))$	Local parameter NFB after clipping.
74 `lp_nfc (V^-1)`	Local parameter NFC after clipping.
75 `lp_ef`	Local parameter EF after clipping.
76 `lp_rg (Ω)`	Local parameter RG after clipping.
77 `lp_rbulk (Ω)`	Local parameter RBULK after clipping.
78 `lp_rwell (Ω)`	Local parameter RWELL after clipping.

79 `lp_rjuns` (Ω) Local parameter RJUNS after clipping.

80 `lp_rjund` (Ω) Local parameter RJUND after clipping.

81 `tk` (K) Device Temperature.

82 `lp_munqs` Local parameter MUNQS after clipping.

83 `cjosbot` (F) Bottom component of total zero-bias source junction capacitance at device temperature.

84 `cjossti` (F) STI-edge component of total zero-bias source junction capacitance at device temperature.

85 `cjosgat` (F) Gate-edge component of total zero-bias source junction capacitance at device temperature.

86 `vbisbot` (V) Built-in voltage of source-side bottom junction at device temperature.

87 `vbissti` (V) Built-in voltage of source-side STI-edge junction at device temperature.

88 `vbisgat` (V) Built-in voltage of source-side gate-edge junction at device temperature.

89 `idsatsbot` (A) Total source-side bottom junction saturation current.

90 `idsatssti` (A) Total source-side STI-edge junction saturation current.

91 `idsatsgat` (A) Total source-side gate-edge junction saturation current.

92 `cjosbotd` (F) Bottom component of total zero-bias drain junction capacitance at device temperature.

93 `cjosstid` (F) STI-edge component of total zero-bias drain junction capacitance at device temperature.

94 `cjosgatd` (F) Gate-edge component of total zero-bias drain junction capacitance at device temperature.

95 `vbisbotd` (V) Built-in voltage of drain-side bottom junction at device temperature.

96 `vbisstid (V)`	Built-in voltage of drain-side STI-edge junction at device temperature.
97 `vbisgatd (V)`	Built-in voltage of drain-side gate-edge junction at device temperature.
98 `idsatsbotd (A)`	Total drain-side bottom junction saturation current.
99 `idsatsstid (A)`	Total drain-side STI-edge junction saturation current.
100 `idsatsgatd (A)`	Total drain-side gate-edge junction saturation current.
101 `lv1 (m)`	alias of l.
102 `lv2 (m)`	alias of w.
103 `lv3` (m^2)	alias of ad.
104 `lv4` (m^2)	alias of as.
105 `lv11 (m)`	alias of pd.
106 `lv12 (m)`	alias of ps.
107 `tempeff (C)`	Effective temperature for a single device.

Operating-Point Parameters

1 `region=triode`	Estimated operating region. %Z outputs the number (0-4) in a rawfile. Possible values are `off`, `triode`, `sat`, `subth`, and `breakdown`.
2 `ctype`	Flag for channel type.
3 `sdint`	Flag for source-drain interchange.
4 `ise (A)`	Total source current.
5 `ige (A)`	Total gate current.
6 `ide (A)`	Total drain current.

7 `ibe (A)`	Total bulk current.
8 `ids (A)`	Drain current, excl. avalanche, tunnel, GISL, GIDL, and junction currents.
9 `idb (A)`	Drain to bulk current.
10 `isb (A)`	Source to bulk current.
11 `igs (A)`	Gate-source tunneling current.
12 `igd (A)`	Gate-drain tunneling current.
13 `igb (A)`	Gate-bulk tunneling current.
14 `igcs (A)`	Gate-channel tunneling current (source component).
15 `igcd (A)`	Gate-channel tunneling current (drain component).
16 `iavl (A)`	Substrate current due to weak avelanche.
17 `igisl (A)`	Gate-induced source leakage current.
18 `igidl (A)`	Gate-induced drain leakage current.
19 `ijs (A)`	Total source junction current.
20 `ijsbot (A)`	Source junction current (bottom component).
21 `ijsgat (A)`	Source junction current (gate-edge component).
22 `ijssti (A)`	Source junction current (STI-edge component).
23 `ijd (A)`	Total drain junction current.
24 `ijdbot (A)`	Drain junction current (bottom component).
25 `ijdgat (A)`	Drain junction current (gate-edge component).
26 `ijdsti (A)`	Drain junction current (STI-edge component).
27 `qg (Coul)`	Intrinsic gate charge.

28 `qd (Coul)`	Intrinsic drain charge.
29 `qb (Coul)`	Intrinsic bulk charge.
30 `qs (Coul)`	Intrinsic source charge.
31 `qgs_ov (Coul)`	Overlap charge for gate-source.
32 `qgd_ov (Coul)`	Overlap charge for gate-drain.
33 `qfgs (Coul)`	Total outerFringe + overlap for gate-source.
34 `qfgd (Coul)`	Total outerFringe + overlap for gate-drain.
35 `qgb_ov (Coul)`	Gate-bulk overlap charge.
36 `qjun_s (Coul)`	Junction charge on source side.
37 `qjun_d (Coul)`	Junction charge on drain side.
38 `vds (V)`	Drain-source voltage.
39 `vgs (V)`	Gate-source voltage.
40 `vsb (V)`	Source-bulk voltage.
41 `vto (V)`	Zero-bias threshold voltage.
42 `vts (V)`	Threshold voltage including back bias effects.
43 `vth (V)`	Threshold voltage including back bias and drain bias effects.
44 `vgt (V)`	Effective gate drive voltage including back bias and drain bias effects.
45 `vdss (V)`	Drain saturation voltage at actual bias.
46 `vsat (V)`	Saturation limit.
47 `pwr (W)`	Power at op point.
48 `gm (1/Ω)`	Transconductance.

49 `gmb (1/Ω)`	Substrate transconductance.
50 `gds (1/Ω)`	Output conductance.
51 `gjs (1/Ω)`	Source junction conductance.
52 `gjd (1/Ω)`	Drain junction conductance.
53 `cdd (F)`	Drain capacitance.
54 `cdg (F)`	Drain-gate capacitance.
55 `cds (F)`	Drain-source capacitance.
56 `cdb (F)`	Drain-bulk capacitance.
57 `cgd (F)`	Gate-drain capacitance.
58 `cgg (F)`	Gate capacitance.
59 `cgs (F)`	Gate-source capacitance.
60 `cgb (F)`	Gate-bulk capacitance.
61 `csd (F)`	Source-drain capacitance.
62 `csg (F)`	Source-gate capacitance.
63 `css (F)`	Source capacitance.
64 `csb (F)`	Source-bulk capacitance.
65 `cbd (F)`	Bulk-drain capacitance.
66 `cbg (F)`	Bulk-gate capacitance.
67 `cbs (F)`	Bulk-source capacitance.
68 `cbb (F)`	Bulk capacitance.
69 `cgsol (F)`	Total gate-source overlap capacitance.
70 `cgdol (F)`	Total gate-drain overlap capacitance.

71 `cgbol (F)`	Total gate-bulk overlap capacitance.
72 `cjs (F)`	Total source junction capacitance.
73 `cjsbot (F)`	Source junction capacitance (bottom component).
74 `cjsgat (F)`	Source junction capacitance (gate-edge component).
75 `cjssti (F)`	Source junction capacitance (STI-edge component).
76 `cjd (F)`	Total drain junction capacitance.
77 `cjdbot (F)`	Drain junction capacitance (bottom component).
78 `cjdgat (F)`	Drain junction capacitance (gate-edge component).
79 `cjdsti (F)`	Drain junction capacitance (STI-edge component).
80 `lpoly (m)`	
81 `u`	Transistor gain.
82 `rout (Ω)`	Small-signal output resistance.
83 `vearly (V)`	Equivalent Early voltage.
84 `beff` (A/V^2)	Gain factor.
85 `fug (Hz)`	Unity gain frequency at actual bias.
86 `rg (Ω)`	Gate resistance.
87 `sfl` (A^2/Hz)	Flicker noise current spectral density at 1 Hz.
88 `sqrtsff` $(V/\sqrt{Hz})$	Input-referred RMS white noise voltage spectral density at 1 kHz.
89 `sqrtsfw` $(V/\sqrt{Hz})$	Input-referred RMS white noise voltage spectral density.
90 `sid` (A^2/Hz)	White noise current spectral density.
91 `sig` (A^2/Hz)	Induced gate noise current spectral density at 1 Hz.

92 `cigid` Imaginary part of correlation coefficient between Sig and Sid.

93 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

94 `sigs (A^2/Hz)` Gate-source current noise spectral density.

95 `sigd (A^2/Hz)` Gate-drain current noise spectral density.

96 `siavl (A^2/Hz)` Impact ionization current noise spectral density.

97 `ssi (A^2/Hz)` Total source junction current noise spectral density.

98 `sdi (A^2/Hz)` Total drain junction current noise spectral density.

99 `vbs (V)` Bulk-source voltage.

100 `lv9 (V)` alias of vth.

101 `lv10 (V)` alias of vdss.

102 `lv36 (F)` alias of cgsol.

103 `lv37 (F)` alias of cgdol.

104 `lv38 (F)` alias of cgbol.

105 `lv51 (m)` alias of tox.

106 `lx4 (A)` alias of ids.

107 `lx3 (V)` alias of vds.

108 `lx2 (V)` alias of vgs.

109 `lx7 (1/Ω)` alias of gm.

110 `lx8 (1/Ω)` alias of gds.

111 `lx9 (1/Ω)` alias of gmb.

112 `lx33 (F)` alias of cdd.

113 `lx32 (F)` alias of cdg.

114 `lx34 (F)` alias of cds.

115 `lx19 (F)` alias of cgd.

116 `lx18 (F)` alias of cgg.

117 `lx20 (F)` alias of cgs.

118 `lx22 (F)` alias of cbd.

119 `lx21 (F)` alias of cbg.

120 `lx23 (F)` alias of cbs.

121 `lx5 (A)` alias of ijs.

122 `lx6 (A)` alias of ijd.

123 `lx28 (F)` alias of cjs.

124 `lx29 (F)` alias of cjd.

125 `lx38 (A)` alias of igs.

126 `lx39 (A)` alias of igd.

127 `lx66 (A)` alias of igb.

128 `lx67 (A)` alias of igcs.

129 `lx68 (A)` alias of igcd.

130 `lx110 (A)` alias of igisl.

131 `lx47 (A)` alias of igidl.

132 `lx60 (F)` alias of csd.

133 `lx59 (F)` alias of csg.

134 `lx58 (F)` alias of css.

135 `lx12 (Coul)` alias of Qb including overlap charge.

136 `lx14 (Coul)` alias of Qg including overlap charge.

137 `lx16 (Coul)` alias of Qd including overlap charge.

138 `lx83 (F)` alias of cgd including overlap cap.

139 `lx84 (F)` alias of cgs including overlap cap.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

PSP MOSFET Model (psp1020)

This is SiMKit 4.0.1.

This device is supported withing altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so.

Instance Definition

Name d g s b ModelName parameter=value ...

Instance Parameters

1	`l=10e-6 m`	Design length.
2	`w=10e-6 m`	Design width.
3	`sa=0.0 m`	Distance between OD-edge and poly from one side.
4	`sb=0.0 m`	Distance between OD-edge and poly from other side.
5	`sd=0.0 m`	Distance between neighboring fingers.
6	`sca=0.0`	Integral of the first distribution function for scattered well dopants.
7	`scb=0.0`	Integral of the second distribution function for scattered well dopants.
8	`scc=0.0`	Integral of the third distribution function for scattered well dopants.
9	`sc=0.0 m`	Distance between OD-edge and nearest well edge.
10	`delvto=0.0 V`	Threshold voltage shift parameter.

11 `factuo=1.0` Zero-field mobility pre-factor.

12 `absource=1E-12 m`^{2} Bottom area of source junction.

13 `lssource=1E-6 m` STI-edge length of source junction.

14 `lgsource=1E-6 m` Gate-edge length of source junction.

15 `abdrain=1E-12 m`^{2} Bottom area of drain junction.

16 `lsdrain=1E-6 m` STI-edge length of drain junction.

17 `lgdrain=1E-6 m` Gate-edge length of drain junction.

18 `as=1E-12 m`^{2} Bottom area of source junction.

19 `ps=1E-6 m` Perimeter of source junction.

20 `ad=1E-12 m`^{2} Bottom area of drain junction.

21 `pd=1E-6 m` Perimeter of drain junction.

22 `mulid0=1` Ids multiplier.

23 `mult=1.0` Number of devices in parallel.

24 `nf=1.0` Number of fingers.

25 `ngcon=1.0` Number of gate contacts.

26 `xgw=1.0E-7 m` Distance from the gate contact to the channel edge.

27 `trise=0.0 K` Temperature rise from ambient.

28 `m=1.0` Multiplicity factor.

29 `isnoisy=yes` Should device generate noise.
Possible values are `no` and `yes`.

Model Definition

model modelName psp1020 parameter=value ...

Model Parameters

1 `level=102` Model level.

2 `type=n` Channel type parameter, n,NMOS p,PMOS.
Possible values are `n` and `p`.

3 `tr=value of tnom C`
nominal (reference) temperature.

4 `swnqs=0` Flag for NQS, 0,off, 1, 2, 3, 5, or 9,number of collocation points.

5 `swigate=0` Flag for gate current, 0,turn off IG.

6 `swimpact=0` Flag for impact ionization current, 0,turn off II.

7 `swgidl=0` Flag for GIDL current, 0,turn off IGIDL.

8 `swjuncap=0` Flag for juncap, 0,turn off juncap.

9 `swjunasym=0` Flag for asymmetric junctions; 0,symmetric, 1,asymmetric.

10 `qmc=1.0` Quantum-mechanical correction factor.

11 `version=102.32` The available versions are 102.2, 102.21, 102.3, 102.32, 102.33, 102.34 and 102.40.

12 `geomod=1` 1 for geometrical model and 0 for electrical model.

13 `binmod=0` 1 for bin model and 0 for non-bin model.

14 `scalelev=102` 102 for local, 1020 for global model and 1021 for bin model.

15 `compatible=spectre`
for compatible.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, and `mica`.

16 `lvaro=0.0 m` Geom. independent difference between actual and programmed gate length.

17 `lvarl=0.0` Length dependence of LVAR.

18 `lvarw=0.0`	Width dependence of LVAR.
19 `lap=0.0 m`	Effective channel length reduction per side.
20 `wvaro=0.0 m`	Geom. independent difference between actual and programmed field-oxide opening.
21 `wvarl=0.0`	Length dependence of WVAR.
22 `wvarw=0.0`	Width dependence of WVAR.
23 `wot=0.0 m`	Effective channel width reduction per side.
24 `dlq=0.0 m`	Effective channel length reduction for CV.
25 `dwq=0.0 m`	Effective channel width reduction for CV.
26 `vfbo=(-1.0) V`	Geometry-independent flat-band voltage at TR.
27 `vfbl=0.0`	Length dependence of flat-band voltage.
28 `vfbw=0.0`	Width dependence of flat-band voltage.
29 `vfblw=0.0`	Area dependence of flat-band voltage.
30 `stvfbo=5e-4 V/K`	Geometry-independent temperature dependence of VFB.
31 `stvfbl=0.0`	Length dependence of temperature dependence of VFB.
32 `stvfbw=0.0`	Width dependence of temperature dependence of VFB.
33 `stvfblw=0.0`	Area dependence of temperature dependence of VFB.
34 `toxo=2e-9 m`	Gate oxide thickness.
35 `epsroxo=3.9`	Relative permittivity of gate dielectric.
36 `nsubo=3e23` m^{-3}	Geometry independent substrate doping.
37 `nsubw=0.0`	Width dependence of background doping NSUBO due to segregation.
38 `wseg=1e-8 m`	Char. length of segregation of background doping NSUBO.

39 `npck=1e24` m^{-3} Pocket doping level.

40 `npckw=0.0` Width dependence of pocket doping NPCK due to segregation.

41 `wsegp=1e-8 m` Char. length of segregation of pocket doping NPCK.

42 `lpck=1e-8 m` Char. length of lateral doping profile.

43 `lpckw=0.0` Width dependence of char. length of lateral doping profile.

44 `fol1=0.0` First length dependence coefficient for short channel body effect.

45 `fol2=0.0` Second length dependence coefficient for short channel body effect.

46 `vnsubo=0.0 V` Effective doping bias-dependence parameter.

47 `nslpo=0.05 V` Effective doping bias-dependence parameter.

48 `dnsubo=0.0 V^-1` Effective doping bias-dependence parameter.

49 `dphibo=0.0 V` Geometry independent offset of PHIB.

50 `dphibl=0.0 V` Length dependence offset of PHIB.

51 `dphiblexp=1.0` Exponent for length dependence of offset of PHIB.

52 `dphibw=0.0` Width dependence of offset of PHIB.

53 `dphiblw=0.0` Area dependence of offset of PHIB.

54 `npo=1e26` m^{-3} Geometry-independent gate poly-silicon doping.

55 `npl=0.0` Length dependence of gate poly-silicon doping.

56 `cto=0.0` Geometry-independent interface states factor.

57 `ctl=0.0` Length dependence of interface states factor.

58 `ctlexp=1.0` Exponent for length dependence of interface states factor.

59 `ctw=0.0` Width dependence of interface states factor.

60 `ctlw=0.0` Area dependence of interface states factor.

61 `toxovo=2e-9 m` Overlap oxide thickness.

62 `toxovdo=2e-9 m` Overlap oxide thickness for drain side.

63 `lov=0 m` Overlap length for gate/drain and gate/source overlap capacitance.

64 `lovd=0 m` Overlap length for gate/drain overlap capacitance.

65 `novo=5e25` m^{-3} Effective doping of overlap region.

66 `novdo=5e25` m^{-3} Effective doping of overlap region for drain side.

67 `cfl=0.0` Length dependence of DIBL-parameter.

68 `cflexp=2.0` Exponent for length dependence of CF.

69 `cfw=0.0` Width dependence of CF.

70 `cfbo=0.0 V^-1` Back-bias dependence of CF.

71 `uo=5e-2` m^2`/V/s` Zero-field mobility at TR.

72 `fbet1=0.0` Relative mobility decrease due to first lateral profile.

73 `fbet1w=0.0` Width dependence of relative mobility decrease due to first lateral profile.

74 `lp1=1e-8 m` Mobility-related characteristic length of first lateral profile.

75 `lp1w=0.0` Width dependence of mobility-related characteristic length of first lateral profile.

76 `fbet2=0.0` Relative mobility decrease due to second lateral profile.

77 `lp2=1e-8 m` Mobility-related characteristic length of second lateral profile.

78 `betw1=0.0` First higher-order width scaling coefficient of BETN.

79 `betw2=0.0` Second higher-order width scaling coefficient of BETN.

80 `wbet=1e-9 m`	Characteristic width for width scaling of BETN.
81 `stbeto=1.0`	Geometry independent temperature dependence of BETN.
82 `stbetl=0.0`	Length dependence of temperature dependence of BETN.
83 `stbetw=0.0`	Width dependence of temperature dependence of BETN.
84 `stbetlw=0.0`	Area dependence of temperature dependence of BETN.
85 `mueo=0.5 m/V`	Geometry independent mobility reduction coefficient at TR.
86 `muew=0.0`	Width dependence of mobility reduction coefficient at TR.
87 `stmueo=0.0`	Temperature dependence of MUE.
88 `themuo=1.5`	Mobility reduction exponent at TR.
89 `stthemuo=1.5`	Temperature dependence of THEMU.
90 `cso=0.0`	Geometry independent coulomb scattering parameter at TR.
91 `csl=0.0`	Length dependence of CS.
92 `cslexp=0.0`	Exponent for length dependence of CS.
93 `csw=0.0`	Width dependence of CS.
94 `cslw=0.0`	Area dependence of CS.
95 `stcso=0.0`	Temperature dependence of CS.
96 `xcoro=0.0 V^-1`	Geometry independent non-universality parameter.
97 `xcorl=0.0`	Length dependence of non-universality parameter.
98 `xcorw=0.0`	Width dependence of non-universality parameter.
99 `xcorlw=0.0`	Area dependence of non-universality parameter.
100 `stxcoro=0.0`	Temperature dependence of XCOR.
101 `fetao=1.0`	Effective field parameter.

102 `rsw1=2.5e3 Ω` Source/drain series resistance for 1 um wide channel at TR.

103 `rsw2=0.0` Higher-order width scaling of RS.

104 `strso=1.0` Temperature dependence of RS.

105 `rsbo=0.0 V^-1` Back-bias dependence of series resistance.

106 `rsgo=0.0 V^-1` Gate-bias dependence of series resistance.

107 `thesato=0.0 V^-1` Geometry independent velocity saturation parameter at TR.

108 `thesatl=0.05 V^-1` Length dependence of THESAT.

109 `thesatlexp=1.0` Exponent for length dependence of THESAT.

110 `thesatw=0.0` Width dependence of velocity saturation parameter.

111 `thesatlw=0.0` Area dependence of velocity saturation parameter.

112 `stthesato=1.0` Geometry independent temperature dependence of THESAT.

113 `stthesatl=0.0` Length dependence of temperature dependence of THESAT.

114 `stthesatw=0.0` Width dependence of temperature dependence of THESAT.

115 `stthesatlw=0.0` Area dependence of temperature dependence of THESAT.

116 `thesatbo=0.0 V^-1` Back-bias dependence of velocity saturation.

117 `thesatgo=0.0 V^-1` Gate-bias dependence of velocity saturation.

118 `axo=18` Geometry independent linear/saturation transition factor.

119 `axl=0.4` Length dependence of AX.

120 `alpl=5e-4` Length dependence of ALP.

121 `alplexp=1.0` Exponent for length dependence of ALP.

122 `alpw=0.0` Width dependence of ALP.

123 `alp1l1=0.0 V`	Length dependence of CLM enhancement factor above threshold.
124 `alp1lexp=0.5`	Exponent for length dependence of ALP1.
125 `alp1l2=0.0`	Second_order length dependence of ALP1.
126 `alp1w=0.0`	Width dependence of ALP1.
127 `alp2l1=0.0 V^-1`	Length dependence of CLM enhancement factor below threshold.
128 `alp2lexp=0.5`	Exponent for length dependence of ALP2.
129 `alp2l2=0.0`	Second_order length dependence of ALP2.
130 `alp2w=0.0`	Width dependence of ALP2.
131 `vpo=0.05 V`	CLM logarithmic dependence parameter.
132 `a1o=1.0`	Geometry independent impact-ionization pre-factor.
133 `a1l=0.0`	Length dependence of A1.
134 `a1w=0.0`	Width dependence of A1.
135 `a2o=10 V`	Impact-ionization exponent at TR.
136 `sta2o=0.0 V`	Temperature dependence of A2.
137 `a3o=1.0`	Geometry independent saturation-voltage dependence of II.
138 `a3l=0.0`	Length dependence of A3.
139 `a3w=0.0`	Width dependence of A3.
140 `a4o=0.0 V^-0.5`	Geometry independent back-bias dependence of II.
141 `a4l=0.0`	Length dependence of A4.
142 `a4w=0.0`	Width dependence of A4.
143 `gcoo=0.0`	Gate tunnelling energy adjustment.

144 `iginvlw=0.0 A`	Gate channel current pre-factor for 1 um^2 channel area.
145 `igovw=0.0 A`	Gate overlap current pre-factor for 1 um wide channel.
146 `igovdw=0.0 A`	Gate overlap current pre-factor for 1 um wide channel for drain side.
147 `stigo=2.0`	Temperature dependence of IGINV and IGOV.
148 `gc2o=0.375`	Gate current slope factor.
149 `gc3o=0.063`	Gate current curvature factor.
150 `chibo=3.1 V`	Tunnelling barrier height.
151 `agidlw=0.0` A/V^3	Width dependence of GIDL pre-factor.
152 `agidldw=0.0` A/V^3	Width dependence of GIDL pre-factor for drain side.
153 `bgidlo=41 V`	GIDL probability factor at TR.
154 `bgidldo=41 V`	GIDL probability factor at TR for drain side.
155 `stbgidlo=0.0 V/K`	Temperature dependence of BGIDL.
156 `stbgidldo=0.0 V/K`	Temperature dependence of BGIDL for drain side.
157 `cgidlo=0.0`	Back-bias dependence of GIDL.
158 `cgidldo=0.0`	Back-bias dependence of GIDL for drain side.
159 `cgbovl=0.0 F`	Oxide capacitance for gate-bulk overlap for 1 um long channel.
160 `cfrw=0.0 F`	Outer fringe capacitance for 1 um wide channel.
161 `cfrdw=0.0 F`	Outer fringe capacitance for 1 um wide channel for drain side.
162 `fnto=1.0`	Thermal noise coefficient.
163 `nfalw=8e22` V^{-1}/m^4	First coefficient of flicker noise for 1 um^2 channel area.

164 `nfblw=3e7 V^-1/m`^{2}
Second coefficient of flicker noise for 1 um^2 channel area.

165 `nfclw=0.0 V^-1` Third coefficient of flicker noise for 1 um^2 channel area.

166 `efo=1.0` Flicker noise frequency exponent.

167 `lintnoi=0.0 m` Length offset for flicker noise.

168 `alpnoi=2.0` Exponent for length offset for flicker noise.

169 `dta=0 K` Temperature offset w.r.t. ambient circuit temperature.

170 `kvthoweo=0` Geometrical independent threshold shift parameter.

171 `kvthowel=0` Length dependent threshold shift parameter.

172 `kvthowew=0` Width dependent threshold shift parameter.

173 `kvthowelw=0` Area dependent threshold shift parameter.

174 `kuoweo=0` Geometrical independent mobility degradation factor.

175 `kuowel=0` Length dependent mobility degradation factor.

176 `kuowew=0` Width dependent mobility degradation factor.

177 `kuowelw=0` Area dependent mobility degradation factor.

178 `vds_max=∞ V`
Maximum allowed voltage cross source and drain.

179 `vgd_max=∞ V`
Maximum allowed voltage cross gate and drain.

180 `vgs_max=∞ V`
Maximum allowed voltage cross gate and source/bulk.

181 `vbd_max=∞ V`
Maximum allowed voltage cross source/drain and bulk.

182 `vbs_max=∞ V`
Maximum allowed voltage cross source and bulk.

183 `vgb_max=∞ V`
Maximum allowed voltage cross gate and bulk.

184 `vgdr_max=∞ V`
Maximum allowed reverse voltage cross gate and drain.

185 `vgsr_max=∞ V`
Maximum allowed reverse voltage cross gate and source.

186 `vgbr_max=∞ V`
Maximum allowed reverse voltage cross gate and bulk.

187 `munqso=1.0` Relative mobility for NQS modeling.

188 `rgo=0.0 Ω` Gate resistance.

189 `rbulko=0.0 Ω` Bulk resistance between node BP and BI.

190 `rwello=0.0 Ω` Well resistance between node BI and B.

191 `rjunso=0.0 Ω` Source-side bulk resistance between node BI and BS.

192 `rjundo=0.0 Ω` Drain-side bulk resistance between node BI and BD.

193 `rint=0.0 Ω/Sqr` Contact resistance between silicide and ploy.

194 `rvpoly=0.0 Ω/Sqr`
Vertical poly resistance.

195 `rshg=0.0 Ω/Sqr` Gate electrode diffusion sheet resistance.

196 `dlsil=0.0 m` Silicide extension over the physical gate length.

197 `saref=1.0e-6 m` Reference distance between OD-edge and poly from one side.

198 `sbref=1.0e-6 m` Reference distance between OD-edge and poly from other side.

199 `wlod=0 m` Width parameter.

200 `kuo=0 m` Mobility degradation/enhancement coefficient.

201 `kvsat=0 m` Saturation velocity degradation/enhancement coefficient.

202 `tkuo=0` Temperature dependence of KUO.

203 `lkuo=0 m^LLODKUO` Length dependence of KUO.

204 `wkuo=0 m^WLODKUO` Width dependence of KUO.

205 `pkuo=0 m^(LLODKUO+WLODKUO)`
Cross-term dependence of KUO.

206 `llodkuo=0` Length parameter for UO stress effect.

207 `wlodkuo=0` Width parameter for UO stress effect.

208 `kvtho=0 Vm` Threshold shift parameter.

209 `lkvtho=0 m^LLODVTH`
Length dependence of KVTHO.

210 `wkvtho=0 m^WLODVTH`
Width dependence of KVTHO.

211 `pkvtho=0 m^(LLODVTH+WLODVTH)`
Cross-term dependence of KVTHO.

212 `llodvth=0` Length parameter for VTH-stress effect.

213 `wlodvth=0` Width parameter for VTH-stress effect.

214 `stetao=0 m` eta0 shift factor related to VTHO change.

215 `lodetao=1.0` eta0 shift modifaction factor for stress effect.

216 `scref=10e-6 m` Distance between OD-edge and well edge of a reference device.

217 `web=0` Coeffecient for SCB.

218 `wec=0` Coeffecient for SCC.

219 `imax=1000 A` Maximum current up to which forward current behaves exponentially.

220 `trj=21 C` reference temperature.

221 `cjorbot=1E-3 Fm`$^{-2}$
Zero-bias capacitance per unit-of-area of bottom component for source-bulk junction.

222 `cjorsti=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for source-bulk junction.

223 `cjorgat=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for source-bulk junction.

224 `vbirbot=1 V`
Built-in voltage at the reference temperature of bottom component for source-bulk junction.

225 `vbirsti=1 V`
Built-in voltage at the reference temperature of STI-edge component for source-bulk junction.

226 `vbirgat=1 V`
Built-in voltage at the reference temperature of gate-edge component for source-bulk junction.

227 `pbot=0.5`
Grading coefficient of bottom component for source-bulk junction.

228 `psti=0.5`
Grading coefficient of STI-edge component for source-bulk junction.

229 `pgat=0.5`
Grading coefficient of gate-edge component for source-bulk junction.

230 `phigbot=1.16 V`
Zero-temperature bandgap voltage of bottom component for source-bulk junction.

231 `phigsti=1.16 V`
Zero-temperature bandgap voltage of STI-edge component for source-bulk junction.

232 `phiggat=1.16 V`
Zero-temperature bandgap voltage of gate-edge component for source-bulk junction.

233 `idsatrbot=1E-12 Am`$^{-2}$
Saturation current density at the reference temperature of bottom component for source-bulk junction.

234 `idsatrsti=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for source-bulk junction.

235 `idsatrgat=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for source-bulk junction.

236 `csrhbot=1E2` Am^{-3}
Shockley-Read-Hall prefactor of bottom component for source-bulk junction.

237 `csrhsti=1E-4` Am^{-2}
Shockley-Read-Hall prefactor of STI-edge component for source-bulk junction.

238 `csrhgat=1E-4` Am^{-2}
Shockley-Read-Hall prefactor of gate-edge component for source-bulk junction.

239 `xjunsti=100E-9 m`
Junction depth of STI-edge component for source-bulk junction.

240 `xjungat=100E-9 m`
Junction depth of gate-edge component for source-bulk junction.

241 `ctatbot=1E2` Am^{-3}
Trap-assisted tunneling prefactor of bottom component for source-bulk junction.

242 `ctatsti=1E-4` Am^{-2}
Trap-assisted tunneling prefactor of STI-edge component for source-bulk junction.

243 `ctatgat=1E-4` Am^{-2}
Trap-assisted tunneling prefactor of gate-edge component for source-bulk junction.

244 `mefftatbot=0.25`
Effective mass (in units of m0) for trap-assisted tunneling of bottom component for source-bulk junction.

245 `mefftatsti=0.25`
Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for source-bulk junction.

246 `mefftatgat=0.25`
Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for source-bulk junction.

247 `cbbtbot=1E-12 AV`$^{-3}$
Band-to-band tunneling prefactor of bottom component for source-bulk junction.

248 `cbbtsti=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of STI-edge component for source-bulk junction.

249 `cbbtgat=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of gate-edge component for source-bulk junction.

250 `fbbtrbot=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component for source-bulk junction.

251 `fbbtrsti=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for source-bulk junction.

252 `fbbtrgat=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for source-bulk junction.

253 `stfbbtbot=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for source-bulk junction.

254 `stfbbtsti=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for source-bulk junction.

255 `stfbbtgat=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for source-bulk junction.

256 `vbrbot=10 V` Breakdown voltage of bottom component for source-bulk junction.

257 `vbrsti=10 V` Breakdown voltage of STI-edge component for source-bulk junction.

258 `vbrgat=10 V` Breakdown voltage of gate-edge component for source-bulk junction.

259 `pbrbot=4 V` Breakdown onset tuning parameter of bottom component for source-bulk junction.

260 `pbrsti=4 V` Breakdown onset tuning parameter of STI-edge component for source-bulk junction.

261 `pbrgat=4 V` Breakdown onset tuning parameter of gate-edge component for source-bulk junction.

262 `cjorbotd=1E-3 Fm`$^{-2}$
Zero-bias capacitance per unit-of-area of bottom component for drain-bulk junction.

263 `cjorstid=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for drain-bulk junction.

264 `cjorgatd=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for drain-bulk junction.

265 `vbirbotd=1 V` Built-in voltage at the reference temperature of bottom component for drain-bulk junction.

266 `vbirstid=1 V` Built-in voltage at the reference temperature of STI-edge component for drain-bulk junction.

267 `vbirgatd=1 V` Built-in voltage at the reference temperature of gate-edge component for drain-bulk junction.

268 `pbotd=0.5` Grading coefficient of bottom component for drain-bulk junction.

269 `pstid=0.5` Grading coefficient of STI-edge component for drain-bulk junction.

270 `pgatd=0.5` Grading coefficient of gate-edge component for drain-bulk junction.

271 `phigbotd=1.16 V` Zero-temperature bandgap voltage of bottom component for drain-bulk junction.

272 `phigstid=1.16 V` Zero-temperature bandgap voltage of STI-edge component for drain-bulk junction.

273 `phiggatd=1.16 V` Zero-temperature bandgap voltage of gate-edge component for drain-bulk junction.

274 `idsatrbotd=1E-12 Am`$^{-2}$
Saturation current density at the reference temperature of bottom component for drain-bulk junction.

275 `idsatrstid=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for drain-bulk junction.

276 `idsatrgatd=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for drain-bulk junction.

277 `csrhbotd=1E2 Am`$^{-3}$
Shockley-Read-Hall prefactor of bottom component for drain-bulk junction.

278 `csrhstid=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of STI-edge component for drain-bulk junction.

279 `csrhgatd=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of gate-edge component for drain-bulk junction.

280 `xjunstid=100E-9 m` Junction depth of STI-edge component for drain-bulk junction.

281 `xjungatd=100E-9 m` Junction depth of gate-edge component for drain-bulk junction.

282 `ctatbotd=1E2 Am`$^{-3}$
Trap-assisted tunneling prefactor of bottom component for drain-bulk junction.

283 `ctatstid=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of STI-edge component for drain-bulk junction.

284 `ctatgatd=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of gate-edge component for drain-bulk junction.

285 `mefftatbotd=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component for drain-bulk junction.

286 `mefftatstid=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for drain-bulk junction.

287 `mefftatgatd=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for drain-bulk junction.

288 `cbbtbotd=1E-12 AV`$^{-3}$
Band-to-band tunneling prefactor of bottom component for drain-bulk junction.

289 `cbbtstid=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of STI-edge component for drain-bulk junction.

290 `cbbtgatd=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of gate-edge component for drain-bulk junction.

291 `fbbtrbotd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component for drain-bulk junction.

292 `fbbtrstid=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for drain-bulk junction.

293 `fbbtrgatd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for drain-bulk junction.

294 `stfbbtbotd=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for drain-bulk junction.

295 `stfbbtstid=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for drain-bulk junction.

296 `stfbbtgatd=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for drain-bulk junction.

297 `vbrbotd=10 V` Breakdown voltage of bottom component for drain-bulk junction.

298 `vbrstid=10 V` Breakdown voltage of STI-edge component for drain-bulk junction.

299 `vbrgatd=10 V` Breakdown voltage of gate-edge component for drain-bulk junction.

300 `pbrbotd=4 V` Breakdown onset tuning parameter of bottom component for drain-bulk junction.

301 `pbrstid=4 V` Breakdown onset tuning parameter of STI-edge component for drain-bulk junction.

302 `pbrgatd=4 V` Breakdown onset tuning parameter of gate-edge component for drain-bulk junction.

303 `swjunexp=0.0` Flag for JUNCAP-express; 0,full model, 1,express model.

304 `vjunref=2.5` Typical maximum source-bulk junction voltage; usually about 2*VSUP.

305 `fjunq=0.03` Fraction below which source-bulk junction capacitance components are considered negligible.

306 `vjunrefd=2.5` Typical maximum drain-bulk junction voltage; usually about 2*VSUP.

307 `fjunqd=0.03` Fraction below which drain-bulk junction capacitance components are considered negligible.

308 `mvto=0.0` DCmatch parameter.

309 `mbeo=0.0` DCmatch parameter.

310 `vthmod` Vth output selector. 'std' outputs model equation Vth. 'vthcc' outputs constant current Vth, and may impact simulation performance. The default value is taken from the options parameter 'vthmod'.
Possible values are `std` and `vthcc`.

311 `ivth (A)` Vth current parameter. The default value is taken from the options parameter 'ivthn' or 'ivthp', depending on the type of the model.

312 `ivthw (m)` Width offset for constant current Vth. The default value is taken from the options parameter 'ivthw'.

313 `ivthl (m)` Length offset for constant current Vth. The default value is taken from the options parameter 'ivthl'.

314 `ivth_vdsmin (V)` Minimum Vds in constant current Vth calculating. The default value is taken from the options parameter 'ivth_vdsmin'.

315 `noisemethod=oldcmi`
Induced gate noise implementation .
Possible values are `oldcmi`, `subckt`, and `newcmi`.

Output Parameters

1 `weff (m)` Effective channel width for geometrical models.

2 `leff (m)` Effective channel length for geometrical models.

3 `lv1 (m)` alias of l.

4 `lv2 (m)` alias of w.

5 `lv3` (m^2) alias of ad.

6 `lv4` (m^2) alias of as.

7 `lv11 (m)` alias of pd.

8 `lv12 (m)` alias of ps.

Operating-Point Parameters

1 `ctype` — Flag for channel type.

2 `sdint` — Flag for source-drain interchange.

3 `ise (A)` — Total source current.

4 `ige (A)` — Total gate current.

5 `ide (A)` — Total drain current.

6 `ibe (A)` — Total bulk current.

7 `ids (A)` — Drain current, excl. avalanche, tunnel, GISL, GIDL, and junction currents.

8 `idb (A)` — Drain to bulk current.

9 `isb (A)` — Source to bulk current.

10 `igs (A)` — Gate-source tunneling current.

11 `igd (A)` — Gate-drain tunneling current.

12 `igb (A)` — Gate-bulk tunneling current.

13 `igcs (A)` — Gate-channel tunneling current (source component).

14 `igcd (A)` — Gate-channel tunneling current (drain component).

15 `iavl (A)` — Substrate current due to weak avelanche.

16 `igisl (A)` — Gate-induced source leakage current.

17 `igidl (A)` — Gate-induced drain leakage current.

18 `ijs (A)` — Total source junction current.

19 `ijsbot (A)` — Source junction current (bottom component).

20 `ijsgat (A)` — Source junction current (gate-edge component).

21 `ijssti (A)`	Source junction current (STI-edge component).
22 `ijd (A)`	Total drain junction current.
23 `ijdbot (A)`	Drain junction current (bottom component).
24 `ijdgat (A)`	Drain junction current (gate-edge component).
25 `ijdsti (A)`	Drain junction current (STI-edge component).
26 `qg (Coul)`	Intrinsic gate charge.
27 `qd (Coul)`	Intrinsic drain charge.
28 `qb (Coul)`	Intrinsic bulk charge.
29 `qs (Coul)`	Intrinsic source charge.
30 `qgs_ov (Coul)`	Overlap charge for gate-source.
31 `qgd_ov (Coul)`	Overlap charge for gate-drain.
32 `qfgs (Coul)`	Total outerFringe + overlap for gate-source.
33 `qfgd (Coul)`	Total outerFringe + overlap for gate-drain.
34 `qgb_ov (Coul)`	Gate-bulk overlap charge.
35 `qjun_s (Coul)`	Junction charge on source side.
36 `qjun_d (Coul)`	Junction charge on drain side.
37 `vds (V)`	Drain-source voltage.
38 `vgs (V)`	Gate-source voltage.
39 `vsb (V)`	Source-bulk voltage.
40 `vto (V)`	Zero-bias threshold voltage.
41 `vts (V)`	Threshold voltage including back bias effects.
42 `vth (V)`	Threshold voltage including back bias and drain bias effects.

43 `vgt (V)`	Effective gate drive voltage including back bias and drain bias effects.
44 `vdss (V)`	Drain saturation voltage at actual bias.
45 `vsat (V)`	Saturation limit.
46 `pwr (W)`	Power at op point.
47 `gm (1/Ω)`	Transconductance.
48 `gmb (1/Ω)`	Substrate transconductance.
49 `gds (1/Ω)`	Output conductance.
50 `gjs (1/Ω)`	Source junction conductance.
51 `gjd (1/Ω)`	Drain junction conductance.
52 `cdd (F)`	Drain capacitance.
53 `cdg (F)`	Drain-gate capacitance.
54 `cds (F)`	Drain-source capacitance.
55 `cdb (F)`	Drain-bulk capacitance.
56 `cgd (F)`	Gate-drain capacitance.
57 `cgg (F)`	Gate capacitance.
58 `cgs (F)`	Gate-source capacitance.
59 `cgb (F)`	Gate-bulk capacitance.
60 `csd (F)`	Source-drain capacitance.
61 `csg (F)`	Source-gate capacitance.
62 `css (F)`	Source capacitance.
63 `csb (F)`	Source-bulk capacitance.

64 `cbd (F)`	Bulk-drain capacitance.
65 `cbg (F)`	Bulk-gate capacitance.
66 `cbs (F)`	Bulk-source capacitance.
67 `cbb (F)`	Bulk capacitance.
68 `cgsol (F)`	Total gate-source overlap capacitance.
69 `cgdol (F)`	Total gate-drain overlap capacitance.
70 `cgbol (F)`	Total gate-bulk overlap capacitance.
71 `cjs (F)`	Total source junction capacitance.
72 `cjsbot (F)`	Source junction capacitance (bottom component).
73 `cjsgat (F)`	Source junction capacitance (gate-edge component).
74 `cjssti (F)`	Source junction capacitance (STI-edge component).
75 `cjd (F)`	Total drain junction capacitance.
76 `cjdbot (F)`	Drain junction capacitance (bottom component).
77 `cjdgat (F)`	Drain junction capacitance (gate-edge component).
78 `cjdsti (F)`	Drain junction capacitance (STI-edge component).
79 `lpoly (m)`	
80 `u`	Transistor gain.
81 `rout (Ω)`	Small-signal output resistance.
82 `vearly (V)`	Equivalent Early voltage.
83 `beff` (A/V^2)	Gain factor.
84 `fug (Hz)`	Unity gain frequency at actual bias.
85 `rg (Ω)`	Gate resistance.

86 `sfl (A`^{2}`/Hz)`	Flicker noise current spectral density at 1 Hz.
87 `sqrtsff` $(V/\sqrt{Hz})$	Input-referred RMS white noise voltage spectral density at 1 kHz.
88 `sqrtsfw` $(V/\sqrt{Hz})$	Input-referred RMS white noise voltage spectral density.
89 `sid (A`^{2}`/Hz)`	White noise current spectral density.
90 `sig (A`^{2}`/Hz)`	Induced gate noise current spectral density at 1 Hz.
91 `cigid`	Imaginary part of correlation coefficient between Sig and Sid.
92 `fknee (Hz)`	Cross-over frequency above which white noise is dominant.
93 `sigs (A`^{2}`/Hz)`	Gate-source current noise spectral density.
94 `sigd (A`^{2}`/Hz)`	Gate-drain current noise spectral density.
95 `siavl (A`^{2}`/Hz)`	Impact ionization current noise spectral density.
96 `ssi (A`^{2}`/Hz)`	Total source junction current noise spectral density.
97 `sdi (A`^{2}`/Hz)`	Total drain junction current noise spectral density.
98 `vbs (V)`	Bulk-source voltage.
99 `lv9 (V)`	alias of vth.
100 `lv10 (V)`	alias of vdss.
101 `lv36 (F)`	alias of cgsol.
102 `lv37 (F)`	alias of cgdol.
103 `lv38 (F)`	alias of cgbol.
104 `lv51 (m)`	alias of tox.
105 `lx4 (A)`	alias of ids.
106 `lx3 (V)`	alias of vds.

107 `lx2 (V)` alias of vgs.

108 `lx7 (1/Ω)` alias of gm.

109 `lx8 (1/Ω)` alias of gds.

110 `lx9 (1/Ω)` alias of gmb.

111 `lx33 (F)` alias of cdd.

112 `lx32 (F)` alias of cdg.

113 `lx34 (F)` alias of cds.

114 `lx19 (F)` alias of cgd.

115 `lx18 (F)` alias of cgg.

116 `lx20 (F)` alias of cgs.

117 `lx22 (F)` alias of cbd.

118 `lx21 (F)` alias of cbg.

119 `lx23 (F)` alias of cbs.

120 `lx5 (A)` alias of ijs.

121 `lx6 (A)` alias of ijd.

122 `lx28 (F)` alias of cjs.

123 `lx29 (F)` alias of cjd.

124 `lx38 (A)` alias of igs.

125 `lx39 (A)` alias of igd.

126 `lx66 (A)` alias of igb.

127 `lx67 (A)` alias of igcs.

128 `lx68 (A)` alias of igcd.

129 `lx110 (A)` alias of igisl.

130 `lx47 (A)` alias of igidl.

131 `lx60 (F)` alias of csd.

132 `lx59 (F)` alias of csg.

133 `lx58 (F)` alias of css.

134 `lx12 (Coul)` alias of Qb including overlap charge.

135 `lx14 (Coul)` alias of Qg including overlap charge.

136 `lx16 (Coul)` alias of Qd including overlap charge.

137 `lx83 (F)` alias of cgd including overlap cap.

138 `lx84 (F)` alias of cgs including overlap cap.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

a1l M-133	factuo I-11	lx23 OP-119	ssi OP-96
a1o M-132	fbbtrbot M-250	lx28 OP-122	sta2o M-136
a1w M-134	fbbtrbotd M-291	lx29 OP-123	stbetl M-82
a2o M-135	fbbtrgat M-252	lx3 OP-106	stbetlw M-84
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a3w M-139	fbbtrstid M-292	lx34 OP-113	stbgidldo M-156

PSP MOSFET Model (psp1021)

This is SiMKit 4.0.1.

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `l=10e-6 m` Design length.

2 `w=10e-6 m`	Design width.
3 `sa=0.0 m`	Distance between OD-edge and poly from one side.
4 `sb=0.0 m`	Distance between OD-edge and poly from other side.
5 `sd=0.0 m`	Distance between neighboring fingers.
6 `sca=0.0`	Integral of the first distribution function for scattered well dopants.
7 `scb=0.0`	Integral of the second distribution function for scattered well dopants.
8 `scc=0.0`	Integral of the third distribution function for scattered well dopants.
9 `sc=0.0 m`	Distance between OD-edge and nearest well edge.
10 `delvto=0.0 V`	Threshold voltage shift parameter.
11 `factuo=1.0`	Zero-field mobility pre-factor.
12 `absource=1E-12` m^2	Bottom area of source junction.
13 `lssource=1E-6 m`	STI-edge length of source junction.
14 `lgsource=1E-6 m`	Gate-edge length of source junction.
15 `abdrain=1E-12` m^2	Bottom area of drain junction.
16 `lsdrain=1E-6 m`	STI-edge length of drain junction.
17 `lgdrain=1E-6 m`	Gate-edge length of drain junction.
18 `as=1E-12` m^2	Bottom area of source junction.
19 `ps=1E-6 m`	Perimeter of source junction.
20 `ad=1E-12` m^2	Bottom area of drain junction.
21 `pd=1E-6 m`	Perimeter of drain junction.

22 `mulid0=1` Ids multiplier.

23 `mult=1.0` Number of devices in parallel.

24 `nf=1.0` Number of fingers.

25 `ngcon=1.0` Number of gate contacts.

26 `xgw=1.0E-7 m` Distance from the gate contact to the channel edge.

27 `trise=0.0 K` Temperature rise from ambient.

28 `m=1.0` Multiplicity factor.

29 `isnoisy=yes` Should device generate noise.
Possible values are `no` and `yes`.

Model Definition

model modelName psp1021 parameter=value ...

Model Parameters

1 `level=102` Model level.

2 `type=n` Channel type parameter, n,NMOS p,PMOS.
Possible values are `n` and `p`.

3 `tr=value of tnom C`
nominal (reference) temperature.

4 `swnqs=0` Flag for NQS, 0,off, 1, 2, 3, 5, or 9,number of collocation points.

5 `swigate=0` Flag for gate current, 0,turn off IG.

6 `swimpact=0` Flag for impact ionization current, 0,turn off II.

7 `swgidl=0` Flag for GIDL current, 0,turn off IGIDL.

8 `swjuncap=0` Flag for juncap, 0,turn off juncap.

9 `swjunasym=0` Flag for asymmetric junctions; 0,symmetric, 1,asymmetric.

10 `qmc=1.0` Quantum-mechanical correction factor.

11 `version=102.32` The available versions are 102.2, 102.21, 102.3, 102.32, 102.33, 102.34 and 102.40.

12 `geomod=1` 1 for geometrical model and 0 for electrical model.

13 `binmod=0` 1 for bin model and 0 for non-bin model.

14 `scalelev=102` 102 for local, 1020 for global model and 1021 for bin model.

15 `compatible=spectre`
for compatible.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, and `mica`.

16 `lvaro=0.0 m` Geom. independent difference between actual and programmed gate length.

17 `lvarl=0.0` Length dependence of LVAR.

18 `lap=0.0 m` Effective channel length reduction per side.

19 `wvaro=0.0 m` Geom. independent difference between actual and programmed field-oxide opening.

20 `wvarw=0.0` Width dependence of WVAR.

21 `wot=0.0 m` Effective channel width reduction per side.

22 `dlq=0.0 m` Effective channel length reduction for CV.

23 `dwq=0.0 m` Effective channel width reduction for CV.

24 `povfb=(-1) V` Coefficient for the geometry independent part of VFB.

25 `plvfb=0.0 V` Coefficient for the length dependence of VFB.

26 `pwvfb=0.0 V` Coefficient for the width dependence of VFB.

27 `plwvfb=0.0 V` Coefficient for the length times width dependence of VFB.

28 `postvfb=0.0005 V/K`
Coefficient for the geometry independent part of STVFB.

29 `plstvfb=0.0 V/K` Coefficient for the length dependence of STVFB.

30 `pwstvfb=0.0 V/K` Coefficient for the width dependence of STVFB.

31 `plwstvfb=0.0 V/K` Coefficient for the length times width dependence of STVFB.

32 `potox=2E-09 m` Coefficient for the geometry independent part of TOX.

33 `poepsrox=3.9` Coefficient for the geometry independent part of EPSOX.

34 `poneff=5E+23 m`$^{-3}$ Coefficient for the geometry independent part of NEFF.

35 `plneff=0.0 m`$^{-3}$ Coefficient for the length dependence of NEFF.

36 `pwneff=0.0 m`$^{-3}$ Coefficient for the width dependence of NEFF.

37 `plwneff=0.0 m`$^{-3}$ Coefficient for the length times width dependence of NEFF.

38 `povnsub=0 V` Coefficient for the geometry independent part of VNSUB.

39 `ponslp=0.05 V` Coefficient for the geometry independent part of NSLP.

40 `podnsub=0 V^-1` Coefficient for the geometry independent part of DNSUB.

41 `podphib=0 V` Coefficient for the geometry independent part of DPHIB.

42 `pldphib=0.0 V` Coefficient for the length dependence of DPHIB.

43 `pwdphib=0.0 V` Coefficient for the width dependence of DPHIB.

44 `plwdphib=0.0 V` Coefficient for the length times width dependence of DPHIB.

45 `ponp=1E+26 m`$^{-3}$ Coefficient for the geometry independent part of NP.

46 `plnp=0.0 m`$^{-3}$ Coefficient for the length dependence of NP.

47 `pwnp=0.0 m`$^{-3}$ Coefficient for the width dependence of NP.

48 `plwnp=0.0 m`$^{-3}$ Coefficient for the length times width dependence of NP.

49 `poct=0` Coefficient for the geometry independent part of CT.

50 `plct=0.0` Coefficient for the length dependence of CT.

51 `pwct=0.0` Coefficient for the width dependence of CT.

52 `plwct=0.0` Coefficient for the length times width dependence of CT.

53 `potoxov=2E-09 m` Coefficient for the geometry independent part of TOXOV.

54 `potoxovd=2E-09 m` Coefficient for the geometry independent part of TOXOV for drain side.

55 `ponov=5E+25 m`$^{-3}$ Coefficient for the geometry independent part of NOV.

56 `plnov=0.0 m`$^{-3}$ Coefficient for the length dependence of NOV.

57 `pwnov=0.0 m`$^{-3}$ Coefficient for the width dependence of NOV.

58 `plwnov=0.0 m`$^{-3}$ Coefficient for the length times width dependence of NOV.

59 `ponovd=5E+25 m`$^{-3}$ Coefficient for the geometry independent part of NOV for drain side.

60 `plnovd=0.0 m`$^{-3}$ Coefficient for the length dependence of NOV for drain side.

61 `pwnovd=0.0 m`$^{-3}$ Coefficient for the width dependence of NOV for drain side.

62 `plwnovd=0.0 m`$^{-3}$ Coefficient for the length times width dependence of NOV for drain side.

63 `pocf=0` Coefficient for the geometry independent part of CF.

64 `plcf=0.0` Coefficient for the length dependence of CF.

65 `pwcf=0.0` Coefficient for the width dependence of CF.

66 `plwcf=0.0` Coefficient for the length times width dependence of CF.

67 `pocfb=0 V^-1` Coefficient for the geometry independent part of CFB.

68 `pobetn=0.07 m`^{2}`/V/s`
Coefficient for the geometry independent part of BETN.

69 `plbetn=0.0 m^2/V/s`
Coefficient for the length dependence of BETN.

70 `pwbetn=0.0 m^2/V/s`
Coefficient for the width dependence of BETN.

71 `plwbetn=0.0 m^2/V/s`
Coefficient for the length times width dependence of BETN.

72 `postbet=1` Coefficient for the geometry independent part of STBET.

73 `plstbet=0.0` Coefficient for the length dependence of STBET.

74 `pwstbet=0.0` Coefficient for the width dependence of STBET.

75 `plwstbet=0.0` Coefficient for the length times width dependence of STBET.

76 `pomue=0.5 m/V` Coefficient for the geometry independent part of MUE.

77 `plmue=0.0 m/V` Coefficient for the length dependence of MUE.

78 `pwmue=0.0 m/V` Coefficient for the width dependence of MUE.

79 `plwmue=0.0 m/V` Coefficient for the length times width dependence of MUE.

80 `postmue=0` Coefficient for the geometry independent part of STMUE.

81 `pothemu=1.5` Coefficient for the geometry independent part of THEMU.

82 `postthemu=1.5` Coefficient for the geometry independent part of STTHEMU.

83 `pocs=0` Coefficient for the geometry independent part of CS.

84 `plcs=0.0` Coefficient for the length dependence of CS.

85 `pwcs=0.0` Coefficient for the width dependence of CS.

86 `plwcs=0.0` Coefficient for the length times width dependence of CS.

87 `postcs=0` Coefficient for the geometry independent part of STCS.

88 `poxcor=0 V^-1` Coefficient for the geometry independent part of XCOR.

89 `plxcor=0.0 V^-1` Coefficient for the length dependence of XCOR.

90 `pwxcor=0.0 V^-1` Coefficient for the width dependence of XCOR.

91 `plwxcor=0.0 V^-1` Coefficient for the length times width dependence of XCOR.

92 `postxcor=0` Coefficient for the geometry independent part of STXCOR.

93 `pofeta=1` Coefficient for the geometry independent part of FETA.

94 `pors=30 Ω` Coefficient for the geometry independent part of RS.

95 `plrs=0.0 Ω` Coefficient for the length dependence of RS.

96 `pwrs=0.0 Ω` Coefficient for the width dependence of RS.

97 `plwrs=0.0 Ω` Coefficient for the length times width dependence of RS.

98 `postrs=1` Coefficient for the geometry independent part of STRS.

99 `porsb=0 V^-1` Coefficient for the geometry independent part of RSB.

100 `porsg=0 V^-1` Coefficient for the geometry independent part of RSG.

101 `pothesat=1 V^-1` Coefficient for the geometry independent part of THESAT.

102 `plthesat=0.0 V^-1` Coefficient for the length dependence of THESAT.

103 `pwthesat=0.0 V^-1` Coefficient for the width dependence of THESAT.

104 `plwthesat=0.0 V^-1`
Coefficient for the length times width dependence of THESAT.

105 `postthesat=1` Coefficient for the geometry independent part of STTHESAT.

106 `plstthesat=0.0` Coefficient for the length dependence of STTHESAT.

107 `pwstthesat=0.0` Coefficient for the width dependence of STTHESAT.

108 `plwstthesat=0.0` Coefficient for the length times width dependence of STTHESAT.

109 `pothesatb=0 V^-1` Coefficient for the geometry independent part of THESATB.

110 `plthesatb=0.0 V^-1`
Coefficient for the length dependence of THESATB.

111 `pwthesatb=0.0 V^-1`
Coefficient for the width dependence of THESATB.

112 `plwthesatb=0.0 V^-1`
Coefficient for the length times width dependence of THESATB.

113 `pothesatg=0 V^-1` Coefficient for the geometry independent part of THESATG.

114 `plthesatg=0.0 V^-1`
Coefficient for the length dependence of THESATG.

115 `pwthesatg=0.0 V^-1`
Coefficient for the width dependence of THESATG.

116 `plwthesatg=0.0 V^-1`
Coefficient for the length times width dependence of THESATG.

117 `poax=3` Coefficient for the geometry independent part of AX.

118 `plax=0.0` Coefficient for the length dependence of AX.

119 `pwax=0.0` Coefficient for the width dependence of AX.

120 `plwax=0.0` Coefficient for the length times width dependence of AX.

121 `poalp=0.01` Coefficient for the geometry independent part of ALP.

122 `plalp=0.0` Coefficient for the length dependence of ALP.

123 `pwalp=0.0` Coefficient for the width dependence of ALP.

124 `plwalp=0.0` Coefficient for the length times width dependence of ALP.

125 `poalp1=0 V` Coefficient for the geometry independent part of ALP1.

126 `plalp1=0.0 V` Coefficient for the length dependence of ALP1.

127 `pwalp1=0.0 V` Coefficient for the width dependence of ALP1.

128 `plwalp1=0.0 V` Coefficient for the length times width dependence of ALP1.

129 `poalp2=0 V^-1` Coefficient for the geometry independent part of ALP2.

130 `plalp2=0.0 V^-1` Coefficient for the length dependence of ALP2.

131 `pwalp2=0.0 V^-1` Coefficient for the width dependence of ALP2.

132 `plwalp2=0.0 V^-1` Coefficient for the length times width dependence of ALP2.

133 `povp=0.05 V` Coefficient for the geometry independent part of VP.

134 `poa1=1` Coefficient for the geometry independent part of A1.

135 `pla1=0.0` Coefficient for the length dependence of A1.

136 `pwa1=0.0` Coefficient for the width dependence of A1.

137 `plwa1=0.0` Coefficient for the length times width dependence of A1.

138 `poa2=10 V` Coefficient for the geometry independent part of A2.

139 `posta2=0 V` Coefficient for the geometry independent part of STA2.

140 `poa3=1` Coefficient for the geometry independent part of A3.

141 `pla3=0.0` Coefficient for the length dependence of A3.

142 `pwa3=0.0` Coefficient for the width dependence of A3.

143 `plwa3=0.0` Coefficient for the length times width dependence of A3.

144 `poa4=0 V^-0.5` Coefficient for the geometry independent part of A4.

145 `pla4=0.0 V^-0.5` Coefficient for the length dependence of A4.

146 `pwa4=0.0 V^-0.5` Coefficient for the width dependence of A4.

147 `plwa4=0.0 V^-0.5` Coefficient for the length times width dependence of A4.

148 `pogco=0` Coefficient for the geometry independent part of GCO.

149 `poiginv=0 A` Coefficient for the geometry independent part of IGINV.

150 `pliginv=0.0 A` Coefficient for the length dependence of IGINV.

151 `pwiginv=0.0 A` Coefficient for the width dependence of IGINV.

152 `plwiginv=0.0 A` Coefficient for the length times width dependence of IGINV.

153 `poigov=0 A` Coefficient for the geometry independent part of IGOV.

154 `pligov=0.0 A` Coefficient for the length dependence of IGOV.

155 `pwigov=0.0 A` Coefficient for the width dependence of IGOV.

156 `plwigov=0.0 A` Coefficient for the length times width dependence of IGOV.

157 `poigovd=0 A` Coefficient for the geometry independent part of IGOV for drain side.

158 `pligovd=0.0 A` Coefficient for the length dependence of IGOV for drain side.

159 `pwigovd=0.0 A` Coefficient for the width dependence of IGOV for drain side.

160 `plwigovd=0.0 A` Coefficient for the length times width dependence of IGOV for drain side.

161 `postig=2` Coefficient for the geometry independent part of STIG.

162 `pogc2=0.375` Coefficient for the geometry independent part of GC2.

163 `pogc3=0.063` Coefficient for the geometry independent part of GC3.

164 `pochib=3.1 V` Coefficient for the geometry independent part of CHIB.

165 `poagidl=0` A/V^3 Coefficient for the geometry independent part of AGIDL.

166 `plagidl=0.0` A/V^3 Coefficient for the length dependence of AGIDL.

167 `pwagidl=0.0` A/V^3 Coefficient for the width dependence of AGIDL.

168 `plwagidl=0.0` A/V^3

Coefficient for the length times width dependence of AGIDL.

169 `poagidld=0` A/V^3 Coefficient for the geometry independent part of AGIDL for drain side.

170 `plagidld=0.0 A/V`^{3}
Coefficient for the length dependence of AGIDL for drain side.

171 `pwagidld=0.0 A/V`^{3}
Coefficient for the width dependence of AGIDL for drain side.

172 `plwagidld=0.0 A/V`^{3}
Coefficient for the length times width dependence of AGIDL for drain side.

173 `pobgidl=41 V` Coefficient for the geometry independent part of BGIDL.

174 `pobgidld=41 V` Coefficient for the geometry independent part of BGIDL for drain side.

175 `postbgidl=0 V/K` Coefficient for the geometry independent part of STBGIDL.

176 `postbgidld=0 V/K` Coefficient for the geometry independent part of STBGIDL for drain side.

177 `pocgidl=0` Coefficient for the geometry independent part of CGIDL.

178 `pocgidld=0` Coefficient for the geometry independent part of CGIDL for drain side.

179 `pocox=1E-14 F` Coefficient for the geometry independent part of COX.

180 `plcox=0.0 F` Coefficient for the length dependence of COX.

181 `pwcox=0.0 F` Coefficient for the width dependence of COX.

182 `plwcox=0.0 F` Coefficient for the length times width dependence of COX.

183 `pocgov=1E-15 F` Coefficient for the geometry independent part of CGOV.

184 `plcgov=0.0 F` Coefficient for the length dependence of CGOV.

185 `pwcgov=0.0 F` Coefficient for the width dependence of CGOV.

186 `plwcgov=0.0 F` Coefficient for the length times width dependence of CGOV.

187 `pocgovd=1E-15 F` Coefficient for the geometry independent part of CGOV for drain side.

188 `plcgovd=0.0 F` Coefficient for the length dependence of CGOV for drain side.

189 `pwcgovd=0.0 F` Coefficient for the width dependence of CGOV for drain side.

190 `plwcgovd=0.0 F` Coefficient for the length times width dependence of CGOV for drain side.

191 `pocgbov=0 F` Coefficient for the geometry independent part of CGBOV.

192 `plcgbov=0.0 F` Coefficient for the length dependence of CGBOV.

193 `pwcgbov=0.0 F` Coefficient for the width dependence of CGBOV.

194 `plwcgbov=0.0 F` Coefficient for the length times width dependence of CGBOV.

195 `pocfr=0 F` Coefficient for the geometry independent part of CFR.

196 `plcfr=0.0 F` Coefficient for the length dependence of CFR.

197 `pwcfr=0.0 F` Coefficient for the width dependence of CFR.

198 `plwcfr=0.0 F` Coefficient for the length times width dependence of CFR.

199 `pocfrd=0 F` Coefficient for the geometry independent part of CFR for drain side.

200 `plcfrd=0.0 F` Coefficient for the length dependence of CFR for drain side.

201 `pwcfrd=0.0 F` Coefficient for the width dependence of CFR for drain side.

202 `plwcfrd=0.0 F` Coefficient for the length times width dependence of CFR for drain side.

203 `pofnt=1` Coefficient for the geometry independent part of FNT.

204 `ponfa=8E+22 V^-1/m`^{4}
Coefficient for the geometry independent part of NFA.

205 `plnfa=0.0 V^-1/m`^{4}
Coefficient for the length dependence of NFA.

206 `pwnfa=0.0 V^-1/m`^{4}
Coefficient for the width dependence of NFA.

207 `plwnfa=0.0 V^-1/m`^{4}
Coefficient for the length times width dependence of NFA.

208 `ponfb=3E+07 V^-1/m`^{2}
Coefficient for the geometry independent part of NFB.

209 `plnfb=0.0 V^-1/m`^{2}
Coefficient for the length dependence of NFB.

210 `pwnfb=0.0 V^-1/m`^{2}
Coefficient for the width dependence of NFB.

211 `plwnfb=0.0 V^-1/m`^{2}
Coefficient for the length times width dependence of NFB.

212 `ponfc=0 V^-1` Coefficient for the geometry independent part of NFC.

213 `plnfc=0.0 V^-1` Coefficient for the length dependence of NFC.

214 `pwnfc=0.0 V^-1` Coefficient for the width dependence of NFC.

215 `plwnfc=0.0 V^-1` Coefficient for the length times width dependence of NFC.

216 `poef=1.0` Coefficient for the flicker noise frequency exponent.

217 `dta=0 K` Temperature offset w.r.t. ambient circuit temperature.

218 `pokvthowe=0` Coefficient for the geometry independent part of KVTHOWE.

219 `plkvthowe=0` Coefficient for the length dependence part of KVTHOWE.

220 `pwkvthowe=0` Coefficient for the width dependence part of KVTHOWE.

221 `plwkvthowe=0` Coefficient for the length times width dependence part of KVTHOWE.

222 `pokuowe=0` Coefficient for the geometry independent part of KUOWE.

223 `plkuowe=0` Coefficient for the length dependence part of KUOWE.

224 `pwkuowe=0` Coefficient for the width dependence part of KUOWE.

225 `plwkuowe=0` Coefficient for the length times width dependence part of KUOWE.

226 `lmin=0 m` Dummy parameter to label binning set.

227 `lmax=1.0 m` Dummy parameter to label binning set.

228 `wmin=0 m` Dummy parameter to label binning set.

229 `wmax=1.0 m` Dummy parameter to label binning set.

230 `vds_max=∞ V` Maximum allowed voltage cross source and drain.

231 `vgd_max=∞ V` Maximum allowed voltage cross gate and drain.

232 `vgs_max=∞ V` Maximum allowed voltage cross gate and source/bulk.

233 `vbd_max=∞ V` Maximum allowed voltage cross source/drain and bulk.

234 `vbs_max=∞ V` Maximum allowed voltage cross source and bulk.

235 `vgb_max=∞ V` Maximum allowed voltage cross gate and bulk.

236 `vgdr_max=∞ V` Maximum allowed reverse voltage cross gate and drain.

237 `vgsr_max=∞ V` Maximum allowed reverse voltage cross gate and source.

238 `vgbr_max=∞ V` Maximum allowed reverse voltage cross gate and bulk.

239 `munqso=1.0` Relative mobility for NQS modeling.

240 `rgo=0.0 Ω` Gate resistance.

241 `rbulko=0.0 Ω` Bulk resistance between node BP and BI.

242 `rwello=0.0 Ω` Well resistance between node BI and B.

243 `rjunso=0.0 Ω` Source-side bulk resistance between node BI and BS.

244 `rjundo=0.0 Ω` Drain-side bulk resistance between node BI and BD.

245 `rint=0.0 Ω/Sqr` Contact resistance between silicide and ploy.

246 `rvpoly=0.0 Ω/Sqr`
Vertical poly resistance.

247 `rshg=0.0 Ω/Sqr` Gate electrode diffusion sheet resistance.

248 `dlsil=0.0 m` Silicide extension over the physical gate length.

249 `saref=1.0e-6 m` Reference distance between OD-edge and poly from one side.

250 `sbref=1.0e-6 m` Reference distance between OD-edge and poly from other side.

251 `wlod=0 m` Width parameter.

252 `kuo=0 m` Mobility degradation/enhancement coefficient.

253 `kvsat=0 m` Saturation velocity degradation/enhancement coefficient.

254 `tkuo=0` Temperature dependence of KUO.

255 `lkuo=0 m^LLODKUO` Length dependence of KUO.

256 `wkuo=0 m^WLODKUO` Width dependence of KUO.

257 `pkuo=0 m^(LLODKUO+WLODKUO)`
Cross-term dependence of KUO.

258 `llodkuo=0` Length parameter for UO stress effect.

259 `wlodkuo=0` Width parameter for UO stress effect.

260 `kvtho=0 Vm` Threshold shift parameter.

261 `lkvtho=0 m^LLODVTH`
Length dependence of KVTHO.

262 `wkvtho=0 m^WLODVTH`
Width dependence of KVTHO.

263 `pkvtho=0 m^(LLODVTH+WLODVTH)`
Cross-term dependence of KVTHO.

264 `llodvth=0` Length parameter for VTH-stress effect.

265 `wlodvth=0` Width parameter for VTH-stress effect.

266 `stetao=0 m` eta0 shift factor related to VTHO change.

267 `lodetao=1.0` eta0 shift modifaction factor for stress effect.

268 `scref=10e-6 m` Distance between OD-edge and well edge of a reference device.

269 `web=0` Coeffecient for SCB.

270 `wec=0` Coeffecient for SCC.

271 `imax=1000 A` Maximum current up to which forward current behaves exponentially.

272 `trj=21 C` reference temperature.

273 `cjorbot=1E-3 Fm`$^{-2}$
Zero-bias capacitance per unit-of-area of bottom component for source-bulk junction.

274 `cjorsti=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for source-bulk junction.

275 `cjorgat=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for source-bulk junction.

276 `vbirbot=1 V` Built-in voltage at the reference temperature of bottom component for source-bulk junction.

277 `vbirsti=1 V` Built-in voltage at the reference temperature of STI-edge component for source-bulk junction.

278 `vbirgat=1 V` Built-in voltage at the reference temperature of gate-edge component for source-bulk junction.

279 `pbot=0.5` Grading coefficient of bottom component for source-bulk junction.

280 `psti=0.5` Grading coefficient of STI-edge component for source-bulk junction.

281 `pgat=0.5` Grading coefficient of gate-edge component for source-bulk junction.

282 `phigbot=1.16 V` Zero-temperature bandgap voltage of bottom component for source-bulk junction.

283 `phigsti=1.16 V` Zero-temperature bandgap voltage of STI-edge component for source-bulk junction.

284 `phiggat=1.16 V` Zero-temperature bandgap voltage of gate-edge component for source-bulk junction.

285 `idsatrbot=1E-12 Am`$^{-2}$
Saturation current density at the reference temperature of bottom component for source-bulk junction.

286 `idsatrsti=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for source-bulk junction.

287 `idsatrgat=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for source-bulk junction.

288 `csrhbot=1E2 Am`$^{-3}$ Shockley-Read-Hall prefactor of bottom component for source-bulk junction.

289 `csrhsti=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of STI-edge component for source-bulk junction.

290 `csrhgat=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of gate-edge component for source-bulk junction.

291 `xjunsti=100E-9 m` Junction depth of STI-edge component for source-bulk junction.

292 `xjungat=100E-9 m` Junction depth of gate-edge component for source-bulk junction.

293 `ctatbot=1E2 Am`$^{-3}$ Trap-assisted tunneling prefactor of bottom component for source-bulk junction.

294 `ctatsti=1E-4 Am`$^{-2}$

Trap-assisted tunneling prefactor of STI-edge component for source-bulk junction.

295 `ctatgat=1E-4 Am`$^{-2}$

Trap-assisted tunneling prefactor of gate-edge component for source-bulk junction.

296 `mefftatbot=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component for source-bulk junction.

297 `mefftatsti=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for source-bulk junction.

298 `mefftatgat=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for source-bulk junction.

299 `cbbtbot=1E-12 AV`$^{-3}$

Band-to-band tunneling prefactor of bottom component for source-bulk junction.

300 `cbbtsti=1E-18 AV`$^{-3}$`m`

Band-to-band tunneling prefactor of STI-edge component for source-bulk junction.

301 `cbbtgat=1E-18 AV`$^{-3}$`m`

Band-to-band tunneling prefactor of gate-edge component for source-bulk junction.

302 `fbbtrbot=1E9 Vm^-1`

Normalization field at the reference temperature for band-to-band tunneling of bottom component for source-bulk junction.

303 `fbbtrsti=1E9 Vm^-1`

Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for source-bulk junction.

304 `fbbtrgat=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for source-bulk junction.

305 `stfbbtbot=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for source-bulk junction.

306 `stfbbtsti=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for source-bulk junction.

307 `stfbbtgat=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for source-bulk junction.

308 `vbrbot=10 V` Breakdown voltage of bottom component for source-bulk junction.

309 `vbrsti=10 V` Breakdown voltage of STI-edge component for source-bulk junction.

310 `vbrgat=10 V` Breakdown voltage of gate-edge component for source-bulk junction.

311 `pbrbot=4 V` Breakdown onset tuning parameter of bottom component for source-bulk junction.

312 `pbrsti=4 V` Breakdown onset tuning parameter of STI-edge component for source-bulk junction.

313 `pbrgat=4 V` Breakdown onset tuning parameter of gate-edge component for source-bulk junction.

314 `cjorbotd=1E-3 Fm`$^{-2}$
Zero-bias capacitance per unit-of-area of bottom component for drain-bulk junction.

315 `cjorstid=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for drain-bulk junction.

316 `cjorgatd=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for drain-bulk junction.

317 `vbirbotd=1 V` Built-in voltage at the reference temperature of bottom component for drain-bulk junction.

318 `vbirstid=1 V` Built-in voltage at the reference temperature of STI-edge component for drain-bulk junction.

319 `vbirgatd=1 V` Built-in voltage at the reference temperature of gate-edge component for drain-bulk junction.

320 `pbotd=0.5` Grading coefficient of bottom component for drain-bulk junction.

321 `pstid=0.5` Grading coefficient of STI-edge component for drain-bulk junction.

322 `pgatd=0.5` Grading coefficient of gate-edge component for drain-bulk junction.

323 `phigbotd=1.16 V` Zero-temperature bandgap voltage of bottom component for drain-bulk junction.

324 `phigstid=1.16 V` Zero-temperature bandgap voltage of STI-edge component for drain-bulk junction.

325 `phiggatd=1.16 V` Zero-temperature bandgap voltage of gate-edge component for drain-bulk junction.

326 `idsatrbotd=1E-12 Am`$^{-2}$
Saturation current density at the reference temperature of bottom component for drain-bulk junction.

327 `idsatrstid=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for drain-bulk junction.

328 `idsatrgatd=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for drain-bulk junction.

329 `csrhbotd=1E2 Am`$^{-3}$
Shockley-Read-Hall prefactor of bottom component for drain-bulk junction.

330 `csrhstid=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of STI-edge component for drain-bulk junction.

331 `csrhgatd=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of gate-edge component for drain-bulk junction.

332 `xjunstid=100E-9 m` Junction depth of STI-edge component for drain-bulk junction.

333 `xjungatd=100E-9 m` Junction depth of gate-edge component for drain-bulk junction.

334 `ctatbotd=1E2 Am`$^{-3}$
Trap-assisted tunneling prefactor of bottom component for drain-bulk junction.

335 `ctatstid=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of STI-edge component for drain-bulk junction.

336 `ctatgatd=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of gate-edge component for drain-bulk junction.

337 `mefftatbotd=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component for drain-bulk junction.

338 `mefftatstid=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for drain-bulk junction.

339 `mefftatgatd=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for drain-bulk junction.

340 `cbbtbotd=1E-12 AV`$^{-3}$
Band-to-band tunneling prefactor of bottom component for drain-bulk junction.

341 `cbbtstid=1E-18 AV^-3m`
Band-to-band tunneling prefactor of STI-edge component for drain-bulk junction.

342 `cbbtgatd=1E-18 AV^-3m`
Band-to-band tunneling prefactor of gate-edge component for drain-bulk junction.

343 `fbbtrbotd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component for drain-bulk junction.

344 `fbbtrstid=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for drain-bulk junction.

345 `fbbtrgatd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for drain-bulk junction.

346 `stfbbtbotd=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for drain-bulk junction.

347 `stfbbtstid=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for drain-bulk junction.

348 `stfbbtgatd=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for drain-bulk junction.

349 `vbrbotd=10 V` Breakdown voltage of bottom component for drain-bulk junction.

350 `vbrstid=10 V` Breakdown voltage of STI-edge component for drain-bulk junction.

351 `vbrgatd=10 V` Breakdown voltage of gate-edge component for drain-bulk junction.

352 `pbrbotd=4 V` Breakdown onset tuning parameter of bottom component for drain-bulk junction.

353 `pbrstid=4 V`	Breakdown onset tuning parameter of STI-edge component for drain-bulk junction.
354 `pbrgatd=4 V`	Breakdown onset tuning parameter of gate-edge component for drain-bulk junction.
355 `swjunexp=0.0`	Flag for JUNCAP-express; 0,full model, 1,express model.
356 `vjunref=2.5`	Typical maximum source-bulk junction voltage; usually about 2*VSUP.
357 `fjunq=0.03`	Fraction below which source-bulk junction capacitance components are considered negligible.
358 `vjunrefd=2.5`	Typical maximum drain-bulk junction voltage; usually about 2*VSUP.
359 `fjunqd=0.03`	Fraction below which drain-bulk junction capacitance components are considered negligible.
360 `mvto=0.0`	DCmatch parameter.
361 `mbeo=0.0`	DCmatch parameter.
362 `vthmod`	Vth output selector. 'std' outputs model equation Vth. 'vthcc' outputs constant current Vth, and may impact simulation performance. The default value is taken from the options parameter 'vthmod'. Possible values are `std` and `vthcc`.
363 `ivth (A)`	Vth current parameter. The default value is taken from the options parameter 'ivthn' or 'ivthp', depending on the type of the model.
364 `ivthw (m)`	Width offset for constant current Vth. The default value is taken from the options parameter 'ivthw'.
365 `ivthl (m)`	Length offset for constant current Vth. The default value is taken from the options parameter 'ivthl'.
366 `ivth_vdsmin (V)`	Minimum Vds in constant current Vth calculating. The default value is taken from the options parameter 'ivth_vdsmin'.

367 `noisemethod=oldcmi`
Induced gate noise implementation .
Possible values are `oldcmi`, `subckt`, and `newcmi`.

Output Parameters

1 `weff (m)` Effective channel width for geometrical models.

2 `leff (m)` Effective channel length for geometrical models.

3 `lv1 (m)` alias of l.

4 `lv2 (m)` alias of w.

5 `lv3 (m`^{2}`)` alias of ad.

6 `lv4 (m`^{2}`)` alias of as.

7 `lv11 (m)` alias of pd.

8 `lv12 (m)` alias of ps.

Operating-Point Parameters

1 `ctype` Flag for channel type.

2 `sdint` Flag for source-drain interchange.

3 `ise (A)` Total source current.

4 `ige (A)` Total gate current.

5 `ide (A)` Total drain current.

6 `ibe (A)` Total bulk current.

7 `ids (A)` Drain current, excl. avalanche, tunnel, GISL, GIDL, and junction currents.

8 `idb (A)` Drain to bulk current.

9 `isb (A)` Source to bulk current.

10 `igs (A)`	Gate-source tunneling current.
11 `igd (A)`	Gate-drain tunneling current.
12 `igb (A)`	Gate-bulk tunneling current.
13 `igcs (A)`	Gate-channel tunneling current (source component).
14 `igcd (A)`	Gate-channel tunneling current (drain component).
15 `iavl (A)`	Substrate current due to weak avelanche.
16 `igisl (A)`	Gate-induced source leakage current.
17 `igidl (A)`	Gate-induced drain leakage current.
18 `ijs (A)`	Total source junction current.
19 `ijsbot (A)`	Source junction current (bottom component).
20 `ijsgat (A)`	Source junction current (gate-edge component).
21 `ijssti (A)`	Source junction current (STI-edge component).
22 `ijd (A)`	Total drain junction current.
23 `ijdbot (A)`	Drain junction current (bottom component).
24 `ijdgat (A)`	Drain junction current (gate-edge component).
25 `ijdsti (A)`	Drain junction current (STI-edge component).
26 `qg (Coul)`	Intrinsic gate charge.
27 `qd (Coul)`	Intrinsic drain charge.
28 `qb (Coul)`	Intrinsic bulk charge.
29 `qs (Coul)`	Intrinsic source charge.
30 `qgs_ov (Coul)`	Overlap charge for gate-source.
31 `qgd_ov (Coul)`	Overlap charge for gate-drain.

32 `qfgs (Coul)`	Total outerFringe + overlap for gate-source.
33 `qfgd (Coul)`	Total outerFringe + overlap for gate-drain.
34 `qgb_ov (Coul)`	Gate-bulk overlap charge.
35 `qjun_s (Coul)`	Junction charge on source side.
36 `qjun_d (Coul)`	Junction charge on drain side.
37 `vds (V)`	Drain-source voltage.
38 `vgs (V)`	Gate-source voltage.
39 `vsb (V)`	Source-bulk voltage.
40 `vto (V)`	Zero-bias threshold voltage.
41 `vts (V)`	Threshold voltage including back bias effects.
42 `vth (V)`	Threshold voltage including back bias and drain bias effects.
43 `vgt (V)`	Effective gate drive voltage including back bias and drain bias effects.
44 `vdss (V)`	Drain saturation voltage at actual bias.
45 `vsat (V)`	Saturation limit.
46 `pwr (W)`	Power at op point.
47 `gm (1/Ω)`	Transconductance.
48 `gmb (1/Ω)`	Substrate transconductance.
49 `gds (1/Ω)`	Output conductance.
50 `gjs (1/Ω)`	Source junction conductance.
51 `gjd (1/Ω)`	Drain junction conductance.
52 `cdd (F)`	Drain capacitance.

53 `cdg (F)`	Drain-gate capacitance.
54 `cds (F)`	Drain-source capacitance.
55 `cdb (F)`	Drain-bulk capacitance.
56 `cgd (F)`	Gate-drain capacitance.
57 `cgg (F)`	Gate capacitance.
58 `cgs (F)`	Gate-source capacitance.
59 `cgb (F)`	Gate-bulk capacitance.
60 `csd (F)`	Source-drain capacitance.
61 `csg (F)`	Source-gate capacitance.
62 `css (F)`	Source capacitance.
63 `csb (F)`	Source-bulk capacitance.
64 `cbd (F)`	Bulk-drain capacitance.
65 `cbg (F)`	Bulk-gate capacitance.
66 `cbs (F)`	Bulk-source capacitance.
67 `cbb (F)`	Bulk capacitance.
68 `cgsol (F)`	Total gate-source overlap capacitance.
69 `cgdol (F)`	Total gate-drain overlap capacitance.
70 `cgbol (F)`	Total gate-bulk overlap capacitance.
71 `cjs (F)`	Total source junction capacitance.
72 `cjsbot (F)`	Source junction capacitance (bottom component).
73 `cjsgat (F)`	Source junction capacitance (gate-edge component).
74 `cjssti (F)`	Source junction capacitance (STI-edge component).

75 `cjd (F)`	Total drain junction capacitance.
76 `cjdbot (F)`	Drain junction capacitance (bottom component).
77 `cjdgat (F)`	Drain junction capacitance (gate-edge component).
78 `cjdsti (F)`	Drain junction capacitance (STI-edge component).
79 `lpoly (m)`	
80 `u`	Transistor gain.
81 `rout` (Ω)	Small-signal output resistance.
82 `vearly (V)`	Equivalent Early voltage.
83 `beff` (A/V^2)	Gain factor.
84 `fug (Hz)`	Unity gain frequency at actual bias.
85 `rg` (Ω)	Gate resistance.
86 `sfl` (A^2/Hz)	Flicker noise current spectral density at 1 Hz.
87 `sqrtsff` ($V/\sqrt{Hz}$)	Input-referred RMS white noise voltage spectral density at 1 kHz.
88 `sqrtsfw` ($V/\sqrt{Hz}$)	Input-referred RMS white noise voltage spectral density.
89 `sid` (A^2/Hz)	White noise current spectral density.
90 `sig` (A^2/Hz)	Induced gate noise current spectral density at 1 Hz.
91 `cigid`	Imaginary part of correlation coefficient between Sig and Sid.
92 `fknee (Hz)`	Cross-over frequency above which white noise is dominant.
93 `sigs` (A^2/Hz)	Gate-source current noise spectral density.
94 `sigd` (A^2/Hz)	Gate-drain current noise spectral density.
95 `siavl` (A^2/Hz)	Impact ionization current noise spectral density.

96 `ssi (A^2/Hz)` Total source junction current noise spectral density.

97 `sdi (A^2/Hz)` Total drain junction current noise spectral density.

98 `vbs (V)` Bulk-source voltage.

99 `lv9 (V)` alias of vth.

100 `lv10 (V)` alias of vdss.

101 `lv36 (F)` alias of cgsol.

102 `lv37 (F)` alias of cgdol.

103 `lv38 (F)` alias of cgbol.

104 `lv51 (m)` alias of tox.

105 `lx4 (A)` alias of ids.

106 `lx3 (V)` alias of vds.

107 `lx2 (V)` alias of vgs.

108 `lx7 (1/Ω)` alias of gm.

109 `lx8 (1/Ω)` alias of gds.

110 `lx9 (1/Ω)` alias of gmb.

111 `lx33 (F)` alias of cdd.

112 `lx32 (F)` alias of cdg.

113 `lx34 (F)` alias of cds.

114 `lx19 (F)` alias of cgd.

115 `lx18 (F)` alias of cgg.

116 `lx20 (F)` alias of cgs.

117 `lx22 (F)` alias of cbd.

118 `lx21 (F)` alias of cbg.

119 `lx23 (F)` alias of cbs.

120 `lx5 (A)` alias of ijs.

121 `lx6 (A)` alias of ijd.

122 `lx28 (F)` alias of cjs.

123 `lx29 (F)` alias of cjd.

124 `lx38 (A)` alias of igs.

125 `lx39 (A)` alias of igd.

126 `lx66 (A)` alias of igb.

127 `lx67 (A)` alias of igcs.

128 `lx68 (A)` alias of igcd.

129 `lx110 (A)` alias of igisl.

130 `lx47 (A)` alias of igidl.

131 `lx60 (F)` alias of csd.

132 `lx59 (F)` alias of csg.

133 `lx58 (F)` alias of css.

134 `lx12 (Coul)` alias of Qb including overlap charge.

135 `lx14 (Coul)` alias of Qg including overlap charge.

136 `lx16 (Coul)` alias of Qd including overlap charge.

137 `lx83 (F)` alias of cgd including overlap cap.

138 `lx84 (F)` alias of cgs including overlap cap.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

PSP local MOSFET Model (psp102e)

This is SiMKit 4.0.1.

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `delvto=0.0 V` Threshold voltage shift parameter.

2 `factuo=1.0` Zero-field mobility pre-factor.

3 `absource=1E-12` m^2 Bottom area of source junction.

4 `lssource=1E-6 m` STI-edge length of source junction.

5 `lgsource=1E-6 m` Gate-edge length of source junction.

6 `abdrain=1E-12` m^2 Bottom area of drain junction.

7 `lsdrain=1E-6 m` STI-edge length of drain junction.

8 `lgdrain=1E-6 m` Gate-edge length of drain junction.

9 `as=1E-12` m^2 Bottom area of source junction.

10 `ps=1E-6 m` Perimeter of source junction.

11 `ad=1E-12 m`^{2} Bottom area of drain junction.

12 `pd=1E-6 m` Perimeter of drain junction.

13 `mulid0=1` Ids multiplier.

14 `jw=1E-6 m` Gate-edge length of source/drain junction.

15 `mult=1.0` Number of devices in parallel.

16 `trise=0.0 K` Temperature rise from ambient.

17 `m=1.0` Multiplicity factor.

18 `isnoisy=yes` Should device generate noise.
Possible values are `no` and `yes`.

Model Definition

model modelName psp102e parameter=value ...

Model Parameters

1 `level=102` Model level.

2 `type=n` Channel type parameter, n,NMOS p,PMOS.
Possible values are `n` and `p`.

3 `tr=value of tnom C`
nominal (reference) temperature.

4 `swnqs=0` Flag for NQS, 0,off, 1, 2, 3, 5, or 9,number of collocation points.

5 `swigate=0` Flag for gate current, 0,turn off IG.

6 `swimpact=0` Flag for impact ionization current, 0,turn off II.

7 `swgidl=0` Flag for GIDL current, 0,turn off IGIDL.

8 `swjuncap=0` Flag for juncap, 0,turn off juncap.

9 `swjunasym=0`	Flag for asymmetric junctions; 0,symmetric, 1,asymmetric.
10 `qmc=1.0`	Quantum-mechanical correction factor.
11 `version=102.32`	The available versions are 102.2, 102.21, 102.3, 102.32, 102.33, 102.34 and 102.40.
12 `geomod=1`	1 for geometrical model and 0 for electrical model.
13 `binmod=0`	1 for bin model and 0 for non-bin model.
14 `scalelev=102`	102 for local, 1020 for global model and 1021 for bin model.
15 `compatible=spectre`	for compatible. Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, and `mica`.
16 `vfb=(-1.0) V`	Flatband voltage at TR.
17 `stvfb=5.0e-4 V/K`	Temperature dependence of VFB.
18 `tox=2.0e-09 m`	Gate oxide thickness.
19 `epsrox=3.9`	Relative permittivity of gate dielectric.
20 `neff=5.0e+23` m^{-3}	Effective substrate doping.
21 `vnsub=0.0 V`	Effective doping bias-dependence parameter.
22 `nslp=0.05 V`	Effective doping bias-dependence parameter.
23 `dnsub=0.0 V^-1`	Effective doping bias-dependence parameter.
24 `dphib=0.0 V`	Offset parameter for PHIB.
25 `np=1.0e+26` m^{-3}	Gate poly-silicon doping.
26 `ct=0.0`	Interface states factor.
27 `toxov=2.0e-09 m`	Overlap oxide thickness.
28 `toxovd=2.0e-09 m`	Overlap oxide thickness for drain side.

29 `nov=5.0e+25` m^{-3}	Effective doping of overlap region.
30 `novd=5.0e+25` m^{-3}	Effective doping of overlap region for drain side.
31 `cf=0.0`	DIBL-parameter.
32 `cfb=0.0 V^-1`	Back bias dependence of CF.
33 `betn=7e-2` m^2`/V/s`	Channel aspect ratio times zero-field mobility.
34 `stbet=1.0`	Temperature dependence of BETN.
35 `mue=0.5 m/V`	Mobility reduction coefficient at TR.
36 `stmue=0.0`	Temperature dependence of MUE.
37 `themu=1.5`	Mobility reduction exponent at TR.
38 `stthemu=1.5`	Temperature dependence of THEMU.
39 `cs=0.0`	Coulomb scattering parameter at TR.
40 `stcs=0.0`	Temperature dependence of CS.
41 `xcor=0.0 V^-1`	Non-universality factor.
42 `stxcor=0.0`	Temperature dependence of XCOR.
43 `feta=1.0`	Effective field parameter.
44 `rs=30` Ω	Series resistance at TR.
45 `strs=1.0`	Temperature dependence of RS.
46 `rsb=0.0 V^-1`	Back-bias dependence of series resistance.
47 `rsg=0.0 V^-1`	Gate-bias dependence of series resistance.
48 `thesat=1.0 V^-1`	Velocity saturation parameter at TR.
49 `stthesat=1.0`	Temperature dependence of THESAT.
50 `thesatb=0.0 V^-1`	Back-bias dependence of velocity saturation.

51	`thesatg=0.0 V^-1`	Gate-bias dependence of velocity saturation.
52	`ax=3.0`	Linear/saturation transition factor.
53	`alp=0.01`	CLM pre-factor.
54	`alp1=0.00 V`	CLM enhancement factor above threshold.
55	`alp2=0.00 V^-1`	CLM enhancement factor below threshold.
56	`vp=0.05 V`	CLM logarithm dependence factor.
57	`a1=1.0`	Impact-ionization pre-factor.
58	`a2=10.0 V`	Impact-ionization exponent at TR.
59	`sta2=0.0 V`	Temperature dependence of A2.
60	`a3=1.0`	Saturation-voltage dependence of impact-ionization.
61	`a4=0.0 V^-0.5`	Back-bias dependence of impact-ionization.
62	`gco=0.0`	Gate tunnelling energy adjustment.
63	`iginv=0.0 A`	Gate channel current pre-factor.
64	`igov=0.0 A`	Gate overlap current pre-factor.
65	`igovd=0.0 A`	Gate overlap current pre-factor for drain side.
66	`stig=2.0`	Temperature dependence of IGINV and IGOV.
67	`gc2=0.375`	Gate current slope factor.
68	`gc3=0.063`	Gate current curvature factor.
69	`chib=3.1 V`	Tunnelling barrier height.
70	`agidl=0.0` A/V^3	GIDL pre-factor.
71	`agidld=0.0` A/V^3	GIDL pre-factor for drain side.
72	`bgidl=41.0 V`	GIDL probability factor at TR.

73 `bgidld=41.0 V` GIDL probability factor at TR for drain side.

74 `stbgidl=0.0 V/K` Temperature dependence of BGIDL.

75 `stbgidld=0.0 V/K` Temperature dependence of BGIDL for drain side.

76 `cgidl=0.0` Back-bias dependence of GIDL.

77 `cgidld=0.0` Back-bias dependence of GIDL for drain side.

78 `cox=1.0e-14 F` Oxide capacitance for intrinsic channel.

79 `cgov=1.0e-15 F` Oxide capacitance for gate-drain/source overlap.

80 `cgovd=1.0e-15 F` Oxide capacitance for gate-drain overlap.

81 `cgbov=0.0 F` Oxide capacitance for gate-bulk overlap.

82 `cfr=0.0 F` Outer fringe capacitance.

83 `cfrd=0.0 F` Outer fringe capacitance for drain side.

84 `fnt=1.0` Thermal noise coefficient.

85 `nfa=8.0e+22 V^-1/m`^{4}
First coefficient of flicker noise.

86 `nfb=3.0e+07 V^-1/m`^{2}
Second coefficient of flicker noise.

87 `nfc=0.0 V^-1` Third coefficient of flicker noise.

88 `ef=1.0` Flicker noise frequency exponent.

89 `munqs=1.0` Relative mobility for NQS modeling.

90 `rg=0.0 Ω` Gate resistance.

91 `rbulk=0.0 Ω` Bulk resistance between node BP and BI.

92 `rwell=0.0 Ω` Well resistance between node BI and B.

93 `rjuns=0.0 Ω` Source-side bulk resistance between node BI and BS.

94 `rjund=0.0 Ω` Drain-side bulk resistance between node BI and BD.

95 `imax=1000 A` Maximum current up to which forward current behaves exponentially.

96 `trj=21 C` reference temperature.

97 `cjorbot=1E-3 Fm`$^{-2}$
Zero-bias capacitance per unit-of-area of bottom component for source-bulk junction.

98 `cjorsti=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for source-bulk junction.

99 `cjorgat=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for source-bulk junction.

100 `vbirbot=1 V` Built-in voltage at the reference temperature of bottom component for source-bulk junction.

101 `vbirsti=1 V` Built-in voltage at the reference temperature of STI-edge component for source-bulk junction.

102 `vbirgat=1 V` Built-in voltage at the reference temperature of gate-edge component for source-bulk junction.

103 `pbot=0.5` Grading coefficient of bottom component for source-bulk junction.

104 `psti=0.5` Grading coefficient of STI-edge component for source-bulk junction.

105 `pgat=0.5` Grading coefficient of gate-edge component for source-bulk junction.

106 `phigbot=1.16 V` Zero-temperature bandgap voltage of bottom component for source-bulk junction.

107 `phigsti=1.16 V` Zero-temperature bandgap voltage of STI-edge component for source-bulk junction.

108 `phiggat=1.16 V` Zero-temperature bandgap voltage of gate-edge component for source-bulk junction.

109 `idsatrbot=1E-12 Am`$^{-2}$
Saturation current density at the reference temperature of bottom component for source-bulk junction.

110 `idsatrsti=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for source-bulk junction.

111 `idsatrgat=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for source-bulk junction.

112 `csrhbot=1E2 Am`$^{-3}$ Shockley-Read-Hall prefactor of bottom component for source-bulk junction.

113 `csrhsti=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of STI-edge component for source-bulk junction.

114 `csrhgat=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of gate-edge component for source-bulk junction.

115 `xjunsti=100E-9 m` Junction depth of STI-edge component for source-bulk junction.

116 `xjungat=100E-9 m` Junction depth of gate-edge component for source-bulk junction.

117 `ctatbot=1E2 Am`$^{-3}$ Trap-assisted tunneling prefactor of bottom component for source-bulk junction.

118 `ctatsti=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of STI-edge component for source-bulk junction.

119 `ctatgat=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of gate-edge component for source-bulk junction.

120 `mefftatbot=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component for source-bulk junction.

121 `mefftatsti=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for source-bulk junction.

122 `mefftatgat=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for source-bulk junction.

123 `cbbtbot=1E-12 AV`$^{-3}$
Band-to-band tunneling prefactor of bottom component for source-bulk junction.

124 `cbbtsti=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of STI-edge component for source-bulk junction.

125 `cbbtgat=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of gate-edge component for source-bulk junction.

126 `fbbtrbot=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component for source-bulk junction.

127 `fbbtrsti=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for source-bulk junction.

128 `fbbtrgat=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for source-bulk junction.

129 `stfbbtbot=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for source-bulk junction.

130 `stfbbtsti=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for source-bulk junction.

131 `stfbbtgat=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for source-bulk junction.

132 `vbrbot=10 V` Breakdown voltage of bottom component for source-bulk junction.

133 `vbrsti=10 V` Breakdown voltage of STI-edge component for source-bulk junction.

134 `vbrgat=10 V` Breakdown voltage of gate-edge component for source-bulk junction.

135 `pbrbot=4 V` Breakdown onset tuning parameter of bottom component for source-bulk junction.

136 `pbrsti=4 V` Breakdown onset tuning parameter of STI-edge component for source-bulk junction.

137 `pbrgat=4 V` Breakdown onset tuning parameter of gate-edge component for source-bulk junction.

138 `cjorbotd=1E-3 Fm`$^{-2}$
Zero-bias capacitance per unit-of-area of bottom component for drain-bulk junction.

139 `cjorstid=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for drain-bulk junction.

140 `cjorgatd=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for drain-bulk junction.

141 `vbirbotd=1 V` Built-in voltage at the reference temperature of bottom component for drain-bulk junction.

142 `vbirstid=1 V` Built-in voltage at the reference temperature of STI-edge component for drain-bulk junction.

143 `vbirgatd=1 V` Built-in voltage at the reference temperature of gate-edge component for drain-bulk junction.

144 `pbotd=0.5` Grading coefficient of bottom component for drain-bulk junction.

145 `pstid=0.5` Grading coefficient of STI-edge component for drain-bulk junction.

146 `pgatd=0.5` Grading coefficient of gate-edge component for drain-bulk junction.

147 `phigbotd=1.16 V` Zero-temperature bandgap voltage of bottom component for drain-bulk junction.

148 `phigstid=1.16 V` Zero-temperature bandgap voltage of STI-edge component for drain-bulk junction.

149 `phiggatd=1.16 V` Zero-temperature bandgap voltage of gate-edge component for drain-bulk junction.

150 `idsatrbotd=1E-12 Am`$^{-2}$
Saturation current density at the reference temperature of bottom component for drain-bulk junction.

151 `idsatrstid=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for drain-bulk junction.

152 `idsatrgatd=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for drain-bulk junction.

153 `csrhbotd=1E2 Am`$^{-3}$
Shockley-Read-Hall prefactor of bottom component for drain-bulk junction.

154 `csrhstid=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of STI-edge component for drain-bulk junction.

155 `csrhgatd=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of gate-edge component for drain-bulk junction.

156 `xjunstid=100E-9 m` Junction depth of STI-edge component for drain-bulk junction.

157 `xjungatd=100E-9 m` Junction depth of gate-edge component for drain-bulk junction.

158 `ctatbotd=1E2 Am`$^{-3}$
Trap-assisted tunneling prefactor of bottom component for drain-bulk junction.

159 `ctatstid=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of STI-edge component for drain-bulk junction.

160 `ctatgatd=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of gate-edge component for drain-bulk junction.

161 `mefftatbotd=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component for drain-bulk junction.

162 `mefftatstid=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for drain-bulk junction.

163 `mefftatgatd=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for drain-bulk junction.

164 `cbbtbotd=1E-12 AV`$^{-3}$
Band-to-band tunneling prefactor of bottom component for drain-bulk junction.

165 `cbbtstid=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of STI-edge component for drain-bulk junction.

166 `cbbtgatd=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of gate-edge component for drain-bulk junction.

167 `fbbtrbotd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component for drain-bulk junction.

168 `fbbtrstid=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for drain-bulk junction.

169 `fbbtrgatd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for drain-bulk junction.

170 `stfbbtbotd=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for drain-bulk junction.

171 `stfbbtstid=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for drain-bulk junction.

172 `stfbbtgatd=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for drain-bulk junction.

173 `vbrbotd=10 V` Breakdown voltage of bottom component for drain-bulk junction.

174 `vbrstid=10 V` Breakdown voltage of STI-edge component for drain-bulk junction.

175 `vbrgatd=10 V` Breakdown voltage of gate-edge component for drain-bulk junction.

176 `pbrbotd=4 V` Breakdown onset tuning parameter of bottom component for drain-bulk junction.

177 `pbrstid=4 V` Breakdown onset tuning parameter of STI-edge component for drain-bulk junction.

178 `pbrgatd=4 V` Breakdown onset tuning parameter of gate-edge component for drain-bulk junction.

179 `swjunexp=0.0` Flag for JUNCAP-express; 0,full model, 1,express model.

180 `vjunref=2.5` Typical maximum source-bulk junction voltage; usually about 2*VSUP.

181 `fjunq=0.03` Fraction below which source-bulk junction capacitance components are considered negligible.

182 `vjunrefd=2.5` Typical maximum drain-bulk junction voltage; usually about 2*VSUP.

183 `fjunqd=0.03` Fraction below which drain-bulk junction capacitance components are considered negligible.

184 `dta=0 K`	Temperature offset w.r.t. ambient circuit temperature.
185 `mvt=0.0`	DCmatch parameter.
186 `mbe=0.0`	DCmatch parameter.
187 `vds_max=∞ V`	Maximum allowed voltage cross source and drain.
188 `vgd_max=∞ V`	Maximum allowed voltage cross gate and drain.
189 `vgs_max=∞ V`	Maximum allowed voltage cross gate and source/bulk.
190 `vbd_max=∞ V`	Maximum allowed voltage cross source/drain and bulk.
191 `vbs_max=∞ V`	Maximum allowed voltage cross source and bulk.
192 `vgb_max=∞ V`	Maximum allowed voltage cross gate and bulk.
193 `vgdr_max=∞ V`	Maximum allowed reverse voltage cross gate and drain.
194 `vgsr_max=∞ V`	Maximum allowed reverse voltage cross gate and source.
195 `vgbr_max=∞ V`	Maximum allowed reverse voltage cross gate and bulk.
196 `vthmod`	Vth output selector. 'std' outputs model equation Vth. 'vthcc' outputs constant current Vth, and may impact simulation performance. The default value is taken from the options parameter 'vthmod'. Possible values are `std` and `vthcc`.
197 `ivth (A)`	Vth current parameter. The default value is taken from the options parameter 'ivthn' or 'ivthp', depending on the type of the model.

198 `ivthw (m)` Width offset for constant current Vth. The default value is taken from the options parameter 'ivthw'.

199 `ivthl (m)` Length offset for constant current Vth. The default value is taken from the options parameter 'ivthl'.

200 `ivth_vdsmin (V)` Minimum Vds in constant current Vth calculating. The default value is taken from the options parameter 'ivth_vdsmin'.

201 `noisemethod=oldcmi`
Induced gate noise implementation .
Possible values are `oldcmi`, `subckt`, and `newcmi`.

Output Parameters

1 `weff (m)` Effective channel width for geometrical models.

2 `leff (m)` Effective channel length for geometrical models.

3 `lv1 (m)` alias of l.

4 `lv2 (m)` alias of w.

5 `lv3` (m^2) alias of ad.

6 `lv4` (m^2) alias of as.

7 `lv11 (m)` alias of pd.

8 `lv12 (m)` alias of ps.

Operating-Point Parameters

1 `ctype` Flag for channel type.

2 `sdint` Flag for source-drain interchange.

3 `ise (A)` Total source current.

4 `ige (A)` Total gate current.

5 `ide (A)` Total drain current.

6 `ibe (A)`	Total bulk current.
7 `ids (A)`	Drain current, excl. avalanche, tunnel, GISL, GIDL, and junction currents.
8 `idb (A)`	Drain to bulk current.
9 `isb (A)`	Source to bulk current.
10 `igs (A)`	Gate-source tunneling current.
11 `igd (A)`	Gate-drain tunneling current.
12 `igb (A)`	Gate-bulk tunneling current.
13 `igcs (A)`	Gate-channel tunneling current (source component).
14 `igcd (A)`	Gate-channel tunneling current (drain component).
15 `iavl (A)`	Substrate current due to weak avelanche.
16 `igisl (A)`	Gate-induced source leakage current.
17 `igidl (A)`	Gate-induced drain leakage current.
18 `ijs (A)`	Total source junction current.
19 `ijsbot (A)`	Source junction current (bottom component).
20 `ijsgat (A)`	Source junction current (gate-edge component).
21 `ijssti (A)`	Source junction current (STI-edge component).
22 `ijd (A)`	Total drain junction current.
23 `ijdbot (A)`	Drain junction current (bottom component).
24 `ijdgat (A)`	Drain junction current (gate-edge component).
25 `ijdsti (A)`	Drain junction current (STI-edge component).
26 `qg (Coul)`	Intrinsic gate charge.

27 `qd (Coul)`	Intrinsic drain charge.
28 `qb (Coul)`	Intrinsic bulk charge.
29 `qs (Coul)`	Intrinsic source charge.
30 `qgs_ov (Coul)`	Overlap charge for gate-source.
31 `qgd_ov (Coul)`	Overlap charge for gate-drain.
32 `qfgs (Coul)`	Total outerFringe + overlap for gate-source.
33 `qfgd (Coul)`	Total outerFringe + overlap for gate-drain.
34 `qgb_ov (Coul)`	Gate-bulk overlap charge.
35 `qjun_s (Coul)`	Junction charge on source side.
36 `qjun_d (Coul)`	Junction charge on drain side.
37 `vds (V)`	Drain-source voltage.
38 `vgs (V)`	Gate-source voltage.
39 `vsb (V)`	Source-bulk voltage.
40 `vto (V)`	Zero-bias threshold voltage.
41 `vts (V)`	Threshold voltage including back bias effects.
42 `vth (V)`	Threshold voltage including back bias and drain bias effects.
43 `vgt (V)`	Effective gate drive voltage including back bias and drain bias effects.
44 `vdss (V)`	Drain saturation voltage at actual bias.
45 `vsat (V)`	Saturation limit.
46 `pwr (W)`	Power at op point.
47 `gm (1/Ω)`	Transconductance.

48 `gmb (1/Ω)`	Substrate transconductance.
49 `gds (1/Ω)`	Output conductance.
50 `gjs (1/Ω)`	Source junction conductance.
51 `gjd (1/Ω)`	Drain junction conductance.
52 `cdd (F)`	Drain capacitance.
53 `cdg (F)`	Drain-gate capacitance.
54 `cds (F)`	Drain-source capacitance.
55 `cdb (F)`	Drain-bulk capacitance.
56 `cgd (F)`	Gate-drain capacitance.
57 `cgg (F)`	Gate capacitance.
58 `cgs (F)`	Gate-source capacitance.
59 `cgb (F)`	Gate-bulk capacitance.
60 `csd (F)`	Source-drain capacitance.
61 `csg (F)`	Source-gate capacitance.
62 `css (F)`	Source capacitance.
63 `csb (F)`	Source-bulk capacitance.
64 `cbd (F)`	Bulk-drain capacitance.
65 `cbg (F)`	Bulk-gate capacitance.
66 `cbs (F)`	Bulk-source capacitance.
67 `cbb (F)`	Bulk capacitance.
68 `cgsol (F)`	Total gate-source overlap capacitance.
69 `cgdol (F)`	Total gate-drain overlap capacitance.

70 `cgbol (F)` Total gate-bulk overlap capacitance.

71 `cjs (F)` Total source junction capacitance.

72 `cjsbot (F)` Source junction capacitance (bottom component).

73 `cjsgat (F)` Source junction capacitance (gate-edge component).

74 `cjssti (F)` Source junction capacitance (STI-edge component).

75 `cjd (F)` Total drain junction capacitance.

76 `cjdbot (F)` Drain junction capacitance (bottom component).

77 `cjdgat (F)` Drain junction capacitance (gate-edge component).

78 `cjdsti (F)` Drain junction capacitance (STI-edge component).

79 `lpoly (m)`

80 `u` Transistor gain.

81 `rout (Ω)` Small-signal output resistance.

82 `vearly (V)` Equivalent Early voltage.

83 `beff` (A/V^2) Gain factor.

84 `fug (Hz)` Unity gain frequency at actual bias.

85 `rg (Ω)` Gate resistance.

86 `sfl` (A^2/Hz) Flicker noise current spectral density at 1 Hz.

87 `sqrtsff` ($V/\sqrt{Hz}$) Input-referred RMS white noise voltage spectral density at 1 kHz.

88 `sqrtsfw` ($V/\sqrt{Hz}$) Input-referred RMS white noise voltage spectral density.

89 `sid` (A^2/Hz) White noise current spectral density.

90 `sig` (A^2/Hz) Induced gate noise current spectral density at 1 Hz.

91 cigid	Imaginary part of correlation coefficient between Sig and Sid.
92 fknee (Hz)	Cross-over frequency above which white noise is dominant.
93 sigs (A^2/Hz)	Gate-source current noise spectral density.
94 sigd (A^2/Hz)	Gate-drain current noise spectral density.
95 siavl (A^2/Hz)	Impact ionization current noise spectral density.
96 ssi (A^2/Hz)	Total source junction current noise spectral density.
97 sdi (A^2/Hz)	Total drain junction current noise spectral density.
98 vbs (V)	Bulk-source voltage.
99 lv9 (V)	alias of vth.
100 lv10 (V)	alias of vdss.
101 lv36 (F)	alias of cgsol.
102 lv37 (F)	alias of cgdol.
103 lv38 (F)	alias of cgbol.
104 lv51 (m)	alias of tox.
105 lx4 (A)	alias of ids.
106 lx3 (V)	alias of vds.
107 lx2 (V)	alias of vgs.
108 lx7 (1/Ω)	alias of gm.
109 lx8 (1/Ω)	alias of gds.
110 lx9 (1/Ω)	alias of gmb.
111 lx33 (F)	alias of cdd.
112 lx32 (F)	alias of cdg.

113 `lx34 (F)` alias of cds.

114 `lx19 (F)` alias of cgd.

115 `lx18 (F)` alias of cgg.

116 `lx20 (F)` alias of cgs.

117 `lx22 (F)` alias of cbd.

118 `lx21 (F)` alias of cbg.

119 `lx23 (F)` alias of cbs.

120 `lx5 (A)` alias of ijs.

121 `lx6 (A)` alias of ijd.

122 `lx28 (F)` alias of cjs.

123 `lx29 (F)` alias of cjd.

124 `lx38 (A)` alias of igs.

125 `lx39 (A)` alias of igd.

126 `lx66 (A)` alias of igb.

127 `lx67 (A)` alias of igcs.

128 `lx68 (A)` alias of igcd.

129 `lx110 (A)` alias of igisl.

130 `lx47 (A)` alias of igidl.

131 `lx60 (F)` alias of csd.

132 `lx59 (F)` alias of csg.

133 `lx58 (F)` alias of css.

134 `lx12 (Coul)` alias of Qb including overlap charge.

135 `lx14 (Coul)` alias of Qg including overlap charge.

136 `lx16 (Coul)` alias of Qd including overlap charge.

137 `lx83 (F)` alias of cgd including overlap cap.

138 `lx84 (F)` alias of cgs including overlap cap.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

PSP NQS MOSFET Model (pspnqs1020)

This is SiMKit 4.0.1.

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1	`l=10e-6 m`	Design length.
2	`w=10e-6 m`	Design width.
3	`sa=0.0 m`	Distance between OD-edge and poly from one side.
4	`sb=0.0 m`	Distance between OD-edge and poly from other side.
5	`sd=0.0 m`	Distance between neighboring fingers.
6	`sca=0.0`	Integral of the first distribution function for scattered well dopants.
7	`scb=0.0`	Integral of the second distribution function for scattered well dopants.

8 `scc=0.0`	Integral of the third distribution function for scattered well dopants.
9 `sc=0.0 m`	Distance between OD-edge and nearest well edge.
10 `delvto=0.0 V`	Threshold voltage shift parameter.
11 `factuo=1.0`	Zero-field mobility pre-factor.
12 `absource=1E-12 m`^{2}	Bottom area of source junction.
13 `lssource=1E-6 m`	STI-edge length of source junction.
14 `lgsource=1E-6 m`	Gate-edge length of source junction.
15 `abdrain=1E-12 m`^{2}	Bottom area of drain junction.
16 `lsdrain=1E-6 m`	STI-edge length of drain junction.
17 `lgdrain=1E-6 m`	Gate-edge length of drain junction.
18 `as=1E-12 m`^{2}	Bottom area of source junction.
19 `ps=1E-6 m`	Perimeter of source junction.
20 `ad=1E-12 m`^{2}	Bottom area of drain junction.
21 `pd=1E-6 m`	Perimeter of drain junction.
22 `mulid0=1`	Ids multiplier.
23 `mult=1.0`	Number of devices in parallel.
24 `nf=1.0`	Number of fingers.
25 `ngcon=1.0`	Number of gate contacts.
26 `xgw=1.0E-7 m`	Distance from the gate contact to the channel edge.
27 `trise=0.0 K`	Temperature rise from ambient.
28 `m=1.0`	Multiplicity factor.

29 `isnoisy=yes` Should device generate noise.
Possible values are `no` and `yes`.

Model Definition

model modelName pspnqs1020 parameter=value ...

Model Parameters

1 `level=102` Model level.

2 `type=n` Channel type parameter, n,NMOS p,PMOS.
Possible values are `n` and `p`.

3 `tr=value of tnom C`
nominal (reference) temperature.

4 `swnqs=0` Flag for NQS, 0,off, 1, 2, 3, 5, or 9,number of collocation points.

5 `swigate=0` Flag for gate current, 0,turn off IG.

6 `swimpact=0` Flag for impact ionization current, 0,turn off II.

7 `swgidl=0` Flag for GIDL current, 0,turn off IGIDL.

8 `swjuncap=0` Flag for juncap, 0,turn off juncap.

9 `swjunasym=0` Flag for asymmetric junctions; 0,symmetric, 1,asymmetric.

10 `qmc=1.0` Quantum-mechanical correction factor.

11 `version=102.32` The available versions are 102.2, 102.21, 102.3, 102.32, 102.33, 102.34 and 102.40.

12 `geomod=1` 1 for geometrical model and 0 for electrical model.

13 `binmod=0` 1 for bin model and 0 for non-bin model.

14 `scalelev=102` 102 for local, 1020 for global model and 1021 for bin model.

15 `compatible=spectre`
for compatible.

	Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, and `mica`.
16 `lvaro=0.0 m`	Geom. independent difference between actual and programmed gate length.
17 `lvarl=0.0`	Length dependence of LVAR.
18 `lvarw=0.0`	Width dependence of LVAR.
19 `lap=0.0 m`	Effective channel length reduction per side.
20 `wvaro=0.0 m`	Geom. independent difference between actual and programmed field-oxide opening.
21 `wvarl=0.0`	Length dependence of WVAR.
22 `wvarw=0.0`	Width dependence of WVAR.
23 `wot=0.0 m`	Effective channel width reduction per side.
24 `dlq=0.0 m`	Effective channel length reduction for CV.
25 `dwq=0.0 m`	Effective channel width reduction for CV.
26 `vfbo=(-1.0) V`	Geometry-independent flat-band voltage at TR.
27 `vfbl=0.0`	Length dependence of flat-band voltage.
28 `vfbw=0.0`	Width dependence of flat-band voltage.
29 `vfblw=0.0`	Area dependence of flat-band voltage.
30 `stvfbo=5e-4 V/K`	Geometry-independent temperature dependence of VFB.
31 `stvfbl=0.0`	Length dependence of temperature dependence of VFB.
32 `stvfbw=0.0`	Width dependence of temperature dependence of VFB.
33 `stvfblw=0.0`	Area dependence of temperature dependence of VFB.
34 `toxo=2e-9 m`	Gate oxide thickness.

35	`epsroxo=3.9`	Relative permittivity of gate dielectric.
36	`nsubo=3e23 m`$^{-3}$	Geometry independent substrate doping.
37	`nsubw=0.0`	Width dependence of background doping NSUBO due to segregation.
38	`wseg=1e-8 m`	Char. length of segregation of background doping NSUBO.
39	`npck=1e24 m`$^{-3}$	Pocket doping level.
40	`npckw=0.0`	Width dependence of pocket doping NPCK due to segregation.
41	`wsegp=1e-8 m`	Char. length of segregation of pocket doping NPCK.
42	`lpck=1e-8 m`	Char. length of lateral doping profile.
43	`lpckw=0.0`	Width dependence of char. length of lateral doping profile.
44	`fol1=0.0`	First length dependence coefficient for short channel body effect.
45	`fol2=0.0`	Second length dependence coefficient for short channel body effect.
46	`vnsubo=0.0 V`	Effective doping bias-dependence parameter.
47	`nslpo=0.05 V`	Effective doping bias-dependence parameter.
48	`dnsubo=0.0 V^-1`	Effective doping bias-dependence parameter.
49	`dphibo=0.0 V`	Geometry independent offset of PHIB.
50	`dphibl=0.0 V`	Length dependence offset of PHIB.
51	`dphiblexp=1.0`	Exponent for length dependence of offset of PHIB.
52	`dphibw=0.0`	Width dependence of offset of PHIB.
53	`dphiblw=0.0`	Area dependence of offset of PHIB.
54	`npo=1e26 m`$^{-3}$	Geometry-independent gate poly-silicon doping.
55	`npl=0.0`	Length dependence of gate poly-silicon doping.

56 `cto=0.0` Geometry-independent interface states factor.

57 `ctl=0.0` Length dependence of interface states factor.

58 `ctlexp=1.0` Exponent for length dependence of interface states factor.

59 `ctw=0.0` Width dependence of interface states factor.

60 `ctlw=0.0` Area dependence of interface states factor.

61 `toxovo=2e-9 m` Overlap oxide thickness.

62 `toxovdo=2e-9 m` Overlap oxide thickness for drain side.

63 `lov=0 m` Overlap length for gate/drain and gate/source overlap capacitance.

64 `lovd=0 m` Overlap length for gate/drain overlap capacitance.

65 `novo=5e25` m^{-3} Effective doping of overlap region.

66 `novdo=5e25` m^{-3} Effective doping of overlap region for drain side.

67 `cfl=0.0` Length dependence of DIBL-parameter.

68 `cflexp=2.0` Exponent for length dependence of CF.

69 `cfw=0.0` Width dependence of CF.

70 `cfbo=0.0 V^-1` Back-bias dependence of CF.

71 `uo=5e-2` m^2`/V/s` Zero-field mobility at TR.

72 `fbet1=0.0` Relative mobility decrease due to first lateral profile.

73 `fbet1w=0.0` Width dependence of relative mobility decrease due to first lateral profile.

74 `lp1=1e-8 m` Mobility-related characteristic length of first lateral profile.

75 `lp1w=0.0` Width dependence of mobility-related characteristic length of first lateral profile.

76 `fbet2=0.0`	Relative mobility decrease due to second lateral profile.
77 `lp2=1e-8 m`	Mobility-related characteristic length of second lateral profile.
78 `betw1=0.0`	First higher-order width scaling coefficient of BETN.
79 `betw2=0.0`	Second higher-order width scaling coefficient of BETN.
80 `wbet=1e-9 m`	Characteristic width for width scaling of BETN.
81 `stbeto=1.0`	Geometry independent temperature dependence of BETN.
82 `stbetl=0.0`	Length dependence of temperature dependence of BETN.
83 `stbetw=0.0`	Width dependence of temperature dependence of BETN.
84 `stbetlw=0.0`	Area dependence of temperature dependence of BETN.
85 `mueo=0.5 m/V`	Geometry independent mobility reduction coefficient at TR.
86 `muew=0.0`	Width dependence of mobility reduction coefficient at TR.
87 `stmueo=0.0`	Temperature dependence of MUE.
88 `themuo=1.5`	Mobility reduction exponent at TR.
89 `stthemuo=1.5`	Temperature dependence of THEMU.
90 `cso=0.0`	Geometry independent coulomb scattering parameter at TR.
91 `csl=0.0`	Length dependence of CS.
92 `cslexp=0.0`	Exponent for length dependence of CS.
93 `csw=0.0`	Width dependence of CS.
94 `cslw=0.0`	Area dependence of CS.
95 `stcso=0.0`	Temperature dependence of CS.
96 `xcoro=0.0 V^-1`	Geometry independent non-universality parameter.
97 `xcorl=0.0`	Length dependence of non-universality parameter.

98 `xcorw=0.0`	Width dependence of non-universality parameter.
99 `xcorlw=0.0`	Area dependence of non-universality parameter.
100 `stxcoro=0.0`	Temperature dependence of XCOR.
101 `fetao=1.0`	Effective field parameter.
102 `rsw1=2.5e3 Ω`	Source/drain series resistance for 1 um wide channel at TR.
103 `rsw2=0.0`	Higher-order width scaling of RS.
104 `strso=1.0`	Temperature dependence of RS.
105 `rsbo=0.0 V^-1`	Back-bias dependence of series resistance.
106 `rsgo=0.0 V^-1`	Gate-bias dependence of series resistance.
107 `thesato=0.0 V^-1`	Geometry independent velocity saturation parameter at TR.
108 `thesatl=0.05 V^-1`	Length dependence of THESAT.
109 `thesatlexp=1.0`	Exponent for length dependence of THESAT.
110 `thesatw=0.0`	Width dependence of velocity saturation parameter.
111 `thesatlw=0.0`	Area dependence of velocity saturation parameter.
112 `stthesato=1.0`	Geometry independent temperature dependence of THESAT.
113 `stthesatl=0.0`	Length dependence of temperature dependence of THESAT.
114 `stthesatw=0.0`	Width dependence of temperature dependence of THESAT.
115 `stthesatlw=0.0`	Area dependence of temperature dependence of THESAT.
116 `thesatbo=0.0 V^-1`	Back-bias dependence of velocity saturation.
117 `thesatgo=0.0 V^-1`	Gate-bias dependence of velocity saturation.
118 `axo=18`	Geometry independent linear/saturation transition factor.
119 `axl=0.4`	Length dependence of AX.

120 `alpl=5e-4` Length dependence of ALP.

121 `alplexp=1.0` Exponent for length dependence of ALP.

122 `alpw=0.0` Width dependence of ALP.

123 `alp1l1=0.0 V` Length dependence of CLM enhancement factor above threshold.

124 `alp1lexp=0.5` Exponent for length dependence of ALP1.

125 `alp1l2=0.0` Second_order length dependence of ALP1.

126 `alp1w=0.0` Width dependence of ALP1.

127 `alp2l1=0.0 V^-1` Length dependence of CLM enhancement factor below threshold.

128 `alp2lexp=0.5` Exponent for length dependence of ALP2.

129 `alp2l2=0.0` Second_order length dependence of ALP2.

130 `alp2w=0.0` Width dependence of ALP2.

131 `vpo=0.05 V` CLM logarithmic dependence parameter.

132 `a1o=1.0` Geometry independent impact-ionization pre-factor.

133 `a1l=0.0` Length dependence of A1.

134 `a1w=0.0` Width dependence of A1.

135 `a2o=10 V` Impact-ionization exponent at TR.

136 `sta2o=0.0 V` Temperature dependence of A2.

137 `a3o=1.0` Geometry independent saturation-voltage dependence of II.

138 `a3l=0.0` Length dependence of A3.

139 `a3w=0.0` Width dependence of A3.

140 `a4o=0.0 V^-0.5` Geometry independent back-bias dependence of II.

141 `a4l=0.0`	Length dependence of A4.
142 `a4w=0.0`	Width dependence of A4.
143 `gcoo=0.0`	Gate tunnelling energy adjustment.
144 `iginvlw=0.0 A`	Gate channel current pre-factor for 1 um^2 channel area.
145 `igovw=0.0 A`	Gate overlap current pre-factor for 1 um wide channel.
146 `igovdw=0.0 A`	Gate overlap current pre-factor for 1 um wide channel for drain side.
147 `stigo=2.0`	Temperature dependence of IGINV and IGOV.
148 `gc2o=0.375`	Gate current slope factor.
149 `gc3o=0.063`	Gate current curvature factor.
150 `chibo=3.1 V`	Tunnelling barrier height.
151 `agidlw=0.0` A/V^3	Width dependence of GIDL pre-factor.
152 `agidldw=0.0` A/V^3	Width dependence of GIDL pre-factor for drain side.
153 `bgidlo=41 V`	GIDL probability factor at TR.
154 `bgidldo=41 V`	GIDL probability factor at TR for drain side.
155 `stbgidlo=0.0 V/K`	Temperature dependence of BGIDL.
156 `stbgidldo=0.0 V/K`	Temperature dependence of BGIDL for drain side.
157 `cgidlo=0.0`	Back-bias dependence of GIDL.
158 `cgidldo=0.0`	Back-bias dependence of GIDL for drain side.
159 `cgbovl=0.0 F`	Oxide capacitance for gate-bulk overlap for 1 um long channel.
160 `cfrw=0.0 F`	Outer fringe capacitance for 1 um wide channel.
161 `cfrdw=0.0 F`	Outer fringe capacitance for 1 um wide channel for drain side.

162 `fnto=1.0` Thermal noise coefficient.

163 `nfalw=8e22 V^-1/m`^{4}
First coefficient of flicker noise for 1 um^2 channel area.

164 `nfblw=3e7 V^-1/m`^{2}
Second coefficient of flicker noise for 1 um^2 channel area.

165 `nfclw=0.0 V^-1` Third coefficient of flicker noise for 1 um^2 channel area.

166 `efo=1.0` Flicker noise frequency exponent.

167 `lintnoi=0.0 m` Length offset for flicker noise.

168 `alpnoi=2.0` Exponent for length offset for flicker noise.

169 `dta=0 K` Temperature offset w.r.t. ambient circuit temperature.

170 `kvthoweo=0` Geometrical independent threshold shift parameter.

171 `kvthowel=0` Length dependent threshold shift parameter.

172 `kvthowew=0` Width dependent threshold shift parameter.

173 `kvthowelw=0` Area dependent threshold shift parameter.

174 `kuoweo=0` Geometrical independent mobility degradation factor.

175 `kuowel=0` Length dependent mobility degradation factor.

176 `kuowew=0` Width dependent mobility degradation factor.

177 `kuowelw=0` Area dependent mobility degradation factor.

178 `vds_max=∞ V`
Maximum allowed voltage cross source and drain.

179 `vgd_max=∞ V`
Maximum allowed voltage cross gate and drain.

180 `vgs_max=∞ V`
Maximum allowed voltage cross gate and source/bulk.

181 `vbd_max=∞ V`
Maximum allowed voltage cross source/drain and bulk.

182 `vbs_max=∞ V`
Maximum allowed voltage cross source and bulk.

183 `vgb_max=∞ V`
Maximum allowed voltage cross gate and bulk.

184 `vgdr_max=∞ V`
Maximum allowed reverse voltage cross gate and drain.

185 `vgsr_max=∞ V`
Maximum allowed reverse voltage cross gate and source.

186 `vgbr_max=∞ V`
Maximum allowed reverse voltage cross gate and bulk.

187 `munqso=1.0` Relative mobility for NQS modeling.

188 `rgo=0.0 Ω` Gate resistance.

189 `rbulko=0.0 Ω` Bulk resistance between node BP and BI.

190 `rwello=0.0 Ω` Well resistance between node BI and B.

191 `rjunso=0.0 Ω` Source-side bulk resistance between node BI and BS.

192 `rjundo=0.0 Ω` Drain-side bulk resistance between node BI and BD.

193 `rint=0.0 Ω/Sqr` Contact resistance between silicide and ploy.

194 `rvpoly=0.0 Ω/Sqr`
Vertical poly resistance.

195 `rshg=0.0 Ω/Sqr` Gate electrode diffusion sheet resistance.

196 `dlsil=0.0 m` Silicide extension over the physical gate length.

197 `saref=1.0e-6 m` Reference distance between OD-edge and poly from one side.

198 `sbref=1.0e-6 m` Reference distance between OD-edge and poly from other side.

199 `wlod=0 m` Width parameter.

200 `kuo=0 m` Mobility degradation/enhancement coefficient.

201 `kvsat=0 m` Saturation velocity degradation/enhancement coefficient.

202 `tkuo=0` Temperature dependence of KUO.

203 `lkuo=0 m^LLODKUO` Length dependence of KUO.

204 `wkuo=0 m^WLODKUO` Width dependence of KUO.

205 `pkuo=0 m^(LLODKUO+WLODKUO)`
Cross-term dependence of KUO.

206 `llodkuo=0` Length parameter for UO stress effect.

207 `wlodkuo=0` Width parameter for UO stress effect.

208 `kvtho=0 Vm` Threshold shift parameter.

209 `lkvtho=0 m^LLODVTH`
Length dependence of KVTHO.

210 `wkvtho=0 m^WLODVTH`
Width dependence of KVTHO.

211 `pkvtho=0 m^(LLODVTH+WLODVTH)`
Cross-term dependence of KVTHO.

212 `llodvth=0` Length parameter for VTH-stress effect.

213 `wlodvth=0` Width parameter for VTH-stress effect.

214 `stetao=0 m` eta0 shift factor related to VTHO change.

215 `lodetao=1.0` eta0 shift modifaction factor for stress effect.

216 `scref=10e-6 m` Distance between OD-edge and well edge of a reference device.

217 `web=0` Coeffecient for SCB.

218 `wec=0` Coeffecient for SCC.

219 `imax=1000 A` Maximum current up to which forward current behaves exponentially.

220 `trj=21 C` reference temperature.

221 `cjorbot=1E-3` Fm^{-2}
Zero-bias capacitance per unit-of-area of bottom component for source-bulk junction.

222 `cjorsti=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for source-bulk junction.

223 `cjorgat=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for source-bulk junction.

224 `vbirbot=1 V` Built-in voltage at the reference temperature of bottom component for source-bulk junction.

225 `vbirsti=1 V` Built-in voltage at the reference temperature of STI-edge component for source-bulk junction.

226 `vbirgat=1 V` Built-in voltage at the reference temperature of gate-edge component for source-bulk junction.

227 `pbot=0.5` Grading coefficient of bottom component for source-bulk junction.

228 `psti=0.5` Grading coefficient of STI-edge component for source-bulk junction.

229 `pgat=0.5` Grading coefficient of gate-edge component for source-bulk junction.

230 `phigbot=1.16 V` Zero-temperature bandgap voltage of bottom component for source-bulk junction.

231 `phigsti=1.16 V` Zero-temperature bandgap voltage of STI-edge component for source-bulk junction.

232 `phiggat=1.16 V` Zero-temperature bandgap voltage of gate-edge component for source-bulk junction.

233 `idsatrbot=1E-12 Am`$^{-2}$
Saturation current density at the reference temperature of bottom component for source-bulk junction.

234 `idsatrsti=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for source-bulk junction.

235 `idsatrgat=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for source-bulk junction.

236 `csrhbot=1E2 Am`$^{-3}$ Shockley-Read-Hall prefactor of bottom component for source-bulk junction.

237 `csrhsti=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of STI-edge component for source-bulk junction.

238 `csrhgat=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of gate-edge component for source-bulk junction.

239 `xjunsti=100E-9 m` Junction depth of STI-edge component for source-bulk junction.

240 `xjungat=100E-9 m` Junction depth of gate-edge component for source-bulk junction.

241 `ctatbot=1E2 Am`$^{-3}$ Trap-assisted tunneling prefactor of bottom component for source-bulk junction.

242 `ctatsti=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of STI-edge component for source-bulk junction.

243 `ctatgat=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of gate-edge component for source-bulk junction.

244 `mefftatbot=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component for source-bulk junction.

245 `mefftatsti=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for source-bulk junction.

246 `mefftatgat=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for source-bulk junction.

247 `cbbtbot=1E-12 AV`$^{-3}$
Band-to-band tunneling prefactor of bottom component for source-bulk junction.

248 `cbbtsti=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of STI-edge component for source-bulk junction.

249 `cbbtgat=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of gate-edge component for source-bulk junction.

250 `fbbtrbot=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component for source-bulk junction.

251 `fbbtrsti=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for source-bulk junction.

252 `fbbtrgat=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for source-bulk junction.

253 `stfbbtbot=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for source-bulk junction.

254 `stfbbtsti=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for source-bulk junction.

255 `stfbbtgat=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for source-bulk junction.

256 `vbrbot=10 V` Breakdown voltage of bottom component for source-bulk junction.

257 `vbrsti=10 V` Breakdown voltage of STI-edge component for source-bulk junction.

258 `vbrgat=10 V` Breakdown voltage of gate-edge component for source-bulk junction.

259 `pbrbot=4 V` Breakdown onset tuning parameter of bottom component for source-bulk junction.

260 `pbrsti=4 V` Breakdown onset tuning parameter of STI-edge component for source-bulk junction.

261 `pbrgat=4 V` Breakdown onset tuning parameter of gate-edge component for source-bulk junction.

262 `cjorbotd=1E-3 Fm`$^{-2}$
Zero-bias capacitance per unit-of-area of bottom component for drain-bulk junction.

263 `cjorstid=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for drain-bulk junction.

264 `cjorgatd=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for drain-bulk junction.

265 `vbirbotd=1 V` Built-in voltage at the reference temperature of bottom component for drain-bulk junction.

266 `vbirstid=1 V` Built-in voltage at the reference temperature of STI-edge component for drain-bulk junction.

267 `vbirgatd=1 V` Built-in voltage at the reference temperature of gate-edge component for drain-bulk junction.

268 `pbotd=0.5` Grading coefficient of bottom component for drain-bulk junction.

269 `pstid=0.5` Grading coefficient of STI-edge component for drain-bulk junction.

270 `pgatd=0.5` Grading coefficient of gate-edge component for drain-bulk junction.

271 `phigbotd=1.16 V` Zero-temperature bandgap voltage of bottom component for drain-bulk junction.

272 `phigstid=1.16 V` Zero-temperature bandgap voltage of STI-edge component for drain-bulk junction.

273 `phiggatd=1.16 V` Zero-temperature bandgap voltage of gate-edge component for drain-bulk junction.

274 `idsatrbotd=1E-12 Am`$^{-2}$
Saturation current density at the reference temperature of bottom component for drain-bulk junction.

275 `idsatrstid=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for drain-bulk junction.

276 `idsatrgatd=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for drain-bulk junction.

277 `csrhbotd=1E2 Am`$^{-3}$
Shockley-Read-Hall prefactor of bottom component for drain-bulk junction.

278 `csrhstid=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of STI-edge component for drain-bulk junction.

279 `csrhgatd=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of gate-edge component for drain-bulk junction.

280 `xjunstid=100E-9 m` Junction depth of STI-edge component for drain-bulk junction.

281 `xjungatd=100E-9 m` Junction depth of gate-edge component for drain-bulk junction.

282 `ctatbotd=1E2 Am`$^{-3}$
Trap-assisted tunneling prefactor of bottom component for drain-bulk junction.

283 `ctatstid=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of STI-edge component for drain-bulk junction.

284 `ctatgatd=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of gate-edge component for drain-bulk junction.

285 `mefftatbotd=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component for drain-bulk junction.

286 `mefftatstid=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for drain-bulk junction.

287 `mefftatgatd=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for drain-bulk junction.

288 `cbbtbotd=1E-12 AV`$^{-3}$
Band-to-band tunneling prefactor of bottom component for drain-bulk junction.

289 `cbbtstid=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of STI-edge component for drain-bulk junction.

290 `cbbtgatd=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of gate-edge component for drain-bulk junction.

291 `fbbtrbotd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component for drain-bulk junction.

292 `fbbtrstid=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for drain-bulk junction.

293 `fbbtrgatd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for drain-bulk junction.

294 `stfbbtbotd=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for drain-bulk junction.

295 `stfbbtstid=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for drain-bulk junction.

296 `stfbbtgatd=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for drain-bulk junction.

297 `vbrbotd=10 V` Breakdown voltage of bottom component for drain-bulk junction.

298 `vbrstid=10 V` Breakdown voltage of STI-edge component for drain-bulk junction.

299 `vbrgatd=10 V` Breakdown voltage of gate-edge component for drain-bulk junction.

300 `pbrbotd=4 V` Breakdown onset tuning parameter of bottom component for drain-bulk junction.

301 `pbrstid=4 V` Breakdown onset tuning parameter of STI-edge component for drain-bulk junction.

302 `pbrgatd=4 V` Breakdown onset tuning parameter of gate-edge component for drain-bulk junction.

303 `swjunexp=0.0` Flag for JUNCAP-express; 0,full model, 1,express model.

304 `vjunref=2.5` Typical maximum source-bulk junction voltage; usually about 2*VSUP.

305 `fjunq=0.03` Fraction below which source-bulk junction capacitance components are considered negligible.

306 `vjunrefd=2.5` Typical maximum drain-bulk junction voltage; usually about 2*VSUP.

307 `fjunqd=0.03` Fraction below which drain-bulk junction capacitance components are considered negligible.

308 `mvto=0.0` DCmatch parameter.

309 `mbeo=0.0` DCmatch parameter.

310 `vthmod` Vth output selector. 'std' outputs model equation Vth. 'vthcc' outputs constant current Vth, and may impact simulation performance. The default value is taken from the options parameter 'vthmod'.
Possible values are `std` and `vthcc`.

311 `ivth (A)` Vth current parameter. The default value is taken from the options parameter 'ivthn' or 'ivthp', depending on the type of the model.

312 `ivthw (m)` Width offset for constant current Vth. The default value is taken from the options parameter 'ivthw'.

313 `ivthl (m)` Length offset for constant current Vth. The default value is taken from the options parameter 'ivthl'.

314 `ivth_vdsmin (V)` Minimum Vds in constant current Vth calculating. The default value is taken from the options parameter 'ivth_vdsmin'.

315 `noisemethod=oldcmi`
Induced gate noise implementation .
Possible values are `oldcmi`, `subckt`, and `newcmi`.

Output Parameters

1 `weff (m)` Effective channel width for geometrical models.

2 `leff (m)` Effective channel length for geometrical models.

3 `lv1 (m)` alias of l.

4 `lv2 (m)` alias of w.

5 `lv3 (m^2)` alias of ad.

6 `lv4 (m^2)` alias of as.

7 `lv11 (m)` alias of pd.

8 `lv12 (m)` alias of ps.

Operating-Point Parameters

1 `ctype` Flag for channel type.

2 `sdint` Flag for source-drain interchange.

3 `ise (A)` Total source current.

4 `ige (A)` Total gate current.

5 `ide (A)` Total drain current.

6 `ibe (A)` Total bulk current.

7 `ids (A)` Drain current, excl. avalanche, tunnel, GISL, GIDL, and junction currents.

8 `idb (A)` Drain to bulk current.

9 `isb (A)` Source to bulk current.

10 `igs (A)` Gate-source tunneling current.

11 `igd (A)` Gate-drain tunneling current.

12 `igb (A)` Gate-bulk tunneling current.

13 `igcs (A)` Gate-channel tunneling current (source component).

14 `igcd (A)` Gate-channel tunneling current (drain component).

15 `iavl (A)` Substrate current due to weak avelanche.

16 `igisl (A)` Gate-induced source leakage current.

17 `igidl (A)` Gate-induced drain leakage current.

18 `ijs (A)` Total source junction current.

19 `ijsbot (A)` Source junction current (bottom component).

20 `ijsgat (A)`	Source junction current (gate-edge component).
21 `ijssti (A)`	Source junction current (STI-edge component).
22 `ijd (A)`	Total drain junction current.
23 `ijdbot (A)`	Drain junction current (bottom component).
24 `ijdgat (A)`	Drain junction current (gate-edge component).
25 `ijdsti (A)`	Drain junction current (STI-edge component).
26 `qg (Coul)`	Intrinsic gate charge.
27 `qd (Coul)`	Intrinsic drain charge.
28 `qb (Coul)`	Intrinsic bulk charge.
29 `qs (Coul)`	Intrinsic source charge.
30 `qgs_ov (Coul)`	Overlap charge for gate-source.
31 `qgd_ov (Coul)`	Overlap charge for gate-drain.
32 `qfgs (Coul)`	Total outerFringe + overlap for gate-source.
33 `qfgd (Coul)`	Total outerFringe + overlap for gate-drain.
34 `qgb_ov (Coul)`	Gate-bulk overlap charge.
35 `qjun_s (Coul)`	Junction charge on source side.
36 `qjun_d (Coul)`	Junction charge on drain side.
37 `vds (V)`	Drain-source voltage.
38 `vgs (V)`	Gate-source voltage.
39 `vsb (V)`	Source-bulk voltage.
40 `vto (V)`	Zero-bias threshold voltage.
41 `vts (V)`	Threshold voltage including back bias effects.

42 `vth (V)`	Threshold voltage including back bias and drain bias effects.
43 `vgt (V)`	Effective gate drive voltage including back bias and drain bias effects.
44 `vdss (V)`	Drain saturation voltage at actual bias.
45 `vsat (V)`	Saturation limit.
46 `pwr (W)`	Power at op point.
47 `gm (1/Ω)`	Transconductance.
48 `gmb (1/Ω)`	Substrate transconductance.
49 `gds (1/Ω)`	Output conductance.
50 `gjs (1/Ω)`	Source junction conductance.
51 `gjd (1/Ω)`	Drain junction conductance.
52 `cdd (F)`	Drain capacitance.
53 `cdg (F)`	Drain-gate capacitance.
54 `cds (F)`	Drain-source capacitance.
55 `cdb (F)`	Drain-bulk capacitance.
56 `cgd (F)`	Gate-drain capacitance.
57 `cgg (F)`	Gate capacitance.
58 `cgs (F)`	Gate-source capacitance.
59 `cgb (F)`	Gate-bulk capacitance.
60 `csd (F)`	Source-drain capacitance.
61 `csg (F)`	Source-gate capacitance.
62 `css (F)`	Source capacitance.

63 `csb (F)`	Source-bulk capacitance.
64 `cbd (F)`	Bulk-drain capacitance.
65 `cbg (F)`	Bulk-gate capacitance.
66 `cbs (F)`	Bulk-source capacitance.
67 `cbb (F)`	Bulk capacitance.
68 `cgsol (F)`	Total gate-source overlap capacitance.
69 `cgdol (F)`	Total gate-drain overlap capacitance.
70 `cgbol (F)`	Total gate-bulk overlap capacitance.
71 `cjs (F)`	Total source junction capacitance.
72 `cjsbot (F)`	Source junction capacitance (bottom component).
73 `cjsgat (F)`	Source junction capacitance (gate-edge component).
74 `cjssti (F)`	Source junction capacitance (STI-edge component).
75 `cjd (F)`	Total drain junction capacitance.
76 `cjdbot (F)`	Drain junction capacitance (bottom component).
77 `cjdgat (F)`	Drain junction capacitance (gate-edge component).
78 `cjdsti (F)`	Drain junction capacitance (STI-edge component).
79 `lpoly (m)`	
80 `u`	Transistor gain.
81 `rout (Ω)`	Small-signal output resistance.
82 `vearly (V)`	Equivalent Early voltage.
83 `beff` (A/V^2)	Gain factor.
84 `fug (Hz)`	Unity gain frequency at actual bias.

85 `rg (Ω)` Gate resistance.

86 `sfl (A^2/Hz)` Flicker noise current spectral density at 1 Hz.

87 `sqrtsff (V/√Hz)` Input-referred RMS white noise voltage spectral density at 1 kHz.

88 `sqrtsfw (V/√Hz)` Input-referred RMS white noise voltage spectral density.

89 `sid (A^2/Hz)` White noise current spectral density.

90 `sig (A^2/Hz)` Induced gate noise current spectral density at 1 Hz.

91 `cigid` Imaginary part of correlation coefficient between Sig and Sid.

92 `fknee (Hz)` Cross-over frequency above which white noise is dominant.

93 `sigs (A^2/Hz)` Gate-source current noise spectral density.

94 `sigd (A^2/Hz)` Gate-drain current noise spectral density.

95 `siavl (A^2/Hz)` Impact ionization current noise spectral density.

96 `ssi (A^2/Hz)` Total source junction current noise spectral density.

97 `sdi (A^2/Hz)` Total drain junction current noise spectral density.

98 `vbs (V)` Bulk-source voltage.

99 `lv9 (V)` alias of vth.

100 `lv10 (V)` alias of vdss.

101 `lv36 (F)` alias of cgsol.

102 `lv37 (F)` alias of cgdol.

103 `lv38 (F)` alias of cgbol.

104 `lv51 (m)` alias of tox.

105 `lx4 (A)` alias of ids.

106 `lx3 (V)` alias of vds.

107 `lx2 (V)` alias of vgs.

108 `lx7 (1/Ω)` alias of gm.

109 `lx8 (1/Ω)` alias of gds.

110 `lx9 (1/Ω)` alias of gmb.

111 `lx33 (F)` alias of cdd.

112 `lx32 (F)` alias of cdg.

113 `lx34 (F)` alias of cds.

114 `lx19 (F)` alias of cgd.

115 `lx18 (F)` alias of cgg.

116 `lx20 (F)` alias of cgs.

117 `lx22 (F)` alias of cbd.

118 `lx21 (F)` alias of cbg.

119 `lx23 (F)` alias of cbs.

120 `lx5 (A)` alias of ijs.

121 `lx6 (A)` alias of ijd.

122 `lx28 (F)` alias of cjs.

123 `lx29 (F)` alias of cjd.

124 `lx38 (A)` alias of igs.

125 `lx39 (A)` alias of igd.

126 `lx66 (A)` alias of igb.

127 `lx67 (A)` alias of igcs.

128 `lx68 (A)` alias of igcd.

129 `lx110 (A)` alias of igisl.

130 `lx47 (A)` alias of igidl.

131 `lx60 (F)` alias of csd.

132 `lx59 (F)` alias of csg.

133 `lx58 (F)` alias of css.

134 `lx12 (Coul)` alias of Qb including overlap charge.

135 `lx14 (Coul)` alias of Qg including overlap charge.

136 `lx16 (Coul)` alias of Qd including overlap charge.

137 `lx83 (F)` alias of cgd including overlap cap.

138 `lx84 (F)` alias of cgs including overlap cap.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

PSP NQS MOSFET Model (pspnqs1021)

This is SiMKit 4.0.1.

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `l=10e-6 m` Design length.

2 `w=10e-6 m` Design width.

3 `sa=0.0 m` Distance between OD-edge and poly from one side.

4 `sb=0.0 m` Distance between OD-edge and poly from other side.

5 `sd=0.0 m` Distance between neighboring fingers.

6 `sca=0.0` Integral of the first distribution function for scattered well dopants.

7 `scb=0.0` Integral of the second distribution function for scattered well dopants.

8 `scc=0.0` Integral of the third distribution function for scattered well dopants.

9 `sc=0.0 m` Distance between OD-edge and nearest well edge.

10 `delvto=0.0 V` Threshold voltage shift parameter.

11 `factuo=1.0` Zero-field mobility pre-factor.

12 `absource=1E-12` m^2 Bottom area of source junction.

13 `lssource=1E-6 m` STI-edge length of source junction.

14 `lgsource=1E-6 m`	Gate-edge length of source junction.
15 `abdrain=1E-12 m`^{2}	Bottom area of drain junction.
16 `lsdrain=1E-6 m`	STI-edge length of drain junction.
17 `lgdrain=1E-6 m`	Gate-edge length of drain junction.
18 `as=1E-12 m`^{2}	Bottom area of source junction.
19 `ps=1E-6 m`	Perimeter of source junction.
20 `ad=1E-12 m`^{2}	Bottom area of drain junction.
21 `pd=1E-6 m`	Perimeter of drain junction.
22 `mulid0=1`	Ids multiplier.
23 `mult=1.0`	Number of devices in parallel.
24 `nf=1.0`	Number of fingers.
25 `ngcon=1.0`	Number of gate contacts.
26 `xgw=1.0E-7 m`	Distance from the gate contact to the channel edge.
27 `trise=0.0 K`	Temperature rise from ambient.
28 `m=1.0`	Multiplicity factor.
29 `isnoisy=yes`	Should device generate noise. Possible values are `no` and `yes`.

Model Definition

model modelName pspnqs1021 parameter=value ...

Model Parameters

1 `level=102`	Model level.
2 `type=n`	Channel type parameter, n,NMOS p,PMOS. Possible values are `n` and `p`.

3 `tr=value of tnom C`
nominal (reference) temperature.

4 `swnqs=0` Flag for NQS, 0,off, 1, 2, 3, 5, or 9,number of collocation points.

5 `swigate=0` Flag for gate current, 0,turn off IG.

6 `swimpact=0` Flag for impact ionization current, 0,turn off II.

7 `swgidl=0` Flag for GIDL current, 0,turn off IGIDL.

8 `swjuncap=0` Flag for juncap, 0,turn off juncap.

9 `swjunasym=0` Flag for asymmetric junctions; 0,symmetric, 1,asymmetric.

10 `qmc=1.0` Quantum-mechanical correction factor.

11 `version=102.32` The available versions are 102.2, 102.21, 102.3, 102.32, 102.33, 102.34 and 102.40.

12 `geomod=1` 1 for geometrical model and 0 for electrical model.

13 `binmod=0` 1 for bin model and 0 for non-bin model.

14 `scalelev=102` 102 for local, 1020 for global model and 1021 for bin model.

15 `compatible=spectre`
for compatible.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, and `mica`.

16 `lvaro=0.0 m` Geom. independent difference between actual and programmed gate length.

17 `lvarl=0.0` Length dependence of LVAR.

18 `lap=0.0 m` Effective channel length reduction per side.

19 `wvaro=0.0 m` Geom. independent difference between actual and programmed field-oxide opening.

20 `wvarw=0.0` Width dependence of WVAR.

21 `wot=0.0 m` Effective channel width reduction per side.

22 `dlq=0.0 m` Effective channel length reduction for CV.

23 `dwq=0.0 m` Effective channel width reduction for CV.

24 `povfb=(-1) V` Coefficient for the geometry independent part of VFB.

25 `plvfb=0.0 V` Coefficient for the length dependence of VFB.

26 `pwvfb=0.0 V` Coefficient for the width dependence of VFB.

27 `plwvfb=0.0 V` Coefficient for the length times width dependence of VFB.

28 `postvfb=0.0005 V/K`
Coefficient for the geometry independent part of STVFB.

29 `plstvfb=0.0 V/K` Coefficient for the length dependence of STVFB.

30 `pwstvfb=0.0 V/K` Coefficient for the width dependence of STVFB.

31 `plwstvfb=0.0 V/K` Coefficient for the length times width dependence of STVFB.

32 `potox=2E-09 m` Coefficient for the geometry independent part of TOX.

33 `poepsrox=3.9` Coefficient for the geometry independent part of EPSOX.

34 `poneff=5E+23` m^{-3} Coefficient for the geometry independent part of NEFF.

35 `plneff=0.0` m^{-3} Coefficient for the length dependence of NEFF.

36 `pwneff=0.0` m^{-3} Coefficient for the width dependence of NEFF.

37 `plwneff=0.0` m^{-3} Coefficient for the length times width dependence of NEFF.

38 `povnsub=0 V` Coefficient for the geometry independent part of VNSUB.

39 `ponslp=0.05 V` Coefficient for the geometry independent part of NSLP.

40 `podnsub=0 V^-1` Coefficient for the geometry independent part of DNSUB.

41 `podphib=0 V` Coefficient for the geometry independent part of DPHIB.

42 `pldphib=0.0 V`	Coefficient for the length dependence of DPHIB.
43 `pwdphib=0.0 V`	Coefficient for the width dependence of DPHIB.
44 `plwdphib=0.0 V`	Coefficient for the length times width dependence of DPHIB.
45 `ponp=1E+26 m`$^{-3}$	Coefficient for the geometry independent part of NP.
46 `plnp=0.0 m`$^{-3}$	Coefficient for the length dependence of NP.
47 `pwnp=0.0 m`$^{-3}$	Coefficient for the width dependence of NP.
48 `plwnp=0.0 m`$^{-3}$	Coefficient for the length times width dependence of NP.
49 `poct=0`	Coefficient for the geometry independent part of CT.
50 `plct=0.0`	Coefficient for the length dependence of CT.
51 `pwct=0.0`	Coefficient for the width dependence of CT.
52 `plwct=0.0`	Coefficient for the length times width dependence of CT.
53 `potoxov=2E-09 m`	Coefficient for the geometry independent part of TOXOV.
54 `potoxovd=2E-09 m`	Coefficient for the geometry independent part of TOXOV for drain side.
55 `ponov=5E+25 m`$^{-3}$	Coefficient for the geometry independent part of NOV.
56 `plnov=0.0 m`$^{-3}$	Coefficient for the length dependence of NOV.
57 `pwnov=0.0 m`$^{-3}$	Coefficient for the width dependence of NOV.
58 `plwnov=0.0 m`$^{-3}$	Coefficient for the length times width dependence of NOV.
59 `ponovd=5E+25 m`$^{-3}$	Coefficient for the geometry independent part of NOV for drain side.
60 `plnovd=0.0 m`$^{-3}$	Coefficient for the length dependence of NOV for drain side.
61 `pwnovd=0.0 m`$^{-3}$	Coefficient for the width dependence of NOV for drain side.

62 `plwnovd=0.0 m^-3` Coefficient for the length times width dependence of NOV for drain side.

63 `pocf=0` Coefficient for the geometry independent part of CF.

64 `plcf=0.0` Coefficient for the length dependence of CF.

65 `pwcf=0.0` Coefficient for the width dependence of CF.

66 `plwcf=0.0` Coefficient for the length times width dependence of CF.

67 `pocfb=0 V^-1` Coefficient for the geometry independent part of CFB.

68 `pobetn=0.07 m^2/V/s`
Coefficient for the geometry independent part of BETN.

69 `plbetn=0.0 m^2/V/s`
Coefficient for the length dependence of BETN.

70 `pwbetn=0.0 m^2/V/s`
Coefficient for the width dependence of BETN.

71 `plwbetn=0.0 m^2/V/s`
Coefficient for the length times width dependence of BETN.

72 `postbet=1` Coefficient for the geometry independent part of STBET.

73 `plstbet=0.0` Coefficient for the length dependence of STBET.

74 `pwstbet=0.0` Coefficient for the width dependence of STBET.

75 `plwstbet=0.0` Coefficient for the length times width dependence of STBET.

76 `pomue=0.5 m/V` Coefficient for the geometry independent part of MUE.

77 `plmue=0.0 m/V` Coefficient for the length dependence of MUE.

78 `pwmue=0.0 m/V` Coefficient for the width dependence of MUE.

79 `plwmue=0.0 m/V` Coefficient for the length times width dependence of MUE.

80 `postmue=0` Coefficient for the geometry independent part of STMUE.

81 `pothemu=1.5`	Coefficient for the geometry independent part of THEMU.
82 `postthemu=1.5`	Coefficient for the geometry independent part of STTHEMU.
83 `pocs=0`	Coefficient for the geometry independent part of CS.
84 `plcs=0.0`	Coefficient for the length dependence of CS.
85 `pwcs=0.0`	Coefficient for the width dependence of CS.
86 `plwcs=0.0`	Coefficient for the length times width dependence of CS.
87 `postcs=0`	Coefficient for the geometry independent part of STCS.
88 `poxcor=0 V^-1`	Coefficient for the geometry independent part of XCOR.
89 `plxcor=0.0 V^-1`	Coefficient for the length dependence of XCOR.
90 `pwxcor=0.0 V^-1`	Coefficient for the width dependence of XCOR.
91 `plwxcor=0.0 V^-1`	Coefficient for the length times width dependence of XCOR.
92 `postxcor=0`	Coefficient for the geometry independent part of STXCOR.
93 `pofeta=1`	Coefficient for the geometry independent part of FETA.
94 `pors=30` Ω	Coefficient for the geometry independent part of RS.
95 `plrs=0.0` Ω	Coefficient for the length dependence of RS.
96 `pwrs=0.0` Ω	Coefficient for the width dependence of RS.
97 `plwrs=0.0` Ω	Coefficient for the length times width dependence of RS.
98 `postrs=1`	Coefficient for the geometry independent part of STRS.
99 `porsb=0 V^-1`	Coefficient for the geometry independent part of RSB.
100 `porsg=0 V^-1`	Coefficient for the geometry independent part of RSG.
101 `pothesat=1 V^-1`	Coefficient for the geometry independent part of THESAT.
102 `plthesat=0.0 V^-1`	Coefficient for the length dependence of THESAT.

103 `pwthesat=0.0 V^-1` Coefficient for the width dependence of THESAT.

104 `plwthesat=0.0 V^-1`
Coefficient for the length times width dependence of THESAT.

105 `postthesat=1` Coefficient for the geometry independent part of STTHESAT.

106 `plstthesat=0.0` Coefficient for the length dependence of STTHESAT.

107 `pwstthesat=0.0` Coefficient for the width dependence of STTHESAT.

108 `plwstthesat=0.0` Coefficient for the length times width dependence of STTHESAT.

109 `pothesatb=0 V^-1` Coefficient for the geometry independent part of THESATB.

110 `plthesatb=0.0 V^-1`
Coefficient for the length dependence of THESATB.

111 `pwthesatb=0.0 V^-1`
Coefficient for the width dependence of THESATB.

112 `plwthesatb=0.0 V^-1`
Coefficient for the length times width dependence of THESATB.

113 `pothesatg=0 V^-1` Coefficient for the geometry independent part of THESATG.

114 `plthesatg=0.0 V^-1`
Coefficient for the length dependence of THESATG.

115 `pwthesatg=0.0 V^-1`
Coefficient for the width dependence of THESATG.

116 `plwthesatg=0.0 V^-1`
Coefficient for the length times width dependence of THESATG.

117 `poax=3` Coefficient for the geometry independent part of AX.

118 `plax=0.0` Coefficient for the length dependence of AX.

119 `pwax=0.0` Coefficient for the width dependence of AX.

120 `plwax=0.0` Coefficient for the length times width dependence of AX.

121 `poalp=0.01`	Coefficient for the geometry independent part of ALP.
122 `plalp=0.0`	Coefficient for the length dependence of ALP.
123 `pwalp=0.0`	Coefficient for the width dependence of ALP.
124 `plwalp=0.0`	Coefficient for the length times width dependence of ALP.
125 `poalp1=0 V`	Coefficient for the geometry independent part of ALP1.
126 `plalp1=0.0 V`	Coefficient for the length dependence of ALP1.
127 `pwalp1=0.0 V`	Coefficient for the width dependence of ALP1.
128 `plwalp1=0.0 V`	Coefficient for the length times width dependence of ALP1.
129 `poalp2=0 V^-1`	Coefficient for the geometry independent part of ALP2.
130 `plalp2=0.0 V^-1`	Coefficient for the length dependence of ALP2.
131 `pwalp2=0.0 V^-1`	Coefficient for the width dependence of ALP2.
132 `plwalp2=0.0 V^-1`	Coefficient for the length times width dependence of ALP2.
133 `povp=0.05 V`	Coefficient for the geometry independent part of VP.
134 `poa1=1`	Coefficient for the geometry independent part of A1.
135 `pla1=0.0`	Coefficient for the length dependence of A1.
136 `pwa1=0.0`	Coefficient for the width dependence of A1.
137 `plwa1=0.0`	Coefficient for the length times width dependence of A1.
138 `poa2=10 V`	Coefficient for the geometry independent part of A2.
139 `posta2=0 V`	Coefficient for the geometry independent part of STA2.
140 `poa3=1`	Coefficient for the geometry independent part of A3.
141 `pla3=0.0`	Coefficient for the length dependence of A3.
142 `pwa3=0.0`	Coefficient for the width dependence of A3.

143 `plwa3=0.0`	Coefficient for the length times width dependence of A3.
144 `poa4=0 V^-0.5`	Coefficient for the geometry independent part of A4.
145 `pla4=0.0 V^-0.5`	Coefficient for the length dependence of A4.
146 `pwa4=0.0 V^-0.5`	Coefficient for the width dependence of A4.
147 `plwa4=0.0 V^-0.5`	Coefficient for the length times width dependence of A4.
148 `pogco=0`	Coefficient for the geometry independent part of GCO.
149 `poiginv=0 A`	Coefficient for the geometry independent part of IGINV.
150 `pliginv=0.0 A`	Coefficient for the length dependence of IGINV.
151 `pwiginv=0.0 A`	Coefficient for the width dependence of IGINV.
152 `plwiginv=0.0 A`	Coefficient for the length times width dependence of IGINV.
153 `poigov=0 A`	Coefficient for the geometry independent part of IGOV.
154 `pligov=0.0 A`	Coefficient for the length dependence of IGOV.
155 `pwigov=0.0 A`	Coefficient for the width dependence of IGOV.
156 `plwigov=0.0 A`	Coefficient for the length times width dependence of IGOV.
157 `poigovd=0 A`	Coefficient for the geometry independent part of IGOV for drain side.
158 `pligovd=0.0 A`	Coefficient for the length dependence of IGOV for drain side.
159 `pwigovd=0.0 A`	Coefficient for the width dependence of IGOV for drain side.
160 `plwigovd=0.0 A`	Coefficient for the length times width dependence of IGOV for drain side.
161 `postig=2`	Coefficient for the geometry independent part of STIG.
162 `pogc2=0.375`	Coefficient for the geometry independent part of GC2.
163 `pogc3=0.063`	Coefficient for the geometry independent part of GC3.

164 `pochib=3.1 V` Coefficient for the geometry independent part of CHIB.

165 `poagidl=0 A/V`^{3} Coefficient for the geometry independent part of AGIDL.

166 `plagidl=0.0 A/V`^{3} Coefficient for the length dependence of AGIDL.

167 `pwagidl=0.0 A/V`^{3} Coefficient for the width dependence of AGIDL.

168 `plwagidl=0.0 A/V`^{3}
Coefficient for the length times width dependence of AGIDL.

169 `poagidld=0 A/V`^{3} Coefficient for the geometry independent part of AGIDL for drain side.

170 `plagidld=0.0 A/V`^{3}
Coefficient for the length dependence of AGIDL for drain side.

171 `pwagidld=0.0 A/V`^{3}
Coefficient for the width dependence of AGIDL for drain side.

172 `plwagidld=0.0 A/V`^{3}
Coefficient for the length times width dependence of AGIDL for drain side.

173 `pobgidl=41 V` Coefficient for the geometry independent part of BGIDL.

174 `pobgidld=41 V` Coefficient for the geometry independent part of BGIDL for drain side.

175 `postbgidl=0 V/K` Coefficient for the geometry independent part of STBGIDL.

176 `postbgidld=0 V/K` Coefficient for the geometry independent part of STBGIDL for drain side.

177 `pocgidl=0` Coefficient for the geometry independent part of CGIDL.

178 `pocgidld=0` Coefficient for the geometry independent part of CGIDL for drain side.

179 `pocox=1E-14 F` Coefficient for the geometry independent part of COX.

180 `plcox=0.0 F` Coefficient for the length dependence of COX.

181 `pwcox=0.0 F`	Coefficient for the width dependence of COX.
182 `plwcox=0.0 F`	Coefficient for the length times width dependence of COX.
183 `pocgov=1E-15 F`	Coefficient for the geometry independent part of CGOV.
184 `plcgov=0.0 F`	Coefficient for the length dependence of CGOV.
185 `pwcgov=0.0 F`	Coefficient for the width dependence of CGOV.
186 `plwcgov=0.0 F`	Coefficient for the length times width dependence of CGOV.
187 `pocgovd=1E-15 F`	Coefficient for the geometry independent part of CGOV for drain side.
188 `plcgovd=0.0 F`	Coefficient for the length dependence of CGOV for drain side.
189 `pwcgovd=0.0 F`	Coefficient for the width dependence of CGOV for drain side.
190 `plwcgovd=0.0 F`	Coefficient for the length times width dependence of CGOV for drain side.
191 `pocgbov=0 F`	Coefficient for the geometry independent part of CGBOV.
192 `plcgbov=0.0 F`	Coefficient for the length dependence of CGBOV.
193 `pwcgbov=0.0 F`	Coefficient for the width dependence of CGBOV.
194 `plwcgbov=0.0 F`	Coefficient for the length times width dependence of CGBOV.
195 `pocfr=0 F`	Coefficient for the geometry independent part of CFR.
196 `plcfr=0.0 F`	Coefficient for the length dependence of CFR.
197 `pwcfr=0.0 F`	Coefficient for the width dependence of CFR.
198 `plwcfr=0.0 F`	Coefficient for the length times width dependence of CFR.
199 `pocfrd=0 F`	Coefficient for the geometry independent part of CFR for drain side.
200 `plcfrd=0.0 F`	Coefficient for the length dependence of CFR for drain side.

201 `pwcfrd=0.0 F` Coefficient for the width dependence of CFR for drain side.

202 `plwcfrd=0.0 F` Coefficient for the length times width dependence of CFR for drain side.

203 `pofnt=1` Coefficient for the geometry independent part of FNT.

204 `ponfa=8E+22 V^-1/m`^{4}
Coefficient for the geometry independent part of NFA.

205 `plnfa=0.0 V^-1/m`^{4}
Coefficient for the length dependence of NFA.

206 `pwnfa=0.0 V^-1/m`^{4}
Coefficient for the width dependence of NFA.

207 `plwnfa=0.0 V^-1/m`^{4}
Coefficient for the length times width dependence of NFA.

208 `ponfb=3E+07 V^-1/m`^{2}
Coefficient for the geometry independent part of NFB.

209 `plnfb=0.0 V^-1/m`^{2}
Coefficient for the length dependence of NFB.

210 `pwnfb=0.0 V^-1/m`^{2}
Coefficient for the width dependence of NFB.

211 `plwnfb=0.0 V^-1/m`^{2}
Coefficient for the length times width dependence of NFB.

212 `ponfc=0 V^-1` Coefficient for the geometry independent part of NFC.

213 `plnfc=0.0 V^-1` Coefficient for the length dependence of NFC.

214 `pwnfc=0.0 V^-1` Coefficient for the width dependence of NFC.

215 `plwnfc=0.0 V^-1` Coefficient for the length times width dependence of NFC.

216 `poef=1.0` Coefficient for the flicker noise frequency exponent.

217 `dta=0 K` Temperature offset w.r.t. ambient circuit temperature.

218 `pokvthowe=0` Coefficient for the geometry independent part of KVTHOWE.

219 `plkvthowe=0` Coefficient for the length dependence part of KVTHOWE.

220 `pwkvthowe=0` Coefficient for the width dependence part of KVTHOWE.

221 `plwkvthowe=0` Coefficient for the length times width dependence part of KVTHOWE.

222 `pokuowe=0` Coefficient for the geometry independent part of KUOWE.

223 `plkuowe=0` Coefficient for the length dependence part of KUOWE.

224 `pwkuowe=0` Coefficient for the width dependence part of KUOWE.

225 `plwkuowe=0` Coefficient for the length times width dependence part of KUOWE.

226 `lmin=0 m` Dummy parameter to label binning set.

227 `lmax=1.0 m` Dummy parameter to label binning set.

228 `wmin=0 m` Dummy parameter to label binning set.

229 `wmax=1.0 m` Dummy parameter to label binning set.

230 `vds_max=∞ V`

Maximum allowed voltage cross source and drain.

231 `vgd_max=∞ V`

Maximum allowed voltage cross gate and drain.

232 `vgs_max=∞ V`

Maximum allowed voltage cross gate and source/bulk.

233 `vbd_max=∞ V`

Maximum allowed voltage cross source/drain and bulk.

234 `vbs_max=∞ V`

Maximum allowed voltage cross source and bulk.

235 `vgb_max=∞ V`

Maximum allowed voltage cross gate and bulk.

236 `vgdr_max=∞ V`
Maximum allowed reverse voltage cross gate and drain.

237 `vgsr_max=∞ V`
Maximum allowed reverse voltage cross gate and source.

238 `vgbr_max=∞ V`
Maximum allowed reverse voltage cross gate and bulk.

239 `munqso=1.0` Relative mobility for NQS modeling.

240 `rgo=0.0 Ω` Gate resistance.

241 `rbulko=0.0 Ω` Bulk resistance between node BP and BI.

242 `rwello=0.0 Ω` Well resistance between node BI and B.

243 `rjunso=0.0 Ω` Source-side bulk resistance between node BI and BS.

244 `rjundo=0.0 Ω` Drain-side bulk resistance between node BI and BD.

245 `rint=0.0 Ω/Sqr` Contact resistance between silicide and ploy.

246 `rvpoly=0.0 Ω/Sqr`
Vertical poly resistance.

247 `rshg=0.0 Ω/Sqr` Gate electrode diffusion sheet resistance.

248 `dlsil=0.0 m` Silicide extension over the physical gate length.

249 `saref=1.0e-6 m` Reference distance between OD-edge and poly from one side.

250 `sbref=1.0e-6 m` Reference distance between OD-edge and poly from other side.

251 `wlod=0 m` Width parameter.

252 `kuo=0 m` Mobility degradation/enhancement coefficient.

253 `kvsat=0 m` Saturation velocity degradation/enhancement coefficient.

254 `tkuo=0` Temperature dependence of KUO.

255 `lkuo=0 m^LLODKUO` Length dependence of KUO.

256 `wkuo=0 m^WLODKUO` Width dependence of KUO.

257 `pkuo=0 m^(LLODKUO+WLODKUO)`
Cross-term dependence of KUO.

258 `llodkuo=0` Length parameter for UO stress effect.

259 `wlodkuo=0` Width parameter for UO stress effect.

260 `kvtho=0 Vm` Threshold shift parameter.

261 `lkvtho=0 m^LLODVTH`
Length dependence of KVTHO.

262 `wkvtho=0 m^WLODVTH`
Width dependence of KVTHO.

263 `pkvtho=0 m^(LLODVTH+WLODVTH)`
Cross-term dependence of KVTHO.

264 `llodvth=0` Length parameter for VTH-stress effect.

265 `wlodvth=0` Width parameter for VTH-stress effect.

266 `stetao=0 m` eta0 shift factor related to VTHO change.

267 `lodetao=1.0` eta0 shift modifaction factor for stress effect.

268 `scref=10e-6 m` Distance between OD-edge and well edge of a reference device.

269 `web=0` Coeffecient for SCB.

270 `wec=0` Coeffecient for SCC.

271 `imax=1000 A` Maximum current up to which forward current behaves exponentially.

272 `trj=21 C` reference temperature.

273 `cjorbot=1E-3` Fm^{-2}
Zero-bias capacitance per unit-of-area of bottom component for source-bulk junction.

274 `cjorsti=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for source-bulk junction.

275 `cjorgat=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for source-bulk junction.

276 `vbirbot=1 V` Built-in voltage at the reference temperature of bottom component for source-bulk junction.

277 `vbirsti=1 V` Built-in voltage at the reference temperature of STI-edge component for source-bulk junction.

278 `vbirgat=1 V` Built-in voltage at the reference temperature of gate-edge component for source-bulk junction.

279 `pbot=0.5` Grading coefficient of bottom component for source-bulk junction.

280 `psti=0.5` Grading coefficient of STI-edge component for source-bulk junction.

281 `pgat=0.5` Grading coefficient of gate-edge component for source-bulk junction.

282 `phigbot=1.16 V` Zero-temperature bandgap voltage of bottom component for source-bulk junction.

283 `phigsti=1.16 V` Zero-temperature bandgap voltage of STI-edge component for source-bulk junction.

284 `phiggat=1.16 V` Zero-temperature bandgap voltage of gate-edge component for source-bulk junction.

285 `idsatrbot=1E-12` Am^{-2}
Saturation current density at the reference temperature of bottom component for source-bulk junction.

286 `idsatrsti=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for source-bulk junction.

287 `idsatrgat=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for source-bulk junction.

288 `csrhbot=1E2 Am`$^{-3}$ Shockley-Read-Hall prefactor of bottom component for source-bulk junction.

289 `csrhsti=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of STI-edge component for source-bulk junction.

290 `csrhgat=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of gate-edge component for source-bulk junction.

291 `xjunsti=100E-9 m` Junction depth of STI-edge component for source-bulk junction.

292 `xjungat=100E-9 m` Junction depth of gate-edge component for source-bulk junction.

293 `ctatbot=1E2 Am`$^{-3}$ Trap-assisted tunneling prefactor of bottom component for source-bulk junction.

294 `ctatsti=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of STI-edge component for source-bulk junction.

295 `ctatgat=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of gate-edge component for source-bulk junction.

296 `mefftatbot=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component for source-bulk junction.

297 `mefftatsti=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for source-bulk junction.

298 `mefftatgat=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for source-bulk junction.

299 `cbbtbot=1E-12 AV`$^{-3}$
Band-to-band tunneling prefactor of bottom component for source-bulk junction.

300 `cbbtsti=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of STI-edge component for source-bulk junction.

301 `cbbtgat=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of gate-edge component for source-bulk junction.

302 `fbbtrbot=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component for source-bulk junction.

303 `fbbtrsti=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for source-bulk junction.

304 `fbbtrgat=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for source-bulk junction.

305 `stfbbtbot=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for source-bulk junction.

306 `stfbbtsti=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for source-bulk junction.

307 `stfbbtgat=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for source-bulk junction.

308 `vbrbot=10 V` Breakdown voltage of bottom component for source-bulk junction.

309 `vbrsti=10 V` Breakdown voltage of STI-edge component for source-bulk junction.

310 `vbrgat=10 V` Breakdown voltage of gate-edge component for source-bulk junction.

311 `pbrbot=4 V` Breakdown onset tuning parameter of bottom component for source-bulk junction.

312 `pbrsti=4 V` Breakdown onset tuning parameter of STI-edge component for source-bulk junction.

313 `pbrgat=4 V` Breakdown onset tuning parameter of gate-edge component for source-bulk junction.

314 `cjorbotd=1E-3 Fm`$^{-2}$
Zero-bias capacitance per unit-of-area of bottom component for drain-bulk junction.

315 `cjorstid=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for drain-bulk junction.

316 `cjorgatd=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for drain-bulk junction.

317 `vbirbotd=1 V` Built-in voltage at the reference temperature of bottom component for drain-bulk junction.

318 `vbirstid=1 V` Built-in voltage at the reference temperature of STI-edge component for drain-bulk junction.

319 `vbirgatd=1 V` Built-in voltage at the reference temperature of gate-edge component for drain-bulk junction.

320 `pbotd=0.5` Grading coefficient of bottom component for drain-bulk junction.

321 `pstid=0.5` Grading coefficient of STI-edge component for drain-bulk junction.

322 `pgatd=0.5` Grading coefficient of gate-edge component for drain-bulk junction.

323 `phigbotd=1.16 V` Zero-temperature bandgap voltage of bottom component for drain-bulk junction.

324 `phigstid=1.16 V` Zero-temperature bandgap voltage of STI-edge component for drain-bulk junction.

325 `phiggatd=1.16 V` Zero-temperature bandgap voltage of gate-edge component for drain-bulk junction.

326 `idsatrbotd=1E-12 Am`$^{-2}$
Saturation current density at the reference temperature of bottom component for drain-bulk junction.

327 `idsatrstid=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for drain-bulk junction.

328 `idsatrgatd=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for drain-bulk junction.

329 `csrhbotd=1E2 Am`$^{-3}$
Shockley-Read-Hall prefactor of bottom component for drain-bulk junction.

330 `csrhstid=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of STI-edge component for drain-bulk junction.

331 `csrhgatd=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of gate-edge component for drain-bulk junction.

332 `xjunstid=100E-9 m` Junction depth of STI-edge component for drain-bulk junction.

333 `xjungatd=100E-9 m` Junction depth of gate-edge component for drain-bulk junction.

334 `ctatbotd=1E2 Am`$^{-3}$
Trap-assisted tunneling prefactor of bottom component for drain-bulk junction.

335 `ctatstid=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of STI-edge component for drain-bulk junction.

336 `ctatgatd=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of gate-edge component for drain-bulk junction.

337 `mefftatbotd=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component for drain-bulk junction.

338 `mefftatstid=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for drain-bulk junction.

339 `mefftatgatd=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for drain-bulk junction.

340 `cbbtbotd=1E-12 AV`$^{-3}$
Band-to-band tunneling prefactor of bottom component for drain-bulk junction.

341 `cbbtstid=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of STI-edge component for drain-bulk junction.

342 `cbbtgatd=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of gate-edge component for drain-bulk junction.

343 `fbbtrbotd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component for drain-bulk junction.

344 `fbbtrstid=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for drain-bulk junction.

345 `fbbtrgatd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for drain-bulk junction.

346 `stfbbtbotd=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for drain-bulk junction.

347 `stfbbtstid=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for drain-bulk junction.

348 `stfbbtgatd=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for drain-bulk junction.

349 `vbrbotd=10 V` Breakdown voltage of bottom component for drain-bulk junction.

350 `vbrstid=10 V`	Breakdown voltage of STI-edge component for drain-bulk junction.
351 `vbrgatd=10 V`	Breakdown voltage of gate-edge component for drain-bulk junction.
352 `pbrbotd=4 V`	Breakdown onset tuning parameter of bottom component for drain-bulk junction.
353 `pbrstid=4 V`	Breakdown onset tuning parameter of STI-edge component for drain-bulk junction.
354 `pbrgatd=4 V`	Breakdown onset tuning parameter of gate-edge component for drain-bulk junction.
355 `swjunexp=0.0`	Flag for JUNCAP-express; 0,full model, 1,express model.
356 `vjunref=2.5`	Typical maximum source-bulk junction voltage; usually about 2*VSUP.
357 `fjunq=0.03`	Fraction below which source-bulk junction capacitance components are considered negligible.
358 `vjunrefd=2.5`	Typical maximum drain-bulk junction voltage; usually about 2*VSUP.
359 `fjunqd=0.03`	Fraction below which drain-bulk junction capacitance components are considered negligible.
360 `mvto=0.0`	DCmatch parameter.
361 `mbeo=0.0`	DCmatch parameter.
362 `vthmod`	Vth output selector. 'std' outputs model equation Vth. 'vthcc' outputs constant current Vth, and may impact simulation performance. The default value is taken from the options parameter 'vthmod'. Possible values are `std` and `vthcc`.
363 `ivth (A)`	Vth current parameter. The default value is taken from the options parameter 'ivthn' or 'ivthp', depending on the type of the model.

364 `ivthw (m)` Width offset for constant current Vth. The default value is taken from the options parameter 'ivthw'.

365 `ivthl (m)` Length offset for constant current Vth. The default value is taken from the options parameter 'ivthl'.

366 `ivth_vdsmin (V)` Minimum Vds in constant current Vth calculating. The default value is taken from the options parameter 'ivth_vdsmin'.

367 `noisemethod=oldcmi`
Induced gate noise implementation .
Possible values are `oldcmi`, `subckt`, and `newcmi`.

Output Parameters

1 `weff (m)` Effective channel width for geometrical models.

2 `leff (m)` Effective channel length for geometrical models.

3 `lv1 (m)` alias of l.

4 `lv2 (m)` alias of w.

5 `lv3` (m^2) alias of ad.

6 `lv4` (m^2) alias of as.

7 `lv11 (m)` alias of pd.

8 `lv12 (m)` alias of ps.

Operating-Point Parameters

1 `ctype` Flag for channel type.

2 `sdint` Flag for source-drain interchange.

3 `ise (A)` Total source current.

4 `ige (A)` Total gate current.

5 `ide (A)` Total drain current.

6 `ibe (A)`	Total bulk current.
7 `ids (A)`	Drain current, excl. avalanche, tunnel, GISL, GIDL, and junction currents.
8 `idb (A)`	Drain to bulk current.
9 `isb (A)`	Source to bulk current.
10 `igs (A)`	Gate-source tunneling current.
11 `igd (A)`	Gate-drain tunneling current.
12 `igb (A)`	Gate-bulk tunneling current.
13 `igcs (A)`	Gate-channel tunneling current (source component).
14 `igcd (A)`	Gate-channel tunneling current (drain component).
15 `iavl (A)`	Substrate current due to weak avelanche.
16 `igisl (A)`	Gate-induced source leakage current.
17 `igidl (A)`	Gate-induced drain leakage current.
18 `ijs (A)`	Total source junction current.
19 `ijsbot (A)`	Source junction current (bottom component).
20 `ijsgat (A)`	Source junction current (gate-edge component).
21 `ijssti (A)`	Source junction current (STI-edge component).
22 `ijd (A)`	Total drain junction current.
23 `ijdbot (A)`	Drain junction current (bottom component).
24 `ijdgat (A)`	Drain junction current (gate-edge component).
25 `ijdsti (A)`	Drain junction current (STI-edge component).
26 `qg (Coul)`	Intrinsic gate charge.

27 qd (Coul)	Intrinsic drain charge.
28 qb (Coul)	Intrinsic bulk charge.
29 qs (Coul)	Intrinsic source charge.
30 qgs_ov (Coul)	Overlap charge for gate-source.
31 qgd_ov (Coul)	Overlap charge for gate-drain.
32 qfgs (Coul)	Total outerFringe + overlap for gate-source.
33 qfgd (Coul)	Total outerFringe + overlap for gate-drain.
34 qgb_ov (Coul)	Gate-bulk overlap charge.
35 qjun_s (Coul)	Junction charge on source side.
36 qjun_d (Coul)	Junction charge on drain side.
37 vds (V)	Drain-source voltage.
38 vgs (V)	Gate-source voltage.
39 vsb (V)	Source-bulk voltage.
40 vto (V)	Zero-bias threshold voltage.
41 vts (V)	Threshold voltage including back bias effects.
42 vth (V)	Threshold voltage including back bias and drain bias effects.
43 vgt (V)	Effective gate drive voltage including back bias and drain bias effects.
44 vdss (V)	Drain saturation voltage at actual bias.
45 vsat (V)	Saturation limit.
46 pwr (W)	Power at op point.
47 gm (1/Ω)	Transconductance.

48 `gmb (1/Ω)`	Substrate transconductance.
49 `gds (1/Ω)`	Output conductance.
50 `gjs (1/Ω)`	Source junction conductance.
51 `gjd (1/Ω)`	Drain junction conductance.
52 `cdd (F)`	Drain capacitance.
53 `cdg (F)`	Drain-gate capacitance.
54 `cds (F)`	Drain-source capacitance.
55 `cdb (F)`	Drain-bulk capacitance.
56 `cgd (F)`	Gate-drain capacitance.
57 `cgg (F)`	Gate capacitance.
58 `cgs (F)`	Gate-source capacitance.
59 `cgb (F)`	Gate-bulk capacitance.
60 `csd (F)`	Source-drain capacitance.
61 `csg (F)`	Source-gate capacitance.
62 `css (F)`	Source capacitance.
63 `csb (F)`	Source-bulk capacitance.
64 `cbd (F)`	Bulk-drain capacitance.
65 `cbg (F)`	Bulk-gate capacitance.
66 `cbs (F)`	Bulk-source capacitance.
67 `cbb (F)`	Bulk capacitance.
68 `cgsol (F)`	Total gate-source overlap capacitance.
69 `cgdol (F)`	Total gate-drain overlap capacitance.

70 `cgbol (F)`	Total gate-bulk overlap capacitance.
71 `cjs (F)`	Total source junction capacitance.
72 `cjsbot (F)`	Source junction capacitance (bottom component).
73 `cjsgat (F)`	Source junction capacitance (gate-edge component).
74 `cjssti (F)`	Source junction capacitance (STI-edge component).
75 `cjd (F)`	Total drain junction capacitance.
76 `cjdbot (F)`	Drain junction capacitance (bottom component).
77 `cjdgat (F)`	Drain junction capacitance (gate-edge component).
78 `cjdsti (F)`	Drain junction capacitance (STI-edge component).
79 `lpoly (m)`	
80 `u`	Transistor gain.
81 `rout (Ω)`	Small-signal output resistance.
82 `vearly (V)`	Equivalent Early voltage.
83 `beff` (A/V^2)	Gain factor.
84 `fug (Hz)`	Unity gain frequency at actual bias.
85 `rg (Ω)`	Gate resistance.
86 `sfl` (A^2/Hz)	Flicker noise current spectral density at 1 Hz.
87 `sqrtsff` ($V/\sqrt{Hz}$)	Input-referred RMS white noise voltage spectral density at 1 kHz.
88 `sqrtsfw` ($V/\sqrt{Hz}$)	Input-referred RMS white noise voltage spectral density.
89 `sid` (A^2/Hz)	White noise current spectral density.
90 `sig` (A^2/Hz)	Induced gate noise current spectral density at 1 Hz.

91 `cigid`	Imaginary part of correlation coefficient between Sig and Sid.
92 `fknee (Hz)`	Cross-over frequency above which white noise is dominant.
93 `sigs (A`^{2}`/Hz)`	Gate-source current noise spectral density.
94 `sigd (A`^{2}`/Hz)`	Gate-drain current noise spectral density.
95 `siavl (A`^{2}`/Hz)`	Impact ionization current noise spectral density.
96 `ssi (A`^{2}`/Hz)`	Total source junction current noise spectral density.
97 `sdi (A`^{2}`/Hz)`	Total drain junction current noise spectral density.
98 `vbs (V)`	Bulk-source voltage.
99 `lv9 (V)`	alias of vth.
100 `lv10 (V)`	alias of vdss.
101 `lv36 (F)`	alias of cgsol.
102 `lv37 (F)`	alias of cgdol.
103 `lv38 (F)`	alias of cgbol.
104 `lv51 (m)`	alias of tox.
105 `lx4 (A)`	alias of ids.
106 `lx3 (V)`	alias of vds.
107 `lx2 (V)`	alias of vgs.
108 `lx7 (1/Ω)`	alias of gm.
109 `lx8 (1/Ω)`	alias of gds.
110 `lx9 (1/Ω)`	alias of gmb.
111 `lx33 (F)`	alias of cdd.
112 `lx32 (F)`	alias of cdg.

113 `lx34 (F)` alias of cds.

114 `lx19 (F)` alias of cgd.

115 `lx18 (F)` alias of cgg.

116 `lx20 (F)` alias of cgs.

117 `lx22 (F)` alias of cbd.

118 `lx21 (F)` alias of cbg.

119 `lx23 (F)` alias of cbs.

120 `lx5 (A)` alias of ijs.

121 `lx6 (A)` alias of ijd.

122 `lx28 (F)` alias of cjs.

123 `lx29 (F)` alias of cjd.

124 `lx38 (A)` alias of igs.

125 `lx39 (A)` alias of igd.

126 `lx66 (A)` alias of igb.

127 `lx67 (A)` alias of igcs.

128 `lx68 (A)` alias of igcd.

129 `lx110 (A)` alias of igisl.

130 `lx47 (A)` alias of igidl.

131 `lx60 (F)` alias of csd.

132 `lx59 (F)` alias of csg.

133 `lx58 (F)` alias of css.

134 `lx12 (Coul)` alias of Qb including overlap charge.

135 `lx14 (Coul)` alias of Qg including overlap charge.

136 `lx16 (Coul)` alias of Qd including overlap charge.

137 `lx83 (F)` alias of cgd including overlap cap.

138 `lx84 (F)` alias of cgs including overlap cap.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

PSP NQS local MOSFET Model (pspnqs102e)

This is SiMKit 4.0.1.

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

Instance Definition

Name d g s b ModelName parameter=value ...

Instance Parameters

1 `delvto=0.0 V` Threshold voltage shift parameter.

2 `factuo=1.0` Zero-field mobility pre-factor.

3 `absource=1E-12 m`^{2} Bottom area of source junction.

4 `lssource=1E-6 m` STI-edge length of source junction.

5 `lgsource=1E-6 m` Gate-edge length of source junction.

6 `abdrain=1E-12 m`^{2} Bottom area of drain junction.

7 `lsdrain=1E-6 m` STI-edge length of drain junction.

8 `lgdrain=1E-6 m` Gate-edge length of drain junction.

9 `as=1E-12 m`^{2} Bottom area of source junction.

10 `ps=1E-6 m` Perimeter of source junction.

11 `ad=1E-12 m`^{2} Bottom area of drain junction.

12 `pd=1E-6 m` Perimeter of drain junction.

13 `mulid0=1` Ids multiplier.

14 `jw=1E-6 m` Gate-edge length of source/drain junction.

15 `mult=1.0` Number of devices in parallel.

16 `trise=0.0 K` Temperature rise from ambient.

17 `m=1.0` Multiplicity factor.

18 `isnoisy=yes` Should device generate noise.
Possible values are `no` and `yes`.

Model Definition

model modelName pspnqs102e parameter=value ...

Model Parameters

1 `level=102` Model level.

2 `type=n` Channel type parameter, n,NMOS p,PMOS.
Possible values are `n` and `p`.

3 `tr=value of tnom C`
nominal (reference) temperature.

4 `swnqs=0` Flag for NQS, 0,off, 1, 2, 3, 5, or 9,number of collocation points.

5 `swigate=0` Flag for gate current, 0,turn off IG.

6 `swimpact=0` Flag for impact ionization current, 0,turn off II.

7 `swgidl=0` Flag for GIDL current, 0,turn off IGIDL.

8 `swjuncap=0` Flag for juncap, 0,turn off juncap.

9 `swjunasym=0` Flag for asymmetric junctions; 0,symmetric, 1,asymmetric.

10 `qmc=1.0` Quantum-mechanical correction factor.

11 `version=102.32` The available versions are 102.2, 102.21, 102.3, 102.32, 102.33, 102.34 and 102.40.

12 `geomod=1` 1 for geometrical model and 0 for electrical model.

13 `binmod=0` 1 for bin model and 0 for non-bin model.

14 `scalelev=102` 102 for local, 1020 for global model and 1021 for bin model.

15 `compatible=spectre`
for compatible.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, and `mica`.

16 `vfb=(-1.0) V` Flatband voltage at TR.

17 `stvfb=5.0e-4 V/K` Temperature dependence of VFB.

18 `tox=2.0e-09 m` Gate oxide thickness.

19 `epsrox=3.9` Relative permittivity of gate dielectric.

20 `neff=5.0e+23` m^{-3} Effective substrate doping.

21 `vnsub=0.0 V`	Effective doping bias-dependence parameter.
22 `nslp=0.05 V`	Effective doping bias-dependence parameter.
23 `dnsub=0.0 V^-1`	Effective doping bias-dependence parameter.
24 `dphib=0.0 V`	Offset parameter for PHIB.
25 `np=1.0e+26 m`$^{-3}$	Gate poly-silicon doping.
26 `ct=0.0`	Interface states factor.
27 `toxov=2.0e-09 m`	Overlap oxide thickness.
28 `toxovd=2.0e-09 m`	Overlap oxide thickness for drain side.
29 `nov=5.0e+25 m`$^{-3}$	Effective doping of overlap region.
30 `novd=5.0e+25 m`$^{-3}$	Effective doping of overlap region for drain side.
31 `cf=0.0`	DIBL-parameter.
32 `cfb=0.0 V^-1`	Back bias dependence of CF.
33 `betn=7e-2 m`^{2}`/V/s`	Channel aspect ratio times zero-field mobility.
34 `stbet=1.0`	Temperature dependence of BETN.
35 `mue=0.5 m/V`	Mobility reduction coefficient at TR.
36 `stmue=0.0`	Temperature dependence of MUE.
37 `themu=1.5`	Mobility reduction exponent at TR.
38 `stthemu=1.5`	Temperature dependence of THEMU.
39 `cs=0.0`	Coulomb scattering parameter at TR.
40 `stcs=0.0`	Temperature dependence of CS.
41 `xcor=0.0 V^-1`	Non-universality factor.
42 `stxcor=0.0`	Temperature dependence of XCOR.

43 `feta=1.0`	Effective field parameter.
44 `rs=30 Ω`	Series resistance at TR.
45 `strs=1.0`	Temperature dependence of RS.
46 `rsb=0.0 V^-1`	Back-bias dependence of series resistance.
47 `rsg=0.0 V^-1`	Gate-bias dependence of series resistance.
48 `thesat=1.0 V^-1`	Velocity saturation parameter at TR.
49 `stthesat=1.0`	Temperature dependence of THESAT.
50 `thesatb=0.0 V^-1`	Back-bias dependence of velocity saturation.
51 `thesatg=0.0 V^-1`	Gate-bias dependence of velocity saturation.
52 `ax=3.0`	Linear/saturation transition factor.
53 `alp=0.01`	CLM pre-factor.
54 `alp1=0.00 V`	CLM enhancement factor above threshold.
55 `alp2=0.00 V^-1`	CLM enhancement factor below threshold.
56 `vp=0.05 V`	CLM logarithm dependence factor.
57 `a1=1.0`	Impact-ionization pre-factor.
58 `a2=10.0 V`	Impact-ionization exponent at TR.
59 `sta2=0.0 V`	Temperature dependence of A2.
60 `a3=1.0`	Saturation-voltage dependence of impact-ionization.
61 `a4=0.0 V^-0.5`	Back-bias dependence of impact-ionization.
62 `gco=0.0`	Gate tunnelling energy adjustment.
63 `iginv=0.0 A`	Gate channel current pre-factor.
64 `igov=0.0 A`	Gate overlap current pre-factor.

65 `igovd=0.0 A` Gate overlap current pre-factor for drain side.

66 `stig=2.0` Temperature dependence of IGINV and IGOV.

67 `gc2=0.375` Gate current slope factor.

68 `gc3=0.063` Gate current curvature factor.

69 `chib=3.1 V` Tunnelling barrier height.

70 `agidl=0.0` A/V^3 GIDL pre-factor.

71 `agidld=0.0` A/V^3 GIDL pre-factor for drain side.

72 `bgidl=41.0 V` GIDL probability factor at TR.

73 `bgidld=41.0 V` GIDL probability factor at TR for drain side.

74 `stbgidl=0.0 V/K` Temperature dependence of BGIDL.

75 `stbgidld=0.0 V/K` Temperature dependence of BGIDL for drain side.

76 `cgidl=0.0` Back-bias dependence of GIDL.

77 `cgidld=0.0` Back-bias dependence of GIDL for drain side.

78 `cox=1.0e-14 F` Oxide capacitance for intrinsic channel.

79 `cgov=1.0e-15 F` Oxide capacitance for gate-drain/source overlap.

80 `cgovd=1.0e-15 F` Oxide capacitance for gate-drain overlap.

81 `cgbov=0.0 F` Oxide capacitance for gate-bulk overlap.

82 `cfr=0.0 F` Outer fringe capacitance.

83 `cfrd=0.0 F` Outer fringe capacitance for drain side.

84 `fnt=1.0` Thermal noise coefficient.

85 `nfa=8.0e+22 V^-1/m`^{4}

First coefficient of flicker noise.

86 `nfb=3.0e+07 V^-1/m`^{2}
Second coefficient of flicker noise.

87 `nfc=0.0 V^-1` Third coefficient of flicker noise.

88 `ef=1.0` Flicker noise frequency exponent.

89 `munqs=1.0` Relative mobility for NQS modeling.

90 `rg=0.0` Ω Gate resistance.

91 `rbulk=0.0` Ω Bulk resistance between node BP and BI.

92 `rwell=0.0` Ω Well resistance between node BI and B.

93 `rjuns=0.0` Ω Source-side bulk resistance between node BI and BS.

94 `rjund=0.0` Ω Drain-side bulk resistance between node BI and BD.

95 `imax=1000 A` Maximum current up to which forward current behaves exponentially.

96 `trj=21 C` reference temperature.

97 `cjorbot=1E-3 Fm`$^{-2}$
Zero-bias capacitance per unit-of-area of bottom component for source-bulk junction.

98 `cjorsti=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for source-bulk junction.

99 `cjorgat=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for source-bulk junction.

100 `vbirbot=1 V` Built-in voltage at the reference temperature of bottom component for source-bulk junction.

101 `vbirsti=1 V` Built-in voltage at the reference temperature of STI-edge component for source-bulk junction.

102 `vbirgat=1 V` Built-in voltage at the reference temperature of gate-edge component for source-bulk junction.

103 `pbot=0.5` Grading coefficient of bottom component for source-bulk junction.

104 `psti=0.5` Grading coefficient of STI-edge component for source-bulk junction.

105 `pgat=0.5` Grading coefficient of gate-edge component for source-bulk junction.

106 `phigbot=1.16 V` Zero-temperature bandgap voltage of bottom component for source-bulk junction.

107 `phigsti=1.16 V` Zero-temperature bandgap voltage of STI-edge component for source-bulk junction.

108 `phiggat=1.16 V` Zero-temperature bandgap voltage of gate-edge component for source-bulk junction.

109 `idsatrbot=1E-12 Am`$^{-2}$
Saturation current density at the reference temperature of bottom component for source-bulk junction.

110 `idsatrsti=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for source-bulk junction.

111 `idsatrgat=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for source-bulk junction.

112 `csrhbot=1E2 Am`$^{-3}$ Shockley-Read-Hall prefactor of bottom component for source-bulk junction.

113 `csrhsti=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of STI-edge component for source-bulk junction.

114 `csrhgat=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of gate-edge component for source-bulk junction.

115 `xjunsti=100E-9 m` Junction depth of STI-edge component for source-bulk junction.

116 `xjungat=100E-9 m` Junction depth of gate-edge component for source-bulk junction.

117 `ctatbot=1E2 Am`$^{-3}$ Trap-assisted tunneling prefactor of bottom component for source-bulk junction.

118 `ctatsti=1E-4 Am`$^{-2}$

Trap-assisted tunneling prefactor of STI-edge component for source-bulk junction.

119 `ctatgat=1E-4 Am`$^{-2}$

Trap-assisted tunneling prefactor of gate-edge component for source-bulk junction.

120 `mefftatbot=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component for source-bulk junction.

121 `mefftatsti=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for source-bulk junction.

122 `mefftatgat=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for source-bulk junction.

123 `cbbtbot=1E-12 AV`$^{-3}$

Band-to-band tunneling prefactor of bottom component for source-bulk junction.

124 `cbbtsti=1E-18 AV`$^{-3}$`m`

Band-to-band tunneling prefactor of STI-edge component for source-bulk junction.

125 `cbbtgat=1E-18 AV`$^{-3}$`m`

Band-to-band tunneling prefactor of gate-edge component for source-bulk junction.

126 `fbbtrbot=1E9 Vm^-1`

Normalization field at the reference temperature for band-to-band tunneling of bottom component for source-bulk junction.

127 `fbbtrsti=1E9 Vm^-1`

Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for source-bulk junction.

128 `fbbtrgat=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for source-bulk junction.

129 `stfbbtbot=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for source-bulk junction.

130 `stfbbtsti=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for source-bulk junction.

131 `stfbbtgat=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for source-bulk junction.

132 `vbrbot=10 V` Breakdown voltage of bottom component for source-bulk junction.

133 `vbrsti=10 V` Breakdown voltage of STI-edge component for source-bulk junction.

134 `vbrgat=10 V` Breakdown voltage of gate-edge component for source-bulk junction.

135 `pbrbot=4 V` Breakdown onset tuning parameter of bottom component for source-bulk junction.

136 `pbrsti=4 V` Breakdown onset tuning parameter of STI-edge component for source-bulk junction.

137 `pbrgat=4 V` Breakdown onset tuning parameter of gate-edge component for source-bulk junction.

138 `cjorbotd=1E-3 Fm`$^{-2}$
Zero-bias capacitance per unit-of-area of bottom component for drain-bulk junction.

139 `cjorstid=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for drain-bulk junction.

140 `cjorgatd=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for drain-bulk junction.

141 `vbirbotd=1 V` Built-in voltage at the reference temperature of bottom component for drain-bulk junction.

142 `vbirstid=1 V` Built-in voltage at the reference temperature of STI-edge component for drain-bulk junction.

143 `vbirgatd=1 V` Built-in voltage at the reference temperature of gate-edge component for drain-bulk junction.

144 `pbotd=0.5` Grading coefficient of bottom component for drain-bulk junction.

145 `pstid=0.5` Grading coefficient of STI-edge component for drain-bulk junction.

146 `pgatd=0.5` Grading coefficient of gate-edge component for drain-bulk junction.

147 `phigbotd=1.16 V` Zero-temperature bandgap voltage of bottom component for drain-bulk junction.

148 `phigstid=1.16 V` Zero-temperature bandgap voltage of STI-edge component for drain-bulk junction.

149 `phiggatd=1.16 V` Zero-temperature bandgap voltage of gate-edge component for drain-bulk junction.

150 `idsatrbotd=1E-12 Am`$^{-2}$
Saturation current density at the reference temperature of bottom component for drain-bulk junction.

151 `idsatrstid=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for drain-bulk junction.

152 `idsatrgatd=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for drain-bulk junction.

153 `csrhbotd=1E2 Am`$^{-3}$
Shockley-Read-Hall prefactor of bottom component for drain-bulk junction.

154 `csrhstid=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of STI-edge component for drain-bulk junction.

155 `csrhgatd=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of gate-edge component for drain-bulk junction.

156 `xjunstid=100E-9 m` Junction depth of STI-edge component for drain-bulk junction.

157 `xjungatd=100E-9 m` Junction depth of gate-edge component for drain-bulk junction.

158 `ctatbotd=1E2 Am`$^{-3}$
Trap-assisted tunneling prefactor of bottom component for drain-bulk junction.

159 `ctatstid=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of STI-edge component for drain-bulk junction.

160 `ctatgatd=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of gate-edge component for drain-bulk junction.

161 `mefftatbotd=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component for drain-bulk junction.

162 `mefftatstid=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for drain-bulk junction.

163 `mefftatgatd=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for drain-bulk junction.

164 `cbbtbotd=1E-12 AV`$^{-3}$
Band-to-band tunneling prefactor of bottom component for drain-bulk junction.

165 `cbbtstid=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of STI-edge component for drain-bulk junction.

166 `cbbtgatd=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of gate-edge component for drain-bulk junction.

167 `fbbtrbotd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component for drain-bulk junction.

168 `fbbtrstid=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for drain-bulk junction.

169 `fbbtrgatd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for drain-bulk junction.

170 `stfbbtbotd=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for drain-bulk junction.

171 `stfbbtstid=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for drain-bulk junction.

172 `stfbbtgatd=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for drain-bulk junction.

173 `vbrbotd=10 V` Breakdown voltage of bottom component for drain-bulk junction.

174 `vbrstid=10 V` Breakdown voltage of STI-edge component for drain-bulk junction.

175 `vbrgatd=10 V` Breakdown voltage of gate-edge component for drain-bulk junction.

176 `pbrbotd=4 V` Breakdown onset tuning parameter of bottom component for drain-bulk junction.

177 `pbrstid=4 V`	Breakdown onset tuning parameter of STI-edge component for drain-bulk junction.
178 `pbrgatd=4 V`	Breakdown onset tuning parameter of gate-edge component for drain-bulk junction.
179 `swjunexp=0.0`	Flag for JUNCAP-express; 0,full model, 1,express model.
180 `vjunref=2.5`	Typical maximum source-bulk junction voltage; usually about 2*VSUP.
181 `fjunq=0.03`	Fraction below which source-bulk junction capacitance components are considered negligible.
182 `vjunrefd=2.5`	Typical maximum drain-bulk junction voltage; usually about 2*VSUP.
183 `fjunqd=0.03`	Fraction below which drain-bulk junction capacitance components are considered negligible.
184 `dta=0 K`	Temperature offset w.r.t. ambient circuit temperature.
185 `mvt=0.0`	DCmatch parameter.
186 `mbe=0.0`	DCmatch parameter.
187 `vds_max=∞ V`	Maximum allowed voltage cross source and drain.
188 `vgd_max=∞ V`	Maximum allowed voltage cross gate and drain.
189 `vgs_max=∞ V`	Maximum allowed voltage cross gate and source/bulk.
190 `vbd_max=∞ V`	Maximum allowed voltage cross source/drain and bulk.
191 `vbs_max=∞ V`	Maximum allowed voltage cross source and bulk.
192 `vgb_max=∞ V`	Maximum allowed voltage cross gate and bulk.

193 `vgdr_max=∞ V`
Maximum allowed reverse voltage cross gate and drain.

194 `vgsr_max=∞ V`
Maximum allowed reverse voltage cross gate and source.

195 `vgbr_max=∞ V`
Maximum allowed reverse voltage cross gate and bulk.

196 `vthmod`
Vth output selector. 'std' outputs model equation Vth. 'vthcc' outputs constant current Vth, and may impact simulation performance. The default value is taken from the options parameter 'vthmod'.
Possible values are `std` and `vthcc`.

197 `ivth (A)`
Vth current parameter. The default value is taken from the options parameter 'ivthn' or 'ivthp', depending on the type of the model.

198 `ivthw (m)`
Width offset for constant current Vth. The default value is taken from the options parameter 'ivthw'.

199 `ivthl (m)`
Length offset for constant current Vth. The default value is taken from the options parameter 'ivthl'.

200 `ivth_vdsmin (V)`
Minimum Vds in constant current Vth calculating. The default value is taken from the options parameter 'ivth_vdsmin'.

201 `noisemethod=oldcmi`
Induced gate noise implementation .
Possible values are `oldcmi`, `subckt`, and `newcmi`.

Output Parameters

1 `weff (m)`
Effective channel width for geometrical models.

2 `leff (m)`
Effective channel length for geometrical models.

3 `lv1 (m)`
alias of l.

4 `lv2 (m)`
alias of w.

5 `lv3 (m^2)`
alias of ad.

6 `lv4 (m2)` alias of as.

7 `lv11 (m)` alias of pd.

8 `lv12 (m)` alias of ps.

Operating-Point Parameters

1 `ctype` Flag for channel type.

2 `sdint` Flag for source-drain interchange.

3 `ise (A)` Total source current.

4 `ige (A)` Total gate current.

5 `ide (A)` Total drain current.

6 `ibe (A)` Total bulk current.

7 `ids (A)` Drain current, excl. avalanche, tunnel, GISL, GIDL, and junction currents.

8 `idb (A)` Drain to bulk current.

9 `isb (A)` Source to bulk current.

10 `igs (A)` Gate-source tunneling current.

11 `igd (A)` Gate-drain tunneling current.

12 `igb (A)` Gate-bulk tunneling current.

13 `igcs (A)` Gate-channel tunneling current (source component).

14 `igcd (A)` Gate-channel tunneling current (drain component).

15 `iavl (A)` Substrate current due to weak avelanche.

16 `igisl (A)` Gate-induced source leakage current.

17 `igidl (A)` Gate-induced drain leakage current.

18 `ijs (A)` Total source junction current.

19 `ijsbot (A)` Source junction current (bottom component).

20 `ijsgat (A)` Source junction current (gate-edge component).

21 `ijssti (A)` Source junction current (STI-edge component).

22 `ijd (A)` Total drain junction current.

23 `ijdbot (A)` Drain junction current (bottom component).

24 `ijdgat (A)` Drain junction current (gate-edge component).

25 `ijdsti (A)` Drain junction current (STI-edge component).

26 `qg (Coul)` Intrinsic gate charge.

27 `qd (Coul)` Intrinsic drain charge.

28 `qb (Coul)` Intrinsic bulk charge.

29 `qs (Coul)` Intrinsic source charge.

30 `qgs_ov (Coul)` Overlap charge for gate-source.

31 `qgd_ov (Coul)` Overlap charge for gate-drain.

32 `qfgs (Coul)` Total outerFringe + overlap for gate-source.

33 `qfgd (Coul)` Total outerFringe + overlap for gate-drain.

34 `qgb_ov (Coul)` Gate-bulk overlap charge.

35 `qjun_s (Coul)` Junction charge on source side.

36 `qjun_d (Coul)` Junction charge on drain side.

37 `vds (V)` Drain-source voltage.

38 `vgs (V)` Gate-source voltage.

39 `vsb (V)` Source-bulk voltage.

40 `vto (V)` Zero-bias threshold voltage.

41 `vts (V)` Threshold voltage including back bias effects.

42 `vth (V)` Threshold voltage including back bias and drain bias effects.

43 `vgt (V)` Effective gate drive voltage including back bias and drain bias effects.

44 `vdss (V)` Drain saturation voltage at actual bias.

45 `vsat (V)` Saturation limit.

46 `pwr (W)` Power at op point.

47 gm (1/Ω) Transconductance.

48 gmb (1/Ω) Substrate transconductance.

49 gds (1/Ω) Output conductance.

50 gjs (1/Ω) Source junction conductance.

51 gjd (1/Ω) Drain junction conductance.

52 `cdd (F)` Drain capacitance.

53 `cdg (F)` Drain-gate capacitance.

54 `cds (F)` Drain-source capacitance.

55 `cdb (F)` Drain-bulk capacitance.

56 `cgd (F)` Gate-drain capacitance.

57 `cgg (F)` Gate capacitance.

58 `cgs (F)` Gate-source capacitance.

59 `cgb (F)` Gate-bulk capacitance.

60 `csd (F)` Source-drain capacitance.

61 `csg (F)`	Source-gate capacitance.
62 `css (F)`	Source capacitance.
63 `csb (F)`	Source-bulk capacitance.
64 `cbd (F)`	Bulk-drain capacitance.
65 `cbg (F)`	Bulk-gate capacitance.
66 `cbs (F)`	Bulk-source capacitance.
67 `cbb (F)`	Bulk capacitance.
68 `cgsol (F)`	Total gate-source overlap capacitance.
69 `cgdol (F)`	Total gate-drain overlap capacitance.
70 `cgbol (F)`	Total gate-bulk overlap capacitance.
71 `cjs (F)`	Total source junction capacitance.
72 `cjsbot (F)`	Source junction capacitance (bottom component).
73 `cjsgat (F)`	Source junction capacitance (gate-edge component).
74 `cjssti (F)`	Source junction capacitance (STI-edge component).
75 `cjd (F)`	Total drain junction capacitance.
76 `cjdbot (F)`	Drain junction capacitance (bottom component).
77 `cjdgat (F)`	Drain junction capacitance (gate-edge component).
78 `cjdsti (F)`	Drain junction capacitance (STI-edge component).
79 `lpoly (m)`	
80 `u`	Transistor gain.
81 `rout (Ω)`	Small-signal output resistance.
82 `vearly (V)`	Equivalent Early voltage.

83 `beff` (A/V^2)	Gain factor.
84 `fug` (Hz)	Unity gain frequency at actual bias.
85 `rg` (Ω)	Gate resistance.
86 `sfl` (A^2/Hz)	Flicker noise current spectral density at 1 Hz.
87 `sqrtsff` (V/ $\sqrt{}$Hz)	Input-referred RMS white noise voltage spectral density at 1 kHz.
88 `sqrtsfw` (V/ $\sqrt{}$Hz)	Input-referred RMS white noise voltage spectral density.
89 `sid` (A^2/Hz)	White noise current spectral density.
90 `sig` (A^2/Hz)	Induced gate noise current spectral density at 1 Hz.
91 `cigid`	Imaginary part of correlation coefficient between Sig and Sid.
92 `fknee` (Hz)	Cross-over frequency above which white noise is dominant.
93 `sigs` (A^2/Hz)	Gate-source current noise spectral density.
94 `sigd` (A^2/Hz)	Gate-drain current noise spectral density.
95 `siavl` (A^2/Hz)	Impact ionization current noise spectral density.
96 `ssi` (A^2/Hz)	Total source junction current noise spectral density.
97 `sdi` (A^2/Hz)	Total drain junction current noise spectral density.
98 `vbs` (V)	Bulk-source voltage.
99 `lv9` (V)	alias of vth.
100 `lv10` (V)	alias of vdss.
101 `lv36` (F)	alias of cgsol.
102 `lv37` (F)	alias of cgdol.
103 `lv38` (F)	alias of cgbol.

104 `lv51 (m)` alias of tox.

105 `lx4 (A)` alias of ids.

106 `lx3 (V)` alias of vds.

107 `lx2 (V)` alias of vgs.

108 `lx7 (1/Ω)` alias of gm.

109 `lx8 (1/Ω)` alias of gds.

110 `lx9 (1/Ω)` alias of gmb.

111 `lx33 (F)` alias of cdd.

112 `lx32 (F)` alias of cdg.

113 `lx34 (F)` alias of cds.

114 `lx19 (F)` alias of cgd.

115 `lx18 (F)` alias of cgg.

116 `lx20 (F)` alias of cgs.

117 `lx22 (F)` alias of cbd.

118 `lx21 (F)` alias of cbg.

119 `lx23 (F)` alias of cbs.

120 `lx5 (A)` alias of ijs.

121 `lx6 (A)` alias of ijd.

122 `lx28 (F)` alias of cjs.

123 `lx29 (F)` alias of cjd.

124 `lx38 (A)` alias of igs.

125 `lx39 (A)` alias of igd.

126 `lx66 (A)` alias of igb.

127 `lx67 (A)` alias of igcs.

128 `lx68 (A)` alias of igcd.

129 `lx110 (A)` alias of igisl.

130 `lx47 (A)` alias of igidl.

131 `lx60 (F)` alias of csd.

132 `lx59 (F)` alias of csg.

133 `lx58 (F)` alias of css.

134 `lx12 (Coul)` alias of Qb including overlap charge.

135 `lx14 (Coul)` alias of Qg including overlap charge.

136 `lx16 (Coul)` alias of Qd including overlap charge.

137 `lx83 (F)` alias of cgd including overlap cap.

138 `lx84 (F)` alias of cgs including overlap cap.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

24

PSP103 Model

PSP103 is a compact MOSFET model intended for digital, analog and RFdesigns. It is jointly developed by NXP Semiconductors Research and Arizona State University, and is a surface-potential based MOS model containing all relevant physical effects (mobility reduction, velocity saturation, DIBL, gate current, lateral doping gradient effects, STI stress, and so forth), to model present-day and upcoming deep-submicron bulk CMOS technologies. The JUNCAP2 source/drain junction model is an integrated part of PSP103.

PSP103 not only gives an accurate description of currents, charges, and their first order derivatives (i.e. transconductance, conductance and capacitances), but also of the higher order derivatives, resulting in an accurate description of electrical distortion behavior. The latter is especially important for analog and RF circuit design. The model, furthermore, gives an accurate description of the noise behavior of MOSFETs.

For a full description of the PSP102 model, see http://pspmodel.asu.edu.

This chapter contains the following information:

Model Usage

Instance Syntax

PSP103 instance has 4 terminals. The ModelName has to be associated with a PSP103 model card.

```
InstanceName (d g s b) PSP103ModelName <parameter=value>
```

Sample Instance Statement

```
q1(v1 v2 v3 v4) psp103_mod w=1e-6 1=0.5e-6
```

Model Syntax

The following syntax specifies PSP103 model:

```
model ModelName psp103 parameter=value ...
```

The third parameter, “psp103”, is the master to indicate this model card is a PSP103 model card.

Version and Master Name

1. Versions 103.0, 103.1, and 103.1.1 are supported
2. There are two master names - psp103 and pspnqs103

Sample Model Statement

Example PSP103.0

```
model psp103_mod psp103 type=n version=103.0
+tr = 25 swigate = 0

+binmod=0 geomod=1 swnqs=9 swgidl = 1 swjuncap = 3
```

Example PSP103.1

```
model psp103_mod psp103 type=n version=103.1
+tr = 25 swigate = 0

+binmod=0 geomod=1 swnqs=9 swgidl = 1 swjuncap = 3
```

Model History and Development

PSP103.0 (SiMKit3.2)

- Implemented in MMSIM7.1.1 in June 2009

PSP103.1 (SiMKit3.3)

- Implemented in MMSIM7.2 in December 2010

Changes

- Added external sheet resistance RSHD for drain diffusion (used when SWJUNASYM=1)
- Extended NUD model to allow retrograde profiles (GFACNUD>1)
- Added value of gate resistance to OP-output
- Bug fix and minor implementation change in NUD-model
- Minor bug fix in contitional for SP-calculation of overlap areas

PSP103.1.1 (SiMKit3.4)

- Implemented in MMSIM10.1 in June 2010

Changes

- Modified implementation of the asymmetrical junction model to improve simulation speed of the verilog-A code.
- Modified implementation of the MULT-scaling factor.
- Modified implementation of the NUD model.
- Modified implementation of the stand-alone JUNCAP2 model.
- Minor bug fix for the output of sfl, sqrtsfw, and fknee

PSP103.2.0 (SiMKit4.0.1)

- Implemented in MMSIM12.1.1 in May 2013

Changes

- Introduction of self heating. The self heating version has an additional temperature terminal `dt`, thermal resistance RTH, and thermal capacitance CTH. Geometry scaling rules for RTH and CTH, as well as temperature dependence of RTH are also provided.
- Implementation of the thermal noise model has been improved:
  - A bug in the sign of the correlation coefficient for negative `Vds` has been fixed
  - Gummel symmetry of `Sid` at very high frequencies has been improved
  - Number of `white_noise` sources has been reduced and the noise voltage values in the noise-subcircuit have been scaled to more physical values (simulation results are not affected).
- The calculation of the surface potential in the gate-diffusion overlap region has been simplified to improve simulation speed of verilog-A code.
- The expression for `qlim2` in QM correction has been modified to avoid unphysical behavior when oxide thickness is large. This modification is relevant for high-k dielectrics.
- Minor bugs in the calculation of OP-output variables have been fixed.
- Minor implementation changes have been made.
- Few OP-output variables have been added.

Reference

Model Description

Geometry Scaling and Stress Model for Intrinsic MOSFET

The physical geometry scaling rules of PSP have been developed to give a good description over the whole geometry range of CMOS technologies. As an alternative, the binning-rules can be used to allow for a more phenomenological geometry dependency. (Note that the user has to choose between the two options; the geometrical scaling rules and the binning scaling rules cannot be used at the same time.) In both cases, the result is a local parameter set (for a transistor of the specified L and W), which is fed into the local model.

Stress and well proximity effects are included in PSP. Use of the stress model and/or well prox-imity effect model leads to modification of some of the local parameters calcul ated from the geometrical or binning scaling rules.

Geometrical scaling rules

The physical scaling rules to calculate the local parameters from a global parameter set are given in this section.

Note:

- After calculation of the local parameters (and possible application of the stress equations), clipping is applied according toSection "Intrinsic Parameters" for the model.
- The geometrical scaling equations are only calculated when SWGEO = 1.

Effective length and width

$$W_f = \frac{W}{\mathbf{NF}}$$

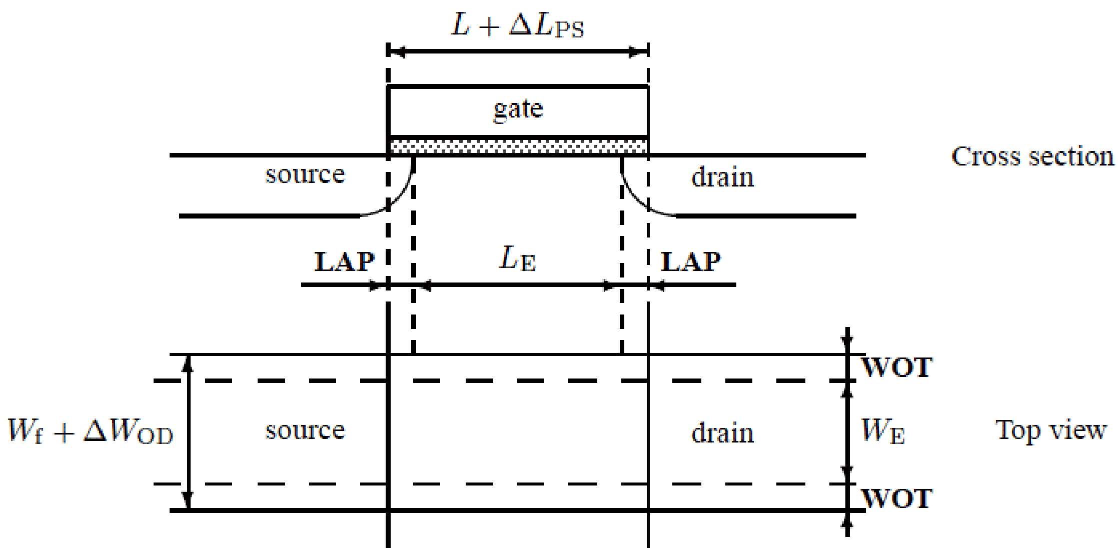
$$L_{EN} = 10^{-6}$$

$$W_{EN} = 10^{-6}$$

$$\Delta L_{PS} = \mathbf{LVARO} \cdot \left(1 + \mathbf{LVARL} \cdot \frac{L_{EN}}{L}\right) \cdot \left(1 + \mathbf{LVARW} \cdot \frac{W_{EN}}{W_f}\right)$$

$$\Delta W_{OD} = \mathbf{WVARO} \cdot \left(1 + \mathbf{WVARL} \cdot \frac{L_{EN}}{L}\right) \cdot \left(1 + \mathbf{WVARW} \cdot \frac{W_{EN}}{W_f}\right)$$

Figure 24-1 Specification of the dimensions of a MOS transistor



$$L_E = L - \Delta L = L + \Delta L_{PS} - 2 \cdot \mathbf{LAP}$$

$$W_E = W_f - \Delta W = W_f + \Delta W_{OD} - 2 \cdot \mathbf{WOT}$$

$$L_{E,CV} = L + \Delta L_{PS} - 2 \cdot \mathbf{LAP} + \mathbf{DLQ}$$

$$W_{E,CV} = W_f + \Delta W_{OD} - 2 \cdot \mathbf{WOT} + \mathbf{DWQ}$$

$$L_{G,CV} = L + \Delta L_{PS} + \mathbf{DLQ}$$

$$W_{G,CV} = W_f + \Delta W_{OD} + \mathbf{DWQ}$$

Note: If the calculated LE, WE, LE,CV, WE,CV, LG,CV, or WG,CV is smaller than 1 nm (10?9 m), the value is clipped to this lower bound of 1 nm.

Process Parameters

$$\mathbf{VFB} = \mathbf{VFBO} + \mathbf{VFBL} \cdot \frac{L_{EN}}{L_E} + \mathbf{VFBW} \cdot \frac{W_{EN}}{W_E} + \mathbf{VFBLW} \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}$$

$$\mathbf{STVFB} = \mathbf{STVFBO} + \mathbf{STVFBL} \cdot \frac{L_{EN}}{L_E} + \mathbf{STVFBW} \cdot \frac{W_{EN}}{W_E} + \mathbf{STVFBLW} \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}$$

$$\mathbf{TOX} = \mathbf{TOXO}$$

$$\mathbf{EPSROX} = \mathbf{EPSROXO}$$

$$N_{\text{subo,eff}} = \mathbf{NSUBO} \cdot \mathrm{MAX}\left(\left[1 + \mathbf{NSUBW} \cdot \frac{W_{\text{EN}}}{W_{\text{E}}} \cdot \ln\left(1 + \frac{W_{\text{E}}}{\mathbf{WSEG}}\right)\right], 10^{-3}\right)$$

$$N_{\text{pck,eff}} = \mathbf{NPCK} \cdot \mathrm{MAX}\left(\left[1 + \mathbf{NPCKW} \cdot \frac{W_{\text{EN}}}{W_{\text{E}}} \cdot \ln\left(1 + \frac{W_{\text{E}}}{\mathbf{WSEGP}}\right)\right], 10^{-3}\right)$$

$$L_{\text{pck,eff}} = \mathbf{LPCK} \cdot \mathrm{MAX}\left(\left[1 + \mathbf{LPCKW} \cdot \frac{W_{\text{EN}}}{W_{\text{E}}} \cdot \ln\left(1 + \frac{W_{\text{E}}}{\mathbf{WSEGP}}\right)\right], 10^{-3}\right)$$

$$a = 7.5 \cdot 10^{10}$$

$$b = \sqrt{N_{\text{subo,eff}} + 0.5 \cdot N_{\text{pck,eff}}} - \sqrt{N_{\text{subo,eff}}}$$

$$N_{\text{sub}} = \begin{cases} N_{\text{subo,eff}} + N_{\text{pck,eff}} \cdot \left[2 - \dfrac{L_{\text{E}}}{L_{\text{pck,eff}}}\right] & \text{for } L_{\text{E}} < L_{\text{pck,eff}} \\ N_{\text{subo,eff}} + N_{\text{pck,eff}} \cdot \dfrac{L_{\text{pck,eff}}}{L_{\text{E}}} & \text{for } L_{\text{pck,eff}} \le L_{\text{E}} \le 2 \cdot L_{\text{pck,eff}} \\ \left[\sqrt{N_{\text{subo,eff}}} + a \cdot \ln\left(1 + 2 \cdot \dfrac{L_{\text{pck,eff}}}{L_{\text{E}}} \cdot \left[\exp\left(\dfrac{b}{a}\right) - 1\right]\right)\right]^2 & \text{for } L_{\text{E}} > 2 \cdot L_{\text{pck,eff}} \end{cases}$$

$$\mathbf{NEFF} = N_{\text{sub}} \cdot \left(1 - \mathbf{FOL1} \cdot \frac{L_{\text{EN}}}{L_{\text{E}}} - \mathbf{FOL2} \cdot \left[\frac{L_{\text{EN}}}{L_{\text{E}}}\right]^2\right)$$

$$\mathbf{FACNEFFAC} = \mathbf{FACNEFFACO} + \mathbf{FACNEFFACL} \cdot \frac{L_{\text{EN}}}{L_{\text{E}}} + \mathbf{FACNEFFACW} \cdot \frac{W_{\text{EN}}}{W_{\text{E}}} + \mathbf{FACNEFFACLW} \cdot \frac{L_{\text{EN}} \cdot W_{\text{EN}}}{L_{\text{E}} \cdot W_{\text{E}}}$$

$$\mathbf{GFACNUD} = \mathbf{GFACNUDO} + \mathbf{GFACNUDL} \cdot \left[\frac{L_{\text{EN}}}{L_{\text{E}}}\right]^{\mathbf{GFACNUDLEXP}} + \mathbf{GFACNUDW} \cdot \frac{W_{\text{EN}}}{W_{\text{E}}} + \mathbf{GFACNUDLW} \cdot \frac{L_{\text{EN}} \cdot W_{\text{EN}}}{L_{\text{E}} \cdot W_{\text{E}}}$$

$$\mathbf{VSBNUD} = \mathbf{VSBNUDO}$$

$$\mathbf{DVSBNUD} = \mathbf{DVSBNUDO}$$

$$\mathbf{VNSUB} = \mathbf{VNSUBO}$$

$$\mathbf{NSLP} = \mathbf{NSLPO}$$

$$\mathbf{DNSUB} = \mathbf{DNSUBO}$$

$$\mathbf{DPHIB} = \mathbf{DPHIBO} + \mathbf{DPHIBL} \cdot \left[\frac{L_{EN}}{L_E}\right]^{\mathbf{DPHIBLEXP}} + \mathbf{DPHIBW} \cdot \frac{W_{EN}}{W_E} + \mathbf{DPHIBLW} \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}$$

$$\mathbf{DELVTAC} = \mathbf{DELVTACO} + \mathbf{DELVTACL} \cdot \left[\frac{L_{EN}}{L_E}\right]^{\mathbf{DELVTACLEXP}} + \mathbf{DELVTACW} \cdot \frac{W_{EN}}{W_E} + \mathbf{DELVTACLW} \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}$$

$$\mathbf{NP} = \mathbf{NPO} \cdot \mathrm{MAX}\left(10^{-6}, 1 + \mathbf{NPL} \cdot \frac{L_{EN}}{L_E}\right)$$

$$\mathbf{CT} = \left(\mathbf{CTO} + \mathbf{CTL} \cdot \left[\frac{L_{EN}}{L_E}\right]^{\mathbf{CTLEXP}}\right) \cdot \left(1 + \mathbf{CTW} \cdot \frac{W_{EN}}{W_E}\right) \cdot \left(1 + \mathbf{CTLW} \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}\right)$$

$$\mathbf{TOXOV} = \mathbf{TOXOVO}$$

$$\mathbf{TOXOVD} = \mathbf{TOXOVDO}$$

$$\mathbf{NOV} = \mathbf{NOVO}$$

$$\mathbf{NOVD} = \mathbf{NOVDO}$$

DIBL Parameters

$$\mathbf{CF} = \mathbf{CFL} \cdot \left[\frac{L_{EN}}{L_E}\right]^{\mathbf{CFLEXP}} \cdot \left(1 + \mathbf{CFW} \cdot \frac{W_{EN}}{W_E}\right)$$

$$\mathbf{CFB} = \mathbf{CFBO}$$

$$F_{\beta 1,\mathrm{eff}} = \mathbf{FBET1} \cdot \left(1 + \mathbf{FBET1W} \cdot \frac{W_{EN}}{W_E}\right)$$

$$L_{P1,\mathrm{eff}} = \mathbf{LP1} \cdot \mathrm{MAX}\left(\left[1 + \mathbf{LP1W} \cdot \frac{W_{EN}}{W_E}\right], 10^{-3}\right)$$

$$G_{P,E} = 1 + F_{\beta 1,\mathrm{eff}} \cdot \frac{L_{P1,\mathrm{eff}}}{L_E} \cdot \left[1 - \exp\left(-\frac{L_E}{L_{P1,\mathrm{eff}}}\right)\right] + \mathbf{FBET2} \cdot \frac{\mathbf{LP2}}{L_E} \cdot \left[1 - \exp\left(-\frac{L_E}{\mathbf{LP2}}\right)\right]$$

$$G_{W,E} = 1 + \mathbf{BETW1} \cdot \frac{W_{EN}}{W_E} + \mathbf{BETW2} \cdot \frac{W_{EN}}{W_E} \cdot \ln\left(1 + \frac{W_E}{\mathbf{WBET}}\right)$$

$$\mathbf{BETN} = \frac{\mathbf{UO}}{G_{\mathrm{P,E}}} \cdot \frac{W_{\mathrm{E}}}{L_{\mathrm{E}}} \cdot G_{\mathrm{W,E}}$$

$$\mathbf{STBET} = \mathbf{STBETO} + \mathbf{STBETL} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{STBETW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{STBETLW} \cdot \frac{W_{\mathrm{EN}} \cdot L_{\mathrm{EN}}}{W_{\mathrm{E}} \cdot L_{\mathrm{E}}}$$

$$\mathbf{MUE} = \mathbf{MUEO} \cdot \left[1 + \mathbf{MUEW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right]$$

$$\mathbf{STMUE} = \mathbf{STMUEO}$$

$$\mathbf{THEMU} = \mathbf{THEMUO}$$

$$\mathbf{STTHEMU} = \mathbf{STTHEMUO}$$

$$\mathbf{CS} = \left(\mathbf{CSO} + \mathbf{CSL} \cdot \left[\frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right]^{\mathbf{CSLEXP}}\right) \cdot \left(1 + \mathbf{CSW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \cdot \left(1 + \mathbf{CSLW} \cdot \frac{W_{\mathrm{EN}} \cdot L_{\mathrm{EN}}}{W_{\mathrm{E}} \cdot L_{\mathrm{E}}}\right)$$

$$\mathbf{STCS} = \mathbf{STCSO}$$

$$\mathbf{XCOR} = \mathbf{XCORO} \cdot \left(1 + \mathbf{XCORL} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right) \cdot \left(1 + \mathbf{XCORW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right) \cdot \left(1 + \mathbf{XCORLW} \cdot \frac{W_{\mathrm{EN}} \cdot L_{\mathrm{EN}}}{W_{\mathrm{E}} \cdot L_{\mathrm{E}}}\right)$$

$$\mathbf{STXCOR} = \mathbf{STXCORO}$$

$$\mathbf{FETA} = \mathbf{FETAO}$$

Series Resistance Parameters

$$\mathbf{RS} = \mathbf{RSW1} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} \cdot \left[1 + \mathbf{RSW2} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right]$$

$$\mathbf{STRS} = \mathbf{STRSO}$$

$$\mathbf{RSB} = \mathbf{RSBO}$$

$$\mathbf{RSG} = \mathbf{RSGO}$$

Velocity Saturation Parameters

$$\mathbf{THESAT} = \left(\mathbf{THESATO} + \mathbf{THESATL} \cdot \frac{G_{W,E}}{G_{P,E}} \cdot \left[\frac{L_{EN}}{L_E}\right]^{\mathbf{THESATLEXP}}\right) \cdot \left(1 + \mathbf{THESATW} \cdot \frac{W_{EN}}{W_E}\right) \cdot \left(1 + \mathbf{THESATLW} \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}\right)$$

$$\mathbf{STTHESAT} = \mathbf{STTHESATO} + \mathbf{STTHESATL} \cdot \frac{L_{EN}}{L_E} + \mathbf{STTHESATW} \cdot \frac{W_{EN}}{W_E} + \mathbf{STTHESATLW} \cdot \frac{W_{EN} \cdot L_{EN}}{W_E \cdot L_E}$$

$$\mathbf{THESATB} = \mathbf{THESATBO}$$

$$\mathbf{THESATG} = \mathbf{THESATGO}$$

Saturation Voltage Parameter

$$\mathbf{AX} = \frac{\mathbf{AXO}}{1 + \mathbf{AXL} \cdot \frac{L_{EN}}{L_E}}$$

Channel Length Modulation (CLM) Parameters

$$\mathbf{ALP} = \mathbf{ALPL} \cdot \left[\frac{L_{EN}}{L_E}\right]^{\mathbf{ALPLEXP}} \cdot \left(1 + \mathbf{ALPW} \cdot \frac{W_{EN}}{W_E}\right)$$

$$\mathbf{ALP1} = \frac{\mathbf{ALP1L1} \cdot \left[\frac{L_{EN}}{L_E}\right]^{\mathbf{ALP1LEXP}}}{1 + \mathbf{ALP1L2} \cdot \left[\frac{L_{EN}}{L_E}\right]^{\mathbf{ALP1LEXP}+1}} \cdot \left(1 + \mathbf{ALP1W} \cdot \frac{W_{EN}}{W_E}\right)$$

$$\mathbf{ALP2} = \frac{\mathbf{ALP2L1} \cdot \left[\frac{L_{EN}}{L_E}\right]^{\mathbf{ALP2LEXP}}}{1 + \mathbf{ALP2L2} \cdot \left[\frac{L_{EN}}{L_E}\right]^{\mathbf{ALP2LEXP}+1}} \cdot \left(1 + \mathbf{ALP2W} \cdot \frac{W_{EN}}{W_E}\right)$$

$$\mathbf{VP} = \mathbf{VPO}$$

Impact Ionization (II) Parameters

$$\mathbf{A1} = \mathbf{A1O} \cdot \left(1 + \mathbf{A1L} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right) \cdot \left(1 + \mathbf{A1W} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right)$$

$$\mathbf{A2} = \mathbf{A2O}$$

$$\mathbf{STA2} = \mathbf{STA2O}$$

$$\mathbf{A3} = \mathbf{A3O} \cdot \left(1 + \mathbf{A3L} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right) \cdot \left(1 + \mathbf{A3W} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right)$$

$$\mathbf{A4} = \mathbf{A4O} \cdot \left(1 + \mathbf{A4L} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}}\right) \cdot \left(1 + \mathbf{A4W} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}}\right)$$

Gate Current Parameters

$$\mathbf{GCO} = \mathbf{GCOO}$$

$$\mathbf{IGINV} = \mathbf{IGINVLW} \cdot \frac{W_{\mathrm{E}} \cdot L_{\mathrm{E}}}{W_{\mathrm{EN}} \cdot L_{\mathrm{EN}}}$$

$$\mathbf{IGOV} = \mathbf{IGOVW} \cdot \frac{W_{\mathrm{E}} \cdot \mathbf{LOV}}{W_{\mathrm{EN}} \cdot L_{\mathrm{EN}}}$$

$$\mathbf{IGOVD} = \mathbf{IGOVDW} \cdot \frac{W_{\mathrm{E}} \cdot \mathbf{LOVD}}{W_{\mathrm{EN}} \cdot L_{\mathrm{EN}}}$$

$$\mathbf{STIG} = \mathbf{STIGO}$$

$$\mathbf{GC2} = \mathbf{GC2O}$$

$$\mathbf{GC3} = \mathbf{GC3O}$$

$$\mathbf{CHIB} = \mathbf{CHIBO}$$

Gate-Induced Drain Leakage (GIDL) Parameters

$$\mathbf{AGIDL} = \mathbf{AGIDLW} \cdot \frac{W_E \cdot \mathbf{LOV}}{W_{EN} \cdot L_{EN}}$$

$$\mathbf{AGIDLD} = \mathbf{AGIDLDW} \cdot \frac{W_E \cdot \mathbf{LOVD}}{W_{EN} \cdot L_{EN}}$$

$$\mathbf{BGIDL} = \mathbf{BGIDLO}$$

$$\mathbf{BGIDLD} = \mathbf{BGIDLDO}$$

$$\mathbf{STBGIDL} = \mathbf{STBGIDLO}$$

$$\mathbf{STBGIDLD} = \mathbf{STBGIDLDO}$$

$$\mathbf{CGIDL} = \mathbf{CGIDLO}$$

$$\mathbf{CGIDLD} = \mathbf{CGIDLDO}$$

Charge Model Parameters

$$\mathbf{COX} = \epsilon_{ox} \cdot \frac{W_{E,CV} \cdot L_{E,CV}}{\mathbf{TOX}}$$

$$\mathbf{CGOV} = \epsilon_{ox} \cdot \frac{W_{E,CV} \cdot \mathbf{LOV}}{\mathbf{TOXOV}}$$

$$\mathbf{CGOVD} = \epsilon_{ox} \cdot \frac{W_{E,CV} \cdot \mathbf{LOVD}}{\mathbf{TOXOVD}}$$

$$\mathbf{CGBOV} = \mathbf{CGBOVL} \cdot \frac{L_{G,CV}}{L_{EN}}$$

$$\mathbf{CFR} = \mathbf{CFRW} \cdot \frac{W_{G,CV}}{W_{EN}}$$

$$\mathbf{CFRD} = \mathbf{CFRDW} \cdot \frac{W_{G,CV}}{W_{EN}}$$

Noise Model Parameters

$$L_{\text{noi}} = \text{MAX}\left(1 - \frac{2 \cdot \textbf{LINTNOI}}{L_\text{E}}, 10^{-3}\right)$$

$$L_{\text{red}} = \frac{1}{L_{\text{noi}}^{\textbf{ALFNOI}}}$$

$$\textbf{NFA} = L_{\text{red}} \cdot \textbf{NFALW} \cdot \frac{W_{\text{EN}} \cdot L_{\text{EN}}}{W_\text{E} \cdot L_\text{E}}$$

$$\textbf{NFB} = L_{\text{red}} \cdot \textbf{NFBLW} \cdot \frac{W_{\text{EN}} \cdot L_{\text{EN}}}{W_\text{E} \cdot L_\text{E}}$$

$$\textbf{NFC} = L_{\text{red}} \cdot \textbf{NFCLW} \cdot \frac{W_{\text{EN}} \cdot L_{\text{EN}}}{W_\text{E} \cdot L_\text{E}}$$

$$\textbf{EF} = \textbf{EFO}$$

WPE Parameters

$$K_{\text{vthowe}} = \textbf{KVTHOWEO} + \textbf{KVTHOWEL} \cdot \frac{L_{\text{EN}}}{L_\text{E}} + \textbf{KVTHOWEW} \cdot \frac{W_{\text{EN}}}{W_\text{E}} + \textbf{KVTHOWELW} \cdot \frac{L_{\text{EN}} \cdot W_{\text{EN}}}{L_\text{E} \cdot W_\text{E}}$$

$$K_{\text{uowe}} = \textbf{KUOWEO} + \textbf{KUOWEL} \cdot \frac{L_{\text{EN}}}{L_\text{E}} + \textbf{KUOWEW} \cdot \frac{W_{\text{EN}}}{W_\text{E}} + \textbf{KUOWELW} \cdot \frac{L_{\text{EN}} \cdot W_{\text{EN}}}{L_\text{E} \cdot W_\text{E}}$$

Note: The parameter equations described in the above section are for Global Model. The equations for the Binning Model are described in the next section with similar headings and names.

Binning Equations

The binning equations are provided as a (phenomenological) alternative to the physical scaling equations for computing local parameters. The physical geometrical scaling rules have been developed to give a good de-scription over the whole geometry range of CMOS technologies. For processes under development, however, it is sometimes useful to have more flexible scaling relation s. In that case on could opt for a binning strategy, where the accuracy with geometry is mostly determined by the number of bins used. The physical scaling rules of Section 3.2 are generally not suitable for binning strategies, since they may result in discontinuities in local parameter values at the bin boundaries. Consequently, special binning geometrical scaling relations have been developed, which guarantee continuity of the resulting local model parameters at the bin boundaries.

Note: The binning equations are only calculated when SWGEO = 2.

Only four different types of binning scaling rules are used, which are based on first order developments of the geometrical scaling rules in terms of LE, 1/LE, WE, and 1/WE (examples below are for a fictitious parameter YYY):

1. Type I

$$\mathbf{YYY} = \mathbf{POYYY} + \mathbf{PLYYY} \cdot \frac{L_{EN}}{L_E} + \mathbf{PWYYY} \cdot \frac{W_{EN}}{W_E} + \mathbf{PLWYYY} \cdot \frac{L_{EN} \cdot W_{EN}}{L_E \cdot W_E}$$

2. Type II

$$\mathbf{YYY} = \mathbf{POYYY} + \mathbf{PLYYY} \cdot \frac{L_E}{L_{EN}} + \mathbf{PWYYY} \cdot \frac{W_E}{W_{EN}} + \mathbf{PLWYYY} \cdot \frac{L_E \cdot W_E}{L_{EN} \cdot W_{EN}}$$

3. Type III

$$\mathbf{YYY} = \mathbf{POYYY} + \mathbf{PLYYY} \cdot \frac{L_{EN}}{L_E} + \mathbf{PWYYY} \cdot \frac{W_E}{W_{EN}} + \mathbf{PLWYYY} \cdot \frac{W_E \cdot L_{EN}}{W_{EN} \cdot L_E}$$

4. Type IV (no binning)

$$\mathbf{YYY} = \mathbf{POYYY}$$

In Table 23.1 a survey of the binning type used for each local parameter is given. In some cases where the geometrical scaling rule is constant, the binning rule is chosen to be more flexible.

When using the binning rules above, the binning parameters for one bin can be directly calculated from the local parameter sets of the four corner devices of the bin. This results in a separate parameter set for each bin. The binning scheme ensures that the local parameters are exactly reproduced at the bin corners and that no humps occur in the local parameter values across bin boundaries.

Note: After calculation of the local parameters from the binning rules (and possible applications of the stress equations and well proximity equations), clipping is applied according to Intricsic Papameters for the model.

Table 24-1 Overview of local parameters and binnings type. the third column indicates whether there is a physical geometrical scaling rule for the local parameters.

#	parameter	physical scaling	binning	#	parameter	physical scaling	binning
0	**VFB**	yes	type I	40	**THESATG**	no	type I
1	**STVFB**	yes	type I	41	**AX**	yes	type I
2	**TOX**	no	no	42	**ALP**	yes	type I
3	**EPSROX**	no	no	43	**ALP1**	yes	type I
4	**NEFF**	yes	type I	44	**ALP2**	yes	type I
5	**FACNEFFAC**	yes	type I	45	**VP**	no	no
6	**GFACNUD**	yes	type I	46	**A1**	yes	type I
7	**VSBNUD**	no	no	47	**A2**	no	no
8	**DVSBNUD**	no	no	48	**STA2**	no	no
9	**VNSUB**	no	no	49	**A3**	yes	type I
10	**NSLP**	no	no	50	**A4**	yes	type I
11	**DNSUB**	no	no	51	**GCO**	no	no
12	**DPHIB**	yes	type I	52	**IGINV**	yes	type II
13	**DELVTAC**	yes	type I	53	**IGOV**	yes	type III
14	**NP**	yes	type I	54	**IGOVD**	yes	type III
15	**CT**	yes	type I	55	**STIG**	no	no
16	**TOXOV**	no	no	56	**GC2**	no	no
17	**TOXOVD**	no	no	57	**GC3**	no	no
18	**NOV**	no	type I	58	**CHIB**	no	no
19	**NOVD**	no	Type I	59	**AGIDL**	yes	type III
20	**CF**	yes	type I	60	**AGIDLD**	yes	type III
21	**CFB**	no	no	61	**BGIDL**	no	no
22	**BETN**	yes	type III	62	**BGIDLD**	no	no
23	**STBET**	yes	type I	63	**STBGIDL**	no	no
24	**MUE**	yes	type I	64	**STBGIDLD**	no	no
25	**STMUE**	no	no	65	**CGIDL**	no	no
26	**THEMU**	no	no	66	**CGIDLD**	no	no
27	**STTHEMU**	no	no	67	**COX**	yes	type II
28	**CS**	yes	type I	68	**CGOV**	yes	type III
29	**STCS**	no	no	69	**CGOVD**	yes	type III
30	**XCOR**	yes	type I	70	**CGBOV**	yes	type II
31	**STXCOR**	no	no	71	**CFR**	yes	type III
32	**FETA**	no	no	72	**CFRD**	yes	type III
33	**RS**	yes	type I	73	**FNT**	no	no
34	**STRS**	no	no	74	**NFA**	yes	type I
35	**RSB**	no	no	75	**NFB**	yes	type I
36	**RSG**	no	no	76	**NFC**	yes	type I
37	**THESAT**	yes	type I	77	**EF**	no	no
38	**STTHESAT**	yes	type I	78	**DTA**	no	no
39	**THESATB**	no	type I				

Effective length and width

$$L_{\mathrm{EN}} = 10^{-6}$$

$$W_{\mathrm{EN}} = 10^{-6}$$

$$\Delta L_{\mathrm{PS}} = \mathbf{LVARO} \cdot \left(1 + \mathbf{LVARL} \cdot \frac{L_{\mathrm{EN}}}{L}\right)$$

$$\Delta W_{\mathrm{OD}} = \mathbf{WVARO} \cdot \left(1 + \mathbf{WVARW} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{f}}}\right)$$

$$L_{\mathrm{E}} = L - \Delta L = L + \Delta L_{\mathrm{PS}} - 2 \cdot \mathbf{LAP}$$

$$W_{\mathrm{E}} = W_{\mathrm{f}} - \Delta W = W_{\mathrm{f}} + \Delta W_{\mathrm{OD}} - 2 \cdot \mathbf{WOT}$$

$$L_{\mathrm{E,CV}} = L + \Delta L_{\mathrm{PS}} - 2 \cdot \mathbf{LAP} + \mathbf{DLQ}$$

$$W_{\mathrm{E,CV}} = W_{\mathrm{f}} + \Delta W_{\mathrm{OD}} - 2 \cdot \mathbf{WOT} + \mathbf{DWQ}$$

$$L_{\mathrm{G,CV}} = L + \Delta L_{\mathrm{PS}} + \mathbf{DLQ}$$

$$W_{\mathrm{G,CV}} = W_{\mathrm{f}} + \Delta W_{\mathrm{OD}} + \mathbf{DWQ}$$

Note: If the calculated L_E, W_E, $L_{E,CV}$, $W_{E,CV}$, $L_{G,CV}$, or $W_{G,CV}$ is smaller than 1 nm ($10^{?9}$ m), the value is clipped to this lower bound of 1 nm.

Process Parameters

$$\mathbf{VFB} = \mathbf{POVFB} + \mathbf{PLVFB} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWVFB} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWVFB} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{STVFB} = \mathbf{POSTVFB} + \mathbf{PLSTVFB} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWSTVFB} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWSTVFB} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{TOX} = \mathbf{POTOX}$$

$$\mathbf{EPSROX} = \mathbf{POEPSROX}$$

$$\mathbf{NEFF} = \mathbf{PONEFF} + \mathbf{PLNEFF} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWNEFF} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWNEFF} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{FACNEFFAC} = \mathbf{POFACNEFFAC} + \mathbf{PLFACNEFFAC} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWFACNEFFAC} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWFACNEFFAC} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{GFACNUD} = \mathbf{POGFACNUD} + \mathbf{PLGFACNUD} \cdot \frac{L_{EN}}{L_E} + \mathbf{PWGFACNUD} \cdot \frac{W_{EN}}{W_E} + \mathbf{PLWGFACNUD} \cdot \frac{L_{EN} \cdot W_{EN}}{L_E \cdot W_E}$$

$$\mathbf{VSBNUD} = \mathbf{POVSBNUD}$$

$$\mathbf{DVSBNUD} = \mathbf{PODVSBNUD}$$

$$\mathbf{VNSUB} = \mathbf{POVNSUB}$$

$$\mathbf{NSLP} = \mathbf{PONSLP}$$

$$\mathbf{DNSUB} = \mathbf{PODNSUB}$$

$$\mathbf{DPHIB} = \mathbf{PODPHIB} + \mathbf{PLDPHIB} \cdot \frac{L_{EN}}{L_E} + \mathbf{PWDPHIB} \cdot \frac{W_{EN}}{W_E} + \mathbf{PLWDPHIB} \cdot \frac{L_{EN} \cdot W_{EN}}{L_E \cdot W_E}$$

$$\mathbf{DELVTAC} = \mathbf{PODELVTAC} + \mathbf{PLDELVTAC} \cdot \frac{L_{EN}}{L_E} + \mathbf{PWDELVTAC} \cdot \frac{W_{EN}}{W_E} + \mathbf{PLWDELVTAC} \cdot \frac{L_{EN} \cdot W_{EN}}{L_E \cdot W_E}$$

$$\mathbf{NP} = \mathbf{PONP} + \mathbf{PLNP} \cdot \frac{L_{EN}}{L_E} + \mathbf{PWNP} \cdot \frac{W_{EN}}{W_E} + \mathbf{PLWNP} \cdot \frac{L_{EN} \cdot W_{EN}}{L_E \cdot W_E}$$

$$\mathbf{CT} = \mathbf{POCT} + \mathbf{PLCT} \cdot \frac{L_{EN}}{L_E} + \mathbf{PWCT} \cdot \frac{W_{EN}}{W_E} + \mathbf{PLWCT} \cdot \frac{L_{EN} \cdot W_{EN}}{L_E \cdot W_E}$$

$$\mathbf{TOXOV} = \mathbf{POTOXOV}$$

$$\mathbf{TOXOVD} = \mathbf{POTOXOVD}$$

$$\mathbf{NOV} = \mathbf{PONOV} + \mathbf{PLNOV} \cdot \frac{L_{EN}}{L_E} + \mathbf{PWNOV} \cdot \frac{W_{EN}}{W_E} + \mathbf{PLWNOV} \cdot \frac{L_{EN} \cdot W_{EN}}{L_E \cdot W_E}$$

$$\mathbf{NOVD} = \mathbf{PONOVD} + \mathbf{PLNOVD} \cdot \frac{L_{EN}}{L_E} + \mathbf{PWNOVD} \cdot \frac{W_{EN}}{W_E} + \mathbf{PLWNOVD} \cdot \frac{L_{EN} \cdot W_{EN}}{L_E \cdot W_E}$$

DIBL Parameters

$$\mathbf{CF} = \mathbf{POCF} + \mathbf{PLCF} \cdot \frac{L_{EN}}{L_E} + \mathbf{PWCF} \cdot \frac{W_{EN}}{W_E} + \mathbf{PLWCF} \cdot \frac{L_{EN} \cdot W_{EN}}{L_E \cdot W_E}$$

$$\mathbf{CFB} = \mathbf{POCFB}$$

Mobility Parameters

$$\mathbf{BETN} = \frac{W_{\mathrm{E}}}{L_{\mathrm{E}}} \cdot \left(\mathbf{POBETN} + \mathbf{PLBETN} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWBETN} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWBETN} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}\right)$$

$$\mathbf{STBET} = \mathbf{POSTBET} + \mathbf{PLSTBET} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWSTBET} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWSTBET} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{MUE} = \mathbf{POMUE} + \mathbf{PLMUE} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWMUE} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWMUE} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{STMUE} = \mathbf{POSTMUE}$$

$$\mathbf{THEMU} = \mathbf{POTHEMU}$$

$$\mathbf{STTHEMU} = \mathbf{POSTTHEMU}$$

$$\mathbf{CS} = \mathbf{POCS} + \mathbf{PLCS} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWCS} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWCS} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{STCS} = \mathbf{POSTCS}$$

$$\mathbf{XCOR} = \mathbf{POXCOR} + \mathbf{PLXCOR} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWXCOR} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWXCOR} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{STXCOR} = \mathbf{POSTXCOR}$$

$$\mathbf{FETA} = \mathbf{POFETA}$$

Series Resistance Parameters

$$\mathbf{RS} = \mathbf{PORS} + \mathbf{PLRS} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWRS} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWRS} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{STRS} = \mathbf{POSTRS}$$

$$\mathbf{RSB} = \mathbf{PORSB}$$

$$\mathbf{RSG} = \mathbf{PORSG}$$

Velocity Saturation Parameters

$$\mathbf{THESAT} = \mathbf{POTHESAT} + \mathbf{PLTHESAT} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWTHESAT} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWTHESAT} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{STTHESAT} = \mathbf{POSTTHESAT} + \mathbf{PLSTTHESAT} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWSTTHESAT} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWSTTHESAT} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{THESATB} = \mathbf{POTHESATB} + \mathbf{PLTHESATB} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWTHESATB} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWTHESATB} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{THESATG} = \mathbf{POTHESATG} + \mathbf{PLTHESATG} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWTHESATG} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWTHESATG} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

Saturation Voltage Parameters

$$\mathbf{AX} = \mathbf{POAX} + \mathbf{PLAX} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWAX} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWAX} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

Channel Length Modulaiton (CLM) Parameters

$$\mathbf{ALP} = \mathbf{POALP} + \mathbf{PLALP} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWALP} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWALP} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{ALP1} = \mathbf{POALP1} + \mathbf{PLALP1} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWALP1} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWALP1} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{ALP2} = \mathbf{POALP2} + \mathbf{PLALP2} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWALP2} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWALP2} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{VP} = \mathbf{POVP}$$

Impact Ionization (II) Parameters

$$\mathbf{A1} = \mathbf{POA1} + \mathbf{PLA1} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWA1} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWA1} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{A2} = \mathbf{POA2}$$

$$\mathbf{STA2} = \mathbf{POSTA2}$$

$$\mathbf{A3} = \mathbf{POA3} + \mathbf{PLA3} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWA3} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWA3} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{A4} = \mathbf{POA4} + \mathbf{PLA4} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWA4} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWA4} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

Gate Current Parameters

$$\mathbf{GCO} = \mathbf{POGCO}$$

$$\mathbf{IGINV} = \mathbf{POIGINV} + \mathbf{PLIGINV} \cdot \frac{L_{\mathrm{E}}}{L_{\mathrm{EN}}} + \mathbf{PWIGINV} \cdot \frac{W_{\mathrm{E}}}{W_{\mathrm{EN}}} + \mathbf{PLWIGINV} \cdot \frac{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}$$

$$\mathbf{IGOV} = \mathbf{POIGOV} + \mathbf{PLIGOV} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWIGOV} \cdot \frac{W_{\mathrm{E}}}{W_{\mathrm{EN}}} + \mathbf{PLWIGOV} \cdot \frac{W_{\mathrm{E}} \cdot L_{\mathrm{EN}}}{W_{\mathrm{EN}} \cdot L_{\mathrm{E}}}$$

$$\mathbf{IGOVD} = \mathbf{POIGOVD} + \mathbf{PLIGOVD} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWIGOVD} \cdot \frac{W_{\mathrm{E}}}{W_{\mathrm{EN}}} + \mathbf{PLWIGOVD} \cdot \frac{W_{\mathrm{E}} \cdot L_{\mathrm{EN}}}{W_{\mathrm{EN}} \cdot L_{\mathrm{E}}}$$

$$\mathbf{STIG} = \mathbf{POSTIG}$$

$$\mathbf{GC2} = \mathbf{POGC2}$$

$$\mathbf{GC3} = \mathbf{POGC3}$$

$$\mathbf{CHIB} = \mathbf{POCHIB}$$

Gate Induced Drain Leakage (GIDL) Parameters

$$\mathbf{AGIDL} = \mathbf{POAGIDL} + \mathbf{PLAGIDL} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWAGIDL} \cdot \frac{W_{\mathrm{E}}}{W_{\mathrm{EN}}} + \mathbf{PLWAGIDL} \cdot \frac{W_{\mathrm{E}} \cdot L_{\mathrm{EN}}}{W_{\mathrm{EN}} \cdot L_{\mathrm{E}}}$$

$$\mathbf{AGIDLD} = \mathbf{POAGIDLD} + \mathbf{PLAGIDLD} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWAGIDLD} \cdot \frac{W_{\mathrm{E}}}{W_{\mathrm{EN}}} + \mathbf{PLWAGIDLD} \cdot \frac{W_{\mathrm{E}} \cdot L_{\mathrm{EN}}}{W_{\mathrm{EN}} \cdot L_{\mathrm{E}}}$$

$$\mathbf{BGIDL} = \mathbf{POBGIDL}$$

$$\mathbf{BGIDLD} = \mathbf{POBGIDLD}$$

$$\mathbf{STBGIDL} = \mathbf{POSTBGIDL}$$

$$\mathbf{STBGIDLD} = \mathbf{POSTBGIDLD}$$

$$\mathbf{CGIDL} = \mathbf{POCGIDL}$$

$$\mathbf{CGIDLD} = \mathbf{POCGIDLD}$$

Charge Model Parameters

$$\mathbf{COX} = \mathbf{POCOX} + \mathbf{PLCOX} \cdot \frac{L_{\mathrm{E,CV}}}{L_{\mathrm{EN}}} + \mathbf{PWCOX} \cdot \frac{W_{\mathrm{E,CV}}}{W_{\mathrm{EN}}} + \mathbf{PLWCOX} \cdot \frac{L_{\mathrm{E,CV}} \cdot W_{\mathrm{E,CV}}}{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}$$

$$\mathbf{CGOV} = \mathbf{POCGOV} + \mathbf{PLCGOV} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E,CV}}} + \mathbf{PWCGOV} \cdot \frac{W_{\mathrm{E,CV}}}{W_{\mathrm{EN}}} + \mathbf{PLWCGOV} \cdot \frac{W_{\mathrm{E,CV}} \cdot L_{\mathrm{EN}}}{W_{\mathrm{EN}} \cdot L_{\mathrm{E,CV}}}$$

$$\mathbf{CGOVD} = \mathbf{POCGOVD} + \mathbf{PLCGOVD} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E,CV}}} + \mathbf{PWCGOVD} \cdot \frac{W_{\mathrm{E,CV}}}{W_{\mathrm{EN}}} + \mathbf{PLWCGOVD} \cdot \frac{W_{\mathrm{E,CV}} \cdot L_{\mathrm{EN}}}{W_{\mathrm{EN}} \cdot L_{\mathrm{E,CV}}}$$

$$\mathbf{CGBOV} = \mathbf{POCGBOV} + \mathbf{PLCGBOV} \cdot \frac{L_{\mathrm{G,CV}}}{L_{\mathrm{EN}}} + \mathbf{PWCGBOV} \cdot \frac{W_{\mathrm{G,CV}}}{W_{\mathrm{EN}}} + \mathbf{PLWCGBOV} \cdot \frac{L_{\mathrm{G,CV}} \cdot W_{\mathrm{G,CV}}}{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}$$

$$\mathbf{CFR} = \mathbf{POCFR} + \mathbf{PLCFR} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{G,CV}}} + \mathbf{PWCFR} \cdot \frac{W_{\mathrm{G,CV}}}{W_{\mathrm{EN}}} + \mathbf{PLWCFR} \cdot \frac{W_{\mathrm{G,CV}} \cdot L_{\mathrm{EN}}}{W_{\mathrm{EN}} \cdot L_{\mathrm{G,CV}}}$$

$$\mathbf{CFRD} = \mathbf{POCFRD} + \mathbf{PLCFRD} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{G,CV}}} + \mathbf{PWCFRD} \cdot \frac{W_{\mathrm{G,CV}}}{W_{\mathrm{EN}}} + \mathbf{PLWCFRD} \cdot \frac{W_{\mathrm{G,CV}} \cdot L_{\mathrm{EN}}}{W_{\mathrm{EN}} \cdot L_{\mathrm{G,CV}}}$$

Noise Model Parameters

$$\mathbf{FNT} = \mathbf{POFNT}$$

$$\mathbf{NFA} = \mathbf{PONFA} + \mathbf{PLNFA} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWNFA} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWNFA} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{NFB} = \mathbf{PONFB} + \mathbf{PLNFB} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWNFB} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWNFB} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{NFC} = \mathbf{PONFC} + \mathbf{PLNFC} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWNFC} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWNFC} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$\mathbf{EF} = \mathbf{POEF}$$

WPE Parameters

$$K_{\mathrm{vthowe}} = \mathbf{POKVTHOWE} + \mathbf{PLKVTHOWE} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWKVTHOWE} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWKVTHOWE} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

$$K_{\mathrm{uowe}} = \mathbf{POKUOWE} + \mathbf{PLKUOWE} \cdot \frac{L_{\mathrm{EN}}}{L_{\mathrm{E}}} + \mathbf{PWKUOWE} \cdot \frac{W_{\mathrm{EN}}}{W_{\mathrm{E}}} + \mathbf{PLWKUOWE} \cdot \frac{L_{\mathrm{EN}} \cdot W_{\mathrm{EN}}}{L_{\mathrm{E}} \cdot W_{\mathrm{E}}}$$

Parasitic resistances

PSP model contains a network of parasitic elements: a gate resistance, two diffusion resistances for source and drain, and four bulk resistances. Note that the junction diodes are no longer directly connected to the bulk terminal of the intrinsic MOS-transistor. The complete circuit is shown in Figure 24-2. At this moment, only the gate resistance is scaled with geometry (facilitating the implementation of multi-finger devices).

Note: The resistance equations are calculated when **SWGEO** = 1 or 2.

$$L_{\mathrm{f}} = L + \Delta L_{\mathrm{PS}}$$

$$L_{\mathrm{sil,f}} = L_{\mathrm{f}} + \mathbf{DLSIL}$$

$$W_{\mathrm{E,f}} = W_{\mathrm{f}} + \Delta W_{\mathrm{OD}}$$

$$X_{\mathrm{GWE}} = \mathbf{XGW} - 0.5 \cdot \Delta W_{\mathrm{OD}}$$

$$\mathbf{RG} = \mathbf{RGO} + \frac{1}{\mathbf{NF}} \cdot \left[\frac{\mathbf{RSHG} \cdot \left(\frac{W_{\mathrm{E,f}}}{3 \cdot \mathbf{NGCON}} + X_{\mathrm{GWE}} \right)}{\mathbf{NGCON} \cdot L_{\mathrm{sil,f}}} + \frac{\mathbf{RINT} + \mathbf{RVPOLY}}{W_{\mathrm{E,f}} \cdot L_{\mathrm{f}}} \right]$$

$$\mathbf{RSE} = \mathbf{NRS} \cdot \mathbf{RSH}$$

$$\mathbf{RDE} = \mathbf{NRD} \cdot \mathbf{RSH}$$

$$\mathbf{RBULK} = \mathbf{RBULKO}$$

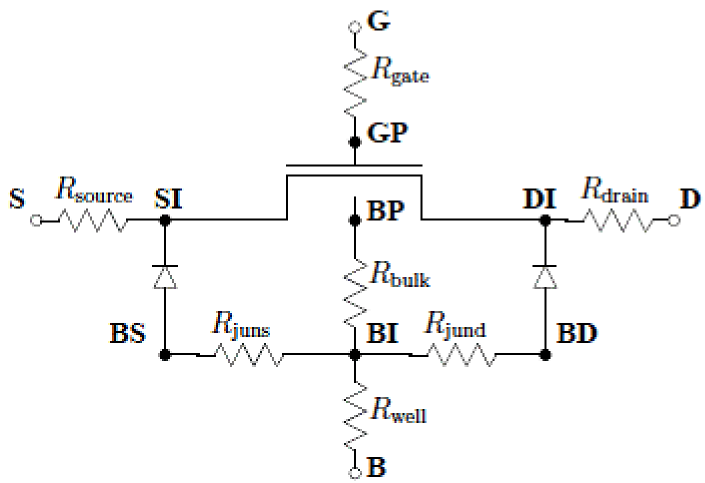
$$\mathbf{RWELL} = \mathbf{RWELLO}$$

$$\mathbf{RJUNS} = \mathbf{RJUNSO}$$

$$\mathbf{RJUND} = \mathbf{RJUNDO}$$

Note: The values of Lf , Lsil,f , WE,f and XGWE are clipped to a minimum value of 1 nm. The calculated local parameters are subject to the boundaries specified in next section.

Figure 24-2 Parasitics Circuit



Stress effects

The stress model of BSIM4.4.0 has been adopted in PSP without any modifications, except fo r two changes:

1. In the original BSIM parameter names all zeros have been replaced by "O"s, in order to comply with PSP conventions.
2. The BSIM parameters STK2 and LODK2 are not available in PSP. Some trivial conversion of parameters BSIM-PSP is still necessary.

The local PSP parameters affected by the stress equations are **BETN**, **THESAT**, **VFB**, and **CF**. Calculation of **SA** and **SB** for irregular layouts is given separeately.

Note:

- After modification of the local parameters by the stress equa tions, clipping is applied according to Section "Intrinsic Parameters for the model".
- If both SA and SB are set to 0, the stress-equations are not computed.
- The stress equations are calculated when SWGEO = 1 or 2.

Layout effects for multi-finger devices

For multi-finger devices, effective values SA_{eff} and SB_{eff} for the instance parameters are calculated.

$$\frac{1}{\mathbf{SA}_{\rm eff}+0.5\cdot L}=\frac{1}{\mathbf{NF}}\cdot\sum_{i=0}^{\mathbf{NF}-1}\frac{1}{\mathbf{SA}+0.5\cdot L+i\cdot(\mathbf{SD}+L)}$$

$$\frac{1}{\mathbf{SB}_{\rm eff}+0.5\cdot L}=\frac{1}{\mathbf{NF}}\cdot\sum_{i=0}^{\mathbf{NF}-1}\frac{1}{\mathbf{SB}+0.5\cdot L+i\cdot(\mathbf{SD}+L)}$$

Layout effects for regular shapes

$$R_{\rm A}=\frac{1}{\mathbf{SA}_{\rm eff}+0.5\cdot L}$$

$$R_{\rm B}=\frac{1}{\mathbf{SB}_{\rm eff}+0.5\cdot L}$$

$$R_{\rm A,ref}=\frac{1}{\mathbf{SAREF}+0.5\cdot L}$$

$$R_{\rm B,ref}=\frac{1}{\mathbf{SBREF}+0.5\cdot L}$$

Figure 24-3 A typical layout of multi-finger devices with an a additional instance parameters SD.

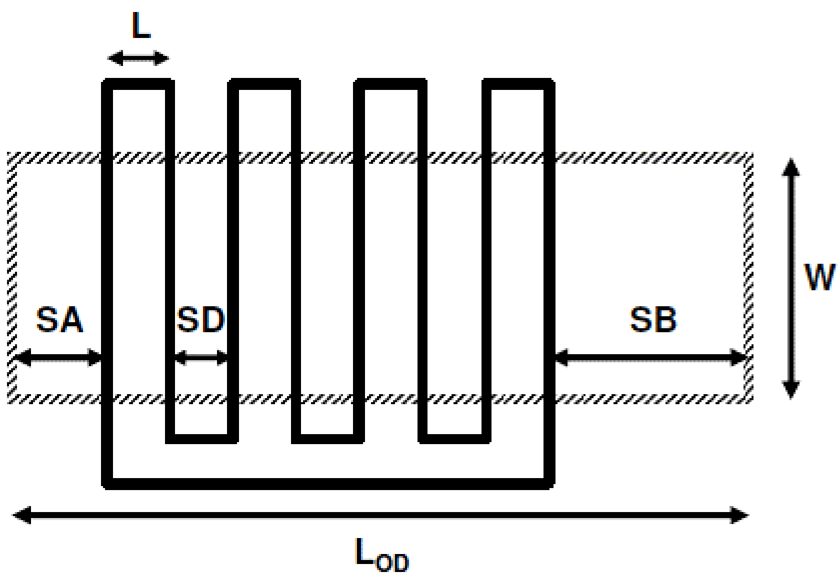
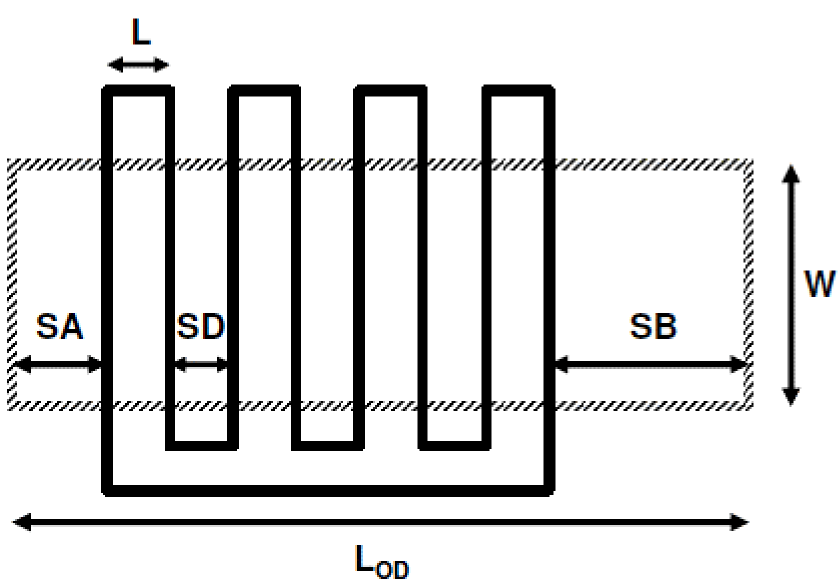


Figure 24-4 Typical layout of a MOSFET. Note that LOD = SA + SB + L, where OD is the active region definition.



Parameter Modifications

Mobility related equations

$$K_{\mathrm{u0}} = \left(1 + \frac{\mathbf{LKUO}}{(L + \Delta L_{\mathrm{PS}})^{\mathbf{LLODKUO}}} + \frac{\mathbf{WKUO}}{(W_{\mathrm{f}} + \Delta W_{\mathrm{OD}} + \mathbf{WLOD})^{\mathbf{WLODKUO}}} + \frac{\mathbf{PKUO}}{(L + \Delta L_{\mathrm{PS}})^{\mathbf{LLODKUO}} \cdot (W_{\mathrm{f}} + \Delta W_{\mathrm{OD}} + \mathbf{WLOD})^{\mathbf{WLODKUO}}}\right) \cdot \left[1 + \mathbf{TKUO} \cdot \left(\frac{T_{\mathrm{KD}}}{T_{\mathrm{KR}}} - 1\right)\right]$$

$$\rho_{\beta} = \frac{\mathbf{KUO}}{K_{\mathrm{u0}}} \cdot (R_{\mathrm{A}} + R_{\mathrm{B}})$$

$$\rho_{\beta,\mathrm{ref}} = \frac{\mathbf{KUO}}{K_{\mathrm{u0}}} \cdot (R_{\mathrm{A,ref}} + R_{\mathrm{B,ref}})$$

$$\mathbf{BETN} = \frac{1 + \rho_{\beta}}{1 + \rho_{\beta,\mathrm{ref}}} \cdot \mathbf{BETN}_{\mathrm{ref}}$$

$$\mathbf{THESAT} = \frac{1 + \rho_{\beta}}{1 + \rho_{\beta,\mathrm{ref}}} \cdot \frac{1 + \mathbf{KVSAT} \cdot \rho_{\beta,\mathrm{ref}}}{1 + \mathbf{KVSAT} \cdot \rho_{\beta}} \cdot \mathbf{THESAT}_{\mathrm{ref}}$$

Threshold Voltage related equations

$$K_{\mathrm{vth0}} = 1 + \frac{\mathbf{LKVTHO}}{(L + \Delta L_{\mathrm{PS}})^{\mathbf{LLODVTH}}} + \frac{\mathbf{WKVTHO}}{(W_{\mathrm{f}} + \Delta W_{\mathrm{OD}} + \mathbf{WLOD})^{\mathbf{WLODVTH}}} + \frac{\mathbf{PKVTHO}}{(L + \Delta L_{\mathrm{PS}})^{\mathbf{LLODVTH}} \cdot (W_{\mathrm{f}} + \Delta W_{\mathrm{OD}} + \mathbf{WLOD})^{\mathbf{WLODVTH}}}$$

$$\Delta R = R_{\mathrm{A}} + R_{\mathrm{B}} - R_{\mathrm{A,ref}} - R_{\mathrm{B,ref}}$$

$$\mathbf{VFB} = \mathbf{VFB}_{\mathrm{ref}} + \mathbf{KVTHO} \cdot \frac{\Delta R}{K_{\mathrm{vth0}}}$$

$$\mathbf{CF} = \mathbf{CF}_{\mathrm{ref}} + \mathbf{STETAO} \cdot \frac{\Delta R}{K_{\mathrm{vth0}}^{\mathbf{LODETAO}}}$$

Well proximity effects

The well proximity effect (WPE) model from BSIM4.5.0 has been adopted in PSP with two changes relative to BSIM4.5.0: (1) in the original BSIM parameter names all zeros have been replaced by `O's in order to comply with PSP naming convention and (2) the BSIM parameter K2WE is not available in PSP. Except for some trivial conversion of parameters BSIM-PSP, WPE parameters from BSIM can be used directly in PSP.

The local PSP parameters affected by the WPE equations are VFB and BETN.

Note:

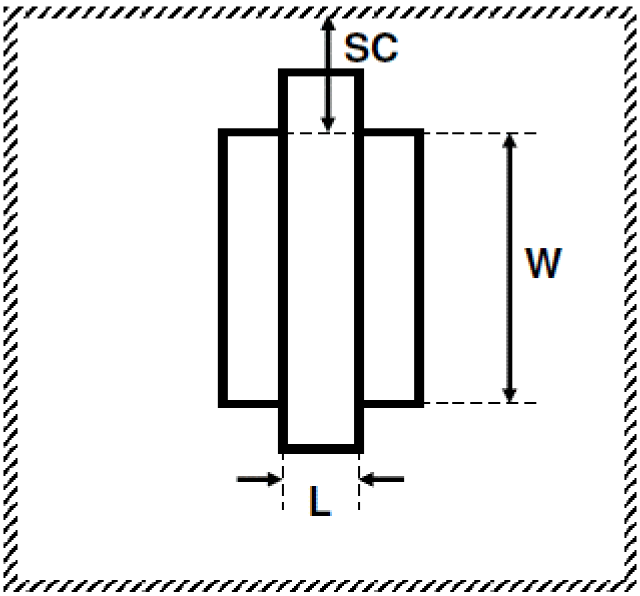
- After modification of the local parameters by the WPE equatio ns, clipping is applied according to Section “Intrinsic Parameters for the model”.
- If SCA, SCB, SCC and SC are all set to 0, the WPE equations are not computed.
- The WPE equations are calculated when SWGEO = 1 or 2.

Parameters for pre-layout simulation

If **SCA** = **SCB** = **SCC** = 0 and **SC** > 0, **SCA**, **SCB**, and **SCC** will be computed from **SC** as shown below. Here, **SC** should be taken as the distance to the nearest well edge (see Figure below). If any of the parameters **SCA**, **SCB**, or **SCC** is positive, all three values as supplied will be used and **SC** will be ignored.

If **SCA** = **SCB** = **SCC** = 0 and **SC** > 0

Figure 24-5 A layout of MOS devices for pre-layout simulation using estimated value for SC.



$$\mathbf{SCB} = \frac{1}{W_\mathrm{f} \cdot \mathbf{SCREF}} \cdot \left[\frac{\mathbf{SCREF}}{10} \cdot \mathbf{SC} \cdot \exp\left(-10 \cdot \frac{\mathbf{SC}}{\mathbf{SCREF}}\right) + \frac{\mathbf{SCREF}^2}{100} \cdot \exp\left(-10 \cdot \frac{\mathbf{SC}}{\mathbf{SCREF}}\right) \right.$$

$$- \frac{\mathbf{SCREF}}{10} \cdot (\mathbf{SC} + W_\mathrm{f}) \cdot \exp\left(-10 \cdot \frac{\mathbf{SC} + W_\mathrm{f}}{\mathbf{SCREF}}\right)$$

$$- \frac{\mathbf{SCREF}}{10} \cdot (\mathbf{SC} + W_\mathrm{f}) \cdot \exp\left(-10 \cdot \frac{\mathbf{SC} + W_\mathrm{f}}{\mathbf{SCREF}}\right)$$

$$\left. - \frac{\mathbf{SCREF}^2}{100} \cdot \exp\left(-10 \cdot \frac{\mathbf{SC} + W_\mathrm{f}}{\mathbf{SCREF}}\right) \right]$$

$$\mathbf{SCC} = \frac{1}{W_\mathrm{f} \cdot \mathbf{SCREF}} \cdot \left[\frac{\mathbf{SCREF}}{20} \cdot \mathbf{SC} \cdot \exp\left(-20 \cdot \frac{\mathbf{SC}}{\mathbf{SCREF}}\right) + \frac{\mathbf{SCREF}^2}{400} \cdot \exp\left(-20 \cdot \frac{\mathbf{SC}}{\mathbf{SCREF}}\right) \right.$$

$$- \frac{\mathbf{SCREF}}{20} \cdot (\mathbf{SC} + W_\mathrm{f}) \cdot \exp\left(-20 \cdot \frac{\mathbf{SC} + W_\mathrm{f}}{\mathbf{SCREF}}\right)$$

Calculation of parameter modifications

The calculation of K_{vthowe} and K_{uowe} is given in Sections for Global Model or Binning Model.

$$\mathbf{VFB} = \mathbf{VFB}_{\mathrm{ref}} + K_{\mathrm{vthowe}} \cdot (\mathbf{SCA} + \mathbf{WEB} \cdot \mathbf{SCB} + \mathbf{WEC} \cdot \mathbf{SCC})$$

$$\mathbf{BETN} = \mathbf{BETN}_{\mathrm{ref}} \cdot [1 + K_{\mathrm{uowe}} \cdot (\mathbf{SCA} + \mathbf{WEB} \cdot \mathbf{SCB} + \mathbf{WEC} \cdot \mathbf{SCC})]$$

Asymmetric junctions

From PSP 102.3 onwards, asymmetric junction can be modeled in PSP. This includes asymmetric source-bulk and drain-bulk junctions, GIDL/GISL, overlap gate currents, overlap capacitances and outer fringe capaci-tances. The asymmetric junction model can be switched on by means of the parameter SWJUNASYM. Note that if SWJUNASYM = 1, the new parameters for the drain side are used all together. Those whose values are not explicitly specified in the model card are set to their default value, not to their counterparts for the source side. In other words, it is not possible to activate the parameters for the drain side on a one-by-one basis. The physical scaling and binning rules to calculate the related local parameters for the drain side are given separately in this chapter.

If **SWJUNASYM** = 0, the related parameters for the drain side are ignored. Effectively, the following assign-ments are applied before evaluation of the calculations described in thr next section.

If SWJUNASYM = 0:

TOXOVD = **TOXOV**

NOVD = **NOV**

AGIDLD = **AGIDL**

BGIDLD = **BGIDL**

STBGIDLD = **STBGIDL**

CGIDLD = **CGIDL**

IGOVD = **IGOV**

CGOVD = **CGOV**

CFRD = **CFR**

RSHD = **RSH**

PSP 103 Model Equations

Internal Parameters (including Temperature Scaling)

In this section, bias-independent internal parameters are calculated, including temperature scaling. These parameters are computed from local parameters. Local parameters are (as usual) denoted by capital characters in bold font, whereas the internal parameters are denoted by symbols in bold font.

Transistor temperature

$$T_{\mathrm{KR}} = T_0 + \mathbf{TR}$$

$$T_{\mathrm{KD}} = T_0 + T_{\mathrm{A}} + \mathbf{DTA}$$

$$\Delta T = T_{\mathrm{KD}} - T_{\mathrm{KR}}$$

$$\phi_{\mathbf{T}} = \frac{k_{\mathrm{B}} \cdot T_{\mathrm{KD}}}{q}$$

Local process parameters

$$\phi_{\mathbf{T}}^{*} = \phi_{\mathbf{T}} \cdot \left(1 + \mathbf{CT} \cdot \frac{T_{\mathrm{KR}}}{T_{\mathrm{KD}}}\right)$$

$$V_{\mathbf{FB}} = \mathbf{VFB} + \mathbf{STVFB} \cdot \Delta T + \mathbf{DELVTO}$$

$$E_{\mathrm{g}}/q = 1.179 - 9.025 \cdot 10^{-5} \cdot T_{\mathrm{KD}} - 3.05 \cdot 10^{-7} \cdot {T_{\mathrm{KD}}}^{2}$$

$$r_{\mathrm{T}} = \left(1.045 + 4.5 \cdot 10^{-4} \cdot T_{\mathrm{KD}}\right) \cdot \left(0.523 + 1.4 \cdot 10^{-3} \cdot T_{\mathrm{KD}} - 1.48 \cdot 10^{-6} \cdot {T_{\mathrm{KD}}}^{2}\right)$$

$$n_{\mathrm{i}} = 2.5 \cdot 10^{25} \cdot {r_{\mathrm{T}}}^{3/4} \cdot (T_{\mathrm{KD}}/300)^{3/2} \cdot \exp\left(-\frac{E_{\mathrm{g}}/q}{2 \cdot \phi_{\mathbf{T}}}\right)$$

$$\phi_{\mathrm{B,dc}}^{\mathrm{cl}} = \mathrm{MAX}\left(\mathbf{DPHIB} + 2 \cdot \phi_{\mathbf{T}} \cdot \ln\left[\mathbf{NEFF}/n_{\mathrm{i}}\right], 0.05\right)$$

$$N_{\mathrm{eff,ac}} = \mathrm{MIN}[\mathrm{MAX}(\mathbf{FACNEFFAC} \cdot \mathbf{NEFF}, 10^{20}), 10^{26}]$$

$$\phi_{\mathrm{B,ac}}^{\mathrm{cl}} = \mathrm{MAX}\left(\mathbf{DPHIB} + \mathbf{DELVTAC} + 2 \cdot \phi_{\mathbf{T}} \cdot \ln\left[N_{\mathrm{eff,ac}}/n_{\mathrm{i}}\right], 0.05\right)$$

$$\epsilon_{\mathrm{ox}} = \mathbf{EPSROX} \cdot \epsilon_{0}$$

$$C_{\mathrm{ox}} = \epsilon_{\mathrm{ox}}/\mathbf{TOX}$$

$$\epsilon_{\mathrm{Si}} = \epsilon_{\mathrm{r,Si}} \cdot \epsilon_{0}$$

$$\gamma_{0,\mathrm{dc}} = \sqrt{2 \cdot q \cdot \epsilon_{\mathrm{Si}} \cdot \mathbf{NEFF}}/C_{\mathrm{ox}}$$

$$\gamma_{0,\mathrm{ac}} = \sqrt{2 \cdot q \cdot \epsilon_{\mathrm{Si}} \cdot N_{\mathrm{eff,ac}}}/C_{\mathrm{ox}}$$

$$G_{0,\mathrm{dc}}^{\mathrm{cl}} = \gamma_{0,\mathrm{dc}}/\sqrt{\phi_{\mathbf{T}}}$$

$$G_{0,\mathrm{ac}}^{\mathrm{cl}} = \gamma_{0,\mathrm{ac}}/\sqrt{\phi_{\mathbf{T}}}$$

Polysilicon depletion parameter

$$\boldsymbol{k_\mathrm{P}} = \begin{cases} \text{if } \mathbf{NP} = 0 & \left\{ \boldsymbol{k_\mathrm{P}} = 0 \right. \\ \text{if } \mathbf{NP} > 0 & \begin{cases} \mathrm{NP}_1 = \mathrm{MAX}(\mathbf{NP},\, 8 \cdot 10^7/\mathbf{TOX}^2) \\ \mathrm{NP}_2 = \mathrm{MAX}(\mathrm{NP}_1,\, 5 \cdot 10^{24}) \\ \boldsymbol{k_\mathrm{P}} = 2 \cdot \boldsymbol{\phi_\mathrm{T}} \cdot C_\mathrm{ox}^2/(q \cdot \epsilon_\mathrm{Si} \cdot \mathrm{NP}_2) \end{cases} \end{cases}$$

Quantum-mechanical correction parameters

$$\boldsymbol{q_\mathrm{lim}} = 10 \cdot \boldsymbol{\phi_\mathrm{T}}$$

$$\boldsymbol{q_\mathrm{q}} = \begin{cases} 0.4 \cdot \mathbf{QMC} \cdot QM_\mathrm{N} \cdot C_\mathrm{ox}^{2/3} & \text{for NMOS} \\ 0.4 \cdot \mathbf{QMC} \cdot QM_\mathrm{P} \cdot C_\mathrm{ox}^{2/3} & \text{for PMOS} \end{cases}$$

$$q_\mathrm{b0,dc} = \gamma_\mathrm{0,dc} \cdot \sqrt{\phi_\mathrm{B,dc}^\mathrm{cl}}$$

$$q_\mathrm{b0,ac} = \gamma_\mathrm{0,ac} \cdot \sqrt{\phi_\mathrm{B,ac}^\mathrm{cl}}$$

$$\boldsymbol{\phi_\mathrm{B,dc}} = \phi_\mathrm{B,dc}^\mathrm{cl} + 0.75 \cdot \boldsymbol{q_\mathrm{q}} \cdot q_\mathrm{b0,dc}^{2/3}$$

$$\boldsymbol{\phi_\mathrm{B,ac}} = \phi_\mathrm{B,ac}^\mathrm{cl} + 0.75 \cdot \boldsymbol{q_\mathrm{q}} \cdot q_\mathrm{b0,ac}^{2/3}$$

$$\boldsymbol{G_\mathrm{0,dc}} = G_\mathrm{0,dc}^\mathrm{cl} \cdot \left(1 + \boldsymbol{q_\mathrm{q}} \cdot q_\mathrm{b0,dc}^{-1/3}\right)$$

$$\boldsymbol{G_\mathrm{0,ac}} = G_\mathrm{0,ac}^\mathrm{cl} \cdot \left(1 + \boldsymbol{q_\mathrm{q}} \cdot q_\mathrm{b0,ac}^{-1/3}\right)$$

VSB-clipping parameters

$$\phi_{\mathbf{X},\mathrm{dc}} = 0.95 \cdot \phi_{\mathbf{B},\mathrm{dc}}$$

$$\phi_{\mathbf{X},\mathrm{ac}} = 0.95 \cdot \phi_{\mathbf{B},\mathrm{ac}}$$

$$\boldsymbol{a}_{\boldsymbol{\phi},\mathrm{dc}} = 2.5 \cdot 10^{-3} \cdot \phi^2_{\mathbf{B},\mathrm{dc}}$$

$$\boldsymbol{a}_{\boldsymbol{\phi},\mathrm{ac}} = 2.5 \cdot 10^{-3} \cdot \phi^2_{\mathbf{B},\mathrm{ac}}$$

$$\boldsymbol{b}_{\boldsymbol{\phi},\mathrm{dc}} = 2.5 \cdot 10^{-3} \cdot \phi^2_{\mathbf{B},\mathrm{dc}}$$

$$\boldsymbol{b}_{\boldsymbol{\phi},\mathrm{ac}} = 2.5 \cdot 10^{-3} \cdot \phi^2_{\mathbf{B},\mathrm{ac}}$$

$$\phi^{\star}_{\mathbf{X},\mathrm{dc}} = 0.5 \cdot \sqrt{\boldsymbol{b}_{\boldsymbol{\phi},\mathrm{dc}}}$$

$$\phi^{\star}_{\mathbf{X},\mathrm{ac}} = 0.5 \cdot \sqrt{\boldsymbol{b}_{\boldsymbol{\phi},\mathrm{ac}}}$$

$$\phi^{\ddagger}_{\mathbf{X},\mathrm{dc}} = \mathrm{MINA}\left(\phi_{\mathbf{X},\mathrm{dc}} - \phi^{\star}_{\mathbf{X},\mathrm{dc}},\, 0,\, \boldsymbol{a}_{\boldsymbol{\phi},\mathrm{dc}}\right)$$

$$\phi^{\ddagger}_{\mathbf{X},\mathrm{ac}} = \mathrm{MINA}\left(\phi_{\mathbf{X},\mathrm{ac}} - \phi^{\star}_{\mathbf{X},\mathrm{ac}},\, 0,\, \boldsymbol{a}_{\boldsymbol{\phi},\mathrm{ac}}\right)$$

NUD parameters

$$\mathbf{u}_{s1} = \sqrt{\mathbf{VSBNUD} + \phi_{\mathbf{B}}} - \sqrt{\phi_{\mathbf{B}}}$$

$$\mathbf{u}_{s21} = \sqrt{\mathbf{DVSBNUD} + \phi_{\mathbf{B}}} - \sqrt{\phi_{\mathbf{B}}} - \mathbf{u}_{s1}$$

Local process parameters in gate overlap region

$$\gamma_{\text{ov}} = \sqrt{2 \cdot q \cdot \epsilon_{\text{Si}} \cdot \mathbf{NOV}} \cdot \mathbf{TOXOV}/\epsilon_{\text{ox}}$$

$$\gamma_{\text{dov}} = \sqrt{2 \cdot q \cdot \epsilon_{\text{Si}} \cdot \mathbf{NOVD}} \cdot \mathbf{TOXOVD}/\epsilon_{\text{ox}}$$

$$\boldsymbol{G}_{\mathbf{ov}} = \gamma_{\text{ov}}/\sqrt{\boldsymbol{\phi}_{\mathbf{T}}}$$

$$\boldsymbol{G}_{\mathbf{dov}} = \gamma_{\text{dov}}/\sqrt{\boldsymbol{\phi}_{\mathbf{T}}}$$

$$\boldsymbol{\xi}_{\mathbf{ov}} = 1 + \boldsymbol{G}_{\mathbf{ov}}/\sqrt{2}$$

$$\boldsymbol{\xi}_{\mathbf{dov}} = 1 + \boldsymbol{G}_{\mathbf{dov}}/\sqrt{2}$$

$$\boldsymbol{x}_{\mathbf{mrgov}} = 10^{-5} \cdot \boldsymbol{\xi}_{\mathbf{ov}}$$

$$\boldsymbol{x}_{\mathbf{mrgdov}} = 10^{-5} \cdot \boldsymbol{\xi}_{\mathbf{dov}}$$

Mobility parameters

$$\beta = \textbf{FACTUO} \cdot \textbf{BETN} \cdot C_{\text{ox}} \cdot (T_{\text{KR}}/T_{\text{KD}})^{\textbf{STBET}}$$

$$\theta_{\mu} = \textbf{THEMU} \cdot (T_{\text{KR}}/T_{\text{KD}})^{\textbf{STTHEMU}}$$

$$\mu_{\text{E}} = \textbf{MUE} \cdot (T_{\text{KR}}/T_{\text{KD}})^{\textbf{STMUE}}$$

$$X_{\text{cor}} = \textbf{XCOR} \cdot (T_{\text{KR}}/T_{\text{KD}})^{\textbf{STXCOR}}$$

$$C_{\text{S}} = \textbf{CS} \cdot (T_{\text{KR}}/T_{\text{KD}})^{\textbf{STCS}}$$

$$E_{\text{eff0}} = 10^{-8} \cdot C_{\text{ox}}/\epsilon_{\text{Si}}$$

$$\eta_{\mu} = \begin{cases} 1/2 \cdot \textbf{FETA} & \text{for NMOS} \\ 1/3 \cdot \textbf{FETA} & \text{for PMOS} \end{cases}$$

$$\eta_{\mu,\text{ac}} = \begin{cases} 1/2 & \text{for NMOS} \\ 1/3 & \text{for PMOS} \end{cases}$$

Series resistance parameter

$$R_{\text{s}} = \textbf{RS} \cdot (T_{\text{KR}}/T_{\text{KD}})^{\textbf{STRS}}$$

$$\theta_{\text{R}} = 2 \cdot \beta \cdot R_{\text{s}}$$

Velocity saturation parameter

$$\theta_{\text{sat}} = \textbf{THESAT} \cdot (T_{\text{KR}}/T_{\text{KD}})^{\textbf{STTHESAT}}$$

Impact-ionization parameter

$$a_2 = \mathbf{A2} \cdot (T_{\mathrm{KD}}/T_{\mathrm{KR}})^{\mathbf{STA2}}$$

Gate current parameters

$$I_{\mathrm{GINV}} = \mathbf{IGINV} \cdot (T_{\mathrm{KD}}/T_{\mathrm{KR}})^{\mathbf{STIG}}$$

$$I_{\mathrm{GOV}} = \mathbf{IGOV} \cdot (T_{\mathrm{KD}}/T_{\mathrm{KR}})^{\mathbf{STIG}}$$

$$I_{\mathrm{GOVD}} = \mathbf{IGOVD} \cdot (T_{\mathrm{KD}}/T_{\mathrm{KR}})^{\mathbf{STIG}}$$

$$B = \frac{4}{3} \cdot \frac{\mathbf{TOX}}{\hbar} \cdot \sqrt{2 \cdot q \cdot m_0 \cdot \mathbf{CHIB}} = 6.830909 \cdot 10^9 \cdot \mathbf{TOX} \cdot \sqrt{\mathbf{CHIB}}$$

$$B_{\mathrm{ov}} = B \cdot \mathbf{TOXOV}/\mathbf{TOX}$$

$$B_{\mathrm{ovd}} = B \cdot \mathbf{TOXOVD}/\mathbf{TOX}$$

$$GC_{\mathrm{Q}} = \begin{cases} -0.99 \cdot \dfrac{\mathbf{GC2}}{2 \cdot \mathbf{GC3}} & \text{for } \mathbf{GC3} < 0 \\ 0 & \text{for } \mathbf{GC3} \geq 0 \end{cases}$$

$$\alpha_{\mathrm{b}} = \frac{E_{\mathrm{g}}/q + \phi_{\mathrm{B}}}{2}$$

$$D_{\mathrm{ch}} = \mathbf{GCO} \cdot \phi_{\mathrm{T}}^{*}$$

$$D_{\mathrm{ov}} = \mathbf{GCO} \cdot \phi_{\mathrm{T}}$$

Gate-induced drain leakage parameters

$$A_{\text{GIDL}} = \mathbf{AGIDL} \cdot \left(\frac{2 \cdot 10^{-9}}{\mathbf{TOXOV}}\right)^2$$

$$A_{\text{GIDLD}} = \mathbf{AGIDLD} \cdot \left(\frac{2 \cdot 10^{-9}}{\mathbf{TOXOVD}}\right)^2$$

$$B_{\text{GIDL}} = \mathbf{BGIDL} \cdot \text{MAX}\left([1 + \mathbf{STBGIDL} \cdot \Delta T], 0\right) \cdot \left(\frac{\mathbf{TOXOV}}{2 \cdot 10^{-9}}\right)$$

$$B_{\text{GIDLD}} = \mathbf{BGIDLD} \cdot \text{MAX}\left([1 + \mathbf{STBGIDLD} \cdot \Delta T], 0\right) \cdot \left(\frac{\mathbf{TOXOVD}}{2 \cdot 10^{-9}}\right)$$

Noise parameter

$$\boldsymbol{N}_{\mathbf{T}} = \mathbf{FNT} \cdot 4 \cdot k_{\text{B}} \cdot T_{\text{KD}}$$

Additional internal parameters

$$\boldsymbol{x}_{\mathbf{1}} = 1.25$$

$$\boldsymbol{x}_{\mathbf{gl}} = \boldsymbol{x}_{\mathbf{1}} + \boldsymbol{G}_{\mathbf{ov}} \cdot \sqrt{\exp(-\boldsymbol{x}_{\mathbf{1}}) + \boldsymbol{x}_{\mathbf{1}} - 1}$$

$$\boldsymbol{x}_{\mathbf{dgl}} = \boldsymbol{x}_{\mathbf{1}} + \boldsymbol{G}_{\mathbf{dov}} \cdot \sqrt{\exp(-\boldsymbol{x}_{\mathbf{1}}) + \boldsymbol{x}_{\mathbf{1}} - 1}$$

Current Model

In this section, the current model equations of the PSP-model are given. Use is made of the applied termi-nal bias values VGS, VDS and VSB, the local parameters listed in Section 'Intrinsic Parameters for the model', and the internal parameters introduced in previous section. Local parameters are denoted by capital characters in bold font, whereas internal (bias-independent) parameters are denoted by symbols in bold font.

Depending on the value of the parameters SWNUD and SWDELVTAC, the surface potential (at source- and drain-side of the channel) and associated computations may be evaluated twice: once for the dc-characteristics and a second time for the ac-characteristics of the model. Details are given below.

Conditioning of Terminal Voltages

$$V_{\mathrm{dsx}} = \sqrt{V_{\mathrm{DS}}{}^2 + 0.01} - 0.1$$

$$\phi_{\mathrm{V,dc}} = \mathrm{MINA}\left(V_{\mathrm{SB}},\ V_{\mathrm{SB}} + V_{\mathrm{DS}},\ \boldsymbol{b}_{\boldsymbol{\phi},\mathrm{dc}}\right) + \boldsymbol{\phi}_{\mathbf{X},\mathrm{dc}}$$

$$\phi_{\mathrm{V,ac}} = \mathrm{MINA}\left(V_{\mathrm{SB}},\ V_{\mathrm{SB}} + V_{\mathrm{DS}},\ \boldsymbol{b}_{\boldsymbol{\phi},\mathrm{ac}}\right) + \boldsymbol{\phi}_{\mathbf{X},\mathrm{ac}}$$

$$V^*_{\mathrm{SB,dc}} = V_{\mathrm{SB}} - \mathrm{MINA}\left(\phi_{\mathrm{V}},\ 0,\ \boldsymbol{a}_{\boldsymbol{\phi},\mathrm{dc}}\right) + \boldsymbol{\phi}^*_{\mathbf{X},\mathrm{dc}}$$

$$V^*_{\mathrm{SB,ac}} = V_{\mathrm{SB}} - \mathrm{MINA}\left(\phi_{\mathrm{V}},\ 0,\ \boldsymbol{a}_{\boldsymbol{\phi},\mathrm{ac}}\right) + \boldsymbol{\phi}^*_{\mathbf{X},\mathrm{ac}}$$

Nonuniform doping effect. are only evaluated when

$\mathbf{SWNUD} \neq 0$ and $\mathbf{GFACNUD} \neq 1$:

$$V_{\mathrm{mB}} = V^*_{\mathrm{SB}} + 0.5 \cdot (V_{\mathrm{DS}} - V_{\mathrm{dsx}})$$

$$u_{\mathrm{s}} = \sqrt{V_{\mathrm{mB}} + \boldsymbol{\phi}_{\mathbf{B}}} - \sqrt{\boldsymbol{\phi}_{\mathbf{B}}}$$

$$p = 2 \cdot \frac{u_{\mathrm{s}} - \mathbf{u_{s1}}}{\mathbf{u_{s21}}} - 1$$

$$u_{\mathrm{s,nud}} = u_{\mathrm{s}} - 0.25 \cdot (1 - \mathbf{GFACNUD}) \cdot \mathbf{u_{s21}} \cdot \left\{p + \sqrt{p^2 + [\ln(2)]^2}\right\}$$

$$V_{\mathrm{mB,nud}} = \left(u_{\mathrm{s,nud}} + 2 \cdot \sqrt{\boldsymbol{\phi}_{\mathbf{B}}}\right) \cdot u_{\mathrm{s,nud}}$$

$$V^{\mathrm{nud}}_{\mathrm{SB}} = V_{\mathrm{mB,nud}} - 0.5 \cdot (V_{\mathrm{DS}} - V_{\mathrm{dsx}})$$

$$V^*_{\mathrm{SB,dc}} = V^{\mathrm{nud}}_{\mathrm{SB}}$$

The surface potential (at source- and drain-side of the channel) and associated computations are evaluated using

$V^*_{\mathrm{SB}} = V^*_{\mathrm{SB,dc}}$, $\boldsymbol{\phi}_{\mathbf{B}} = \boldsymbol{\phi}_{\mathbf{B},\mathrm{dc}}$, and $\boldsymbol{G}_{\mathbf{0}} = \boldsymbol{G}_{\mathbf{0},\mathrm{dc}}$.

If SWNUD = 1 or SWDELVTAC = 1, calculations are done a second time using

$V^*_{\mathrm{SB}} = V^*_{\mathrm{SB,ac}}$, $\boldsymbol{\phi_B} = \boldsymbol{\phi}_{\mathbf{B},\mathrm{ac}}$, and $\boldsymbol{G_0} = \boldsymbol{G}_{\mathbf{0},\mathrm{ac}}$.

$$V^*_{\mathrm{DB}} = V_{\mathrm{DS}} + V^*_{\mathrm{SB}}$$

$$V_{\mathrm{sbx}} = V^*_{\mathrm{SB}} + \frac{V_{\mathrm{DS}} - V_{\mathrm{dsx}}}{2}$$

Drain-induced barrier lowering:

$$\Delta V_{\mathrm{G}} = \mathbf{CF} \cdot V_{\mathrm{dsx}} \cdot (1 + \mathbf{CFB} \cdot V_{\mathrm{sbx}})$$

$$V^*_{\mathrm{GB}} = V_{\mathrm{GS}} + V^*_{\mathrm{SB}} + \Delta V_{\mathrm{G}} - \boldsymbol{V}_{\mathbf{FB}}$$

$$x_{\mathrm{g}} = V^*_{\mathrm{GB}} / \phi^*_{\mathbf{T}}$$

Bias-Dependent Body Factor

$$D_{\mathrm{nsub}} = \mathbf{DNSUB} \cdot \mathrm{MAXA}\left(0,\, V_{\mathrm{GS}} + V_{\mathrm{SB}} - \mathbf{VNSUB},\, \mathbf{NSLP}\right)$$

$$G = \boldsymbol{G_0} \cdot \sqrt{1 + D_{\mathrm{nsub}}}$$

Surface Potential at Source Side and Related Variables

$$\xi = 1 + G/\sqrt{2}$$

$$x_{\mathrm{ns}} = \frac{\phi_{\mathbf{B}} + V_{\mathrm{SB}}^{*}}{\phi_{\mathbf{T}}^{*}}$$

$$\Delta_{\mathrm{ns}} = \exp\left(-x_{\mathrm{ns}}\right)$$

$$x_{\mathrm{mrg}} = 10^{-5} \cdot \xi$$

$$\text{if } x_\mathrm{g} < -x_\mathrm{mrg} \begin{cases} y_\mathrm{g} = -x_\mathrm{g} \\ z = 1.25 \cdot y_\mathrm{g}/\xi \\ \eta = \left[z + 10 - \sqrt{(z-6)^2 + 64}\right]/2 \\ a = (y_\mathrm{g} - \eta)^2 + G^2 \cdot (\eta + 1) \\ c = 2 \cdot (y_\mathrm{g} - \eta) - G^2 \\ \tau = -\eta + \ln\left(a/G^2\right) \\ y_0 = \sigma_1(a,\, c,\, \tau,\, \eta) \\ \Delta_0 = \exp\left(y_0\right) \\ p = 2 \cdot (y_\mathrm{g} - y_0) + G^2 \cdot [\Delta_0 - 1 + \Delta_\mathrm{ns} \cdot (1 - \chi'(y_0) - 1/\Delta_0)] \\ q = (y_\mathrm{g} - y_0)^2 + G^2 \cdot [y_0 - \Delta_0 + 1 + \Delta_\mathrm{ns} \cdot (1 + \chi(y_0) - 1/\Delta_0 - 2 \cdot y_0)] \\ x_\mathrm{s} = -y_0 - \dfrac{2 \cdot q}{p + \sqrt{p^2 - 2 \cdot q \cdot \{2 - G^2 \cdot [\Delta_0 + \Delta_\mathrm{ns} \cdot (1/\Delta_0 - \chi''(y_0))]\}}} \end{cases}$$

$$\text{if } |x_\mathrm{g}| \le x_\mathrm{mrg} \left\{ x_\mathrm{s} = \frac{x_\mathrm{g}}{\xi} \cdot \left[1 + G \cdot x_\mathrm{g} \cdot \frac{1 - \Delta_\mathrm{ns}}{\xi^2 \cdot 6 \cdot \sqrt{2}}\right] \right.$$

$$\text{if } x_\mathrm{g} > x_\mathrm{mrg} \begin{cases} \hat{x}_\mathrm{g1} = x_1 + G \cdot \sqrt{\exp(-x_1) + x_1 - 1} \\ \bar{x} = \dfrac{x_\mathrm{g}}{\xi} \cdot [1 + x_\mathrm{g} \cdot (\xi \cdot x_1 - \hat{x}_\mathrm{g1})/\hat{x}_\mathrm{g1}^2] \\ x_0 = x_\mathrm{g} + G^2/2 - G \cdot \sqrt{x_\mathrm{g} + G^2/4 - 1 + \exp(-\bar{x})} \\ b_\mathrm{x} = x_\mathrm{ns} + 3 \\ \eta = \mathrm{MINA}(x_0,\, b_\mathrm{x},\, 5) - \left(b_\mathrm{x} - \sqrt{b_\mathrm{x}^2 + 5}\right)/2 \\ a = (x_\mathrm{g} - \eta)^2 - G^2 \cdot [\exp(-\eta) + \eta - 1 - \Delta_\mathrm{ns} \cdot (\eta + 1 + \chi(\eta))] \\ b = 1 - G^2/2 \cdot [\exp(-\eta) - \Delta_\mathrm{ns} \cdot \chi''(\eta)] \\ c = 2 \cdot (x_\mathrm{g} - \eta) + G^2 \cdot [1 - \exp(-\eta) - \Delta_\mathrm{ns} \cdot (1 + \chi'(\eta))] \\ \tau = x_\mathrm{ns} - \eta + \ln\left(a/G^2\right) \\ y_0 = \sigma_2(a,\, b,\, c,\, \tau,\, \eta) \\ \Delta_0 = \exp\left(y_0\right) \\ p = 2 \cdot (x_\mathrm{g} - y_0) + G^2 \cdot [1 - 1/\Delta_0 + \Delta_\mathrm{ns} \cdot (\Delta_0 - 1 - \chi'(y_0))] \\ q = (x_\mathrm{g} - y_0)^2 - G^2 \cdot [y_0 + 1/\Delta_0 - 1 + \Delta_\mathrm{ns} \cdot (\Delta_0 - y_0 - 1 - \chi(y_0))] \\ x_\mathrm{s} = y_0 + \dfrac{2 \cdot q}{p + \sqrt{p^2 - 2 \cdot q \cdot \{2 - G^2 \cdot [1/\Delta_0 + \Delta_\mathrm{ns} \cdot (\Delta_0 - \chi''(y_0))]\}}} \end{cases}$$

Calculations are only done for $x_g > 0$.

$$E_s = \exp(-x_s)$$

$$D_s = [1/E_s - x_s - 1 - \chi(x_s)] \cdot \Delta_{ns}$$

$$P_s = x_s - 1 + E_s$$

$$x_{gs} = \begin{cases} x_g - x_s & \text{for } x_g \le 0 \\ G \cdot \sqrt{D_s + P_s} & \text{for } x_g > 0 \end{cases}$$

$$\psi_{ss} = \phi_T^* \cdot x_s$$

Drain Saturation Voltage

Calculations are only done for x_g > 0.

$$q_{\rm is} = \frac{G^2 \cdot \phi_{\rm T}^* \cdot D_{\rm s}}{x_{\rm gs} + G \cdot \sqrt{P_{\rm s}}}$$

$$\alpha_{\rm s} = 1 + \frac{G \cdot (1 - E_{\rm s})}{2 \cdot \sqrt{P_{\rm s}}}$$

$$q_{\rm bs} = \phi_{\rm T}^* \cdot G \cdot \sqrt{P_{\rm s}}$$

$$\rho_{\rm b} = \begin{cases} 1 + \mathbf{RSB} \cdot V_{\rm sbx} & \text{for } \mathbf{RSB} \geq 0 \\ \dfrac{1}{1 - \mathbf{RSB} \cdot V_{\rm sbx}} & \text{for } \mathbf{RSB} < 0 \end{cases}$$

$$\rho_{\rm g,s} = \begin{cases} \dfrac{1}{1 + \mathbf{RSG} \cdot q_{\rm is}} & \text{for } \mathbf{RSG} \geq 0 \\ 1 - \mathbf{RSG} \cdot q_{\rm is} & \text{for } \mathbf{RSG} < 0 \end{cases}$$

$$\rho_{\rm s} = \boldsymbol{\theta}_{\mathbf{R}} \cdot \rho_{\rm b} \cdot \rho_{\rm g,s} \cdot q_{\rm is}$$

$$\mu_{\rm x} = \frac{1 + \boldsymbol{X}_{\rm cor} \cdot V_{\rm sbx}}{1 + 0.2 \cdot \boldsymbol{X}_{\rm cor} \cdot V_{\rm sbx}}$$

$$E_{\rm eff,s} = \boldsymbol{E}_{\rm eff0} \cdot \left(q_{\rm bs} + \boldsymbol{\eta}_{\boldsymbol{\mu}} \cdot q_{\rm is}\right)$$

$$G_{\rm mob,s} = \frac{1 + (\boldsymbol{\mu}_{\mathbf{E}} \cdot E_{\rm eff,s})^{\boldsymbol{\theta}_{\boldsymbol{\mu}}} + \boldsymbol{C}_{\mathbf{S}} \cdot \left(\dfrac{q_{\rm bs}}{q_{\rm is} + q_{\rm bs}}\right)^2 + \rho_{\rm s}}{\mu_{\rm x}}$$

$$\xi_{\rm tb} = \begin{cases} 1 + \mathbf{THESATB} \cdot V_{\rm sbx} & \text{for } \mathbf{THESATB} \geq 0 \\ \dfrac{1}{1 - \mathbf{THESATB} \cdot V_{\rm sbx}} & \text{for } \mathbf{THESATB} < 0 \end{cases}$$

$$w_{\mathrm{sat,s}} = \frac{100 \cdot q_{\mathrm{is}} \cdot \xi_{\mathrm{tb}}}{100 + q_{\mathrm{is}} \cdot \xi_{\mathrm{tb}}}$$

$$\theta^*_{\mathrm{sat,s}} = \begin{cases} \dfrac{\boldsymbol{\theta}_{\mathbf{sat}}}{G_{\mathrm{mob,s}}} \cdot (1 + \mathbf{THESATG} \cdot w_{\mathrm{sat,s}}) & \text{for } \mathbf{THESATG} \geq 0 \\ \dfrac{\boldsymbol{\theta}_{\mathbf{sat}}}{G_{\mathrm{mob,s}}} \cdot \dfrac{1}{1 - \mathbf{THESATG} \cdot w_{\mathrm{sat,s}}} & \text{for } \mathbf{THESATG} < 0 \end{cases}$$

$$\phi_\infty = q_{\mathrm{is}}/\alpha_{\mathrm{s}} + \phi^*_{\mathrm{T}}$$

$$y_{\mathrm{sat}} = \begin{cases} \theta^*_{\mathrm{sat,s}} \cdot \phi_\infty/\sqrt{2} & \text{for NMOS} \\ \dfrac{\theta^*_{\mathrm{sat,s}} \cdot \phi_\infty/\sqrt{2}}{\sqrt{1 + \theta^*_{\mathrm{sat,s}} \cdot \phi_\infty/\sqrt{2}}} & \text{for PMOS} \end{cases}$$

$$z_{\mathrm{a}} = \frac{2}{1 + \sqrt{1 + 4 \cdot y_{\mathrm{sat}}}}$$

$$\phi_0 = \phi_\infty \cdot z_{\mathrm{a}} \cdot \left[1 + 0.86 \cdot z_{\mathrm{a}} \cdot y_{\mathrm{sat}} \cdot \frac{1 - z_{\mathrm{a}}^2 \cdot y_{\mathrm{sat}}}{1 + 4 \cdot z_{\mathrm{a}}^3 \cdot y_{\mathrm{sat}}^2}\right]$$

$$a_{\mathrm{sat}} = x_{\mathrm{gs}} + G^2/2$$

$$\phi_2 = \frac{\phi^*_{\mathrm{T}} \cdot 0.98 \cdot G^2 \cdot D_{\mathrm{s}}}{a_{\mathrm{sat}} + \sqrt{a_{\mathrm{sat}}^2 - 0.98 \cdot G^2 \cdot D_{\mathrm{s}}}}$$

$$\phi_{\mathrm{sat}} = \frac{2 \cdot \phi_0 \cdot \phi_2}{\phi_0 + \phi_2 + \sqrt{(\phi_0 + \phi_2)^2 - 3.96 \cdot \phi_0 \cdot \phi_2}}$$

$$V_{\mathrm{dsat}} = \phi_{\mathrm{sat}} - \phi^*_{\mathrm{T}} \cdot \ln\left[1 + \frac{\phi_{\mathrm{sat}} \cdot \left(\phi_{\mathrm{sat}} - 2 \cdot a_{\mathrm{sat}} \cdot \phi^*_{\mathrm{T}}\right)}{G^2 \cdot D_{\mathrm{s}} \cdot {\phi^*_{\mathrm{T}}}^2}\right]$$

$$V_{\mathrm{dse}} = \frac{V_{\mathrm{DS}}}{\left[1 + (V_{\mathrm{DS}}/V_{\mathrm{dsat}})^{\mathbf{AX}}\right]^{1/\mathbf{AX}}}$$

Surface Potential at Drain Side and Related Variables

Calculations are only done for $x_g > 0$.

$$x_{\mathrm{nd}} = \frac{\phi_{\mathrm{B}} + V_{\mathrm{SB}}^{*} + V_{\mathrm{dse}}}{\phi_{\mathrm{T}}^{*}}$$

$$k_{\mathrm{ds}} = \exp\left(-V_{\mathrm{dse}}/\phi_{\mathrm{T}}^{*}\right)$$

$$\Delta_{\mathrm{nd}} = \Delta_{\mathrm{ns}} \cdot k_{\mathrm{ds}}$$

$$\text{if } x_{\mathrm{g}} \le x_{\mathrm{mrg}} \left\{ \; x_{\mathrm{d}} = \frac{x_{\mathrm{g}}}{\xi} \cdot \left[1 + G \cdot x_{\mathrm{g}} \cdot \frac{1 - \Delta_{\mathrm{nd}}}{\xi^2 \cdot 6 \cdot \sqrt{2}}\right] \right.$$

$$\text{if } x_{\mathrm{g}} > x_{\mathrm{mrg}} \left\{ \begin{aligned} & b_{\mathrm{x}} = x_{\mathrm{nd}} + 3.0 \\ & \eta = \mathrm{MINA}(x_0,\, b_{\mathrm{x}},\, 5) - \left(b_{\mathrm{x}} - \sqrt{b_{\mathrm{x}}^2 + 5}\right)/2 \\ & a = (x_{\mathrm{g}} - \eta)^2 - G^2 \cdot [\exp(-\eta) + \eta - 1 - \Delta_{\mathrm{nd}} \cdot (\eta + 1 + \chi(\eta))] \\ & b = 1 - G^2/2 \cdot [\exp(-\eta) - \Delta_{\mathrm{nd}} \cdot \chi''(\eta)] \\ & c = 2 \cdot (x_{\mathrm{g}} - \eta) + G^2 \cdot [1 - \exp(-\eta) - \Delta_{\mathrm{nd}} \cdot (1 + \chi'(\eta))] \\ & \tau = x_{\mathrm{nd}} - \eta + \ln\left(a/G^2\right) \\ & y_0 = \sigma_2(a,\, b,\, c,\, \tau,\, \eta) \\ & \Delta_0 = \exp(y_0) \\ & p = 2 \cdot (x_{\mathrm{g}} - y_0) + G^2 \cdot [1 - 1/\Delta_0 + \Delta_{\mathrm{nd}} \cdot (\Delta_0 - 1 - \chi'(y_0))] \\ & q = (x_{\mathrm{g}} - y_0)^2 - G^2 \cdot [y_0 + 1/\Delta_0 - 1 + \Delta_{\mathrm{nd}} \cdot (\Delta_0 - y_0 - 1 - \chi(y_0))] \\ & x_{\mathrm{d}} = y_0 + \frac{2 \cdot q}{p + \sqrt{p^2 - 2 \cdot q \cdot \{2 - G^2 \cdot [1/\Delta_0 + \Delta_{\mathrm{nd}} \cdot (\Delta_0 - \chi''(y_0))]\}}} \end{aligned} \right.$$

$$x_{\mathrm{ds}} = x_{\mathrm{d}} - x_{\mathrm{s}}$$

$$\text{if } x_{\mathrm{ds}} < 10^{-10} \left\{ \begin{aligned} & p = 2 \cdot x_{\mathrm{gs}} + G^2 \cdot [1 - E_{\mathrm{s}} + \Delta_{\mathrm{nd}} \cdot (1/E_{\mathrm{s}} - 1 - \chi'(x_{\mathrm{s}}))] \\ & q = G^2 \cdot (1 - k_{\mathrm{ds}}) \cdot D_{\mathrm{s}} \\ & \xi = 1 - G^2/2 \cdot [E_{\mathrm{s}} + \Delta_{\mathrm{nd}}\,(1/E_{\mathrm{s}} - \chi''(x_{\mathrm{s}}))] \\ & x_{\mathrm{ds}} = \frac{2 \cdot q}{p + \sqrt{p^2 - 4 \cdot \xi \cdot q}} \\ & x_{\mathrm{d}} = x_{\mathrm{s}} + x_{\mathrm{ds}} \end{aligned} \right.$$

$$E_{\mathrm{d}} = \exp(-x_{\mathrm{d}})$$

$$D_{\mathrm{d}} = (1/E_{\mathrm{d}} - x_{\mathrm{d}} - 1 - \chi(x_{\mathrm{d}})) \cdot \Delta_{\mathrm{nd}}$$

$$\Delta\psi = \phi_{\mathrm{T}}^{*} \cdot x_{\mathrm{ds}}$$

$$\psi_{\mathrm{sd}} = \phi_{\mathrm{T}}^{*} \cdot x_{\mathrm{d}}$$

Mid-Point Surface Potential and Related Variables

$$\text{if } x_{\mathrm{g}} > 0 \begin{cases} x_{\mathrm{m}} = (x_{\mathrm{s}} + x_{\mathrm{d}})/2 \\ E_{\mathrm{m}} = \sqrt{E_{\mathrm{s}} \cdot E_{\mathrm{d}}} \\ \bar{D} = (D_{\mathrm{s}} + D_{\mathrm{d}})/2 \\ D_{\mathrm{m}} = \bar{D} + x_{\mathrm{ds}}^2/8 \cdot \left(E_{\mathrm{m}} - 2/G^2\right) \\ P_{\mathrm{m}} = x_{\mathrm{m}} - 1 + E_{\mathrm{m}} \\ x_{\mathrm{gm}} = G \cdot \sqrt{D_{\mathrm{m}} + P_{\mathrm{m}}} \end{cases}$$

$$\text{if } x_{\mathrm{g}} \leq 0 \begin{cases} x_{\mathrm{m}} = x_{\mathrm{s}} \\ x_{\mathrm{gm}} = x_{\mathrm{g}} - x_{\mathrm{s}} \end{cases}$$

Polysilicon Depletion

Calculations are only done for $k_P > 0$ and $x_g > 0$ (otherwise $np = 1$):

$$x_{\mathrm{m}}^{(0)} = x_{\mathrm{m}}, \qquad x_{\mathrm{ds}}^{(0)} = x_{\mathrm{ds}}, \qquad D_{\mathrm{m}}^{(0)} = D_{\mathrm{m}}, \qquad E_{\mathrm{m}}^{(0)} = E_{\mathrm{m}},$$

$$d_0 = 1 - E_{\mathrm{m}}^{(0)} + 2 \cdot x_{\mathrm{gm}} / G^2$$

$$\eta_{\mathrm{p}} = 1 / \sqrt{1 + \boldsymbol{k_{\mathrm{P}}} \cdot x_{\mathrm{gm}}}$$

$$x_{\mathrm{pm}} = \boldsymbol{k_{\mathrm{P}}} \cdot \left[\frac{\eta_{\mathrm{p}} \cdot x_{\mathrm{gm}}}{1 + \eta_{\mathrm{p}}} \right]^2 \cdot \frac{D_{\mathrm{m}}^{(0)}}{D_{\mathrm{m}}^{(0)} + P_{\mathrm{m}}}$$

$$p = 2 \cdot (x_{\mathrm{gm}} - x_{\mathrm{pm}}) + G^2 \cdot \left(1 - E_{\mathrm{m}}^{(0)} + D_{\mathrm{m}}^{(0)} \right)$$

$$q = x_{\mathrm{pm}} \cdot (x_{\mathrm{pm}} - 2 \cdot x_{\mathrm{gm}})$$

$$\xi_{\mathrm{p}} = 1 - G^2 / 2 \cdot \left(E_{\mathrm{m}}^{(0)} + D_{\mathrm{m}}^{(0)} \right)$$

$$u_{\mathrm{p}} = \frac{p \cdot q}{p^2 - \xi_{\mathrm{p}} \cdot q}$$

$$x_{\mathrm{m}} = x_{\mathrm{m}}^{(0)} + u_{\mathrm{p}}$$

$$E_{\mathrm{m}} = E_{\mathrm{m}}^{(0)} \cdot \exp(-u_{\mathrm{p}})$$

$$D_{\mathrm{m}} = D_{\mathrm{m}}^{(0)} \cdot \exp(u_{\mathrm{p}})$$

$$P_{\mathrm{m}} = x_{\mathrm{m}} - 1 + E_{\mathrm{m}}$$

$$x_{\mathrm{gm}} = G \cdot \sqrt{D_{\mathrm{m}} + P_{\mathrm{m}}}$$

$$x_{\mathrm{ds}} = x_{\mathrm{ds}}^{(0)} \cdot \frac{\exp(u_{\mathrm{p}}) \cdot [\bar{D} + d_0]}{1 - E_{\mathrm{m}} + 2 \cdot x_{\mathrm{gm}} \cdot \eta_{\mathrm{p}} / G^2 + \exp(u_{\mathrm{p}}) \cdot \bar{D}}$$

$$\Delta\psi = \phi_{\mathrm{T}}^{*} \cdot x_{\mathrm{ds}}$$

Potential Mid-Point Inversion Charge and Related Variables

Calculations are only done for $x_g > 0$.

$$q_{\mathrm{im}} = \frac{G^2 \cdot \phi_{\mathrm{T}}^{*} \cdot D_{\mathrm{m}}}{x_{\mathrm{gm}} + G \cdot \sqrt{P_{\mathrm{m}}}}$$

$$\alpha_{\mathrm{m}} = \eta_{\mathrm{p}} + \frac{G \cdot (1 - E_{\mathrm{m}})}{2 \cdot \sqrt{P_{\mathrm{m}}}}$$

$$q_{\mathrm{im}}^{*} = q_{\mathrm{im}} + \phi_{\mathrm{T}}^{*} \cdot \alpha_{\mathrm{m}}$$

$$q_{\mathrm{bm}} = \phi_{\mathrm{T}}^{*} \cdot G \cdot \sqrt{P_{\mathrm{m}}}$$

Series resistance:

$$\rho_{\mathrm{g}} = \begin{cases} \dfrac{1}{1 + \mathbf{RSG} \cdot q_{\mathrm{im}}} & \text{for } \mathbf{RSG} \geq 0 \\ 1 - \mathbf{RSG} \cdot q_{\mathrm{im}} & \text{for } \mathbf{RSG} < 0 \end{cases}$$

$$\rho_{\mathrm{s}} = \boldsymbol{\theta}_{\mathbf{R}} \cdot \rho_{\mathrm{b}} \cdot \rho_{\mathrm{g}} \cdot q_{\mathrm{im}}$$

Mobility reduction:

$$E_{\mathrm{eff}} = \boldsymbol{E}_{\mathbf{eff0}} \cdot \left(q_{\mathrm{bm}} + \boldsymbol{\eta}_{\boldsymbol{\mu}} \cdot q_{\mathrm{im}}\right)$$

$$q_{\mathrm{eff1}} = q_{\mathrm{bm}} + \boldsymbol{\eta}_{\boldsymbol{\mu},ac} \cdot q_{\mathrm{im}}$$

$$G_{\mathrm{mob}} = \frac{1 + (\mu_{\mathrm{E}} \cdot E_{\mathrm{eff}})^{\boldsymbol{\theta}_{\boldsymbol{\mu}}} + C_{\mathrm{S}} \cdot \left(\frac{q_{\mathrm{bm}}}{q_{\mathrm{im}} + q_{\mathrm{bm}}}\right)^2 + \rho}{\mu_{\mathrm{x}}}$$

Drain Source Channel Current

Calculations are only done for $x_g > 0$

Channel Length Modulation

$$R_1 = q_{\rm im}/q^*_{\rm im}$$

$$R_2 = \phi^*_{\bf T} \cdot \alpha_{\rm m}/q^*_{\rm im}$$

$$T_1 = \ln\left(\frac{1+\dfrac{V_{\rm DS}-\Delta\psi}{\bf VP}}{1+\dfrac{V_{\rm dse}-\Delta\psi}{\bf VP}}\right)$$

$$T_2 = \ln\left(1+\frac{V_{\rm dsx}}{\bf VP}\right)$$

$$\Delta L/L = {\bf ALP} \cdot T_1$$

$$G_{\Delta L} = \frac{1}{1+\Delta L/L+(\Delta L/L)^2}$$

$$\Delta L_1/L = \left[{\bf ALP} + \frac{\bf ALP1}{q^*_{\rm im}} \cdot R_1\right] \cdot T_1 + {\bf ALP2} \cdot q_{\rm bm} \cdot R_2^2 \cdot T_2$$

$$F_{\Delta L} = \left[1+\Delta L_1/L+(\Delta L_1/L)^2\right] \cdot G_{\Delta L}$$

Velocity Saturation

$$w_{\rm sat} = \frac{100 \cdot q_{\rm im} \cdot \xi_{\rm tb}}{100 + q_{\rm im} \cdot \xi_{\rm tb}}$$

$$\theta^*_{\rm sat} = \begin{cases} \dfrac{\theta_{\rm sat}}{G_{\rm mob,s} \cdot G_{\Delta L}} \cdot (1 + \mathbf{THESATG} \cdot w_{\rm sat}) & \text{for } \mathbf{THESATG} \geq 0 \\ \dfrac{\theta_{\rm sat}}{G_{\rm mob,s} \cdot G_{\Delta L}} \cdot \dfrac{1}{1 - \mathbf{THESATG} \cdot w_{\rm sat}} & \text{for } \mathbf{THESATG} < 0 \end{cases}$$

$$z_{\rm sat} = \begin{cases} (\theta^*_{\rm sat} \cdot \Delta\psi)^2 & \text{for NMOS} \\ \dfrac{(\theta^*_{\rm sat} \cdot \Delta\psi)^2}{1 + \theta^*_{\rm sat} \cdot \Delta\psi} & \text{for PMOS} \end{cases}$$

$$G_{\rm vsat} = \frac{G_{\rm mob} \cdot G_{\Delta L}}{2} \cdot \left(1 + \sqrt{1 + 2 \cdot z_{\rm sat}}\right)$$

Auxiliary Variables for Calculation of Intrinsic Charges and Gate Current. are only calculated for $x_g > 0$.

$$V_{\rm oxm} = \phi^*_{\rm T} \cdot x_{\rm gm}$$

$$\alpha'_{\rm m} = \alpha_{\rm m} \cdot \left[1 + \frac{z_{\rm sat}}{2} \cdot \left(\frac{G_{\rm mob} \cdot G_{\Delta L}}{G_{\rm vsat}}\right)^2\right]$$

$$H = \frac{G_{\rm mob} \cdot G_{\Delta L}}{G_{\rm vsat}} \cdot \frac{q^*_{\rm im}}{\alpha'_{\rm m}}$$

In the remainder of this section, some variables (e.g. x_g) are labeled 'dc' or 'ac' (e.g., $x_{g,dc}$ or $x_{g,ac}$). Variables labeled `dc' result from the first evaluation some calculations. For variables labeled 'ac', there are two possibilities. If **SWNUD** = 1 or **SWDELVTAC** = 1, their values result from the second evaluation od the same equations. In any other case, their value is equal to their 'dc'-counterpart.

This applies to the following variables:

$x_{\rm g}$, $q_{\rm eff1}$, $V_{\rm oxm}$, $q_{\rm im}$, $q^*_{\rm im}$, $\alpha_{\rm m}$, $\Delta\psi$, $G_{\Delta L}$, $F_{\Delta L}$, H, $\eta_{\rm p}$, $G_{\rm vsat}$, $V_{\rm dse}$, $G_{\rm mob}$, $x_{\rm m}$, G, $x_{\rm gm}$, $\theta^*_{\rm sat}$.

Drain source channel current

$$I_{\rm DS} = \begin{cases} 0 & \text{for } x_{\rm g,dc} \le 0 \\ \beta \cdot F_{\Delta L,\rm dc} \cdot \dfrac{q^*_{\rm im,dc}}{G_{\rm vsat,dc}} \cdot \Delta\psi_{\rm dc} & \text{for } x_{\rm g,dc} > 0 \end{cases}$$

Impact Ionization or Weak-Avalanche

The equations in this section are only calculated when **SWIMPACT** = 1 and x_g > 0.

$$a^*_2 = \mathbf{a_2} \cdot \left[1 + \mathbf{A4} \cdot \left(\sqrt{V^*_{\rm SB,dc} + \phi_{\mathbf{B}}} - \sqrt{\phi_{\mathbf{B}}}\right)\right]$$

$$\Delta V_{\rm sat} = V_{\rm DS} - \mathbf{A3} \cdot \Delta\psi_{\rm dc}$$

$$M_{\rm avl} = \begin{cases} 0 & \text{for } \Delta V_{\rm sat} \le 0 \\ \mathbf{A1} \cdot \Delta V_{\rm sat} \cdot \exp\left(-\dfrac{a^*_2}{\Delta V_{\rm sat}}\right) & \text{for } \Delta V_{\rm sat} > 0 \end{cases}$$

$$I_{\rm avl} = M_{\rm avl} \cdot I_{\rm DS}$$

Surface Potential in Gate Overlap Regions

$$x_{\mathrm{sov}}\left(x_{\mathrm{g}}\right)=\begin{cases}\text{if } x_{\mathrm{g}}<-x_{\mathbf{mrgov}} & \begin{cases}y_{\mathrm{g}}=-x_{\mathrm{g}}\\ z=x_1\cdot y_{\mathrm{g}}/\xi_{\mathbf{ov}}\\ \eta=\left[z+10-\sqrt{(z-6)^2+64}\right]/2\\ a=\left(y_{\mathrm{g}}-\eta\right)^2+G_{\mathbf{ov}}^2\cdot(\eta+1)\\ c=2\cdot\left(y_{\mathrm{g}}-\eta\right)-G_{\mathbf{ov}}^2\\ \tau=-\eta+\ln\left(a/G_{\mathbf{ov}}^2\right)\\ y_0=\sigma_1(a,\,c,\,\tau,\,\eta)\\ \Delta_0=\exp\left(y_0\right)\\ p=2\cdot\left(y_{\mathrm{g}}-y_0\right)+G_{\mathbf{ov}}^2\cdot\left(\Delta_0-1\right)\\ q=\left(y_{\mathrm{g}}-y_0\right)^2+G_{\mathbf{ov}}^2\cdot\left(y_0-\Delta_0+1\right)\\ x_{\mathrm{sov}}=-y_0-\dfrac{2\cdot q}{p+\sqrt{p^2-2\cdot q\cdot\left(2-G_{\mathbf{ov}}^2\cdot\Delta_0\right)}}\end{cases}\\ \text{if } \left|x_{\mathrm{g}}\right|<x_{\mathbf{mrgov}} & \begin{cases}x_{\mathrm{sov}}=x_{\mathrm{g}}/\xi_{\mathbf{ov}}\end{cases}\\ \text{if } x_{\mathrm{g}}>x_{\mathbf{mrgov}} & \begin{cases}\bar{x}=x_{\mathrm{g}}/\xi_{\mathbf{ov}}\cdot\left[1+x_{\mathrm{g}}\cdot\left(\xi_{\mathbf{ov}}\cdot x_1-x_{\mathrm{g1}}\right)/x_{\mathrm{g1}}^2\right]\\ \omega=1-\exp\left(-\bar{x}\right)\\ x_0=x_{\mathrm{g}}+G_{\mathbf{ov}}^2/2-G_{\mathbf{ov}}\cdot\sqrt{x_{\mathrm{g}}+G_{\mathbf{ov}}^2/4-\omega}\\ \Delta_0=\exp\left(-x_0\right)\\ p=2\cdot\left(x_{\mathrm{g}}-x_0\right)+G_{\mathbf{ov}}^2\cdot\left(1-\Delta_0\right)\\ q=\left(x_{\mathrm{g}}-x_0\right)^2-G_{\mathbf{ov}}^2\cdot\left(x_0+\Delta_0-1\right)\\ x_{\mathrm{sov}}=x_0+\dfrac{2\cdot q}{p+\sqrt{p^2-2\cdot q\cdot\left(2-G_{\mathbf{ov}}^2\cdot\Delta_0\right)}}\end{cases}\end{cases}$$

$$x_{\text{dov}}(x_{\text{g}}) = \begin{cases} \text{if } x_{\text{g}} < -\boldsymbol{x}_{\mathbf{mrgdov}} & \begin{cases} y_{\text{g}} = -x_{\text{g}} \\ z = \boldsymbol{x_1} \cdot y_{\text{g}} / \boldsymbol{\xi}_{\mathbf{dov}} \\ \eta = \left[z + 10 - \sqrt{(z-6)^2 + 64} \right] / 2 \\ a = (y_{\text{g}} - \eta)^2 + \boldsymbol{G}^2_{\mathbf{dov}} \cdot (\eta + 1) \\ c = 2 \cdot (y_{\text{g}} - \eta) - \boldsymbol{G}^2_{\mathbf{dov}} \\ \tau = -\eta + \ln\left(a / \boldsymbol{G}^2_{\mathbf{dov}}\right) \\ y_0 = \sigma_1(a, c, \tau, \eta) \\ \Delta_0 = \exp(y_0) \\ p = 2 \cdot (y_{\text{g}} - y_0) + \boldsymbol{G}^2_{\mathbf{dov}} \cdot (\Delta_0 - 1) \\ q = (y_{\text{g}} - y_0)^2 + \boldsymbol{G}^2_{\mathbf{dov}} \cdot (y_0 - \Delta_0 + 1) \\ x_{\text{dov}} = -y_0 - \dfrac{2 \cdot q}{p + \sqrt{p^2 - 2 \cdot q \cdot (2 - \boldsymbol{G}^2_{\mathbf{dov}} \cdot \Delta_0)}} \end{cases} \\ \text{if } |x_{\text{g}}| < \boldsymbol{x}_{\mathbf{mrgdov}} & \begin{cases} x_{\text{dov}} = x_{\text{g}} / \boldsymbol{\xi}_{\mathbf{dov}} \end{cases} \\ \text{if } x_{\text{g}} > \boldsymbol{x}_{\mathbf{mrgdov}} & \begin{cases} \bar{x} = x_{\text{g}} / \boldsymbol{\xi}_{\mathbf{dov}} \cdot \left[1 + x_{\text{g}} \cdot (\boldsymbol{\xi}_{\mathbf{dov}} \cdot \boldsymbol{x_1} - \boldsymbol{x}_{\mathbf{dgl}}) / \boldsymbol{x}^2_{\mathbf{dgl}} \right] \\ \omega = 1 - \exp(-\bar{x}) \\ x_0 = x_{\text{g}} + \boldsymbol{G}^2_{\mathbf{dov}}/2 - \boldsymbol{G}_{\mathbf{dov}} \cdot \sqrt{x_{\text{g}} + \boldsymbol{G}^2_{\mathbf{dov}}/4 - \omega} \\ \Delta_0 = \exp(-x_0) \\ p = 2 \cdot (x_{\text{g}} - x_0) + \boldsymbol{G}^2_{\mathbf{dov}} \cdot (1 - \Delta_0) \\ q = (x_{\text{g}} - x_0)^2 - \boldsymbol{G}^2_{\mathbf{dov}} \cdot (x_0 + \Delta_0 - 1) \\ x_{\text{dov}} = x_0 + \dfrac{2 \cdot q}{p + \sqrt{p^2 - 2 \cdot q \cdot (2 - \boldsymbol{G}^2_{\mathbf{dov}} \cdot \Delta_0)}} \end{cases} \end{cases}$$

$$\psi_{\text{sov}} = -\boldsymbol{\phi}_{\mathbf{T}} \cdot x_{\text{sov}} \left(-\frac{V_{\text{GS}}}{\boldsymbol{\phi}_{\mathbf{T}}} \right)$$

$$\psi_{\text{dov}} = -\boldsymbol{\phi}_{\mathbf{T}} \cdot x_{\text{dov}} \left(-\frac{V_{\text{GS}} - V_{\text{DS}}}{\boldsymbol{\phi}_{\mathbf{T}}} \right)$$

$$V_{\text{ov}_0} = V_{\text{GS}} - \psi_{\text{sov}}$$

$$V_{\text{ov}_{\text{L}}} = V_{\text{GS}} - V_{\text{DS}} - \psi_{\text{dov}}$$

Gate Current

The equations in this Section are only calculated when **SWIGATE** = 1.

Source/Drain gate overlap current

$$I_{\mathrm{GSov}}(V_{\mathrm{GX}}, \psi_{\mathrm{ov}}, V_{\mathrm{ov}}) = \begin{cases} V^*_{\mathrm{ov}} = \sqrt{V^2_{\mathrm{ov}} + 10^{-6}} \\ \psi_{\mathrm{tov}} = \mathrm{MINA}\left(0,\, V_{\mathrm{ov}} + \boldsymbol{D_{\mathrm{ov}}},\, 0.01\right) \\ z_{\mathrm{g}} = \begin{cases} \mathrm{MINA}\left(\dfrac{V^*_{\mathrm{ov}}}{\mathbf{CHIB}},\, GC_{\mathbf{Q}},\, 10^{-6}\right) & \textbf{for GC3} < 0 \\ \dfrac{V^*_{\mathrm{ov}}}{\mathbf{CHIB}} & \textbf{for GC3} \geq 0 \end{cases} \\ \Delta_{\mathrm{Siov}} = \exp\left(\dfrac{3.0 \cdot \phi_{\mathbf{T}} + \psi_{\mathrm{ov}} + \psi_{\mathrm{tov}}}{\phi_{\mathbf{T}}}\right) \\ F_{\mathrm{Sov}} = \ln\left[\dfrac{1 + \Delta_{\mathrm{Siov}}}{1 + \Delta_{\mathrm{Siov}} \cdot \exp\left(-V_{\mathrm{GX}}/\phi_{\mathbf{T}}\right)}\right] \\ I_{\mathrm{Gov}} = \boldsymbol{I_{\mathrm{GOV}}} \cdot F_{\mathrm{Sov}} \cdot \\ \qquad \exp\left(\boldsymbol{B_{\mathrm{ov}}} \cdot \left[-\dfrac{3}{2} + z_{\mathrm{g}} \cdot (\mathbf{GC2} + \mathbf{GC3} \cdot z_{\mathrm{g}})\right]\right) \end{cases}$$

$$I_{\mathrm{GDov}}(V_{\mathrm{GX}}, \psi_{\mathrm{ov}}, V_{\mathrm{ov}}) = \begin{cases} V^*_{\mathrm{ov}} = \sqrt{V^2_{\mathrm{ov}} + 10^{-6}} \\ \psi_{\mathrm{tov}} = \mathrm{MINA}\left(0,\, V_{\mathrm{ov}} + \boldsymbol{D_{\mathrm{ov}}},\, 0.01\right) \\ z_{\mathrm{g}} = \begin{cases} \mathrm{MINA}\left(\dfrac{V^*_{\mathrm{ov}}}{\mathbf{CHIB}},\, GC_{\mathbf{Q}},\, 10^{-6}\right) & \textbf{for GC3} < 0 \\ \dfrac{V^*_{\mathrm{ov}}}{\mathbf{CHIB}} & \textbf{for GC3} \geq 0 \end{cases} \\ \Delta_{\mathrm{Siov}} = \exp\left(\dfrac{3.0 \cdot \phi_{\mathbf{T}} + \psi_{\mathrm{ov}} + \psi_{\mathrm{tov}}}{\phi_{\mathbf{T}}}\right) \\ F_{\mathrm{Sov}} = \ln\left[\dfrac{1 + \Delta_{\mathrm{Siov}}}{1 + \Delta_{\mathrm{Siov}} \cdot \exp\left(-V_{\mathrm{GX}}/\phi_{\mathbf{T}}\right)}\right] \\ I_{\mathrm{Gov}} = \boldsymbol{I_{\mathrm{GOVD}}} \cdot F_{\mathrm{Sov}} \cdot \\ \qquad \exp\left(\boldsymbol{B_{\mathrm{dov}}} \cdot \left[-\dfrac{3}{2} + z_{\mathrm{g}} \cdot (\mathbf{GC2} + \mathbf{GC3} \cdot z_{\mathrm{g}})\right]\right) \end{cases}$$

$$I_{\text{GSov}} = I_{\text{GSov}}\left(V_{\text{GS}},\, \psi_{\text{sov}},\, V_{\text{ov}_0}\right)$$

$$I_{\text{GDov}} = I_{\text{GDov}}\left(V_{\text{GS}} - V_{\text{DS}}\,,\, \psi_{\text{dov}}\,,\, V_{\text{ov}_\text{L}}\right)$$

Gate-channel current:

$$V_{\text{m}} = V^{*}_{\text{SB,dc}} + \phi^{*}_{\text{T}} \cdot \left[\frac{x_{\text{ds,dc}}}{2} - \ln\left(\frac{1 + \exp(x_{\text{ds,dc}} - V_{\text{dse,dc}}/\phi^{*}_{\text{T}})}{2}\right)\right]$$

$$\psi_{\text{t}} = \text{MINA}\left(0,\, V_{\text{oxm,dc}} + \boldsymbol{D_{\text{ch}}},\, 0.01\right)$$

$$V^{*}_{\text{oxm}} = \sqrt{V^{2}_{\text{oxm,dc}} + 10^{-6}}$$

$$z_{\text{g}} = \begin{cases} \text{MINA}\left(\dfrac{V^{*}_{\text{oxm}}}{\mathbf{CHIB}},\, \boldsymbol{GC_{\text{Q}}},\, 10^{-6}\right) & \textbf{for GC3} < 0 \\ \dfrac{V^{*}_{\text{oxm}}}{\mathbf{CHIB}} & \textbf{for GC3} \geq 0 \end{cases}$$

$$\Delta_{\text{Si}} = \exp\left(x_{\text{m,dc}} - \frac{\boldsymbol{\alpha_{\text{b}}} + V_{\text{m}} - \psi_{\text{t}}}{\phi^{*}_{\text{T}}}\right)$$

$$F_{\text{S}} = \ln\left[\frac{1 + \Delta_{\text{Si}}}{1 + \Delta_{\text{Si}} \cdot \exp\left(-\dfrac{V_{\text{GS}} + V^{*}_{\text{SB,dc}} - V_{\text{m}}}{\phi^{*}_{\text{T}}}\right)}\right]$$

$$I_{\text{GCO}} = \boldsymbol{I_{\text{GINV}}} \cdot F_{\text{S}} \cdot \exp\left(\boldsymbol{B} \cdot \left[-3/2 + z_{\text{g}} \cdot (\mathbf{GC2} + \mathbf{GC3} \cdot z_{\text{g}})\right]\right)$$

$$\textbf{if } x_{\text{g,dc}} > 0 \begin{cases} u_0 = \mathbf{CHIB}/\left[\boldsymbol{B} \cdot (\mathbf{GC2} + 2 \cdot \mathbf{GC3} \cdot z_{\text{g}})\right] \\ x = \Delta\psi_{\text{dc}}/\left(2 \cdot u_0\right) \\ b = u_0/H_{\text{dc}} \\ B_{\text{g}} = b \cdot (1 - b)/2 \\ A_{\text{g}} = 1/2 - 3 \cdot B_{\text{g}} \\ p_{\text{gc}} = (1 - b) \cdot \dfrac{\sinh(x)}{x} + b \cdot \cosh(x) \\ p_{\text{gd}} = \dfrac{p_{\text{gc}}}{2} - B_{\text{g}} \cdot \sinh(x) - A_{\text{g}} \cdot \dfrac{\sinh(x)}{x} \cdot \left[\coth(x) - \dfrac{1}{x}\right] \end{cases}$$

$$\text{if } x_{\mathrm{g,dc}} \leq 0 \begin{cases} p_{\mathrm{gc}} = 1 \\ p_{\mathrm{gd}} = 1/2 \end{cases}$$

$$S_{\mathrm{g}} = \frac{1}{2} \cdot \left(1 + \frac{x_{\mathrm{g,dc}}}{\sqrt{x_{\mathrm{g,dc}}^2 + 10^{-6}}}\right)$$

$$I_{\mathrm{GC}} = I_{\mathrm{GCO}} \cdot p_{\mathrm{gc}} \cdot S_{\mathrm{g}}$$

$$I_{\mathrm{GCD}} = I_{\mathrm{GCO}} \cdot p_{\mathrm{gd}} \cdot S_{\mathrm{g}}$$

$$I_{\mathrm{GCS}} = I_{\mathrm{GC}} - I_{\mathrm{GCD}}$$

$$I_{\mathrm{GB}} = I_{\mathrm{GCO}} \cdot p_{\mathrm{gc}} \cdot (1 - S_{\mathrm{g}})$$

Gate-Induced Drain/Source Leakage Current

The equations in this section are only calculated when **SWGIDL** = 1.

$$I_{\text{gisl}}(V_{\text{ov}}, V) = \begin{cases} V_{\text{tov}} = \sqrt{V_{\text{ov}}^2 + \mathbf{CGIDL}^2 \cdot V^2 + 10^{-6}} \\ t = V \cdot V_{\text{tov}} \cdot V_{\text{ov}} \\ I_{\text{gisl}} = \begin{cases} -A_{\text{GIDL}} \cdot t \cdot \exp\left(-\dfrac{B_{\text{GIDL}}}{V_{\text{tov}}}\right) & \text{for } V_{\text{ov}} < 0 \\ 0 & \text{for } V_{\text{ov}} \geq 0 \end{cases} \end{cases}$$

$$I_{\text{gidl}}(V_{\text{ov}}, V) = \begin{cases} V_{\text{tov}} = \sqrt{V_{\text{ov}}^2 + \mathbf{CGIDLD}^2 \cdot V^2 + 10^{-6}} \\ t = V \cdot V_{\text{tov}} \cdot V_{\text{ov}} \\ I_{\text{gidl}} = \begin{cases} -A_{\text{GIDLD}} \cdot t \cdot \exp\left(-\dfrac{B_{\text{GIDLD}}}{V_{\text{tov}}}\right) & \text{for } V_{\text{ov}} < 0 \\ 0 & \text{for } V_{\text{ov}} \geq 0 \end{cases} \end{cases}$$

$$I_{\text{gisl}} = I_{\text{gisl}}(V_{\text{ov}_0}, V_{\text{SB}})$$

$$I_{\text{gidl}} = I_{\text{gidl}}(V_{\text{ov}_\text{L}}, V_{\text{DS}} + V_{\text{SB}})$$

Total Terminal Currents

$$I_{\text{D}} = I_{\text{DS}} + I_{\text{avl}} - I_{\text{GDov}} - I_{\text{GCD}} + I_{\text{gidl}}$$

$$I_{\text{S}} = -I_{\text{DS}} - I_{\text{GSov}} - I_{\text{GCS}} + I_{\text{gisl}}$$

$$I_{\text{G}} = I_{\text{GC}} + I_{\text{GB}} + I_{\text{GDov}} + I_{\text{GSov}}$$

$$I_{\text{B}} = -I_{\text{avl}} - I_{\text{GB}} - I_{\text{gidl}} - I_{\text{gisl}}$$

Charge Model

In this section, the charge model equations of the PSP-model are given. Use is made of the applied termi-nal bias values VGS, VDS and VSB, the local parameters listed in section “Intrinsic Parameters” and the internal parameters introduced in the Model Equations section. The parameters are denoted by capital characters in bold font, whereas internal (bias-independent) parameters are denoted by symbols in bold font.

Quantum-Mechanical Corrections

$$q_{\mathrm{eff,ac}} = \begin{cases} V_{\mathrm{oxm,ac}} & \text{for } x_{\mathrm{g,ac}} \leq 0 \\ q_{\mathrm{eff1},ac} & \text{for } x_{\mathrm{g,ac}} > 0 \end{cases}$$

$$C_{\mathrm{OX}}^{\mathrm{qm}} = \begin{cases} \mathbf{COX} & \text{for } \boldsymbol{q}_{\mathbf{q}} = 0 \\ \dfrac{\mathbf{COX}}{1 + \boldsymbol{q}_{\mathbf{q}} / ({q_{\mathrm{eff,ac}}}^2 + {\boldsymbol{q}_{\mathbf{lim}}}^2)^{1/6}} & \text{for } \boldsymbol{q}_{\mathbf{q}} > 0 \end{cases}$$

Intrinsic Charge Model

$$\text{if } x_g > 0 \begin{cases} F_j = \Delta\psi_{ac}/\,(2 \cdot H_{ac}) \\ q_{\Delta L} = (1 - G_{\Delta L,ac}) \cdot (q_{im,ac} - \alpha_{m,ac} \cdot \Delta\psi_{ac}/2) \\ q^*_{\Delta L} = q_{\Delta L,ac} \cdot (1 + G_{\Delta L,ac}) \\ Q_G^{(i)} = C_{OX}^{qm} \cdot \left[V_{oxm,ac} + \dfrac{\eta_{p,ac} \cdot \Delta\psi_{ac}}{2} \cdot \left(\dfrac{G_{\Delta L,ac}}{3} \cdot F_j + G_{\Delta L,ac} - 1\right)\right] \\ Q_I^{(i)} = -C_{OX}^{qm} \cdot \left[G_{\Delta L,ac} \cdot \left(q_{im,ac} + \dfrac{\alpha_{m,ac} \cdot \Delta\psi_{ac}}{6} \cdot F_j\right) + q_{\Delta L,ac}\right] \\ Q_D^{(i)} = -\dfrac{C_{OX}^{qm}}{2} \cdot \left[G^2_{\Delta L,ac} \cdot \left(q_{im,ac} + \dfrac{\alpha_{m,ac} \cdot \Delta\psi_{ac}}{6} \cdot \left[\dfrac{F_j^2}{5} + F_j - 1\right]\right) + q^*_{\Delta L}\right] \end{cases}$$

$$\text{if } x_g \le 0 \begin{cases} Q_G^{(i)} = C_{OX}^{qm} \cdot V_{oxm,ac} \\ Q_I^{(i)} = 0 \\ Q_D^{(i)} = 0 \end{cases}$$

$$Q_S^{(i)} = Q_I^{(i)} - Q_D^{(i)}$$

$$Q_B^{(i)} = -Q_I^{(i)} - Q_G^{(i)}$$

Extrinsic Charge Model

The charges of the source and drain overlap regions:

$$Q_{\rm sov} = \mathbf{CGOV} \cdot (V_{\rm GS} - \psi_{\rm sov})$$

$$Q_{\rm dov} = \mathbf{CGOVD} \cdot (V_{\rm GS} - V_{\rm DS} - \psi_{\rm dov})$$

The charge of the bulk overlap region

$$Q_{\rm bov} = \mathbf{CGBOV} \cdot (V_{\rm GS} + V_{\rm SB})$$

Outer fringe charge:

$$Q_{\rm ofs} = \mathbf{CFR} \cdot V_{\rm GS}$$

$$Q_{\rm ofd} = \mathbf{CFRD} \cdot (V_{\rm GS} - V_{\rm DS})$$

Total Terminal Charges

$$Q_{\rm G} = Q_{\rm G}^{(i)} + Q_{\rm sov} + Q_{\rm dov} + Q_{\rm ofs} + Q_{\rm ofd} + Q_{\rm bov}$$

$$Q_{\rm S} = Q_{\rm S}^{(i)} - Q_{\rm sov} - Q_{\rm ofs}$$

$$Q_{\rm D} = Q_{\rm D}^{(i)} - Q_{\rm dov} - Q_{\rm ofd}$$

$$Q_{\rm B} = Q_{\rm B}^{(i)} - Q_{\rm bov}$$

Noise Model

Equations are only calculated for $x_g > 0$. In these equations f_{op} represents the operation frequency of the transistor and $j = \sqrt{-1}$

$$N^* = \frac{C_{\mathrm{ox}}}{q} \cdot \alpha_{\mathrm{m,dc}} \cdot \phi_{\mathbf{T}}$$

$$N^*_{\mathrm{m}} = \frac{C_{\mathrm{ox}}}{q} \cdot q^*_{\mathrm{im,dc}}$$

$$\Delta N = \frac{C_{\mathrm{ox}}}{q} \cdot \alpha_{\mathrm{m,dc}} \cdot \Delta\psi_{\mathrm{dc}}$$

$$S_{\mathrm{fl}} = \frac{q \cdot \phi_{\mathbf{T}}^2 \cdot \beta \cdot I_{\mathrm{DS}}}{(f_{\mathrm{op}})^{\mathbf{EF}} \cdot C_{\mathrm{ox}} \cdot G_{\mathrm{vsat,dc}} \cdot N^*} \cdot \left[(\mathbf{NFA} - \mathbf{NFB} \cdot N^* + \mathbf{NFC} \cdot N^{*\,2}) \cdot \ln\left(\frac{N^*_{\mathrm{m}} + \Delta N/2}{N^*_{\mathrm{m}} - \Delta N/2}\right) + \left(\mathbf{NFB} + \mathbf{NFC} \cdot [N^*_{\mathrm{m}} - 2 \cdot N^*]\right) \cdot \Delta N \right]$$

$$H_0 = \frac{q^*_{\text{im,dc}}}{\alpha_{\text{m,dc}}}$$

$$t_1 = \frac{q_{\text{im,dc}}}{q^*_{\text{im,dc}}}$$

$$t_2 = \left(\frac{\Delta\psi_{\text{dc}}}{12 \cdot H_0}\right)^2$$

$$R = \frac{H_0}{H} - 1$$

$$l_c = 1 - 12 \cdot t_2 \cdot R$$

$$g_{\text{ideal}} = \frac{\beta \cdot q^*_{\text{im,dc}}}{G_{\text{vsat,dc}}} \cdot F_{\Delta L,\text{dc}}$$

$$C_{\text{Geff}} = \left(\frac{G_{\text{vsat,ac}}}{G_{\text{mob,ac}} \cdot G_{\Delta L,\text{ac}}}\right)^2 \cdot C_{\text{OX}}^{\text{qm}} \cdot \eta_{\text{p,ac}}$$

$$m_{\text{id}} = \frac{g_{\text{ideal}}}{l_c^2} \cdot [t_1 + 12 \cdot t_2 - 24 \cdot (1 + t_1) \cdot t_2 \cdot R]$$

$$S_{th} = N_T \cdot m_{id}$$

$$m_{\text{ig}} = \frac{1}{l_c^2 \cdot g_{\text{ideal}}} \cdot \left[\frac{t_1}{12} - t_2 \cdot \left(t_1 + \frac{1}{5} - 12 \cdot t_2\right) - \frac{8}{5} \cdot t_2 \cdot (t_1 + 1 - 12 \cdot t_2) \cdot R\right]$$

$$S_{\text{ig}} = \mathbf{N_T} \cdot \frac{(2 \cdot \pi \cdot f_{\text{op}} \cdot C_{\text{Geff}})^2 \cdot m_{\text{ig}}}{1 + (2 \cdot \pi \cdot f_{\text{op}} \cdot C_{\text{Geff}} \cdot m_{\text{ig}})^2}$$

$$m_{\text{igid}} = \frac{\sqrt{t_2}}{l_c^2} \cdot \left[1 - 12 \cdot t_2 - \left(t_1 + \frac{96}{5} \cdot t_2 - 12 \cdot t_1 \cdot t_2\right) \cdot R\right]$$

$$S_{\text{ig}th} = \mathbf{N_T} \cdot \frac{2 \cdot \pi \cdot j \cdot f_{\text{op}} \cdot C_{\text{Geff}} \cdot m_{\text{igid}}}{1 + 2 \cdot \pi \cdot j \cdot f_{\text{op}} \cdot C_{\text{Geff}} \cdot m_{\text{ig}}}$$

Gate current shot noise

$$S_{hotgs} = 2 \cdot q \cdot (I_{\mathrm{GCS}} + I_{\mathrm{GSov}})$$

$$S_{hotgd} = 2 \cdot q \cdot (I_{GCD} + I_{GDov})$$

Avalanche current shot noise

$$S_{jnoise} = 2 \cdot q \cdot I_{js}$$

$$D_{jnoise} = 2 \cdot q \cdot ((1 + M_{avl}) \cdot I_{avl} + I_{jd})$$

Thermal noise for parasitic resistances

$$S_{\mathrm{R_G}} = 4 \cdot k_{\mathrm{B}} \cdot T_{\mathrm{KD}} / R_{\mathrm{gate}}$$

$$S_{\mathrm{R_{BULK}}} = 4 \cdot k_{\mathrm{B}} \cdot T_{\mathrm{KD}} / R_{\mathrm{bulk}}$$

$$S_{\mathrm{R_{WELL}}} = 4 \cdot k_{\mathrm{B}} \cdot T_{\mathrm{KD}} / R_{\mathrm{well}}$$

$$S_{\mathrm{R_{JUNS}}} = 4 \cdot k_{\mathrm{B}} \cdot T_{\mathrm{KD}} / R_{\mathrm{juns}}$$

$$S_{\mathrm{R_{JUND}}} = 4 \cdot k_{\mathrm{B}} \cdot T_{\mathrm{KD}} / R_{\mathrm{jund}}$$

Non-quasi-static RF model

For high-frequency modeling and fast transient simulations, a special version of the PSP model is available, which enables the simulation of non-quasi-static (NQS) effects, and includes several parasitic resistances.

NQS-effects

In the PSP-NQS model, NQS-effects are introduced by applying the one-dimensional current continuity equa-tion ($\partial_I/\partial_y \times \alpha - \partial_p/\partial_t$) to the channel. A full numerical solution of this equation is too inefficient for compact modeling, therefore an approximate technique is used. The channel is partitioned into N + 1 sections of equal length by assigning N equidistant collocation points. The charge density (per unit channel area) along the channel is then approximated by a cubic spline through these collocation points, assuring that both the charge and its first and second spatial derivatives are continuous a long the channel. Within this approximation, the current continuity equation reduces to a system of N coupled first order ordinary differential equations, from which the channel charge at each collocation point can be found:

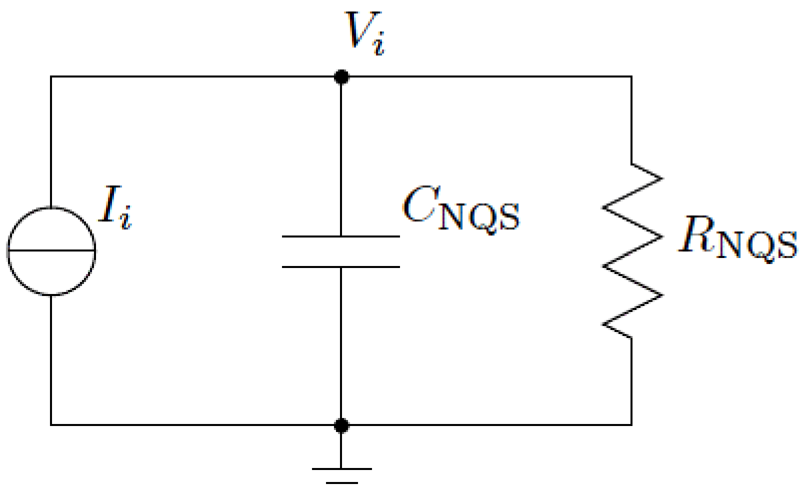
$$\begin{cases} \dfrac{\mathrm{d}Q_1}{\mathrm{d}t} & = & f_1(Q_1,\ldots,Q_N) \\ \vdots & & \vdots \\ \dfrac{\mathrm{d}Q_N}{\mathrm{d}t} & = & f_N(Q_1,\ldots,Q_N) \end{cases}$$

Here, Q_i is the charge density at the i-th collocation point and fi are functions, which contain the complete PSP-charge model. These equations are implemented by the definition of appropriate subcircuits (see left part of figure below) and solved by the circuit simulator. Finally, the four terminal charges are calculated from the channel charges, using the Ward-Dutton partitioning scheme for the source and drain charges.

NQS Model Equations

In this section, several symbols and notations are used which were defined in Section 4. Moreover, y denotes the (normalized) position along the channel (y = 0 is source side, y = 1 is drain side), while x denotes the surface potential (normalized to φ*T) at a certain position.

Figure 24-6 The subcircuit used to solve one of the differential equations



The current is set to $I_i = C_{NQS} \cdot f(V_1, \ldots, V_N)$, where the voltage V_i represents the charge density Q_i at the i-th collocation point and is solved by the circuit simulator. N of these circuits are defined and they are coupled through the dependence of Ii on the voltages of the other circuits. The resistance R_{NQS} has a very large value and is present only for convergence purposes. Right: The full network of parasitic elements in the PSP-NQS model. The large full dots indicate the five additional internal nodes.

Internal constants

Equations in this section are independent of bias conditions and time. Consequently, they have to be computed only once.

Note: In PSP only **SWNQS** = 0, 1, 2, 3, 5, 9 are allowed.

$$n = \mathbf{SWNQS} + 1$$

$$h = 1/n$$

The matrix A is a square (n + 1) × (n + 1)-matrix with elements $A_{i,j}$ ($0 \le i, j \le n$), which are used in equations. They are computed using the following algorithm:

Initial values

$$A_{i,j} = 0 \qquad \text{for } 0 \le i, j \le n$$

$$v_i = 0 \qquad \text{for } 0 \le i \le n$$

First loop

$$\left.\begin{aligned}
&p = 2 + v_{i-1}/2 \\
&v_i = -1/(2 \cdot p) \\
&A_{i,i-1} = 1/h \\
&A_{i,i} = -2/h \\
&A_{i,i+1} = 1/h \\
&A_{i,j} = \frac{1}{p} \cdot (3 \cdot A_{i,j}/h - A_{i-1,j}/2) \quad \Big\} \text{for } j = 0 \ldots n
\end{aligned}\right\} \text{for } i = 1 \ldots (n-1)$$

Second loop (back substitution)

$$\left.A_{i,j} = v_i \cdot A_{i+1,j} + A_{i,j} \qquad \text{for } j = 0 \ldots n \right\} \text{for } i = (n-1) \ldots 0$$

Position independent quantities

The following quantities depend on the bias conditions, but are constant along the channel:

$$\text{if } x_{\mathrm{g,ac}} > 0 \begin{cases} y_{\mathrm{m}} = \dfrac{1}{2} \cdot \left(1 + \dfrac{\Delta\psi_{\mathrm{ac}}}{4 \cdot H_{\mathrm{ac}}}\right) \\[2ex] p_{\mathrm{d}} = \dfrac{x_{\mathrm{gm,ac}}}{x_{\mathrm{g,ac}} - x_{\mathrm{m,ac}}} \\[2ex] G_{\mathrm{p}} = G_{\mathrm{ac}}/p_{\mathrm{d}} \end{cases}$$

$$\text{if } x_{\mathrm{g,ac}} \le 0 \begin{cases} y_{\mathrm{m}} = 1/2 \\ p_{\mathrm{d}} = 1 \\ G_{\mathrm{p}} = G_{\mathrm{ac}} \end{cases}$$

$$a_{\mathrm{p}} = 1 + G_{\mathrm{p}}/\sqrt{2}$$

$$p_{\mathrm{mrg}} = 10^{-5} \cdot a_{\mathrm{p}}$$

Position dependent surface potential and charge

Interpolated (quasi-static) surface potential along the channel:

$$\Psi(y) = x_{\mathrm{m,ac}} + \frac{H_{\mathrm{ac}}}{\phi_{\mathrm{T}}^{*}} \cdot \left(1 - \sqrt{1 - \frac{2 \cdot \Delta\psi_{\mathrm{ac}}}{H_{\mathrm{ac}}} \cdot (y - y_{\mathrm{m}})}\right)$$

Normalized bulk-charge and its first two derivatives as functions of surface potential:

$$q_{\mathrm{b}}(x) = -\mathrm{sgn}(x) \cdot G_{\mathrm{p}} \cdot \sqrt{\exp(-x) + x - 1}$$

$$q'_{\mathrm{b}}(x) = \frac{G_{\mathrm{p}}^2 \cdot [1 - \exp(-x)]}{2 \cdot q_{\mathrm{b}}(x)}$$

$$q''_{\mathrm{b}}(x) = -q'_{\mathrm{b}}(x) - \frac{q'_{\mathrm{b}}(x)^2 - G_{\mathrm{p}}^2/2}{q_{\mathrm{b}}(x)}$$

Surface potential as a function of normalized inversion charge

$$\Pi(x_g) = \begin{cases} \text{if } x_g < -p_{mrg} & \begin{cases} y_g = -x_g \\ z = 1.25 \cdot y_g / a_p \\ \eta = \left[z + 10 - \sqrt{(z-6)^2 + 64} \right] / 2 \\ a = (y_g - \eta)^2 + G_p^2 \cdot (\eta + 1) \\ c = 2 \cdot (y_g - \eta) - G_p^2 \\ \tau = -\eta + \ln\left(a / G_p^2\right) \\ y_0 = \sigma_1(a,\, c,\, \tau,\, \eta) \\ \Delta_0 = \exp(y_0) \\ \xi = 1 - G_p^2 \cdot \Delta_0 / 2 \\ p = 2 \cdot (y_g - y_0) + G_p^2 \cdot (\Delta_0 - 1) \\ q = (y_g - y_0)^2 + G_p^2 \cdot (y_0 - \Delta_0 + 1) \\ \Pi = -y_0 - \dfrac{2 \cdot q}{p + \sqrt{p^2 - 4 \cdot q \cdot \xi}} \end{cases} \\ \text{if } |x_g| \le p_{mrg} & \begin{cases} \Pi = \dfrac{x_g}{a_p} \end{cases} \\ \text{if } x_g > p_{mrg} & \begin{cases} \hat{x}_{g1} = x_1 + G_p \cdot \sqrt{\exp(-x_1) + x_1 - 1} \\ \bar{x} = \dfrac{x_g}{a_p} \cdot [1 + x_g \cdot (x_1 \cdot a_p / \hat{x}_{g1} - 1) / \hat{x}_{g1}] \\ x_0 = x_g + G_p^2/2 - G_p \cdot \sqrt{x_g + G_p^2/4 - 1 + \exp(-\bar{x})} \\ \Delta_0 = \exp(-x_0) \\ \xi = 1 - G_p^2 \cdot \Delta_0 / 2 \\ p = 2 \cdot (x_g - x_0) + G_p^2 \cdot (1 - \Delta_0) \\ q = (x_g - x_0)^2 - G_p^2 \cdot (x_0 + \Delta_0 - 1) \\ \Pi = x_0 + \dfrac{2 \cdot q}{p + \sqrt{p^2 - 4 \cdot q \cdot \xi}} \end{cases} \end{cases}$$

$$X(x_g, q_{inv}) = \Pi(x_g + q_{inv} / p_d)$$

Auxiliary functions

$$q(x) = -p_{\mathrm{d}} \cdot (x_{\mathrm{g}} - x) - q_{\mathrm{b}}(x)$$

$$\psi(q, q_{x1}) = \frac{q}{q_{x1}} - 1$$

$$\phi(q, q_{x1}, q_{x2}) = \left(1 - \frac{q \cdot q_{x2}}{q_{x1}^2}\right) / q_{x1}$$

Normalized right-hand side of continuity equation

$$f(x_{\mathrm{g}}, q, q', q'') = \begin{cases} x_{\mathrm{z}} = X(x_{\mathrm{g}}, q) \\ q_{x1} = \dfrac{\partial q}{\partial x}(x_{\mathrm{z}}) = p_{\mathrm{d}} - q_{\mathrm{b}}'(x_{\mathrm{z}}) \\ q_{x2} = \dfrac{\partial^2 q}{\partial x^2}(x_{\mathrm{z}}) = q_{\mathrm{b}}''(x_{\mathrm{z}}) \\ f_0 = \psi(q, q_{x1}) \cdot q'' + \phi(q, q_{x1}, q_{x2}) \cdot q'^2 \\ x_{y1} = \dfrac{\partial x_{\mathrm{z}}}{\partial y} = q' / q_{x1} \\ z_{\mathrm{sat}} = \begin{cases} \left(\theta^*_{\mathrm{sat,ac}} \cdot \phi^*_{\mathrm{T}} \cdot x_{y1}\right)^2 & \text{for NMOS} \\ \dfrac{\left(\theta^*_{\mathrm{sat,ac}} \cdot \phi^*_{\mathrm{T}} \cdot x_{y1}\right)^2}{1 + \theta^*_{\mathrm{sat,ac}} \cdot \Delta\psi_{\mathrm{ac}}} & \text{for PMOS} \end{cases} \\ \zeta = \sqrt{1 + 2 \cdot z_{\mathrm{sat}}} \\ F_{\mathrm{vsat}} = 2/(1+\zeta) \\ f = F_{\mathrm{vsat}} \cdot \left[f_0 - F_{\mathrm{vsat}} \cdot \dfrac{z_{\mathrm{sat}}}{\zeta} \cdot \psi(q, q_{x1}) \cdot (q'' + x_{y1}^2 \cdot q_{\mathrm{b}}''(x_{\mathrm{z}}))\right] \end{cases}$$

Normalization constant:

$$T_{\mathrm{norm}} = \frac{\mathbf{MUNQS} \cdot \phi^*_{\mathrm{T}} \cdot \beta}{C_{\mathrm{OX}}^{\mathrm{qm}}} \cdot G_{\mathrm{mob,ac}} \cdot G_{\Delta L,\mathrm{ac}}$$

Cubic spline interpolation

Using cubic spline interpolation, the spatial derivatives $\frac{\partial qi}{\partial y} \cdot (t)$ and $\frac{\partial^2 qi}{\partial y^2} \cdot (t)$ can be expressed as functions of $q_i(t)$.

$$q_0'' = 0$$

$$q_n'' = 0$$

$$q_i'' = \sum_{j=0}^{n} A_{i,j} \cdot q_i \qquad \text{for } 1 \leq i \leq n-1$$

$$q_i' = \frac{q_{i+1} - q_i}{h} - \frac{h}{6} \cdot (2 \cdot q_i'' + q_{i+1}'') \qquad \text{for } 1 \leq i \leq n-1$$

Continuity equation

Initial value for the q_i $(0 \leq i \leq n)$. These values are used for the DC operating point.

$$x_{i,0} = \Psi(i \cdot h)$$

$$q_{i,0} = q(x_{i,0})$$

Note: $x_{0,0} = x_s$ and $x_{n,0} = x_d$. Moreover, these values coincide with those in the quasi-static part of PSP.

The core of the NQS-model is the solution of q(y, t) from the charge continuity equation along the channel. By approximating the y-dependence by a cubic spline through a number of collocation points, the problem is reduced to solving the $q_i(t)$ from the following set of coupled differential equations.

$$\begin{cases} \frac{\partial q_i}{\partial t}(t) + T_{\text{norm}} \cdot f\left(x_{\text{g,ac}},\, q_i(t),\, \frac{\partial q_i}{\partial y}(t),\, \frac{\partial^2 q_i}{\partial y^2}(t)\right) = 0 \\ q_i(0) = q_{i,0} \end{cases} \qquad \text{for } 1 \leq i \leq n-1$$

Note that the boundary points $q_0(t) = q(x_s) = q_{is}$ and $q_n(t) = q(x_d) = q_{id}$ remain fixed to their quasi-static values; they are not solved from the equation above. The set of differential equations defined above is solved by the circuit simulator via the subcircuits shown in the left part of Figure 24-6.

Non-quasi-static terminal charges

Once the q_i are known, the NQS terminal charges can be computed:

$$S_0 = \sum_{i=1}^{n-1} q_i$$

$$S_2 = \sum_{i=1}^{n-1} q_i''$$

$$q_{\mathrm{I}}^{\mathrm{NQS}} = \int_0^1 q(y)\,\mathrm{d}y = h \cdot S_0 + \frac{h}{2} \cdot (u_0 + u_n) - \frac{h^3}{12} \cdot S_2$$

$$U_0 = \sum_{i=1}^{n-1} i \cdot q_i$$

$$U_2 = \sum_{i=1}^{n-1} i \cdot q_i''$$

$$q_{\mathrm{D}}^{\mathrm{NQS}} = \int_0^1 y \cdot q(y)\,\mathrm{d}y = h^2 \cdot U_0 + \frac{h^2}{6} \cdot [q_0 + (3n-1)u_n] - \frac{h^4}{12} \cdot U_2$$

$$q_{\mathrm{S}}^{\mathrm{NQS}} = q_{\mathrm{I}}^{\mathrm{NQS}} - q_{\mathrm{D}}^{\mathrm{NQS}}$$

Currently, only **SWNQS** = 0, 1, 2, 3, 5, 9 are allowed. For odd values of **SWNQS** the gate charge is integrated along the channel using Simpson's Rule. If **SWNQS** = 2, Simpson's 3/8-rule is used.

If **SWNQS** is odd (that is, n is even):

$$q_{\mathrm{G}}^{\mathrm{NQS}} = p_{\mathrm{d}} \cdot \left[x_{\mathrm{g,ac}} - \frac{h}{3} \cdot \left(X(x_{\mathrm{g,ac}}, q_0) + 4 \cdot \sum_{i=1}^{n/2} X(x_{\mathrm{g,ac}}, q_{2i-1}) + 2 \cdot \sum_{i=1}^{n/2-1} X(x_{\mathrm{g,ac}}, q_{2i}) + X(x_{\mathrm{g,ac}}, q_n) \right) \right]$$

If **SWNQS** = 2 (that is, n = 3):

$$q_{\mathrm{G}}^{\mathrm{NQS}} = p_{\mathrm{d}} \cdot \left[x_{\mathrm{g,ac}} - \frac{3 \cdot h}{8} \cdot \left(X(x_{\mathrm{g,ac}}, q_0) + 3 \cdot X(x_{\mathrm{g,ac}}, q_1) + 3 \cdot X(x_{\mathrm{g,ac}}, q_2) + X(x_{\mathrm{g,ac}}, q_3) \right) \right]$$

Converting back to conventional units:

$$Q_{\mathrm{S}}^{\mathrm{NQS}} = C_{\mathrm{OX}}^{\mathrm{qm}} \cdot \phi_{\mathrm{T}}^{*} \cdot q_{\mathrm{S}}^{\mathrm{NQS}}$$

$$Q_{\mathrm{D}}^{\mathrm{NQS}} = C_{\mathrm{OX}}^{\mathrm{qm}} \cdot \phi_{\mathrm{T}}^{*} \cdot q_{\mathrm{D}}^{\mathrm{NQS}}$$

$$Q_{\mathrm{G}}^{\mathrm{NQS}} = C_{\mathrm{OX}}^{\mathrm{qm}} \cdot \phi_{\mathrm{T}}^{*} \cdot q_{\mathrm{G}}^{\mathrm{NQS}}$$

$$Q_{\mathrm{B}}^{\mathrm{NQS}} = -(Q_{\mathrm{S}}^{\mathrm{NQS}} + Q_{\mathrm{D}}^{\mathrm{NQS}} + Q_{\mathrm{G}}^{\mathrm{NQS}})$$

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1	`l=10e-6 m`	Design length.
2	`w=10e-6 m`	Design width.
3	`sa=0.0 m`	Distance between OD-edge and poly from one side.
4	`sb=0.0 m`	Distance between OD-edge and poly from other side.
5	`sd=0.0 m`	Distance between neighboring fingers.

6 `sca=0.0` Integral of the first distribution function for scattered well dopants.

7 `scb=0.0` Integral of the second distribution function for scattered well dopants.

8 `scc=0.0` Integral of the third distribution function for scattered well dopants.

9 `sc=0.0 m` Distance between OD-edge and nearest well edge.

10 `nf=1` Number of fingers.

11 `ngcon=1.0` Number of gate contacts.

12 `xgw=1.0E-7 m` Distance from the gate contact to the channel edge.

13 `nrs=0.0` Number of squares of source diffusion.

14 `nrd=0.0` Number of squares of drain diffusion.

15 `trise=0.0 k` Temperature rise from ambient.

16 `jw=1E-6 m` Gate-edge length of source/drain junction.

17 `delvto=0.0 V` Threshold voltage shift parameter.

18 `factuo=1.0` Zero-field mobility pre-factor.

19 `absource=1E-12 m^2`
Bottom area of source junction.

20 `lssource=1E-6 m` STI-edge length of source junction.

21 `lgsource=1E-6 m` Gate-edge length of source junction.

22 `abdrain=1E-12 m^2` Bottom area of drain junction.

23 `lsdrain=1E-6 m` STI-edge length of drain junction.

24 `lgdrain=1E-6 m` Gate-edge length of drain junction.

25 `as=1E-12 m^2` Bottom area of source junction.

26 `ps=1E-6 m` Perimeter of source junction.

27 `ad=1E-12 m^2` Bottom area of drain junction.

28 `pd=1E-6 m` Perimeter of drain junction.

29 `mult=1.0` Number of devices in parallel.

30 `mulid0=1` Ids multiplier.

31 `m=1.0` Multiplicity factor.

32 `isnoisy=yes` Should device generate noise.
Possible values are `no` or `yes`.

Model Definition

model modelName psp103 parameter=value ...

Model Parameters

1 `level=103` Model level.

2 `type=n` Channel type parameter, n,NMOS p,PMOS.
Possible values are `n` or `p`.

3 `tr=value of tnom C`
nominal (reference) temperature.

4 `swnqs=0` Flag for NQS, 0,off, 1, 2, 3, 5, or 9,number of collocation points.

5 `swgeo=1` Flag for geometrical model, 0,local, 1,global, 2,binning.

6 `swigate=0` Flag for gate current, 0,turn off IG.

7 `swimpact=0` Flag for impact ionization current, 0,turn off II.

8 `swgidl=0` Flag for GIDL current, 0,turn off IGIDL.

9 `swjuncap=0` Flag for juncap, 0,turn off juncap.

10 `swjunasym=0` Flag for asymmetric junctions; 0,symmetric, 1,asymmetric.

11	`swnud=0`	Flag for NUD-effect; 0,off, 1,on, 2,on+CV-correction.
12	`swdelvtac=0`	Flag for separate capacitance calculation; 0,off, 1,on.
13	`qmc=1.0`	Quantum-mechanical correction factor.
14	`version=103.0`	Model version selector. The available versions are 103.0, 103.1 and 103.11.
15	`minr=0.0`	Minimum resistance, in order to be compatible with the orignal model, set its default to 0.0.
16	`mvt=0.0`	DCmatch parameter.
17	`mvto=0.0`	DCmatch parameter.
18	`mbe=0.0`	DCmatch parameter.
19	`mbeo=0.0`	DCmatch parameter.
20	`vfb=-1.0 V`	Flat band voltage at TR.
21	`stvfb=5.0E-4 V/K`	Temperature dependence of VFB.
22	`tox=2.0e-09 m`	Gate oxide thickness.
23	`epsrox=3.9`	Relative permittivity of gate dielectric.
24	`neff=5.0e+23 m^-3`	Effective substrate doping.
25	`facneffac=1.0`	Pre-factor for effective substrate doping in separate charge calculation.
26	`gfacnud=1.0`	Bodyfactor change due to NUD-effect.
27	`vsbnud=0.0 V`	Lower Vsb value for NUD-effect.
28	`dvsbnud=1.0`	Vsb-range for NUD-effect.
29	`vnsub=0.0 V`	Effective doping bias-dependence parameter.
30	`nslp=0.05 V`	Effective doping bias-dependence parameter.

31 `dnsub=0.0 V^-1` Effective doping bias-dependence parameter.

32 `dphib=0.0 V` Offset parameter for PHIB.

33 `delvtac=0.0 V` Offset parameter for PHIB in separate charge calculation.

34 `np=1.0E+26 m^-3` Gate poly-silicon doping.

35 `ct=0.0` Interface states factor.

36 `toxov=2.0e-09 m` Overlap oxide thickness.

37 `toxovd=2.0e-09 m` Overlap oxide thickness for drain side.

38 `nov=5.0e+25 m^-3` Effective doping of overlap region.

39 `novd=5.0e+25 m^-3` Effective doping of overlap region for drain side.

40 `cf=0.0` DIBL-parameter.

41 `cfb=0.0 V^-1` Back bias dependence of CF.

42 `betn=7e-2 m^2/V/s` Channel aspect ratio times zero-field mobility.

43 `stbet=1.0` Temperature dependence of BETN.

44 `mue=0.5 m/V` Mobility reduction coefficient at TR.

45 `stmue=0.0` Temperature dependence of MUE.

46 `themu=1.5` Mobility reduction exponent at TR.

47 `stthemu=1.5` Temperature dependence of THEMU.

48 `cs=0.0` Coulomb scattering parameter at TR.

49 `stcs=0.0` Temperature dependence of CS.

50 `xcor=0.0 V^-1` Non-universality factor.

51 `stxcor=0.0` Temperature dependence of XCOR.

52 `feta=1.0` Effective field parameter.

53 `rs=30 Ohm`	Series resistance at TR.
54 `strs=1.0`	Temperature dependence of RS.
55 `rsb=0.0 V^-1`	Back-bias dependence of series resistance.
56 `rsg=0.0 V^-1`	Gate-bias dependence of series resistance.
57 `thesat=1.0 V^-1`	Velocity saturation parameter at TR.
58 `stthesat=1.0`	Temperature dependence of THESAT.
59 `thesatb=0.0 V^-1`	Back-bias dependence of velocity saturation.
60 `thesatg=0.0 V^-1`	Gate-bias dependence of velocity saturation.
61 `ax=3.0`	Linear/saturation transition factor.
62 `alp=0.01`	CLM pre-factor.
63 `alp1=0.00 V`	CLM enhancement factor above threshold.
64 `alp2=0.00 V^-1`	CLM enhancement factor below threshold.
65 `vp=0.05 V`	CLM logarithm dependence factor.
66 `a1=1.0`	Impact-ionization pre-factor.
67 `a2=10.0 V`	Impact-ionization exponent at TR.
68 `sta2=0.0 V`	Temperature dependence of A2.
69 `a3=1.0`	Saturation-voltage dependence of impact-ionization.
70 `a4=0.0 V^-0.5`	Back-bias dependence of impact-ionization.
71 `gco=0.0`	Gate tunneling energy adjustment.
72 `iginv=0.0 A`	Gate channel current pre-factor.
73 `igov=0.0 A`	Gate overlap current pre-factor.
74 `igovd=0.0 A`	Gate overlap current pre-factor for drain side.

75 `stig=2.0` Temperature dependence of IGINV and IGOV.

76 `gc2=0.375` Gate current slope factor.

77 `gc3=0.063` Gate current curvature factor.

78 `chib=3.1 V` Tunneling barrier height.

79 `agidl=0.0 A/V^3` GIDL pre-factor.

80 `agidld=0.0 A/V^3` GIDL pre-factor for drain side.

81 `bgidl=41.0 V` GIDL probability factor at TR.

82 `bgidld=41.0 V` GIDL probability factor at TR for drain side.

83 `stbgidl=0.0 V/K` Temperature dependence of BGIDL.

84 `stbgidld=0.0 V/K` Temperature dependence of BGIDL for drain side.

85 `cgidl=0.0` Back-bias dependence of GIDL.

86 `cgidld=0.0` Back-bias dependence of GIDL for drain side.

87 `cox=1.0e-14 F` Oxide capacitance for intrinsic channel.

88 `cgov=1.0e-15 F` Oxide capacitance for gate-drain/source overlap.

89 `cgovd=1.0e-15 F` Oxide capacitance for gate-drain overlap.

90 `cgbov=0.0 F` Oxide capacitance for gate-bulk overlap.

91 `cfr=0.0 F` Outer fringe capacitance.

92 `cfrd=0.0 F` Outer fringe capacitance for drain side.

93 `fnt=1.0` Thermal noise coefficient.

94 `nfa=8.0e+22 V^-1/m^4`
First coefficient of flicker noise.

95 `nfb=3.0e+07 V^-1/m^2`
Second coefficient of flicker noise.

96 `nfc=0.0 V^-1` Third coefficient of flicker noise.

97 `ef=1.0` Flicker noise frequency exponent.

98 `munqs=1.0` Relative mobility for NQS modeling.

99 `rg=0.0 Ohm` Gate resistance.

100 `rse=0.0 Ohm` External source resistance.

101 `rde=0.0 Ohm` External drain resistance.

102 `rbulk=0.0 Ohm` Bulk resistance between node BP and BI.

103 `rwell=0.0 Ohm` Well resistance between node BI and B.

104 `rjuns=0.0 Ohm` Source-side bulk resistance between node BI and BS.

105 `rjund=0.0 Ohm` Drain-side bulk resistance between node BI and BD.

106 `povfb=-1 V` Coefficient for the geometry independent part of VFB.

107 `plvfb=0.0 V` Coefficient for the length dependence of VFB.

108 `pwvfb=0.0 V` Coefficient for the width dependence of VFB.

109 `plwvfb=0.0 V` Coefficient for the length times width dependence of VFB.

110 `postvfb=0.0005 V/K`
Coefficient for the geometry independent part of STVFB.

111 `plstvfb=0.0 V/K` Coefficient for the length dependence of STVFB.

112 `pwstvfb=0.0 V/K` Coefficient for the width dependence of STVFB.

113 `plwstvfb=0.0 V/K` Coefficient for the length times width dependence of STVFB.

114 `potox=2E-09 m` Coefficient for the geometry independent part of TOX.

115 `poepsrox=3.9` Coefficient for the geometry independent part of EPSOX.

116 `poneff=5E+23 m^-3` Coefficient for the geometry independent part of NEFF.

117 `plneff=0.0 m^-3`	Coefficient for the length dependence of NEFF.
118 `pwneff=0.0 m^-3`	Coefficient for the width dependence of NEFF.
119 `plwneff=0.0 m^-3`	Coefficient for the length times width dependence of NEFF.
120 `pofacneffac=1.0`	Coefficient for the geometry independent part of FACNEFFAC.
121 `plfacneffac=0.0`	Coefficient for the length dependence of FACNEFFAC.
122 `pwfacneffac=`0.0	Coefficient for the width dependence of FACNEFFAC.
123 `plwfacneffac=0.0`	Coefficient for the length times width dependence of FACNEFFAC.
124 `pogfacnud=1.0`	Coefficient for the geometry independent part of GFACNUD.
125 `plgfacnud=0.0`	Coefficient for the length dependence of GFACNUD.
126 `pwgfacnud=0.0`	Coefficient for the width dependence of GFACNUD.
127 `plwgfacnud=0.0`	Coefficient for the length times width dependence of GFACNUD.
128 `povsbnud=0.0 V`	Coefficient for the geometry independent part of VSBNUD.
129 `podvsbnud=1.0 V`	Coefficient for the geometry independent part of DVSBNUD.
130 `povnsub=0 V`	Coefficient for the geometry independent part of VNSUB.
131 `ponslp=0.05 V`	Coefficient for the geometry independent part of NSLP.
132 `podnsub=0 V^-1`	Coefficient for the geometry independent part of DNSUB.
133 `podphib=0 v`	Coefficient for the geometry independent part of DPHIB.
134 `pldphib=0.0 V`	Coefficient for the length dependence of DPHIB.
135 `pwdphib=0.0 V`	Coefficient for the width dependence of DPHIB.
136 `plwdphib=0.0 V`	Coefficient for the length times width dependence of DPHIB.
137 `podelvtac=0 V`	Coefficient for the geometry independent part of DELVTAC.

138 `pldelvtac=0.0 V`	Coefficient for the length dependence of DELVTAC.
139 `pwdelvtac=0.0 V`	Coefficient for the width dependence of DELVTAC.
140 `plwdelvtac=0.0 V`	Coefficient for the length times width dependence of DELVTAC.
141 `ponp=1E+26 m^-3`	Coefficient for the geometry independent part of NP.
142 `plnp=0.0 m^-3`	Coefficient for the length dependence of NP.
143 `pwnp=-.0 m^-3`	Coefficient for the width dependence of NP.
144 `plwnp=0.0 m^-3`	Coefficient for the length times width dependence of NP.
145 `poct=0`	Coefficient for the geometry independent part of CT.
146 `plct=0.0`	Coefficient for the length dependence of CT.
147 `pwct=0.0`	Coefficient for the width dependence of CT.
148 `plwct=0.0`	Coefficient for the length times width dependence of CT.
149 `potoxov=2E-09 m`	Coefficient for the geometry independent part of TOXOV.
150 `potoxovd=2E-09 m`	Coefficient for the geometry independent part of TOXOV for drain side.
151 `ponov=5E+25 m^-3`	Coefficient for the geometry independent part of NOV.
152 `plnov=0.0 m^-3`	Coefficient for the length dependence of NOV.
153 `pwnov=0.0 m^-3`	Coefficient for the width dependence of NOV.
154 `plwnov=0.0 m^-3`	Coefficient for the length times width dependence of NOV.
155 `ponovd=5E+25 m^-3`	Coefficient for the geometry independent part of NOV for drain side.
156 `plnovd=0.0 m^-3`	Coefficient for the length dependence of NOV for drain side.
157 `pwnovd=0.0 m^-3`	Coefficient for the width dependence of NOV for drain side.

158 `plwnovd=0.0 m^-3` Coefficient for the length times width dependence of NOV for drain side.

159 `pocf=0` Coefficient for the geometry independent part of CF.

160 `plcf=0.0` Coefficient for the length dependence of CF.

161 `pwcf=0.0` Coefficient for the width dependence of CF.

162 `plwcf=0.0` Coefficient for the length times width dependence of CF.

163 `pocfb=0 V^-1` Coefficient for the geometry independent part of CFB.

164 `pobetn=0.07 m^2/V/s`
Coefficient for the geometry independent part of BETN.

165 `plbetn=0.0 m^2/V/s`
Coefficient for the length dependence of BETN.

166 `pwbetn=0.0 m^2/V/s`
Coefficient for the width dependence of BETN.

167 `plwbetn=0.0 m^2/V/s`
Coefficient for the length times width dependence of BETN.

168 `postbet=1` Coefficient for the geometry independent part of STBET.

169 `plstbet=0.0` Coefficient for the length dependence of STBET.

170 `pwstbet=0.0` Coefficient for the width dependence of STBET.

171 `plwstbet=0.0` Coefficient for the length times width dependence of STBET.

172 `pomue=0.5 m/V` Coefficient for the geometry independent part of MUE.

173 `plmue=0.0 m/V` Coefficient for the length dependence of MUE.

174 `pwmue=0.0 m/V` Coefficient for the width dependence of MUE.

175 `plwmue=0.0 m/V` Coefficient for the length times width dependence of MUE.

176 `postmue=0` Coefficient for the geometry independent part of STMUE.

177 `pothemu=1.5` Coefficient for the geometry independent part of THEMU.

178 `postthemu=1.5` Coefficient for the geometry independent part of STTHEMU.

179 `pocs=0` Coefficient for the geometry independent part of CS.

180 `plcs=0.0` Coefficient for the length dependence of CS.

181 `pwcs=0.0` Coefficient for the width dependence of CS.

182 `plwcs=0.0` Coefficient for the length times width dependence of CS.

183 `postcs=0` Coefficient for the geometry independent part of STCS.

184 `poxcor=0 V^-1` Coefficient for the geometry independent part of XCOR.

185 `plxcor=0.0 V^-1` Coefficient for the length dependence of XCOR.

186 `pwxcor=0.0 V^-1` Coefficient for the width dependence of XCOR.

187 `plwxcor=0.0 V^-1` Coefficient for the length times width dependence of XCOR.

188 `postxcor=0` Coefficient for the geometry independent part of STXCOR.

189 `pofeta=1` Coefficient for the geometry independent part of FETA.

190 `pors=30 Ohm` Coefficient for the geometry independent part of RS.

191 `plrs=0.0 Ohm` Coefficient for the length dependence of RS.

192 `pwrs=0.0 Ohm` Coefficient for the width dependence of RS.

193 `plwrs=0.0 Ohm` Coefficient for the length times width dependence of RS.

194 `postrs=1` Coefficient for the geometry independent part of STRS.

195 `porsb=0 V^-1` Coefficient for the geometry independent part of RSB.

196 `porsg=0 V^-1` Coefficient for the geometry independent part of RSG.

197 `pothesat=1 V^-1` Coefficient for the geometry independent part of THESAT.

198 `plthesat=0.0 V^-1` Coefficient for the length dependence of THESAT.

199 `pwthesat=0.0 V^-1` Coefficient for the width dependence of THESAT.

200 `plwthesat=0.0 V^-1`
Coefficient for the length times width dependence of THESAT.

201 `postthesat=1` Coefficient for the geometry independent part of STTHESAT.

202 `plstthesat=0.0` Coefficient for the length dependence of STTHESAT.

203 `pwstthesat=0.0` Coefficient for the width dependence of STTHESAT.

204 `plwstthesat=0.0` Coefficient for the length times width dependence of STTHESAT.

205 `pothesatb=0 V^-1` Coefficient for the geometry independent part of THESATB.

206 `plthesatb=0.0 V^-1`
Coefficient for the length dependence of THESATB.

207 `pwthesatb=0.0 V^-1`
Coefficient for the width dependence of THESATB.

208 `plwthesatb=0.0 V^-1`
Coefficient for the length times width dependence of THESATB.

209 `pothesatg=0 V^-1` Coefficient for the geometry independent part of THESATG.

210 `plthesatg=0.0 V^-1`
Coefficient for the length dependence of THESATG.

211 `pwthesatg=0.0 V^-1`
Coefficient for the width dependence of THESATG.

212 `plwthesatg=0.0 V^-1`
Coefficient for the length times width dependence of THESATG.

213 `poax=3` Coefficient for the geometry independent part of AX.

214 `plax=0.0` Coefficient for the length dependence of AX.

215 `pwax=0.0` Coefficient for the width dependence of AX.

216 `plwax=0.0` Coefficient for the length times width dependence of AX.

217 `poalp=0.01`	Coefficient for the geometry independent part of ALP.
218 `plalp=0.0`	Coefficient for the length dependence of ALP.
219 `pwalp=0.0`	Coefficient for the width dependence of ALP.
220 `plwalp=0.0`	Coefficient for the length times width dependence of ALP.
221 `poalp1=0 V`	Coefficient for the geometry independent part of ALP1.
222 `plalp1=0.0 V`	Coefficient for the length dependence of ALP1.
223 `pwalp1=0.0 V`	Coefficient for the width dependence of ALP1.
224 `plwalp1=0.0 V`	Coefficient for the length times width dependence of ALP1.
225 `poalp2=0 V^-1`	Coefficient for the geometry independent part of ALP2.
226 `plalp2=0.0 V^-1`	Coefficient for the length dependence of ALP2.
227 `pwalp2=0.0 V^-1`	Coefficient for the width dependence of ALP2.
228 `plwalp2=0.0 V^-1`	Coefficient for the length times width dependence of ALP2.
229 `povp=0.05 V`	Coefficient for the geometry independent part of VP.
230 `poa1=1`	Coefficient for the geometry independent part of A1.
231 `pla1=0.0`	Coefficient for the length dependence of A1.
232 `pwa1=0.0`	Coefficient for the width dependence of A1.
233 `plwa1=0.0`	Coefficient for the length times width dependence of A1.
234 `poa2=10 V`	Coefficient for the geometry independent part of A2.
235 `posta2=0 V`	Coefficient for the geometry independent part of STA2.
236 `poa3=1`	Coefficient for the geometry independent part of A3.
237 `pla3=0.0`	Coefficient for the length dependence of A3.
238 `pwa3=0.0`	Coefficient for the width dependence of A3.

239 `plwa3=0.0`	Coefficient for the length times width dependence of A3.
240 `poa4=0 V^-0.5`	Coefficient for the geometry independent part of A4.
241 `pla4=0.0 V^-0.5`	Coefficient for the length dependence of A4.
242 `pwa4=0.0 V^-0.5`	Coefficient for the width dependence of A4.
243 `plwa4=0.0 V^-0.5`	Coefficient for the length times width dependence of A4.
244 `pogco=0`	Coefficient for the geometry independent part of GCO.
245 `poiginv=0 A`	Coefficient for the geometry independent part of IGINV.
246 `pliginv=0.0 A`	Coefficient for the length dependence of IGINV.
247 `pwiginv=0.0 A`	Coefficient for the width dependence of IGINV.
248 `plwiginv=0.0 A`	Coefficient for the length times width dependence of IGINV.
249 `poigov=0 A`	Coefficient for the geometry independent part of IGOV.
250 `pligov=0.0 A`	Coefficient for the length dependence of IGOV.
251 `pwigov=0.0 A`	Coefficient for the width dependence of IGOV.
252 `plwigov=0.0 A`	Coefficient for the length times width dependence of IGOV.
253 `poigovd=0 A`	Coefficient for the geometry independent part of IGOV for drain side.
254 `pligovd=0.0 A`	Coefficient for the length dependence of IGOV for drain side.
255 `pwigovd=0.0 A`	Coefficient for the width dependence of IGOV for drain side.
256 `plwigovd=0.0 A`	Coefficient for the length times width dependence of IGOV for drain side.
257 `postig=2`	Coefficient for the geometry independent part of STIG.
258 `pogc2=0.375`	Coefficient for the geometry independent part of GC2.
259 `pogc3=0.063`	Coefficient for the geometry independent part of GC3.

260 `pochib=3.1 V` Coefficient for the geometry independent part of CHIB.

261 `poagidl=0 A/V^3` Coefficient for the geometry independent part of AGIDL.

262 `plagidl=0.0 A/V^3` Coefficient for the length dependence of AGIDL.

263 `pwagidl=0.0 A/V^3` Coefficient for the width dependence of AGIDL.

264 `plwagidl=0.0 A/V^3`
Coefficient for the length times width dependence of AGIDL.

265 `poagidld=0 A/V^3` Coefficient for the geometry independent part of AGIDL for drain side.

266 `plagidld=0.0 A/V^3`
Coefficient for the length dependence of AGIDL for drain side.

267 `pwagidld=0.0 A/V^3`
Coefficient for the width dependence of AGIDL for drain side.

268 `plwagidld=0.0 A/V^3`
Coefficient for the length times width dependence of AGIDL for drain side.

269 `pobgidl=41 V` Coefficient for the geometry independent part of BGIDL.

270 `pobgidld=41 V` Coefficient for the geometry independent part of BGIDL for drain side.

271 `postbgidl=0 V/K` Coefficient for the geometry independent part of STBGIDL.

272 `postbgidld=0 V/K` Coefficient for the geometry independent part of STBGIDL for drain side.

273 `pocgidl=0` Coefficient for the geometry independent part of CGIDL.

274 `pocgidld=0` Coefficient for the geometry independent part of CGIDL for drain side.

275 `pocox=1E-14 F` Coefficient for the geometry independent part of COX.

276 `plcox=0.0 F` Coefficient for the length dependence of COX.

277 `pwcox=0.0 F`	Coefficient for the width dependence of COX.
278 `plwcox=0.0 F`	Coefficient for the length times width dependence of COX.
279 `pocgov=1E-15 F`	Coefficient for the geometry independent part of CGOV.
280 `plcgov=0.0 F`	Coefficient for the length dependence of CGOV.
281 `pwcgov=0.0 F`	Coefficient for the width dependence of CGOV.
282 `plwcgov=0.0 F`	Coefficient for the length times width dependence of CGOV.
283 `pocgovd=1E-15 F`	Coefficient for the geometry independent part of CGOV for drain side.
284 `plcgovd=0.0 F`	Coefficient for the length dependence of CGOV for drain side.
285 `pwcgovd=0.0 F`	Coefficient for the width dependence of CGOV for drain side.
286 `plwcgovd=0.0 F`	Coefficient for the length times width dependence of CGOV for drain side.
287 `pocgbov=0 F`	Coefficient for the geometry independent part of CGBOV.
288 `plcgbov=0.0 F`	Coefficient for the length dependence of CGBOV.
289 `pwcgbov=0.0 F`	Coefficient for the width dependence of CGBOV.
290 `plwcgbov=0.0 F`	Coefficient for the length times width dependence of CGBOV.
291 `pocfr=0 F`	Coefficient for the geometry independent part of CFR.
292 `plcfr=0.0 F`	Coefficient for the length dependence of CFR.
293 `pwcfr=0.0 F`	Coefficient for the width dependence of CFR.
294 `plwcfr=0.0 F`	Coefficient for the length times width dependence of CFR.
295 `pocfrd=0 F`	Coefficient for the geometry independent part of CFR for drain side.
296 `plcfrd=0.0 F`	Coefficient for the length dependence of CFR for drain side.

297 `pwcfrd=0.0 F` Coefficient for the width dependence of CFR for drain side.

298 `plwcfrd=0.0 F` Coefficient for the length times width dependence of CFR for drain side.

299 `pofnt=1` Coefficient for the geometry independent part of FNT.

300 `ponfa=8E+22 V^-1/m^4`
Coefficient for the geometry independent part of NFA.

301 `plnfa=0.0 V^-1/m^4`
Coefficient for the length dependence of NFA.

302 `pwnfa=0.0 V^-1/m^4`
Coefficient for the width dependence of NFA.

303 `plwnfa=0.0 V^-1/m^4`
Coefficient for the length times width dependence of NFA.

304 `ponfb=0.0 V^-1/m^2`
Coefficient for the geometry independent part of NFB.

305 `plnfb=0.0 V^-1/m^2`
Coefficient for the length dependence of NFB.

306 `pwnfb=0.0 V^-1/m^2`
Coefficient for the width dependence of NFB.

307 `plwnfb=0.0 V^-1/m^2`
Coefficient for the length times width dependence of NFB.

308 `ponfc=0 V^-1` Coefficient for the geometry independent part of NFC.

309 `plnfc=0.0 V^-1` Coefficient for the length dependence of NFC.

310 `pwnfc=0.0 V^-1` Coefficient for the width dependence of NFC.

311 `plwnfc=0.0 V^-1` Coefficient for the length times width dependence of NFC.

312 `poef=1.0` Coefficient for the flicker noise frequency exponent.

313 `pokvthowe=0` Coefficient for the geometry independent part of KVTHOWE.

314 `plkvthowe=0`	Coefficient for the length dependence part of KVTHOWE.
315 `pwkvthowe=0`	Coefficient for the width dependence part of KVTHOWE.
316 `plwkvthowe=0`	Coefficient for the length times width dependence part of KVTHOWE.
317 `pokuowe=0`	Coefficient for the geometry independent part of KUOWE.
318 `plkuowe=0`	Coefficient for the length dependence part of KUOWE.
319 `pwkuowe=0`	Coefficient for the width dependence part of KUOWE.
320 `plwkuowe=0`	Coefficient for the length times width dependence part of KUOWE.
321 `lmin=0 m`	Dummy parameter to label binning set.
322 `lmax=1.0 m`	Dummy parameter to label binning set.
323 `wmin=0 m`	Dummy parameter to label binning set.
324 `wmax=1.0 m`	Dummy parameter to label binning set.
325 `lvaro=0.0 m`	Geom. independent difference between actual and programmed gate length.
326 `lvarl=0.0`	Length dependence of LVAR.
327 `lvarw=0.0`	Width dependence of LVAR.
328 `lap=0.0 m`	Effective channel length reduction per side.
329 `wvaro=0.0 m`	Geom. independent difference between actual and programmed field-oxide opening.
330 `wvarl=0.0`	Length dependence of WVAR.
331 `wvarw=0.0`	Width dependence of WVAR.
332 `wot=0.0 m`	Effective channel width reduction per side.
333 `dlq=0.0 m`	Effective channel length reduction for CV.

334 `dwq=0.0 m`	Effective channel width reduction for CV.
335 `vfbo=-1.0 V`	Geometry-independent flat-band voltage at TR.
336 `vfbl=0.0 V`	Length dependence of flat-band voltage.
337 `vfbw=0.0 V`	Width dependence of flat-band voltage.
338 `vfblw=0.0 V`	Area dependence of flat-band voltage.
339 `stvfbo=5e-4 V/K`	Geometry-independent temperature dependence of VFB.
340 `stvfbl=0.0 V/K`	Length dependence of temperature dependence of VFB.
341 `stvfbw=0.0 V/K`	Width dependence of temperature dependence of VFB.
342 `stvfblw=0.0 V/K`	Area dependence of temperature dependence of VFB.
343 `toxo=2e-9 m`	Gate oxide thickness.
344 `epsroxo=3.9`	Relative permittivity of gate dielectric.
345 `nsubo=3e23 m^-3`	Geometry independent substrate doping.
346 `nsubw=0.0`	Width dependence of background doping NSUBO due to segregation.
347 `wseg=1e-8m`	Char. length of segregation of background doping NSUBO.
348 `npck=1e24 m^-3`	Pocket doping level.
349 `npckw=0.0`	Width dependence of pocket doping NPCK due to segregation.
350 `wsegp=1e-8 m`	Char. length of segregation of pocket doping NPCK.
351 `lpck=1e-8 m`	Char. length of lateral doping profile.
352 `lpckw=0.0`	Width dependence of char. length of lateral doping profile.
353 `fol1=0.0`	First length dependence coefficient for short channel body effect.
354 `fol2=0.0`	Second length dependence coefficient for short channel body effect.

355 `facneffaco=1.0`	Geom. independent pre-factor for effective substrate doping in separate charge calculation.
356 `facneffacl=0.0`	Length dependence of FACNEFFAC.
357 `facneffacw=0.0`	Width dependence of FACNEFFAC.
358 `facneffaclw=0.0`	Area dependence of FACNEFFAC.
359 `gfacnudo=1.0`	Geom. independent bodyfactor change due to NUD-effect.
360 `gfacnudl=0.0`	Length dependence of GFACNUD.
361 `gfacnudlexp=1.0`	Exponent for length dependence of GFACNUD.
362 `gfacnudw=0.0`	Width dependence of GFACNUD.
363 `gfacnudlw=`0.0	Area dependence of GFACNUD.
364 `vsbnudo=0.0 V`	Lower Vsb value for NUD-effect.
365 `dvsbnudo=1.0 V`	Vsb range for NUD-effect.
366 `vnsubo=0.0 V`	Effective doping bias-dependence parameter.
367 `nslpo=0.05 V`	Effective doping bias-dependence parameter.
368 `dnsubo=0.0 V^-1`	Effective doping bias-dependence parameter.
369 `dphibo=0.0 V`	Geometry independent offset of PHIB.
370 `dphibl=0.0 V`	Length dependence offset of PHIB.
371 `dphiblexp=1.0`	Exponent for length dependence of offset of PHIB.
372 `dphibw=0.0 V`	Width dependence of offset of PHIB.
373 `dphiblw=0.0 V`	Area dependence of offset of PHIB.
374 `delvtaco=0.0 V`	Geom. independent offset parameter for PHIB in separate charge calculation.
375 `delvtacl=0.0 V`	Length dependence of DELVTAC.

376 `delvtaclexp=1.0`	Exponent for length dependence of offset of DELVTAC.
377 `delvtacw=0.0 V`	Width dependence of DELVTAC.
378 `delvtaclw=0.0 V`	Area dependence of DELVTAC.
379 `npo=1e26 m^-3`	Geometry-independent gate poly-silicon doping.
380 `npl=0.0`	Length dependence of gate poly-silicon doping.
381 `cto=0.0`	Geometry-independent interface states factor.
382 `ctl=0.0`	Length dependence of interface states factor.
383 `ctlexp=1.0`	Exponent for length dependence of interface states factor.
384 `ctw=0.0`	Width dependence of interface states factor.
385 `ctlw=0.0`	Area dependence of interface states factor.
386 `toxovo=2e-9 m`	Overlap oxide thickness.
387 `toxovdo=2e-9 m`	Overlap oxide thickness for drain side.
388 `lov=0 m`	Overlap length for gate/drain and gate/source overlap capacitance.
389 `lovd=0 m`	Overlap length for gate/drain overlap capacitance.
390 `novo=5e25 m^-3`	Effective doping of overlap region.
391 `novdo=5e25 m^-3`	Effective doping of overlap region for drain side.
392 `cfl=0.0`	Length dependence of DIBL-parameter.
393 `cflexp=2.0`	Exponent for length dependence of CF.
394 `cfw=0.0`	Width dependence of CF.
395 `cfbo=`0.0 V^-1	Back-bias dependence of CF.
396 `uo=5e-2 m^2/V/s`	Zero-field mobility at TR.

397 `fbet1=0.0` Relative mobility decrease due to first lateral profile.

398 `fbet1w=0.0` Width dependence of relative mobility decrease due to first lateral profile.

399 `lp1=1e-8 m` Mobility-related characteristic length of first lateral profile.

400 `lp1w=0.0` Width dependence of mobility-related characteristic length of first lateral profile.

401 `fbet2=0.0` Relative mobility decrease due to second lateral profile.

402 `lp2=1e-8 m` Mobility-related characteristic length of second lateral profile.

403 `betw1=0.0` First higher-order width scaling coefficient of BETN.

404 `betw2=0.0` Second higher-order width scaling coefficient of BETN.

405 `wbet=1e-9 m` Characteristic width for width scaling of BETN.

406 `stbeto=1.0` Geometry independent temperature dependence of BETN.

407 `stbetl=0.0` Length dependence of temperature dependence of BETN.

408 `stbetw=0.0` Width dependence of temperature dependence of BETN.

409 `stbetlw=0.0` Area dependence of temperature dependence of BETN.

410 `mueo=0.5 m/V` Geometry independent mobility reduction coefficient at TR.

411 `muew=0.0` Width dependence of mobility reduction coefficient at TR.

412 `stmueo=0.0` Temperature dependence of MUE.

413 `themuo=1.5` Mobility reduction exponent at TR.

414 `stthemuo=1.5` Temperature dependence of THEMU.

415 `cso=0.0` Geometry independent coulomb scattering parameter at TR.

416 `csl=0.0` Length dependence of CS.

417 `cslexp=1.0` Exponent for length dependence of CS.

418 `csw=0.0` Width dependence of CS.

419 `cslw=0.0` Area dependence of CS.

420 `stcso=0.0` Temperature dependence of CS.

421 `xcoro=0.0 V^-1` Geometry independent non-universality parameter.

422 `xcorl=0.0` Length dependence of non-universality parameter.

423 `xcorw=0.0` Width dependence of non-universality parameter.

424 `xcorlw=0.0` Area dependence of non-universality parameter.

425 `stxcoro=0.0` Temperature dependence of XCOR.

426 `fetao=1.0` Effective field parameter.

427 `rsw1=50.0 Ohm` Source/drain series resistance for 1 um wide channel at TR.

428 `rsw2=0.0` Higher-order width scaling of RS.

429 `strso=1.0` Temperature dependence of RS.

430 `rsbo=`0.0 V^-1 Back-bias dependence of series resistance.

431 `rsgo=`0.0 V^-1 Gate-bias dependence of series resistance.

432 `thesato=0.0 V^-1` Geometry independent velocity saturation parameter at TR.

433 `thesatl=0.05 V^-1` Length dependence of THESAT.

434 `thesatlexp=1.0` Exponent for length dependence of THESAT.

435 `thesatw=0.0` Width dependence of velocity saturation parameter.

436 `thesatlw=0.0` Area dependence of velocity saturation parameter.

437 `stthesato=1.0` Geometry independent temperature dependence of THESAT.

438 `stthesatl=0.0` Length dependence of temperature dependence of THESAT.

439 `stthesatw=0.0` Width dependence of temperature dependence of THESAT.

440	`stthesatlw=0.0`	Area dependence of temperature dependence of THESAT.
441	`thesatbo=0.0 V^-1`	Back-bias dependence of velocity saturation.
442	`thesatgo=0.0 V^-1`	Gate-bias dependence of velocity saturation.
443	`axo=18`	Geometry independent linear/saturation transition factor.
444	`axl=0.4`	Length dependence of AX.
445	`alpl=`5e-4	Length dependence of ALP.
446	`alplexp=1.0`	Exponent for length dependence of ALP.
447	`alpw=0.0`	Width dependence of ALP.
448	`alp1l1=0.0 V`	Length dependence of CLM enhancement factor above threshold.
449	`alp1lexp=0.5`	Exponent for length dependence of ALP1.
450	`alp1l2=0.0`	Second_order length dependence of ALP1.
451	`alp1w=0.0`	Width dependence of ALP1.
452	`alp2l1=0.5`	Length dependence of CLM enhancement factor below threshold.
453	`alp2lexp=0.0`	Exponent for length dependence of ALP2.
454	`alp2l2=0.0`	Second_order length dependence of ALP2.
455	`alp2w=0.0`	Width dependence of ALP2.
456	`vpo=0.05 V`	CLM logarithmic dependence parameter.
457	`a1o=1.0`	Geometry independent impact-ionization pre-factor.
458	`a1l=0.0`	Length dependence of A1.
459	`a1w=0.0`	Width dependence of A1.
460	`a2o=10 V`	Impact-ionization exponent at TR.

461 `sta2o=0.0 V` Temperature dependence of A2.

462 `a3o=1.0` Geometry independent saturation-voltage dependence of II.

463 `a3l=0.0` Length dependence of A3.

464 `a3w=0.0` Width dependence of A3.

465 `a4o=0.0 V^-0.5` Geometry independent back-bias dependence of II.

466 `a4l=0.0` Length dependence of A4.

467 `a4w=0.0` Width dependence of A4.

468 `gcoo=0.0` Gate tunneling energy adjustment.

469 `iginvlw=0.0 A` Gate channel current pre-factor for 1 um^2 channel area.

470 `igovw=0.0 A` Gate overlap current pre-factor for 1 um wide channel.

471 `igovdw=0.0 A` Gate overlap current pre-factor for 1 um wide channel for drain side.

472 `stigo=2.0` Temperature dependence of IGINV and IGOV.

473 `gc2o=0.375` Gate current slope factor.

474 `gc3o=0.063` Gate current curvature factor.

475 `chibo=3.1 V` Tunneling barrier height.

476 `agidlw=0.0 A/V^3` Width dependence of GIDL pre-factor.

477 `agidldw=0.0 A/V^3` Width dependence of GIDL pre-factor for drain side.

478 `bgidlo=41 V` GIDL probability factor at TR.

479 `bgidldo=41 V` GIDL probability factor at TR for drain side.

480 `stbgidlo=0.0 V/K` Temperature dependence of BGIDL.

481 `stbgidldo=0.0 V/K` Temperature dependence of BGIDL for drain side.

482 `cgidlo=0.0` Back-bias dependence of GIDL.

483 `cgidldo=0.0` Back-bias dependence of GIDL for drain side.

484 `cgbovl=0.0 F` Oxide capacitance for gate-bulk overlap for 1 um long channel.

485 `cfrw=0.0 F` Outer fringe capacitance for 1 um wide channel.

486 `cfrdw=0.0 F` Outer fringe capacitance for 1 um wide channel for drain side.

487 `fnto=1.0` Thermal noise coefficient.

488 `nfalw=8e22 V^-1/m^4`
First coefficient of flicker noise for 1 um^2 channel area.

489 `nfblw=3e7 V^-1/m^2`
Second coefficient of flicker noise for 1 um^2 channel area.

490 `nfclw=.0 V^-1` Third coefficient of flicker noise for 1 um^2 channel area.

491 `efo=1.0` Flicker noise frequency exponent.

492 `lintnoi=0.0 m` Length offset for flicker noise.

493 `alpnoi=2.0` Exponent for length offset for flicker noise.

494 `kvthoweo=0` Geometrical independent threshold shift parameter.

495 `kvthowel=0` Length dependent threshold shift parameter.

496 `kvthowew=0` Width dependent threshold shift parameter.

497 `kvthowelw=0` Area dependent threshold shift parameter.

498 `kuoweo=0` Geometrical independent mobility degradation factor.

499 `kuowel=0` Length dependent mobility degradation factor.

500 `kuowew=0` Width dependent mobility degradation factor.

501 `kuowelw=0` Area dependent mobility degradation factor.

502 `munqso=1.0` Relative mobility for NQS modeling.

503 `rgo=0.0 Ohm` Gate resistance.

504 `rint=.0 Ohm m^2` Contact resistance between silicide and ploy.

505 `rvpoly=.0 Ohm m^2`
Vertical poly resistance.

506 `rshg=0.0 Ohm/Sqr` Gate electrode diffusion sheet resistance.

507 `dlsil=0.0 m` Silicide extension over the physical gate length.

508 `rsh=0.0 Ohm/sq` Sheet resistance of source diffusion.

509 `rshd=0.0 Ohm/sq` Sheet resistance of drain diffusion.

510 `rbulko=0.0 Ohm` Bulk resistance between node BP and BI.

511 `rwello=0.0 Ohm` Well resistance between node BI and B.

512 `rjunso=0.0 Ohm` Source-side bulk resistance between node BI and BS.

513 `rjundo=0.0 Ohm` Drain-side bulk resistance between node BI and BD.

514 `saref=1.0e-6 m` Reference distance between OD-edge and poly from one side.

515 `sbref=1.0e-6 m` Reference distance between OD-edge and poly from other side.

516 `wlod=0 m` Width parameter.

517 `kuo=0 m` Mobility degradation/enhancement coefficient.

518 `kvsat=0 m` Saturation velocity degradation/enhancement coefficient.

519 `tkuo=0` Temperature dependence of KUO.

520 `lkuo=0 m^LLODKUO` Length dependence of KUO.

521 `wkuo=`0 m^WLODKUO Width dependence of KUO.

522 `pkuo=0 m^(LLODKUO+WLODKUO`
Cross-term dependence of KUO.

523 `llodkuo=0` Length parameter for UO stress effect.

524 `wlodkuo=0` Width parameter for UO stress effect.

525 `kvtho=0 Vm` Threshold shift parameter.

526 `lkvtho=0 m^LLODVTH`
Length dependence of KVTHO.

527 `wkvtho=0 m^WLODVTH`
Width dependence of KVTHO.

528 `pkvtho=0 m^(LLODVTH+WLODVTH`
Cross-term dependence of KVTHO.

529 `llodvth=0` Length parameter for VTH-stress effect.

530 `wlodvth=0` Width parameter for VTH-stress effect.

531 `stetao=0 m` eta0 shift factor related to VTHO change.

532 `lodetao=1.0` eta0 shift modification factor for stress effect.

533 `scref=1.0e-6 m` Distance between OD-edge and well edge of a reference device.

534 `web=0` Coefficient for SCB.

535 `wec=0` Coefficient for SCC.

536 `imax=1000 A` Maximum current up to which forward current behaves exponentially.

537 `trj=21 C` reference temperature.

538 `cjorbot=1E-3 Fm^-2`
Zero-bias capacitance per unit-of-area of bottom component for source-bulk junction.

539 `cjorsti=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for source-bulk junction.

540 `cjorgat=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for source-bulk junction.

541 `vbirbot=1 V` Built-in voltage at the reference temperature of bottom component for source-bulk junction.

542 `vbirsti=1 V` Built-in voltage at the reference temperature of STI-edge component for source-bulk junction.

543 `vbirgat=1 V` Built-in voltage at the reference temperature of gate-edge component for source-bulk junction.

544 `pbot=`0.5 Grading coefficient of bottom component for source-bulk junction.

545 `psti=`0.5 Grading coefficient of STI-edge component for source-bulk junction.

546 `pgat=`0.5 Grading coefficient of gate-edge component for source-bulk junction.

547 `phigbot=1.16 V` Zero-temperature bandgap voltage of bottom component for source-bulk junction.

548 `phigsti=1.16 V` Zero-temperature bandgap voltage of STI-edge component for source-bulk junction.

549 `phiggat=1.16 V` Zero-temperature bandgap voltage of gate-edge component for source-bulk junction.

550 `idsatrbot=1E-12 Am^-2`
Saturation current density at the reference temperature of bottom component for source-bulk junction.

551 `idsatrsti=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for source-bulk junction.

552 `idsatrgat=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for source-bulk junction.

553 `csrhbot=1E2 Am^-3` Shockley-Read-Hall prefactor of bottom component for source-bulk junction.

554 `csrhsti=1E-4 Am^-2`
Shockley-Read-Hall prefactor of STI-edge component for source-bulk junction.

555 `csrhgat=1E-4 Am^-2`
Shockley-Read-Hall prefactor of gate-edge component for source-bulk junction.

556 `xjunsti=100E-9 m` Junction depth of STI-edge component for source-bulk junction.

557 `xjungat=100E-9 m` Junction depth of gate-edge component for source-bulk junction.

558 `ctatbot=1E2 Am^-3` Trap-assisted tunneling prefactor of bottom component for source-bulk junction.

559 `ctatsti=1E-4 Am^-2`
Trap-assisted tunneling prefactor of STI-edge component for source-bulk junction.

560 `ctatgat=1E-4 Am^-2`
Trap-assisted tunneling prefactor of gate-edge component for source-bulk junction.

561 `mefftatbot=`0.25 Effective mass (in units of m0) for trap-assisted tunneling of bottom component for source-bulk junction.

562 `mefftatsti=`0.25 Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for source-bulk junction.

563 `mefftatgat=`0.25 Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for source-bulk junction.

564 `cbbtbot=1E-12 AV^-3`
Band-to-band tunneling prefactor of bottom component for source-bulk junction.

565 `cbbtsti=1E-18 AV^-3m`
Band-to-band tunneling prefactor of STI-edge component for source-bulk junction.

566 `cbbtgat= 1E-18 AV^-3m`
Band-to-band tunneling prefactor of gate-edge component for source-bulk junction.

567 `fbbtrbot=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component for source-bulk junction.

568 `fbbtrsti=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for source-bulk junction.

569 `fbbtrgat=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for source-bulk junction.

570 `stfbbtbot=-1E-3 K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for source-bulk junction.

571 `stfbbtsti=-3 K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for source-bulk junction.

572 `stfbbtgat=-1E-3 K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for source-bulk junction.

573 `vbrbot=10 V` Breakdown voltage of bottom component for source-bulk junction.

574 `vbrsti=10 V` Breakdown voltage of STI-edge component for source-bulk junction.

575 `vbrgat=10 V` Breakdown voltage of gate-edge component for source-bulk junction.

576 `pbrbot=4 V` Breakdown onset tuning parameter of bottom component for source-bulk junction.

577 `pbrsti=4 V` Breakdown onset tuning parameter of STI-edge component for source-bulk junction.

578 `pbrgat=4 V` Breakdown onset tuning parameter of gate-edge component for source-bulk junction.

579 `cjorbotd=1E-3 Fm^-2`
Zero-bias capacitance per unit-of-area of bottom component for drain-bulk junction.

580 `cjorstid=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for drain-bulk junction.

581 `cjorgatd=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for drain-bulk junction.

582 `vbirbotd=1 V` Built-in voltage at the reference temperature of bottom component for drain-bulk junction.

583 `vbirstid=1 V` Built-in voltage at the reference temperature of STI-edge component for drain-bulk junction.

584 `vbirgatd=1 V` Built-in voltage at the reference temperature of gate-edge component for drain-bulk junction.

585 `pbotd=`0.5 Grading coefficient of bottom component for drain-bulk junction.

586 `pstid=`0.5 Grading coefficient of STI-edge component for drain-bulk junction.

587 `pgatd=`0.5 Grading coefficient of gate-edge component for drain-bulk junction.

588 `phigbotd=`1.16 V Zero-temperature bandgap voltage of bottom component for drain-bulk junction.

589 `phigstid=1.16 V` Zero-temperature bandgap voltage of STI-edge component for drain-bulk junction.

590 `phiggatd=1.16 V` Zero-temperature bandgap voltage of gate-edge component for drain-bulk junction.

591 `idsatrbotd=1E-12 Am^-2`
Saturation current density at the reference temperature of bottom component for drain-bulk junction.

592 `idsatrstid=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for drain-bulk junction.

593 `idsatrgatd=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for drain-bulk junction.

594 `csrhbotd=1E2 Am^-3`
Shockley-Read-Hall prefactor of bottom component for drain-bulk junction.

595 `csrhstid=1E-4 Am^-2`
Shockley-Read-Hall prefactor of STI-edge component for drain-bulk junction.

596 `csrhgatd=1E-4 Am^-2`
Shockley-Read-Hall prefactor of gate-edge component for drain-bulk junction.

597 `xjunstid=100E-9 m` Junction depth of STI-edge component for drain-bulk junction.

598 `xjungatd=100E-9 m` Junction depth of gate-edge component for drain-bulk junction.

599 `ctatbotd=1E2 Am^-3`
Trap-assisted tunneling prefactor of bottom component for drain-bulk junction.

600 `ctatstid=1E-4 Am^-2`
Trap-assisted tunneling prefactor of STI-edge component for drain-bulk junction.

601 `ctatgatd=1E-4 Am^-2`
Trap-assisted tunneling prefactor of gate-edge component for drain-bulk junction.

602 `mefftatbotd=`0.25 Effective mass (in units of m0) for trap-assisted tunneling of bottom component for drain-bulk junction.

603 `mefftatstid=`0.25 Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for drain-bulk junction.

604 `mefftatgatd=`0.25 Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for drain-bulk junction.

605 `cbbtbotd=1E-12 AV^-3`
Band-to-band tunneling prefactor of bottom component for drain-bulk junction.

606 `cbbtstid=1E-18 AV^-3m`
Band-to-band tunneling prefactor of STI-edge component for drain-bulk junction.

607 `cbbtgatd=1E-18 AV^-3m`
Band-to-band tunneling prefactor of gate-edge component for drain-bulk junction.

608 `fbbtrbotd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component for drain-bulk junction.

609 `fbbtrstid=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for drain-bulk junction.

610 `fbbtrgatd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for drain-bulk junction.

611 `stfbbtbotd=-1E-3 K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for drain-bulk junction.

612 `stfbbtstid=-1E-3 K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for drain-bulk junction.

613 `stfbbtgatd=1E-3 K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for drain-bulk junction.

614 `vbrbotd=10 V` Breakdown voltage of bottom component for drain-bulk junction.

615 `vbrstid=10 V` Breakdown voltage of STI-edge component for drain-bulk junction.

616 `vbrgatd=10 V` Breakdown voltage of gate-edge component for drain-bulk junction.

617 `pbrbotd=4 V` Breakdown onset tuning parameter of bottom component for drain-bulk junction.

618 `pbrstid=4 V` Breakdown onset tuning parameter of STI-edge component for drain-bulk junction.

619 `pbrgatd=`4 V Breakdown onset tuning parameter of gate-edge component for drain-bulk junction.

620 `swjunexp=0` Flag for JUNCAP-express; 0,full model, 1,express model.

621 `vjunref=2.5` Typical maximum source-bulk junction voltage; usually about 2*VSUP.

622 `fjunq=0.03` Fraction below which source-bulk junction capacitance components are considered negligible.

623 `vjunrefd=2.5` Typical maximum drain-bulk junction voltage; usually about 2*VSUP.

624 `fjunqd=0.03` Fraction below which drain-bulk junction capacitance components are considered negligible.

625 `dta=0.0 K` Temperature offset w.r.t. ambient temperature.

626 `w=10e-6 m` Default width.

627 `l=`10e-6 m Default length.

628 `nf=1` Number of fingers, It served as the default value of instance nf.

629 `vds_max=infinity V`
Maximum allowed voltage cross source and drain.

630 `vgd_max=infinity V`
Maximum allowed voltage cross gate and drain.

631 `vgs_max=infinity V`
Maximum allowed voltage cross gate and source/bulk.

632 `vbd_max=infinity V`
Maximum allowed voltage cross source/drain and bulk.

633 `vbs_max=infinity V`
Maximum allowed voltage cross source and bulk.

634 `vgb_max=infinity V`
Maximum allowed voltage cross gate and bulk.

635 `vthmod` Vth output selector. std outputs model equation Vth. vthcc outputs constant current Vth, and may impact simulation performance. The default value is taken from the options parameter vthmod.
Possible values are `std` or `vthcc`.

636 `ivth (A)` Vth current parameter. The default value is taken from the options parameter ivthn or ivthp, depending on the type of the model.

637 `ivthw (m)` Width offset for constant current Vth. The default value is taken from the options parameter ivthw.

638 `ivthl (m)` Length offset for constant current Vth. The default value is taken from the options parameter ivthl.

639 `ivth_vdsmin (V)` Minimum Vds in constant current Vth calculating. The default value is taken from the options parameter ivth_vdsmin.

Output Parameters

1 `lv2 (m)` alias of w.

2 `lv1 (m)` alias of l.

3 `lv3 (m^2)` alias of ad.

4 `lv4 (m^2)` alias of as.

5 `lv11 (m)` alias of pd.

6 `lv12 (m)` alias of ps.

7 `table_pseff (m)`
For table model.

8 `table_pdeff (m)`
For table model.

Operating-Point Parameters

1 `l=10e-6 m`	Design length.
2 `w=10e-6 m`	Design width.
3 `sa=0.0 m`	Distance between OD-edge and poly from one side.
4 `sb=0.0 m`	Distance between OD-edge and poly from other side.
5 `sd=0.0 m`	Distance between neighboring fingers.
6 `sca=`0.0	Integral of the first distribution function for scattered well dopants.
7 `scb=`0.0	Integral of the second distribution function for scattered well dopants.
8 `scc=`0.0	Integral of the third distribution function for scattered well dopants.
9 `sc=0.0 m`	Distance between OD-edge and nearest well edge.
10 `nf=1`	Number of fingers.
11 `ngcon=1.0`	Number of gate contacts.
12 `xgw=` 1.0E-7 m	Distance from the gate contact to the channel edge.
13 `nrs=0.0`	Number of squares of source diffusion.
14 `nrd=0.0`	Number of squares of drain diffusion.
15 `trise=0.0 K`	Temperature rise from ambient.
16 `jw=1E-6 m`	Gate-edge length of source/drain junction.
17 `delvto=0.0 V`	Threshold voltage shift parameter.

18 `factuo=1.0` Zero-field mobility pre-factor.

19 `absource=1E-12 m^2`
Bottom area of source junction.

20 `lssource=1E-6 m` STI-edge length of source junction.

21 `lgsource=1E-6 m` Gate-edge length of source junction.

22 `abdrain=1E-12 m^2` Bottom area of drain junction.

23 `lsdrain=1E-6 m` STI-edge length of drain junction.

24 `lgdrain=1E-6 m` Gate-edge length of drain junction.

25 `as=1E-12 m^2` Bottom area of source junction.

26 `ps=1E-6 m` Perimeter of source junction.

27 `ad=1E-12 m^2` Bottom area of drain junction.

28 `pd=1E-6 m` Perimeter of drain junction.

29 `ctype` Flag for channel type.

30 `sdint` Flag for source-drain interchange.

31 `ise (A)` Total source current.

32 `ige (A)` Total gate current.

33 `ide (A)` Total drain current.

34 `ibe (A)` Total bulk current.

35 `ids (A)` Drain current, excl. avalanche, tunnel, GISL, GIDL, and junction currents.

36 `idb (A)` Drain to bulk current.

37 `isb (A)` Source to bulk current.

38 `igs (A)` Gate-source tunneling current.

39 `igd (A)`	Gate-drain tunneling current.
40 `igb (A)`	Gate-bulk tunneling current.
41 `igcs (A)`	Gate-channel tunneling current (source component.
42 `igcd (A)`	Gate-channel tunneling current (drain component.
43 `iavl (A)`	Substrate current due to weak avelanche.
44 `igisl (A)`	Gate-induced source leakage current.
45 `igidl (A)`	Gate-induced drain leakage current.
46 `ijs (A)`	Total source junction current.
47 `ijsbot (A)`	Source junction current (bottom component.
48 `ijsgat (A)`	Source junction current (gate-edge component.
49 `ijssti (A)`	Source junction current (STI-edge component.
50 `ijd (A)`	Total drain junction current.
51 `ijdbot (A)`	Drain junction current (bottom component.
52 `ijdgat (A)`	Drain junction current (gate-edge component.
53 `ijdsti (A)`	Drain junction current (STI-edge component.
54 `qg (Coul)`	Intrinsic gate charge.
55 `qd (Coul)`	Intrinsic drain chargen.
56 `qb (Coul)`	Intrinsic bulk charge.
57 `qs (Coul)`	Intrinsic source charge.
58 `qgs_ov (Coul)`	Overlap charge for gate-source.
59 `qgd_ov (Coul)`	Overlap charge for gate-drain.
60 `qfgs (Coul)`	Total outerFringe + overlap for gate-source.

61 `qfgd (Coul)`	Total outerFringe + overlap for gate-drain.
62 `qgb_ov (Coul)`	Gate-bulk overlap charge.
63 `qjun_s (Coul)`	Junction charge on source side.
64 `qjun_d (Coul)`	Junction charge on drain side.
65 `vds (V)`	Drain-source voltage.
66 `vgs (V)`	Gate-source voltage.
67 `vsb (V)`	Source-bulk voltage.
68 `vto (V)`	Zero-bias threshold voltage.
69 `vts (V)`	Threshold voltage including back bias effects.
70 `vth (V)`	Threshold voltage including back bias and drain bias effects.
71 `vgt (V)`	Effective gate drive voltage including back bias and drain bias effects.
72 `vdss (V)`	Drain saturation voltage at actual bias.
73 `vsat`	Saturation limit.
74 `gm (1/Ohm)`	Transconductance.
75 `gmb (1/Ohm)`	Substrate transconductance.
76 `gds (1/Ohm)`	Output conductance.
77 `gjs (1/Ohm)`	Source junction conductance.
78 `gjd (1/Ohm)`	Drain junction conductance.
79 `cdd (F)`	Drain capacitance.
80 `cdg (F)`	Drain-gate capacitance.
81 `cds (F)`	Drain-source capacitance.

82 `cdb (F)`	Drain-bulk capacitance.
83 `cgd (F)`	Gate-drain capacitance.
84 `cgg (F)`	Gate capacitance.
85 `cgs (F)`	Gate-source capacitance.
86 `cgb (F)`	Gate-bulk capacitance.
87 `csd (F)`	Source-drain capacitance.
88 `csg (F)`	Source-gate capacitance.
89 `css (F)`	Source capacitance.
90 `csb (F)`	Source-bulk capacitance.
91 `cbd (F)`	Bulk-drain capacitance.
92 `cbg (F)`	Bulk-gate capacitance.
93 `cbs (F)`	Bulk-source capacitance.
94 `cbb (F)`	Bulk capacitance.
95 `cgsol (F)`	Total gate-source overlap capacitance.
96 `cgdol (F)`	Total gate-drain overlap capacitance.
97 `cgbol (F)`	Total gate-bulk overlap capacitance.
98 `cjs (F)`	Total source junction capacitance.
99 `cjsbot (F)`	Source junction capacitance (bottom component.
100 `cjsgat (F)`	Source junction capacitance (gate-edge component.
101 `cjssti (F)`	Source junction capacitance (STI-edge component.
102 `cjd (F)`	Total drain junction capacitance.
103 `cjdbot (F)`	Drain junction capacitance (bottom component.

104 `cjdgat (F)`	Drain junction capacitance (gate-edge component.
105 `cjdsti (F)`	Drain junction capacitance (STI-edge component.
106 `weff (m)`	Effective channel width for geometrical models.
107 `leff (m)`	Effective channel length for geometrical models.
108 `lpoly (m)`	
109 `u`	Transistor gain.
110 `rout (Ohm)`	Small-signal output resistance.
111 `vearly (V)`	Equivalent Early voltage.
112 `beff (A/V^2)`	Gain factor.
113 `fug (Hz)`	Unity gain frequency at actual bias.
114 `rg (Ohm)`	Gate resistance.
115 `sfl`	Flicker noise current density at 1 Hz.
116 `sqrtsff`	Input-referred RMS white noise voltage density at 1 kHz.
117 `sqrtsfw`	Input-referred RMS white noise voltage density.
118 `sid`	White noise current density.
119 `sig`	Induced gate noise current density at 1 Hz.
120 `cigid`	Imaginary part of correlation coefficient between Sig and Sid.
121 `fknee`	Cross-over frequency above which white noise is dominant.
122 `sigs`	Gate-source current noise spectral density.
123 `sigd`	Gate-drain current noise spectral density.
124 `siavl`	Impact ionization current noise spectral density.
125 `ssi`	Total source junction current noise spectral density.

126 `sdi`	Total drain junction current noise spectral density.
127 `lp_vfb (V)`	Local parameter VFB after T-scaling and clipping.
128 `lp_stvfb (V/K)`	Local parameter STVFB after clipping.
129 `lp_tox (m)`	Local parameter TOX after clipping.
130 `lp_epsrox`	Local parameter EPSROX after clipping.
131 `lp_neff (m^-3)`	Local parameter NEFF after clipping.
132 `lp_facneffac`	Local parameter FACNEFFAC after clipping.
133 `lp_gfacnud`	Local parameter GFACNUD after clipping.
134 `lp_vsbnud (V)`	Local parameter VSBNUD after clipping.
135 `lp_dvsbnud (V)`	Local parameter DVSBNUD after clipping.
136 `lp_vnsub (V)`	Local parameter VNSUB after clipping.
137 `lp_nslp (V)`	Local parameter NSLP after clipping.
138 `lp_dnsub (V^-1)`	Local parameter DNSUB after clipping.
139 `lp_dphib (V)`	Local parameter DPHIB after clipping.
140 `lp_delvtac (V)`	Local parameter DELVTAC after clipping.
141 `lp_np (m^-3)`	Local parameter NP after clipping.
142 `lp_ct`	Local parameter CT after clipping.
143 `lp_toxov (m)`	Local parameter TOXOV after clipping.
144 `lp_toxovd (m)`	Local parameter TOXOVD after clipping.
145 `lp_nov (m^-3)`	Local parameter NOV after clipping.
146 `lp_novd (m^-3)`	Local parameter NOVD after clipping.

147 `lp_cf` Local parameter CF after clipping.

148 `lp_cfb (V^-1)` Local parameter CFB after clipping.

149 `lp_betn (m^2/V s)`
Local parameter BETN after T-scaling and clipping.

150 `lp_stbet` Local parameter STBET after clipping.

151 `lp_mue (m/V)` Local parameter MUE after T-scaling and clipping.

152 `lp_stmue` Local parameter STMUE after clipping.

153 `lp_themu` Local parameter THEMU after T-scaling and clipping.

154 `lp_stthemu` Local parameter STTHEMU after clipping.

155 `lp_cs` Local parameter CS after T-scaling and clipping.

156 `lp_stcs` Local parameter STCS after clipping.

157 `lp_xcor (V^-1)` Local parameter XCOR after T-scaling and clipping.

158 `lp_stxcor` Local parameter STXCOR after clipping.

159 `lp_feta` Local parameter FETA after clipping.

160 `lp_rs (Ohm)` Local parameter RS after T-scaling and clipping.

161 `lp_strs` Local parameter STRS after clipping.

162 `lp_rsb (V^-1)` Local parameter RSB after clipping.

163 `lp_rsg (V^-1)` Local parameter RSG after clipping.

164 `lp_thesat (V^-1)`
Local parameter THESAT after T-scaling and clipping.

165 `lp_stthesat` Local parameter STTHESAT after clipping.

166 `lp_thesatb (V^-1)`
Local parameter THESATB after clipping.

167 `lp_thesatg (V^-1)`
Local parameter THESATG after clipping.

168 `lp_ax` Local parameter AX after clipping.

169 `lp_alp` Local parameter ALP after clipping.

170 `lp_alp1 (V)` Local parameter ALP1 after clipping.

171 `lp_alp2 (V^-1)` Local parameter ALP2 after clipping.

172 `lp_vp (V)` Local parameter VP after clipping.

173 `lp_a1` Local parameter A1 after clipping.

174 `lp_a2 (V)` Local parameter A2 after T-scaling and clipping.

175 `lp_sta2` Local parameter STA2 after clipping.

176 `lp_a3` Local parameter A3 after clipping.

177 `lp_a4 (1/sqrt(V)`
Local parameter A4 after clipping.

178 `lp_gco` Local parameter GCO after clipping.

179 `lp_iginv (A)` Local parameter IGINV after T-scaling and clipping.

180 `lp_igov (A)` Local parameter IGOV after T-scaling and clipping.

181 `lp_igovd (A)` Local parameter IGOVD after T-scaling and clipping.

182 `lp_stig` Local parameter STIG after clipping.

183 `lp_gc2` Local parameter GC2 after clipping.

184 `lp_gc3` Local parameter GC3 after clipping.

185 `lp_chib (V)` Local parameter CHIB after clipping.

186 `lp_agidl (A/V^3)`
Local parameter AGIDL after clipping.

187 `lp_agidld (A/V^3)`
Local parameter AGIDLD after clipping.

188 `lp_bgidl (V)` Local parameter BGIDL after T-scaling and clipping.

189 `lp_bgidld (V)` Local parameter BGIDLD after T-scaling and clipping.

190 `lp_stbgidl (V/K)`
Local parameter STBGIDL after clipping.

191 `lp_stbgidld (V/K)`
Local parameter STBGIDLD after clipping.

192 `lp_cgidl` Local parameter CGIDL after clipping.

193 `lp_cgidld` Local parameter CGIDLD after clipping.

194 `lp_cox (F)` Local parameter COX after clipping.

195 `lp_cgov (F)` Local parameter CGOV after clipping.

196 `lp_cgovd (F)` Local parameter CGOVD after clipping.

197 `lp_cgbov (F)` Local parameter CGBOV after clipping.

198 `lp_cfr (F)` Local parameter CFR after clipping.

199 `lp_cfrd (F)` Local parameter CFRD after clipping.

200 `lp_fnt` Local parameter FNT after clipping.

201 `lp_nfa (1/(V m^4)`
Local parameter NFA after clipping.

202 `lp_nfb (1/(V m^2)`
Local parameter NFB after clipping.

203 `lp_nfc (V^-1)` Local parameter NFC after clipping.

204 `lp_ef` Local parameter EF after clipping.

205 `lp_rg (Ohm)` Local parameter RG after clipping.

206 `lp_rse (Ohm)`	Local parameter RSE after clipping.
207 `lp_rde (Ohm)`	Local parameter RDE after clipping.
208 `lp_rbulk (Ohm)`	Local parameter RBULK after clipping.
209 `lp_rwell (Ohm)`	Local parameter RWELL after clipping.
210 `lp_rjuns (Ohm)`	Local parameter RJUNS after clipping.
211 `lp_rjund (Ohm)`	Local parameter RJUND after clipping.
212 `lp_munqs`	Local parameter MUNQS after clipping.
213 `lv13`	alias of nrd.
214 `lv14`	alias of nrs.
215 `lv36 (F)`	alias of cgsol.
216 `lv37 (F)`	alias of cgdol.
217 `lv38 (F)`	alias of cgbol.
218 `table_ids (A)`	For table model.
219 `table_vth (V)`	For table model.
220 `table_qg (coul)`	For table model.
221 `table_qd (coul)`	For table model.
222 `table_qb (Coul)`	For table model.
223 `table_id (A)`	For table model.
224 `table_isub (A)`	For table model.
225 `table_ibs (A)`	For table model.

226 `table_ibd (A)` For table model.

227 `table_igd (A)` For table model.

228 `table_igb (A)` For table model.

229 `table_igs (A)` For table model.

230 `table_gds (1/Ohm)`
For table model.

231 `table_gm (1/Ohm)`
For table model.

232 `table_gmbs (1/Ohm)`
For table model.

233 `table_qbs (Coul)`
For table model.

234 `table_qbd (Coul)`
For table model.

235 `table_vdsat (V)`
For table model.

236 `table_leff (m)` For table model.

237 `table_weff (m)` For table model.

238 `table_aseff (m^2)`
For table model.

239 `table_adeff (m^2)`
For table model.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

PSP NQS MOSFET Model (pspnqs103)

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `l=10e-6 m` Design length.

2 `w=10e-6 m` Design width.

3 `sa=0.0 m` Distance between OD-edge and poly from one side.

4 `sb=0.0 m` Distance between OD-edge and poly from other side.

5 `sd=0.0 m` Distance between neighboring fingers.

6 `sca=0.0` Integral of the first distribution function for scattered well dopants.

7 `scb=0.0` Integral of the second distribution function for scattered well dopants.

8 `scc=0.0` Integral of the third distribution function for scattered well dopants.

9 `sc=0.0 m` Distance between OD-edge and nearest well edge.

10 `nf=1` Number of fingers.

11 `ngcon=1.0` Number of gate contacts.

12 `xgw=1.0E-7 m` Distance from the gate contact to the channel edge.

13 `nrs=0.0` Number of squares of source diffusion.

14 `nrd=0.0` Number of squares of drain diffusion.

15 `trise=0.0 K` Temperature rise from ambient.

16 `jw=1E-6 m` Gate-edge length of source/drain junction.

17 `delvto=0.0 V` Threshold voltage shift parameter.

18 `factuo=1.0` Zero-field mobility pre-factor.

19 `absource=1E-12 m^2`
Bottom area of source junction.

20 `lssource=1E-6 m` STI-edge length of source junction.

21 `lgsource=1E-6 m` Gate-edge length of source junction.

22 `abdrain=1E-12 m^2` Bottom area of drain junction.

23 `lsdrain=1E-6 m` STI-edge length of drain junction.

24 `lgdrain=1E-6 m` Gate-edge length of drain junction.

25 `as=1E-12 m^2` Bottom area of source junction.

26 `ps=1E-6 m` Perimeter of source junction.

27 `ad=1E-12 m^2` Bottom area of drain junction.

28 `pd=1E-6 m` Perimeter of drain junction.

29 `mult=1.0` Number of devices in parallel.

30 `mlid0=1` Ids multiplier.

31 `m=1.0` Multiplicity factor.

32 `isnoisy=yes` Should device generate noise.
Possible values are `no` or `yes`.

Model Definition

```
model modelName pspnqs103 parameter=value ...
```

Model Parameters

1 `level=103` Model level.

2 `type=n` Channel type parameter, n,NMOS p,PMOS.
Possible values are `n` or `p`.

3 `tr=value of tnom C`
nominal (reference) temperature.

4 `swnqs=0` Flag for NQS, 0,off, 1, 2, 3, 5, or 9,number of collocation points.

5 `swgeo=0` Flag for geometrical model, 0,local, 1,global, 2,binning.

6 `swigate=0` Flag for gate current, 0,turn off IG.

7 `swimpact=0`	Flag for impact ionization current, 0,turn off II.
8 `swgidl=0`	Flag for GIDL current, 0,turn off IGIDL.
9 `swjuncap=0`	Flag for juncap, 0,turn off juncap.
10 `swjunasym=0`	Flag for asymmetric junctions; 0,symmetric, 1,asymmetric.
11 `swnud=0`	Flag for NUD-effect; 0,off, 1,on, 2,on+CV-correction.
12 `swdelvtac=`0	Flag for separate capacitance calculation; 0,off, 1,on.
13 `qmc=0`	Quantum-mechanical correction factor.
14 `version=103.0`	Model version selector. The available versions are 103.0, 103.1 and 103.11.
15 `minr=0.0`	Minimum resistance, in order to be compatible with the orignal model, set its default to 0.0.
16 `mvt=0.0`	DCmatch parameter.
17 `mvto=0.0`	DCmatch parameter.
18 `mbe=0.0`	DCmatch parameter.
19 `mbeo=0.0`	DCmatch parameter.
20 `vfb=1.0 V`	Flat band voltage at TR.
21 `stvfb=5.0e-4 V/K`	Temperature dependence of VFB.
22 `tox=2.0e-09 m`	Gate oxide thickness.
23 `epsrox=3.9`	Relative permittivity of gate dielectric.
24 `neff=5.0e+23 m^-3`	Effective substrate doping.
25 `facneffac=1.0`	Pre-factor for effective substrate doping in separate charge calculation.
26 `gfacnud=`1.0	Bodyfactor change due to NUD-effect.

27 `vsbnud=0.0 V` Lower Vsb value for NUD-effect.

28 `dvsbnud=1.0 V` Vsb-range for NUD-effect.

29 `vnsub=0.0 V` Effective doping bias-dependence parameter.

30 `nslp=0.05 V` Effective doping bias-dependence parameter.

31 `dnsub=0.0 V^-1` Effective doping bias-dependence parameter.

32 `dphib=0.0 V` Offset parameter for PHIB.

33 `delvtac=0.0 V` Offset parameter for PHIB in separate charge calculation.

34 `np=1.0e+26 m^-3` Gate poly-silicon doping.

35 `ct=0.0` Interface states factor.

36 `toxov=2.0e-09 m` Overlap oxide thickness.

37 `toxovd=2.0e-09 m` Overlap oxide thickness for drain side.

38 `nov=5.0e+25 m^-3` Effective doping of overlap region.

39 `novd=5.0e+25 m^-3` Effective doping of overlap region for drain side.

40 `cf=0.0` DIBL-parameter.

41 `cfb=0.0 V^-1` Back bias dependence of CF.

42 `betn=7e-2 m^2/V/s` Channel aspect ratio times zero-field mobility.

43 `stbet=1.0` Temperature dependence of BETN.

44 `mue=0.5 m/V` Mobility reduction coefficient at TR.

45 `stmue=0.0` Temperature dependence of MUE.

46 `themu=1.5` Mobility reduction exponent at TR.

47 `stthemu=1.5` Temperature dependence of THEMU.

48 `cs=0.0` Coulomb scattering parameter at TR.

49 `stcs=0.0`	Temperature dependence of CS.
50 `xcor=0.0 V^-1`	Non-universality factor.
51 `stxcor=0.0`	Temperature dependence of XCOR.
52 `feta=1.0`	Effective field parameter.
53 `rs=30 Ohm`	Series resistance at TR.
54 `strs=1.0`	Temperature dependence of RS.
55 `rsb=0.0 V^-1`	Back-bias dependence of series resistance.
56 `rsg=0.0 V^-1`	Gate-bias dependence of series resistance.
57 `thesat=1.0 V^-1`	Velocity saturation parameter at TR.
58 `stthesat=1.0`	Temperature dependence of THESAT.
59 `thesatb=0.0 V^-1`	Back-bias dependence of velocity saturation.
60 `thesatg=0.0 V^-1`	Gate-bias dependence of velocity saturation.
61 `ax=3.0`	Linear/saturation transition factor.
62 `alp=0.01`	CLM pre-factor.
63 `alp1=0.00 V`	CLM enhancement factor above threshold.
64 `alp2=0.00 V^-1`	CLM enhancement factor below threshold.
65 `vp=0.05 V`	CLM logarithm dependence factor.
66 `a1=`0.05 V	Impact-ionization pre-factor.
67 `a2=1.0`	Impact-ionization exponent at TR.
68 `sta2=0.0 V`	Temperature dependence of A2.
69 `a3=0`	Saturation-voltage dependence of impact-ionization.
70 `a4=0.0 V^-0.5`	Back-bias dependence of impact-ionization.

71 `gco=0.0`	Gate tunneling energy adjustment.
72 `iginv=0.0 A`	Gate channel current pre-factor.
73 `igov=0.0 A`	Gate overlap current pre-factor.
74 `igovd=0.0 A`	Gate overlap current pre-factor for drain side.
75 `stig=2.0`	Temperature dependence of IGINV and IGOV.
76 `gc2=`0.375	Gate current slope factor.
77 `gc3=`0.063	Gate current curvature factor.
78 `chib=3.1 V`	Tunneling barrier height.
79 `agidl=`0.0 A/V^3	GIDL pre-factor.
80 `agidld=0.0 A/V^3`	GIDL pre-factor for drain side.
81 `bgidl=41.0 V`	GIDL probability factor at TR.
82 `bgidld=41.0 V`	GIDL probability factor at TR for drain side.
83 `stbgidl=0.0 V/K`	Temperature dependence of BGIDL.
84 `stbgidld=0.0 V/K`	Temperature dependence of BGIDL for drain side.
85 `cgidl=0.0`	Back-bias dependence of GIDL.
86 `cgidld=0.0`	Back-bias dependence of GIDL for drain side.
87 `cox=1.0e-14 F`	Oxide capacitance for intrinsic channel.
88 `cgov=1.0e-15 F`	Oxide capacitance for gate-drain/source overlap.
89 `cgovd=1.0e-15 F`	Oxide capacitance for gate-drain overlap.
90 `cgbov=0.0 F`	Oxide capacitance for gate-bulk overlap.
91 `cfr=0.0 F`	Outer fringe capacitance.
92 `cfrd=0.0 F`	Outer fringe capacitance for drain side.

93 `fnt=1.0` Thermal noise coefficient.

94 `nfa=8.0e+22 V^-1/m^4`
First coefficient of flicker noise.

95 `nfb=3.0e+07 V^-1/m^2`
Second coefficient of flicker noise.

96 `nfc=0.0 V^-1` Third coefficient of flicker noise.

97 `ef=1.0` Flicker noise frequency exponent.

98 `munqs=1.0` Relative mobility for NQS modeling.

99 `rg=0.0 Ohm` Gate resistance.

100 `rse=0.0 Ohm` External source resistance.

101 `rde=0.0 Ohm` External drain resistance.

102 `rbulk=0.0 Ohm` Bulk resistance between node BP and BI.

103 `rwell=0.0 Ohm` Well resistance between node BI and B.

104 `rjuns=0.0 Ohm` Source-side bulk resistance between node BI and BS.

105 `rjund=0.0 Ohm` Drain-side bulk resistance between node BI and BD.

106 `povfb=1 V` Coefficient for the geometry independent part of VFB.

107 `plvfb=0.0 V` Coefficient for the length dependence of VFB.

108 `pwvfb=0.0 V` Coefficient for the width dependence of VFB.

109 `plwvfb=0.0 V` Coefficient for the length times width dependence of VFB.

110 `postvfb=0.0005 V/K`
Coefficient for the geometry independent part of STVFB.

111 `plstvfb=0.0 V/K` Coefficient for the length dependence of STVFB.

112 `pwstvfb=0.0 V/K` Coefficient for the width dependence of STVFB.

113 `plwstvfb=0.0 V/K` Coefficient for the length times width dependence of STVFB.

114 `potox=2E-09 m` Coefficient for the geometry independent part of TOX.

115 `poepsrox=3.9` Coefficient for the geometry independent part of EPSOX.

116 `poneff=5E+23 m^-3` Coefficient for the geometry independent part of NEFF.

117 `plneff=`0.0 m^-3 Coefficient for the length dependence of NEFF.

118 `pwneff=0.0 m^-3` Coefficient for the width dependence of NEFF.

119 `plwneff=0.0 m^-3` Coefficient for the length times width dependence of NEFF.

120 `pofacneffac=1.0` Coefficient for the geometry independent part of FACNEFFAC.

121 `plfacneffac=0.0` Coefficient for the length dependence of FACNEFFAC.

122 `pwfacneffac=`0.0 Coefficient for the width dependence of FACNEFFAC.

123 `plwfacneffac=0.0` Coefficient for the length times width dependence of FACNEFFAC.

124 `pogfacnud=1.0` Coefficient for the geometry independent part of GFACNUD.

125 `plgfacnud=0.0` Coefficient for the length dependence of GFACNUD.

126 `pwgfacnud=0.0` Coefficient for the width dependence of GFACNUD.

127 `plwgfacnud=0.0` Coefficient for the length times width dependence of GFACNUD.

128 `povsbnud=0.0 V` Coefficient for the geometry independent part of VSBNUD.

129 `podvsbnud=1.0 V` Coefficient for the geometry independent part of DVSBNUD.

130 `povnsub=0 V` Coefficient for the geometry independent part of VNSUB.

131 `ponslp=0.05 V` Coefficient for the geometry independent part of NSLP.

132 `podnsub=0 V^-1` Coefficient for the geometry independent part of DNSUB.

133 `podphib=0 V` Coefficient for the geometry independent part of DPHIB.

134 `pldphib=0.0 V` Coefficient for the length dependence of DPHIB.

135 `pwdphib=` 0.0 V Coefficient for the width dependence of DPHIB.

136 `plwdphib=0.0 V` Coefficient for the length times width dependence of DPHIB.

137 `podelvtac=0 V` Coefficient for the geometry independent part of DELVTAC.

138 `pldelvtac=0.0 V` Coefficient for the length dependence of DELVTAC.

139 `pwdelvtac=0.0 V` Coefficient for the width dependence of DELVTAC.

140 `plwdelvtac=0.0 V` Coefficient for the length times width dependence of DELVTAC.

141 `ponp=1E+26 m^-3` Coefficient for the geometry independent part of NP.

142 `plnp=0.0 m^-3` Coefficient for the length dependence of NP.

143 `pwnp=0.0 m^-3` Coefficient for the width dependence of NP.

144 `plwnp=0.0 m^-3` Coefficient for the length times width dependence of NP.

145 `poct=0` Coefficient for the geometry independent part of CT.

146 `plct=0.0` Coefficient for the length dependence of CT.

147 `pwct=0.0` Coefficient for the width dependence of CT.

148 `plwct=0.0` Coefficient for the length times width dependence of CT.

149 `potoxov=2E-09 m` Coefficient for the geometry independent part of TOXOV.

150 `potoxovd=2E-09 m` Coefficient for the geometry independent part of TOXOV for drain side.

151 `ponov=5E+25 m^-3` Coefficient for the geometry independent part of NOV.

152 `plnov=0.0 m^-3` Coefficient for the length dependence of NOV.

153 `pwnov=0.0 m^-3` Coefficient for the width dependence of NOV.

154 `plwnov=0.0 m^-3` Coefficient for the length times width dependence of NOV.

155 `ponovd=5E+25 m^-3` Coefficient for the geometry independent part of NOV for drain side.

156 `plnovd=0.0 m^-3` Coefficient for the length dependence of NOV for drain side.

157 `pwnovd=0.0 m^-3` Coefficient for the width dependence of NOV for drain side.

158 `plwnovd=0.0 m^-3` Coefficient for the length times width dependence of NOV for drain side.

159 `pocf=0` Coefficient for the geometry independent part of CF.

160 `plcf=0.0` Coefficient for the length dependence of CF.

161 `pwcf=0.0` Coefficient for the width dependence of CF.

162 `plwcf=0.0` Coefficient for the length times width dependence of CF.

163 `pocfb=0 V^-1` Coefficient for the geometry independent part of CFB.

164 `pobetn=0.07 m^2/V/s`
Coefficient for the geometry independent part of BETN.

165 `plbetn=0.0 m^2/V/s`
Coefficient for the length dependence of BETN.

166 `pwbetn=0.0 m^2/V/s`
Coefficient for the width dependence of BETN.

167 `plwbetn=0.0 m^2/V/s`
Coefficient for the length times width dependence of BETN.

168 `postbet=1` Coefficient for the geometry independent part of STBET.

169 `plstbet=0.0` Coefficient for the length dependence of STBET.

170 `pwstbet=0.0` Coefficient for the width dependence of STBET.

171 `plwstbet=0.0` Coefficient for the length times width dependence of STBET.

172 `pomue=0.5 m/V` Coefficient for the geometry independent part of MUE.

173 `plmue=0.0 m/V` Coefficient for the length dependence of MUE.

174 `pwmue=0.0 m/V`	Coefficient for the width dependence of MUE.
175 `plwmue=0.0 m/V`	Coefficient for the length times width dependence of MUE.
176 `postmue=0`	Coefficient for the geometry independent part of STMUE.
177 `pothemu=1.5`	Coefficient for the geometry independent part of THEMU.
178 `postthemu=1.5`	Coefficient for the geometry independent part of STTHEMU.
179 `pocs=0`	Coefficient for the geometry independent part of CS.
180 `plcs=0.0`	Coefficient for the length dependence of CS.
181 `pwcs=0.0`	Coefficient for the width dependence of CS.
182 `plwcs=0.0`	Coefficient for the length times width dependence of CS.
183 `postcs=0`	Coefficient for the geometry independent part of STCS.
184 `poxcor=0 V^-1`	Coefficient for the geometry independent part of XCOR.
185 `plxcor=0 V^-1`	Coefficient for the length dependence of XCOR.
186 `pwxcor=0 V^-1`	Coefficient for the width dependence of XCOR.
187 `plwxcor=0 V^-1`	Coefficient for the length times width dependence of XCOR.
188 `postxcor=0`	Coefficient for the geometry independent part of STXCOR.
189 `pofeta=1`	Coefficient for the geometry independent part of FETA.
190 `pors=`30 Ohm	Coefficient for the geometry independent part of RS.
191 `plrs=0.0 Ohm`	Coefficient for the length dependence of RS.
192 `pwrs=0.0 Ohm`	Coefficient for the width dependence of RS.
193 `plwrs=0.0 Ohm`	Coefficient for the length times width dependence of RS.
194 `postrs=1`	Coefficient for the geometry independent part of STRS.
195 `porsb=0 V^-1`	Coefficient for the geometry independent part of RSB.

196 `porsg=0 V^-1` Coefficient for the geometry independent part of RSG.

197 `pothesat=1 V^-1` Coefficient for the geometry independent part of THESAT.

198 `plthesat=0.0 V^-1` Coefficient for the length dependence of THESAT.

199 `pwthesat=0.0 V^-1` Coefficient for the width dependence of THESAT.

200 `plwthesat=0.0 V^-1`
Coefficient for the length times width dependence of THESAT.

201 `postthesat=1` Coefficient for the geometry independent part of STTHESAT.

202 `plstthesat=0.0` Coefficient for the length dependence of STTHESAT.

203 `pwstthesat=0.0` Coefficient for the width dependence of STTHESAT.

204 `plwstthesat=0.0` Coefficient for the length times width dependence of STTHESAT.

205 `pothesatb=0 V^-1` Coefficient for the geometry independent part of THESATB.

206 `plthesatb=0.0 V^-1`
Coefficient for the length dependence of THESATB.

207 `pwthesatb=0.0 V^-1`
Coefficient for the width dependence of THESATB.

208 `plwthesatb=0.0 V^-1`
Coefficient for the length times width dependence of THESATB.

209 `pothesatg=0 V^-1` Coefficient for the geometry independent part of THESATG.

210 `plthesatg=0.0 V^-1`
Coefficient for the length dependence of THESATG.

211 `pwthesatg=0.0 V^-1`
Coefficient for the width dependence of THESATG.

212 `plwthesatg=0.0 V^-1`
Coefficient for the length times width dependence of THESATG.

213 `poax=3` Coefficient for the geometry independent part of AX.

214 `plax=0.0`	Coefficient for the length dependence of AX.
215 `pwax=0.0`	Coefficient for the width dependence of AX.
216 `plwax=0.0`	Coefficient for the length times width dependence of AX.
217 `poalp=0.01`	Coefficient for the geometry independent part of ALP.
218 `plalp=0.0`	Coefficient for the length dependence of ALP.
219 `pwalp=0.0`	Coefficient for the width dependence of ALP.
220 `plwalp=0.0`	Coefficient for the length times width dependence of ALP.
221 `poalp1=0 V`	Coefficient for the geometry independent part of ALP1.
222 `plalp1=0.0 V`	Coefficient for the length dependence of ALP1.
223 `pwalp1=0.0 V`	Coefficient for the width dependence of ALP1.
224 `plwalp1=0.0 V`	Coefficient for the length times width dependence of ALP1.
225 `poalp2=`0 V^-1	Coefficient for the geometry independent part of ALP2.
226 `plalp2=0.0 V^-1`	Coefficient for the length dependence of ALP2.
227 `pwalp2=0.0 V^-1`	Coefficient for the width dependence of ALP2.
228 `plwalp2=0.0 V^-1`	Coefficient for the length times width dependence of ALP2.
229 `povp=0.05 V`	Coefficient for the geometry independent part of VP.
230 `poa1=1`	Coefficient for the geometry independent part of A1.
231 `pla1=0.0`	Coefficient for the length dependence of A1.
232 `pwa1=0.0`	Coefficient for the width dependence of A1.
233 `plwa1=0.0`	Coefficient for the length times width dependence of A1.
234 `poa2=10 V`	Coefficient for the geometry independent part of A2.
235 `posta2=0 V`	Coefficient for the geometry independent part of STA2.

236 `poa3=1`	Coefficient for the geometry independent part of A3.
237 `pla3=0.0`	Coefficient for the length dependence of A3.
238 `pwa3=0.0`	Coefficient for the width dependence of A3.
239 `plwa3=0.0`	Coefficient for the length times width dependence of A3.
240 `poa4=0 V^-0.5`	Coefficient for the geometry independent part of A4.
241 `pla4=0.0 V^-0.5`	Coefficient for the length dependence of A4.
242 `pwa4=0.0 V^-0.5`	Coefficient for the width dependence of A4.
243 `plwa4=0.0 V^-0.5`	Coefficient for the length times width dependence of A4.
244 `pogco=0`	Coefficient for the geometry independent part of GCO.
245 `poiginv=0 A`	Coefficient for the geometry independent part of IGINV.
246 `pliginv=0.0 A`	Coefficient for the length dependence of IGINV.
247 `pwiginv=0.0 A`	Coefficient for the width dependence of IGINV.
248 `plwiginv=0.0 A`	Coefficient for the length times width dependence of IGINV.
249 `poigov=0 A`	Coefficient for the geometry independent part of IGOV.
250 `pligov=0.0 A`	Coefficient for the length dependence of IGOV.
251 `pwigov=0.0 A`	Coefficient for the width dependence of IGOV.
252 `plwigov=0.0 A`	Coefficient for the length times width dependence of IGOV.
253 `poigovd=0 A`	Coefficient for the geometry independent part of IGOV for drain side.
254 `pligovd=0.0 A`	Coefficient for the length dependence of IGOV for drain side.
255 `pwigovd=0.0 A`	Coefficient for the width dependence of IGOV for drain side.
256 `plwigovd=0.0 A`	Coefficient for the length times width dependence of IGOV for drain side.

257 `postig=2` Coefficient for the geometry independent part of STIG.

258 `pogc2=`0.375 Coefficient for the geometry independent part of GC2.

259 `pogc3=`0.063 Coefficient for the geometry independent part of GC3.

260 `pochib=3.1 V` Coefficient for the geometry independent part of CHIB.

261 `poagidl=0 A/V^3` Coefficient for the geometry independent part of AGIDL.

262 `plagidl=0.0 A/V^3` Coefficient for the length dependence of AGIDL.

263 `pwagidl=0.0 A/V^3` Coefficient for the width dependence of AGIDL.

264 `plwagidl=0.0 A/V^3`
Coefficient for the length times width dependence of AGIDL.

265 `poagidld=0 A/V^3` Coefficient for the geometry independent part of AGIDL for drain side.

266 `plagidld=0.0 A/V^3`
Coefficient for the length dependence of AGIDL for drain side.

267 `pwagidld=0.0 A/V^3`
Coefficient for the width dependence of AGIDL for drain side.

268 `plwagidld=0.0 A/V^3`
Coefficient for the length times width dependence of AGIDL for drain side.

269 `pobgidl=41 V` Coefficient for the geometry independent part of BGIDL.

270 `pobgidld=41 V` Coefficient for the geometry independent part of BGIDL for drain side.

271 `postbgidl=0 V/K` Coefficient for the geometry independent part of STBGIDL.

272 `postbgidld=0 V/K` Coefficient for the geometry independent part of STBGIDL for drain side.

273 `pocgidl=`0 Coefficient for the geometry independent part of CGIDL.

274 `pocgidld=0`	Coefficient for the geometry independent part of CGIDL for drain side.
275 `pocox=1E-14 F`	Coefficient for the geometry independent part of COX.
276 `plcox=0.0 F`	Coefficient for the length dependence of COX.
277 `pwcox=0.0 F`	Coefficient for the width dependence of COX.
278 `plwcox=0.0 F`	Coefficient for the length times width dependence of COX.
279 `pocgov=1E-15 F`	Coefficient for the geometry independent part of CGOV.
280 `plcgov=0.0 F`	Coefficient for the length dependence of CGOV.
281 `pwcgov=0.0 F`	Coefficient for the width dependence of CGOV.
282 `plwcgov=0.0 F`	Coefficient for the length times width dependence of CGOV.
283 `pocgovd=1E-15 F`	Coefficient for the geometry independent part of CGOV for drain side.
284 `plcgovd=`0.0 F	Coefficient for the length dependence of CGOV for drain side.
285 `pwcgovd=0.0 F`	Coefficient for the width dependence of CGOV for drain side.
286 `plwcgovd=0.0 F`	Coefficient for the length times width dependence of CGOV for drain side.
287 `pocgbov=0 F`	Coefficient for the geometry independent part of CGBOV.
288 `plcgbov=0.0 F`	Coefficient for the length dependence of CGBOV.
289 `pwcgbov=0.0 F`	Coefficient for the width dependence of CGBOV.
290 `plwcgbov=0.0 F`	Coefficient for the length times width dependence of CGBOV.
291 `pocfr=0 F`	Coefficient for the geometry independent part of CFR.
292 `plcfr=0.0 F`	Coefficient for the length dependence of CFR.
293 `pwcfr=`0.0 F	Coefficient for the width dependence of CFR.

294 `plwcfr=0.0 F` Coefficient for the length times width dependence of CFR.

295 `pocfrd=0 F` Coefficient for the geometry independent part of CFR for drain side.

296 `plcfrd=0.0 F` Coefficient for the length dependence of CFR for drain side.

297 `pwcfrd=0.0 F` Coefficient for the width dependence of CFR for drain side.

298 `plwcfrd=0.0 F` Coefficient for the length times width dependence of CFR for drain side.

299 `pofnt=1` Coefficient for the geometry independent part of FNT.

300 `ponfa=8E+22 V^-1/m^4`
Coefficient for the geometry independent part of NFA.

301 `plnfa=0.0 V^-1/m^4`
Coefficient for the length dependence of NFA.

302 `pwnfa=0.0 V^-1/m^4`
Coefficient for the width dependence of NFA.

303 `plwnfa=0.0 V^-1/m^4`
Coefficient for the length times width dependence of NFA.

304 `ponfb=3E+07 V^-1/m^2`
Coefficient for the geometry independent part of NFB.

305 `plnfb=0.0 V^-1/m^2`
Coefficient for the length dependence of NFB.

306 `pwnfb=0.0 V^-1/m^2`
Coefficient for the width dependence of NFB.

307 `plwnfb=0.0 V^-1/m^2`
Coefficient for the length times width dependence of NFB.

308 `ponfc=0 V^-1` Coefficient for the geometry independent part of NFC.

309 `plnfc=0.0 V^-1` Coefficient for the length dependence of NFC.

310 `pwnfc=0.0 V^-1` Coefficient for the width dependence of NFC.

311 `plwnfc=0.0 V^-1`	Coefficient for the length times width dependence of NFC.
312 `poef=1.0`	Coefficient for the flicker noise frequency exponent.
313 `pokvthowe=0`	Coefficient for the geometry independent part of KVTHOWE.
314 `plkvthowe=0`	Coefficient for the length dependence part of KVTHOWE.
315 `pwkvthowe=0`	Coefficient for the width dependence part of KVTHOWE.
316 `plwkvthowe=0`	Coefficient for the length times width dependence part of KVTHOWE.
317 `pokuowe=0`	Coefficient for the geometry independent part of KUOWE.
318 `plkuowe=0`	Coefficient for the length dependence part of KUOWE.
319 `pwkuowe=0`	Coefficient for the width dependence part of KUOWE.
320 `plwkuowe=0`	Coefficient for the length times width dependence part of KUOWE.
321 `lmin=0 m`	Dummy parameter to label binning set.
322 `lmax=1.0 m`	Dummy parameter to label binning set.
323 `wmin=0 m`	Dummy parameter to label binning set.
324 `wmax=1.0 m`	Dummy parameter to label binning set.
325 `lvaro=0.0 m`	Geom. independent difference between actual and programmed gate length.
326 `lvarl=0.0`	Length dependence of LVAR.
327 `lvarw=0.0`	Width dependence of LVAR.
328 `lap=0.0 m`	Effective channel length reduction per side.
329 `wvaro=0.0 m`	Geom. independent difference between actual and programmed field-oxide opening.
330 `wvarl=0.0`	Length dependence of WVAR.

331 `wvarw=0.0`	Width dependence of WVAR.
332 `wot=0.0 m`	Effective channel width reduction per side.
333 `dlq=`0.0 m	Effective channel length reduction for CV.
334 `dwq=0.0 m`	Effective channel width reduction for CV.
335 `vfbo=1.0 V`	Geometry-independent flat-band voltage at TR.
336 `vfbl=0.0 V`	Length dependence of flat-band voltage.
337 `vfbw=0.0 V`	Width dependence of flat-band voltage.
338 `vfblw=0.0 V`	Area dependence of flat-band voltage.
339 `stvfbo=5e-4 V/K`	Geometry-independent temperature dependence of VFB.
340 `stvfbl=0.0 V/K`	Length dependence of temperature dependence of VFB.
341 `stvfbw=0.0 V/K`	Width dependence of temperature dependence of VFB.
342 `stvfblw=0.0 V/K`	Area dependence of temperature dependence of VFB.
343 `toxo=2e-9 m`	Gate oxide thickness.
344 `epsroxo=3.9`	Relative permittivity of gate dielectric.
345 `nsubo=3e23 m^-3`	Geometry independent substrate doping.
346 `nsubw=0.0`	Width dependence of background doping NSUBO due to segregation.
347 `wseg=`1e-8 m	Char. length of segregation of background doping NSUBO.
348 `npck=`1e24 m^-3	Pocket doping level.
349 `npckw=0.0`	Width dependence of pocket doping NPCK due to segregation.
350 `wsegp=1e-8 m`	Char. length of segregation of pocket doping NPCK.
351 `lpck=1e-8 m`	Char. length of lateral doping profile.

352 `lpckw=0.0`	Width dependence of char. length of lateral doping profile.
353 `fol1=0.0`	First length dependence coefficient for short channel body effect.
354 `fol2=0.0`	Second length dependence coefficient for short channel body effect.
355 `facneffaco=1.0`	Geom. independent pre-factor for effective substrate doping in separate charge calculation.
356 `facneffacl=0.0`	Length dependence of FACNEFFAC.
357 `facneffacw=0.0`	Width dependence of FACNEFFAC.
358 `facneffaclw=0.0`	Area dependence of FACNEFFAC.
359 `gfacnudo=1.0`	Geom. independent bodyfactor change due to NUD-effect.
360 `gfacnudl=0.0`	Length dependence of GFACNUD.
361 `gfacnudlexp=1.0`	Exponent for length dependence of GFACNUD.
362 `gfacnudw=0.0`	Width dependence of GFACNUD.
363 `gfacnudlw=0.0`	Area dependence of GFACNUD.
364 `vsbnudo=0.0 V`	Lower Vsb value for NUD-effect.
365 `dvsbnudo=1.0 V`	Vsb range for NUD-effect.
366 `vnsubo=0.0 V`	Effective doping bias-dependence parameter.
367 `nslpo=0.05 V`	Effective doping bias-dependence parameter.
368 `dnsubo=0.0 V^-1`	Effective doping bias-dependence parameter.
369 `dphibo=0.0 V`	Geometry independent offset of PHIB.
370 `dphibl=0.0 V`	Length dependence offset of PHIB.
371 `dphiblexp=1.0`	Exponent for length dependence of offset of PHIB.
372 `dphibw=0.0 V`	Width dependence of offset of PHIB.

373 `dphiblw=0.0 V` Area dependence of offset of PHIB.

374 `delvtaco=0.0 V` Geom. independent offset parameter for PHIB in separate charge calculation.

375 `delvtacl=0.0 V` Length dependence of DELVTAC.

376 `delvtaclexp=1.0` Exponent for length dependence of offset of DELVTAC.

377 `delvtacw=0.0 V` Width dependence of DELVTAC.

378 `delvtaclw=0.0 V` Area dependence of DELVTAC.

379 `npo=1e26 m^-3` Geometry-independent gate poly-silicon doping.

380 `npl=`0.0 Length dependence of gate poly-silicon doping.

381 `cto=`0.0 Geometry-independent interface states factor.

382 `ctl=`0.0 Length dependence of interface states factor.

383 `ctlexp=1.0` Exponent for length dependence of interface states factor.

384 `ctw=`0.0 Width dependence of interface states factor.

385 `ctlw=`0.0 Area dependence of interface states factor.

386 `toxovo=2e-9 m` Overlap oxide thickness.

387 `toxovdo=2e-9 m` Overlap oxide thickness for drain side.

388 `lov=0 m` Overlap length for gate/drain and gate/source overlap capacitance.

389 `lovd=0 m` Overlap length for gate/drain overlap capacitance.

390 `novo=5e25 m^-3` Effective doping of overlap region.

391 `novdo=5e25 m^-3` Effective doping of overlap region for drain side.

392 `cfl=0.0` Length dependence of DIBL-parameter.

393 `cflexp=2.0` Exponent for length dependence of CF.

394 `cfw=0.0`	Width dependence of CF.
395 `cfbo=0.0 V^-1`	Back-bias dependence of CF.
396 `uo=`5e-2 m^2/V/s	Zero-field mobility at TR.
397 `fbet1=0.0`	Relative mobility decrease due to first lateral profile.
398 `fbet1w=`0.0	Width dependence of relative mobility decrease due to first lateral profile.
399 `lp1=1e-8 m`	Mobility-related characteristic length of first lateral profile.
400 `lp1w=0.0`	Width dependence of mobility-related characteristic length of first lateral profile.
401 `fbet2=0.0`	Relative mobility decrease due to second lateral profile.
402 `lp2=1e-8 m`	Mobility-related characteristic length of second lateral profile.
403 `betw1=0.0`	First higher-order width scaling coefficient of BETN.
404 `betw2=0.0`	Second higher-order width scaling coefficient of BETN.
405 `wbet=1e-9 m`	Characteristic width for width scaling of BETN.
406 `stbeto=1.0`	Geometry independent temperature dependence of BETN.
407 `stbetl=0.0`	Length dependence of temperature dependence of BETN.
408 `stbetw=0.0`	Width dependence of temperature dependence of BETN.
409 `stbetlw=0.0`	Area dependence of temperature dependence of BETN.
410 `mueo=0.5 m/V`	Geometry independent mobility reduction coefficient at TR.
411 `muew=0.0`	Width dependence of mobility reduction coefficient at TR.
412 `stmueo=0.0`	Temperature dependence of MUE.
413 `themuo=1.5`	Mobility reduction exponent at TR.
414 `stthemuo=1.5`	Temperature dependence of THEMU.

415 `cso=0.0`	Geometry independent coulomb scattering parameter at TR.
416 `csl=0.0`	Length dependence of CS.
417 `cslexp=1.0`	Exponent for length dependence of CS.
418 `csw=0.0`	Width dependence of CS.
419 `cslw=0.0`	Area dependence of CS.
420 `stcso=0.0`	Temperature dependence of CS.
421 `xcoro=0.0 V^-1`	Geometry independent non-universality parameter.
422 `xcorl=`0.0	Length dependence of non-universality parameter.
423 `xcorw=`0.0	Width dependence of non-universality parameter.
424 `xcorlw=`0.0	Area dependence of non-universality parameter.
425 `stxcoro=`0.0	Temperature dependence of XCOR.
426 `fetao=1.0`	Effective field parameter.
427 `rsw1=50.0 Ohm`	Source/drain series resistance for 1 um wide channel at TR.
428 `rsw2=0.0`	Higher-order width scaling of RS.
429 `strso=1.0`	Temperature dependence of RS.
430 `rsbo=0.0 V^-1`	Back-bias dependence of series resistance.
431 `rsgo=0.0 V^-1`	Gate-bias dependence of series resistance.
432 `thesato=0.0 V^-1`	Geometry independent velocity saturation parameter at TR.
433 `thesatl=0.05 V^-1`	Length dependence of THESAT.
434 `thesatlexp=1.0`	Exponent for length dependence of THESAT.
435 `thesatw=`0.0	Width dependence of velocity saturation parameter.
436 `thesatlw=`0.0	Area dependence of velocity saturation parameter.

437 `stthesato=1.0` Geometry independent temperature dependence of THESAT.

438 `stthesatl=`0.0 Length dependence of temperature dependence of THESAT.

439 `stthesatw=`0.0 Width dependence of temperature dependence of THESAT.

440 `stthesatlw=`0.0 Area dependence of temperature dependence of THESAT.

441 `thesatbo=0.0 V^-1` Back-bias dependence of velocity saturation.

442 `thesatgo=0.0 V^-1` Gate-bias dependence of velocity saturation.

443 `axo=18` Geometry independent linear/saturation transition factor.

444 `axl=0.4` Length dependence of AX.

445 `alpl=`5e-4 Length dependence of ALP.

446 `alplexp=1.0` Exponent for length dependence of ALP.

447 `alpw=0.0` Width dependence of ALP.

448 `alp1l1=0.0 V` Length dependence of CLM enhancement factor above threshold.

449 `alp1lexp=0.5` Exponent for length dependence of ALP1.

450 `alp1l2=0.0` Second_order length dependence of ALP1.

451 `alp1w=0.0` Width dependence of ALP1.

452 `alp2l1=0.0 V^-1` Length dependence of CLM enhancement factor below threshold.

453 `alp2lexp=0.5` Exponent for length dependence of ALP2.

454 `alp2l2=0.0` Second_order length dependence of ALP2.

455 `alp2w=0.0` Width dependence of ALP2.

456 `vpo=0.05 V` CLM logarithmic dependence parameter.

457 `a1o=1.0` Geometry independent impact-ionization pre-factor.

458 `a1l=`0.0 Length dependence of A1.

459 `a1w=`0.0 Width dependence of A1.

460 `a2o=10 V` Impact-ionization exponent at TR.

461 `sta2o=0.0 V` Temperature dependence of A2.

462 `a3o=1.0` Geometry independent saturation-voltage dependence of II.

463 `a3l=`0.0 Length dependence of A3.

464 `a3w=`0.0 Width dependence of A3.

465 `a4o=0.0 V^-0.5` Geometry independent back-bias dependence of II.

466 `a4l=`0.0 Length dependence of A4.

467 `a4w=`0.0 Width dependence of A4.

468 `gcoo=`0.0 Gate tunneling energy adjustment.

469 `iginvlw=0.0 A` Gate channel current pre-factor for 1 um^2 channel area.

470 `igovw=0.0 A` Gate overlap current pre-factor for 1 um wide channel.

471 `igovdw=0.0 A` Gate overlap current pre-factor for 1 um wide channel for drain side.

472 `stigo=2.0` Temperature dependence of IGINV and IGOV.

473 `gc2o=`0.375 Gate current slope factor.

474 `gc3o=`0.063 Gate current curvature factor.

475 `chibo=3.1 V` Tunneling barrier height.

476 `agidlw=0.0 A/V^3` Width dependence of GIDL pre-factor.

477 `agidldw=0.0 A/V^3` Width dependence of GIDL pre-factor for drain side.

478 `bgidlo=41 V` GIDL probability factor at TR.

479 `bgidldo=41 V` GIDL probability factor at TR for drain side.

480 `stbgidlo=0.0 V/K` Temperature dependence of BGIDL.

481 `stbgidldo=0.0 V/K` Temperature dependence of BGIDL for drain side.

482 `cgidlo=`0.0 Back-bias dependence of GIDL.

483 `cgidldo=`0.0 Back-bias dependence of GIDL for drain side.

484 `cgbovl=0.0 F` Oxide capacitance for gate-bulk overlap for 1 um long channel.

485 `cfrw=0.0 F` Outer fringe capacitance for 1 um wide channel.

486 `cfrdw=0.0 F` Outer fringe capacitance for 1 um wide channel for drain side.

487 `fnto=1.0` Thermal noise coefficient.

488 `nfalw=8e22 V^-1/m^4`
First coefficient of flicker noise for 1 um^2 channel area.

489 `nfblw=3e7 V^-1/m^2`
Second coefficient of flicker noise for 1 um^2 channel area.

490 `nfclw=0.0 V^-1` Third coefficient of flicker noise for 1 um^2 channel area.

491 `efo=1.0` Flicker noise frequency exponent.

492 `lintnoi=0.0 m` Length offset for flicker noise.

493 `alpnoi=2.0` Exponent for length offset for flicker noise.

494 `kvthoweo=0` Geometrical independent threshold shift parameter.

495 `kvthowel=0` Length dependent threshold shift parameter.

496 `kvthowew=0` Width dependent threshold shift parameter.

497 `kvthowelw=0` Area dependent threshold shift parameter.

498 `kuoweo=0` Geometrical independent mobility degradation factor.

499 `kuowel=0` Length dependent mobility degradation factor.

500 `kuowew=0` Width dependent mobility degradation factor.

501 `kuowelw=0` Area dependent mobility degradation factor.

502 `munqso=1.0` Relative mobility for NQS modeling.

503 `rgo=0.0 Ohm` Gate resistance.

504 `rint=0.0 Ohm m^2` Contact resistance between silicide and ploy.

505 `rvpoly=0.0 Ohm m^2`
Vertical poly resistance.

506 `rshg=0.0 Ohm/Sqr` Gate electrode diffusion sheet resistance.

507 `dlsil=0.0 m` Silicide extension over the physical gate length.

508 `rsh=0.0 Ohm/sq` Sheet resistance of source diffusion.

509 `rshd=0.0 Ohm/sq` Sheet resistance of drain diffusion.

510 `rbulko=0.0 Ohm` Bulk resistance between node BP and BI.

511 `rwello=0.0 Ohm` Well resistance between node BI and B.

512 `rjunso=0.0 Ohm` Source-side bulk resistance between node BI and BS.

513 `rjundo=0.0 Ohm` Drain-side bulk resistance between node BI and BD.

514 `saref=1.0e-6 m` Reference distance between OD-edge and poly from one side.

515 `sbref=1.0e-6 m` Reference distance between OD-edge and poly from other side.

516 `wlod=0 m` Width parameter.

517 `kuo=0 m` Mobility degradation/enhancement coefficient.

518 `kvsat=0 m` Saturation velocity degradation/enhancement coefficient.

519 `tkuo=0` Temperature dependence of KUO.

520 `lkuo=0 m^LLODKUO` Length dependence of KUO.

521 `wkuo=0 m^WLODKUO` Width dependence of KUO.

522 `pkuo=0 m^(LLODKUO+WLODKUO`
Cross-term dependence of KUO.

523 `llodkuo=0` Length parameter for UO stress effect.

524 `wlodkuo=0` Width parameter for UO stress effect.

525 `kvtho=0 Vm` Threshold shift parameter.

526 `lkvtho=0 m^LLODVTH`
Length dependence of KVTHO.

527 `wkvtho=0 m^WLODVTH`
Width dependence of KVTHO.

528 `pkvtho=0 m^(LLODVTH+WLODVTH`
Cross-term dependence of KVTHO.

529 `llodvth=0` Length parameter for VTH-stress effect.

530 `wlodvth=0` Width parameter for VTH-stress effect.

531 `stetao=0 m` eta0 shift factor related to VTHO change.

532 `lodetao=1.0` eta0 shift modification factor for stress effect.

533 `scref=1.0e-6 m` Distance between OD-edge and well edge of a reference device.

534 `web=0` Coefficient for SCB.

535 `wec=0` Coefficient for SCC.

536 `imax=1000 A` Maximum current up to which forward current behaves exponentially.

537 `trj=21 C` reference temperature.

538 `cjorbot=1E-3 Fm^-2`
Zero-bias capacitance per unit-of-area of bottom component for source-bulk junction.

539 `cjorsti=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for source-bulk junction.

540 `cjorgat=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for source-bulk junction.

541 `vbirbot=1 V` Built-in voltage at the reference temperature of bottom component for source-bulk junction.

542 `vbirsti=1 V` Built-in voltage at the reference temperature of STI-edge component for source-bulk junction.

543 `vbirgat=1 V` Built-in voltage at the reference temperature of gate-edge component for source-bulk junction.

544 `pbot=`0.5 Grading coefficient of bottom component for source-bulk junction.

545 `psti=`0.5 Grading coefficient of STI-edge component for source-bulk junction.

546 `pgat=`0.5 Grading coefficient of gate-edge component for source-bulk junction.

547 `phigbot=1.16 V` Zero-temperature bandgap voltage of bottom component for source-bulk junction.

548 `phigsti=1.16 V` Zero-temperature bandgap voltage of STI-edge component for source-bulk junction.

549 `phiggat=` 1.16 V Zero-temperature bandgap voltage of gate-edge component for source-bulk junction.

550 `idsatrbot=1E-12 Am^-2`
Saturation current density at the reference temperature of bottom component for source-bulk junction.

551 `idsatrsti=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for source-bulk junction.

552 `idsatrgat=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for source-bulk junction.

553 `csrhbot=1E2 Am^-3` Shockley-Read-Hall prefactor of bottom component for source-bulk junction.

554 `csrhsti=1E-4 Am^-2`
Shockley-Read-Hall prefactor of STI-edge component for source-bulk junction.

555 `csrhgat=1E-4 Am^-2`
Shockley-Read-Hall prefactor of gate-edge component for source-bulk junction.

556 `xjunsti=100E-9 m` Junction depth of STI-edge component for source-bulk junction.

557 `xjungat=`100E-9 m Junction depth of gate-edge component for source-bulk junction.

558 `ctatbot=1E2 Am^-3` Trap-assisted tunneling prefactor of bottom component for source-bulk junction.

559 `ctatsti=1E-4 Am^-2`
Trap-assisted tunneling prefactor of STI-edge component for source-bulk junction.

560 `ctatgat=1E-4 Am^-2`
Trap-assisted tunneling prefactor of gate-edge component for source-bulk junction.

561 `mefftatbot=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component for source-bulk junction.

562 `mefftatsti=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for source-bulk junction.

563 `mefftatgat=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for source-bulk junction.

564 `cbbtbot=1E-12 AV^-3`
Band-to-band tunneling prefactor of bottom component for source-bulk junction.

565 `cbbtsti=1E-18 AV^-3m`
Band-to-band tunneling prefactor of STI-edge component for source-bulk junction.

566 `cbbtgat=1E-18 AV^-3m`
Band-to-band tunneling prefactor of gate-edge component for source-bulk junction.

567 `fbbtrbot=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component for source-bulk junction.

568 `fbbtrsti=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for source-bulk junction.

569 `fbbtrgat=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for source-bulk junction.

570 `stfbbtbot=1E-3 K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for source-bulk junction.

571 `stfbbtsti=1E-3 K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for source-bulk junction.

572 `stfbbtgat=1E-3 K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for source-bulk junction.

573 `vbrbot=10 V` Breakdown voltage of bottom component for source-bulk junction.

574 `vbrsti=10 V` Breakdown voltage of STI-edge component for source-bulk junction.

575 `vbrgat=10 V` Breakdown voltage of gate-edge component for source-bulk junction.

576 `pbrbot=4 V` Breakdown onset tuning parameter of bottom component for source-bulk junction.

577 `pbrsti=4 V` Breakdown onset tuning parameter of STI-edge component for source-bulk junction.

578 `pbrgat=`4 V Breakdown onset tuning parameter of gate-edge component for source-bulk junction.

579 `cjorbotd=1E-3 Fm^-2`
Zero-bias capacitance per unit-of-area of bottom component for drain-bulk junction.

580 `cjorstid=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component for drain-bulk junction.

581 `cjorgatd=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component for drain-bulk junction.

582 `vbirbotd=1 V` Built-in voltage at the reference temperature of bottom component for drain-bulk junction.

583 `vbirstid=1 V` Built-in voltage at the reference temperature of STI-edge component for drain-bulk junction.

584 `vbirgatd=1 V` Built-in voltage at the reference temperature of gate-edge component for drain-bulk junction.

585 `pbotd=`0.5 Grading coefficient of bottom component for drain-bulk junction.

586 `pstid=`0.5 Grading coefficient of STI-edge component for drain-bulk junction.

587 `pgatd=`0.5 Grading coefficient of gate-edge component for drain-bulk junction.

588 `phigbotd=1.16 V` Zero-temperature bandgap voltage of bottom component for drain-bulk junction.

589 `phigstid=1.16 V` Zero-temperature bandgap voltage of STI-edge component for drain-bulk junction.

590 `phiggatd=1.16 V` Zero-temperature bandgap voltage of gate-edge component for drain-bulk junction.

591 `idsatrbotd=1E-12 Am^-2`
Saturation current density at the reference temperature of bottom component for drain-bulk junction.

592 `idsatrstid=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component for drain-bulk junction.

593 `idsatrgatd=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component for drain-bulk junction.

594 `csrhbotd=1E2 Am^-3`
Shockley-Read-Hall prefactor of bottom component for drain-bulk junction.

595 `csrhstid=1E-4 Am^-2`
Shockley-Read-Hall prefactor of STI-edge component for drain-bulk junction.

596 `csrhgatd=1E-4 Am^-2`
Shockley-Read-Hall prefactor of gate-edge component for drain-bulk junction.

597 `xjunstid=`100E-9 m Junction depth of STI-edge component for drain-bulk junction.

598 `xjungatd=100E-9 m` Junction depth of gate-edge component for drain-bulk junction.

599 `ctatbotd=1E2 Am^-3`
Trap-assisted tunneling prefactor of bottom component for drain-bulk junction.

600 `ctatstid=1E-4 Am^-2`
Trap-assisted tunneling prefactor of STI-edge component for drain-bulk junction.

601 `ctatgatd=1E-4 Am^-2`
Trap-assisted tunneling prefactor of gate-edge component for drain-bulk junction.

602 `mefftatbotd=`0.25 Effective mass (in units of m0) for trap-assisted tunneling of bottom component for drain-bulk junction.

603 `mefftatstid=`0.25 Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component for drain-bulk junction.

604 `mefftatgatd=`0.25 Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component for drain-bulk junction.

605 `cbbtbotd=1E-12 AV^-3`
Band-to-band tunneling prefactor of bottom component for drain-bulk junction.

606 `cbbtstid=1E-18 AV^-3m`
Band-to-band tunneling prefactor of STI-edge component for drain-bulk junction.

607 `cbbtgatd=1E-18 AV^-3m`
Band-to-band tunneling prefactor of gate-edge component for drain-bulk junction.

608 `fbbtrbotd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component for drain-bulk junction.

609 `fbbtrstid=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component for drain-bulk junction.

610 `fbbtrgatd=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component for drain-bulk junction.

611 `stfbbtbotd=-1E-3 K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component for drain-bulk junction.

612 `stfbbtstid=-1E-3 K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component for drain-bulk junction.

613 `stfbbtgatd=-1E-3 K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component for drain-bulk junction.

614 `vbrbotd=10 V` Breakdown voltage of bottom component for drain-bulk junction.

615 `vbrstid=10 V` Breakdown voltage of STI-edge component for drain-bulk junction.

616 `vbrgatd=10 V` Breakdown voltage of gate-edge component for drain-bulk junction.

617 `pbrbotd=4 V` Breakdown onset tuning parameter of bottom component for drain-bulk junction.

618 `pbrstid=4 V` Breakdown onset tuning parameter of STI-edge component for drain-bulk junction.

619 `pbrgatd=4 V` Breakdown onset tuning parameter of gate-edge component for drain-bulk junction.

620 `swjunexp=0` Flag for JUNCAP-express; 0,full model, 1,express model.

621 `vjunref=2.5` Typical maximum source-bulk junction voltage; usually about 2*VSUP.

622 `fjunq=0.03` Fraction below which source-bulk junction capacitance components are considered negligible.

623 `vjunrefd=2.5` Typical maximum drain-bulk junction voltage; usually about 2*VSUP.

624 `fjunqd=`0.03 Fraction below which drain-bulk junction capacitance components are considered negligible.

625 `dta=0.0 K` Temperature offset w.r.t. ambient temperature.

626 `w=10e-6 m` Default width.

627 `l=10e-6 m` Default length.

628 `nf=1` Number of fingers, It served as the default value of instance nf.

629 `vds_max=infinity V`
Maximum allowed voltage cross source and drain.

630 `vgd_max=infinity V`
Maximum allowed voltage cross gate and drain.

631 `vgs_max=infinity V`
Maximum allowed voltage cross gate and source/bulk.

632 `vbd_max=infinity V`
Maximum allowed voltage cross source/drain and bulk.

633 `vbs_max=infinity V`
Maximum allowed voltage cross source and bulk.

634 `vgb_max=infinity V`
Maximum allowed voltage cross gate and bulk.

635 `vthmod`
Vth output selector. std outputs model equation Vth. vthcc outputs constant current Vth, and may impact simulation performance. The default value is taken from the options parameter vthmod.
Possible values are `std` or `vthcc`.

636 `ivth (m)`
Vth current parameter. The default value is taken from the options parameter ivthn or ivthp, depending on the type of the model.

637 `ivthw (m)`
Width offset for constant current Vth. The default value is taken from the options parameter ivthw.

638 `ivthl (V)`
Length offset for constant current Vth. The default value is taken from the options parameter ivthl.

639 `ivth_vdsmin (V)`
Minimum Vds in constant current Vth calculating. The default value is taken from the options parameter ivth_vdsmin.

Output Parameters

1 `lv2 (m)` alias of w.

2 `lv1 (m)` alias of l.

3 `lv3 (m^2)` alias of ad.

4 `lv4 (m^2)` alias of as.

5 `lv11 (m)` alias of pd.

6 `lv12 (m)` alias of ps.

7 `table_pseff (m)`
For table model.

8 `table_pdeff (m)`
For table model.

Operating-Point Parameters

1 `l=10e-6 m` Design length.

2 `w=10e-6 m` Design width.

3 `sa=0.0 m` Distance between OD-edge and poly from one side.

4 `sb=0.0 m` Distance between OD-edge and poly from other side.

5 `sd=0.0 m` Distance between neighboring fingers.

6 `sca=`0.0 Integral of the first distribution function for scattered well dopants.

7 `scb=`0.0 Integral of the second distribution function for scattered well dopants.

8 `scc=`0.0 Integral of the third distribution function for scattered well dopants.

9 `sc=0.0 m` Distance between OD-edge and nearest well edge.

10 `nf=1` Number of fingers.

11 `ngcon=1.0` Number of gate contacts.

12 `xgw=1.0E-7 m` Distance from the gate contact to the channel edge.

13 `nrs=0.0` Number of squares of source diffusion.

14 `nrd=0.0` Number of squares of drain diffusion.

15 `trise=0.0 K` Temperature rise from ambient.

16 `jw=1E-6 m` Gate-edge length of source/drain junction.

17 `delvto=0.0 V`	Threshold voltage shift parameter.
18 `factuo=`1.0	Zero-field mobility pre-factor.
19 `absource=1E-12 m^2`	Bottom area of source junction.
20 `lssource=1E-6 m`	STI-edge length of source junction.
21 `lgsource=1E-6 m`	Gate-edge length of source junction.
22 `abdrain=1E-12 m^2`	Bottom area of drain junction.
23 `lsdrain=1E-6 m`	STI-edge length of drain junction.
24 `lgdrain=1E-6 m`	Gate-edge length of drain junction.
25 `as=1E-12 m^2`	Bottom area of source junction.
26 `ps=1E-6 m`	Perimeter of source junction.
27 `ad=1E-12 m^2`	Bottom area of drain junction.
28 `pd=1E-6 m`	Perimeter of drain junction.
29 `ctype`	Flag for channel type.
30 `sdint`	Flag for source-drain interchange.
31 `ise (A)`	Total source current.
32 `ige (A)`	Total gate current.
33 `ide (A)`	Total drain current.
34 `ibe (A)`	Total bulk current.
35 `ids (A)`	Drain current, excl. avalanche, tunnel, GISL, GIDL, and junction currents.
36 `idb (A)`	Drain to bulk current.
37 `isb (A)`	Source to bulk current.

38 `igs (A)`	Gate-source tunneling current.
39 `igd (A)`	Gate-drain tunneling current.
40 `igb (A)`	Gate-bulk tunneling current.
41 `igcs (A)`	Gate-channel tunneling current (source component.
42 `igcd (A)`	Gate-channel tunneling current (drain component.
43 `iavl (A)`	Substrate current due to weak avelanche.
44 `igisl (A)`	Gate-induced source leakage current.
45 `igidl (A)`	Gate-induced drain leakage current.
46 `ijs (A)`	Total source junction current.
47 `ijsbot (A)`	Source junction current (bottom component.
48 `ijsgat (A)`	Source junction current (gate-edge component.
49 `ijssti (A)`	Source junction current (STI-edge component.
50 `ijd (A)`	Total drain junction current.
51 `ijdbot (A)`	Drain junction current (bottom component.
52 `ijdgat (A)`	Drain junction current (gate-edge component.
53 `ijdsti (A)`	Drain junction current (STI-edge component.
54 `qg (Coul)`	Intrinsic gate charge.
55 `qd (Coul)`	Intrinsic drain chargen.
56 `qb (Coul)`	Intrinsic bulk charge.
57 `qs (Coul)`	Intrinsic source charge.
58 `qgs_ov (Coul)`	Overlap charge for gate-source.
59 `qgd_ov (Coul)`	Overlap charge for gate-drain.

60 `qfgs (Coul)`	Total outerFringe + overlap for gate-source.
61 `qfgd (Coul)`	Total outerFringe + overlap for gate-drain.
62 `qgb_ov (Coul)`	Gate-bulk overlap charge.
63 `qjun_s (Coul)`	Junction charge on source side.
64 `qjun_d (Coul)`	Junction charge on drain side.
65 `vds (V)`	Drain-source voltage.
66 `vgs (V)`	Gate-source voltage.
67 `vsb (V)`	Source-bulk voltage.
68 `vto (V)`	Zero-bias threshold voltage.
69 `vts (V)`	Threshold voltage including back bias effects.
70 `vth (V)`	Threshold voltage including back bias and drain bias effects.
71 `vgt (V)`	Effective gate drive voltage including back bias and drain bias effects.
72 `vdss (V)`	Drain saturation voltage at actual bias.
73 `vsat`	Saturation limit.
74 `gm (1/Ohm)`	Transconductance.
75 `gmb (1/Ohm)`	Substrate transconductance.
76 `gds (1/Ohm)`	Output conductance.
77 `gjs (1/Ohm)`	Source junction conductance.
78 `gjd (1/Ohm)`	Drain junction conductance.
79 `cdd (F)`	Drain capacitance.
80 `cdg (F)`	Drain-gate capacitance.

81 `cds (F)`	Drain-source capacitance.
82 `cdb (F)`	Drain-bulk capacitance.
83 `cgd (F)`	Gate-drain capacitance.
84 `cgg (F)`	Gate capacitance.
85 `cgs (F)`	Gate-source capacitance.
86 `cgb (F)`	Gate-bulk capacitance.
87 `csd (F)`	Source-drain capacitance.
88 `csg (F)`	Source-gate capacitance.
89 `css (F)`	Source capacitance.
90 `csb (F)`	Source-bulk capacitance.
91 `cbd (F)`	Bulk-drain capacitance.
92 `cbg (F)`	Bulk-gate capacitance.
93 `cbs (F)`	Bulk-source capacitance.
94 `cbb (F)`	Bulk capacitance.
95 `cgsol (F)`	Total gate-source overlap capacitance.
96 `cgdol (F)`	Total gate-drain overlap capacitance.
97 `cgbol (F)`	Total gate-bulk overlap capacitance.
98 `cjs (F)`	Total source junction capacitance.
99 `cjsbot (F)`	Source junction capacitance (bottom component.
100 `cjsgat (F)`	Source junction capacitance (gate-edge component.
101 `cjssti (F)`	Source junction capacitance (STI-edge component.
102 `cjd (F)`	Total drain junction capacitance.

103 `cjdbot (F)`	Drain junction capacitance (bottom component.
104 `cjdgat (F)`	Drain junction capacitance (gate-edge component.
105 `cjdsti (F)`	Drain junction capacitance (STI-edge component.
106 `weff (m)`	Effective channel width for geometrical models.
107 `leff (m)`	Effective channel length for geometrical models.
108 `lpoly (m)`	
109 `u`	Transistor gain.
110 `rout (Ohm)`	Small-signal output resistance.
111 `vearly ()`	Equivalent Early voltage.
112 `beff (V)`	Gain factor.
113 `fug (Hz)`	Unity gain frequency at actual bias.
114 `rg (Ohm)`	Gate resistance.
115 `sfl`	Flicker noise current density at 1 Hz.
116 `sqrtsff`	Input-referred RMS white noise voltage density at 1 kHz.
117 `sqrtsfw`	Input-referred RMS white noise voltage density.
118 `sid`	White noise current density.
119 `sig`	Induced gate noise current density at 1 Hz.
120 `cigid`	Imaginary part of correlation coefficient between Sig and Sid.
121 `fknee`	Cross-over frequency above which white noise is dominant.
122 `sigs`	Gate-source current noise spectral density.
123 `sigd`	Gate-drain current noise spectral density.
124 `siavl`	Impact ionization current noise spectral density.

125 `ssi` Total source junction current noise spectral density.

126 `sdi` Total drain junction current noise spectral density.

127 `lp_vfb (V)` Local parameter VFB after T-scaling and clipping.

128 `lp_stvfb (V/K)` Local parameter STVFB after clipping.

129 `lp_tox (m)` Local parameter TOX after clipping.

130 `lp_epsrox` Local parameter EPSROX after clipping.

131 `lp_neff (m^-3)` Local parameter NEFF after clipping.

132 `lp_facneffac`
Local parameter FACNEFFAC after clipping.

133 `lp_gfacnud` Local parameter GFACNUD after clipping.

134 `lp_vsbnud (V)` Local parameter VSBNUD after clipping.

135 `lp_dvsbnud (V)` Local parameter DVSBNUD after clipping.

136 `lp_vnsub (V)` Local parameter VNSUB after clipping.

137 `lp_nslp (V)` Local parameter NSLP after clipping.

138 `lp_dnsub (V^-1)`
Local parameter DNSUB after clipping.

139 `lp_dphib (V)` Local parameter DPHIB after clipping.

140 `lp_delvtac (V)` Local parameter DELVTAC after clipping.

141 `lp_np (m^-3)` Local parameter NP after clipping.

142 `lp_ct` Local parameter CT after clipping.

143 `lp_toxov (m)` Local parameter TOXOV after clipping.

144 `lp_toxovd (m)` Local parameter TOXOVD after clipping.

145 `lp_nov (m^-3)` Local parameter NOV after clipping.

146 `lp_novd (m^-3)` Local parameter NOVD after clipping.

147 `lp_cf` Local parameter CF after clipping.

148 `lp_cfb (V^-1)` Local parameter CFB after clipping.

149 `lp_betn (m^2/(V s)`
Local parameter BETN after T-scaling and clipping.

150 `lp_stbet` Local parameter STBET after clipping.

151 `lp_mue (m/V)` Local parameter MUE after T-scaling and clipping.

152 `lp_stmue` Local parameter STMUE after clipping.

153 `lp_themu` Local parameter THEMU after T-scaling and clipping.

154 `lp_stthemu` Local parameter STTHEMU after clipping.

155 `lp_cs` Local parameter CS after T-scaling and clipping.

156 `lp_stcs` Local parameter STCS after clipping.

157 `lp_xcor (V^-1)` Local parameter XCOR after T-scaling and clipping.

158 `lp_stxcor` Local parameter STXCOR after clipping.

159 `lp_feta` Local parameter FETA after clipping.

160 `lp_rs (Ohm)` Local parameter RS after T-scaling and clipping.

161 `lp_strs` Local parameter STRS after clipping.

162 `lp_rsb (V^-1)` Local parameter RSB after clipping.

163 `lp_rsg (V^-1)` Local parameter RSG after clipping.

164 `lp_thesat (V^-1)`
Local parameter THESAT after T-scaling and clipping.

165 `lp_stthesat` Local parameter STTHESAT after clipping.

166 `lp_thesatb (V^-1)`
Local parameter THESATB after clipping.

167 `lp_thesatg (V^-1)`
Local parameter THESATG after clipping.

168 `lp_ax` Local parameter AX after clipping.

169 `lp_alp` Local parameter ALP after clipping.

170 `lp_alp1 (V)` Local parameter ALP1 after clipping.

171 `lp_alp2 (V^-1)` Local parameter ALP2 after clipping.

172 `lp_vp (V)` Local parameter VP after clipping.

173 `lp_a1` Local parameter A1 after clipping.

174 `lp_a2 (V)` Local parameter A2 after T-scaling and clipping.

175 `lp_sta2` Local parameter STA2 after clipping.

176 `lp_a3` Local parameter A3 after clipping.

177 `lp_a4 (1/sqrt(V)`
Local parameter A4 after clipping.

178 `lp_gco` Local parameter GCO after clipping.

179 `lp_iginv (A)` Local parameter IGINV after T-scaling and clipping.

180 `lp_igov (A)` Local parameter IGOV after T-scaling and clipping.

181 `lp_igovd (A)` Local parameter IGOVD after T-scaling and clipping.

182 `lp_stig` Local parameter STIG after clipping.

183 `lp_gc2` Local parameter GC2 after clipping.

184 `lp_gc3` Local parameter GC3 after clipping.

185 `lp_chib (V)` Local parameter CHIB after clipping.

186 `lp_agidl (A/V^3)`
Local parameter AGIDL after clipping.

187 `lp_agidld (A/V^3)`
Local parameter AGIDLD after clipping.

188 `lp_bgidl (V)` Local parameter BGIDL after T-scaling and clipping.

189 `lp_bgidld (V)` Local parameter BGIDLD after T-scaling and clipping.

190 `lp_stbgidl (V/K)`
Local parameter STBGIDL after clipping.

191 `lp_stbgidld (V/K)`
Local parameter STBGIDLD after clipping.

192 `lp_cgidl` Local parameter CGIDL after clipping.

193 `lp_cgidld` Local parameter CGIDLD after clipping.

194 `lp_cox (F)` Local parameter COX after clipping.

195 `lp_cgov (F)` Local parameter CGOV after clipping.

196 `lp_cgovd (F)` Local parameter CGOVD after clipping.

197 `lp_cgbov (F)` Local parameter CGBOV after clipping.

198 `lp_cfr (F)` Local parameter CFR after clipping.

199 `lp_cfrd (F)` Local parameter CFRD after clipping.

200 `lp_fnt` Local parameter FNT after clipping.

201 `lp_nfa (1/(V m^4)`
Local parameter NFA after clipping.

202 `lp_nfb (1/(V m^2)`
Local parameter NFB after clipping.

203 `lp_nfc (V^-1)` Local parameter NFC after clipping.

204 `lp_ef` Local parameter EF after clipping.

205 `lp_rg (Ohm)` Local parameter RG after clipping.

206 `lp_rse (Ohm)` Local parameter RSE after clipping.

207 `lp_rde (Ohm)` Local parameter RDE after clipping.

208 `lp_rbulk (Ohm)` Local parameter RBULK after clipping.

209 `lp_rwell (Ohm)` Local parameter RWELL after clipping.

210 `lp_rjuns (Ohm)` Local parameter RJUNS after clipping.

211 `lp_rjund (Ohm)` Local parameter RJUND after clipping.

212 `lp_munqs` Local parameter MUNQS after clipping.

213 `lv13` alias of nrd.

214 `lv14` alias of nrs.

215 `lv36 (F)` alias of cgsol.

216 `lv37 (F)` alias of cgdol.

217 `lv38 (F)` alias of cgbol.

218 `table_ids (A)` For table model.

219 `table_vth (V)` For table model.

220 `table_qg (Coul)` For table model.

221 `table_qd (Coul)` For table model.

222 `table_qb (Coul)` For table model.

223 `table_id (A)` For table model.

224 `table_isub (A)` For table model.

225 `table_ibs (A)` For table model.

226 `table_ibd (A)` For table model.

227 `table_igd (A)` For table model.

228 `table_igb (A)` For table model.

229 `table_igs (A)` For table model.

230 `table_gds (1/Ohm)`
For table model.

231 `table_gm (1/Ohm)`
For table model.

232 `table_gmbs (1/Ohm)`
For table model.

233 `table_qbs (Coul)`
For table model.

234 `table_qbd (Coul)`
For table model.

235 `table_vdsat (V)`
For table model.

236 `table_leff (m)` For table model.

237 `table_weff (m)` For table model.

238 `table_aseff (m^2)`
For table model.

239 `table_adeff (m^2)`
For table model.

Parameter Index

In the following index, I refers to instance parameters, M refers to the model parameters section, O refers to the output parameters section, and OP refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of M-35 means the 35th model parameter.

25

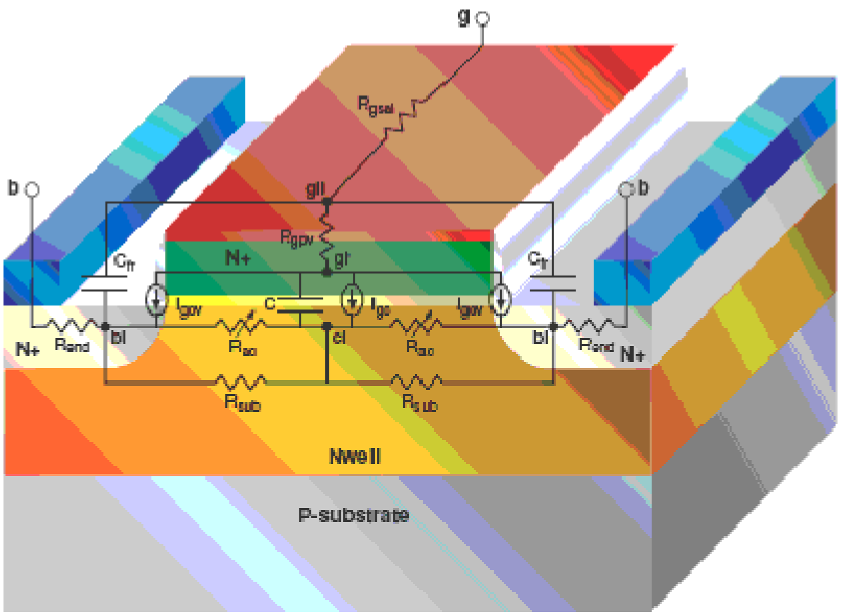
PSP-Based MOS Varactor Model (mosvar)

The PSP-based varactor model is intended for analog and radio-frequency circuit design. It includes dynamic inversion, finite poly doping, quantum mechanics, gate tunneling for different polarity combinations, and parasitics to model advanced MOS technologies.

This chapter contains the following information about the PSP model:

Device Structure

The following figure shows a cross section of the standard MOS varactor offered in the current MOS technologies with its equivalent circuit model overlapped on it. g, bi and b are the external terminals while gii, gi and ci are the internal nodes.



The following table explains the meanings of the symbols in the above figure.

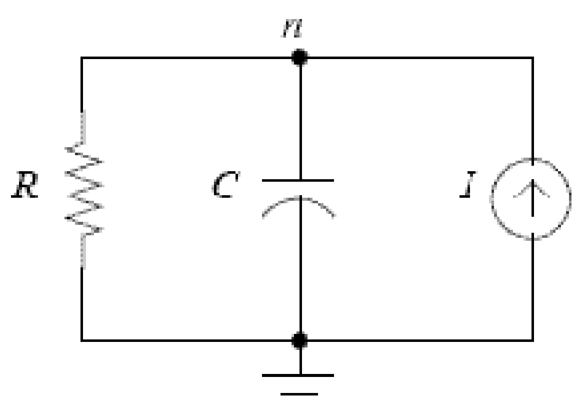
No.	Name	Description
1	C	Gate-channel capacitance
2	C_{fr}	Fringe and overlap capacitance
3	I_{gc}	Gate-channel current
4	I_{gov}	Gate-overlap current
5	R_{gsal}	Metal resistance
6	R_{gpv}	Poly gate resistance
7	R_{ac}	Accumulation resistance
8	R_{sub}	Substrate (in well region) resistance
9	R_{end}	End resistance

Model Version Updates

Version 1.2.0

- Parameter `EPSROXO` has been added for relative dielectric permittivity
- Gate current computations has been revised to avoid numerical problems and to use `GC3HVO` for HVB current
- Parameter `RACNOISE` has been added to select noise equations for `Rac`.
- Noise names have been made more descriptive.
- Shot noise for gate currents has been added.

RC Circuit Model for Inversion Charge



$$q_i = q_i0 - TAU \cdot \frac{dq}{dt}$$

Parameter Initializing

Capacitance of Oxide and Body Factors

$$C_{ox} = \varepsilon_{ox}/TOXO$$

$$\Upsilon s = \sqrt{2 \cdot q \cdot \varepsilon_{si} \cdot NSUBO/C_{ox}}$$

$$\Upsilon p = \sqrt{2 \cdot q \cdot \varepsilon_{si} \cdot NPO/C_{ox}}$$

$$\Upsilon ov,s = \sqrt{2 \cdot q \cdot \varepsilon_{si} \cdot NOVO/C_{ox}}$$

If QMC>0,

$$q_q = \begin{cases} 0.4 \cdot QMN \cdot QMC \cdot (C_{ox})^{2/3} & if\ \text{TYPE>0} \\ 0.4 \cdot QMP \cdot QMC \cdot (C_{ox})^{2/3} & otherwise \end{cases}$$

else

q_q=0.

$$\eta_\mu = \begin{cases} 0.5 \cdot FETA & if\ \text{TYPE} > 0 \\ \frac{1}{3} \cdot FETA & otherwise \end{cases}$$

$$norm_{tox} = TOXO/10^{-9}$$

Initializing Parameters

Temperature-Related Parameters

$$\mathrm{TR1} = \begin{cases} \mathbf{TR}, & \text{if } \mathbf{TR} \geq -273 \\ -273, & \text{if } \mathbf{TR} < -273 \end{cases}$$

$$T_{\mathrm{KR}} = 273.15 + \mathrm{TR1}$$

$$T_{\mathrm{KD}} = \mathrm{T_A} + \mathbf{DTA}$$

$$\Delta T = T_{\mathrm{KD}} - T_{\mathrm{KR}}$$

$$\phi_{\mathrm{T}} = k_{\mathrm{B}} \cdot T_{\mathrm{KD}}/q$$

$$q_{\mathrm{lim2}} = 100 \cdot \phi_{\mathrm{T}}^2$$

$$V_{\mathrm{fb,\,T}} = \mathbf{VFBO} + \Delta T \cdot \mathbf{STVFB}$$

$$R_{\mathrm{shg,\,T}} = \mathbf{RSHG} \cdot \left(\frac{T_{\mathrm{KR}}}{T_{\mathrm{KD}}}\right)^{\mathbf{STRSHG}}$$

$$R_{\mathrm{pv,\,T}} = \mathbf{RPV} \cdot \left(\frac{T_{\mathrm{KR}}}{T_{\mathrm{KD}}}\right)^{\mathbf{STRPV}}$$

$$R_{\mathrm{end,\,T}} = \mathbf{REND} \cdot \left(\frac{T_{\mathrm{KR}}}{T_{\mathrm{KD}}}\right)^{\mathbf{STREND}}$$

$$R_{\mathrm{shs,\,T}} = \mathbf{RSHS} \cdot \left(\frac{T_{\mathrm{KR}}}{T_{\mathrm{KD}}}\right)^{\mathbf{STRSHS}}$$

$$U_{\mathrm{ac,\,T}} = \mathbf{UAC} \cdot \left(\frac{T_{\mathrm{KD}}}{T_{\mathrm{KR}}}\right)^{\mathbf{STUAC}}$$

General Parameters

$$nt0 = 4 \cdot \text{`KBOL} \cdot T_{\text{KD}}$$

$$L_{\text{eff}} = L + \mathbf{DLQ}$$

$$W_{\text{eff}} = W + \mathbf{DWQ}$$

$$M_{\text{eff}} = \text{M\_SEG} \cdot \text{` MFACTOR\_USE}$$

$$\text{INV}_{\text{Meff}} = 1.0 \; / \; M_{\text{eff}}$$

$$E_{\text{g}} = 1.179 - T_{\text{KD}} \cdot \left(9.025 \cdot 10^{-5} + 3.05 \cdot 10^{-7} \cdot T_{\text{KD}}\right)$$

$$r_{\text{T}} = (1.045 + 4.5 \cdot 10^{-4} \cdot T_{\text{KD}}) \cdot (0.523 + 1.4 \cdot 10^{-3} \cdot T_{\text{KD}} - 1.48 \cdot 10^{-6} \cdot T_{\text{KD}}^2) \cdot \frac{T_{\text{KD}}^2}{90000}$$

$$\text{INV}_{\text{ni}} = 4 \cdot 10^{-26} \cdot r_{\text{T}}^{-0.75}$$

$$\phi_{\text{b}} = E_{\text{g}} + 2 \cdot \phi_{\mathbf{T}} \cdot \ln\left(\mathbf{NSUBO} \cdot \text{INV}_{\text{ni}}\right)$$

$$k_{\text{se1}} = 230.26$$

$$k_{\text{se2}} = 460.52$$

Parameters Related to Polysilicon and Overlap Regions

$$G_{\mathrm{p}} = \gamma_{\mathrm{p}} / \sqrt{\phi_{\mathrm{T}}}$$

$$\xi_{\mathrm{p}} = 1 + G_{\mathrm{p}} / \sqrt{2}$$

$$x_{\mathrm{mrgp}} = 10^{-5} \cdot \xi_{\mathrm{p}}$$

$$\phi_{\mathrm{p}} = E_{\mathrm{g}} + 2 \cdot \phi_{\mathrm{T}} \cdot \ln\left(\mathbf{NPO} \cdot \mathrm{INV_{ni}}\right)$$

$$x_{\mathrm{np}} = \phi_{\mathrm{p}} / \phi_{\mathrm{T}}$$

$$\Delta_{\mathrm{np}} = \begin{cases} \exp(-x_{\mathrm{np}}), & \text{if } x_{\mathrm{np}} < k_{\mathrm{se2}} \\ \dfrac{10^{-200}}{\mathrm{P3}\left(x_{\mathrm{np}} - k_{\mathrm{se2}}\right)}, & \text{otherwise} \end{cases}$$

$$G_{\mathrm{ov,\,s}} = \gamma_{\mathrm{ov,\,s}} / \sqrt{\phi_{\mathrm{T}}}$$

$$\xi_{\mathrm{ov,\,s}} = 1 + G_{\mathrm{ov,\,s}} / \sqrt{2}$$

$$x_{\mathrm{mrgov,\,s}} = 10^{-5} \cdot \xi_{\mathrm{ov,\,s}}$$

$$\phi_{\mathrm{b,\,ov}} = E_{\mathrm{g}} + 6 \cdot \phi_{\mathrm{T}}$$

$$x_1 = 1.25$$

$$x_{\mathrm{g1,\,ov}} = x_1 + G_{\mathrm{ov,\,s}} \cdot \sqrt{\exp(-x_1) + x_1 - 1}$$

Resistances

$$\text{If } \mathbf{SWRES} = \text{true} \begin{cases} R_{\text{gsal}} = \dfrac{R_{\text{shg, T}} \cdot W}{L \cdot [3 + 9 \cdot (\mathbf{NGCON} - 1)]} \\ R_{\text{gpv}} = \dfrac{R_{\text{pv, T}}}{W \cdot L} \\ R_{\text{end}} = \dfrac{R_{\text{end, T}}}{2 \cdot (W + \mathbf{DWR})} \\ R_{\text{sub}} = \dfrac{R_{\text{shs, T}} \cdot L}{12 \cdot (W + \mathbf{DWR})} \\ R_{\text{gsal}} = \text{` CLIP\_BOTH}(R_{\text{gsal}},\ 1.0e-03,\ 1e01) \\ R_{\text{gpv}} = \text{` CLIP\_BOTH}(R_{\text{gpv}},\ 1.0e-03,\ 1e02) \\ R_{\text{end}} = \text{` CLIP\_BOTH}(R_{\text{end}},\ 1.0e-03,\ 1e01) \\ R_{\text{sub}} = \text{` CLIP\_BOTH}(R_{\text{sub}},\ 1.0e-03,\ 1e03) \\ U_{\text{ac,T}} = \text{` CLIP\_BOTH}(U_{\text{ac,T}},\ 1.0e-03,\ 2e01) \\ G_{\text{gsal}} = 1/R_{\text{gsal}} \\ G_{\text{gpv}} = 1/R_{\text{gpv}} \\ G_{\text{end}} = 1/R_{\text{end}} \\ G_{\text{sub}} = 1/R_{\text{sub}} \\ G_{\text{ac0}} = 12 \cdot U_{\text{ac, T}} \cdot W/L \end{cases}$$

$$\text{If } \mathbf{SWRES} = \text{false} \begin{cases} G_{\text{gsal}} = 0.0 \\ G_{\text{gpv}} = 0.0 \\ G_{\text{end}} = 0.0 \\ G_{\text{sub}} = 0.0 \\ G_{\text{ac0}} = 0.0 \end{cases}$$

Gate Tunneling Parameters

$$
\text{If } \mathbf{SWIGATE} = \text{true} \begin{cases}
I_{\text{ginv}} = \mathbf{IGINVLW} \cdot W_{\text{eff}} \cdot L_{\text{eff}} \cdot 10^{12} \cdot \left(\dfrac{T_{\text{KD}}}{T_{\text{KR}}}\right)^{\mathbf{STIG}} \\
I_{\text{gov}} = 2 \cdot \mathbf{IGOVW} \cdot \mathbf{LOV} \cdot W_{\text{eff}} \cdot 10^{12} \cdot \left(\dfrac{T_{\text{KD}}}{T_{\text{KR}}}\right)^{\mathbf{STIG}} \\
I_{\text{gcHVB}} = \mathbf{IGCHVLW} \cdot W_{\text{eff}} \cdot L_{\text{eff}} \cdot 10^{12} \cdot \left(\dfrac{T_{\text{KD}}}{T_{\text{KR}}}\right)^{\mathbf{STIG}} \\
I_{\text{govHVB}} = 2 \cdot \mathbf{IGOVHVW} \cdot \mathbf{LOV} \cdot W_{\text{eff}} \cdot 10^{12} \cdot \left(\dfrac{T_{\text{KD}}}{T_{\text{KR}}}\right)^{\mathbf{STIG}} \\
\text{INV}_{\text{CHIB}} = 1/\mathbf{CHIBO} \\
\text{INV}_{\text{CHIB, HVB}} = 1/\mathbf{CHIBPO} \\
B_{\text{CH}} = (4/3) \cdot \mathbf{TOXO} \cdot \sqrt{2 \cdot q \cdot m_0 \cdot \mathbf{CHIBO}}\,/\hbar \\
B_{\text{OV}} = B_{\text{CH}} \\
B_{\text{CH, HVB}} = (4/3) \cdot \mathbf{TOXO} \cdot \sqrt{2 \cdot q \cdot m_0 \cdot \mathbf{CHIBPO}}\,/\hbar \\
B_{\text{OV, HVB}} = B_{\text{CH, HVB}} \\
\text{If } \mathbf{GC3O} < 0, \quad Q_{\text{CQ}} = -0.495 \cdot \mathbf{GC2O}/\mathbf{GC3O}, \\
\text{else } \; Q_{\text{CQ}} = 0.0 \text{ , endif} \\
\alpha_{\text{b, s}} = 0.5 \cdot (E_{\text{g}} + \mathbf{TYPE} \cdot \phi_{\text{b}}) \\
\alpha_{\text{b, ov}} = 0.5 \cdot (E_{\text{g}} + \mathbf{TYPE} \cdot \phi_{\text{b, ov}}) \\
D_{\text{ch}} = \mathbf{GCOO} \cdot \phi_{\text{T}} \\
D_{\text{ch, HVB}} = \mathbf{GCOO} \cdot \phi_{\text{T}}
\end{cases}
$$

$$
\text{If } \mathbf{SWIGATE} = \text{false} \begin{cases}
I_{\text{ginv}} & = 0 \\
I_{\text{gov}} & = 0 \\
I_{\text{gcHVB}} & = 0 \\
I_{\text{govHVB}} & = 0 \\
\text{INV}_{\text{CHIB}} & = 0.1 \\
\text{INV}_{\text{CHIB, HVB}} & = 0.1 \\
B_{\text{CH}} & = 0 \\
B_{\text{OV}} & = 0 \\
B_{\text{CH, HVB}} & = 0 \\
B_{\text{OV, HVB}} & = 0 \\
Q_{\text{CQ}} & = 0 \\
\alpha_{\text{b, s}} & = 0 \\
\alpha_{\text{b, ov}} & = 0 \\
D_{\text{ch}} & = 0 \\
D_{\text{ch. HVB}} & = 0
\end{cases}
$$

Parameter Extraction

Capacitance-Related Model Parameter Extraction

$$C(V) = C_o(V) \cdot L \cdot W \cdot m + C_{fr} \cdot m$$

where C_0 is the bias-dependent capacitance of an intrinsic device,

$$L = L_g + DLQ, \mathrm{W} = W_g + DWQ$$

and m is the multiplicity factor. Parameters DWQ and DLQ describe the deviations of the effective channel length (L) and Width (W) from their drawn values L_g and W_g.

The total fringe capacitance is given by

$$C_{fr} = 2 \cdot (CFRW \cdot W + CFRL \cdot L)$$

Auxiliary Equations

$$\mathrm{MINA}\,(x,\ y,\ a) = \frac{1}{2}\cdot\left[x + y - \sqrt{(x-y)^2 + a}\right]$$

$$\mathrm{MAXA}\,(x,\ y,\ a) = \frac{1}{2}\cdot\left[x + y + \sqrt{(x-y)^2 + a}\right]$$

$$\nu = a + c$$

$$\mu_1 = \frac{\upsilon^2}{\tau} + \frac{c^2}{2} - a$$

$$\sigma_1\,(a,\ c,\ \tau,\ \eta) = \frac{a\cdot\nu}{\mu_1 + (c^2/3 - a)\cdot c\cdot\nu/\mu_1} + \eta$$

$$\mu_2 = \frac{\upsilon^2}{\tau} + \frac{c^2}{2} - a\cdot b$$

$$\sigma_2\,(a,\ b,\ c,\ \tau,\ \eta) = \frac{a\cdot\nu}{\mu_2 + (c^2/3 - a\cdot b)\cdot c\cdot\nu/\mu_2} + \eta$$

$$\mathrm{P3}(u) = 1 + u\cdot[1 + 0.5\cdot u\cdot(1 + u/3)]$$

$$\mathrm{expl}(x) = \begin{cases} \exp(x), & \text{if } |x| < k_{\mathrm{sel}} \\ \dfrac{10^{-100}}{\mathrm{P3}(-k_{\mathrm{sel}} - x)}, & \text{if } x < -k_{\mathrm{sel}} \\ 10^{100}\cdot\mathrm{P3}(x - k_{\mathrm{sel}}), & \text{otherwise} \end{cases}$$

$$\mathrm{expl}_{\mathrm{low}}(x) = \begin{cases} \exp(x), & \text{if } x > -k_{\mathrm{sel}} \\ \dfrac{10^{-100}}{\mathrm{P3}(-k_{\mathrm{sel}} - x)}, & \text{otherwise} \end{cases}$$

$$\mathrm{expl}_{\mathrm{high}}(x) = \begin{cases} \exp(x), & \text{if } x < k_{\mathrm{sel}} \\ 10^{100}\cdot\mathrm{P3}(x - k_{\mathrm{sel}}), & \text{otherwise} \end{cases}$$

Component Statements

This device is supported within altergroups.

Instance Definition

```
Name g bi b ModelName <parameter=value> ...
```

Instance Parameters

1 `m=1.0` Multiplicity factor.

2 `w=1.0e-06 m` Design width of varactor.

3 `l=1.0e-06 m` Design length of varactor.

4 `ngcon=1` Number of gate contacts.

5 `dta=0.0 degC` Local temperature delta to ambient.

Model Definition

```
model modelName mosvar parameter=value ...
```

Model Parameters

1 `version=1.1` The available versions are 1.1 and 1.2.

2 `subversion=0.0` Model subversion.

3 `revision=0.0` Model revision.

4 `level=1000` Model level.

5 `tmin=(-100.0) degC`
Minimum reference/ambient temperature.

6 `tmax=500.0 degC` Maximum reference/ambient temperature.

7 `vmax=10000.0 V` Maximum voltage applied between nodes g and b.

8 `tr=21.0 degC`	Nominal (reference) temperature.
9 `lmin=1.0e-08 m`	Minimum allowed drawn length.
10 `lmax=9.9e+09 m`	Maximum allowed drawn length.
11 `wmin=1.0e-08 m`	Minimum allowed drawn width.
12 `wmax=9.9e+09 m`	Maximum allowed drawn width.
13 `swres=1`	Switch to control series resistance: 0=exclude and 1=include.
14 `type=(-1)`	Substrate doping TYPE: -1=n-TYPE and +1=p-TYPE.
15 `typep=(-1)`	Polysilicon doping TYPE: -1=n-TYPE and +1=p-TYPE.
16 `toxo=20.0e-10 m`	Oxide thickness.
17 `epsroxo=3.9`	Relative permittivity.
18 `tau=0.1 s`	Time constant for inversion charge recombination/generation.
19 `vfbo=0.0 V`	Flatband voltage (for p-TYPE substrate).
20 `nsubo=3.0e+23` $/m^3$	Substrate doping level.
21 `mnsubo=1.0`	Maximum change in absolute doping, limited to 1 order of mag up.
22 `dnsubo=0.0`	Doping profile slope parameter.
23 `vnsubo=0.0`	Doping profile corner voltage parameter.
24 `nslpo=0.1`	Doping profile smoothing parameter.
25 `npo=1.0e+27` $/m^3$	Polysilicon doping level.
26 `qmc=1.0`	Quantum mechanical correction factor.
27 `dlq=0.0 m`	Length delta for capacitor size.
28 `dwq=0.0 m`	Width delta for capacitor size.

29 `dwr=0.0 m` Width delta for substrate resistance calculation.

30 `cfrl=0.0 F/m` Fringing capacitance in length direction.

31 `cfrw=0.0 F/m` Fringing capacitance in width direction.

32 `rshg=1.0 Ω/sq` Gate sheet resistance.

33 `rpv=0.0 Ω m`^{2} Vertical resistance down through gate in units of ohm*m^2.

34 `rend=1.0e-04 Ω m`

End resistance (extrinsic well res. plus vertical contact res. to well) per width.

35 `rshs=1000.0 Ω/sq`

Substrate sheet resistance.

36 `uac=5.0e-02 m`^{2}`/V/s`

Accumulation layer zero bias mobility.

37 `uacred=0.0 /V` Accumulation layer mobility degradation factor.

38 `stvfb=0.0 V/K` Temperature dependence of VFB.

39 `strshg=0.0` Temperature dependence of RSHG.

40 `strpv=0.0` Temperature dependence of RPV.

41 `strend=0.0` Temperature dependence of REND.

42 `strshs=0.0` Temperature dependence of RSHS.

43 `stuac=0.0` Temperature dependence of UAC.

44 `feta=1.0` Effective field parameter.

45 `swigate=0` Flag for gate current: 0=turn off and 1=turn on.

46 `chibo=3.1 V` Tunneling barrier height for electrons.

47 `chibpo=4.5 V` Tunneling barrier height for holes.

48 `stig=2.0` Common temperature coefficient for gate currents (ECB, HVB and HVB).

49 `lov=0.0 m` Overlap length.

50 `novo=5.0e+25 /m`^{3} Effective doping level of overlap regions.

51 `iginvlw=0.0 A` ECB gate channel current pre-factor for 1 um^2 channel area.

52 `igovw=0.0 A` ECB gate overlap current pre-factor for 1 um wide gate overlap region.

53 `gcoo=0.0` ECB gate tunneling energy adjustment.

54 `gc2o=0.375` ECB gate current slope factor.

55 `gc3o=0.063` ECB gate current curvature factor.

56 `igchvlw=0.0 A` HVB gate channel current pre-factor for 1 um^2 channel area.

57 `igovhvw=0.0 A` HVB gate overlap current pre-factor for 1 um wide gate overlap region.

58 `gcohvo=0.0` HVB gate tunneling energy adjustment.

59 `gc2hvo=0.375` HVB gate current slope factor.

60 `gc3hvo=0.063` HVB gate current curvature factor.

61 `minr=0.001` Minimum resistor between bi and b.

62 `igmax=1.0e-05 A` Maximum gate tunneling current.

63 `compatible=spectre`
Compatible parameters.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, and `mica`.

64 `racnoise=1` Rac noise selector.

Output Parameters

1 `tempeff (C)` Effective temperature for a single device.

2 `meff` Effective multiplicity factor (m-factor).

Operating-Point Parameters

1 `v` voltage across capacitor.

2 `i` Current through capacitor.

3 `cap` LOw frequency capacitance.

4 `qg` Intrinsic charge.

5 `igc` Gate tunneling current.

6 `igover` Gate overlap tunneling current.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

26

EKV MOSFET Model (ekv)

The EPFL-EKV MOSFET model was developed by the Electronics Laboratories, Swiss Federal Institute of Technology (EPFL), Switzerland. This chapter contains the following information for the EKV MOSFET model:

This section provides a description of the equations used for the EPFL-EKV MOSFET model. The description concentrates on the intrinsic part of the MOSFET. The extrinsic part of the MOSFET is handled as it is commonly made for other MOSFET models.

The EPFL-EKV MOSFET model is formulated as a *single expression*, which preserves the continuity of first- and higher-order derivatives with respect to any terminal voltage, in the entire range of validity of the model.

The EPFL-EKV MOSFET model version 2.6 includes modeling of the following physical effects:

- Basic geometrical and process-related aspects, such as oxide thickness, junction depth, and effective channel length and width
- Effects of doping profile and substrate effects
- Modeling of weak, moderate, and strong inversion behavior
- Modeling of mobility effects due to vertical and lateral fields and velocity saturation
- Short-channel effects, such as channel-length modulation (CLM), source and drain charge-sharing (including for narrow channel widths), and reverse short-channel effect (RSCE)
- Quasi-static charge-based dynamic model
- Thermal and flicker noise modeling
- First-order nonquasi-static model for the transadmittances

Coherence of Static and Dynamic Models

All aspects regarding the static, the quasi-static, and nonquasi-static dynamic and noise models are all derived in a coherent way from a single characteristic, the normalized transconductance-to-current ratio. Symmetric normalized forward and reverse currents are used throughout these expressions. The Virtuoso® Spectre® circuit simulator supports only one dynamic model, a charge-based model for the node charges and transcapacitances. The dynamic model, including the time constant for the nonquasi-static model, is described in symmetrical terms of the forward and reverse normalized currents. The charge formulation is further used to express the effective mobility dependence of the local field.

Bulk Reference and Symmetry

Voltages are all referred to the local substrate:

$V_G = V_{GB}$ Intrinsic gate-to-bulk voltage

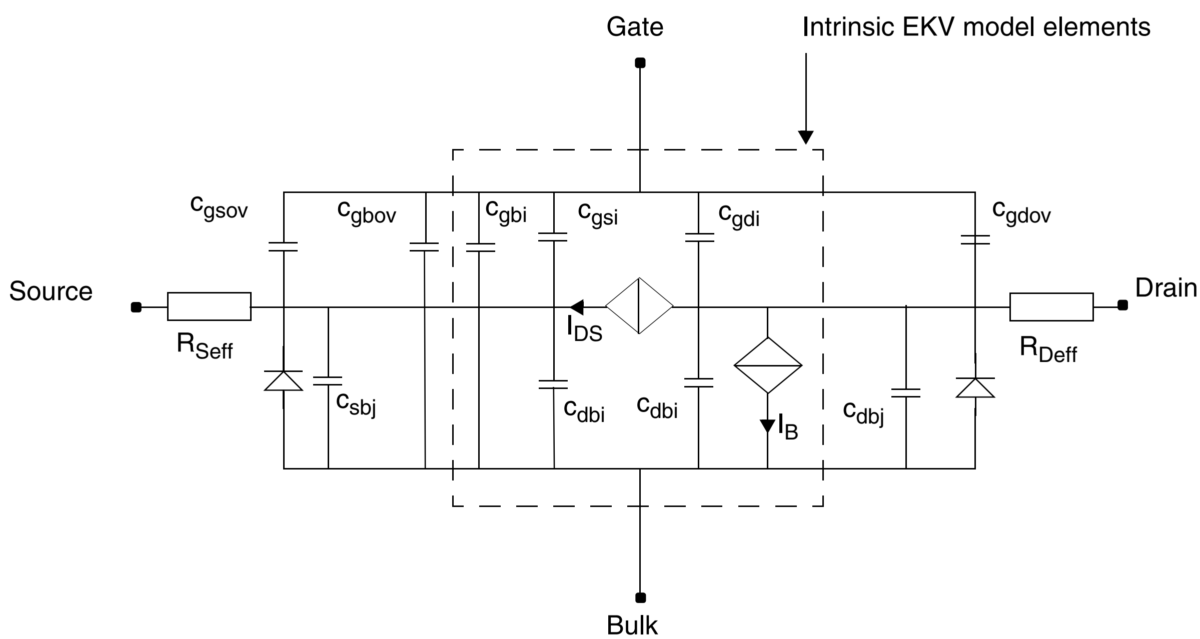
$V_S = V_{SB}$Intrinsic source-to-bulk voltage

$V_D = V_{DB}$Intrinsic drain-to-bulk voltage

V_S and V_D are the intrinsic voltages, which means that the voltage drop over extrinsic resistive elements is supposed to already be accounted for externally. V_D is the electrical drain voltage such that $V_D \geq V_S$. Bulk reference allows the model to be handled symmetrically with respect to source and drain, a symmetry that is inherent in common MOS technologies (excluding asymmetric source-drain layouts).

Note: Intrinsic model equations are present for an N-channel MOSFET. P-channel MOSFETs are dealt with as pseudo-N-channels; that is, the polarity of the voltages (V_G, V_S, V_D, as well as VTO) is inverted before computing the current for PMOS, which is given a negative sign. No other distinctions are made between NMOS and PMOS, with the exception of the η factor for effective mobility calculation.

Equivalent Circuit



This figure represents the intrinsic and extrinsic elements of the MOS transistor. For quasi-static dynamic operation, only the intrinsic capacitances from the simpler capacitances model are shown in the figure. However, a charge-based transcapacitances model is also available for computer simulation.

Static Intrinsic Model

Basic Relations

$$\varepsilon_0 \varepsilon_{si} = SCALE \cdot 104.5 \times 10^{-12} [F/m]$$

Thermal voltage

$$V_t = \frac{k \cdot T}{q}$$

Energy Gap

$$E_g(T) = 1.16 - 0.000702 \cdot \frac{T^2}{T + 1108}$$

Intrinsic Parameters Initialization

The basic intrinsic model parameters COX, $GAMMA$, PHI, VTO, KP, and $UCRIT$ are related to the fundamental process parameters TOX, $NSUB$, VFB, UO, $VMAX$, respectively, similarly as in early SPICE models. For more information, see Chapter 12, “Common MOSFET Equations”.

If $UCRIT$ is not specified, it is initialized as

$$UCRIT = \begin{cases} VMAX/(UO \cdot 10^{-4}) & \text{for } VMAX > 0, UO > 0 \\ default & otherwise \end{cases}$$

If $E0$ is not specified, a simplified mobility model is used with the parameter $THETA$:

$$E0 = \begin{cases} 0 & if\ THETA\ specified \\ default & otherwise \end{cases}$$

Note: The value zero is given to $E0$ here, indicating that the simplified mobility model is used in conjunction with $THETA$ instead of the standard mobility model.

Intrinsic Parameters Temperature Dependence

$$VTO(T) = VTO - TCV \cdot (T - Tnom)$$

$$KP(T) = KP \cdot \left(\frac{T}{Tnom}\right)^{BEX}$$

$$UCRIT(T) = UCRIT \cdot \left(\frac{T}{Tnom}\right)^{UCEX}$$

$$PHI(T) = PHI \cdot \frac{T}{Tnom} - 3 \cdot V_t \cdot \ln\left(\frac{T}{Tnom}\right) - E_g Tnom \cdot \frac{T}{Tnom} + E_g(T)$$

$$IBB(T) = IBB \cdot [1.0 + IBBT \cdot (T - Tnom)]$$

Effective Channel Length and Width

$$W_{eff} = W + DW$$

$$L_{eff} = L + DL$$

Note: Contrary to the convention adopted in other MOSFET models, DL and DW usually have a negative value because of the preceding definition.

Short Distance Matching

Random mismatch between two transistors with identical layout and close to each other is in most cases suitably described by a law following the inverse of the square root of the transistors' area. The following relationships have been adopted:

$$VTO_a = VTO + \frac{AVTO}{\sqrt{NP \cdot W_{eff} \cdot NS \cdot L_{eff}}}$$

$$KP_a = KP \cdot \left(1 + \frac{AKP}{\sqrt{NP \cdot W_{eff} \cdot NS \cdot L_{eff}}}\right)$$

$$GAMMA_a = GAMMA + \frac{AGAMMA}{\sqrt{NP \cdot W_{eff} \cdot NS \cdot L_{eff}}}$$

Note: Because negative values for both KP_a and $GAMMA_a$ are not physically meaningful, these are clipped at zero.

Reverse Short-Channel Effect (RSCE)

$$C_\varepsilon = 4 \cdot (22 \times 10^{-3})^2$$

$$C_A = 0.028$$

$$\xi = C_A \cdot \left(10 \cdot \frac{L_{eff}}{LK} - 1\right)$$

$$\Delta V_{RSCE} = \frac{2 \cdot Q0}{COX} \cdot \frac{1}{\left[1 + \frac{1}{2} \cdot \left(\xi + \sqrt{\xi^2 + C_\xi}\right)\right]^2}$$

Effective Gate Voltage Including RSCE

$$V_G' = V_G - VTO_a - \Delta V_{RSCE} + PHI + GAMMA_a\sqrt{PHI}$$

Effective Substrate Factor Including Charge-Sharing for Short and Narrow Channels

Pinchoff Voltage for Narrow-Channel Effect

$$V_{P0} = \begin{cases} V_G' - PHI - GAMMA_a\left(\sqrt{V_G' + \left(\frac{GAMMA_a}{2}\right)^2} - \frac{GAMMA_a}{2}\right) & \text{for } V_G' > 0 \\ -PHI & \text{for } V_G' \le 0 \end{cases}$$

Effective Substrate Factor Accounting for Charge Sharing

$$V'_{S(D)} = \frac{1}{2} \cdot \left[V_{S(D)} + PHI + \sqrt{(V_{S(D)} + PHI)^2 + (4V_t)^2}\right]$$

Note: The preceding equation prevents the argument of the square roots in the subsequent code from becoming negative.

$$\gamma^o = GAMMA_a - \frac{\varepsilon_0 \cdot \varepsilon_{Si}}{COX} \cdot \left[\frac{LETA}{L_{eff}} \cdot (\sqrt{V'_S} + \sqrt{V'_D}) - \frac{3 \cdot WETA}{W_{eff}}(\sqrt{V_{P0} + PHI + 0.1 \cdot V_t})\right]$$

$$\gamma' = \frac{1}{2} \cdot \left(\gamma^o + \sqrt{\gamma^{o2} + 0.1 \cdot V_t}\right)$$

Note: The purpose of the preceding equation is to prevent the effective substrate factor from becoming negative.

Pinchoff Voltage Including Short- and Narrow-Channel Effects

$$V_P = \begin{cases} V_G' - PHI - \gamma'\left(\sqrt{V_G' + \left(\frac{\gamma'}{2}\right)^2} - \frac{\gamma'}{2}\right) & \text{for } V_G' > 0 \\ -PHI & \text{for } V_G' \le 0 \end{cases}$$

Slope Factor

$$n = 1 + \frac{GAMMA_a}{2 \cdot \sqrt{V_P + PHI + 4V_t}}$$

Large-Signal Interpolation Function

F(v) is the large-scale interpolation function relating the normalized currents to the normalized voltages. A simple and accurate expression for the transconductance interpolation allows a consistent formulation of the static large-signal interpolation function, the dynamic model for the intrinsic charges (and capacitances), and the intrinsic time constant and the thermal noise model.

$$gms \cdot V_t / I_D = \frac{\sqrt{0.25 + i} - 0.5}{i}$$

Large-signal interpolation function:

$$y = \sqrt{0.25 + i} - 0.5$$

$$v = 2y + \ln(y)$$

Unfortunately, the preceding equation cannot be inverted analytically. However, it can be inverted using a Newton-Raphson iterative scheme. Currently, a simplification of this algorithm that avoids iteration is used, leading to a continuous expression for the large-signal interpolation function.

Large-Signal Interpolation Function for Hand Calculation

For hand calculations, an analytically simple interpolation function, presenting the same asymptotic behavior with slightly reduced accuracy in moderate inversion, can be used:

$$F(v) = [\ln(1 + \exp(v/2))]^2$$

Forward Normalized Current

$$i_f = F\left[\frac{V_P - V_S}{V_t}\right]$$

Velocity Saturation Voltage

$$V_C = UCRIT \cdot L_{eff}$$

$$V_{DSS} = V_C \cdot \left[\sqrt{\frac{1}{4} + \frac{V_t}{V_C} \cdot \sqrt{i_f}} - \frac{1}{2}\right]$$

Note: The variable V_{DSS} in this formulation for computer simulation is half the value of the actual saturation voltage.

Drain-to-Source Saturation Voltage for Reverse Normalized Current

$$V_{DSS} = V_C \cdot \left[\sqrt{\frac{1}{4} + \frac{V_t}{V_C} \cdot \left(\sqrt{i_f} - \frac{3}{4} \cdot \ln(i_f)\right)} - \frac{1}{2}\right] + V_t \cdot \left[\ln\left(\frac{V_C}{2V_t}\right) - 0.6\right]$$

Channel-Length Modulation

$$\Delta V = 4 \cdot V_t \cdot \sqrt{LAMBDA \cdot \left(\sqrt{i_f} - \frac{V_{DSS}}{V_t}\right) + \frac{1}{64}}$$

$$\Delta L = LAMBDA \cdot L_C \cdot \ln\left(1 + \frac{V_{ds} - V_{ip}}{L_C \cdot UCRIT}\right)$$

$$V_{ds} = \frac{V_D - V_S}{2}$$

$$L_C = \sqrt{\frac{\varepsilon_0 \varepsilon_{si}}{COX} \cdot XJ}$$

$$V_{ip} = \sqrt{V_{DSS}^2 + \Delta V^2} - \sqrt{(V_{ds} - V_{DSS})^2 + \Delta V^2}$$

Equivalent Channel Length Including Channel-Length Modulation and Velocity Saturation

$$L' = L_{eff} - \Delta L + \frac{V_{ds} + V_{ip}}{UCRIT}$$

$$L_{min} = L_{eff} / 10$$

$$L_{eq} = \frac{1}{2} \cdot \left(L' + \sqrt{L'^2 + L_{min}^2}\right)$$

Note: The preceding equation prevents the equivalent channel length from becoming zero or negative.

Reverse Normalized Current

Reverse Normalized Current

$$i_r' = F\left[\frac{V_P - V_{ds} - V_S - \sqrt{V_{DSS}^2 + \Delta V^2} + \sqrt{(V_{ds} - V_{DSS})^2 + \Delta V^2}}{V_t}\right]$$

Reverse Normalized Current for Mobility Model, Intrinsic Charges/Capacitances, and NQS Time Constant

$$i_r = F\left[\frac{V_P - V_D}{V_t}\right]$$

Transconductance Factor and Mobility Reduction Due to Vertical Field

$$\beta_0 = KP_a \cdot \frac{NP \cdot W_{eff}}{NS \cdot L_{eq}}$$

Note: The use of the device parameter NP (or M) gives accurate results for the simulation of parallel devices, whereas the use of NS for series devices is only approximate.

$$\eta = \begin{cases} 1/2 & \text{for NMOS} \\ 1/3 & \text{for PMOS} \end{cases}$$

$$q_{B0} = GAMMA_a \cdot \sqrt{PHI}$$

$$\beta_0' = \beta_0 \cdot \left(1 + \frac{COX}{E0 \cdot \varepsilon_0 \varepsilon_{si}} \cdot q_{B0}\right)$$

$$\beta = \frac{\beta_0'}{1 + \frac{COX}{E0 \cdot \varepsilon_0 \varepsilon_{si}} \cdot V_t \cdot |q_B + \eta \cdot q_I|}$$

For the definition of the normalized bulk and inversion charges q_B and q_I, refer to “Normalized Intrinsic Node Charges” on page 2055.

Note: This formulation arises from the exact integration of the local effective field as a function of depletion and inversion charge densities along the channel. The bias dependence, in particular with the substrate bias, is accounted for due to the dependency on the channel charges.

Mobility Reduction Model Used in Former EKV Model Versions

For reasons of compatibility with EKV model versions before 2.6, a simpler mobility reduction model that uses the parameter $THETA$ can be used. The choice among model versions is made using the model version selector $UPDATE$. Check with the documentation in your simulator. If a model version $UPDATE$<2.6 is specified, the former mobility reduction model is chosen:

$$V_P' = \frac{1}{2} \cdot \left(V_P + \sqrt{V_P^2 + 2V_t}\right)^2$$

$$\beta = \frac{\beta_0}{1 + THETA \cdot V_P'}$$

Specific Current

$$I_S = 2 \cdot n \cdot \beta \cdot V_t^2$$

Drain-to-Source Current

$$I_{DS} = I_S \cdot (i_f - i'_r)$$

Note: This drain current expression is a single equation, valid in all operating regions: weak, moderate, and strong inversion; conduction; and saturation. It is therefore not only continuous among all these regions, it is also continuously derivable.

Impact Ionization Current

$$V_{ib} = V_D - V_S - IBN \cdot 2 \cdot V_{DSS}$$

$$I_B = \begin{cases} I_{DS} \cdot \frac{IBA}{IBB} \cdot V_{ib} \cdot \exp\left(\frac{-IBB \cdot L_C}{V_{ib}}\right) & \text{for } V_{ib} > 0 \\ 0 & \text{for } V_{ib} \le 0 \end{cases}$$

Note: The factor 2 in the expression for V_{ib} accounts for the fact that the numerical value of V_{DSS} is half the actual saturation voltage. The substrate current is intended to be treated as a component of the total extrinsic drain current, flowing from the drain to the bulk. It therefore also affects the total extrinsic conductances, in particular the drain conductance.

Quasi-static Model

Both a charge-based model for transcapacitances, allowing charge conservation during transient analysis, and a simpler capacitances-based model are available.

Note: The charges model is in principle formulated in symmetric terms of the forward and reverse normalized currents, that is, symmetrical for both drain and source sides. Further, short-channel effects, such as charge sharing and reverse short-channel effects, are included in the dynamic model through the pinchoff voltage.

Dynamic Model for the Intrinsic Node Charges

$$n_q = 1 + \frac{GAMMA_a}{2 \cdot \sqrt{V_P + PHI + 10^{-6}}}$$

Normalized Intrinsic Node Charges

$$x_f = \sqrt{\frac{1}{4} + i_f}$$

$$x_r = \sqrt{\frac{1}{4} + i_r}$$

$$qQ_d = -n_q \cdot \left(\frac{4}{15} \cdot \frac{3x_r^3 + 6x_r^2 x_f + 4x_r x_f^2 + 2x_f^3}{(x_f + x_r)^2} - \frac{1}{2}\right)$$

$$q_S = -n_q \cdot \left(\frac{4}{15} \cdot \frac{3x_f^3 + 6x_f^2 x_r + 4x_f x_r^2 + 2x_r^3}{(x_f + x_r)^2} - \frac{1}{2}\right)$$

$$q_I = q_S + q_D = -n_q \cdot \left(\frac{4}{3} \cdot \frac{x_f^2 + x_f x_r + x_r^2}{x_f + x_r} - 1\right)$$

$$q_B = \begin{cases} \left(-GAMMA_a \cdot \sqrt{V_P + PHI + 10^{-6}}\right) \cdot \frac{1}{V_t} - \left(\frac{n_q - 1}{n_q}\right) \cdot q_I & \text{for } V'_G > 0 \\ -V'_G \cdot \frac{1}{V_t} & \text{for } V'_G \le 0 \end{cases}$$

$$q_G = -q_I - q_{OX} - q_B$$

q_{OX} is a fixed-oxide charge assumed to be zero. The preceding equation expresses the charge conservation among the four nodes of the transistor.

Total Node Charges

$$C_{OX} = COX \cdot NP \cdot W_{eff} \cdot NS \cdot L_{eff}$$

$$Q_{(I,B,D,S,G)} = C_{ox} \cdot V_t \cdot q_{(I,B,D,S,G)}$$

Intrinsic Capacitances

Transcapacitances

The intrinsic capacitances are obtained through derivation of the node charges with respect to the terminal voltages. This results in simple analytical functions for all the trancapacitances in terms of x_f, x_r, the pinchoff voltage, the slope factor, and derivatives thereof.

Normalized Intrinsic Capacitances

A simpler model using the five intrinsic capacitances corresponding to the equivalent circuit shown in "Equivalent Circuit" on page 2045 can be obtained when neglecting the slight dependence on the slope factor n, resulting in the following simple functions:

$$c_{gs} = \frac{2}{3} \cdot \left(1 - \frac{x_r^2 - x_r + \frac{1}{2}x_f}{(x_f + x_r)^2}\right)$$

$$c_{gd} = \frac{2}{3} \cdot \left(1 - \frac{x_f^2 - x_f + \frac{1}{2}x_r}{(x_f + x_r)^2}\right)$$

$$c_{gb} = \left(\frac{n_q - 1}{n_q}\right) \cdot (1 - c_{gs} - c_{gd})$$

$$c_{sb} = (n_q - 1) \cdot c_{gs}$$

$$c_{db} = (n_q - 1) \cdot c_{gd}$$

Total Intrinsic Capacitances

$$C_{(gs,gd,gb,sb,db)} = C_{ox} \cdot c_{(gs,gd,gb,sb,db)}$$

Nonquasi-static (NQS) Model

The EKV model includes a first-order NQS model for small-signal (`.AC`) simulations. The expression of the NQS drain current is obtained from the quasi-static value of the drain current, which is then first-order low-pass filtered. NQS is a flag (model parameter) allowing you to disable the NQS model, and τ is the bias-dependent characteristic time constant.

Intrinsic Time Constant

τ_0 is the intrinsic time constant defined as

$$\tau_0 = \frac{COX}{2 \cdot \beta \cdot V_t} = \frac{(NS \cdot L_{eff})^2}{2 \cdot \mu_{eff} \cdot V_t}$$

$$\tau = \tau_0 \cdot \frac{4}{15} \cdot \frac{(x_f^2 + 3x_f x_r + x_r^2)}{(x_f + x_r)^3}$$

$$I_{DS}(s) = \frac{I_{DSq}(s)}{1 + NQS \cdot s \cdot \tau}$$

The corresponding small-signal (`.AC`) transadmittances are then given by

$$Y_m(s) = \frac{g_m}{1 + NQS \cdot s \cdot \tau}$$

$$Y_{ms}(s) = \frac{g_{ms}}{1 + NQS \cdot s \cdot \tau}$$

$$Y_{ds}(s) = \frac{g_{ds}}{1 + NQS \cdot s \cdot \tau}$$

$$Y_{mbs}(s) = Y_{ms}(s) - Y_m(s) - Y_{ds}(s)$$

where g_m, g_{ms}, and g_{ds} are the transconductances and output conductance evaluated at the operating point.

Intrinsic Noise Model

The noise is modeled by a current source I_{NDS} betwe en intrinsic source and drain. It is composed of a thermal noise component and a flicker noise component and has the following power spectral density (PSD):

$$S_{INDS} = S_{thermal} + S_{flicker}$$

Thermal Noise

If model parameter `nlevel=1`,

$$S_{thermal} = \frac{8 \times kT \times |gm|}{3}$$

else

$$S_{thermal} = 4kT \cdot \frac{\mu_{eff}}{(NS \cdot L_{eff})^2} \cdot |Q_I| = 4kT \cdot \beta \cdot |q_I|$$

Note: The thermal noise expression is *valid in all regions of operation*, including for small V_{DS}.

Flicker Noise

When model parameter `noisemod=1`,

$$S_{flicker} = \frac{KF \times |Ids|^{AF}}{NP \cdot W_{eff} \cdot NS \cdot L_{eff} \cdot COX \cdot f^{EF}}$$

When model parameter `noisemod=2`,

$$S_{flicker} = \frac{KF \cdot |Ids|^{AF}}{NP \cdot L_{eff} \cdot NS \cdot L_{eff} \cdot COX \cdot f^{EF}}$$

When model parameter `noisemod=3`,

$$S_{flicker} = \frac{KF \cdot gm^2}{NP \cdot W_{eff} \cdot NS \cdot L_{eff} \cdot COX \cdot f^{AF}}$$

Scaling Effects

For scaling effects, see Scaling Factors (scale and scalem) on page 242.

Component Statements

This device is supported within altergroups.

Sample Instance Statement

mn1 (dn gn sn 0) ekvnmos w=1.5u l=1u ad=2.6p as=2.6p pd=6.6p ps=6.6p nrd=1.54 nrs=1.54

Sample Model Statement

model ekvnmos ekv type=n update=2.6 xqc=0.4 cox=3.4e-3 xj=0.145e-6 vto=0.6 gamma=0.71 phi=0.967 kp=155e-6 e0=88e6 iba=200e6 ibb=350e6 tnom=25 tcv=1.55e-3 bex=-1.45 kf=1e-27 af=1 hdif=0.94e-6 rsh=512 jsw=1.5e-10

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1	w (m)	Channel width.
2	l (m)	Channel length.
3	as (m^2)	Area of source diffusion.
4	ad (m^2)	Area of drain diffusion.
5	ps (m)	Perimeter of source diffusion.
6	pd (m)	Perimeter of drain diffusion.
7	nrd (m/m)	Number of squares of drain diffusion.
8	nrs (m/m)	Number of squares of source diffusion.
9	rdc (Ohm)	Drain contact resistance.
10	rsc (Ohm)	Source contact resistance.
11	m=1	Multiplicity factor (number of MOSFETs in parallel).
12	ns=1	Series Multiplicity factor (number of MOSFETs in series).
13	region=triode	Estimated operating region. Spectre outputs number (0-3) in a rawfile. Possible values are off, triode, sat, or subth.
14	trise	Temperature rise from ambient.
15	isnoisy=yes	Should device generate noise. Possible values are no or yes.

Model Definition

```
model modelName ekv parameter=value ...
```

Model Parameters

Device type parameters:

1 type=n Transistor type. Possible values are n or p.

2 vnds=-1.0 m Reverse diode current transition point.

3 nds=1.0 m Reverse bias slope coefficient.

4 compatible=spectre

Encourage device equations to be compatible with a foreign simulator. This option does not affect input syntax. Possible values are spectre, spice2, spice3, cdsspice, hspice, spiceplus, eldo, or sspice.

Process parameters:

5 tox=2e-8 m Gate oxide thickness.

6 cox=7e-4 F/m^2 Gate oxide capacitance. (Overrides Tox).

7 xj=1.0e-7 m Metallurgical junction depth.

8 dw=0 m Channel Width Correction.

9 dl=0 m Channel Length Correction.

10 nfs=0 cm^-2 Fast surface state density.

11 nsub=1.13e16 cm^-3

Channel doping concentration.

Drain current model parameters:

12	vto=0.5 V	Threshold voltage at zero body bias.
13	gamma=1.0 sqrt(V)	
		Body-effect parameter.
14	phi=0.7 V	Surface potential at strong inversion.
15	kp=5.0e-5 A/V^2	Transconductance parameter.
16	e0=1.0e12 V/m	Vertical Critical Field.
17	ucrit=2.0e6 V/cm	Longitudinal Critical field for mobility degradation.
18	theta=0.0 1/V	Mobility reduction coefficient.
19	uo=710 cm^2/V*s	Carrier surface mobility.
20	vmax (m/s)	Carrier saturation velocity.
21	vfb (V)	Flat-band voltage.
22	lambda=0.5	Channel length modulation parameter.
23	weta=0.25	Narrow Channel Effect Coefficient.
24	leta=0.1	Short Channel Effect Coefficient.
25	xw=0 m	Width variation due to masking and etching.
26	xl=0 m	Length variation due to masking and etching.
27	meto=0 m	Metal overlap in fringing field.

Impact ionization parameters:

28	iba=0 1/m	First Impact Ionization Coefficient.
29	ibb=3.0e8 V/m	Second Impact Ionization Coefficient.
30	ibc=0	Third Impact Ionization Coefficient.

31	ibn=1.0	Saturation velocity factor for impact ionization.

Reverse Short Channel parameters:

32	q0=0 A*s/m^2	Reverse short channel peak charge density.
33	lk=2.9e-7 m	Reverse short channel characteristic length.

Charge model selection parameters:

34	xqc=0.0	Drain/source channel charge partition in saturation for charge

models, e.g. use 0.4 for 40/60, 0.5 for 50/50, 0 for 0/100.

Junction diode model parameters:

35	is=1e-14 A	Bulk junction reverse saturation current.
36	js (A/m^2)	Bulk junction reverse saturation current density.
37	jsw=0 A/m	Bulk junction reverse saturation sidewall current density.
38	n=1	Junction emission coefficient.
39	dskip=yes	Use simple piece-wise linear model for diode currents below 0.1*`iabstol'. Possible values are no or yes.
40	imelt=`imax' A	Explosion current, diode is linearized beyond this current to aid convergence.

Junction capacitance model parameters:

41	cbd=0 F	Bulk-drain zero-bias p-n capacitance.
42	cbs=0 F	Bulk-source zero-bias p-n capacitance.
43	cj=0 F/m^2	Zero-bias junction bottom capacitance density.
44	cjsw=0 F/m	Zero-bias junction sidewall capacitance density.

45	mj=0.5	Bulk junction bottom grading coefficient.
46	mjsw=0.33	Bulk junction sidewall grading coefficient.
47	cjswg=0 F/m	Gate-side zero-bias junction sidewall capacitance density.
48	mjswg=0.33	Gate-side bulk junction sidewall grading coefficient.
49	pbswg=0.8 V	Gate-side junction built-in potential.
50	fc=0.5	Forward-bias capacitance coefficient.
51	pb=0.8 V	ulk p-n bottom contact potential.
52	pbsw=0.8 V	Side-wall contact potential.
53	tt=0.0 V	Bulk p-n transit time.
54	fcsw=0.5	Side-wall forward-bias depletion capacitance threshold.

Overlap capacitance parameters:

55	cgso=0 F/m	Gate-source overlap capacitance.
56	cgdo=0 F/m	Gate-drain overlap capacitance.
57	cgbo=0 F/m	ate-bulk overlap capacitance.

Parasitic resistance parameters:

58	rs=0 Ohm	Source resistance.
59	rd=0 Ohm	Drain resistance.
60	rsh=0 Ohm/sqr	Source/drain diffusion sheet resistance.
61	rss=0 Ohm*m	Scalable source resistance.
62	rdd=0 Ohm*m	Scalable drain resistance.
63	rsc=0 Ohm	Source contact resistance.

64	rdc=0 Ohm	Drain contact resistance.
65	minr=0.1 Ohm	Minimum source/drain resistance.
66	ldif=0 m	Lateral diffusion beyond the gate.
67	hdif=0 m	Length of heavily doped diffusion.

Short distance matching parameters:

68	avto=0 V*m	Area related threshold voltage mismatch parameter.
69	akp=0 m	Area related gain mismatch parameter.
70	agamma=0 sqrt(V)*m	Area related body effect mismatch parameter.

Operating region warning control parameters:

71	alarm=none	Forbidden operating region. Possible values are none, off, triode, sat, subth, or rev.
72	imax=1 A	Maximum current, currents above this limit generate a warning.
73	jmax=1e8 A/m^2	Maximum current density, currents above this limit generate a warning.
74	vbox=1e9*tox V	Oxide breakdown voltage.
75	bvj=infinity V	Junction reverse breakdown voltage.

Temperature effects parameters:

76	tnom (C)	Parameters measurement temperature. Default set by `options'.
77	trise=0 C	Temperature rise from ambient.
78	tcv=1.0e-3 V/C	Threshold voltage temperature coefficient.
79	bex=-1.5	Mobility temperature exponent.

80	ucex=0.8	Longitudinal critical field temp. exponent.
81	ibbt=9.0e-4 1/C	Temperature coefficient for IBB.
82	xti=3	Saturation current temperature exponent.
83	tlev=0	DC temperature selector.
84	tlevc=0	C temperature selector.
85	phitmod=0	hi(T) selector for sanyo.
86	eg=1.12452 V	Energy band gap.
87	gap1=7.02e-4 V/C	Band gap temperature coefficient.
88	gap2=1108 C	Band gap temperature offset.
89	tr1=0.6	First source-drain resistance temperature coefficient.
90	tr2=0.6	Second source-drain resistance temperature coefficient.
91	ptc=0 V/C	Surface potential temperature coefficient.
92	pta=0 V/C	Junction potential temperature coefficient.
93	ptp=0 V/C	Sidewall junction potential temperature coefficient.
94	cta=0 1/C	Junction capacitance temperature coefficient.
95	ctp=0 1/C	Sidewall junction capacitance temperature coefficient.

Default instance parameters:

96	w=3e-6 m	Default channel width.
97	l=3e-6 m	Default channel length.
98	as=0 m^2	Default area of source diffusion.
99	ad=0 m^2	Default area of drain diffusion.
100	ps=0 m	Default perimeter of source diffusion.

101	pd=0 m	Default perimeter of drain diffusion.
102	nrd=0 m/m	Default number of squares of drain diffusion.
103	nrs=0 m/m	Default number of squares of source diffusion.

Noise model parameters:

104	noisemod=1	Noise model selector.
105	kf=0	Flicker (1/f) noise coefficient.
106	af=1	Flicker (1/f) noise exponent.
107	ef=1	Flicker (1/f) noise frequency exponent.
108	nlevel=1	Noise level selector just for spice3 compatible.

Model selection parameters:

109	nqs=0	Nonquasi-static flag.
110	satlim=exp(4)	Ratio defining saturation limit.
111	ekvint=0.0	Interpolation function selector.
112	scalem=1.0	Model scaling factor.
113	update=2.6	Model version selector.

Auto Model Selector parameters:

114	wmax=1.0 m	Maximum channel width for which the model is valid.
115	wmin=0.0 m	Minimum channel width for which the model is valid.
116	lmax=1.0 m	Maximum channel length for which the model is valid.
117	lmin=0.0 m	Minimum channel length for which the model is valid.

118 msgskip=off Skip some warning message customer requested. Possible values are off or on.

DC-mismatch model parameters:

119 mvtwl=0.0 V*m Threshold mismatch area dependence.

120 mvtwl2=0.0 v*m^1.5

Threshold mismatch area square dependence.

121 mvt0=0.0 V Threshold mismatch intercept.

122 mbe0=0.0 Beta mismatch intercept.

123 mbewl=0.0 m Beta mismatch area dependence.

Imax and Imelt

The `imax' parameter aids convergence and prevents numerical overflow. The junctioncharacteristics of the device are accurately modeled for current up to `imax'. If `imax'is exceeded during iterations, the linear model is substituted until the current dropsbelow 'imax' or until convergence is achieved. If convergence is achieved with thecurrent exceeding `imax', the results are inaccurate, and a warning is printed out.

A separate model parameter, `imelt', is used as a limit warning for the junctioncurrent. This parameter can be set to the maximum current rating of the device. When any component of the junction current exceeds `imelt', note that base and collector currentsare composed of many exponential terms, a warning will be issued and the results become inaccurate. The junction current is linearized above the value of `imelt' to preventarithmetic exception, with the exponential term replaced by a linear equation at `imelt'.

Both of these parameters have current density counterparts, `jmax' and `jmelt', that you can specify if you want the absolute current values to depend on the device area.

Auto Model Selection

Many models need to be characterized for different geometries in order to obtain accurate results for model development. The model selector program automatically searches for a model with the length and width range specified in the instance statement and uses this model in the simulations.

For the auto model selector program to find a specific model, the models to be searched should be grouped together within braces. Such a group is called a model group. An opening brace is required at the end of the line defining each model group. Every model in the group is given a name followed by a colon and the list of parameters. Also, the four geometric parameters `lmax', `lmin', `wmax', and `wmin' should be given. The selection criteria to choose a model is as follows:

lmin <= inst_length < lmax and wmin <= inst_width < wmax

Example:

```
model ModelName ModelType {
  1:   <model parameters> lmin=2 lmax=4 wmin=1 wmax=2
  2:   <model parameters> lmin=1 lmax=2 wmin=2 wmax=4
  3:   <model parameters> lmin=2 lmax=4 wmin=4 wmax=6
}
```

Then for a given instance

M1 1 2 3 4 ModelName w=3 l=1.5

the program would search all the models in the model group with the name `ModelName` and then pick the first model whose geometric range satisfies the selection criteria. In the preceding example, the auto model selector program would choose ModelName.2.

You must specify both length (l) and width (w) on the device instance line to enable automatic model selection.

Output Parameters

1	weff (m)	Effective channel width(alias lv2).
2	leff (m)	Effective channel length(alias lv1).
3	rseff (Ohm)	Effective source resistance(alias lv16).
4	rdeff (Ohm)	Effective drain resistance(alias lv17).
5	aseff (m^2)	Effective source area (alias=lv4).

6	adeff (m^2)	Effective drain area (alias=lv3).
7	pseff (m)	Effective source perimeter (alias=lv12).
8	pdeff (m)	Effective drain perimeter (alias=lv11).

Operating-Point Parameters

1	type=n	Transistor type. Possible values are n or p.
2	region=triode	Estimated operating region. Spectre outputs number (0-3) in a rawfile. Possible values are off, triode, sat, or subth.
3	reversed	Reverse mode indicator. Possible values are no or yes.
4	ids (A)	Resistive drain-to-source current.
5	vgs (V)	Gate-source voltage(alias lx2).
6	vds (V)	Drain-source voltage(alias lx3).
7	vbs (V)	Bulk-source voltage(alias lx1).
8	vp (V)	Pinchoff voltage.
9	vth (V)	Threshold voltage.
10	vdss (V)	Drain-source saturation voltage.
11	gm (S)	Common-source transconductance(alias lx7).
12	gds (S)	Common-source output conductance(alias lx8).
13	gmbs (S)	Body-transconductance(alias lx9).
14	nfac	Slope factor.
15	if (A)	Forward current.
16	ir (A)	Reverse current.
17	irprime (A)	Reverse current.

18	isub (A)	Substrate Current.
19	ibd (A)	Bulk-drain junction current.
20	ibs (A)	Bulk-source junction current.
21	pwr (W)	Power at op point.
22	gmoverid (1/V)	\`Gm'/\`Ids'.
23	gamma (sqrt(V))	Body-effect parameter.
24	cjd (F)	Drain-bulk junction capacitance(alias lx29).
25	cjs (F)	Source-bulk junction capacitance(alias lx28).
26	cgg (F)	Gate-gate capacitance.
27	cgd (F)	Gate-drain capacitance(alias lx19).
28	cgs (F)	Gate-source capacitance(alias lx20).
29	cgb (F)	Gate-bulk capacitance.
30	cdg (F)	Drain-gate capacitance(alias lx32).
31	cdd (F)	Drain-drain capacitance(alias lx33).
32	cds (F)	Drain-source capacitance(alias lx34).
33	cdb (F)	Drain-bulk capacitance.
34	csg (F)	Source-gate capacitance.
35	csd (F)	Source-drain capacitance.
36	css (F)	Source-source capacitance.
37	csb (F)	Source-bulk capacitance.
38	cbg (F)	Bulk-gate capacitance(alias lx21).
39	cbd (F)	Bulk-drain capacitance(alias lx22).

40	cbs (F)	Bulk-source capacitance(alias lx23).
41	cbb (F)	Bulk-bulk capacitance.
42	vm (V)	Early voltage.
43	vovrdr (V)	Overdrive voltage.
44	tau (s)	NQS time constant.
45	tau0 (s)	Intrinsic time constant.
46	ron (Ohm)	On-resistance.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

27

EKV3 MOSFET Model (ekv3)

This chapter contains the following information for the EKV3 MOSFET model:

Modes

The low-frequency macro model of the EKV3 model is shown in Figure 26.1. The EKV3 model supports five versions of internal circuitry. Each version covers the needs of certain areas. These versions are listed in table 26.1. Also, some simple schematics that correspond to each mode, are provided in Figure 26.2.

Figure 27-1 EKV3 low-frequency macro model

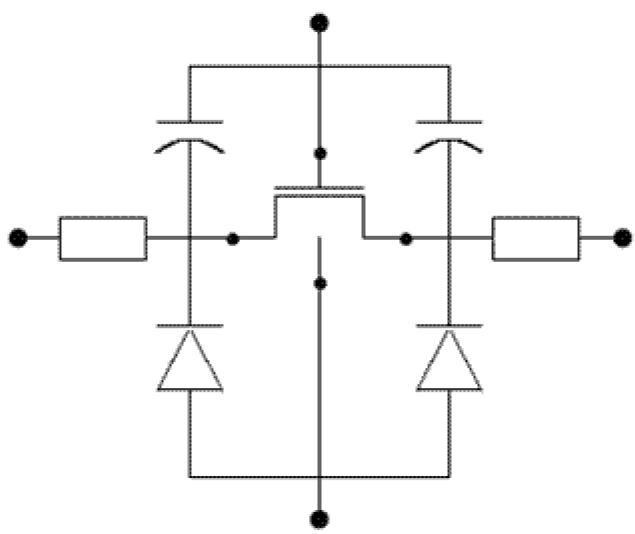
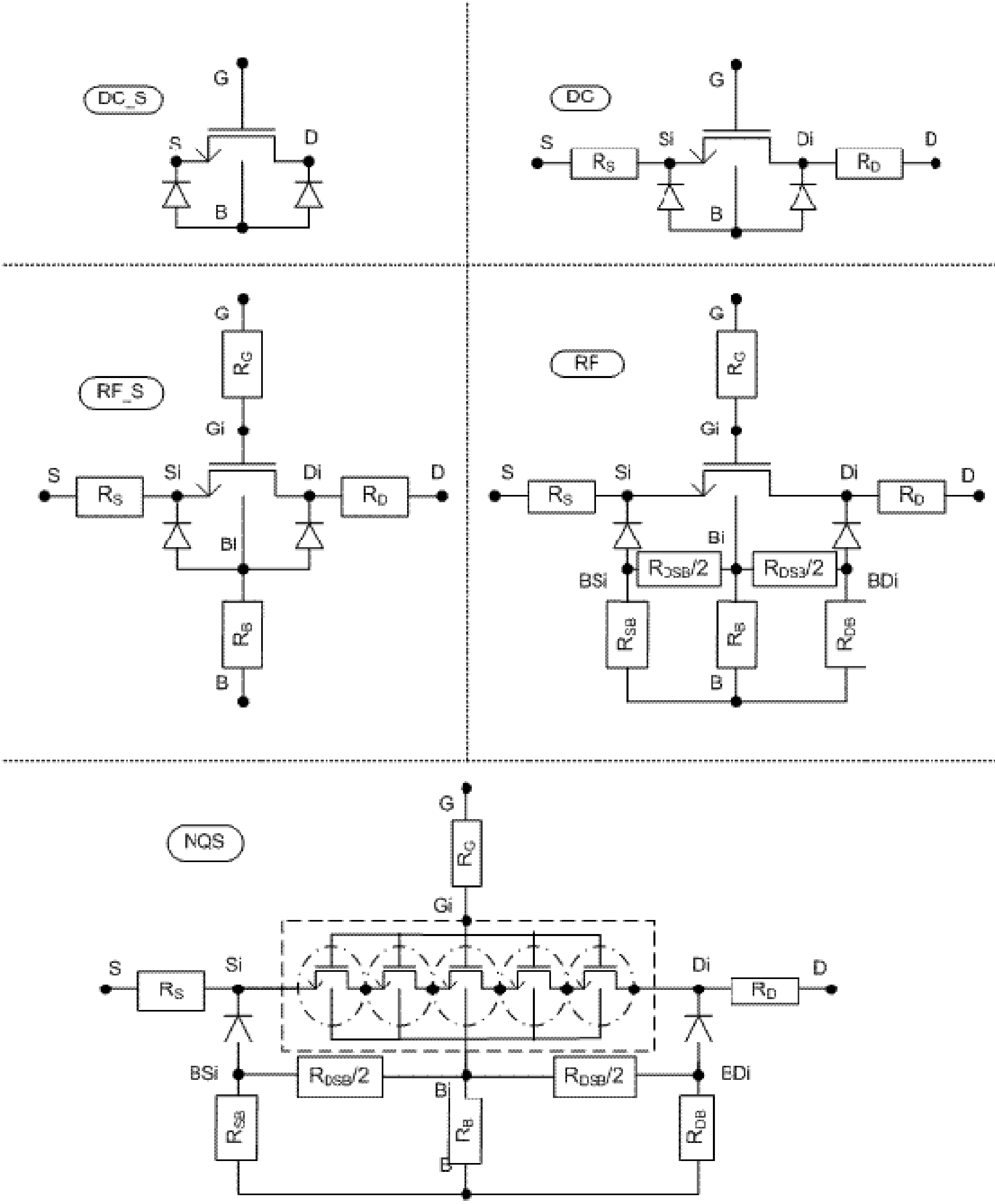


Table 27-1 Modes of the EKV3 model

Mode Name	Description	Internal Nodes
DC_S	No external resistors	0
DC	External series resistors	2
RF_S	External series resistors, gate resistor and 4 single substrate resistor	4
RF	External series resistors, gate resistor and 6 full substrate resistor network	6
NQS	External series resistors, gate resistor and 10 full substrate resistor network; minimal channel segmentation	10

Figure 27-2 Schematic representing the EKV3 Modes



General Equations

$$t_{si} = \frac{\epsilon_{si}}{COX}$$

$$t_{ox} = \frac{\epsilon_{ox}}{COX}$$

$$LC = \sqrt{t_{si} \cdot XJ}$$

Instance Level

Effective Geometry

$$L_{scaled} = L \cdot SCALE + XL$$

$$W_{scaled} = W \cdot SCALE + WL$$

$$L_{eff} = L_{scaled} + DL + \frac{WDL}{W_{scaled}} + \frac{LL}{L_{scaled}^{LLN}}$$

$$W_{eff} = W_{scaled} + DW + \frac{LDW}{L_{scaled}}$$

$$L_{eff,C} = L_{eff} + DLC$$

$$W_{eff,C} = W_{eff} + DWC$$

Matching

$$VTO_a = VTO + \frac{AVTO \cdot 10^6}{\sqrt{W_{eff} \cdot L_{eff}}}$$

$$GAMMA_a = GAMMA + \frac{AGAMMA \cdot 10^6}{\sqrt{W_{eff} \cdot L_{eff}}}$$

$$KP_a = KP\left(1 + \frac{AKP \cdot 10^6}{\sqrt{W_{eff} \cdot L_{eff}}}\right)$$

Long and wide channel correction of VTO and GAMMA

$$\Delta VT_L = -\mathbf{AVT} \cdot MX_S(\ln\frac{L_{eff}}{\mathbf{LVT}}, 0, 10^{-2})$$

$$\Delta VT_W = -\mathbf{AVT} \cdot MX_S(\ln\frac{W_{eff}}{\mathbf{WVT}}, 0, 10^{-2})$$

$$\Delta GAMMA_L = -\mathbf{AGAM} \cdot MX_S(\ln\frac{L_{eff}}{\mathbf{LGAM}}, 0, 10^{-2})$$

$$\Delta GAMMA_W = -\mathbf{AGAM} \cdot MX_S(\ln\frac{W_{eff}}{\mathbf{WGAM}}, 0, 10^{-2})$$

Parameter width and length scaling

$$LR_g = \mathbf{LR} + \frac{\mathbf{WLR}}{W_{eff}}$$

$$QLR_g = \mathbf{QLR} \cdot \left(1 + \frac{\mathbf{WQLR}}{W_{eff}}\right)$$

$$NLR_g = \mathbf{NLR} \cdot \left(1 + \frac{\mathbf{WNLR}}{W_{eff}}\right)$$

$$E0_g = \mathbf{E0} \cdot \left(1 + \frac{\mathbf{WE0}}{W_{eff}}\right)$$

$$E1_g = \mathbf{E1} \cdot \left(1 + \frac{\mathbf{WE1}}{W_{eff}}\right)$$

$$UCRIT_g = \mathbf{UCRIT} \cdot \left(1 + \frac{\mathbf{WUCRIT}}{W_{eff}}\right)$$

$$LAMBDA_g = \mathbf{LAMBDA} \cdot \left(1 + \frac{\mathbf{WLAMBDA}}{W_{eff}}\right)$$

$$ETAD_g = \mathbf{ETAD} \cdot \left(1 + \frac{\mathbf{WETAD}}{W_{eff}}\right)$$

$$UCEX_g = \mathbf{UCEX} \cdot \left(1 + \frac{\mathbf{WUCEX}}{W_{eff}}\right)$$

$$WR_g = \mathbf{WR} + \frac{\mathbf{LWR}}{L_{eff}}$$

$$QWR_g = \mathbf{QWR} \cdot \left(1 + \frac{\mathbf{LQWR}}{L_{eff}}\right)$$

$$NWR_g = \mathbf{NWR} \cdot \left(1 + \frac{\mathbf{LNWR}}{L_{eff}}\right)$$

$$TCV_g = \mathbf{TCV} + \frac{\mathbf{TCVL}}{L_{eff}} + \frac{\mathbf{TCVW}}{W_{eff}} + \frac{\mathbf{TCVWL}}{W_{eff} \cdot L_{eff}}$$

Reverse short channel effect (RSCE)

$$\Delta VT_{RSCE} = \frac{2 \cdot QLR_g \cdot \left(1 - \exp\left(\left(\frac{L_{eff}}{LR_g}\right)^2\right)\right)}{COX \cdot \frac{L_{eff}}{LR_g}}$$

$$GAMMA_{RSCE} = \sqrt{1.0 + \frac{2 \cdot NLR_g \cdot \left(1 - \exp\left(\left(\frac{L_{eff}}{LR_g}\right)^2\right)\right)}{COX \cdot \frac{L_{eff}}{LR_g}}}$$

$$\Delta\Phi_{f,RSCE} = U_T \cdot FLR \cdot \ln\left(1 + \frac{2 \cdot NLR_g \cdot \left(1 - \exp\left(\left(\frac{L_{eff}}{LR_g}\right)^2\right)\right)}{COX \cdot \frac{L_{eff}}{LR_g}}\right)$$

Inverse narrow width effect (INWE)

$$\Delta VT_{INWE} = -\frac{2 \cdot QWR_g \cdot \left(1 - \exp\left(\left(\frac{W_{eff}}{WR_g}\right)^2\right)\right)}{COX \cdot \frac{W_{eff}}{WR_g}}$$

$$GAMMA_{INWE} = \frac{1}{\sqrt{1.0 + \frac{2 \cdot NWR_g \cdot \left(1 - \exp\left(\left(\frac{W_{eff}}{WR_g}\right)^2\right)\right)}{COX \cdot \frac{W_{eff}}{WR_g}}}}$$

Mobility Scaling

$$KP_l = \frac{1}{\left(1 + \frac{KA \cdot LA}{L_{eff}}\right) \cdot \left(1 - \exp\left(-\frac{L_{eff}}{LA}\right)\right) + \left(1 + \frac{KB \cdot LB}{L_{eff}}\right) \cdot \left(1 - \exp\left(-\frac{L_{eff}}{LB}\right)\right)}$$

$$KP_w = 1 + WKP2 \cdot \exp\left(-\left(\frac{\ln\left(\frac{W_{eff}}{WKP1}\right)}{WKP3}\right)^2\right)$$

Instance level parameters

$$VTO_g = VTO_a + \Delta VT_L + \Delta VT_W + \Delta VT_{RSCE} + \Delta VT_{INWE}$$

$$GAMMA_g = (GAMMA_a + \Delta GAMMA_L + \Delta GAMMA_W) \cdot \cdot GAMMA_{RSCE} \cdot GAMMA_{INWE}$$

$$\Phi_{f,g} = PHIF + \Delta\Phi_{f,RSCE}$$

$$KP_g = KP \cdot KP_l \cdot KP_w$$

Temperature scaling

$$\Delta T = T - TNOM$$

$$rT = \frac{T}{TNOM}$$

$$VTO_{gt} = VTO_g - TCV_g \cdot \Delta T$$

$$KP_{gt} = KP_g \cdot rT^{BEX}$$

$$ETA_t = ETA - TETA \cdot \Delta T$$

$$E0_{gt} = E0_g \cdot rT^{TE0EX}$$

$$E1_{gt} = E1_g \cdot rT^{TE1EX}$$

$$\Phi_{f,gt} = \Phi_{f,g} \cdot rT - \frac{E_g(T) - E_g(TNOM) \cdot rT - 3 \cdot U_T \cdot \ln rT}{2}$$

Normalizing

$$\phi_f = \frac{\Phi_{f,gt}}{U_T}$$

$$vto = \frac{VTO_{gt}}{U_T}$$

$$\gamma = \frac{GAMMA_g}{\sqrt{U_T}}$$

$$\gamma_g = \frac{GAMMAG}{\sqrt{U_T}}$$

$$\gamma_v = \frac{GAMMAOV}{\sqrt{U_T}}$$

$$vfb_{ov} = \frac{VFBOV}{U_T}$$

$$ucrit = \frac{UCRIT}{U_T}$$

$$xb = \frac{XB}{U_T}$$

$$ub = \frac{EB \cdot t_{ox}}{XB}$$

Slope factor nQ0

$$n_{Q0} = \begin{cases} 1 + \frac{\gamma}{2 \cdot \sqrt{2 \cdot \phi_f}}, & \text{if TG} = 0 \text{ or } 1 \\ \text{dfrac11} + \frac{\gamma^2}{\gamma_g^2} \cdot \frac{2 \cdot \sqrt{2 \cdot \phi_f}}{\gamma} + \frac{\gamma}{2 \cdot \sqrt{2 \cdot \phi_f}}, & \text{if TG} = -1 \end{cases}$$

Quantum mechanic effect

$$\alpha_{qma} = \text{AQMA} \cdot \frac{\text{COX}^{2/3}}{\text{U}_T^{1/3}} \cdot \text{ETAQM}^{2/3}$$

$$\delta_{qmi} = \frac{1}{3} \cdot \text{AQMI} \cdot \frac{\gamma \cdot \text{COX}}{2 \cdot \phi_f \cdot \sqrt{\text{U}_T}} \left(\frac{2 \cdot \text{ETAQM} \cdot n_{Q0} \cdot \sqrt{2 \cdot \phi_f}}{\gamma} - 1 \right)$$

$$\Delta\Psi_0 = \text{AQMI} \cdot \frac{2}{3} \cdot \left(\gamma \cdot \text{COX} \cdot \sqrt{2 \cdot \phi_f} \right)^{2/3}$$

$$\Delta\psi_0 = \frac{\Delta\Psi_0}{\text{U}_T}$$

$$\phi = 2 \cdot \phi_f + \ln\left(4 \cdot n_{Q0} \cdot \frac{\sqrt{2 \cdot \phi_f}}{\gamma} \right) + \Delta\psi_0$$

Normalization factor for charges

$$Q_0 = -\text{W}_{\text{eff,C}} \cdot \text{NF} \cdot \text{L}_{\text{eff,C}} \cdot \text{U}_T \cdot \frac{\text{COX}}{1 + \delta_{qmi}} \frac{\text{W}_{\text{eff}} - \text{WEDGE}}{\text{W}_{\text{eff}}}$$

$$Q_{0OV} = -\text{W}_{\text{eff}} \cdot \text{NF} \cdot \text{LOV} \cdot \text{U}_T \cdot \frac{\text{COX}}{1 + \delta_{qmi}}$$

Normalization of potentials

$$v_g = \frac{\text{V}_{GB}}{\text{U}_T}$$

$$v_d = \begin{cases} \frac{\text{V}_{DB}}{\text{U}_T}, & \text{if } \text{V}_D \geq \text{V}_S \\ \frac{\text{V}_{SB}}{\text{U}_T}, & \text{if } \text{V}_D < \text{V}_S \end{cases}$$

$$v_s = \begin{cases} \frac{\text{V}_{SB}}{\text{U}_T}, & \text{if } \text{V}_D \geq \text{V}_S \\ \frac{\text{V}_{DB}}{\text{U}_T}, & \text{if } \text{V}_D < \text{V}_S \end{cases}$$

Charge sharing effect

$$\mathrm{CHSH_L} = \mathrm{LETA0} + \frac{\mathrm{LETA}}{\mathrm{L_{eff}}} + \frac{\mathrm{LETA2}}{\mathrm{L_{eff}^2}}$$

$$\mathrm{CHSH_W} = \frac{\mathrm{WETA}}{\mathrm{W_{eff}}}$$

$$\mathrm{NUV} = \mathrm{N0} + 3 \cdot \mathrm{NCS} \cdot \mathrm{t_{ox}} \cdot \mathrm{CHSH_L}$$

$$\mathrm{A_1} = 1 - \frac{\mathrm{CHSH_L} \cdot \mathrm{t_{si}}}{\gamma}\left(\sqrt{\mathrm{MX_2}\left(\mathrm{v_{bi}} + \mathrm{v_s}, 0, \mathrm{U_1^2}\right)} - \sqrt{\mathrm{MX_2}\left(\mathrm{v_{bi}} + \mathrm{v_d}, 0, \mathrm{U_1^2}\right)}\right)$$

$$\mathrm{A_2} = 2 \cdot \mathrm{A_1} - 1 + 2 \cdot \mathrm{CHSH_W} \cdot \frac{\sqrt{\phi}}{\gamma}$$

$$\mathrm{A_3} = 1 + \mathrm{CHSH_W} \cdot \mathrm{t_{si}} \cdot \frac{\gamma}{\gamma_g} \cdot \mathrm{A_2}$$

$$\gamma_{\mathrm{chsh}} = \gamma \cdot \frac{\mathrm{A_1}}{1 + \mathrm{CHSH_W}}$$

$$\gamma_{\mathrm{eff}} = \gamma \cdot \frac{\mathrm{A_1}}{\mathrm{A_3}}$$

$$\mathrm{A_{1,0}} = 1 - 2 \cdot \frac{\mathrm{CHSH_L} \cdot \mathrm{t_{si}}}{\gamma} \cdot \sqrt{\mathrm{v_{bi}}}$$

$$\mathrm{A_{2,0}} = 2 \cdot \mathrm{A_{1,0}} - 1 + 2 \cdot \mathrm{CHSH_W} \cdot \frac{\sqrt{\phi}}{\gamma}$$

$$\mathrm{A_{3,0}} = 1 + \mathrm{CHSH_W} \cdot \mathrm{t_{si}} \cdot \frac{\gamma^2}{\gamma_g^2} \cdot \mathrm{A_{2,0}}$$

$$\gamma_{\mathrm{chsh},0} = \gamma \cdot \frac{\mathrm{A_{1,0}}}{1 + \mathrm{CHSH_W}}$$

Flat-band voltage

$$\mathrm{v_{fb}} = \mathrm{v_{to}} - \phi \cdot \left(1 + \mathrm{CHSH_W} \cdot \mathrm{t_{si}} + \frac{\gamma^2}{\gamma_g^2} \cdot \left(1 - 2 \cdot \mathrm{CHSH_L} \cdot \mathrm{t_{si}} \cdot \frac{\sqrt{\mathrm{v_{bi}}}}{\gamma}\right)^2\right) -$$
$$- \gamma \cdot \left(1 - 2 \cdot \mathrm{CHSH_L} \cdot \frac{\sqrt{\mathrm{v_{bi}}}}{\gamma} \cdot \sqrt{\phi}\right)$$

Effective gate-voltage

$$v'_g = v_g - v_{fb}$$

$$v'_{g,chsh} = \frac{v'_g}{1 + CHSH_W \cdot t_{si}}$$

$$v'_{g,chsh,pd} = \frac{v'_g}{A_3}$$

$$v'_{g,chsh,pd,0} = \frac{v'_g}{A_{3,0}}$$

Pinch-off surface potential

Approximation around zero

$$\psi_{po} = MX_S\left(v'_{g,chsh} - 6 \cdot \left(1 + \frac{\gamma_{chsh}}{\sqrt{2}}\right), 0, 6 \cdot v'_{g,chsh}\right)$$

$$\psi_{po\,0} = MX_S\left(v'_{g,chsh} - 6 \cdot \left(1 + \frac{\gamma_{chsh,0}}{\sqrt{2}}\right), 0, 6 \cdot v'_{g,chsh}\right)$$

Exact solution

$$\psi_p = \begin{cases} -\ln\left(1 - \psi_{po} + \left(\frac{\psi_{po} - v'_{g,chsh}}{\gamma_{chsh}}\right)^2\right), & \text{if } v'_g < 0 \\ \left(\sqrt{v_{g,chsh,pd} - 1 + \exp(-\psi_{po}) + \frac{\gamma_{eff}^2}{4}} - \frac{\gamma_{eff}}{2}\right)^2 + 1 - \exp(-\psi_{po}), & \text{if } v'_g \geq 0 \end{cases} \quad (2.90)$$

$$\psi_{p0} = \begin{cases} -\ln\left(1 - \psi_{po,0} + \left(\frac{\psi_{po,0} - v'_{g,chsh}}{\gamma_{chsh,0}}\right)^2\right), & \text{if } v'_g < 0 \\ \left(\sqrt{v_{g,chsh,pd,0} - 1 + \exp(-\psi_{po,0}) + \frac{\gamma_{chsh,0}^2}{4}} - \frac{\gamma_{chsh,0}}{2}\right)^2 + 1 - \exp(-\psi_{po,0}), & \text{if } v'_g \geq 0 \end{cases}$$

Pinch-off voltage

$$v_p = \psi_p - \phi$$

Velocity saturation

$$e_{clm} = \frac{2}{u_{crit} \cdot L_{eff}}$$

$$q_{sat} = \frac{2 \cdot e_{clm} \cdot i_f}{e_{clm} + 2 + 2 \cdot e_{clm} \cdot q_s + \sqrt{(e_{clm} + 2)^2 + 8 \cdot e_{clm} \cdot q_s}}$$

$$v_{d,sat} = v_p - \frac{(2 \cdot q_{sat} + \ln q_{sat})(1 + e_{clm} \cdot (q_s - q_{sat}))}{\sqrt{1 + \frac{2 \cdot (e_{clm} \cdot (2 - \mathbf{DELTA}) \cdot (q_s - q_{sat}))^2}{0.1 + e_{clm} \cdot (2 - \mathbf{DELTA}) \cdot (q_s - q_{sat})}} + e_{clm} \cdot (q_s - q_{sat})}$$

$$v_{ds,sat} = MX_S(v_{d,sat} - v_s, 3, 4)$$

$$dv = \frac{\mathbf{ACLM}}{\mathbf{DELTA}} \cdot \frac{4 \cdot q_{sat} + \mathbf{DELTA}}{q_s + 1}$$

$$v'_d = \frac{1}{2} \cdot \sqrt{\left((v_d - v_s) \cdot \sqrt{1 + \frac{4 \cdot dv}{v_{ds,sat}}} + v_{ds,sat}\right)^2 + 4 \cdot dv \cdot v_{ds,sat}} - \frac{1}{2} \cdot \sqrt{\left((v_d - v_s) \cdot \sqrt{1 + \frac{4 \cdot dv}{v_{ds,sat}}} - v_{ds,sat}\right)^2 + 4 \cdot dv \cdot v_{ds,sat}} + v_s$$

Channel length modulation

$$u_{clm} = \frac{e_{clm} \cdot L_{eff}}{L_C \cdot (v_d - v'_d)}$$

$$\alpha_{clm} = \frac{L_C}{L_{eff} - 2 \cdot L_C}$$

$$\delta L = \mathrm{LAMBDA}_{g,t} \cdot L_C \cdot \ln \frac{\alpha_{clm} + u_{clm} + \sqrt{u_{clm}^2 + 2 \cdot \alpha_{clm} \cdot u_{clm} + 1}}{\alpha_{clm} + 1}$$

Normalized drain inversion charge

$$q_d = q(v_p + \delta\psi_s - v'_d)$$

Normalized forward current

$$i_r = q_d + q_d^2$$

Slope factor n_V

$$n_v = A_3 + \gamma \cdot \frac{A_4}{2 \cdot \sqrt{\psi_P}}$$

Drain induced barrier lowering effect

$$l_0 = ETA_g \cdot t_{si} \cdot \sqrt{\frac{2 \cdot \sqrt{\phi}}{\gamma}}$$

$$v_c = 4 + 40 \cdot \frac{l_0}{L_{eff}}$$

$$dv = MNS(v_P, MNS(v_s, v_d, v_o^2), v_o^2)$$

$$\delta\psi_s = \exp\left(-\frac{L_{eff}}{2 \cdot l_0}\right) \cdot \left(2 + SIGMAD \cdot \frac{L_{eff}}{2 \cdot l_0} \cdot \frac{dv}{2 \cdot \phi}\right) \cdot \sqrt{(nul - v_s - dv) \cdot (nul + v_d - dv)} \quad (2.97)$$

Normalized source inversion charge

$$q(v) = \left| \begin{array}{l} \text{if } \frac{v}{NUV} < -0.8 \\ \quad z_1 = \frac{1}{4} \cdot (\frac{v}{NUV} - 1.4 + \sqrt{\frac{v}{NUV} \cdot (\frac{v}{NUV} - 0.384936) + 9.662671}) \\ \quad z_2 = \frac{\frac{v}{NUV} - (2 \cdot z_1 + \ln z_1)}{2 \cdot z_1 + 1} \\ \quad z_1(1 + z_2 \cdot (1 + 0.07 \cdot z_2)) \cdot NUV \\ \text{if } \frac{v}{NUV} \geq -0.8 \\ \quad z_{1,ln} = 0.5 \cdot (\frac{v}{NUV} - 0.201491 - \sqrt{\frac{v}{NUV} \cdot (\frac{v}{NUV} - 0.402982) + 2.446562}) \\ \quad z_1 = \frac{1}{4} \cdot (\frac{v}{NUV} - 1.4 + \sqrt{\frac{v}{NUV} \cdot (\frac{v}{NUV} - 0.384936) + 9.662671}) \\ \quad z_2 = \frac{\frac{v}{NUV} - (2 \cdot \exp(z_{1,ln}) + z_{1,ln})}{2z_1 + 1} \\ \quad z_1(1 + z_2 \cdot (1 + 0.483 \cdot z_2)) \cdot NUV \end{array} \right.$$

$$q_s = q(v_P - \delta\psi_s - v_s)$$

Normalized forward current

$$i_f = q_s + q_s^2$$

Slope factor n_Q

$$\psi_{sa} = \psi_P \quad q_s \quad q_d \tag{2.112}$$

$$n_Q = \begin{cases} \text{if TG} < 0 \\ \dfrac{1 + \dfrac{\gamma^2}{\gamma_g^2} + \dfrac{\text{GAMMA}}{\sqrt{U_T}(\sqrt{\psi_P} + \sqrt{\psi_{sa}})}}{\dfrac{1}{2} + \dfrac{\gamma^2}{\gamma_g^2}\dfrac{\sqrt{U_T}\sqrt{\psi_{sa}}}{\text{GAMMA}} + \sqrt{\left(\dfrac{1}{2} + \dfrac{\gamma^2}{\gamma_g^2}\dfrac{\sqrt{U_T}\sqrt{\psi_{sa}}}{\text{GAMMA}}\right)^2 + \left(1 + \dfrac{\gamma^2}{\gamma_g^2} + \dfrac{\text{GAMMA}}{\sqrt{U_T}(\sqrt{\psi_P} + \sqrt{\psi_{sa}})}\right)\dfrac{q_s + q_d}{\gamma_g^2}}} \\ \text{if TG} \geq 0 \\ 1 + \dfrac{\text{GAMMA}}{\sqrt{U_T} \cdot (\sqrt{\psi_P} + \sqrt{\psi_{sa}})} \end{cases}$$

Charge model

$$v_o = v'_{g,chsh} - \psi_{p,0}$$

Quantum mechanic effect

$$q_{bo} = v'_{g,chsh} - \psi_p, \quad \text{if } v'_g < 0$$

$$q_{bo} = \frac{v'_{g,chsh}}{1 + \dfrac{\gamma^2}{\gamma_g^2}} \quad \psi_{p,0}, \quad \text{if } v'_g < 0$$

$$\delta\psi_v = \alpha_{qma} \cdot \left(\left(\sqrt{\frac{q_{bo}^2}{4} + 4 \cdot \alpha_{qma} \cdot \gamma_{chsh}^2} - \frac{q_{bo}}{2} \right)^{2/3} - \left(\sqrt{\frac{9 \cdot \gamma_{chsh}^2}{2} + 4 \cdot \alpha_{qma} \cdot \gamma_{chsh}^2} - \frac{3 \cdot \gamma_{chsh}}{\sqrt{2}} \right)^{2/3} \right)$$

$$v_{o,qm} = v_o + \delta\psi_v$$

$\mathbf{Q_S}$, $\mathbf{Q_D}$, $\mathbf{Q_G}$, $\mathbf{Q_B}$

$$q_S = \frac{n_Q}{3 \cdot (1 + \delta q_{mi})} \cdot \left(2 \cdot q_s + q_d + \frac{(1 + \frac{4}{5} \cdot q_s + \frac{6}{5} \cdot q_d) \cdot (q_s - q_d)^2}{2 \cdot (q_s + q_d + 1)^2} \right)$$

$$q_D = \frac{n_Q}{3 \cdot (1 + \delta q_{mi})} \cdot \left(q_s - 2 \cdot q_d + \frac{(1 + \frac{6}{5} \cdot q_s + \frac{4}{5} \cdot q_d) \cdot (q_s - q_d)^2}{2 \cdot (q_s + q_d + 1)^2} \right)$$

$$q_G = \begin{cases} \text{if } TG < 0 \\ \dfrac{v_{o,qm} + \frac{2 \cdot q_s}{1 + \delta_{qmi}}}{1 + 2 \cdot \sqrt{\frac{1}{4} + \frac{v_{o,qm} + \frac{2 \cdot q_s}{1 + \delta_{qmi}}}{\gamma_g^2}}} + \dfrac{v_{o,qm} + \frac{2 \cdot q_d}{1 + \delta_{qmi}}}{1 + 2 \cdot \sqrt{\frac{1}{4} + \frac{v_{o,qm} + \frac{2 \cdot q_d}{1 + \delta_{qmi}}}{\gamma_g^2}}} + \\ -\dfrac{1}{3 \cdot (1 + \delta_{qmi})} \cdot \dfrac{(q_s - q_d)^2}{\left(\sqrt{\frac{1}{4} + \frac{v_{o,qm} + \frac{2 \cdot q_s}{1 + \delta_{qmi}}}{\gamma_g^2}} + \sqrt{\frac{1}{4} + \frac{v_{o,qm} + \frac{2 \cdot q_d}{1 + \delta_{qmi}}}{\gamma_g^2}} \right)^3} \cdot \\ \cdot \dfrac{4}{5} \cdot \left(\sqrt{\frac{1}{4} + \frac{v_{o,qm} + \frac{2 \cdot q_s}{1 + \delta_{qmi}}}{\gamma_g^2}} + \sqrt{\frac{1}{4} + \frac{v_{o,qm} + \frac{2 \cdot q_d}{1 + \delta_{qmi}}}{\gamma_g^2}} \right)^2 + \\ -\dfrac{4}{5} \cdot \sqrt{\frac{1}{4} + \frac{v_{o,qm} + \frac{2 \cdot q_s}{1 + \delta_{qmi}}}{\gamma_g^2}} \cdot \sqrt{\frac{1}{4} + \frac{v_{o,qm} + \frac{2 \cdot q_d}{1 + \delta_{qmi}}}{\gamma_g^2}} + \dfrac{2}{\gamma_g^2} \\ \text{if } TG \geq 0 \\ v_{o,qm} + q_s + q_s + \dfrac{1}{3 \cdot (1 + \delta_{qmi})} \cdot \dfrac{(q_s - q_d)^2}{q_s + q_d + 1} \end{cases}$$

$$q_I = q_S + q_D$$

$$q_B = q_G - q_S - q_D$$

Mobility effects

Coulomb scattering

$$\beta_{coul} = \frac{THC}{(1 + n_v \cdot ZC \cdot q_s) \cdot (1 + n_v \cdot ZC \cdot q_d)}$$

Vertical field effect

$$e_{q0} = q_B + ETA_t \cdot n_v \cdot q_I$$

$$e_{q1} = \left(\gamma_{eff} \cdot \sqrt{\psi_p} + n_v \cdot (1 - ETA_t) - 1\right)^2 + (n_v \cdot (1 - ETA_t) - 1)^2 \cdot (1 + 2 \cdot i_f + 2 \cdot i_r) - \frac{8}{3} \cdot (n_v \cdot (1 - ETA_t) - 1) \cdot (\gamma_{eff} \cdot \sqrt{\psi_p} + n_v \cdot (1 - ETA_t) - 1) \cdot \frac{i_f + i_r + 0.5 + \sqrt{(i_f + 0.25) \cdot (i_r + 0.25)}}{\sqrt{i_f + 0.25} + \sqrt{i_r + 0.25}}$$

$$\beta_{rvf,coul} = \frac{1 + \frac{U_T}{E0_{g,t} \cdot t_{si}} \cdot \gamma_{eff} \cdot \sqrt{\phi} + \left(\frac{U_T}{E1_{g,t} \cdot t_{si}} \cdot \gamma_{eff} \cdot \sqrt{\phi}\right)^2}{1 + \frac{U_T}{E0_{g,t} \cdot t_{si}} \cdot e_{q0} + \left(\frac{U_T}{E1_{g,t} \cdot t_{si}}\right)^2 \cdot e_{q1} + \beta_{coul}}$$

Channel length modulation

$$\beta_{clm} = \left(\sqrt{1 + \frac{2 \cdot (e_{clm} \cdot (2 - DELTA) \cdot (q_s - q_d))^2}{0.1 + e_{clm} \cdot (2 - DELTA) \cdot (q_s - q_d)} + (e_{clm} \cdot (q_s - q_d))^2}\right)^{-1}$$

Overall effect

$$\beta = KP_{g,t} \cdot \beta_{rvf,coul} \cdot \beta_{clm}$$

Specific current

$$I_{SPEC} = \frac{2 \cdot n_Q \cdot U_T^2 \cdot \beta}{1 + \delta_{qmi}} \cdot \frac{(W_{eff} - WEDGE) \cdot NF}{L_{eff} - \delta L}$$

Drain induced threshold shift

$$va_{dits} = \frac{\dfrac{1}{1 + FPROUT \cdot \dfrac{L_{eff}}{q_I + 2}}}{PDITS} \cdot (1 + (1 + PDITSL \cdot L_{eff}) \cdot \exp(PDITSD \cdot (v_d - v_s) \cdot U_T))$$

$$v_{ds,dits} = v_{ds,sat} - MXS(v_{ds,sat} - (v_d - v_s) - DDITS, 0, 4 \cdot DDITS \cdot v_{ds,sat})$$

$$f_{dits} = 1 + \frac{v_d - v_s - v_{ds,dits}}{va_{dits}}$$

Denormalizing

$$Q_S = q_S \cdot Q_0$$

$$Q_D = q_D \cdot Q_0$$

$$Q_G = -q_G \cdot Q_0$$

$$Q_B = q_B \cdot Q_0$$

$$I_{ds} = I_{SPEC} \cdot (i_f - i_r) \cdot f_{dits}$$

Edge Conductance

Normalization Factors (Edge Device)

$$I_{SPEC,edge} = \frac{2 \cdot n_Q \cdot U_T^2 \cdot \beta}{1 + \delta_{qmi}} \frac{W_{eff} \cdot NF}{L_{eff} - \delta L} \cdot \frac{W_{eff} - WEDGE}{W_{eff}}$$

$$Q_{0,edge} = -W_{eff,C} \cdot NF \cdot L_{eff,C} \cdot U_T \cdot \frac{COX}{1 + \delta_{qmi}} \cdot \frac{WEDGE}{W_{eff}}$$

Scaling - Normalizing

$$\delta\gamma_{edge} = \frac{DGAMMAEDGE}{\sqrt{U_T}} \cdot \left(1.0 + \frac{WLDGAMMAEDGE}{W_{eff} \cdot L_{eff}}\right)$$

$$\delta\phi_{edge} = \frac{DPHIEDGE}{U_T} \cdot \left(1.0 + \frac{LDPHIEDGE}{L_{eff}}\right) \cdot \left(1.0 + \frac{WDPHIEDGE}{W_{eff}}\right) \cdot \left(1.0 + \frac{WLDPHIEDGE}{W_{eff} \cdot L_{eff}}\right)$$

$$\delta v_{p,edge} = -\delta\gamma_{edge} \cdot \frac{\psi_p}{\sqrt{\psi_p} + \frac{\gamma}{2}} - \delta\phi_{edge}$$

Normalized Inversion Charges (Edge Device)

$$q_{s,edge} = q\left(v_p + \delta v_{p,edge} + \delta\psi_s - v_s\right)$$

$$q_{d,edge} = q\left(v_p + \delta v_{p,edge} + \delta\psi_s - v_d'\right)$$

Normalized Currents (Edge Device)

$$i_{f,edge} = q_{s,edge}^2 + q_{s,edge}$$
$$i_{r,edge} = q_{d,edge}^2 + q_{d,edge}$$

Drain Current (Edge Device)

$$I_{DS,edge} = I_{SPEC,edge} \cdot (i_{f,edge} - i_{r,edge}) \cdot f_{dits}$$

Edge Device: Charge Model

$$\psi_{p,edge} = \psi_P - \delta\gamma_{edge} \cdot \frac{\psi_P}{\sqrt{\psi_P} + \frac{\gamma}{2}}$$

$$\gamma_{edge} = \gamma + \delta\gamma_{edge}$$

$n_{q,edge}$

$Q_{S,edge}, Q_{D,edge}, Q_{G,edge}, Q_{B,edge}$

Overlap Capacitances

$$v'_{gs,ov} = v_g - VOV \cdot v_s - vfb_{ov}$$

if $TG < 0$

$$\gamma_{dep,sov} = \begin{cases} \gamma_{g,ov} & \text{if } v'_{gs,ov} \geq 0 \\ \gamma_{ov} & \text{if } v'_{gs,ov} < 0 \end{cases}$$

$$\gamma_{acc,sov} = \begin{cases} \gamma_{ov} & \text{if } v'_{gs,ov} \geq 0 \\ \gamma_{g,ov} & \text{if } v'_{gs,ov} < 0 \end{cases}$$

$$v_{0,sov} = \begin{cases} v'_{gs,ov} & \text{if } v'_{gs,ov} \geq 0 \\ -v'_{gs,ov} & \text{if } v'_{gs,ov} < 0 \end{cases}$$

$$a_{0,sov} = 1.0 + \frac{\gamma_{acc,sov}}{\sqrt{2}}$$

$$a_{1,sov} = \frac{\gamma_{dep,sov}}{\gamma_{acc,sov}}$$

$$a_{2,sov} = \frac{a_{0,sov}}{a_{0,sov} + a_{1,sov}}$$

$$a_{3,sov} = 1 + \frac{\gamma_{dep,sov}}{\sqrt{2}} + a_{1,sov}$$

$$v_{1,sov} = \frac{v_{0,sov}}{2} - 3 \cdot a_{2,sov} \cdot a_{3,sov}$$

$$\delta\psi_{gs0} = v_{1,sov} + \sqrt{v_{1,sov}^2 + 6 \cdot a_{0,sov} \cdot a_{3,sov}}$$

$$\gamma_{dep2,sov} = \gamma_{dep,sov} \cdot \left(\frac{1}{2} + \frac{3}{3 \cdot \sqrt{2} \cdot \gamma_{acc,sov} + v_{0,sov} - \delta\psi_{gs0}}\right)$$

$$a_{4,sov} = 1 - \exp\left(-\delta\psi_{gs0}\right)$$

$$v_{2,sov} = v_{0,sov} - a_{4,sov}$$

$$\delta\psi_{gs} = \left(\frac{v_{2,sov}}{\gamma_{dep2,sov} + \sqrt{\gamma_{dep2,sov}^2 + v_{2,sov}}}\right)^2 - a_{4,sov}$$

$$v_{2b,sov} = v_{0,sov} - \delta\psi_{gs}$$

$$v_{3,sov} = \frac{v_{2b,sov}}{2}$$

$$\delta\psi_{ox,s} = \begin{cases} v_{3,sov} - 3 \cdot a_{0,sov} + \sqrt{\left(\frac{v_{3,sov}}{3 \cdot a_{0,sov}}\right)^2 - 6 \cdot v_{2b,sov}} & \text{if } v'_{gs,ov} > 0 \\ \left(v_{3,sov} - 3 \cdot a_{0,sov} + \sqrt{\left(\frac{v_{3,sov}}{3 \cdot a_{0,sov}}\right)^2 - 6 \cdot v_{2b,sov}}\right) & \text{if } v'_{gs,ov} < 0 \end{cases}$$

if $\mathbf{TG} \geq 0$

if $v'_{gs,ov} \geq 0$

$$\gamma_{acc,sov} = \gamma_{ov}$$

$$v_{0,sov} = v_{gs,ov}$$

$$a_{0,sov} = 1 + \frac{\gamma_{acc,sov}}{\sqrt{2}}$$

$$v_{1,sov} = \frac{v_{0,sov}}{2} - 3 \cdot a_{0,sov}^2$$

$$\delta\psi_{gs0} = v_{1,sov} + \sqrt{v_{1,sov}^2}$$

$$\delta\psi_{gs} = 1 - \exp\left(-\delta\psi_{gs0}\right)$$

$$v_{2b,sov} = v_{0,sov} - \delta\psi_{gs}$$

$$v_{3,sov} = \frac{v_{2b,sov}}{2}$$

$$\delta\psi_{ox,s} = v_{3,sov} - 2 \cdot a_{0,sov} + \sqrt{(v_{3,sov} + 3 \cdot a_{0,sov})^2 - 6 \cdot v_{2b,sov}}$$

$$\text{if } v'_{gs,ov} < 0$$

$$\gamma_{dep,sov} = \gamma_{ov}$$

$$v_{0,sov} = -v_{gs,ov}$$

$$a_{3,sov} = 1 + \frac{\gamma_{dep,sov}}{\sqrt{2}}$$

$$v_{1,sov} = \frac{v_{0,sov}}{2} - 3 \cdot a_{3,sov}^2$$

$$\delta\psi_{gs0} = v_{1,sov} + \sqrt{v_{1,sov}^2 + 6 \cdot v_{0,sov}}$$

$$\gamma_{dep2,sov} = \gamma_{dep,sov} 2$$

$$a_{4,sov} = 1 - \exp\left(-\delta\psi_{gs0}\right)$$

$$v_{2,sov} = v_{0,sov} - a_{4,sov}$$

$$\delta\psi_{gs} = \left(\frac{v_{2,sov}}{\gamma_{dep2,sov} + \sqrt{\gamma_{dep2,sov}^2 + v_{2,sov}}}\right)^2 + a_{4,sov}$$

$$v_{2b,sov} = v_{0,sov} \quad \delta\psi_{gs}$$

$$\delta\psi_{ox,s} = -v_{2b,sov}$$

Denormalizing (Overlap)

$$Q_{S,OV} = -Q_{0,OV} \cdot \delta\psi_{ox,s}$$

$$Q_{D,OV} = -Q_{0,OV} \cdot \delta\psi_{ox,d}$$

Fringing Capacitance

$$Q_{S,FR} = W_{eff,c} \cdot \mathbf{NF} \cdot \mathbf{KJF}(1 + \mathbf{CJF} \cdot U_T \cdot v_s) \cdot \sqrt{MX_S\left(v_{bi} + \frac{\mathbf{VFR}}{U_T} + v_s - (\psi_P - 2 \cdot q_s), 0, \mathbf{DFR}\right)} \tag{2.192}$$

$$Q_{D,FR} = W_{eff,c} \cdot \mathbf{NF} \cdot \mathbf{KJF}\left(1 + \mathbf{CJF} \cdot U_T \cdot v'_d\right) \cdot \sqrt{MX_S\left(v_{bi} + \frac{\mathbf{VFR}}{U_T} + v'_d - (\psi_P - 2 \cdot q'_d), 0, \mathbf{DFR}\right)}$$

Bias-Independent Overlap Capacitances

$$C_{GSO} = \mathbf{CGSO} \cdot W_{eff}$$

$$C_{GDO} = \mathbf{CGDO} \cdot W_{eff}$$

$$C_{GBO} = \mathbf{CGBO} \cdot 2 \cdot L_{eff}$$

Gate Induced Drain and Source Current

$$v_{gs,e} = v_{fb} + \psi_P - 2 \cdot q_s$$

$$I_{GIDL} = \mathbf{AGIDL} \cdot W_{eff} \cdot \mathbf{NF} \frac{(v'_d - v_s - v_{gs,e}) \cdot U_T - \mathbf{EGIDL}}{3 \cdot T_{OX}} \cdot \exp\left(-\frac{3 \cdot T_{OX} \cdot \mathbf{BGIDL}}{(v'_d - v_s - v_{gs,e}) \cdot U_T - \mathbf{EGIDL}}\right) \cdot \frac{(v_d \cdot U_T)^3}{\mathbf{CGIDL} + (v_d \cdot U_T)^3}$$

$$v_{gd,e} = v_{fb} + \psi_P - 2 \cdot q'_d$$

$$I_{GISL} = \mathbf{AGIDL} \cdot W_{eff} \cdot \mathbf{NF} \frac{(v_d - v'_d - v_{gd,e}) \cdot U_T - \mathbf{EGIDL}}{3 \cdot T_{OX}} \cdot \exp\left(-\frac{3 \cdot T_{OX} \cdot \mathbf{BGIDL}}{(v_s - v'_d - v_{gd,e}) \cdot U_T - \mathbf{EGIDL}}\right) \cdot \frac{(v_s \cdot U_T)^3}{\mathbf{CGIDL} + (v_s \cdot U_T)^3}$$

Gate Current

if $((\psi_p \geq 0)$ and $(\mathbf{TG} < 0))$ or $((\psi_p < 0)$ and $(\mathbf{TG} \geq 0))$

$$v_1 = \sqrt{\frac{1}{4} + \frac{v_o + 2 \cdot q_s}{\gamma_g^2}}$$

$$v_2 = v_1 + \frac{1}{2}$$

$$\psi_{ox} = \frac{v_o + 2 \cdot q_s}{v_2}$$

$$\delta\psi_{dq} = \frac{2}{v_2} \cdot \left(1 - \frac{v_o + 2 \cdot q_s}{2 \cdot v_1 \cdot v_2 \gamma_g^2}\right)$$

if $((\psi_p \leq 0)$ and $(\mathbf{TG} \leq 0))$ or $((\psi_p > 0)$ and $(\mathbf{TG} > 0))$

$$\psi_{ox} = \frac{v_o + 2 \cdot q_s}{v_2}$$

$$\delta\psi_{dq} = 2$$

$$\psi_x = \frac{|\psi_{ox}|}{x_b}$$

$$p_{tun} = \begin{cases} \exp\left(-u_b\left(\frac{1}{1 + \sqrt{1 - \psi_x}} + \sqrt{1 - \psi_x}\right)\right) & \text{if } \psi_x < 1 \\ \exp\left(-\frac{u_b}{\psi_x}\right) & \text{if } \psi_x > 1 \end{cases}$$

$$i_{go} = q_s \cdot \psi_{ox} \cdot p_{tun}$$

if $(v_s = v_d)$ or $(\psi_{ox} = 0)$

$$n_{igc} = i_{go} \cdot n_Q$$

$$n_{igs} = \frac{n_{igc}}{2}$$

$$n_{igd} = n_{igs}$$

if $(v_s \neq v_d)$ and $(\psi_{ox} \neq 0)$

$$\delta q_{\delta\xi} = \frac{i'_r - i_\xi}{1 + 2 \cdot q_s}$$

$$a_{gc} = \delta q_{\delta\xi} \cdot \left(\frac{1}{q_s} + \frac{\delta\psi_{dq}}{\psi_{ox}} \right)$$

if $\psi_x < 1$

$$b_{gc} = \begin{cases} \delta q_{\delta\xi} \cdot \delta\psi_{dq} \cdot \dfrac{u_b}{x_b} \cdot \dfrac{3 + \psi_x}{4 + 2\sqrt{1 - \psi_x} \cdot (2 + \psi_x)} & \text{if } \psi_{ox} > 0 \\ -\delta q_{\delta\xi} \cdot \delta\psi_{dq} \cdot \dfrac{u_b}{x_b} \cdot \dfrac{3 + \psi_x}{4 + 2\sqrt{1 - \psi_x} \cdot (2 + \psi_x)} & \text{if } \psi_{ox} < 0 \end{cases}$$

if $\psi_x \geq 1$

$$b_{gc} = \delta q_{\delta\xi} \cdot \delta\psi_{dq} \cdot \frac{u_b}{\psi_x + \psi_{ox}}$$

$$n_{igc} = i_{go} \cdot n_Q \cdot \frac{2 + a_{gc}}{2 - b_{gc}}$$

$$n_{igs} = \frac{1}{2} \cdot i_{go} \cdot n_Q \cdot \frac{3 + a_{gc}}{3 - b_{gc}}$$

$$n_{igd} = n_{igc} - n_{igs}$$

if $v_g \geq v_{fb}$

$$I_{GB} = 0$$

$$I_G = 2 \cdot \mathbf{KG} \cdot W_{eff} \cdot \mathbf{NF} \cdot L_{eff} \cdot U_T^2 \cdot n_{igc} \cdot p_{tun} \cdot T_{OX}^{-2}$$

$$I_{GD} = 2 \cdot \mathbf{KG} \cdot W_{eff} \cdot \mathbf{NF} \cdot L_{eff} \cdot U_T^2 \cdot n_{igd} \cdot p_{tun} \cdot T_{OX}^{-2}$$

$$I_{GS} = I_G - I_{GD}$$

if $v_g < v_{fb}$

$$I_{GB} = \mathbf{KG} \cdot W_{eff} \cdot \mathbf{NF} \cdot L_{eff} \cdot U_T^2 \cdot \psi_{ox} \cdot |\psi_{ox}| \cdot p_{tun} \cdot T_{OX}^{-2}$$

$$I_G = 0$$

$$I_{GD} = 0$$

$$I_{GS} = 0$$

Overlap Gate Current

Gate - Source (Overlap Current)

$$\psi_{oxr,sov} = \begin{cases} v_g - v_s - \left(\sqrt{v_g - v_s - v_{fb,ov} + \frac{\gamma_g^2}{4}} - \frac{\gamma_g}{2}\right)^2 & \text{if } v_g - v_s > v_{fb,ov} \\ v_g - v_s + \left(\sqrt{-v_g + v_s + v_{fb,ov} + \frac{\gamma_{ov}^2}{4}} - \frac{\gamma_{ov}}{2}\right)^2 & \text{if } v_g - v_s < v_{fb,ov} \end{cases}$$

$$\psi_{xr,sov} = \frac{|\psi_{oxr,sov}|}{x_b}$$

$$p_{tun,sov} = \begin{cases} \exp\left(-u_b\left(\frac{1}{1+\sqrt{1-\psi_{xr,sov}}} + \sqrt{1-\psi_{xr,sov}}\right)\right) & \text{if } \psi_{xr,sov} < 1 \\ \exp\left(-\frac{u_b}{\psi_{xr,sov}}\right) & \text{if } \psi_{xr,sov} > 1 \end{cases}$$

$$I_{GSOV} = \mathbf{KG} \cdot W_{eff} \cdot \mathbf{NF} \cdot \mathbf{LOVIG} \cdot \psi_{oxr,sov} \cdot |\psi_{oxr,sov}| \cdot U_T^2 \cdot p_{tun} \cdot T_{OX}^{-2}$$

Gate - Drain (Overlap Current)

Equations similar to Gate - Source (Overlap Current)

Impact Ionization Current

$$\mathrm{v_{ib}} = \mathrm{v_d} - \mathrm{v_s} - 2 \cdot \mathbf{IBN} \cdot \mathrm{v_{ds,sat}}$$

$$\mathrm{I_{DB}} = \begin{cases} I_{DS} \cdot v_{ib} \cdot U_T \cdot \exp\left(\dfrac{IBB_t \cdot L_C}{v_{ib} \cdot U_T}\right) \cdot \dfrac{\mathbf{IBA}}{IBB_t} & \text{if } v_{ib} > 0 \\ 0 & \text{if } v_{ib} < 0 \end{cases}$$

Noise

Thermal Noise

$$\mathrm{g_n} = \frac{2}{(1 + \mathrm{e_{clm}} \cdot (\mathrm{q_s} - \mathrm{q'_d}))^2 \cdot (\mathrm{q_s} + \mathrm{q'_d} + 1)} \cdot \frac{1}{3} \cdot (\mathrm{q_s^2} + \mathrm{q_s} + \mathrm{q'_d} + \mathrm{q'^2_d}) + \mathrm{e^2_{clm}} \cdot \frac{(\mathrm{i_f} - \mathrm{i'_r})^2}{4} +$$
$$+ \frac{(\mathrm{e_{clm}} \cdot (\mathrm{i_f} - \mathrm{i'_r}) + 1) \cdot (\mathrm{q_s} + \mathrm{q'_d})}{4} +$$
$$+ \frac{\mathrm{e_{clm}} \cdot (\mathrm{i_f} - \mathrm{i'_r}) - 1}{8} \cdot \mathrm{e^2_{clm}} \cdot (\mathrm{i_f} - \mathrm{i'_r}) \cdot (\mathrm{q_s} + \mathrm{q'_d} + 1) \cdot \ln \frac{\mathrm{q_s} + \frac{1}{2} + \frac{\mathrm{e_{clm}} \cdot (\mathrm{i_f} - \mathrm{i'_r})}{2}}{\mathrm{q'_d} + \frac{1}{2} + \frac{\mathrm{e_{clm}} \cdot (\mathrm{i_f} - \mathrm{i'_r})}{2}}$$

$$\mathrm{thermal} = 4 \cdot \mathrm{K} \cdot \mathrm{T} \frac{\mathrm{I_{SPEC}}}{\mathrm{U_T}} \cdot \mathrm{g_n} \cdot \mathbf{TH\_NOI}$$

Flicker Noise

$$\mathrm{g_{mg}} = \frac{\mathrm{I_{SPEC}}}{\mathrm{U_T}} \cdot \frac{\mathrm{q_s} - \mathrm{q'_d}}{\mathrm{n_v}}$$

$$\mathrm{flicker} = \frac{\mathbf{KF} \cdot \mathrm{g_{mg}^{\mathbf{EF}}} \cdot (\delta \mathrm{q_{mi}} + 1)}{\mathrm{W_{eff}} \cdot \mathbf{NF} \cdot \mathrm{L_{eff}} \cdot \mathbf{COX}}$$

$$\mathrm{s_{id,flicker}}(\mathrm{f}) = \frac{\mathrm{flicker}}{\mathrm{f^{AF}}}$$

Induced Gate Noise

$$\omega_{spec} = \frac{\beta \cdot U_T}{COX \cdot L_{eff}^2}$$

$$x_f = q_s + \frac{1}{2}$$

$$x_r = q_d' + \frac{1}{2}$$

$$s_{n,idid} = \frac{4 \cdot x_f^2 - 3 \cdot x_f + 4 \cdot x_f \cdot x_r - 3 \cdot x_r + 4 \cdot x_r^2}{6 \cdot (x_f + x_r)}$$

$$s_{n,igig} = \frac{\omega^2}{\omega_{spec}^2} \frac{16x_f^4 + 16x_r^4 + 80x_f x_r^3 + 80x_f^3 x_r + 168x_f^2 x_r^2 - 15x_r^3 - 15x_f^3 - 75x_f^2 x_r - 75x_r^2 x_f}{540 n_{q0}^2 (x_f + x_r)^5}$$

$$s_{n,ibib} = \frac{s_{n,igig}}{(n_{q0} - 1)^2}$$

$$s_{n,igid} = \frac{j \cdot \frac{\omega}{\omega_{spec}}}{18 \cdot n_{q0}} \cdot \frac{(x_f - x_r) \cdot (x_f^2 + 4 \cdot x_f \cdot x_r + x_r^2)}{(x_f + x_r)^3}$$

$$c_{igid} = j \frac{s_{n,igid}}{\sqrt{s_{n,idid} \cdot s_{n,igig}}}$$

Shot and Flicker Gate Noise

$$s_{ig,shot} = 2 \cdot q_e \cdot I_G$$

$$s_{ig,flicker}(f) = \frac{KGFN \cdot I_G^2}{f}$$

Here is a table that lists the parameter names and their meaning in the Spectre Noise Summary table for the EKV3.0 model.

Parameter	Meaning
`fn_id`	Channel current flicker noise

Parameter	**Meaning**
fn_ig	Channel current gate noise
rs	Source parasitic resistor thermal noise
rd	Drain parasitic resistor thermal noise
rg	Gate parasitic resistor thermal noise
rsb	Thermal noise for the substrate resistor connected between BSi and B (see Figure 27-2 on page 2077).
rdb	Thermal noise for the substrate resistor connected between BDi and B (see Figure 27-2 on page 2077).
rbbs	Thermal noise for the substrate resistor connected between BSi and Bi (see Figure 27-2 on page 2077 where it is labeled R_{DSB}/2
rbbd	Thermal noise for the substrate resistor connected between BDi and Bi (see Figure 27-2 on page 2077 where it is labeled R_{DSB}/2
id	Thermal noise of the channel resistor
cor	Induced gate noise
shot_ig	Gate current shot noise

Diodes

Temperature Dependence

$$\mathrm{JS_t} = \mathbf{JS} \cdot \exp\left(\frac{\frac{\mathrm{E_{g,nom}}}{\mathrm{U_{T,nom}}} - \frac{\mathrm{E_g}}{\mathrm{U_T}} + \mathbf{XTI} \cdot \frac{\mathrm{T}}{\mathrm{T_{NOM}}}}{\mathbf{ND}}\right)$$

$$\mathrm{JSW_t} = \mathbf{JSW} \cdot \exp\left(\frac{\frac{\mathrm{E_{g,nom}}}{\mathrm{U_{T,nom}}} - \frac{\mathrm{E_g}}{\mathrm{U_T}} + \mathbf{XTI} \cdot \frac{\mathrm{T}}{\mathrm{T_{NOM}}}}{\mathbf{ND}}\right)$$

$$\mathrm{JSWG_t} = \mathbf{JSWG} \cdot \exp\left(\frac{\frac{\mathrm{E_{g,nom}}}{\mathrm{U_{T,nom}}} - \frac{\mathrm{E_g}}{\mathrm{U_T}} + \mathbf{XTI} \cdot \frac{\mathrm{T}}{\mathrm{T_{NOM}}}}{\mathbf{ND}}\right)$$

$$\mathrm{PB_t} = \mathbf{PB} - \mathbf{TPB} \cdot (\mathrm{T} - \mathrm{T_{NOM}})$$

$$\mathrm{PBSW_t} = \mathbf{PBSW} - \mathbf{TPBSW} \cdot (\mathrm{T} - \mathrm{T_{NOM}})$$

$$\mathrm{PBSWG_t} = \mathbf{PBSWG} - \mathbf{TPBSWG} \cdot (\mathrm{T} - \mathrm{T_{NOM}})$$

$$\mathrm{CJ_t} = \mathbf{CJ} \cdot (1 + \mathbf{TCJ} \cdot (\mathrm{T} - \mathrm{T_{NOM}}))$$

$$\mathrm{CJSW_t} = \mathbf{CJSW} \cdot (1 + \mathbf{TCJSW} \cdot (\mathrm{T} - \mathrm{T_{NOM}}))$$

$$\mathrm{CJSWG_t} = \mathbf{CJSWG} \cdot (1 + \mathbf{TCJSWG} \cdot (\mathrm{T} - \mathrm{T_{NOM}}))$$

$$\mathrm{JTS_t} = \mathbf{JTS} \cdot \exp\left(\frac{\mathrm{E_{g,nom}}}{\mathrm{U_T}} \cdot \mathbf{XTS} \cdot \left(1 - \frac{\mathrm{T}}{\mathrm{T_{NOM}}}\right)\right)$$

$$\mathrm{JTSW_t} = \mathbf{JTSW} \cdot \exp\left(\frac{\mathrm{E_{g,nom}}}{\mathrm{U_T}} \cdot \mathbf{XTSW} \cdot \left(1 - \frac{\mathrm{T}}{\mathrm{T_{NOM}}}\right)\right)$$

$$\mathrm{JTSWG_t} = \mathbf{JTSWG} \cdot \exp\left(\frac{\mathrm{E_{g,nom}}}{\mathrm{U_T}} \cdot \mathbf{XTSWG} \cdot \left(1 - \frac{\mathrm{T}}{\mathrm{T_{NOM}}}\right)\right)$$

$$\mathrm{NJTS_t} = \mathbf{NJTS} \cdot \left(1 + \left(\frac{\mathrm{T}}{\mathrm{T_{NOM}}} - 1\right) \cdot \mathbf{TNJTS}\right)$$

$$\mathrm{NJTSSW_t} = \mathbf{NJTSSW} \cdot \left(1 + \left(\frac{\mathrm{T}}{\mathrm{T_{NOM}}} - 1\right) \cdot \mathbf{TNJTSSW}\right)$$

$$\mathrm{NJTSSWG_t} = \mathbf{NJTSSWG} \cdot \left(1 + \left(\frac{\mathrm{T}}{\mathrm{T_{NOM}}} - 1\right) \cdot \mathbf{TNJTSSWG}\right)$$

Area and Perimeter

$$\mathrm{AS} = 2 \cdot \mathbf{HDIF} \cdot \mathrm{W_{eff}} \cdot \mathbf{NF}$$

$$\mathrm{AD} = 2 \cdot \mathbf{HDIF} \cdot \mathrm{W_{eff}} \cdot \mathbf{NF}$$

$$\mathrm{PS} = (4 \cdot \mathbf{HDIF} + \mathrm{W_{eff}}) \cdot \mathbf{NF}$$

$$\mathrm{PD} = (4 \cdot \mathbf{HDIF} + \mathrm{W_{eff}}) \cdot \mathbf{NF}$$

Junction Current

$$I_{S,D} = JS_t \cdot AD + JSW_t \cdot PD + JSWG_t \cdot W_{eff} \cdot \mathbf{NF}$$

$$f_{breakdown,d} = 1 + \mathbf{XJBV} \cdot \exp\left(-\frac{-V(di,b) + \mathbf{BV}}{U_T \cdot \mathbf{ND} \cdot T_{NOM}}\right)$$

$$\begin{aligned} I_{DE,tun} =& W_{eff} \cdot \mathbf{NF} \cdot JTSWG_t \cdot \left(\exp\left(\frac{V(di,b) \cdot T}{T_{NOM} \cdot U_T \cdot NJTSSWG_t} \frac{\mathbf{VTSSWG}}{\mathbf{VTSSWG} + V(di,b)}\right) - 1\right) \\ &+ PD \cdot JTSW_t \cdot \left(\exp\left(\frac{V(di,b) \cdot T}{T_{NOM} \cdot U_T \cdot NJTSSW_t} \frac{\mathbf{VTSSW}}{\mathbf{VTSSW} + V(di,b)}\right) - 1\right) \\ &+ AD \cdot JT_t \cdot \left(\exp\left(\frac{V(di,b) \cdot T}{T_{NOM} \cdot U_T \cdot NJTS_t} \frac{\mathbf{VTS}}{\mathbf{VTS} + V(di,b)}\right) - 1\right) \end{aligned}$$

$$I_{DBJ} = I_{S,D} \cdot \left(1 - \exp\left(-\frac{V(di,b) \cdot T}{T_{NOM} \cdot U_T \cdot \mathbf{ND}}\right)\right) \cdot f_{breakdown,d} + V(di,b) \cdot \mathbf{GMIN}$$

Junction Capacitance

if $V(di,b) \geq 0$

$$\begin{aligned} C_{DBJ} =& CJ_t \cdot AD \cdot \exp\left(\mathbf{MJ} \cdot \ln\left(1 + \frac{V(di,b)}{PB_t}\right)\right) + \\ &+ CJSW_t \cdot PD \cdot \exp\left(\mathbf{MJSW} \cdot \ln\left(1 + \frac{V(di,b)}{PBSW_t}\right)\right) + \\ &+ CJSWG_t \cdot W_{eff} \cdot \mathbf{NF} \cdot \exp\left(\mathbf{MJSWG} \cdot \ln\left(1 - \frac{V(di,b)}{PBSWG_t}\right)\right) \end{aligned}$$

if $V(di,b) < 0$

$$\begin{aligned} C_{DBJ} =& CJ_t \cdot AD \cdot \left(1 - \mathbf{MJ} \cdot \frac{V(di,b)}{PB_t}\right) + \\ &+ CJSW_t \cdot PD \cdot \left(1 - \mathbf{MJSW} \cdot \frac{V(di,b)}{PBSW_t}\right) + \\ &+ CJSWG_t \cdot W_{eff} \cdot \mathbf{NF} \cdot \left(1 - \mathbf{MJSWG} \cdot \frac{V(di,b)}{PBSWG_t}\right) \end{aligned}$$

External Resistors (Gate, Series, Bulk)

$$\mathrm{RS} = \frac{\mathbf{HDIF} \cdot \mathbf{RSH} + \left(\mathbf{LDIF} - \frac{\mathbf{DL}}{2}\right) \cdot \mathbf{RS}}{\mathrm{W_{eff}}\mathbf{NF}}$$

$$\mathrm{RD} = \frac{\mathbf{HDIF} \cdot \mathbf{RSH} + \left(\mathbf{LDIF} - \frac{\mathbf{DL}}{2}\right) \cdot \mathbf{RD}}{\mathrm{W_{eff}}\mathbf{NF}}$$

$$\mathrm{RS_g} = \mathrm{RS} \cdot \left(1 + \frac{\mathbf{WRLX}}{\mathrm{W_{eff}}}\right)$$

$$\mathrm{RD_g} = \mathrm{RD} \cdot \left(1 + \frac{\mathbf{WRLX}}{\mathrm{W_{eff}}}\right)$$

$$\mathrm{RG} = \mathbf{RGSH} \cdot \frac{\mathrm{W_{eff}}}{3 \cdot \mathbf{GC}^2 \cdot \mathbf{NF} \cdot \mathrm{L_{eff}}}$$

$$\mathrm{RDSB} = \mathbf{RDSBSH} \cdot \frac{\mathrm{L_{eff}}}{\mathrm{L_{eff}} \cdot \mathbf{NF}}$$

if $\mathbf{RINGTYPE} = 1(\mathrm{HORSE-SHOE})$

$$\mathrm{RB} = \begin{cases} \dfrac{\mathbf{RBWSH}}{2 \cdot W_{eff}} & \text{if } \mathrm{RBN} = 0 \\ \dfrac{1}{\dfrac{2 \cdot W_{eff}}{\mathbf{RBWSH}} + \dfrac{\mathbf{NF}}{\mathbf{RBN}}} & \text{if } \mathrm{RBN} \neq 0 \end{cases}$$

if **NF** is even

$$\mathrm{RSB} = \begin{cases} \dfrac{\mathbf{RSBWSH}}{2 \cdot W_{eff}} & \text{if } \mathbf{RSBN} = 0 \\ \dfrac{1}{\dfrac{2 \cdot W_{eff}}{\mathbf{RSBWSH}} + \dfrac{\mathbf{NF}}{\mathbf{RSBN}}} & \text{if } \mathbf{RSBN} \neq 0 \end{cases}$$

$$\mathrm{RDB} = \begin{cases} \dfrac{\mathbf{RDBWSH}}{2 \cdot W_{eff}} & \text{if } \mathbf{RDBN} = 0 \\ \dfrac{1}{\dfrac{2 \cdot W_{eff}}{\mathbf{RDBWSH}} + \dfrac{\mathbf{NF}}{\mathbf{RDBN}}} & \text{if } \mathbf{RDBN} \neq 0 \end{cases}$$

if **NF** is odd

$$\mathrm{RSB} = \begin{cases} \dfrac{\mathbf{RSBWSH}}{W_{eff}} & \text{if } \mathbf{RSBN} = 0 \\ \dfrac{1}{\dfrac{W_{eff}}{\mathbf{RSBWSH}} + \dfrac{\mathbf{NF}}{\mathbf{RSBN}}} & \text{if } \mathbf{RSBN} \neq 0 \end{cases}$$

$$\mathrm{RDB} = \mathrm{RSB}$$

if $\mathbf{RINGTYPE} = 2(SYMMETRIC)$

$$\mathrm{RB} = \frac{\mathbf{RBWSH}}{2 \cdot \mathrm{W_{eff}}}$$

if $\mathbf{NF}$ is even

$$\mathrm{RSB} = \frac{\mathbf{RSBWSH}}{2 \cdot \mathrm{W_{eff}}}$$

$$\mathrm{RDB} = \frac{\mathbf{RDBWSH}}{2 \cdot \mathrm{W_{eff}}}$$

if $\mathbf{NF}$ is odd

$$\mathrm{RSB} = \frac{\mathbf{RSBWSH}}{\mathrm{W_{eff}}}$$

$$\mathrm{RDB} = \mathrm{RSB}$$

Temperature Dependence

$$\mathrm{RS_{gt}} = \mathrm{RS_g} \cdot (1 + \mathbf{TR} \cdot (\mathrm{T} - \mathrm{T_{NOM}}) + \mathbf{TR2} \cdot (\mathrm{T} - \mathrm{T_{NOM}})^2)$$

$$\mathrm{RD_{gt}} = \mathrm{RD_g} \cdot (1 + \mathbf{TR} \cdot (\mathrm{T} - \mathrm{T_{NOM}}) + \mathbf{TR2} \cdot (\mathrm{T} - \mathrm{T_{NOM}})^2)$$

$$\mathrm{RG_t} = \mathrm{RG} \cdot (1 + \mathbf{TR} \cdot (\mathrm{T} - \mathrm{T_{NOM}}) + \mathbf{TR2} \cdot (\mathrm{T} - \mathrm{T_{NOM}})^2)$$

$$\mathrm{RB_t} = \mathrm{RB} \cdot (1 + \mathbf{TR} \cdot (\mathrm{T} - \mathrm{T_{NOM}}) + \mathbf{TR2} \cdot (\mathrm{T} - \mathrm{T_{NOM}})^2)$$

$$\mathrm{RSB_t} = \mathrm{RSB} \cdot (1 + \mathbf{TR} \cdot (\mathrm{T} - \mathrm{T_{NOM}}) + \mathbf{TR2} \cdot (\mathrm{T} - \mathrm{T_{NOM}})^2)$$

$$\mathrm{RDB_t} = \mathrm{RDB} \cdot (1 + \mathbf{TR} \cdot (\mathrm{T} - \mathrm{T_{NOM}}) + \mathbf{TR2} \cdot (\mathrm{T} - \mathrm{T_{NOM}})^2)$$

$$\mathrm{RDSB_t} = \mathrm{RDSB} \cdot (1 + \mathbf{TR} \cdot (\mathrm{T} - \mathrm{T_{NOM}}) + \mathbf{TR2} \cdot (\mathrm{T} - \mathrm{T_{NOM}})^2)$$

Component Statements

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `exp_cr=80.0` This parameter is used by simulator

2 `cmi_limexp_method=1.0`
This parameter is used by simulator.

3 `cmi_compactable=1.0`
This parameter is used by simulator.

4 `l=10.0E-06` GATES LENGTH.

5 `w=10.0E-06` GATES WIDTH.

6 `nf=1` NUMBER OF FINGERS.

7 `m=1` NUMBER OF DEVICES IN PARALLEL.

8 `ad=0.0` DRAINS AREA.

9 `as=0.0` SOURCES AREA.

10 `pd=0.0` DRAINS PERIMETER.

11 `ps=0.0` SOURCES PERIMETER.

12 `sa=0.0` STI PARAMETER; DISTANCE FROM STI.

13 `sb=0.0` STI PARAMETER; DISTANCE FROM STI.

14 `sd=0.0` STI PARAMETER; DISTANCE BETWEEN GATES.

15 `trise=0.0` TEMPERATURE CHANGE FOR PARTICULAR TRANSISTOR.

Model Definition

```
model modelName ekv3 parameter=value ...
```

Model Parameters

1 `sign=1` Sign = 1 for nmos; sign = -1 for pmos.

2 `tg=(-1)` Type of gate: -1 enhancement type; 1 depletion type.

3	`tnom=27.0`	Nominal temperature (in celsius degrees).
4	`scale=1.0`	Scaling factor for gate length and with.
5	`qoff=0.0`	Charge partition flag.
6	`xl=0.0`	Optical offset for gate length.
7	`xw=0.0`	Optical offset for gate width.
8	`nqs_noi=1.0`	NQS noise flag (on/off), includes thermal noise with no short channel effects.
9	`th_noi=0.0`	Thermal noise flag (on/off), includes short channel effects but no gate induced noise.
10	`info_level=0.0`	Information level.
11	`avto=0.0`	Matching parameter for threshold voltage (VTO).
12	`agamma=0.0`	Matching parameter for body factor (GAMMA).
13	`akp=0.0`	Matching parameter for mobility (KP).
14	`cox=0.012`	Oxide capacitance per unit area.
15	`xj=20.0E-09`	Depth of active areas.
16	`vto=0.3`	Threshold voltage.
17	`phif=0.45`	Fermi bulk potential.
18	`gamma=0.3`	Body effect coefficient.
19	`gammag=4.1`	Body effect coefficient for gate.
20	`n0=1.0`	Long channel slope factor fine tuning.
21	`vbi=0.0`	Built-in voltage drop.
22	`aqma=0.5`	Quantum effect coefficient for accumulation region.
23	`aqmi=0.4`	Quantum effect coefficient for inversion region.

24	`etaqm=0.75`	Quantum effect factor.
25	`kp=500.0E-06`	Mobility multiplied by cOX.
26	`e0=1.0E+10`	First order coefficient for mobility reduction due to vertical field.
27	`e1=3.1E+08`	Mobility reduction due to vertical field factor.
28	`eta=0.5`	Mobility reduction due to vertical field factor.
29	`zc=1.0E-6`	Coulomb scattering coefficient.
30	`thc=0.0`	Coulomb scattering coefficient.
31	`la=1.0`	First critical length for mobility length dependence.
32	`lb=1.0`	Second critical length for mobility length dependence.
33	`ka=0.0`	First factor for mobility length dependence.
34	`kb=0.0`	Second factor for mobility length dependence.
35	`wkp1=1.0E-6`	Width parameter for mobility profile vs. width.
36	`wkp2=0.0`	Amplitude parameter for mobility profile vs. width.
37	`wkp3=1.0`	Span parameter for mobility profile vs. width.
38	`dl=(-10.0E-9)`	Effective length parameter.
39	`dlc=0.0`	Effective length parameter for capacitance.
40	`dw=(-10.0E-9)`	Effective width parameter.
41	`dwc=0.0`	Effective width parameter for capacitance.
42	`ldw=0.0`	Length dependence of effective width.
43	`wdl=0.0`	Width dependence of effective length.
44	`ll=0.0`	Base for exponential dependence of effective length.
45	`lln=1.0`	Exponent for exponential dependence of effective length.

46 `avt=0.0`	Amplitude for long and wide channel threshold voltage correction.
47 `lvt=1.0`	Length for long channel threshold voltage correction.
48 `wvt=1.0`	Width for wide channel threshold voltage correction.
49 `agam=0.0`	Amplitude for long and wide channel body effect coefficient correction.
50 `lgam=1.0`	Length for long channel body effect coefficient correction.
51 `wgam=1.0`	Width for wide channel body effect coefficient correction.
52 `nfvta=0.0`	Number of fingers parameter for threshold voltage dependence on NF.
53 `nfvtb=10000.0`	Factor for threshold voltage dependence on NF.
54 `ucrit=5.0E+06`	Critical velocity of electrons.
55 `lambda=0.5`	Early effect factor.
56 `delta=2.0`	Order of velocity saturation model (variable order model 1,2).
57 `aclm=0.83`	Channel length modulation factor.
58 `lr=50.0E-09`	Length factor for RSCE.
59 `qlr=0.5E-3`	Threshold voltage factor of RSCE.
60 `nlr=10.0E-3`	Body effect coefficient factor of RSCE.
61 `flr=0.0`	Bulk fermi potential of RSCE.
62 `leta0=0.0`	Short channel charge sharing coefficient.
63 `leta=500.0E-3`	Long channel charge sharing coefficient.
64 `leta2=0.0`	Short channel dependence coefficient.
65 `weta=200.0E-3`	Narrow channel charge sharing coefficient.

66 `ncs=1.0`	Slope factor dependence from charge sharing.
67 `etad=1.0`	Primary DIBL coefficient.
68 `sigmad=1.0`	Secondary DIBL coefficient.
69 `wr=90.0E-09`	Width factor for INWE.
70 `qwr=0.3E-3`	Threshold voltage factor of INWE.
71 `nwr=5.0E-3`	Body effect coefficient factor of INWE.
72 `fprout=1.0E6`	Output resistance for DITS effect.
73 `pdits=0.0`	DITS parameter.
74 `pditsl=0.0`	DITS dependence on length.
75 `pditsd=1.0`	DITS dependence on drain bias.
76 `ddits=0.3`	Smooth factor of DITS effect.
77 `iba=000.0E+06`	Impact ionization current first parameter.
78 `ibb=300.0E+06`	Impact ionization current second parameter.
79 `ibn=1.0`	Impact ionization current coefficient
80 `xb=3.1`	Silicon to silicon oxide tunneling barrier height.
81 `eb=29.0E+09`	Characteristic electrical field.
82 `kg=00.0E-6`	Mobility for gate current.
83 `lovig=20.0E-9`	Overlap length for gate current.
84 `agidl=0.0`	First GIDL parameter.
85 `bgidl=2.3E+09`	Second GIDL parameter.
86 `cgidl=0.5`	Third GIDL parameter.
87 `egidl=0.8`	Fourth GIDL parameter.

88 `kf=0.0`	Flicker noise factor.
89 `af=1.0`	Frequency exponent for flicker noise.
90 `ef=2.0`	Transconductance exponent for flicker noise.
91 `kgfn=0.0`	Gate flicker noise factor.
92 `lqwr=0.0`	Length dependence of QWR.
93 `lnwr=0.0`	Length dependence of NWR.
94 `lwr=0.0`	Length dependence of WR.
95 `ldphiedge=0.0`	Length dependence of DPHIEDGE.
96 `wqlr=0.0`	Width dependence of QLR.
97 `wnlr=0.0`	Width dependence of NLR.
98 `wlr=0.0`	Width dependence of LR.
99 `wucrit=0.0`	Width dependence of UCRIT.
100 `wlambda=0.0`	Width dependence of LAMBDA.
101 `wetad=0.0`	Width dependence of ETAD.
102 `we0=0.0`	Width dependence of E0.
103 `we1=0.0`	Width dependence of E1.
104 `wrlx=0.0`	Width dependence of RLX.
105 `wucex=0.0`	Width dependence of UCEX.
106 `wdphiedge=0.0`	Width dependence of DPHIEDGE.
107 `wldphiedge=0.0`	Area dependence (fine tuning for short and narrow) of DPHIEDGE.
108 `wldgammaedge=0.0`	Area dependence (fine tuning for short and narrow) of DGAMMAEDGE.

109 `wedge=0.0`	Area dependence (fine tuning for short and narrow) of DGAMMAEDGE.
110 `dgammaedge=0.0`	Difference of body effect coefficient of edge conduction area with respect to the main part of the channel.
111 `dphiedge=0.0`	Difference of fermi potential of edge conduction area with respect to the main part of the channel.
112 `saref=0.0`	Reference distance from STI, for SA.
113 `sbref=0.0`	Reference distance from STI, for SB.
114 `wlod=0.0`	Width of common area between device and STI.
115 `kkp=0.0`	Mobility dependence on STI.
116 `lkkp=0.0`	Length dependence of mobility dependence on STI.
117 `wkkp=0.0`	Width dependence of mobility dependence on STI.
118 `pkkp=0.0`	Area dependence (fine tuning for short and narrow channel devices) of mobility dependence on STI.
119 `tkkp=0.0`	Temperature dependence of mobility dependence on STI.
120 `llodkkp=1.0`	Exponent of length dependence of mobility dependence on STI.
121 `wlodkkp=1.0`	Exponent of width dependence of mobility dependence on STI.
122 `kvto=0.0`	Threshold voltage dependence on STI.
123 `lkvto=0.0`	Length dependence of threshold voltage dependence on STI.
124 `wkvto=0.0`	Width dependence of threshold voltage dependence on STI.
125 `pkvto=0.0`	Area dependence (fine tuning for short and narrow channel devices) of threshold voltage dependence on STI.
126 `llodkvto=1.0`	Exponent of length dependence of threshold voltage dependence on STI.

127 `wlodkvto=1.0`	Exponent of width dependence of threshold voltage dependence on STI.
128 `kgamma=0.0`	Body effect dependence on STI.
129 `lodkgamma=1.0`	Exponential dependence of body effect on STI.
130 `ketad=0.0`	Primary DIBL dependence on STI.
131 `lodketad=1.0`	Exponential dependence of primary DIBL dependence on STI.
132 `kucrit=0.0`	Critical velocity of electrons dependence of STI.
133 `teta=(-0.9E-3)`	Temperature dependence of ETA.
134 `tlambda=0.0`	Temperature dependence of LAMBDA.
135 `tcv=600.0E-6`	Temperature dependence of VTO (threshold voltage).
136 `bex=(-1.5)`	Temperature dependence of KP (mobility).
137 `ucex=1.5`	Temperature dependence of UCRIT.
138 `te0ex=0.5`	Temperature dependence of E0.
139 `te1ex=0.5`	Temperature dependence of E1.
140 `ibbt=800.0E-6`	Temperature dependence of 1BB.
141 `tcvl=0.0`	Length dependence of TCV.
142 `tcvw=0.0`	Width dependence of TCV.
143 `tcvwl=0.0`	Area dependence of TCV.
144 `gammaov=1.6`	Length of the overlap area.
145 `gammagov=10.0`	Body effect coefficient of the gate of the overlap area.
146 `vfbov=0.0`	Flat-band voltage of the overlap area.
147 `lov=20.0E-9`	Length of the overlap area.

148 `vov=1.0`	Vs dependence of vgsov.
149 `cgso=0.0`	Bias-independent gate to source overlap capacitance.
150 `cgdo=0.0`	Bias-independent gate to drain overlap capacitance.
151 `cgbo=0.0`	Bias-independent gate to bulk overlap capacitance.
152 `kjf=0.0`	Fringing capacitance factor
153 `cjf=0.0`	Fringing capacitor bias factor.
154 `vfr=0.0`	Built-in correction for fringing capacitance.
155 `dfr=1.0E-3`	Smooth factor of fringing capacitance model.
156 `hdif=0.0e-6`	Half length of active area.
157 `rsh=0.0`	Square resistance of active area.
158 `ldif=0.0`	Distance between the middle of the active area and the start of the channel.
159 `rs=0.0`	LDD source series resistance.
160 `rd=0.0`	LDD drain series resistance.
161 `rlx=(-1.0)`	External series resistance.
162 `rsx=(-1.0)`	Source series resistance.
163 `rdx=(-1.0)`	Drain series resistance.
164 `tr=0.0`	First order temperature coefficient of resistors.
165 `tr2=0.0`	Second order temperature coefficient of resistors.
166 `gmin=0.0`	Minimum conductance of diode.
167 `njs=1.0`	Slope factor for parasitic diodes(S).
168 `xjbvs=0.0`	Breaddown effect coefficient.

169 `bvs=10.0`	Breakdown voltage(S).
170 `jss=0.0E-09`	Area component of diode current(S).
171 `jssws=0.0E-12`	Perimeter component of diode current(S).
172 `jsswgs=0.0E-12`	Gate side component of diode current(S).
173 `jtss=0.0E-09`	Area component of trap-assisted diode current(S).
174 `jtssws=0.0E-12`	Perimeter component of trap-assisted diode current(S).
175 `jtsswgs=0.0E-12`	Gate side component of trap-assisted diode current(S).
176 `njtss=1.0`	Area slope factor of trap-assisted diode current(S).
177 `njtssws=1.0`	Perimeter slope factor of trap-assisted diode current(S).
178 `njtsswgs=1.0`	Gate side slope factor of trap-assisted diode current(S).
179 `vtss=0.0`	Area voltage factor of trap-assisted diode current(S).
180 `vtssws=0.0`	Perimeter voltage factor of trap-assisted diode current(S).
181 `vtsswgs=0.0`	Gate side voltage factor of trap-assisted diode current(D).
182 `cjs=0.0E-06`	Area component of diode capacitance(S).
183 `cjsws=0.0E-09`	Perimeter component of diode capacitance(S).
184 `cjswgs=0.0E-09`	Gate side component of diode capacitance(S).
185 `pbs=0.800`	Area parameter of diode capacitance(S).
186 `pbsws=0.600`	Perimeter parameter of diode capacitance(S).
187 `pbswgs=0.600`	Gate side parameter of diode capacitance(S).
188 `mjs=0.900`	Area exponent of diode capacitance(S).
189 `mjsws=0.700`	Perimeter exponent of diode capacitance(S).
190 `mjswgs=0.700`	Gate side exponent of diode capacitance(S).

191 `xtis=3.0`	Temperature dependence of diode(S).
192 `xtss=0.0`	Area component of temperature dependence of trap-assisted diode current(S).
193 `xtssws=0.0`	Perimeter component of temperature dependence of trap-assisted diode current(S).
194 `xtsswgs=0.0`	Gate side component of temperature dependence of trap-assisted diode current(S).
195 `tnjtss=0.0`	Temperature dependence of njtss.
196 `tnjtssws=0.0`	Temperature dependence of njtssws.
197 `tnjtsswgs=0.0`	Temperature dependence of njtsswgs.
198 `tcj=0.0`	Temperature dependence of CJ.
199 `tcjsw=0.0`	Temperature dependence of CJSW.
200 `tcjswg=0.0`	Temperature dependence of CJSWG.
201 `tpb=0.0`	Temperature dependence of PB.
202 `tpbsw=0.0`	Temperature dependence of PBSW.
203 `tpbswg=0.0`	Temperature dependence of PBSWG.
204 `njd=1.0`	Slope factor for parasitic diodes(D).
205 `xjbvd=0.0`	Breakdown effect coefficient(D).
206 `bvd=10.0`	Breakdown Voltage(D).
207 `jsd=0.0E-09`	Area component of diode current(D).
208 `jsswd=0.0E-12`	Perimeter component of diode current(D).
209 `jsswgd=0.0E-12`	Gate side component of diode current(D).
210 `jtsd=0.0E-09`	Area component of trap-assisted diode current(D).

211 `jtsswd=0.0E-12`	Perimeter component of trap-assisted diode current(D).
212 `jtsswgd=0.0E-12`	Gate side component of trap-assisted diode current(D).
213 `njtsd=1.0`	Area slope factor of trap-assisted diode current(D).
214 `njtsswd=1.0`	Perimeter slope factor of trap-assisted diode current(D).
215 `njtsswgd=1.0`	Gate side slope factor of trap-assisted diode current(D).
216 `vtsd=0.0`	Area voltage factor of trap-assisted diode current(D).
217 `vtsswd=0.0`	Perimeter voltage factor of trap-assisted diode current(D).
218 `vtsswgd=0.0`	Gate side voltage factor of trap-assisted diode current(D).
219 `cjd=0.0E-06`	Area component of diode capacitance(D).
220 `cjswd=0.0E-09`	Perimeter component of diode capacitance(D).
221 `cjswgd=0.0E-09`	Gate side component of diode capacitance(D).
222 `pbd=0.800`	Area parameter of diode capacitance(D).
223 `pbswd=0.600`	Perimeter parameter of diode capacitance(D).
224 `pbswgd=0.600`	Gate side parameter of diode capacitance(D).
225 `mjd=0.900`	Area exponent of diode capacitance(D).
226 `mjswd=0.700`	Perimeter exponent of diode capacitance(D).
227 `mjswgd=0.700`	Gate side exponent of diode capacitance(D).
228 `xtid=3.0`	Temperature dependence of diode(D).
229 `xtsd=0.0`	Area component of temperature dependence of trap-assisted diode current(D).
230 `xtsswd=0.0`	Perimeter component of temperature dependence of trap-assisted diode current(D).

231 `xtsswgd=0.0`	Gate side component of temperature dependence of trap-assisted diode current(D).
232 `tnjtsd=0.0`	Temperature dependence of njtsd.
233 `tnjtsswd=0.0`	Temperature dependence of njtsswd.
234 `tnjtsswgd=0.0`	Temperature dependence of njtsswgd..
235 `rgsh=3.0`	Gate square resistance.
236 `gc=1`	Gate contacts (single sided = 1, double sided = 2).
237 `krgl1=0.0`	Length dependence of rg.
238 `rdsbsh=1.0E+3`	Drain to source substrate sheet resistance.
239 `rbwsh=3.0E-3`	Inner bulk to bulk sheet resistance.
240 `rbn=0.0`	Inner bulk to bulk resistance per finger (for RINGTYPE=2).
241 `rsbwsh=1.0E-3`	Inner bulk-source side to bulk sheet resistance.
242 `rsbn=0.0`	Inner bulk-source side to bulk resistance per finger (for RINGTYPE=2).
243 `rdbwsh=1.0E-3`	Inner bulk-drain side to bulk sheet resistance.
244 `rdbn=0.0`	Inner bulk-drain side to bulk resistance per finger (for RINGTYPE=2).
245 `ringtype=1.0`	Type of guard ring (bulk contacts) (two sides/symmetric: 1, three sides/horse shoe: 2).

Output Parameters

1 `d`	node: Drain.
2 `g`	node: Gate.
3 `s`	node: Source.
4 `b`	node: Bulk.

5 `di` node: Internal drain.

6 `si` node: Internal source.

7 `noi` node: Noise.

Operating-Point Parameters

1 `exp_cr=(80.0)` The parameter is used by simulator.

2 `cmi_limexp_method=(1.0)`
The parameter is used by simulator.

3 `cmi_compactable=1.0`
The parameter is used by simulator.

4 `qs (C)` Source charge.

5 `qd (C)` Drain charge.

6 `qg (C)` Gate charge.

7 `qb (C)` Bulk charge.

8 `ids (A)` Resistive drain-to-source current.

9 `idb (A)` Impact ionization current.

10 `qsedge (C)` Edge charge.

11 `qdedge (C)` Edge charge.

12 `qgedge (C)` Edge charge.

13 `qbedge (C)` Edge charge.

14 `qsov (C)` Source side overlap charge.

15 `qdov (C)` Drain side overlap charge.

16 `qsfr (C)` Source side fringing charge.

17 `qdfr (C)` Drain side fringing charge.

18 `igidl (A)` Gate induced drain current.

19 `igisl (A)` Gate induced source current.

20 `igb (A)` Gate current(bulk).

21 `igd (A)` Gate current(drain).

22 `igs (A)` Gate current(source).

23 `igdov (A)` Overlap gate current(drain).

24 `igsov (A)` Overlap gate current(source).

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Device ekv3_nqs (ekv3_nqs)

This device is supported within altergroups.

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `exp_cr=(80.0)` The parameter is used by simulator.

2 `cmi_limexp_method=(1.0)` The parameter is used by simulator.

3 `m=(1.0)` Multiplicity factor (number of MOSFETs in parallel).

4 `l=(10.0E-06)` GATES LENGTH.

5 `w=(10.0E-06)` GATES WIDTH.

6 `nf=(1)` NUMBER OF FINGERS.

7 `ad=(0.0)` DRAINS AREA.

8 `as=(0.0)` SOURCES AREA.

9 `pd=(0.0)` DRAINS PERIMETER.

10 `ps=(0.0)` SOURCES PERIMETER.

11 `sa=(0.0)` STI PARAMETER; DISTANCE FROM STI.

12 `sb=(0.0)` STI PARAMETER; DISTANCE FROM STI.

13 `sd=(0.0)` STI PARAMETER; DISTANCE BETWEEN GATES.

14 `avto=(0.0)` MATCHING PARAMETER FOR THRESHOLD VOLTAGE (VTO).

15 `agamma=(0.0)` MATCHING PARAMETER FOR BODY FACTOR (GAMMA).

16 `akp=(0.0)` MATCHING PARAMETER FOR MOBILITY (KP).

Model Definition

```
model modelName ekv3_nqs parameter=value ...
```

Model Parameters

1 `sign=(1)` SIGN = 1 FOR NMOS; SIGN = -1 FOR PMOS.

2 `tg=((-1))` TYPE OF GATE: -1 ENHANCEMENT TYPE; 1 DEPLETION TYPE.

3 `tnom=(27.0)` Parameters measurement temperature.

4 `scale=(1.0)` Scaling Factor for Gate Length and Width.

5 `qoff=(0.0)` Charge partitioning flag.

6 `xl=(0.0)` Optical offset for Gate Length.

7 `xw=(0.0)` Optical offset for Gate Width.

8 `nqs_noi=(1.0)` NQS noise flag(on/off). Includes thermal noise with no short channel effects.

9 `th_noi=(0.0)` Thermal noise flag(on/off). Includes short channel effects but no gate induced noise.

10 `cox=(0.012)` Oxide Capacitance per unit Area.

11 `xj=(20.0E-09)`	Depth of Active Areas.
12 `vto=(0.3)`	THRESHOLD VOLTAGE.
13 `phif=(0.45)`	FERMI BULK POTENTIAL.
14 `gamma=(0.3)`	Body Effect Coefficient.
15 `gammag=(4.1)`	Body Effect Coefficient for Gate.
16 `n0=(1.0)`	Long Channel Slope Factor Fine Tuning.
17 `vbi=(0.0)`	Built-in Voltage Drop.
18 `aqma=(0.5)`	Quantum Effect Coefficient for Accumulation Region.
19 `aqmi=(0.4)`	Quantum Effect Coefficient for Inversion Region.
20 `etaqm=(0.75)`	Quantum Effect Factor.
21 `kp=(500.0E-06)`	Mobility multiplied by COX.
22 `e0=(1.0E+10)`	First Order Coefficient for Mobility Reduction due to Vertical Field.
23 `e1=(3.1E+08)`	Second Order Coefficient for Mobility Reduction due to Vertical Field.
24 `eta=(0.5)`	Mobility Reduction due to Vertical Field Factor.
25 `zc=(1.0E-6)`	Coulomb Scattering coefficient.
26 `thc=(0.0)`	Coulomb Scattering coefficient.
27 `la=(1.0)`	First critical length for mobility length scaling.
28 `lb=(1.0)`	Second critical length for mobility length scaling.
29 `ka=(0.0)`	First factor for mobility length scaling.
30 `kb=(0.0)`	Second factor for mobility length scaling.
31 `wkp1=(1.0E-6)`	Width parameter for mobility profile vs. width.

32 `wkp2=(0.0)`	Amplitude parameter for mobility profile vs. width.
33 `wkp3=(1.0)`	Span parameter for mobility profile vs. width.
34 `dl=((-10.0E-9))`	Effective Length Parameter.
35 `dlc=(0.0)`	Effective Length Parameter for Capacitance.
36 `dw=((-10.0E-9))`	Effective Width Parameter.
37 `dwc=(0.0)`	Effective Width Parameter for Capacitance.
38 `ldw=(0.0)`	Length Dependence of Effective Width.
39 `wdl=(0.0)`	Width Dependence of Effective Length.
40 `ll=(0.0)`	Base for Exponential Dependence of Effective Length.
41 `lln=(1.0)`	Exponent for Exponential Dependence of Effective Length.
42 `avt=(0.0)`	Amplitude for long and wide channel threshold voltage correction.
43 `lvt=(1.0)`	Length for long channel threshold voltage correction.
44 `wvt=(1.0)`	Width for wide channel threshold voltage correction.
45 `agam=(0.0)`	Amplitude for long and wide channel body effect coefficient correction.
46 `lgam=(1.0)`	Length for long channel body effect coefficient correction.
47 `wgam=(1.0)`	Width for wide channel body effect coefficient correction.
48 `nfvta=(0.0)`	Number of fingers parameter for threshold voltage dependence on NF.
49 `nfvtb=(10000.0)`	Factor for threshold voltage dependence on NF.
50 `ucrit=(5.0E+06)`	Critical Velocity of Electrons.
51 `lambda=(0.5)`	Early effect factor.

52 `delta=(2.0)`	Order of velocity saturation model (variable order model 1~2).
53 `aclm=(0.83)`	Channel Length Modulation Factor.
54 `lr=(50.0E-09)`	Length Factor for RSCE.
55 `qlr=(0.5E-3)`	Threshold Voltage Factor of RSCE.
56 `nlr=(10.0E-3)`	Body Effect Coefficient Factor of RSCE.
57 `flr=(0.0)`	Bulk Fermi Potential of RSCE.
58 `leta0=(0.0)`	Long Channel Charge Sharing Coefficient.
59 `leta=(500.0E-3)`	Short Channel Charge Sharing Coefficient.
60 `leta2=(0.0)`	Short Channel Scaling Coefficient.
61 `weta=(200.0E-3)`	Narrow Channel Charge Sharing Coefficient.
62 `ncs=(1.0)`	Slope Factor Dependence from Charge Sharing.
63 `etad=(1.0)`	Primary DIBL Coefficient.
64 `sigmad=(1.0)`	Secondary DIBL Coefficient.
65 `wr=(90.0E-09)`	Width Factor for INWE.
66 `qwr=(0.3E-3)`	Threshold Voltage Factor of INWE.
67 `nwr=(5.0E-3)`	Body Effect Coefficient Factor of INWE.
68 `fprout=(1.0E6)`	Output resistance for DITS effect.
69 `pdits=(0.0)`	DITS parameter.
70 `pditsl=(0.0)`	DITS dependence on length.
71 `pditsd=(1.0)`	DITS dependence on drain bias.
72 `ddits=(0.3)`	Smooth factor of DITS effect.
73 `iba=(000.0E+06)`	Impact Ionization Current first parameter.

74 `ibb=(300.0E+06)` Impact Ionization Current second parameter.

75 `ibn=(1.0)` Impact Ionization Current coefficient.

76 `xb=(3.1)` Silicon to Silicon oxide tunneling barrier height.

77 `eb=(29.0E+09)` Characteristic electrical field.

78 `kg=(00.0E-6)` Mobility for Gate Current.

79 `lovig=(20.0E-9)` Overlap Length for Gate current.

80 `agidl=(0.0)` First GIDL parameter.

81 `bgidl=(2.3E+09)` Second GIDL parameter.

82 `cgidl=(0.5)` Third GIDL parameter.

83 `egidl=(0.8)` Fourth GIDL parameter.

84 `kf=(0.0)` Flicker noise factor.

85 `af=(1.0)` Frequency exponent for flicker noise.

86 `ef=(2.0)` Transconductance exponent for flicker noise.

87 `kgfn=(0.0)` Gate flicker noise factor.

88 `lqwr=(0.0)` Length scaling of QWR.

89 `lnwr=(0.0)` Length scaling of NWR.

90 `lwr=(0.0)` Length scaling of WR.

91 `ldphiedge=(0.0)` Length scaling of DPHIEDGE.

92 `wqlr=(0.0)` Width scaling of QLR.

93 `wnlr=(0.0)` Width scaling of NLR.

94 `wlr=(0.0)` Width scaling of LR.

95 `wucrit=(0.0)` Width scaling of UCRIT.

96 `wlambda=(0.0)` Width scaling of LAMBDA.

97 `wetad=(0.0)` Width scaling of ETAD.

98 `we0=(0.0)` Width scaling of E0.

99 `we1=(0.0)` Width scaling of E1.

100 `wrlx=(0.0)` Width scaling of RLX.

101 `wucex=(0.0)` Width scaling of UCEX.

102 `wdphiedge=(0.0)` Width scaling of DPHIEDGE.

103 `wldphiedge=(0.0)` Area scaling (fine tuning for short and narrow) of DPHIEDGE.

104 `wldgammaedge=(0.0)`
Area scaling (fine tuning for short and narrow) of DGAMMAEDGE.

105 `wedge=(0.0)` Width of edge conduction area.

106 `dgammaedge=(0.0)` Difference of body effect coefficient of edge conduction area with respect to the main part of the channel.

107 `dphiedge=(0.0)` Difference of fermi potential of edge conduction area with respect to the main part of the channel.

108 `saref=(0.0)` Reference distance from STI, for SA.

109 `sbref=(0.0)` Reference distance from STI, for SB.

110 `wlod=(0.0)` Width of common area between device and STI.

111 `kkp=(0.0)` Mobility dependence on STI.

112 `lkkp=(0.0)` Length scaling of mobility dependence on STI.

113 `wkkp=(0.0)` Width scaling of mobility dependence on STI.

114 `pkkp=(0.0)` Area scaling (fine tuning for short and narrow channel devices) of mobility dependence on STI.

115 `tkkp=(0.0)`	Temperature scaling of mobility dependence on STI.
116 `llodkkp=(1.0)`	Exponent of length scaling of mobility dependence on STI.
117 `wlodkkp=(1.0)`	Exponent of width scaling of mobility dependence on STI.
118 `kvto=(0.0)`	Threshold voltage dependence on STI.
119 `lkvto=(0.0)`	Length scaling of threshold voltage dependence on STI.
120 `wkvto=(0.0)`	Width scaling of threshold voltage dependence on STI.
121 `pkvto=(0.0)`	Area scaling (fine tuning for short and narrow channel devices) of threshold voltage dependence on STI.
122 `llodkvto=(1.0)`	Exponent of length scaling of threshold voltage dependence on STI.
123 `wlodkvto=(1.0)`	Exponent of width scaling of threshold voltage dependence on STI.
124 `kgamma=(0.0)`	Body effect dependence on STI.
125 `lodkgamma=(1.0)`	Exponential dependence of body effect on STI.
126 `ketad=(0.0)`	Primary DIBL dependence on STI.
127 `lodketad=(1.0)`	Exponential dependence of Primary DIBL dependence on STI.
128 `kucrit=(0.0)`	Critical Velocity of Electrons dependence of STI.
129 `teta=((-0.9E-3))`	Temperature dependence of ETA.
130 `tlambda=(0.0)`	Temperature dependence of LAMBDA.
131 `tcv=(600.0E-6)`	Temperature dependence of VTO (threshold voltage).
132 `bex=((-1.5))`	Temperature dependence of KP (mobility).
133 `ucex=(1.5)`	Temperature dependence of UCRIT.
134 `te0ex=(0.5)`	Temperature dependence of E0.

135 `te1ex=(0.5)` Temperature dependence of E1.

136 `ibbt=(800.0E-6)` Temperature dependence of IBB.

137 `tcvl=(0.0)` Length dependence of TCV.

138 `tcvw=(0.0)` Width dependence of TCV.

139 `tcvwl=(0.0)` Area dependence of TCV.

140 `gammaov=(1.6)` Body effect coefficient of the overlap area.

141 `gammagov=(10.0)` Body effect coefficient of the gate of the overlap area.

142 `vfbov=(0.0)` Flat-band voltage of the overlap area.

143 `lov=(20.0E-9)` Length of the overlap area.

144 `vov=(1.0)` Vs dependence of Vgsov.

145 `cgso=(0.0)` Bias-independent gate to source overlap capacitance.

146 `cgdo=(0.0)` Bias-independent gate to drain overlap capacitance.

147 `cgbo=(0.0)` Bias-independent gate to bulk overlap capacitance.

148 `kjf=(0.0)` Fringing capacitance factor.

149 `cjf=(0.0)` Fringing capacitance bias factor.

150 `vfr=(0.0)` Built-in correction for fringing capacitance.

151 `dfr=(1.0E-3)` Smooth factor of fringing capacitance model.

152 `hdif=(0.0e-6)` Half length of active area.

153 `rsh=(0.0)` Square resistance of active area.

154 `ldif=(0.0)` Distance between the middle of the active area and the start of the channel.

155 `rs=(0.0)` Source series resistance.

156 `rd=(0.0)` Drain series resistance.

157 `rlx=((-1.0))` Series resistance (symmetric model).

158 `rsx=((-1.0))` Source series resistance (asymmetric model).

159 `rdx=((-1.0))` Drain series resistance (asymmetric model).

160 `tr=(0.0)` First order temperature coefficient of resistors.

161 `tr2=(0.0)` Second order temperature coefficient of resistors.

162 `gmin=(0.0)` Minimum conductance of diode.

163 `njs=(1.0)` Slope factor for parasitic diodes(S).

164 `xjbvs=(0.0)` Breakdown effect coefficient(S).

165 `bvs=(10.0)` Breakdown Voltage(S).

166 `jss=(0.0E-09)` Area component of diode current(S).

167 `jssws=(0.0E-12)` Perimeter component of diode current(S).

168 `jsswgs=(0.0E-12)` Gate side component of diode current(S).

169 `jtss=(0.0E-09)` Area component of trap-assisted diode current(S).

170 `jtssws=(0.0E-12)` Perimeter component of trap-assisted diode current(S).

171 `jtsswgs=(0.0E-12)`
Gate side component of trap-assisted diode current(S).

172 `njtss=(1.0)` Area slope factor of trap-assisted diode current(S).

173 `njtssws=(1.0)` Perimeter slope factor of trap-assisted diode current(S).

174 `njtsswgs=(1.0)` Gate side slope factor of trap-assisted diode current(S).

175 `vtss=(0.0)` Area voltage factor of trap-assisted diode current(S).

176 `vtssws=(0.0)` Perimeter voltage factor of trap-assisted diode current(S).

177 `vtsswgs=(0.0)`	Gate side voltage factor of trap-assisted diode current(D).
178 `cjs=(0.0E-06)`	Area component of diode capacitance(S).
179 `cjsws=(0.0E-09)`	Perimeter component of diode capacitance(S).
180 `cjswgs=(0.0E-09)`	Gate side component of diode capacitance(S).
181 `pbs=(0.800)`	Area parameter of diode capacitance(S).
182 `pbsws=(0.600)`	Perimeter parameter of diode capacitance(S).
183 `pbswgs=(0.600)`	Gate side parameter of diode capacitance(S).
184 `mjs=(0.900)`	Area exponent of diode capacitance(S).
185 `mjsws=(0.700)`	Perimeter exponent of diode capacitance(S).
186 `mjswgs=(0.700)`	Gate side exponent of diode capacitance(S).
187 `xtis=(3.0)`	Temperature dependence of diode(S).
188 `xtss=(0.0)`	Area component of temperature dependence of trap-assisted diode current(S).
189 `xtssws=(0.0)`	Perimeter component of temperature dependence of trap-assisted diode current(S).
190 `xtsswgs=(0.0)`	Gate side component of temperature dependence of trap-assisted diode current(S).
191 `tnjtss=(0.0)`	Temperature dependence of njtss.
192 `tnjtssws=(0.0)`	Temperature dependence of njtssws.
193 `tnjtsswgs=(0.0)`	Temperature dependence of njtsswgs.
194 `tcj=(0.0)`	Temperature dependence of CJ.
195 `tcjsw=(0.0)`	Temperature dependence of CJSW.
196 `tcjswg=(0.0)`	Temperature dependence of CJSWG.

197 `tpb=(0.0)` Temperature dependence of PB.

198 `tpbsw=(0.0)` Temperature dependence of PBSW.

199 `tpbswg=(0.0)` Temperature dependence of PBSWG.

200 `njd=(1.0)` Slope factor for parasitic diodes(D).

201 `xjbvd=(0.0)` Breakdown effect coefficient(D).

202 `bvd=(10.0)` Breakdown Voltage(D).

203 `jsd=(0.0E-09)` Area component of diode current(D).

204 `jsswd=(0.0E-12)` Perimeter component of diode current(D).

205 `jsswgd=(0.0E-12)` Gate side component of diode current(D).

206 `jtsd=(0.0E-09)` Area component of trap-assisted diode current(D).

207 `jtsswd=(0.0E-12)` Perimeter component of trap-assisted diode current(D).

208 `jtsswgd=(0.0E-12)`
Gate side component of trap-assisted diode current(D).

209 `njtsd=(1.0)` Area slope factor of trap-assisted diode current(D).

210 `njtsswd=(1.0)` Perimeter slope factor of trap-assisted diode current(D).

211 `njtsswgd=(1.0)` Gate side slope factor of trap-assisted diode current(D).

212 `vtsd=(0.0)` Area voltage factor of trap-assisted diode current(D).

213 `vtsswd=(0.0)` Perimeter voltage factor of trap-assisted diode current(D).

214 `vtsswgd=(0.0)` Gate side voltage factor of trap-assisted diode current(D).

215 `cjd=(0.0E-06)` Area component of diode capacitance(D).

216 `cjswd=(0.0E-09)` Perimeter component of diode capacitance(D).

217 `cjswgd=(0.0E-09)` Gate side component of diode capacitance(D).

218 `pbd=(0.800)`	Area parameter of diode capacitance(D).
219 `pbswd=(0.600)`	Perimeter parameter of diode capacitance(D).
220 `pbswgd=(0.600)`	Gate side parameter of diode capacitance(D).
221 `mjd=(0.900)`	Area exponent of diode capacitance(D).
222 `mjswd=(0.700)`	Perimeter exponent of diode capacitance(D).
223 `mjswgd=(0.700)`	Gate side exponent of diode capacitance(D).
224 `xtid=(3.0)`	Temperature dependence of diode(D).
225 `xtsd=(0.0)`	Area component of temperature dependence of trap-assisted diode current(D).
226 `xtsswd=(0.0)`	Perimeter component of temperature dependence of trap-assisted diode current(D).
227 `xtsswgd=(0.0)`	Gate side component of temperature dependence of trap-assisted diode current(D).
228 `tnjtsd=(0.0)`	Temperature dependence of njtsd.
229 `tnjtsswd=(0.0)`	Temperature dependence of njtsswd.
230 `tnjtsswgd=(0.0)`	Temperature dependence of njtsswgd.
231 `rgsh=(3.0)`	Gate square resistance.
232 `gc=(1)`	Gate contacts (single sided = 1, double sided = 2).
233 `krgl1=(0.0)`	Length dependence of rg.
234 `rdsbsh=(1.0E+3)`	Drain to source substrate sheet resistance.
235 `rbwsh=(3.0E-3)`	Inner bulk to bulk sheet resistance.
236 `rbn=(0.0)`	Inner bulk to bulk resistance per finger (for RINGTYPE=2).
237 `rsbwsh=(1.0E-3)`	Inner bulk-source side to bulk sheet resistance.

238 `rsbn=(0.0)` Inner bulk-source side to bulk resistance per finger (for RINGTYPE=2).

239 `rdbwsh=(1.0E-3)` Inner bulk-drain side to bulk sheet resistance.

240 `rdbn=(0.0)` Inner bulk-drain side to bulk resistance per finger (for RINGTYPE=2).

241 `ringtype=(1.0)` Type of guard ring (bulk contacts) (two sides/symmetric: 1, three sides/horse shoe: 2).

Output Parameters

1 `d` node: Drain.

2 `g` node: Gate.

3 `s` node: Source.

4 `b` node: Bulk.

5 `di` node: Internal drain.

6 `si` node: Internal source.

7 `gi` node: Internal gate.

8 `bi` node: Internal bulk.

9 `bdi` node: Internal bulk(D).

10 `bsi` node: Internal bulk(S).

11 `m1` node: NQS related node(1).

12 `m2` node: NQS related node(2).

13 `m3` node: NQS related node(3).

14 `m4` node: NQS related node(4).

15 `noi` node: Noise.

Operating-Point Parameters

1 `exp_cr=(80.0)` The parameter is used by simulator.

2 `cmi_limexp_method=(1.0)`
The parameter is used by simulator.

3 `l=(10.0E-06)` GATES LENGTH.

4 `w=(10.0E-06)` GATES WIDTH.

5 `nf=(1)` NUMBER OF FINGERS.

6 `ad=(0.0)` DRAINS AREA.

7 `as=(0.0)` SOURCES AREA.

8 `pd=(0.0)` DRAINS PERIMETER.

9 `ps=(0.0)` SOURCES PERIMETER.

10 `sa=(0.0)` STI PARAMETER; DISTANCE FROM STI.

11 `sb=(0.0)` STI PARAMETER; DISTANCE FROM STI.

12 `sd=(0.0)` STI PARAMETER; DISTANCE BETWEEN GATES.

13 `avto=(0.0)` MATCHING PARAMETER FOR THRESHOLD VOLTAGE (VTO).

14 `agamma=(0.0)` MATCHING PARAMETER FOR BODY FACTOR (GAMMA).

15 `akp=(0.0)` MATCHING PARAMETER FOR MOBILITY (KP).

16 `idb` Impact ionization current.

17 `igsov` Overlap gate current(source).

18 `igdov` Overlap gate current(drain).

19 `igb` Gate current(bulk).

20 `igd` Gate current(drain).

21	`igs`	Gate current(source).
22	`igidl`	Gate induced drain current.
23	`igisl`	Gate induced source current.
24	`qsfr`	Fringing charge.
25	`qdfr`	Fringing charge.
26	`qsov`	Overlap charge.
27	`qdov`	Overlap charge.
28	`idsedge`	Edge drain current.
29	`qsedge`	Edge charge.
30	`qdedge`	Edge charge.
31	`qgedge`	Edge charge.
32	`qbedge`	Edge charge.
33	`qs`	Source charge.
34	`qd`	Drain charge.
35	`qg`	Gate charge.
36	`qb`	Bulk charge.
37	`ids`	Resistive drain-to-source current.
38	`vdb`	Drain-bulk voltage.
39	`vgb`	Gate-bulk voltage.
40	`vsb`	Source-bulk voltage.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Device ekv3_r4 (ekv3_r4)

This device is supported within altergroups.

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `exp_cr=(80.0)` The parameter is used by simulator.

2 `cmi_limexp_method=(1.0)` The parameter is used by simulator.

3 `m=(1.0)` Multiplicity factor (number of MOSFETs in parallel).

4 `l=(10.0E-06)` GATES LENGTH.

5 `w=(10.0E-06)` GATES WIDTH.

6 `nf=(1)` NUMBER OF FINGERS.

7 `ad=(0.0)` DRAINS AREA.

8 `as=(0.0)` SOURCES AREA.

9 `pd=(0.0)` DRAINS PERIMETER.

10 `ps=(0.0)` SOURCES PERIMETER.

11 `sa=(0.0)` STI PARAMETER; DISTANCE FROM STI.

12 `sb=(0.0)` STI PARAMETER; DISTANCE FROM STI.

13 `sd=(0.0)` STI PARAMETER; DISTANCE BETWEEN GATES.

14 `avto=(0.0)` MATCHING PARAMETER FOR THRESHOLD VOLTAGE (VTO).

15 `agamma=(0.0)` MATCHING PARAMETER FOR BODY FACTOR (GAMMA).

16 `akp=(0.0)` MATCHING PARAMETER FOR MOBILITY (KP).

Model Definition

```
model modelName ekv3_r4 parameter=value ...
```

Model Parameters

1 `sign=(1)` SIGN = 1 FOR NMOS; SIGN = -1 FOR PMOS.

2 `tg=((-1))` TYPE OF GATE: -1 ENHANCEMENT TYPE; 1 DEPLETION TYPE.

3 `tnom=(27.0)` Parameters measurement temperature.

4 `scale=(1.0)` Scaling Factor for Gate Length and Width.

5 `qoff=(0.0)` Charge partitioning flag.

6 `xl=(0.0)` Optical offset for Gate Length.

7 `xw=(0.0)` Optical offset for Gate Width.

8 `nqs_noi=(1.0)` NQS noise flag(on/off). Includes thermal noise with no short channel effects.

9 `th_noi=(0.0)` Thermal noise flag(on/off). Includes short channel effects but no gate induced noise.

10 `cox=(0.012)` Oxide Capacitance per unit Area.

11 `xj=(20.0E-09)` Depth of Active Areas.

12 `vto=(0.3)` THRESHOLD VOLTAGE.

13 `phif=(0.45)` FERMI BULK POTENTIAL.

14 `gamma=(0.3)` Body Effect Coefficient.

15 `gammag=(4.1)`	Body Effect Coefficient for Gate.
16 `n0=(1.0)`	Long Channel Slope Factor Fine Tuning.
17 `vbi=(0.0)`	Built-in Voltage Drop.
18 `aqma=(0.5)`	Quantum Effect Coefficient for Accumulation Region.
19 `aqmi=(0.4)`	Quantum Effect Coefficient for Inversion Region.
20 `etaqm=(0.75)`	Quantum Effect Factor.
21 `kp=(500.0E-06)`	Mobility multiplied by COX.
22 `e0=(1.0E+10)`	First Order Coefficient for Mobility Reduction due to Vertical Field.
23 `e1=(3.1E+08)`	Second Order Coefficient for Mobility Reduction due to Vertical Field.
24 `eta=(0.5)`	Mobility Reduction due to Vertical Field Factor.
25 `zc=(1.0E-6)`	Coulomb Scattering coefficient.
26 `thc=(0.0)`	Coulomb Scattering coefficient.
27 `la=(1.0)`	First critical length for mobility length scaling.
28 `lb=(1.0)`	Second critical length for mobility length scaling.
29 `ka=(0.0)`	First factor for mobility length scaling.
30 `kb=(0.0)`	Second factor for mobility length scaling.
31 `wkp1=(1.0E-6)`	Width parameter for mobility profile vs. width.
32 `wkp2=(0.0)`	Amplitude parameter for mobility profile vs. width.
33 `wkp3=(1.0)`	Span parameter for mobility profile vs. width.
34 `dl=((-10.0E-9))`	Effective Length Parameter.
35 `dlc=(0.0)`	Effective Length Parameter for Capacitance.

36 `dw=((-10.0E-9))` Effective Width Parameter.

37 `dwc=(0.0)` Effective Width Parameter for Capacitance.

38 `ldw=(0.0)` Length Dependence of Effective Width.

39 `wdl=(0.0)` Width Dependence of Effective Length.

40 `ll=(0.0)` Base for Exponential Dependence of Effective Length.

41 `lln=(1.0)` Exponent for Exponential Dependence of Effective Length.

42 `avt=(0.0)` Amplitude for long and wide channel threshold voltage correction.

43 `lvt=(1.0)` Length for long channel threshold voltage correction.

44 `wvt=(1.0)` Width for wide channel threshold voltage correction.

45 `agam=(0.0)` Amplitude for long and wide channel body effect coefficient correction.

46 `lgam=(1.0)` Length for long channel body effect coefficient correction.

47 `wgam=(1.0)` Width for wide channel body effect coefficient correction.

48 `nfvta=(0.0)` Number of fingers parameter for threshold voltage dependence on NF.

49 `nfvtb=(10000.0)` Factor for threshold voltage dependence on NF.

50 `ucrit=(5.0E+06)` Critical Velocity of Electrons.

51 `lambda=(0.5)` Early effect factor.

52 `delta=(2.0)` Order of velocity saturation model (variable order model 1~2).

53 `aclm=(0.83)` Channel Length Modulation Factor.

54 `lr=(50.0E-09)` Length Factor for RSCE.

55 `qlr=(0.5E-3)` Threshold Voltage Factor of RSCE.

56 `nlr=(10.0E-3)`	Body Effect Coefficient Factor of RSCE.
57 `flr=(0.0)`	Bulk Fermi Potential of RSCE.
58 `leta0=(0.0)`	Long Channel Charge Sharing Coefficient.
59 `leta=(500.0E-3)`	Short Channel Charge Sharing Coefficient.
60 `leta2=(0.0)`	Short Channel Scaling Coefficient.
61 `weta=(200.0E-3)`	Narrow Channel Charge Sharing Coefficient.
62 `ncs=(1.0)`	Slope Factor Dependence from Charge Sharing.
63 `etad=(1.0)`	Primary DIBL Coefficient.
64 `sigmad=(1.0)`	Secondary DIBL Coefficient.
65 `wr=(90.0E-09)`	Width Factor for INWE.
66 `qwr=(0.3E-3)`	Threshold Voltage Factor of INWE.
67 `nwr=(5.0E-3)`	Body Effect Coefficient Factor of INWE.
68 `fprout=(1.0E6)`	Output resistance for DITS effect.
69 `pdits=(0.0)`	DITS parameter.
70 `pditsl=(0.0)`	DITS dependence on length.
71 `pditsd=(1.0)`	DITS dependence on drain bias.
72 `ddits=(0.3)`	Smooth factor of DITS effect.
73 `iba=(000.0E+06)`	Impact Ionization Current first parameter.
74 `ibb=(300.0E+06)`	Impact Ionization Current second parameter.
75 `ibn=(1.0)`	Impact Ionization Current coefficient.
76 `xb=(3.1)`	Silicon to Silicon oxide tunneling barrier height.
77 `eb=(29.0E+09)`	Characteristic electrical field.

78 `kg=(00.0E-6)` Mobility for Gate Current.

79 `lovig=(20.0E-9)` Overlap Length for Gate current.

80 `agidl=(0.0)` First GIDL parameter.

81 `bgidl=(2.3E+09)` Second GIDL parameter.

82 `cgidl=(0.5)` Third GIDL parameter.

83 `egidl=(0.8)` Fourth GIDL parameter.

84 `kf=(0.0)` Flicker noise factor.

85 `af=(1.0)` Frequency exponent for flicker noise.

86 `ef=(2.0)` Transconductance exponent for flicker noise.

87 `kgfn=(0.0)` Gate flicker noise factor.

88 `lqwr=(0.0)` Length scaling of QWR.

89 `lnwr=(0.0)` Length scaling of NWR.

90 `lwr=(0.0)` Length scaling of WR.

91 `ldphiedge=(0.0)` Length scaling of DPHIEDGE.

92 `wqlr=(0.0)` Width scaling of QLR.

93 `wnlr=(0.0)` Width scaling of NLR.

94 `wlr=(0.0)` Width scaling of LR.

95 `wucrit=(0.0)` Width scaling of UCRIT.

96 `wlambda=(0.0)` Width scaling of LAMBDA.

97 `wetad=(0.0)` Width scaling of ETAD.

98 `we0=(0.0)` Width scaling of E0.

99 `we1=(0.0)` Width scaling of E1.

100 `wrlx=(0.0)` Width scaling of RLX.

101 `wucex=(0.0)` Width scaling of UCEX.

102 `wdphiedge=(0.0)` Width scaling of DPHIEDGE.

103 `wldphiedge=(0.0)` Area scaling (fine tuning for short and narrow) of DPHIEDGE.

104 `wldgammaedge=(0.0)`
Area scaling (fine tuning for short and narrow) of DGAMMAEDGE.

105 `wedge=(0.0)` Width of edge conduction area.

106 `dgammaedge=(0.0)` Difference of body effect coefficient of edge conduction area with respect to the main part of the channel.

107 `dphiedge=(0.0)` Difference of fermi potential of edge conduction area with respect to the main part of the channel.

108 `saref=(0.0)` Reference distance from STI, for SA.

109 `sbref=(0.0)` Reference distance from STI, for SB.

110 `wlod=(0.0)` Width of common area between device and STI.

111 `kkp=(0.0)` Mobility dependence on STI.

112 `lkkp=(0.0)` Length scaling of mobility dependence on STI.

113 `wkkp=(0.0)` Width scaling of mobility dependence on STI.

114 `pkkp=(0.0)` Area scaling (fine tuning for short and narrow channel devices) of mobility dependence on STI.

115 `tkkp=(0.0)` Temperature scaling of mobility dependence on STI.

116 `llodkkp=(1.0)` Exponent of length scaling of mobility dependence on STI.

117 `wlodkkp=(1.0)` Exponent of width scaling of mobility dependence on STI.

118 `kvto=(0.0)` Threshold voltage dependence on STI.

119 `lkvto=(0.0)`	Length scaling of threshold voltage dependence on STI.
120 `wkvto=(0.0)`	Width scaling of threshold voltage dependence on STI.
121 `pkvto=(0.0)`	Area scaling (fine tuning for short and narrow channel devices) of threshold voltage dependence on STI.
122 `llodkvto=(1.0)`	Exponent of length scaling of threshold voltage dependence on STI.
123 `wlodkvto=(1.0)`	Exponent of width scaling of threshold voltage dependence on STI.
124 `kgamma=(0.0)`	Body effect dependence on STI.
125 `lodkgamma=(1.0)`	Exponential dependence of body effect on STI.
126 `ketad=(0.0)`	Primary DIBL dependence on STI.
127 `lodketad=(1.0)`	Exponential dependence of Primary DIBL dependence on STI.
128 `kucrit=(0.0)`	Critical Velocity of Electrons dependence of STI.
129 `teta=((-0.9E-3))`	Temperature dependence of ETA.
130 `tlambda=(0.0)`	Temperature dependence of LAMBDA.
131 `tcv=(600.0E-6)`	Temperature dependence of VTO (threshold voltage).
132 `bex=((-1.5))`	Temperature dependence of KP (mobility).
133 `ucex=(1.5)`	Temperature dependence of UCRIT.
134 `te0ex=(0.5)`	Temperature dependence of E0.
135 `te1ex=(0.5)`	Temperature dependence of E1.
136 `ibbt=(800.0E-6)`	Temperature dependence of IBB.
137 `tcvl=(0.0)`	Length dependence of TCV.
138 `tcvw=(0.0)`	Width dependence of TCV.

139 `tcvwl=(0.0)`	Area dependence of TCV.
140 `gammaov=(1.6)`	Body effect coefficient of the overlap area.
141 `gammagov=(10.0)`	Body effect coefficient of the gate of the overlap area.
142 `vfbov=(0.0)`	Flat-band voltage of the overlap area.
143 `lov=(20.0E-9)`	Length of the overlap area.
144 `vov=(1.0)`	Vs dependence of Vgsov.
145 `cgso=(0.0)`	Bias-independent gate to source overlap capacitance.
146 `cgdo=(0.0)`	Bias-independent gate to drain overlap capacitance.
147 `cgbo=(0.0)`	Bias-independent gate to bulk overlap capacitance.
148 `kjf=(0.0)`	Fringing capacitance factor.
149 `cjf=(0.0)`	Fringing capacitance bias factor.
150 `vfr=(0.0)`	Built-in correction for fringing capacitance.
151 `dfr=(1.0E-3)`	Smooth factor of fringing capacitance model.
152 `hdif=(0.0e-6)`	Half length of active area.
153 `rsh=(0.0)`	Square resistance of active area.
154 `ldif=(0.0)`	Distance between the middle of the active area and the start of the channel.
155 `rs=(0.0)`	Source series resistance.
156 `rd=(0.0)`	Drain series resistance.
157 `rlx=((-1.0))`	Series resistance (symmetric model).
158 `rsx=((-1.0))`	Source series resistance (asymmetric model).
159 `rdx=((-1.0))`	Drain series resistance (asymmetric model).

160 `tr=(0.0)` First order temperature coefficient of resistors.

161 `tr2=(0.0)` Second order temperature coefficient of resistors.

162 `gmin=(0.0)` Minimum conductance of diode.

163 `njs=(1.0)` Slope factor for parasitic diodes(S).

164 `xjbvs=(0.0)` Breakdown effect coefficient(S).

165 `bvs=(10.0)` Breakdown Voltage(S).

166 `jss=(0.0E-09)` Area component of diode current(S).

167 `jssws=(0.0E-12)` Perimeter component of diode current(S).

168 `jsswgs=(0.0E-12)` Gate side component of diode current(S).

169 `jtss=(0.0E-09)` Area component of trap-assisted diode current(S).

170 `jtssws=(0.0E-12)` Perimeter component of trap-assisted diode current(S).

171 `jtsswgs=(0.0E-12)`
Gate side component of trap-assisted diode current(S).

172 `njtss=(1.0)` Area slope factor of trap-assisted diode current(S).

173 `njtssws=(1.0)` Perimeter slope factor of trap-assisted diode current(S).

174 `njtsswgs=(1.0)` Gate side slope factor of trap-assisted diode current(S).

175 `vtss=(0.0)` Area voltage factor of trap-assisted diode current(S).

176 `vtssws=(0.0)` Perimeter voltage factor of trap-assisted diode current(S).

177 `vtsswgs=(0.0)` Gate side voltage factor of trap-assisted diode current(D).

178 `cjs=(0.0E-06)` Area component of diode capacitance(S).

179 `cjsws=(0.0E-09)` Perimeter component of diode capacitance(S).

180 `cjswgs=(0.0E-09)` Gate side component of diode capacitance(S).

181 `pbs=(0.800)` Area parameter of diode capacitance(S).

182 `pbsws=(0.600)` Perimeter parameter of diode capacitance(S).

183 `pbswgs=(0.600)` Gate side parameter of diode capacitance(S).

184 `mjs=(0.900)` Area exponent of diode capacitance(S).

185 `mjsws=(0.700)` Perimeter exponent of diode capacitance(S).

186 `mjswgs=(0.700)` Gate side exponent of diode capacitance(S).

187 `xtis=(3.0)` Temperature dependence of diode(S).

188 `xtss=(0.0)` Area component of temperature dependence of trap-assisted diode current(S).

189 `xtssws=(0.0)` Perimeter component of temperature dependence of trap-assisted diode current(S).

190 `xtsswgs=(0.0)` Gate side component of temperature dependence of trap-assisted diode current(S).

191 `tnjtss=(0.0)` Temperature dependence of njtss.

192 `tnjtssws=(0.0)` Temperature dependence of njtssws.

193 `tnjtsswgs=(0.0)` Temperature dependence of njtsswgs.

194 `tcj=(0.0)` Temperature dependence of CJ.

195 `tcjsw=(0.0)` Temperature dependence of CJSW.

196 `tcjswg=(0.0)` Temperature dependence of CJSWG.

197 `tpb=(0.0)` Temperature dependence of PB.

198 `tpbsw=(0.0)` Temperature dependence of PBSW.

199 `tpbswg=(0.0)` Temperature dependence of PBSWG.

200 `njd=(1.0)` Slope factor for parasitic diodes(D).

201 `xjbvd=(0.0)` Breakdown effect coefficient(D).

202 `bvd=(10.0)` Breakdown Voltage(D).

203 `jsd=(0.0E-09)` Area component of diode current(D).

204 `jsswd=(0.0E-12)` Perimeter component of diode current(D).

205 `jsswgd=(0.0E-12)` Gate side component of diode current(D).

206 `jtsd=(0.0E-09)` Area component of trap-assisted diode current(D).

207 `jtsswd=(0.0E-12)` Perimeter component of trap-assisted diode current(D).

208 `jtsswgd=(0.0E-12)`
Gate side component of trap-assisted diode current(D).

209 `njtsd=(1.0)` Area slope factor of trap-assisted diode current(D).

210 `njtsswd=(1.0)` Perimeter slope factor of trap-assisted diode current(D).

211 `njtsswgd=(1.0)` Gate side slope factor of trap-assisted diode current(D).

212 `vtsd=(0.0)` Area voltage factor of trap-assisted diode current(D).

213 `vtsswd=(0.0)` Perimeter voltage factor of trap-assisted diode current(D).

214 `vtsswgd=(0.0)` Gate side voltage factor of trap-assisted diode current(D).

215 `cjd=(0.0E-06)` Area component of diode capacitance(D).

216 `cjswd=(0.0E-09)` Perimeter component of diode capacitance(D).

217 `cjswgd=(0.0E-09)` Gate side component of diode capacitance(D).

218 `pbd=(0.800)` Area parameter of diode capacitance(D).

219 `pbswd=(0.600)` Perimeter parameter of diode capacitance(D).

220 `pbswgd=(0.600)` Gate side parameter of diode capacitance(D).

221 `mjd=(0.900)` Area exponent of diode capacitance(D).

222 `mjswd=(0.700)`	Perimeter exponent of diode capacitance(D).
223 `mjswgd=(0.700)`	Gate side exponent of diode capacitance(D).
224 `xtid=(3.0)`	Temperature dependence of diode(D).
225 `xtsd=(0.0)`	Area component of temperature dependence of trap-assisted diode current(D).
226 `xtsswd=(0.0)`	Perimeter component of temperature dependence of trap-assisted diode current(D).
227 `xtsswgd=(0.0)`	Gate side component of temperature dependence of trap-assisted diode current(D).
228 `tnjtsd=(0.0)`	Temperature dependence of njtsd.
229 `tnjtsswd=(0.0)`	Temperature dependence of njtsswd.
230 `tnjtsswgd=(0.0)`	Temperature dependence of njtsswgd.
231 `rgsh=(3.0)`	Gate square resistance.
232 `gc=(1)`	Gate contacts (single sided = 1, double sided = 2).
233 `krgl1=(0.0)`	Length dependence of rg.
234 `rdsbsh=(1.0E+3)`	Drain to source substrate sheet resistance.
235 `rbwsh=(3.0E-3)`	Inner bulk to bulk sheet resistance.
236 `rbn=(0.0)`	Inner bulk to bulk resistance per finger (for RINGTYPE=2).
237 `rsbwsh=(1.0E-3)`	Inner bulk-source side to bulk sheet resistance.
238 `rsbn=(0.0)`	Inner bulk-source side to bulk resistance per finger (for RINGTYPE=2).
239 `rdbwsh=(1.0E-3)`	Inner bulk-drain side to bulk sheet resistance.
240 `rdbn=(0.0)`	Inner bulk-drain side to bulk resistance per finger (for RINGTYPE=2).

241 `ringtype=(1.0)` Type of guard ring (bulk contacts) (two sides/symmetric: 1, three sides/horse shoe: 2).

Output Parameters

1 `d` node: Drain.

2 `g` node: Gate.

3 `s` node: Source.

4 `b` node: Bulk.

5 `di` node: Internal drain.

6 `si` node: Internal source.

7 `gi` node: Internal gate.

8 `bi` node: Internal bulk.

9 `noi` node: Noise.

Operating-Point Parameters

1 `exp_cr=(80.0)` The parameter is used by simulator.

2 `cmi_limexp_method=(1.0)`
The parameter is used by simulator.

3 `l=(10.0E-06)` GATES LENGTH.

4 `w=(10.0E-06)` GATES WIDTH.

5 `nf=(1)` NUMBER OF FINGERS.

6 `ad=(0.0)` DRAINS AREA.

7 `as=(0.0)` SOURCES AREA.

8 `pd=(0.0)` DRAINS PERIMETER.

9 `ps=(0.0)`	SOURCES PERIMETER.
10 `sa=(0.0)`	STI PARAMETER; DISTANCE FROM STI.
11 `sb=(0.0)`	STI PARAMETER; DISTANCE FROM STI.
12 `sd=(0.0)`	STI PARAMETER; DISTANCE BETWEEN GATES.
13 `avto=(0.0)`	MATCHING PARAMETER FOR THRESHOLD VOLTAGE (VTO).
14 `agamma=(0.0)`	MATCHING PARAMETER FOR BODY FACTOR (GAMMA).
15 `akp=(0.0)`	MATCHING PARAMETER FOR MOBILITY (KP).
16 `idb`	Impact ionization current.
17 `igsov`	Overlap gate current(source).
18 `igdov`	Overlap gate current(drain).
19 `igb`	Gate current(bulk).
20 `igd`	Gate current(drain).
21 `igs`	Gate current(source).
22 `igidl`	Gate induced drain current.
23 `igisl`	Gate induced source current.
24 `qsfr`	Fringing charge.
25 `qdfr`	Fringing charge.
26 `qsov`	Overlap charge.
27 `qdov`	Overlap charge.
28 `idsedge`	Edge drain current.
29 `qsedge`	Edge charge.
30 `qdedge`	Edge charge.

31	`qgedge`	Edge charge.
32	`qbedge`	Edge charge.
33	`qs`	Source charge.
34	`qd`	Drain charge.
35	`qg`	Gate charge.
36	`qb`	Bulk charge.
37	`ids`	Resistive drain-to-source current.
38	`vdb`	Drain-bulk voltage.
39	`vgb`	Gate-bulk voltage.
40	`vsb`	Source-bulk voltage.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Device ekv3_rf (ekv3_rf)

Description

ekv3_rf model (compiled=Jun 2 2008 cmi=4.0 developer=admsXml-2.2.7, interface=spectre500 2.1.1, version=unknown)

This device is supported within altergroups.

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `exp_cr=(80.0)` The parameter is used by simulator.

2 `cmi_limexp_method=(1.0)`
The parameter is used by simulator.

3 `m=(1.0)` Multiplicity factor (number of MOSFETs in parallel).

4 `l=(10.0E-06)` GATES LENGTH.

5 `w=(10.0E-06)` GATES WIDTH.

6 `nf=(1)` NUMBER OF FINGERS.

7 `ad=(0.0)` DRAINS AREA.

8 `as=(0.0)` SOURCES AREA.

9 `pd=(0.0)` DRAINS PERIMETER.

10 `ps=(0.0)` SOURCES PERIMETER.

11 `sa=(0.0)` STI PARAMETER; DISTANCE FROM STI.

12 `sb=(0.0)` STI PARAMETER; DISTANCE FROM STI.

13 `sd=(0.0)` STI PARAMETER; DISTANCE BETWEEN GATES.

14 `avto=(0.0)` MATCHING PARAMETER FOR THRESHOLD VOLTAGE (VTO).

15 `agamma=(0.0)` MATCHING PARAMETER FOR BODY FACTOR (GAMMA).

16 `akp=(0.0)` MATCHING PARAMETER FOR MOBILITY (KP).

Model Definition

model modelName ekv3_rf parameter=value ...

Model Parameters

1 `sign=(1)` SIGN = 1 FOR NMOS; SIGN = -1 FOR PMOS.

2 `tg=((-1))` TYPE OF GATE: -1 ENHANCEMENT TYPE; 1 DEPLETION TYPE.

3 `tnom=(27.0)` Parameters measurement temperature.

4 `scale=(1.0)`	Scaling Factor for Gate Length and Width.
5 `qoff=(0.0)`	Charge partitioning flag.
6 `xl=(0.0)`	Optical offset for Gate Length.
7 `xw=(0.0)`	Optical offset for Gate Width.
8 `nqs_noi=(1.0)`	NQS noise flag(on/off). Includes thermal noise with no short channel effects.
9 `th_noi=(0.0)`	Thermal noise flag(on/off). Includes short channel effects but no gate induced noise.
10 `cox=(0.012)`	Oxide Capacitance per unit Area.
11 `xj=(20.0E-09)`	Depth of Active Areas.
12 `vto=(0.3)`	THRESHOLD VOLTAGE.
13 `phif=(0.45)`	FERMI BULK POTENTIAL.
14 `gamma=(0.3)`	Body Effect Coefficient.
15 `gammag=(4.1)`	Body Effect Coefficient for Gate.
16 `n0=(1.0)`	Long Channel Slope Factor Fine Tuning.
17 `vbi=(0.0)`	Built-in Voltage Drop.
18 `aqma=(0.5)`	Quantum Effect Coefficient for Accumulation Region.
19 `aqmi=(0.4)`	Quantum Effect Coefficient for Inversion Region.
20 `etaqm=(0.75)`	Quantum Effect Factor.
21 `kp=(500.0E-06)`	Mobility multiplied by COX.
22 `e0=(1.0E+10)`	First Order Coefficient for Mobility Reduction due to Vertical Field.
23 `e1=(3.1E+08)`	Second Order Coefficient for Mobility Reduction due to Vertical Field.

24 `eta=(0.5)`	Mobility Reduction due to Vertical Field Factor.
25 `zc=(1.0E-6)`	Coulomb Scattering coefficient.
26 `thc=(0.0)`	Coulomb Scattering coefficient.
27 `la=(1.0)`	First critical length for mobility length scaling.
28 `lb=(1.0)`	Second critical length for mobility length scaling.
29 `ka=(0.0)`	First factor for mobility length scaling.
30 `kb=(0.0)`	Second factor for mobility length scaling.
31 `wkp1=(1.0E-6)`	Width parameter for mobility profile vs. width.
32 `wkp2=(0.0)`	Amplitude parameter for mobility profile vs. width.
33 `wkp3=(1.0)`	Span parameter for mobility profile vs. width.
34 `dl=((-10.0E-9))`	Effective Length Parameter.
35 `dlc=(0.0)`	Effective Length Parameter for Capacitance.
36 `dw=((-10.0E-9))`	Effective Width Parameter.
37 `dwc=(0.0)`	Effective Width Parameter for Capacitance.
38 `ldw=(0.0)`	Length Dependence of Effective Width.
39 `wdl=(0.0)`	Width Dependence of Effective Length.
40 `ll=(0.0)`	Base for Exponential Dependence of Effective Length.
41 `lln=(1.0)`	Exponent for Exponential Dependence of Effective Length.
42 `avt=(0.0)`	Amplitude for long and wide channel threshold voltage correction.
43 `lvt=(1.0)`	Length for long channel threshold voltage correction.
44 `wvt=(1.0)`	Width for wide channel threshold voltage correction.

45 `agam=(0.0)`	Amplitude for long and wide channel body effect coefficient correction.
46 `lgam=(1.0)`	Length for long channel body effect coefficient correction.
47 `wgam=(1.0)`	Width for wide channel body effect coefficient correction.
48 `nfvta=(0.0)`	Number of fingers parameter for threshold voltage dependence on NF.
49 `nfvtb=(10000.0)`	Factor for threshold voltage dependence on NF.
50 `ucrit=(5.0E+06)`	Critical Velocity of Electrons.
51 `lambda=(0.5)`	Early effect factor.
52 `delta=(2.0)`	Order of velocity saturation model (variable order model 1~2).
53 `aclm=(0.83)`	Channel Length Modulation Factor.
54 `lr=(50.0E-09)`	Length Factor for RSCE.
55 `qlr=(0.5E-3)`	Threshold Voltage Factor of RSCE.
56 `nlr=(10.0E-3)`	Body Effect Coefficient Factor of RSCE.
57 `flr=(0.0)`	Bulk Fermi Potential of RSCE.
58 `leta0=(0.0)`	Long Channel Charge Sharing Coefficient.
59 `leta=(500.0E-3)`	Short Channel Charge Sharing Coefficient.
60 `leta2=(0.0)`	Short Channel Scaling Coefficient.
61 `weta=(200.0E-3)`	Narrow Channel Charge Sharing Coefficient.
62 `ncs=(1.0)`	Slope Factor Dependence from Charge Sharing.
63 `etad=(1.0)`	Primary DIBL Coefficient.
64 `sigmad=(1.0)`	Secondary DIBL Coefficient.
65 `wr=(90.0E-09)`	Width Factor for INWE.

66 `qwr=(0.3E-3)` Threshold Voltage Factor of INWE.

67 `nwr=(5.0E-3)` Body Effect Coefficient Factor of INWE.

68 `fprout=(1.0E6)` Output resistance for DITS effect.

69 `pdits=(0.0)` DITS parameter.

70 `pditsl=(0.0)` DITS dependence on length.

71 `pditsd=(1.0)` DITS dependence on drain bias.

72 `ddits=(0.3)` Smooth factor of DITS effect.

73 `iba=(000.0E+06)` Impact Ionization Current first parameter.

74 `ibb=(300.0E+06)` Impact Ionization Current second parameter.

75 `ibn=(1.0)` Impact Ionization Current coefficient.

76 `xb=(3.1)` Silicon to Silicon oxide tunneling barrier height.

77 `eb=(29.0E+09)` Characteristic electrical field.

78 `kg=(00.0E-6)` Mobility for Gate Current.

79 `lovig=(20.0E-9)` Overlap Length for Gate current.

80 `agidl=(0.0)` First GIDL parameter.

81 `bgidl=(2.3E+09)` Second GIDL parameter.

82 `cgidl=(0.5)` Third GIDL parameter.

83 `egidl=(0.8)` Fourth GIDL parameter.

84 `kf=(0.0)` Flicker noise factor.

85 `af=(1.0)` Frequency exponent for flicker noise.

86 `ef=(2.0)` Transconductance exponent for flicker noise.

87 `kgfn=(0.0)` Gate flicker noise factor.

88 `lqwr=(0.0)` Length scaling of QWR.

89 `lnwr=(0.0)` Length scaling of NWR.

90 `lwr=(0.0)` Length scaling of WR.

91 `ldphiedge=(0.0)` Length scaling of DPHIEDGE.

92 `wqlr=(0.0)` Width scaling of QLR.

93 `wnlr=(0.0)` Width scaling of NLR.

94 `wlr=(0.0)` Width scaling of LR.

95 `wucrit=(0.0)` Width scaling of UCRIT.

96 `wlambda=(0.0)` Width scaling of LAMBDA.

97 `wetad=(0.0)` Width scaling of ETAD.

98 `we0=(0.0)` Width scaling of E0.

99 `we1=(0.0)` Width scaling of E1.

100 `wrlx=(0.0)` Width scaling of RLX.

101 `wucex=(0.0)` Width scaling of UCEX.

102 `wdphiedge=(0.0)` Width scaling of DPHIEDGE.

103 `wldphiedge=(0.0)` Area scaling (fine tuning for short and narrow) of DPHIEDGE.

104 `wldgammaedge=(0.0)`
Area scaling (fine tuning for short and narrow) of DGAMMAEDGE.

105 `wedge=(0.0)` Width of edge conduction area.

106 `dgammaedge=(0.0)` Difference of body effect coefficient of edge conduction area with respect to the main part of the channel.

107 `dphiedge=(0.0)` Difference of fermi potential of edge conduction area with respect to the main part of the channel.

108 `saref=(0.0)`	Reference distance from STI, for SA.
109 `sbref=(0.0)`	Reference distance from STI, for SB.
110 `wlod=(0.0)`	Width of common area between device and STI.
111 `kkp=(0.0)`	Mobility dependence on STI.
112 `lkkp=(0.0)`	Length scaling of mobility dependence on STI.
113 `wkkp=(0.0)`	Width scaling of mobility dependence on STI.
114 `pkkp=(0.0)`	Area scaling (fine tuning for short and narrow channel devices) of mobility dependence on STI.
115 `tkkp=(0.0)`	Temperature scaling of mobility dependence on STI.
116 `llodkkp=(1.0)`	Exponent of length scaling of mobility dependence on STI.
117 `wlodkkp=(1.0)`	Exponent of width scaling of mobility dependence on STI.
118 `kvto=(0.0)`	Threshold voltage dependence on STI.
119 `lkvto=(0.0)`	Length scaling of threshold voltage dependence on STI.
120 `wkvto=(0.0)`	Width scaling of threshold voltage dependence on STI.
121 `pkvto=(0.0)`	Area scaling (fine tuning for short and narrow channel devices) of threshold voltage dependence on STI.
122 `llodkvto=(1.0)`	Exponent of length scaling of threshold voltage dependence on STI.
123 `wlodkvto=(1.0)`	Exponent of width scaling of threshold voltage dependence on STI.
124 `kgamma=(0.0)`	Body effect dependence on STI.
125 `lodkgamma=(1.0)`	Exponential dependence of body effect on STI.
126 `ketad=(0.0)`	Primary DIBL dependence on STI.
127 `lodketad=(1.0)`	Exponential dependence of Primary DIBL dependence on STI.

128 `kucrit=(0.0)`	Critical Velocity of Electrons dependence of STI.
129 `teta=((-0.9E-3))`	Temperature dependence of ETA.
130 `tlambda=(0.0)`	Temperature dependence of LAMBDA.
131 `tcv=(600.0E-6)`	Temperature dependence of VTO (threshold voltage).
132 `bex=((-1.5))`	Temperature dependence of KP (mobility).
133 `ucex=(1.5)`	Temperature dependence of UCRIT.
134 `te0ex=(0.5)`	Temperature dependence of E0.
135 `te1ex=(0.5)`	Temperature dependence of E1.
136 `ibbt=(800.0E-6)`	Temperature dependence of IBB.
137 `tcvl=(0.0)`	Length dependence of TCV.
138 `tcvw=(0.0)`	Width dependence of TCV.
139 `tcvwl=(0.0)`	Area dependence of TCV.
140 `gammaov=(1.6)`	Body effect coefficient of the overlap area.
141 `gammagov=(10.0)`	Body effect coefficient of the gate of the overlap area.
142 `vfbov=(0.0)`	Flat-band voltage of the overlap area.
143 `lov=(20.0E-9)`	Length of the overlap area.
144 `vov=(1.0)`	Vs dependence of Vgsov.
145 `cgso=(0.0)`	Bias-independent gate to source overlap capacitance.
146 `cgdo=(0.0)`	Bias-independent gate to drain overlap capacitance.
147 `cgbo=(0.0)`	Bias-independent gate to bulk overlap capacitance.
148 `kjf=(0.0)`	Fringing capacitance factor.
149 `cjf=(0.0)`	Fringing capacitance bias factor.

150 `vfr=(0.0)` Built-in correction for fringing capacitance.

151 `dfr=(1.0E-3)` Smooth factor of fringing capacitance model.

152 `hdif=(0.0e-6)` Half length of active area.

153 `rsh=(0.0)` Square resistance of active area.

154 `ldif=(0.0)` Distance between the middle of the active area and the start of the channel.

155 `rs=(0.0)` Source series resistance.

156 `rd=(0.0)` Drain series resistance.

157 `rlx=((-1.0))` Series resistance (symmetric model).

158 `rsx=((-1.0))` Source series resistance (asymmetric model).

159 `rdx=((-1.0))` Drain series resistance (asymmetric model).

160 `tr=(0.0)` First order temperature coefficient of resistors.

161 `tr2=(0.0)` Second order temperature coefficient of resistors.

162 `gmin=(0.0)` Minimum conductance of diode.

163 `njs=(1.0)` Slope factor for parasitic diodes(S).

164 `xjbvs=(0.0)` Breakdown effect coefficient(S).

165 `bvs=(10.0)` Breakdown Voltage(S).

166 `jss=(0.0E-09)` Area component of diode current(S).

167 `jssws=(0.0E-12)` Perimeter component of diode current(S).

168 `jsswgs=(0.0E-12)` Gate side component of diode current(S).

169 `jtss=(0.0E-09)` Area component of trap-assisted diode current(S).

170 `jtssws=(0.0E-12)` Perimeter component of trap-assisted diode current(S).

171 `jtsswgs=(0.0E-12)`
Gate side component of trap-assisted diode current(S).

172 `njtss=(1.0)` Area slope factor of trap-assisted diode current(S).

173 `njtssws=(1.0)` Perimeter slope factor of trap-assisted diode current(S).

174 `njtsswgs=(1.0)` Gate side slope factor of trap-assisted diode current(S).

175 `vtss=(0.0)` Area voltage factor of trap-assisted diode current(S).

176 `vtssws=(0.0)` Perimeter voltage factor of trap-assisted diode current(S).

177 `vtsswgs=(0.0)` Gate side voltage factor of trap-assisted diode current(D).

178 `cjs=(0.0E-06)` Area component of diode capacitance(S).

179 `cjsws=(0.0E-09)` Perimeter component of diode capacitance(S).

180 `cjswgs=(0.0E-09)` Gate side component of diode capacitance(S).

181 `pbs=(0.800)` Area parameter of diode capacitance(S).

182 `pbsws=(0.600)` Perimeter parameter of diode capacitance(S).

183 `pbswgs=(0.600)` Gate side parameter of diode capacitance(S).

184 `mjs=(0.900)` Area exponent of diode capacitance(S).

185 `mjsws=(0.700)` Perimeter exponent of diode capacitance(S).

186 `mjswgs=(0.700)` Gate side exponent of diode capacitance(S).

187 `xtis=(3.0)` Temperature dependence of diode(S).

188 `xtss=(0.0)` Area component of temperature dependence of trap-assisted diode current(S).

189 `xtssws=(0.0)` Perimeter component of temperature dependence of trap-assisted diode current(S).

190 `xtsswgs=(0.0)` Gate side component of temperature dependence of trap-assisted diode current(S).

191 `tnjtss=(0.0)` Temperature dependence of njtss.

192 `tnjtssws=(0.0)` Temperature dependence of njtssws.

193 `tnjtsswgs=(0.0)` Temperature dependence of njtsswgs.

194 `tcj=(0.0)` Temperature dependence of CJ.

195 `tcjsw=(0.0)` Temperature dependence of CJSW.

196 `tcjswg=(0.0)` Temperature dependence of CJSWG.

197 `tpb=(0.0)` Temperature dependence of PB.

198 `tpbsw=(0.0)` Temperature dependence of PBSW.

199 `tpbswg=(0.0)` Temperature dependence of PBSWG.

200 `njd=(1.0)` Slope factor for parasitic diodes(D).

201 `xjbvd=(0.0)` Breakdown effect coefficient(D).

202 `bvd=(10.0)` Breakdown Voltage(D).

203 `jsd=(0.0E-09)` Area component of diode current(D).

204 `jsswd=(0.0E-12)` Perimeter component of diode current(D).

205 `jsswgd=(0.0E-12)` Gate side component of diode current(D).

206 `jtsd=(0.0E-09)` Area component of trap-assisted diode current(D).

207 `jtsswd=(0.0E-12)` Perimeter component of trap-assisted diode current(D).

208 `jtsswgd=(0.0E-12)`

Gate side component of trap-assisted diode current(D).

209 `njtsd=(1.0)` Area slope factor of trap-assisted diode current(D).

210 `njtsswd=(1.0)` Perimeter slope factor of trap-assisted diode current(D).

211 `njtsswgd=(1.0)` Gate side slope factor of trap-assisted diode current(D).

212 `vtsd=(0.0)` Area voltage factor of trap-assisted diode current(D).

213 `vtsswd=(0.0)` Perimeter voltage factor of trap-assisted diode current(D).

214 `vtsswgd=(0.0)` Gate side voltage factor of trap-assisted diode current(D).

215 `cjd=(0.0E-06)` Area component of diode capacitance(D).

216 `cjswd=(0.0E-09)` Perimeter component of diode capacitance(D).

217 `cjswgd=(0.0E-09)` Gate side component of diode capacitance(D).

218 `pbd=(0.800)` Area parameter of diode capacitance(D).

219 `pbswd=(0.600)` Perimeter parameter of diode capacitance(D).

220 `pbswgd=(0.600)` Gate side parameter of diode capacitance(D).

221 `mjd=(0.900)` Area exponent of diode capacitance(D).

222 `mjswd=(0.700)` Perimeter exponent of diode capacitance(D).

223 `mjswgd=(0.700)` Gate side exponent of diode capacitance(D).

224 `xtid=(3.0)` Temperature dependence of diode(D).

225 `xtsd=(0.0)` Area component of temperature dependence of trap-assisted diode current(D).

226 `xtsswd=(0.0)` Perimeter component of temperature dependence of trap-assisted diode current(D).

227 `xtsswgd=(0.0)` Gate side component of temperature dependence of trap-assisted diode current(D).

228 `tnjtsd=(0.0)` Temperature dependence of njtsd.

229 `tnjtsswd=(0.0)` Temperature dependence of njtsswd.

230 `tnjtsswgd=(0.0)` Temperature dependence of njtsswgd.

231 `rgsh=(3.0)` Gate square resistance.

232 `gc=(1)`	Gate contacts (single sided = 1, double sided = 2).
233 `krgl1=(0.0)`	Length dependence of rg.
234 `rdsbsh=(1.0E+3)`	Drain to source substrate sheet resistance.
235 `rbwsh=(3.0E-3)`	Inner bulk to bulk sheet resistance.
236 `rbn=(0.0)`	Inner bulk to bulk resistance per finger (for RINGTYPE=2).
237 `rsbwsh=(1.0E-3)`	Inner bulk-source side to bulk sheet resistance.
238 `rsbn=(0.0)`	Inner bulk-source side to bulk resistance per finger (for RINGTYPE=2).
239 `rdbwsh=(1.0E-3)`	Inner bulk-drain side to bulk sheet resistance.
240 `rdbn=(0.0)`	Inner bulk-drain side to bulk resistance per finger (for RINGTYPE=2).
241 `ringtype=(1.0)`	Type of guard ring (bulk contacts) (two sides/symmetric: 1, three sides/horse shoe: 2).

Output Parameters

1 `d`	node: Drain.
2 `g`	node: Gate.
3 `s`	node: Source.
4 `b`	node: Bulk.
5 `di`	node: Internal drain.
6 `si`	node: Internal source.
7 `gi`	node: Internal gate.
8 `bi`	node: Internal bulk.
9 `bdi`	node: Internal bulk(D).

10 `bsi` node: Internal bulk(S).

11 `noi` node: Noise.

Operating-Point Parameters

1 `exp_cr=(80.0)` The parameter is used by simulator.

2 `cmi_limexp_method=(1.0)`
The parameter is used by simulator.

3 `l=(10.0E-06)` GATES LENGTH.

4 `w=(10.0E-06)` GATES WIDTH.

5 `nf=(1)` NUMBER OF FINGERS.

6 `ad=(0.0)` DRAINS AREA.

7 `as=(0.0)` SOURCES AREA.

8 `pd=(0.0)` DRAINS PERIMETER.

9 `ps=(0.0)` SOURCES PERIMETER.

10 `sa=(0.0)` STI PARAMETER; DISTANCE FROM STI.

11 `sb=(0.0)` STI PARAMETER; DISTANCE FROM STI.

12 `sd=(0.0)` STI PARAMETER; DISTANCE BETWEEN GATES.

13 `avto=(0.0)` MATCHING PARAMETER FOR THRESHOLD VOLTAGE (VTO).

14 `agamma=(0.0)` MATCHING PARAMETER FOR BODY FACTOR (GAMMA).

15 `akp=(0.0)` MATCHING PARAMETER FOR MOBILITY (KP).

16 `idb` Impact ionization current.

17 `igsov` Overlap gate current(source).

18 `igdov` Overlap gate current(drain).

19	`igb`	Gate current(bulk).
20	`igd`	Gate current(drain).
21	`igs`	Gate current(source).
22	`igidl`	Gate induced drain current.
23	`igisl`	Gate induced source current.
24	`qsfr`	Fringing charge.
25	`qdfr`	Fringing charge.
26	`qsov`	Overlap charge.
27	`qdov`	Overlap charge.
28	`idsedge`	Edge drain current.
29	`qsedge`	Edge charge.
30	`qdedge`	Edge charge.
31	`qgedge`	Edge charge.
32	`qbedge`	Edge charge.
33	`qs`	Source charge.
34	`qd`	Drain charge.
35	`qg`	Gate charge.
36	`qb`	Bulk charge.
37	`ids`	Resistive drain-to-source current.
38	`vdb`	Drain-bulk voltage.
39	`vgb`	Gate-bulk voltage.
40	`vsb`	Source-bulk voltage.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Device ekv3_s (ekv3_s)

This device is supported within altergroups.

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `exp_cr=(80.0)` The parameter is used by simulator.

2 `cmi_limexp_method=(1.0)` The parameter is used by simulator.

3 `m=(1.0)` Multiplicity factor (number of MOSFETs in parallel).

4 `l=(10.0E-06)` GATES LENGTH.

5 `w=(10.0E-06)` GATES WIDTH.

6 `nf=(1)` NUMBER OF FINGERS.

7 `ad=(0.0)` DRAINS AREA.

8 `as=(0.0)` SOURCES AREA.

9 `pd=(0.0)` DRAINS PERIMETER.

10 `ps=(0.0)` SOURCES PERIMETER.

11 `sa=(0.0)` STI PARAMETER; DISTANCE FROM STI.

12 `sb=(0.0)` STI PARAMETER; DISTANCE FROM STI.

13 `sd=(0.0)` STI PARAMETER; DISTANCE BETWEEN GATES.

14 `avto=(0.0)` MATCHING PARAMETER FOR THRESHOLD VOLTAGE (VTO).

15 `agamma=(0.0)` MATCHING PARAMETER FOR BODY FACTOR (GAMMA).

16 `akp=(0.0)` MATCHING PARAMETER FOR MOBILITY (KP).

Model Definition

model modelName ekv3_s parameter=value ...

Model Parameters

1 `sign=(1)`	SIGN = 1 FOR NMOS; SIGN = -1 FOR PMOS.
2 `tg=((-1))`	TYPE OF GATE: -1 ENHANCEMENT TYPE; 1 DEPLETION TYPE.
3 `tnom=(27.0)`	Parameters measurement temperature.
4 `scale=(1.0)`	Scaling Factor for Gate Length and Width.
5 `qoff=(0.0)`	Charge partitioning flag.
6 `xl=(0.0)`	Optical offset for Gate Length.
7 `xw=(0.0)`	Optical offset for Gate Width.
8 `nqs_noi=(1.0)`	NQS noise flag(on/off). Includes thermal noise with no short channel effects.
9 `th_noi=(0.0)`	Thermal noise flag(on/off). Includes short channel effects but no gate induced noise.
10 `cox=(0.012)`	Oxide Capacitance per unit Area.
11 `xj=(20.0E-09)`	Depth of Active Areas.
12 `vto=(0.3)`	THRESHOLD VOLTAGE.
13 `phif=(0.45)`	FERMI BULK POTENTIAL.
14 `gamma=(0.3)`	Body Effect Coefficient.
15 `gammag=(4.1)`	Body Effect Coefficient for Gate.
16 `n0=(1.0)`	Long Channel Slope Factor Fine Tuning.
17 `vbi=(0.0)`	Built-in Voltage Drop.

18 `aqma=(0.5)`	Quantum Effect Coefficient for Accumulation Region.
19 `aqmi=(0.4)`	Quantum Effect Coefficient for Inversion Region.
20 `etaqm=(0.75)`	Quantum Effect Factor.
21 `kp=(500.0E-06)`	Mobility multiplied by COX.
22 `e0=(1.0E+10)`	First Order Coefficient for Mobility Reduction due to Vertical Field.
23 `e1=(3.1E+08)`	Second Order Coefficient for Mobility Reduction due to Vertical Field.
24 `eta=(0.5)`	Mobility Reduction due to Vertical Field Factor.
25 `zc=(1.0E-6)`	Coulomb Scattering coefficient.
26 `thc=(0.0)`	Coulomb Scattering coefficient.
27 `la=(1.0)`	First critical length for mobility length scaling.
28 `lb=(1.0)`	Second critical length for mobility length scaling.
29 `ka=(0.0)`	First factor for mobility length scaling.
30 `kb=(0.0)`	Second factor for mobility length scaling.
31 `wkp1=(1.0E-6)`	Width parameter for mobility profile vs. width.
32 `wkp2=(0.0)`	Amplitude parameter for mobility profile vs. width.
33 `wkp3=(1.0)`	Span parameter for mobility profile vs. width.
34 `dl=((-10.0E-9))`	Effective Length Parameter.
35 `dlc=(0.0)`	Effective Length Parameter for Capacitance.
36 `dw=((-10.0E-9))`	Effective Width Parameter.
37 `dwc=(0.0)`	Effective Width Parameter for Capacitance.
38 `ldw=(0.0)`	Length Dependence of Effective Width.

39 `wdl=(0.0)`	Width Dependence of Effective Length.
40 `ll=(0.0)`	Base for Exponential Dependence of Effective Length.
41 `lln=(1.0)`	Exponent for Exponential Dependence of Effective Length.
42 `avt=(0.0)`	Amplitude for long and wide channel threshold voltage correction.
43 `lvt=(1.0)`	Length for long channel threshold voltage correction.
44 `wvt=(1.0)`	Width for wide channel threshold voltage correction.
45 `agam=(0.0)`	Amplitude for long and wide channel body effect coefficient correction.
46 `lgam=(1.0)`	Length for long channel body effect coefficient correction.
47 `wgam=(1.0)`	Width for wide channel body effect coefficient correction.
48 `nfvta=(0.0)`	Number of fingers parameter for threshold voltage dependence on NF.
49 `nfvtb=(10000.0)`	Factor for threshold voltage dependence on NF.
50 `ucrit=(5.0E+06)`	Critical Velocity of Electrons.
51 `lambda=(0.5)`	Early effect factor.
52 `delta=(2.0)`	Order of velocity saturation model (variable order model 1~2).
53 `aclm=(0.83)`	Channel Length Modulation Factor.
54 `lr=(50.0E-09)`	Length Factor for RSCE.
55 `qlr=(0.5E-3)`	Threshold Voltage Factor of RSCE.
56 `nlr=(10.0E-3)`	Body Effect Coefficient Factor of RSCE.
57 `flr=(0.0)`	Bulk Fermi Potential of RSCE.
58 `leta0=(0.0)`	Long Channel Charge Sharing Coefficient.

59 `leta=(500.0E-3)`	Short Channel Charge Sharing Coefficient.
60 `leta2=(0.0)`	Short Channel Scaling Coefficient.
61 `weta=(200.0E-3)`	Narrow Channel Charge Sharing Coefficient.
62 `ncs=(1.0)`	Slope Factor Dependence from Charge Sharing.
63 `etad=(1.0)`	Primary DIBL Coefficient.
64 `sigmad=(1.0)`	Secondary DIBL Coefficient.
65 `wr=(90.0E-09)`	Width Factor for INWE.
66 `qwr=(0.3E-3)`	Threshold Voltage Factor of INWE.
67 `nwr=(5.0E-3)`	Body Effect Coefficient Factor of INWE.
68 `fprout=(1.0E6)`	Output resistance for DITS effect.
69 `pdits=(0.0)`	DITS parameter.
70 `pditsl=(0.0)`	DITS dependence on length.
71 `pditsd=(1.0)`	DITS dependence on drain bias.
72 `ddits=(0.3)`	Smooth factor of DITS effect.
73 `iba=(000.0E+06)`	Impact Ionization Current first parameter.
74 `ibb=(300.0E+06)`	Impact Ionization Current second parameter.
75 `ibn=(1.0)`	Impact Ionization Current coefficient.
76 `xb=(3.1)`	Silicon to Silicon oxide tunneling barrier height.
77 `eb=(29.0E+09)`	Characteristic electrical field.
78 `kg=(00.0E-6)`	Mobility for Gate Current.
79 `lovig=(20.0E-9)`	Overlap Length for Gate current.
80 `agidl=(0.0)`	First GIDL parameter.

81 `bgidl=(2.3E+09)` Second GIDL parameter.

82 `cgidl=(0.5)` Third GIDL parameter.

83 `egidl=(0.8)` Fourth GIDL parameter.

84 `kf=(0.0)` Flicker noise factor.

85 `af=(1.0)` Frequency exponent for flicker noise.

86 `ef=(2.0)` Transconductance exponent for flicker noise.

87 `kgfn=(0.0)` Gate flicker noise factor.

88 `lqwr=(0.0)` Length scaling of QWR.

89 `lnwr=(0.0)` Length scaling of NWR.

90 `lwr=(0.0)` Length scaling of WR.

91 `ldphiedge=(0.0)` Length scaling of DPHIEDGE.

92 `wqlr=(0.0)` Width scaling of QLR.

93 `wnlr=(0.0)` Width scaling of NLR.

94 `wlr=(0.0)` Width scaling of LR.

95 `wucrit=(0.0)` Width scaling of UCRIT.

96 `wlambda=(0.0)` Width scaling of LAMBDA.

97 `wetad=(0.0)` Width scaling of ETAD.

98 `we0=(0.0)` Width scaling of E0.

99 `we1=(0.0)` Width scaling of E1.

100 `wrlx=(0.0)` Width scaling of RLX.

101 `wucex=(0.0)` Width scaling of UCEX.

102 `wdphiedge=(0.0)` Width scaling of DPHIEDGE.

103 `wldphiedge=(0.0)` Area scaling (fine tuning for short and narrow) of DPHIEDGE.

104 `wldgammaedge=(0.0)`
Area scaling (fine tuning for short and narrow) of DGAMMAEDGE.

105 `wedge=(0.0)` Width of edge conduction area.

106 `dgammaedge=(0.0)` Difference of body effect coefficient of edge conduction area with respect to the main part of the channel.

107 `dphiedge=(0.0)` Difference of fermi potential of edge conduction area with respect to the main part of the channel.

108 `saref=(0.0)` Reference distance from STI, for SA.

109 `sbref=(0.0)` Reference distance from STI, for SB.

110 `wlod=(0.0)` Width of common area between device and STI.

111 `kkp=(0.0)` Mobility dependence on STI.

112 `lkkp=(0.0)` Length scaling of mobility dependence on STI.

113 `wkkp=(0.0)` Width scaling of mobility dependence on STI.

114 `pkkp=(0.0)` Area scaling (fine tuning for short and narrow channel devices) of mobility dependence on STI.

115 `tkkp=(0.0)` Temperature scaling of mobility dependence on STI.

116 `llodkkp=(1.0)` Exponent of length scaling of mobility dependence on STI.

117 `wlodkkp=(1.0)` Exponent of width scaling of mobility dependence on STI.

118 `kvto=(0.0)` Threshold voltage dependence on STI.

119 `lkvto=(0.0)` Length scaling of threshold voltage dependence on STI.

120 `wkvto=(0.0)` Width scaling of threshold voltage dependence on STI.

121 `pkvto=(0.0)` Area scaling (fine tuning for short and narrow channel devices) of threshold voltage dependence on STI.

122 `llodkvto=(1.0)`	Exponent of length scaling of threshold voltage dependence on STI.
123 `wlodkvto=(1.0)`	Exponent of width scaling of threshold voltage dependence on STI.
124 `kgamma=(0.0)`	Body effect dependence on STI.
125 `lodkgamma=(1.0)`	Exponential dependence of body effect on STI .
126 `ketad=(0.0)`	Primary DIBL dependence on STI.
127 `lodketad=(1.0)`	Exponential dependence of Primary DIBL dependence on STI.
128 `kucrit=(0.0)`	Critical Velocity of Electrons dependence of STI.
129 `teta=((-0.9E-3))`	Temperature dependence of ETA.
130 `tlambda=(0.0)`	Temperature dependence of LAMBDA.
131 `tcv=(600.0E-6)`	Temperature dependence of VTO (threshold voltage).
132 `bex=((-1.5))`	Temperature dependence of KP (mobility).
133 `ucex=(1.5)`	Temperature dependence of UCRIT.
134 `te0ex=(0.5)`	Temperature dependence of E0.
135 `te1ex=(0.5)`	Temperature dependence of E1.
136 `ibbt=(800.0E-6)`	Temperature dependence of IBB.
137 `tcvl=(0.0)`	Length dependence of TCV.
138 `tcvw=(0.0)`	Width dependence of TCV.
139 `tcvwl=(0.0)`	Area dependence of TCV.
140 `gammaov=(1.6)`	Body effect coefficient of the overlap area.
141 `gammagov=(10.0)`	Body effect coefficient of the gate of the overlap area.
142 `vfbov=(0.0)`	Flat-band voltage of the overlap area.

143 `lov=(20.0E-9)`	Length of the overlap area.
144 `vov=(1.0)`	Vs dependence of Vgsov.
145 `cgso=(0.0)`	Bias-independent gate to source overlap capacitance.
146 `cgdo=(0.0)`	Bias-independent gate to drain overlap capacitance.
147 `cgbo=(0.0)`	Bias-independent gate to bulk overlap capacitance.
148 `kjf=(0.0)`	Fringing capacitance factor.
149 `cjf=(0.0)`	Fringing capacitance bias factor.
150 `vfr=(0.0)`	Built-in correction for fringing capacitance.
151 `dfr=(1.0E-3)`	Smooth factor of fringing capacitance model.
152 `hdif=(0.0e-6)`	Half length of active area.
153 `rsh=(0.0)`	Square resistance of active area.
154 `ldif=(0.0)`	Distance between the middle of the active area and the start of the channel.
155 `rs=(0.0)`	Source series resistance.
156 `rd=(0.0)`	Drain series resistance.
157 `rlx=((-1.0))`	Series resistance (symmetric model).
158 `rsx=((-1.0))`	Source series resistance (asymmetric model).
159 `rdx=((-1.0))`	Drain series resistance (asymmetric model).
160 `tr=(0.0)`	First order temperature coefficient of resistors.
161 `tr2=(0.0)`	Second order temperature coefficient of resistors.
162 `gmin=(0.0)`	Minimum conductance of diode.
163 `njs=(1.0)`	Slope factor for parasitic diodes(S).

164 `xjbvs=(0.0)` Breakdown effect coefficient(S).

165 `bvs=(10.0)` Breakdown Voltage(S).

166 `jss=(0.0E-09)` Area component of diode current(S).

167 `jssws=(0.0E-12)` Perimeter component of diode current(S).

168 `jsswgs=(0.0E-12)` Gate side component of diode current(S).

169 `jtss=(0.0E-09)` Area component of trap-assisted diode current(S).

170 `jtssws=(0.0E-12)` Perimeter component of trap-assisted diode current(S).

171 `jtsswgs=(0.0E-12)`
Gate side component of trap-assisted diode current(S).

172 `njtss=(1.0)` Area slope factor of trap-assisted diode current(S).

173 `njtssws=(1.0)` Perimeter slope factor of trap-assisted diode current(S).

174 `njtsswgs=(1.0)` Gate side slope factor of trap-assisted diode current(S).

175 `vtss=(0.0)` Area voltage factor of trap-assisted diode current(S).

176 `vtssws=(0.0)` Perimeter voltage factor of trap-assisted diode current(S).

177 `vtsswgs=(0.0)` Gate side voltage factor of trap-assisted diode current(D).

178 `cjs=(0.0E-06)` Area component of diode capacitance(S).

179 `cjsws=(0.0E-09)` Perimeter component of diode capacitance(S).

180 `cjswgs=(0.0E-09)` Gate side component of diode capacitance(S).

181 `pbs=(0.800)` Area parameter of diode capacitance(S).

182 `pbsws=(0.600)` Perimeter parameter of diode capacitance(S).

183 `pbswgs=(0.600)` Gate side parameter of diode capacitance(S).

184 `mjs=(0.900)` Area exponent of diode capacitance(S).

185 `mjsws=(0.700)`	Perimeter exponent of diode capacitance(S).
186 `mjswgs=(0.700)`	Gate side exponent of diode capacitance(S).
187 `xtis=(3.0)`	Temperature dependence of diode(S).
188 `xtss=(0.0)`	Area component of temperature dependence of trap-assisted diode current(S).
189 `xtssws=(0.0)`	Perimeter component of temperature dependence of trap-assisted diode current(S).
190 `xtsswgs=(0.0)`	Gate side component of temperature dependence of trap-assisted diode current(S).
191 `tnjtss=(0.0)`	Temperature dependence of njtss.
192 `tnjtssws=(0.0)`	Temperature dependence of njtssws.
193 `tnjtsswgs=(0.0)`	Temperature dependence of njtsswgs.
194 `tcj=(0.0)`	Temperature dependence of CJ.
195 `tcjsw=(0.0)`	Temperature dependence of CJSW.
196 `tcjswg=(0.0)`	Temperature dependence of CJSWG.
197 `tpb=(0.0)`	Temperature dependence of PB.
198 `tpbsw=(0.0)`	Temperature dependence of PBSW.
199 `tpbswg=(0.0)`	Temperature dependence of PBSWG.
200 `njd=(1.0)`	Slope factor for parasitic diodes(D).
201 `xjbvd=(0.0)`	Breakdown effect coefficient(D).
202 `bvd=(10.0)`	Breakdown Voltage(D).
203 `jsd=(0.0E-09)`	Area component of diode current(D).
204 `jsswd=(0.0E-12)`	Perimeter component of diode current(D).

205 `jsswgd=(0.0E-12)` Gate side component of diode current(D).

206 `jtsd=(0.0E-09)` Area component of trap-assisted diode current(D).

207 `jtsswd=(0.0E-12)` Perimeter component of trap-assisted diode current(D).

208 `jtsswgd=(0.0E-12)`
Gate side component of trap-assisted diode current(D).

209 `njtsd=(1.0)` Area slope factor of trap-assisted diode current(D).

210 `njtsswd=(1.0)` Perimeter slope factor of trap-assisted diode current(D).

211 `njtsswgd=(1.0)` Gate side slope factor of trap-assisted diode current(D).

212 `vtsd=(0.0)` Area voltage factor of trap-assisted diode current(D).

213 `vtsswd=(0.0)` Perimeter voltage factor of trap-assisted diode current(D).

214 `vtsswgd=(0.0)` Gate side voltage factor of trap-assisted diode current(D).

215 `cjd=(0.0E-06)` Area component of diode capacitance(D).

216 `cjswd=(0.0E-09)` Perimeter component of diode capacitance(D).

217 `cjswgd=(0.0E-09)` Gate side component of diode capacitance(D).

218 `pbd=(0.800)` Area parameter of diode capacitance(D).

219 `pbswd=(0.600)` Perimeter parameter of diode capacitance(D).

220 `pbswgd=(0.600)` Gate side parameter of diode capacitance(D).

221 `mjd=(0.900)` Area exponent of diode capacitance(D).

222 `mjswd=(0.700)` Perimeter exponent of diode capacitance(D).

223 `mjswgd=(0.700)` Gate side exponent of diode capacitance(D).

224 `xtid=(3.0)` Temperature dependence of diode(D).

225 `xtsd=(0.0)` Area component of temperature dependence of trap-assisted diode current(D).

226 `xtsswd=(0.0)`	Perimeter component of temperature dependence of trap-assisted diode current(D).
227 `xtsswgd=(0.0)`	Gate side component of temperature dependence of trap-assisted diode current(D).
228 `tnjtsd=(0.0)`	Temperature dependence of njtsd.
229 `tnjtsswd=(0.0)`	Temperature dependence of njtsswd.
230 `tnjtsswgd=(0.0)`	Temperature dependence of njtsswgd.
231 `rgsh=(3.0)`	Gate square resistance.
232 `gc=(1)`	Gate contacts (single sided = 1, double sided = 2).
233 `krgl1=(0.0)`	Length dependence of rg.
234 `rdsbsh=(1.0E+3)`	Drain to source substrate sheet resistance.
235 `rbwsh=(3.0E-3)`	Inner bulk to bulk sheet resistance.
236 `rbn=(0.0)`	Inner bulk to bulk resistance per finger (for RINGTYPE=2).
237 `rsbwsh=(1.0E-3)`	Inner bulk-source side to bulk sheet resistance.
238 `rsbn=(0.0)`	Inner bulk-source side to bulk resistance per finger (for RINGTYPE=2).
239 `rdbwsh=(1.0E-3)`	Inner bulk-drain side to bulk sheet resistance.
240 `rdbn=(0.0)`	Inner bulk-drain side to bulk resistance per finger (for RINGTYPE=2).
241 `ringtype=(1.0)`	Type of guard ring (bulk contacts) (two sides/symmetric: 1, three sides/horse shoe: 2).

Output Parameters

1 `d`	node: Drain.
2 `g`	node: Gate.

3 `s` node: Source.

4 `b` node: Bulk.

5 `noi` node: Noise.

Operating-Point Parameters

1 `exp_cr=(80.0)` The parameter is used by simulator.

2 `cmi_limexp_method=(1.0)`
The parameter is used by simulator.

3 `l=(10.0E-06)` GATES LENGTH.

4 `w=(10.0E-06)` GATES WIDTH.

5 `nf=(1)` NUMBER OF FINGERS.

6 `ad=(0.0)` DRAINS AREA.

7 `as=(0.0)` SOURCES AREA.

8 `pd=(0.0)` DRAINS PERIMETER.

9 `ps=(0.0)` SOURCES PERIMETER.

10 `sa=(0.0)` STI PARAMETER; DISTANCE FROM STI.

11 `sb=(0.0)` STI PARAMETER; DISTANCE FROM STI.

12 `sd=(0.0)` STI PARAMETER; DISTANCE BETWEEN GATES.

13 `avto=(0.0)` MATCHING PARAMETER FOR THRESHOLD VOLTAGE (VTO).

14 `agamma=(0.0)` MATCHING PARAMETER FOR BODY FACTOR (GAMMA).

15 `akp=(0.0)` MATCHING PARAMETER FOR MOBILITY (KP).

16 `idb` Impact ionization current.

17 `igsov` Overlap gate current(source).

18 `igdov`	Overlap gate current(drain).
19 `igb`	Gate current(bulk).
20 `igd`	Gate current(drain).
21 `igs`	Gate current(source).
22 `igidl`	Gate induced drain current.
23 `igisl`	Gate induced source current.
24 `qsfr`	Fringing charge.
25 `qdfr`	Fringing charge.
26 `qsov`	Overlap charge.
27 `qdov`	Overlap charge.
28 `idsedge`	Edge drain current.
29 `qsedge`	Edge charge.
30 `qdedge`	Edge charge.
31 `qgedge`	Edge charge.
32 `qbedge`	Edge charge.
33 `qs`	Source charge.
34 `qd`	Drain charge.
35 `qg`	Gate charge.
36 `qb`	Bulk charge.
37 `ids`	Resistive drain-to-source current.
38 `vdb`	Drain-bulk voltage.
39 `vgb`	Gate-bulk voltage.

40 `vsb` Source-bulk voltage.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

28

BSIMSOI MOSFET Model (bsimsoi)

The BSIMSOI model is a Silicon-on-Insulator (SOI) MOSFET model. It was developed by the BSIM/SOI modeling group at the University of California, Berkeley.

There are two modes in BSIMSOI depending on the value of *soiMod*:

- PD mode (`soiMod=0`), where the body potential is independent of ΔV_{bi} (V_{BS}>ΔV_{bi}). Hence the calculation of ΔV_{bi} is skipped in this mode.
- DD (Unified) mode (`soiMod=1`), where both ΔV_{bi} and body current/charge are calculated to capture the floating-body behavior exhibited in FD devices.
- FD mode (`soiMod=2`), where the body potential is equal to ΔV_{bi}. Hence the calculation of body current/charge, which is essential to the PD model, is skipped.

This chapter contains the following information for the BSIMSOI model:

Instance

BSIMSOI instance may have 4 to 7 terminals: drain (d), gate (g) source (s), back-gate (e), external-bulk (p), bulk (b), and temperature node (t). When more than 4 terminals are given, instance parameter “tnodeout” is specified, the last terminal is interpreted as temperature terminal. All the possible terminal connects are follows:

- InstanceName d g s eModelName parameter=value
- InstanceName d g s e [p]ModelName parameter=value
- InstanceName d g s e [p b]ModelName parameter=value
- InstanceName d g s e [p b t]ModelName parameter=value
- InstanceName d g s e [t]ModelName **tnodeout** parameter=value
- InstanceName d g s e [p t]ModelName **tnodeout** parameter=value
- InstanceName d g s e [p b t]ModelName **tnodeout** parameter=value

To specify BSIMSOI instance element, the ModelName has to be associated with a BSIMSOI model card.

Simple Instance statement

```
MN1 (Vd Vg Vs Ve ) nmos_soi1  l=1e-6 w=5e-6
```

For detailed list of Instance parameters, see Section Component Statements on page 2234.

Model

The following syntax specified BSIMSOI model:

```
model ModelName bsimsoi parameter=value ...
```

The third parameter, `bsimsoi`, is the master to indicate this model is a BSIMSOI model card.

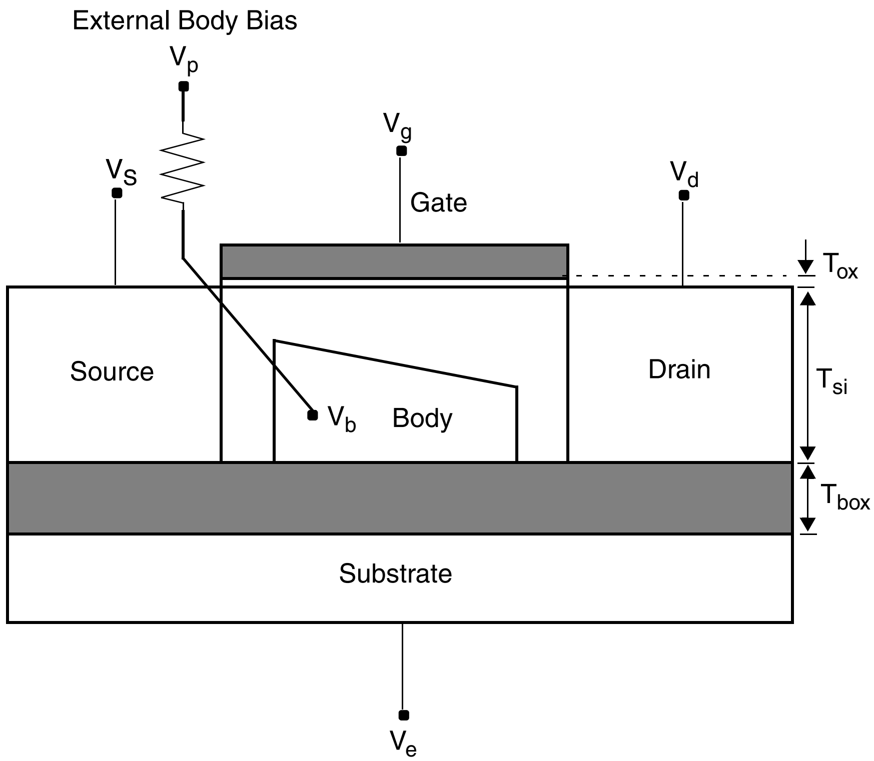
Simple Model statement

```
model bsimsoi_nmos1 bsimsoi type=n version=4.0 tnom=25 tox=3.0e-9 tsi=41e-9
tbox=100e-9 toxm=3.0e-9 vth0=0.29 nch=4e17 nsub=1e16 rbody=0 rbsh=0
```

Note: For detailed list of model parameters, see Section Component Statements on page 2234.

Device Structure

BSIMSOI device's typical structure is shown in the following figure.



In the floating body configuration, there are four external biases: drain voltage (Vd), gate voltage (Vg), source voltage (Vs) and backgate voltage (Ve). The voltage of floating body is solved by iterating in circuit simulation. If body contact is applied, there is one mode external bias: bulk voltage (Vp).

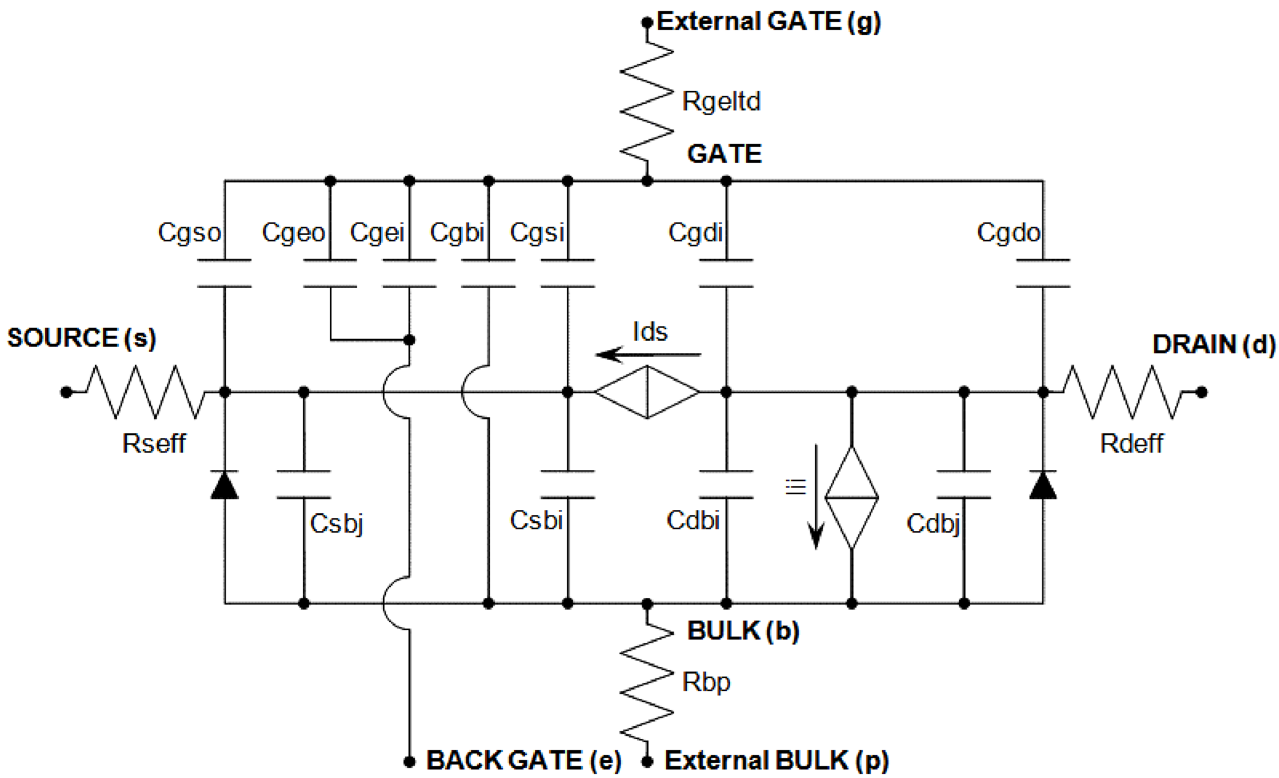
Since the backgate is decoupled by the isolated layer, there are three models to describe the behaviors of the floating body (selected by model parameter 'soimod'):

- PD mode (soimod=0): the body potential is independent for ?Vbi;
- DD mode (soimod=1): both ?Vbi and body current/charge are concerned to capture the floating body behavior;
- FD mode (soimod=2): the body potential is equal to ?vbi

Auto mode (soimod=3): determine the floating body model by with model parameters automitically.

Equivalent Circuit

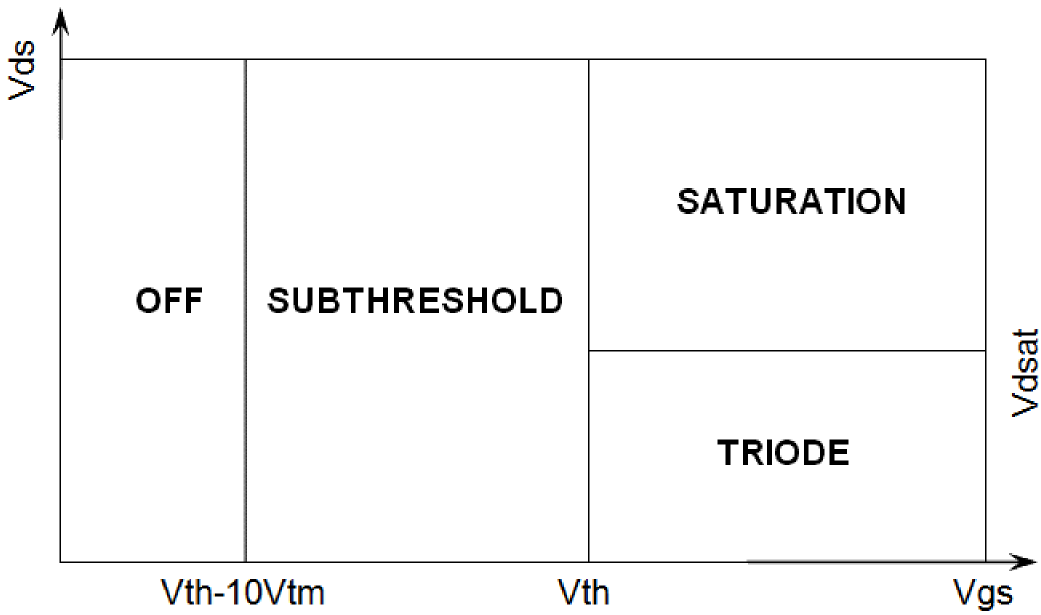
Since BSIMSOI model is developed based on BSIM3v3 model, it shares the similar basic equivalent circuit with BSIM3v3 model except the part of floating body. The followings show the equivalent circuits for BSIMSOI devices:



Device Regions

This section describes devices region for the BSIMSOI model. Device region is determined by both Vds and Vgs. The following figure shows the region of N-type BSIMSOI device. For P-type device, all the voltage in figure is negative.

V_{tm} is the thermal voltage which is about 0.026V for 300°K termperature.



Global Control Options

The following global options affect BSIMSOI model.

1. GMIN: GMIN helps solver convergence. It places a conductance in parallel with both the channel and source junction. The default GMIN is 1.0e-12.
2. MINR: Source, drain and gate parasitic resistors inside devices less than minr will be removed. The order of checking inside devices is:
   - Check if resistors are smaller than local minr, if so then remove the parasitic resistors, give warning message.
   - Check global minr, parasitic resistors less than global minr will be removed and warning message will be issued.

In Spectre, both model parameter minr and global minr take effect at same time. So, for global minr to be activated, the value for minr has to be set both globally and locally.

Note: Local minr is specified by model parameter minr. The default value is 0.1

COMPATIBLE: Encourage device equations to be compatible with a foreign simulator. This option does not affect input syntax. Possible values are spectre, spice2, spice3, or hspice.

Model Version Update

Version 3.2

1. Add model selector “soimod”. “soimod” will determine the operation of BSIMSOI: If soimod=0 (default), the model equation is identical to the BSIMPD equation; if soimod=1 the model equation is an unified model for PD FD; if soimod=2, the model equation is identical to the BSIMFD equation
2. Implements a flicker noise and thermal noise model compatible with BSIM4 has been. In addition, the new noise model includes gate tunneling-induced shot noise and thermal noise due to gate electrode resistance.

Version 4.0

1. A scalable stress effect model for process induced stress effect, device performance becoming thus a function of the active area geometry and the location of the device in the active area;
2. Asymmetric current/capacitance model S/D diode and asymmetric S/D resistance;
3. Improved GIDL model with BSIM4 GIDL compatibility;
4. Noise model Improvements;
   - Improved width/length dependence on flicker noise
   - SPICE2 thermal noise model is introduced as TNOIMOD=2 with parameter NTNOI that adjusts the magnitude of the noise density
   - Body contact resistance induced thermal noise
   - Thermal noise induced by the body resistance network
   - Shot noises induced by Ibs and Ibd separated
5. A two resistance body resistance network introduced for RF simulation;
6. Threshold voltage model enhancement;
   - Long channel DIBL effect model added
   - Channel-length dependence of body effect improved
7. Drain induced threshold shift (DITS) model introduced in output conductance;
8. Improved model accuracy in moderate inversion region with BSIM4 compatible Vgsteff;

9. Multi-finger device with instance parameter NF;
10. A new instance parameter AGBCPD to improve gate current for body contact;
11. A new instance parameter DELVTO representing threshold voltage variation;
12. FRBODY is both instance/model parameters.

Version 4.1

1. New Material Model
2. New Mobility Model for High k Material
3. New GIDL/GISL Model
4. New Impact Ionization Current Model
5. New Body Contact Model
6. New DITS Model
7. Improved VgsteffCV model
8. Improved Built Improved Built-in Potential Lowering (?Vbi) Model

Version 4.2

1. No new features are added in this version.
2. Bug-fix for charge and capacitance
3. Bug-fix for gate to bulk tunneling current “Igb” calculation
4. Bug-fix for vgsteff derivative calculation.

Version 4.3

1. No new features are added in this version.
2. Bug-fix for temperature derivative calculation with selfheating.
3. Bug-fix for dc swapping issue.
4. Bug-fix for Abulk discontinuity issue.
5. Bug-fix for vgst, vfbeff, vfbeff2, vgsteff, vgsteff 2, Qs2 and I_{ii} derivative calculation.

6. Bug-fix for missing number of finger in some calculation.
7. Add source and drain edge components of Gate-source, Gate-drain diffusion tunneling currents.
8. I_{gisl} and I_{gidl} current formulations revised for continuity and consistency.

Version 4.31

1. No new features are added in this version.
2. Bug-fix for new material model
3. Bug-fix for missing number of finger in Ig_agbcp2 current.
4. Bug-fix for Igcs/Igcd derivative calculation.

Version 4.4

1. Extensive derivative fixes for SOIMOD=1 and 2 are provided
2. A new sidewall fringe capacitance model parameter `cfrcoeff` is added.
3. Limiting for peak channel doping concentration parameter `nch` when soimod=2.

Version 4.5

1. Support added for correlated thermal noise at `tnoimod=3`.
2. `dc` and `ac` DIBL parameters have been decoupled
3. New model parameters `EGGBCP2`, `EGGDEP`, `AGB1`, `BGB1`, `AGB2`, `BGB2`, `AGBC2N`, `AGBC2P`, `BGBC2N`, `BGBC2P`, and `VTM00` have been added.
4. The source/drain conductance is now set to `1.0e3` instead of 0 when the value of `NRS` and `NRD` is 0.
5. Inconsistency in drain current when selfheating is on has been addressed.
6. `GISL/GIDL` model for `gidlMod=0` and `gidlMod=1`has been modified.
7. In `capmod=3`, XDC calculation has been modified.
8. `pwr` is now positive in `white_noise(pwr,name)` in the thermal noise model implementation.
9. `NTNOI` and `NOIF` parameters are now limited to positive values only.

10. Thermal noise contribution due to `rbody` has been included.

11. Calculation of A_{bulk} has been updated to avoid non-monotonic behavior at high body bias.

12. Some bugs have been fixed.

Special bug fixed

Rth thermal resistance

R_{th} is the thermal resistance of one device and should be the total resistance of the shunt connected fingers.

UC Berkeley

```
Rth = Rth0 / (Weff + Wth0) * Nseg;
```

Cadence

```
Rth = Rth0 / (NF* (Weff + Wth0)) * Nseg;
```

It is fixed in MMSIM611_ISR16

Cth thermal capacity

C_{th} is the thermal capacity of one device and should be the total resistance of the shunt connected fingers.

UC Berkeley

```
    Cth = Cth0 * (Weff + Wth0) / Nseg;
```

Cadence

```
Cth = Cth0 * (NF* (Weff + Wth0)) / Nseg;
```

It is fixed in MMSIM611_ISR16

ExpVgst bug handling

In the original BSIMSOI model, ExpVgst was multiplied by itself by a mistake when calculate the effective Vgst for charge model. To fix this issue UC Berkeley added Vgstcvmod flag in BSIMSOI 4.1

`Vgstcvmod=0`: keep the bug (Cadence fixed it for version > 4.0)

`Vgstcvmod=1: the bug fixed in UC Berkeley code`

Vgstcvmod=2: New charge model (introduced in 4.1)

It is released in MMSIM711 with BSIMSOI version 4.1. The default value of Vgstcvmod is 0.

In BSIMSOI version 4.2 released in MMSIM72, the default value of $V_{gstcvmod}$ is changed to 1.

Temperature node tolerance and quantity

Spectre supports handling different node behavior and temperature node property should be different from electric node. BSIMSOI temperature node is not properly implemented in Spectre which may cause convergence issue.

It is fixed in MMSIM711_ISR6 (April, 2009)

I_{ii} (substrate current)

I_{ii} is the impact ionization current from channel to bulk body for one finger and should multiply with number of ginger to get the total impact ionization current. Cadence fixed it as I_{ii} * NF

It is fixed in MMSIM72 base release with BSIMSOI version 4.2.

Bugfix control methodology

Spectre BSIMSOI model introduced a new methodology to control all bugfix Cadence did. A new model flag parameter "bugfix_selector" was add to BSIMSOI model to control the special bugfix cadence did in BSIMSOI model. It is an unsigned int. Every bit of its binary format controls one bugfix. With this methodology, every bugfix can be turned on or off independently.

Currently, there are three bugfixes are controlled:

1. Bit0 for bugfix of double ExpVgst when VgstcvMod = 0. (Version != 4.01)
2. Bit1 for bugfix of Vgsteff derivative when VgstcvMod = 0. (Version >= 3.2)

Bit2 for bugfix of channel thermal noise when nf > 1. (Version < 4.31)

That means:

bugfix_selecor		Bugfix list		
Value in base 10	Value in base 2	a	b	c
0	0000-0000-0000-0000	×	×	×
1	0000-0000-0000-0001	●	×	×
2	0000-0000-0000-0010	×	●	×
3	0000-0000-0000-0011	●	●	×
4	0000-0000-0000-0100	×	×	●
5	0000-0000-0000-0101	●	×	●
6	0000-0000-0000-0110	×	●	●
7	0000-0000-0000-0111	●	●	●
8	0000-0000-0000-1000	×	×	×
…	…	…	…	…

Model Equations

DC current

$$I_{ds,MOSFET} = \frac{I_{ds0}}{1+\frac{R_{ds}I_{ds0}}{V_{dseff}}}\left(1+\frac{V_{ds}-V_{dseff}}{V_A}\right)$$

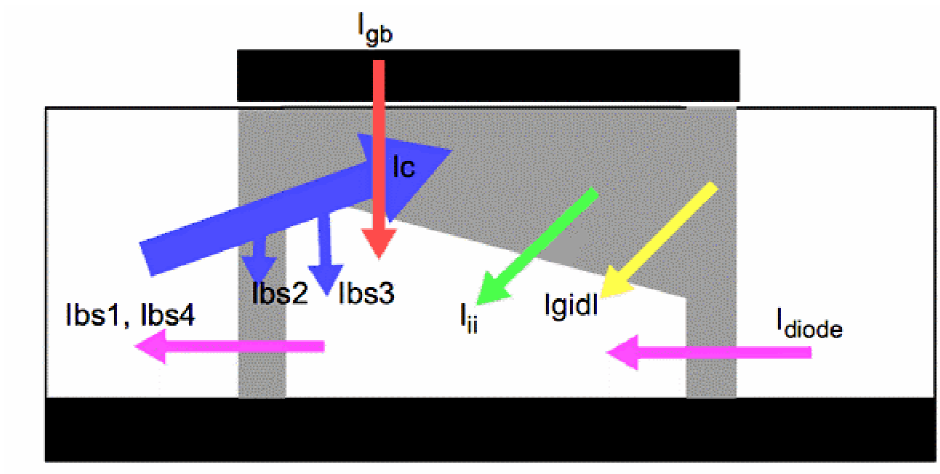
$$I_{ds0} = \frac{\beta V_{gsteff}\left(1-A_{bulk}\frac{V_{dseff}}{2\left(V_{gsteff}+2V_t\right)}\right)V_{dseff}}{1+\frac{V_{dseff}}{E_{sat}L_{eff}}}$$

$$\beta = \mu_{eff} f C_{ox}\frac{W_{eff}}{L_{eff}}$$

Where Abulk is the bulk charge factor:

$$A_{bulk}=1+\left(\frac{K_{1ox}\cdot\sqrt{1+\frac{LPEB}{L_{eff}}}}{2\sqrt{(\phi_s+Keta)-\frac{V_{bsh}}{1+Keta\cdot V_{bsh}}}}\left(\frac{A_0L_{eff}}{L_{eff}+2\sqrt{T_{si}X_{dep}}}\left(1-A_{gs}V_{gsteff}\left(\frac{L_{eff}}{L_{eff}+2\sqrt{T_{si}X_{dep}}}\right)^2\right)+\frac{B_0}{W_{eff}+B_1}\right)\right)$$

Body current



The backward injection current in the B-S/D diode can be expressed as

$$I_{bs1} = W_{dios} T_{si} j_{sdif} \left(e^{\frac{V_{bs}}{n_{diode} V_t}} - 1 \right)$$

$$I_{bd1} = W_{diod} T_{si} j_{ddif} \left(e^{\frac{V_{bd}}{n_{dioded} V_t}} - 1 \right)$$

The carrier recombination and trap-assisted tunneling current in the space-charge region is modeled by

$$I_{bs2} = W_{dios} T_{si} j_{srec} \left(e^{\frac{V_{bs}}{0.026\, n_{recf}}} - e^{\frac{V_{sb}}{0.026\, n_{recr}} \frac{V_{rec0}}{V_{rec0+Vsb}}} \right)$$

$$I_{bd2} = W_{diod} T_{si} j_{drec} \left(e^{\frac{V_{bd}}{0.026\, n_{recfd}}} - e^{\frac{V_{db}}{0.026\, n_{recrd}} \frac{V_{rec0d}}{V_{rec0d+Vdb}}} \right)$$

The reverse bias tunneling current, which may be significant in junctions with high doping concentration, can be expressed as

$$I_{bs4} = W_{dios} T_{si} j_{stun} \left(1 - e^{\frac{V_{sb}}{0.026 n_{tun}} \frac{V_{tun0}}{V_{tun0+Vsb}}} \right)$$

$$I_{bd4} = W_{diod} T_{si} j_{dtun} \left(1 - e^{\frac{V_{db}}{0.026 n_{tund}} \frac{V_{tun0d}}{V_{tun0d+Vdb}}} \right)$$

The recombination current in the neutral body can be described by

$$I_{bs3} = (1 - \alpha_{bjt}) I_{en} \left(e^{\frac{V_{bs}}{n_{diode} V_t}} - 1 \right) \frac{1}{\sqrt{E_{hlis} + 1}}$$

$$I_{bd3} = (1 - \alpha_{bjt}) I_{en} \left(e^{\frac{V_{bd}}{n_{dioded} V_t}} - 1 \right) \frac{1}{\sqrt{E_{hlid} + 1}}$$

$$I_{en} = W'_{eff} T_{si} j_{sbjt} \left(L_{bjt0} \left(\frac{1}{L_{eff}} + \frac{1}{L_n} \right) \right)^N$$

$$E_{hlis} = A_{hli\_eff} \left(e^{\frac{V_{bs}}{n_{dio} V_t}} - 1 \right)$$

$$E_{hlid} = A_{hli\_eff} \left(e^{\frac{V_{bd}}{n_{dio} V_t}} - 1 \right)$$

$$\alpha_{bjt} = e^{-0.5 \left(\frac{L_{eff}}{L_n} \right)^2}$$

The BJT collector current is modeled as

$$I_c = \alpha_{bjt} I_{en} \left(e^{\frac{V_{bs}}{n_{diodes} V_t}} - e^{\frac{V_{bd}}{n_{dioded} V_t}} \right) \frac{1}{E_{2nd}}$$

$$E_{2nd} = \frac{E_{ely} + \sqrt{E_{ely}^{\ 2} + 4E_{hli}}}{2}$$

$$E_{ely} = 1 + \frac{V_{bs} + V_{bd}}{V_{Abjt} + A_{ely} L_{eff}}$$

$$E_{hli} = E_{hlis} + E_{hlid}$$

Impact Ionization Current Equation is modeled as

$$I_{ii} = \alpha_0 \left(I_{ds,MOSFET} + I_{ii\_BJT} \right) e^{\frac{V_{diff}}{\beta_2 + \beta_1 V_{diff} + \beta_0 V_{diff}^{\ 2}}}$$

In this expression, the parasitic BJT effect current is modeled as

- $\mathrm{IiiMod} = 0$

$$I_{ii\_BJT} = F_{bjtii} I_c$$

$$V_{diff} = V_{ds} - V_{dsatii}$$

$$V_{dsatii} = V_{gsStep} + \left(V_{dsatii0} \left(1 + T_{ii} \left(\frac{T}{T_{nom}} - 1 \right) \right) - \frac{L_{ii}}{L_{eff}} \right)$$

$$V_{gsStep} = \left(\frac{E_{satii} L_{eff}}{1 + E_{satii} L_{eff}} \right) \left(\frac{1}{1 + S_{ii1} V_{gsteff}} + S_{ii2} \right) \left(\frac{S_{ii0} V_{gst}}{1 + S_{iid} V_{ds}} \right)$$

- $\mathrm{IiiMod} = 1$

$$I_{ii\_BJT} = \frac{CBJTII + EBJTII \cdot L_{eff}}{L_{eff}} I_c (V_{bci} - V_{bd}) e^{-ABJTii \cdot (V_{bci} - V_{bd})^{(MBJTII-1)}}$$

$$V_{bci} = VBCI \left(1 + TVBCI \left(\frac{T}{T_{nom}} - 1 \right) \right)$$

If body contact is applied, there is one more bulk contact current flow into bulk. It is modeled as:

$$I_{bp} = \frac{V_{bp}}{R_{bp} + R_{bodyext}}$$

$$R_{bp} = \left(R_{body} \frac{W'_{eff}}{L_{eff}} \right) \Bigg\| \left(R_{halo} \frac{W'_{eff}}{2} \right)$$

$$R_{bodyext} = R_{bsh} N_{rb}$$

Leakage current

Gate Induced Source/Drain Leakage Current is modeled as:

gidlMod = 0

$$I_{GIDL} = A_{GIDL} \cdot W_{diod} \cdot Nf \frac{V_{ds} - V_{gse} - E_{GIDL} + V_{fbsd}}{3T_{oxe}} e^{-\frac{3T_{oxe}B_{GIDL}}{V_{ds}-V_{gse}-E_{GIDL}}} \frac{{V_{db}}^3}{C_{GIDL} + {V_{db}}^3}$$

$$I_{GISL} = A_{GISL} \cdot W_{dios} \cdot Nf \frac{-V_{ds} - V_{gde} - E_{GISL} + V_{fbsd}}{3T_{oxe}} e^{-\frac{3T_{oxe}B_{GISL}}{-V_{ds}-V_{gde}-E_{GISL}}} \frac{{V_{sb}}^3}{C_{GISL} + {V_{sb}}^3}$$

gidlMod = 1

$$I_{GIDL} = A_{GIDL} \cdot W_{diod} \cdot Nf \frac{V_{ds} - R_{GIDL}V_{gse} - E_{GIDL} + V_{fbsd}}{3T_{oxe}} e^{-\frac{3T_{oxe}B_{GIDL}}{V_{ds}-V_{gse}-E_{GIDL}}} e^{\frac{K_{GIDL}}{V_{bd}-F_{GIDL}}}$$

$$I_{GISL} = A_{GISL} \cdot W_{dios} \cdot Nf \frac{-V_{ds} - R_{GISL}V_{gde} - E_{GISL} + V_{fbsd}}{3T_{oxe}} e^{-\frac{3T_{oxe}B_{GISL}}{-V_{ds}-V_{gde}-E_{GISL}}} e^{\frac{K_{GISL}}{V_{bs}-F_{GISL}}}$$

For thin oxide (below 2nm), oxide tunneling is important in the determination of floating-body potential. In inversion, the tunneling current is:

$$J_{gb} = A\frac{V_{gb}V_{aux}}{{T_{ox}}^2}\left(\frac{T_{oxref}}{T_{oxqm}}\right)^{N_{tox}} e^{\frac{-B(\alpha_{gb1}-\beta_{gb1}|V_{ox}|)T_{ox}}{1-\frac{|V_{ox}|}{V_{gb1}}}}$$

$$V_{aux} = V_{EVB}\ln\left(1+e^{\frac{|V_{ox}|-\varphi_g}{V_{EVB}}}\right)$$

$$A = \frac{q^3}{8\pi h\phi_b}$$

$$B = \frac{8\pi\sqrt{2m_{ox}}{\phi_b}^{3/2}}{3hq}$$

$$\phi_b = 4.2eV$$

$$m_{ox} = 0.3m_0$$

In accumulation, the tunneling current is:

$$J_{gb} = A\frac{V_{gb}V_{aux}}{T_{ox}^{2}}\left(\frac{T_{oxref}}{T_{oxqm}}\right)^{N_{tox}} e^{\frac{-B(\alpha_{gb2}-\beta_{gb2}|V_{ox}|)T_{ox}}{1-\frac{|V_{ox}|}{V_{gb2}}}}$$

$$V_{aux} = V_{ECB}\ln\left(1+e^{-\frac{V_{gb}-V_{fb}}{V_{ECB}}}\right)$$

$$A = \frac{q^3}{8\pi h\phi_b}$$

$$B = \frac{8\pi\sqrt{2m_{ox}}\phi_b^{3/2}}{3hq}$$

$$\phi_b = 3.2eV$$

$$m_{ox} = 0.4m_0$$

In BSIMSOI4.1, the instance parameter Agbcp2 represents the parasitic gate to body overlap area due to the body contact. This parameter applies for the opposite-type gate. The tunneling current in this region is modeled as:

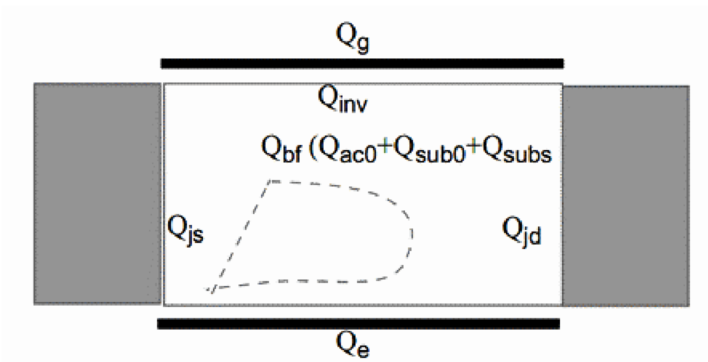
$$I_{g\_agbcp2} = A\cdot A_{agbcp2}\min(V_{gp}-V_{fb2},0)\cdot V_{gp\_eff}T_{oxRatio}e^{-B\cdot T_{oxqm}(A_{IGBCP2}-B_{IGBCP2}V_{gp\_eff})(1+C_{IGBCP2}V_{gp\_eff})}$$

$$V_{gp\_eff} = 0.5\left(\sqrt{(V_{gp}-V_{fb2})^2+\delta^2}-(V_{gp}-V_{fb2})-\delta\right)$$

$$\delta = 0.01$$

Charge and Capacitance

The following is the schematic of Charge model in BSIMSOI model.



For intrinsic charge, BSIMSOI PD model uses similar expressions to $BSIM_{3v3}$ for inversion charge (Q_{inv}) and front gate body charge (Q_{Bf}). The bulk charge constant A_{bulkCV} is defined as:

$$A_{bulkCV} = A_{bulk0}\left(1+\left(\frac{CLC}{L_{active}}\right)^{CLE}\right)$$

$$A_{bulk0} = A_{bulk}\left(V_{gsteff} = 0\right)$$

The effective CV V_{gst} has two equations selected by model parameter `vgstcvmod`:

vg4stcvmod = 0 and 1

$$V_{gsteffCV} = nV_t \ln\left(1+e^{\frac{V_{gs}-V_{th}}{nV_t}}\cdot e^{-\frac{delvt}{nV_t}}\right)$$

The difference between `vgstcvmod` = 0 and 1 is that `vgstcvmod` = 1 fixed the bug of vgstcvmod = 0. The default value for `vgstcvmod` has been changed to 1 from 0 after BSIMSOI model version 4.2.

vgstcvmod = 2

$$V_{gsteffCV} = \frac{nV_t \ln\left(1 + e^{\frac{m^{*CV}\left(V_{gs\_eff} - V_{th} - delvt\right)}{nV_t}}\right)}{m^{*CV} + nC_{ox}\sqrt{\frac{2\phi_s}{q\varepsilon_{si}N_{dep}}}\, e^{-\frac{\left(1-m^{*CV}\right)\left(V_{gs\_eff} - V_{th} - delvt\right) - V_{offCV}}{nV_t}}}$$

$$m^{*CV} = 0.5 + \frac{\arctan\left(MINCV\right)}{\pi}$$

Then the inversion charge can be expressed as:

$$Q_{inv} = -W_{active}L_{active}C_{ox}\left(\left(V_{gsteffCV} - \frac{A_{bulkCV}}{2}V_{dsCV}\right) + \frac{{A_{bulkCV}}^2 {V_{dsCV}}^2}{12\left(V_{gsteffCV} - \frac{A_{bulkCV}}{2}V_{dsCV}\right)}\right)$$

$$V_{dsCV} = V_{dsatCV} - \frac{1}{2}\left(V_{dsatCV} - V_{ds} - \delta + \sqrt{\left(V_{dsatCV} - V_{ds} - \delta\right)^2 + 4\delta V_{dsatCV}}\right)$$

$$V_{dsatCV} = V_{gsteffCV} / A_{bulkCV}$$

The accumulation charge can be calculated as:

$$Q_{ac0} = -F_{body}W_{active}L_{activeB}C_{ox}\left(V_{FBeff} - V_{fb}\right)$$

$$V_{FBeff} = V_{fb} - 0.5\left(\left(V_{fb} - V_{gb} - \delta\right) + \sqrt{\left(V_{fb} - V_{gb} - \delta\right)^2 + \delta^2}\right)$$

$$V_{gb} = V_{gs} - V_{bseff}$$

$$V_{fb} = V_{th} - \phi_s - K_{1eff}\sqrt{\phi_s - V_{bseff}}$$

The gate-induced depletion charge and drain-induced depletion charge can be expressed as:

$$Q_{sub0} = -F_{body} W_{active} L_{activeB} C_{ox} \frac{K_{1eff}^{2}}{2} \left(-1 + \sqrt{1 + \frac{4(V_{gs} - V_{FBeff} - V_{gsteffCV} - V_{bseff})}{K_{1eff}^{2}}} \right)$$

$$Q_{subs} = F_{body} W_{active} L_{activeB} K_{1eff} C_{ox} \left(1 - A_{bulkCV}\right) \left(\frac{V_{dsCV}}{2} - \frac{A_{bulkCV} V_{dsCV}^{2}}{12\left(V_{gsteffCV} - A_{bulkCV} V_{dsCV}/2\right)} \right)$$

The back gate body charge can be modeled by

$$Q_e = F_{body} W_{active} L_{activeBG} C_{box} \left(V_{es} - V_{fbb} - V_{bseff}\right)$$

For `capmod`=3, the flat band voltage is calculated from the bias-independent threshold voltage, which is different from `capMod`=2.

In BSIMSOI PD model, both the depletion and diffusion capacitance of the junction are considered. The diffusion charges Qbddif/Qbsdif are modeled as:

$$Q_{bsdif} = \tau \frac{W_{eff}'}{N_{seg}} T_{si} J_{sbjt} \left(1 + L_{dif0} \left(L_{bj0} \left(\frac{1}{L_{eff}} - \frac{1}{L_n} \right) \right) \right)^{N_{dif}} \left(e^{\frac{V_{bs}}{n_{dios} V_t}} - 1 \right) \frac{1}{\sqrt{E_{hlis} + 1}}$$

$$Q_{bddif} = \tau \frac{W_{eff}'}{N_{seg}} T_{si} J_{dbjt} \left(1 + L_{dif0} \left(L_{bj0} \left(\frac{1}{L_{eff}} - \frac{1}{L_n} \right) \right) \right)^{N_{dif}} \left(e^{\frac{V_{bd}}{n_{diod} V_t}} - 1 \right) \frac{1}{\sqrt{E_{hlid} + 1}}$$

The depletion charges Q_{bddep}/Q_{bsdep} are modeled as:

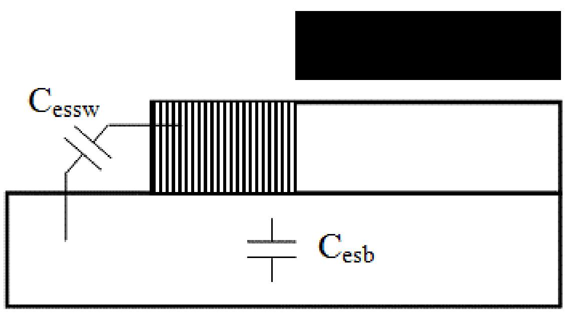
$$Q_{bsdep} = W_{dioCV} C_{jswgs} \frac{T_{si}}{10^{-7}} \frac{P_{bswgs}}{1 - M_{jswgs}} \left(1 - \left(1 - \frac{V_{bs}}{P_{bswgs}} \right)^{1 - M_{jswgs}} \right)$$

$$Q_{bddep} = W_{dioCV} C_{jswgd} \frac{T_{si}}{10^{-7}} \frac{P_{bswgd}}{1 - M_{jswgd}} \left(1 - \left(1 - \frac{V_{bd}}{P_{bswgd}} \right)^{1 - M_{jswgd}} \right)$$

For `capmod=3`, the inversion charge layer thickness is given by:

$$X_{dc} = \frac{ADOS \times 1.9 \times 10^{-9} m}{1 + \left(\frac{V_{gsteff} + 4(VTH0 - VFB - \Phi_s)}{2TOXP}\right)^{0.7 \times BDOS}}$$

Expressions for source/drain-to-gate overlap capacitance and source/drain-to-gate fringing capacitance are taken from BSIM3v3. New SOI-specific parameters added are substrate-to-source sidewall capacitance (C_{esw}), substrate-to-drain sidewall capacitance (C_{edw}), substrate-to-source bottom capacitance (C_{esb}), and substrate-to-drain bottom capacitance (C_{edb}). The following figure shows the BSIMSOI extrinsic charge components.



The substrate-to-source bottom capacitance (per unit source/drain area) C_{esb} is:

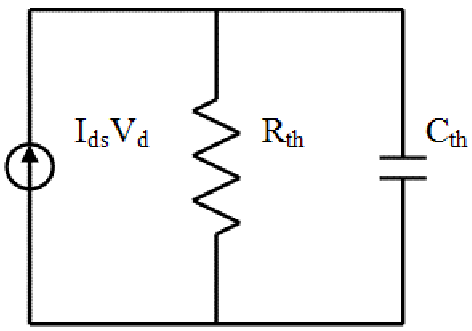
$$C_{esb} = \begin{cases} C_{box} & if \quad V_{se} < V_{sdfb} \\ C_{box} - \frac{1}{A_{sd}}(C_{box} - C_{min})\left(\frac{V_{se} - V_{sdfb}}{V_{sdth} - V_{sdfb}}\right)^2 & elseif \quad V_{se} < V_{sdfb} + A_{sd}(V_{sdth} - V_{sdfb}) \\ C_{min} - \frac{1}{1 - A_{sd}}(C_{box} - C_{min})\left(\frac{V_{se} - V_{sdth}}{V_{sdth} - V_{sdfb}}\right)^2 & elseif \quad V_{se} < V_{sdth} \\ C_{min} & else \end{cases}$$

The sidewall source/drain to substrate capacitance (per unit source/drain perimeter length) $C_{s/d,esw}$ is:

$$C_{s/d,esw} = C_{sdesw} \log\left(1 + \frac{T_{si}}{T_{box}}\right)$$

Selfheating

An equivalent circuit for self-heating simulation is shown below:



BSIMPD models the self-heating by an auxiliary $R_{th}C_{th}$ circuit shown in the figure above. The temperature node (T node) is created in SPICE simulation if the self-heating selector shMod is on and the thermal resistance is non-zero. The T node is treated as a voltage node and is connected to ground through a thermal resistance Rth and a thermal capacitance Cth.

$$R_{th} = \frac{R_{th0}}{W'_{eff} + W_{th0}}$$

$$C_{th} = C_{th0}\left(W'_{eff} + W_{th0}\right)$$

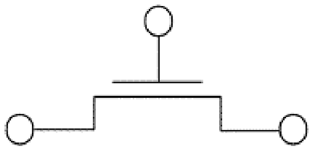
where Rth0 and Cth0 are normalized thermal resistance and capacitance respectively. Wth0 is the minimum width for thermal resistance calculation. The current source is driving a current equal to the power dissipated in the device.

$$P = \left|I_{ds}V_{ds}\right|$$

RF model

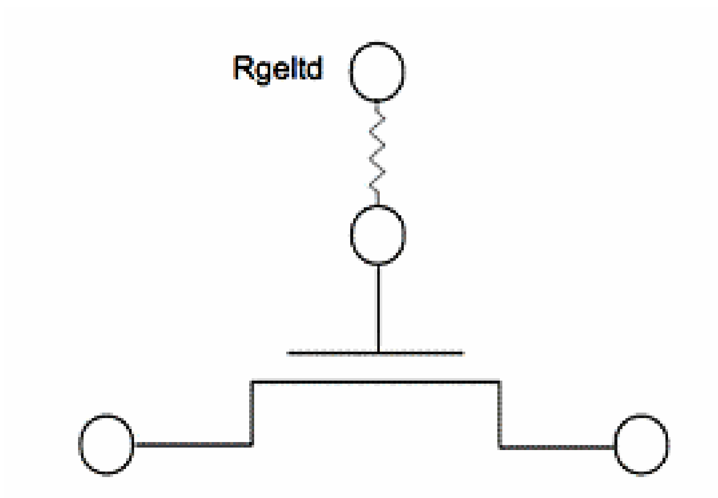
BSIMSOI provides the gate resistance model used in RF application. You have the following options for modeling gate electrode resistance (bias independent) and intrinsic-input resistance (R_{ii}, bias-dependent):

RgateMod=0 (zero-resistance)



In this case, no gate resistance is generated.

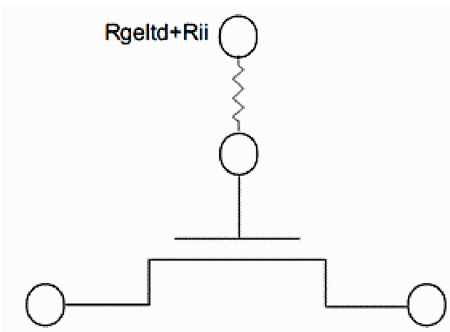
RgateMod=1 (constant-resistance)



In this case, only electrode gate resistance (bias-independent) is generated by adding an internal gate node. The electrode gate resistance is given by

$$R_{geltd} = \frac{R_{SHG}\left(X_{GW} + \frac{W_{eff}}{3N_{GCON} \cdot N_{seg}}\right)}{N_{GCON}\left(L_{drawn} - X_{GL}\right)}$$

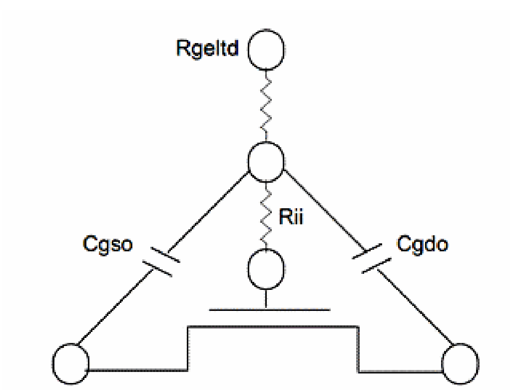
RgateMod=2 (R_{ii} model with variable resistance)



The gate resistance here is the sum of the electrode resistance and the intrinsic-input resistance R_{ii}, as given by:

$$\frac{1}{R_{ii}} = X_{RGRFG1}\left(\frac{I_{ds}}{V_{dseff}} + X_{RCRG2}\frac{W_{eff}\mu_{eff}C_{oxeff}k_B T}{qL_{eff}}\right)$$

RgateMod=3 (R_{ii} model with two nodes)



The gate electrode resistance here is in series with the intrinsic-input resistance R_{ii} through the two internal gate nodes so the overlap capacitance current does not pass through the intrinsic-input resistance.

Noise

In BSIMSOI model, flicker noise and thermal noise models are compatible with BSIM4. Gate tunneling induced shot noise and thermal noise due to gate electrode resistance are also included.

Two flicker noise models are provided in BSIMSOI model:

fnoiMod=0

$$S_{id}(f) = \left(\frac{W_{eff}}{W_{0FLK}}\right)^{1-af} \frac{K_f I_{ds}{}^{af}}{C_{oxe} L_{eff}{}^2 f^{ef}}$$

fnoiMod=1

The noise density in inversion region is given by:

$$S_{id,inv}(f) = \frac{k_B T q^2 \mu_{eff} I_{ds}}{C_{oxe} L_{eff}{}^2 A_{bulk} f^{ef} \cdot 10^{10}} \left(Noia\left(\frac{N_0 + N^*}{N_l + N^*}\right) + Noib(N_0 - N_l) + \frac{Noic}{2}\left(N_0{}^2 - N_l{}^2\right)\right) + \frac{k_B T \cdot I_{ds}{}^2 \Delta L_{clm}}{W_{eff} L_{eff}{}^2 f^{ef} \cdot 10^{10}} \frac{Noia + Noib \cdot N_l + Noic \cdot N_l{}^2}{\left(N_l + N^*\right)^2}$$

The noise density in subthreshold region is given by:

$$S_{id,subV_t}(f) = \frac{Noia \cdot k_B T \cdot I_{ds}{}^2}{W_{eff} L_{eff} f^{ef} \left(N^*\right)^2 \cdot 10^{10}}$$

The total flicker noise density is:

$$S_{id}(f) = \frac{S_{id,inv}(f) \times S_{id,subV_t}(f)}{S_{id,inv}(f) + S_{id,subV_t}(f)}$$

Following thermal noise models are provided in BSIMSOI model:

tnoiMod=0

$$\overline{i_d^{\ 2}} = \frac{4k_B T\Delta f}{R_{ds} + \dfrac{L_{eff}^{\ 2}}{\mu_{eff}\left|Q_{inv}\right|}} N_{tnoi}$$

tnoiMod=1

The noise voltage source partitioned to the source side is given by:

$$\overline{v_d^{\ 2}} = 4k_B T \cdot \theta_{tnoi}^{\ 2} \frac{V_{dseff}\Delta f}{I_{ds}}$$

The noise current source put in the channel region with gate and body amplification is given by:

$$\overline{i_d^{\ 2}} = 4k_B T \frac{V_{dseff}\Delta f}{I_{ds}} \left(G_{ds} + \beta_{tnoi}\left(G_m + G_{mbs}\right)\right)^2 - \overline{v_d^{\ 2}}\left(G_{ds} + G_m + G_{mbs}\right)^2$$

The junction currents (I_{bs}, I_{bd}) for shot noise(`fb_ibs`, `fb_ibd`) are given by:

$$\overrightarrow{I_{bs}^2} = 2qI_{bs} = 2q(I_{bs1} + I_{bs2} + I_{bs3} + I_{bs4})$$

$$\overrightarrow{I_{bd}^2} = 2qI_{bd} = 2q(I_{bd1} + I_{bd2} + I_{bd3} + I_{bd4})$$

tnoimod=2 (SPICE2 model)

$$\overline{i_d^{\ 2}} = \frac{8k_B T\Delta f}{3} \cdot NTNOI \cdot (G_m + G_{mbs} + G_{ds})$$

The `NTNOI` parameter provides the flexibility to tune the magnitude of noise density.

tnoimod=3

In this noise model, noise for both gate and drain is implemented as current noise sources. The drain current noise flows from drain to source, whereas the induced gate current noise flows from gate to source and drain. The correlatoin between the two noise sources can be tuned with the parameter RNOIC.

$$V_b = \frac{V_{gsteff} + 2v_t}{A_{bulk}}$$

$$\eta = 1 - \frac{V_{dseff}}{V_b}$$

$$L_{vsat} = L_{eff} \cdot \left[1 + \frac{V_{dseff}}{E_{sat} L_{eff}}\right]$$

$$\alpha = A_{bulk}$$

$$\gamma = \frac{L}{L_{vsat}} \left[\frac{1+\eta}{2} + \frac{(1-\eta)^2}{6\left[(1+\eta) + \frac{2V_t\alpha}{V_{gsteff}}\right]}\right]$$

$$\delta = \frac{1}{6}\left(\frac{L_{vsat}}{L}\right)^3 \left[\frac{1+\eta}{\left[(1+\eta) + \frac{2\alpha V_t}{V_{gsteff}}\right]^2} - \frac{\left[6(1+\eta) + \frac{2\alpha V_t}{V_{gsteff}}\right](1-\eta)^2}{15\left[(1+\eta) + \frac{2\alpha V_t}{V_{gsteff}}\right]^4} + \frac{(1-\eta)^4}{9\left[(1+\eta) + \frac{2\alpha V_t}{V_{gsteff}}\right]^5}\right]$$

$$\epsilon = \frac{1}{6} \cdot \frac{L_{vsat}}{L} \left[\frac{1-\eta}{\left[(1+\eta) + \frac{2\alpha V_t}{V_{gsteff}}\right]} + \frac{(1-\eta)^3}{3\left[(1+\eta) + \frac{2\alpha V_t}{V_{gsteff}}\right]^3}\right]$$

$$n_c = RNOIC.\left[1 + TNOIC.\ L_{eff} \cdot \left(\frac{V_{gsteff}}{E_{sat} L_{eff}}\right)^2\right]$$

$$c_{tnoi} = \frac{\epsilon}{\sqrt{\gamma.\delta}} . \left(\frac{n_c}{0.395}\right)$$

$$n_\beta = RNOIA.\left[1 + TNOIA.\ L_{eff} \cdot \left(\frac{V_{gsteff}}{E_{sat} L_{eff}}\right)^2\right]$$

$$n_\theta = RNOIB.\left[1 + TNOIB.\ L_{eff} \cdot \left(\frac{V_{gsteff}}{E_{sat}L_{eff}}\right)^2\right]$$

$$g_{d0} = NF \times \frac{\mu_{eff} C_{oxeff} \frac{W_{eff}}{L_{eff}} V_{gsteff}}{1 + gche \cdot R_{ds}}$$

$$S_{id} = 4kT.\gamma.(3n_\beta{}^2)\,g_{d0}$$

$$C_0 = NF \times C_{oxeff} W_{eff,CV} L_{eff,CV}$$

$$sf = \frac{g_{d0}}{\sqrt{\delta \times 3.75 \times n_\theta{}^2 / \gamma}}$$

$$I(di,si) <+\ white\_noise\ \left(S_{id} \times |1 - c_{tnoi}{}^2|\right)$$

$$I(N) <+\ V(N) \times sf \times SCALEN$$

$$I(N) <+ white\_noise\ \left(\frac{S_{id}}{sf^2 \times SCALEN^2}\right)$$

$$I(di,si) <+\ c_{tnoi} \times V(N) \times sf \times SCALEN$$

$$I(gi,si) <+\ ddt\left(0.5 \times C_0 \times SCALEN \times V(N)\right)$$

$$I(gi,di) <+\ ddt\left(0.5 \times C_0 \times SCALEN \times V(N)\right)$$

Component Statements

This device is supported within altergroups.

Instance Parameters

1 `w (m)` Channel width(alias=lv2).

2 `l (m)`	Channel length(alias=lv1).
3 `nf=1.0`	Number of fingers.
4 `as` (m^2)	Area of source diffusion(alias=lv4).
5 `ad` (m^2)	Area of drain diffusion(alias=lv3).
6 `ps (m)`	Perimeter of source diffusion(alias=lv12).
7 `pd (m)`	Perimeter of drain diffusion(alias=lv11).
8 `nrd (m/m)`	Number of squares of drain diffusion.
9 `nrs (m/m)`	Number of squares of source diffusion.
10 `nrb (m/m)`	Number of body squares.
11 `nbc=0 m/m`	Number of body contact isolation edge.
12 `nseg=1 m/m`	Number of segments for channel width partitioning.
13 `pdbcp=0 m`	Perimeter length for body contact parasitic at drain.
14 `psbcp=0 m`	Perimeter length for body contact parasitic at source.
15 `agbcp=0` m^2	Gate to body overlap area for body contact parasitic.
16 `aebcp=0` m^2	Substrate to body overlap area for body contact parasitic.
17 `m=1`	Multiplicity factor (number of MOSFETs in parallel).
18 `soimod=0`	SOI model selector. SoiMod=0:PD module. SoiMod=1: DD module. SoiMod=2: FD module.
19 `rgatemod`	Rgate flag(available from Version 3.1).
20 `rbodymod`	Body R model selector.
21 `tnodeout`	Temperature node flag associated with T node(Given or NOT Given).

22 `isnoisy=yes`	Should device generate noise. Possible values are `no` and `yes`.
23 `region=triode`	Estimated operating region. Possible values are `off`, `triode`, `sat`, and `subth`.
24 `rth0 ((m C)/w)`	Thermal resistance.
25 `cth0 (w s/(m C))`	Thermal capacitance.
26 `bjtoff=0`	BJT off flag.
27 `vbsusr=0 V`	Optional initial value of Vbs for transient.
28 `frbody=1`	Layout dependent body-resistance coefficient.
29 `sa=0 m`	Distance between OD edge to poly of one side.
30 `sb=0 m`	Distance between OD edge to poly of the other side.
31 `sd=0 m`	Distance between neighbor fingers.
32 `rbdb (Ω)`	Body resistance.
33 `rbsb (Ω)`	Body resistance.
34 `agbcpd=agbcp` m^2	Gate to body overlap area for bc parasitics in DC.
35 `agbcp2=0` m^2	Parasitic Gate to body overlap area for bc parasitics.
36 `delvto=0 V`	Zero bias threshold voltage variation.
37 `trise (C)`	Temperature rise from ambient.

Note:

1. `tnodeout` is a flag parameter of instance. If it is specified and the instance has more than 4 terminals, then the last terminal is interpreted as temperature node. It does not need to assign any value for this parameter. `tnodeout`, `tnodeout=0` and `tnodeout=1` all indicate that `tnodeout` is specified in instance statement, it will treat the last terminal as temperature terminal.

2. `region` can set the initial device work state for simulator, a correct `region` value can help simulator converge faster but will not effect the final result.

Model Parameters

Device type parameters

1 `type=n`	Transistor type. Possible values are `n` and `p`.
2 `version=3.0`	Model parameter "version" only accepts real number value, like 2.23 for version=2.2.3. The available version is 2.23(2.2.3), 3.0, 3.11(3.1.1), 3.2, 4.0, 4.1, 4.2, 4.3, 4.31(4.3.1), 4.4 and 4.5.
3 `binunit=1`	Bin parameter unit selector. 1 for microns and 2 for meters.
4 `cdnver=1`	Cadence version selector.
5 `soimod=0`	SOI model selector. SoiMod=0: PD module. SoiMod=1: DD module. SoiMod=2: FD module.
6 `mtrlmod=0`	parameter for non-silicon substrate or metal gate selector.
7 `mobmod=1`	Mobility model selector.
8 `fdmod=0`	Improved dVbi model selector.
9 `gidlmod=0`	parameter for GIDL selector.
10 `gatetype=h`	Gate structure type selector. Possible values are `h` and `non_h`.
11 `capmod=2`	Intrinsic charge model.
12 `vgstcvmod=0`	Improved VgsteffCV selector.
13 `igmod=0`	Gate tunneling current model selector.
14 `igbmod=0`	Gate-body tunneling current model selector.
15 `igcmod=0`	Gate-channel tunneling current model selector.
16 `iiimod=0`	parameter for Iii selector.
17 `rbodymod=0`	Body R model selector.

18 `rdsmod=0`	Bias-dependent S/D resistance model selector.
19 `rgatemod=0`	Rgate flag.
20 `shmod=0`	Self-heating selector.
21 `tlev=0`	DC temperature selector.
22 `tlevc=0`	AC temperature selector.
23 `noimod=1`	Noise model selector.
24 `fnoimod=1`	Flicker Noise model selector.
25 `tnoimod=0`	Thermal Noise model selector.

Process parameters

26 `nsub=6e16 cm`$^{-3}$	Substrate doping concentration.
27 `nch=1.7e17 cm`$^{-3}$	Peak channel doping concentration.
28 `ngate=0 cm`$^{-3}$	Poly-gate doping concentration.
29 `nsd=1.0e20 cm`$^{-3}$	S/D doping concentration.
30 `xj=0.15e-6 m`	Source/drain junction depth.
31 `tsi=1e-7 m`	Silicon film thickness.
32 `etsi=1e-7 m`	Effective Silicon-on-insulator thickness in meters.
33 `tbox=3e-7 m`	Buried oxide thickness.
34 `tox=1e-8 m`	Gate oxide thickness.
35 `toxm (m)`	Gate oxide thickness used in extraction.
36 `toxp=tox`	Physical gate oxide thickness.
37 `xt=1.55e-7 m`	Doping depth.

38 `rdsw=100 Ω µm^wr`
Width dependence of drain-source resistance.

39 `prwb=0 1/√V` Body-effect coefficient for Rds.

40 `prwg=0 1/V` Gate-effect coefficient for Rds.

41 `wr=1` Width offset for parasitic resistance.

42 `dwg=0 m/V` Gate-bias dependence of channel width.

43 `dwb=0 m/√V` Body-bias dependence of channel width.

44 `dwbc=0 m` Width offset for body contact isolation edge.

45 `lint=0 m` Lateral diffusion for one side.

46 `wint=0 m` Width reduction for one side.

47 `ll=0 m^lln` Length dependence of delta L.

48 `lln=1` Length exponent of delta L.

49 `llc=0 m^lln` Length dependence of delta LC.

50 `lwc=0 m^wln` Width dependence of delta LC.

51 `lwlc=0 m^(lln+lwn)`
Area dependence of delta LC.

52 `lw=0 m^lwn` Width dependence of delta L.

53 `lwn=1` Width exponent of delta L.

54 `lwl=0 m^(lln+lwn)` Area dependence of delta L.

55 `wl=0 m^wln` Length dependence of delta W.

56 `wlc=0 m^wln` Length dependence of delta WC.

57 `wwc=0 m^wwn` Width dependence of delta WC.

58 `wwlc=0 m^(wwn+wln)`
Area dependence of delta WC.

59 `wln=1` Length exponent of delta W.

60 `ww=0 m^wwn` Width dependence of delta W.

61 `wwn=1` Width exponent of delta W.

62 `wwl=0 m^(wwn+wln)` Area dependence of delta W.

63 `xl=0 m` Length variation due to masking and etching.

64 `xw=0 m` Width variation due to masking and etching.

Material model parameters (Version 4.1 or later)

65 `eot=100.0e-10 m` Effective SiO2 thickness.

66 `epsrox=3.9` Dielectric constant of the gate oxide relative to vacuum.

67 `epsrsub=11.7` Dielectric constant of substrate relative to vacuum.

68 `ni0sub=1.45e10` cm^{-3}
Intrinsic carrier concentration of substrate at Tnom.

69 `bg0sub=1.16 eV` Band-gap of substrate at T=0K.

70 `tbgasub=7.02e-4 V/K`
First parameter of band-gap change due to temperature.

71 `tbgbsub=1108.0 K` Second parameter of band-gap change due to temperature.

72 `phig=4.05 eV` Work function of gate.

73 `easub=4.05 eV` Electron affinity of substrate.

74 `leffeot=1.0 µm` Effective length for extraction of EOT.

75 `weffeot=10.0 µm` Effective width for extraction of EOT.

76 `vddeot=1.5 V` Voltage for extraction of EOT.

77	`tempeot=300.15 K`	Temperature for extraction of EOT.
78	`ados=1.0`	Charge centroid parameter.
79	`bdos=1.0`	Charge centroid parameter.
80	`epsrgate=11.7`	Dielectric constant of gate relative to vacuum.

Threshold voltage parameters

81	`vtho (V)`	Threshold voltage at zero body bias for long-channel devices. For enhancement-mode devices, vtho > 0 for n-channel and vth < 0 for p-channel. Default value is calculated from other model parameters.
82	`k1=0.53 √V`	Body-effect coefficient.
83	`k1w1=0 m`	First body effect width dependent parameter.
84	`k1w2=0 m`	Second body effect width dependent parameter.
85	`k2=-0.0186`	Charge-sharing parameter.
86	`k3=0`	Narrow width coefficient.
87	`k3b=0 1/V`	Narrow width coefficient.
88	`w0=2.5e-6 m`	Narrow width coefficient.
89	`lpe0=1.74e-7 m`	Lateral nonuniform doping coefficient.
90	`nlx=1.74e-7 m`	Lateral nonuniform doping coefficient.
91	`lpeb=0 m`	Lateral non-uniform doping effect for body bias.
92	`dvt0=2.2`	First coefficient of short-channel effects.
93	`dvt1=0.53`	Second coefficient of short-channel effects.
94	`dvt2=-0.032 1/V`	Body-bias coefficient of short-channel effects.
95	`dvt0w=0`	First coefficient of narrow-width effects.

96 `dvt1w=5.3e6` Second coefficient of narrow-width effects.

97 `dvt2w=-0.032 1/V` Body-bias coefficient of narrow-width effects.

98 `vbx=0 V` Threshold voltage transition body voltage.

99 `vbm=-3 V` Maximum applied body voltage.

100 `vfb=-1.0 V` Flat Band Voltage.

101 `a0=1` Nonuniform depletion width effect coefficient.

102 `b0=0 m` Bulk charge coefficient due to narrow width effect.

103 `b1=0 m` Bulk charge coefficient due to narrow width effect.

104 `a1=0` No-saturation coefficient.

105 `a2=1` No-saturation coefficient.

106 `ags=0 1/V` Gate-bias dependence of abulk.

107 `keta=-0.6 1/V` Body-bias coefficient for non-uniform depletion width effect.

108 `ketas=0 V` Surface Potential adjustment for bulk charge effect.

109 `dvtp0=0 m` First parameter for Vth shift due to pocket.

110 `dvtp1=0 1/V` Second parameter for Vth shift due to pocket.

111 `dvtp2=0` Third parameter for Vth shift due to pocket.

112 `dvtp3=0` Forth parameter for Vth shift due to pocket.

113 `dvtp4=0` Fifth parameter for Vth shift due to pocket.

114 `minv=0` For moderate inversion in Vgsteff.

115 `pdits=1e-20 1/V` Coefficient for drain-induced Vth shifts.

116 `pditsl=0 1/m` Length dependence of drain-induced Vth shifts.

117 `pditsd=0 1/V` Vds dependence of drain-induced Vth shifts.

118 `gamma1=0 √V` Body-effect coefficient near the surface.

119 `gamma2=0 √V` Body-effect coefficient in the bulk.

Mobility parameters

120 `u0=670 cm^2/V s` Low-field surface mobility at `tnom`. Default is 250 for PMOS.

121 `vsat=8e4 m/s` Carrier saturation velocity at `tnom`.

122 `ua=2.25e-9 m/V` First-order mobility reduction coefficient.

123 `ub=5.87e-19 m^2/V^2`
Second-order mobility reduction coefficient.

124 `uc=-4.65e-11 m/V^2`
Body-bias dependence of mobility. Default is -0.046 and unit is 1/V for mobmod=3.

125 `ud=0 /m^2` Coulomb scattering factor of mobility.

126 `eu=1.67` Mobility exponent.

127 `ucs=1.67` Mobility exponent.

Subthreshold parameters

128 `cdsc=2.4e-4 F/m^2` Source/drain and channel coupling capacitance.

129 `cdscb=0 F/m^2 V` Body-bias dependence of `cdsc`.

130 `cdscd=0 F/m^2 V` Drain-bias dependence of `cdsc`.

131 `nfactor=1` Subthreshold swing coefficient.

132 `cit=0 F/m^2` Interface trap parameter for subthreshold swing.

133 `voff=-0.08 V` Threshold voltage offset.

134 `noff=1.0 1/V` C-V turn-on/off parameter.

135 `dsub=drout` DIBL effect in subthreshold region.

136 `eta0=0.08` DIBL coefficient subthreshold region.

137 `etab=-0.07 1/V` Body-bias dependence of `et0`.

Output resistance parameters

138 `drout=0.56` DIBL effect on output resistance coefficient.

139 `fprout=0 V/ m`
Rout degradation coefficient for pocket devices.

140 `pclm=1.3` Channel length modulation coefficient.

141 `pdiblc1=0.39` First coefficient of drain-induced barrier lowering.

142 `pdiblc2=8.6e-3` Second coefficient of drain-induced barrier lowering.

143 `pdiblcb=0 1/V` Body-effect coefficient for DIBL.

144 `pvag=0` Gate dependence of Early voltage.

145 `delta=0.01 V` Effective drain voltage smoothing parameter.

Substrate current parameters

146 `alpha0=0 m/V` Substrate current impact ionization coefficient.

147 `beta0=0 1/V` First Vds dependent parameter of impact ionization current.

148 `fbjtii=0` Fraction of bipolar current affecting the impact ionization.

149 `beta1=0` Second Vds dependent parameter of impact ionization current.

150 `beta2=0 V` Third Vds dependent parameter of impact ionization current.

151 `vdsatii0=0.9 V` Nominal drain saturation voltage at threshold for impact ionization current.

152 `vbci=0 V` Internal B-C built-in potential.

153 `tii=0` Temperature dependent parameter for impact ionization current.

154 `lii=0` Channel length dependent parameter at threshold for impact ionization current.

155 `esatii=1e7 V/m` Saturation channel electric field for impact ionization current.

156 `sii0=0.5 1/V` First Vgs dependent parameter for impact ionization current.

157 `sii1=0.1 1/V` Second Vgs dependent parameter for impact ionization current.

158 `sii2=0 1/V` Third Vgs dependent parameter for impact ionization current.

159 `siid=0 1/V` Vds dependent parameter of drain saturation voltage for impact ionization current.

160 `ebjtii=0 1/V` Impact ionization parameter for BJT part.

161 `cbjtii=0 1/m/V` Length scaling parameter for II BJT part.

162 `abjtii=0` Exponent factor for avalanche current.

163 `mbjtii=0.4` Internal B-C grading coefficient.

SOI specific parameters

164 `ngidl=1.2 V` GIDL Vds enhancement coefficient.

165 `egidl=1.2 V` GIDL first parameter.

166 `agidl=0 S` GIDL constant.

167 `bgidl=0 V/m` GIDL exponential coefficient.

168 `cgidl=0` V^3 GIDL vb parameter.

169 `rgidl=1.0 1/V` GIDL vg parameter.

170 `kgidl=0 1/V` GIDL vb parameter.

171 `fgidl=0 V` GIDL vb parameter.

172 `egisl=egidl` GISL first parameter.

173 `agisl=agidl` GISL constant.

174 `bgisl=bgidl`	GISL exponential coefficient.
175 `cgisl=cgidl`	GISL vb parameter.
176 `rgisl=Rgidl`	GISL vg parameter.
177 `kgisl=kgidl`	GISL vb parameter.
178 `fgisl=fgidl`	GISL vb parameter.
179 `ntun=10`	Reverse tunneling non-ideality factor.
180 `ntund=ntun`	Reverse tunneling non-ideality factor.
181 `ndioded=ndiode`	Diode non-ideality factor.
182 `nrecf0=2.0`	Recombination non-ideality factor at forward bias.
183 `nrecr0=10`	Recombination non-ideality factor at reversed bias.
184 `nrecf0d=nrecf0`	Recombination non-ideality factor at forward bias.
185 `nrecr0d=nrecr0`	Recombination non-ideality factor at reversed bias.
186 `isbjt=1e-6 A/m`^{2}	BJT saturation current.
187 `isdif=0 A/m`^{2}	Diffusion saturation current.
188 `isrec=1e-5 A/m`^{2}	Recombination saturation current.
189 `istun=0 A/m`^{2}	Tunneling saturation current.
190 `idbjt=isbjt A/m`^{2}	BJT injection saturation current.
191 `iddif=isdif A/m`^{2}	Body to source/drain injection saturation current.
192 `idrec=isrec A/m`^{2}	Recombination saturation current.
193 `idtun=idtun A/m`^{2}	Tunneling saturation current.
194 `ln=2e-6 m`	Electron diffusion length.
195 `vrec0=0 V`	Voltage dependent parameter for recombination current.

196 `vtun0=0 V`	Voltage dependent parameter for tunneling current.
197 `vrec0d=vrec0 V`	Voltage dependent parameter for recombination current.
198 `vtun0d=vtun0 V`	Voltage dependent parameter for tunneling current.
199 `nbjt=1`	Power coefficient of channel length dependency for bipolar current.
200 `lbjt0=0.20e-6 m`	Reference channel length for bipolar current.
201 `vabjt=10 V`	Early voltage for bipolar current.
202 `aely=0 V/m`	Channel length dependency of early voltage for bipolar current.
203 `ahli=0`	High level injection parameter for bipolar current.
204 `ahlid=ahli`	High level injection parameter for bipolar current.
205 `ndiode=1`	Diode non-ideality factor.
206 `vbsa=0 V`	Non-ideal offset voltage.
207 `nofffd=1.0`	Smooth parameter in FD module.
208 `vofffd=0`	Smooth parameter in FD module.
209 `k1b=1.0`	First backgate body effect parameter.
210 `k2b=0`	Second backgate body effect parameter for short channel effect.
211 `dk2b=0`	Third backgate body effect parameter for short channel effect.
212 `dvbd0=0`	First short-channel effect parameter in FD module.
213 `dvbd1=0`	Second short-channel effect parameter in FD module.
214 `moinfd=1.0e3`	Gate bias dependence coefficient of surface potential.
215 `vbs0pd=0 V`	Upper bound of built-in potential lowering for PD operation.
216 `vbs0fd=0.5 V`	Lower bound of built-in potential lowering for FD operation.

Parasitic resistance parameters

217 `rbody=0 Ω` Body resistance.

218 `rbsh=0 Ω` Extrinsic body contact sheet resistance.

219 `rsh=0 Ω/sqr` Source/drain diffusion sheet resistance.

220 `rs=0 Ω` Source resistance.

221 `rd=0 Ω` Drain resistance.

222 `rsc=0 Ω` Source contact resistance.

223 `rdc=0 Ω` Drain contact resistance.

224 `rsw=50 Ω` Source resistance per width.

225 `rdw=50 Ω` Drain resistance per width.

226 `rswmin=0 Ω` Source resistance per width at high Vg.

227 `rdwmin=0 Ω` Drain resistance per width at high Vg.

228 `rss=0 Ω m` Scalable source resistance.

229 `rdd=0 Ω m` Scalable drain resistance.

230 `rhalo=1.0e15 Ω/sqr`
Body halo sheet resistance.

231 `frbody=1` Layout dependent body-resistance coefficient.

232 `minr=0.1 Ω` Minimum source/drain resistance.

233 `hdif=0 m` Length of heavily doped diffusion.

234 `ldif=0 m` Lateral diffusion beyond the gate.

Gate tunneling parameters

235 `ntox=1.0` Power term of gate current.

236 `toxqm=Tox m`	Effective oxide thickness considering quantum effects.
237 `toxref=2.5e-9 m`	Target oxide thickness.
238 `ebg=1.2 V`	Effective bandgap in gate current calculation.
239 `alphagb1=0.35`	First Vox dependent parameter for gate current in inversion.
240 `betagb1=0.03`	Second Vox dependent parameter for gate current in inversion.
241 `vgb1=300`	Third Vox dependent parameter for gate current in inversion.
242 `vevb=0.075`	Vaux parameter for valence-band electron tunneling.
243 `nevb=3.0`	Valence-band electron non-ideality factor.
244 `alphagb2=0.43`	First Vox dependent parameter for gate current in accumulation.
245 `betagb2=0.05`	Second Vox dependent parameter for gate current in accumulation.
246 `vgb2=17`	Third Vox dependent parameter for gate current in accumulation.
247 `vecb=0.026`	Vaux parameters for conduction-band electron tunneling.
248 `necb=1.0`	Conduction-band electron non-ideality factor.
249 `aigc=0.43`	Parameter for Igc.
250 `bigc=0.054`	Parameter for Igc.
251 `cigc=0.075 1/V`	Parameter for Igc.
252 `aigsd=0.43`	Parameter for Igs/Igd.
253 `bigsd=0.054`	Parameter for Igs/Igd.
254 `cigsd=0.075 1/V`	parameter for Igs/Igd.
255 `nigc=1.0`	Parameter for Igc slope.
256 `pigcd=1.0`	Parameter for Igc partition.

257 `poxedge=1.0` Factor for the gate edge Tox.

258 `dlcig=lint m` Delta Length for Ig model.

259 `voxh=5.0 V` Limit of Vox in gate current calculation.

260 `deltavox=0.005 V` Smoothing parameter in the Vox smoothing function.

261 `aigbcp2=0.043` First Vgp dependent parameter for gate current in accumulation in AGBCP2 region.

262 `bigbcp2=0.0054` Second Vgp dependent parameter for gate current in accumulation in AGBCP2 region.

263 `cigbcp2=0.0075` Third Vgp dependent parameter for gate current in accumulation in AGBCP2 region.

Overlap capacitance parameters

264 `cgso=0 F/m` Gate-source overlap capacitance.

265 `cgdo=0 F/m` Gate-drain overlap capacitance.

266 `cgeo=0 F/m` Gate-substrate overlap capacitance.

267 `cgbo=0 F/m` Gate-bulk overlap capacitance.

268 `cgsl=0 F/m` Gate-source overlap capacitance in LDD region.

269 `cgdl=0 F/m` Gate-drain overlap capacitance in LDD region.

270 `ckappa=0.6` Overlap capacitance fitting parameter.

Junction capacitance model parameters

271 `cjswg=1e-10` F/m^2 Zero-bias gate-side junction capacitance density.

272 `mjswg=0.5` Gate-side junction grading coefficient.

273 `pbswg=0.7 V` Gate-side junction built-in potential.

274 `cjswgd=cjswg F/m`^{2}

Drain (gate side) sidewall junction capacitance per unit width.

275 `mjswgd=mjswg V` Drain (gate side) sidewall junction capacitance grading coefficient.

276 `pbswgd=pbswg V` Drain (gate side) sidewall junction capacitance built in potential.

277 `tt=1e-12 s` Transit time.

278 `ndif=-1` Power coefficient of channel length dependency for diffusion capacitance.

279 `ldif0=1` Power coefficient of channel length dependency for diffusion capacitance.

280 `asd=0.3` Source/Drain diffusion smoothing parameter.

281 `vsdfb (F/m)` Source/Drain diffusion flatband voltage.

282 `vsdth` Source/Drain diffusion threshold voltage.

283 `csdmin (F)` Source/Drain diffusion bottom minimum capacitance.

284 `csdesw=0 F/m` Source/drain sidewall fringing constant.

Charge model selection parameters

285 `cf=0 F/m` Fringe capacitance parameter.

286 `cfrcoeff=1.0` Sidewall fringe capacitance parameter.

287 `clc=1e-8 m` Intrinsic capacitance fitting parameter.

288 `cle=0` Intrinsic capacitance fitting parameter.

289 `dlc=lint m` Delta L for capacitance model.

290 `dlcb=0 m` Length offset fitting parameter for body charge.

291 `dlbg=0 m` Length offset fitting parameter for backgate charge.

292 `dwc=wint m` Delta W for capacitance model.

293 `delvt=0 V`	Threshold voltage adjustment for C-V.
294 `fbody=1.0`	Scaling factor for body charge.
295 `voffcv=-0.08 V`	CV Threshold voltage offset.
296 `minvcv=0`	For moderate inversion in VgsteffCV.
297 `dtoxcv=0 m`	Delta oxide thickness in Capmod3.
298 `kb1=1`	Scaling factor for backgate charge.
299 `kb3=1`	Backgate coupling coefficient at subthreshold.
300 `xpart=0`	Drain/source channel charge partition in saturation for BSIM charge model, use 0.0 for 40/60, 0.5 for 50/50, or 1.0 for 0/100.
301 `vsce=0 V`	SCE parameter for improved dVbi model.
302 `cdsbs=0` F/m^2	coupling from Vd to Vbs for improved dVbi model.

RF model parameters

303 `rshg=0.1`	Gate sheet resistance.
304 `xrcrg1`	First fitting parameter the bias-dependent Rg.
305 `xrcrg2`	Second fitting parameter the bias-dependent Rg.
306 `ngcon`	Number of gate contact.
307 `xgw`	Distance from gate contact center to device edge.
308 `xgl`	Variation in Ldrawn.
309 `rbdb=50 Ω`	Resistance between bNode and dbNode.
310 `rbsb=50 Ω`	Resistance between bNode and sbNode.
311 `gbmin=1e-12 S`	Minimum body conductance.

Temperature effects parameters

312 `tnom=27.0 C` Parameters measurement temperature. Default set by `options`.

313 `trise=0 C` Temperature rise from ambient.

314 `tmax=500 C` Maximum device temperature above ambient.

315 `kt1=-0.11 V` Temperature coefficient for threshold voltage.

316 `kt1l=0 V m` Temperature coefficient for threshold voltage.

317 `kt2=0.022` Temperature coefficient for threshold voltage.

318 `at=3.3e4 m/s` Temperature coefficient for `vsat`.

319 `tcjswg=0 1/K` Temperature coefficient of Cjswg.

320 `tpbswg=0 V/K` Temperature coefficient of Pbswg.

321 `tcjswgd=tcjswg 1/K`
Temperature coefficient of Cjswgd.

322 `tpbswgd=tpbswg V/K`
Temperature coefficient of Pbswgd.

323 `ua1=4.31e-9 m/V` Temperature coefficient for `ua`.

324 `ub1=-7.61e-18` m^2/V^2
Temperature coefficient for `ub`.

325 `uc1=-5.5e-11` m/V^2
Temperature coefficient for `uc`. Default is -0.056 for mobmod=3.

326 `ucste=-4.775e-3 1/K`
Temperature coefficient of UCS.

327 `ud1=0` $/m^2/K$ Temperature coefficient of ud.

328 `prt=0 Ω` Temperature coefficient for Rds.

329 `ute=-1.5` Mobility temperature exponent.

330 `cth0=1e-5 w s/(m C)`
Self-heating thermal capacitance.

331 `rth0=0 (m C)/w` Self-heating thermal resistance.

332 `ntrecf=0` Temperature coefficient of Nrecf.

333 `ntrecr=0` Temperature coefficient of Nrecr.

334 `xbjt=1` BJT current temperature exponent.

335 `xdif=2` Diffusion current temperature exponent.

336 `xrec=1` Recombination current temperature exponent.

337 `xtun=0` Tunneling current temperature exponent.

338 `xdifd=xdif` Temperature coefficient for Iddif.

339 `xrecd=xrec` Temperature coefficient for Idrec.

340 `xtund=xtun` Temperature coefficient for Idtun.

341 `wth0=0 µm` Minimum width for thermal resistance calculation.

342 `tvbci=0 V/K` Temperature coefficient for vbci.

343 `trs=0 1/C` Temperature parameter for source resistance.

344 `trd=0 1/C` Temperature parameter for drain resistance.

Noise model parameters

345 `tnoia=1.5` Thermal noise parameter.

346 `tnoib=3.5` Thermal noise parameter.

347 `rnoia=0.577` Thermal noise coefficient.

348 `rnoib=0.37` Thermal noise coefficient.

349 `ntnoi=1.0` Thermal noise coefficient.

350 `noif=1`	Floating body excess noise ideality factor.
351 `w0flk=0 m`	Width constant for flicker noise equation.
352 `bf=2.0`	Flicker noise length dependence exponent.
353 `kf=0`	Flicker (1/f) noise coefficient.
354 `af=1`	Flicker (1/f) noise exponent.
355 `ef=1`	Flicker (1/f) noise frequency exponent.
356 `noia=1e20`	Oxide trap density coefficient. Default is 9.9e18 for pmos.
357 `noib=5e4`	Oxide trap density coefficient. Default is 2.4e3 for pmos.
358 `noic=-1.4e-12`	Oxide trap density coefficient. Default is 1.4e-8 for pmos.
359 `em=4.1e7 V/m`	Maximum electric field.

Stress model parameters

360 `saref=1e-6 m`	Reference distance between OD edge to poly of one side.
361 `sbref=1e-6 m`	Reference distance between OD edge to poly of the other side.
362 `wlod=0 m`	Width parameter for stress effect.
363 `ku0=0 m`	Mobility degradation/enhancement coefficient for LOD.
364 `tku0=0`	Temperature coefficient of KU0.
365 `llodku0=0`	Length parameter for u0 LOD effect.
366 `wlodku0=0`	Width parameter for u0 LOD effect.
367 `kvth0=0 V m`	Threshold degradation/enhancement parameter for LOD.
368 `llodvth=0`	Length parameter for vth LOD effect.
369 `wlodvth=0`	Width parameter for vth LOD effect.

370 `kvsat=0 m` Saturation velocity degradation/enhancement parameter for LOD.

371 `stk2=0 m` K2 shift factor related to stress effect on vth.

372 `lodk2=1.0` K2 shift modification factor for stress effect.

373 `steta0=0 m` eta0 shift factor related to stress effect on vth.

374 `lodeta0=1.0` eta0 shift modification factor for stress effect.

Default instance parameters

375 `w=5e-6 m` Default channel width.

376 `l=5e-6 m` Default channel length.

377 `as=0` m^2 Default area of source diffusion.

378 `ad=0` m^2 Default area of drain diffusion.

379 `ps=0 m` Default perimeter of source diffusion.

380 `pd=0 m` Default perimeter of drain diffusion.

381 `nrd=1 m/m` Default number of squares of drain diffusion.

382 `nrs=1 m/m` Default number of squares of source diffusion.

383 `nrb=1 m/m` Default body squares.

384 `paramchk=1` Model parameter checking selector.

Auto Model Selector parameters

385 `wmax=1 m` Maximum channel width for which the model is valid.

386 `wmin=0 m` Minimum channel width for which the model is valid.

387 `lmax=1 m` Maximum channel length for which the model is valid.

388 `lmin=0 m` Minimum channel length for which the model is valid.

Compatibility model parameters

389 `compatible=spectre`
Encourage device equations to be compatible with a foreign simulator. This option does not affect input syntax.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, and `mica`.

Junction diode model parameters

390 `dskip=yes` Use simple piece-wise linear model for diode currents below 0.1*`iabstol`.
Possible values are `no` and `yes`.

Operating region warning control parameters

391 `alarm=none` Forbidden operating region.
Possible values are `none`, `off`, `triode`, `sat`, `subth`, and `rev`.

392 `imax=1 A` Maximum allowable current.

393 `bvj=infinity V` Junction reverse breakdown voltage.

394 `vbox=1e9 tox V` Oxide breakdown voltage.

395 `warn=on` Parameter to turn warnings on and off.
Possible values are `off` and `on`.

DC-mismatch dependent parameters

396 `mismatchmod=0` select Mismatch mode.

397 `mismatchdist=0 m` Mismatch Distance.

398 `mvtwl=0 V m` Threshold mismatch area dependence.

399 `mvtwl2=0 V m^1.5` Threshold mismatch area square dependence.

400 `mvt0=0 V` Threshold mismatch intercept.

401 `mbewl=0 m` Beta mismatch area dependence.

402 `mbe0=0` Beta mismatch intercept.

Length dependent parameters

403 `lnch=0` Length dependence of nch.

404 `lnsub=0` Length dependence of nsub.

405 `lngate=0` Length dependence of ngate.

406 `lvtho=0` Length dependence of vtho.

407 `lk1=0` Length dependence of k1.

408 `lk1w1=0` Length dependence of k1w1.

409 `lk1w2=0` Length dependence of k1w2.

410 `lk2=0` Length dependence of k2.

411 `lk3=0` Length dependence of k3.

412 `lk3b=0` Length dependence of k3b.

413 `lkb1=0` Length dependence of kb1.

414 `lw0=0` Length dependence of w0.

415 `lnlx=0` Length dependence of nlx.

416 `ldvt0=0` Length dependence of dvt0.

417 `ldvt1=0` Length dependence of dvt1.

418 `ldvt2=0` Length dependence of dvt2.

419 `ldvt0w=0` Length dependence of dvt0w.

420 `ldvt1w=0` Length dependence of dvt1w.

421 `ldvt2w=0` Length dependence of dvt2w.

422 `lu0=0` Length dependence of u0.

423 `lua=0` Length dependence of ua.

424 `lub=0` Length dependence of ub.

425 `luc=0` Length dependence of uc.

426 `lvsat=0` Length dependence of vsat.

427 `la0=0` Length dependence of a0.

428 `lags=0` Length dependence of ags.

429 `lb0=0` Length dependence of b0.

430 `lb1=0` Length dependence of b1.

431 `lketa=0` Length dependence of keta.

432 `lketas=0` Length dependence of ketas.

433 `la1=0` Length dependence of a1.

434 `la2=0` Length dependence of a2.

435 `lrdsw=0` Length dependence of rdsw.

436 `lprwb=0` Length dependence of prwb.

437 `lprwg=0` Length dependence of prwg.

438 `lwr=0` Length dependence of wr.

439 `lnfactor=0` Length dependence of nfactor.

440 `ldwg=0` Length dependence of dwg.

441 `ldwb=0` Length dependence of dwb.

442 `lvoff=0` Length dependence of voff.

443 `leta0=0` Length dependence of eta0.

444 `letab=0` Length dependence of etab.

445 `ldsub=0`	Length dependence of dsub.
446 `lcit=0`	Length dependence of cit.
447 `lcdsc=0`	Length dependence of cdsc.
448 `lcdscb=0`	Length dependence of cdscb.
449 `lcdscd=0`	Length dependence of cdscd.
450 `lpclm=0`	Length dependence of pclm.
451 `lpdiblc1=0`	Length dependence of pdiblc1.
452 `lpdiblc2=0`	Length dependence of pdiblc2.
453 `lpdiblcb=0`	Length dependence of pdiblcb.
454 `ldrout=0`	Length dependence of drout.
455 `lpvag=0`	Length dependence of pvag.
456 `ldelta=0`	Length dependence of delta.
457 `lalpha0=0`	Length dependence of alpha0.
458 `lfbjtii=0`	Length dependence of fbjtii.
459 `lbeta0=0`	Length dependence of beta0.
460 `lbeta1=0`	Length dependence of beta1.
461 `lbeta2=0`	Length dependence of beta2.
462 `lvdsatii0=0`	Length dependence of vdstaii0.
463 `llii=0`	Length dependence of lii.
464 `lesatii=0`	Length dependence of esatii.
465 `lsii0=0`	Length dependence of sii0.
466 `lsii1=0`	Length dependence of sii1.

467 `lsii2=0` Length dependence of sii2.

468 `lsiid=0` Length dependence of siid.

469 `lagidl=0` Length dependence of agidl.

470 `lbgidl=0` Length dependence of bgidl.

471 `lngidl=0` Length dependence of ngidl.

472 `lntun=0` Length dependence of ntun.

473 `lndiode=0` Length dependence of ndoide.

474 `lnrecf0=0` Length dependence of nrecf0.

475 `lnrecr0=0` Length dependence of nrecr0.

476 `lisbjt=0` Length dependence of isbjt.

477 `lisdif=0` Length dependence of isdif.

478 `lisrec=0` Length dependence of isrec.

479 `listun=0` Length dependence of istun.

480 `lvrec0=0` Length dependence of vrec0.

481 `lvtun0=0` Length dependence of vtun0.

482 `lnbjt=0` Length dependence of nbjt.

483 `llbjt0=0` Length dependence of lbjt0.

484 `lvabjt=0` Length dependence of vabjt.

485 `laely=0` Length dependence of aely.

486 `lahli=0` Length dependence of ahli.

487 `lxrcrg1=0` Length dependence of xrcrg1.

488 `lxrcrg2=0` Length dependence of xrcrg2.

489 `lvsdfb=0`	Length dependence of vsdfb.
490 `lvsdth=0`	Length dependence of vsdth.
491 `ldelvt=0`	Length dependence of delvt.
492 `lacde=0`	Length dependence of acde.
493 `lmoin=0`	Length dependence of moin.
494 `laigc=0`	Length dependence of aigc.
495 `lbigc=0`	Length dependence of bigc.
496 `lcigc=0`	Length dependence of cigc.
497 `laigsd=0`	Length dependence of aigsd.
498 `lbigsd=0`	Length dependence of bigsd.
499 `lcigsd=0`	Length dependence of cigsd.
500 `lnigc=0`	Length dependence of nigc.
501 `lpigcd=0`	Length dependence of pigcd.
502 `lpoxedge=0`	Length dependence of poxedge.
503 `lxj=0`	Length dependence of xj.
504 `lalphagb1=0`	Length dependence of alphagb1.
505 `lalphagb2=0`	Length dependence of alphagb2.
506 `lbetagb1=0`	Length dependence of betagb1.
507 `lbetagb2=0`	Length dependence of betagb2.
508 `lcgsl=0`	Length dependence of cgsl.
509 `lcgdl=0`	Length dependence of cgdl.
510 `lckappa=0`	Length dependence of ckappa.

511 `lndif=0`	Length dependence of ndif.
512 `lute=0`	Length dependence of ute.
513 `lkt1=0`	Length dependence of kt1.
514 `lkt1l=0`	Length dependence of kt1l.
515 `lkt2=0`	Length dependence of kt2.
516 `lua1=0`	Length dependence of ua1.
517 `lub1=0`	Length dependence of ub1.
518 `luc1=0`	Length dependence of uc1.
519 `lat=0`	Length dependence of at.
520 `lprt=0`	Length dependence of prt.
521 `lntrecf=0`	Length dependence of ntrecf.
522 `lntrecr=0`	Length dependence of ntrecr.
523 `lxbjt=0`	Length dependence of xbjt.
524 `lxdif=0`	Length dependence of xdif.
525 `lxrec=0`	Length dependence of xrec.
526 `lxtun=0`	Length dependence of xtun.
527 `lxdifd=0`	Length dependence of xdifd.
528 `lxrecd=0`	Length dependence of xrecd.
529 `lxtund=0`	Length dependence of xtund.
530 `llpe0=0`	Length dependence of lpe0.
531 `llpeb=0`	Length dependence of lpeb.
532 `lrsw=0`	Length dependence of Rsw.

533 `lrdw=0`	Length dependence of Rdw.
534 `lcgidl=0`	Length dependence of cgidl.
535 `legidl=0`	Length dependence of egidl.
536 `lntund=0`	Length dependence of ntund.
537 `lndioded=0`	Length dependence of ndioded.
538 `lnrecf0d=0`	Length dependence of nrecf0d.
539 `lnrecr0d=0`	Length dependence of nrecr0d.
540 `lidbjt=0`	Length dependence of idbjt.
541 `liddif=0`	Length dependence of iddif.
542 `lidrec=0`	Length dependence of idrec.
543 `lidtun=0`	Length dependence of idtun.
544 `lvrec0d=0`	Length dependence of vrec0d.
545 `lvtun0d=0`	Length dependence of vtun0d.
546 `lahlid=0`	Length dependence of lahlid.
547 `lnoff=0`	Length dependence of noff.
548 `ldvtp0=0`	Length dependence of dvtp0.
549 `ldvtp1=0`	Length dependence of dvtp1.
550 `lminv=0`	Length dependence of minv.
551 `lfprout=0`	Length dependence of pdiblcb.
552 `lpdits=0`	Length dependence of pdits.
553 `lpditsd=0`	Length dependence of pditsd.
554 `lku0=0`	Length dependence of ku0.

555 `lkvth0=0`	Length dependence of kvth0.
556 `lvoffcv=0`	Length dependence of voffcv.
557 `lminvcv=0`	Length dependence of minvcv.
558 `lud=0`	Length dependence of ud.
559 `lud1=0`	Length dependence of ud1.
560 `lebjtii=0`	Length dependence of ebjtii.
561 `lcbjtii=0`	Length dependence of cbjtii.
562 `labjtii=0`	Length dependence of abjtii.
563 `lmbjtii=0`	Length dependence of mbjtii.
564 `lvbci=0`	Length dependence of vbci.
565 `ldvtp2=0`	Length dependence of dvtp2.
566 `ldvtp3=0`	Length dependence of dvtp3.
567 `ldvtp4=0`	Length dependence of dvtp4.
568 `laigbcp2=0`	Length dependence of aigbcp2.
569 `lbigbcp2=0`	Length dependence of bigbcp2.
570 `lcigbcp2=0`	Length dependence of cigbcp2.
571 `lnsd=0`	Length dependence of nsd.
572 `lvfb=0`	Length dependence of vfb.
573 `leu=0`	Length dependence of eu.
574 `lucs=0`	Length dependence of ucs.
575 `lucste=0`	Length dependence of ucste.
576 `legisl=0`	Length dependence of egisl.

577 `lagisl=0` Length dependence of agisl.

578 `lbgisl=0` Length dependence of bgisl.

579 `lcgisl=0` Length dependence of cgisl.

580 `lrgidl=0` Length dependence of rgidl.

581 `lkgidl=0` Length dependence of kgidl.

582 `lfgidl=0` Length dependence of fgidl.

583 `lrgisl=0` Length dependence of rgisl.

584 `lkgisl=0` Length dependence of kgisl.

585 `lfgisl=0` Length dependence of fgisl.

Width dependent parameters

586 `wnch=0` Width dependence of nch.

587 `wnsub=0` Width dependence of nsub.

588 `wngate=0` Width dependence of ngate.

589 `wvtho=0` Width dependence of vto.

590 `wk1=0` Width dependence of k1.

591 `wk1w1=0` Width dependence of k1w1.

592 `wk1w2=0` Width dependence of k1w2.

593 `wk2=0` Width dependence of k2.

594 `wk3=0` Width dependence of k3.

595 `wk3b=0` Width dependence of k3b.

596 `wkb1=0` Width dependence of kb1.

597 `ww0=0` Width dependence of w0.

598 `wnlx=0` Width dependence of nlx.

599 `wdvt0=0` Width dependence of dvt0.

600 `wdvt1=0` Width dependence of dvt1.

601 `wdvt2=0` Width dependence of dvt2.

602 `wdvt0w=0` Width dependence of dvt0w.

603 `wdvt1w=0` Width dependence of dvt1w.

604 `wdvt2w=0` Width dependence of dvt2w.

605 `wu0=0` Width dependence of u0.

606 `wua=0` Width dependence of ua.

607 `wub=0` Width dependence of ub.

608 `wuc=0` Width dependence of uc.

609 `wvsat=0` Width dependence of vsat.

610 `wa0=0` Width dependence of a0.

611 `wags=0` Width dependence of ags.

612 `wb0=0` Width dependence of b0.

613 `wb1=0` Width dependence of b1.

614 `wketa=0` Width dependence of keta.

615 `wketas=0` Width dependence of ketas.

616 `wa1=0` Width dependence of a1.

617 `wa2=0` Width dependence of a2.

618 `wrdsw=0` Width dependence of rdsw.

619 `wprwb=0` Width dependence of prwb.

620 `wprwg=0` Width dependence of prwg.

621 `wwr=0` Width dependence of wr.

622 `wnfactor=0` Width dependence of nfactor.

623 `wdwg=0` Width dependence of dwg.

624 `wdwb=0` Width dependence of dwb.

625 `wvoff=0` Width dependence of voff.

626 `weta0=0` Width dependence of eta0.

627 `wetab=0` Width dependence of etab.

628 `wdsub=0` Width dependence of dsub.

629 `wcit=0` Width dependence of cit.

630 `wcdsc=0` Width dependence of cdsc.

631 `wcdscb=0` Width dependence of cdscb.

632 `wcdscd=0` Width dependence of cdscd.

633 `wpclm=0` Width dependence of pclm.

634 `wpdiblc1=0` Width dependence of pdiblc1.

635 `wpdiblc2=0` Width dependence of pdiblc2.

636 `wpdiblcb=0` Width dependence of pdiblcb.

637 `wdrout=0` Width dependence of drout.

638 `wpvag=0` Width dependence of pvag.

639 `wdelta=0` Width dependence of delta.

640 `walpha0=0` Width dependence of alpha0.

641 `wfbjtii=0` Width dependence of fbjtii.

642 `wbeta0=0` Width dependence of beta0.

643 `wbeta1=0` Width dependence of beta1.

644 `wbeta2=0` Width dependence of beta2.

645 `wvdsatii0=0` Width dependence of vdsatii0.

646 `wlii=0` Width dependence of lii.

647 `wesatii=0` Width dependence of esatii.

648 `wsii0=0` Width dependence of sii0.

649 `wsii1=0` Width dependence of sii1.

650 `wsii2=0` Width dependence of sii2.

651 `wsiid=0` Width dependence of siid.

652 `wagidl=0` Width dependence of agidl.

653 `wbgidl=0` Width dependence of bgidl.

654 `wngidl=0` Width dependence of ngidl.

655 `wntun=0` Width dependence of wntun.

656 `wndiode=0` Width dependence of ndiode.

657 `wnrecf0=0` Width dependence of nrecf0.

658 `wnrecr0=0` Width dependence of nrecr0.

659 `wisbjt=0` Width dependence of isbjt.

660 `wisdif=0` Width dependence of isdif.

661 `wisrec=0` Width dependence of isrec.

662 `wistun=0` Width dependence of istun.

663 `wvrec0=0` Width dependence of vrec0.

664 `wvtun0=0`	Width dependence of vtun0.
665 `wnbjt=0`	Width dependence of nbjt.
666 `wlbjt0=0`	Width dependence of lbjt0.
667 `wvabjt=0`	Width dependence of vabjt.
668 `waely=0`	Width dependence of aely.
669 `wahli=0`	Width dependence of ahli.
670 `wxrcrg1=0`	Width dependence of xrcrg1.
671 `wxrcrg2=0`	Width dependence of xrcrg2.
672 `wvsdfb=0`	Width dependence of vsdfb.
673 `wvsdth=0`	Width dependence of vsdth.
674 `wdelvt=0`	Width dependence of delvt.
675 `wacde=0`	Width dependence of acde.
676 `wmoin=0`	Width dependence of moin.
677 `waigc=0`	Width dependence of aigc.
678 `wbigc=0`	Width dependence of bigc.
679 `wcigc=0`	Width dependence of cigc.
680 `waigsd=0`	Width dependence of aigsd.
681 `wbigsd=0`	Width dependence of bigsd.
682 `wcigsd=0`	Width dependence of cigsd.
683 `wnigc=0`	Width dependence of nigc.
684 `wpigcd=0`	Width dependence of pigcd.
685 `wpoxedge=0`	Width dependence of poxedge.

686 `wxj=0` Width dependence of xj.

687 `walphagb1=0` Width dependence of alphagb1.

688 `walphagb2=0` Width dependence of alpagb2.

689 `wbetagb1=0` Width dependence of betagb1.

690 `wbetagb2=0` Width dependence of betabg2.

691 `wcgsl=0` Width dependence of cgsl.

692 `wcgdl=0` Width dependence of cgdl.

693 `wckappa=0` Width dependence of ckappa.

694 `wndif=0` Width dependence of ndif.

695 `wute=0` Width dependence of ute.

696 `wkt1=0` Width dependence of kt1.

697 `wkt1l=0` Width dependence of kt1l.

698 `wkt2=0` Width dependence of kt2.

699 `wua1=0` Width dependence of ua1.

700 `wub1=0` Width dependence of ub1.

701 `wuc1=0` Width dependence of uc1.

702 `wat=0` Width dependence of at.

703 `wprt=0` Width dependence of prt.

704 `wntrecf=0` Width dependence of ntrecf.

705 `wntrecr=0` Width dependence of ntrecr.

706 `wxbjt=0` Width dependence of xbjt.

707 `wxdif=0` Width dependence of xdif.

708 `wxrec=0` Width dependence of xrec.

709 `wxdifd=0` Width dependence of xdifd.

710 `wxrecd=0` Width dependence of xrecd.

711 `wxtund=0` Width dependence of xtund.

712 `wlpe0=0` Width dependence of lpe0.

713 `wlpeb=0` Width dependence of lpeb.

714 `wrsw=0` Width dependence of rsw.

715 `wrdw=0` Width dependence of rdw.

716 `wcgidl=0` Width dependence of Cgidl.

717 `wegidl=0` Width dependence of Egidl.

718 `wntund=0` Width dependence of ntund.

719 `wndioded=0` Width dependence of ndioded.

720 `wnrecf0d=0` Width dependence of nrecf0d.

721 `wnrecr0d=0` Width dependence of nrecr0d.

722 `widbjt=0` Width dependence of Idbjt.

723 `widdif=0` Width dependence of iddif.

724 `widrec=0` Width dependence of idrec.

725 `widtun=0` Width dependence of idtun.

726 `wvrec0d=0` Width dependence of Vrec0d.

727 `wvtun0d=0` Width dependence of Vtun0d.

728 `wahlid=0` Width dependence of Ahlid.

729 `wxtun=0` Width dependence of xtun.

730 `wnoff=0` Width dependence of noff.

731 `wdvtp0=0` Width dependence of dvtp0.

732 `wdvtp1=0` Width dependence of dvtp1.

733 `wminv=0` width dependence of minv.

734 `wfprout=0` Width dependence of pdiblcb.

735 `wpdits=0` Width dependence of pdits.

736 `wpditsd=0` Width dependence of pditsd.

737 `wku0=0` Width dependence of ku0.

738 `wkvth0=0` Width dependence of kvth0.

739 `wvoffcv=0` Width dependence of voffcv.

740 `wminvcv=0` Width dependence of minvcv.

741 `wud=0` Width dependence of ud.

742 `wud1=0` Width dependence of ud1.

743 `webjtii=0` Width dependence of ebjtii.

744 `wcbjtii=0` Width dependence of cbjtii.

745 `wabjtii=0` Width dependence of abjtii.

746 `wmbjtii=0` Width dependence of mbjtii.

747 `wvbci=0` Width dependence of vbci.

748 `wdvtp2=0` Width dependence of dvtp2.

749 `wdvtp3=0` Width dependence of dvtp3.

750 `wdvtp4=0` Width dependence of dvtp4.

751 `waigbcp2=0` Width dependence of aigbcp2.

752 `wbigbcp2=0` Width dependence of bigbcp2.

753 `wcigbcp2=0` Width dependence of cigbcp2.

754 `wnsd=0` Width dependence of nsd.

755 `wvfb=0` Width dependence of vfb.

756 `weu=0` Width dependence of eu.

757 `wucs=0` Width dependence of ucs.

758 `wucste=0` Width dependence of ucste.

759 `wegisl=0` Width dependence of egisl.

760 `wagisl=0` Width dependence of agisl.

761 `wbgisl=0` Width dependence of bgisl.

762 `wcgisl=0` Width dependence of cgisl.

763 `wrgidl=0` Width dependence of rgidl.

764 `wkgidl=0` Width dependence of kgidl.

765 `wfgidl=0` Width dependence of fgidl.

766 `wrgisl=0` Width dependence of rgisl.

767 `wkgisl=0` Width dependence of kgisl.

768 `wfgisl=0` Width dependence of fgisl.

Cross-term dependent parameters

769 `pnch=0` Cross-term dependence of nch.

770 `pnsub=0` Cross-term dependence of nsub.

771 `pngate=0` Cross-term dependence of ngate.

772 `pvtho=0` Cross-term dependence of vto.

773 `pk1=0` Cross-term dependence of k1.

774 `pk1w1=0` Cross-term dependence of k1w1.

775 `pk1w2=0` Cross-term dependence of k1w2.

776 `pk2=0` Cross-term dependence of k2.

777 `pk3=0` Cross-term dependence of k3.

778 `pk3b=0` Cross-term dependence of k3b.

779 `pkb1=0` Cross-term dependence of kb1.

780 `pw0=0` Cross-term dependence of w0.

781 `pnlx=0` Cross-term dependence of nlx.

782 `pdvt0=0` Cross-term dependence of dvt0.

783 `pdvt1=0` Cross-term dependence of dvt1.

784 `pdvt2=0` Cross-term dependence of dvt2.

785 `pdvt0w=0` Cross-term dependence of dvt0w.

786 `pdvt1w=0` Cross-term dependence of dvt1w.

787 `pdvt2w=0` Cross-term dependence of dvt2w.

788 `pu0=0` Cross-term dependence of u0.

789 `pua=0` Cross-term dependence of ua.

790 `pub=0` Cross-term dependence of ub.

791 `puc=0` Cross-term dependence of uc.

792 `pvsat=0` Cross-term dependence of vsat.

793 `pa0=0` Cross-term dependence of a0.

794 `pags=0` Cross-term dependence of ags.

795 `pb0=0` Cross-term dependence of b0.

796 `pb1=0` Cross-term dependence of b1.

797 `pketa=0` Cross-term dependence of keta.

798 `pketas=0` Cross-term dependence of ketas.

799 `pa1=0` Cross-term dependence of a1.

800 `pa2=0` Cross-term dependence of a2.

801 `prdsw=0` Cross-term dependence of rdsw.

802 `pprwb=0` Cross-term dependence of prwb.

803 `pprwg=0` Cross-term dependence of prwg.

804 `pwr=0` Cross-term dependence of wr.

805 `pnfactor=0` Cross-term dependence of nfactor.

806 `pdwg=0` Cross-term dependence of dwg.

807 `pdwb=0` Cross-term dependence of dwb.

808 `pvoff=0` Cross-term dependence of voff.

809 `peta0=0` Cross-term dependence of eta0.

810 `petab=0` Cross-term dependence of etab.

811 `pdsub=0` Cross-term dependence of dsub.

812 `pcit=0` Cross-term dependence of cit.

813 `pcdsc=0` Cross-term dependence of cdsc.

814 `pcdscb=0` Cross-term dependence of cdscb.

815 `pcdscd=0` Cross-term dependence of cdscd.

816 `ppclm=0` Cross-term dependence of pclm.

817 `ppdiblc1=0` Cross-term dependence of pdiblc1.

818 `ppdiblc2=0` Cross-term dependence of pdiblc2.

819 `ppdiblcb=0` Cross-term dependence of pdiblcb.

820 `pdrout=0` Cross-term dependence of drout.

821 `ppvag=0` Cross-term dependence of pvag.

822 `pdelta=0` Cross-term dependence of delta.

823 `palpha0=0` Cross-term dependence of alpha0.

824 `pfbjtii=0` Cross-term dependence of fbjtii.

825 `pbeta0=0` Cross-term dependence of beta0.

826 `pbeta1=0` Cross-term dependence of beta1.

827 `pbeta2=0` Cross-term dependence of beta2.

828 `pvdsatii0=0` Cross-term dependence of vdsatii0.

829 `plii=0` Cross-term dependence of lii.

830 `pesatii=0` Cross-term dependence of esatii.

831 `psii0=0` Cross-term dependence of sii0.

832 `psii1=0` Cross-term dependence of sii1.

833 `psii2=0` Cross-term dependence of sii2.

834 `psiid=0` Cross-term dependence of siid.

835 `pagidl=0` Cross-term dependence of agidl.

836 `pbgidl=0` Cross-term dependence of bgidl.

837 `pngidl=0` Cross-term dependence of ngidl.

838 `pntun=0` Cross-term dependence of ntun.

839 `pndiode=0`	Cross-term dependence of ndiode.
840 `pnrecf0=0`	Cross-term dependence of nrecf0.
841 `pnrecr0=0`	Cross-term dependence of nrecr0.
842 `pisbjt=0`	Cross-term dependence of isbjt.
843 `pisdif=0`	Cross-term dependence of isdif.
844 `pisrec=0`	Cross-term dependence of isrec.
845 `pistun=0`	Cross-term dependence of istun.
846 `pvrec0=0`	Cross-term dependence of vrec0.
847 `pvtun0=0`	Cross-term dependence of vtun0.
848 `pnbjt=0`	Cross-term dependence of nbjt.
849 `plbjt0=0`	Cross-term dependence of lbjt0.
850 `pvabjt=0`	Cross-term dependence of vabjt.
851 `paely=0`	Cross-term dependence of aely.
852 `pahli=0`	Cross-term dependence of ahli.
853 `pxrcrg1=0`	Cross-term dependence of xrcrg1.
854 `pxrcrg2=0`	Cross-term dependence of xrcrg2.
855 `pvsdfb=0`	Cross-term dependence of vsdfb.
856 `pvsdth=0`	Cross-term dependence of vsdth.
857 `pdelvt=0`	Cross-term dependence of delvt.
858 `pacde=0`	Cross-term dependence of acde.
859 `pmoin=0`	Cross-term dependence of moin.
860 `paigc=0`	Cross-term dependence of aigc.

861 `pbigc=0` Cross-term dependence of bigc.

862 `pcigc=0` Cross-term dependence of cigc.

863 `paigsd=0` Cross-term dependence of aigsd.

864 `pbigsd=0` Cross-term dependence of bigsd.

865 `pcigsd=0` Cross-term dependence of cigsd.

866 `pnigc=0` Cross-term dependence of nigc.

867 `ppigcd=0` Cross-term dependence of pigcd.

868 `ppoxedge=0` Cross-term dependence of poxedge.

869 `pxj=0` Cross-term dependence of xj.

870 `palphagb1=0` Cross-term dependence of alphagb1.

871 `palphagb2=0` Cross-term dependence of alphagb2.

872 `pbetagb1=0` Cross-term dependence of betagb1.

873 `pbetagb2=0` Cross-term dependence of betagb2.

874 `pcgsl=0` Cross-term dependence of cgsl.

875 `pcgdl=0` Cross-term dependence of cgdl.

876 `pckappa=0` Cross-term dependence of ckappa.

877 `pndif=0` Cross-term dependence of ndif.

878 `pute=0` Cross-term dependence of ute.

879 `pkt1=0` Cross-term dependence of kt1.

880 `pkt1l=0` Cross-term dependence of kt1l.

881 `pkt2=0` Cross-term dependence of kt2.

882 `pua1=0` Cross-term dependence of ua1.

883 `pub1=0`	Cross-term dependence of ub1.
884 `puc1=0`	Cross-term dependence of uc1.
885 `pat=0`	Cross-term dependence of at.
886 `pprt=0`	Cross-term dependence of prt.
887 `pntrecf=0`	Cross-term dependence of ntrecf.
888 `pntrecr=0`	Cross-term dependence of ntrecr.
889 `pxbjt=0`	Cross-term dependence of xbjt.
890 `pxdif=0`	Cross-term dependence of xdif.
891 `pxrec=0`	Cross-term dependence of xrec.
892 `pxtun=0`	Cross-term dependence of xtun.
893 `pxdifd=0`	Cross-term dependence of xdifd.
894 `pxrecd=0`	Cross-term dependence of xrecd.
895 `pxtund=0`	Cross-term dependence of xtund.
896 `plpe0=0`	Cross-term dependence of lpe0.
897 `plpeb=0`	Cross-term dependence of lpeb.
898 `prsw=0`	Cross-term dependence of rsw.
899 `prdw=0`	Cross-term dependence of rdw.
900 `pcgidl=0`	Cross-term dependence of cgidl.
901 `pegidl=0`	Cross-term dependence of egidl.
902 `pntund=0`	Cross-term dependence of ntund.
903 `pndioded=0`	Cross-term dependence of ndioded.
904 `pnrecf0d=0`	Cross-term dependence of nrecf0d.

905 `pnrecr0d=0`	Cross-term dependence of nrecr0d.
906 `pidbjt=0`	Cross-term dependence of Idbjt.
907 `piddif=0`	Cross-term dependence of Iddif.
908 `pidrec=0`	Cross-term dependence of Idrec.
909 `pidtun=0`	Cross-term dependence of idtun.
910 `pvrec0d=0`	Cross-term dependence of vrec0d.
911 `pvtun0d=0`	Cross-term dependence of vtun0d.
912 `pahlid=0`	Cross-term dependence of ahlid.
913 `pnoff=0`	Cross-term dependence of noff.
914 `pdvtp0=0`	Cross-term dependence of dvtp0.
915 `pdvtp1=0`	Cross-term dependence of dvtp1.
916 `pminv=0`	Cross-term dependence of minv.
917 `pfprout=0`	Cross-term dependence of pdiblcb.
918 `ppdits=0`	Cross-term dependence of pdits.
919 `ppditsd=0`	Cross-term dependence of pditsd.
920 `pku0=0`	Cross-term dependence of ku0.
921 `pkvth0=0`	Cross-term dependence of kvth0.
922 `pvoffcv=0`	Cross-term dependence of voffcv.
923 `pminvcv=0`	Cross-term dependence of minvcv.
924 `pud=0`	Cross-term dependence of ud.
925 `pud1=0`	Cross-term dependence of ud1.
926 `pebjtii=0`	Cross-term dependence of ebjtii.

927 `pcbjtii=0` Cross-term dependence of cbjtii.

928 `pabjtii=0` Cross-term dependence of abjtii.

929 `pmbjtii=0` Cross-term dependence of mbjtii.

930 `pvbci=0` Cross-term dependence of vbci.

931 `pdvtp2=0` Cross-term dependence of dvtp2.

932 `pdvtp3=0` Cross-term dependence of dvtp3.

933 `pdvtp4=0` Cross-term dependence of dvtp4.

934 `paigbcp2=0` Cross-term dependence of aigbcp2.

935 `pbigbcp2=0` Cross-term dependence of bigbcp2.

936 `pcigbcp2=0` Cross-term dependence of cigbcp2.

937 `pnsd=0` Cross-term dependence of nsd.

938 `pvfb=0` Cross-term dependence of vfb.

939 `peu=0` Cross-term dependence of eu.

940 `pucs=0` Cross-term dependence of ucs.

941 `pucste=0` Cross-term dependence of ucste.

942 `pegisl=0` Cross-term dependence of egisl.

943 `pagisl=0` Cross-term dependence of agisl.

944 `pbgisl=0` Cross-term dependence of bgisl.

945 `pcgisl=0` Cross-term dependence of cgisl.

946 `prgidl=0` Cross-term dependence of rgidl.

947 `pkgidl=0` Cross-term dependence of kgidl.

948 `pfgidl=0` Cross-term dependence of fgidl.

949 `prgisl=0` Cross-term dependence of rgisl.

950 `pkgisl=0` Cross-term dependence of kgisl.

951 `pfgisl=0` Cross-term dependence of fgisl.

952 `eta0cv=0.08` Subthreshold region DIBL coefficient for C-V.

953 `etabcv=(-0.07)` Subthreshold region DIBL coefficient for C-V.

954 `steta0cv=0.0` eta0cv shift factor related to stress effect on vth.

955 `lodeta0cv=1.0` eta0cv shift modification factor for stress effect.

956 `leta0cv=0.0` Length dependence of eta0cv.

957 `letabcv=0.0` Length dependence of etabcv.

958 `weta0cv=0.0` Width dependence of eta0cv.

959 `wetabcv=0.0` Width dependence of etabcv.

960 `peta0cv=0.0` Cross-term dependence of eta0cv.

961 `petabcv=0.0` Cross-term dependence of etabcv.

962 `tnoic=3.5` Length dependent parameter for Correlation Coefficient.

963 `rnoic=0.395` Correlation Coefficient parameter.

964 `scalen=1e5` scale factor for correlated noise.

965 `eggbcp2=1.12` Bandgap in Agbcp2 region.

966 `eggdep=1.12` Bandgap for gate depletion effect.

967 `agb1=3.7622e-7` 'A' for Igb1 Tunneling current model.

968 `bgb1=(-3.1051e10)`
'B' for Igb1 Tunneling current model.

969 `agb2=4.9758e-7` 'A' for Igb2 Tunneling current model.

970 `bgb2=(-2.357e10)` 'B' for Igb2 Tunneling current model.

971 `agbc2n=3.4254e-7` NMOS 'A' for tunneling current model.

972 `agbc2p=4.9723e-7` PMOS 'A' for tunneling current model.

973 `bgbc2n=1.1665e12` NMOS 'B' for tunneling current model.

974 `bgbc2p=7.4567e11` PMOS 'B' for tunneling current model.

975 `vtm00=0.026` Thermal voltage at 25 degC.

Auto Model Selection

Many models need to be characterized for different geometries in order to obtain accurate results for model development. The model selector program automatically searches for a model with the length and width range specified in the instance statement and uses this model in the simulations.

For the auto model selector program to find a specific model, the models to be searched should be grouped together within braces. Such a group is called a model group. An opening brace is required at the end of the line defining each model group. Every model in the group is given a name followed by a colon and the list of parameters. Also, the four geometric parameters `lmax`, `lmin`, `wmax`, and `wmin` should be given. The selection criteria to choose a model is as follows:

```
lmin <= inst_length < lmax  and   wmin <= inst_width  < wmax
```

Example:

model ModelName ModelType {

1: <model parameters> lmin=2 lmax=4 wmin=1 wmax=2

2: <model parameters> lmin=1 lmax=2 wmin=2 wmax=4

3: <model parameters> lmin=2 lmax=4 wmin=4 wmax=6

}

Then for a given instance

M1 1 2 3 4 ModelName w=3 l=1.5

the program would search all the models in the model group with the name `ModelName` and then pick the first model whose geometric range satisfies the selection criteria. In the preceding example, the auto model selector program would choose ModelName.2.

You must specify both length (l) and width (w) on the device instance line to enable automatic model selection.

Output Parameters

1 `tempeff (C)`	Effective temperature for a single device.
2 `meff`	Effective multiplicity factor (m-factor).
3 `weff (m)`	Effective channel width(alias=lx62).
4 `leff (m)`	Effective channel length(alias=lx63).
5 `lpoly (m)`	Effective Poly Length.
6 `leffcv (m)`	Effective channel length for CV(alias=lx65).
7 `weffcv (m)`	Effective channel width for CV(alias=lx64).
8 `rtheff (Ω)`	Effective thermal resistance.
9 `ctheff (F)`	Effective thermal capacitance.
10 `rseff (Ω)`	Effective source resistance.
11 `rdeff (Ω)`	Effective drain resistance.
12 `phi (V)`	Surface potential (phi alias=lv50).
13 `tox (m)`	Oxide thickness (tox alias=lv51).
14 `gseff (S)`	Effective source parasitic conductance(alias=lv16).
15 `gdeff (S)`	Effective drain parasitic conductance(alias=lv17).
16 `rds (Ω)`	Drain resistance (squares) (alias=lv13).
17 `rss (Ω)`	Source resistance (squares)(alias=lv14).

Operating-Point Parameters

1	`type=n`	Transistor type. Possible values are `n` and `p`.
2	`region=triode`	Estimated operating region. Possible values are `off`, `triode`, `sat`, and `subth`.
3	`reversed`	Reverse mode indicator. Possible values are `no` and `yes`.
4	`vgs (V)`	Gate-source voltage.
5	`vds (V)`	Drain-source voltage.
6	`vbs (V)`	Bulk-source voltage.
7	`vbgs (V)`	Back-Gate-source voltage.
8	`ids (A)`	Resistive drain-to-source current.
9	`ido (A)`	Alias for ids, opposite sign when reversed(alias=lx4).
10	`ibp (A)`	Bulk to source substrate current(alias=lx50).
11	`ic (A)`	BJT collector current(alias=lx45).
12	`igisl (A)`	Source GIDL current.
13	`igidl (A)`	Drain GIDL current.
14	`iii (A)`	Impact ionization current(alias=lx46).
15	`ibd (A)`	Resistive bulk-to-drain junction current.
16	`igbt (A)`	Gate-to-body tunneling current.
17	`ibs (A)`	Resistive bulk-to-source junction current.
18	`vth (V)`	Threshold voltage.
19	`vdsat (V)`	Drain-source saturation voltage.

20 `vfbeff (V)`	Flat-band voltage (vfbeff=lv26).
21 `gm (S)`	Common-source transconductance(alias=lx7).
22 `gds (S)`	Common-source output conductance(alias=lx8).
23 `gmb (S)`	Body-transconductance(alias=lx9).
24 `gmbg (S)`	Back-gate-transconductance.
25 `ueff` (cm^2/V s)	Effective mobility.
26 `betaeff` (A/V^2)	Effective `beta`.
27 `qg (Coul)`	Gate charge.
28 `qd (Coul)`	Drain charge.
29 `qs (Coul)`	Source charge.
30 `qb (Coul)`	Body charge.
31 `qbg (Coul)`	Back-Gate charge.
32 `cgg (F)`	dQg_dVg(alias=lx18).
33 `cgd (F)`	dQg_dVd.
34 `cgs (F)`	dQg_dVs.
35 `cgb (F)`	dQg_dVbk .
36 `cdg (F)`	dQd_dVg(alias=lx32).
37 `cdd (F)`	dQd_dVd(alias=lx33).
38 `cds (F)`	dQd_dVs(alias=lx34).
39 `cdb (F)`	dQd_dVb.
40 `csg (F)`	dQs_dVg(alias=lx59).
41 `csd (F)`	dQs_dVd(alias=lx60).

42 `css (F)`	dQs_dVs(alias=lx58).
43 `csb (F)`	dQs_dVb.
44 `cbg (F)`	dQb_dVg(alias=lx21).
45 `cbd (F)`	dQb_dVd(alias=lx22).
46 `cbs (F)`	dQb_dVs(alias=lx23).
47 `cbb (F)`	dQb_dVb.
48 `id (A)`	Total resistive drain current.
49 `is (A)`	Total resistive source current.
50 `ib (A)`	Total resistive bulk current.
51 `pwr (W)`	Power at op point.
52 `gmoverid (1/V)`	Gm/Ids.
53 `tdev (C)`	Temperature rise from ambient.
54 `qbint (Coul)`	Qb intrinsic, opposite sign for pmos(alias=lx12).
55 `qgint (Coul)`	Qg intrinsic, opposite sign for pmos(alias=lx14).
56 `qdint (Coul)`	Qd intrinsic, opposite sign for pmos(alias=lx16).
57 `qbs (Coul)`	Source junction diode charge(alias=lx26).
58 `qbd (Coul)`	Drain junction diode charge(alias=lx24).
59 `ibdo (A)`	Drain junction diode current(alias=lx6).
60 `ibso (A)`	Source junction diode current(alias=lx5).
61 `cap_bs (F)`	Extrinsic drain to substrate Capacitancesi(alias=lx28).
62 `cap_bd (F)`	Extrinsic source to substrate Capacitances(alias=lx29).
63 `cdebo (F)`	intrinsic drain-to-substrate capacitance(alias=lx37).

64 `cbebo (F)`	intrinsic floating body-to-substrate capacitance(alias=lx38).
65 `ceebo (F)`	intrinsic substrate capacitance(alias=lx39).
66 `i2 (A)`	Hspice alias of Total tunneling gate current.
67 `i3 (A)`	Hspice alias of Total resistive source current.
68 `igcs (A)`	Igcs.
69 `igcd (A)`	Igcd.
70 `cbgg (F)`	intrinsic substrate-to-gate capacitance(alias=lx40).
71 `cbgd (F)`	intrinsic substrate-to-drain capacitance(alias=lx41).
72 `cbgs (F)`	intrinsic substrate-to-drain capacitance(alias=lx41).
73 `rbp (Ω)`	
74 `cgbg (F)`	intrinsic gate-to-substrate capacitance(alias=lx57).
75 `csbg (F)`	intrinsic source-to-substrate capacitance(alias=lx61).
76 `cggbm (F)`	Total gate capacitance, and all overlap and fringing components(alias=lx82).
77 `cgdbm (F)`	Total gate-to-drain capacitance, and all overlap and fringing components(alias=lx83).
78 `cgsbm (F)`	Total gate-to-source capacitance, and all overlap and fringing components(alias=lx84).
79 `cddbm (F)`	Total drain capacitance, and all overlap and fringing components(alias=lx85).
80 `cdsbm (F)`	Total drain-to-source capacitance(alias=lx86).
81 `cdgbm (F)`	Total drain-to-gate capacitance, and overlap and fringing components(alias=lx87).
82 `cbgbm (F)`	Total bulk-to-gate capacitance, and overlap and fringing components(alias=lx88).

83 `cbdbm (F)`	Total floating body-to-drain capacitance, and overlap and fringing components(alias=lx89).
84 `cbsbm (F)`	Total floating body-to-gate capacitance, and overlap and fringing components(alias=lx90).
85 `cdbgbm (F)`	Total drain-to-substrate capacitance, and overlap and fringing components(alias=lx92).
86 `csgbm (F)`	Total source-to-gate capacitance, and overlap and fringing components(alias=lx93).
87 `cssbm (F)`	Total source capacitance, and overlap and fringing components(alias=lx94).
88 `csbgbm (F)`	Total source-to-substrate capacitance, and overlap and fringing components(alias=lx95).
89 `cbgbgbm (F)`	Total substrate capacitance, and overlap and fringing components(alias=lx96).
90 `ig (A)`	Total tunneling gate current.
91 `vth_cv (V)`	Threshold voltage for C-V.

Note:

1. The output of charge “qb”, “qd”, and “qs” are the sum of intrinsic charge and junction charge. The output of capacitors “cdd”, “cdb”, “csb”, “cbd”, “cbb”, and “cbs” are the sum of intrinsic capacitors and junction capacitors.
2. “reversed” means that vds is negative for NMOS or nonnegative for PMOS devices. It is not the same with SPICE3.

Parameter Index

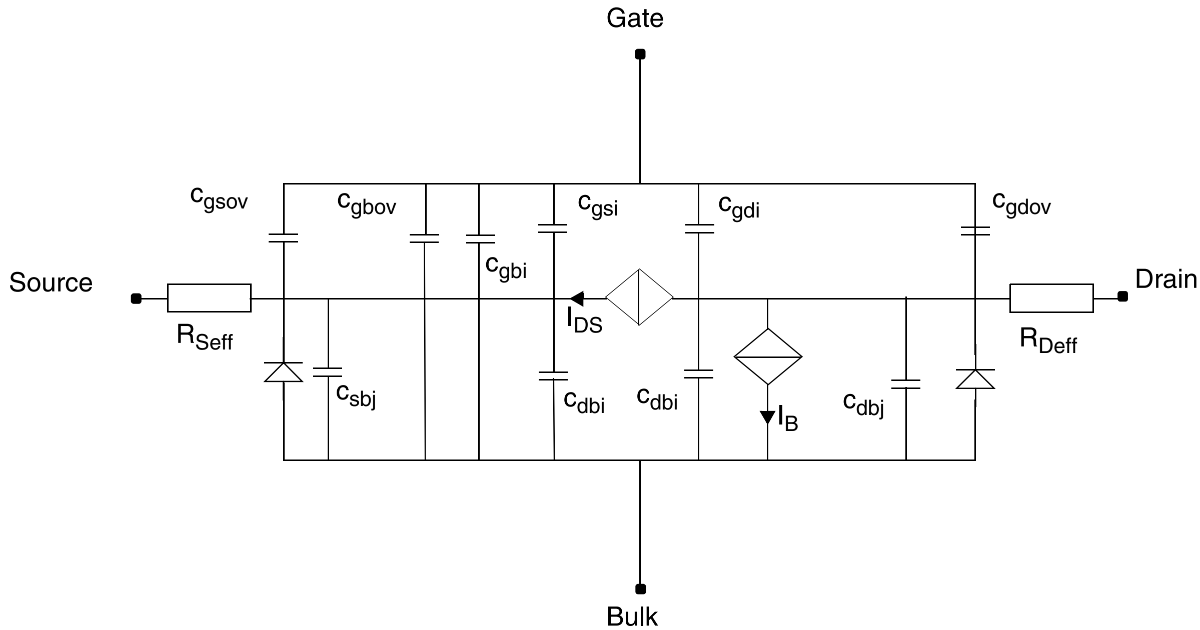
In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the

description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

29

B3SOI-PD Transistor Model (b3soipd)

The B3SOIPD model was developed by the BSIM/SOI modeling group at the University of California, Berkeley. This chapter contains the following information for for the B3SOI-PD transistor model:



BSIMPD2.0.1 IV

Model Parameter Notes

1. BSIMPD2.0 supports `capmod`=2 and 3 only. `capmod`=0 and 1 are not supported.
2. In modern SOI technology, source/drain extension or LDD is commonly used. As a result, the source/drain junction depth (X_j) can be different from the silicon film thickness (T_{si}). By default, if X_j is not given, it is set to T_{si}. X_j is not allowed to be greater than T_{si}.
3. BSIM3 SOI refers to the silicon substrate beneath the buried oxide, not to the well region in BSIM3. It is used to calculate backgate flat-band voltage (V_{fbb}) and parameters related to the source/drain diffusion bottom capacitance (V_{sdth},V_{sdfb}, and C_{sdmin}). Positive n_{sub} means the same type of doping as the body, and negative n_{sub} means the opposite type of doping.

Body Voltages

1. If $cgso$ is not given, it is calculated using the following:

   If dlc is given and is greater than 0, then

$$cgso = p1 = (dlc \times cox) - cgs1$$

If the previously calculated $cgso$<0, then

$$cgso = 0$$

else

$$cgso = 0.6 \times Tsi \times cox$$

2. $Cgdo$ is calculated in a way similar to $Csdo$.
3. If n_{sub} is positive,

$$V_{sdfb} = -\frac{kT}{q}\log\left(\frac{10^{20} \cdot n_{sub}}{n_i \cdot n_i}\right) - 0.3$$

else

$$V_{sdfb} = -\frac{kT}{q}\log\left(\frac{10^{20}}{n_{sub}}\right) + 0.3$$

4. If n_{sub} is positive,

$$\phi_{sd} = 2\frac{kT}{q}\log\left(\frac{n_{sub}}{n_i}\right), \Upsilon_{sd} = \frac{5.753 \times 10^{-12}\sqrt{n_{sub}}}{C_{box}}$$

$$V_{sdth} = V_{sdfb} + \phi_{sd} + \Upsilon_{sd}\sqrt{\phi_{sd}}$$

else

$$\phi_{sd} = 2\frac{kT}{q}\log\left(-\frac{n_{sub}}{n_i}\right), \Upsilon_{sd} = \frac{5.753 \times 10^{-12}\sqrt{-n_{sub}}}{C_{box}}$$

$$V_{sdth} = V_{sdfb} - \phi_{sd} - \Upsilon_{sd}\sqrt{\phi_{sd}}$$

5.

$$X_{sddep} = \sqrt{\frac{2\varepsilon_{si}\phi_{sd}}{q\left|n_{sub} \cdot 10^{6}\right|}}$$

$$C_{sddep} = \frac{\varepsilon_{si}}{X_{sddep}}$$

$$C_{sd\,min} = \frac{C_{sddep}C_{box}}{C_{sddep}+C_{box}}$$

6. If `cf` is not given, it is calculated using

$$CF = \frac{2\varepsilon_{ox}}{\pi}\ln\left(1+\frac{4\times10^{-7}}{T_{ox}}\right)$$

7. For `mobmod`=1 and 2, the unit is m/V^2. The default is -5.6x10^{-11}. For `mobmod`=3, the unit is 1/V, and the default is -0.056.

V_{bsh} is equal to the V_{bs} bounded between (V_{bsc}, ϕ_{s1}). V_{bsh} is used in V_{th} and A_{bulk} calculation.

$$T1 = V_{bsc} + 0.5\left[V_{bs} - V_{bsc} - \delta + \sqrt{(V_{bs} - V_{bsc} - \delta)^2 - 4\delta V_{bsc}}\right], V_{bsc} = -5V$$

$$V_{bsh} = \phi_{s1} - 0.5\left[\phi_{s1} - T1 - \delta + \sqrt{(\phi_{s1} - T1 - \delta)^2 + 4\delta T_1}\right], \phi_{s1} = 1.5V$$

V_{bsh} is further limited to 0.95ϕ_s to give V_{bseff}.

$$V_{bseff} = \phi_{s0} - 0.5\left[\phi_{s0} - V_{bsh} - \delta + \sqrt{(\phi_{s0} - V_{bsh} - \delta)^2 + 4\delta V_{bsh}}\right], \phi_{s0} = 0.95\phi_s$$

Effective Channel Length and Width

$$dW' = W_{int} + \frac{W_l}{L^{W_{ln}}} + \frac{W_w}{W^{W_{wn}}} + \frac{W_{wl}}{L^{W_{ln}}W^{W_{wn}}}$$

$$dW = dW' + dW_g V_{gsteff} + dW_b(\sqrt{\Phi_s - V_{bseff}} - \sqrt{\Phi_s})$$

$$dL = L_{int} + \frac{L_l}{L^{L_{ln}}} + \frac{L_w}{W^{L_{wn}}} + \frac{L_{wl}}{L^{L_{ln}}W^{L_{wn}}}$$

$$L_{eff} = L_{drawn} - 2dL$$

$$W_{eff} = W_{drawn} - N_{bc}dW_{bc} - (2 - N_{bc})dW$$

$$W_{eff}' = W_{drawn} - N_{bc}dW_{bc} - (2 - N_{bc})dW'$$

$$W_{diod} = \frac{W_{eff}'}{N_{seg}} + P_{dbcp}$$

$$W_{dios} = \frac{W_{eff}'}{N_{seg}} + P_{sbcp}$$

Threshold Voltage

$$\begin{aligned}
V_{TH} &= V_{tho} + K_{1eff}(sqrtPhisExt - \sqrt{\Phi_s}) \\
&- K_2 V_{bseff} + K_{1eff}\left(\sqrt{1 + \frac{N_{LX}}{L_{eff}}} - 1\right)\sqrt{\Phi_s} + (K_3 + K_{3b}V_{bseff})\frac{T_{ox}}{W'_{eff} + W_o}\Phi_s \\
&- D_{VT0w}\left(\exp\left(-D_{VT1w}\frac{W'_{eff}L_{eff}}{2l_{tw}}\right) + 2\exp\left(-D_{VT1w}\frac{W'_{eff}L_{eff}}{l_{tw}}\right)\right)(V_{bi} - \Phi_s) \\
&- D_{VT0}\left(\exp\left(-D_{VT1}\frac{L_{eff}}{2l_t}\right) + 2\exp\left(-D_{VT1}\frac{L_{eff}}{l_t}\right)\right)(V_{bi} - \Phi_s) \\
&- \left(\exp\left(-D_{sub}\frac{L_{eff}}{2l_{to}}\right) + 2\exp\left(-D_{sub}\frac{L_{eff}}{l_{to}}\right)\right)(E_{tao} + E_{tab}V_{bseff})V_{ds}
\end{aligned}$$

$$l_t = \sqrt{\varepsilon_{si}X_{dep}/C_{ox}}(1 + D_{VT2}V_{bseff})$$

$$sqrtPhisExt = \sqrt{\phi_s - V_{bseff}} + s(V_{bsh} - V_{bseff})$$

$$s = -\frac{1}{2\sqrt{\phi_s - \phi_{s0}}}$$

$$K_{1eff} = K_1\left(1 + \frac{K_{1w1}}{W'_{eff} + K_{1w2}}\right)$$

$$l_{tw} = \sqrt{\varepsilon_{si} X_{dep} / C_{ox}}(1 + D_{VT2w} V_{bseff})$$

$$l_{to} = \sqrt{\varepsilon_{si} X_{dep0} / C_{ox}}$$

$$X_{dep} = \sqrt{\frac{2\varepsilon_{si}(\Phi_s - V_{bseff})}{qN_{ch}}}$$

$$X_{dep0} = \sqrt{\frac{2\varepsilon_{si}\Phi_s}{qN_{ch}}}$$

$$V_{bi} = v_t \ln\left(\frac{N_{ch}N_{DS}}{n_i^2}\right)$$

Poly Depletion Effect

$$V_{poly} + \frac{1}{2} X_{poly} E_{poly} = \frac{qN_{gate} X_{poly}^2}{2\varepsilon_{si}}$$

$$\varepsilon_{ox} E_{ox} = \varepsilon_{si} E_{poly} = \sqrt{2q\varepsilon_{si} N_{gate} V_{poly}}$$

$$V_{gs} - V_{FB} - \phi_x = V_{poly} + V_{ox}$$

$$a(V_{gs} - V_{FB} - \phi_s - V_{poly})^2 - V_{poly} = 0$$

$$a = \frac{\varepsilon_{ox}^2}{2q\varepsilon_{si} N_{gate} T_{ox}^2}$$

$$V_{gs\_eff} = V_{FB} + \phi_s + \frac{q\varepsilon_{si}N_{gate}T_{ox}^2}{\varepsilon_{ox}^2} \times \left(\sqrt{1 + \frac{2\varepsilon_{ox}^2(V_{gs} - V_{FB} - \phi_s)}{q\varepsilon_{si}N_{gate}T_{ox}^2}} - 1\right)$$

Effective Vgst for All Regions (with Polysilicon Depletion Effect)

$$V_{gsteff} = \frac{2nv_t \ln\left[1 + \exp\left(\frac{V_{gs\_eff} - V_{th}}{2nv_t}\right)\right]}{1 + 2nC_{ox}\sqrt{\frac{2\Phi_s}{q\varepsilon_{si}N_{ch}}}\exp\left(-\frac{V_{gs\_eff} - V_{th} - 2V_{off}}{2nv_t}\right)}$$

$$n = 1 + N_{factor}\frac{\varepsilon_{si}/X_{dep}}{C_{ox}} + \frac{C_{it}}{C_{ox}} +$$

$$\frac{(C_{dsc} + C_{dscd}V_{ds} + C_{dscb}V_{bseff})\left[\exp\left(-D_{VT1}\frac{L_{eff}}{2l_t}\right) + 2\exp\left(-D_{VT1}\frac{L_{eff}}{l_t}\right)\right]}{C_{ox}}$$

Effective Bulk Charge Factor

$$A_{bulk} = 1 + \left[\left(\frac{K_{1eff}}{2\sqrt{(\phi_s + Ketas) - \frac{V_{bsh}}{1 + Keta \cdot V_{bsh}}}}\right) \times\right.$$

$$\left.\left(\frac{A_0L_{eff}}{L_{eff} + 2\sqrt{T_{si}X_{dep}}}\left(1 - A_{gs}V_{gsteff}\left(\frac{L_{eff}}{L_{eff} + 2\sqrt{T_{si}X_{dep}}}\right)^2\right) + \frac{B_0}{W'_{eff} + B_1}\right)\right]$$

$$A_{bulk0} = A_{bulk}(V_{gsteff} = 0)$$

Mobility and Saturation Velocity

For `Mobmod`=1

$$\mu_{eff} = \frac{\mu_0}{1 + (U_a + U_c V_{bseff})\left(\frac{V_{gsteff} + 2V_{th}}{T_{ox}}\right) + U_b\left(\frac{V_{gsteff} + 2V_{th}}{T_{ox}}\right)^2}$$

For `Mobmod`=2

$$\mu_{eff} = \frac{\mu_0}{1 + (U_a + U_c V_{bseff})\left(\frac{V_{gsteff}}{T_{ox}}\right) + U_b\left(\frac{V_{gsteff}}{T_{ox}}\right)^2}$$

For `Mobmod`=3

$$\mu_{eff} = \frac{\mu_0}{1 + \left[U_a\left(\frac{V_{gsteff} + 2V_{th}}{T_{ox}}\right) + U_b\left(\frac{V_{gsteff} + 2V_{th}}{T_{ox}}\right)^2\right](1 + U_c V_{bseff})}$$

Drain Saturation Voltage

For R_{ds} > 0 or $\lambda \neq 1$,

$$V_{dsat} = \frac{-b - \sqrt{b^2 - 4ac}}{2a}$$

$$a = A_{bulk}^2 W_{eff} v_{sat} C_{ox} R_{ds} + \left(\frac{1}{\lambda} - 1\right) A_{bulk}$$

$$b = -\left[(V_{gsteff} + 2v_t)\left(\frac{2}{\lambda} - 1\right) + A_{bulk} E_{sat} L_{eff} + 3A_{bulk}(V_{gsteff} + 2v_t) W_{eff} v_{sat} C_{ox} R_{ds}\right]$$

$$c = (V_{gsteff} + 2v_t) E_{sat} L_{eff} + 2(V_{gsteff} + 2v_t)^2 W_{eff} v_{sat} C_{ox} R_{ds}$$

$$\lambda = A_1 V_{gsteff} + A_2$$

For R_{ds} = 0 or λ = 1,

$$V_{dsat} = \frac{E_{sat}L_{eff}(V_{gsteff} + 2v_t)}{A_{bulk}E_{sat}L_{eff} + (V_{gsteff} + 2v_t)}$$

$$E_{sat} = \frac{2v_{sat}}{\mu_{eff}}$$

Vdseff

$$V_{dseff} = V_{dsat} - \frac{1}{2}\left(V_{dsat} - V_{ds} - \delta + \sqrt{(V_{dsat} - V_{ds} - \delta)^2 + 4\delta V_{dsat}}\right)$$

Drain Current Expression

$$I_{ds,\,MOSFET} = \frac{1}{N_{seg}} \frac{I_{ds0}(V_{dseff})}{1 + \dfrac{R_{ds}I_{dso}(V_{dseff})}{V_{dseff}}}\left(1 + \frac{V_{ds} - V_{dseff}}{V_A}\right)$$

$$\beta = \mu_{eff}C_{ox}\frac{W_{eff}}{L_{eff}}$$

$$I_{dso} = \frac{\beta V_{gsteff}\left(1 - A_{bulk}\dfrac{V_{dseff}}{2(V_{gsteff} + 2v_t)}\right)V_{dseff}}{1 + \dfrac{V_{dseff}}{E_{sat}L_{eff}}}$$

$$V_A = V_{Asat} + \left(1 + \frac{P_{vag}V_{gsteff}}{E_{sat}L_{eff}}\right)\left(\frac{1}{V_{ACLM}} + \frac{1}{V_{ADIBLC}}\right)^{-1}$$

$$V_{ACLM} = \frac{A_{bulk}E_{sat}L_{eff} + V_{gsteff}}{P_{clm}A_{bulk}E_{sat}litl}(V_{ds} - V_{dseff})$$

$$V_{ADIBLC} = \frac{(V_{gsteff} + 2v_t)}{\theta_{rout}(1 + P_{DIBLCB}V_{bseff})}\left(1 - \frac{A_{bulk}V_{dsat}}{A_{bulk}V_{dsat} + 2v_t}\right)$$

$$\theta_{rout} = P_{DIBLC1}\left[\exp\left(-D_{ROUT}\frac{L_{eff}}{2l_{t0}}\right) + 2\exp\left(-D_{ROUT}\frac{L_{eff}}{l_{t0}}\right)\right] + P_{DIBLC2}$$

$$V_{Asat} = \frac{E_{sat}L_{eff} + V_{dsat} + 2R_{ds}v_{sat}C_{ox}W_{eff}V_{gsteff}\left[1 - \frac{A_{bulk}V_{dsat}}{2(V_{gsteff} + 2v_t)}\right]}{2/\lambda - 1 + R_{ds}v_{sat}C_{ox}W_{eff}A_{bulk}}$$

$$litl = \sqrt{\frac{\varepsilon_{si}T_{ox}T_{Si}}{\varepsilon_{ox}}}$$

Drain/Source Resistance

$$R_{ds} = R_{dsw}\frac{1 + P_{rwg}V_{gsteff} + P_{rwb}(\sqrt{\phi_s - V_{bseff}} - \sqrt{\phi_s})}{(10^6 W'_{eff})^{Wr}}$$

Impact Ionization Current

$$I_{ii} = \alpha_0(I_{ds,MOSFET} + F_{bjtii}I_c)\exp\left(\frac{V_{diff}}{\beta_2 + \beta_1 V_{diff} + \beta_0 V_{diff}^2}\right)$$

$$V_{diff} = V_{ds} - V_{dsatii}$$

$$V_{dsatii} = VgsStep + \left[V_{dsatii0}\left(1 + T_{ii}\left(\frac{T}{T_{nom}} - 1\right)\right) + \frac{L_{ii}}{L_{eff}}\right]$$

$$VgsStep = \left(\frac{E_{satii}L_{eff}}{1 + E_{satii}L_{eff}}\right)\left(\frac{1}{1 + S_{ii1}V_{gsteff}} + S_{ii2}\right)\left(\frac{S_{ii0}V_{gst}}{1 + S_{iid}V_{ds}}\right)$$

Gate-Induced-Drain-Leakage (GIDL)

At drain,

$$I_{dgidl} = W_{diod}\alpha_{gidl}E_s\exp\left(-\frac{\beta_{gidl}}{E_s}\right)$$

$$E_s = \frac{V_{ds} - V_{gs} - \chi}{3T_{ox}}$$

At source,

$$I_{sgidl} = W_{dios}\alpha_{gidl}E_s\exp\left(-\frac{\beta_{gidl}}{E_s}\right)$$

$$E_s = \frac{-V_{gs} - \chi}{3T_{ox}}$$

If E_s is negative, I_{gidl} is set to zero for both drain and source.

Body Contact Current

$$R_{bp} = R_{body0}\frac{W'_{eff}/N_{seg}}{L_{eff}}$$

$$R_{bodyext} = R_{bsh}N_{rb}$$

For 4-T device,

$$I_{bp} = 0$$

For 5-T device,

$$I_{bp} = \frac{V_{bp}}{R_{bp} + R_{bodyext}}$$

Diode and BJT Currents

Bipolar Transport Factor

$$\alpha_{bjt} = \exp\left[-0.5\left(\frac{L_{eff}}{L_n}\right)^2\right]$$

Body-to-Source/Drain Diffusion

$$I_{bs1} = W_{dios} T_{si} j_{sdif}\left(\exp\left(\frac{V_{bs}}{n_{dio} V_t}\right) - 1\right)$$

$$I_{bd1} = W_{diod} T_{si} j_{sdif}\left(\exp\left(\frac{V_{bd}}{n_{dio} V_t}\right) - 1\right)$$

Recombination/Trap-Assisted Tunneling Current in Depletion Region

$$I_{bs2} = W_{dios} T_{si} j_{srec}\left(\exp\left(\frac{V_{bs}}{0.026 n_{recf}}\right) - \exp\left(\frac{V_{sb}}{0.026 n_{recr}} \frac{V_{rec0}}{V_{rec0} + V_{sb}}\right)\right)$$

$$I_{bd2} = W_{diod} T_{si} j_{srec}\left(\exp\left(\frac{V_{bd}}{0.026 n_{recf}}\right) - \exp\left(\frac{V_{db}}{0.026 n_{recr}} \frac{V_{rec0}}{V_{rec0} + V_{db}}\right)\right)$$

Reversed Bias Tunneling Leakage

$$I_{bs4} = W_{dios} T_{si} j_{stun}\left(1 - \exp\left(\frac{n_{tun} V_{sb}}{V_{tun0} + V_{sb}}\right)\right)$$

$$I_{bd4} = W_{diod} T_{si} j_{stun}\left(1 - \exp\left(\frac{n_{tun} V_{db}}{V_{tun0} + V_{db}}\right)\right)$$

Recombination Current in Neutral Body

$$I_{bs3} = (1 - \alpha_{bjt}) I_{en}\left[\exp\left(\frac{V_{bs}}{n_{dio} V_t}\right) - 1\right]\frac{1}{\sqrt{E_{hlis}} + 1}$$

$$I_{bd3} = (1 - \alpha_{bjt}) I_{en}\left[\exp\left(\frac{V_{bd}}{n_{dio} V_t}\right) - 1\right]\frac{1}{\sqrt{E_{hlid}} + 1}$$

$$I_{en} = \frac{W'_{eff}}{N_{seg}} T_{si} j_{sbjt}\left[L_{bjt0}\left(\frac{1}{L_{eff}} + \frac{1}{L_n}\right)\right]^{N_{bjt}}$$

$$E_{hlis} = A_{hli\_\mathrm{eff}}\left[\exp\left(\frac{V_{bs}}{n_{dio} V_t}\right) - 1\right]$$

$$E_{hlid} = A_{hli\_\mathrm{eff}}\left[\exp\left(\frac{V_{bd}}{n_{dio} V_t}\right) - 1\right]$$

BJT Collector Current

$$I_c = \alpha_{bjt} I_{en}\left\{\exp\left[\frac{V_{bs}}{n_{dio} V_t}\right] - \exp\left[\frac{V_{bd}}{n_{dio} V_t}\right]\right\}\frac{1}{E_{2nd}}$$

$$E_{2nd} = \frac{E_{ely} + \sqrt{E_{ely}^2 + 4E_{hli}}}{2}$$

$$E_{ely} = 1 + \frac{V_{bs} + V_{bd}}{V_{Abjt} + A_{ely}L_{eff}}$$

$$E_{hli} = E_{hlis} + E_{hlid}$$

Total Body-Source/Drain Current

$$I_{bs} = I_{bs1} + I_{bs2} + I_{bs3} + I_{bs4}$$

$$I_{bd} = I_{bd1} + I_{bd2} + I_{bd3} + I_{bd4}$$

Total Body Current

$$I_{ii} + I_{dgidl} + I_{sgidl} - I_{bs} - I_{bd} - I_{bp} = 0$$

Temperature Effects

$$A_{hli\_\mathrm{eff}} = A_{hli}\exp\left[\frac{-E_g(300K)}{n_{dio}V_t}X_{bjt}\left(1 - \frac{T}{T_{nom}}\right)\right]$$

$$V_{th(T)} = V_{th(Tnom)} + (K_{T1} + K_{t1l}/L_{eff} + K_{T2}V_{bseff})(T/T_{nom} - 1)$$

$$\mu_{o(T)} = \mu_{o(Tnom)}\left(\frac{T}{T_{nom}}\right)^{\mu te}$$

$$v_{sat(T)} = v_{sat(Tnom)} - A_T(T/T_{nom} - 1)$$

$$R_{dsw(T)} = R_{dsw}(T_{nom}) + P_{rt}\left(\frac{T}{T_{nom}} - 1\right)$$

$$U_{a(T)} = U_{a(Tnom)} + U_{a1}(T/T_{nom} - 1)$$

$$U_{b(T)} = U_{b(Tnom)} + U_{b1}(T/T_{nom} - 1)$$

$$U_{c(T)} = U_{c(Tnom)} + U_{c1}(T/T_{nom} - 1)$$

$$R_{th} = \frac{R_{th0}}{W'_{eff}/N_{seg}}, C_{th} = C_{th0}\frac{W'_{eff}}{N_{seg}}$$

$$j_{sbjt} = j_{sbjt0}\exp\left[-\frac{E_g(300K)}{n_{dio}V_t}X_{bjt}\left(1 - \frac{T}{T_{nom}}\right)\right]$$

$$j_{sdif} = j_{sdif0}\exp\left[-\frac{E_g(300K)}{n_{dio}V_t}X_{dif}\left(1 - \frac{T}{T_{nom}}\right)\right]$$

$$j_{srec} = j_{srec0}\exp\left[-\frac{E_g(300K)}{n_{recf0}V_t}X_{rec}\left(1 - \frac{T}{T_{nom}}\right)\right]$$

$$j_{stun} = j_{stun0}\exp\left[X_{tun}\left(\frac{T}{T_{nom}} - 1\right)\right]$$

$$n_{recf} = n_{recf0}\left[1 + nt_{recf}\left(\frac{T}{T_{nom}} - 1\right)\right]$$

$$n_{recr} = n_{recr0}\left[1 + nt_{recr}\left(\frac{T}{T_{nom}} - 1\right)\right]$$

E_g is the energy gap energy.

BSIMPD2.0.1 CV

Model Parameter Notes

1. If $cgso$ is not given, it is calculated using the following:

If dlc is given and is greater than 0, then

$$cgso = p1 = (dlc \times cox) - cgs1$$

If the previously calculated $cgso$<0, then

$$cgso = 0$$

else

$$cgso = 0.6 \times Tsi \times cox$$

2. $Cgdo$ is calculated in a way similar to $Csdo$.

3. If n_{sub} is positive,

$$V_{sdfb} = -\frac{kT}{q}\log\left(\frac{10^{20} \cdot n_{sub}}{n_i \cdot n_i}\right) - 0.3$$

else

$$V_{sdfb} = -\frac{kT}{q}\log\left(\frac{10^{20}}{n_{sub}}\right) + 0.3$$

4. If n_{sub} is positive,

$$\phi_{sd} = 2\frac{kT}{q}\log\left(\frac{n_{sub}}{n_i}\right), \Upsilon_{sd} = \frac{5.753 \times 10^{-12}\sqrt{n_{sub}}}{C_{box}}$$

$$V_{sdth} = V_{sdfb} + \phi_{sd} + \Upsilon_{sd}\sqrt{\phi_{sd}}$$

else

$$\phi_{sd} = 2\frac{kT}{q}\log\left(-\frac{n_{sub}}{n_i}\right),\ \Upsilon_{sd} = \frac{5.753\times 10^{-12}\sqrt{-n_{sub}}}{C_{box}}$$

$$V_{sdth} = V_{sdfb} - \phi_{sd} - \Upsilon_{sd}\sqrt{\phi_{sd}}$$

5.

$$X_{sddep} = \sqrt{\frac{2\varepsilon_{si}\phi_{sd}}{q\left|n_{sub}\cdot 10^{6}\right|}}$$

$$C_{sddep} = \frac{\varepsilon_{si}}{X_{sddep}}$$

$$C_{sd\ min} = \frac{C_{sddep}C_{box}}{C_{sddep}+C_{box}}$$

6. If `cf` is not given, it is calculated using

$$CF = \frac{2\varepsilon_{ox}}{\pi}\ln\left(1+\frac{4\times 10^{-7}}{T_{ox}}\right)$$

7. For `mobmod`=1 and 2, the unit is m/V^2. The default is -5.6×10^{-11}. For `mobmod`=3, the unit is 1/V, and the default is -0.056.

Dimension Dependence

$$W_{active} = W_{drawn} - N_{bc}dW_{bc} - (2-N_{bc})\delta W_{eff}$$

$$\delta W_{eff} = DWC + \frac{W_{lc}}{L^{W_{\ln}}} + \frac{W_{wc}}{L^{W_{wn}}} + \frac{W_{wlc}}{L^{W_{\ln}}W^{W_{wn}}}$$

$$L_{active} = L_{drawn} - 2\delta L_{eff}$$

$$\delta L_{eff} = DLC + \frac{L_{lc}}{L^{L_{\ln}}} + \frac{L_{wc}}{W^{L_{wn}}} + \frac{L_{wlc}}{L^{L_{\ln}}W^{L_{wn}}}$$

$$L_{activeB} = L_{active} - DLCB$$

$$L_{activeBG} = L_{activeB} + 2\delta L_{bg}$$

$$W_{diosCV} = \frac{W_{active}}{N_{seg}} + P_{sbcp}$$

$$W_{diodCV} = \frac{W_{active}}{N_{seg}} + P_{dbcp}$$

Charge Conservation

$$Q_{Bf} = Q_{acc} + Q_{sub0} + Q_{subs}$$

$$Q_{inv} = Q_{inv,\,s} + Q_{inv,\,d}$$

$$Q_g = -(Q_{inv} + Q_{Bf})$$

$$Q_b = Q_{Bf} - Q_e + Q_{js} + Q_{jd}$$

$$Q_s = Q_{inv,\,s} - Q_{js}$$

$$Q_d = Q_{inv,\,d} - Q_{jd}$$

$$Q_g + Q_e + Q_b + Q_s + Q_d = 0$$

Intrinsic Charges

capMod = 2

Front Gate Body Charge

Accumulation charge:

$$V_{fbeff} = V_{fb} - 0.5\left((V_{fb} - V_{gb} - \delta) + \sqrt{(V_{fb} - V_{gb} - \delta)^2 + \delta^2}\right)$$

where

$$V_{gb} = V_{gs} - V_{bseff}$$

$$V_{fb} = V_{th} - \phi_s - K_{1eff}\sqrt{\phi_s - V_{bseff}} + delvt$$

$$V_{gsteffCV} = nv_t \ln\left(1 + \exp\left[\frac{V_{gs} - V_{th}}{nv_t}\right] \cdot \exp\left[-\frac{delvt}{nv_t}\right]\right)$$

$$Q_{acc} = -F_{body}\left(\frac{W_{active}L_{activeB}}{N_{seg}} + A_{gbcp}\right)C_{ox}(V_{FBeff} - V_{fb})$$

Gate-induced depletion charge:

$$Q_{sub0} = -F_{body}\left(\frac{W_{active}L_{activeB}}{N_{seg}} + A_{gbcp}\right)C_{ox}\frac{K_{1eff}^2}{2}\left(-1 + \sqrt{1 + \frac{4(V_{gs} - V_{FBeff} - V_{gsteffCV} - V_{bseff})}{K_{1eff}^2}}\right)$$

Drain-induced depletion charge:

$$V_{dsat,cv} = V_{gsteffCV}/A_{bulkCV}, A_{bulkCV} = A_{bulk0}\left[1+\left(\frac{CLC}{L_{activeB}}\right)^{CLE}\right]$$

$$V_{dsCV} = V_{dsatCV} - \frac{1}{2}\left(V_{dsatCV} - V_{ds} - \delta + \sqrt{(V_{dsatCV} - V_{ds} - \delta)^2 + 4\delta V_{dsatCV}}\right)$$

$$Q_{subs} = F_{body}\left(\frac{W_{active}L_{activeB}}{N_{seg}} + A_{gbcp}\right)K_{1eff}C_{ox}(A_{bulkCV} - 1) \times$$
$$\left[\frac{V_{dsCV}}{2} - \frac{A_{bulkCV}V_{dsCV}^2}{12(V_{gsteffCV} - A_{bulkCV}V_{dsCV}/2)}\right]$$

Back Gate Body Charge

$$Q_e = k_{b1}F_{body}\left(\frac{W_{active}L_{activeBG}}{N_{seg}} + A_{ebcp}\right)C_{box}(V_{es} - V_{fbb} - V_{bseff})$$

Inversion Charge

$$V_{cveff} = V_{dsat,CV} - 0.5\left(V_4 + \sqrt{V_4^2 + 4\delta_4 V_{dsat,CV}}\right)$$

where

$$V_4 = V_{dsat,CV} - V_{ds} - \delta_4; \delta_4 = 0.02$$

$$Q_{inv} = -\left(\frac{W_{active}L_{active}}{N_{seg}} + A_{gbcp}\right)C_{ox} \times$$

$$\left(\left(V_{gsteffCV} - \frac{A_{bulkCV}}{2}V_{cveff}\right) + \frac{A_{bulkCV}^2 V_{cveff}^2}{12\left(V_{gsteffCV} - \frac{A_{bulkCV}^2}{2}V_{cveff}\right)}\right)$$

50/50 charge partition:

$$Q_{inv,\,s} = Q_{inv,\,d} = 0.5Q_{inv}$$

40/60 charge partition:

$$Q_{inv,\,s} = -\frac{\left(\frac{W_{active}L_{active}}{N_{seg}} + A_{gbcp}\right)C_{ox}}{2\left(V_{gsteffCV} - \frac{A_{bulkCV}}{2}V_{cveff}\right)^2} \times$$

$$\left(V_{gsteffCV}^3 - \frac{4}{3}V_{gsteffCV}^2(A_{bulkCV}V_{cveff}) + \frac{2}{3}V_{gsteff}(A_{bulkCV}V_{cveff})^2 - \frac{2}{15}(A_{bulkCV}V_{cveff})^3\right)$$

$$Q_{inv,\,d} = -\frac{\left(\frac{W_{active}L_{active}}{N_{seg}} + A_{gbcp}\right)C_{ox}}{2\left(V_{gsteffCV} - \frac{A_{bulkCV}}{2}V_{cveff}\right)^2} \times$$

$$\left(V_{gsteffCV}^3 - \frac{5}{3}V_{gsteffCV}^2(A_{bulkCV}V_{cveff}) + V_{gsteff}(A_{bulkCV}V_{cveff})^2 - \frac{1}{5}(A_{bulkCV}V_{cveff})^3\right)$$

0/100 charge partition:

$$Q_{inv,\,s} = -\frac{W_{active}L_{active} + A_{gbcp}}{N_{seg}}C_{ox} \times$$

$$\left(\frac{V_{gsteffCV}}{2} + \frac{A_{bulkCV}V_{cveff}}{4} - \frac{(A_{bulkCV}V_{cveff})^2}{24\left(V_{gsteffCV} - \frac{A_{bulkCV}}{2}V_{cveff}\right)}\right)$$

$$Q_{inv,\,d} = -\frac{W_{active}L_{active} + A_{gbcp}}{N_{seg}}C_{ox} \times$$

$$\left(\frac{V_{gsteffCV}}{2} + \frac{3A_{bulkCV}V_{cveff}}{4} + \frac{(A_{bulkCV}V_{cveff})^2}{8\left(V_{gsteffCV} - \frac{A_{bulkCV}}{2}V_{cveff}\right)}\right)$$

capMod = 3 (Charge-Thickness Model)

`capMod` = 3 supports only zero-bias flat-band voltage, which is calculated from bias-independent threshold voltage. This is different from `capMod` = 2. For the finite thickness (X_{DC}) formulation, refer to Chapter 4 of the *BSIM3v3.2 User's Manual*.

Front Gate Body Charge

Accumulation charge:

$$V_{fbeff} = V_{fb} - 0.5\left((V_{fb} - V_{gb} - \delta) + \sqrt{(V_{fb} - V_{gb} - \delta)^2 + \delta^2}\right)$$

where

$$V_{gb} = V_{gs} - V_{bseff}$$

$$V_{fb} = V_{th} - \phi_s - K_{1eff}\sqrt{\phi_s - V_{bseff}}$$

$$Q_{acc} = -F_{body}\left(\frac{W_{active}L_{activeB}}{N_{seg}} + A_{gbcp}\right)C_{oxeff}V_{gbacc}$$

$$V_{gbacc} = 0.5\left(V_0 + \sqrt{V_0^2 + 4\delta V_{fb}}\right)$$

$$V_0 = V_{fb} + V_{bseff} - V_{gs} - \delta$$

$$C_{oxeff} = \frac{C_{ox}C_{cen}}{C_{ox} + C_{cen}}$$

$$C_{cen} = \varepsilon_{Si}/X_{DC}$$

Gate-induced depletion charge:

$$Q_{sub0} = -F_{body}\left(\frac{W_{active}L_{activeB}}{N_{seg}} + A_{gbcp}\right)C_{oxeff}\frac{K_{1eff}^2}{2} \times$$
$$\left(-1 + \sqrt{1 + \frac{4(V_{gs} - V_{FBeff} - V_{gsteffCV} - V_{bseff})}{K_{1eff}^2}}\right)$$

Drain-induced depletion charge

$$V_{dsat,cv} = (V_{gsteffCV} - \Phi_\delta)/A_{bulkCV}$$

$$\Phi_\delta = \Phi_s - 2\Phi_B = v_t \ln\left[1 + \frac{V_{gsteffCV}(V_{gsteffCV} + 2K_{1e\beta ff}\sqrt{2\Phi_B})}{moinK_{1eff}v_t^2}\right]$$

$$V_{dsCV} = V_{dsatCV} - \frac{1}{2}\left(V_{dsatCV} - V_{ds} - \delta + \sqrt{(V_{dsatCV} - V_{ds} - \delta)^2 + 4\delta V_{dsatCV}}\right)$$

$$Q_{subs} = F_{body}\left(\frac{W_{active}L_{activeB}}{N_{seg}} + A_{gbcp}\right)K_{1eff}C_{oxeff}(A_{bulkCV} - 1) \times$$
$$\left[\frac{V_{dsCV}}{2} - \frac{A_{bulkCV}V_{dsCV}^2}{12(V_{gsteffCV} - \Phi_\delta - A_{bulkCV}V_{dsCV}/2)}\right]$$

Back Gate Body Charge

$$k_{b1}F_{body}\left(\frac{W_{active}L_{activeBG}}{N_{seg}} + A_{ebcp}\right)C_{box}(V_{es} - V_{fbb} - V_{bseff})$$

Inversion Charge

$$V_{cveff} = V_{dsat,\,CV} - 0.5\left(V_4 + \sqrt{V_4^2 + 4\delta_4 V_{dsat,\,CV}}\right)$$

where

$$V_4 = V_{dsat,\,CV} - V_{ds} - \delta_4;\delta_4 = 0.02$$

$$Q_{inv} = -\left(\frac{W_{active}L_{active}}{N_{seg}} + A_{gbcp}\right)C_{oxeff} \times$$

$$\left(\left(V_{gsteffCV} - \Phi_\delta - \frac{A_{bulkCV}}{2}V_{cveff}\right) + \frac{A_{bulkCV}^2V_{cveff}^2}{12\left(V_{gsteffCV} - \Phi_\delta - \frac{A_{bulkCV}^2}{2}V_{cveff}\right)}\right)$$

50/50 charge partition:

$$Q_{inv,\,s} = Q_{inv,\,d} = 0.5Q_{inv}$$

40/60 charge partition:

$$Q_{inv,s} = -\frac{\left(\frac{W_{active}L_{active}}{N_{seg}} + A_{gbcp}\right)C_{oxeff}}{2\left(V_{gsteffCV} - \Phi_{\delta} - \frac{A_{bulkCV}}{2}V_{cveff}\right)^2} \times \left((V_{gsteffCV} - \Phi_{\delta})^3 - \right.$$

$$\frac{4}{3}(V_{gsteffCV} - \Phi_{\delta})^2(A_{bulkCV}V_{cveff}) + \frac{2}{3}(V_{gsteffCV} - \Phi_{\delta})(A_{bulkCV}V_{cveff})^2$$

$$\left. - \frac{2}{15}(A_{bulkCV}V_{cveff})^3\right)$$

$$Q_{inv,d} = -\frac{\left(\frac{W_{active}L_{active}}{N_{seg}} + A_{gbcp}\right)C_{oxeff}}{2\left(V_{gsteffCV} - \Phi_{\delta} - \frac{A_{bulkCV}}{2}V_{cveff}\right)^2} \times \left((V_{gsteffCV} - \Phi_{\delta})^3\right.$$

$$- \frac{5}{3}(V_{gsteffCV} - \Phi_{\delta})^2(A_{bulkCV}V_{cveff}) + (V_{gsteffCV} - \Phi_{\delta})(A_{bulkCV}V_{cveff})^2$$

$$\left. - \frac{1}{5}(A_{bulkCV}V_{cveff})^3\right)$$

$$Q_{inv,s} = -\frac{W_{active}L_{active} + A_{gbcp}}{N_{seg}} C_{oxeff} \times$$

$$\left(\frac{V_{gsteffCV} - \Phi_\delta}{2} + \frac{A_{bulkCV}V_{cveff}}{4} - \frac{(A_{bulkCV}V_{cveff})^2}{24\left(V_{gsteffCV} - \Phi_\delta - \frac{A_{bulkCV}}{2}V_{cveff}\right)} \right)$$

0/100 charge partition:

$$Q_{inv,s} = -\frac{W_{active}L_{active} + A_{gbcp}}{N_{seg}} C_{oxeff} \times$$

$$\left(\frac{V_{gsteffCV} - \Phi_\delta}{2} + \frac{A_{bulkCV}V_{cveff}}{4} - \frac{(A_{bulkCV}V_{cveff})^2}{24\left(V_{gsteffCV} - \Phi_\delta - \frac{A_{bulkCV}}{2}V_{cveff}\right)} \right)$$

Overlap Capacitance

Source Overlap Charge

$$Q_{inv,d} = -\frac{W_{active}L_{active} + A_{gbcp}}{N_{seg}} C_{oxeff} \times$$

$$\left(\frac{V_{gsteffCV} - \Phi_\delta}{2} - \frac{3A_{bulkCV}V_{cveff}}{4} + \frac{(A_{bulkCV}V_{cveff})^2}{8\left(V_{gsteffCV} - \Phi_\delta - \frac{A_{bulkCV}}{2}V_{cveff}\right)} \right)$$

$$V_{gs,overlap} = \frac{1}{2}\left\{ (V_{gs} + \delta) + \sqrt{(V_{gs} + \delta)^2 + 4\delta} \right\}$$

$$\frac{Q_{overlap,s}}{W_{diosCV}} = CGS0 \cdot V_{gs} + CGS1\left\{V_{gs} - V_{gs\_overlap} + \frac{CKAPPA}{2}\left(-1 + \sqrt{1 + \frac{4V_{gs\_overlap}}{CKAPPA}}\right)\right\}$$

Drain Overlap Charge

$$V_{gd,\,overlap} = \frac{1}{2}\left\{(V_{gd} + \delta) + \sqrt{(V_{gd} + \delta)^2 + 4\delta}\right\}$$

$$\frac{Q_{overlap,d}}{W_{diodCV}} = CGD0 \cdot V_{gd} + CGD1\left\{V_{gd} - V_{gd\_overlap} + \frac{CKAPPA}{2}\left(-1 + \sqrt{1 + \frac{4V_{gd\_overlap}}{CKAPPA}}\right)\right\}$$

Gate Overlap Charge

$$Q_{overlap,\,g} = -(Q_{overlap,\,s} + Q_{overlap,\,d})$$

Source/Drain Junction Charge

For $V_{bs} < 0.95\phi_s$

$$Q_{jswg} = Q_{bsdep} + Q_{bsdif}$$

else

$$Q_{jswg} = C_{bsdep}(0.95\phi_s)(V_{bs} - 0.95\phi_s) + Q_{bsdif}$$

For $V_{bd} < 0.95\phi_s$

$$Q_{jdwg} = Q_{bddep} + Q_{bddif}$$

else

$$Q_{jdwg} = C_{bddep}(0.95\phi_s)(V_{bd} - 0.95\phi_s) + Q_{bddif}$$

where

$$Q_{bsdep} = W_{diosCV} C_{jswg} \frac{T_{si}}{10^{-7}} \frac{P_{bswg}}{1 - Mj_{swg}} \left[1 - \left(1 - \frac{V_{bs}}{P_{bswg}}\right)^{1 - M_{jswg}}\right]$$

$$Q_{bddep} = W_{diodCV} C_{jswg} \frac{T_{si}}{10^{-7}} \frac{P_{bswg}}{1 - Mj_{swg}} \left[1 - \left(1 - \frac{V_{bd}}{P_{bswg}}\right)^{1 - M_{jswg}}\right]$$

$$Q_{bsdif} = \frac{W_{eff}'}{N_{seg}} T_{si} J_{sbjt} \left[1 + L_{dif0} \cdot \left(L_{bj0} \cdot \left(\frac{1}{L_{eff}} + \frac{1}{L_n}\right)^{N_{dif}}\right)\right] \left[\exp\left(\frac{V_{bs}}{n_{dio} V_t}\right) - 1\right] \frac{1}{\sqrt{E_{hlis} + 1}}$$

$$Q_{bddif} = \frac{W_{eff}'}{N_{seg}} T_{si} J_{sbjt} \left[1 + L_{dif0} \cdot \left(L_{bj0} \cdot \left(\frac{1}{L_{eff}} + \frac{1}{L_n}\right)^{N_{dif}}\right)\right] \left[\exp\left(\frac{V_{bd}}{n_{dio} V_t}\right) - 1\right] \frac{1}{\sqrt{E_{hlid} + 1}}$$

$$C_{jswg} = C_{jswg0}[1 + t_{cjswg}(T - T_{nom})]$$

$$P_{bswg} = P_{bswg0} - t_{pbswg}(T - T_{nom})$$

Extrinsic Capacitance

Bottom S/D to Substrate Capacitance

$$C_{sld,e} = \begin{cases} C_{box} & \text{if } V_{sld,e} < V_{sdfb} \\ C_{box} - \frac{1}{A_{sd}}(C_{box} - C_{min})\left(\frac{V_{sld,e} - V_{sdfb}}{V_{sdth} - V_{sdfb}}\right)^2 & \text{else if } V_{sld,e} < V_{sdfb} + A_{sd}(V_{sdth} - V_{sdfb}) \\ C_{min} + \frac{1}{1 - A_{sd}}(C_{box} - C_{min})\left(\frac{V_{sld,e} - V_{sdth}}{V_{sdth} - V_{sdfb}}\right)^2 & \text{else if } V_{sld,e} < V_{sdth} \\ C_{min} & \text{else} \end{cases}$$

Sidewall S/D to Substrate Capacitance

$$C_{sld,esw} = C_{sdesw}\log\left(1 + \frac{T_{si}}{T_{box}}\right)$$

BSIMPD2.2

If the parameters *Wth0* and *Rhalo* are set to default values, version 2.2 is compliant with version 2.1.

If `IgbMod=0`, the model version is 2.0.

If `IgbMod=1`, the model version is 2.2.

Oxide Tunneling Current

Oxide tunneling is important in the determination of floating-body potential for thin oxide (below 20A).

In inversion

$$J_{gb} = A\frac{V_{gb}V_{aux}}{T^2_{ox}}\left(\frac{T_{oxref}}{T_{oxqm}}\right)^{N_{tox}} exp\left(\frac{-B(\alpha_{gb1}-\beta_{gb1}|V_{ox}|)T_{ox}}{1-|V_{ox}|/V_{gb1}}\right)$$

$$V_{aux} = V_{EVB}\ln\left(1 + exp\left(\frac{|V_{ox}| - \phi_g}{V_{EVB}}\right)\right)$$

$$A = \frac{q^3}{8\pi h\phi_b}$$

$$B = \frac{8\pi\sqrt{2m_{ox}}\phi_b^{3/2}}{3hq}$$

$$\phi_b = 4.2eV$$

$$m_{ox} = 0.3m_0$$

In accumulation,

$$J_{gb} = A\frac{v_{gb}V_{aux}}{T_{ox}^2}\left(\frac{T_{oxref}}{T_{oxqm}}\right)^{N_{tox}}\exp\left(\frac{-B(\alpha_{gb2} - \beta_{gb2}|V_{ox}|)T_{ox}}{1 - |V_{ox}|/V_{gb2}}\right)$$

$$V_{aux} = V_{ECB}V_t\ln\left(1 + \exp\left(-\frac{V_{gb} - V_{fb}}{V_{ECB}}\right)\right)$$

$$A = \frac{q^3}{8\pi h\phi_b}$$

$$B = \frac{8\pi\sqrt{2m_{ox}}\phi_b^{3/2}}{3hq}$$

$$\phi_b = 3.1eV$$

$$m_{ox} = 0.4m_0$$

Body Contact Current

In BSIMPD2.2, a body resistor is connected bertween the body (B node) and the body contact (P node) if the transistor has a body-tie. The body resistance is modeled by

$$R_{bp} = \left(R_{body}\frac{W_{eff}}{L_{eff}}\right) \| \left(R_{halo}\frac{W_{eff}}{2}\right)R_{bodytext} = R_{bsh}N_{rb}$$

where R_{bp} is intrinsic body resistance

$R_{bodytext}$ is extrinsic body resistance

R_{body} is intrinsic body sheet resistance

R_{halo} is the halo implant effect

N_{rb} is the number of squares from body contact to device edge and

R_{bsh} is the sheet resistance of the body contact diffusion.

The body contact current I_{bp} is defined as the current flowing through the body resistor and is calculated by the following equation.

$$I_{bp} = \frac{V_{bp}}{R_{bp} + R_{bodytext}}$$

where V_{bp} is the voltage across node B and P.

Note: I_{bp}=0 if the transistor has a floating body.

Scaling Effects

For scaling effects, see Scaling Factors (scale and scalem) on page 242.

Component Statements

Instance Definition

```
Name  d  g  s  e  [p]  [b]  [t] ModelName parameter=value ...
```

Instance Parameters

1	w (m)	Channel width.
2	l (m)	Channel length.
3	as (m^2)	Area of source diffusion.
4	ad (m^2)	Area of drain diffusion.
5	ps (m)	Perimeter of source diffusion.
6	pd (m)	Perimeter of drain diffusion.
7	nrd (m/m)	Number of squares of drain diffusion.

8 `nrs (m/m)`	Number of squares of source diffusion.
9 `nrb (m/m)`	Number of body squares.
10 `m=1`	Multiplicity factor (number of MOSFETs in parallel).
11 `region=triode`	Estimated operating region. Spectre outputs number (0-3) in a rawfile. Possible values are `off`, `triode`, `sat`, or `subth`.
12 `rth0 (Ω)`	Thermal resistance.
13 `cth0 (F)`	Thermal capacitance.
14 `bjtoff=0`	BJT off flag.
15 `nbc=0 m/m`	Number of body contact isolation edge.
16 `nseg=1 m/m`	Number of segments for channel width partitioning.
17 `pdbcp=0 m`	Perimeter length for body contact parasitic at drain.
18 `psbcp=0 m`	Perimeter length for body contact parasitic at source.
19 `agbcp=0 m`	Gate to body overlap for body contact parasitic.
20 `aebcp=0 m`	Gate to body overlap for body contact parasitic.
21 `vbsusr=0.0 V`	Optional initial value of Vbs for transient.
22 `tnodeout=0`	Temperature node flag associated with T node.
23 `isnoisy=yes`	Should resistor generate noise. Possible values are `no` or `yes`.

Model Definition

```
model modelName b3soipd parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n`	Transistor type. Possible values are `n` or `p`.
2 `version=2.2`	Model version selector. The available versions are 2.2, 2.22 and 2.23.

Threshold voltage parameters

3 `vtho (V)`	Threshold voltage at zero body bias for long-channel devices. For enhancement-mode devices, vtho > 0 for n-channel and vth < 0 for p-channel. Default value is calculated from other model parameters.
4 `k1=0.5 √V`	Body-effect coefficient.
5 `k1w1=0.0 m`	First body effect width dependent parameter.
6 `k1w2=0.0 m`	Second body effect width dependent parameter.
7 `k2=-0.0186`	Charge-sharing parameter.
8 `k3=0`	Narrow width coefficient.
9 `k3b=0 1/V`	Narrow width coefficient.
10 `w0=2.5e-6 m`	Narrow width coefficient.
11 `nlx=1.74e-7 m`	Lateral nonuniform doping coefficient.
12 `gamma1 (√V )`	Body-effect coefficient near the surface.
13 `gamma2 (√V )`	Body-effect coefficient in the bulk.
14 `vbx (V)`	Threshold voltage transition body voltage.
15 `vbm=-3 V`	Maximum applied body voltage.
16 `dvt0=2.2`	First coefficient of short-channel effects.

17 `dvt1=0.53`	Second coefficient of short-channel effects.
18 `dvt2=-0.032 1/V`	Body-bias coefficient of short-channel effects.
19 `dvt0w=0`	First coefficient of narrow-width effects.
20 `dvt1w=5.3e6`	Second coefficient of narrow-width effects.
21 `dvt2w=-0.032 1/V`	Body-bias coefficient of narrow-width effects.
22 `a0=1`	Nonuniform depletion width effect coefficient.
23 `b0=0 m`	Bulk charge coefficient due to narrow width effect.
24 `b1=0 m`	Bulk charge coefficient due to narrow width effect.
25 `a1=0`	No-saturation coefficient.
26 `a2=1`	No-saturation coefficient.
27 ags=0 F/m^2 V	Gate-bias dependence of abulk.
28 `keta=-0.6 1/V`	Body-bias coefficient for non-uniform depletion width effect.
29 `ketas=0.0 V`	Surface Potential adjustment for bulk charge effect.

Process parameters

30 nsub=6e16 cm^{-3}	Substrate doping concentration.
31 nch=1.7e17 cm^{-3}	Peak channel doping concentration.
32 ngate (cm^{-3})	Poly-gate doping concentration.
33 `xj=0.15e-6 m`	Source/drain junction depth.
34 `lint=0 m`	Lateral diffusion for one side.
35 `wint=0 m`	Width reduction for one side.
36 `ll=0 m`	Length dependence of delta L.
37 `lln=1`	Length exponent of delta L.

38 `lw=0 m`	Width dependence of delta L.
39 `lwn=1`	Width exponent of delta L.
40 `lwl=0` m^2	Area dependence of delta L.
41 `wl=0 m`	Length dependence of delta W.
42 `wln=1`	Length exponent of delta W.
43 `ww=0 m`	Width dependence of delta W.
44 `wwn=1`	Width exponent of delta W.
45 `wwl=0` m^2	Area dependence of delta W.
46 `dwg=0 m/v`	Gate-bias dependence of channel width.
47 `dwb=0` $m/\sqrt{v}$	Body-bias dependence of channel width.
48 `dwbc=0.0 m`	Width offset for body contact isolation edge.
49 `tox=1e-8 m`	Gate oxide thickness.
50 `tbox=3e-7 m`	Buried oxide thickness.
51 `tsi=1e-7 m`	Silicon film thickness.
52 `xt=1.55e-7 m`	Doping depth.
53 `rdsw=100` Ω μm	Width dependence of drain-source resistance.
54 `prwb=0` $1/\sqrt{v}$	Body-effect coefficient for Rds.
55 `prwg=0 1/V`	Gate-effect coefficient for Rds.
56 `wr=1`	Width offset for parasitic resistance.
57 `xl=0 m`	Length variation due to masking and etching.
58 `xw=0 m`	Width variation due to masking and etching.
59 `binunit=1`	Bin parameter unit selector. 1 for microns and 2 for meters.

Mobility parameters

60 `mobmod=1` Mobility model selector.

61 `u0=670 cm2/V s` Low-field surface mobility at `tnom`. Default is 250 for PMOS.

62 `vsat=8e4 m/s` Carrier saturation velocity at `tnom`.

63 `ua=2.25e-9 m/v` First-order mobility reduction coefficient.

64 `ub=5.87e-19 m2/v2`
Second-order mobility reduction coefficient.

65 `uc=-4.65e-11 m/v2`
Body-bias dependence of mobility. Default is -0.046 and unit is 1/V for mobmod=3.

Output resistance parameters

66 `drout=0.56` DIBL effect on output resistance coefficient.

67 `pclm=1.3` Channel length modulation coefficient.

68 `pdiblc1=0.39` First coefficient of drain-induced barrier lowering.

69 `pdiblc2=8.6e-3` Second coefficient of drain-induced barrier lowering.

70 `pdiblcb=0 1/V` Body-effect coefficient for DIBL.

71 `pvag=0` Gate dependence of Early voltage.

72 `delta=0.01 V` Effective drain voltage smoothing parameter.

Subthreshold parameters

73 `cdsc=2.4e-4 F/m2` Source/drain and channel coupling capacitance.

74 `cdscb=0 F/m2 V` Body-bias dependence of `cdsc`.

75 `cdscd=0 F/m2 V` Drain-bias dependence of `cdsc`.

76 `nfactor=1` Subthreshold swing coefficient.

77 `cit=0 F`	Interface trap parameter for subthreshold swing.
78 `voff=-0.08 V`	Threshold voltage offset.
79 `dsub=drout`	DIBL effect in subthreshold region.
80 `eta0=0.08`	DIBL coefficient subthreshold region.
81 `etab=-0.07 1/V`	Body-bias dependence of `et0`.

Substrate current parameters

82 `alpha0=0 m/v`	Substrate current impact ionization coefficient.
83 `beta0=0 1/V`	First Vds dependent parameter of impact ionization current.
84 `fbjtii=0.0`	Fraction of bipolar current affecting the impact ionization.
85 `beta1=0`	Second Vds dependent parameter of impact ionization current.
86 `beta2=0 V`	Third Vds dependent parameter of impact ionization current.
87 `vdsatii0=0.9 V`	Nominal drain saturation voltage at threshold for impact ionization current.
88 `tii=0`	Temperature dependent parameter for impact ionization current.
89 `lii=0`	Channel length dependent parameter at threshold for impact ionization current.
90 `esatii=1e7 V/m`	Saturation channel electric field for impact ionization current.
91 `sii0=0.5 1/V`	First Vgs dependent parameter for impact ionization current.
92 `sii1=0.1 1/V`	Second Vgs dependent parameter for impact ionization current.
93 `sii2=0.0 1/V`	Third Vgs dependent parameter for impact ionization current.
94 `siid=0 1/V`	Vds dependent parameter of drain saturation voltage for impact ionization current.

Parasitic resistance parameters

95 `rbsh=0 Ω`	Extrinsic body contact sheet resistance.
96 `rsh=0 Ω/sqr`	Source/drain diffusion sheet resistance.
97 `rs=0 Ω`	Source resistance.
98 `rd=0 Ω`	Drain resistance.
99 `rbody=0 F`	Body resistance.
100 `rsc=0 Ω`	Source contact resistance.
101 `rdc=0 Ω`	Drain contact resistance.
102 `rss=0 Ω m`	Scalable source resistance.
103 `rdd=0 Ω m`	Scalable drain resistance.
104 `hdif=0 m`	Length of heavily doped diffusion.
105 `ldif=0 m`	Lateral diffusion beyond the gate.
106 `minr=0.1 Ω`	Minimum source/drain resistance.

Junction diode model parameters

107 `dskip=yes`	Use simple piece-wise linear model for diode currents below 0.1*`iabstol`. Possible values are `no` or `yes`.
108 `imelt=`imax' A`	Explosion current.

Overlap capacitance parameters

109 `cgso (F/m)`	Gate-source overlap capacitance.
110 `cgdo (F/m)`	Gate-drain overlap capacitance.
111 `cgeo=0.0 F/m`	Gate-substrate overlap capacitance.

112 `cgbo=2 Dwc Cox F/m`
Gate-bulk overlap capacitance..

113 `meto=0 m` Metal overlap in fringing field.

114 `cgsl=0 F/m` Gate-source overlap capacitance in LDD region.

115 `cgdl=0 F/m` Gate-drain overlap capacitance in LDD region.

116 `ckappa=0.6` Overlap capacitance fitting parameter.

Junction capacitance model parameters

117 `cjswg=cjsw F/m` Zero-bias gate-side junction capacitance density.

118 `mjswg=0.5` Gate-side junction grading coefficient.

119 `pbswg=0.7 V` Gate-side junction built-in potential.

120 `tt=1e-12 s` Transit time.

121 `ndif=1` Power coefficient of channel length dependency for diffusion capacitance.

122 `ldif0=1` Power coefficient of channel length dependency for diffusion capacitance.

Charge model selection parameters

123 `capmod=2` Intrinsic charge model.

124 `dwc=wint m` Delta W for capacitance model.

125 `delvt=0.0 V` Threshold voltage adjustment for C-V.

126 `fbody=1.0` Scaling factor for body charge.

127 `dlc=lint m` Delta L for capacitance model.

128 `dlcb=lint m` Length offset fitting parameter for body charge.

129 `dlbg=0.0 m` Length offset fitting parameter for backgate charge.

130 `clc=1e-8 m` Intrinsic capacitance fitting parameter.

131 `cle=0.0` Intrinsic capacitance fitting parameter.

132 `cf (F/m)` Fringe capacitance parameter.

133 `vfbcv=-1` Flat-band voltage for capmod=0.

134 `xpart=0` Drain/source channel charge partition in saturation for BSIM charge model, use 0.0 for 40/60, 0.5 for 50/50, or 1.0 for 0/100.

Default instance parameters

135 `w=5e-6 m` Default channel width.

136 `l=5e-6 m` Default channel length.

137 `as=0` m^2 Default area of source diffusion.

138 `ad=0` m^2 Default area of drain diffusion.

139 `ps=0 m` Default perimeter of source diffusion.

140 `pd=0 m` Default perimeter of drain diffusion.

141 `nrd=0 m/m` Default number of squares of drain diffusion.

142 `nrs=0 m/m` Default number of squares of source diffusion.

143 `nrb=0 m/m` Default body squares.

Temperature effects parameters

144 `tnom (C)` Parameters measurement temperature. Default set by `options`.

145 `tmax=500 C` Maximum device temperature above ambient.

146 `shmod=0` Self-heating selector.

147 `tlev=0` DC temperature selector.

148 `tlevc=0` AC temperature selector.

149 `eg=1.12452 V` Energy band gap.

150 `gap1=7.02e-4 V/C` Band gap temperature coefficient.

151 `gap2=1108 C` Band gap temperature offset.

152 `kt1=-0.11 V` Temperature coefficient for threshold voltage.

153 `kt1l=0 v m` Temperature coefficient for threshold voltage.

154 `kt2=0.022` Temperature coefficient for threshold voltage.

155 `at=3.3e4 m/s` Temperature coefficient for `vsat`.

156 `tcjswg=0 1/K` Temperature coefficient of Cjswg.

157 `tpbswg=0 V/K` Temperature coefficient of Pbswg.

158 `ua1=4.31e-9 m/v` Temperature coefficient for `ua`.

159 `ub1=-7.61e-18` m^2/v^2
Temperature coefficient for `ub`.

160 `uc1=-5.5e-11` m/v^2
Temperature coefficient for `uc`. Default is -0.056 for mobmod=3.

161 `prt=0 Ω` Temperature coefficient for Rds.

162 `trs=0 1/C` Temperature parameter for source resistance.

163 `trd=0 1/C` Temperature parameter for drain resistance.

164 `ute=-1.5` Mobility temperature exponent.

165 `dt1=0` First temperature coefficient for tau.

166 `dt2=0` Second temperature coefficient for tau.

167 `cth0=0 F` Self-heating thermal capacitance.

168 `rth0=0 Ω` Self-heating thermal resistance.

169 `ntrecf=0` Temperature coefficient of Ntrecf.

170 `ntrecr=0`	Temperature coefficient of Ntrecr.
171 `xbjt=2`	BJT current temperature exponent.
172 `xdif=2`	Diffusion current temperature exponent.
173 `xrec=20`	Recombination current temperature exponent.
174 `xtun=0`	Tunneling current temperature exponent.

Noise model parameters

175 `noimod=1`	Noise model selector.
176 `kf=0`	Flicker (1/f) noise coefficient.
177 `af=1`	Flicker (1/f) noise exponent.
178 `ef=1`	Flicker (1/f) noise frequency exponent.
179 `noia=1e20`	Oxide trap density coefficient. Default is 9.9e18 for pmos.
180 `noib=5e4`	Oxide trap density coefficient. Default is 2.4e3 for pmos.
181 `noic=-1.4e-12`	Oxide trap density coefficient. Default is 1.4e-8 for pmos.
182 `em=4.1e7 V/m`	Maximum electric field.

Auto Model Selector parameters

183 `wmax=1 m`	Maximum channel width for which the model is valid.
184 `wmin=0 m`	Minimum channel width for which the model is valid.
185 `lmax=1 m`	Maximum channel length for which the model is valid.
186 `lmin=0 m`	Minimum channel length for which the model is valid.

Operating region warning control parameters

187 `alarm=none`	Forbidden operating region. Possible values are `none`, `off`, `triode`, `sat`, `subth`, or `rev`.

188 `imax=1 A`	Maximum allowable current.
189 `bvj=∞ V`	Junction reverse breakdown voltage.
190 `vbox=1e9 tox V`	Oxide breakdown voltage.
191 `warn=on`	Parameter to turn warnings on and off. Possible values are `off` or `on`.

SOI specific parameters

192 `vbsa=0 V`	Vbs0t offset voltage.
193 `delp=0.02`	Offset constant for limiting Vbseff to Phis.
194 `kb1=1`	Scaling factor for backgate charge.
195 `kb3=1`	Backgate coupling coefficient at subthreshold.
196 `dvbd0=0 V`	First coefficient of short-channel effect on Vbs0t.
197 `dvbd1=0`	First coefficient of short-channel effect on Vbs0t.
198 `abp=1`	Gate bias coefficient for Xcsat calculation.
199 `mxc=-0.9`	A smoothing parameter for Xcsat calculation.
200 `agidl=0`	GIDL constant.
201 `bgidl=0 V/m`	GIDL exponential coefficient.
202 `ngidl=1.2 V`	GIDL Vds enhancement coefficient.
203 `ntun=10`	Reverse tunneling non-ideality factor.
204 `nrecf0=2.0`	Recombination non-ideality factor at forward bias.
205 `nrecr0=10`	Recombination non-ideality factor at reversed bias.
206 `vsdfb (F/m)`	Source/Drain diffusion flatband voltage.
207 `vsdth`	Source/Drain diffusion threshold voltage.

208 `csdmin (F)`	Source/Drain diffusion bottom minimum capacitance.
209 `csdesw=0`	Source/drain sidewall fringing constant.
210 `aii=0`	First parameter for critical field.
211 `bii=0`	Second parameter for critical field.
212 `cii=0`	Gate dependence of critical field.
213 `dii=-1`	Body dependence of critical field.
214 `ndiode=1`	Diode non-ideality factor.
215 `asd=0.3`	Source/Drain diffusion smoothing parameter.
216 `isbjt=1e-6 A`	BJT saturation current.
217 `isdif=0 A`	Diffusion saturation current.
218 `isrec=1e-5 A`	Recombination saturation current.
219 `istun=0 A`	Tunneling saturation current.
220 `ln=2e-6 m`	Electron diffusion length.
221 `vrec0=0 V`	Voltage dependent parameter for recombination current.
222 `vtun0=0 V`	Voltage dependent parameter for tunneling current.
223 `nbjt=1`	Power coefficient of channel length dependency for bipolar current.
224 `lbjt0=0.20e-6 m`	Reference channel length for bipolar current.
225 `vabjt=10 V`	Early voltage for bipolar current.
226 `aely=0 V`	Channel length dependency of early voltage for bipolar current.
227 `ahli=0`	High level injection parameter for bipolar current.
228 `kbjt1=0 m`	Parasitic bipolar base width.

Gate tunneling parameters

229 `wth0=0.0 µm` Minimum width for thermal resistance calculation..

230 `rhalo=1.0e15 Ω/sqr`
Body halo sheet resistance.

231 `ntox=1.0` Power term of gate current.

232 `toxref=2.5e-9 m` Target oxide thickness.

233 `ebg=1.2 V` Effective bandgap in gate current calculation.

234 `nevb=3.0` Valence-band electron non-ideality factor.

235 `alphagb1=0.35` First Vox dependent parameter for gate current in inversion..

236 `betagb1=0.03` Second Vox dependent parameter for gate current in inversion..

237 `vgb1=300` Third Vox dependent parameter for gate current in inversion..

238 `alphagb2=0.43` First Vox dependent parameter for gate current in accumulation..

239 `betagb2=0.05` Second Vox dependent parameter for gate current in accumulation..

240 `necb=1.0` Conduction-band electron non-ideality factor.

241 `vgb2=17` Third Vox dependent parameter for gate current in accumulation..

242 `toxqm=Tox m` Effective oxide thickness considering quantum effects..

243 `voxh=5.0 V` Limit of Vox in gate current calculation..

244 `deltavox=0.005 V` Smoothing parameter in the Vox smoothing function..

245 `igmod=0` Gate current model selector.

Length dependent parameters (Not listed)

Width dependent parameters (Not listed)

Cross-term dependent parameters

246 `paramchk=1`	Model parameter checking selector.
247 `noif=1`	Floating body excess noise ideality factor.
248 `w0flk=0 m`	Width constant for flicker noise equation.
249 `frbody=1`	Layout dependent body-resistance coefficient.
250 `vevb=0.075`	Vaux parameter for valence-band electron tunneling.
251 `vecb=0.026`	Vaux parameters for conduction-band electron tunneling.
252 `dtoxcv=0.0 m`	Delta oxide thickness in Capmod3.
253 `llc=0 m`	Length dependence of delta LC.
254 `lwc=0 m`	Width dependence of delta LC.
255 `lwlc=0` m^2	Area dependence of delta LC.
256 `wlc=0 m`	Length dependence of delta WC.
257 `wwc=0 m`	Width dependence of delta WC.
258 `wwlc=0` m^2	Area dependence of delta WC.

Shrink Parameters

259 `shrink=0`	linear shrink parameter.
260 `shrink2=0`	area shrink parameter.

The `jmelt` parameter is used to aid convergence and prevent numerical overflow. The junction characteristics of the FET are accurately modeled for current (density) up to `jmelt`. For current density above `jmelt`, the junction is modeled as a linear resistor and a warning is printed.

Auto Model Selection:

Many models need to be characterized for different geometries in order to obtain accurate results for model development. The model selector program automatically searches for a model with the length and width range specified in the instance statement and uses this model in the simulations.

For the auto model selector program to find a specific model, the models to be searched should be grouped together within braces. Such a group is called a model group. An opening brace is required at the end of the line defining each model group. Every model in the group is given a name followed by a colon and the list of parameters. Also, the four geometric parameters `lmax`, `lmin`, `wmax`, and `wmin` should be given. The selection criteria to choose a model is as follows:

lmin <= inst_length < lmax and wmin <= inst_width < wmax

Example:

model ModelName ModelType {

1: <model parameters> lmin=2 lmax=4 wmin=1 wmax=2

2: <model parameters> lmin=1 lmax=2 wmin=2 wmax=4

3: <model parameters> lmin=2 lmax=4 wmin=4 wmax=6

}

Then for a given instance

M1 1 2 3 4 ModelName w=3 l=1.5

the program would search all the models in the model group with the name `ModelName` and then pick the first model whose geometric range satisfies the selection criteria. In the preceding example, the auto model selector program would choose ModelName.2.

You must specify both length (l) and width (w) on the device instance line to enable automatic model selection.

Output Parameters

1	`weff (m)`	Effective channel width.
2	`leff (m)`	Effective channel length.

3 `rtheff (Ω)` Effective thermal resistance.

4 `Ctheff (F)` Effective thermal capacitance.

5 `rseff (Ω)` Effective source resistance.

6 `rdeff (Ω)` Effective drain resistance.

Operating-Point Parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

2 `region=triode` Estimated operating region. Spectre outputs number (0-3) in a rawfile.
Possible values are `off`, `triode`, `sat`, or `subth`.

3 `reversed` Reverse mode indicator.
Possible values are `no` or `yes`.

4 `vgs (V)` Gate-source voltage.

5 `vds (V)` Drain-source voltage.

6 `vbs (V)` Bulk-source voltage.

7 `vbgs (V)` Back-Gate-source voltage.

8 `ids (A)` Resistive drain-to-source current.

9 `ic (A)` BJT collector current.

10 `isgidl (A)` Source GIDL current.

11 `idgidl (A)` Drain GIDL current.

12 `iii (A)` Impact ionization current.

13 `ibd (A)` Resistive bulk-to-drain junction current.

14 `igbt (A)` Gate-to-body tunneling current.

15 `ibs (A)` Resistive bulk-to-source junction current.

16 `vth (V)`	Threshold voltage.
17 `vdsat (V)`	Drain-source saturation voltage.
18 `gm (S)`	Common-source transconductance.
19 `gds (S)`	Common-source output conductance.
20 `gmb (S)`	Body-transconductance.
21 `gmbg (S)`	Back-gate-transconductance.
22 `ueff` (cm^2/V s)	Effective mobility.
23 `betaeff` (A/V^2)	Effective `beta`.
24 `qg (Coul)`	Gate charge.
25 `qd (Coul)`	Drain charge.
26 `qs (Coul)`	Source charge.
27 `qb (Coul)`	Body charge.
28 `qbg (Coul)`	Back-Gate charge.
29 `cgg (F)`	dQg_dVg.
30 `cgd (F)`	dQg_dVd.
31 `cgs (F)`	dQg_dVs.
32 `cgb (F)`	dQg_dVbk .
33 `cdg (F)`	dQd_dVg.
34 `cdd (F)`	dQd_dVd.
35 `cds (F)`	dQd_dVs.
36 `cdb (F)`	dQd_dVb.
37 `csg (F)`	dQs_dVg.

38 `csd (F)`	dQs_dVd.
39 `css (F)`	dQs_dVs.
40 `csb (F)`	dQs_dVb.
41 `cbg (F)`	dQb_dVg.
42 `cbd (F)`	dQb_dVd.
43 `cbs (F)`	dQb_dVs.
44 `cbb (F)`	dQb_dVb.
45 `id (A)`	Total resistive drain current.
46 `is (A)`	Total resistive source current.
47 `ib (A)`	Total resistive bulk current.
48 `pwr (W)`	Power at op point.
49 `gmoverid (1/V)`	Gm/Ids.
50 `tdev (C)`	Temperature rise from ambient.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

30

HiSIM2 Model (hisim2)

The HiSIM2 (Hiroshima-university STARC IGFET Model) model was developed at Hiroshima University in collaboration with the STARC research center. This is the first complete surface-potential-based MOSFET model for circuit simulation based on the drift-diffusion approximation, which was originally developed by Pao and Sah. The most important advantage of the surface-potential-based modeling is the unified description of device characteristics for all bias conditions. The physical reliability of the drift-diffusion approximation has been proved by 2D device simulations with channel lengths even down to below 0.1μm.

This chapter contains the following information about the HiSIM2 model:

Model Concepts

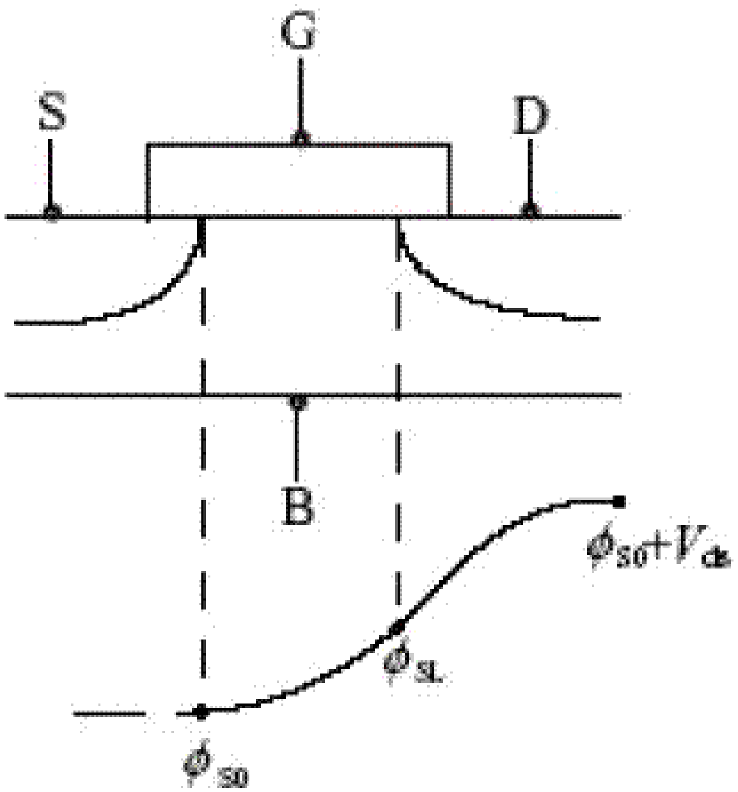


Figure 30-1 Schematic of the surface potential distribution in the channel

The figure shows the schematic of the surface potential distribution in the channel. To obtain analytical solutions for describing device performances, the charge sheet approximation of the inversion layer with zero thickness has been introduced. Together with the gradual-channel approximation all device characteristics are then described analytically by the channel-surface potentials at the source side (ϕ_{S0}) and at the drain side (ϕ_{SL}). These surface potentials are functions of applied voltages on the four MOSFET terminals; the gate voltage Vg, the drain voltage Vd, the bulk voltage Vb and the reference potential of the source Vs. This is the long-channel basis of the HiSIM model, and extensions of the model approximations are done for advanced technologies. All newly appearing phenomena such as short-channel and reverse-short-channel effects are included in the surface potential calculations causing modifications resulting from the features of these advanced technologies.

Model Usage

HiSIM2 model definition is used to describe the behavior of devices which has same model characteristic and the instance parameters can be used to describe the characteristics that belong to the specific device.

Instance Syntax

HiSIM2 instance need specify 4 terminals. To specify HiSIM2 instance element, the ModelName has to be associated with a HiSIM2 model card.

```
InstanceName d g s b [th] HiSIM2ModelName parameter=value ...
```

Sample Instance Statement

```
m1 (vdd vgg vss vbb) n_ch w=10u l=2u m=1 nf=10
```

For more instance parameters, refer to Reference on page 2363.

Model Syntax

The following syntax specifies HiSIM2 model:

```
model ModelName hisim2 parameter=value ...
```

The third parameter, `hisim2`, is the master to indicate this model card is a HiSIM2 model card.

Sample Model Statement

```
model n_ch hisim2 type=n version=2.60 tox=3e-8 corsrd=-1 rs=1e-3 rd=5e-2
```

For more model parameters, refer to Reference on page 2363.

Model Version and Development

Cadence Virtuoso® Spectre/APS and Ultrasim supports the following versions of HiSIM2 model: 2.50, 2.51, 2.60, 2.61, and 2.70. Different model versions can be obtained by setting different model parameter VERSION = 2.50/2.51/2.60/2.61/2.70. 2.50 is set as the default version.

The following lists the recent model versions and their corresponding simulator version for your reference:

HiSIM2 Version 2.51	MMSIM101_ISR10
HiSIM2 Version 2.60	MMSIM111_ISR6
HiSIM2 Version 2.61	MMSIM111_ISR11
HiSIM2 Version 2.70	MMSIM131

If you still have any questions, please contact with Cadence support team.

Version Update and Enhancement

Version 2.70 Enhancement

- Unit conversion from CGS to MKS
- Change in model descriptions
  - Suppression of error messages from the range check when new the model flag `COERRREP` is set to 0
  - Improvement of GIDL current model with new model parameters `GIDL6` and `GIDL7`
  - Improvement of STI effect model with new model parameters `NSUBCSTI1`, `NSUBCSTI2`, and `NSUBCSTI3`
  - Introduction of gate length dependence for `VFBC` with new model parameters `VFBCL` and `VFBCLP`
  - Improvement of smoothness of the NSUBPFAC model with the new model parameter `NSUBPDLT`
  - Invalidation of the `NSUBPFAC` model when `NSUBPFAC = 1`
  - Range check of model parameters `NSUBPFAC` and `NSUBPDLT`
- Bug fixes:
  - Calculation of `MUEPH1` when `CODFM=1`
  - Resetting of `SC4` value when `CORECIP=1`
  - Calculation of some derivatives

- Floating point exception in the smoothing functions
- High-field effect model with model parameter GDLD
- Code improvements of Fn_POW and Fn_SZ functions for higher exception robustness

Version 2.61 Enhancement

- Missing initialization of NSUBC, NSUBP, and MUEPH1 in the Initialize for repeating simulation
- Unit converting in the Initialize
- Derivative calculations in the Q_{over} model code
- Floating point exception in the QME model code
- Floating point exception in the smoothing functions

Version 2.60 Enhancement

- Introduction of the Well Proximity Effect model with new parameters:
  - Instance parameters: SCA , SCB, and SCC
  - Model parameters: WEB , WEC , NSUBCWPE , NSUBPWPE, and NPEXTWPE
- Improvement of the overlap capacitance model
- Activation of Induced Gate Noise model
- Change the default value of the instance parameters NRD and NRS.

Reference

Model Equations

Effective Length and Width

L_{gate} and W_{gate} are the gate length and gate width. They are calculated from the gate drawn length and width.

$$L_{gate} = L_{drawn} + XL$$

$$W_{gate} = \frac{W_{drawn}}{NF} + XW$$

$$L_{poly} = L_{gate} - 2 \text{ X} \frac{LL}{(L_{gate} + LLD)^{LLN}}$$

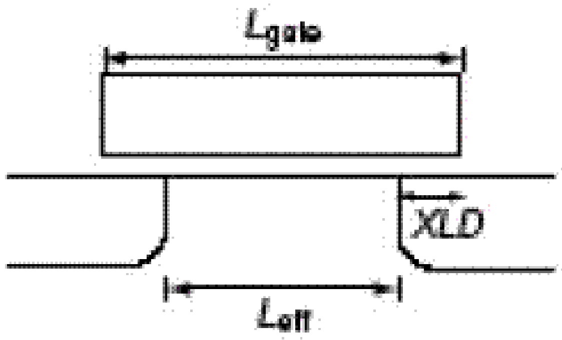
$$W_{poly} = W_{gate} - 2 \text{ X} \frac{WL}{(W_{gate} + WLD)^{WLN}}$$

$$L_{eff} = L_{poly} - 2 \text{ X } XLD$$

$$W_{eff} = W_{poly} - 2 \text{ X } XWD$$

where XLD and XWD account for the overlaps of source/drain contact and gate oxide. LL, LLD, LLN, WL, WLD, and WLN are further model parameters for including L_{gate} or W_{gate} dependencies on L_{eff} and W_{eff}.

Figure 30-2 Cross section of the device



Charge

All device characteristics are determined on the basis of the charge control by applied voltages and by expressing the MOSFET charges as functions of the surface potentials.

Under the charge-sheet approximation the charges on the four MOSFET terminals Q_G(gate), Q_B (bulk), Q_D (drain), and Q_S (source), are described as:

$$Q_G = -(Q_B + Q_I) = -Q_{SP}$$

$$Q_B = W_{eff} {}^* NF {}^* \int_0^{L_{eff}} Q_b(y)dy$$

$$Q_I = W_{eff} \int_0^{L_{eff}} Q_i(y)dy$$

$$Q_D = W_{eff} \int_0^{L_{eff}} \frac{y}{L_{eff}} Q_i(y)dy$$

$$Q_S = Q_I - Q_D$$

where Q_I is the inversion charge, Q_{SP} is the space charge, and y is the position along the channel. L_{eff} and 0 are the channel-end positions at the drain side and the source side, respectively.

By applying the Gauss law, the space charge density Q_{SP} is derived from the Poisson equation.

$$-Q_{SP} = C_{ox}(V_G' - \varphi_s(y))$$

$$C_{ox} = \frac{\varepsilon_{ox}}{TOX}$$

$$V_G' = V_{gs} - VFBC + \Delta Vth$$

$$\beta = \frac{q}{kT}$$

where VFBC is the at-band voltage, TOX is the physical gate-oxide thickness, and ΔVth is the threshold voltage shift in comparison to the threshold voltage of a long-channel transistor. The electron charge is denoted by q, and ε_{si} and N_{sub} are the silicon permittivity and the substrate impurity concentration, respectively. The Boltzmann constant and the lattice temperature in Kelvin are k and T, respectively.

The quasi-Fermi potential ϕ_f (f) preserves the following relationship:

$$\varphi_f(L_{eff}) - \varphi_f(0) = V_{ds,eff}$$

The electron concentration at equilibrium condition n_{p0} is

$$n_{p0} = \frac{n_i^2}{P_{p0}}$$

where the intrinsic carrier concentration n_i is

$$n_i = n_{i0} T^{\frac{1}{2}} \exp\left(-\frac{E_g}{2q}\beta\right)$$

p_{p0} is approximated to be N_{sub}, and E_g describes the temperature dependence of the bandgap.

The Poisson equation and the Gauss law are used to derive the inversion charge and bulk charge related charge-density equations under the assumption of a homogeneous substrate impurity distribution as

$$Q_b(y) = -\sqrt{\frac{2\varepsilon_{si} q N_{sub}}{\beta}} [\exp\{-\beta(\varphi_s(y) - V_{bs})\} + \beta(\varphi_s(y) - V_{bs})]^{1/2}$$

$$Q_i(y) = -C_{ox}(V_G' - \varphi_s(y)) + \sqrt{\frac{2\varepsilon_{si} q N_{sub}}{\beta}} [\exp\{-\beta(\varphi_s(y) - V_{bs})\} + \beta(\varphi_s(y) - V_{bs}) - 1]^{1/2}$$

Drain Current

Under gradual-channel approximation with further approximations of an idealized gate structure and uniform channel doping, the drift-diffusion approximation describes the drain current I_{ds} as:

$$I_{ds} = \frac{W_{eff}*NF}{L_{eff}}*\mu*\frac{I_{dd}}{\beta}$$

$$I_{dd} = C_{ox}(\beta V_G' + 1)(\varphi_{SL} - \varphi_{S0}) - \frac{\beta}{2}C_{ox}(\varphi_{SL}^2 - \varphi_{S0}^2)$$

$$-\frac{2}{3}const0[\{\beta(\varphi_{SL} - V_{bs}) - 1\}^{3/2} - \{\beta(\varphi_{S0} - V_{bs}) - 1\}^{3/2}]$$

$$+const0[\{\beta(\varphi_{SL} - V_{bs}) - 1\}^{1/2} - \{\beta(\varphi_{S0} - V_{bs}) - 1\}^{1/2}]$$

$$\varphi_{S0} = 2\varphi_B, \varphi_B = \frac{2}{\beta}1n\left(\frac{N_{sub}}{n_i}\right)$$

$$\varphi_{SL} = 2\varphi_B + V_{ds}$$

The description for the long-channel case is obtained as:

$$I_{ds} = \frac{W_{eff}*NF}{L_{eff}}\mu*C_{ox}\left[(V_G' - V_{th})V_{ds} - \left(\frac{1}{2} + \frac{\sqrt{2\varepsilon_{si} \cdot qN_{sub}}}{4C_{ox}\sqrt{2\varphi_B}}\right)V_{ds}^2\right]$$

$$V_{th} = VFBC + 2\varphi_B + \frac{\sqrt{2\varepsilon_{si} \cdot qN_{sub}}}{C_{ox}}\sqrt{2\varphi_B}$$

Threshold Voltage Shift

Different from the drift approximation, the drift-diffusion approximation does not require a threshold voltage parameter Vth for describing device performances. The MOSFET device parameters, such as the oxide thickness T_{OX} and the substrate doping concentration NSUBC determine the complete MOSFET behavior including the subthreshold characteristics automatically and consistently. The measured V_{th} is influenced by various phenomena, such as the short-channel effects, which cause a reduction of Vth for short-channel transistors in comparison to long-channel transistors as shown in Fig. 5. This so-called ΔV_{th} roll-off is very much dependent on the technology applied for MOSFET fabrication. Therefore, HiSIM can derive many detailed information on the MOSFET fabrication technology, which is relevant for modeling device characteristics, from the V_{th} changes (ΔV_{th}) as a function of gate length (L_{gate}). The modeled ΔV_{th} is incorporated in the ϕ_S iteration, and can be viewed as consisting of two main effects or components:

1. The short-channel effect: $\Delta V_{th,SC}$
2. The reverse-short-channel effect: $\Delta V_{th,R}$ and $\Delta V_{th,P}$

The separation into these components is shown below:

Short-Channel Effect

Four important phenomena are observed:

1. Reduction of Vth for reduced Lgate
2. Vth dependence on Vds
3. Reduction of the body effect
4. Increase of the subthreshold swing, which is often not obvious for the normal case of fabrication technologies. Recent advanced technologies utilize aggressive scaling, which induces observable subthreshold degradation.

$$\Delta V_{th,SC} = \frac{\varepsilon_{si}}{C_{ox}} W_d \frac{dE_y}{dy}$$

where W_d is the depletion-layer thickness written as

$$W_d = \sqrt{\frac{2\varepsilon_{si}(2\varphi_B - V_{bs})}{qN_{sub}}}$$

$$2\varphi_B = \frac{2}{\beta} 1n\left(\frac{N_{sub}}{n_i}\right)$$

dE_y/dy is derived with model parameters in the form

$$\frac{dE_y}{dy} = \frac{2\{VBI - 2\varphi_B\}}{(L_{gate} - PARL2)^2}\left(SC1 + SC2 * V_{ds} + SC3 * \frac{2\varphi_B - V_{bs}}{L_{gate}} + SC4 \cdot V_{ds}(2\varphi_B - V_{bs})\right)$$

Reverse-Short-Channel Effects

Impurity concentration inhomogeneity in the direction vertical to the channel (Retrograded Implantation)

$$\Delta V_{th,R} = \frac{Q_{dep}}{C_{ox}} - \frac{Q_{dep}(long)}{C_{ox}}$$

$$Q_{dep} = q\int_0^{Wd} N_{sub}(\chi)d\chi$$

$$Q_{dep} = QDEPCC + \frac{QDEPCL}{L_{gate}^{QDEPCS}} + \left(QDEPBC + \frac{QDEPBL}{L_{gate}^{QDEPBS}}\right)\sqrt{2\varphi_B - V_{bs}}$$

$$Q_{Bmod} = \sqrt{2q \cdot N_{sub} \cdot \varepsilon_{si} \cdot \left(2\varphi_B - V_{bs} - \frac{BS1}{BS2 - V_{bs}}\right)}$$

where BS1 represents the strength of the deviation and BS2 is the starting value of Vbs where the deviation becomes visible.

Impurity concentration inhomogeneity in the lateral direction parallel to the channel (Pocket Implantation)

$$\Delta V_{th,P} = (\Delta V_{th,R} - V_{th0})\frac{\varepsilon_{si}}{C_{ox}} W_d \frac{dE_{y,P}}{dy} + dqb$$

$$V_{th,R} = VFBC + 2\varphi_B + \frac{Q_{B0}}{C_{ox}} + \frac{1}{\beta}\log\left(\frac{N_{subb}}{NSUBC}\right)$$

$$Q_{B0} = \sqrt{2q \cdot N_{sub} \cdot \varepsilon_{si} \cdot (2\varphi_B - V_{bs})}$$

$$V_{th0} = VFBC + 2\varphi_{BC} + \frac{\sqrt{2q \cdot NSUBC \cdot \varepsilon_{si} \cdot (2\varphi_{BC} - V_{bs})}}{C_{ox}}$$

$$N_{subb} = 2 \cdot NSUBP - \frac{(NSUBP - NSUBC) \cdot L_{gate}}{LP} - NSUBC$$

$$dqp = \frac{Q_{B0} - Q_{Bmod}}{C_{ox}}$$

$$\varphi_{BC} = \frac{2}{\beta} 1n\left(\frac{NSUBC}{n_i}\right)$$

$$\varphi_B = \frac{2}{\beta} 1n\left(\frac{N_{sub}}{n_i}\right)$$

$$N_{sub} = \frac{NSUBC(L_{gate} - LP) + NSUBP \cdot LP}{L_{gate}}$$

$$\Delta V_{th,P} = \Delta V_{th,P} - \frac{SCP22}{(SCP21 + V_{ds})^2}$$

$$N_{sub} = N_{sub} + \frac{NPEXT - N_{subc}}{\left(\frac{1}{\chi\chi} + \frac{1}{LPEXT}\right) L_{gate}}$$

where

$$\chi\chi = 0.5 \cdot L_{gate} - LP$$

CORECIP = 1 for Accurate Reciprocity Calculation of Capacitances

The model CORECIP enables accurate calculation of the capacitance reciprocity. If CORECIP = 1 is selected, the V_{ds} dependence is moved to the puchthrough model described in the next section. Accordingly, model parameters SC2,SC4,SCP2 and SCP4 must be set to zero, and PT2 and PT4 activated.

Short Channel Effects

Punchthrough Effect

The origin of the punchthrough effect is the bipolar effect through source, substrate, and drain.The effect is described by a power function of the potential difference instead of the exponential function as

$$POTENTIAL = (VBI - \varphi_{s0})^{PTP}$$

The final drain current I_{ds} is written

$$I_{ds} = I_{ds} + PUNCH$$

$$PUNCH = \frac{W_{eff} \cdot NF}{L_{eff}} \frac{\mu}{\beta} \cdot (\varphi_{SL} - \varphi_{S0})$$

$$\cdot \left\{ C_{ox} \cdot \beta \frac{PTL}{(L_{gate} \cdot 10^6)^{PTLP}} \cdot POTENTIAL \cdot \left(1 + PT2 \cdot V_{ds} + \frac{PT4 \cdot (\varphi_{s0} - V_{bs})}{(L_{gate} \cdot 10^6)^{PT4P}} \right) \right\}$$

Channel Conductance

The high field under the saturation condition causes the pinch-off region and the current flows away from the surface. This effect is considered as the lateral-field-induced charge for the capacitance. The simplified formulation is applied to consider the effect as

$$I_{ds} = I_{ds} + \frac{W_{eff} \cdot NF}{L_{eff}} \frac{\mu}{\beta} \cdot (\varphi_{SL} - \varphi_{S0}) \cdot CONDUCTANCE$$

$$CONDUCTANCE = C_{ox} \cdot \beta \frac{GDL}{(L_{gate} \cdot 10^6 + GDLD \cdot 10^6)^{GDLP}} \cdot V_{ds}$$

Pocket Impurity Concentration Reduction

If the gate length becomes shorter, the pocket-impurity concentration may become lower than for long channels. This effect is modeled as:

$$N_{subp} = NSUBP \cdot \left(\frac{2 \cdot (1 - NSUBPFAC)}{NSUBPL} \cdot L_{gate} \cdot 10^6 + 2 \cdot NSUBPFAC - 1 \right)$$

Depletion Effect of the Gate Poly-Si

Carrier depletion in the gate poly-Si occurs due to the relatively low impurity concentration of the poly-Si in the region above the gate-oxide. Nevertheless, this concentration is usually much higher than the impurity concentration in the substrate. Therefore, carrier depletion in the poly-Si near the gate-oxide interface starts after the formation of the inversion layer in the substrate. For modeling the gate poly-Si depletion a physical model parameter, namely the impurity concentration in the gate poly-Si (N_{pg}), is introduced.

$$V_G{}' - \varphi_S - \varphi_{Spg} = -\frac{Q_{SP}}{C_{ox}} = \frac{\varepsilon_{si} E_{Si}}{C_{ox}}$$

$$E_{pg} = qN_{pg} L_{D,pg} \sqrt{2}\left[\{\exp(-\beta\varphi_{Spg}) + \beta\varphi_{Spg} - 1\} + \frac{n_{p0,pg}}{p_{p0,pg}}\{\exp(-\beta\varphi_{Spg}) - \beta\varphi_{Spg} - 1\}\right]^{\frac{1}{2}}$$

$$E_{pg} = qN_{pg} L_{D,pg} \sqrt{2}(\beta\varphi_{Spg} - 1)^{\frac{1}{2}}$$

$$\varphi_{Spg} = PGD1\left(1 + \frac{1}{L_{gate} \cdot 10^6}\right)^{PGD4} \exp\left(\frac{V_{gs} - PGD2}{V}\right)$$

Quantum-Mechanical Effects

The main quantum-mechanical phenomenon, which has to be included into a MOSFET model for circuit simulation, is the repulsion of the channel's carrier-density peak into the substrate away from the surface. This can be described phenomenologically by an increased effective oxide thickness T_{ox}. Two major approximations are introduced to derive a simple set of equations for T_{ox}: First, a triangular potential perpendicular to the channel is approximated and second, carriers are assumed to occupy only the lowest quantized energy level. The resulting effective oxide thickness T_{ox} can be written as:

$$T_{ox} = TOX + \Delta T_{ox}$$

For HiSIM2.5

$$\Delta T_{ox} = \frac{QME1}{QME2^2}(V_{gs} - V_{th}(T_{ox} = TOX) - QME2)^2 + QME3$$

For HiSIM2.5.1

$$\Delta T_{ox} = \frac{QME1}{V_{gb} - V_{th}(T_{ox} = TOX) + QME2} + QME3$$

Mobility Model

Here E_{eff} is the effective field normal to the surface and is written as:

$$\frac{1}{\mu_0} = \frac{1}{\mu_{CB}} + \frac{1}{\mu_{PH}} + \frac{1}{\mu_{SR}}$$

$$\mu_{CB}(Coulomb) = M_{Coulomb0} + M_{Coulomb1}\frac{Q_i}{q \cdot 10^{11}}$$

$$\mu_{PH}(phonon) = \frac{Muephonon}{E_{eff}^{MUEPH0}}$$

$$\mu_{SR}(roughness) = \frac{MUESR1}{E_{eff}^{M_{uesurface}}}$$

Here E_{eff} is the effective field normal to the surface and is written as

$$E_{eff} = \frac{1}{\varepsilon_{Si}}(N_{dep} \cdot Q_b + NINV \cdot Q_i) \cdot f(\varphi_s)$$

$$f(\varphi_s) = \frac{1}{1 + (\varphi_{S0} - \varphi_{SL}) \cdot NINVD}$$

where N_{dep} considers the gate length dependence with two model parameters NDEPL and NDEPLP as:

$$N_{dep} = NDEP\frac{(L_{gate} \cdot 10^6)^{NDEPLP}}{NDEPL + (L_{gate} \cdot 10^6)^{NDEPLP}}$$

The mobility preserves the following conditions:

$$MUEPH0 \approx 0.3$$
$$M_{uesurface} = 2.0$$
$$NDEP = 1.0$$
$$NINV = 0.5$$

Due to the carrier ow at increasing distance from the surface with reducing Lgate, the electric field experienced by the carriers is different from the field in the long Lgate case. This results in a modification of $M_{uephonon}$, which is modeled as:

$$M_{uephonon} = MUEPH1 \cdot \left(1 + \frac{MUEPHL}{(L_{gate} \cdot 10^6 + MUEPLD \cdot 10^6)^{MUEPLP}}\right) \cdot \left(1 + \frac{MUEPHL2}{(L_{gate} \cdot 10^6)^{MUEPLP2}}\right)$$

The surface roughness co-efficient $M_{uesurface}$ is modelled to have a similar channel length dependence written as:

$$M_{uesurface} = MUESR0 \cdot \left(1 + \frac{MUESRL}{(L_{gate} \cdot 10^6)^{MUESLP}}\right)$$

The high field mobility is modeled as:

$$\mu = \frac{\mu_0}{\left(1 + \left(\frac{\mu_0 E_y}{V_{max}}\right)^{BB}\right)^{\frac{1}{BB}}}$$

where the maximum velocity V_{max} is temperature dependent. V_{max} should be the maximum electron-saturation velocity (' 1_107cm=s), which is exceeded at reduced L_{gate}. This is called velocity overshoot, and is included in the mobility model in the following manner:

$$V_{max} = VMAX \cdot \left(1 + \frac{VOVER}{(L_{gate} \cdot 10^6)^{VOVERP}}\right)$$

Channel-Length Modulation

The gradual-channel approximation is applied to derive analytical equations for describing device characteristics. However, this approximation is not valid for large Vds causing the pinch-off phenomenon in the channel. Without taking into account the pinch-off phenomenon, the calculated channel conductance gds enters abruptly into the saturation condition. To include the pinch-off phenomenon in HiSIM, we apply the conventional method of modeling the pinch-off region (ΔL) separately from the rest of the channel.

$$\Delta L = \varepsilon_{Si} \frac{E_D - E_C}{qN_{sub} + Q_i / W_d}$$

where

$$E^2{}_D = E^2{}_C + \frac{2qN_{sub}}{\varepsilon_{Si}}(\varphi_S(\Delta L) - \varphi_{SL})$$

and E_c is the electric field at y=0'.

$$E_C = \frac{Idd}{\beta(L_{eff} - \Delta L)Q_i}$$

The above equation can be simplified as follows:

$$E_C = \frac{Idd}{\beta L_{eff} Q_i}$$

$$\varphi_S(\Delta L) = (1 - CLM1) \cdot \varphi_{SL} + CLM1 \cdot (\varphi_{S0} + V_{ds})$$

Narrow Channel Effects

Threshold Voltage Modification

$$\Delta V_{th,W} = \left(\frac{1}{C_{ox}} - \frac{1}{C_{ox} + 2C_{ef}/(L_{eff}W_{eff})}\right) qN_{sub}W_d + \frac{WVTH0}{W_{gate} \cdot 10^6}$$

where WVTH0 is the parameter for including the basic width dependence and

$$C_{ef} = \frac{2\varepsilon_{ox}}{\pi} L_{eff} 1n\left(\frac{2T_{fox}}{T_{ox}}\right) = \frac{WFC}{2} L_{eff}$$

Here, T_{fox} is the thickness of the oxide at the trench edge, and WFC is the model parameter for including the edge-fringing-capacitance effects.

$$\Delta V_{th} = \Delta V_{th,SC} + \Delta V_{th,R} + \Delta V_{th,P} + \Delta V_{th,W} - \varphi_{Spg}$$

Mobility Change

$$M_{uephonon} = M_{uephonon} \cdot \left(1 + \frac{MUEPHW}{(W_{gate} \cdot 10^6 + MUEPWP \cdot 10^6)^{MUEPWP}}\right) \cdot \left(1 + \frac{MUEPHW2}{(W_{gate} \cdot 10^6)^{MUEPWP2}}\right)$$

$$M_{uesurface} = M_{uesurface} \cdot \left(1 + \frac{MUESRW}{(W_{gate} \cdot 10^6)^{MUESWP}}\right)$$

Transistor Leakage due to Shallow Trench Isolation (STI): Hump in Ids

The shallow trench isolation induces also an undesired hump in the subthreshold region of the Ids-Vgs characteristics. This is due to an increased electric field at the edge of the trench. At this trench edge, the impurity concentration as well as the oxide thickness are different from the MOSFET middle position along the width direction. Therefore, the surface potential values are expected to be different at the trench edge and are found to cause a Vth reduction there. Thus a MOSFET leakage current occurs at these edges, which is smaller than the main MOSFET. The leakage current equation is written as:

$$I_{ds,STI} = 2\frac{W_{STI}}{L_{eff} - \Delta L}\mu\frac{Q_{i,STI}}{\beta}[1 - \exp(-\beta V_{ds})]$$

where W_{STI} determines the width of the high-field region.

$$W_{STI} = WSTI\left(1 + \frac{WSTIL}{(L_{gate,sm} \cdot 10^6)^{WSTILP}}\right)\left(1 + \frac{WSTIW}{(W_{gate} \cdot 10^6)^{WSTIWP}}\right)$$

Small Geometry

Small size devices do not show the same scaling characteristic as long-channel or wide-channel devices, but deviate significantly. The reason is mainly due to the resolution inaccuracy of the lithography. The small geometry effects are modeled first as the threshold voltage shift

$$\Delta V_{th} = \Delta V_{th,SC} + \Delta V_{th,R} + \Delta V_{th,P} + \Delta V_{th,W} + \Delta V_{th,sm} - \varphi_{Spg}$$

$$\Delta V_{th,sm} = \frac{WL2}{wl^{WL2P}}$$

The mobility modification due to the small device geometry is also modeled in the phonon scattering as

$$M_{uephonon} = M_{uephonon} \cdot \left(1 + \frac{MUEPHS}{wl^{MUEPSP}}\right)$$

$$V_{max} = V_{max} \cdot \left(1 + \frac{VOVERS}{wl^{VOVERSP}}\right)$$

Effects of the Source/Drain Diffusion Length for Shallow Trench Isolation (STI) Technologies

The diffusion length, LOD between MOSFET gate and STI edge affects the MOSFET characteristics.

$$N_{substi} = \frac{1 + T1 \cdot T2}{1 + T1 \cdot T3}$$

where

$$T1 = \frac{1}{1 + NSUBPSTI2}$$

$$T2 = \left(\frac{NSUBPSTI1}{L_{od\_\mathrm{half}}}\right)^{NSUBPSTI3}$$

$$T3 = \left(\frac{NSUBPSTI1}{L_{od\_\mathrm{half\_ref}}}\right)^{NSUBPSTI3}$$

$$N_{subp} = N_{subp} \cdot N_{substi}$$

$$M_{uesti} = \frac{1 + T1 \cdot T2}{1 + T1 \cdot T3}$$

where

$$T1 = \frac{1}{1 + MUESTI2}$$

$$T2 = \left(\frac{MUESTI1}{L_{od\_\mathrm{half}}}\right)^{MUESTI3}$$

$$T3 = \left(\frac{MUESTI1}{L_{od\_\mathrm{half\_ref}}}\right)^{MUESTI3}$$

$$M_{uephonon} = M_{uephonon} \cdot M_{uesti}$$

Temperature Dependences

The temperature dependence is included automatically in the surface potentials through β, which is the inverse of the thermal voltage. Additionally the bandgap, the intrinsic carrier concentration, the carrier mobility, and the carrier saturation velocity are also temperature dependent. The temperature dependence of the bandgap determines the temperature dependence of V_{th} and is modeled as:

$$E_g = E_{g,TNOM} - BGTMP1 \cdot (T - TNOM) - BGTMP2 \cdot (T^2 - TNOM^2)$$

where T is the given temperature, and

$$E_{g,TNOM} = EG0 - 90.25 \times 10^{-6} \cdot TNOM - 1.0 \times 10^{-7} \cdot TNOM^2$$

where T is the given temperature. The temperature dependence of the intrinsic carrier concentration is given by

$$n_i = n_{i0} \cdot T^{\frac{3}{2}} \cdot \exp\left(-\frac{E_g}{2q}\beta\right)$$

$$\mu_{PH}(phonon) = \frac{M_{uephonon}}{(T/TNOM)^{MUETMP} \times E_{eff}{}^{MUEPH0}}$$

$$V_{max} = \frac{VMAX}{1.8 + 0.4(T/TNOM) + 0.1(T/TNOM)^2 - VTMP \times (1 - T/TNOM)}$$

The temperature dependence of the gate current is given by modifying the bandgap specific for the gate current as:

$$E_{gp} = E_{g,TNOM} + EGIG + IGTEMP2\left(\frac{1}{T} - \frac{1}{TNOM}\right) + IGTEMP3\left(\frac{1}{T^2} - \frac{1}{TNOM^2}\right)$$

Resistances

The source and the drain resistances R_s and R_d are considered by voltage drops on each terminal as:

$$V_{gs,eff} = V_{gs} - I_{ds} \cdot R_s$$
$$V_{ds,eff} = V_{ds} - I_{ds} \cdot (R_s + R_d)$$
$$V_{bs,eff} = V_{bs} - I_{ds} \cdot R_s$$

where

$$R_s = \frac{RS}{W_{eff} \cdot NF} + NRS \cdot RSH$$
$$R_d = \frac{RD}{W_{eff} \cdot NF} + NRD \cdot RSH$$

The flag CORSRD is provided for the selection of one of the possible approaches. `CORSRD = 0` refers to no contact resistance. `CORSRD =1, 2, -1` means "internal", "analytical", and "external" source/drain resistances, respectively. `CORSRD = 0` is the default. `CORSRD=2` is introduced to avoid simulation time penalty with an analytical description of the resistance effect as:

$$I_{ds} = \frac{I_{ds0}}{1 + I_{ds0}\frac{R_d}{V_{ds}}}$$

where I_{ds0} is the drain current without the resistance effect.

$$R_g = \frac{RSHG \cdot \left(XGW + \frac{W_{eff}}{3 \cdot NGCON}\right)}{NGCON \cdot (L_{drawn} - XGL) \cdot NF}$$

Capacitances

Intrinsic Capacitances

$$Q_y = \varepsilon_{Si} W_{eff} \cdot NF \cdot W_d\left(\frac{\varphi_{S0} + V_{ds} - \varphi_S(\Delta L)}{XQY}\right) + \frac{XQY1 \cdot W_{eff} \times 10^6 \cdot NF}{(L_{gate} \times 10^6)^{XQY2}} V_{bs}$$

Overlap Capacitances

Surface Potential-Based Model

under the depletion and the accumulation conditions

$$Q_{over} = W_{eff} \cdot NF \cdot LOVER\left(\sqrt{\frac{2\varepsilon_{Si} qNOVER}{\beta}}\sqrt{\beta(\varphi_S + V_{ds}) - 1}\right)$$

under inverse condition

$$Q_{over} = W_{eff} \cdot NF \cdot LOVER \cdot C_{ox}(V_{gs} - VFBOVER - \varphi_S)$$

Simplified Bias Dependent Model

$$Q_{god} = W_{eff} NF\, C_{ox}[(V_{gs} - V_{ds})LOVER - OVSLP \cdot (1.2 - (\varphi_{SL} - V_{ds})) \cdot (OVMAG + (V_{gs} - V_{ds}))]$$

Extrinsic Capacitances

$$C_f = \frac{\varepsilon_{ox}}{\pi/2} W_{gate} \cdot NF \cdot 1n\left(1 + \frac{TPOLY}{T_{ox}}\right)$$

Leakage Currents

Substrate Current

$$I_{sub} = X_{sub1} \cdot P_{sisubsat} \cdot I_{ds} \cdot \exp\left(-\frac{X_{sub2}}{P_{sisubsat}}\right)$$

$$X_{sub1} = SUB1 \cdot \left(1 + \frac{SUB1L}{L_{gate}^{SUB1LP}}\right)$$

$$X_{sub2} = SUB2 \cdot \left(1 + \frac{SUB2L}{L_{gate}}\right)$$

$$P_{sisubsat} = SVDS \cdot V_{ds} + \varphi_{S0} - \frac{L_{gate} \cdot P_{sislsat}}{X_{gate} + L_{gate}}$$

$$X_{gate} = SLG \cdot \left(1 + \frac{SIGL}{L_{gate}^{SLGLP}}\right)$$

$$P_{sislsat} = V_{g2} + \frac{q \cdot \varepsilon_{Si} \cdot N_{sub}}{C_{ox}^{2}} \cdot \left\{1 - \sqrt{1 + \frac{2C_{ox}^{2}}{q \cdot \varepsilon_{Si} \cdot N_{sub}}\left(V_{g2} - \frac{1}{\beta} - X_{vbs} \cdot V_{bs}\right)}\right\}$$

$$X_{vbs} = SVBS \cdot \left(1 + \frac{SVBSL}{L_{gate}^{SVBSLP}}\right)$$

$$V_{g2} = SVGS \cdot \left(1 + \frac{SVGSL}{L_{gate}^{SVGSLP}}\right) \cdot \frac{W_{gate}^{SVGSWP}}{W_{gate}^{SVGSWP} + SVGSW} \cdot V_{gp}$$

Impact-Ionization Induced Bulk Potential Change

$$\Delta I_{ds} = \frac{2}{3}\sqrt{\frac{2\varepsilon_{Si} q N_{sub}}{\beta}}\left[\{\beta(\phi_{SL} - V_{bs}) - 1\}^{\frac{3}{2}}\frac{3}{2}\frac{\beta\Delta V_{bulk}}{\beta(\phi_{SL} - V_{bs}) - 1}\right.$$

$$\left. - \{\beta(\phi_{S0} - V_{bs}) - 1\}^{\frac{3}{2}}\frac{3}{2}\frac{\beta\Delta V_{bulk}}{\beta(\phi_{S0} - V_{bs}) - 1}\right]$$

$$- \sqrt{\frac{2\varepsilon_{Si} q N_{sub}}{\beta}}\left[\{\beta(\phi_{SL} - V_{bs}) - 1\}^{\frac{1}{2}}\frac{1}{2}\frac{\beta\Delta V_{bulk}}{\beta(\phi_{SL} - V_{bs}) - 1}\right.$$

$$\left. - \{\beta(\phi_{S0} - V_{bs}) - 1\}^{\frac{1}{2}}\frac{1}{2}\frac{\beta\Delta V_{bulk}}{\beta(\phi_{S0} - V_{bs}) - 1}\right]$$

where

$$\Delta V_{bulk} = IBPC1(1 + IBPC2 \cdot \Delta V_{th}) \cdot I_{sub}$$

IBPC1 and IBPC2 are model parameters.

Gate Current

Between Gate and Channel, Igate

$$I_{gate} = q \cdot GLEAK1 \cdot \frac{E^2}{E_{gp}^{\frac{1}{2}}} \cdot \exp\left(-\frac{E_{gp}^{\frac{3}{2}} \times GLEAK2}{E}\right) \cdot \sqrt{\frac{Q_i}{const0}} \cdot W_{eff} \cdot NF \cdot L_{eff}$$

$$\cdot \frac{GLEAK6}{GLEAK6 + V_{ds}} \cdot \frac{GLEAK7}{GLEAK7 + W_{eff} + L_{eff}}$$

where

$$E = \frac{V_G - GLEAK3 \times \varphi_S(\Delta L)}{T_{ox}} \cdot \left(1 + \frac{E_y}{GLEAK5}\right)$$

$$V_G = V_{gs} - VFBC + GLEAK4 \cdot \Delta V_{th} \cdot L_{eff}$$

$$\Delta V_{th} = \Delta V_{th,SC} + \Delta V_{th,P} + \Delta V_{th,W} + \varphi_{Spg}$$

$$I_{gate} = I_{gate,s} + I_{gate,d}$$

$$I_{gate,s} = (1 - P_{artition}) \cdot I_{gate}$$

$$I_{gate,d} = P_{artition} \cdot I_{gate}$$

$$I_{gate,d} = \int_0^{L_{eff}} \frac{y}{L_{eff}} I_{gate}(y)dy = P_{artition} \cdot I_{gate}$$

Between Gate and Bulk, Igb

$$E_{gb} = -\frac{V_{gb} - VFBC + GLKB3}{T_{ox}}$$

$$I_{gb} = GLKB1 \cdot E_{gb}{}^2 \cdot \exp\left(-\frac{GLKB2}{E_{gb}}\right) W_{eff} \cdot NF \cdot L_{eff}$$

Between Gate and Source/Drain. Igs/Igd

$$I_{gs} = sign \cdot GLKSD1 \cdot E_{gs}^{2} \exp(T_{ox}(-GLKSD2 \cdot V_{gs} + GLKSD3))W_{eff} \cdot NF$$

$$E_{gs} = \frac{V_{gs}}{T_{ox}}$$

$$I_{gd} = sign \cdot GLKSD1 \cdot E_{gd}^{2} \exp(T_{ox}(-GLKSD2 \cdot V_{gd} + GLKSD3))W_{eff} \cdot NF$$

$$E_{gd} = \frac{V_{gs} - Vlds}{T_{ox}}$$

Gate-Induced Drain Leakage (GIDL)

HiSIM 2.5

$$I_{GIDL} = q \cdot GIDL1 \cdot \frac{E^2}{E_g^{\frac{1}{2}}} \cdot \exp\left(-GIDL2 \cdot \frac{E_g^{\frac{3}{2}}}{E}\right) \cdot W_{eff} \cdot NF$$

HiSIM 2.5.1

$$I_{GIDL} = q \cdot GIDL1 \cdot \frac{E^2}{E_g^{\frac{1}{2}}} \cdot \exp\left(-GIDL2 \cdot \frac{E_g^{\frac{3}{2}}}{E}\right) \cdot W_{eff} \cdot NF \cdot \frac{V_{db}^{3}}{V_{db}^{3} + small}$$

$$E = \frac{GIDL3 \cdot (V_{ds} + GIDL4) - V_G'}{T_{ox}}$$

$$V_G' = V_{gs} + \Delta V_{th} \cdot GIDL5$$

$$\Delta V_{th} = \Delta V_{th,SC} + \Delta V_{th,P}$$

$$V_{db} = V_{ds} - V_{bs}$$

$$small = 0.5$$

Conservation of Symmetry at Vds=0

HiSIM preserves the symmetry at Vds = 0 automatically due to the drift-diffusion approximation. However, modeling of the short-channel effects induces a small asymmetry. To eliminate the asymmetry caused by the artifacts of the modeling, the V_{th} modeling has to include a damping of the short-channel effects as V_{ds} approaches zero. This corresponds to a vanishing of shortchannel effects as V_{ds} gets near to zero, which is actually also observed in 2D simulations. In HiSIM, the damping is done by a mathematical function with two parameters: VZADD0 and PZADD0.

The values of these parameters are fixed, and it is recommended not to change them. Other modeled phenomena, which include a Vds dependence, cause a similar symmetry problem as the short-channel effects. They are therefore also damped.

Source/Bulk and Drain/Bulk Diode Model

Diode Current

The model equations for the source/bulk and drain/bulk diode currents are based on the concepts of BSIM3v3, but include a number of modifications.

These regions are distinguished in the modeling and are treated separately according to their origins.

Between Drain and Bulk

With these current densities and the area parameter AD and the perimeter parameter PD of the drain region, the forward and backward currents between drain and bulk are calculated as

$$I_{sbd} = AD \cdot j_s + PD \cdot J_{ssw}$$

$$I_{sbd2} = AD \cdot j_{s2} + PD \cdot J_{ssw2}$$

$$T_{tnom} = \frac{T}{TNOM}$$

$$j_s = JS0 \cdot \exp\left\{\frac{E_g(T = TNOM) \cdot \beta(T = TNOM) - E_g\beta + XTI \cdot \log(T_{tnom})}{NJ}\right\}$$

$$j_{ssw} = JS0SW \cdot \exp\left\{\frac{E_g(T = TNOM) \cdot \beta(T = TNOM) - E_g\beta + XTI \cdot \log(T_{tnom})}{NJSW}\right\}$$

$$j_{s2} = JS0 \cdot \exp\left\{\frac{E_g(T = TNOM) \cdot \beta(T = TNOM) - E_g\beta + XTI2 \cdot \log(T_{tnom})}{NJ}\right\}$$

$$j_{ssw2} = JS0SW \cdot \exp\left\{\frac{E_g(T = TNOM) \cdot \beta(T = TNOM) - E_g\beta + XTI2 \cdot \log(T_{tnom})}{NJSW}\right\}$$

$$N_{vtm} = \frac{NJ}{\beta}$$

a) Vbd ≥T1

$$I_{bd} = I_{sbd}\left\{\exp\left(\frac{T_1}{N_{vtm}}\right) - 1\right\} + \frac{I_{sbd}}{N_{vtm}}\exp\left(\frac{T_1}{N_{vtm}}\right)(V_{bd} - T1)$$

$$+I_{sbd2} \cdot CISB\left\{\exp\left(\frac{-V_{bd}CVBK}{N_{vtm}}\right) - 1\right\}\exp\{(T_{nom} - 1)CTEMP\}$$

$$+CISBK\left\{\exp\left(\frac{-V_{bd}CVBK}{N_{vtm}}\right) - 1\right\}$$

b) T1≥Vbd

$$I_{bd} = I_{sbd}\left\{\exp\left(\frac{V_{bd}}{N_{vtm}}\right) - 1\right\}$$

$$+I_{sbd2} \cdot CISB\left\{\exp\left(\frac{-V_{bd}CVB}{N_{vtm}}\right) - 1\right\}\exp\{(T_{nom} - 1)CTEMP\}$$

$$+CISBK\left\{\exp\left(\frac{-V_{bd}CVBK}{N_{vtm}}\right) - 1\right\}$$

$$T_1 = N_{vtm} \cdot \log\left\{\frac{VDIFFJ}{I_{sbd}} \cdot (T_{tnom})^2 + 1\right\}$$

$$I_{bd} = I_{bd} + DIVX \cdot I_{sbd2} \cdot V_{bd}$$

Between Source and Bulk

The area parameter AS and the perimeter parameter PS of the source region are used to calculate the forward and backward currents between source and bulk.

$$I_{sbs} = AS \cdot j_s + PS + j_{ssw}$$

$$I_{sbs2} = AS \cdot j_{s2} + PS \cdot J_{ssw2}$$

a) Vbs ≥T2

$$I_{bs} = I_{sbs}\left\{\exp\left(\frac{T_2}{N_{vtm}}\right) - 1\right\} + \frac{I_{sbs}}{N_{vtm}}\exp\left(\frac{T_2}{N_{vtm}}\right)(V_{bs} - T2)$$

$$+I_{sbs2} \cdot CISB\left\{\exp\left(\frac{-V_{bs}CVBK}{N_{vtm}}\right) - 1\right\}\exp\{(T_{nom} - 1)CTEMP\}$$

$$+CISBK\left\{\exp\left(\frac{-V_{bs}CVBK}{N_{vtm}}\right) - 1\right\}$$

b) T2≥Vbs

$$I_{bs} = I_{sbs}\left\{\exp\left(\frac{V_{bs}}{N_{vtm}}\right) - 1\right\}$$

$$+I_{sbs2} \cdot CISB\left\{\exp\left(\frac{-V_{bs}CVB}{N_{vtm}}\right) - 1\right\}\exp\{(T_{nom} - 1)CTEMP\}$$

$$+CISBK\left\{\exp\left(\frac{-V_{bs}CVBK}{N_{vtm}}\right) - 1\right\}$$

$$T_2 = N_{vtm} \cdot \log\left\{\frac{VDIFFJ}{I_{sbs}} \cdot (T_{tnom})^2 + 1\right\}$$

$$I_{bs} = I_{bs} + DIVX \cdot I_{sbs2} \cdot V_{bs}$$

Diode Capacitance

The notations

Θ= S; θ= s (for source/bulk junction) and

Θ = D;θ = d (for drain/bulk junction) apply.

$$c_{zb\theta} = CJ \cdot A\Theta$$

$P_{\Theta} > W_{eff}$

$$c_{zb\theta sw} = CJSW(P\Theta - W_{eff} \cdot NF)$$
$$C_{zb\theta swg} = CJSWG \cdot W_{eff} \cdot NF$$

(i) $V_{b\theta} = 0$

$$Q_{b\theta} = 0$$

$$C_{apb\theta} = c_{zb\theta} + c_{zb\theta sw} + c_{zb\theta swg}$$

(ii) $V_{b\theta} < 0$

1-1 $C_{zb\theta} > 0$

$$\arg = 1 - \frac{V_{b\theta}}{PB}$$

α) $MJ = 0.5$

$$\text{sarg} = \frac{1}{\sqrt{\arg}}$$

β) $MJ \neq 0.5$

$$s\arg = \exp(-MJ \cdot \log(\arg))$$

$$Q_{b\theta} = \frac{PB \cdot C_{zb\theta}(1 - \arg \cdot s\arg)}{1 - MJ}$$

$$C_{apb\theta} = c_{zb\theta} \cdot s\arg$$

1-2 $c_{zb\theta} \le 0$

$$Q_{b\theta} = 0$$

$$C_{apb\theta} = 0$$

2) $c_{zb\theta sw} > 0$

$$\arg = 1 - \frac{V_{b\theta}}{PBSW}$$

α) $\mathrm{MJSW} = 0.5$

$$\mathrm{sarg} = \frac{1}{\sqrt{\arg}}$$

β) $\mathrm{MJSW} \neq 0.5$

$$s\arg = \exp(-MJSW \cdot \log(\arg))$$

$$Q_{b\theta}+ = \frac{PBSW \cdot c_{zb\theta sw}(1 - \arg \cdot s\arg)}{1 - MJSW}$$

$$C_{apb\theta} = C_{zb\theta sw} \cdot s\arg$$

3) $c_{zb\theta swg} > 0$

$$\arg = 1 - \frac{V_{b\theta}}{PBSWG}$$

α) $\mathrm{MJSWG} = 0.5$

$$\mathrm{sarg} = \frac{1}{\sqrt{\arg}}$$

β) $\mathrm{MJSWG} \neq 0.5$

$$s\arg = \exp(-MJSWG \cdot \log(\arg))$$

$$Q_{b\theta}+ = \frac{PBSWG \cdot c_{zb\theta swg}(1 - \arg \cdot s\arg)}{1 - MJSWG}$$

$$C_{apb\theta} = c_{zb\theta swg} \cdot s\arg$$

$P\Theta \leq W_{eff}$

$$c_{zb\theta swg} = CJSWG \cdot P\Theta$$

(i) $V_{b\theta} = 0$

$$Q_{b\theta} = 0$$

$$C_{apb\theta} = c_{zb\theta} + c_{zb\theta swg}$$

(ii) $V_{b\theta} < 0$

1-1 $C_{zb\theta} > 0$

$$\arg = 1 - \frac{V_{b\theta}}{PB}$$

α) MJ = 0.5

$$\text{sarg} = \frac{1}{\sqrt{\arg}}$$

β) MJ $\neq$ 0.5

$$s\arg = \exp(-MJ \cdot \log(\arg))$$

$$Q_{b\theta} = \frac{PB \cdot c_{zb\theta}(1 - \arg \cdot s\arg)}{1 - MJ}$$

$$C_{apb\theta} = c_{zb\theta} \cdot s\arg$$

1-2 $C_{zb\theta} \leq 0$

$$Q_{b\theta} = 0$$

$$C_{apb\theta} = 0$$

$$c_{zb\theta swg} > 0$$

$$\arg = 1 - \frac{V_{b\theta}}{PBSWG}$$

α) MJSWG = 0.5

$$\mathrm{sarg} = \frac{1}{\sqrt{\arg}}$$

β) MJSWG $\neq$ 0.5

$$s\arg = \exp(-MJSWG \cdot \log(\arg))$$

$$Q_{b\theta}+ = \frac{PBSWG \cdot c_{zb\theta swg}(1 - \arg \cdot s\arg)}{1 - MJSWG}$$

$$C_{apb\theta}+ = c_{zb\theta swg} \cdot \mathrm{sarg}$$

(iii) $V_{b\theta} > 0$

$$Q_{b\theta} = V_{b\theta}(c_{zb\theta} + c_{zb\theta swg}) + V^2{}_{b\theta}\left(\frac{1}{2}\frac{c_{zb\theta} \cdot MJ}{PB} + \frac{1}{2}\frac{c_{zb\theta swg} \cdot MJSWG}{PBSWG}\right)$$

$$Q_{apb\theta} = c_{zb\theta} + c_{zb\theta swg} + V_{b\theta}\left(\frac{c_{zb\theta} \cdot MJ}{PB} + \frac{c_{zb\theta swg} \cdot MJSWG}{PBSWG}\right)$$

Noise Models

1/f Noise Model

$$fn = \frac{I_{ds}{}^2 NFTRP}{\beta f^{FALPH}(L_{eff} - \Delta L) W_{eff} \cdot NF}$$

$$\cdot \left[\frac{1}{(N_0 + N^*)(N_L + N^*)} + \frac{2\mu E_y NFALP}{N_L - N_0} 1n\left(\frac{N_L + N^*}{N_0 + N^*}\right) + (\mu E_y NFALP)^2\right]$$

$$N^* = \frac{C_{ox} - C_{dep} + CIT}{q\beta}$$

$$N_{flick} = fn \cdot f^{FALPH}$$

Thermal Noise Model

$$id = 4kT\frac{W_{eff} \cdot NF \cdot C_{ox} V_g V_t \mu}{(L_{eff} - \Delta L)} \cdot \frac{(1 + 3\eta + 6\eta^2)\mu d^2 + (3 + 4\eta + 3\eta^2)\mu_d \mu_s + (6 + 3\eta + \eta^2)\mu_s}{15(1 + \eta)\mu_{av}{}^2}$$

where where μs, μd and μav are mobility at the source side, the drain side, and averaged, respectively.

$$\eta = 1 - \frac{(\varphi_{SL} - \varphi_0) + \chi(\varphi_{SL} - \varphi_0)}{V_g V_t}$$

$$\chi = 2\frac{cnst0}{C_{ox}}\left[\left[\frac{2}{3}\frac{1}{\beta}\frac{\{\beta(\varphi_{SL} - V_{bs}) - 1\}^{\frac{3}{2}} - \{\beta(\varphi_{S0} - V_{bs}) - 1\}^{\frac{3}{2}}}{\varphi_{SL} - V_{bs}}\right] - \sqrt{\beta(\varphi_{S0} - V_{bs}) - 1}\right]$$

$$N_{thrml} = id/(4kT)$$

Shot Noise

HiSIM 2.5

$$shot = 2q \cdot I_{ds}$$

HiSIM 2.5.1

shot noise due to Igs

$$i_{gs} = 2q \cdot I_{gs}$$

shot noise due to Igd

$$i_{gd} = 2q \cdot I_{gd}$$

shot noise due to Igb

$$i_{gb} = 2q \cdot I_{gb}$$

Induced Gate Noise Model

$$N_{igate} = S_{igate}/f^2$$

Non-Quasi-Static (NQS) Model

Carrier Formation

$$q(t_i) = \frac{q(t_{i-1}) + \frac{\Delta t}{\tau}Q(t_i)}{1 + \frac{\Delta t}{\tau}}$$

Delay Mechanism

$$\tau_{diff} = DLY1$$

$$\tau_{cond} = DLY2 \cdot \frac{Q_i}{I_{ds}}$$

$$\frac{1}{\tau} = \frac{1}{\tau_{diff}} + \frac{1}{\tau_{cond}}$$

$$\tau_B = DLY3 \cdot C_{ox}$$

Time-Domain Analysis

The total drain/source/bulk terminal currents are derived from the superposition of the transport current and the charging current. The transport current is a function of the instantaneous terminal voltages and is approximated by the steady-state solution. The source/drain/bulk charging currents are the time derivatives of the associated non-quasi-static charges, q_S, q_D, and q_B, respectively.

AC Analysis

$$\left.\left(i\omega\frac{\partial q_I}{\partial v} + \frac{1}{\tau}\left(\frac{\partial q_I}{\partial v} - \frac{\partial Q_I}{\partial v}\right)\right)\right|_{v = v0} \cdot V_e^{ist} = 0$$

$$\left.\left(i\omega\frac{\partial q_B}{\partial v} + \frac{1}{\tau}\left(\frac{\partial q_B}{\partial v} - \frac{\partial Q_B}{\partial v}\right)\right)\right|_{v = v0} \cdot V_e^{ist} = 0$$

where

$$\frac{\partial q_I}{\partial v} = \frac{1}{1 + i\omega\tau}\frac{\partial Q_I}{\partial v}$$

$$\frac{\partial q_B}{\partial v} = \frac{1}{1 + i\omega\tau_B}\frac{\partial Q_B}{\partial v}$$

DFM Model

To support design for manufacturability (DFM) HiSIM2 introduces an option for considering the variation of device parameters.

Accurate prediction of device performance for a wide range of the substrate-impurity-concentration variations is secured by introducing an impurity concentration dependent mobility due to the phonon scattering as

$$M_{uephonon} = MUEPH1[MPHDFM\{1n(NSUBCDFM) - 1n(NSUBC)\} + 1]$$
$$NSUBP = NSUBP + (NSUBCDFM - NSUBC)$$
$$NPEXT = NPEXT + (NSUBCDFM - NSUBC)$$

where NSUBCDFM is an instance parameter and MPHDFM is a model parameter describing the mobility reduction as the substrate impurity concentration is increased. This model parameter MPHDFM is required, if the model flag CODFM is switched to one. The default value is sufficient for the most applications. The DFM model is activated, if the instance parameter NSUBCDFM is also given.

Binning Model

Binning option is introduced in HiSIM2.4 to secure enough accuracy of model calculation results, even though the effects observed are not modeled yet. The binning method is the same as that used in BSIM3/4

$$Bin\_HiSIM\_model\_parameter = HiSSIM\_model\_parameter + \frac{P1}{L_{bin}} + \frac{P2}{W_{bin}} + \frac{P3}{L_{bin}W_{bin}}$$

where P1, P2, and P3 are model parameters for L HiSIM model parameter, W HiSIM model parameter, and L* HiSIM model parameter, respectively and

$$L_{bin} = (L_{gate} \cdot 10^6)^{LBINN}$$
$$W_{bin} = (W_{gate} \cdot 10^6)^{WBINN}$$

Component Statements

This device is supported within altergroups.

Sample Instance Statement

```
m4 (0 2 1 1) nch w=2u l=0.8u as=250p ad=250p pd=168p ps=168p m=2
```

Sample Model Statement

```
model nch hisim2 type=n version=2.50 corsrd=0 conqs=0 cgso=7.43e-10 cgdo=7.43e-10
cgbo=2.56e-11
```

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1	w (m)	Gate width.
2	l (m)	Gate length.
3	as (m^2)	Area of source junction.
4	ad (m^2)	Area of drain junction.
5	ps (m)	Perimeter of source junction.
6	pd (m)	Perimeter of drain junction.
7	temp (C)	Device temperature.
8	dtemp (C)	Device temperature rise from ambient.
9	nrs=0	Number of squares of source diffusion, default value is 1.0 for version 2.50 and 2.51.
10	nrd=0	Number of squares of drain diffusion, default value is 1.0 for version 2.50 and 2.51.
11	corbnet	Substrate resistance network selector.

12 `rbpb (Ω)`	Substrate resistance network.
13 `rbpd (Ω)`	Substrate resistance network.
14 `rbps (Ω)`	Substrate resistance network.
15 `rbdb (Ω)`	Substrate resistance network.
16 `rbsb (Ω)`	Substrate resistance network.
17 `corg`	Gate-contact resistance selector.
18 `ngcon=1.0`	Number of gate contacts.
19 `xgw=0.0 m`	Distance from gate contact to channel edge.
20 `xgl=0.0 m`	Offset of gate length due to variation in patterning.
21 `nf=1.0`	Number of gate fingers.
22 `lod=1.0E-5 m`	Length of diffusion between gate and STI.
23 `m=1`	Multiplicity factor (number of MOSFETs in parallel).
24 `sa=0.0 m`	Distance from STI edge to Gate edge,existed from 2.40.
25 `sb=0.0 m`	Distance from STI edge to Gate edge,existed from 2.40.
26 `sd=0.0 m`	Distance from Gate edge to Gate edge,existed from 2.40.
27 `nsubcdfm` (cm^{-3})	Constant part of Nsub for DFM,existed from 2.40.
28 `mphdfm`	NSUBCDFM dependence of phonon scattering for DFM.
29 `isnoisy=yes`	Should device generate noise. Possible values are `no` and `yes`.
30 `sca=0.0`	WPE sca.
31 `scb=0.0`	WPE scb.
32 `scc=0.0`	WPE scc.

Model Definition

model modelName hisim2 parameter=value ...

Model Parameters

Device type parameters

1	`type=n`	Transistor type. Possible values are `n` and `p`.
2	`version=2.50`	The available versions are 2.50, 2.51, 2.60, 2.61 and 2.70..
3	`subvers="sc8"`	Model sub-version selector.
4	`corsrd=0`	Contact resistances Rs and Rd selector. 0 : no(default). 1 : yes, as internal resistances. -1 : yes, as external resistances.
5	`coiprv=1`	Previous Ids is used for calculating source/drain resistance effect. 0 : no. 1 : yes.
6	`copprv=1`	Previous surface potential is used for the initial guess. 0 : no. 1 : yes.
7	`coadov=1`	Selector for lateral field induced and overlap charges/ capacitances being added to intrinsic ones. 0 : no. 1 : yes(default).
8	`coisub=0`	Substrate current selector. 0 : no(default). 1 : yes.
9	`cogidl=0`	GIDL current calculation selector. 0 : no(default). 1 : yes.
10	`coiigs=0`	Gate current calculation selector. 0 : no(default). 1 : yes.
11	`coovlp=1`	Overlap capacitance calculation selector. 0 : constant overlap capacitance(default). 1 : yes.
12	`coflick=0`	1/f noise calculation selector.
13	`coisti=0`	STI leakage current calculation selector. 0 : no(default). 1 : yes.
14	`conqs=0`	Non-quasi-static mode selector. 0 : no(default). 1 : yes.

15	`cothrml=0`	Thermal noise calculation selector. 0 : no(default). 1 : yes.
16	`tnom (C)`	Parameters measurement temperature. Default set by `options`.
17	`corg=0`	Gate-contact resistance calculation selector. 0 : no(default). 1 : yes.
18	`corbnet=0`	Substrate resistance network selector.
19	`coign=0`	Induced gate and cross correlation noise calculation selector.
20	`compatible`	Compatible with spice3, default is spectre compatible. Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, and `sspice`.
21	`alarm=none`	Forbidden operating region. Possible values are `none`, `off`, `triode`, `sat`, `subth`, and `rev`.
22	`codfm=0`	Calculation of model for DFM selector,existed from 2.40.
23	`corecip=1`	capacitance reciprocity takes first priority.
24	`coqy=0`	calculate lateral-field-induced charge/capacitance.

Safe Operating Areas Parameters

25	`vds_max=∞ V`	Maximum allowed voltage cross source and drain.
26	`vgd_max=∞ V`	Maximum allowed voltage cross drain and gate.
27	`vgs_max=∞ V`	Maximum allowed voltage cross source/bulk and gate.
28	`vbd_max=∞ V`	Maximum allowed voltage cross drain/source and bulk.
29	`vbs_max=∞ V`	Maximum allowed voltage cross source and bulk.
30	`vgb_max=∞ V`	Maximum allowed voltage cross gate and bulk.

Default for instance parameters

31 `w=5e-6 m` Default gate width.

32 `l=5e-6 m` Default gate length.

33 `as=0` m^2 Default area of source junction.

34 `ad=0` m^2 Default area of drain junction.

35 `ps=0 m` Default perimeter of source junction.

36 `pd=0 m` Default perimeter of drain junction.

37 `temp=27 C` Default device temperature.

38 `dtemp=0 C` Default device temperature rise from ambient.

Basic Device Parameters

39 `tox=3.0e-9 m` Physical oxide thickness.

40 `xld=0 m` Gate-overlap length.

41 `xwd=0 m` Gate-overlap width.

42 `tpoly=2.0E-7 m` Height of the gate poly-si for fringing capacitance.

43 `nsubc=5.0e+17` cm^{-3}
Substrate-impurity concentration.

44 `nsubp=1.0e+18` cm^{-3}
Maximum pocket concentration.

45 `rs=0.0` Ω `m` Source contact resistance in LDD region.

46 `rd=0.0` Ω `m` Drain contact resistance in LDD region.

47 `vfbc=-1.0 V` Constant part of flat-band voltage.

48 `lp=1.5e-8 m` Length of the pocket penetration into the channel.

49 `xqy=10e-9 m`	Distance from channel/drain junction to maximum electric field point.
50 `lover=5.0E-8 m`	overlap length.
51 `ll=0.0`	gate length parameter.
52 `lld=0.0 m`	gate length parameter.
53 `lln=0.0`	gate length parameter.
54 `wl=0.0`	gate width parameter.
55 `wld=0.0 m`	gate width parameter.
56 `wln=0.0`	gate width parameter.
57 `vbi=1.0 V`	built-in potential.
58 `nsubpw=0.0` cm^{-3}	pocket implant parameter.
59 `nsubpwp=1.0`	pocket implant parameter.
60 `lpext=1.0E-50 m`	Pocket extension.
61 `npext=5.0E17` cm^{-3}	Pocket extension.
62 `rsh=0.0 V/A m`	Source/drain diffusion sheet resistance.
63 `rshg=0.0 V/A m`	Gate-electrode sheet resistance.
64 `rbpb=50.0` Ω	Substrate resistance network.
65 `rbpd=50.0` Ω	Substrate resistance network.
66 `rbps=50.0` Ω	Substrate resistance network.
67 `rbdb=50.0` Ω	Substrate resistance network.
68 `rbsb=50.0` Ω	Substrate resistance network.
69 `gbmin=1.0E-12`	Minimum conductance for substrate resistance network.

70 `xl=0 m` Gate length offset due to mask/etch effect,existed from 2.40.

71 `xw=0 m` Gate width offset due to mask/etch effect,existed from 2.40.

72 `xqy1=0.0 F m^{XQY2}`
Vbs dependence of Qy,existed from 2.40.

73 `xqy2=2.0` Lgate dependence of Qy,existed from 2.40.

74 `nsubpl=0.001 µm` gate-length dependence of NSUBP.

75 `nsubpfac=1.0` gate-length dependence of NSUBP.

Temperature dependence effects

76 `eg0=1.1785 eV` constant bandgap.

77 `bgtmp1=9.025e-5 eV/K`
First order temperature coefficient for band gap.

78 `bgtmp2=1.0e-7 eV/K`^{2}
Second order temperature coefficient for band gap.

Quantum Mechanical Effects

79 `qme1=0.0 m/V`^{2} Coefficient for quantum mechanical effect.

80 `qme2=0.0 V` Coefficient for quantum mechanical effect.

81 `qme3=0.0 m` Coefficient for quantum mechanical effect.

82 `kappa=3.9` dielectric constant for high-k stacked gate.

Poly Depletion Effects

83 `pgd1=1.0E-4 V` Strength of poly depletion.

84 `pgd2=0.3 V` Threshold voltage of poly depletion.

85 `pgd3=0.8` Vds dependence of poly depletion.

86	`pgd4=0.0`	parameter for gate-poly depletion.

Short Channel Effects

87	`parl2=1.0e-8 m`	Depletion width of channel/contact junction.
88	`sc1=1.0 1/V`	Short-channel coefficient 1.
89	`sc2=0.0` $1/V^2$	Short-channel coefficient 2.
90	`sc2b=0.0` $1/V^3$	Short-channel coefficient 2 Vb dependency coefficient.
91	`sc3=0.0` m/V^2	Short-channel coefficient 3.
92	`scp1=1.0 1/V`	Short-channel coefficient 1 for pocket.
93	`scp2=0.0` $1/V^2$	Short-channel coefficient 2 for pocket.
94	`scp3=0.0` m/V^2	Short-channel coefficient 3 for pocket.
95	`scp22=0.0` V^4	Short-channel-effect modification for small Vds.
96	`scp21=0.0 V`	Short-channel-effect modification for small Vds.
97	`bs1=0.0` V^2	Body-coefficient modification by impurity profile.
98	`bs2=0.9 V`	Body-coefficient modification by impurity profile.
99	`sc4=0.0`	Short-channel coefficient 4.

Narrow channel effects

100	`wfc=0.0` $m\ F/cm^2$	Threshold voltage reduction.
101	`mueph2=0.0`	Mobility reduction.
102	`w0=0.0 log(cm)`	Minimum gate width.
103	`wvthsc=0.0`	Short-channel effect at the STI edge.
104	`nsti=1.0e17` cm^{-3}	Substrate-impurity concentration at the SIT edge.

105 `wsti=0.0 m` Width of the high-field region at STI.

106 `muephw=0.0` phonon scattering parameter.

107 `muepwp=1.0` phonon scattering parameter.

108 `wvth0=0.0` threshold voltage shift.

109 `mueswp=1.0` change of surface roughness related mobility.

110 `vthsti=0.0` parameter for STI.

111 `muesti1=0.0` STI Stress mobility parameter.

112 `muesti2=0.0` STI Stress mobility parameter.

113 `muesti3=1.0` STI Stress mobility parameter.

114 `nsubpsti1=0.0 m` STI Stress pocket implant parameter.

115 `nsubpsti2=0.0 m` STI Stress pocket implant parameter.

116 `nsubpsti3=1.0 m` STI Stress pocket implant parameter.

117 `wstil=0.0` Parameter for STI.

118 `wstilp=1.0` Parameter for STI.

119 `scsti1=0.0` Parameter for STI.

120 `scsti2=0.0 1/V` Parameter for STI.

121 `scsti3=0.0 m/V` Parameter for STI.

122 `saref=1e-6 m` Reference distance from STI edge to Gate edge,existed from 2.40.

123 `sbref=1e-6 m` Reference distance from STI edge to Gate edge,existed from 2.40.

124 `wstiw=0.0` Parameter for STI,existed from 2.40.

125 `wstiwp=1.0` Parameter for STI,existed from 2.40.

126 `vdsti=0.0` parameter for STI,existed from 2.40.

127 `nsubcw=0.0` Parameter for narrow channel effect.

128 `nsubcwp=1.0` Parameter for narrow channel effect.

129 `nsubcmax=5e18` Parameter for narrow channel effect.

Mobility Effects

130 `vds0=0.05 V` Drain voltage for extracting the low-field mobility.

131 `muecb0=1000.0` cm^2`/(V s)`
Coulomb scattering.

132 `muecb1=100.0` cm^2`/(V s)`
Coulomb scattering.

133 `mueph0=0.3` cm^2 `(V/cm)^(muesr1)/(V s)`
Phonon scattering.

134 `mueph1=2.5e4` Phonon scattering.

135 `muetmp=1.5` Temperature dependence of phonon scattering.

136 `muesr0=2.0` cm^2 `(V/cm)^(muesr1)/(V s)`
Surface-roughness scattering.

137 `muesr1=1.0e15` Surface-roughness scattering.

138 `ndep=1.0` Coefficient of effective electric field.

139 `ninv=0.5` Coefficient of effective electric field.

140 `bb=2.0` High-field mobility degradation.

141 `vmax=1.0e7 cm/s` Maximum of electron saturation velocity.

142 `vover=0.3 cm^(voverp)`
Parameter for velocity overshoot.

143 `voverp=0.3` Lgate dependence of velocity overshoot.

144 `vovers=0.0` Parameter for overshoot.

145 `voversp=0.0` Parameter for overshoot.

146 `vtmp=0.0 cm/s` Temperature dependence of the saturation velocity.

147 `muephl=0.0` phonon scattering parameter.

148 `mueplp=1.0` phonon scattering parameter.

149 `muesrl=0.0` surface roughness parameter.

150 `muesrw=0.0` change of surface roughness related mobility.

151 `mueslp=1.0` surface roughness parameter.

152 `ndepl=0.0` Modification of Qb contribution for short-channel case, existed from 2.40.

153 `ndeplp=1.0` Modification of Qb contribution for short-channel case, existed from 2.40.

154 `ninvd=0.0 1/V` modification of Vdse dependence on Eeff.

Small size parameters

155 `wl1=0.0` Threshold voltage shift of STI leakage due to small size effect.

156 `wl1p=1.0` Threshold voltage shift of STI leakage due to small size effect.

157 `wl2=0.0` Threshold voltage shift due to small size effect.

158 `wl2p=1.0` Threshold voltage shift due to small size effect.

159 `muephs=0.0` Mobility modification due to small size.

160 `muepsp=1.0` Mobility modification due to small size.

161 `muepwd=0.0` phonon scattering parameter.

162 `muepld=0.0` phonon scattering parameter.

Channel Length Modulation Effects

163 `clm1=0.7` First parameter for CLM.

164 `clm2=2.0 1/m` Second parameter for CLM.

165 `clm3=1.0` Third parameter for CLM.

166 `clm4=5.0E-4` Smoothing coefficient for gds.

167 `clm5=1.0` Effect of pocket implantation.

168 `clm6=0.0` Effect of pocket implantation.

Substrate Current Effects

169 `sub1=10.0 1/V` First parameter for Isub.

170 `sub2=25.0 V` Second parameter for Isub.

171 `svgs=0.8` Substrate current dependence on Vgs.

172 `svbs=0.5` Substrate current dependence on Vbs.

173 `svbsl=0.0` Lgate dependence of SVBS.

174 `svds=0.8` Substrate current dependence on Vds.

175 `slg=3.0E-8` Substrate current dependence on Lgate.

176 `sub1l=2.5E-3` Lgate dependence of SUB1.

177 `sub2l=2.0E-6` Lgate dependence of SUB2.

178 `fn1=0.0` Coefficient of Fowler-Nordheim-current contribution.

179 `fn2=0.0` Coefficient of Fowler-Nordheim-current contribution.

180 `fn3=0.0` Coefficient of Fowler-Nordheim-current contribution.

181 `fvbs=0.0` Modification of Vbs dependence.

182 `svgsl=0.0` Lgate dependence of SVGS.

183 `svgslp=1.0` Lgate dependence of SVGS.

184 `svgswp=1.0` Wgate dependence of SVGS.

185 `svgsw=0.0` Wgate dependence of SVGS.

186 `svbslp=1.0` Lgate dependence of SVBS.

187 `slgl=0.0` Substrate current dependence on Lgate.

188 `slglp=1.0` Substrate current dependence on Lgate.

189 `sub1lp=1.0` Lgate dependence of SUB1.

190 `ibpc1=0.0` Impact-ionization induced bulk potential change.

191 `ibpc2=0.0` Impact-ionization induced bulk potential change.

Gate Current Effects

192 `glpart1=0.5` partitioning of gate current.

193 `gleak1=50.0 A/(V^(3/2) c^(1/2))`
First gate current coefficient.

194 `gleak2=1.0E7 1/(V^(1/2) c^(3/2) m)`
Second gate current coefficient.

195 `gleak3=6.0E-2` Third gate current coefficient.

196 `gleak4=4.0` parameter for gate current.

197 `gleak5=7.5E3` parameter for gate current.

198 `glksd1=1.0E-15` parameter for gate current.

199 `glksd2=5e-6` parameter for gate current.

200 `glksd3=-5e-6` parameter for gate current.

201 `glkb0=0.0 V` parameter for gate current.

202 `glkb1=5.0E-16` parameter for gate current.

203 `glkb2=1.0` parameter for gate current.

204 `igtemp1=0.0` parameter for gate current.

205 `igtemp2=0.0` parameter for gate current.

206 `igtemp3=0.0` parameter for gate current.

207 `gleak6=0.25 V` Parameter for gate current.

208 `gleak7=1.0E-6` m^2 Parameter for gate current.

209 `glkb3=0e0 V` parameter for gate current,existed from 2.40.

210 `egig=1.1 V` parameter for gate current,existed from 2.40.

GIDL Current Effects

211 `gidl1=2.0 A m/(V^(3/2) c^(1/2))`
First parameter for GIDL.

212 `gidl2=3.0E7 1/(V^(1/2) c^(3/2) m)`
Second parameter for GIDL.

213 `gidl3=0.9` Third parameter for GIDL.

214 `gidl4=0.9` Parameter for GIDL.

215 `gidl5=0.2` Parameter for GIDL.

Noise 1/f Effects

216 `nfalp=1.0e-19` Flicker (1/f) noise contribution of the mobility fluctuation.

217 `nftrp=1.0e10` Flicker (1/f) noise ratio of trap density to attenuation coefficient.

218 `cit=0.0` Flicker (1/f) noise interface trapped carriers capacitance.

219 `falph=1.0` parameter for 1/f noise.

Subthreshold swing parameters

220 `pthroub=0.0 1/V` modify subthreshold sloop.

NQS parameters

221 `dly1=1.0E-10` parameter for transit time.

222 `dly2=0.7` parameter for transit time.

223 `dly3=8.0E-7 Ω` parameter for transforming bulk charge.

Symmetry for short-channel mosfet

224 `vzadd0=20.0e-3 V` Vzadd at Vds=0.

225 `pzadd0=20.0e-3 V` Pzadd at Vds=0.

P-N junctions parameters

226 `js0=5.0e-7 A/m`^{2} Junction saturation current density.

227 `js0sw=0.0 A/m` Side-wall saturation current density.

228 `nj=1.0` Junction emission coefficient.

229 `njsw=1.0` Junction emission coefficient (sidewall).

230 `xti=2.0` Junction saturation current temperature exponent coefficient.

231 `cj=5.0e-4 F/m`^{2} Bottom junction capacitance per unit area at zero bias.

232 `cjsw=5e-10 F/m` Source/drain sidewall junction capacitance per unit length at zero bias.

233 `cjswg=5e-10 F/m` Source/drain sidewall junction capacitance grading coefficient per unit length at zero bias.

234 `mj=0.5` Bulk junction bottom grading coefficient.

235 `mjsw=0.33` Source/drain sidewall junction capacitance grading coefficient.

236 `mjswg=0.33`	Bottom junction capacitance grading coefficient.
237 `pb=1.0 V`	Bottom junction build-in potential.
238 `pbsw=1.0 V`	Source/drain sidewall junction build-in potential.
239 `pbswg=1.0 V`	Source/drain gate sidewall junction build-in potential.
240 `vdiffj=6.0E-4 V`	threshold voltage for S/D junction diode.
241 `xti2=0.0`	Temperature coefficient.
242 `cisb=0.0`	Reverse bias saturation current.
243 `cvb=0.0`	Bias dependence coefficient of cisb.
244 `ctemp=0.0`	Temperature coefficient.
245 `cisbk=0.0 A`	Reverse bias saturation current.
246 `cvbk=0.0`	Bias dependence coefficient of cisb.
247 `divx=0.0 1/V`	Parameter for junction.
248 `tcjbs=0.0`	Temperature dependence of czbs.
249 `tcjbd=0.0`	Temperature dependence of czbd.
250 `tcjbssw=0.0`	Temperature dependence of czbssw.
251 `tcjbdsw=0.0`	Temperature dependence of czbdsw.
252 `tcjbsswg=0.0`	Temperature dependence of czbsswg.
253 `tcjbdswg=0.0`	Temperature dependence of czbdswg.

Overlap capacitance parameters

254 `cgso=0.0 F/m`	Gate-source overlap capacitance.
255 `cgdo=0.0 F/m`	Gate-drain overlap capacitance.
256 `cgbo=0.0 F/m`	Gate-bulk overlap capacitance.

257 `ovslp=2.1E-7` Parameter for overlap capacitance.

258 `ovmag=0.6` Parameter for overlap capacitance.

259 `vfbover=0.0 V` Flat-band voltage in overlap region,existed from 2.40.

260 `nover=1e19 cm`$^{-3}$ Impurity concentration in overlap region,existed from 2.40.

Smoothing coefficient between linear and saturation

261 `ddltmax=10.0` Coefficient of effective electric field,existed from 2.40.

262 `ddltslp=0.0` Lgate dependence of smoothing coefficient,existed from 2.40.

263 `ddltict=10.0` Lgate dependence of smoothing coefficient,existed from 2.40.

DFM parameters

264 `mphdfm=-0.3` NSUBCDFM dependence of phonon scattering for DFM,existed from 2.40.

WPE: Well Proximity Effects parameters

265 `web=0.0` Modification of layout characterization factor.

266 `wec=0.0` Modification of layout characterization factor.

267 `nsubcwpe=0.0 cm`$^{-3}$
Channel concentration change due to WPE.

268 `npextwpe=0.0 cm`$^{-3}$
Pocket-tail concentration change due to WPE.

269 `nsubpwpe=0.0 cm`$^{-3}$
Pocket concentration change due to WPE.

Binning model parameters which are existed from 2.40

270 `lbinn=1.0` L modulation coefficient for binning.

271 `wbinn=1.0` W modulation coefficient for binning.

272 `lvmax=0.0 cm/s` Length dependence of vmax.

273 `lbgtmp1=0.0 eV/K` Length dependence of bgtmp1.

274 `lbgtmp2=0.0 eV/K`^{2}
Length dependence of bgtmp2.

275 `leg0=0.0 eV` Length dependence of eg0.

276 `llover=0.0 m` Length dependence of lover.

277 `lvfbover=0.0 V` Length dependence of vfbover.

278 `lnover=0.0 cm`$^{-3}$ Length dependence of nover.

279 `lwl2=0.0` Length dependence of wl2.

280 `lvfbc=0.0 V` Length dependence of vfbc.

281 `lnsubc=0.0 cm`$^{-3}$ Length dependence of nsubc.

282 `lnsubp=0.0 cm`$^{-3}$ Length dependence of nsubp.

283 `lscp1=0.0 1/V` Length dependence of scp1.

284 `lscp2=0.0 1/V`^{2} Length dependence of scp2.

285 `lscp3=0.0 m/V`^{2} Length dependence of scp3.

286 `lsc1=0.0 1/V` Length dependence of sc1.

287 `lsc2=0.0 1/V`^{2} Length dependence of sc2.

288 `lsc3=0.0 m/V`^{2} Length dependence of sc3.

289 `lpgd1=0.0 V` Length dependence of pgd1.

290 `lpgd3=0.0` Length dependence of pgd3.

291 `lndep=0.0` Length dependence of ndep.

292 `lninv=0.0` Length dependence of ninv.

293 `lmuecb0=0.0 cm`^{2}`/(V s)`
Length dependence of muecb0.

294 `lmuecb1=0.0 cm`^{2}`/(V s)`
Length dependence of muecb1.

295 `lmueph1=0.0` Length dependence of mueph1.

296 `lvtmp=0.0 cm/s` Length dependence of vtmp.

297 `lwvth0=0.0` Length dependence of wvth0.

298 `lmuesr1=0.0` Length dependence of muesr1.

299 `lmuetmp=0.0` Length dependence of muetmp.

300 `lsub1=0.0 1/V` Length dependence of sub1.

301 `lsub2=0.0 V` Length dependence of sub2.

302 `lsvds=0.0` Length dependence of svds.

303 `lsvbs=0.0` Length dependence of svbs.

304 `lsvgs=0.0` Length dependence of svgs.

305 `lfn1=0.0` Length dependence of fn1.

306 `lfn2=0.0` Length dependence of fn2.

307 `lfn3=0.0` Length dependence of fn3.

308 `lfvbs=0.0` Length dependence of fvbs.

309 `lnsti=0.0 cm`$^{-3}$ Length dependence of nsti.

310 `lwsti=0.0 m` Length dependence of wsti.

311 `lscsti1=0.0` Length dependence of scsti1.

312 `lscsti2=0.0 1/V` Length dependence of scsti2.

313 `lvthsti=0.0` Length dependence of vthsti.

314 `lmuesti1=0.0` Length dependence of muesti1.

315 `lmuesti2=0.0` Length dependence of muesti2.

316 `lmuesti3=0.0` Length dependence of muesti3.

317 `lnsubpsti1=0.0 m` Length dependence of nsubpsti1.

318 `lnsubpsti2=0.0 m` Length dependence of nsubpsti2.

319 `lnsubpsti3=0.0 m` Length dependence of nsubpsti3.

320 `lcgso=0.0 F/m` Length dependence of cgso.

321 `lcgdo=0.0 F/m` Length dependence of cgdo.

322 `ljs0=0.0 A/m`^{2} Length dependence of js0.

323 `ljs0sw=0.0 A/m` Length dependence of js0sw.

324 `lnj=0.0` Length dependence of nj.

325 `lcisbk=0.0 A` Length dependence of cisbk.

326 `lclm1=0.0` Length dependence of clm1.

327 `lclm2=0.0 1/m` Length dependence of clm2.

328 `lclm3=0.0` Length dependence of clm3.

329 `lwfc=0.0 m F/cm`^{2} Length dependence of wfc.

330 `lgidl1=0.0 A m/(V^(3/2) c^(1/2))`
Length dependence of gidl1.

331 `lgidl2=0.0 1/(V^(1/2) c^(3/2) m)`
Length dependence of gidl2.

332 `lgleak1=0.0 A/(V^(3/2) c^(1/2))`
Length dependence of gleak1.

333 `lgleak2=0.0 1/(V^(1/2) c^(3/2) m)`
Length dependence of gleak2.

334 `lgleak3=0.0` Length dependence of gleak3.

335 `lgleak6=0.0 V` Length dependence of gleak6.

336 `lglksd1=0.0` Length dependence of glksd1.

337 `lglksd2=0.0` Length dependence of glksd2.

338 `lglkb1=0.0` Length dependence of glkb1.

339 `lglkb2=0.0` Length dependence of glkb2.

340 `lnftrp=0.0` Length dependence of nftrp.

341 `lnfalp=0.0` Length dependence of nfalp.

342 `lvdiffj=0.0 V` Length dependence of vdiffj.

343 `libpc1=0.0` Length dependence of ibpc1.

344 `libpc2=0.0` Length dependence of ibpc2.

345 `lsc4=0.0` Length dependence of sc4.

346 `wvmax=0.0 cm/s` Width dependence of vmax.

347 `wbgtmp1=0.0 eV/K` Width dependence of bgtmp1.

348 `wbgtmp2=0.0` eV/K^2
Width dependence of bgtmp2.

349 `weg0=0.0 eV` Width dependence of eg0.

350 `wlover=0.0 m` Width dependence of lover.

351 `wvfbover=0.0 V` Width dependence of vfbover.

352 `wnover=0.0` cm^{-3} Width dependence of nover.

353 `wwl2=0.0` Width dependence of wl2.

354 `wvfbc=0.0 V` Width dependence of vfbc.

355 `wnsubc=0.0 cm`$^{-3}$ Width dependence of nsubc.

356 `wnsubp=0.0 cm`$^{-3}$ Width dependence of nsubp.

357 `wscp1=0.0 1/V` Width dependence of scp1.

358 `wscp2=0.0 1/V`^{2} Width dependence of scp2.

359 `wscp3=0.0 m/V`^{2} Width dependence of scp3.

360 `wsc1=0.0 1/V` Width dependence of sc1.

361 `wsc2=0.0 1/V`^{2} Width dependence of sc2.

362 `wsc3=0.0 m/V`^{2} Width dependence of sc3.

363 `wpgd1=0.0 V` Width dependence of pgd1.

364 `wpgd3=0.0` Width dependence of pgd3.

365 `wndep=0.0` Width dependence of ndep.

366 `wninv=0.0` Width dependence of ninv.

367 `wmuecb0=0.0 cm`^{2}`/(V s)`
Width dependence of muecb0.

368 `wmuecb1=0.0 cm`^{2}`/(V s)`
Width dependence of muecb1.

369 `wmueph1=0.0` Width dependence of mueph1.

370 `wvtmp=0.0 cm/s` Width dependence of vtmp.

371 `wwvth0=0.0` Width dependence of wvth0.

372 `wmuesr1=0.0` Width dependence of muesr1.

373 `wmuetmp=0.0` Width dependence of muetmp.

374 `wsub1=0.0 1/V` Width dependence of sub1.

375 `wsub2=0.0 V`	Width dependence of sub2.
376 `wsvds=0.0`	Width dependence of svds.
377 `wsvbs=0.0`	Width dependence of svbs.
378 `wsvgs=0.0`	Width dependence of svgs.
379 `wfn1=0.0`	Width dependence of fn1.
380 `wfn2=0.0`	Width dependence of fn2.
381 `wfn3=0.0`	Width dependence of fn3.
382 `wfvbs=0.0`	Width dependence of fvbs.
383 `wnsti=0.0 cm`$^{-3}$	Width dependence of nsti.
384 `wwsti=0.0 m`	Width dependence of wsti.
385 `wscsti1=0.0`	Width dependence of scsti1.
386 `wscsti2=0.0 1/V`	Width dependence of scsti2.
387 `wvthsti=0.0`	Width dependence of vthsti.
388 `wmuesti1=0.0`	Width dependence of muesti1.
389 `wmuesti2=0.0`	Width dependence of muesti2.
390 `wmuesti3=0.0`	Width dependence of muesti3.
391 `wnsubpsti1=0.0 m`	Width dependence of nsubpsti1.
392 `wnsubpsti2=0.0 m`	Width dependence of nsubpsti2.
393 `wnsubpsti3=0.0 m`	Width dependence of nsubpsti3.
394 `wcgso=0.0 F/m`	Width dependence of cgso.
395 `wcgdo=0.0 F/m`	Width dependence of cgdo.
396 `wjs0=0.0 A/m`^{2}	Width dependence of js0.

397 `wjs0sw=0.0 A/m` Width dependence of js0sw.

398 `wnj=0.0` Width dependence of nj.

399 `wcisbk=0.0 A` Width dependence of cisbk.

400 `wclm1=0.0` Width dependence of clm1.

401 `wclm2=0.0 1/m` Width dependence of clm2.

402 `wclm3=0.0` Width dependence of clm3.

403 `wwfc=0.0 m F/cm`^{2} Width dependence of wfc.

404 `wgidl1=0.0 A m/(V^(3/2) c^(1/2))`
Width dependence of gidl1.

405 `wgidl2=0.0 1/(V^(1/2) c^(3/2) m)`
Width dependence of gidl2.

406 `wgleak1=0.0 A/(V^(3/2) c^(1/2))`
Width dependence of gleak1.

407 `wgleak2=0.0 1/(V^(1/2) c^(3/2) m)`
Width dependence of gleak2.

408 `wgleak3=0.0` Width dependence of gleak3.

409 `wgleak6=0.0 V` Width dependence of gleak6.

410 `wglksd1=0.0` Width dependence of glksd1.

411 `wglksd2=0.0` Width dependence of glksd2.

412 `wglkb1=0.0` Width dependence of glkb1.

413 `wglkb2=0.0` Width dependence of glkb2.

414 `wnftrp=0.0` Width dependence of nftrp.

415 `wnfalp=0.0` Width dependence of nfalp.

416 `wvdiffj=0.0 V` Width dependence of vdiffj.

417 `wibpc1=0.0` Width dependence of ibpc1.

418 `wibpc2=0.0` Width dependence of ibpc2.

419 `wsc4=0.0` Width dependence of sc4.

420 `pvmax=0.0 cm/s` Cross-term dependence of vmax.

421 `pbgtmp1=0.0 eV/K` Cross-term dependence of bgtmp1.

422 `pbgtmp2=0.0 eV/K`^{2} Cross-term dependence of bgtmp2.

423 `peg0=0.0 eV` Cross-term dependence of eg0.

424 `plover=0.0 m` Cross-term dependence of lover.

425 `pvfbover=0.0 V` Cross-term dependence of vfbover.

426 `pnover=0.0 cm`$^{-3}$ Cross-term dependence of nover.

427 `pwl2=0.0` Cross-term dependence of wl2.

428 `pvfbc=0.0 V` Cross-term dependence of vfbc.

429 `pnsubc=0.0 cm`$^{-3}$ Cross-term dependence of nsubc.

430 `pnsubp=0.0 cm`$^{-3}$ Cross-term dependence of nsubp.

431 `pscp1=0.0 1/V` Cross-term dependence of scp1.

432 `pscp2=0.0 1/V`^{2} Cross-term dependence of scp2.

433 `pscp3=0.0 m/V`^{2} Cross-term dependence of scp3.

434 `psc1=0.0 1/V` Cross-term dependence of sc1.

435 `psc2=0.0 1/V`^{2} Cross-term dependence of sc2.

436 `psc3=0.0 m/V`^{2} Cross-term dependence of sc3.

437 `ppgd1=0.0 V` Cross-term dependence of pgd1.

438 `ppgd3=0.0` Cross-term dependence of pgd3.

439 `pndep=0.0` Cross-term dependence of ndep.

440 `pninv=0.0` Cross-term dependence of ninv.

441 `pmuecb0=0.0` cm^2/(V s)
Cross-term dependence of muecb0.

442 `pmuecb1=0.0` cm^2/(V s)
Cross-term dependence of muecb1.

443 `pmueph1=0.0` Cross-term dependence of mueph1.

444 `pvtmp=0.0 cm/s` Cross-term dependence of vtmp.

445 `pwvth0=0.0` Cross-term dependence of wvth0.

446 `pmuesr1=0.0` Cross-term dependence of muesr1.

447 `pmuetmp=0.0` Cross-term dependence of muetmp.

448 `psub1=0.0 1/V` Cross-term dependence of sub1.

449 `psub2=0.0 V` Cross-term dependence of sub2.

450 `psvds=0.0` Cross-term dependence of svds.

451 `psvbs=0.0` Cross-term dependence of svbs.

452 `psvgs=0.0` Cross-term dependence of svgs.

453 `pfn1=0.0` Cross-term dependence of fn1.

454 `pfn2=0.0` Cross-term dependence of fn2.

455 `pfn3=0.0` Cross-term dependence of fn3.

456 `pfvbs=0.0` Cross-term dependence of fvbs.

457 `pnsti=0.0` cm^{-3} Cross-term dependence of nsti.

458 `pwsti=0.0 m` Cross-term dependence of wsti.

459 `pscsti1=0.0` Cross-term dependence of scsti1.

460 `pscsti2=0.0 1/V` Cross-term dependence of scsti2.

461 `pvthsti=0.0` Cross-term dependence of vthsti.

462 `pmuesti1=0.0` Cross-term dependence of muesti1.

463 `pmuesti2=0.0` Cross-term dependence of muesti2.

464 `pmuesti3=0.0` Cross-term dependence of muesti3.

465 `pnsubpsti1=0.0 m` Cross-term dependence of nsubpsti1.

466 `pnsubpsti2=0.0 m` Cross-term dependence of nsubpsti2.

467 `pnsubpsti3=0.0 m` Cross-term dependence of nsubpsti3.

468 `pcgso=0.0 F/m` Cross-term dependence of cgso.

469 `pcgdo=0.0 F/m` Cross-term dependence of cgdo.

470 `pjs0=0.0 A/m`^{2} Cross-term dependence of js0.

471 `pjs0sw=0.0 A/m` Cross-term dependence of js0sw.

472 `pnj=0.0` Cross-term dependence of nj.

473 `pcisbk=0.0 A` Cross-term dependence of cisbk.

474 `pclm1=0.0` Cross-term dependence of clm1.

475 `pclm2=0.0 1/m` Cross-term dependence of clm2.

476 `pclm3=0.0` Cross-term dependence of clm3.

477 `pwfc=0.0 m F/cm`^{2} Cross-term dependence of wfc.

478 `pgidl1=0.0 A m/(V^(3/2) c^(1/2))`
Cross-term dependence of gidl1.

479 `pgidl2=0.0 1/(V^(1/2) c^(3/2) m)`
Cross-term dependence of gidl2.

480 `pgleak1=0.0 A/(V^(3/2) c^(1/2))`
Cross-term dependence of gleak1.

481 `pgleak2=0.0 1/(V^(1/2) c^(3/2) m)`
Cross-term dependence of gleak2.

482 `pgleak3=0.0` Cross-term dependence of gleak3.

483 `pgleak6=0.0 V` Cross-term dependence of gleak6.

484 `pglksd1=0.0` Cross-term dependence of glksd1.

485 `pglksd2=0.0` Cross-term dependence of glksd2.

486 `pglkb1=0.0` Cross-term dependence of glkb1.

487 `pglkb2=0.0` Cross-term dependence of glkb2.

488 `pnftrp=0.0` Cross-term dependence of nftrp.

489 `pnfalp=0.0` Cross-term dependence of nfalp.

490 `pvdiffj=0.0 V` Cross-term dependence of vdiffj.

491 `pibpc1=0.0` Cross-term dependence of ibpc1.

492 `pibpc2=0.0` Cross-term dependence of ibpc2.

493 `psc4=0.0` Cross-term dependence of sc4.

494 `vgsmin=-5 type V`
minimal/maximal expected Vgs (NMOS/PMOS).

495 `sc3vbs=0.0 V` Vbs value for clamping sc3.

496 `muecb0lp=0.0` L dependence of MUECB0.

497 `muecb1lp=0.0` L dependence of MUECB1.

498 `coqovsm=1` select smoothing method of Qover.

499 `ndepw=0.0` coeff. of Qbm for Eeff.

500 `ndepwp=1.0` coeff. of Qbm for Eeff.

501 `npextw=0.0`

502 `npextwp=0.0`

503 `minr=0.001 Ω` Minimum source/drain resistance.

Auto Model Selector parameters

504 `wmax=1 m` Maximum channel width for which the model is valid.

505 `wmin=0 m` Minimum channel width for which the model is valid.

506 `lmax=1 m` Maximum channel length for which the model is valid.

507 `lmin=0 m` Minimum channel length for which the model is valid.

508 `nsubcsti1=0.0 m` STI Stress Parameter for Nsubc [-].

509 `nsubcsti2=0.0 m` STI Stress Parameter for Nsubc [-].

510 `nsubcsti3=1.0 m` STI Stress Parameter for Nsubc [-].

511 `gidl6=0` parameter for GIDL [-].

512 `gidl7=1` parameter for GIDL [-].

513 `lnsubcsti1=0.0 m` Length dependence of nsubcsti1.

514 `lnsubcsti2=0.0 m` Length dependence of nsubcsti2.

515 `lnsubcsti3=0.0 m` Length dependence of nsubcsti3.

516 `wnsubcsti1=0.0 m` Wength dependence of nsubcsti1.

517 `wnsubcsti2=0.0 m` Wength dependence of nsubcsti2.

518 `wnsubcsti3=0.0 m` Wength dependence of nsubcsti3.

519 `pnsubcsti1=0.0 m` Cross-term dependence of nsubcsti1.

520 `pnsubcsti2=0.0 m` Cross-term dependence of nsubcsti2.

521 `pnsubcsti3=0.0 m` Cross-term dependence of nsubcsti3.

522 `nsubpdlt=0.01` Delta for nsubp smoothing [-].

523 `vfbcl=0.0` gate-length dependence of VFBC [um].

524 `vfbclp=1.0` gate-length dependence of VFBC [-].

525 `coerrrep=1` selector for error report.

Output Parameters

1 `tempeff (C)` Effective temperature for a single device.

2 `weff (m)` Effective channel width.

3 `leff (m)` Effective channel length.

4 `rseff (Ω)` Effective source resistance.

5 `rdeff (Ω)` Effective drain resistance.

Operating-Point Parameters

1 `reversed` Reverse mode indicator.
Possible values are `no` and `yes`.

2 `ids (A)` Resistive drain-to-source current.

3 `vgs (V)` Gate-source voltage.

4 `vds (V)` Drain-source voltage.

5 `vbs (V)` Bulk-source voltage.

6 `vth (V)` Threshold voltage.

7 `vdsat (V)` Drain-source saturation voltage.

8 `gm (S)` Common-source transconductance.

9 `gds (S)` Common-source output conductance.

10 `gmbs (S)`	Body-transconductance.
11 `qb (Coul)`	Total bulk charge.
12 `qd (Coul)`	Total drain charge.
13 `qg (Coul)`	Total gate charge.
14 `qs (Coul)`	Total source charge.
15 `cjd (F)`	Drain-bulk junction capacitance.
16 `cjs (F)`	Source-bulk junction capacitance.
17 `cgg (F)`	dQg_dVg.
18 `cgd (F)`	dQg_dVd.
19 `cgs (F)`	dQg_dVs.
20 `cgb (F)`	dQg_dVb.
21 `cdg (F)`	dQd_dVg.
22 `cdd (F)`	dQd_dVd.
23 `cds (F)`	dQd_dVs.
24 `cdb (F)`	dQd_dVb.
25 `csg (F)`	dQs_dVg.
26 `csd (F)`	dQs_dVd.
27 `css (F)`	dQs_dVs.
28 `csb (F)`	dQs_dVb.
29 `cbg (F)`	dQb_dVg.
30 `cbd (F)`	dQb_dVd.
31 `cbs (F)`	dQb_dVs.

32 `cbb (F)`	dQb_dVb.
33 `id (A)`	Resistive drain current.
34 `ig (A)`	Gate current.
35 `is (A)`	Resistive source current.
36 `ibulk (A)`	Resistive bulk current.
37 `pwr (W)`	Power at operating point.
38 `ps0 (V)`	Surface potential at source side.
39 `psl (V)`	Surface potential at drain side.
40 `pds (V)`	Delta surface potential between psl and ps0.
41 `isub (A)`	Substrate current Isub.
42 `gbds (S)`	Substrate trans conductance (dIsub/dVds).
43 `gbgs (S)`	Substrate trans conductance (dIsub/dVgs).
44 `gbbs (S)`	Substrate transconductance (dIsub/dVbs).
45 `igate (A)`	Gate current due to tunneling.
46 `igates (A)`	Tunneling current from gate to source.
47 `igateb (A)`	Tunneling current from gate to bulk.
48 `igated (A)`	Tunneling current from gate to drain.
49 `igisl (A)`	Gate-induced source leakage current.
50 `igidl (A)`	Gate-induced drain leakage current.
51 `ibs (A)`	Source-bulk diode current.
52 `ibd (A)`	Source-drain diode current.
53 `cgso (F)`	Gate-source overlap capacitance.

54 `cgbo (F)` Gate-bulk overlap capacitance.

55 `cgdo (F)` Gate-drain overlap capacitance.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

31

HISIM_HV Model (hisim_hv)

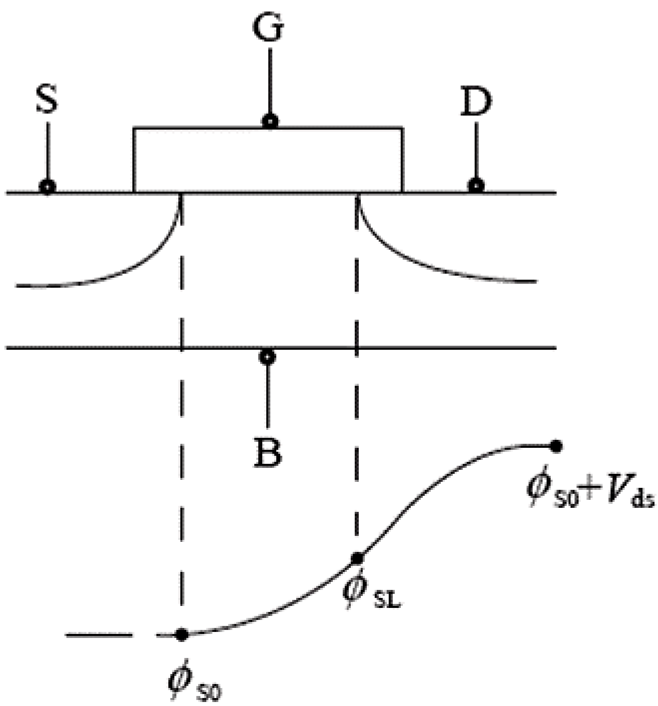
HiSIM_HV is an extension of HiSIM model that is a surface potential based MOSFET model. HiSIM_HV added high voltage device specific feature, like drift region resistance, etc. It can be used to model both laterally diffused MOS (LDMOS) and high voltage MOS (HVMOS) types of device structures. HiSIM_HV is elected as CMC's standard high voltage device model. The latest model version is HiSIM_HV 2.10.

This chapter contains the following information about the HiSIM_HV model:

Model Concepts

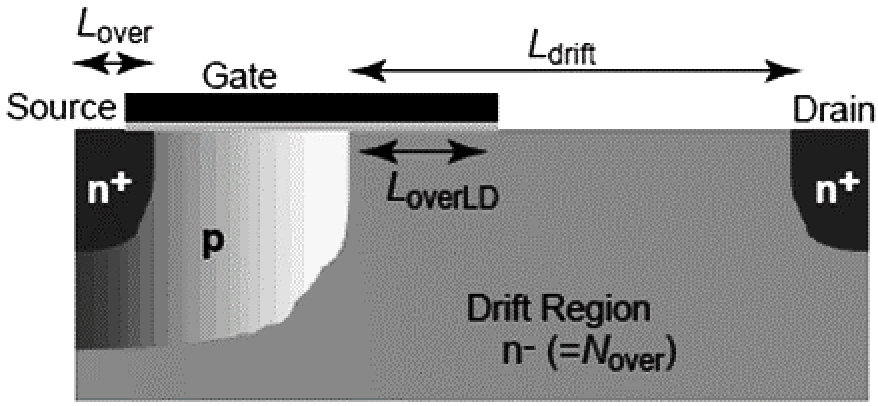
HiSIM (Hiroshima-university STARC IGFET Model) is the first complete surface-potential-based MOSFET model for circuit simulation based on the drift-diffusion theory, which was originally developed by Pao and Sah. The most important advantage of the surface-potential-based modeling is the unified description of device characteristics for all bias conditions. The physical reliability of the drift-diffusion theory has been proved by 2D device simulations with channel lengths even down to below 0.1um.

Figure 31-1 Schematic of the surface potential distribution in the channel



The most important feature of LDMOS/HVMOS devices, different from the conventional MOSFET, is that the drift region is introduced to achieve the sustainable high voltages. By varying the length as well as the dopant concentration of the drift region, various devices with various operating bias conditions are realized as shown in Fig. 31-2 or the LDMOS structure. In any cases, the drift region affects as the resistance for the current flow and also induces additional charge, which causes the especially unique features of the LDMOS capacitances. Thus accurate modeling of the drift region is the main task of HiSIM_HV.

Figure 31-2 Schematic of the typical LDMOS structure and device parameters



For the LDMOS/HVMOS device the iterative solution is only one possible solution to model the specific features of this device accurately, because the resistance effect in the drift region is dependent on the bias condition as well as the geometrical structure. The basic modeling method is taken over from the HiSIM2 model, and additional equations for capturing the drift-region effects are included. Since the overlap length is relatively long for LDMOS/HVMOS, accurate surface potential calculation for the overlap region is also necessary for accurate prediction of the high-voltage MOS capacitances.

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Three types of devices structure can be modeled since HiSIM_HV version 1.2.0 and 1.1.1: Asymmetrical LDMOS, Symmetrical HV-MOS and Asymmetrical HV-MOS. Model parameter **COSYM** determines the devices symmetry and L_{drift}, the overlap length L_{over}, as well as the impurity concentration of the drift region N_{over} determine the characteristics of respectively side. In the LDMOS case independent structures at the source side and the drain side are distinguished, and the L_{drift} region is not introduced at the source side. In the HVMOS case, the parameter values for the drain side have to be determined, and are copied to the source side automatically. If parameters for the source side are determined explicitly, these values are taken. If parameters are not determined, values at the drain side are taken. If the parameter values are not determined, default values are taken. This is valid for any structural cases. Fig. 31-3 shows three different devices structures and table 31-1 shows the model parameters used by different structures.

Figure 31-3 Three different devices structure and related model parameters

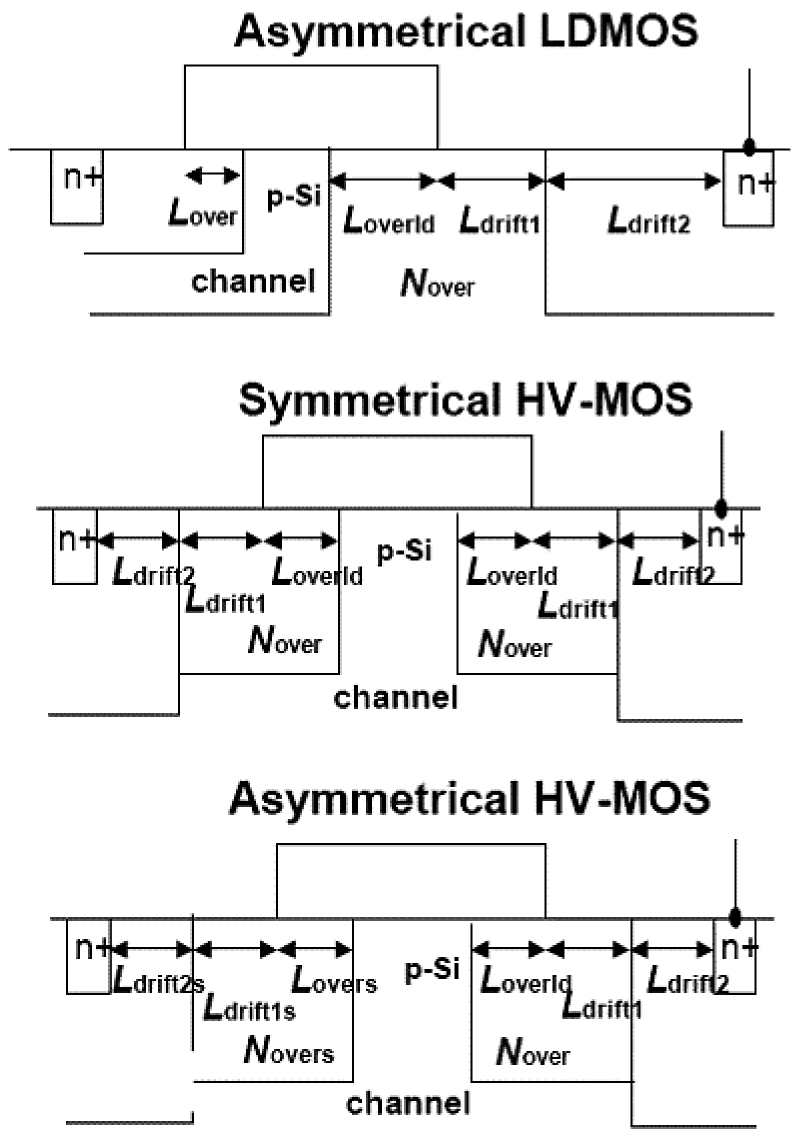


Table 31-1 The different model parameters used by different structures

	Structure	Source	Drain
COSYM=0	LDMOS	LOVERS	LOVERLD
			LDRIFT1
			LDRIFT2
			NOVER
COSYM=1	Symmetrical HVMOS		LOVERLD
			LDRIFT1
			LDRIFT2
			NOVER
COSYM=1	Asymmetrical HVMOS	LOVERS	LOVERLD
		LDRIFT1S	LDRIFT1
		LDRIFT2S	LDRIFT2
		NOVERS	NOVER

Model Usage

HiSIM_HV model definition is used to describe the behavior of devices which has same model characteristics and the instance parameters can be used to describe the characteristics that belong to the specific device.

Instance Syntax

HiSIM_HV instance need specify at least 4 terminals and up to 6 terminals can be supplied. If the 5th terminal is given and **COSUBNODE**=0, it is used as external self-heating node and the self-heating information can be obtained with it when the self-heating effect is activated. If 5th terminal is not given and the self-heating effect is activated, another internal self-heating node is created and used to save related information. If the 5th terminal is given and **COSUBNODE**=1, it is used as substrate node and the self-heating information will be saved with internal node when **COSELFHEAT**=1. If 6 nodes are specified, the 5th node is substrate node and the 6th node is thermal node. To specify HiSIM_HV instance element, the ModelName has to be associated with a HiSIM_HV model card.

```
InstanceName d g s b [sub|th][th] ModelName parameter=value ...
```

Sample Instance Statement

m4 (d g s b) nch w=2u l=0.8u as=250p ad=250p pd=168p ps=168p m=2

Model Syntax

The following syntax specifies HiSIM_HV model:

```
model ModelName hisim_hv parameter=value ...
```

The third parameter, “hisim_hv”, is the master to indicate this model card is a HiSIM_HV model card.

Sample Model Statement

model nch hisim_hv type=n version=2.10 corsrd=3 rs=2.0e-3 rd=1.0e-3 rdtemp1=1e-4 xldld=0

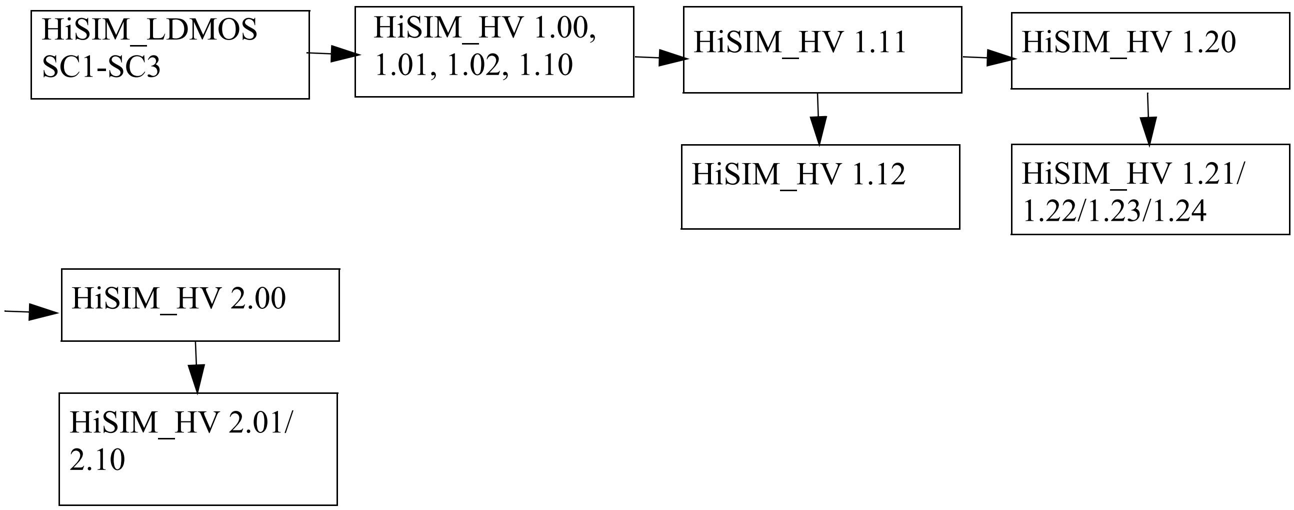
Model Version and Development

Cadence Virtuoso® Spectre and Ultrasim support all HiSIM_HV versions with different simulator versions. Version control takes effect with all MMSIM versions starting with MMSIM711. Different model versions are supported by different MMSIM releases . For example, MMSIM72 supports version 1.11, 1.12, 1.20, and 1.21, MMSIM101, MMSIM 111, MMSIM121, and MMSIM 131 support version 1.11, 1.12, 1.20, 1.21, 1.22, 1.23, 1.24, 2.00, 2.01, and 2.10. The latest model version is 2.10. Different model versions can be obtained by setting different model parameter VERSION = 1.11/1.12/1.20/1.21/1.22/1.23/1.24/2.00/2.01/2.10. If no version is set in the model card, the latest version is used by different versions of simulator. For example, 2.10 is used by MMSIM131 and 1.21 is used by MMSIM72.

There are some known issues in the old model versions 1.11 and 1.12. These issues have been resolved in versions 1.2X and 2.XX. Therefore, starting with the MMSIM 121 ISR12 release, the old versions 1.11 and 1.12 have been retired. However, you can use the `enable_pre_ver=yes` option to activate these versions.

The following figure shows the model version and development flow for the HiSIM_HV model.

Figure 31-4 HiSIM_HV Model Version and Development Flow



Following lists the model versions and their corresponding simulator version for your reference:

HiSIM_LDMOS SC3	MMSIM 7.0
HiSIM_HV 1.00 (LDMOS SC4)	MMSIM 7.0 ISR
HiSIM_HV 1.02	MMSIM 7.1
HiSIM_HV 1.11/1.12	MMSIM 7.1.1
HiSIM_HV 1.11/1.12/1.20/1.21	MMSIM 7.2ISR
HiSIM_HV 1.11/1.12/1.20/1.21/1.22	MMSIM 10.1ISR
HiSIM_HV 1.11/1.12/1.20/1.21/1.22/2.00 beta version	MMSIM 10.1ISR14
HiSIM_HV 1.11/1.12/1.20/1.21/1.22/2.00 final version	MMSIM 10.1ISR17
HiSIM_HV 1.11/1.12/1.20/1.21/1.22/2.00 default	MMSIM 10.1ISR20
HiSIM_HV 1.11/1.12/1.20/1.21/1.22/2.00/ 2.01	MMSIM 11.1 ISR9
HiSIM_HV 1.11/1.12/1.20/1.21/1.22/1.23/ 2.00/2.01	MMSIM 11.1 ISR10

HiSIM_HV 1.11/1.12/1.20/1.21/1.22/1.23/ 2.00/2.01/2.10	MMSIM 12.1 ISR8
HiSIM_HV 1.11/1.12/1.20/1.21/1.22/1.23/ 1.24/2.00/2.01/2.10	MMSIM 12.1 ISR12
HiSIM_HV 1.11/1.12/1.20/1.21/1.22/1.23/ 1.24/2.00/2.01/2.10	MMSIM 13.1

For any questions, please contact the Cadence support team.

Version Update and Enhancement

Version 1.24 Enhancement

The 1.24 version of HiSIM_HV contains the following bug fixes:

- Incorrect referencing to total W instead of W per finger
- Derivative calculations with respect to the temperature

Version 2.10 Enhancement

The 2.10 version of HiSIM_HV contains the following enhancements and bug fixes:

- Degradation of mobility in the drift region with new model parameter `RDRBB`.
- Additional overlap capacitance with new model parameter `QOVADD`.
- Improved smoothness of drift resistance at `Vds=0`.
- Changed default/min/max values of model parameters `NOVER`, `NOVERS`, `SCP1`, `SC1`, `FN1`, `NSTI`, `RDRMAX`, `RDRQOVER`, `QME1` and `QME2` in the source code.
- Changed range check method for model parameter VBFC.
- Bug fixes done for:
    - Range check of `CGSO`, `CGDO`, `CGBO`, `NSUBCDFM`, `SUB2L`, and `SSC4`.
    - Calculation of derivatives
    - Temperature dependence of the output parameter VOH for the threshold voltage
    - NF dependence of RD, RDVD, RD23, and RTH

- Calculation of the temperature derivatives
- Temperation dependence of the output parameter Vth
- Calculation of the output parameter Vdsat

Version 2.01 Enhancement

Version 2.01 is a bug fix version of 2.00 and includes the following bug fixes and enhancements:

- Reference voltage (V_{bs} -> V_{bse}) in the Q_{over} model is used when model parameter `CVDSOVER != 0`
- Derivative calculations with respect to temperature
- Derivative calculations in the Q_{over} model code.
- Floating point exception in the QME model code
- Floating point exception in the smoothing functions
- Floating point exception when model parameters `RDVDL << 0` and `RD23L << 0`
- Floating point exception when model flag/parameters `COSUBNODE !=0` , `COSYM=0`, and `NOVER * (NSUBSUB+NOVER) = 0`
- Floating point exception when model flag `CORDRIFT=1` and model parameter `RDRDJUNC = 0`
- Derivative calculations when model parameter `COSUBNODE = 1`

Version 1.23 Enhancement

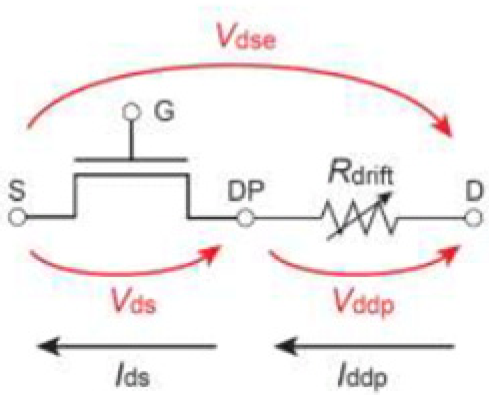
Version 1.23 is a bug fix version of 1.22, which includes the same bug fixes and enhancement as version 2.01 compared with version 2.00.

Version 2.00 Enhancement

Based on version 1.22, following enhancements are done in version 2.00:

New Rdrift Model

A new Rdrift model has been introduced in version 2.00. A flag `CORDIFT` (default= 1) has been introduced to control the evaluation of R_{drift}. The R_{drift} depends on V_{ddp} as well as the V_g in the new version. The mechanism of R_{drift} is shown as following figure:

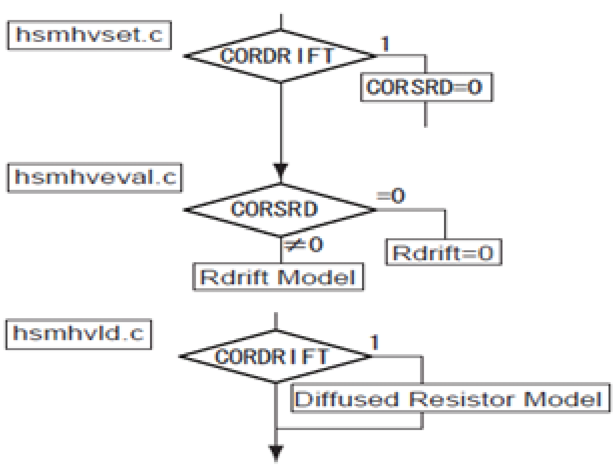


$$I_{ds} = f(V_{ds}, V_{gs}, V_{bs})$$

$$I_{ddp} = f(V_{ddp}) = \frac{V_{ddp}}{R_{drift}}$$

$$R_{drift} = f(V_{ddp}, V_{gse})$$

The usage of the flag is shown in the following figure:



When `CORDIFT=1` (default value), R_{drift} is re-evaluated, otherwise, the old evaluation of R_{drift} is used.

Fitting Improvements

Smoothing of C_{gg} with new model parameter `VGSMIN`.

Asymmetrical Diode Model

Introduction of new model parameters for source/drain independently.

Change of Model Descriptions

- Introduction of new impact-ionization description in drift region with new model parameters `XPDV`, `XPVDH`, and `XPVDHG`
- Improvement of the impact-ionization model in channel of core MOSFET with new model parameters `IBPC1L`, `IBPC1LP`, `SUBLDL`, and `SUBLDLP`
- Independent fitting capability for C-V and I-V characteristics by selectively using model parameters `LOVERLD` and `XLDLD`
- Introduction of new punch-through model for core MOSFET
- Improvement of quantum effect model for core MOSFET
- Improvement of gate-poly depletion model for core MOSFET
- Introduction of the channel leakage conductance with new model parameter `DSLEAK`
- Removing of the following model parameters `PGD3`, `PTHROU`, `RD26`, and `QOVSM`
- Resetting of parameter values to within the defined ranges for the following critical model parameters: `VFBC`, `XLDLD`, `SCP22`, and `RDRCX`

Fixed Bugs

Following bugs are fixed in version 2.00:

- Derivative calculation of drain current with respect to the temperature
- Inaccurate capacitance reciprocity when model parameter `CVDSOVER` is not equal to `0`
- Incorrect recognition of the fifth terminal connected to ground (0) when `COSUBNODE=0` is chosen
- Derivative calculation in self-heating model

Version 1.22 Enhancement

Based on version 1.21, following enhacments have been made in version 1.22:

1. The default value of RDSLP1 changed to 1.0

2. Qover model is enhanced

Version 1.12 Enhancement

Based on version 1.11, much enhancement is done and some bugs are fixed, thus version 1.12 is presented. The difference from version 1.11 to 1.12 consists of two parts: 1) the bug fix that had been included by version 1.20, please refer to session 32.5.5 for the details; 2) the enhancement from version 1.20 to 1.21.

Version 1.21 Enhancement

Based on version 1.20, enhancement is done with the overlap charge and capacitance evaluation, thus latest version 1.21 comes into being to include the change. Following lists the enhancement:

1. Improvements in the lateral-field-induced charge (Qy) model

2. Improvements in the overlap capacitance (Qover) model

New options are provided to calculate Qover. These options are selected by new model parameter COQOVSM:

COQOVSM=0: Qover is calculated with an analytical equation excluding the inversion charge

COQOVSM=1: Qover is calculated with an iterative procedure including the inversion charge (Default)

COQOVSM=2: Qover is calculated with an analytical equation including the inversion charge

Version 1.20 Enhancement

Update information of HiSIM_HV 1.2.0 from HiSIM_HV 1.1.1.

Inclusion of LDMOS-device Structures with a Substrate Node Vsub

HiSIM_HV 1.2.0 additionally covers device structures with a substrate node V_{sub}. The substrate node bias $V_{sub,s}$ increases the depletion width W_{dep} at the drift/substrate (NSUBSUB) junction. The W_{dep} extension into the drift region causes a reduction of the effective drift depth (DDRIFT), and thus an increase of the sheet resistance.

Activate 5th and 6th Terminal

With the latest HiSIM_HV 1.20 model, up to 6 terminals are supported.

- If 5 nodes are specified and COSUBNODE=0, the 5th node is thermal node.
- If 5 nodes are specified and COSUBNODE=1, the 5th node is substrate node, if COSELFHEAT=1 is set too, internal thermal node is created.
- If 6 nodes are specified, the 5th node is substrate node and the 6th node is thermal node.

COSUBNODE is a new instance parameter at the same time recognized as a model parameter for the specification and the recognition of the node order.

Model and Instance Parameters Changes

Following new model parameters are added:

- XWDLD: Increase of the effective device width in the drift region due to 2D spreading.
- XWDC: Different effective device width for capacitances.
- NINVDW and NINVDWP: Vds dependence in the low-field-mobility width dependence.
- VMAXT1 and VMAXT2: Temperature dependence of Vmax.
- NINVDT1 and NINVDT2: Temperature dependence in the low-field-mobility Vds dependence.
- RTHTEMP1 and RTHTEMP2: Temperature dependence of the self-heating effect.
- PRATTEMP1 and PRATTEMP1: Temperature dependence of the thermal dissipation.
- COTEMP: The model flag to select different temperature effects of rd, rs, rdvd, rsvd, vmax and ninvd.
- COLDRIFT: The flag to select different Ldrift.
- Following binning option are added for following model parameters: NPEXT FALPH RD RS RD22 RD23 RD24 RDVG11 RDICT1 RDOV13 RDSLP1 RDVB RDVD RTH0 VOVER CGBO CVDSOVER POWRAT
- COSUBNODE: The model and instance flag for substrate node.
- COSELFHEAT: The flag was model parameter with the older version model. New instance flag is added with version 1.20

Flag for Temperature Dependent Model Selection

In the HiSIM_HV 1.1.1 versions, temperature dependence of the drift resistance RDVD includes no self-heating effect, whereas RD includes the effect. To treat all temperature dependent models (RD, RDVD, VMAX, NINVD) after users convenience, the flag COTEMP is introduced. Following is the selection of COTEMP:

COTEMP	RD (RS)	RDVD (RSVD)	Vmax	Ninvd
0	T	T0	T0	T0
1	T0	T0	T0	T0
2	T	T	T	T
3	T	T	T0	T0

where T is T0+∂T, and ∂T is the temperature increase due to the self-heating effect.

The Older Version Bug Fix

Following bugs are fixed with the latest 1.20 and the older 1.11 version.

- NF in Diode model
- Ra discontinuity at Vds=0
- Rs temperature dependency
- Smoothing function in overlap capacitance model
- Other minor bugs

Reference

Model Equations

Some important model equations are listed as following for your reference:

Charge

All device characteristics are determined on the basis of the charge controlled by applied voltages and by expressing the MOSFET charges as functions of the surface potentials. Under the charge-sheet approximation the charges on the four MOSFET terminals Q_G(gate), Q_B(bulk), Q_D(drain), and Q_S(source), are described for the symmetrical the source/drain contacts as:

$$Q_G = -(Q_B + Q_I)$$

$$Q_B = W_{eff}\int_0^{L_{eff}} Q_b(y)dy$$

$$Q_I = W_{eff}\int_0^{L_{eff}} Q_i(y)dy$$

$$Q_D = W_{eff}\int_0^{L_{eff}} \frac{y}{L_{eff}} Q_i(y)dy$$

$$Q_S = Q_I - Q_D$$

where Q_B and Q_I are the depletion charge and the inversion charge, respectively, and y is the position along the channel. Leff and 0 are the channel-end positions at the drain side and the source side, respectively.

Drain Current

The drift-diffusion theory describes the drain current I_{ds} as:

$$I_{ds} = W_{eff} \cdot NF \cdot q \cdot \mu \cdot n(y) \cdot \left(-\frac{d\phi_S(y)}{dy} + \frac{1}{\beta} \cdot \frac{d\ln n(y)}{dy} \right)$$

where n(y) is the carrier density calculated from the relationship

$$Q_i(y) = q \cdot n(y)$$

Under the gradual-channel approximation with further approximations of an idealized gate structure and uniform channel doping, the final equation for I_{ds} is written:

$$I_{ds} = \frac{W_{eff} \cdot NF}{L_{eff}} \cdot \mu \cdot \frac{I_{dd}}{\beta}$$

$$\begin{aligned} I_{dd} = {} & C_{ox}(\beta V_G' + 1)(\phi_{SL} - \phi_{S0}) - \frac{\beta}{2} C_{ox}\left(\phi_{SL}^2 - \phi_{S0}^2\right) \\ & - \frac{2}{3} const0 \left[\{\beta(\phi_{SL} - V_{bs}) - 1\}^{\frac{3}{2}} - \{\beta(\phi_{S0} - V_{bs}) - 1\}^{\frac{3}{2}} \right] \\ & + const0 \left[\{\beta(\phi_{SL} - V_{bs}) - 1\}^{\frac{1}{2}} - \{\beta(\phi_{s0} - V_{bs}) - 1\}^{\frac{1}{2}} \right] \end{aligned}$$

Threshold Voltage Shift

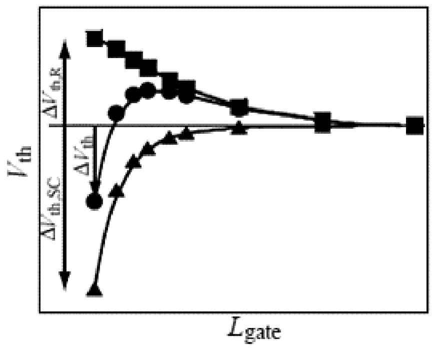
Different with convitional bsim model, all HiSIM_HV can be determined by oxide thickness Tox and the substrate doping concentration **NSUBC**. The measured V_{th} is influenced by various phenomena such as the short-channel effects, which cause a reduction of V_{th} for short-channel transistors in comparison to long-channel transistors as shown in Figure 31-5. This so-called V_{th} roll-off is very much dependent on the technology applied for MOSFET fabrication. Therefore, HiSIM can derive many detailed information on the MOSFET fabrication technology, which are relevant for modeling device characteristics, from the V_{th} changes (ΔV_{th}) as a function of gate length (L_{gate}). The modeled V_{th} is incorporated in the ϕS iteration can be viewed as consisting of two main effects or components:

(I) the short-channel effect: $\Delta V_{th, SC}$

(II) the reverse-short-channel effect: $\Delta V_{th, R}$ and $\Delta V_{th, P}$

The separation into these two components ($\Delta V_{th} = \Delta V_{th, SC} + \Delta V_{th, R}$ (or $\Delta V_{th, P}$)) is schematically shown in Figure 31-5.

Figure 31-5 Schematic plot of the separation of Vth into the contributions of the short-channel and the reverse short-channel effect.



Mobility Model

The low-field mobility is described with the following expressions and includes the three independent mechanisms of Coulomb, phonon and surface-roughness scattering:

$$\frac{1}{\mu_0} = \frac{1}{\mu_{CB}} + \frac{1}{\mu_{PH}} + \frac{1}{\mu_{SR}}$$

$$\mu_{CB}(Coulomb) = MUECB0 + MURCB1 \cdot \frac{Q_i}{q \times 10^{11}}$$

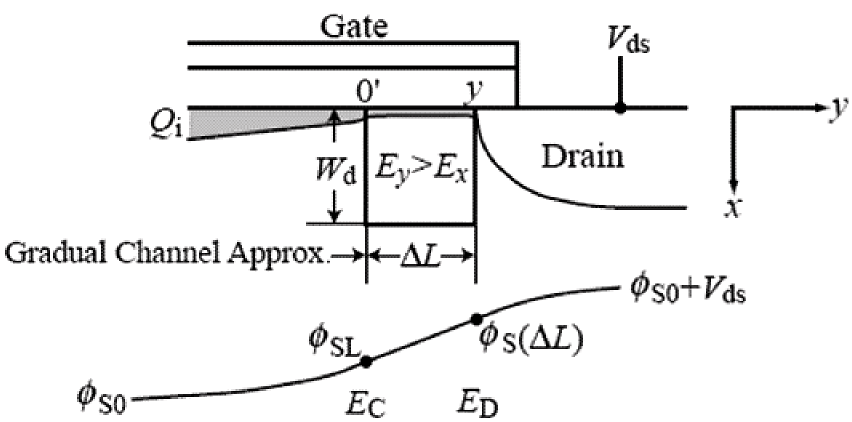
$$\mu_{PH}(phonon) = \frac{M_{uephonon}}{E_{eff}^{MUEPH0}}$$

$$\mu_{SR}(surface \quad roughness) = \frac{MUESR1}{E_{eff}^{Mueserface}}$$

Channel-Length Modulation

As the gradual-channel approximation is not valid for large V_{ds} causing the pinch-off phenomenon in the channel. Without taking into account the pinch-off phenomenon, the calculated channel conductance gds enters abruptly into the saturation condition. To include the pinch-off phenomenon in HiSIM, we apply the conventional method of modeling the pinch-off region (ΔL) separately from the rest of the channel as depicted in Figure 31-6:

Figure 31-6 Schematic showing the correlation among physical quantities in the pinch-off region.



After taking into all effects, the final ΔL is derived as:

$$\Delta L = \frac{1}{2}\left[-\frac{1}{L_{eff}}\left(2\frac{I_{dd}}{\beta Q_i}z + 2\frac{N_{sub}}{\varepsilon_{Si}}\left(\phi_s(\Delta L)-\phi_{SL}\right)z^2 + E_0 z^2 \right)\right]$$

$$+\frac{1}{2}\sqrt{\frac{1}{L_{eff}^2}\left(2\frac{I_{dd}}{\beta Q_i}z - 2\frac{N_{sub}}{\varepsilon_{Si}}(\phi_s(\Delta L)-\phi_{SL})z^2 \right)^2 + 4\left(2\frac{N_{sub}}{\varepsilon_{Si}}(\phi_s(\Delta L)-\phi_{SL})z^2 + E_0 z^2 \right)}$$

Narrow-Channel Effects

The shallow-trench-isolation(STI) technology induces a V_{th} reduction for reduced channel width (W_{gate}). This phenomenon is modeled under inclusion of the edge-fringing capacitances C_{ef} at the edge of the trench as:

$$\Delta V_{th,W} = \left(\frac{1}{C_{ox}} - \frac{1}{C_{ox} + 2C_{ef}/(L_{eff}W_{eff})} \right) qN_{sub}W_d + \frac{WVTH0}{W_{gate}\times 10^4}$$

So the total threshold shift becomes:

$$\Delta V_{th} = \Delta V_{th,SC} + \Delta V_{th,R} + \Delta V_{th,P} + \Delta V_{th,W} - \phi_{spg}$$

In addition, the mobility should be adjusted with small geometrical size. The shallow trench isolation induces also an undesired hump in the sub-threshold region of the I_{ds}-V_{gs} characteristics.

Temperature Dependences

The temperature dependence is included automatically in the surface potentials through β, which is the inverse of the thermal voltage. Additionally the band gap, the intrinsic carrier concentration, the carrier mobility, and the carrier saturation velocity are also temperature dependent.

$$E_g = EG0 - BGTMP1 \cdot (T - TNOM) - BGTMP2 \cdot (T - TNOM)^2$$

$$\mu_{PH}(phonon) = \frac{M_{uephonon}}{(T / TNOM)^{MUETMP} \times E_{eff}^{MUEPH0}}$$

$$V_{\max} = \frac{VMAX}{1.8 + 0.4(T / TNOM) + 0.1(T / TNOM)^2 - VTMP \times (1 - T / TNOM)}$$

$$E_{gp} = E_{g0} + EGIG + IGTEMP2(1/T - 1/TNOM) + IGTEMP3(1/T^2 - 1/TNOM^2)$$

Resistances

$$R_{d0.temp} = RDTEMP1 \cdot (T - TNOM) + RDTEMP2 \cdot (T - TNOM)^2$$

$$R_{dvd.temp} = RDVDTEMP1 \cdot (TEMP - TNOM) + RDVDTEMP2 \cdot (TEMP^2 - TNOM^2)$$

Junction Capacitance at Drain side

$$CJ = CJ \cdot (1 + TCJBD \cdot (T - TNOM))$$

$$CJSW = CJSW \cdot (1 + TCJBDSW \cdot (T - TNOM))$$

$$CJSWG = CJSWG \cdot (1 + TCJBDSWG \cdot (T - TNOM))$$

Junction Capacitance at Drain side

$$CJ = CJ \cdot (1 + TCJBS \cdot (T - TNOM))$$

$$CJSW = CJSW \cdot (1 + TCJBSSW \cdot (T - TNOM))$$

$$CJSWG = CJSWG \cdot (1 + TCJBSSWG \cdot (T - TNOM))$$

Junction Current

$$T_{tnom} = \frac{T}{TNOM}$$

$$j_S = JS0 \exp\left\{ \frac{(E_g (T = TNOM) \cdot \beta(T = TNOM) - E_g \beta + XTI \cdot \log(T_{tnom}))}{NJ} \right\}$$

$$j_{SSW} = JS0SW \exp\left\{ \frac{(E_g (T = TNOM) \cdot \beta(T = TNOM) - E_g \beta + XTI \cdot \log(T_{tnom}))}{NJSW} \right\}$$

$$j_{S2} = JS0 \exp\left\{ \frac{(E_g (T = TNOM) \cdot \beta(T = TNOM) - E_g \beta + XTI2 \cdot \log(T_{tnom}))}{NJ} \right\}$$

$$j_{SSW2} = JS0SW \exp\left\{ \frac{(E_g (T = TNOM) \cdot \beta(T = TNOM) - E_g \beta + XTI2 \cdot \log(T_{tnom}))}{NJSW} \right\}$$

$$CISB = CISB \cdot \exp\{(T_{tnom} - 1)CTEMP\}$$

$$VDIFFJ = VDIFFJ \cdot (T_{tnom})^2$$

Resistance

For the symmetrical/asymmetrical HVMOS case, the resistance at the source side is modeled with the same equations for the drain side without the V_{ds} dependence. The source and the drain resistances R_s and R_d are considered by voltage drops on each terminal as

$$V_{gs,eff} = V_{gs} - I_{ds} \cdot R_s$$

$$V_{ds,eff} = V_{ds} - I_{ds} \cdot (R_s + R_{drift})$$

$$V_{bs,eff} = V_{bs} - I_{ds} \cdot R_s$$

for the DC condition, where the effective voltages are referred as internal node potentials. The resistance values are modeled as

$$R_s = \frac{RS}{W_{eff}} + NRS \cdot RSH$$

$$R_{drift} = (R_d + V_{ds} \cdot R_{DVD})(1 + RDVG11 - \frac{RDVG11}{RDVG12} \cdot V_{gs}) \cdot (1 - V_{bs} \cdot RDVB)$$

$$R_d = \frac{R_{d0}}{W_{eff}}(1 + \frac{RDS}{(W_{gate} \cdot 10^4 \times L_{gate} \cdot 10^4)^{RDSP}}) + RSH \cdot NRD$$

$$R_{d0} = (RD + R_{d0.temp}) f_1 \cdot f_2$$

$$R_{DVD} = \frac{RDVD + R_{dvd,temp}}{W_{eff}} \cdot \exp(-RDVDL \times (L_{gate} \cdot 10^4)^{RDVDLP}) \cdot \left(1 + \frac{RDVDS}{(W_{gate} \cdot 10^4 \times L_{gate} \cdot 10^4)^{RDVDSP}}\right) \cdot f_1 \cdot f_2 \cdot f_3$$

$$f_1(L_{drift1}) = \frac{LDRIFT1}{1um} \cdot RDSLP1 + RDICT1$$

$$f_2(L_{drift2}) = \frac{LDRIFT2}{1um} \cdot RDSLP2 + RDICT2$$

$$f_3(L_{over}) = 1 + (RDOV11 - \frac{RDOV11}{RDOV12}) \cdot \frac{LOVERLD}{1um} + (1 - RDOV13) \cdot \frac{LOVERLD}{1um}$$

Different resistance effects modeling approaches are supplies by HiSIM_HV model, it can be treated as external resistance or the total current can be obtained by a simple analytical description. Flag **CORSRD** is provided for the selection of one of the possible approaches. In the HiSIM HV 1.1.1 version the resistances is treated only as the extrinsic resistances.

CORSRD=2 is originally introduced to avoid simulation time penalty with an analytical description of the resistance effect as

$$I_{ds} = \frac{I_{ds0}}{1 + I_{ds0} \dfrac{R_d}{V_{ds}}}$$

where I_{ds0} is the drain current without the resistance effect and

$$R_d = \frac{1}{W_{eff}}(R_d^{'} \cdot V_{ds}^{RD21} + V_{bs} \cdot V_{ds}^{RD22D} \cdot RD22)$$

The selection of the resistance model is summarized here:

CORSRD = 0 : no resistance

CORSRD = 1 : solved by circuit simulator with internal nodes

Model parameters are:

RS, NRS, RSH

RDVG11, RDVG12, RDVB, RDS, RDSP, NRD

RD, RDVD, RDVDL, RDVDLP, RDVDS, RDVDSP

RDSLP1, RDICT1, RDSLP2, RDICT2, RDOV11, RDOV12, RDOV13

CORSRD = 2 : solved with the analytical approach

Model parameters are:

RD21, RD22, RD22D, RD23, RD23L, RD23LP

RD23S, RD23SP, RD24, RD25, RD20

CORSRD = 3 : Both **CORSRD** = 1 and **CORSRD** = 2 are considered.

	Structure	**Source**	**Drain**
COSYM=0	LDMOS	RS (bias independent)	RD
COSYM=1	Symmetrical HVMOS		RD
COSYM=1	Asymmetrical HVMOS	RS	RD

Capacitance

Intrinsic Capacitance

The intrinsic capacitances are derivatives of the node charges determined as

$$C_{jk} = \delta \frac{\partial Q_j}{\partial V_k}$$
$$\delta = -1 \text{ for } j \neq k$$
$$\delta = 1 \text{ for } j = k$$

Overlap Capacitance

Three different overlap capacitance models are supplied to modeling the overlap capacitance: Constant model, Simplified model and Surface-potential-based model. Flag COOVLP (COOVLPS) and NOVER (NOVERS) are used to select the corresponding model.

Figure 31-7 Model options of the overlap capacitance at the drain side are summarized.

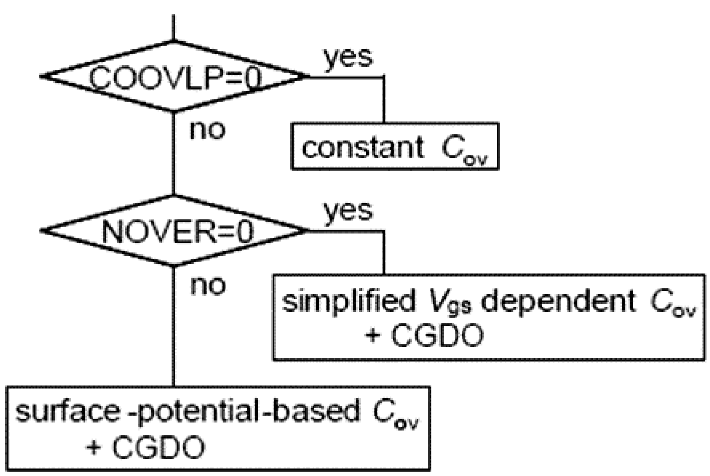
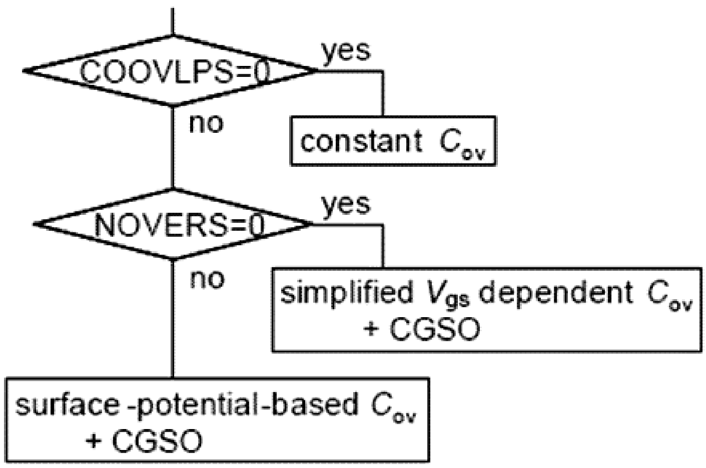


Figure 31-8 Model options of the overlap capacitance at the source side are summarized.

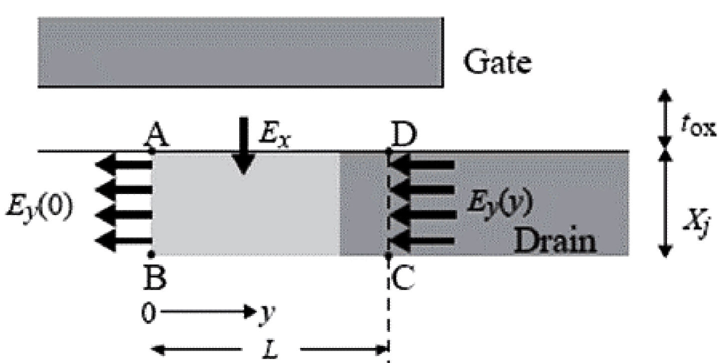


Leakage Currents

Substrate Current

The substrate current Isub is generated by impact ionization in the depletion region at the drain junction

$$I_{\rm sub} = \int_0^{\delta L} I_{\rm ds} C_1 \exp\left(-\frac{C_2}{E_y}\right) dy.$$



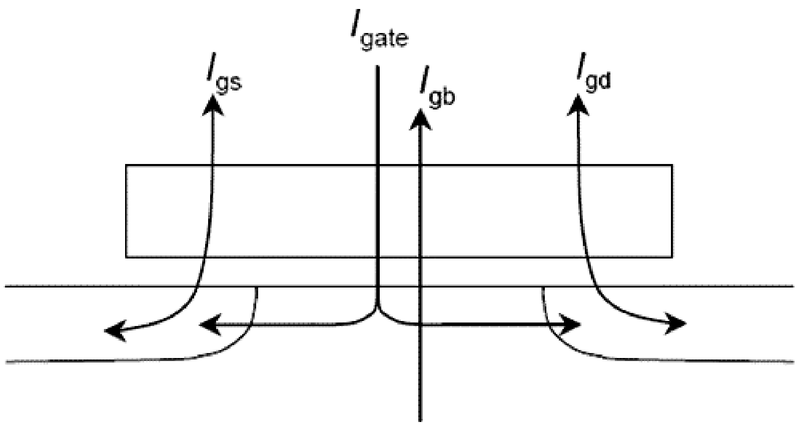
where C1 and C2 are fitting parameters.

Gate Current

All possible gate leakage currents are schematically shown in Fig. 32.8

Between Gate and Channel, I_{gate}

$$I_{gate} = q \cdot GLEAK1 \cdot \frac{E^2}{E_{gp}^{\frac{1}{2}}} \cdot \exp\left(-\frac{E_{gp}^{\frac{3}{2}} \times GLEAK2}{E}\right) \cdot \sqrt{\frac{Q_i}{const0}} \cdot W_{eff} \cdot NF \cdot L_{eff}$$
$$\cdot \frac{GLEAK6}{GLEAK6 + V_{ds}} \cdot \frac{GLEAK7}{GLEAK7 + W_{eff} \cdot NF \cdot L_{eff}}$$



Between Gate and Bulk, I_{gb}

The I_{gb} current under the accumulation condition is modeled as

$$I_{gb} = GLKB1 \cdot E_{gb}^2 \cdot \exp\left(-\frac{GLKB2}{E_{gb}}\right) W_{eff} \cdot NF \cdot L_{eff}$$
$$E_{gb} = -\frac{V_{gs} - VFBC + GLKB3}{T_{ox}}$$

The Fowler-Nordheim tunneling mechanism is also considered

$$I_{FN} = \frac{q \cdot FN1 \cdot E_{FN}^2}{E_{g12}} \cdot \exp\left(-\frac{FN2 \cdot E_{g32}}{E_{FN}}\right) \cdot W_{eff} \cdot NF \cdot L_{eff}$$

Total substrate current is the sum of the two components as

$$I_{gb} = I_{gb} + I_{FN}$$

Between Gate and Source/Drain, I_{gs}/I_{gd}

$$I_{gs} = signGIKSD1 \cdot E_{gs}^2 \exp(T_{ox}(GLKSD2 \cdot V_{gs} + GLKSD3)) \cdot W_{eff} \cdot NF$$

$$I_{gd} = signGIKSD1 \cdot E_{gd}^2 \exp(T_{ox}(GLKSD2 \cdot (-V_{gs} + V_{ds}) + GLKSD3)) \cdot W_{eff} \cdot NF$$

GIDL (Gate-Induced Drain Leakage)

$$I_{GIDL} = q \cdot GIDL1 \cdot \frac{E^2}{E_g^{\frac{1}{2}}} \cdot \exp(-GIDL2 \cdot \frac{E_g^{\frac{3}{2}}}{E}) \cdot W_{eff} \cdot NF$$

Source/Bulk and Drain/Bulk Diode Models

Diode Current

$$j_s = JS0$$
$$j_{ssw} = JS0SW$$
$$j_{s2} = JS0$$
$$j_{ssw2} = JS0SW$$

Between Drain and Bulk

$$V_{bd} \geq V_1$$

$$I_{bd} = I_{sbd} \cdot \left\{ \exp\left(\frac{V_1}{N_{vtm}}\right) - 1 \right\} + \frac{I_{sbd}}{N_{vtm}} \exp\left(\frac{V_1}{N_{vtm}}\right)(V_{bd} - V_1)$$
$$+ I_{sbd2} \cdot CISB \cdot \left\{ \exp\left(-\frac{V_{bd} \cdot CVB}{N_{vtm}}\right) - 1 \right\} + CISBK \cdot \left\{ \exp\left(-\frac{V_{bd} \cdot CVB}{N_{vtm}}\right) - 1 \right\}$$

$$V_1 \geq V_{bd}$$

$$I_{bd} = I_{sbd} \cdot \left\{ \exp\left(\frac{V_{bd}}{N_{vtm}} \right) - 1 \right\} + I_{sbd2} \cdot CISB \cdot \left\{ \exp\left(-\frac{V_{bd} \cdot CVB}{N_{vtm}} \right) - 1 \right\} + CISBK \cdot \left\{ \exp\left(-\frac{V_{bd} \cdot CVB}{N_{vtm}} \right) - 1 \right\}$$

$$N_{vtm} = \frac{NJ}{\beta}$$

$$V_1 = N_{vtm} \cdot \log\left\{ \frac{VDIFFJ}{I_{sbd}} + 1 \right\}$$

$$I_{bd} = I_{bd} + DIVX \cdot I_{sbd2} \cdot V_{bd}$$

Between Source and Bulk

$$V_{bs} \geq V_2$$

$$I_{bs} = I_{sbs} \cdot \left\{ \exp\left(\frac{V_2}{N_{vtm}} \right) - 1 \right\} + \frac{I_{sbs}}{N_{vtm}} \exp\left(\frac{V_2}{N_{vtm}} \right) (V_{bs} - V_2)$$
$$+ I_{sbs2} \cdot CISB \cdot \left\{ \exp\left(-\frac{V_{bs} \cdot CVB}{N_{vtm}} \right) - 1 \right\} + CISBK \cdot \left\{ \exp\left(-\frac{V_{bs} \cdot CVB}{N_{vtm}} \right) - 1 \right\}$$

$$V_2 \geq V_{bs}$$

$$I_{bs} = I_{sbs} \cdot \left\{ \exp\left(\frac{V_{bs}}{N_{vtm}} \right) - 1 \right\} + I_{sbs2} \cdot CISB \cdot \left\{ \exp\left(-\frac{V_{bs} \cdot CVB}{N_{vtm}} \right) - 1 \right\} + CISBK \cdot \left\{ \exp\left(-\frac{V_{bs} \cdot CVB}{N_{vtm}} \right) - 1 \right\}$$

$$V_2 = N_{vtm} \cdot \log\left\{ \frac{VDIFFJ}{I_{sbs}} + 1 \right\}$$

$$I_{bs} = I_{bs} + DIVX \cdot Isbs2 \cdot V_{bs}$$

Noise Models

1/f Noise Models

The 1/f noise is caused by both the carrier fluctuation and the mobility fluctuation. The final description for the drift-diffusion model is

$$S_{I_{ds}} = \frac{I_{ds}^2 NFTRP}{\beta f (L_{eff} - \Delta L) W_{eff} \cdot NF} \left[\frac{1}{(N_0 + N^*)(N_L + N^*)} + \frac{2\mu E_y NFALP}{N_L - N_0} \ln\left(\frac{N_L + N^*}{N_0 + N^*} \right) + (\mu E_y NFALP)^2 \right]$$

where the parameters **NFALP** and **NFTRP** represent the contribution of the mobility fluctuation and the ratio of trap density to attenuation coefficient, respectively.

Thermal Noise Model

Van der Ziel derived the equation for the spectral density of the thermal drain-noise current at temperature T by integrating the trans-conductance along the channel direction y based on the Nyquist theorem

$$S_{id} = 4kT \frac{W_{eff} \cdot NF \cdot C_{ox} \cdot Vg \cdot Vt \cdot \mu}{(L_{eff} - \Delta L)} \frac{(1+3\eta+6\eta^2)\mu_d^2 + (3+4\eta+3\eta^2)\mu_d\mu_s + (6+3\eta+\eta^2)\mu_s}{15(1+\eta)\mu_{av}^2}$$

where $?_s$, $?_d$ and $?_{av}$ are mobilities at the source side, the drain side, and averaged, respectively.

Induced Gate Noise Model

$$N_{igate} = S_{igate} / f^2$$

Coupling Noise Model

$$N_{cross} = \frac{S_{igid}}{\sqrt{S_{igate} \cdot S_{id}}}$$

Non-Quasi-Static (NQS) Model

Formation of carrier

Carriers in the channel take time to build-up as opposed to the Quasi-Static (QS) approximation. To consider this phenomenon in HiSIM, the carrier formation is modeled as

$$q(t_i) = \frac{q(t_i - 1) + \frac{\Delta t}{\tau} Q(t_i)}{1 + \frac{\Delta t}{\tau}}$$

where $q(t_i)$ and $Q(t_i)$ represent the non-quasi-static and the quasi-static carrier density at time ti, respectively, and $\Delta t = t_i - t_{i-1}$ is valid. Above equation implies that the formation of carriers under the NQS approximation is always delayed in comparison to the QS approximation, which is the basic origin of the NQS effect.

Delay Mechanisms

Weak inversion

$$\tau_{diff} = DLY1$$

Strong inversion

$$\tau_{cond} = DLY2 \cdot \frac{Q_i}{I_{ds}}$$

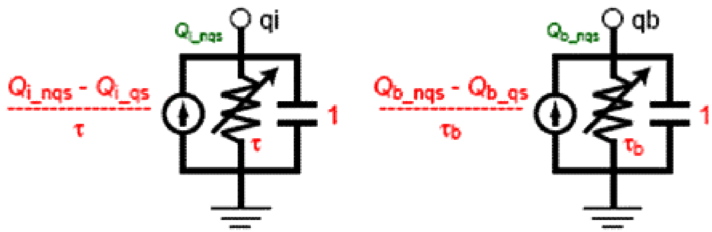
These two delay mechanisms (diffusion and conduction) are combined using the Matthiessen rule:

$$\frac{1}{\tau} = \frac{1}{\tau_{diff}} + \frac{1}{\tau_{cond}}$$

Applying the same approach for the formation of bulk carriers, leads to the approximation of the bulk carrier delay as an RC delay in the form

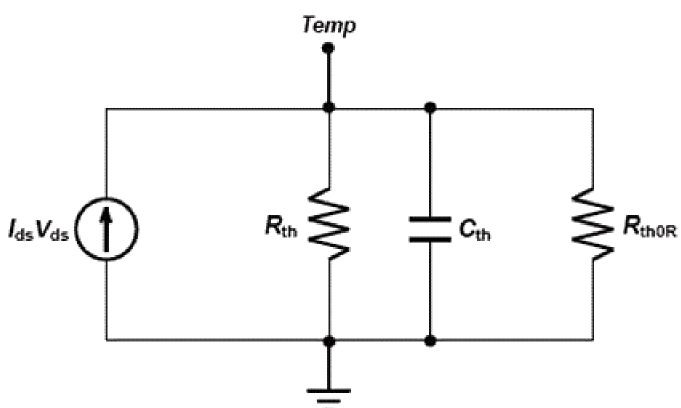
$$\tau_B = DLY3 \cdot C_{ox}$$

NQS model implementation into circuit simulator is listed as following figure:



Self-Heating Effect Model

The self-heating effect is modeled with the thermal network shown in the folowing figure. The flag COSELFHEAT must be equal to one and RTH0 must not be equal to zero to activate the model.



The total temperature of the devices is the sum of the original temperature and the temperature rise due to self-heating.

$$T = T + R_{th} \cdot I_{ds} \cdot V_{ds}$$

where R_{th} as well as C_{th} are a function of W_{eff} as

$$R_{th} = \frac{RTH0}{W_{eff}} \cdot \left(\frac{1}{NF^{RTH0NF}}\right)\left(1 + \frac{RTH0W}{\left(W_{gate} \cdot 10^4\right)^{RTH0WP}}\right)$$

$$C_{th} = CTH0 \cdot W_{eff}$$

HiSIM HV 1.1.1 models the thermal dissipation in a different way with that of previous version as:

$$T = T + R_{th} \cdot I_{ds} \cdot V'_{ds}$$
$$V'_{ds} = V_{dsi} + POWRAT(V_{ds} - V_{dsi})$$

where **POWRAT** is a model parameter. The external node potential is represented by V_{ds} and the internal node potential within the drift region at the channel/drift junction is by V_{dsi}, which is calculated during the simulation.

DFM Model

To support design for manufacturability (DFM) HiSIM introduces an option for considering the variation of device parameters.

$$M_{uephonon} = MUEPH1[MPHDFN\{\ln(NSUBCDFM) - \ln(N_{SUBC})\} + 1]$$
$$NSUBP = NSUBP + (N_{SUBCDFM} - N_{SUBC})$$
$$NEXT = NEXT + (NSUBCDFM - N_{SUBC})$$

Component Statements

Instance Parameters

1 `w (m)` Gate width.

2 `l (m)` Gate length.

3 `as (m`^{2}`)` Area of source junction.

4 `ad (m`^{2}`)` Area of drain junction.

5 `ps (m)` Perimeter of source junction.

6 `pd (m)` Perimeter of drain junction.

7 `dtemp (C)` Device temperature rise from ambient.

8 `nrs=1`	Number of squares of source diffusion.
9 `nrd=1`	Number of squares of drain diffusion.
10 `corbnet=0`	Substrate resistance network selector.
11 `rbpb (Ω)`	Substrate resistance network.
12 `rbpd (Ω)`	Substrate resistance network.
13 `rbps (Ω)`	Substrate resistance network.
14 `cosubnode=0`	Instance flag to switch tempnode to subnode. 1: 5th node is subnode; 0: 5th node is thermal node.
15 `coselfheat=0`	Calculation of self heating model.
16 `corg=0`	Gate-contact resistance selector.
17 `ngcon=1.0`	Number of gate contacts.
18 `xgw=0.0 m`	Distance from gate contact to channel edge.
19 `xgl=0.0 m`	Offset of gate length due to variation in patterning.
20 `nf=1.0`	Number of gate fingers.
21 `lod=1.0e-5 m`	Length of diffusion between gate and STI.
22 `m=1`	Multiplicity factor (number of MOSFETs in parallel).
23 `subld1`	Parameter for impact-ionization current in the drift region.
24 `subld2 ((V^(3/2))/m)`	Parameter for impact-ionization current in the drift region.
25 `ldrift1 (m)`	Parameter for drift region length-1.
26 `ldrift2 (m)`	Parameter for drift region length-2.
27 `lover (m)`	Overlap length on source side.
28 `lovers (m)`	Overlap length on source side.

29 `loverld (m)` Overlap length on drain side.

30 `ldrift1s (m)` Parameter for drift region length-1 on source side.

31 `ldrift2s (m)` Parameter for drift region length-2 on source side.

32 `sa=0.0 m` Distance from STI edge to Gate edge.

33 `sb=0.0 m` Distance from STI edge to Gate edge.

34 `sd=0.0 m` Distance from Gate edge to Gate edge.

35 `nsubcdfm (cm`$^{-3}$`)` Constant part of Nsub for DFM.

36 `isnoisy=yes` Should device generate noise.
Possible values are `no` and `yes`.

Model Definition

model modelName hisim_hv parameter=value ...

Model Parameters

Device type parameters

1 `type=n` Transistor type.
Possible values are `n` and `p`.

2 `level=73` Level selector for spice compatible. 73 is valid level for hisim_hv model.

3 `version=2.10` 2.10 is the latest version of HiSIM_HV. The available versions are 1.11/1.12, 1.20/1.21/1.22/1.23/1.24, 2.00/2.01/2.10. Version 1.11/1.12 are not maintained and options of enable_pre_ver=yes is necessary to activate such old versions..

4 `corsrd=3` Contact resistances Rs and Rd selector. 0 : no. 1 : yes, as external resistances. 2 : yes, as analytical resistances. 3: yes, as external and analytical resistance.

5 `coiprv=1` Previous Ids is used for calculating source/drain resistance effect. 0 : no(default). 1 : yes.

6	`copprv=1`	Previous surface potential is used for the initial guess. 0 : no(default). 1 : yes.
7	`coadov=1`	Selector for lateral field induced and overlap charges/ capacitances being added to intrinsic ones. 0 : no. 1 : yes(default).
8	`coisub=0`	Substrate current selector. 0 : no(default). 1 : yes.
9	`cogidl=0`	GIDL current calculation selector. 0 : no(default). 1 : yes.
10	`coiigs=0`	Gate current calculation selector. 0 : no(default). 1 : yes.
11	`coovlp=1`	Overlap capacitance calculation selector on drain side. 0 : constant overlap capacitance. 1 : including the bias dependent overlap capacitances(default).
12	`coovlps=0`	Overlap capacitance calculation selector on source side. 0 : constant overlap capacitance(default). 1 : including the bias dependent overlap capacitances.
13	`coflick=0`	1/f noise calculation selector.
14	`coisti=0`	STI leakage current calculation selector. 0 : no(default). 1 : yes.
15	`conqs=0`	Non-quasi-static mode selector. 0 : no(default). 1 : yes.
16	`cothrml=0`	Thermal noise calculation selector. 0 : no(default). 1 : yes.
17	`tnom (C)`	Parameters measurement temperature. Default set by `options`.
18	`corg=0`	Gate-contact resistance calculation selector. 0 : no(default). 1 : yes.
19	`corbnet=0`	Substrate resistance network selector.
20	`coign=0`	Induced gate and cross correlation noise calculation selector..
21	`compatible`	Compatible with spice3, default is spectre compatible. Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, and `sspice`.

22 `alarm=none` Forbidden operating region.
Possible values are `none`, `off`, `triode`, `sat`, `subth`, and `rev`.

23 `codfm=0` Calculation of model for DFM selector.

24 `coselfheat=0` Calculation of self heating model.

25 `cosubnode=0` Flag to switch tempnode to subnode. 1: 5th node is subnode; 0: 5th node is thermal node.

26 `cosym=0` Model selector for symmetry device.

27 `coqovsm=1` Selector for smoothing method of Qover. 0: analytically solved without inversion condition; 1: iteratively solved (default); 2: analytically solved with inversion condition (Old model).

28 `cotemp=0` Model flag for temperature dependence.

29 `coldrift=0` Selector for Ldrift parameter.

30 `cordrift=1` Flag for rdrift evaluation.

Default for instance parameters

31 `w=5e-6 m` Default gate width.

32 `l=2e-6 m` Default gate length.

33 `as=0` m^2 Default area of source junction.

34 `ad=0` m^2 Default area of drain junction.

35 `ps=0 m` Default perimeter of source junction.

36 `pd=0 m` Default perimeter of drain junction.

37 `temp=27 C` Default device temperature.

38 `dtemp=0 C` Default device temperature rise from ambient.

Basic Device Parameters

39 `tox=3e-8 m`	Physical oxide thickness. The default value is 7e-9 since version 2.00.
40 `xld=3e-8 m`	Gate-overlap length. The default value is 0 for version 2.00/2.01 and 1.23.
41 `xwd=0 m`	Gate-overlap width.
42 `xwdc=0.0 m`	Gate-overlap width, for capacitance.
43 `tpoly=2.0e-7 m`	Height of the gate poly-si for fringing capacitance on source side.
44 `nsubc=1.0e17` cm^{-3}	Substrate-impurity concentration. The default value is 5.0e17 for version 1.23 and 3.0e17 for version 2.00/2.01.
45 `nsubp=1.0e17` cm^{-3}	Maximum pocket concentration. The default value is 1.0e18 for version 2.00/2.01 and version 1.23.
46 `rs=0.0 Ω m`	Source contact resistance in LDD region.
47 `rd=5.0e-3 Ω m`	Drain contact resistance in LDD region. The default value is 0.0 since version 2.00.
48 `vfbc=-1.0 V`	Constant part of flat-band voltage.
49 `lp=0.0 m`	Length of the pocket penetration into the channel. The default value is 1.5e-8 since version 2.00.
50 `xqy=0.0 m`	Distance from channel/drain junction to maximum electric field point.
51 `lover=3.0e-8 m`	Overlap length on source side.
52 `ll=0.0`	Gate length parameter.
53 `lld=0.0 m`	Gate length parameter.
54 `lln=0.0`	Gate length parameter.

55 `wl=0.0` Gate width parameter.

56 `wld=0.0 m` Gate width parameter.

57 `wln=0.0` Gate width parameter.

58 `vbi=1.1 V` Built-in potential.

59 `nsubp0=0.0 cm`$^{-3}$ Pocket implant parameter.

60 `nsubwp=1.0` Pocket implant parameter.

61 `lpext=1.0E-50 m` Pocket extension.

62 `npext=1.0e17 cm`$^{-3}$
Pocket extension. The default value is 5.0e17 since version 2.00.

63 `rsh=0.0 V/A m` Source/drain diffusion sheet resistance.

64 `rshg=0.0 V/A m` Gate-electrode sheet resistance.

65 `rbpb=50.0 Ω` Substrate resistance network.

66 `rbpd=50.0 Ω` Substrate resistance network.

67 `rbps=50.0 Ω` Substrate resistance network.

68 `gbmin=1.0e-12` Minimum conductance for substrate resistance network.

69 `xl=0 m` Gate length offset due to mask/etch effect.

70 `xw=0 m` Gate width offset due to mask/etch effect.

71 `xqy1=0.0 F m^{XQY2}`
Vbs dependence of Qy.

72 `xqy2=0.0` Lgate dependence of Qy. The default value is 2.0 since version 2.00.

73 `xldld=1.0e-6 m` Lateral diffusion of Drain under the gate.

74 `xwdld=1.0e-6 m` Widening of drift width.

75 `rdov11=0.0` Dependence coeff. for overlap length.

76 `rdov12=1.0` Dependence coeff. for overlap length.

77 `rdov13=1.0` Dependence coeff. for overlap length.

78 `rdslp1=0.0` LDRIFT1 dependence of resistance for CORSRD=1,3. Default value changed to 1.0 for version 1.22 and later.

79 `rdict1=1.0` LDRIFT1 dependence of resistance for CORSRD=1,3.

80 `rdslp2=1.0` LDRIFT2 dependence of resistance for CORSRD=1,3.

81 `rdict2=0.0` LDRIFT2 dependence of resistance for CORSRD=1,3.

82 `loverld=1.0e-6 m` Overlap length on the drain side.

83 `lovers=3.0e-8 m` Overlap length on source side.

84 `ldrift1=1.0e-6 m` Drift region length-1 on the drain side.

85 `ldrift1s=0.0 m` Drift region length-1 on the source side.

86 `ldrift2=1.0e-6 m` Drift region length-2 on the drain side.

87 `ldrift2s=1.0e-6 m` Drift region length-2 on the source side.

88 `subld1=0.0` Impact-ionization current in the drift region.

89 `subld11=0.0 µm^subld11p`
Parameter for impact-ionization current in the drift region.

90 `subld11p=1.0` Parameter for impact-ionization current in the drift region.

91 `subld2=0.0 (V^(3/2))/m`
Impact-ionization current in the drift region.

92 `xpdv=0.0 1/m` Parameter for impact-ionization current in the drift region.

93 `xpvdth=20.0 V` Parameter for impact-ionization current in the drift region.

94 `xpvdthg (1/V)` Parameter for impact-ionization current in the drift region.

95 `qovadd=0.0` Parameter for additional Qover Charge.

96 `rdrbb=1.0` Degradation of the mobility in drift region.

Temperature dependence effects

97 `eg0=1.1785 eV` Constant bandgap.

98 `bgtmp1=9.025e-5 eV/K`
First order temperature coefficient for band gap.

99 `bgtmp2=1.0e-7` eV/K^2
Second order temperature coefficient for band gap.

100 `igtemp2=0.0 1/K` Temperature dependence of gate current.

101 `igtemp3=0.0` $1/K^2$ Temperature dependence of gate current.

102 `vmaxt1=0.0 1/K` Temperature dependence of velocity.

103 `vmaxt2=0.0` $1/K^2$ Temperature dependence of velocity.

104 `ninvdt1=0.0 1/K` Temperature dependence of universal mobility model.

105 `ninvdt2=0.0` $1/K^2$ Temperature dependence of universal mobility model.

106 `rdtemp1=0.0 1/K` Temperature-dependence of Rd.

107 `rdtemp2=0.0` $1/K^2$ Temperature-dependence of Rd.

108 `rdvdtemp1=0.0 1/K` Temperature-dependence of RDVD.

109 `rdvdtemp2=0.0` $1/K^2$
Temperature-dependence of RDVD.

110 `rthtemp1=0.0 1/K` Temperature dependence of thermal resistance.

111 `rthtemp2=0.0` $1/K^2$
Temperature dependence of thermal resistance.

112 `prattemp1=0.0 1/K` Temperature dependence of thermal dissipation.

113 `prattemp2=0.0 1/K`^{2}
Temperature dependence of thermal dissipation.

Quantum Mechanical Effects

114 `qme1=0.0 m/V`^{2} Coefficient for quantum mechanical effect.

115 `qme2=1.0 V` Coefficient for quantum mechanical effect. Default as 0.0 for version 1.23, 2.0 for version 2.10.

116 `qme3=0.0 m` Coefficient for quantum mechanical effect.

117 `kappa=3.9` Dielectric constant for high-k stacked gate.

Poly Depletion Effects

118 `pgd1=0.0 V` Strength of poly depletion.

119 `pgd2=1.0 V` Threshold voltage of poly depletion.

120 `pgd3=0.8` Vds dependence of poly depletion.

121 `pgd4=0.0` Parameter for gate-poly depletion.

Short Channel Effects

122 `parl2=1.0e-8 m` Depletion width of channel/contact junction.

123 `sc1=1.0 1/V` Short-channel coefficient 1, defaulted as 0 since version 2.10 .

124 `sc2=1.0 1/V`^{2} Short-channel coefficient 2. The default value is 0.0 for version 2.00/2.01 and version 1.23.

125 `sc3=0.0 m/V`^{2} Short-channel coefficient 3.

126 `sc4=0.0 1/V` Parameter for SCE.

127 `scp1=1.0 1/V` Short-channel coefficient 1 for pocket, defaulted as 0.0 since version 2.10.

128 `scp2=0.1 1/V`^{2}	Short-channel coefficient 2 for pocket. The default value is 0.0 for version 2.00/2.01 and version 1.23.
129 `scp3=0.0 m/V`^{2}	Short-channel coefficient 3 for pocket.
130 `scp22=0.0 V`^{4}	Short-channel-effect modification for small Vds.
131 `scp21=0.0 V`	Short-channel-effect modification for small Vds.
132 `bs1=0.0 V`^{2}	Body-coefficient modification by impurity profile.
133 `bs2=0.9 V`	Body-coefficient modification by impurity profile.

Narrow channel effects

134 `wfc=0.0 m F/cm`^{2}	Threshold voltage reduction.
135 `nsubcw=0.0`	Width dependence of substrate-impurity concentration.
136 `nsubcwp=1.0`	Width dependence of substrate-impurity concentration.
137 `nsti=1.0e17 cm`$^{-3}$	Substrate-impurity concentration at the SIT edge, defaulted as 5e17 since version 2.10.
138 `wsti=0.0 m`	Width of the high-field region at STI.
139 `muephw=0.0`	Phonon scattering parameter.
140 `muepwp=1.0`	Phonon scattering parameter.
141 `wvth0=0.0`	Threshold voltage shift.
142 `mueswp=1.0`	Change of surface roughness related mobility.
143 `vthsti=0.0`	Parameter for STI.
144 `muesti1=0.0`	STI Stress mobility parameter.
145 `muesti2=0.0`	STI Stress mobility parameter.
146 `muesti3=1.0`	STI Stress mobility parameter.
147 `nsubpsti1=0.0 m`	STI Stress pocket implant parameter.

148 `nsubpsti2=0.0 m` STI Stress pocket implant parameter.

149 `nsubpsti3=1.0 m` STI Stress pocket implant parameter.

150 `wstil=0.0` Parameter for STI.

151 `wstilp=1.0` Parameter for STI.

152 `scsti1=0.0` Parameter for STI.

153 `scsti2=0.0 1/V` Parameter for STI.

154 `saref=1e-6 m` Reference distance from STI edge to Gate edge.

155 `sbref=1e-6 m` Reference distance from STI edge to Gate edge.

156 `wstiw=0.0` Parameter for STI.

157 `wstiwp=1.0` Parameter for STI.

158 `vdsti=0.0` Parameter for STI.

Mobility Effects

159 `muecb0=1.0e3` cm^2`/(V s)`
Coulomb scattering.

160 `muecb1=1.0e2` cm^2`/(V s)`
Coulomb scattering.

161 `mueph0=0.3` cm^2 `(V/cm)^(Muesr1)/(V s)`
Phonon scattering.

162 `mueph1=2.5e4` Phonon scattering. The default value is 2.0e4 since version 2.00.

163 `muetmp=1.7` Temperature dependence of phonon scattering. The default value is 1.5 for version 2.00/2.01 and version 1.23.

164 `muesr0=2.0` cm^2 `(V/cm)^(Muesr1)/(V s)`
Surface-roughness scattering.

165 `muesr1=1.0e16` Surface-roughness scattering. The default value is 6.0e14 since version 2.00.

166 `ndep=1.0` Coefficient of effective electric field.

167 `ninv=0.5` Coefficient of effective electric field.

168 `ninvd=0.0 1/V` Modification of Vdse dependence on Eeff.

169 `ninvdw=0.0` Coeff of modification of Vdse dependence on Eeff.

170 `ninvdwp=1.0` Coeff of modification of Vdse dependence on Eeff.

171 `bb=2.0` High-field mobility degradation.

172 `vmax=1.0e7 cm/s` Saturation velocity.

173 `vover=0.3 cm^(voverp)`
Parameter for velocity overshoot.

174 `voverp=0.3` Lgate dependence of velocity overshoot.

175 `vovers=0.0` Parameter for overshoot.

176 `voversp=0.0` Parameter for overshoot.

177 `vtmp=0.0 cm/s` Temperature dependence of the saturation velocity.

178 `muephl=0.0` Phonon scattering parameter.

179 `mueplp=1.0` Phonon scattering parameter.

180 `muesrl=0.0` Surface roughness parameter.

181 `muesrw=0.0` Change of surface roughness related mobility.

182 `mueslp=1.0` Surface roughness parameter.

183 `ndepl=0.0` Modification of Qb contribution for short-channel case.

184 `ndeplp=1.0` Modification of Qb contribution for short-channel case.

Small size parameters

185 `wl1=0.0` Threshold voltage shift of STI leakage due to small size effect.

186 `wl1p=1.0`	Threshold voltage shift of STI leakage due to small size effect.
187 `wl2=0.0`	Threshold voltage shift due to small size effect.
188 `wl2p=1.0`	Threshold voltage shift due to small size effect.
189 `muephs=0.0`	Mobility modification due to small size.
190 `muepsp=1.0`	Mobility modification due to small size.

Channel Length Modulation Effects

191 `clm1=50e-3`	First parameter for CLM. Default as 0.7 for version 1.23.
192 `clm2=2.0 1/m`	Second parameter for CLM.
193 `clm3=1.0`	Third parameter for CLM.
194 `clm5=1.0`	Effect of pocket implantation.
195 `clm6=0.0`	Effect of pocket implantation.

Substrate Current Effects

196 `sub1=50e-3 1/V`	First parameter for Isub. The default value is 10 for version 2.00/ 2.01 and version 1.23.
197 `sub2=1.0e2 V`	Second parameter for Isub. The default value is 25 for version 2.00/2.01 and version 1.23.
198 `svgs=0.8`	Substrate current dependence on Vgs.
199 `svbs=0.5`	Substrate current dependence on Vbs.
200 `svbsl=0.0`	Lgate dependence of SVBS.
201 `svds=0.8`	Substrate current dependence on Vds.
202 `slg=3.0e-8`	Substrate current dependence on Lgate.
203 `sub1l=2.5e-3`	Lgate dependence of SUB1.

204 `sub2l=2.0e-6` Lgate dependence of SUB2.

205 `fn1=50.0` Coefficient of Fowler-Nordheim-current contribution. The default value is 0.0 since version 2.00.

206 `fn2=1.7e-4` Coefficient of Fowler-Nordheim-current contribution.

207 `fn3=0.0` Coefficient of Fowler-Nordheim-current contribution.

208 `fvbs=1.2e-2` Modification of Vbs dependence.

209 `svgsl=0.0` Lgate dependence of SVGS.

210 `svgslp=1.0` Lgate dependence of SVGS.

211 `svgswp=1.0` Wgate dependence of SVGS.

212 `svgsw=0.0` Wgate dependence of SVGS.

213 `svbslp=1.0` Lgate dependence of SVBS.

214 `slgl=0.0` Substrate current dependence on Lgate.

215 `slglp=1.0` Substrate current dependence on Lgate.

216 `sub1lp=1.0` Lgate dependence of SUB1.

217 `ibpc1=0.0` Impact-ionization induced bulk potential change.

218 `ibpc1l=0.0` Parameter for impact-ionization induced bulk potential change.

219 `ibpc1lp=-1.0` Parameter for impact-ionization induced bulk potential change.

220 `ibpc2=0.0` Impact-ionization induced bulk potential change.

Gate Current Effects

221 `glpart1=0.5` Partitioning of gate current.

222 `gleak1=50.0 A/(V^(3/2) c^(1/2))`
First gate current coefficient.

223 `gleak2=1.0e7 1/(V^(1/2) c^(3/2) m)`
Second gate current coefficient.

224 `gleak3=6.0e-2` Third gate current coefficient.

225 `gleak4=4.0` Parameter for gate current.

226 `gleak5=7.5e3` Parameter for gate current.

227 `glksd1=1.0e-15` Parameter for gate current.

228 `glksd2=5e6` Parameter for gate current. The default value is 1e3 since version 2.00.

229 `glksd3=-5e6` Parameter for gate current. The default value is -1e3 since version 2.00.

230 `glkb1=5.0e-16` Parameter for gate current.

231 `glkb2=1.0` Parameter for gate current.

232 `gleak6=0.25 V` Parameter for gate current.

233 `gleak7=1.0e-6` m^2 Parameter for gate current.

234 `glkb3=0.0 V` Parameter for gate current.

235 `egig=0.0 V` Parameter for gate current.

GIDL Current Effects

236 `gidl1=2.0 A m/(V^(3/2) c^(1/2))`
First parameter for GIDL.

237 `gidl2=3.0E7 1/(V^(1/2) c^(3/2) m)`
Second parameter for GIDL.

238 `gidl3=0.9` Third parameter for GIDL.

239 `gidl4=0.9` Parameter for GIDL. The default value is 0.0 for version 2.00/2.01 and version 1.23.

240 `gidl5=0.2` Parameter for GIDL.

Noise 1/f Effects

241 `nfalp=1.0e-19` Flicker (1/f) noise contribution of the mobility fluctuation.

242 `falph=1.0` Parameter for 1/f noise.

243 `nftrp=1.0e10` Flicker (1/f) noise ratio of trap density to attenuation coefficient.

244 `cit=0.0` Flicker (1/f) noise interface trapped carriers capacitance.

Subthreshold swing parameters

245 `pthrou=0.0` Modify subthreshold sloop.

NQS parameters

246 `dly1=1.0e-10` Parameter for transit time.

247 `dly2=0.7` Parameter for transit time.

248 `dly3=8.0e-7 Ω` Parameter for transforming bulk charge.

249 `dlyov=0.0 Ω` Parameter for transforming overlap charge.

250 `minr=1.0e-3` Minimum parasitic resistance, resistance smaller than minr will be clamped as minr.

251 `minc=1.0e-30` Minimum diagonal capacitance.

252 `coclampc=1` The flag of clamp minc.

Symmetry for short-channel mosfet

253 `vzadd0=1.0e-2 V` Vzadd at Vds=0.

254 `pzadd0=5.0e-3 V` Pzadd at Vds=0.

P-N junctions parameters

255 `js0=5.0e-7` A/m^2 Junction saturation current density.

256 `js0sw=0.0 A/m`	Side-wall saturation current density.
257 `nj=1.0`	Junction emission coefficient.
258 `njsw=1.0`	Junction emission coefficient (sidewall).
259 `xti=2.0`	Junction saturation current temperature exponent coefficient.
260 `cj=5.0e-4 F/m`^{2}	Bottom junction capacitance per unit area at zero bias.
261 `cjsw=5e-10 F/m`	Source/drain sidewall junction capacitance per unit length at zero bias.
262 `cjswg=5e-10 F/m`	Source/drain sidewall junction capacitance grading coefficient per unit length at zero bias.
263 `tcjbd=0.0`	Temperature dependence of czbd.
264 `tcjbdsw=0.0`	Temperature dependence of czbdsw.
265 `tcjbdswg=0.0`	Temperature dependence of czbdswg.
266 `tcjbs=0.0`	Temperature dependence of czbs.
267 `tcjbssw=0.0`	Temperature dependence of czbssw.
268 `tcjbsswg=0.0`	Temperature dependence of czbsswg.
269 `mj=0.5`	Bulk junction bottom grading coefficient.
270 `mjsw=0.33`	Source/drain sidewall junction capacitance grading coefficient.
271 `mjswg=0.33`	Bottom junction capacitance grading coefficient.
272 `pb=1.0 V`	Bottom junction build-in potential.
273 `pbsw=1.0 V`	Source/drain sidewall junction build-in potential.
274 `pbswg=1.0 V`	Source/drain gate sidewall junction build-in potential.
275 `vdiffj=6.0e-4 V`	Threshold voltage for S/D junction diode.
276 `xti2=0.0`	Temperature coefficient.

277 `cisb=0.0`	Reverse bias saturation current.
278 `cvb=0.0`	Bias dependence coefficient of cisb.
279 `ctemp=0.0`	Temperature coefficient.
280 `cisbk=0.0 A`	Reverse bias saturation current.
281 `cvbk=0.0`	Bias dependence coefficient of cisb.
282 `divx=0.0 1/V`	Parameter for junction.

Overlap capacitance parameters

283 `cgso=0.0 F/m`	Gate-source overlap capacitance.
284 `cgdo=0.0 F/m`	Gate-drain overlap capacitance.
285 `cgbo=0.0 F/m`	Gate-bulk overlap capacitance.
286 `ovslp=2.0e-8`	Parameter for overlap capacitance. The default value is 2.1e-7 for version 2.00/2.01 and version 1.23.
287 `ovmag=500.0`	Parameter for overlap capacitance. The default value is 0.6 for version 2.00/2.01 and version 1.23.
288 `vfbover=-0.5 V`	Flat-band voltage in overlap region.
289 `nover=3.0e16` cm^{-3}	Impurity concentration in overlap region. Defaulted as 1.0e17 for version 2.00/2.01.
290 `novers=0.0` cm^{-3}	Impurity concentration in overlap region. Defaulted as 1.0e17 since version 2.10.

Smoothing coefficient between linear and saturation

291 `ddltmax=1.0`	Coefficient of effective electric field. The default value is 10 for version 2.00/2.01 and 1.23.
292 `ddltslp=0.0`	Lgate dependence of smoothing coefficient.

293 `ddltict=10.0` Lgate dependence of smoothing coefficient.

DFM parameters

294 `mphdfm=-0.3` NSUBCDFM dependence of phonon scattering for DFM.

Substrate model parameters

295 `rdvsub=1.0` Vsub dependence of depletion width.

296 `rdvdsub=0.3` Vds dependence of depletion width.

297 `ddrift=1.0e-6 m` Depth of the drift region.

298 `vbisub=0.7 V` Built-in potential at the drift/substrate junction.

299 `nsubsub=1.0e15 cm`$^{-3}$
Impurity concentration of the substrate required for Vsub dependence.

Operating region warning control parameters

300 `warn=off` Parameter to turn warnings on and off.
Possible values are `off` and `on`.

301 `bvd (V)` Drain diode breakdown voltage, take effect when bvj not given.

302 `bvs (V)` Source diode breakdown voltage, take effect when bvj not given.

303 `bvj (V)` Junction reverse breakdown voltage.

304 `vbox=3e9 tox V` Oxide breakdown voltage.

Mismatch parameters

305 `mvtwl=0.0 V m` Threshold mismatch area dependence.

306 `mvt0=0.0 V` Threshold mismatch intercept.

307 `mbewl=0.0 m` Beta mismatch area dependence.

308 `mbe0=0.0` Beta mismatch intercept.

309 `mvtwl2=0.0 V m^1.5`
Threshold mismatch area square dependence.

310 `mismatchmod=0` Mismatch mode selector. The available modes are 0, 1, 2 and 3.

311 `mismatchdist=0 m` Mismatch Distance.

LDMOS special parameters

312 `rdvg11=0.0` Vgs dependence of RD.

313 `rdvg12=1.0e2` Vgs dependence of RD.

314 `vbsmin=-10.5 V` Minimum back bias voltage to be treated in hsmhveval.

315 `rth0=0.1 Kcm/W` Thermal resistance.

316 `cth0=1.0e-7 Ws/Kcm`
Thermal capacitance.

317 `qdftvd=1.0` Qdrift Vd dependence.

318 `rdvd=7.0e-2` Vds dependence of RD.

319 `rdvb=0.0` Vbs dependence of RD.

320 `rd20=0.0` RD23 boundary.

321 `rd21=1.0` Vds dependence of RD.

322 `rd22=0.0` Vbs dependence of RD.

323 `rd22d=0.0` Vbs dependence of RD.

324 `rd23=5e-3` Modification of RD.

325 `rd24=0.0` Vgs dependence of RD.

326 `rd25=0.0` Vgs dependence of RD.

327 `rd26=0.2` Smoothing Qover at depletion/inversion transition.

328 `qovsm=0.2` Smoothing Qover at depletion/inversion transition.

329 `rdvdl=0.0` Lgate dependence of RD.

330 `rdvdlp=1.0` Lgate dependence of RD.

331 `rdvds=0.0` Small size dependence of RD.

332 `rdvdsp=1.0` Small size dependence of RD.

333 `rd23l=0.0` Lgate dependence of RD23 boundary.

334 `rd23lp=1.0` Lgate dependence of RD23 boundary.

335 `rd23s=0.0` Small size dependence of RD23.

336 `rd23sp=1.0` Small size dependence of RD23.

337 `rds=0.0` Small size dependence of RD.

338 `rdsp=1.0` Small size dependence of RD.

339 `ldrift=1.0e-6` Length of drift region.

340 `rth0r=0.0` Heat radiation for SHE.

341 `rth0w=0.0` Width-dependence of RTH0.

342 `rth0wp=1.0` Width-dependence of RTH0.

343 `rth0nf=0.0` Nf-dependence of RTH0.

344 `cvdsover=0.0` Modification of the Cgg spikes for Vds is not zero.

345 `powrat=1.0` Thermal dissipation.

346 `shemax=500.0 K` The maximum temperature rise due to the selfheating.

347 `vgsmin=-100 V` Minimal/maximal expected Vgs (NMOS/PMOS).

Auto Model Selector parameters

348 `wmax=1 m` Maximum channel width for which the model is valid.

349 `wmin=0 m` Minimum channel width for which the model is valid.

350 `lmax=1 m` Maximum channel length for which the model is valid.

351 `lmin=0 m` Minimum channel length for which the model is valid.

Safe Operating Areas Parameters

352 `vds_max=∞ V`
Maximum allowed voltage cross source and drain.

353 `vgd_max=∞ V`
Maximum allowed voltage cross drain and gate.

354 `vgs_max=∞ V`
Maximum allowed voltage cross source/bulk and gate.

355 `vbd_max=∞ V`
Maximum allowed voltage cross drain/source and bulk.

356 `vbs_max=∞ V`
Maximum allowed voltage cross source and bulk.

357 `vgb_max=∞ V`
Maximum allowed voltage cross gate and bulk.

358 `vgdr_max=∞ V`
Maximum allowed reverse voltage cross gate and drain.

359 `vgsr_max=∞ V`
Maximum allowed reverse voltage cross gate and source.

360 `vgbr_max=∞ V`
Maximum allowed reverse voltage cross gate and bulk.

361 `ptl=0.0` Strength for punchthrough effect.

362 `ptp=3.5` Strength for punchthrough effect.

363 `pt2=0.0` Vds dependence of punchthrough effect.

364 `ptlp=1.0` Channel-length dependence of punchthrough effect.

365 `gdl=0.0`	Strength of high-field effect.
366 `gdlp=0.0`	Channel-length dependence of high-field effect.
367 `gdld=0.0`	Channel-length dependence of high-field effect.
368 `pt4=0.0`	Vbs dependence of punchthrough effect.
369 `pt4p=1.0`	Vbs dependence of punchthrough effect.
370 `rdrmue=2.0e3`	Field dependent mobility in the drift region for cordrift=1.
371 `rdrvmax=1.0e7`	Saturation velocity in drift region, defaulted as 3e7 since version 2.10.
372 `rdrmuetmp=0.0`	Temperature dependence of resistance for cordrift=1.
373 `rdrvtmp=0.0`	Temperature dependence of resistance for cordrift=1.
374 `rdrdjunc=1.0e-6`	Junction depth at channel/drift region.
375 `rdrcx=0.0`	Exude of current flow from Xov.
376 `rdrcar=0.0`	High field injection in drift region.
377 `rdrdl1=0.0`	Effective ldrift of current in drift region.
378 `rdrdl2=0.0`	Pinch-off length in drift region.
379 `rdrvmaxw=0.0`	Saturation velocity Wgate dependence.
380 `rdrvmaxwp=1.0`	Saturation velocity Wgate dependence.
381 `rdrvmaxl=0.0`	Saturation velocity Lgate dependence.
382 `rdrvmaxlp=1.0`	Saturation velocity Lgate dependence.
383 `rdrmuel=0.0`	Mobility in drift region Lgate dependence.
384 `rdrmuelp=1.0`	Mobility in drift region Lgate dependence.
385 `rdrqover=0.0`	Inclusion of the overlap charge into rdrift, defaulted as 1.0e5 since version 2.10.

386 `js0d=js0 A/m`^{2}	Saturation current density for drain junction.
387 `js0swd=js0sw A/m`	Side wall saturation current density for drain junction.
388 `njd=nj`	Emission coefficient for drain junction.
389 `njswd=njsw`	Emission coefficient for drain junction.
390 `xtid=xti`	Junction current temperature exponent coefficient for drain junction.
391 `cjd=cj F/m`^{2}	Bottom junction capacitance per unit area at zero bias for drain junction.
392 `cjswd=cjsw F/m`	Sidewall junction capacitance grading coefficient per unit length at zero bias for drain junction.
393 `cjswgd=cjswg F/m`	Gate sidewall junction capacitance per unit length at zero bias for drain junction.
394 `mjd=mj`	Bottom junction capacitance grading coefficient for drain junction.
395 `mjswd=mjsw`	Sidewall junction capacitance grading coefficient for drain junction.
396 `mjswgd=mjswg`	Gate sidewall junction capacitance grading coefficient for drain junction.
397 `pbd=pb V`	Bottom junction build-in potential for drain junction.
398 `pbswd=pbsw V`	Sidewall junction build-in potential for drain junction.
399 `pbswgd=pbswg V`	Gate sidewall junction build-in potential for drain junction.
400 `xti2d=xti2`	Temperature coefficient for drain junction.
401 `cisbd=cisb`	Reverse bias saturation current for drain junction.
402 `cvbd=cvb`	Bias dependence coefficient of cisb for drain junction.
403 `ctempd=ctemp`	Temperature coefficient for drain junction.

404 `cisbkd=cisbk A`	Reverse bias saturation current for drain junction.
405 `divxd=divx 1/V`	Reverse coefficient coefficient for drain junction.
406 `vdiffjd=vdiffj V`	Reverse coefficient coefficient for drain junction.
407 `js0s=js0d` A/m^2	Saturation current density for source junction.
408 `js0sws=js0swd A/m`	Side wall saturation current density for source junction.
409 `njs=njd`	Emission coefficient for source junction.
410 `njsws=njswd`	Sidewall emission coefficient for source junction.
411 `xtis=xtid`	Junction current temperature exponent coefficient for source junction.
412 `cjs=cjd` F/m^2	Bottom junction capacitance per unit area at zero bias for source junction.
413 `cjsws=cjswd F/m`	Sidewall junction capacitance grading coefficient per unit length at zero bias for source junction.
414 `cjswgs=cjswgd F/m`	Gate sidewall junction capacitance per unit length at zero bias for source junction.
415 `mjs=mjd`	Bottom junction capacitance grading coefficient for source junction.
416 `mjsws=mjswd`	Sidewall junction capacitance grading coefficient for source junction.
417 `mjswgs=mjswgd`	Gate sidewall junction capacitance grading coefficient for source junction.
418 `pbs=pbd V`	Bottom junction build-in potential for source junction.
419 `pbsws=pbswd V`	Sidewall junction build-in potential for source junction.
420 `pbswgs=pbswgd V`	Gate sidewall junction build-in potential for source junction.
421 `xti2s=xti2d`	Temperature coefficient for source junction.

422 `cisbs=cisbd` Reverse bias saturation current for source junction.

423 `cvbs=cvbd` Bias dependence coefficient of cisb for source junction.

424 `ctemps=ctempd` Temperature coefficient for source junction.

425 `cisbks=cisbkd A` Reverse bias saturation current for source junction.

426 `divxs=divxd 1/V` Reverse coefficient coefficient for source junction.

427 `vdiffjs=vdiffjd V` Threshold voltage for junction diode for source junction.

Binning model parameters

428 `lbinn=1.0` L modulation coefficient for binning.

429 `wbinn=1.0` W modulation coefficient for binning.

430 `lvmax=0.0 cm/s` Length dependence of vmax.

431 `lbgtmp1=0.0 eV/K` Length dependence of bgtmp1.

432 `lbgtmp2=0.0` eV/K^2

Length dependence of bgtmp2.

433 `leg0=0.0 eV` Length dependence of eg0.

434 `lnovers=0.0` cm^{-3} Length dependence of novers.

435 `lvfbover=0.0 V` Length dependence of vfbover.

436 `lnover=0.0` cm^{-3} Length dependence of nover.

437 `lwl2=0.0` Length dependence of wl2.

438 `lvfbc=0.0 V` Length dependence of vfbc.

439 `lnsubc=0.0` cm^{-3} Length dependence of nsubc.

440 `lnsubp=0.0` cm^{-3} Length dependence of nsubp.

441 `lscp1=0.0 1/V` Length dependence of scp1.

442 `lscp2=0.0 1/V`^{2} Length dependence of scp2.

443 `lscp3=0.0 m/V`^{2} Length dependence of scp3.

444 `lsc1=0.0 1/V` Length dependence of sc1.

445 `lsc2=0.0 1/V`^{2} Length dependence of sc2.

446 `lsc3=0.0 m/V`^{2} Length dependence of sc3.

447 `lpgd1=0.0 V` Length dependence of pgd1.

448 `lpgd3=0.0` Length dependence of pgd3.

449 `lndep=0.0` Length dependence of ndep.

450 `lninv=0.0` Length dependence of ninv.

451 `lmuecb0=0.0 cm`^{2}`/(V s)`
Length dependence of muecb0.

452 `lmuecb1=0.0 cm`^{2}`/(V s)`
Length dependence of muecb1.

453 `lmueph1=0.0` Length dependence of mueph1.

454 `lvtmp=0.0 cm/s` Length dependence of vtmp.

455 `lwvth0=0.0` Length dependence of wvth0.

456 `lmuesr1=0.0` Length dependence of muesr1.

457 `lmuetmp=0.0` Length dependence of muetmp.

458 `lsub1=0.0 1/V` Length dependence of sub1.

459 `lsub2=0.0 V` Length dependence of sub2.

460 `lsvds=0.0` Length dependence of svds.

461 `lsvbs=0.0` Length dependence of svbs.

462 `lsvgs=0.0` Length dependence of svgs.

463 `lfn1=0.0` Length dependence of fn1.

464 `lfn2=0.0` Length dependence of fn2.

465 `lfn3=0.0` Length dependence of fn3.

466 `lfvbs=0.0` Length dependence of fvbs.

467 `lnsti=0.0 cm`$^{-3}$ Length dependence of nsti.

468 `lwsti=0.0 m` Length dependence of wsti.

469 `lscsti1=0.0` Length dependence of scsti1.

470 `lscsti2=0.0 1/V` Length dependence of scsti2.

471 `lvthsti=0.0` Length dependence of vthsti.

472 `lmuesti1=0.0` Length dependence of muesti1.

473 `lmuesti2=0.0` Length dependence of muesti2.

474 `lmuesti3=0.0` Length dependence of muesti3.

475 `lnsubpsti1=0.0 m` Length dependence of nsubpsti1.

476 `lnsubpsti2=0.0 m` Length dependence of nsubpsti2.

477 `lnsubpsti3=0.0 m` Length dependence of nsubpsti3.

478 `lcgso=0.0 F/m` Length dependence of cgso.

479 `lcgdo=0.0 F/m` Length dependence of cgdo.

480 `ljs0=0.0 A/m`^{2} Length dependence of js0.

481 `ljs0sw=0.0 A/m` Length dependence of js0sw.

482 `lnj=0.0` Length dependence of nj.

483 `lcisbk=0.0 A` Length dependence of cisbk.

484 `lclm1=0.0` Length dependence of clm1.

485 `lclm2=0.0 1/m` Length dependence of clm2.

486 `lclm3=0.0` Length dependence of clm3.

487 `lwfc=0.0 m F/cm`^{2} Length dependence of wfc.

488 `lgidl1=0.0 A m/(V^(3/2) c^(1/2))`
Length dependence of gidl1.

489 `lgidl2=0.0 1/(V^(1/2) c^(3/2) m)`
Length dependence of gidl2.

490 `lgleak1=0.0 A/(V^(3/2) c^(1/2))`
Length dependence of gleak1.

491 `lgleak2=0.0 1/(V^(1/2) c^(3/2) m)`
Length dependence of gleak2.

492 `lgleak3=0.0` Length dependence of gleak3.

493 `lgleak6=0.0 V` Length dependence of gleak6.

494 `lglksd1=0.0` Length dependence of glksd1.

495 `lglksd2=0.0` Length dependence of glksd2.

496 `lglkb1=0.0` Length dependence of glkb1.

497 `lglkb2=0.0` Length dependence of glkb2.

498 `lnftrp=0.0` Length dependence of nftrp.

499 `lnfalp=0.0` Length dependence of nfalp.

500 `lpthrou=0.0` Length dependence of pthrou.

501 `lvdiffj=0.0 V` Length dependence of vdiffj.

502 `libpc1=0.0` Length dependence of ibpc1.

503 `libpc2=0.0` Length dependence of ibpc2.

504 `lcgbo=0.0` Length dependence of cgbo.

505 `lcvdsover=0.0` Length dependence of cvdsover.

506 `lfalph=0.0` Length dependence of falph.

507 `lnpext=0.0` Length dependence of npext.

508 `lpowrat=0.0` Length dependence of powrat.

509 `lrd=0.0` Length dependence of rd.

510 `lrd22=0.0` Length dependence of rd22.

511 `lrd23=0.0` Length dependence of rd23.

512 `lrd24=0.0` Length dependence of rd24.

513 `lrdict1=0.0` Length dependence of rdict1.

514 `lrdov13=0.0` Length dependence of rdov13.

515 `lrdslp1=0.0` Length dependence of rdslp1.

516 `lrdvb=0.0` Length dependence of rdvb.

517 `lrdvd=0.0` Length dependence of rdvd.

518 `lrdvg11=0.0` Length dependence of rdvg11.

519 `lrs=0.0` Length dependence of rs.

520 `lrth0=0.0` Length dependence of rth0.

521 `lvover=0.0` Length dependence of vover.

522 `ljs0d=ljs0` Length dependence of js0d.

523 `ljs0swd=ljs0sw` Length dependence of js0swd.

524 `lnjd=lnj` Length dependence of njd.

525 `lcisbkd=lcisbk` Length dependence of cisbkd.

526 `lvdiffjd=lvdiffj` Length dependence of vdiffjd.

527 `ljs0s=ljs0d` Length dependence of js0s.

528 `ljs0sws=ljs0swd` Length dependence of js0sws.

529 `lnjs=lnjd` Length dependence of njs.

530 `lcisbks=lcisbkd` Length dependence of cisbks.

531 `lvdiffjs=lvdiffjd`
Length dependence of vdiffjs.

532 `wvmax=0.0 cm/s` Width dependence of vmax.

533 `wbgtmp1=0.0 eV/K` Width dependence of bgtmp1.

534 `wbgtmp2=0.0 eV/K`^{2}
Width dependence of bgtmp2.

535 `weg0=0.0 eV` Width dependence of eg0.

536 `wnovers=0.0 cm`$^{-3}$ Width dependence of novers.

537 `wvfbover=0.0 V` Width dependence of vfbover.

538 `wnover=0.0 cm`$^{-3}$ Width dependence of nover.

539 `wwl2=0.0` Width dependence of wl2.

540 `wvfbc=0.0 V` Width dependence of vfbc.

541 `wnsubc=0.0 cm`$^{-3}$ Width dependence of nsubc.

542 `wnsubp=0.0 cm`$^{-3}$ Width dependence of nsubp.

543 `wscp1=0.0 1/V` Width dependence of scp1.

544 `wscp2=0.0 1/V`^{2} Width dependence of scp2.

545 `wscp3=0.0 m/V`^{2} Width dependence of scp3.

546 `wsc1=0.0 1/V` Width dependence of sc1.

547 `wsc2=0.0 1/V`^{2} Width dependence of sc2.

548 `wsc3=0.0 m/V`^{2} Width dependence of sc3.

549 `wpgd1=0.0 V` Width dependence of pgd1.

550 `wpgd3=0.0` Width dependence of pgd3.

551 `wndep=0.0` Width dependence of ndep.

552 `wninv=0.0` Width dependence of ninv.

553 `wmuecb0=0.0 cm`^{2}`/(V s)`
Width dependence of muecb0.

554 `wmuecb1=0.0 cm`^{2}`/(V s)`
Width dependence of muecb1.

555 `wmueph1=0.0` Width dependence of mueph1.

556 `wvtmp=0.0 cm/s` Width dependence of vtmp.

557 `wwvth0=0.0` Width dependence of wvth0.

558 `wmuesr1=0.0` Width dependence of muesr1.

559 `wmuetmp=0.0` Width dependence of muetmp.

560 `wsub1=0.0 1/V` Width dependence of sub1.

561 `wsub2=0.0 V` Width dependence of sub2.

562 `wsvds=0.0` Width dependence of svds.

563 `wsvbs=0.0` Width dependence of svbs.

564 `wsvgs=0.0` Width dependence of svgs.

565 `wfn1=0.0` Width dependence of fn1.

566 `wfn2=0.0` Width dependence of fn2.

567 `wfn3=0.0` Width dependence of fn3.

568 `wfvbs=0.0` Width dependence of fvbs.

569 `wnsti=0.0` cm^{-3} Width dependence of nsti.

570 `wwsti=0.0 m` Width dependence of wsti.

571 `wscsti1=0.0` Width dependence of scsti1.

572 `wscsti2=0.0 1/V` Width dependence of scsti2.

573 `wvthsti=0.0` Width dependence of vthsti.

574 `wmuesti1=0.0` Width dependence of muesti1.

575 `wmuesti2=0.0` Width dependence of muesti2.

576 `wmuesti3=0.0` Width dependence of muesti3.

577 `wnsubpsti1=0.0 m` Width dependence of nsubpsti1.

578 `wnsubpsti2=0.0 m` Width dependence of nsubpsti2.

579 `wnsubpsti3=0.0 m` Width dependence of nsubpsti3.

580 `wcgso=0.0 F/m` Width dependence of cgso.

581 `wcgdo=0.0 F/m` Width dependence of cgdo.

582 `wjs0=0.0` A/m^2 Width dependence of js0.

583 `wjs0sw=0.0 A/m` Width dependence of js0sw.

584 `wnj=0.0` Width dependence of nj.

585 `wcisbk=0.0 A` Width dependence of cisbk.

586 `wclm1=0.0` Width dependence of clm1.

587 `wclm2=0.0 1/m` Width dependence of clm2.

588 `wclm3=0.0` Width dependence of clm3.

589 `wwfc=0.0 m` F/cm^2 Width dependence of wfc.

590 `wgidl1=0.0 A m/(V^(3/2) c^(1/2))`
Width dependence of gidl1.

591 `wgidl2=0.0 1/(V^(1/2) c^(3/2) m)`
Width dependence of gidl2.

592 `wgleak1=0.0 A/(V^(3/2) c^(1/2))`
Width dependence of gleak1.

593 `wgleak2=0.0 1/(V^(1/2) c^(3/2) m)`
Width dependence of gleak2.

594 `wgleak3=0.0` Width dependence of gleak3.

595 `wgleak6=0.0 V` Width dependence of gleak6.

596 `wglksd1=0.0` Width dependence of glksd1.

597 `wglksd2=0.0` Width dependence of glksd2.

598 `wglkb1=0.0` Width dependence of glkb1.

599 `wglkb2=0.0` Width dependence of glkb2.

600 `wnftrp=0.0` Width dependence of nftrp.

601 `wnfalp=0.0` Width dependence of nfalp.

602 `wpthrou=0.0` Width dependence of pthrou.

603 `wvdiffj=0.0 V` Width dependence of vdiffj.

604 `wibpc1=0.0` Width dependence of ibpc1.

605 `wibpc2=0.0` Width dependence of ibpc2.

606 `wcgbo=0.0` Width dependence of cgbo.

607 `wcvdsover=0.0` Width dependence of cvdsover.

608 `wfalph=0.0` Width dependence of falph.

609 `wnpext=0.0` Width dependence of npext.

610 `wpowrat=0.0` Width dependence of powrat.

611 `wrd=0.0` Width dependence of rd.

612 `wrd22=0.0` Width dependence of rd22.

613 `wrd23=0.0` Width dependence of rd23.

614 `wrd24=0.0` Width dependence of rd24.

615 `wrdict1=0.0` Width dependence of rdict1.

616 `wrdov13=0.0` Width dependence of rdov13.

617 `wrdslp1=0.0` Width dependence of rdslp1.

618 `wrdvb=0.0` Width dependence of rdvb.

619 `wrdvd=0.0` Width dependence of rdvd.

620 `wrdvg11=0.0` Width dependence of rdvg11.

621 `wrs=0.0` Width dependence of rs.

622 `wrth0=0.0` Width dependence of rth0.

623 `wvover=0.0` Width dependence of vover.

624 `wjs0d=wjs0` Width dependence of js0d.

625 `wjs0swd` Width dependence of js0swd.

626 `wnjd` Width dependence of njd.

627 `wcisbkd` Width dependence of cisbkd.

628 `wvdiffjd` Width dependence of vdiffjd.

629 `wjs0s` Width dependence of js0s.

630 `wjs0sws` Width dependence of js0sws.

631 `wnjs` Width dependence of njs.

632 `wcisbks` Width dependence of cisbks.

633 `wvdiffjs` Width dependence of vdiffjs.

634 `pvmax=0.0 cm/s` Cross-term dependence of vmax.

635 `pbgtmp1=0.0 eV/K` Cross-term dependence of bgtmp1.

636 `pbgtmp2=0.0 eV/K`^{2} Cross-term dependence of bgtmp2.

637 `peg0=0.0 eV` Cross-term dependence of eg0.

638 `pnovers=0.0 cm`$^{-3}$ Cross-term dependence of novers.

639 `pvfbover=0.0 V` Cross-term dependence of vfbover.

640 `pnover=0.0 cm`$^{-3}$ Cross-term dependence of nover.

641 `pwl2=0.0` Cross-term dependence of wl2.

642 `pvfbc=0.0 V` Cross-term dependence of vfbc.

643 `pnsubc=0.0 cm`$^{-3}$ Cross-term dependence of nsubc.

644 `pnsubp=0.0 cm`$^{-3}$ Cross-term dependence of nsubp.

645 `pscp1=0.0 1/V` Cross-term dependence of scp1.

646 `pscp2=0.0 1/V`^{2} Cross-term dependence of scp2.

647 `pscp3=0.0 m/V`^{2} Cross-term dependence of scp3.

648 `psc1=0.0 1/V` Cross-term dependence of sc1.

649 `psc2=0.0 1/V`^{2} Cross-term dependence of sc2.

650 `psc3=0.0 m/V`^{2} Cross-term dependence of sc3.

651 `ppgd1=0.0 V` Cross-term dependence of pgd1.

652 `ppgd3=0.0` Cross-term dependence of pgd3.

653 `pndep=0.0` Cross-term dependence of ndep.

654 `pninv=0.0` Cross-term dependence of ninv.

655 `pmuecb0=0.0` $cm^2/(V\ s)$
Cross-term dependence of muecb0.

656 `pmuecb1=0.0` $cm^2/(V\ s)$
Cross-term dependence of muecb1.

657 `pmueph1=0.0` Cross-term dependence of mueph1.

658 `pvtmp=0.0 cm/s` Cross-term dependence of vtmp.

659 `pwvth0=0.0` Cross-term dependence of wvth0.

660 `pmuesr1=0.0` Cross-term dependence of muesr1.

661 `pmuetmp=0.0` Cross-term dependence of muetmp.

662 `psub1=0.0 1/V` Cross-term dependence of sub1.

663 `psub2=0.0 V` Cross-term dependence of sub2.

664 `psvds=0.0` Cross-term dependence of svds.

665 `psvbs=0.0` Cross-term dependence of svbs.

666 `psvgs=0.0` Cross-term dependence of svgs.

667 `pfn1=0.0` Cross-term dependence of fn1.

668 `pfn2=0.0` Cross-term dependence of fn2.

669 `pfn3=0.0` Cross-term dependence of fn3.

670 `pfvbs=0.0` Cross-term dependence of fvbs.

671 `pnsti=0.0` cm^{-3} Cross-term dependence of nsti.

672 `pwsti=0.0 m` Cross-term dependence of wsti.

673 `pscsti1=0.0` Cross-term dependence of scsti1.

674 `pscsti2=0.0 1/V` Cross-term dependence of scsti2.

675 `pvthsti=0.0` Cross-term dependence of vthsti.

676 `pmuesti1=0.0` Cross-term dependence of muesti1.

677 `pmuesti2=0.0` Cross-term dependence of muesti2.

678 `pmuesti3=0.0` Cross-term dependence of muesti3.

679 `pnsubpsti1=0.0 m` Cross-term dependence of nsubpsti1.

680 `pnsubpsti2=0.0 m` Cross-term dependence of nsubpsti2.

681 `pnsubpsti3=0.0 m` Cross-term dependence of nsubpsti3.

682 `pcgso=0.0 F/m` Cross-term dependence of cgso.

683 `pcgdo=0.0 F/m` Cross-term dependence of cgdo.

684 `pjs0=0.0 A/m`^{2} Cross-term dependence of js0.

685 `pjs0sw=0.0 A/m` Cross-term dependence of js0sw.

686 `pnj=0.0` Cross-term dependence of nj.

687 `pcisbk=0.0 A` Cross-term dependence of cisbk.

688 `pclm1=0.0` Cross-term dependence of clm1.

689 `pclm2=0.0 1/m` Cross-term dependence of clm2.

690 `pclm3=0.0` Cross-term dependence of clm3.

691 `pwfc=0.0 m F/cm`^{2} Cross-term dependence of wfc.

692 `pgidl1=0.0 A m/(V^(3/2) c^(1/2))`
Cross-term dependence of gidl1.

693 `pgidl2=0.0 1/(V^(1/2) c^(3/2) m)`
Cross-term dependence of gidl2.

694 `pgleak1=0.0 A/(V^(3/2) c^(1/2))`
Cross-term dependence of gleak1.

695 `pgleak2=0.0 1/(V^(1/2) c^(3/2) m)`
Cross-term dependence of gleak2.

696 `pgleak3=0.0` Cross-term dependence of gleak3.

697 `pgleak6=0.0 V` Cross-term dependence of gleak6.

698 `pglksd1=0.0` Cross-term dependence of glksd1.

699 `pglksd2=0.0` Cross-term dependence of glksd2.

700 `pglkb1=0.0` Cross-term dependence of glkb1.

701 `pglkb2=0.0` Cross-term dependence of glkb2.

702 `pnftrp=0.0` Cross-term dependence of nftrp.

703 `pnfalp=0.0` Cross-term dependence of nfalp.

704 `ppthrou=0.0` Cross-term dependence of pthrou.

705 `pvdiffj=0.0 V` Cross-term dependence of vdiffj.

706 `pibpc1=0.0` Cross-term dependence of ibpc1.

707 `pibpc2=0.0` Cross-term dependence of ibpc2.

708 `pcgbo=0.0` Cross-term dependence of cgbo.

709 `pcvdsover=0.0` Cross-term dependence of cvdsover.

710 `pfalph=0.0` Cross-term dependence of falph.

711 `pnpext=0.0` Cross-term dependence of npext.

712 `ppowrat=0.0` Cross-term dependence of powrat.

713 `prd=0.0` Cross-term dependence of rd.

714 `prd22=0.0` Cross-term dependence of rd22.

715	`prd23=0.0`	Cross-term dependence of rd23.
716	`prd24=0.0`	Cross-term dependence of rd24.
717	`prdict1=0.0`	Cross-term dependence of rdict1.
718	`prdov13=0.0`	Cross-term dependence of rdov13.
719	`prdslp1=0.0`	Cross-term dependence of rdslp1.
720	`prdvb=0.0`	Cross-term dependence of rdvb.
721	`prdvd=0.0`	Cross-term dependence of rdvd.
722	`prdvg11=0.0`	Cross-term dependence of rdvg11.
723	`prs=0.0`	Cross-term dependence of rs.
724	`prth0=0.0`	Cross-term dependence of rth0.
725	`pvover=0.0`	Cross-term dependence of vover.
726	`pjs0d`	Cross-term dependence of js0d.
727	`pjs0swd`	Cross-term dependence of js0swd.
728	`pnjd`	Cross-term dependence of njd.
729	`pcisbkd`	Cross-term dependence of cisbkd.
730	`pvdiffjd`	Cross-term dependence of vdiffjd.
731	`pjs0s`	Cross-term dependence of js0s.
732	`pjs0sws`	Cross-term dependence of js0sws.
733	`pnjs`	Cross-term dependence of njs.
734	`pcisbks`	Cross-term dependence of cisbks.
735	`pvdiffjs`	Cross-term dependence of vdiffjs.
736	`gdsleak=0.0 S`	Channel leakage conductance.

737 `coerrrep=1` selector for error report.

Output Parameters

1 `tempeff (C)` Effective temperature for a single device.

2 `weff (m)` Effective channel width.

3 `leff (m)` Effective channel length.

Operating-Point Parameters

1 `temp (C)` Device temperature.

2 `shetemp (C)` Temperature rise due to self-heating.

3 `reversed` Reverse mode indicator.
Possible values are `no` and `yes`.

4 `ids (A)` Resistive drain-to-source current.

5 `vgs (V)` Gate-source voltage.

6 `vds (V)` Drain-source voltage.

7 `vbs (V)` Bulk-source voltage.

8 `vth (V)` Threshold voltage.

9 `vdsat (V)` Drain-source saturation voltage.

10 `gm (S)` Common-source transconductance.

11 `gds (S)` Common-source output conductance.

12 `gmbs (S)` Body-transconductance.

13 `qb (Coul)` Total bulk charge.

14 `qd (Coul)` Total drain charge.

15 `qg (Coul)` Total gate charge.

16 `qs (Coul)`	Total source charge.
17 `qb_itr (Coul)`	Intrinsic bulk charge.
18 `qd_itr (Coul)`	Intrinsic drain charge.
19 `qg_itr (Coul)`	Intrinsic gate charge.
20 `qs_itr (Coul)`	Intrinsic source charge.
21 `qdp (Coul)`	Total external drain charge.
22 `qsp (Coul)`	Total external source charge.
23 `cjd (F)`	Drain-bulk junction capacitance.
24 `cjs (F)`	Source-bulk junction capacitance.
25 `cgg (F)`	Intrinsic dQg_dVg.
26 `cgd (F)`	dQg_dVd.
27 `cgs (F)`	dQg_dVs.
28 `cgb (F)`	dQg_dVb.
29 `cdg (F)`	dQd_dVg.
30 `cdd (F)`	Intrinsic dQd_dVd.
31 `cds (F)`	dQd_dVs.
32 `cdb (F)`	dQd_dVb.
33 `csg (F)`	dQs_dVg.
34 `csd (F)`	dQs_dVd.
35 `css (F)`	Intrinsic dQs_dVs.
36 `csb (F)`	dQs_dVb.
37 `cbg (F)`	dQb_dVg.

38 `cbd (F)`	dQb_dVd.
39 `cbs (F)`	dQb_dVs.
40 `cbb (F)`	Intrinsic dQb_dVb.
41 `cdd_tot (F)`	Total dQd_dVd.
42 `cgg_tot (F)`	Total dQg_dVg.
43 `css_tot (F)`	Total dQs_dVs.
44 `cbb_tot (F)`	Total dQb_dVb.
45 `id (A)`	Resistive drain current.
46 `ig (A)`	Gate current.
47 `is (A)`	Resistive source current.
48 `ibulk (A)`	Resistive bulk current.
49 `pwr (W)`	Power at operating point.
50 `ps0 (V)`	Surface potential at source side.
51 `psl (V)`	Surface potential at drain side.
52 `pds (V)`	Delta surface potential between psl and ps0.
53 `isub (A)`	Substrate current Isub.
54 `isubld (A)`	Substrate current IsubLD.
55 `idsibpc (A)`	Impact-Ionization Induced Bulk Potential Change (IBPC).
56 `gbds (S)`	Substrate trans conductance (dIsub/dVds).
57 `gbgs (S)`	Substrate trans conductance (dIsub/dVgs).
58 `gbbs (S)`	Substrate transconductance (dIsub/dVbs).
59 `igate (A)`	Gate current due to tunneling.

60 `igates (A)`	Tunneling current from gate to source.
61 `igateb (A)`	Tunneling current from gate to bulk.
62 `igated (A)`	Tunneling current from gate to drain.
63 `igisl (A)`	Gate-induced source leakage current.
64 `igidl (A)`	Gate-induced drain leakage current.
65 `ibs (A)`	Source-bulk diode current.
66 `ibd (A)`	Source-drain diode current.
67 `cgso (F)`	Gate-source overlap capacitance.
68 `cgbo (F)`	Gate-bulk overlap capacitance.
69 `cgdo (F)`	Gate-drain overlap capacitance.
70 `cggo (F)`	Gate-gate overlap capacitance.
71 `cddo (F)`	Drain-drain overlap capacitance.
72 `csso (F)`	Source-source overlap capacitance.
73 `cbbo (F)`	Bulk-bulk overlap capacitance.
74 `rseff (Ω)`	Effective source resistance.
75 `rdeff (Ω)`	Effective drain resistance.
76 `rsdrift (Ω)`	The resistance of drift region for source side.
77 `rdrift (Ω)`	The resistance of drift region for drain side.
78 `gmt (S)`	Temp transconductance.
79 `lx4 (A)`	Resistive drain-to-source current.
80 `lx7 (S)`	Common-source transconductance.
81 `lx8 (S)`	Common-source output conductance.

82 `lv9 (V)` Threshold voltage.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

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HiSIM_IGBT Model (hisim_igbt)

HiSIM_IGBTs (Insulated Gate Bipolar Transistors) have been developed for high voltage applications at 500V and above, which require low switching power and fast switching speed. The complicated IGBT structure, which combines a bipolar junction transistor (BJT) with a MOSFET for base-current switching, imposes challenging problems on compact modeling for circuit simulation. HiSIM_IGBT model combines surface-potential-based HiSIM_HV model with a thick base BJT model and make is possible to modeling real device and complicated circuit.

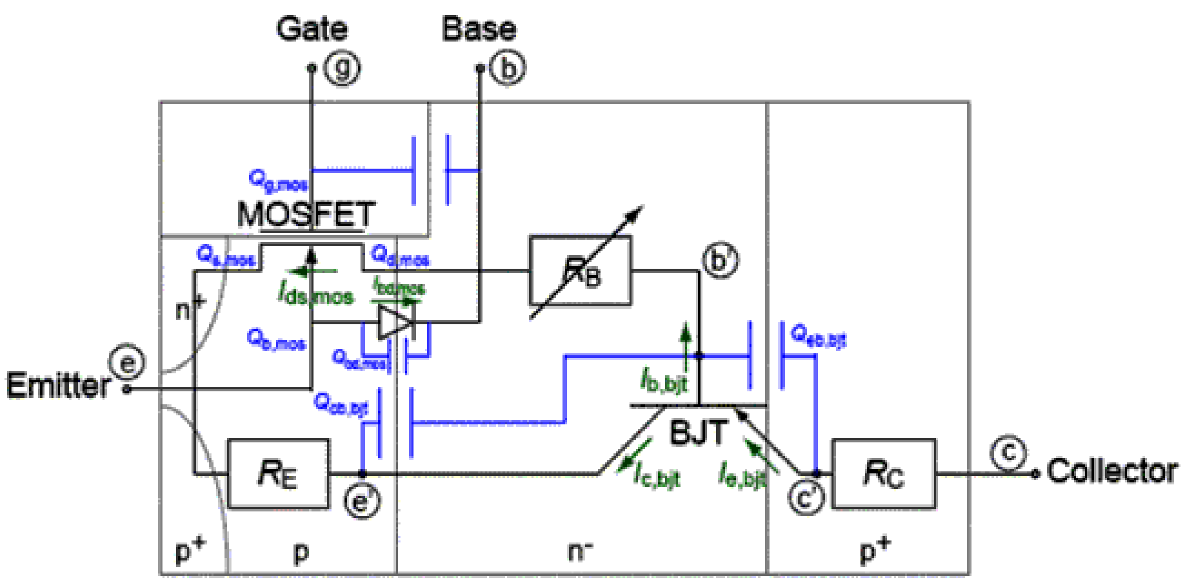
This chapter contains the following information:

Model Concepts

While an IGBT generally has 3 terminals (Collector, Gate, and Emitter), HiSIM_IGBT considers 4 terminals (Collector, Gate, Emitter, and Base). HiSIM_IGBT has been developed based on the MOSFET-model framework, together with the bipolar-junction-transistor (BJT) model. Therefore newly developed MOSFET models as well as BJT models can be easily incorporated with future model extensions. Since the HiSIM_IGBT has been developed as a 4-terminal device, users have to treat the model as a 4-terminal device and let the base terminal float by connecting a zero-ampere current source between the base terminal and the ground, or by not connecting any circuit element to the base terminal.

The circuit diagram of HiSIM-IGBT is shown in Fig. 34.1. In addition to 4 external terminals, three internal nodes (b', c', e') are considered to describe all important features of IGBT. Between the internal and the external nodes, resistances are inserted to describe potential drops. Among the resistances the base resistance between the MOSFET part and the BJT part, determines the most IGBT characteristics. All current flows and induced charges are also considered.

Figure 32-1 Equivalent circuit for HiSIM_IGBT



A surface-potential-based model for high-voltage MOSFET HiSIM_HV 1.1.1 is applied as the MOSFET part. Its source and bulk terminals are connected together and are named as the "emitter" terminal. The drain terminal is connected to the "base" node within the IGBT framework. The surplus models of HiSIM_HV 1.1.1 for HiSIM_IGBT are inactivated by setting model parameters to zero. The activated model parts include: Drain-source current and related conductance; Intrinsic charges/capacitances; Overlap/parasitic charges/

capacitances; STI leakage current; Bulk-drain junction diode currents/conductance; Bulk-drain junction diode charges/capacitances; Binning options. The inactivated model parts include: Source/drain drift resistances; Gate resistance; Bulk resistance network; NQS effect; Substrate leakage current; Gate leakage currents; Gate-induced drain leakage currents; Noises; Self-heating effect. As some HiSIM_HV model effects are inactivated in HiSIM_IGBT model, some redundant model parameters exist there, which will be cleaned with coming version. For the effects details of MOSFET part, please refer to the HiSIM_HV model.

Model Usage

Instance Syntax

HiSIM_IGBT instance need specify 4 or 5 terminals. The 4th terminal needs to be set as float by connecting a zero-ampere current source between the base terminal and the ground, or by not connecting any circuit element to the base terminal. Although selfheating is inactivate now and being testing, the 5th terminal can be set and will be treated as external selfheating node. To specify HiSIM_IGBT instance element, the Model Name has to be associated with a HiSIM_IGBT model card.

```
InstanceName c g e b ModelName parameter=value ...
```

Sample Instance Statement

```
m1 (vcc vgg vee vbb) n_ch w=0.1u l=0.21 m=1e-7
```

For more instance parameters, refer to the Reference of this model.

Model Syntax

The following syntax specifies HiSIM_IGBT model:

```
model ModelName hisim_igbt parameter=value ...
```

The third parameter, “hisim_igbt”, is the master to indicate this model card is a HiSIM_IGBT model card.

Sample Model Statement

```
model n_ch hisim_igbt coadov=1 tox=1e-7 nsubc=1e17
```

For more model parameters, refer to the Reference of this model.

Reference

Component Statements

Instance Parameters

1	w (m)	Gate width.
2	l (m)	Gate length.
3	as (m^2)	Area of source junction.
4	ad (m^2)	Area of drain junction.
5	ps (m)	Perimeter of source junction.
6	pd (m)	Perimeter of drain junction.
7	temp (C)	Device temperature.
8	dtemp (K)	Device temperature rise from ambient.
9	nrs=1	Number of squares of source diffusion.
10	nrd=1	Number of squares of drain diffusion.
11	corbnet	Substrate resistance network selector. Inactive in HiSIM_IGBT model.
12	rbpb (Ohm)	Substrate resistance network.
13	rbpd (Ohm)	Substrate resistance network.
14	rbps (Ohm)	Substrate resistance network.
15	rbdb (Ohm)	Substrate resistance network.
16	rbsb (Ohm)	Substrate resistance network.
17	corg	Gate-contact resistance selector. Inactive in HiSIM_IGBT model.

18	ngcon=1.0	Number of gate contacts.
19	xgw=0.0 m	Distance from gate contact to channel edge.
20	xgl=0.0 m	Offset of gate length due to variation in patterning.
21	nf=1.0	Number of gate fingers.
22	lod=1.0e-5 m	Length of diffusion between gate and STI.
23	m=1	Multiplicity factor (number of MOSFETs in parallel).
24	subld1	Parameter for impact-ionization current in the drift region.
25	subld2 ((V^(3/2))/m)	
		Parameter for impact-ionization current in the drift region.
26	ldrift1 (m)	Parameter for drift region length-1.
27	ldrift2 (m)	Parameter for drift region length-2.
28	lover (m)	Overlap length on source side.
29	lovers (m)	Overlap length on source side.
30	loverld (m)	Overlap length on drain side.
31	ldrift1s (m)	Parameter for drift region length-1 on souce side.
32	ldrift2s (m)	Parameter for drift region length-2 on souce side.
33	sa=0.0 m	Distance from STI edge to Gate edge.
34	sb=0.0 m	Distance from STI edge to Gate edge.
35	sd=0.0 m	Distance from Gate edge to Gate edge.
36	nsubcdfm (cm^-3)	Constant part of Nsub for DFM.
37	isnoisy=yes	Should device generate noise. Possible values are no and yes.

Model Parameters

Device type parameters:

1	type=n	Transistor type. Possible values are n and p.
2	version=1.00	Model version 1.00. 1.00 is the latest version of HiSIM_IGBT.
3	corsrd=0	Contact resistances Rs and Rd selector. Inactive in HiSIM_IGBT model.
4	coiprv=0	Previous Ids is used for calculating source/drain resistance effect. 0 : no(default). 1 : yes.
5	copprv=1	Previous surface potential is used for the initial guess. 0 : no(default). 1 : yes.
6	coadov=1	Selector for lateral field induced and overlap charges/ capacitances being added to intrinsic ones. 0 : no. 1 : yes(default).
7	coisub=0	Substrate current selector. Inactive in HiSIM_IGBT model.
8	cogidl=0	GIDL current calculation selector. Inactive in HiSIM_IGBT model.
9	coiigs=0	Gate current calculation selector. Inactive in HiSIM_IGBT model.
10	coovlp=1	Overlap capacitance calculation selector on drain side. 0 : constant overlap capacitance(default). 1 : yes.
11	coovlps=0	Overlap capacitance calculation selector on source side. 0 : constant overlap capacitance(default). 1 : yes.
12	coflick=0	1/f noise calculation selector. Inactive in HiSIM_IGBT model.
13	coisti=0	STI leakage current calculation selector. 0 : no(default). 1 : yes.
14	conqs=0	Non-quasi-static mode selector. Inactive in HiSIM_IGBT model.
15	cothrml=0	Thermal noise calculation selector. Inactive in HiSIM_IGBT model.

16	tnom (C)	Parameters measurement temperature. Default set by `options'.
17	corg=0	Gate-contact resistance calculation selector. Inactive in HiSIM_IGBT model.
18	corbnet=0	Substrate resistance network selector. Inactive in HiSIM_IGBT model.
19	coign=0	Induced gate and cross correlation noise calculation selector. Inactive in HiSIM_IGBT model.
20	compatible	Compatible with spice3, default is spectre compatible. Possible values are spectre, spice3 and hspice.
21	alarm=none	Forbidden operating region. Possible values are none, off, triode, sat, subth, and rev.
22	codfm=0	Calculation of model for DFM selector.
23	coselfheat=0	Calculation of self heating model.
24	cosym=0	Model selector for symmetry device.

Default for instance parameters:

25	w=5e-6 m	Default gate width.
26	l=2e-6 m	Default gate length.
27	as=0 m^2	Default area of source junction.
28	ad=0 m^2	Default area of drain junction.
29	ps=0 m	Default perimeter of source junction.
30	pd=0 m	Default perimeter of drain junction.
31	temp=27 C	Default device temperature.
32	dtemp=0 K	Default device temperature rise from ambient.

Basic Device Parameters:

33	tox=1e-7 m	Physical oxide thickness.
34	xld=3e-8 m	Gate-overlap length.
35	xwd=0 m	Gate-overlap width.
36	tpoly=2.0e-7 m	Height of the gate poly-si for fringing capacitance on source side.
37	nsubc=1.0e17 cm^-3	Substrate-impurity concentration.
38	nsubp=1.0e17 cm^-3	Maximum pocket concentration.
39	rs=0.0 Ohm*m	Source contact resistance in LDD region.
40	rd=5.0e-3 Ohm*m	Drain contact resistance in LDD region.
41	vfbc=-1.0 V	Constant part of flat-band voltage.
42	lp=0.0 m	Length of the pocket penetration into the channel.
43	xqy=0.0 m	Distance from channel/drain junction to maximum electric field point.
44	lover=3.0e-8 m	Overlap length on source side.
45	ll=0.0	Gate length parameter.
46	lld=0.0 m	Gate length parameter.
47	lln=0.0	Gate length parameter.
48	wl=0.0	Gate width parameter.
49	wld=0.0 m	Gate width parameter.
50	wln=0.0	Gate width parameter.

51	vbi=1.0 V	Built-in potential.
52	nsubp0=0.0 cm^-3	Pocket implant parameter.
53	nsubwp=1.0	Pocket implant parameter.
54	lpext=1.0E-50 m	Pocket extension.
55	npext=1.0e17 cm^-3	Pocket extension.
56	rsh=0.0 V/A*m	Source/drain diffusion sheet resistance.
57	rshg=0.0 V/A*m	Gate-electrode sheet resistance.
58	rbpb=50.0 Ohm	Substrate resistance network.
59	rbpd=50.0 Ohm	Substrate resistance network.
60	rbps=50.0 Ohm	Substrate resistance network.
61	rbdb=50.0 Ohm	Substrate resistance network.
62	rbsb=50.0 Ohm	Substrate resistance network.
63	gbmin=1.0e-12	Minimum conductance for substrate resistance network.
64	xl=0 m	Gate length offset due to mask/etch effect.
65	xw=0 m	Gate width offset due to mask/etch effect.
66	xqy1=0.0 F m^{XQY2}	Vbs dependence of Qy.
67	xqy2=2.0	Lgate dependence of Qy.
68	xldld=1.0e-6 m	Lateral diffusion of Drain under the gate.
69	rd2=0.0 Ohm*m	Drain contact resistance in LDD region.
70	rd3=0.0 Ohm*m	Drain contact resistance in LDD region.
71	rdov11=0.0	Dependence coeff. for overlap length.
72	rdov12=1.0	Dependence coeff. for overlap length.

73 rdov13=1.0 Dependence coeff. for overlap length.

74 rdslp1=0.0 LDRIFT1 dependence of resistance for CORSRD=1,3.

75 rdict1=1.0 LDRIFT1 dependence of resistance for CORSRD=1,3.

76 rdslp2=1.0 LDRIFT2 dependence of resistance for CORSRD=1,3.

77 rdict2=0.0 LDRIFT2 dependence of resistance for CORSRD=1,3.

78 loverld=1.0e-6 m Overlap length on the drain side.

79 lovers=3.0e-8 m Overlap length on source side.

80 ldrift1=1.0e-6 m Drift region length-1 on the drain side.

81 ldrift1s=0.0 m Drift region length-1 on the source side.

82 ldrift2=1.0e-6 m Drift region length-2 on the drain side.

83 ldrift2s=1.0e-6 m Drift region length-2 on the source side.

84 subld1=0.0 Impact-ionization current in the drift region.

85 subld2=0.0 (V^(3/2))/m
Impact-ionization current in the drift region.

Temperature dependence effects:

86 eg0=1.1785 eV Constant bandgap.

87 bgtmp1=9.025e-5 eV/K
First order temperature coefficient for band gap.

88 bgtmp2=1.0e-7 eV/K^2
Second order temperature coefficient for band gap.

89 rdtemp1=0.0 1/K Temperature-dependence of Rd.

90 rdtemp2=0.0 1/K^2
Temperature-dependence of Rd.

91 rdvdtemp1=0.0 1/K Temperature-dependence of RDVD.

92 rdvdtemp2=0.0 1/K^2
Temperature-dependence of RDVD.

Quantum Mechanical Effects:

93 qme1=0.0 m/V^2 Coefficient for quantum mechanical effect.

94 qme2=1.0 V Coefficient for quantum mechanical effect.

95 qme3=0.0 m Coefficient for quantum mechanical effect.

96 kappa=3.9 Dielectric constant for high-k stacked gate.

Poly Depletion Effects:

97 pgd1=0.0 V Strength of poly depletion.

98 pgd2=1.0 V Threshold voltage of poly depletion.

99 pgd3=0.8 Vds dependence of poly depletion.

100 pgd4=0.0 Parameter for gate-poly depletion.

Short Channel Effects:

101 parl2=1.0e-8 m Depletion width of channel/contact junction.

102 sc1=1.0 1/V Short-channel coefficient 1.

103 sc2=1.0 1/V^2 Short-channel coefficient 2.

104 sc2b=0.0 1/V^3 Short-channel coefficient 2 Vb dependency coefficient.

105 sc3=0.0 m/V^2 Short-channel coefficient 3.

106 sc4=0.0 1/V Parameter for SCE.

107 scp1=1.0 1/V Short-channel coefficient 1 for pocket.

108 scp2=0.1 1/V^2 Short-channel coefficient 2 for pocket.

109	scp3=0.0 m/V^2	Short-channel coefficient 3 for pocket.
110	scp22=0.0 V^4	Short-channel-effect modification for small Vds.
111	scp21=0.0 V	Short-channel-effect modification for small Vds.
112	bs1=0.0 V^2	Body-coefficient modification by impurity profile.
113	bs2=0.9 V	Body-coefficient modification by impurity profile.

Narrow channel effects:

114	wfc=0.0 m*F/cm^2	Threshold voltage reduction.
115	nsubcw=0.0	Parameter for narrow channel effect.
116	nsubcwp=1.0	Parameter for narrow channel effect.
117	mueph2=0.0	Mobility reduction.
118	w0=0.0 log(cm)	Minimum gate width.
119	wvthsc=0.0	Short-channel effect at the STI edge.
120	nsti=1.0e17 cm^-3	Substrate-impurity concentration at the SIT edge.
121	wsti=0.0 m	Width of the high-field region at STI.
122	muephw=0.0	Phonon scattering parameter.
123	muepwp=1.0	Phonon scattering parameter.
124	wvth0=0.0	Threshold voltage shift.
125	mueswp=1.0	Change of surface roughness related mobility.
126	vthsti=0.0	Parameter for STI.
127	muesti1=0.0	STI Stress mobility parameter.
128	muesti2=0.0	STI Stress mobility parameter.

129	muesti3=1.0	STI Stress mobility parameter.
130	nsubpsti1=0.0 m	STI Stress pocket implant parameter.
131	nsubpsti2=0.0 m	STI Stress pocket implant parameter.
132	nsubpsti3=1.0 m	STI Stress pocket implant parameter.
133	wstil=0.0	Parameter for STI.
134	wstilp=1.0	Parameter for STI.
135	scsti1=0.0	Parameter for STI.
136	scsti2=0.0 1/V	Parameter for STI.
137	scsti3=0.0 m/V	Parameter for STI.
138	saref=1e-6 m	Reference distance from STI edge to Gate edge.
139	sbref=1e-6 m	Reference distance from STI edge to Gate edge.
140	wstiw=0.0	Parameter for STI.
141	wstiwp=1.0	Parameter for STI.
142	vdsti=0.0	parameter for STI.

Mobility Effects:

143	vds0=0.05 V	Drain voltage for extracting the low-field mobility.
144	muecb0=1.0e3 cm^2/(V*s)	Coulomb scattering.
145	muecb1=1.0e2 cm^2/(V*s)	Coulomb scattering.
146	mueph0=0.3 cm^2*(V/cm)^(Muesr1)/(V*s)	Phonon scattering.
147	mueph1=2.5e4	Phonon scattering.

148 muetmp=1.7 Temperature dependence of phonon scattering.

149 muesr0=2.0 cm^2*(V/cm)^(Muesr1)/(V*s)
Surface-roughness scattering.

150 muesr1=1.0e16 Surface-roughness scattering.

151 ndep=1.0 Coefficient of effective electric field.

152 ninv=0.5 Coefficient of effective electric field.

153 ninvd=0.0 1/V Modification of Vdse dependence on Eeff.

154 bb=2.0 High-field mobility degradation.

155 vmax=1.0e7 cm/s Maximum of electron saturation velocity.

156 vover=0.3 cm^(voverp)
Parameter for velocity overshoot.

157 voverp=0.3 Lgate dependence of velocity overshoot.

158 vovers=0.0 Parameter for overshoot.

159 voversp=0.0 Parameter for overshoot.

160 vtmp=0.0 cm/s Temperature dependence of the saturation velocity.

161 muephl=0.0 Phonon scattering parameter.

162 mueplp=1.0 Phonon scattering parameter.

163 muesrl=0.0 Surface roughness parameter.

164 muesrw=0.0 Change of surface roughness related mobility.

165 mueslp=1.0 Surface roughness parameter.

166 ndepl=0.0 Modification of Qb contribution for short-channel case.

167 ndeplp=1.0 Modification of Qb contribution for short-channel case.

Small size parameters:

168	wl1=0.0	Threshold voltage shift of STI leakage due to small size effect.
169	wl1p=1.0	Threshold voltage shift of STI leakage due to small size effect.
170	wl2=0.0	Threshold voltage shift due to small size effect.
171	wl2p=1.0	Threshold voltage shift due to small size effect.
172	muephs=0.0	Mobility modification due to small size.
173	muepsp=1.0	Mobility modification due to small size.

Channel Length Modulation Effects:

174	clm1=50e-3	First parameter for CLM.
175	clm2=2.0 1/m	Second parameter for CLM.
176	clm3=1.0	Third parameter for CLM.
177	clm4=5.0e-4	Smoothing coefficient for gds.
178	clm5=1.0	Effect of pocket implantation.
179	clm6=0.0	Effect of pocket implantation.

Substrate Current Effects:

180	sub1=50e-3 1/V	First parameter for Isub.
181	sub2=1.0e2 V	Second parameter for Isub.
182	svgs=0.8	Substrate current dependence on Vgs.
183	svbs=0.5	Substrate current dependence on Vbs.
184	svbsl=0.0	Lgate dependence of SVBS.
185	svds=0.8	Substrate current dependence on Vds.

186 slg=3.0e-8 Substrate current dependence on Lgate.

187 sub1l=2.5e-3 Lgate dependence of SUB1.

188 sub2l=2.0e-6 Lgate dependence of SUB2.

189 fn1=50.0 Coefficient of Fowler-Nordheim-current contribution.

190 fn2=1.7e-4 Coefficient of Fowler-Nordheim-current contribution.

191 fn3=0.0 Coefficient of Fowler-Nordheim-current contribution.

192 fvbs=1.2e-2 Modification of Vbs dependence.

193 svgsl=0.0 Lgate dependence of SVGS.

194 svgslp=1.0 Lgate dependence of SVGS.

195 svgswp=1.0 Wgate dependence of SVGS.

196 svgsw=0.0 Wgate dependence of SVGS.

197 svbslp=1.0 Lgate dependence of SVBS.

198 slgl=0.0 Substrate current dependence on Lgate.

199 slglp=1.0 Substrate current dependence on Lgate.

200 sub1lp=1.0 Lgate dependence of SUB1.

201 ibpc1=0.0 Impact-ionization induced bulk potential change.

202 ibpc2=0.0 Impact-ionization induced bulk potential change.

Gate Current Effects

203 glpart1=0.5 Partitioning of gate current.

204 gleak1=50.0 A/(V^(3/2)*c^(1/2))
First gate current coefficient.

205 gleak2=1.0e7 1/(V^(1/2)*c^(3/2)*m)
Second gate current coefficient.

206 gleak3=6.0e-2 Third gate current coefficient.

207 gleak4=4.0 Parameter for gate current.

208 gleak5=7.5e3 Parameter for gate current.

209 glksd1=1.0e-15 Parameter for gate current.

210 glksd2=5e6 Parameter for gate current.

211 glksd3=-5e6 Parameter for gate current.

212 glkb0=0.0 V Parameter for gate current.

213 glkb1=5.0e-16 Parameter for gate current.

214 glkb2=1.0 Parameter for gate current.

215 igtemp1=0.0 Temperature dependence of gate current.

216 igtemp2=0.0 1/K Temperature dependence of gate current.

217 igtemp3=0.0 1/K^2
Temperature dependence of gate current.

218 gleak6=0.25 V Parameter for gate current.

219 gleak7=1.0e-6 m^2
Parameter for gate current.

220 glkb3=0.0 V Parameter for gate current.

221 egig=0.0 V Parameter for gate current.

GIDL Current Effects

222 gidl1=2.0 A*m/(V^(3/2)*c^(1/2))
First parameter for GIDL.

223 gidl2=3.0E7 1/(V^(1/2)*c^(3/2)*m)
Second parameter for GIDL.

224 gidl3=0.9 Third parameter for GIDL.

225	gidl4=0.9	Parameter for GIDL.
226	gidl5=0.2	Parameter for GIDL.

Noise 1/f Effects:

227	nfalp=1.0e-19	Flicker (1/f) noise contribution of the mobility fluctuation.
228	falph=1.0	Parameter for 1/f noise.
229	nftrp=1.0e10	Flicker (1/f) noise ratio of trap density to attenuation coefficient.
230	cit=0.0	Flicker (1/f) noise interface trapped carriers capacitance.

Subthreshold swing parameters:

231	pthrou=0.0	Modify subthreshold sloop.
232	pthroub=0.0 1/V	Modify subthreshold sloop.

NQS parameters:

233	dly1=1.0e-10	Parameter for transit time.
234	dly2=0.7	Parameter for transit time.
235	dly3=8.0e-7 Ohm	Parameter for transforming bulk charge.
236	dlyov=0.0 Ohm	Parameter for transforming overlap charge.

Symmetry for short-channel mosfet:

237	vzadd0=1.0e-2 V	Vzadd at Vds=0.
238	pzadd0=5.0e-3 V	Pzadd at Vds=0.

P-N junctions parameters

239	js0=5.0e-7 A/m^2 J	unction saturation current density.

240	js0sw=0.0 A/m	Side-wall saturation current density.
241	nj=1.0	Junction emission coefficient.
242	njsw=1.0	Junction emission coefficient (sidewall).
243	xti=2.0	Junction saturation current temperature exponent coefficient.
244	cj=5.0e-4 F/m^2	Bottom junction capacitance per unit area at zero bias.
245	cjsw=5e-10 F/m	Source/drain sidewall junction capacitance per unit length at zero bias.
246	cjswg=5e-10 F/m	Source/drain sidewall junction capacitance grading coefficient per unit length at zero bias.
247	tcjbd=0.0	Temperature dependence of czbd.
248	tcjbdsw=0.0	Temperature dependence of czbdsw.
249	tcjbdswg=0.0	Temperature dependence of czbdswg.
250	tcjbs=0.0	Temperature dependence of czbs.
251	tcjbssw=0.0	Temperature dependence of czbssw.
252	tcjbsswg=0.0	Temperature dependence of czbsswg.
253	mj=0.5	Bulk junction bottom grading coefficient.
254	mjsw=0.33	Source/drain sidewall junction capacitance grading coefficient.
255	mjswg=0.33	Bottom junction capacitance grading coefficient.
256	pb=1.0 V	Bottom junction build-in potential.
257	pbsw=1.0 V	Source/drain sidewall junction build-in potential.
258	pbswg=1.0 V	Source/drain gate sidewall junction build-in potential.
259	vdiffj=6.0e-4 V	Threshold voltage for S/D junction diode.
260	xti2=0.0	Temperature coefficient.

261 cisb=0.0 Reverse bias saturation current.

262 cvb=0.0 Bias dependence coefficient of cisb.

263 ctemp=0.0 Temperature coefficient.

264 cisbk=0.0 A Reverse bias saturation current.

265 cvbk=0.0 Bias dependence coefficient of cisb.

266 divx=0.0 1/V Parameter for junction.

Overlap capacitance parameters:

267 cgso=0.0 F/m Gate-source overlap capacitance.

268 cgdo=0.0 F/m Gate-source overlap capacitance.

269 cgbo=0.0 F/m Gate-source overlap capacitance.

270 ovslp=2.0e-8 Parameter for overlap capacitance.

271 ovmag=500.0 Parameter for overlap capacitance.

272 vfbover=-0.5 V Flat-band voltage in overlap region.

273 nover=1.0e14 cm^-3
Impurity concentration in overlap region.

274 novers=0.0 cm^-3 Impurity concentration in overlap region.

Smoothing coefficient between linear and saturation:

275 ddltmax=1.0 Coefficient of effective electric field.

276 ddltslp=0.0 Lgate dependence of smoothing coefficient.

277 ddltict=10.0 Lgate dependence of smoothing coefficient.

DFM parameters:

278 mphdfm=-0.3 NSUBCDFM dependence of phonon scattering for DFM.

Operating region warning control parameters:

279 warn=off Parameter to turn warnings on and off. Possible values are off and on.

280 bvd (V) Drain diode breakdown voltage.

281 bvs (V) Source diode breakdown voltage.

282 bvj (V) Junction reverse breakdown voltage, take effect when bvd and bvs not given.

283 vbox=3e9*tox V Oxide breakdown voltage.

Mismatch parameters:

284 mvtwl=0.0 V*m Threshold mismatch area dependence.

285 mvt0=0.0 V Threshold mismatch intercept.

286 mbewl=0.0 m Beta mismatch area dependence.

287 mbe0=0.0 Beta mismatch intercept.

288 mvtwl2=0.0 V*m^1.5 Threshold mismatch area square dependence.

289 mismatchmod=0 Mismatch mode selector. The available modes are 0, 1, 2 and 3.

290 mismatchdist=0 m Mismatch Distance.

LDMOS special parameters:

291 rdvg11=0.0 Vgs dependence of RD.

292 rdvg12=1.0e2 Vgs dependence of RD.

293	vbsmin=-10.5 V	Minimum back bias voltage to be treated in hsmigbteval.
294	rth0=0.1 Kcm/W	Thermal resistance.
295	cth0=1.0e-7 Ws/Kcm	Thermal capacitance.
296	qdftvd=1.0	Qdrift Vd dependence.
297	rdvd=7.0e-2	Vds dependence of RD.
298	rdvb=0.0	Vbs dependence of RD.
299	rd20=0.0	RD23 boundary.
300	rd21=1.0	Vds dependence of RD.
301	rd22=0.0	Vbs dependence of RD.
302	rd22d=0.0	Vbs dependence of RD.
303	rd23=5e-3	Modification of RD.
304	rd24=0.0	Vgs dependence of RD.
305	rd25=0.0	Vgs dependence of RD.
306	rd26=0.2	Smoothing Qover at depletion/inversion transition.
307	qovsm=0.2	Smoothing Qover at depletion/inversion transition.
308	rdvdl=0.0	Lgate dependence of RD.
309	rdvdlp=1.0	Lgate dependence of RD.
310	rdvds=0.0	Small size dependence of RD.
311	rdvdsp=1.0	Small size dependence of RD.
312	rd23l=0.0	Lgate dependence of RD21 boundary.
313	rd23lp=1.0	Lgate dependence of RD21 boundary.

314	rd23s=0.0	Small size dependence of RD21.
315	rd23sp=1.0	Small size dependence of RD21.
316	rds=0.0	Small size dependence of RD.
317	rdsp=1.0	Small size dependence of RD.
318	ldrift=1.0e-6	Length of drift region.
319	rth0r=0.0	Heat radiation for SHE.
320	rth0w=0.0	Width-dependence of RTH0.
321	rth0wp=1.0	Width-dependence of RTH0.
322	rth0nf=0.0	Nf-dependence of RTH0.
323	cvdsover=0.0	Modification of the Cgg spikes for Vds is not zero.
324	powrat=1.0	Thermal dissipation.

Parameters for bjt part:

325	bjtninj=0	Electron injection into the depletion layer.
326	bjtninjmax=1.0	Parameter for Wdep.
327	bjtwdepmax=1.0	Parameter for Wdep.
328	bjtmuep=50.0 cm^2/(V*s)	Hole mobility in the quasi-neutral region.
329	bjtmuen=100.0 cm^2/(V*s)	Elec. mobility in the quasi-neutral region.
330	bjtmueqn=1.0	Parameter for mobility.
331	bjttaue=3.0e-5 s	Basic lifetime in the emitter.
332	bjttaub=1.0e-5 s	Basic lifetime in the base.
333	bjttauc=3.0e-5 s	Basic lifetime in the collector.

334 bjtnref=1.0e17 cm^-3
Reference doping concentration.

335 bjtgminc=0 Coefficient for minimum conductance.

336 bjtgmine=0 Coefficient for minimum conductance.

337 bjtldec=1.0 Parameter for excess carrier distribution.

338 bjtpmin=1.0e14 cm^-3
Minimum carrier density in the base.

339 bjtrb=1.0 Coefficient for base resistance.

340 bjtrbvg11=0 Gate-voltage dependence on RBase.

341 bjtrbvg12=20.0 V Gate-voltage dependence on RBase.

342 bjtrc=1.0e4 Ohm*m
Collector resistance.

343 bjtre=0 Ohm*m Emitter resistance.

344 bjtqdep=1.0 Coefficient for Qdep.

345 bjtqex=1.0 Coefficient for Qexcess.

346 bjtne=1.0e17 cm^-3
Emitter impurity concentration.

347 bjtnb=1.0e14 cm^-3
Base impurity concentration.

348 bjtnc=1.0e18 cm^-3
Base impurity concentration.

349 bjtwb=1.0e-4 m Base width.

350 bjtwhalfcell=2.0e-6 m
Half cell width.

Auto Model Selector parameters:

351 wmax=1 m Maximum channel width for which the model is valid.

352 wmin=0 m Minimum channel width for which the model is valid.

353 lmax=1 m Maximum channel length for which the model is valid.

354 lmin=0 m Minimum channel length for which the model is valid.

Safe Operating Areas Parameters:

355 vds_max=infinity V
Maximum allowed voltage cross source and drain.

356 vgd_max=infinity V
Maximum allowed voltage cross drain and gate.

357 vgs_max=infinity V
Maximum allowed voltage cross source/bulk and gate.

358 vbd_max=infinity V
Maximum allowed voltage cross drain/source and bulk.

Binning model parameters :

359 lbinn=1.0 L modulation coefficient for binning.

360 wbinn=1.0 W modulation coefficient for binning.

361 lvmax=0.0 cm/s Length dependence of vmax.

362 lbgtmp1=0.0 eV/K Length dependence of bgtmp1.

363 lbgtmp2=0.0 eV/K^2
Length dependence of bgtmp2.

364 leg0=0.0 eV Length dependence of eg0.

365 lnovers=0.0 cm^-3
Length dependence of novers.

366	lvfbover=0.0 V	Length dependence of vfbover.
367	lnover=0.0 cm^-3	Length dependence of nover.
368	lwl2=0.0	Length dependence of wl2.
369	lvfbc=0.0 V	Length dependence of vfbc.
370	lnsubc=0.0 cm^-3	Length dependence of nsubc.
371	lnsubp=0.0 cm^-3	Length dependence of nsubp.
372	lscp1=0.0 1/V	Length dependence of scp1.
373	lscp2=0.0 1/V^2	Length dependence of scp2.
374	lscp3=0.0 m/V^2	Length dependence of scp3.
375	lsc1=0.0 1/V	Length dependence of sc1.
376	lsc2=0.0 1/V^2	Length dependence of sc2.
377	lsc3=0.0 m/V^2	Length dependence of sc3.
378	lpgd1=0.0 V	Length dependence of pgd1.
379	lpgd3=0.0	Length dependence of pgd3.
380	lndep=0.0	Length dependence of ndep.
381	lninv=0.0	Length dependence of ninv.
382	lmuecb0=0.0 cm^2/(V*s)	Length dependence of muecb0.
383	lmuecb1=0.0 cm^2/(V*s)	Length dependence of muecb1.
384	lmueph1=0.0	Length dependence of mueph1.
385	lvtmp=0.0 cm/s	Length dependence of vtmp.
386	lwvth0=0.0	Length dependence of wvth0.

387	lmuesr1=0.0	Length dependence of muesr1.
388	lmuetmp=0.0	Length dependence of muetmp.
389	lsub1=0.0 1/V	Length dependence of sub1.
390	lsub2=0.0 V	Length dependence of sub2.
391	lsvds=0.0	Length dependence of svds.
392	lsvbs=0.0	Length dependence of svbs.
393	lsvgs=0.0	Length dependence of svgs.
394	lfn1=0.0	Length dependence of fn1.
395	lfn2=0.0	Length dependence of fn2.
396	lfn3=0.0	Length dependence of fn3.
397	lfvbs=0.0	Length dependence of fvbs.
398	lnsti=0.0 cm^-3	Length dependence of nsti.
399	lwsti=0.0 m	Length dependence of wsti.
400	lscsti1=0.0	Length dependence of scsti1.
401	lscsti2=0.0 1/V	Length dependence of scsti2.
402	lvthsti=0.0	Length dependence of vthsti.
403	lmuesti1=0.0	Length dependence of muesti1.
404	lmuesti2=0.0	Length dependence of muesti2.
405	lmuesti3=0.0	Length dependence of muesti3.
406	lnsubpsti1=0.0 m	Length dependence of nsubpsti1.
407	lnsubpsti2=0.0 m	Length dependence of nsubpsti2.
408	lnsubpsti3=0.0 m	Length dependence of nsubpsti3.

409 lcgso=0.0 F/m Length dependence of cgso.

410 lcgdo=0.0 F/m Length dependence of cgdo.

411 ljs0=0.0 A/m^2 Length dependence of js0.

412 ljs0sw=0.0 A/m Length dependence of js0sw.

413 lnj=0.0 Length dependence of nj.

414 lcisbk=0.0 A Length dependence of cisbk.

415 lclm1=0.0 Length dependence of clm1.

416 lclm2=0.0 1/m Length dependence of clm2.

417 lclm3=0.0 Length dependence of clm3.

418 lwfc=0.0 m*F/cm^2
Length dependence of wfc.

419 lgidl1=0.0 A*m/(V^(3/2)*c^(1/2))
Length dependence of gidl1.

420 lgidl2=0.0 1/(V^(1/2)*c^(3/2)*m)
Length dependence of gidl2.

421 lgleak1=0.0 A/(V^(3/2)*c^(1/2))
Length dependence of gleak1.

422 lgleak2=0.0 1/(V^(1/2)*c^(3/2)*m)
Length dependence of gleak2.

423 lgleak3=0.0 Length dependence of gleak3.

424 lgleak6=0.0 V Length dependence of gleak6.

425 lglksd1=0.0 Length dependence of glksd1.

426 lglksd2=0.0 Length dependence of glksd2.

427 lglkb1=0.0 Length dependence of glkb1.

428 lglkb2=0.0 Length dependence of glkb2.

429 lnftrp=0.0 Length dependence of nftrp.

430 lnfalp=0.0 Length dependence of nfalp.

431 lpthrou=0.0 Length dependence of pthrou.

432 lvdiffj=0.0 V Length dependence of vdiffj.

433 libpc1=0.0 Length dependence of ibpc1.

434 libpc2=0.0 Length dependence of ibpc2.

435 wvmax=0.0 cm/s Width dependence of vmax.

436 wbgtmp1=0.0 eV/K Width dependence of bgtmp1.

437 wbgtmp2=0.0 eV/K^2
Width dependence of bgtmp2.

438 weg0=0.0 eV Width dependence of eg0.

439 wnovers=0.0 cm^-3
Width dependence of novers.

440 wvfbover=0.0 V Width dependence of vfbover.

441 wnover=0.0 cm^-3 Width dependence of nover.

442 wwl2=0.0 Width dependence of wl2.

443 wvfbc=0.0 V Width dependence of vfbc.

444 wnsubc=0.0 cm^-3 Width dependence of nsubc.

445 wnsubp=0.0 cm^-3 Width dependence of nsubp.

446 wscp1=0.0 1/V Width dependence of scp1.

447 wscp2=0.0 1/V^2 Width dependence of scp2.

448 wscp3=0.0 m/V^2 Width dependence of scp3.

449 wsc1=0.0 1/V Width dependence of sc1.

450 wsc2=0.0 1/V^2 Width dependence of sc2.

451 wsc3=0.0 m/V^2 Width dependence of sc3.

452 wpgd1=0.0 V Width dependence of pgd1.

453 wpgd3=0.0 Width dependence of pgd3.

454 wndep=0.0 Width dependence of ndep.

455 wninv=0.0 Width dependence of ninv.

456 wmuecb0=0.0 cm^2/(V*s)
Width dependence of muecb0.

457 wmuecb1=0.0 cm^2/(V*s)
Width dependence of muecb1.

458 wmueph1=0.0 Width dependence of mueph1.

459 wvtmp=0.0 cm/s Width dependence of vtmp.

460 wwvth0=0.0 Width dependence of wvth0.

461 wmuesr1=0.0 Width dependence of muesr1.

462 wmuetmp=0.0 Width dependence of muetmp.

463 wsub1=0.0 1/V Width dependence of sub1.

464 wsub2=0.0 V Width dependence of sub2.

465 wsvds=0.0 Width dependence of svds.

466 wsvbs=0.0 Width dependence of svbs.

467 wsvgs=0.0 Width dependence of svgs.

468 wfn1=0.0 Width dependence of fn1.

469 wfn2=0.0 Width dependence of fn2.

470	wfn3=0.0	Width dependence of fn3.
471	wfvbs=0.0	Width dependence of fvbs.
472	wnsti=0.0 cm^-3	Width dependence of nsti.
473	wwsti=0.0 m	Width dependence of wsti.
474	wscsti1=0.0	Width dependence of scsti1.
475	wscsti2=0.0 1/V	Width dependence of scsti2.
476	wvthsti=0.0	Width dependence of vthsti.
477	wmuesti1=0.0	Width dependence of muesti1.
478	wmuesti2=0.0	Width dependence of muesti2.
479	wmuesti3=0.0	Width dependence of muesti3.
480	wnsubpsti1=0.0 m	Width dependence of nsubpsti1.
481	wnsubpsti2=0.0 m	Width dependence of nsubpsti2.
482	wnsubpsti3=0.0 m	Width dependence of nsubpsti3.
483	wcgso=0.0 F/m	Width dependence of cgso.
484	wcgdo=0.0 F/m	Width dependence of cgdo.
485	wjs0=0.0 A/m^2	Width dependence of js0.
486	wjs0sw=0.0 A/m	Width dependence of js0sw.
487	wnj=0.0	Width dependence of nj.
488	wcisbk=0.0 A	Width dependence of cisbk.
489	wclm1=0.0	Width dependence of clm1.
490	wclm2=0.0 1/m	Width dependence of clm2.
491	wclm3=0.0	Width dependence of clm3.

492 wwfc=0.0 m*F/cm^2
Width dependence of wfc.

493 wgidl1=0.0 A*m/(V^(3/2)*c^(1/2))
Width dependence of gidl1.

494 wgidl2=0.0 1/(V^(1/2)*c^(3/2)*m)
Width dependence of gidl2.

495 wgleak1=0.0 A/(V^(3/2)*c^(1/2))
Width dependence of gleak1.

496 wgleak2=0.0 1/(V^(1/2)*c^(3/2)*m)
Width dependence of gleak2.

497 wgleak3=0.0 Width dependence of gleak3.

498 wgleak6=0.0 V Width dependence of gleak6.

499 wglksd1=0.0 Width dependence of glksd1.

500 wglksd2=0.0 Width dependence of glksd2.

501 wglkb1=0.0 Width dependence of glkb1.

502 wglkb2=0.0 Width dependence of glkb2.

503 wnftrp=0.0 Width dependence of nftrp.

504 wnfalp=0.0 Width dependence of nfalp.

505 wpthrou=0.0 Width dependence of pthrou.

506 wvdiffj=0.0 V Width dependence of vdiffj.

507 wibpc1=0.0 Width dependence of ibpc1.

508 wibpc2=0.0 Width dependence of ibpc2.

509 pvmax=0.0 cm/s Cross-term dependence of vmax.

510 pbgtmp1=0.0 eV/K Cross-term dependence of bgtmp1.

511 pbgtmp2=0.0 eV/K^2
Cross-term dependence of bgtmp2.

512 peg0=0.0 eV Cross-term dependence of eg0.

513 pnovers=0.0 cm^-3
Cross-term dependence of novers.

514 pvfbover=0.0 V Cross-term dependence of vfbover.

515 pnover=0.0 cm^-3 Cross-term dependence of nover.

516 pwl2=0.0 Cross-term dependence of wl2.

517 pvfbc=0.0 V Cross-term dependence of vfbc.

518 pnsubc=0.0 cm^-3 Cross-term dependence of nsubc.

519 pnsubp=0.0 cm^-3 Cross-term dependence of nsubp.

520 pscp1=0.0 1/V Cross-term dependence of scp1.

521 pscp2=0.0 1/V^2 Cross-term dependence of scp2.

522 pscp3=0.0 m/V^2 Cross-term dependence of scp3.

523 psc1=0.0 1/V Cross-term dependence of sc1.

524 psc2=0.0 1/V^2 Cross-term dependence of sc2.

525 psc3=0.0 m/V^2 Cross-term dependence of sc3.

526 ppgd1=0.0 V Cross-term dependence of pgd1.

527 ppgd3=0.0 Cross-term dependence of pgd3.

528 pndep=0.0 Cross-term dependence of ndep.

529 pninv=0.0 Cross-term dependence of ninv.

530 pmuecb0=0.0 cm^2/(V*s)
Cross-term dependence of muecb0.

531 pmuecb1=0.0 cm^2/(V*s)
Cross-term dependence of muecb1.

532 pmueph1=0.0 Cross-term dependence of mueph1.

533 pvtmp=0.0 cm/s Cross-term dependence of vtmp.

534 pwvth0=0.0 Cross-term dependence of wvth0.

535 pmuesr1=0.0 Cross-term dependence of muesr1.

536 pmuetmp=0.0 Cross-term dependence of muetmp.

537 psub1=0.0 1/V Cross-term dependence of sub1.

538 psub2=0.0 V Cross-term dependence of sub2.

539 psvds=0.0 Cross-term dependence of svds.

540 psvbs=0.0 Cross-term dependence of svbs.

541 psvgs=0.0 Cross-term dependence of svgs.

542 pfn1=0.0 Cross-term dependence of fn1.

543 pfn2=0.0 Cross-term dependence of fn2.

544 pfn3=0.0 Cross-term dependence of fn3.

545 pfvbs=0.0 Cross-term dependence of fvbs.

546 pnsti=0.0 cm^-3 Cross-term dependence of nsti.

547 pwsti=0.0 m Cross-term dependence of wsti.

548 pscsti1=0.0 Cross-term dependence of scsti1.

549 pscsti2=0.0 1/V Cross-term dependence of scsti2.

550 pvthsti=0.0 Cross-term dependence of vthsti.

551 pmuesti1=0.0 Cross-term dependence of muesti1.

552 pmuesti2=0.0 Cross-term dependence of muesti2.

553 pmuesti3=0.0 Cross-term dependence of muesti3.

554 pnsubpsti1=0.0 m Cross-term dependence of nsubpsti1.

555 pnsubpsti2=0.0 m Cross-term dependence of nsubpsti2.

556 pnsubpsti3=0.0 m Cross-term dependence of nsubpsti3.

557 pcgso=0.0 F/m Cross-term dependence of cgso.

558 pcgdo=0.0 F/m Cross-term dependence of cgdo.

559 pjs0=0.0 A/m^2 Cross-term dependence of js0.

560 pjs0sw=0.0 A/m Cross-term dependence of js0sw.

561 pnj=0.0 Cross-term dependence of nj.

562 pcisbk=0.0 A Cross-term dependence of cisbk.

563 pclm1=0.0 Cross-term dependence of clm1.

564 pclm2=0.0 1/m Cross-term dependence of clm2.

565 pclm3=0.0 Cross-term dependence of clm3.

566 pwfc=0.0 m*F/cm^2
Cross-term dependence of wfc.

567 pgidl1=0.0 A*m/(V^(3/2)*c^(1/2))
Cross-term dependence of gidl1.

568 pgidl2=0.0 1/(V^(1/2)*c^(3/2)*m)
Cross-term dependence of gidl2.

569 pgleak1=0.0 A/(V^(3/2)*c^(1/2))
Cross-term dependence of gleak1.

570 pgleak2=0.0 1/(V^(1/2)*c^(3/2)*m)
Cross-term dependence of gleak2.

571	pgleak3=0.0	Cross-term dependence of gleak3.
572	pgleak6=0.0 V	Cross-term dependence of gleak6.
573	pglksd1=0.0	Cross-term dependence of glksd1.
574	pglksd2=0.0	Cross-term dependence of glksd2.
575	pglkb1=0.0	Cross-term dependence of glkb1.
576	pglkb2=0.0	Cross-term dependence of glkb2.
577	pnftrp=0.0	Cross-term dependence of nftrp.
578	pnfalp=0.0	Cross-term dependence of nfalp.
579	ppthrou=0.0	Cross-term dependence of pthrou.
580	pvdiffj=0.0 V	Cross-term dependence of vdiffj.
581	pibpc1=0.0	Cross-term dependence of ibpc1.
582	pibpc2=0.0	Cross-term dependence of ibpc2.

Operating Point Parameters

1	shetemp (C)	Temperature rise due to self-heating.
2	reversed	Reverse mode indicator. Possible values are no and yes.
3	ids (A)	Resistive drain-to-source current.
4	vgs (V)	Gate-source voltage.
5	vds (V)	Drain-source voltage.
6	vbs (V)	Bulk-source voltage.
7	vth (V)	Threshold voltage.
8	vdsat (V)	Drain-source saturation voltage.
9	gm (S)	Common-source transconductance.

10	gds (S)	Common-source output conductance.
11	gmbs (S)	Body-transconductance.
12	qb (Coul)	Total bulk charge.
13	qd (Coul)	Total drain charge.
14	qg (Coul)	Total gate charge.
15	qs (Coul)	Total source charge.
16	qb_itr (Coul)	Intrinsic bulk charge.
17	qd_itr (Coul)	Intrinsic drain charge.
18	qg_itr (Coul)	Intrinsic gate charge.
19	qs_itr (Coul)	Intrinsic source charge.
20	qdp (Coul)	Total external drain charge.
21	qsp (Coul)	Total external source charge.
22	cjd (F)	Drain-bulk junction capacitance.
23	cjs (F)	Source-bulk junction capacitance.
24	cgg (F)	Intrinsic dQg_dVg.
25	cgd (F)	dQg_dVd.
26	cgs (F)	dQg_dVs.
27	cgb (F)	dQg_dVb.
28	cdg (F)	dQd_dVg.
29	cdd (F)	Intrinsic dQd_dVd.
30	cds (F)	dQd_dVs.
31	cdb (F)	dQd_dVb.

32	csg (F)	dQs_dVg.
33	csd (F)	dQs_dVd.
34	css (F)	Intrinsic dQs_dVs.
35	csb (F)	dQs_dVb.
36	cbg (F)	dQb_dVg.
37	cbd (F)	dQb_dVd.
38	cbs (F)	dQb_dVs.
39	cbb (F)	Intrinsic dQb_dVb.
40	cdd_tot (F)	Total dQd_dVd.
41	cgg_tot (F)	Total dQg_dVg.
42	css_tot (F)	Total dQs_dVs.
43	cbb_tot (F)	Total dQb_dVb.
44	id (A)	Resistive drain current.
45	ig (A)	Gate current.
46	is (A)	Resistive source current.
47	ibulk (A)	Resistive bulk current.
48	pwr (W)	Power at operating point.
49	ps0 (V)	Surface potential at source side.
50	psl (V)	Surface potential at drain side.
51	pds (V)	Delta surface potential between psl and ps0.
52	isub (A)	Substrate current Isub.
53	gbds (S)	Substrate trans conductance (dIsub/dVds).

54	gbgs (S)	Substrate trans conductance (dIsub/dVgs).
55	gbbs (S)	Substrate transconductance (dIsub/dVbs).
56	igate (A)	Gate current due to tunneling.
57	igates (A)	Tunneling current from gate to source.
58	igateb (A)	Tunneling current from gate to bulk.
59	igated (A)	Tunneling current from gate to drain.
60	igisl (A)	Gate-induced source leakage current.
61	igidl (A)	Gate-induced drain leakage current.
62	ibs (A)	Source-bulk diode current.
63	ibd (A)	Source-drain diode current.
64	cgso (F)	Gate-source overlap capacitance.
65	cgbo (F)	Gate-bulk overlap capacitance.
66	cgdo (F)	Gate-drain overlap capacitance.
67	cggo (F)	Gate-gate overlap capacitance.
68	cddo (F)	Drain-drain overlap capacitance.
69	weff (m)	Effective channel width.
70	leff (m)	Effective channel length.
71	rseff (Ohm)	Effective source resistance.
72	rdeff (Ohm)	Effective drain resistance.
73	rsdrift (Ohm)	The resistance of drift region for source side.
74	rdrift (Ohm)	The resistance of drift region for drain side.
75	gmt (S)	Temp transconductance.

76	ic_bjt (A)	Internal collector current of BJT.
77	ie_bjt (A)	Internal emitter current of BJT.
78	ibase_bjt (A)	Internal base current of BJT.
79	ice (A)	Collector-Emitter current of HiSIM_IGBT.
80	vce (A)	Collector-Emitter voltage of HiSIM_IGBT.
81	qex (Coul)	Excess charge in the base.
82	qdep (Coul)	Depletion charge in the base at the emitter side.
83	rbase (Ohm)	Effective internal base resistance.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

33

HiSIM_Diode Model (hisim_diode)

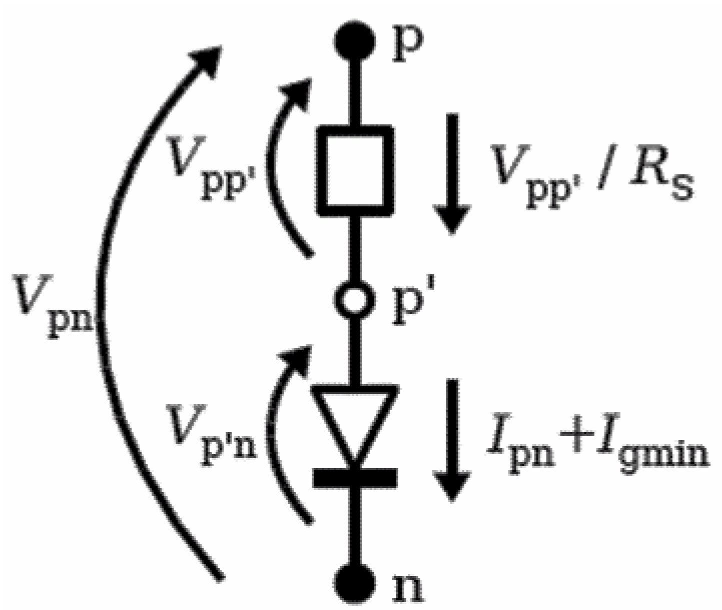
HiSIM_Diode is a compact diode model with reverse recovery. It supports DC, AC and transient analyses.

This chapter contains the following information:

Model Concepts

Elements considered in HiSIM_Diode model are summarized in Fig. 35.1. The internal node p' is determined when the parasitical resistor is given. The applied voltage V_{pn} is reduced effectively to $V_{p'n}$ due to the potential drop $V_{pp'}$ induced by the resistance R_s.

Figure 33-1 Framework of HiSIM_Diode Model



The basic model concept is consistent with that of conventional diode. The reverse recovery effect is additionally introduced in the HiSIM_Diode model. A high voltage p-i-n structure operating in high level injection is assumed as typical for most power diodes. In actual diodes, reverse recovery is caused by diffusion of charge from the center of the i region, thus, one or more charge storage nodes must be added to provide for this diffusion current. In HiSIM_Diode model, modified lumped charge concept is implemented and charge storage node is adopted. Two model parameters are introduced in the model: The carrier transit time TAUTRAN and the recovery time TAUREC.

Model Usage

Instance Syntax

HiSIM_Diode instance need specify 2 terminals, anode and cathode node respectively. To specify HiSIM_Diode instance element, the Model Name has to be associated with a HiSIM_Diode model card.

```
InstanceName p n ModelName parameter=value ...
```

Sample Instance Statement

```
d1 (vpp vnn) n_dio area=1e-12
```

For more instance parameters, refer to the Reference of this model.

Model Syntax

The following syntax specifies HiSIM_Diode model:

```
model ModelName hisim_diode parameter=value ...
```

The third parameter, “hisim_diode”, is the master to indicate this model card is a HiSIM_Diode model card.

Sample Model Statement

```
model n_dio hisim_diode eg0=1.17 rs=1e-1 bgtmp1=1e-4 rst1=1e-3
```

For more model parameters, refer to the Reference of this model.

Reference

Component Statements

Instance Parameters

1	area=1.0 m^2	Junction area.

2 trise=0 C Temperature rise from ambient.

Model Parameters

Junction hsmdiode model parameters

1 compatible=spectre
Spice compatible flag. Possible values are spectre, spice2, spice3, cdsspice, hspice, spiceplus, eldo, sspice, and mica.

2 js0=5.0e-7 A/m^2 Saturation current.

3 eg0=1.1785 V Band gap.

4 nj=1 Emission coefficient.

5 vdiffj=0.6e-3 V Diode threshold voltage..

6 cj=5.0e-4 F/m^2 Bottom junction capacitance per unit area at zero bias.

7 pb=1.0 V Bottom junction build-in potential..

8 mj=0.5 Bottom junction capacitance grading coefficient.

9 divx=0.0 1/V Reverse current coefficient.

10 tautran=5.0e-8 s Transit time.

11 taurec=1.0e-9 s Recovery time.

Parasitic resistance parameters

12 rs=0 ohmm^2 Series resistance per unit area.

13 rsv1=0 1/C Voltage dependence for the resistance.

14 rsv2=0 C^-2 Voltage dependence for the resistance.

15 rsi1=0 1/C Current dependence for the resistance.

16 rsi2=0 C^-2 Current dependence for the resistance.

Temperature effects parameters

17 tnom (C) Parameters measurement temperature. Default set by `options'.

18 bgtmp1=90.25e-6 1/C
Temperature dependence of bandgap.

19 bgtmp2=1.0e-7 C^-2
Temperature dependence of bandgap.

20 rst1=0 1/C Temperature dependence for the resistance.

21 rst2=0 C^-2 Temperature dependence for the resistance.

22 tcjbd=0 1/C Temperature dependence of hsmdiode capacitance.

23 xti=2 Temperature coefficient for forward-current densities.

Operating Point Parameters

1 vd (V) Diode voltage.

2 id (A) Diode current .

3 gd (S) Diode conductance .

4 cd (F) Diode capacitance .

5 rdio (Ohm) Diode equivalent resistance .

6 charge (Coul) Diode capacitor charge.

7 p (W) Diode power.

8 region Estimated operating region. Spectre outputs number (0-2) in a rawfile. Possible values are off and on.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the

description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

area I-1	gd OP-3	rs M-12	tcjbd M-22
bgtmp1 M-18	id OP-2	rsi1 M-15	tnom M-17
bgtmp2 M-19	js0 M-2	rsi2 M-16	trise I-2
cd OP-4	mj M-8	rst1 M-20	vd OP-1
charge OP-6	nj M-4	rst2 M-21	vdiffj M-5
cj M-6	p OP-7	rsv1 M-13	xti M-23
compatible M-1	pb M-7	rsv2 M-14	
divx M-9	rdio OP-5	taurec M-11	
eg0 M-3	region OP-8	tautran M-10	

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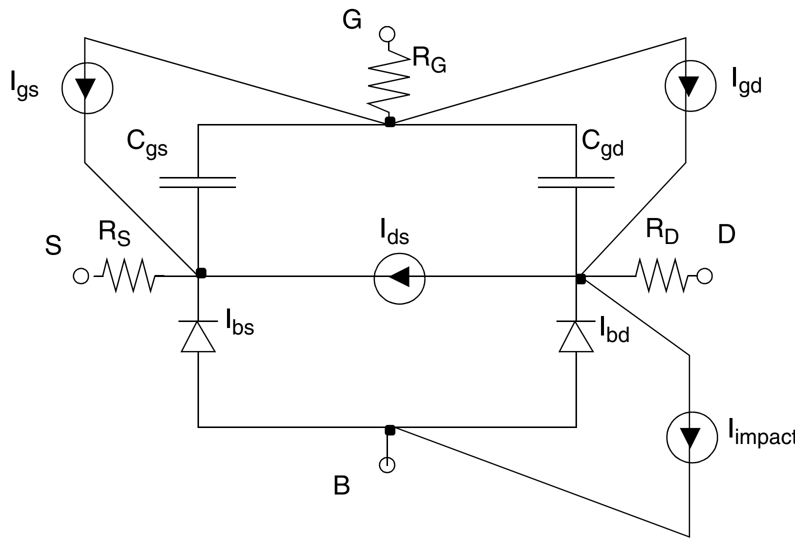
Surface Potential Based Compact MOSFET Model (spmos)

This chapter contains the following information about the SPMOS model:

Equivalent Circuit



Core Model

Lateral Gradient Factor

The lateral field gradient in SPMOS is reduced with surface potential through the following semi-empirical formula:

$$f = f_0 + B_t x_f$$

where

$$f_0 = \frac{F_0}{1 + B_f V_{sbx1} + (C_f V_{dsx} + A_f V_{sbx1})(1 + EF \cdot A_f V_{sbx1}) + h_{lo}} + 0.01$$

$$h_{lo} = Hlo1 \cdot V_{hlo}^2 \Big| Hlo2 \cdot \sqrt{V_{hlo}}$$

$$V_{hlo} = \frac{V_{dsx} \cdot W_{hlo}}{V_{dsx} + W_{hlo} + 10^{-8}}$$

$$V_{dsx} = \sqrt{V_{hlo}^2 + 0.01} - 0.1$$

$$V_{sbx1} = MAXA(V_{sbx}, 0, 10^{-4})$$

$$v_{sbx} = V_{sb} + \frac{1}{2}(V_{ds} - V_{dsx})$$

$$B_t = (f_0 - 0.01)B_f V_t$$

$$x_f = \frac{\phi_f}{V_t}$$

Effective Drain-Source Voltage

The saturation voltage is given by

$$V_{dsat} = \phi_{sat} - V_t \cdot \ln\left[1 + \frac{\phi_{sat} \cdot (\phi_{sat} - (2 \cdot a_{sat} \cdot V_t))}{G_f^2 \cdot \Delta_s \cdot V_t^2}\right]$$

where

$$a_{sat} = x_{gs} + \frac{1}{2} \cdot G_f^2$$

$$\phi_{sat} = \frac{2 \cdot \phi_0 \cdot \phi_2}{\phi_0 + \phi_2 + \sqrt{(\phi_0 + \phi_2)^2 - 3.96 \cdot \phi_0 \cdot \phi_2}}$$

$$\phi_0 = \psi_0 \cdot \frac{V_c + \frac{V_2}{4} + \psi_0 \cdot \left(\frac{1}{8} + \frac{\delta_0^2}{2}\right)}{V_c + V_2 \cdot \delta_0 \cdot (1 - \delta_0) + \psi_0 \cdot \delta_0^2}$$

$$\phi_2 = \frac{V_t \cdot G_f^2 \cdot \Delta_s \cdot S0}{a_{sat} + \sqrt{a_{sat}^2 - G_f^2 \cdot \Delta_s \cdot S0}}$$

$$\delta_0 = \frac{\psi_0}{\psi_0 + G_{hf}V_c}$$

$$\psi_0 = \frac{2 \cdot V_2}{1 + \frac{V_2}{4 \cdot V_c} + \sqrt{1 + \frac{V_2}{V_c} + \left(\frac{V_2}{4 \cdot V_c}\right)^2}}$$

$$V_2 = \frac{V_1}{\alpha_s} + V_t$$

$$V_c = \frac{u_{sat}L}{\mu_s}$$

$$u_{sat} = \frac{VSAT}{1 + K_{sm} \cdot w_{sat}}$$

$$w_{sat} = \frac{100 \cdot V_1 \cdot (1 + STX \cdot V_{sbx})}{100 + V_1 \cdot (1 + STX \cdot V_{sbx})}$$

$$\alpha_s = 1 + \frac{G_f \cdot (1 - E_s)}{2 \cdot S_s}$$

The effective drain-source voltage is given by

$$V_{dse} = \frac{V_{ds}}{\left[1 + \left(\frac{V_{ds}}{V_{dsat}}\right)^{a_x}\right]^{\frac{1}{a_x}}}$$

Surface Potential

Surface Potential at Source End of Channel

The approximate analytical solution for surface potential is

$$x = \theta(V_{gb}, \phi_n)$$

where the normalized imref splitting is

$$\phi_n = (F_p - F_n)/q$$

$$x_s = \theta(V_{gb}, V_{sb})$$

In the process of computing surface potential, the following are computed as well

$$E_s = \exp(-x_s)$$

$$\Delta_s = \Delta_{ns}/E_s$$

$$D_s = (E_s^{-1} + E_s - 2x_s) \cdot \Delta_{ns}$$

where

$$\Delta_{ns} = \frac{1}{f} \cdot \exp(-x_{ns})$$

and

$$x_{ns} = (2\phi_b + V_{sb})/V_t$$

The evaluation of E_s , Δ_s , Δ_{ns} is carefully ordered to avoid over/underflow problems.

After evaluating surface potential x_s , you can compute the normalized inversion charge at the source

$$V_1 = \frac{G_f^2 V_t D_s}{x_{gs} + G_f S_s}$$

where

$$S_s = \sqrt{P_s}$$

$$P_s = x_s - 1 + E_s$$

$$x_{gs} = G_f\sqrt{D_s + P_s}$$

$$G_f = G\sqrt{f}$$

Series resistance is given by:

$$R_t = \frac{R_{t1}(1 + RB \cdot V_{sbx})}{1 + R_g V_1}$$

Series resistance factor is given by:

$$\rho = MU0(C_{ox}/L)R_t V_1$$

Effective vertical field is given by:

$$E_{eff} = E_{eff0}(q_b + \eta_\mu V_1)$$

$$q_b = V_t G_f S_s$$

where $\eta_\mu = 1/2$ for n-channel and $\eta_\mu = 1/3$ for p-channel MOSFETs.

Effective mobility at the source end of the channel is given by:

$$\mu_s = \frac{MU0 \cdot \mu_x}{1 + (\mu_E \cdot E_{eff})^{\theta_{MU}} + CS \cdot \frac{q_b^2}{(V_1 + q_b)^2} + \rho}$$

The variable is given by

$$\mu_x = (1 + X_{cor} \cdot V_{sbx})/(1 + 0.2X_{cor} \cdot V_{sbx})$$

where the term $(1 + X_{cor} \cdot V_{sbx})$ introduces non-universality. The denominator assures that μ_x does not exceed 5 for extreme (and unphysical) V_{sbx}.

V_1 and μ_s are temporary variables. Eventually these will be changed to assure the symmetry of the model. Also, $\rho = 0$ if external model of series resistance is used.

Surface Potential at Drain End of Channel

Surface potential at the drain end of the channel is

$$\phi_{sd} = x_d V_t$$

where

$$x_d = \theta(V_{gb}, V_{sb} + V_{dse})$$

The above equation is used when

$$x_g > x_{g23} = x_{g23} + G\sqrt{f_{23}(x_{23} - 1)}$$

where

$$f_{23} = f_0 + B_t x_{23}$$

$$x_{23} = \begin{cases} (\phi_b + V_{sb})/V_t & for V_{sb} \geq 0 \\ (\phi_b + 0.5V_{sb})/V_t & for V_{sb} < 0 \end{cases}$$

For $x_g < x_{g23}$, it is more efficient to:

1. Compute x_s
2. Determine normalized drain-source surface potential difference $\varphi = \phi/V_t$
3. Compute $x_d = x_s + \varphi$.

While computing x_d, the following variables are computed as well:

$$E_d = \exp(-x_d)$$

$$D_d = (E_d^{-1} - E_d - 2x_d)\Delta_{nd}$$

where

$$\Delta_{nd} = \frac{1}{f}\exp(-x_{nd})$$

$$x_{nd} = (2\phi_b + V_{sb} + V_{dse})/V_t$$

Mid-Point Surface Potential

$$\phi_m = \frac{1}{2}(\phi_{ss} + \phi_{sd})$$

The following variables are used:

$$x_m = \frac{1}{2}(x_s + x_d)$$

$$E_m = \sqrt{E_s E_d}$$

$$D_m = \frac{1}{2}(D_s + D_d) + \frac{1}{8}\varphi^2\left(E_m - \frac{2}{G_f^2}\right)$$

$$P_m = x_m - 1 + E_m$$

$$x_{gm} = G_f\sqrt{D_m + P_m}$$

$$S_m = \sqrt{P_m}$$

Normalized inversion charge is calculated by:

$$V_m = \frac{G_f^2 V_t D_m}{x_{gm} + G_f S_m}$$

Linearization coefficient is

$$\alpha = 1 + \frac{G_f(1 - E_m)}{2S_m}$$

Series resistance:

$$R_t = \frac{R_{t1}(1 + RB \cdot V_{sbx})}{1 + R_g V_m}$$

Series resistance factor:

$$\rho = MU0(C_{ox}/L)R_t V_m$$

Effective vertical field is

$$E_{eff} = E_{eff0}(q_b + \eta_\mu V_m)$$

$$q_b = V_t G_f S_m$$

where $\eta_\mu = 1/2$ for n-channel and $\eta_\mu = 1/3$ for p-channel MOSFETs.

Effective mobility

$$\mu_m = \frac{MU0 \cdot \mu_x}{1 + (\mu_E \cdot E_{eff})^{\theta_{MU}} + CS \cdot \frac{q_b^2}{(V_m + q_b)^2} + \rho}$$

Quantum Mechanical Corrections

In SPMOS quantum-mechanical (QM) corrections are considered in the most common case $\phi_s \geq 3V_t$ which is of interest for the charge-sheet models.

QM corrections are directly used for $x_m = \phi_m / V_t$ and $\varphi = (\phi_{sd} - \phi_{ss})/V_t$.

This is preferable to correcting ϕ_{ss} and ϕ_{sd}, especially in the case when φ is a small difference of two large variables.

In the following equations, superscript 0 refers to variables uncorrected for QM effects.

For $x_g \geq 0$ (i.e. for $V_{gb} \geq V_{fb}$)

$$x_m = x_m^{(0)} + u_{QM}$$

$$\varphi = \varphi^{(0)} \cdot \frac{k_m(\bar{D} + d_0)}{d + k_m \bar{D} \alpha_{QM}}$$

where

$$u_{QM} = \frac{q_{QM}}{p_{QM} - q_{QM}/p_{QM}}$$

$$q_{QM} = G_f^2 D_m^{(0)} \Delta e'_g$$

$$\Delta e'_g = g_{QMP} \Delta e_g$$

$$\Delta e_g = q_q x_{gm}^{2/3}$$

$$g_{QMP} = \frac{D_m^{(0)}}{D_m^{(0)} + P_m^{(0)}}$$

$$p_{QM} = 2x_{gm} + G_f^2 [1 - E_m^{(0)} + D_m^{(0)} \alpha_{QM}]$$

$$\alpha_{QM} = 1 + \frac{2\Delta e'_g}{3x_{gm}}$$

$$k_m = \exp(\alpha_{QM} u_{QM} - \Delta e'_g)$$

$$\bar{D} = \frac{D_s + D_d}{2}$$

$$d_0 = 1 - E_m^{(0)} + 2x_{gm}/G_f^2$$

$$d = d_0 + (E_m^{(0)} - 2/G_f^2) u_{QM}$$

For $x_g < 0$,

$$x_m = x_m^{(0)} - \frac{\Delta e_g' \phi_m^2}{\phi_m^2 + \frac{0.04}{1 + 3|\phi_m|}}$$

There is no correction for φ. This form is introduced to eliminate the singularity or unphysical behavior near $V_{gb} = V_{fb}$. Coefficients 0.04 and 3 are not affected by model parameters and are fixed.

In addition to correcting ϕ_m and x_m, QM effects are introduced into

$$D_m = k_m D_m^{(0)}$$

and variables P_m, x_{gm}, which are given by the above expressions but with x_m corrected for QM effects.

Polysilicon Depletion

In SPMOS polysilicon depletion equations are conditioned to provide smooth device characteristics for a wide voltage range but at present the poly effects are only included for $\upsilon_{gb} > V_{fb}$.

The normalized poly surface potential at midpoint

$$x_{pm} = k_p \left[\frac{x_{gm}^{(0)}}{1 + \eta_p^{-1}} \right]^2$$

where

$$\eta_p = [1 + k_p x_{gm}^{(0)}]^{-1/2}$$

In this section the superscript 0 indicates that the variable is not corrected for poly depletion effect.

Poly corrections are introduced into $x_m = \phi_m / V_t$ and $\varphi = (\phi_{sd} - \phi_{ss}) / V_t$ rather than into ϕ_{ss} and ϕ_{sd} directly.

The corrected midpoint surface potential is

$$x_m = x_m^{(0)} + u_p$$

where

$$u_p = \frac{q}{p - q/p}$$

$$p = 2[x_{gm}^{(0)} - x_{pm}] + G_f^2[1 - E_m^{(0)} + D_m^{(0)}]$$

$$q = x_{pm}[x_{pm} - 2x_{gm}^{(0)}]$$

The correction to normalized surface potential difference φ is as follows

$$\varphi = \varphi^{(0)} \cdot \frac{k_m(d_0 + \bar{D})}{d + k_m\bar{D}}$$

where d_0 is given in section "Quantum Mechanical Corrections" on page 2594 with superscript 0 indicating that the variable is not corrected for poly depletion effect

$$d = 1 + E_m^{(0)} - 2\eta_p x_{gm} / G_f^2$$

$$k_m = \exp(u_p)$$

In addition to changing the surface potentials, poly correction affects the linearization of inversion charge and intrinsic charges. The expressions in sections "Drain Current" on page 2598 and "Intrinsic Charges" on page 2599 include these corrections.

The case of no poly effect can be recovered by setting $\eta_p = 1$. While physically this corresponds to $NP \to \infty$, in SPMOS eliminating poly effects is formally prescribed by setting $NP = 0$ in the parameter file.

Drain Current

$$V_c = L \cdot \frac{u_{sat}}{\mu_m}$$

$$u_{sat} = \frac{VSAT}{1 + K_{sm} \cdot w_{sat}}$$

$$w_{sat} = \frac{100 \cdot V_m \cdot (1 + STX \cdot V_{sbx})}{100 + V_m \cdot (1 + STX \cdot V_{sbx})}$$

This ensures that $w_{sat} < 100$ and $u_{sat} < 0.3VSAT$ during SPICE convergence when V_m can be unphysically high.

$$\delta = \frac{\phi}{\phi + G_{hf} \cdot V_c}$$

$$L_{sat} = \frac{\delta\phi\mu_m}{u_{sat}}$$

The channel length modulation factor is calculated by the following equation:

$$L_{CLM} = \delta L_{q2d} \ln[1 + CLM3 \cdot (V_{ds} - \phi)]$$

Drain current is calculated by

$$I_d = \frac{\mu_m W C_{OX}(V_m + \alpha V_t)\phi}{L_{red} + L_{sat}}$$

where the inversion charge linearization (including polysilicon depletion effect) is:

$$\alpha = \eta_p + \frac{G_f(1 - E_m)}{2S_m}$$

The reduced channel length is

$$L_{red} = \frac{L}{1 + \frac{L_{CLM}}{L}}$$

Intrinsic Charges

All charges are normalized to C_{oxt}.

$$C_{oxt} = C_{ox}(L + 10^{-6}DLQ)(W + 10^{-6}DWQ)$$

Gate charge

$$Q_g = x_{gm}V_t + \frac{\eta_p\phi}{2}\left(\frac{\phi r_L}{6H} - 1 + r_L\right)$$

where

$$H = \frac{V_m/\alpha + V_t}{1 + L_{sat}/L_{red}}$$

$$r_L = L_{red}/L$$

Inversion layer charge

$$|Q_I| = r_L(V_m + \alpha\phi^2/12H) + Q_{CLM}$$

$$Q_{CLM} = (1 - r_L)(V_m - 0.5\alpha\phi)$$

Drain charge (computed using Ward-Dutton partition)

$$|Q_D| = \frac{1}{2}r_L^2\left\{V_m - \frac{\alpha\phi}{6}\left[1 - \frac{\phi}{2H} - \frac{1}{5}\left(\frac{\phi}{2H}\right)^2\right]\right\} + \frac{1}{2}Q_{CLM}(1 + r_L)$$

Source charge

$$|Q_S| = |Q_I| - |Q_D|$$

Bulk charge

$$|Q_B| = Q_G - |Q_I|$$

Bias-Dependent Body Factor

If NSLP>10^{-3},

$$\gamma = \gamma_0\sqrt{1 + D_{nsub}}$$

$$D_{nsub} = D_{nsubL} \cdot MAXA(0, (V_{gs} + VNSUB) \cdot NSLP, 0.1)$$

Otherwise

$$\gamma = \gamma_0$$

Normalized body factor is

$$G = \gamma/(\sqrt{V_t})$$

Extrinsic Model

Bias-Independent Variables

Overlap capacitance

$$C_{oxov} = \frac{\varepsilon_{ox}}{TOXOV}$$

Overlap body factor

$$\gamma_{ov} = \frac{\sqrt{2q\varepsilon_{Si}NOV}}{C_{oxov}}$$

Normalized overlap body factor ° °°°°°°

$$G_{ov} = \frac{\gamma_{ov}}{\sqrt{V_t}}$$

Tunneling current density constant (in A/m^2)

$$J_0 = \frac{qm_0 k_B^2 TABS^2}{2\pi^2 h^3} = 1.082 \cdot 10^{11} \cdot \left(\frac{TABS}{300}\right)^2$$

Channel tunneling current density exponential constant (dimensionless)

$$B = 2TOX(2qm_0\chi_B)^{1/2}/h = 6.831 \cdot 10^9 \cdot TOX \cdot \sqrt{\chi_B}$$

Overlap tunneling current density exponential constant (dimensionless)

$$B_{ov} = 2TOXOV((2qm_0\chi_B)^{1/2}/h) = 6.831 \cdot 10^9 TOXOV\sqrt{\chi_B}$$

Auxiliary variable of gate current model

$$\alpha_b = E_g/(2q) + \phi_b$$

The Si / SiO_2 conduction band offset

$$\chi_B = 3.13V$$

Streamlined Surface Potential Approximation

The availability of the surface potential in the overlap regions is essential to the physical modeling of the charge and gate current components. The streamlined analytical approximation of the surface potential excludes the effects of minority carriers and consequently is even simpler and more efficient than the one employed in the channel region.

Let

$$\xi = 1 + G_{ov}/\sqrt{2}$$

and

$$x_{margin} = 10^{-7}\xi$$

If $|x| < x_{margin}$

$$x = -x_g/\xi$$

For $x_g < -x_{margin}$, proceed in the follow steps

$$y_g = -x_g$$

$$z = 1.25 y_g / \xi$$

$$\eta = \frac{1}{2}\{z + 10 - [(z-6)^2 + 64]^{1/2}\}$$

$$a = (y_g - \eta)^2 + G_{ov}^2(\eta + 1)$$

$$c = 2(y_g - \eta) - G_{ov}^2$$

$$\tau = -\eta + \log\left(\frac{a}{G_{ov}^2}\right)$$

$$y_0 = \eta + \sigma(a, c, \tau)$$

$$\Delta_0 = \exp(y_o)$$

$$p = 2(y_g - y_0) + G_{ov}^2(\Delta_0 - 1)$$

$$q = (y_g - y_0)^2 + G_{ov}^2(y_0 - \Delta_0 + 1)$$

$$x = -y_0 - \frac{2q}{p + \sqrt{p^2 - 2q(2 - G_{ov}^2\Delta_0)}}$$

For $x_g > x_{margin}$, compute

$$x_1 = 1.25$$

$$x_{g1} = x_1 + G_{ov}\sqrt{\exp(-x_1) + x_1 - 1}$$

$$\bar{x} = \left(\frac{x_g}{\xi}\right)\left[1 + x_g \frac{(\xi x_1 - x_{g1})}{x_{g1}^2}\right]$$

$$\bar{E} = \exp(-\bar{x})$$

$$\omega = 1 - \bar{E}$$

$$x_0 = x_g + \frac{G_{ov}^2}{2} - G_{ov}\left(x_g + \frac{G_{ov}^2}{4} - \omega\right)^{1/2}$$

$$\Delta_1 = \exp(-x_0)$$

$$p = 2(x_g - x_0) + G_{ov}^2(1 - \Delta_1)$$

$$q = (x_g - x_0)^2 - G_{ov}^2(x_o + \Delta_1 - 1)$$

$$x = x_0 + \frac{2q}{p + \sqrt{p^2 - 2q(2 - G_{ov}^2 \Delta_1)}}$$

The evaluation of Δ_0 and Δ_1 is carefully ordered to avoid over/underflow problems.

Charge Model

Source overlap region charge

$$Q_{sov} = W \cdot LOV \cdot C_{oxov} \cdot (V_{gs} - \phi_{sov})$$

Drain overlap region charge

$$Q_{dov} = W \cdot LOV \cdot C_{oxov} \cdot (V_{gd} - \phi_{dov})$$

Bulk overlap region charge

$$Q_{bov} = L \cdot CGBO \cdot V_{gb}$$

Inner fringe charge correction

$$\Delta Q_G = -\Delta Q_S - \Delta Q_D$$

$$\Delta Q_S = IFKJ \cdot W(1 + IFCJV_{sb})(IFVBI + V_{sb} - \phi_{ss})^{1/2}$$

$$\Delta Q_D = IFKJ \cdot W(1 + IFCJV_{db})(IFVBI + V_{db} - \phi_{sd})^{1/2}$$

Outer fringe charge

$$Q_{ofs} = W \cdot CF \cdot V_{gs}$$

$$Q_{ofd} = W \cdot CF \cdot V_{gd}$$

Terminal charges

$$Q_G = Q_G^{(i)} + Q_{sov} + Q_{dov} + \Delta Q_G + Q_{ofs} + Q_{ofd} + Q_{bov}$$

$$Q_S = Q_S^{(i)} - Q_{sov} + \Delta Q_S - Q_{ofs}$$

$$Q_D = Q_D^{(i)} - Q_{dov} + \Delta Q_D - Q_{ofd}$$

$$Q_B = Q_B^{(i)} - Q_{bov}$$

where the superscript *(i)* indicates that the value for that parameter is taken from the SP intrinsic model.

Gate Current Model

$$I_g = I_{gc} + I_{gsov} + I_{gdov}$$

Channel contribution

$$I_{gc} = I_{gc0} \cdot i_{gc}$$

$$I_{gc0} = W \cdot L \cdot J_{gc}$$

$$J_{gc} = (J_0 \cdot F_s) \cdot \exp\left\{B \cdot \left[-GC1 + \frac{U_{oxm}}{\chi_B}\left(GC2 + \frac{GC3 \cdot U_{oxm}}{\chi_B}\right)\right]\right\}$$

$$U_{oxm} = \sqrt{V_{oxm}^2 + 10^{-6}}$$

where F_s is the supply function describing the difference of the population of carriers across the oxide at mid-point and is given by

$$F_s = \ln\left[\frac{1 + \Delta_{Si}}{1 + \Delta_{Si}\exp(-V_{gs}/V_t)}\right]$$

$$\Delta_{Si} = \exp\left[\frac{\phi_{ss} - \alpha_b - V_x - \psi_t}{V_t}\right]$$

$$\psi_t = MINA(0, V_{ox} + D, 0.05)$$

$$D = GC0 \cdot V_t$$

$$i_{gc} = (1 - b)\frac{\sinh(x)}{x} + b \cdot \cosh(x)$$

$$x = \frac{\phi}{2u_0}$$

$$b = \frac{u_0}{H}$$

$$u_0 = \frac{\chi_B}{[GC2 + 2GC3 \cdot (U_{oxm}/\chi_B)]}$$

Source-Drain Partition

The partition of the gate current in the channel area into the source and drain is essential for the MOSFET compact modeling, which is accomplished in SPMOS using the symmetrical linearization method.

The drain portion is given by

$$I_{gcd} = I_{gc0} i_{gcd}$$

$$i_{gcd} = \frac{i_{gc}}{2} - B_g \sinh(x) - A_g \frac{\sinh(x)}{x}\left[\coth(x) - \frac{1}{x}\right]$$

$$A_g = (1 - 3b + 3b^2)/2$$

$$B_g = b(1 - b)/2$$

and the source portion is given by

$$I_{gcs} = I_{gc} - I_{gcd}$$

Source Overlap Region Contribution

$$I_{gsov} = W \cdot LOV \cdot J_{gsov}$$

$$J_{gsov} = J_0 F_{sovs} \exp\left\{B_{ov} \cdot \left[-GC1 + \frac{U_{oxovs}}{\chi_B}\left(GC2 + \frac{GC3 \cdot U_{oxovs}}{\chi_B}\right)\right]\right\}$$

$$U_{oxovs} = \sqrt{V_{oxovs}^2 + 10^{-6}}$$

The supply function, F_{sovs}, describing the difference of the population of carriers across the oxide in the source overlap region, given by

$$F_{sovs} = \ln\left[\frac{1 + \Delta_{Siovs}}{1 + \Delta_{Siovs} \exp(-V_{gs}/V_t)}\right]$$

$$\Delta_{Siovs} = \exp\left[\frac{3.0 + \phi_{sov} + \psi_{tovs}}{V_t}\right]$$

$$\psi_{tovs} = MINA(0, Voxovs + GC0 \cdot V_t, 0.05)$$

Drain overlap region contribution

$$I_{gdov} = W \cdot LOV \cdot J_{gdov}$$

$$J_{gdov} = J_0 F_{sovd} \exp\left\{B_{ov} \cdot \left[-GC1 + \frac{U_{oxovd}}{\chi_B}\left(GC2 + \frac{GC3 \cdot U_{oxovd}}{\chi_B}\right)\right]\right\}$$

$$U_{oxovd} = \sqrt{V_{oxovd}^2 + 10^{-6}}$$

The supply function, F_{sovd}, describing the difference of the population of carriers across the oxide in the drain overlap region, given by

$$F_{sovd} = \ln\left[\frac{1 + \Delta_{Siovd}}{1 + \Delta_{Siovd}\exp(-V_{gd}/V_t)}\right]$$

$$\Delta_{Siovd} = \exp\left[\frac{3.0 + \phi_{dov} + \psi_{tovd}]}{V_t}\right]$$

$$\psi_{tovd} = MINA(0, V_{oxovd} + GC0 \cdot V_t, 0.05)$$

By setting SW_IGATE to 0 (default value) gate current model is turned off.

Substrate Current Model

The substrate current of MOSFETs due to impact ionization is given by

$$I_b = a_1 \cdot (V_{ds} - a3\phi) \cdot \exp\left(-\frac{a_2}{(V_{ds} - a_3\phi)}\right) \cdot I_d$$

$$a_1 = IIA1 + IIA1L \cdot A_L + IIA1W \cdot B_w + IIA1P \cdot A_L \cdot B_w$$

$$a_2 = IIA2[1 + a_4(\sqrt{V_{sb} + 2\phi_b} - \sqrt{2\phi_b})]\left(\frac{TABS}{T_n}\right)^{TK\_\text{IIA2}}$$

$$a_3 = IIA3 + IIA3L \cdot A_L$$

$$a_4 = IIA4 + IIA4L \cdot A_L$$

Total Terminal Currents

The effect of I_b and I_g on the gate, source, drain and body components are as follows

$$I_G = I_{gc} + I_{gsov} + I_{gdov}$$

$$I_S = I_S^{(i)} - (1 - IIPARTITION)I_b - I_{gcs}S_g(x_g) - I_{gsov}$$

$$I_D = I_d^{(i)} + I_b - I_{gcd}S_g(x_g) - I_{gdov}$$

$$I_B = I_B^{(i)} - IIPARTITION \cdot I_b - I_{gc}[1 - S_g(x_g)]$$

where $I_S^{(i)}$, $I_D^{(i)}$ and $I_B^{(i)}$ are terminal currents produced by the intrinsic (core) SPMOS model and

$$S_g(x_g) = \frac{1}{2}\left(1 + \frac{x_g}{\sqrt{x_g^2 + \varepsilon}}\right)$$

The computation of the impact ionization current be turned off by setting the parameter SW_IMPACT to 0 (default) and turned on by setting SW_IMPACT to 1.

Noise Model

Channel Thermal Noise

$$S_{I_d^2} = \frac{4k_B \cdot TABS}{L_{red}^2} \cdot \left(\mu_m Q_{inv} + NDELTA\frac{I_{d/m}\phi}{E_{crit}^2}\right)$$

$$Q_{inv} = WLC_{ox}(Q_I - Q_{CLM})$$

$$E_{crit} = VSAT/\mu_m$$

Flicker Noise

if SW_FLICKER = 0 (default)

$$S_{I_d^2}(f) = S_{I_d^2}(drift) + S_{I_d^2}(diff)$$

$$S_{I_d^2}(drift) = \frac{C_{ox}\phi_t I_d \mu_m}{\alpha_m \gamma_{FN} L_{red}^2 f^{NEF}} \Big\{ [NOIC \cdot (V_m - 2 \cdot V_*) + B^* - u_n V_*]\alpha_m \phi +$$
$$\left(A^* - 2B^* \cdot V_* + 3 \cdot NOIC \cdot V_*^2\right) \ln(q_+/q_-) \Big\}$$

$$S_{I_d^2}(diff) = \frac{C_{ox}\phi_t^2 I_d \mu_m}{\gamma_{FN} L_{red}^2 f^{NEF}} \{[(NOIC + u_n)\alpha_m \phi + (B^* - 2 \cdot NOIC \cdot V_*) \ln(q_+/q_-)]\}$$

$$\gamma_{FN} = 10^{10} [m^{-1}]$$

$$V_* = \phi_t \left(1 + \frac{G}{2\sqrt{x_m + 10^{-6}}}\right)$$

$$A^* = NOIA \cdot q^2 / C_{ox}^2$$

$$B^* = NOIB \cdot q / C_{ox}$$

$$u_n = (A^* - B^* \cdot V_* + NOIC \cdot V_*^2)/(q_+ q_-)$$

$$q_+ = V_* + V_m + \alpha_m \phi$$

$$q_- = V_* + V_m - \alpha_m \phi$$

If SW_FLICKER is set to 1 then

$$S_{I_d^2} = \frac{KF \cdot g_m^2}{C_{ox} WLf^{NEF}}$$

Series resistance thermal noise

$$S_{R_D} = \frac{4kT}{r_{drain}}$$

$$S_{R_S} = \frac{4kT}{r_{source}}$$

$$S_{R_G} = \frac{4kT}{r_{gate}}$$

where

$$r_{drain} = RSH \cdot NRD$$

$$r_{source} = RSH \cdot NRS$$

$$r_{gate} = RGSH \cdot \frac{W_{drawn}}{L_{drawn} \cdot NF}$$

Channel induced gate noise

$$S_{I_g^2} = DVDZ \cdot \frac{TABS \cdot 16k_B \pi^2 f^2 WC_{ox} L_{red}^3}{\mu_m \alpha_m H^3} \left[\frac{\phi^4}{1728H^2} - \phi^2 \left(\frac{1}{720} + \frac{H'}{144H} \right) + \frac{HH'}{12} \right]$$

where

$$H' = \frac{V_m/\alpha - V_t L_{sat}/L_{red}}{1 + L_{sat}/L_{red}}$$

Cross correlation coefficient

$$S_{I_g I_d} = j \cdot \frac{TABS \cdot 8k_B \pi f W C_{ox} L_{red}}{H^2} \left(\frac{H\phi}{12} - \frac{\phi^3}{144H} \right)$$

$$c = \frac{S_{I_g I_d}}{\sqrt{S_{I_g^2} \cdot S_{I_d^2}}}$$

Gate Induced Drain/Source Leakage Current Model

GIDL Model Equations

For $V_{oxovd} \geq 0$

$$I_{GIDL} = 0$$

For $V_{oxovd} < 0$

$$I_{GIDL} = -A_{GIDL0} V_{db} V_{oxovd} V_{tovd} \exp\left(-\frac{B_{GIDL0}}{V_{tovd}} \right)$$

$$A_{GIDL0} = 10^{13} \cdot AGIDL \cdot W_{eff} L_{OV}$$

$$B_{GIDL0} = BGIDL \cdot (1 + dt \cdot TK\_\mathrm{BGIDL})$$

$$V_{tovd} = \sqrt{V_{oxovd}^2 + CGIDL^2 \cdot V_{db}^2 + 10^{-6}}$$

GISL Model Equations

$$I_{GISL} = -A_{GIDL0} V_x V_{oxovs}^2 \exp\left(-\frac{B_{GIDL0}}{V_{tovs}} \right)$$

$$V_{tovs} = \sqrt{V_{oxovs}^2 + CGIDL^2 \cdot V_{sb}^2 + 10^{-6}}$$

Scaling Equations

The drawn channel dimensions are denoted as L_{DR}, W_{DR} (in m) or as $L_{DR,\mu m}$, $W_{DR,\mu m}$ (in µm). The minimum device dimensions for a given technology are L_{REF}, W_{REF} (in m) or as $L_{REF,\mu m}$, $W_{REF,\mu m}$ (in µm).

Effective channel length in µm

$$L_{\mu m} = L_{DR,\,\mu m} - DL0 - DLL \cdot A_L - DLW \cdot B_w$$

where

$$A_L = \frac{1}{L_{REF,\,\mu m}} - \frac{1}{L_{DR,\,\mu m}}$$

$$B_W = \frac{1}{W_{REF,\,\mu m}} - \frac{1}{W_{DR,\,\mu m}}$$

Effective channel length in m

$$L = 10^{-6} L_{\mu m}$$

Effective channel width in µm,

$$W_{\mu m} = W_{DR,\,\mu m} - DW0 - DWL \cdot A_l - DWW \cdot B_W - DWP \cdot A_L \cdot B_W$$

Effective channel width in m

$$W = 10^{-6} W_{\mu m}$$

Total oxide capacitance,

$$C_{oxt} = C_{ox}(L + 10^{-6} \cdot DLQ)(W + 10^{-6} \cdot DWQ)$$

Flat-band voltage (which in SPMOS includes reverse short-channel effect if any)

$$V_{fb} = FB0 + \frac{FB1}{W_{\mu m}} + \frac{FB2}{W_{\mu m}^2} + \Delta V_{RSE}$$

$$\Delta V_{RSE} = \left(1 + \frac{FB3}{W_{\mu m}} + \frac{FB4}{W_{\mu m}^2}\right) \cdot \left(\frac{FB5}{L_{DR,\ \mu m}} + \frac{FB6}{L_{DR,\ \mu m}^2} + \frac{FB7}{L_{DR,\ \mu m}^3}\right)$$

Drift velocity local parameters

$$K_{sm} = ST0 + ST1 \cdot B_W$$

$$G_{hf} = \left(GH0 + \frac{GH1}{L_{\mu m}} + \frac{GH2}{L_{\mu m}^2}\right) \cdot \left(1 + \frac{GH3}{W_{\mu m}}\right) + \frac{GH4}{L_{\mu m}^2 W_{\mu m}^2}$$

Local parameters for the lateral field gradient

$$F_0 = 1 - \frac{FL1}{L_{\mu m}} - \frac{FL2}{L_{\mu m}^2}$$

$$A_f = \left(AF0 + \frac{AFL}{L_{\mu m}^2}\right) \cdot C_{LW}$$

$$B_f = min\left\{\frac{BFL}{L_{\mu m}^2}, \frac{1 - F_0}{F_0 + 0.01}\right\}$$

$$C_f = \left(CF0 + \frac{CFL}{L_{\mu m}^2}\right)\left(1 + KL \cdot \frac{AL}{L_{\mu m}}\right)C_{LW}$$

and

$$C_{LW} = \frac{1}{1 + KW/W_{\mu m}}$$

Mobility model parameter

$$\mu_E = MU1\left(1 + \frac{MU1W}{W_{\mu m}}\right)$$

$$\theta_{MU} = MU2\left(1 + \frac{MU3}{W_{\mu m}}\right)$$

Mobility model parameter (correction for “non-universality”)

$$X_{cor} = NU0 + \frac{NUL}{L_{\mu m}}(1 + NUW \cdot W_{\mu m})$$

Bias-independent part of the series resistance

$$R_{t1} = R0 + R1 \cdot A_L + R2 \cdot B_W + R3 \cdot A_L \cdot B_W$$

Constant used to describe gate bias dependence of the series resistance

$$R_g = R4 + R5 \cdot A_L + R6 \cdot W_{\mu m}$$

Triode-saturation transition variable

$$a_x = \frac{AS0}{1 + ASL/L_{\mu m}}$$

Characteristic length of the quai-2D theory

$$L_{q2d} = (1 + GDL \cdot L_{\mu m})(CLM0 + CLM1 \cdot A_L + CLM2 \cdot B_W)\sqrt{2 \cdot 10^{-7}\varepsilon_{si}/C_{OX}}$$

Subthreshold slope parameter

$$cT = 1 + \frac{T_n}{TABS} \cdot \frac{ITL}{L_{\mu m}^2}$$

Substrate doping variable

$$D_{nsubL} = (1 + NPKT \cdot A_L)^{-1}$$

Halo-doping effect parameters

$$Hl01 = GDS1 + GDS1L \cdot L_{DR,\ \mu m} + GDS1A \cdot A_L$$

$$Hl02 = GDS2 + GDS2L \cdot L_{DR,\ \mu m} + GDS2A \cdot A_L$$

Effective doping

$$Nsub = NSUB\left[1 + \frac{LPKT}{L_{\mu m}}(1 - e^{-L_{\mu m}/(YPKT)})\right]$$

Temperature Dependence (-55°°?° to 150°°?°)

SPMOS uses up to 13 temperature coefficients.×

Flat-band voltage: TK_VFB0, TK_VFBL, TK_VFBW, TK_VFBP.

Mobility: TK_MU0, TK_MUW, TK_MUL, TK_MUP, TK_MU1, TK_THM, TK_CS.

Saturation velocity: TK_VS, TK_AS.

Coefficients TK_VFBL, TK_VFBW, TK_VFBP, TK_MUL, TK_MUP and TK_AS are expected to be zero for mature processes.

The temperature dependence of bulk and surface potentials is not adjusted and is obtained essentially from the first principles. The temperature dependence of the flat-band voltage, mobility and saturation velocity is as follows. In these equations Tn is nominal temperature and

$$\Delta T = TABS - T_n$$

Flat-band voltage

$$V_{fb} = V_{fb}(T_n) + \frac{k_B \Delta T}{q}\left(TK\_\mathrm{VFB} + \frac{TK\_\mathrm{VFBL}}{L_{\mu m}} + \frac{TK\_\mathrm{VFBW}}{W_{\mu m}} + \frac{TK\_\mathrm{VFBP}}{W_{\mu m} L_{\mu m}}\right)$$

Mobility

$$\mathrm{MU0} = \mathrm{MU0}(T_n)\left(\frac{T_n}{TABS}\right)^{n_{\mu 0}}$$

$$n_{\mu 0} = TK\_\mathrm{MU0} + \frac{\Delta T}{T_n}\left(\frac{TK\_\mathrm{MUL}}{L_{\mu m}} + \frac{TK\_\mathrm{MUW}}{W_{\mu m}} + \frac{TK\_\mathrm{MUP}}{W_{\mu m} L_{\mu m}}\right)$$

$$\theta_{mu} = \theta_{mu}(T_n)\left(\frac{T_n}{TABS}\right)^{TK\_\mathrm{THM}}$$

$$\mu_E = \mu_E(T_n)\frac{1 + TK\_\mathrm{MU1}\exp(\Delta T/20)}{1 + TK\_\mathrm{MU1}}$$

$$X_{cor} = X_{cor}(T_n)\left(\frac{T_n}{TABS}\right)^{n_{\mu 0}}$$

$$CS = CS(T_n)\left(\frac{T_n}{TABS}\right)^{TK\_CS}$$

Saturation velocity

$$VSAT = VSAT(T_n)(1 + TK\_VS \cdot \Delta T)$$

$$G_{hf} = G_{hf}(T_n)\frac{1 + TK\_VS / W_{\mu m}}{1 + (TK\_VS / W_{\mu m})\exp(\Delta T / 20)}$$

The default values and ranges for temperature coefficients are given in the table below.

Table 34-1 Temperature Coefficients

Parameter	Unit	Description	Default	MIN	MAX
TK_VFB0	None	$V_{fb}(T)$ parameter	0	None	None
TK_VFBL	μm	$V_{fb}(T)$ scaling parameter (L)	0	None	None
TK_VFBW	μm	$V_{fb}(T)$ scaling parameter (W)	0	None	None
TK_VFBP	μm^2	$V_{fb}(T)$ scaling parameter (LW)	0	None	None
TK_MU0	None	MU0(T) parameter	1.5	See Note [1]	
TK_MUL	μm	MU0(T) scaling parameter (L)	0		
TK_MUW	μm	MU0(T) scaling parameter (W)	0		
TK_MUP	μm^2	MU0(T) scaling parameter (LW)	0		
TK_MU1	None	$\mu_E(T)$ parameter	0	0	0.1
TK_THM	None	$\theta_{mu}(T)$ parameter	0	-5	5
TK _CS	None	CS(T) parameter	0	-5	5

TK_VS	K^{-1}	VSAT(T) parameter	0	-0	005
TK_AS	µm	A_s(T) parameter	0	0	0.1

1. Instead of limiting TK_MU0, TK_MUL, TK_MUW and TK_MUP, SPMOS sets

$$n_{\mu 0} = min\left\{5, max\left[-5, TK\_\mathrm{MU0} + \frac{\Delta T}{T_n}\left(\frac{TK\_\mathrm{MUL}}{L_{\mu m}} + \frac{TK\_\mathrm{MUW}}{W_{\mu m}} + \frac{TK\_\mathrm{MUP}}{L_{\mu m}W_{\mu m}}\right)\right]\right\}$$

Parameter Descriptions

Table 34-2 Process Parameters Group

Parameter	Unit	Description	Default	MIN	MAX
ITL	μm^2	Interface states scaling factor	0	0	$2P_L^2 L_{CLAMP}^2, \mu m$
LPKT	µm	Pocket length	0	$-\frac{3}{4}PL_L L_{CLAMP}, \mu m$	$9L_{CLAMP}, \mu m$
NP	cm^{-3}	Polysilicon doping	10^{22}	$max(3 \cdot 10^{19}, 80/TOX^2)$ (See Note[1])	None
NSUB	cm^{-3}	Substrate doping	$5 \cdot 10^{17}$	10^{15}	$5 \cdot 10^{18}$
QMC None	None	QM correction factor	0	0	$min(0.6, 3 \cdot 10^{26} \cdot TOX/\mathrm{NSUB})$
TOX	m	Oxide thickness	$4 \cdot 10^{-9}$	10^{-9}	$2 \cdot 10^{-7}$

1. Setting NP=0 or NP > $10^{28}m^{-3}$ turns off polysilicon depletion effect.

At present, PL = 0.2.

Table 34-3 Effective Geometry Group

Parameter	Unit	Description	Default	MIN	MAX
DL0	µm	Channel length offset	0	See Note[1]	
DLL	μm^2	Channel length adjustment (L)	0		
DLW	μm^2	Channel length adjustment (W)	0	See Note[2]	
DW0	µm	Channel width offset	0		
DWL	μm^2	Channel width adjustment (L)	0		
DWW	μm^2	Channel width adjustment (W)	0		
DWP	μm^3	Channel width perimeter factor	0		
DLQ	µm	Decoupling parameter	0	$-L_{\mu m}/2$	none
DWQ	µm	Decoupling parameter	0	$-W_{\mu m}/2$	none

1. Instead of limiting the values of DL0, DLL and DLW, SPMOS sets the channel length offset as

$$DL_{\mu m} = DLO + DLL \cdot A_L + DLW \cdot B_W$$

and the effective channel length (in µm) as

$$L_{\mu m} = max\{L_{DR, \mu m} - DL_{\mu m}, P_L L_{CLAMP, \mu m}\}$$

2. Instead of limiting parameter values of DW0, DWL, DWW and DWP, SPMOS sets the channel width offset as

$$DW_{\mu m} = DW0 + DWL \cdot A_L + DWW \cdot B_W + DWP \cdot A_L \cdot B_W$$

and the effective channel length (in µm) as

$$W_{\mu m} = max\{W_{DR, \mu m} - DW_{\mu m}, P_W L_{CLAMP, \mu m}\}$$

At present, P_w=1/4.

Table 34-4 Mobility Group

Parameter	Unit	Description	Default	MIN	MAX
MU0	cm^2/Vs	Low-field mobility	500	0.01	10^4
NU0	V^{-1}	Non-universality factor	0	0	1
NUL	μm	Non-universality factor (L)	0	See Note[1]	
NUW	μm^{-1}	Non-universality factor (W)	0		
MU1	m/V	Magnitude of the vertical field dependence	0.5	0	$5 \cdot 10^8 TOX$
MU1W	μm	Scaling parameter (W)	0	$-0.9P_W W_{CLAMP} \mu m$	$0.9P_W W_{CLAMP} \mu m$
MU2	None	Sharpness of the vertical field dependence	1.5	0	3
MU3	μm	Scaling parameter (W)	0	$-0.9P_W W_{CLAMP} \mu m$	$0.9P_W W_{CLAMP} \mu m$
CS	None	Coulomb scattering	0	0	10

1. Instead of limiting NU0, NUL and NUW, SPMOS sets

$$X_{cor} = max\{X_{cor}, 0\}$$

Table 34-5 Series Resistance Group

Parameter	Unit	Description	Default	MIN	MAX
R0	$\Omega \cdot m$	Fixed component of series resistance	$2 \cdot 10^{-3}$	See Note[1]	
R1	$\Omega \cdot m \cdot \mu m$	Scaling factor (L)	0		
R2	$\Omega \cdot m \cdot \mu m$	Scaling factor (W)	0		
R3	$\Omega \cdot m \cdot \mu m^2$	Scaling factor (L,W)	0		
R4	V^{-1}	Gate bias dependence	0	0	None
R5	$\mu m / V$	Scaling factor (L) gate bias dependence	0.02	$-\frac{P_L}{2} R_4 L_{CLAMP, \mu m}$	$\frac{R_4}{2A_{mr}}$
R6	$\mu m / V$	Scaling factor (W) for gate bias dependence	0	See Note[2]	
RB	V^{-1}	Back bias factor	0	0	1.0

1. Instead of limiting the values of R0, R1, R2, and R3, SPMOS sets

$$R_{t1} = max\{R_0 + R_1 \cdot A_L + R_2 \cdot B_W + R_3 \cdot A_L \cdot B_W, 0\}$$

2. Instead of limiting the values of R6, SPMOS sets

$$R_g = max\{R_4 + R_5 \cdot A_L + R_6 \cdot W_{\mu m}, 0\}$$

Table 34-6 Velocity Saturation Group

Parameter	Unit	Description	Default	MIN	MAX
VSAT	m/s	Saturation velocity	80,000	50,000	150,000
ST0	V^{-1}	Gate bias dependence of saturation velocity	0	0	0.3
ST1	$\mu m / V$	Adjustment of saturation velocity (W)	0	$ST1_{min}$ See Note[1]	$ST1_{max}$ See Note[2]

Parameter	Unit	Description	Default	MIN	MAX
STX	V^{-1}	Back bias dependence of saturation velocity	0	0	1
GH0	None	Grotjohn/Hofflinger (GH) factor	0.5	0.05	5
GH1	μm	GH Scaling parameter (L^{-1})	0	See Note[3]	
GH2	μm^2	GH Scaling parameter (L^{-2})	0		
GH3	μm^3	GH Scaling parameter ($L^{-2}W^{-1}$)	0		
GH4	μm^4	GH Scaling parameter ($L^{-2}W^{-2}$)	0		
AS0	None	Transition from triode to saturation	12	6	100
ASL	None	Scaling factor (L) for triode-saturation	0.6	See Note[4]	
S0	None	V_{dsat} adjustment	0.98	0.9	0.99

1. $ST1_{min} = -min\{(0.3 - ST0)/B_{mr}, ST0 \cdot W_{CLAMP, \mu m}\}$

2. $ST1_{max} = min\{(0.3 - ST0)W_{CLAMP, \mu m}, ST0/B_{mr}\}$

3. Instead of limiting the values of GH1, GH2, GH3, and GH4, SPMOS forces G_{hf} to be in the range [0.05, 5]

$$G_{hf} = min\left\{5, max\left[0.05, \left(GH0 + \frac{GH1}{L_{\mu m}} + \frac{GH2}{L_{\mu m}^2}\right)\left(\left(1 + \frac{GH3}{W_{\mu m}}\right) + \frac{GH4}{L_{\mu m}^2 W_{\mu m}^2}\right)\right]\right\}$$

4. Instead of limiting the values of ASL, SPMOS forces a_x to be in the range [2,20]

$$a_x = min\{20, max\{2, a_x\}\}$$

Table 34-7 Flat-band Voltage Group

Parameter	Unit	Description	Default
FB0	V	V_{fb} for long wide devices $L, W \rightarrow \infty$	-1
FB1	$V \cdot \mu m$	Scaling parameter (W^{-1})	0
FB2	$V \cdot \mu m^2$	Scaling parameter (W^{-2})	0
FB3	μm	RSE parameter (W^{-1})	0
FB4	μm^2	RSE parameter (W^{-2})	0
FB5	$V \cdot \mu m$	RSE parameter (L^{-1})	0
FB6	$V \cdot \mu m^2$	RSE parameter (L^{-2})	0
FB7	$V \cdot \mu m^2$	RSE parameter (L^{-3})	0

There are no limits on flat-band voltage parameters.

Table 34-8 Lateral Gradient Factor Group

Parameter	Unit	Description	Default	MIN	MAX
FL1	μm	Scaling parameter for F_0	0.1	See Note[1]	
FL2	μm^2	Scaling parameter for F_0	0.01		
AF0	V^{-1}	Scaling parameter for A_f	0.004	0	10
AFL	$\mu m^2 / V$	Scaling parameter for A_f	0	$-AF0 \cdot P_L^2 L_{CLAMP,\ \mu m}^2$	10
BFL	$\mu m^2 / V$	Scaling parameter for B_f	0.015	0	10
CF0	V^{-1}	Scaling parameter for C_f	0.0005	0	10
CFL	$\mu m^2 / V$	Scaling parameter for C_f	0.01	$-CF0 \cdot P_L^2 L_{CLAMP,\ \mu m}^2$	10
KL	μm^2	Scaling parameter for C_{LW}	0	-KL0 (See Note[2])	KLO

Parameter	Unit	Description	Default	MIN	MAX
KW	μm	Scaling parameter for C_{LW}	0	$-0.9P_W W_{CLAMP,\,\mu m}$	10
DF	None	Sharpness of f(V_{ds}) dependence	0	0	3
EF	None	Sharpness of f(V_{sb}) dependence	0	0	3

1. Instead of limiting the values of FL1 and FL2, SPMOS forces F_0 to be in the range [0.001, 1]

$$F_0 = min\{1, max\{0.001, F_0\}\}$$

2. Instead of limiting the values of GDS1 and GDS2, SPMOS forces

$$\frac{\partial}{\partial V_{dsx}}\left(\frac{F_0}{f_0} - 1 - B_f V_{sbx1}\right) > 0$$

$$KL0 = min\left\{3.6L^2_{CLAMP,\,\mu m}, 0.9L_{CLAMP,\,\mu m}/A_{mr}\right\}$$

Table 34-9 Channel Length Modulation Group

Parameter	Unit	Description	Default	MIN	MAX
CLM0	None	L_{q2d} parameter	0.1	0	none
CLM1	μm	L_{q2d} scaling parameter (L)	0	$-\frac{1}{2}CLM0 \cdot L_{CLAMP,\,\mu m}$	$min\{10, CLM0/2A_{mr}\}$
CLM2	μm	L_{q2d} scaling parameter (W)	0	$-\frac{1}{2}CLM0 \cdot W_{CLAMP,\,\mu m}$	$min\{10, CLM0/2B_{mr}\}$
CLM3	V^{-1}	Logarithm dependence factor	10	0	1000
GDL	μm^{-1}	Scaling parameter (L)	0	0	0.9

New Parameters for SPMOS Version 34

The following parameters have been added to version 34.

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Parameter	Unit	Description	Default	MIN	MAX
NCG		Instance parameter for factor of Rgate	1	1	2
SW_GIDL		Flag og gidl	0	0	1
IT0		Interface states scaling factor	0	0	2
NPKT	um	Effective doping parameter	1.0	0	2
NSLP	1/V	Effective doping parameter	0	0	2
YPKT		Effective doping parameter	0.001	0.001	2
VNSUB	V	Effective doping parameter	0		
GDS1		V_{ds} dependence of G_{ds} slope	0		
GDS2		V_{ds} dependence of G_{ds} slope	0		
GDS1L	1/μm	Scaling parameter for Hlo1	0		
GDS2L	1/μm	Scaling parameter for Hlo2	0		
GDS1A	μm	Scaling parameter for Hlo1	0		

Parameter	Unit	Description	Default	MIN	MAX
GDS2A	μm	Scaling parameter for Hlo1	0		
TK_BGIDL	1/K	Temperature dependence	0.0	0.0	1.0
TK_IIA2		Substrate current scaling parameter	0.0	0.0	1.0
KGOV		Decouples tunneling and CV overlap fitting	1	0.1	10
CHIB	eV	Band offset	3.13	2.5	4
AGIDL		I_{GIDL} coefficient	0.7	0	
BGIDL	V	Tunnelling barrier adjustment	28	1	100
CGIDL	1/V	Lateral field dependence	0.007	0	1
IIA1W	μm/ $V^{1/2}$	Substrate current scaling parameter	0	-1	1
IIA1P	μm/ $V^{1/2}$	Substrate current scaling parameter	0	-1	1

Parameters with Different Default Values for SPMOS Version 34

Model Parameter	Old Default Value	New Default Value
noia	0.0	1.0e+20
noib	0.0	5.0e+04
noic	0.0	1.4e-12

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MOS Level-0 Transistor (mos0)

The MOS0 model is a simplified MOS level-1 model. The MOS0 DC drain current model is different from the Shichman and Hodges model because body effects are not modeled. The intrinsic MOS gate capacitances are replaced by the following linear overlap capacitances:

Gate to source/drain (`capmod` = `overlap`)

Gate to bulk (`capmod` = `bulk`

Gate, source, and drain to ground (`capmod` = `gnd`)

MOS0 is usually used as a MOS switch. This model recognizes all the MOS and BSIM instance parameters but only uses `l` and `w`, ignoring all other parameters. MOS0 transistors require that you use a model statement.

This device is not supported within altergroup.

Sample Instance Statement

```
mp1 (0 1 2 2) pchmod0 l=2u w=30u ad=120p as=75p pd=36u ps=6u
```

Sample Model Statement

```
model pchmod0 mos0 type=p vto=-0.683 tox=0.21e-7 ld=0.45e-6 tnom=27
```

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `w (m)` Channel width.

2 `l (m)` Channel length.

3 `m=1` Multiplicity factor (number of MOSFETs in parallel).

Model Definition

model modelName mos0 parameter=value ...

Model Parameters

Device type parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

Drain current model parameters

2 `vto=0 V` Threshold voltage at zero body bias.

3 `kp=2.0718e-5 A/V`^{2}
Transconductance parameter.

4 `lambda=0.02 1/V` Channel length modulation parameter.

5 `tox=1e-7 m` Gate oxide thickness.

6 `ld=0 m` Lateral diffusion.

7 `wd=0 m` Field-oxide encroachment.

Charge model selection parameters

8 `capmod=gnd` Intrinsic charge model.
Possible values are `none`, `overlap`, `bulk`, or `gnd`.

Temperature parameters

9 `tnom (C)` Parameters measurement temperature. Default set by `options`.

10 `trise=0 C` Temperature rise from ambient.

Default device parameters

11 `w=3e-6 m` Default channel width.

12 `l=3e-6 m` Default channel length.

Operating-Point Parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

2 `id (A)` Resistive drain current.

3 `vgs (V)` Gate-source voltage.

4 `vds (V)` Drain-source voltage.

5 `vbs (V)` Bulk-source voltage.

6 `vth (V)` Threshold voltage.

7 `vdsat (V)` Drain-source saturation voltage.

8 `gm (S)` Common-source transconductance.

9 `gds (S)` Common-source output conductance.

10 `cgs (F)` Gate-source capacitance.

11 `cgd (F)` Gate-drain capacitance.

12 `cgate (F)` Gate-Ground capacitance.

13 `ron (Ω)` On-resistance.

14 `pwr (W)` Power at op point.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the

description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

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MOS Level-15 Transistor (mos15)

The MOS15 model is the AMS level 15 model which is the modified Berkeley SPICE level-2 model with the DC model replaced by that of AMS. It is an analytical one-dimensional model that incorporates most of the second-order small-size effects. A smoother version of the level-15 model (with continuous Gds at Vdsat) was also developed. Three charge models are available. MOS15 transistors require the use of a model statement.

This device is not supported within altergroup.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.sun4v/cmi/lib/5.0.doc/libstmodels_sh.so

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `w (m)` Channel width.

2 `l (m)` Channel length.

3 `as (m`^{2}`)` Area of source diffusion.

4 `ad (m`^{2}`)` Area of drain diffusion.

5 `ps (m)` Perimeter of source diffusion.

6 `pd (m)` Perimeter of drain diffusion.

7 `nrd (m/m)` Number of squares of drain diffusion.

8 `nrs (m/m)` Number of squares of source diffusion.

9 `ld (m)` Length of drain diffusion region.

10 `ls (m)` Length of source diffusion region.

11 `m=1` Multiplicity factor (number of MOSFETs in parallel).

12 `region=triode` Estimated operating region. Spectre outputs number (0-3) in a rawfile.
Possible values are `off`, `triode`, `sat`, or `subth`.

13 `trise` Temperature rise from ambient.

Model Definition

```
model modelName mos15 parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

Drain current model parameters

2 `vto=0.5 V` Threshold voltage at zero body bias.

3 `kp=2.0718e-5 A/V`^{2}
Transconductance parameter.

4 `lambda=0.5 1/V` Channel length modulation parameter.

5 `phi=0.7 V` Surface potential at strong inversion.

6 `gamma=1.0 √V` Body-effect parameter.

7 `uo=600 cm`^{2}`/V s` Carrier surface mobility.

8 `vmax=8.0e4 m/s` Carrier saturation velocity.

9 `ucrit=2.0e6 V/cm` Critical field for mobility degradation.

10 `uexp=0` Critical field exponent for mobility degradation.

11 `utra=0 1/V` Transverse field for mobility.

12 `neff=1` Total channel charge coefficient.

13 `delta=0` Width effect on threshold voltage.

Process parameters

14 `nsub=1.13e16` cm^{-3}
Channel doping concentration.

15 `nss=0` cm^{-2} Surface state density.

16 `nfs=0` cm^{-2} Fast surface state density.

17 `tpg=+1` Type of gate (+1 = opposite of substrate, -1 = same as substrate, 0 = aluminum).

18 `tox=1e-7 m` Gate oxide thickness.

19 `ld=0 m` Lateral diffusion.

20 `wd=0 m` Field-oxide encroachment.

21 `xw=0 m` Width variation due to masking and etching.

22 `xl=0 m` Length variation due to masking and etching.

23 `xj=0.15e-6 m` Source/drain junction depth.

Impact ionization parameters

24 `ai0=0 1/V` Impact ionization current coefficient.

25 `lai0=0 µm/V` Length sensitivity of `ai0`.

26 `wai0=0 µm/V` Width sensitivity of `ai0`.

27 `bi0=0 V` Impact ionization current exponent.

28 `lbi0=0 µm V` Length sensitivity of `bi0`.

29 `wbi0=0 µm V` Width sensitivity of `bi0`.

Overlap capacitance parameters

30 `cgso=0 F/m` Gate-source overlap capacitance.

31 `cgdo=0 F/m` Gate-drain overlap capacitance.

32 `cgbo=0 F/m` Gate-bulk overlap capacitance.

33 `meto=0 m` Metal overlap in fringing field.

Charge model selection parameters

34 `capmod=bsim` Intrinsic charge model.
Possible values are `none`, `meyer`, `yang`, or `bsim`.

35 `xpart=1` Drain/source channel charge partition in saturation for BSIM charge model, use 0.0 for 40/60, 0.5 for 50/50, or 1.0 for 0/100.

36 `xqc=0` Drain/source channel charge partition in saturation for charge models, e.g. use 0.4 for 40/60, 0.5 for 50/50, 0 for 0/100.

Parasitic resistance parameters

37 `rs=0 Ω` Source resistance.

38 `rd=0 Ω` Drain resistance.

39 `rsh=0 Ω/sqr` Source/drain diffusion sheet resistance.

40 `rss=0 Ω m` Scalable source resistance.

41 `rdd=0 Ω m` Scalable drain resistance.

42 `rsc=0 Ω` Source contact resistance.

43 `rdc=0 Ω` Drain contact resistance.

44 `minr=0.1 Ω` Minimum source/drain resistance.

45 `ldif=0 m` Lateral diffusion beyond the gate.

46 `hdif=0 m` Length of heavily doped diffusion.

47 `lgcs=0 m` Gate-to-contact length of source side.

48 `lgcd=0 m` Gate-to-contact length of drain side.

49 `sc=∞ m` Spacing between contacts.

Junction diode model parameters

50 `js` (A/m^2) Bulk junction reverse saturation current density.

51 `is=1e-14 A` Bulk junction reverse saturation current.

52 `n=1` Junction emission coefficient.

53 `dskip=yes` Use simple piece-wise linear model for diode currents below 0.1*iabstol.
Possible values are `no` or `yes`.

54 `imax=1 A` Explosion current.

55 `jmax=1e8` A/m^2 Explosion current density.

Junction capacitance model parameters

56 `cbs=0 F` Bulk-source zero-bias junction capacitance.

57 `cbd=0 F` Bulk-drain zero-bias junction capacitance.

58 `cj=0` F/m^2 Zero-bias junction bottom capacitance density.

59 `mj=1/2` Bulk junction bottom grading coefficient.

60 `pb=0.8 V` Bulk junction built-in potential.

61 `fc=0.5` Forward-bias depletion capacitance threshold.

62 `cjsw=0 F/m` Zero-bias junction sidewall capacitance density.

63 `mjsw=1/3` Bulk junction sidewall grading coefficient.

64 `pbsw=0.8 V`	Side-wall junction built-in potential.
65 `fcsw=0.5`	Side-wall forward-bias depletion capacitance threshold.

Operating region warning control parameters

66 `alarm=none`	Forbidden operating region. Possible values are `none`, `off`, `triode`, `sat`, `subth`, or `rev`.
67 `bvj=∞ V`	Junction reverse breakdown voltage.

Temperature effects parameters

68 `tnom (C)`	Parameters measurement temperature. Default set by options.
69 `trise=0 C`	Temperature rise from ambient.
70 `uto=0 C`	Mobility temperature offset.
71 `ute=-1.5`	Mobility temperature exponent.
72 `tlev=0`	DC temperature selector.
73 `tlevc=0`	AC temperature selector.
74 `eg=1.12452 V`	Energy band gap.
75 `gap1=7.02e-4 V/C`	Band gap temperature coefficient.
76 `gap2=1108 C`	Band gap temperature offset.
77 `f1ex=0`	Temperature exponent for `ucrit`.
78 `lamex=0 1/C`	Temperature parameter for `lambda` and `kappa`.
79 `trs=0 1/C`	Temperature parameter for source resistance.
80 `trd=0 1/C`	Temperature parameter for drain resistance.
81 `xti=3`	Saturation current temperature exponent.
82 `ptc=0 V/C`	Surface potential temperature coefficient.

83 `tcv=0 V/C` Threshold voltage temperature coefficient.

84 `pta=0 V/C` Junction potential temperature coefficient.

85 `ptp=0 V/C` Sidewall junction potential temperature coefficient.

86 `cta=0 1/C` Junction capacitance temperature coefficient.

87 `ctp=0 1/C` Sidewall junction capacitance temperature coefficient.

Default instance parameters

88 `w=3e-6 m` Default channel width.

89 `l=3e-6 m` Default channel length.

90 `as=0` m^2 Default area of source diffusion.

91 `ad=0` m^2 Default area of drain diffusion.

92 `ps=0 m` Default perimeter of source diffusion.

93 `pd=0 m` Default perimeter of drain diffusion.

94 `nrd=0 m/m` Default number of squares of drain diffusion.

95 `nrs=0 m/m` Default number of squares of source diffusion.

96 `ldd=0 m` Default length of drain diffusion region.

97 `lds=0 m` Default length of source diffusion region.

Noise model parameters

98 `kf=0` Flicker (1/f) noise coefficient.

99 `af=1` Flicker (1/f) noise exponent.

100 `ef=1` Flicker (1/f) noise frequency exponent.

101 `noisemod=1` Noise model selector.

The `imax` (`jmax`) parameter is used to aid convergence and prevent numerical overflow. The junction characteristics of the FET are accurately modeled for current (density) up to `imax` (`jmax`). For currents (density) above `imax` (`jmax`), the junction is modeled as a linear resistor and a warning is printed.

Output Parameters

1 `weff (m)`	Effective channel width.
2 `leff (m)`	Effective channel length.
3 `rseff (Ω)`	Effective source resistance.
4 `rdeff (Ω)`	Effective drain resistance.

Operating-Point Parameters

1 `type=n`	Transistor type. Possible values are `n` or `p`.
2 `region=triode`	Estimated operating region. Spectre outputs number (0-3) in a rawfile. Possible values are `off`, `triode`, `sat`, or `subth`.
3 `reversed`	Reverse mode indicator. Possible values are `no` or `yes`.
4 `id (A)`	Resistive drain current.
5 `vgs (V)`	Gate-source voltage.
6 `vds (V)`	Drain-source voltage.
7 `vbs (V)`	Bulk-source voltage.
8 `vth (V)`	Threshold voltage.
9 `vdsat (V)`	Drain-source saturation voltage.
10 `gm (S)`	Common-source transconductance.
11 `gds (S)`	Common-source output conductance.

12 `gmbs (S)`	Body-transconductance.
13 `gameff (√V )`	Effective body effect coefficient.
14 `betaeff (A/V`^{2}`)`	Effective beta.
15 `cbd (F)`	Drain-bulk junction capacitance.
16 `cbs (F)`	Source-bulk junction capacitance.
17 `cgs (F)`	Gate-source capacitance.
18 `cgd (F)`	Gate-drain capacitance.
19 `cgb (F)`	Gate-bulk capacitance.
20 `ron (Ω)`	On-resistance.
21 `ib (A)`	Resistive bulk current.
22 `pwr (W)`	Power at op point.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

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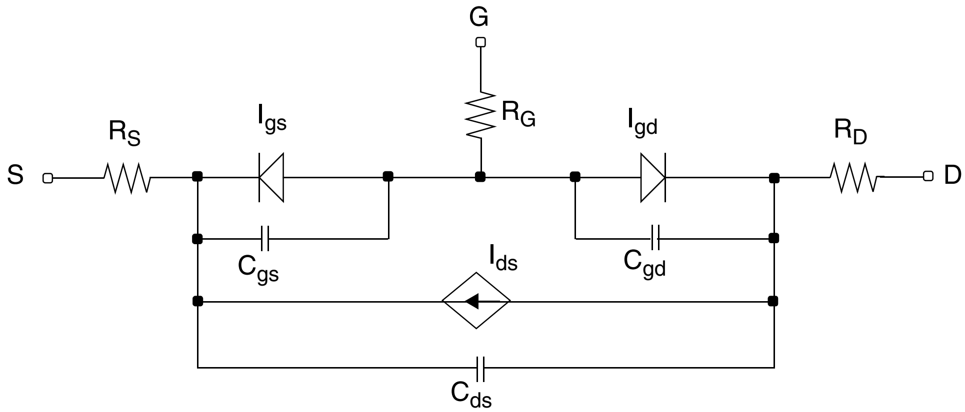
GaAs Model (gaas)

The GaAs MESFET model is derived from the model by H. Statz and others at Raytheon. The model is completely symmetric and is slightly modified to make it conserve charge. This chapter contains the following information for the GaAs MESFET model:



Note: The charge model in GaAs is a charge-conserving model. The capacitances are nonreciprocal.

$$V_{GST} \equiv V_{GS} - vto$$

$$V_{GDT} \equiv V_{GST} - V_{DS}$$

Drain Current for the Subthreshold Region

Note: This equation applies when $V_{GST} \leq 0$.

$$I_{DS} = 0$$

Drain Current for the Triode Region

Note: These equations apply when $V_{GST} \geq 0$, $V_{DS} \leq 3/alpha$.

$$I_{DS} = \frac{betaV_{GST}^2}{1 + bV_{GST}}(1 + lambdaV_{DS})(1 - Fac^3)$$

where

$$Fac = 1 - \frac{alphaV_{DS}}{3}$$

Drain Current for the Saturation Region

Note: This equation applies when $V_{GST} \geq 0$ and $V_{DS} \geq 3/alpha$.

$$I_{DS} = \frac{betaV_{GST}^2}{1 + bV_{GST}}(1 + lambdaV_{DS})$$

Gate Junction Currents

$$I_{GS(GD)} = \begin{cases} is\left(e^{\frac{V_{GS(GD)}}{nV_t}} - 1\right) & \text{if } V_{GS(GD)} \leq V_{Expl} \\ I_{offset} + G_{Expl}V_{GS(GD)} & \text{otherwise} \end{cases}$$

where V_t is the thermal voltage given by

$$V_t = \frac{kT}{q} \quad ,$$

$$V_{Expl} = nV_t \ln\left[1 + \frac{imelt}{is}\right]$$

is the forward explosion voltage,

$$G_{Expl} = \frac{(imelt + is)}{nV_t}$$

is the conductance at V_{Expl}, and

$$I_{offset} = imelt - V_{Expl}G_{Expl}$$

is the current linearly extrapolated to V = 0 from V_{Expl}.

Gate Junction Capacitance

$$C_{GS(V)} = \begin{cases} C_{gs,\,Fwd} & \text{if } V_{DS} \geq 1/alpha \\ cgs & \text{if } V_{DS} \leq -1/alpha \\ T_{fs}C_{gs,\,Fwd} + T_{fd}cgs & \text{otherwise} \end{cases}$$

$$C_{GD(V)} = \begin{cases} cgd & \text{if } V_{DS} \geq 1/alpha \\ C_{gd,\,Fwd} & \text{if } V_{DS} \leq -1/alpha \\ T_{fs}cgd + T_{fd}C_{gd,\,Fwd} & \text{otherwise} \end{cases}$$

where

$$C_{GS,\,Fwd} = \begin{cases} \dfrac{cgsV_{GST}}{2\sqrt{1 - V_{ps}/pb}\sqrt{V_{GST}^2 + delta^2}} & \text{if } V_{ps} \leq fc * pb \\ \dfrac{cgsV_{GST}}{2\sqrt{1 - fc}\sqrt{V_{GST}^2 + delta^2}} & \text{otherwise} \end{cases}$$

$$C_{GD,\,Fwd} = \begin{cases} \dfrac{cgdV_{GDT}}{2\sqrt{1 - V_{pd}/pb}\sqrt{V_{GDT}^2 + delta^2}} & \text{if } V_{pd} \leq fc * pb \\ \dfrac{cgdV_{GDT}}{2\sqrt{1 - fc}\sqrt{V_{GDT}^2 + delta^2}} & \text{otherwise} \end{cases}$$

$$V_{ps} \equiv \frac{1}{2}[V_{GS} + vto + \sqrt{V_{GST}^2 + delta^2}]$$

$$V_{pd} \equiv \frac{1}{2}[V_{GD} + vto + \sqrt{V_{GDT}^2 + delta^2}]$$

$$T_{fs} = \frac{1}{4}[2 + 3alphaV_{DS} - (alphaV_{DS})^3]$$

$$T_{fd} = 1 - T_{fs}$$

Temperature Effect

Junction Potential

$$pb = pb_{nom}\left(\frac{T}{Tnom}\right) - 3V_t\ln\left[\frac{T}{Tnom}\right] - E_{g,\,nom}\left(\frac{T}{Tnom}\right) + E_g$$

Gate Junction Current

$$is = is_{nom}\left(\frac{T}{Tnom}\right)^{xti}\exp\left[\frac{E_{g,\,nom}}{V_{t,\,nom}} - \frac{E_g}{V_t}\right]$$

where, if SPICE compatibility is required (set by the options),

$$E_g = 1.16 - \frac{7.02 \times 10^{-4}T^2}{1108 + T}$$

$$E_{g,\,nom} = 1.16 - \frac{7.02 \times 10^{-4}Tnom^2}{1108 + Tnom}$$

otherwise,

$$E_g = 1.17 - \frac{4.73 \times 10^{-4} T^2}{636 + T}$$

$$E_{g,\,nom} = 1.17 - \frac{4.73 \times 10^{-4} Tnom^2}{636 + Tnom}$$

Noise Model

Source Series Resistance Thermal Noise

$$\overline{i_{R_S}^2} = \frac{4kT}{rs} \Delta f$$

Drain Series Resistance Thermal Noise

$$\overline{i_{R_D}^2} = \frac{4kT}{rd} \Delta f$$

Channel Conductance Thermal and Flicker Noise

$$\overline{i_{DS}^2} = \frac{8kT(g_m + g_{ds})}{3}\left(\frac{3}{2} - \frac{V'_{DS}}{2V_{DSAT}}\right) + kf\frac{I_{DS}^{af}}{f}\Delta f$$

where

$$V'_{DS} = MAX(V_{DS}, V_{DSAT})$$

g_m is the transconductance, g_{ds} is the channel conductance, and kf and af are constants for a given device. The Virtuoso® Spectre® circuit simulator defaults for kf and af are 0.0 and 1.0, respectively.

Scaling Effects

The following are the Spectre scaling effects:

- *is*, *cgs*, *cgd*, and *beta* are multiplied by *area*.
- *rs* and *rd* are divided by *area*.
- All noises are multiplied by *area*.

Component Statements

This device is supported within altergroups.

There are some convergence problems with this model because of `Cgs` going to zero beyond pinchoff. The problems occur when the gate is driven from an inductive source, and there is no other capacitance at the gate. To prevent these problems, avoid setting `Cgd` to zero and add side wall capacitance to the gate-source and gate-drain junctions. A good estimate for these capacitors is C = pi*epsilon*w/2 where w is the gate width in microns and epsilon = 0.116 fF/micron.

Sample Instance Statement

```
m1 (1 2 0) nmes area=1 m=2
```

Sample Model Statement

```
model nmes gaas type=n vto=-2 beta=0.06 lambda=0 b=0.25 rs=3.65 alpha=1.9 rd=1.98
is=1.1e-9 n=1.28 fc=0.5 cgs=0.365e-12
```

Instance Definition

```
Name  d  g  s ModelName parameter=value ...
```

Instance Parameters

1 `area=1` Junction area factor.

2 `m=1` Multiplicity factor.

3 `isnoisy=yes` Should resistor generate noise.
Possible values are `no` or `yes`.

4 `region=fwd` Estimated operating region. Spectre outputs number (0-4) in a rawfile.
Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.

Model Definition

```
model modelName gaas parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

Drain current parameters

2 `vto=-2 V` Pinch-off voltage.

3 `beta=0.0001 A/V`^{2} Transconductance parameter.

4 `lambda=0 1/V` Channel length modulation parameter.

5 `b=0.3 1/V` Doping tail extending parameter.

6 `alpha=2 1/V` Saturation voltage parameter.

Parasitic resistance parameters

7 `rd=0 Ω` Drain resistance (/area).

8 `rs=0 Ω` Source resistance (/area).

9 `rg=0 Ω` Gate resistance (/area).

10 `minr=0.1 Ω` Minimum source/drain/gate resistance.

Junction diode model parameters

11 `is=1e-14 A` Gate saturation current (*area).

12 `n=1` Emission coefficient for the gate junction.

13 `imelt=`imax' A` Explosion current (*area).

14 `dskip=yes` Use simple piece-wise linear model for diode currents below 0.1*`iabstol`.
Possible values are `no` or `yes`.

Junction capacitance model parameters

15 `capmod=2` Charge model selector.

16 `cgs=0 F` Gate-source zero-bias junction capacitance (*area).

17 `cgd=0 F` Gate-drain zero-bias junction capacitance (*area).

18 `pb=1 V` Gate junction potential.

19 `fc=0.5` Junction capacitor forward-bias threshold.

20 `delta=0.2 V` Gate capacitance pinch-off transition width.

Temperature effects parameters

21 `tnom (C)` Parameters measurement temperature. Default set by options.

22 `trise=0 C` Temperature rise from ambient.

23 `xti=3` Temperature exponent for effect on `is`.

Operating region warning control parameters

24 `alarm=none` Forbidden operating region.
Possible values are `none`, `off`, `triode`, `sat`, `subth`, or `rev`.

25 `imax=1 A` Maximum allowable current (*area).

26 `bvj=∞ V` Junction reverse breakdown voltage.

Noise model parameters

27 `kf=0` Flicker noise (1/f) coefficient.

28 `af=1` Flicker noise (1/f) exponent.

Imax and Imelt:

The `imax` parameter aids convergence and prevents numerical overflow. The junction characteristics of the device are accurately modeled for current up to `imax`. If `imax` is exceeded during iterations, the linear model is substituted until the current drops below imax or until convergence is achieved. If convergence is achieved with the current exceeding `imax`, the results are inaccurate, and Spectre prints a warning.

A separate model parameter, `imelt`, is used as a limit warning for the junction current. This parameter can be set to the maximum current rating of the device. When any component of the junction current exceeds `imelt`, note that base and collector currents are composed of many exponential terms, Spectre issues a warning and the results become inaccurate. The junction current is linearized above the value of `imelt` to prevent arithmetic exception, with the exponential term replaced by a linear equation at `imelt`.

The `bv` parameter detects the junction breakdown only. The breakdown currents of the junctions are not modeled.

Operating-Point Parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

2 `region=fwd` Estimated operating region. Spectre outputs number (0-4) in a rawfile.
Possible values are `off`, `triode`, `sat`, `subth`, or `breakdown`.

3 `ids (A)` Resistive drain current.

4 `vth (V)` Threshold voltage.

5 `vgs (V)` Gate-source voltage.

6 `vds (V)` Drain-source voltage.

7 `vdsat (V)` Drain saturation voltage.

8 `gm (S)` Common-source transconductance.

9 `gds (S)` Common-source output conductance.

10 `cgs (F)` Gate-source capacitance.

11 `cgd (F)` Gate-drain capacitance.

12 `ig (A)` Resistive gate current.

13 `pwr (W)` Power at operating point.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

af M-28	delta M-20	lambda M-4	trise M-22
alarm M-24	dskip M-14	m I-2	type M-1
alpha M-6	fc M-19	minr M-10	type OP-1
area I-1	gds OP-9	n M-12	vds OP-6
b M-5	gm OP-8	pb M-18	vdsat OP-7
beta M-3	ids OP-3	pwr OP-13	vgs OP-5
bvj M-26	ig OP-12	rd M-7	vth OP-4
capmod M-15	imax M-25	region I-4	vto M-2

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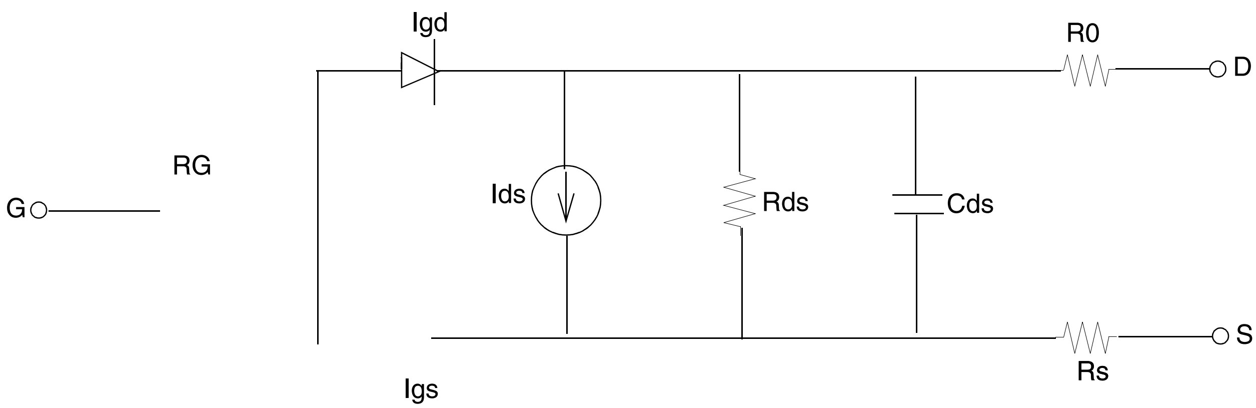
TriQuint Owned Models (tom2 and tom3/ tom3v1)

The TOM2 and TOM3/TOM3V1 models are developed by TriQuint. This chapter contains the following information for the two models:222

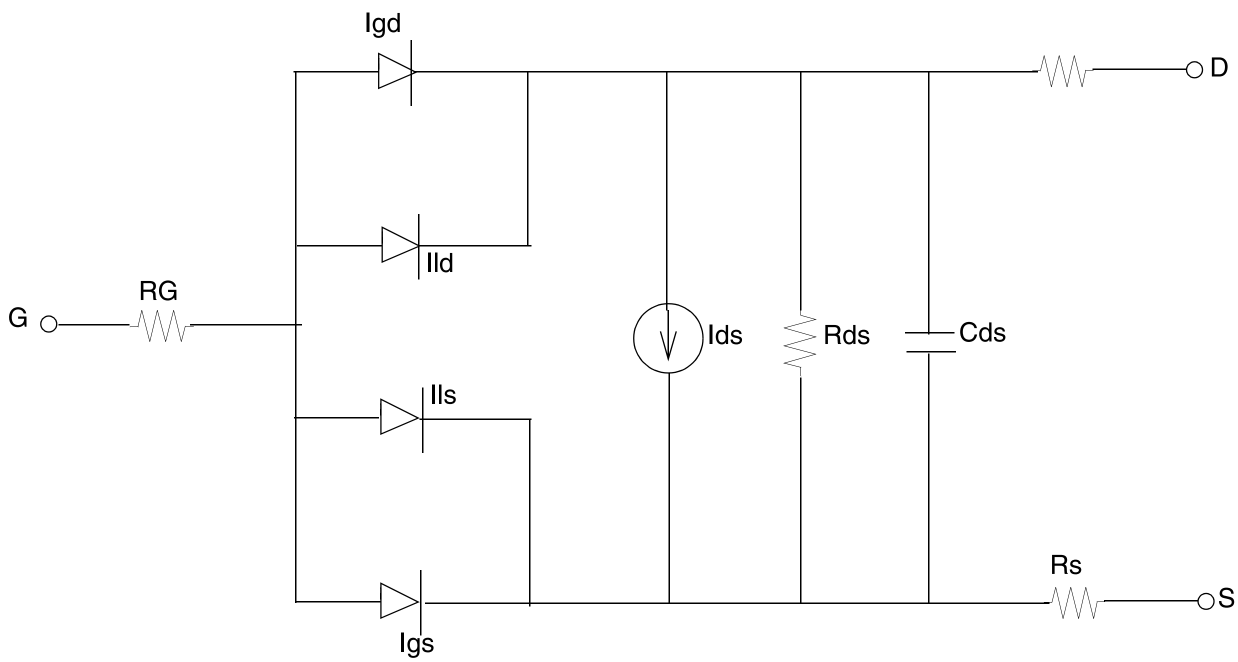
Circuit Diagrams

TOM2

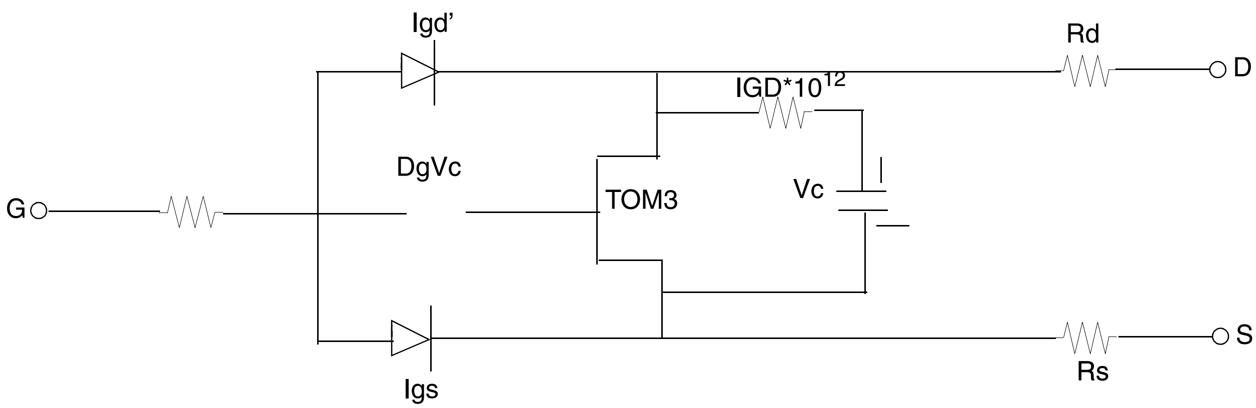


TOM3

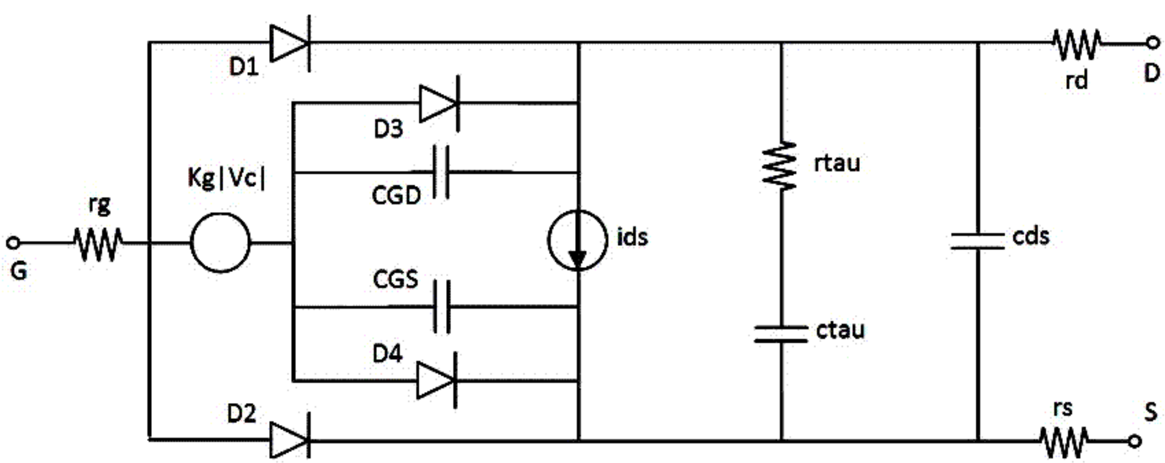
Spectre Implementation



TOM3 with SubCircuit



TOM3V1



Channel Current Ids

TOM2

$$I_{DS} = \frac{I_{ds0}}{1 + \delta V_{ds} I_{ds0}}$$

where

$$I_{ds0} = \beta V_{gsteff}{}^{Q}\frac{\alpha V_{ds}}{\sqrt{(\alpha V_{ds})^2 + 1}}$$

TOM3/TOM3V1

$$I_{DS} = I_0(1 + \lambda V_{ds})$$

where

$$I_0 = \beta(V_G)^Q f_k$$

$$f_k = \frac{\alpha V_{ds}}{\left[1 + (\alpha V_{ds})^k\right]^{1/k}}$$

$$V_G = QV_{ST}\log[1 + \exp(u)]$$

$$u = \frac{V_{GSI} - V_{TO} + \gamma V_{ds}}{QV_{ST}}$$

$$V_{ST} = V_{ST0}(1 + M_{ST0}V_{ds})$$

Gate Current Ig

TOM2

$$I_{gs} = I_s\left(e^{\frac{V_{gs}}{\eta V_T}} - 1\right)$$

$$I_{gd} = I_s\left(e^{\frac{V_{gd}}{\eta V_T}} - 1\right)$$

TOM3/TOM3V1

$$I_{gs} = I_s\left(e^{\frac{V_{gs}}{\eta V_T}} - 1\right)$$

$$I_{gd} = I_s\left(e^{\frac{V_{gd}}{\eta V_T}} - 1\right)$$

$$I_{ls} = I_{LK}\left(1 - e^{\frac{-V_{gsi}}{\varphi LK}}\right)$$

$$I_{ld} = I_{LK}\left(1 - e^{\frac{-V_{gdi}}{\varphi LK}}\right)$$

Gate Capacitance

TOM2

In the TOM2 model, the calculation of capacitances follows the Statz charge model.

$$C_{gs} = \frac{C_{gs0}(T)}{\sqrt{1 - V_1/(V_{bi}(T))}}F_1F_2 + C_{gs0}(T)F_3$$

$$C_{gd} = \frac{C_{gd0}(T)}{\sqrt{1 - V_1/(V_{bi}(T))}}F_1F_2 + C_{gd0}(T)F_3$$

where

$$F_1 = 0.5\frac{\partial V_2}{\partial x}\left(1 + \frac{V_2 - V_{toeff}}{\sqrt{(V_2 - V_{toeff})^2 + V_\delta^2}}\right)$$

$$x = V_{gs}, V_{gd}$$

$$F_2 = 0.5\left[1 + \frac{V_{gs} - V_{gd}}{\sqrt{(V_{gs} - V_{gd})^2 + (1/(\alpha(T)))^2}}\right]$$

$$F_3 = 1 - F_2$$

$$V_1 = \begin{matrix} A_1, A_1 < V_{max} \\ V_{max}, A_1 \geq V_{max} \end{matrix}$$

$$A_1 = 0.5\left[V_2 + V_{toeff} + \sqrt{(V_2 - V_{toeff})^2 + V_\delta^2}\right]$$

$$V_2 = 0.5\left[V_{gs} + V_{gd} + \sqrt{(V_{gs} - V_{gd})^2 + (1/(\alpha(T)))^2}\right]$$

TOM3/TOM3V1

In the TOM3 model, the low and high power capacitance is combined with a transition function.

High power gate charge/capacitance

$$Q_{GH} = Q_{GQH}\log\left(1 + \frac{I_{ds}}{Q_{GIO}}\right) + Q_{GSH}V_{GSI} + Q_{GDH}V_{GDI}$$

$$C_{GSH} = (g_m + g_{ds})\left(\frac{Q_{GQH}}{I_{ds} + Q_{GIO}}\right) + Q_{GSH}$$

$$C_{GDH} = -g_{ds}\left(\frac{Q_{GQH}}{I_{ds} + Q_{GIO}}\right) + Q_{GDH}$$

Low Power Gate Charge

$$Q_{GL} = qgl + Q_{GCL}(V_{GSI} + V_{GDI})$$

where

$$qgl = Q_{GQL}e^{[Q_{GAG}(V_{gsi} + V_{gdi})]}\cosh(Q_{GAD}Vds)$$

$$C_{GSL} = qgl[Q_{GAG} + Q_{GAD}\tanh(Q_{GAD}V_{ds})] + Q_{GCL}$$

$$C_{GDL} = qgl[Q_{GAG} - Q_{GAD}\tanh(Q_{GAD}V_{ds})] + Q_{GCL}$$

Transition Function

$$f_T = \exp[-Q_{GCB}I_{ds}V_{ds}]$$

The derivatives are as follows:

$$\frac{\partial f_T}{\partial V_{GSI}} = -Q_{GGB}[I_{ds} + (g_m + g_{ds})V_{ds}]f_T$$

$$\frac{\partial f_T}{\partial V_{GDI}} = Q_{GGB}[I_{ds} + g_{ds}V_{ds}]f_T$$

Combined Gate Charge/Capacitance

$$Q_{GG} = Q_{GL}f_T + Q_{GH}(1 - f_T) + Q_{GG0}(V_{GSI} + V_{GDI})$$

$$C_{GS} = C_{GSL}f_T + C_{GSH}(1 - f_T) + (Q_{GL} - Q_{GH})\left(\frac{\partial f_T}{\partial V_{GSI}}\right) + Q_{GG0}$$

$$C_{GD} = C_{GDL}f_T + C_{GDH}(1 - f_T) + (Q_{GL} - Q_{GH})\left(\frac{\partial f_T}{\partial V_{GDI}}\right) + Q_{GG0}$$

TOM3V1

capmod=1

$$I_{CGS} = CGS\frac{dV_{gm,si}}{dt}$$

$$I_{CGD} = CGD\frac{dV_{gm,di}}{dt}$$

capmod=2

$$I_{CGS} = \frac{1}{2}\frac{dQGG}{dt}$$

$$I_{CGD} = \frac{1}{2}\frac{dQGG}{dt}$$

Temperature Effect

$$\alpha(T) = \alpha_0 \cdot 1.01^{\alpha_{tce}\Delta T}$$

$$\Gamma(T) = \Gamma_0 + \Gamma_{tc}\Delta T$$

TOM2

$$V_{bi}(T) = V_{bi0} + V_{bitc}\Delta T$$

TOM3/TOM3V1

$$V_{st}(T) = V_{st}(T_{nom}) + T_{V_{st}}(T - T_{nom})$$

$$M_{st}(T) = M_{st}(T_{nom}) + T_{M_{st}}(T - T_{nom})$$

Noise Model

Source Resistance Thermal Noise

$$i_{R_s}^2 = \frac{4kT}{Rs}\Delta f$$

Drain Resistance Thermal Noise

$$i_{R_d}^2 = \frac{4kT}{Rd}\Delta f$$

Channel Conductance Thermal and Flicker Noise

$$i_{DS}^2 = \frac{8kT(g_m + g_{ds})}{3}\left(\frac{3}{2} - \frac{V'_{ds}}{2V_{DSAT}}\right) + k_f\frac{I_{DS}^{af}}{f}\Delta f$$

where

$$V'_{DS} = MAX(V_{DS}, V_{DSAT})$$

Gate Resistance Thermal Noise (TOM3V1)

$$i_{Rg}^2 = \frac{4kT}{Rd}\Delta f$$

Channel Conductance Thermal and Flicker Noise (TOM3V1)

$$i_{DS}^2 = 4kTg_m P + k_f \frac{I_{DS}^{af}}{f}\Delta f$$

Scaling Effects

The following are the Spectre scaling effects:

- is and $beta$ are multiplied by $area$.
- rs and rd are divided by $area$.
- All noises are multiplied by $area$.

New feature from TOM3 to TOM3v1

1. Added capmod to run a capacitance or charge based models for the gate-drain and gate-source reactance.
2. Noise implementation is enhanced.

Component Statements

TOM2

Sample Instance Statement

```
mt1 (2 1 0) tom2mos area=1 region=fwd
```

Sample Model Statement

```
model tom2mos tom2 vto=-0.55 alpha=3.9 beta=0.001 gamma=0.075 delta=100 ng=1 rd=550
rs=550 rg=1 is=0.295e-14 n=1.2 cgs=1.4e-15 cgd=2e-16 cds=3e-16
```

Instance Definition

```
Name  d  g  s ModelName parameter=value ...
```

Instance Parameters

1 `area=1` Junction area factor.

2 `m=1` Multiplicity factor.

3 `isnoisy=yes` Should resistor generate noise.
Possible values are `no` or `yes`.

4 `trise=0 C` Temperature rise from ambient.

5 `region=fwd` Estimated operating region. Spectre outputs number (0-3) in a rawfile.
Possible values are `off`, `triode`, `sat`, or `subth`.

Model Definition

```
model modelName tom2 parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

Drain current parameters

2 `vto=-2.5 V` Threshold voltage.

3 `alpha=2 1/V` Knee-voltage parameter.

4 `beta=0.1 A/V`^{2} Transconductance parameter.

5 `gamma=0 1/V`	Threshold shifting parameter.
6 `delta=0.2 V`	Output feedback parameter.
7 `q=2`	Power-law parameter.

Subthreshold parameters

8 `ng=0`	Subthreshold slope gate parameter.
9 `nd=0 1/V`	Subthreshold slope drain pull parameter.

Parasitic resistance parameters

10 `rd=0 Ω`	Drain resistance (/area).
11 `rs=0 Ω`	Source resistance (/area).
12 `rg=0 Ω`	Gate resistance (/area).
13 `minr=0.1 Ω`	Minimum source/drain/gate resistance.

Junction diode model parameters

14 `is=1e-14 A`	Gate diode saturation current (*area).
15 `n=1`	Emission coefficient for the gate junction.
16 `imelt=`imax' A`	Explosion current (*area).
17 `dskip=yes`	Use simple piece-wise linear model for diode currents below 0.1*`iabstol`. Possible values are `no` or `yes`.

Junction capacitance model parameters

18 `capmod=2`	Charge model selector.
19 `cgs=0 F`	Gate-source zero-bias junction capacitance (*area).

20 `cgd=0 F`	Gate-drain zero-bias junction capacitance (*area).
21 `cds=0 F`	Drain-to-source capacitance.
22 `vbi=1 V`	Gate diode built-in potential.
23 `vmax=0.95`	Gate diode capacitance limiting voltage.
24 `vdelta=0.2 V`	Capacitance transition voltage.
25 `tau=0 s`	Conduction current delay time.

Temperature effects parameters

26 `tnom (C)`	Parameters measurement temperature. Default set by options.
27 `xti=0`	Temperature exponent for effect on `is`.
28 `eg=1.11 V`	Energy band gap.
29 `vtotc=0 V/C`	Temperature coefficient for `vto`.
30 `vbitc=0 V/C`	Temperature coefficient for `vbi`.
31 `alphatce=0 1/C`	Temperature coefficient for `alpha`.
32 `betatce=0 1/C`	Temperature coefficient for `beta`.
33 `gammatc=0 1/C`	Temperature coefficient for `gamma`.
34 `trs1=0 1/C`	Temperature parameter for source resistance.
35 `trd1=0 1/C`	Temperature parameter for drain resistance.
36 `trg1=0 1/C`	Temperature parameter for gate resistance.
37 `cgdtce=0 1/C`	Drain junction capacitance temperature coefficient.
38 `cgstce=0 1/C`	Source junction capacitance temperature coefficient.

Operating region warning control parameters

39 `imax=1 A`	Maximum allowable current (*area).
40 `bvj=∞ V`	Junction reverse breakdown voltage.

Noise model parameters

41 `kf=0`	Flicker (1/f) noise coefficient.
42 `af=1`	Flicker (1/f) noise exponent.
43 `kfd=0`	Flicker noise (1/f) coefficient for gate diodes.
44 `afg=1`	Flicker noise (1/f) exponent for gate diodes.

The `imax` parameter aids convergence and prevents numerical overflow. The junction characteristics of the FET are accurately modeled for currents up to `imax`. For currents above `imax`, the junction is modeled as a linear resistor and a warning is printed. The `bv` parameter detects the junction breakdown only. The breakdown currents of the junctions are not modeled.

Operating-Point Parameters

1 `type=n`	Transistor type. Possible values are `n` or `p`.
2 `region=fwd`	Estimated operating region. Spectre outputs number (0-3) in a rawfile. Possible values are `off`, `triode`, `sat`, or `subth`.
3 `vgs (V)`	Gate-source voltage.
4 `vds (V)`	Drain-source voltage.
5 `id (A)`	Drain current.
6 `ig (A)`	Gate current.
7 `ids (A)`	Drain-to-source current.
8 `gm (S)`	Common-source transconductance.

9 `gds (S)` Common-source output conductance.

10 `vth (V)` Threshold voltage.

11 `cgs (F)` Gate-source capacitance.

12 `cgd (F)` Gate-drain capacitance.

13 `cds (F)` Drain-source capacitance.

14 `pwr (W)` Power at op point.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

GaAs MESFET (tom3)

TOM3 stands for Triquint Own Model version-3. It is an improved GaAs MESFET developed by David H. Smith.

This device is supported within altergroups.

Sample Instance Statement

```
mt1 (2 1 0) tom3mos area=1 region=fwd
```

Sample Model Statement

```
model tom3mos tom3 vto=-0.55 alpha=3.9 beta=0.001 gamma=0.075 delta=100 rd=550
rs=550 rg=1 is=1.0e-30 cds=3e-16
```

Instance Definition

```
Name  d  g  s ModelName parameter=value ...
```

Instance Parameters

1	`area=1`	Junction area factor.
2	`m=1`	Multiplicity factor.
3	`isnoisy=yes`	Should resistor generate noise. Possible values are `no` or `yes`.

4 `region=triode` Estimated operating region.
Possible values are `off`, `triode`, `sat`, or `subth`.

5 `trise=0 C` Temperature rise from ambient.

Model Definition

```
model modelName tom3 parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

Drain current parameters

2 `vto=-2.5 V` Threshold voltage.

3 `alpha=2 1/V` Knee-voltage parameter.

4 `beta=0.1 A/V`^{2} Transconductance parameter.

5 `gamma=0 1/V` Threshold shifting parameter.

6 `lambda=0.0 V` Slope of drain characteristic.

7 `q=2` Power-law parameter.

8 `k=2.0` knee-function factor.

Subthreshold parameters

9 `vst=1 V` Subthreshold slope.

10 `mst=0 1/V` Subthreshold slope drain parameter.

Parasitic resistance parameters

11 `rd=0 Ω` Drain resistance (/area).

12 `rs=0 Ω` Source resistance (/area).

13 `rg=0 Ω` Gate resistance (/area).

14 `minr=0.1 Ω` Minimum source/drain/gate resistance.

Junction diode model parameters

15 `is=0.0 A` Gate diode saturation current (*area).

16 `n=1` Emission coefficient for the gate junction.

17 `imelt=`imax' A` Explosion current (*area).

18 `dskip=yes` Use simple piece-wise linear model for diode currents below 0.1*`iabstol`.
Possible values are `no` or `yes`.

19 `ilk=0.0 A` Gate leakage diode saturation current (*area).

20 `plk=1.0 V` Gate leakage diode potential.

Junction capacitance model parameters

21 `cds=0 F` Drain-to-source capacitance.

22 `tau=0 s` Conduction current delay time.

23 `qgqh=0.0` Charge parameter.

24 `qgsh=0.0` Charge parameter.

25 `qgdh=0.0` Charge parameter.

26 `qgio=1.0e-06` Charge parameter.

27 `qgql=0.0` Charge parameter.

28 `qgag=1.0` Charge parameter.

29 `qgad=1.0` Charge parameter.

30 `qgcl=0.0` Charge parameter.

31 `qggb=1.0` Charge parameter.

32 `qggo=0.0` Charge parameter.

Temperature effects parameters

33 `tnom (C)` Parameters measurement temperature. Default set by options.

34 `xti=0` Temperature exponent for effect on `is`.

35 `eg=1.11 V` Energy band gap.

36 `vtotc=0 V/C` Temperature coefficient for `vto`.

37 `alphatce=0 1/C` Temperature coefficient for `alpha`.

38 `betatce=0 1/C` Temperature coefficient for `beta`.

39 `gammatc=0 1/C` Temperature coefficient for `gamma`.

40 `trs1=0 1/C` Temperature parameter for source resistance.

41 `trd1=0 1/C` Temperature parameter for drain resistance.

42 `trg1=0 1/C` Temperature parameter for gate resistance.

43 `vsttc=0 1/C` Temperature coefficient for Vst.

44 `msttc=0 1/C` Temperature coefficient for Mst.

Operating region warning control parameters

45 `imax=1 A` Maximum allowable current (*area).

46 `bvj=∞ V` Junction reverse breakdown voltage.

Noise model parameters

47 `kf=0`	Flicker (1/f) noise coefficient.
48 `af=1`	Flicker (1/f) noise exponent.
49 `kfd=0`	Flicker noise (1/f) coefficient for gate diodes.
50 `afd=1`	Flicker noise (1/f) exponent for gate diodes.

The `imax` parameter aids convergence and prevents numerical overflow. The junction characteristics of the FET are accurately modeled for currents up to `imax`. For currents above `imax`, the junction is modeled as a linear resistor and a warning is printed. The `bv` parameter detects the junction breakdown only. The breakdown currents of the junctions are not modeled.

Operating-Point Parameters

1 `type=n`	Transistor type. Possible values are `n` or `p`.
2 `region=triode`	Estimated operating region. Possible values are `off`, `triode`, `sat`, or `subth`.
3 `vgs (V)`	Gate-source voltage.
4 `vds (V)`	Drain-source voltage.
5 `id (A)`	Drain current.
6 `ig (A)`	Gate current.
7 `ids (A)`	Drain-to-source current.
8 `gm (S)`	Common-source transconductance.
9 `gds (S)`	Common-source output conductance.
10 `vth (V)`	Threshold voltage.
11 `cgs (F)`	Gate-source capacitance.
12 `cgd (F)`	Gate-drain capacitance.

13 `cds (F)` Drain-source capacitance.

14 `qg (Coul)` Gate charge.

15 `qd (Coul)` Drain charge.

16 `qs (Coul)` Source charge.

17 `pwr (W)` Power at op point.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

af M-48	id OP-5	pwr OP-17	rg M-13
afd M-50	ids OP-7	q M-7	rs M-12
alpha M-3	ig OP-6	qd OP-15	tau M-22
alphatce M-37	ilk M-19	qg OP-14	tnom M-33
area I-1	imax M-45	qgad M-29	trd1 M-41
beta M-4	imelt M-17	qgag M-28	trg1 M-42
betatce M-38	is M-15	qgcl M-30	trise I-5
bvj M-46	isnoisy I-3	qgdh M-25	trs1 M-40
cds M-21	k M-8	qggb M-31	type M-1
cds OP-13	kf M-47	qggo M-32	type OP-1
cgd OP-12	kfd M-49	qgio M-26	vds OP-4

GaAs MESFET (TOM3V1)

TOM3_V1 stands for Triquint Own Model version-3. It is an improved GaAs MESFET.

This device is supported within altergroups.

Sample Instance Statement

```
mt1 (2 1 0) tom3v1mos w=5 ng=2 m=2
```

Sample Model Statement

```
model tom3v1mos tom3v1 vto=-1.9 alpha=2.8 beta=0.01 lambda=-0.044 gamma=0.2
q=2.5 k=3.5 vst=0.03 mst=0.1 ilk=5.0e-7 plk=2 kgamma=0.66 taugd=5.0e-9
ctau=5.0e-15 qgql=1.0e-16 qgqh=-3.0e-16 qgi0=3.0e-16 qgag=3.0 qgad=2.3
qggb=90.0 qgcl=3.0e-16 qgsh=5.0e-16 qgdh=1e-16 qgg0=3e-16 capmod=2 cds=0.26e-15
tau=3.0e-12 rd=0.01 rg=0.01 rgmet=0 rs=0.01 is=7.0e-12 eta=1.9
alphatce=6.7337e-3 gammatc=2.3e-3 msttc=2e-3 vsttc=0.00031 vtotc=-119e-6
betatce=1e-3 rdtc=3e-3 rstc=3e-3 xti=2.0 eg=1.91 p=0.5 af=1.3 kf=3.86e-11 ffe=2.0
```

Instance Definition

```
Name ( d g s ) ModelName <parameter=value> ...
```

Instance Parameters

1	m=1	Multiplicity factor.
2	w=50 um	Gate width.
3	ng=6	Number of gate fingers.
4	trise=0.0 C	Temperature rise from ambient.

Model Definition

```
model ModelName tom3v1 <parameter=value> ...
```

Model Parameters

1	tnom=25 C	Parameters measurement temperature.
2	vto=-2.0 V	Threshold voltage.
3	alpha=3.0 1/V	Knee-voltage parameter.
4	beta=0.05 A/V^q	Transconductance parameter.
5	lambda=0.0 1/V	Slope of drain characteristic.
6	gamma=0.1	Threshold shifting parameter.
7	q=2.0	Power-law parameter.
8	k=3.0	knee-function factor.
9	vst=0.05 V	Subthreshold slope.
10	mst=0.0 1/V	Subthreshold slope drain parameter.
11	ilk=1.0e-7 A/um	Gate leakage diode saturation current (/w).
12	plk=2.25 V	Gate leakage diode potential.
13	kgamma=0.33	Internal vcvs parameter.
14	taugd=1.0e-9 s	Time constant for Ctau.

15	ctau=1.0e-15 F	Drain-to-source dispersion capacitance.
16	qgql=5.0e-16 Coul/um	Charge parameter.
17	qgqh=-2.0e-16 Coul/um	Charge parameter.
18	qgi0=1.0e-16 A/um	Charge parameter.
19	qgag=1.0 1/V	Charge parameter.
20	qgad=1.0 1/V	Charge parameter.
21	qggb=100.0 um/W	Charge parameter.
22	qgcl=2.0e-16 F/um	Charge parameter.
23	qgsh=1.0e-16 F/um	Charge parameter.
24	qgdh=0.0 F/um	Charge parameter.
25	qgg0=0.0 F/um	Charge parameter.
26	capmod=1	Capacitance model selector.
27	cds=0.0 F	Drain-to-source capacitance.
28	tau=1.0e-12 s	Conduction current delay time.
29	rd=0.0 Ohm*um	Drain resistance (*w).
30	rg=0.0 Ohm*um	Gate resistance (*w).
31	rgmet=0.0 Ohm/um	Metal resistance in gate (/w).

32	rs=0.0 Ohm*um	Source resistance (*w).
33	is=1.0e-12 A/um	Gate diode saturation current (/w).
34	eta=1.0	Parameter for 'is'.
35	alphatce=7.7337e-3 1/C	
		Temperature parameter for `alpha'.
36	gammatc=0.0 1/C	Temperature parameter for `gamma'.
37	msttc=0.0 1/(V*C)	
		emperature parameter for 'mst'.
38	vsttc=0.0 V/C	Temperature parameter for 'vst'.
39	vtotc=-1.49e-4 V/C	
		Temperature parameter for `vto'.
40	betatce=0.0 1/C	Temperature coefficient for `beta'.
41	rdtc=0.0 1/C	Temperature parameter for rd.
42	rstc=0.0 1/C	Temperature parameter for rs.
43	xti=0.0	Temperature exponent for effect on `is'.
44	eg=1.11 V	Energy band gap.
45	p=0.32	White noise coefficient.
46	af=1.0	Flicker (1/f) noise exponent.
47	kf=0.0	Flicker (1/f) noise coefficient.
48	ffe=1.0	Flicker (1/f) noise coefficient..

Operating-Point Parameters

1	vgs (V)	Gate-source voltage.

2	vds (V)	Drain-source voltage.
3	id (A)	Drain current.
4	ig (A)	Gate current.
5	is (A)	Source current.
6	ids (A)	Drain-to-source current.
7	gm (S)	Common-source transconductance.
8	gds (S)	Common-source output conductance.
9	vth (V)	Threshold voltage.
10	cgs (F)	Gate-source capacitance.
11	cgd (F)	Gate-drain capacitance.
12	pwr (W)	Power at operating point.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

af M-46	gm OP-7	plk M-12	rgmet M-31
alpha M-3	id OP-3	pwr OP-12	rs M-32
alphatce M-35	ids OP-6	q M-7	rstc M-42
beta M-4	ig OP-4	qgad M-20	tau M-28
betatce M-40	ilk M-11	qgag M-19	taugd M-14

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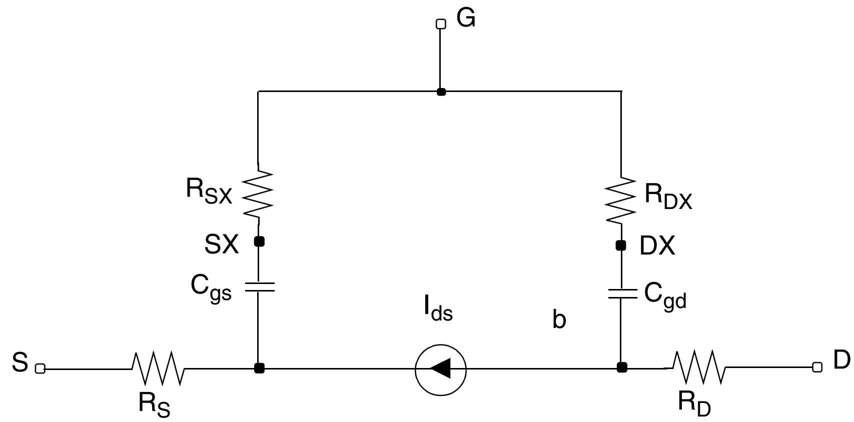
RPI TFT Models

The Poly-Si (PSITFT) and amorphous-Si (ATFT) TFT models are developed by the Semiconductor Devices Research Group at Rensselaer Polytechnic Institute (RPI). This chapter contains the following information for these models:

Poly-Si TFT Model (PSITFT)

Equivalent Circuit



Model Features

- Unified DC Model includes all four regimes for channel lengths down to 4 um
  - Leakage (thermionic emission)
  - Sub-threshold (diffusion like model)
  - Above threshold (c-Si like with m FET)
  - Kink (impact ionization with feedback)
- AC model accurately reproduces C_{gs} frequency dispersion
- Automatic scaling of model parameters to accurately model a wide range of device geometries.
- Above threshold
  - Based on the crystalline MOSFET Model
  - Field effect mobility becomes a funcion of gate bias
  - Field effect mobility accounts for trap states
- Sub-threshold
  - Diffusion like model

- Leakage Current
  - Reverse bias drain current function of
    - Electric field near drain
    - Temperature
  - Independent of channel length

Channel Width and Length

$$w = \begin{cases} w \cdot Wmlt + Xw - 2Wd \text{ , if ACM is given} \\ w \text{ , if ACM is not given} \end{cases}$$

$$l = \begin{cases} l \cdot Lmlt + Xl - 2Ld \text{ , if ACM is given} \\ l \text{ , if ACM is not given} \end{cases}$$

Drain and Source Parasitic Resistance

If ACM is not given,

$$rd = \begin{cases} rd \text{ , if rd is given} \\ rsh \cdot nrd \text{ , otherwise} \end{cases}$$

$$rs = \begin{cases} rs \text{ , if rs is given} \\ rsh \cdot nrs \text{ , otherwise} \end{cases}$$

ACM=0:

$$rd = \begin{cases} nrd \cdot rsh + rdc \text{ , if } (nrd \cdot rsh) > 0 \\ rd + rdc \text{ , otherwise} \end{cases}$$

$$rs = \begin{cases} nrs \cdot rsh + rsc \text{ , if } (nrs \cdot rsh) > 0 \\ rs + rsc \text{ , otherwise} \end{cases}$$

If ACM=1,

$$rd = (Ld + Ldif) \cdot rd/w + nrd \cdot rsh + rdc$$

$$rs = (Ld + Ldif) \cdot rs/w + nrs \cdot rsh + rsc$$

If ACM=2, 3,

$$rd = \begin{cases} (Ld + Ldif) \cdot rd/w + nrd \cdot rsh + rdc \text{ , if nrd is given} \\ rdc + \dfrac{Hdif \cdot rsh + (Ld + Ldif) \cdot rd}{w} \text{ , otherwise} \end{cases}$$

$$rs = \begin{cases} (Ld + Ldif) \cdot rs/w + nrs \cdot rsh + rsc \text{ , if nrd is given} \\ rsc + \dfrac{Hdif \cdot rsh + (Ld + Ldif) \cdot rs}{w} \text{ , otherwise} \end{cases}$$

Threshold Voltage

$$V_{TH} = V_{thx} - \frac{at \cdot V_{ds}^{2} + bt}{l \cdot \left(1 + e^{\left(\frac{V_{gs} - V_{thx} - vsigmat}{vsigma}\right)}\right)}$$

Effective Mobility

$$mueff = mus + \frac{mufet}{1 + \dfrac{theta}{tox} \cdot V_{gte}}$$

$$\frac{1}{mufet} = \frac{1}{mu0} + \frac{1}{\mu_1 \cdot \left(\dfrac{2 \cdot V_{gte}}{eta_f \cdot V_t}\right)^{mmu}}$$

where

$$V_t = k \cdot T/q$$

$$V_{gte} = eta \cdot V_t \cdot \left(1 + \frac{\alpha_{sat} \cdot V_{gt}}{2 \cdot eta \cdot V_t} + \sqrt{delta^2 + \left[\frac{\alpha_{sat} \cdot V_{gt}}{2 \cdot eta \cdot V_t} - 1\right]^2}\right)$$

$$V_{gt} = V_{gs} - V_{th}$$

Unified Electron Sheet Charge Density Per Unit Area

$$eta_f = \frac{eta}{1 + meta \cdot reta \cdot \frac{i1}{1 + i1}}$$

where

$$reta = (eta - 1)/(eta)$$

$$i1 = Kinkfac \cdot (V_{ds} - V_{dse}) \cdot e^{-vkink/(V_{ds} - V_{dse})}$$

$$Kinkfac = A_{kink} \cdot w/l$$

$$A_{kink} = \frac{(lkink/l)^{mkink}}{vkink}$$

$$V_{dse} = \frac{V_{ds}}{\left(1 + \left(\frac{V_{ds}}{V_{dsat}}\right)^{mss}\right)^{1/mss}}$$

where

$$V_{sat} = V_{gte}$$

$$n_s = 2 \cdot n_0 \cdot \log\left(1 + \frac{1}{2} \cdot e^{\frac{V_{gt}}{etaf \cdot V_t}}\right)$$

$$n_0 = \frac{\varepsilon_{SiO_2} \cdot eta \cdot V_t}{2 \cdot q \cdot tox}$$

Channel Conductance

$$g_{ch} = \frac{g_{chi}}{1 + g_{chi} \cdot RT}$$

$$g_{chi} = q \cdot \frac{w}{l} \cdot mueff \cdot n_s$$

Saturation Voltage

$$V_{DSAT} = \frac{Isat}{g_{ch}}$$

$$I_{sat} = \frac{g_{chi} \cdot V_{gte}}{\left(1 + \frac{V_{gte}}{V_l}\right) + g_{chi} \cdot RSS + \sqrt{1 + 2 \cdot RSS \cdot g_{chi} + (1 + V_{gte}/V_l)^2}}$$

$$V_l = \frac{vmax \cdot l}{mueff}$$

Channel Current

$$i_{choo} = \frac{g_{ch} \cdot V_{ds} \cdot (1 + lambda \cdot V_{ds})}{\left[1 + \left(\frac{Vds}{V_{dsat}}\right)^{me}\right]^{1/(me)}}$$

$$V_{satnew} = \frac{2 \cdot vmax \cdot l \cdot q \cdot (n_s - i_{choo} \cdot CRC)}{q \cdot (n_s - i_{choo} \cdot CRC) \cdot mueff + 2 \cdot vmax \cdot l \cdot \frac{C_{ox}}{\alpha_{sat}}}$$

where

$$C_{ox} = \frac{\varepsilon_{SiO_2}}{tox}$$

If Isubmod=1

lambda=0

$$I_{ds} = \frac{i_{choo}}{1 - deltal/l}$$

$$deltal = \frac{ls \cdot \ln\left(1 + \frac{V_{disi} - V_{dsenew}}{vp}\right) / (\ln(10))}{1 + \frac{V_{dsenew}}{V_p} + w \cdot CRL \cdot mueff \cdot V_{dsenew}}$$

$$V_{disi} = V_{ds} - i_{choo} \cdot RT$$

$$V_{dsenew} = \frac{V_{disi}}{\left(1 + \left(\frac{V_{disi}}{V_{satnew}}\right)^{mss}\right)^{1/mss}}$$

else

$$I_{ds} = i_{choo}$$

Kink Effect Current

$$I_{kink} = A_{kink} \cdot I_{ds} \cdot (V_{ds} - V_{dsenew}) \cdot e^{\left(-\frac{vkink}{V_{ds} - V_{dsenew}}\right)}$$

Kink effect current is added to the drain current

Subthreshold Leakage Current

$$I_{leak} = clk \cdot w \cdot \left[e^{\frac{blk \cdot V_{ds}}{V_t}} - 1\right] \cdot [X_{TFE} + X_{TE}] + I_{diode}$$

$$X_{TFE} = \frac{X_{TFE, lo} \cdot X_{TFE, hi}}{X_{TFE, lo} + X_{TFE, hi}}$$

$$X_{TE} = e^{-W_C}$$

$$W_C = (E_c - E_t)/(k \cdot T) = 0.55eV/(k \cdot T)$$

$$X_{TFE,lo} = \begin{cases} \frac{4\sqrt{\pi}}{3} \cdot f \cdot e^{\left(\frac{4}{27} \cdot f^2 - W_C\right)} & \text{for f <= flo} \\ X_{TFE,lo}(f_{lo}) \cdot e^{\left[\left(\frac{1}{f_{lo}} + \frac{8}{27} \cdot f_{lo}\right) \cdot (f - f_{lo})\right]} & \text{for f > flo} \end{cases}$$

$$f = \frac{1}{2} \cdot FMIN \cdot \left(1 + \frac{f_0}{FMIN} + \sqrt{delta^2 + \left(\frac{f_0}{FMIN} - 1\right)^2}\right)$$

where FMIN=0.0001

$$f_0 = \left(\frac{V_{ds}}{dd} - \frac{V_{gs} - vfb}{dg}\right)/F_0$$

where

$$F_0 = (k \cdot T)^{3/2} \cdot \frac{4}{3} \cdot \frac{2\pi\sqrt{2m}}{qh}$$

$$m = 0.27 \cdot m_0$$

$$f_{lo} = \frac{3}{2} \cdot (\sqrt{W_C + 1} - 1)$$

$$X_{TFE,hi} = \begin{cases} \frac{2 \cdot W_c}{3} \cdot e^{\left(1 - \frac{2 \cdot W_C}{3}\right)} & \text{for f <= fhi} \\ \left(1 - \frac{W_c^{1/3}}{2 \cdot f}\right)^{-1} \cdot e^{\left(\frac{-W_C^{3/2}}{f}\right)} & \text{for f > fhi} \end{cases}$$

$$f_{hi} = 3 \cdot \left(\frac{W_C^{3/2}}{2 \cdot W_C - 3}\right)$$

$$I_{diode} = i00 \cdot w \cdot e^{\left(\frac{eb}{k \cdot T}\right)} \cdot \left[1 - e^{\left(-\frac{V_{ds}}{V_t}\right)}\right]$$

Parasitic Resistance Dependence

If intdsnod=0 , extrinsic characteristics are used.

$$RSS = rs$$

$$RT = rs + rd$$

$$CRC = C_{ox} \cdot rd / q$$

$$CRL = C_{ox} \cdot rs / l$$

Else, intrinsic characteristics are used.

$$RSS = RT = CRC = CRL = 0.0$$

Gate-Drain/Source Resistance

$$\frac{1}{R_{ch}} = \frac{dI_d}{dV_{ds}}$$

If rsx is not specified,

$$rsx = \left.\frac{Rch}{kss}\right|_{V_{ds} = 0V}$$

If rdx is not specified

$$rdx = \left.\frac{Rch}{kss}\right|_{V_{ds}}$$

Temperature Dependence

$$V_{thx} = vto - dvto \cdot (T - T_{nom})$$

$$\mu_1 = mu1 + dmu1 \cdot (T - T_{nom})$$

$$\alpha_{sat} = asat - \frac{lasat}{l} - dasat \cdot (T - T_{nom})$$

Capacitance

When `capmod=0`,

$$C_{gs} = C_f + \frac{2}{3} \cdot C_{gcs} \cdot \left[1 - \left(\frac{V_{dsat} - V_{dse}}{2 \cdot V_{dsat} - V_{dse}}\right)^2\right]$$

$$C_{gd} = C_f + \frac{2}{3} \cdot C_{gcd} \cdot \left[1 - \left(\frac{V_{dsat}}{2 \cdot V_{dsat} - V_{dse}}\right)^2\right]$$

$$C_f = \frac{1}{2} \cdot \varepsilon_{si} \cdot w$$

$$C_{gcs} = \frac{w \cdot l \cdot \varepsilon_{SiO_2} / tox}{1 + etac0 \cdot e^{\left(-\frac{V_{gt}}{etac0 \cdot V_t}\right)}}$$

$$C_{gcd} = \frac{w \cdot l \cdot \varepsilon_{SiO_2} / tox}{1 + \eta_{cd} \cdot e^{\left(-\frac{V_{gt} - V_{dse}}{\eta_{cd} \cdot V_t}\right)}}$$

$$\eta_{cd} = etac0 + etac00 \cdot V_{dse}$$

$$V_{dsex} = \frac{V_{ds}}{\left(1 + \left(\frac{V_{ds}}{V_{dsat}}\right)^{mc}\right)^{1/mc}}$$

$$V_{gt} = Vgs - Vthx$$

When `capmod=1`

If `ZEROC=1`,

$$C_{gcs} = C_{gcd} = 0$$

If `ZEROC=0`,

$C_{gs} = C_{gd} = 0$ if $V_{gt} < -\frac{phi}{2}$ where $phi = 0.6$

$C_{gs} = w \cdot l \cdot \varepsilon_{SiO_2} / tox \cdot \left(\frac{4 \cdot V_{gt}}{3 \cdot phi} + \frac{2}{3}\right)$ $C_{gd} = 0$ if $\frac{-phi}{2} \le V_{gt} < 0$

if $V_{gt} < -\frac{phi}{2}$

$$\begin{cases} C_{gs} = \dfrac{2 \cdot w \cdot l \cdot \varepsilon_{SiO_2}}{3 \cdot tox}, C_{gd} = 0, V_{ds} \ge V_{dsat} \\ C_{gs} = \dfrac{2 \cdot w \cdot l \cdot \varepsilon_{SiO_2}}{3 \cdot tox} \cdot \left[1 - \left(\dfrac{V_{dsat} - V_{dse}}{2 \cdot V_{dsat} - V_{dse}}\right)^2\right], C_{gs} = \dfrac{2 \cdot w \cdot l \cdot \varepsilon_{SiO_2}}{3 \cdot tox} \cdot \left[1 - \left(\dfrac{V_{dsat}}{2 \cdot V_{dsat} - V_{dse}}\right)^2\right] \\ V_{ds} < V_{dsat} \end{cases}$$

When `capmod=2`

Charge conservation capacitance model

$$V_{gsteff, cv} = noff \cdot eta \cdot V_t \cdot log\left(1 + e^{\left(\frac{V_{gs} - V_{thx} - voffcv}{noff \cdot eta \cdot V_t}\right)}\right)$$

$V_{gs} = V_{sxs}$ for Qs evaluation

$V_{gs} = V_{dxs}$ for Qd evaluation

$$V_{dsat, cv} = \frac{V_{gsteff, cv}}{A_{sat}}$$

$$A_{sat} = \left(1 + \left(\frac{CLC}{L_{activ}}\right)^{CLE}\right) / \alpha_{sat}$$

$$V_{cveff} = V_{dsat,cv} - 0.5\left(V_4 + \sqrt{V_4^2 + 4\delta_4 V_{dsat,cv}}\right)$$

where

$$V_4 = V_{dsat,cv} - V_{ds} - \delta_4$$

$$\delta_4 = 0.02$$

$$L_{active} = l \cdot LMLT + XL - 2DLC$$

$$W_{active} = w \cdot WMLT + XW - 2DWC$$

$$Q_g = -W_{active} \cdot L_{active} \cdot \varepsilon_{SiO_2}/tox\left(\left(V_{gsteff,cv} - \frac{1}{2}V_{cveff}\right) + \frac{A_{sat}V^2{}_{cveff}}{12\left(V_{gsteff,cv} - \frac{A_{sat}}{2}V_{cveff}\right)}\right)$$

$$Q_s = -\left(\frac{W_{active} \cdot L_{active} \cdot \varepsilon_{SiO_2}/tox}{2\left(V_{gsteff,cv} - \frac{A_{sat}}{2}V_{cveff}\right)^2}\left(V^3_{gsteff,cv} - \frac{1}{3}V^2_{gsteff,cv}V_{cveff} - V^2_{gsteff,cv}A_{sat}V_{cveff} + \right.\right.$$

$$\left.\left.\frac{5}{12}V_{gsteff,cv}A_{sat}V^2{}_{cveff} + \frac{1}{4}V_{gsteff,cv}(A_{sat}V_{cveff})^2 - \frac{2}{15}(A_{sat}V_{cveff})^2 V_{cveff}\right)\right)$$

$$Q_d = -\left(\frac{W_{active} \cdot L_{active} \cdot \varepsilon_{SiO_2}/tox}{2\left(V_{gsteff,cv} - \frac{A_{sat}}{2}V_{cveff}\right)^2}\left(V^3_{gsteff,cv} - \frac{2}{3}V^2_{gsteff,cv}V_{cveff} - V^2_{gsteff,cv}A_{sat}V_{cveff} + \right.\right.$$

$$\left.\left.\frac{3}{4}V_{gsteff,cv}A_{sat}V^2{}_{cveff} + \frac{1}{4}V_{gsteff,cv}(A_{sat}V_{cveff})^2 - \frac{1}{5}(A_{sat}V_{cveff})^2 V_{cveff}\right)\right)$$

$$Q_{sx} = -Q_s\, Q_{dx} = -Q_d$$

$$Q_{dx} = -Q_d$$

$$C_{ss} = \frac{dQ_s}{dV_s}\ C_{sd} = \frac{dQ_s}{dV_d}\ C_{ssx} = \frac{dQ_s}{dV_{sx}}\ C_{sdx} = 0$$

$$C_{ds} = \frac{dQ_d}{dV_s}\ C_{dd} = \frac{dQ_d}{dV_d}\ C_{ddx} = \frac{dQ_d}{dV_{dx}}\ C_{dsx} = 0$$

$$C_{sxs} = \frac{dQ_{sx}}{dV_s}\ C_{sxd} = \frac{dQ_{sx}}{dV_d}\ C_{sxsx} = \frac{dQ_{sx}}{dV_{sx}}\ C_{sxdx} = 0$$

$$C_{dxs} = \frac{dQ_{dx}}{dV_s}\ C_{dxd} = \frac{dQ_{dx}}{dV_d}\ C_{dxdx} = \frac{dQ_{dx}}{dV_{dx}}\ C_{dxsx} = 0$$

$$C_{gs} = C_{sxs} + C_{dxs}\ C_{gd} = C_{dxd} + C_{sxd}\ C_{gg} = C_{gs} + C_{gd}$$

Overlap Capacitances

When `capmod=2`

$$OverlapC_{gs} = Cgso \cdot W_{active}$$

$$OverlapC_{gd} = Cgdo \cdot W_{active}$$

For other values of `capmod`

If Acm parameter is given,

$$OverlapC_{gs} = \begin{cases} (w + 2Wd) \cdot Cgso\text{ , if Cgso is given} \\ (w + 2Wd) \cdot (Ld + Meto) \cdot \varepsilon_{SiO_2}/tox\text{, if Cgso is not given} \end{cases}$$

$$OverlapC_{gd} = \begin{cases} (w + 2Wd) \cdot Cgdo\text{ , if Cgdo is given} \\ (w + 2Wd) \cdot (Ld + Meto) \cdot \varepsilon_{SiO_2}/tox\text{, if Cgdo is not given} \end{cases}$$

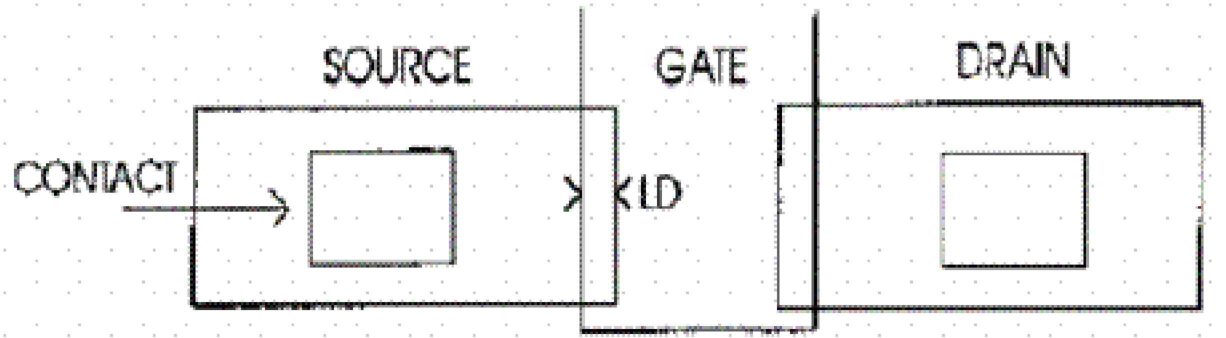
Else,

$$OverlapC_{gs} = w \cdot Cgso$$

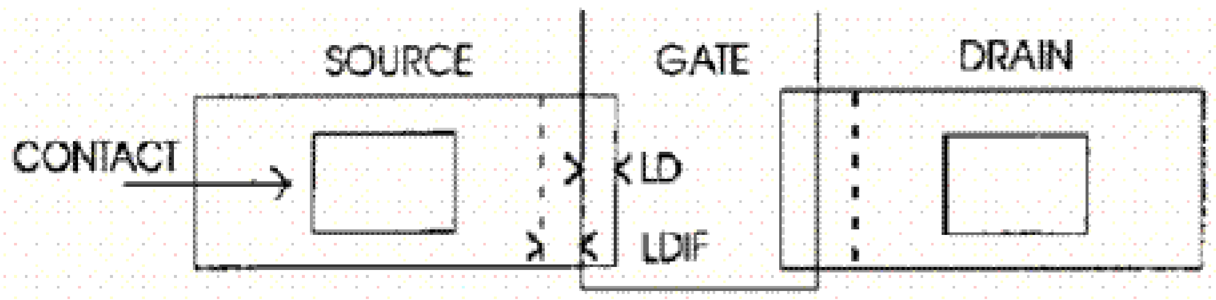
$$OverlapC_{gd} = w \cdot Cgdo$$

ACM Option

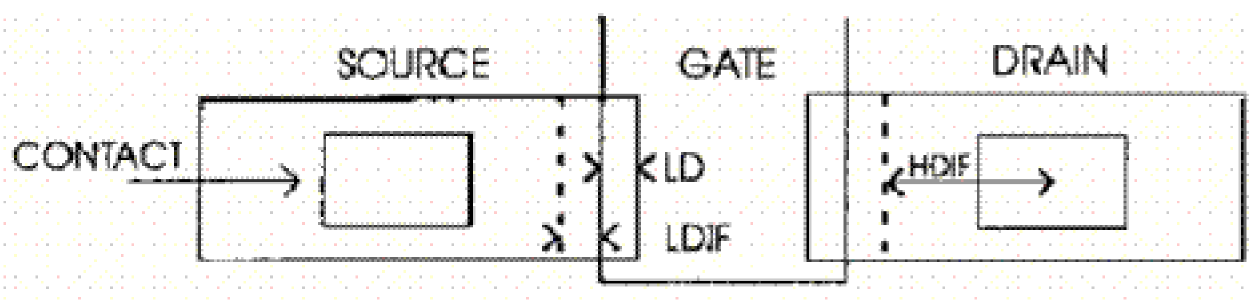
When ACM=0



When ACM=1



When ACM=2



Scaling Effects

For scaling effects, see Scaling Factors (scale and scalem) on page 242.

Component Statements

This device is supported within altergroups.

Sample Instance Statement

```
m4 (0 2 1 1) nch w=2u l=0.8u
```

Sample Model Statement

```
model nch psitft type=p
```

Instance Definition

```
Name  d  g  s  [b]  [t] ModelName parameter=value ...
```

Instance Parameters

1 `w (m)`	Channel width.
2 `l (m)`	Channel length.
3 `nrd (m/m)`	Drain squares.
4 `nrs (m/m)`	Source squares.
5 `m=1`	Multiplicity factor (number of MOSFETs in parallel).
6 `region=triode`	Estimated operating region. Possible values are `off`, `triode`, `sat`, or `subth`.
7 `isnoisy=yes`	Should resistor generate noise. Possible values are `no` or `yes`.
8 `rth0 (Ω)`	Thermal resistance.
9 `cth0 (F)`	Thermal capacitance.
10 `nseg=1 m/m`	Number of segments for channel width partitioning.

Model Definition

```
model modelName psitft parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

Drain current model parameters

2 `vto=0 V` Threshold voltage at zero body bias (BIN).

3 `lambda=0.048 1/V` Channel length modulation parameter (BIN).

4 `tox=1e-7 m` Gate oxide thickness.

5 `eta=7` Subthreshold ideality factor (BIN).

6 `etai` Alias to eta (BIN).

7 `asat=1` Proportionality constant of Vsat (BIN).

8 `alphasat` Alias to asat (BIN).

9 `delta=4` Transition width parameter (BIN).

10 `mus=1` cm^2`/V s` Subthreshold mobility (BIN).

11 `mu0=100` cm^2`/V s` High field mobility (BIN).

12 `muo (`cm^2`/V s)` Alias to mu0 (BIN).

13 `mu1=0.004` cm^2`/V s`
Low field mobility parameter (BIN).

14 `mmu=1.7` Low field mobility exponent (BIN).

15 `m` Alias to mmu (BIN).

16 `vfb=-0.1 V` Flat band voltage (BIN).

17 `dd=1400e-10 m` Vds field constant (BIN).

18 `dg=2000e-10 m`	Vds field constant (BIN).
19 `blk=0.001`	Leakage barrier lowering constant (BIN).
20 `clk=6 A/m`	Leakage scaling constant (BIN).
21 `i0=6.0 A/m`	Alias of clk (BIN).
22 `lkink=19e-6 m`	Kink effect constant (BIN).
23 `mkink=1.3`	Kink effect exponent (BIN).
24 `mk=1.3`	Alias of mkink (BIN).
25 `vkink=9.1 V`	Kink effect voltage (BIN).
26 `rs=0 Ω`	Source resistance.
27 `rd=0 Ω`	Drain resistance.
28 `rsx=0 Ω`	Resistance in series with Cgs.
29 `rdx=0 Ω`	Resistance in series with Cgd.
30 `at=3e-8 m/V`	DIBL parameter 1 (BIN).
31 `bt=1.9e-6 m/V`	DIBL parameter 2 (BIN).
32 `eb=0.68 eV`	Barrier height of diode (BIN).
33 `i00=150 A/m`	Reverse diode saturation current (BIN).
34 `ioo (A/m)`	Alias to i00 (BIN).
35 `etac0`	Capacitance subthreshold ideality factor at zero drain bias (BIN).
36 `etac00=0 1/V`	Capacitance subthreshold coefficient of drain bias (BIN).
37 `mc=3`	Capacitance knee shape parameter (BIN).
38 `dvto=0 V/C`	Temperature coefficient of VTO (BIN).
39 dmu1=0 cm^2/V s C	Temperature coefficient of MU1 (BIN).

40 `dasat=0 1/C`	Temperature coefficient of ASAT (BIN).
41 `lasat=0 m`	Coefficient of length dependence of ASAT (BIN).
42 `von=0 V`	On-Voltage (BIN).
43 `cgso=0 F/m`	Gate-source overlap capacitance.
44 `cgdo=0 F/m`	Gate-drain overlap capacitance.
45 `vsigma=0.2 V`	Above threshold DIBL parameter (BIN).
46 `vsigmat=1.7 V`	Above threshold DIBL parameter (BIN).
47 `me=2.5`	Long channel saturation transition parameter (BIN).
48 `ms`	Alias to me (BIN).
49 `minme=2.0`	Minimum value of me parameter..
50 `meta=1`	ETA floating-body parameter (BIN).
51 `ls=35e-9 m`	Channel-length modulation coefficient 1 (BIN).
52 `vp=0.2 V`	Channel-length modulation coefficient 2 (BIN).
53 `isubmod=0`	Channel-length modulation model version.
54 `vmax=4e4 m/s`	Carrier saturation velocity (BIN).
55 `theta=0 1/V`	Mobility modulation coefficient (BIN).
56 `mss=1.5`	Vdse transition parameter (BIN).
57 `kss=0`	Fractions of the channel resistance coefficient.
58 `rsh=0 Ω/sqr`	Source/drain diffusion sheet resistance.
59 `capmod=0`	Intrinsic charge model.
60 `zeroc=0`	Zero gate-source (gate-drain) capacitance flag (Cgs=Cgd=0 if zeroc=1 and capmod=1).

61 `intdsnod=0` Intrinsic source and drain nodes usage flag.

62 `minr=0.1 Ω` Minimum source/drain resistance.

63 `version=2` Version control parameter. The available versions are 1, 2.

64 `compatible=spectre`
Spice compatible flag.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, or `sspice`.

65 `cdnver=1` Cadence version flag, 0 without improvement, 1 with improvement.

Temperature effects parameters

66 `tnom (C)` Parameter measurement temperature.

67 `trise=0 C` Temperature rise from ambient.

68 `shmod=0` Self-heating selector.

69 `cth0=0.0 F` Self-heating thermal capacitance.

70 `rth0=0 Ω` Self-heating thermal resistance.

71 `wth0=0.0 µm` Minimum width for thermal resistance calculation..

72 `tmax=500 C` Maximum device temperature above ambient.

Operating region warning control parameters

73 `alarm=none` Forbidden operating region.
Possible values are `none`, `off`, `triode`, `sat`, `subth`, or `rev`.

Default device parameters

74 `w=3e-6 m` Default channel width.

75 `l=3e-6 m` Default channel length.

76 `nrd=1 m/m` Default drain squares.

77 `nrs=1 m/m` Default source squares.

Auto Model Selector parameters

78 `wmax=1 m` Maximum channel width for which the model is valid.

79 `wmin=0 m` Minimum channel width for which the model is valid.

80 `lmax=1 m` Maximum channel length for which the model is valid.

81 `lmin=0 m` Minimum channel length for which the model is valid.

Acm related parameters

82 `acm=0` Area calculation method.

83 `xl=0.0 m` Accounts for masking and etching effects.

84 `xw=0.0 m` Accounts for masking and etching effects.

85 `ld (m)` Lateral diffusion into channel from source and drain diffusion.

86 `wd=0.0 m` Lateral diffusion into channel from bulk along width.

87 `lmlt=1.0` Length diffusion layer shrink reduction factor.

88 `wmlt=1.0` Width diffusion layer shrink reduction factor.

89 `ldif=0.0 m` Length of heavily doped diffusion adjacent to gate (BIN).

90 `hdif=0.0 m` Length of heavily doped diffusion from contact to lightly doped region.

91 `xj=1.5E-7 m` Metallurgical junction depth.

92 `meto=0.0 m` Fringing field factor for gate to source and gate to drain overlap capacitance.

93 `rdc=0.0 Ω` Additional drain resistance due to contact resistance.

94 `rsc=0.0 Ω` Additional source resistance due to contact resistance.

Capmod=2 related parameters

Special parameters of version 1

95 `dvt=0 V` The difference between von and the threshold (BIN).

96 `vsi=2.0 V` Above threshold DIBL parameter (BIN).

97 `vst=2.0 V` Above threshold DIBL parameter (BIN).

Binning parameters

98 `binunit=1` Bin parameter unit selector. 1 for microns and 2 for meters.

99 `binflag=0` Binflag=2 is to open xl/xw binning.

Length dependent parameters (Not listed)

Width dependent parameters (Not listed)

Cross-term dependent parameters (Not listed)

Output Parameters

1 `rtheff (Ω)` Effective thermal resistance.

2 `Ctheff (F)` Effective thermal capacitance.

3 `weff (m)` Effective channel width.

4 `leff (m)` Effective channel length.

5 `rseff (m)` Effective source resistance.

6 `rdeff (m)` Effective drain resistance.

Operating-Point Parameters

1	`type=n`	Transistor type. Possible values are `n` or `p`.
2	`region=triode`	Estimated operating region. Possible values are `off`, `triode`, `sat`, or `subth`.
3	`reversed`	Reverse mode indicator. Possible values are `no` or `yes`.
4	`ids (A)`	Resistive drain-to-source current (alias = lx4).
5	`vgs (V)`	Gate-source voltage (alias = lx2).
6	`vds (V)`	Drain-source voltage (alias = lx3).
7	`vth (V)`	Threshold voltage (alias = lv9).
8	`vdsat (V)`	Drain-source saturation voltage (alias = lv10).
9	`gm (S)`	Common-source transconductance (alias = lx7).
10	`gds (S)`	Common-source output conductance (alias = lx8).
11	`tdev (C)`	Temperature rise from ambient.
12	`cgd (F)`	Gate-drain capacitance (alias = lx19).
13	`cgs (F)`	Gate-source capacitance (alias = lx20).
14	`cgg (F)`	Cgg (only for capmod=2).
15	`css (F)`	Intrinsic capacitance dQs_dVs (only for capmod=2).
16	`csd (F)`	Intrinsic capacitance dQs_dVd (only for capmod=2).
17	`cssx (F)`	Intrinsic capacitance dQs_dVsx (only for capmod=2).
18	`csdx (F)`	Intrinsic capacitance dQs_dVdx (only for capmod=2).
19	`cds (F)`	Intrinsic capacitance dQd_dVs (only for capmod=2).

20 `cdd (F)` Intrinsic capacitance dQd_dVd (only for capmod=2).

21 `cdsx (F)` Intrinsic capacitance dQd_dVsx (only for capmod=2).

22 `cddx (F)` Intrinsic capacitance dQd_dVdx (only for capmod=2).

23 `csxs (F)` Intrinsic capacitance dQsx_dVs (only for capmod=2).

24 `csxd (F)` Intrinsic capacitance dQsx_dVd (only for capmod=2).

25 `csxsx (F)` Intrinsic capacitance dQsx_dVsx (only for capmod=2).

26 `csxdx (F)` Intrinsic capacitance dQsx_dVdx (only for capmod=2).

27 `cdxs (F)` Intrinsic capacitance dQdx_dVs (only for capmod=2).

28 `cdxd (F)` Intrinsic capacitance dQdx_dVd (only for capmod=2).

29 `cdxsx (F)` Intrinsic capacitance dQdx_dVsx (only for capmod=2).

30 `cdxdx (F)` Intrinsic capacitance dQdx_dVdx (only for capmod=2).

31 `cgso (F)` Gate-Source overlap capacitance.

32 `cgdo (F)` Gate-Drain overlap capacitance.

33 `qs (Coul)` Qs (only for capmod=2).

34 `qd (Coul)` Qd (only for capmod=2).

35 `qg (Coul)` Qg (only for capmod=2).

36 `qsx (Coul)` Charge of sx internal node (only for capmod=2).

37 `qdx (Coul)` Charge of dx internal node (only for capmod=2).

38 `ron (Ω)` On-resistance.

39 `id (A)` Resistive drain current.

40 `is (A)` Resistive source current.

41 `pwr (W)` Power at op point.

42 `igs (A)` Gate-to-source current.

43 `igd (A)` Gate-to-drain current.

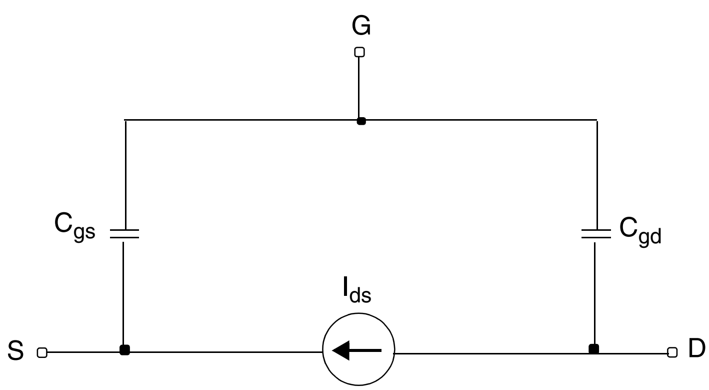
44 `i1 (A)` Resistive drain current.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Amorphous-Si TFT Model (ATFT)

Equivalent Circuit



Model Features

Features of the ATFT model include:

- The unified DC model covers all regimes of operation
- The model parameters are automatically scaled to accurately model a wide range of device geometries

- The modified charge control model includes induced charge trapped in localized states
- Above threshold includes:
  - Field effect mobility becoming a function of gate bias
  - Band mobility dominated by lattice scattering
- Below threshold includes:
  - Fermi level located in deep localized states
  - Realting position of fermi level, incluing deep DOS, back to the gate bias
- Emperical expression for current at large negative gate biases for hole-induced leakage current
- Temperature effects include:
  - Linear dependence of threshold voltage
  - Temperature activated field-effect mobility
  - Temperature activated leakage current
  - Dependence of subthreshold slope includinga possible back channel effect.

Drain Current

$$I_{ds} = I_{leakage} + I_{ab}$$

$$I_{leakage} = I_{hl} + I_{min}$$

where

$$I_{min} = sigma0 \cdot V_{ds}$$

$$I_{hl} = IOL\left[\exp\left(\frac{V_{ds}}{VDSL}\right) - 1\right]\exp\left(-\frac{V_{gs}}{VGSL}\right)\exp\left[\frac{EL}{q}\left(\frac{1}{V_{tho}} - \frac{1}{V_{th}}\right)\right]$$

$$I_{ab} = g_{ch}V_{dse}(1 + LAMBDA \cdot V_{ds})$$

$$V_{dse} = \frac{V_{ds}}{\left[1 + \left(\frac{V_{ds}}{V_{sate}}\right)^{M}\right]^{\frac{1}{M}}}$$

$$V_{sate} = \alpha_{sat} V_{gte}$$

$$g_{ch} = \frac{g_{chi}}{1 + g_{chi}(RS + RD)}$$

$$g_{chi} = q \cdot n_s \cdot MUBAND \cdot \frac{W}{L}$$

$$n_s = \frac{n_{sa} n_{sb}}{n_{sa} + n_{sb}}$$

$$n_{sa} = \frac{EPSI \cdot V_{gte}}{q \cdot TOX}\left(\frac{V_{gte}}{V_{aat}}\right)^{GAMMA}$$

$$n_{sb} = n_{so}\left(\frac{t_m}{TOX}\frac{V_{gfbe}}{V0}\frac{EPSI}{EPS}\right)^{\frac{2VO}{V}}$$

$$n_{so} = N_c t_m \frac{V_e}{V_0} \exp\left(-\frac{DEF0}{V_{th}}\right)$$

$$N_c = 3.0 \cdot 10^{25} m^{-3}$$

$$V_e = \frac{2 \cdot V_0 \cdot V_{tho}}{2 \cdot V0 - V_{th}}$$

$$t_m = \sqrt{\frac{EPS}{2q \cdot GMIN}}$$

$$V_{gte} = \frac{VMIN}{2}\left[1 + \frac{V_{gt}}{VMIN} + \sqrt{DELTA^2 + \left(\frac{V_{gt}}{VMIN} - 1\right)^2}\right]$$

$$V_{gt} = V_{gs} - V_T$$

$$V_{gfbe} = \frac{VMIN}{2}\left[1 + \frac{V_{gfb}}{VMIN} + \sqrt{DELTA^2 + \left(\frac{V_{gfb}}{VMIN} - 1\right)^2}\right]$$

$$V_{gfb} = V_{gs} - VFB$$

Drain and Source Parasitic Resistance

If ACM is not given,

$$rd = \begin{cases} rd \text{ , if rd is given} \\ rsh \cdot nrd \text{ , otherwise} \end{cases}$$

$$rs = \begin{cases} rs \text{ , if rs is given} \\ rsh \cdot nrs \text{ , otherwise} \end{cases}$$

ACM=0:

$$rd = \begin{cases} nrd \cdot rsh + rdc \text{ , if } (nrd \cdot rsh) > 0 \\ rd + rdc \text{ , otherwise} \end{cases}$$

$$rs = \begin{cases} nrs \cdot rsh + rsc \text{ , if } (nrs \cdot rsh) > 0 \\ rs + rsc \text{ , otherwise} \end{cases}$$

If ACM=1,

$$rd = (Ld + Ldif) \cdot rd/w + nrd \cdot rsh + rdc$$

$$rs = (Ld + Ldif) \cdot rs/w + nrs \cdot rsh + rsc$$

If ACM=2, 3,

$$rd = \begin{cases} (Ld + Ldif) \cdot rd/w + nrd \cdot rsh + rdc \text{ , if nrd is given} \\ rdc + \dfrac{Hdif \cdot rsh + (Ld + Ldif) \cdot rd}{w} \text{ , otherwise} \end{cases}$$

$$rs = \begin{cases} (Ld + Ldif) \cdot rs/w + nrs \cdot rsh + rsc \text{ , if nrd is given} \\ rsc + \dfrac{Hdif \cdot rsh + (Ld + Ldif) \cdot rs}{w} \text{ , otherwise} \end{cases}$$

Temperature Dependence

$$V_{tho} = k_B \cdot TNOM/q$$

$$V_{th} = k_B \cdot T/q$$

$$V_{aat} = VAA \cdot \exp\left[\frac{EMU}{q \cdot GAMMA}\left(\frac{1}{V_{th}} - \frac{1}{V_{tho}}\right)\right]$$

$$V_T = VTO + KVT(TEMP - TNOM)$$

$$\alpha_{sat} = ALPHASAT + KASAT(TEMP - TNOM)$$

Capacitance

$$C_{gs} = C_f + \frac{2}{3}C_{gc}\left[1 - \left(\frac{V_{sate} - V_{dse}}{2V_{sate} - V_{dse}}\right)\right]$$

$$C_{gd} = C_f + \frac{2}{3}C_{gc}\left[1 - \left(\frac{V_{sate}}{2V_{sate} - V_{dse}}\right)\right]$$

$$C_f = 0.5 \cdot EPS \cdot W$$

$$C_{gc} = q\frac{dn_{sc}}{dV_{gs} \cdot L_{eff} \cdot W_{eff}}$$

$$n_{sc} = \frac{n_{sac}n_{sbc}}{n_{sac} + n_{sbc}}$$

$$n_{sac} = \frac{EPSI \cdot V_{gte}}{q \cdot TOX}$$

$$n_{sbc} = n_{sb}$$

Scaling Effects

For scaling effects, see Scaling Factors (scale and scalem) on page 242.

Component Statements

This device is supported within altergroups.

Sample Instance Statement:

```
m4 (0 2 1 1) nch w=2u l=0.8u
```

Sample Model Statement

model nch atft type=n

Instance Definition

```
Name  d  g  s  [b] ModelName parameter=value ...
```

Instance Parameters

1	`w (m)`	Channel width.
2	`l (m)`	Channel length.
3	`m=1`	Multiplicity factor (number of MOSFETs in parallel).
4	`trise=0`	Temperature rise from ambient.
5	`region=triode`	Estimated operating region. Possible values are `off`, `triode`, `sat`, or `subth`.
6	`nrd (m/m)`	Drain squares.
7	`nrs (m/m)`	Source squares.

Model Definition

model modelName atft parameter=value ...

Model Parameters

Device type parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

Drain current model parameters

2 `compatible=spectre`
Spice compatible flag.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, or `sspice`.

3 `cdnver=1` Cadence version selector.

4 `vto=0 V` Zero-bias threshold voltage.

5 `lambda=0.0008 1/V` Channel length modulation parameter.

6 `tox=1e-7 m` Thin-oxide thickness.

7 `def0=0.6 eV` Dark Fermi level position.

8 `alphasat=0.6` Saturation modulation parameter.

9 `delta=5` Transition width parameter.

10 `el=0.35 eV` Activation energy of the hole leakage current.

11 `emu=0.06 eV` Field effect mobility activation energy.

12 `eps=11` Relative dielectric constant of substrate.

13 `epsi=7.4` Relative dielectric constant of gate insulator.

14 `vfb=-3 V` Flat band voltage.

15 `gamma=0.4` Power law mobility parameter.

16 `gmin=1.0e23 1/m`^{3} `eV`
Minimum density of deep states.

17 `iol=3.0e-14 A` Zero bias leakage current parameter.

18 `kasat=0.006 1/C` Temperature coefficient of ALPHASAT.

19 `kvt=-0.036 V/C` Threshold voltage temperature coefficient.

20 `m=2.5` Knee shape parameter.

21 `muband=0.001 m`^{2}`/V s`
Conduction band mobility.

22 `rs=0` Ω Source resistance.

23 `rd=0` Ω Drain resistance.

24 `sigma0=1.0e-14 A` Minimum leakage current parameter.

25 `v0=0.12 V` Characteristic voltage for deep states.

26 `vaa=7.5e3 V` Characteristic voltage for field effect mobility.

27 `vdsl=7 V` Hole leakage current drain voltage parameter.

28 `vgsl=7 V` Hole leakage current drain voltage parameter.

29 `vmin=0.3 V` Convergence parameter.

30 `cgdo=0 F/m` Gate-drain overlap capacitance.

31 `cgso=0 F/m` Gate-source overlap capacitance.

ACM parameters

32 `acm=0` Area calculation method.

33 `xw=0.0 m` Accounts for masking and etching effects.

34 `xl=0.0 m`	Accounts for masking and etching effects.
35 `ld (m)`	Lateral diffusion into channel from source and drain diffusion.
36 `wd=0.0 m`	Lateral diffusion into channel from bulk along width.
37 `lmlt=1.0`	Length diffusion layer shrink reduction factor.
38 `wmlt=1.0`	Width diffusion layer shrink reduction factor.
39 `rsh=0 Ω/sqr`	Source/drain diffusion sheet resistance.
40 `rdc=0.0 Ω`	Additional drain resistance due to contact resistance.
41 `rsc=0.0 Ω`	Additional source resistance due to contact resistance.
42 `ldif=0.0 m`	Length of heavily doped diffusion adjacent to gate.
43 `hdif=0.0 m`	Length of heavily doped diffusion from contact to lightly doped region.
44 `meto=0.0 m`	Fringing field factor for gate to source and gate to drain overlap capacitance.
45 `xj=0.0 m`	Metallurgical junction depth.

Temperature effects parameters

46 `tnom (C)`	Parameter measurement temperature.
47 `trise=0 C`	Temperature rise from ambient.

Operating region warning control parameters

48 `alarm=none`	Forbidden operating region. Possible values are `none`, `off`, `triode`, `sat`, `subth`, or `rev`.

Auto Model Selector parameters

49 `wmax=1 m`	Maximum channel width for which the model is valid.

50 `wmin=0 m` Minimum channel width for which the model is valid.

51 `lmax=1 m` Maximum channel length for which the model is valid.

52 `lmin=0 m` Minimum channel length for which the model is valid.

Noise model parameters

53 `noisemod=1` Noise model selector.

54 `kf=0` Flicker (1/f) noise coefficient.

55 `af=1` Flicker (1/f) noise exponent.

56 `ef=1` Flicker (1/f) noise frequency exponent.

57 `wnoi=1e-5 m` Channel width at which noise parameters were extracted.

Operating-Point Parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

2 `region=triode` Estimated operating region.
Possible values are `off`, `triode`, `sat`, or `subth`.

3 `reversed` Reverse mode indicator.
Possible values are `no` or `yes`.

4 `ids (A)` Resistive drain-to-source current.

5 `vgs (V)` Gate-source voltage.

6 `vds (V)` Drain-source voltage.

7 `vth (V)` Threshold voltage.

8 `vdsat (V)` Drain-source saturation voltage.

9 `gm (S)` Common-source transconductance.

10 `gds (S)` Common-source output conductance.

11 `cgd (F)` Gate-drain capacitance.

12 `cgs (F)` Gate-source capacitance.

13 `ron (Ω)` On-resistance.

14 `id (A)` Resistive drain current.

15 `pwr (W)` Power at op point.

16 `i1 (A)` Resistive drain current.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

40

Three-Terminal Nonlinear (Diffused and Poly-Silicon) Resistor Model and JFET Model (r3)

The r3 model is a nonlinear 3-terminal resistor model that includes self-heating, velocity saturation, statistical variations, and parasitic capacitances and currents. The core depletion pinching model formulation is for p-n junctions of diffused resistors, but is also applicable for the MOS behavior of polysilicon resistors. As p-n junction depletion pinching controls JFET device behavior, the r3 model is also applicable to JFETs.

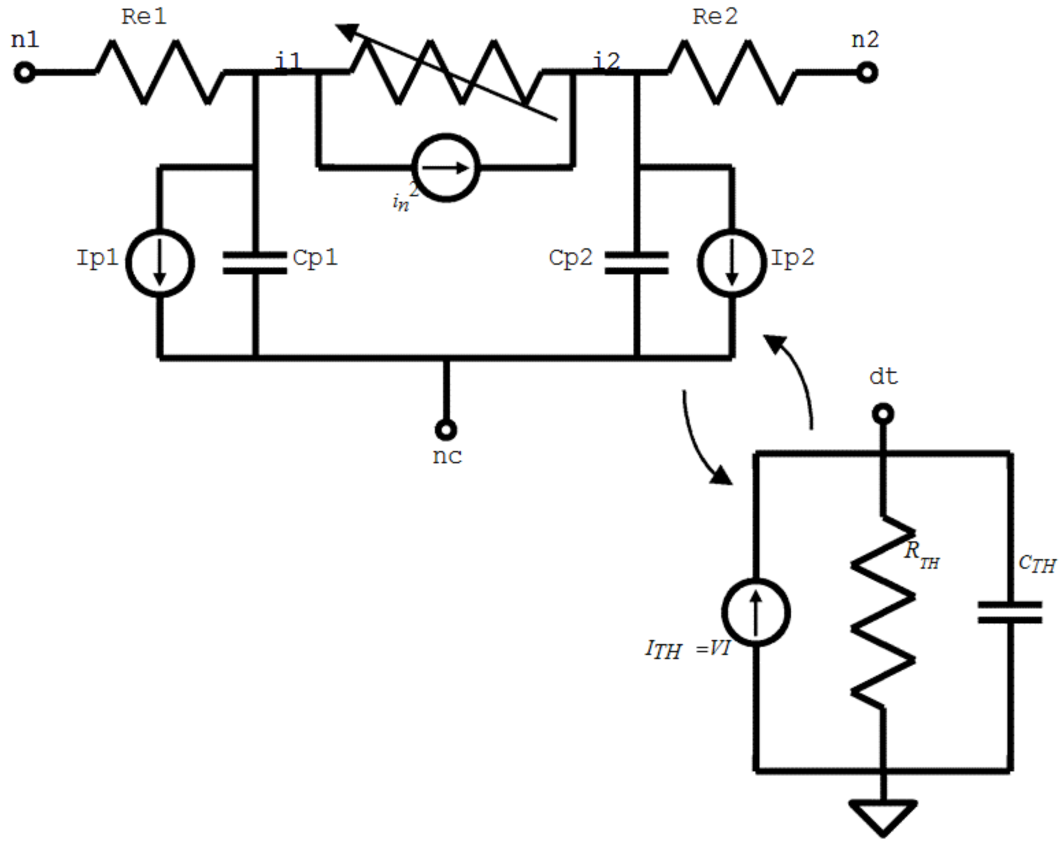
This chapter covers the following information about the r3 model:

Usage

Exact usage may be simulator dependent; e.g. whether the local temperature rise node for self-heating is made available or not, and whether the initial instance key-letter “r” is required.)

```
r<instanceName>  (<n1>  <nc>  <n2>)  <modelName>  <instanceParameters>
.model  <modelName>  r3 <modelParameters>
```

Figure 40-1 r3 Model Equivalent Network



Example

r00 `n1 n2 n3 p0  l = 2e-6 w = 10e-6 m = 10 sw_et = 1`

model p0 `r3 type=1 shrink=50 xw=0.01 nwxw=0.1 wexw=0.1 xl=0.01xlw=0.2 dxlsat=0.01`

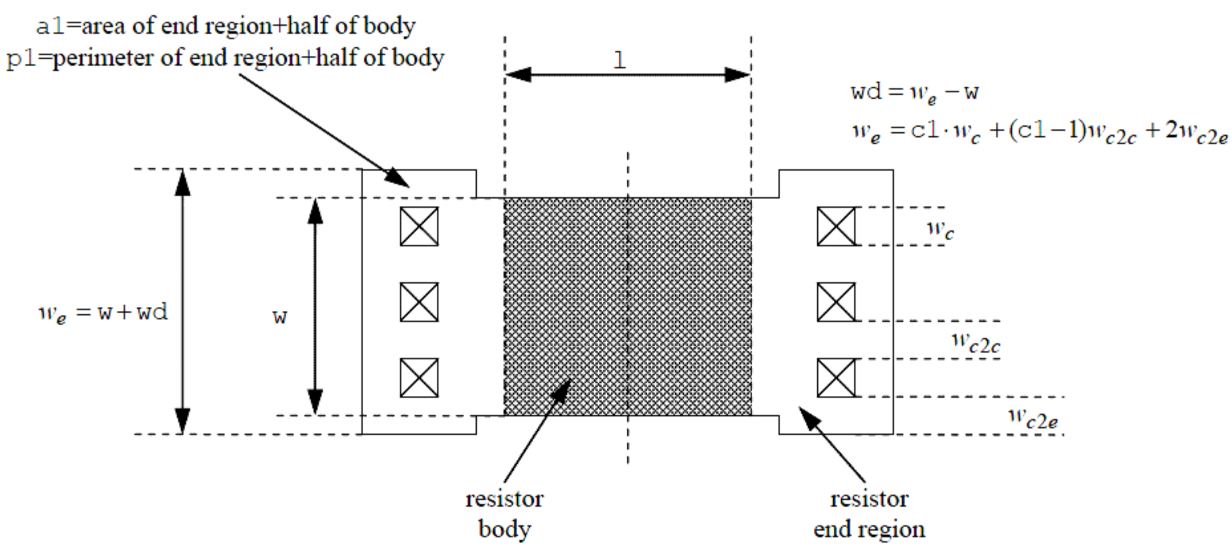
```
+rcw=0.01 ca=1e-4 cja=1e-4 cp=1e-10 cjp=1e-10 dfw=1e-3 dfl=1e-3 dfwl=1e-3
+tc1=1e-3 tc2=1e-4 tc1l=1e-3 tc2l=1e-4 tc1w=1e-3 tc2w=1e-4 tc1rc=1e-3 tc2rc=1e-4
tc1kfn=1e-3
```

```
+tc1vbv=1e-3 tc2vbv=1e-4 tc1nbv=1e-3 sw_dfgeo=0 rc=1
```

Instance Parameters

The paramater examples are given below. For a complete list of model parameters, please refer to section

Figure 40-2 Instance Parameter examples. The end region dogbone may be asymmetric.



Bias Dependence of Resistor Body Current

The r3 model includes three basic forms of bias dependence. First, from the depletion (p-n junction or MOS) pinching of the conducting channel of the resistor. Second, from velocity saturation. And third, from self-heating.

The basic p-n junction depletion pinching bias dependence comes from the analysis of [1], with the simplification of [2] (which merges the vertical and lateral bias dependence into a single bias dependent form with geometry dependent parameters). The applicability of the same general form of bias dependence for poly resistors, where the MOS depletion effect pinches the resistor body, was shown in [3]. The fundamental form of the depletion pinching model is

$$I_{depl} = gV_{21}, \quad g = gf \cdot \left(1 - df\sqrt{dp + V_i}\right), \quad V_i = V_{21} + 2V_{1c}$$

where V_{21} = V(i2) - V(i1) and V_{1c} = V(i1) - V(nc) . Here, dp is the depletion potemtial (which is just the model parameter dp), df is the depletion factor, and gf is the conductance factor; these are determined from instance and model parameters as detailed in the section on geometry dependence.

The velocity saturation model is a mobility reduction term that divides the conductance factor. The model is smooth and symmetric, has value 1 when V_{21} = 0 , and asymptotically approaches 1+(E ?ecorn)/ecrit for large field E= V_{21}/(leff_um + dx1sat) (leff_um is defined in the next section).

$$\mu_{red} = 1 + \sqrt{\left(\frac{E - E_{ce}}{2\,\mathrm{ecrit}}\right)^2 + \frac{\mathrm{du}\,E_{ce}}{\mathrm{ecrit}}} + \sqrt{\left(\frac{E + E_{ce}}{2\,\mathrm{ecrit}}\right)^2 + \frac{\mathrm{du}\,E_{ce}}{\mathrm{ecrit}}} - \sqrt{\left(\frac{E_{ce}}{\mathrm{ecrit}}\right)^2 + \frac{4\,\mathrm{du}\,E_{ce}}{\mathrm{ecrit}}}$$

(see Figure 40-3) where

$$E_{ce} = \sqrt{\mathrm{ecorn}^2 + (2\,\mathrm{du}\cdot\mathrm{ecrit})^2} - 2\,\mathrm{du}\cdot\mathrm{ecrit}.$$

The V_{21} used in the above expressions is smoothly limited so as not to exceed a saturation voltage V_{sat} , which is calculated as the V_{21} at which the output conductance becomes zero. To determine V_{sat} a slightly modified form of the velocity saturation model is used (the asymptotic form noted above), that allows closed form solution and guarantees that any imprecision in calculation of V_{sat} is such that the output conductance at saturation is positive, so that there are no “wiggles” around the transition to saturation. The smooth transition is implemented through the above equation.

$$V_{21,eff} = \frac{2V_{21}V_{sat}}{\sqrt{(V_{21} - V_{sat})^2 + 4\,\mathrm{ats}^2} + \sqrt{(V_{21} + V_{sat})^2 + 4\,\mathrm{ats}^2}}$$

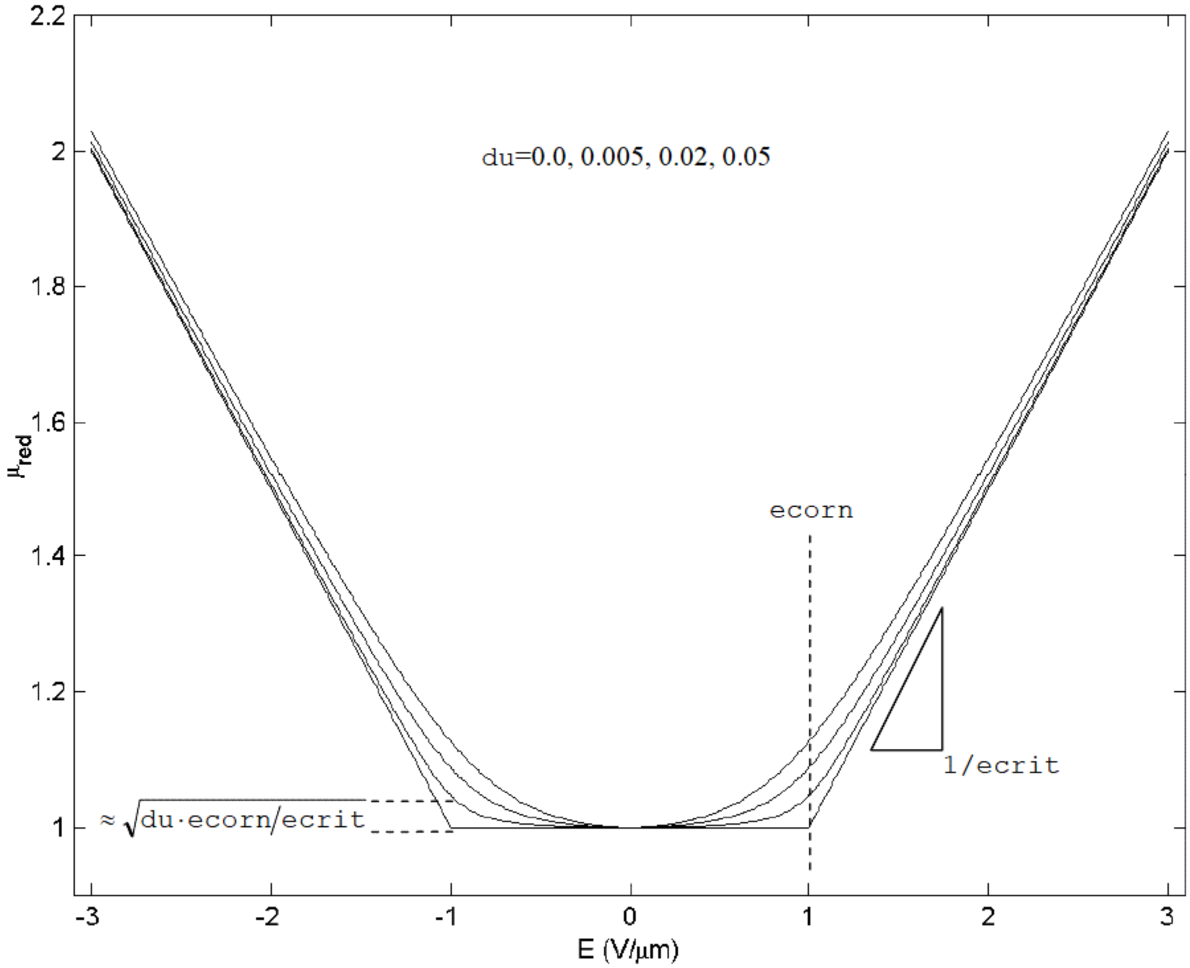
where `ats` is a model parameter that controls the limiting. This limiting function differs from those often used in compact MOSFET models; it preserves symmetry. The control voltage used is also limited, to the pinch-off voltage

$$V_{1c,eff} = V_{po} - \mathtt{nst} V_{tv} \ln\left(1 + \exp\left(\frac{V_{po} - V_{1c}}{\mathtt{nst} V_{tv}}\right)\right), \quad V_{po} = \frac{1}{2df^2} - 0.5dp, \quad V_{tv} = kT/q \,.$$

The self-heating affects the current through the temperature variation of the model parameters, primarily the sheet resistance. The current flowing between nodes n2 and n1 in Figure 40-1 is then

$$I_{21} = I_{depl} / \mu_{red}$$

Figure 40-3 Velocity Saturarion Model



Bias Dependence of Parasitics

If there are no area or perimeter component of saturation current, e.g. for poly resistors,

$$I_{p1} = I_{p2} = 0$$

If there are area and/or perimeter components of saturation current, e.g. as for diffused resistors, the parasitic diode currents are

$$I_{p1} = p1\_um \cdot I_{sp}(T)\left(\exp(V_{c1}/(\mathrm{np} \cdot V_{tv})) - 1\right) + a1\_um2 \cdot I_{sa}(T)\left(\exp(V_{c1}/(\mathrm{na} \cdot V_{tv})) - 1\right) + \mathrm{gmin} \cdot V_{c1}$$

$$I_{p2} = p2\_um \cdot I_{sp}(T)\left(\exp(V_{c2}/(\mathrm{np} \cdot V_{tv})) - 1\right) + a2\_um2 \cdot I_{sa}(T)\left(\exp(V_{c2}/(\mathrm{na} \cdot V_{tv})) - 1\right) + \mathrm{gmin} \cdot V_{c2}$$

where V_{c1} = `V(nc)` - `V(i1)` and V_{c2} = `V(nc)` - `V(i2)`. Each individual component of the diode currents is linearized for forward biases greater than the voltage at which the component is `imax`.

The breakdown currents, which are added to each parasitic current, are

$$I_{b1} = -\mathrm{ibv}\left(\exp(-(V_{c1} + V_{bv}(T))/(n_{bv}(T)V_{tv})) - \exp(-V_{bv}(T)/(n_{bv}(T)V_{tv}))\right),$$

$$I_{b2} = -\mathrm{ibv}\left(\exp(-(V_{c2} + V_{bv}(T))/(n_{bv}(T)V_{tv})) - \exp(-V_{bv}(T)/(n_{bv}(T)V_{tv}))\right)$$

and each of these is linearized for reverse biases greater than the voltage as which the magnitude of the current is imax.

The parasitic capacitances comprise a bias independent component (intended for poly resistor modeling) and a bias dependent component (intended for diffused resistor modeling). The capacitances are implemented as bias dependent charges, but the resulting capacitances are given here

$$C_{p1} = p1\_um\left(\mathrm{cp} + \frac{C_{jp}(T)}{(1 - V_{c1}/P_p(T))^{\mathrm{mp}}}\right) + a1\_um2\left(\mathrm{ca} + \frac{C_{ja}(T)}{(1 - V_{c1}/P_a(T))^{\mathrm{ma}}}\right)$$

$$C_{p2} = p2\_um\left(\mathrm{cp} + \frac{C_{jp}(T)}{(1 - V_{c2}/P_p(T))^{\mathrm{mp}}}\right) + a2\_um2\left(\mathrm{ca} + \frac{C_{ja}(T)}{(1 - V_{c2}/P_a(T))^{\mathrm{ma}}}\right).$$

The forward bias junction capacitance components are modified so that when the junction voltage (V_{c1} or V_{c2}) reaches `fc` multiplied by the associated built-in potential, the capacitance becomes linear in voltage, to avoid the singularity at the built-in potential. If the smoothing parameters `aja` and `ajp` are positive, then the transition from depletion to linear capacitance is done smoothly and not abruptly.

The thermal resistance and capacitance for the self-heating model are linear, and do not depend on temperature. The thermal power used for self-heating modeling is the sum of the powers of all dissipative (non-storage) elements in the equivalent circuit; i.e. the resistor body, the two end resistances, and two parasitic current sources.

Geometry Dependence

Unless otherwise noted, all `r3` model quantities scale with the multiplicity parameter m as defined in the *Verilog-A Language Reference Manual (LRM)*, version 2.2.

The `r3` model includes several mechanisms for deviations of the effective electrical length and width of a resistor from the drawn (design, or mask) values. The drawn length and width of the resistor, in units of microns, are

$$l\_um = \mathtt{l} \cdot \mathtt{scale} \cdot (1 - \mathtt{shrink}/100) \cdot 10^6 ,$$

$$w\_um = \mathtt{w} \cdot \mathtt{scale} \cdot (1 - \mathtt{shrink}/100) \cdot 10^6$$

Because subcircuit models for resistors can consist of multiple resistance sections connected in series, it is desirable to be able to switch on and off the “end corrections” for length to facilitate implementation of such multi-section models. This is the function of the `c1` and `c2` instance parameters of the `r3` model. The effective length offset is

$$xleff = (\mathtt{xl} + \mathtt{xlw}/w\_um)((\mathtt{c1} > 0) + (\mathtt{c2} > 0))/2$$

(which is zero if neither end is contacted, `xl+xlw/w_um` if both ends are contacted, and one half of the latter if only one end is contacted). The effective electrical length, in microns, is

$$leff\_um = l\_um + xleff$$

For flexibility of separately fitting low bias resistance and velocity saturation, an additional offset `dxlsat` is added to `leff _ um` for calculation of the electric field used in the velocity saturation model.

The effective width offset includes the physical effect models derived in [4]. These comprise a fixed offset for mask bias, lithography, and etching effects, and geometry dependent offsets for LOCOS, the webbing effect, and the finite dopant source effect. The effective electrical width, in microns, is

$$weff\_um = \frac{w\_um + \mathtt{xw} + (\mathtt{nwxw}/w\_um) + \mathtt{fdxwinf}\left(1 - \exp(-w\_um/\mathtt{fdrw})\right)}{1 - \mathtt{wexw} \cdot wd\_um/(l\_um \cdot w\_um)}$$

where the width of the dogbone (see Figure 40-2), for the webbing effect model, in units of microns, is

$$wd\_um = \mathtt{wd} \cdot \mathtt{scale} \cdot (1 - \mathtt{shrink}/100) \cdot 10^6$$

The depletion potential does not have a geometry dependence, so `dp=dp`. The depletion factor depends on geometry as

$$df = \mathtt{dfinf} + \frac{\mathtt{dfw}}{W} + \frac{\mathtt{dfl}}{L} + \frac{\mathtt{dfwl}}{WL}$$

where the width `W` and length `L` are effective geometries if `sw_dfgeo=1` and design geometries otherwise (in units of micron). The zero-bias resistance, which factors in the zero-bias depletion pinching, is then

$$R_0 = \mathtt{rsh}\frac{leff\_um}{weff\_um}\left(1.0 - df\sqrt{dp}\right), \quad gf = 1/R_0$$

Although end effects, such as spreading resistance and contact resistance, are assumed to be modeled via the `xl` parameter, the temperature coefficients of the end effects may differ from those of the body of the resistor. Simple analysis shows that these different temperature coefficients can be accounted for by introducing inverse length dependence to the temperature coefficients. A width dependence of temperature coefficients of resistance is also included in the model. Therefore in `r3`

$$T_{C1}^{eff} = \mathtt{tc1} + \frac{0.5\left((\mathtt{c1} > 0) + (\mathtt{c2} > 0)\right)\mathtt{tc1l}}{leff\_um} + \frac{\mathtt{tc1w}}{weff\_um},$$

$$T_{C2}^{eff} = \mathtt{tc2} + \frac{0.5\left((\mathtt{c1} > 0) + (\mathtt{c2} > 0)\right)\mathtt{tc2l}}{leff\_um} + \frac{\mathtt{tc2w}}{weff\_um}$$

where the length dependence is switched on, off, or halved, depending on whether the resistor is contacted at both ends, not contacted, or contacted at only one end, respectively. The dependence of the temperature coefficients on whether a resistor is contacted or not enables consistent modeling of temperature coefficients for single or multiple section models.

The thermal conductance and capacitance include area, perimeter, contact, and fixed components. Asymptotically for a large area device, the heat flow is perpendicular to the plane of heat generation in the resistor, and the heat energy stored in a device depends on its volume, hence the area dependent component. For a long resistor, as it becomes narrower more of the heat flow is conducted by a “fringe” path at the edges of the device, hence the perimeter dependent component. As both length and width decrease, the thermal conditions in the device asymptotically approach that of a point source in an infinite medium, hence the fixed component. Contacts conduct heat flow, hence the contact component. The thermal conductance and capacitance are therefore

$$g_{TH} = \mathrm{gth0} + \mathrm{gthp} \cdot p\_um2 + \mathrm{gtha} \cdot a\_um2 + \mathrm{gthc} \cdot (\mathrm{c1} + \mathrm{c2})$$

$$c_{TH} = \mathrm{cth0} + \mathrm{cthp} \cdot p\_um2 + \mathrm{ctha} \cdot a\_um2 + \mathrm{cthc} \cdot (\mathrm{c1} + \mathrm{c2})$$

the area and perimeter are calculated as

$$a\_um2 = l\_um \cdot w\_um$$

$$p\_um = 2l\_um + ((\mathrm{c1} > 0) + (\mathrm{c2} > 0))w\_um \,.$$

The calculated perimeter therefore depends on whether the ends are contacted or not. Note that often the design dimensions of the body of a resistor differ from the overall dimensions of the device, for example if the design length is considered to be the unsalicided length of a poly resistor, the total resistor length will typically include silicided contact regions. So it is not readily apparent what dimension should be used in calculation of the thermal conductance and capacitance. That is why the design dimensions, rather than some effective dimensions (whose value is calculated to best fit DC electrical data), are used. This turns out to be reasonable (with the exception that differences between the perimeter components along length and width dimensions are ignored), because if there is some difference Δ between design and effective dimensions for thermal conductance modeling, then for a device contacted at both ends

$$\begin{aligned} g_{TH} &= \mathrm{gth0} + \mathrm{gthp}(2l\_um + 2w\_um + 4\Delta) + \mathrm{gtha}(l\_um + \Delta)(w\_um + \Delta) \\ &= (\mathrm{gth0} + 4\mathrm{gthp} \cdot \Delta + \mathrm{gtha} \cdot \Delta^2) + (\mathrm{gthp} + 0.5\mathrm{gtha} \cdot \Delta)p\_um + \mathrm{gtha} \cdot a\_\mathrm{um2} \end{aligned}$$

therefore any difference between design and effective dimensions can be taken into account by appropriate characterization of the fixed, perimeter, and area component parameters.

Because the *local* thermal conductance differs between the edge of a device and the center of a device, it is higher at the edge because of *fringing* conductance, the temperature of a resistor undergoing self-heating is not spatially uniform, but is lower at the edges than in the middle. This is not taken into account in the `r3` model.

The end resistances are calculated from the resistance per contact and the number of contacts (parallel to the width dimension; adding contacts parallel to the length dimension, which can be done for reliability purposes, does not alter the resistance much – unless the contact adjacent to the resistor body fails)

$$R_{e1} = \frac{\mathtt{rc} + \mathtt{rcw}/w\_um}{\mathtt{c1}}, \quad R_{e2} = \frac{\mathtt{rc} + \mathtt{rcw}/w\_um}{\mathtt{c2}}$$

The velocity saturation model includes geometry dependence in the bias dependent portion of the model evaluation, as it is formulated in terms of the electric field $E=V_{21}/(\mathtt{leff\_um}+\mathtt{dxlsat})$.

The areas and perimeters of the end region partitions, used in parasitic calculations, are in units of microns

$$p1\_um = \mathtt{p1} \cdot \mathtt{scale} \cdot (1 - \mathtt{shrink}/100) \cdot 10^6,$$

$$a1\_um2 = \mathtt{a1} \cdot \left(\mathtt{scale} \cdot (1 - \mathtt{shrink}/100) \cdot 10^6\right)^2,$$

$$p2\_um = \mathtt{p2} \cdot \mathtt{scale} \cdot (1 - \mathtt{shrink}/100) \cdot 10^6,$$

and

$$a2\_um2 = \mathtt{a2} \cdot \left(\mathtt{scale} \cdot (1 - \mathtt{shrink}/100) \cdot 10^6\right)^2.$$

If the number of contacts is not known, it can be calculated (see Figure 40-2). Let the contact width (in the direction parallel to the resistor width) be w_c, the minimum spacing from a contact to the edge of the region it is in at the contact head of the resistor be w_{c2e}, and the (minimum) spacing between contacts be w_{c2c}. If (as in some older technologies) contacts can be scaled, then `rc` should be set to be the resistance of a minimum width contact and

$$c[1,2] = \frac{\max(\mathrm{w} + \mathrm{wd}, w_c + 2w_{c2e}) - 2w_{c2e}}{w_c}$$

and for technologies where the contact width is fixed (assuming the maximum possible number of contacts are places)

$$c[1,2] = \mathrm{int}\left(\frac{\max(\mathrm{w} + \mathrm{wd}, w_c + 2w_{c2e}) - 2w_{c2e} + w_{c2c}}{w_c + w_{c2c}}\right).$$

Temperature Dependence

The zero-bias resistance R0 varies with temperature as

$$R_0(T) = R_0\left(1 + T_{C1}^{eff}\, dT + T_{C2}^{eff}\, dT^2\right)$$

where R_0 is the nominal value of the zero-bias resistance at the nominal temperature `tnom`, `dT`is the temperature difference (including self-heating) with respect to `tnom`, and T^{eff}_{C1} and T^{eff}_{C2} are first (linear) and secon (quadatic) order effective temperature coefficients. Smooth limiting of the resistance temperature coefficient is implemented to a minimum value of 0.01. The conductance factor is then

$$gf = 1/R_0(T).$$

The end resistances vary with temperature as

$$R_{e[1,2]}(T) = R_{e[1,2]}\left(1 + \mathrm{tc1rc} \cdot dT + \mathrm{tc2rc} \cdot dT^2\right)$$

and again the temperature coefficient is limited to a lower value of 0.01.

The parasitic diode saturation currents vary with temperature as

$$I_{sa}(T) = \mathtt{isa} \cdot rT^{\mathtt{xis}/\mathtt{na}} \exp\left(-\mathtt{ea}\frac{1-rT}{\mathtt{na} \cdot V_{tv}}\right)$$

$$I_{sp}(T) = \mathtt{isp} \cdot rT^{\mathtt{xis}/\mathtt{np}} \exp\left(-\mathtt{ea}\frac{1-rT}{\mathtt{np} \cdot V_{tv}}\right)$$

where `rT` is the ratio ofdevicetonominal temperature (in Kelvin), and V_{tv}= `kT/q` is the thermal voltage. The temperature dependence of the junction built-in potentials is

$$P_a(T) = \mathtt{pa} \cdot rT - 3V_{tv} \ln(rT) - \mathtt{ea}(rT - 1)$$

$$P_p(T) = \mathtt{pp} \cdot rT - 3V_{tv} \ln(rT) - \mathtt{ea}(rT - 1)$$

with a physically based modification to smoothly limit the potential to zero for high temperatures, and not allow it to become negative. The area and perimeter junction zero-bias capacitance temperature variations are

$$C_{ja}(T) = \mathtt{cja}\left(\frac{\mathtt{pa}}{P_a(T)}\right)^{\mathtt{ma}}$$

and

$$C_{jp}(T) = \mathtt{cjp}\left(\frac{\mathtt{pp}}{P_p(T)}\right)^{\mathtt{mp}}.$$

The flicker noise coefficient varies with temperature as

$$K_{FN}(T) = \mathtt{kfn}(1 + \mathtt{tc1kfn} \cdot dT)$$

where `kfn` and `tc1kfn` are model parameters (and the resulting K_{FN} is clipped to zero as a lower limit).

The breakdown voltage and ideality factor vary with temperature as

$$V_{bv}(T) = \mathtt{vbv}\left(1 + \mathtt{tc1vbv} \cdot dT + \mathtt{tc2vbv} \cdot dT^2\right),$$

$$n_{bv}(T) = \mathtt{nbv}\left(1 + \mathtt{tc1nbv} \cdot dT\right).$$

Noise

The noise model comprises two body components, a thermal (white) noise component and a flicker (`1/f`) noise component, thermal noise components for each contact resistance, and short noise components for each parasitic diode. These components are noise current spectral density (in A^2/Hz) that are implemented as a noise current sources in parallel with the associated element.

The thermal noise component of the resistor body is based on its DC conductance,

$$i^2_{thermal,body} = 4kT_K G_{eff}(T)$$

where `k` is Boltzmann's constant, T_K is the device temperature (in Kelvin, including the effect of self-heating), and G_{eff} is the effective conductance of the resistor (at the temperature `T`). Similarly the thermal noise of each end resistances is

$$i^2_{thermal,end} = 4kT_K / R_e(T)\ .$$

The flicker noise component is DC current dependent and scales with geometry per the physical restrictions mentioned earlier.

$$i^2_{flicker,body} = K_{FN}(T)\left(\frac{I_{21}}{W}\right)^{\mathtt{afn}} \frac{W}{L} \frac{1}{f^{\mathtt{bfn}}}$$

where `f` is frequency (in Hz), `afn` and `bfn` are model parameters, $K_{FN}(T)$ is the temperature dependent flicker noise coefficient, I_{21} is the DC current in the resistor body, and `W` and `L` are the resistor width and length respectively, in units micron (µm). If the switch parameter for flicker noise geometry calculation `sw_fngeo` is 0 (false) then `W` and `L` are design geometries, `w_um` and `l_um` respectively, else if it is 1 (true) then `W` and `L` are effective geometries, `weff_um` and `leff_um` respectively.

The shot noise components are

$$i^2_{shot,diode} = 2qI_{diode}$$

for each parasitic diode, where I_{diode} is the current in the diode.

Note that if self-heating is included, then possibly there is a frequency dependence to the flicker noise because of the thermal time constant. There is no data to verify this at present so a frequency independent noise current spectral density is used.

Operating Point Information

Name	Units	Description
`v`	V	voltage across resistor
`ibody`	A	current through resistor body
`power`	W	dissipated power
`leff_um`	μm	effective electrical length in μm
`weff_um`	μm	effective electrical width in μm
`r0`	Ω	zero-bias resistance
`r_dc`	Ω	DC Resistance (including bias dependence)
`r_ac`	Ω	AC Resistance (including bias dependence)
`rth`	K/W	thermal resistance
`cth`	sW/K	thermal capacitance
`dt_et`	K	self-heating temperature rise

Table 40-1 Operating Point Parameters

All flow and parameter quantities are for the overall device and include the rffect of the multliplicity parameter `m`.

Statistical Variation

The `r3` model includes both global (inter-die, correlated between individual devices) and local (mismatch, uncorrelated between individual devices) variations. These can be added “on top” of a core model using sub-circuits, however this can involve increased complexity in model parameter files and increased computational overhead during simulation. Therefore statistical variation is “built-in” to the `r3` model, including instance parameters for control of mismatch variation for individual devices.

Besides convenience and efficiency, the statistical variation modeling in `r3` naturally embodies the geometry dependence of total variation in a device, which is not possible with statistical modeling based on a geometry independent global variation and geometry dependent correlation coefficients. Since it is based on independent statistical parameters for global variation and instance specific local variation, it does not require generation of correlated samples for distributional (i.e. Monte Carlo-like) simulation; if correlations were used then N (N ?1) 2 of them are required for each statistical parameter for each of N devices.

Statistical variations are modeled in three parameters; the sheet resistance, the effective length variation, and the effective width variation. These are considered as the primary physical process parameters that determine the resistor behavior. At present, there is no variation (global or local) in other physical quantities such as contact resistance, other parasitics (zero-bias depletion capacitance for diffused resistors varies with doping), or the parameters that control the nonlinearity of the model. If experimental data shows that linkage to more fundamental physical quantities such as doping levels and layer thicknesses is required to model correlations and statistical variations, this will be added in the future.

The local variation of the effective width is controlled by line edge roughness in the length dimension; its variance is therefore inversely proportional to the resistor length `L`. The local variation of the effective length is controlled by line edge roughness in the width dimension; its variance is therefore inversely proportional to the resistor width `W`.The local variation of the sheet resistance is controlled by random dopant fluctuations; its variance is therefore inversely proportional to the area of the resistor, `WL`. For flexibility in fitting experimental data, the `sw_mmgeo` flag allows the controlling geometries `W` and `L` to be either drawn or effective (as calculated before the statistical variations are applied, to avoid an implicit dependency that requires an iterative solution).

The total variance of a parameter is the sum of the variances of the global variance (which is independent of geometry) and the local variance (which depends on geometry `g` , which can include area, width, and length),

$$\sigma_{total}^2 = \sigma_{global}^2 + \sigma_{local}^2(\vec{g}) .$$

Note that this naturally embodies the geometry dependence of the overall variance of a particular parameter. For statistical simulation, the perturbations of the global variation and the individual instance variation are expected to be statistically independent. But “proper” statistical simulation of a circuit requires inclusion of both global parameters and local parameters for every instance of a device type in a circuit. This can cause the number of statistical parameters included in a statistical simulation to increase proportionally with the number of devices in the circuit, with a concomitant explosion in the number of (local) statistical parameters needed to be included for a “proper” analysis. This is, for brute force statistical simulation, clearly impractical.

The `r3` model therefore includes a mechanism for more efficiently accounting for the geometry dependence of the overall variation. The `sw_mman` switch is provided to allow specification on an instance-by-instance basis of whether a device is being included in mismatch analysis. If yes, then both global and local (instance specific) statistical variation parameters are expected to be generated for each device instance, and the global and local variations are modeled separately. If no, which is appropriate for devices for which local variation is not expected to affect circuit performance, then the global variance for a device is adjusted to be the total variance for that device. This appropriately models the geometry dependent total variance for the device, with the consequence that it makes the total variation completely

correlated between all devices (that are not selected for individual mismatch analysis); this will cause overestimation of the variation of the circuit performances, i.e. the simulations from this will be pessimistic.

If mismatch analysis is selected, then the statistical variations are

$$weff\_um = weff\_um_{nom} + \mathtt{nsig\_w} \cdot \mathtt{sig\_w} + \frac{\mathtt{nsmm\_w} \cdot \mathtt{smm\_w}}{\sqrt{\mathtt{m} \cdot L}}$$

$$leff\_um = leff\_um_{nom} + \mathtt{nsig\_l} \cdot \mathtt{sig\_l} + \frac{\mathtt{nsmm\_l} \cdot \mathtt{smm\_l}}{\sqrt{\mathtt{m} \cdot W}}$$

$$rsh = \mathtt{rsh}_{nom} \exp\left(0.01\left(\mathtt{nsig\_rsh} \cdot \mathtt{sig\_rsh} + \frac{\mathtt{nsmm\_rsh} \cdot \mathtt{smm\_rsh}}{\sqrt{\mathtt{m} \cdot WL}}\right)\right)$$

where the nominal values are those defined in the section on geometry dependence. (The above expressions are used to update the effective geometries and resistance values, and all previous model equations actually use the values calculated earlier. However, for clarity of presentation and ease of interpretation, the previous equations are not cluttered with the statistical variations).

Note that the variations in effective length and width are absolute, and are additive, and that the variation in sheet resistance is multiplicative. For small variations exp $\langle\chi\rangle \approx \langle 1+\chi\rangle$ hence the rsh variation is relative (it is more natural to think in terms of a % variation than an absolute variation). For large variations, as can be seen in some resistors, statistical sampling can generate very small or negative values of rsh, which are unphysical. Quantities with large variations typically exhibit a log-normal distribution, and the exponential mapping transforms the normally distributed basic statistical parameters into a log-normal distribution for rsh if the variation is large. Note that strictly the unit "%" for the standard deviations of rsh is only for a small variation; if the variation is large then the exponential transformation modifies this.

This approach allows statistical modeling via uncorrelated normal variables, yet can capture log-normal distributions and correlations between parameters, via the dependencies on the fundamental process parameters that control the device behavior. Note that mismatch is modeled via independent perturbations in individual devices, which is physically correct. To simulate mismatch between two devices the mismatch instance parameters for both devices must be selected for statistical perturbation, and this easily extends to more than two devices, and implicitly accounts for geometry differences between different devices. If mismatch is characterized from differential measurements between two identically sized devices, then the measured standard deviations need to be divided by 2 when mapped into the model parameters smm_w, smm_l, and smm_rsh.

If mismatch analysis is not selected, then the total variance is used as the global variance,

$$weff\_um = weff\_um_{nom} + \mathrm{nsig\_w}\sqrt{\mathrm{sig\_w}^2 + \mathrm{smm\_w}^2/(\mathrm{m}\cdot L)}$$

$$leff\_um = leff\_um_{nom} + \mathrm{nsig\_l}\sqrt{\mathrm{sig\_l}^2 + \mathrm{smm\_l}^2/(\mathrm{m}\cdot W)}$$

$$rsh = \mathrm{rsh}_{nom}\exp\left(0.01\cdot\mathrm{nsig\_rsh}\left(\mathrm{sig\_rsh}^2 + \mathrm{smm\_rsh}^2/(\mathrm{m}\cdot WL)\right)\right).$$

Note that the nsig parameters should be equated to global statistical variables in model files, as they are model parameters, not instance parameters. These parameters then should vary with case/corner and distributional simulations.

Notes on Parameter Extraction

This section provides some information that can help in setting up parameter extraction algorithms. It describes techniques to get initial values that can then be refined by optimization. It does not give a complete and perfect procedure for parameter extraction. As this section does not deal with the details of the model, but how to determine parameters from measured data, `V` and `I` have been used in this section only as the voltage across, and current through, the complete resistor (and not just the core resistor body, as is done in previous sections).

Techniques for extraction of basic parameters, such as `rsh`, `xl`, and `xw`, some temperature coefficients and their geometric scaling, etc. are provided earlier and are not repeated here. Additional extraction techniques for the core bias dependence are provided here.

The fundamental depletion (`p-n` junction or MOS) pinching component of the model is given earlier. Velocity saturation and self-heating affect the bias dependence for `E=VL` significantly different from zero. Therefore the basic parameters of the model for one geometry, `gf`, `df`, and `dp`, should come from analysis of data where depletion pinching dominates, i.e. from low `V`, ideally extrapolated to, or measured (from small-signal AC excitation) at `V=0`. (The large signal conductanc `eg=IV` cannot be directly calculated at `V=0`, but is equal to the small signal conductance `g=I/V` at that bias).

There are at least three approaches to determine the basic depletion pinching parameters, for diffused resistors. If the conductanc `eg` is known from measurements at three different biases, then the parameters can be calculated as follows. For these biases, ($V_i = V + 2V_{1c}$ for the i[th] values of `V` and V_{1c})

$$g_i = gf\left(1 - df\sqrt{dp + V_i}\right)$$

therefore

$$g_i - g_j = gf\ df\left(\sqrt{dp + V_j} - \sqrt{dp + V_i}\right)$$

and manipulating the above equation for two pairs of biases, and forming the difference, gives

$$\frac{\sqrt{dp + V_2} - \sqrt{dp + V_1}}{g_1 - g_2} - \frac{\sqrt{dp + V_3} - \sqrt{dp + V_1}}{g_1 - g_3} = 0\ .$$

Starting with an initial estimate of dp = 2 , the equation can be solved using Newton-Raphson iteration. Then

$$df = \frac{g_1 - g_3}{g_1\sqrt{dp + V_3} - g_3\sqrt{dp + V_1}}$$

and

$$gf = \frac{g_1}{1 - df\sqrt{dp + V_1}} .$$

An alternative is to, assuming that the depletion pinching effect is small, initialize gf to g at the lowest (zero) V_i, set dp = 2 , and then calculate an initial df at the highest V_i.A 3 dimensional Newton-Raphson iteration can then be used to solve for gf, df, and dp at the three V_i values.

A direct solution also exists.

$$\frac{1}{df^2} + \frac{g_i^2}{df^2 gf^2} - \frac{2g_i}{df^2 gf} = dp + V_i$$

and forming the difference between this quantity for two combinations of the selected three bias points gives

$$\begin{bmatrix} g_1^2 - g_2^2 & 2(g_2 - g_1) \\ g_1^2 - g_3^2 & 2(g_3 - g_1) \end{bmatrix} \begin{bmatrix} p_1 \\ p_2 \end{bmatrix} = \begin{bmatrix} V_1 - V_2 \\ V_1 - V_3 \end{bmatrix}$$

where

where $p_1 = 1/df^2 gf^2$ and $p_2 = 1/df^2 gf$.

These two quantities can be calculated from the V_i and gi data using the above equation

$$gf = p_2 / p_1 \ ,$$

$$df = 1 \Big/ \sqrt{p_2 gf} \ ,$$

$$dp = \frac{1}{df^2} + \frac{g_1^2}{df^2 gf^2} - \frac{2g_1}{df^2 gf} - V_i \ .$$

The nonlinearity from the depletion pinching has the greatest sensitivity to dp for small V_i, therefore one bias should be at as small a V as possible (zero, if small-signal conductance is being used as opposed to large signal conductance) and $V_{1c}=0$.

Preferably data should be taken for 3 or more V_{1c} values (including zero). If such data are available then the other points used for extraction should be at the smallest V_{ds} and the second lowest V_{1c}, and the smallest V and the highest V_{1c}. If data for only two V_{1c} values (including zero) are available, besides the lowest V and lowest V_{1c} point, use the lowest V_{1c} point with a V higher than the smallest value and both small enough to ensure self-heating and velocity saturation effects are negligible and large enough to be sufficiently different from the lowest V value (so as not to be sensitive to measurement noise), and again as a third bias use the smallest V and the highest V1c point.

For poly resistors, the *pinching* effect is from the depletion region at the bottom of the resistor, and the conductance of a poly resistor is

$$g = \frac{XW}{\rho L}\left(1 - \frac{k_{Si} T_{ox}}{k_{ox} X \sqrt{V_0}} \sqrt{V_0 + 2V_{1c}}\right)$$

where X, W and L are the thickness, width, and length of the polysilicon film that makes up the resistor, k_{Si} and k_{ox} are the relative dielectric permittivities of silicon and silicon dioxide, T_{ox} is the oxide thickness, ρ is the resistivity, and $V_0=q\varepsilon_{Si}N/C^2_{ox}$. This can be seen to have the same general form, which is why the basic depletion pinching bias dependence of the r3 model is also, with appropriate parameters, suitable for modeling poly resistors.

For typical poly resistors on relatively thick oxides, the V_0, which can be identified as the several tens or hundreds of volts, compared to the 1-2V value (twice the built-in potential) for `dp` resistor. Therefore the resistor conductance is

$$g \approx gf\left(1 - df\sqrt{dp} - df\,V_{1c}/\sqrt{dp}\right).$$

which, as measured data also shows, has a linear $g(V_{1c})$ dependence. This means that there are only two independent quantities that can be extracted from measured data, the zero-bias value $g_0 = gf\langle 1 - df\sqrt{dp}\rangle$ and the slope $s = -(gfdf)/(\sqrt{dp})$ .Yet thereare three parameters for the model. Physical quantities areneeded tobreak this indeterminacy.

The value of $V_0 = q\varepsilon_{Si}N/C^2_{ox}$ can be calculated; however because of incomplete dopant activation this can overestimate its value. It is better to calculate it from the poly sheet resistance

$$dp = \frac{\varepsilon_{Si}T_{ox}^2}{\mu_0 X \rho_s \varepsilon_{ox}^2}$$

where μ_0 and ρ_s are the low field mobility and sheet resistance of the poly, respectively. Therefore from the slope and zero-bias conductance

$$df = -\frac{s\sqrt{dp}}{g_0 - s\sqrt{dp}}$$

Calculating large signal conductance `g=I/V` for small `V` can be problematic; `V` needs to be small enough so that self-heating and velocity saturation effects do not affect the device, but large enough so that `g` can be calculated reliably. For poly resistors, there is an alternative method to characterize the depletion pinching parameters. If $V_{1c}=0$, and `V` is swept from a negative to a positive value (this is not possible for diffused resistors, as the parasitic junction diodes would become forward biased), then the conductance `g(V)` has a roughly parabolic shape near `V=0`. For poly resistors with negative temperature coefficients of resistance, the conductance increases (from self-heating) as the magnitude of the applied `V` bias increases (for sufficiently high `V` the conductance starts to decrease from velocity saturation, leading to a *horned* characteristic in the plot). If the temperature coefficient of resistance is positive, the conductance will decrease as `V` increases (in roughly the same manner as the effect of velocity saturation, which makes them difficult to distinguish, without including additional data such as the frequency dependence of the output conductance).

For some magnitude of applied `V`, of both positive and negative signs, the effects of velocity saturation and self-heating should be the same (with the difference noted below). Therefore the plot of `g(V)` should, to first order, be symmetric about `V=0`.

However because the V_{2c} bias differs between the positive and negative `V` cases, the amount of depletion pinching is different, and this introduces a slight asymmetry in the characteristic. (If the currents differ then so will the self-heating, but this should be a second order effect and so is ignored here). Because the effects of velocity saturation and self-heating affect the zero bias conductance and the mobility reduction parts of the model, the ratio of the magnitudes of currents with positive and negative `V` of equal magnitude cancel these

$$gf = \frac{g_0}{1 - df\sqrt{dp}}\,.$$

and therefore reveal the effect of depletion pinching. As with the low `V` bias analysis above, `dp` can be calculated and then `df`, or at least in initial value of it for optimization, can be determined from the slope of the ratio in the above equation versus `V` (once it stabilizes, the ratio tends to be *noisy* for low `V`).

For poly resistors where self-heating dominates the non-linearity, at low `V`, the `g(V)` parabolic shape is primarily determined from mobility reduction due to self-heating, therefore

$$\frac{I_p}{I_m} = \left.\frac{I(+V)}{I(-V)}\right|_{V_{c1}=0} = \frac{1 - df\sqrt{dp + V}}{1 - df\sqrt{dp - V}} \approx 1 - V\frac{df}{\sqrt{dp}}$$

`gtha` is allowed to be estimated.

One other recommendation is that one basic goal of the model is to model the deviation from linearity (which is important for distortion modeling), and to extract model parameters.

Because of local variation (mismatch), it can be difficult to merge data from different devices for model parameter extraction. Therefore extraction from individual devices can be beneficial. Modeling the deviation from linearity for individual devices does both of these.

Reference

Component Statements

Instance Parameters

1 exp_cr=(80.0) instance parameter.

2 cmi_limexp_method=(1.0)
instance parameter.

3 cmi_compactable=(1.0)
instance parameter.

4 m=(1.0) instance parameter.

5 w=(1.0e-06) design width of resistor body.

6 l=(1.0e-06) design length of resistor body.

7 wd=(0.0) dogbone width (total; not per side).

8 a1=(0.0) area of node n1 partition.

9 p1=(0.0) perimeter of node n1 partition.

10 c1=(0) # contacts at node n1 terminal .

11 a2=(0.0) area of node n2 partition .

12 p2=(0.0) perimeter of node n2 partition .

13 c2=(0) # contacts at node n2 terminal .

14 trise=(0.0) local temperature delta to ambient (before self-heating) .

15 dta=(0.0) alias of trise .

16 dtemp=(0.0) alias of trise .

17 sw_noise=(1) switch for including noise: 0=no and 1=yes .

18 sw_et=(1) switch for self-heating: 0=no and 1=yes .

19 sw_mman=(0) switch for mismatch analysis: 0=no and 1=yes .

20 nsmm_rsh=(0.0) number of standard deviations of local variation for rsh.

21 nsmm_w=(0.0) number of standard deviations of local variation for w.

22 nsmm_l=(0.0) number of standard deviations of local variation for l.

Model Parameters

1 version=(1) model parameter: model version.

2 subversion=(0) model parameter: model subversion.

3 revision=(0) model parameter: model revision.

4 level=(1003) model parameter: model level.

5 type=((-1)) model parameter: resistor type: -1=n-body and +1=p-body.

6 scale=(1.0) model parameter: scale factor for instance geometries.

7 shrink=(0.0) model parameter: shrink percentage for instance geometries.

8 tmin=((-100.0)) model parameter: minimum ambient temperature.

9 tmax=(500.0) model parameter: maximum ambient temperature.

10 rthresh=(1.0e-03)

model parameter: threshold to switch end resistance to V=I*R form.

11 gmin=(1.0e-12) model parameter: minimum conductance.

12 imax=(1.0) model parameter: current at which to linearize diode currents.

13 tnom=(27.0) model parameter: nominal (reference) temperature.

14 lmin=(0.0) model parameter: minimum allowed drawn length.

15 lmax=(9.9e09) model parameter: maximum allowed drawn length.

16	wmin=(0.0)	model parameter: minimum allowed drawn width.
17	wmax=(9.9e09)	model parameter: maximum allowed drawn width.
18	jmax=(100.0)	model parameter: maximum current density.
19	vmax=(9.9e09)	model parameter: maximum voltage w.r.t. control node nc.
20	tminclip=((-100.0))	model parameter: clip minimum temperature.
21	tmaxclip=(500.0)	model parameter: clip maximum temperature.
22	rsh=(100.0)	model parameter: sheet resistance.
23	xw=(0.0)	model parameter: width offset (total).
24	nwxw=(0.0)	model parameter: narrow width width offset correction coefficient.
25	wexw=(0.0)	model parameter: webbing effect width offset correction coefficient (for dogboned devices).
26	fdrw=(1.0)	model parameter: finite doping width offset reference width.
27	fdxwinf=(0.0)	model parameter: finite doping width offset width value for wide devices.
28	xl=(0.0)	model parameter: length offset (total).
29	xlw=(0.0)	model parameter: width dependence of length offset.
30	dxlsat=(0.0)	model parameter: additional length offset for velocity saturation calculation.
31	nst=(1.0)	model parameter: subthreshold slope parameter.
32	ats=(0.0)	model parameter: saturation smoothing parameter.
33	dfinf=(0.01)	model parameter: depletion factor for wide/long device.
34	dfw=(0.0)	model parameter: depletion factor 1/w coefficient.

35	dfl=(0.0)	model parameter: depletion factor 1/l coefficient.
36	dfwl=(0.0)	model parameter: depletion factor 1/(w*l) coefficient.
37	sw_dfgeo=(1)	model parameter: switch for depletion factor geometry dependence: 0=drawn and 1=effective.
38	dp=(2.0)	model parameter: depletion potential.
39	ecrit=(4.0)	model parameter: velocity saturation critical field.
40	ecorn=(0.4)	model parameter: velocity saturation corner field.
41	du=(0.02)	model parameter: mobility reduction at ecorn.
42	rc=(0.0)	model parameter: resistance per contact.
43	rcw=(0.0)	model parameter: width adjustment for contact resistance.
44	fc=(0.9)	model parameter: depletion capacitance linearization factor.
45	isa=(0.0)	model parameter: diode saturation current per unit area.
46	na=(1.0)	model parameter: ideality factor for isa.
47	ca=(0.0)	model parameter: fixed capacitance per unit area.
48	cja=(0.0)	model parameter: depletion capacitance per unit area.
49	pa=(0.75)	model parameter: built-in potential for cja.
50	ma=(0.33)	model parameter: grading coefficient for cja.
51	aja=((-0.5))	model parameter: smoothing parameter for cja.
52	isp=(0.0)	model parameter: diode saturation current per unit perimeter.
53	np=(1.0)	model parameter: ideality factor for isp.
54	cp=(0.0)	model parameter: fixed capacitance per unit perimeter.
55	cjp=(0.0)	model parameter: depletion capacitance per unit perimeter.

56	pp=(0.75)	model parameter: built-in potential for cjp.
57	mp=(0.33)	model parameter: grading coefficient for cjp.
58	ajp=((-0.5))	model parameter: smoothing parameter for cjp.
59	vbv=(0.0)	model parameter: breakdown voltage.
60	ibv=(1.0e-06)	model parameter: current at breakdown.
61	nbv=(1.0)	model parameter: ideality factor for breakdown current.
62	kfn=(0.0)	model parameter: flicker noise coefficient (unit depends on afn).
63	afn=(2.0)	model parameter: flicker noise current exponent.
64	bfn=(1.0)	model parameter: flicker noise 1/f exponent.
65	sw_fngeo=(0)	model parameter: switch for flicker noise geometry calculation: 0=drawn and 1=effective.
66	ea=(1.12)	model parameter: activation voltage for diode temperature dependence.
67	xis=(3.0)	model parameter: exponent for diode temperature dependence.
68	tc1=(0.0)	model parameter: resistance linear TC.
69	tc2=(0.0)	model parameter: resistance quadratic TC.
70	tc1l=(0.0)	model parameter: resistance linear TC length coefficient.
71	tc2l=(0.0)	model parameter: resistance quadratic TC length coefficient.
72	tc1w=(0.0)	model parameter: resistance linear TC width coefficient.
73	tc2w=(0.0)	model parameter: resistance quadratic TC width coefficient.
74	tc1rc=(0.0)	model parameter: contact resistance linear TC.
75	tc2rc=(0.0)	model parameter: contact resistance quadratic TC.
76	tc1kfn=(0.0)	model parameter: flicker noise coefficient linear TC.

77	tc1vbv=(0.0)	model parameter: breakdown voltage linear TC.
78	tc2vbv=(0.0)	model parameter: breakdown voltage quadratic TC.
79	tc1nbv=(0.0)	model parameter: breakdown ideality factor linear TC.
80	gth0=(1.0e+06)	model parameter: thermal conductance fixed component.
81	gthp=(0.0)	model parameter: thermal conductance perimeter component.
82	gtha=(0.0)	model parameter: thermal conductance area component.
83	gthc=(0.0)	model parameter: thermal conductance contact component.
84	cth0=(0.0)	model parameter: thermal capacitance fixed component.
85	cthp=(0.0)	model parameter: thermal capacitance perimeter component.
86	ctha=(0.0)	model parameter: thermal capacitance area component.
87	cthc=(0.0)	model parameter: thermal capacitance contact component.
88	nsig_rsh=(0.0)	model parameter: number of standard deviations of global variation for rsh.
89	nsig_w=(0.0)	model parameter: number of standard deviations of global variation for w.
90	nsig_l=(0.0)	model parameter: number of standard deviations of global variation for l.
91	sig_rsh=(0.0)	model parameter: global variation standard deviation for rsh (relative).
92	sig_w=(0.0)	model parameter: global variation standard deviation for w (absolute).
93	sig_l=(0.0)	model parameter: global variation standard deviation for l (absolute).
94	smm_rsh=(0.0)	model parameter: local variation standard deviation for rsh (relative).

95	smm_w=(0.0)	model parameter: local variation standard deviation for w (absolute).
96	smm_l=(0.0)	model parameter: local variation standard deviation for l (absolute).
97	sw_mmgeo=(0)	model parameter: switch for flicker noise geometry calculation: 0=drawn and 1=effective.
98	mr=(0.0)	model parameter: resistor mismatch dependence.
99	mrl=(0.0)	model parameter: resistor mismatch length dependence.
100	mrlp=(0.0)	model parameter: resistor mismatch length power dependence.
101	mrw=(0.0)	model parameter: resistor mismatch width dependence.
102	mrwp=(0.0)	model parameter: resistor mismatch width power dependence.
103	mrlw1=(0.0)	model parameter: resistor mismatch area 1 dependence.
104	mrlw1p=(0.0)	model parameter: resistor mismatch area 1 power dependence.
105	mrlw2=(0.0)	model parameter: resistor mismatch area 2 dependence.
106	mrlw2p=(0.0)	model parameter: resistor mismatch area 2 power dependence.

Output Parameters

1	n1	node: external node.
2	nc	node: external node.
3	n2	node: external node.
4	i1	node: internal node.
5	i2	node: internal node.
6	dt	node: self-heating node.

Operating Point Parameters

1	exp_cr=(80.0) i	nstance parameter.
2	cmi_limexp_method=(1.0)	instance parameter.
3	cmi_compactable=(1.0)	instance parameter.
4	m=(1.0)	instance parameter.
5	w=(1.0e-06)	design width of resistor body.
6	l=(1.0e-06)	design length of resistor body.
7	wd=(0.0)	dogbone width (total; not per side).
8	a1=(0.0)	area of node n1 partition.
9	p1=(0.0)	perimeter of node n1 partition.
10	c1=(0)	# contacts at node n1 terminal .
11	a2=(0.0)	area of node n2 partition .
12	p2=(0.0)	perimeter of node n2 partition .
13	c2=(0)	# contacts at node n2 terminal .
14	trise=(0.0)	local temperature delta to ambient (before self-heating) .
15	sw_noise=(1)	switch for including noise: 0=no and 1=yes .
16	sw_et=(1)	switch for self-heating: 0=no and 1=yes .
17	sw_mman=(0)	switch for mismatch analysis: 0=no and 1=yes .
18	nsmm_rsh=(0.0)	number of standard deviations of local variation for rsh.
19	nsmm_w=(0.0)	number of standard deviations of local variation for w.
20	nsmm_l=(0.0)	number of standard deviations of local variation for l.

21	v	voltage across resistor.
22	ibody	current through resistor body.
23	power	dissipated power .
24	leff_um	effective electrical length in um .
25	weff_um	effective electrical width in um .
26	r0	zero-bias resistance (per segment).
27	r_dc	DC resistance (including bias dependence and m).
28	r_ac	AC resistance (including bias dependence and m).
29	rth	thermal resistance.
30	cth	thermal capacitance.
31	dt_et	self-heating temperature rise.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

41

IGBT0 Model (igbt0)

The IGBT0 (Insulated Gate Bipolar Transistor Level 0) model is a simplified IGBT model that is compatible with Cadence PSpice IGBT model. IGBT0 model was introduced to model the application of high voltage and current. The voltage can be up to several thousand volts and the current up to several hundred amperes.

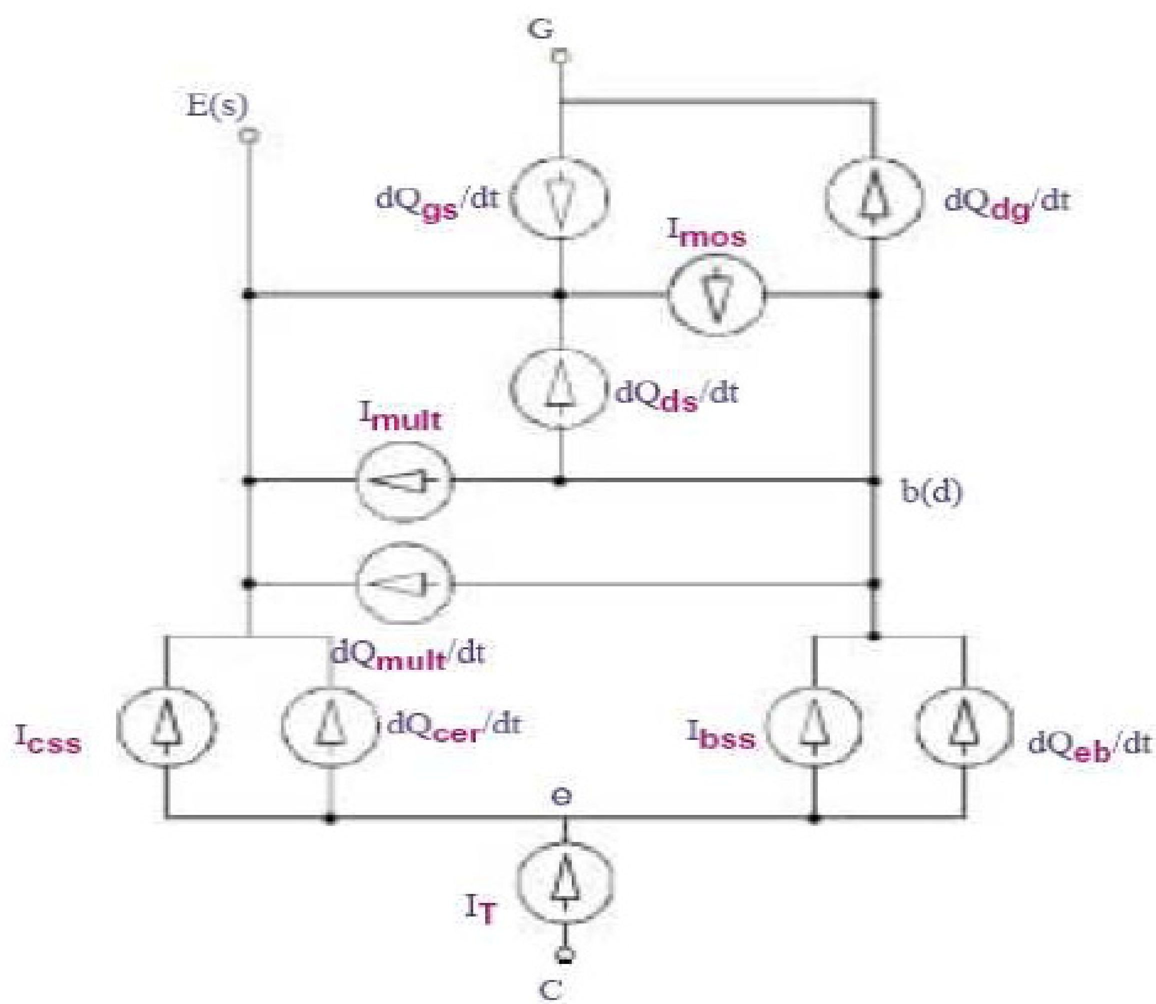
This chapter contains the following information:

Model Concepts

The equivalent circuit for the IGBT is shown in Figure 41-1 on page 2758. It is modeled as a thick base BJT driven by MOSFET. Five DC current components and six charge (capacitive) components are included in the model. For the meaning of specific component, please refer to the Model Equation part of the model.

As the simplified IGBT model, only the basic characteristics are modeled by IGBT0 model. Combining BJT with MOSFET, p_type IGBT0 devices are hard to modeling and seldom used. Only N-type devices are supported. Different with MOSFET, there's only the leakage current exist when the devices are reversed (Vc < Ve)

Figure 41-1 The equivalent circuit for IGBT0



Component Statements

Instance Syntax

IGBT0 instance need specify 3 terminals and the number cannot be changed any more. To specify IGBT0 instance element, the Model Name has to be associated with a IGBT0 model card.

```
InstanceName c g e ModelName parameter=value ...
```

Sample Instance Statement

```
m1 (vcc vgg vee) n_ch area=0.1u kp=0.21 tau=1e-7 agd=1e-8
```

For more instance parameters, refer to Reference on page 2760.

Model Syntax

The following syntax specifies IGBT0 model:

```
model ModelName igbt0 parameter=value ...
```

The third parameter, "igbt0", is the master to indicate this model card is a IGBT0 model card.

Sample Model Statement

```
model n_ch igbt0 vt=4.5 mun=1.7e3 mup=5e2 cgs=1e-10 nb=3e14 jsne=1e-13
```

For more model parameters, refer to Reference on page 2760.

Reference

Model Equations

Some important model equations are listed as following for your reference:

Equations for DC current

MOSFET channel current

$$
\begin{cases}
0 & \text{For } V_{gs} < VT \\[2ex]
\dfrac{\mathbf{KF} \cdot \mathbf{KP} \cdot \left((V_{gs} - \mathbf{VT}) \cdot V_{ds} - \dfrac{\mathbf{KF} \cdot {V_{ds}}^2}{2} \right)}{1 + \mathbf{THETA} \cdot (V_{gs} - \mathbf{VT})} & \text{For } V_{ds} \le \ (V_{gs} - \\[2ex]
\dfrac{\mathbf{KP} \cdot (V_{gs} - \mathbf{VT})^2}{2 \cdot (1 + \mathbf{THETA} \cdot (V_{gs} - \mathbf{VT}))} & \text{For } V_{ds} > \ (V_{gs} -
\end{cases}
$$

Anode current: current through the resistor Rb

$$I_T = \frac{V_{Ce}}{R_b}$$

Steady-state collector current

$$
I_{css} = \begin{cases}
0 & \text{For } V_{eb} \le 0 \\[2ex]
\left(\dfrac{1}{1+b}\right) \cdot I_T + \left(\dfrac{b}{1+b}\right) \cdot \left(\dfrac{4 \cdot D_p}{W^2}\right) \cdot Q_{eb} & \text{For } V_{eb} > 0
\end{cases}
$$

Steady-state base current

$$I_{bss} = \begin{cases} 0 & \text{For } V_{eb} \le 0 \\ \dfrac{Q_{eb}}{\mathbf{TAU}} + \left(\dfrac{Q_{eb}^{2}}{Q_B}\right) \cdot \left(\dfrac{4 \cdot \mathbf{NB}^2}{n_i^{2}}\right) \cdot (\mathbf{JSNE} \cdot \mathbf{AREA}) & \text{For } V_{eb} > 0 \end{cases}$$

Avalanche multiplication current

$$I_{mult} = (M - 1) \cdot (I_{mos} + I_{css}) + M \cdot I_{gen}$$

Equations for capacitance and charge

Gate Source

$$C_{gs} = \mathrm{CGS} \qquad Q_{gs} = \mathbf{CGS} \cdot V_{gs}$$

Drain Source

$$C_{ds} = \frac{(\mathbf{AREA} - \mathbf{AGD}) \cdot \varepsilon_{si}}{W_{dsj}} \qquad Q_{ds} = q \cdot (\mathbf{AREA} - \mathbf{AGD}) \cdot \mathbf{NB} \cdot W_{dsj}$$

Where

$$W_{dsj} = \sqrt{\frac{2 \cdot \varepsilon_{si} \cdot (V_{ds} + 0.6)}{q \cdot \mathbf{NB}}}$$

Gate Drain

For $V_{ds} < V_{gs} - \mathrm{VTD}$

$$C_{dg} = \mathrm{COXD} \qquad Q_{dg} = \mathrm{COXD} \cdot V_{dg}$$

For $V_{ds} \geq V_{gs} - \mathrm{VTD}$

$$C_{dg} = \frac{C_{dgj} \cdot \mathrm{COXD}}{C_{dgj} + \mathrm{COXD}}$$

$$Q_{dg} = \frac{q \cdot \mathrm{NB} \cdot \varepsilon_{si} \cdot \mathrm{AGD}^2}{\mathrm{COXD}}\left(\frac{\mathrm{COXD} \cdot W_{dgj}}{\varepsilon_{si} \cdot \mathrm{AGD}} - \log\left(1 + \frac{\mathrm{COXD} \cdot W_{dgj}}{\varepsilon_{si} \cdot \mathrm{AGD}}\right)\right) - \mathrm{COXD} \cdot \mathrm{VTD}$$

where

$$C_{dgj} = \frac{\mathrm{AGD} \cdot \varepsilon_{si}}{W_{dgj}}$$

$$W_{dgj} = \sqrt{\frac{2 \cdot \varepsilon_{si} \cdot (V_{dg} + \mathrm{VTD})}{q \cdot \mathrm{NB}}}$$

Instance Parameters

1	area (m^2)	Area of the device.
2	wb (m)	Metallurgical base width.
3	tau (s)	Ambipolar recombination lifetime.
4	agd (m^2)	Gate-drain overlap area.
5	kp (A/V^2)	MOS transconductance.
6	trise (C)	Device temperature increased.

Model Parameters

Default for instance parameters

1 area=1.0e-5 m^2 Default area of the device.

2 wb=9.0e-5 m Default metallurgical base width.

3 tau=7.1e-6 s Default ambipolar recombination lifetime.

4 agd=5.0e-6 m^2 Default gate-drain overlap area.

5 kp=0.38 A/V^2 Default MOS transconductance.

Basic Device Parameters

6 vt=4.7 V Threshold voltage.

7 kf=1.0 Triode region factor.

8 theta=0.02 1/V Transverse field factor.

9 nb=2.0e14 cm^-3 Base doping.

10 mun=1.5e3 cm^2/(V*s)

Electron mobility.

11 mup=4.5e2 cm^2/(V*s)

Hole mobility.

12 jsne=6.5e-13 A/(cm^2)

Emitter saturation current density.

13 bvn=4.0 Avalanche multiplication exponent.

14 bvf=1.0 Avalanche uniformity exponent.

15 cgs=1.24e-8 F/(cm^2)

Gate-source capacitance per unit area.

16 coxd=3.5e-8 F/(cm^2)

Gate-drain oxide capacitance per unit area.

17 vtd=1.0e-3 V Gate-drain overlap depletion threshold.

Operating Point Parameters

1 ice (A) Collector-emitter current.

2 vce (V) Collector-emitter voltage.

3 vds (V) Internal Vds of mosfet.

4 vge (V) Gate-emitter voltage.

5 vdsat (V) Drain-source saturation voltage.

6 gm (S) Common-source transconductance.

7 ic_bjt (A) Resistive collector current.

8 ie (A) Resistive emitter current.

9 imult (A) Avalanche multiplication current.

10 ib_bjt (A) Steady-state base current.

11 imos (A) MOSFET channel current.

12 cge (F) dQg_dVe.

13 cgg (F) dQg_dVg.

14 pwr (W) Power at operating point.

15 cdg (F) dQd_dVg.

16 cds (F) dQd_dVs.

17 qgs (Coul) Qgs for mosfet.

18	qds (Coul)	Qds for mosfet.
19	qdg (Coul)	Qdg for mosfet.
20	qeb (Coul)	Qeb for bjt.

Parameter Index

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

42

Laterally Double Diffused Metal Oxide Semiconductor FET Model (LDMOS)

The LDMOS is a high voltage MOS device with a non-uniform channel doping profile. It was developed by Cadence Design Systems, Inc. This chapter covers the following information about the LDMOS model:

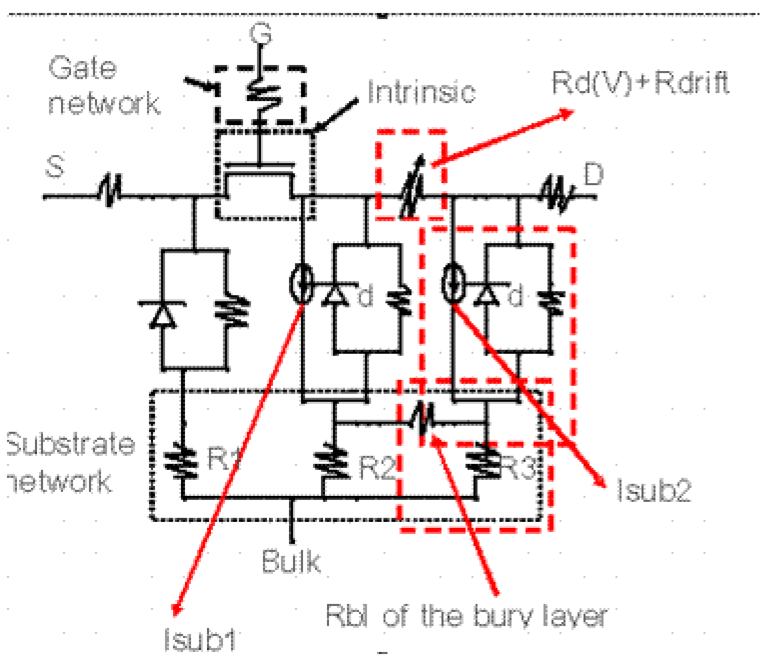
DC Model

The LDMOS DC model covers the pinch-off phenomenon and includes the self-heating effect. Its drain current rises when the value of Vgs increases.

CV Model

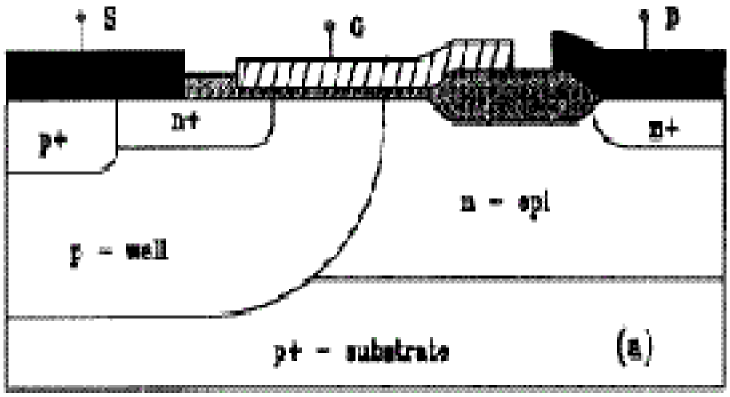
The LDMOS CV model is based on charge conservation. It includes gate and substrate network for RF modeling.

Equivalent Circuit



- The intrinsic transistor is the same as BSIM3.

- The LDMOS model consists of three diodes – source body junction diode, drain-body junction diode, and drain-substrate junction diode. The following shows a cross-section of a conventional diode:



- Different Isubs are used for the Kirk effect (peak electric field shift with the drain current). Isub1 is for small drain current and Isub2 is for high drain current.
- The RF network (gate and substrate) is used for high frequency applications and is ignored for base band applications.

Model Features

The LDMOS model includes an accurate description of all physical effects important for LDMOS devices.

- Bias dependent drift region resistance modeling

  LDMOS shows a significant quasi-saturation effect for the drain currents at high Vgs biases. This is caused by the bias-dependent drift region resistance, which is important for both current and capacitance modeling. In high Ids region carrier, drift velocity may saturate and the effective conducting area changes as a result of the depletion width change controlled by the drain-to-substrate bias. In the model, the drift region resistance mainly depends on Vgs and Vds.

- Overlap region resistance modeling

  Gate-to-drain overlap region is under accumulation when device is turned on. The resistance in this region is modulated by the gate bias due to field dependent mobility and conduction width modulation from the junction depletion layer. The Rdv model used in LDMOS model is adopted from the BSIM4 model.

- Substrate current modeling with double-peak Isub

Lateral electric field peak positions depend on the gate bias, resulting in different substrate current components at different biases and different positions. Two Isub components are introduced to account for such effect.

- Multiple junction effect

  Two diode s between the drain and body are introduced for accurately modeling the drain leakage current and dynamic behavior of the device. In addition, one diode between the body and source is introduced.

- Gate/substrate resistance network for RF modeling

  LDMOS is widely used in RF power amplifier, and the gate/substrate resistor networks are used for accurately modeling high frequency behavior of the device.

- Model scalability for both temperature and geometry

  The scalabilities of the drift region length and device width are emphasized in this model for accurate DC and AC modeling. The model also considers the scalability for other geometry parameters, including the overlap region length and width and the channel length.

  All parameter temperature dependences are the same as that in BSIM3, except the drift region resistor Rdrift and the overlap region resistor Rd(V). Rd(V) is temperature independent while Rdrift is temperature dependent.

- Self-heating effect

  Self-heating effect is significant in LDMOS devices and can be modeled by a thermal network. Self-heating function is implemented in LDMOS by adding a temperature node tothe model as an inner node. The internal self-heating network can be turned on by switching the flag `shmod` from the default value `0` to `1`.

- Overlap capacitance model

  In some technologies, LDMOS devices have much larger overlap region than channel region. In such devices, overlap capacitance dominates device CV behavior. Overlap region is working in accumulation region when device is on, and in depletion region and possibly inversion region when device is off. Overlap region charges are function of gate, body, internal drain and external drain voltage.

- Non uniform lateral doping in the channel

  The appearance of the non-uniform doping in the channel is due to the fact that the channel is formed by a lateral diffusion. As a result, threshold voltage is a function of position in the channel, the inversion charge density along the channel is not uniform even at Vds=0, and the drain side channel gets inverted before the source side. In order to describe LDMOS in a more accurate way, it's therefore necessary to adopt the non uniform doping channel model.

Parameter Descriptions

Table 42-1 Instance Parameters

Parameter Name	Description	Default Value	Unit
W	Channel widt	5e-6	m
L	Channel length	5e-6	m
As	Area of source diffusion	0	m^2
Ad	Area of DRAIN diffusion	0	m^2
Ps	Perimeter of source diffusion	0	m
Pd	Perimeter of drain diffusion	0	m
Nrs	Number of squares of source diffusion	0	
Nrd	Number of squares of drain diffusion	0	
Trise	Temperature rise from ambient	0	
M	Multiplicity factor (number of MOSFETs in parallel)	1	
Rth0	Thermal resistance per unit width	0	
Cth0	Thermal capacitance per unit width	1e-5	
Ae	Area of external diffusion	0	m^2
Pe	Perimeter of external diffusion	0	m
Nseg	Number of segments for channel width partitioning	1	
Rdc	Drain contact resistance	0	Ω
Rsc	Source contact resistance	0	Ω

Parameter Name	Description	Default Value	Unit
Lov	Overlap region length	0.1e-6	m
Wov	Overlap region width		m
Ldrift	Drift region length	3e-6	m

Table 42-2 Model Selectors/Controllers

Parameter Name	Description	Default Value	Unit
ABULK0FLG	Specifies whether ABULK0 is bias dependent	1	
APWARN	When APWARN is greater than 0, it turns off the warning message for Ps, Pd < Weff	0	
BINFLAG	If BINFLAG > 0.9, WREF and LREF are used for binning	0	
BINUNIT	Binning unit selector	1	NA
CALCHARGE	Specifies whether to calculate charge	1	
CALDDC	Calculates Diode IV	1	
CALMOSDC	Specifies whether to calculate MOSFET current	1	
CALNQS	Specifies whether to calculate NQS	0	
CAPMOD	Capacitance model selector (LDMOS uses CAPMOD=2 only)	2	
DEBUG	Specifies whether debug is on.		
DEFAD	Default area of drain diffusion	0	m2
DEFAS	Default area of source diffusion	0	m2
DEFPD	Default perimeter of drain diffusion	0	m

Parameter Name	Description	Default Value	Unit
DEFPS	Default perimeter of source diffusion	0	m
DIGITALMOD	Digital flag	0	
ERRMSG	Set to 1 to retrieve errors and warnings caused by UltraSim functions	0	
EXTRDS	Specifies whether to use external resistance	1	
GMIN	PN junction parallel transient conductance	1.00E-12	
ISDISPLAY	Set to 1 to perform additional converting calculations		
LEVEL	Model selector	99	
MOBMOD	Mobility model selector	1	
NLEV	NLEV noise model		
NOIMOD	Noise model selector	1	
NQSMOD	NQS model selector	0	
PARAMCHK	Switch for parameter value check	0	
RBODYMOD	Substrate network selector	0	
RDRIFTMOD	Drift region resistor selector	0	
SFVTFLAG	Spline function for VTH	0	
SHAREPARAS	Parameter sharing By UltraSim	2	
SHMOD	Self heating flag		
SIMULATOR	Compatible simulator (such as Spectre and HSPICE)	1	
TYPE	Channel type of MOSFET (nmos or pmos)	1	
VERSION	Model version number	1	
VFBFLAG	VFB selector for CAPMOD = 0	0	

Parameter Name	Description	Default Value	Unit
XPART	S/D partition	0	

Table 42-3 Process Parameters

Parameter Name	Description	Default Value	Unit
DLC	Length offset fitting parameter from CV	LINT	
DWC	Width offset fitting parameter from C-V	WINT	
HDIF	Length of heavily doped diffusion from contact to lightly doped region, acm=2, 3 only	0	
HDIF2	Length of drain-substrate junction, acm=2,3 only	0	
LD	Lateral diffusion into channel from source and drain diffusion	0	
LDIF	Length of lightly doped diffusion adjacent to gate acm12	0	
LINT	Length offset	0	
LMLT	diffusion layer length shrinking factor		
NI	Intrinsic carrier concentration	1.45E+10	cm^3
SETDEFAULT	Set model parameters to their default values (used by BSIMProPlus only).	0	
TNOM	Temperature at which parameters are extracted	25c=	c
TOX	Oxide thickness	1.50E-08	m
TOXM	Tox at which parameters are extracted	TOX	

Parameter Name	Description	Default Value	Unit
WINT	Width offset	0	
WMLT	Diffusion layer width shrinking factor	1	
XL	Length offset for masking and etching effects	0	
XW	Width offset for masking and etching effects	0	

Table 42-4 Noise Model Parameters

Parameter Name	Description	Default Value	Unit
AF	Flicker noise exponent	1	
EF	Flicker noise frequency exponent	1	
EM	Saturation electric field	4.10E+07	V/m
KF	Flicker noise coefficient	0	
NOIA	Noise parameter A	1.00E+20	
NOIB	Noise parameter B	5.00E+04	
NOIC	Noise parameter C	-1.40E-12	

Table 42-5 Junction Diode Parameters

Parameter Name	Description	Default Value	Unit
ACM		12	
CBD	Zero bias bulk-drain junction capacitance used only when CJ and CJSW=0		

Parameter Name	Description	Default Value	Unit
CBDE	Zero bias bulk-ext-drain junction capacitance used only when CJ and CJSW=0		
CBS	Zero bias bulk-source junction saturation current used only when CJ and CJSW=0		
CJGATE	Zero bias gate edge sidewall bulk junction capacitance		
CJ	Bottom junction capacitance per unit area at zero bias	5.00WE-04	f/m^2
CJSW	Source/drain side wall junction capacitance per unit area	5.00E-10	f/m
CJSWG	Source/drain gate side wall junction capacitance per unit area		
EG	Band gap	1.17e	V/k
FC	Forward bias depletion capacitance coefficient	0.5	
FCSW	Side-wall forward-bias depletion capacitance	0.5	
GAP1	First bandgap correction factor	7.02E-04e	V/k
GAP2	Second bandgap correction factor	1108k	
GEO	Stacked device		
IJTH	Diode Limiting Current	0.1	amp
IJTH2	External Diode Limiting Current	0.1	amp
JS	Bulk junction saturation current	1.00E-04	amp/m^2
JS2	External bulk junction saturation curr	1.00E-04	amp/m^2
JSW	Sidewall bulk junction saturation current	0	
JSW2	External sidewall bulk junction	0	amp/m

Parameter Name	Description	Default Value	Unit
IGCD	Gate-to-contact length of drain side	0	m
IGCS	Gate-to-contact length of source side	0	m
LGCD			
LGCS			
LRD	Drain resistance length sensitivity. Use this parameter with WRD and PRD to factor model for device size		
LRS	Source resistance length sensitivity. Use this parameter with WRS and PRS to factor model for device size		
LS	Bulk junction saturation current for ASPEC=1	1.00E-14p	am
MINR	Minimum source/drain resistance	0.1	ohm
MJ	Bottom junction capacitance grading coefficient	0.5	
MJSW	Source/drain side wall junction capacitance grading coefficient	0.33	
MJSWG	Source/drain gate side wall junction capacitance grading coefficient		
NDS	Reverse bias slope coefficient	1	
NDS2	Reverse bias slope coefficient of external junction	1	
NJ	Emission coefficient of junction		
NJ2	Emission coefficient of external junction	1	
PB	Bottom junction built in potential	1	V
PBSW	Side wall junction built in potential	1	V

Parameter Name	Description	Default Value	Unit
PBSWG	Side wall junction built in potential		
PHP	Bulk sidewall junction contact potential	0.8	V
PRD	Drain resistance product sensitivity		
PRS	Source resistance product sensitivity		
PTA	Temperature coefficient for Pb	0	V/k
PTC	Potential phi temperature coefficient	0	V/k
PTP	PHP temperature coefficient	0	V/k
RD	Drain ohmic resistance. This parameter is usually the sheet resistance of a lightly-doped region for acm ≥ 1.	0	ohm/sq
RDC	Additional drain resistance due to contact resistance	0	ohm
RDD	Scalable drain resistance	0	ohm*m
RSH	Source drain sheet resistance in ohm pre square	0	
RS	Source ohmic resistance. This parameter is usually the sheet resistance of a lightly-doped region for acm ≥ 1		
RSC	Additional source resistance due to contact resistance	0	ohm
RSS	Scalable source resistance	0	ohm*m
SC	Spacing between contacts	1.00E+31	m
TCJ	Temperature coefficient of CJ	0	1/k
TCJSW	Temperature coefficient of CJSW	0	1/k
TCJSWG	Temperature coefficient of CJSWG	0	1/k

Parameter Name	Description	Default Value	Unit
TLEV	Diode DC temperature model selector	0	
TLEVC	diode CV temperature model selector	0	
TPB	Temperature coefficient for PB	0	V/k
TPBSW	Temperature coefficient for PBSW	0	V/k
TPBSWG	Temperature coefficient for PBSWG	0	V/k
TRD	rd temperature coefficient	0	1/k
TRS	rs temperature coefficient	0	1/k
TT	Transit time	0	s
VNDS	Reverse diode current transition point	-1	V
VNDS2	Reverse diode current transition point of external junction	-1	V
WRD	Drain resistance width sensitivity used with lrd		
WRS	Source resistance width sensitivity used with IRS		
XTI	Junction current temperature exponent coefficient	0	
XTI2	External Junction current temperature exponent coefficient	0	

Table 42-6 Threshold Voltage Parameters

Parameter Name	Description	Default Value	Unit
CDSC	Drain/source to channel coupling capacitance	2.40E-04	F/m^2
CDSCB	Body bias sensitivity of CDSC	0	$F/V/m^2$

Parameter Name	Description	Default Value	Unit
CDSCD	Drain bias sensitivity of CDSC	0	$F/V/m^2$
CIT	Interface trap capacitance	0	F/m^2
DVT0	First coefficient of short channel effect on VTH	2.2	
DVT1	Second coefficient of short channel effect on Vth	0.53	
DVT2	Body bias coefficient of short channel effect on VTH	-0.032	1/V
DVT0W	First coefficient of narrow channel effect on VTH	0	
DVT1W	Second coefficient of narrow channel effect on VTH	5.30E+06	
DVT2W	Body bias coefficient of narrow channel effect on VTH	-0.032	1/V
GAMMA1	Body-effect coefficient near the surface		
GAMMA2	Body-effect coefficient in the bulk		
K1	First order body effect coefficient	0.53	$V^{1/2}$
K2	Second order body effect coefficient	-0.0186	
K3	Narrow width coefficient	80	
K3B	Body effect coefficient of K3		
NCH	Channel doping concentration	$1.70E+17^3$	1/cm
NFACTOR	Subthreshold swing factor	1	
NLX	Lateral non-uniform doping parameter	1.74E-07	m
NSUB	Substrate doping concentration	6.00E+16	
VBM	Maximum applied body bias in VTH calculation	-3	V

Parameter Name	Description	Default Value	Unit
VBX	Body bias to completely deplete channel		
VFB	Flat band voltage		
VOFF			
VTH0	Threshold Voltage at VBS=0 for large channel length	0.7	V

Table 42-7 Mobility Parameters

Parameter Name	Description	Default Value	Units
NGATE	Gate doping concentration	0	cm^3
PRWB	Body bias coefficient of RDSW	0	$V^{-.5}$
PRWG	Gate bias coefficient of RDSW	0	1/V
RDSW	Parasitic resistance per unit width	0	$ohm*um^{wr}$
U0	Constant Mobility	0.067	m^2/V/S
UA	First order mobility degradation coefficient	2.25E-09	m/V
UB	Second order mobility degradation coefficient	5.87E-19	m^2/V^2
UC	Bulk effect of mobility degradation coefficient	-4.65E-11	1/V
W0	Gate doping concentration	2.50E-06	m
WR	Width offset from WEFF for RDS	1	
XJ	Junction depth	1.50E-07	m
XT	Doping depth	1.55E-07	m

Table 42-8 Saturation Voltage Parameters

Parameter Name	Description	Default Value	Unit
A0	bulk charge effect coefficient for channel length	1	
A1	First non-saturation coefficient	0	1/V
A2	Second non-saturation coefficient	1	
AGS	gate bias dependence of ABULK	0	1/V
ALPHA0	First parameter of impact ionization current	0	m/V
ALPHA1	Isub parameter for length scaling	0	1/V
ALPHA2	Isub parameter for length scaling	0	1/V
B0	Bulk charge effect coefficient for channel width	0	m
B1	Bulk charge effect width offset	0	m
BETA0	Second parameter of impact ionization current	30V	V
DWB	Coefficient of Weff's body dependence	0	$m/V^{.5}$
DWG	Coefficient of WEFF's gate dependence	0	m/V
KETA	Body-bias coefficient for non-uniform depletion width effect	-0.047	1/V
VSAT	Saturation velocity	8.00E+04	m/sec

Table 42-9 Output Resistance Parameters

Parameter Name	Description	Default Value	Unit
DELTA	Effective VDS parameter	0.01	V

Parameter Name	Description	Default Value	Unit
DROUT	L dependence coefficient of the DIBL correction in Rout	0.56	
DSUB	DIBL coefficient exponent in subthreshold region	0.56	
ETA0	DIBL coefficient in subthreshold region	0.08	
ETAB	Body bias coefficient for subthreshold	-0.07	V
PCLM	channel length modulation	1.3	
PDIBLC1	First output resistance DIBL correction parameter	0.39	
PDIBLC2	Second output resistance DIBL correction parameter		
PDIBLCB	Body effect coefficient of DIBL correction on output resistance		
PSCBE1	First substrate current body effect parameter	4.24E+08	V/m
PSCBE2	Second substrate current body effect parameter	1.00E-05	V/m
PVAG	Gate dependence of Early voltage	0	

Table 42-10 Parasitic Resistance Parameters

Parameter Name	Description	Default Value	Unit
BETA1	Gate bias dependence of drift region resistance	1	1/V
GAMMA	Drain bias dependence of drift region resistance	1	

Parameter Name	Description	Default Value	Unit
R1S	Substrate network resistance	50	ohm
R2S	substrate network resistance	50	ohm
R3S	substrate network resistance	50	ohm
RBL	Substrate network resistance for the bury layer under the drift region	50	ohm
RDW	Zero-biased gate-drain overlap resistance		ohm
RDWMIN	minimum gate-drain overlap region resistance	1	ohm
RGATE	Gate resistance	0	ohm
RSHDRIFT	Drift region sheet resistance	100	ohm/ square
THETA	Gate bias dependence of drift region resistance for RDRIFTMOD=0	1	
THETA1	Gate bias dependence of drift region resistance for RDRIFTMOD=1	1	
THETA2	Gate bias dependence of drift region resistance for RDRIFTMOD=2	1	

Table 42-11 Capacitance Parameters

Parameter Name	Description	Default Value	Unit
ACDE	Exponential Coefficient for charge thickness in CAPMOD=3 for accumulation and depletion regions	1	m/V
CF	Fringing field capacitance		

Parameter Name	Description	Default Value	Unit
CGDL	Lightly doped drain-gate overlap region capacitance	0	F/m
CGDSLOPE	Offset coefficient of source and drain charge partition	1	
CGSL	Lightly doped source-gate overlap region capacitance		
CKAPPA	Coefficient for lightly doped region overlap capacitance	0.6	V
CLC	Constant term for short channel model	1.00E-07	m
CLE	Exponential term for short channel model	0.6	
MOIN	Coefficient for the gate-bias dependents	15	
NOFF	CV parameter in VGSTEFF CV for weak to strong inversion	1	
ULD_ALPHA	Work function difference between source and drain ends of channel	-0.002	
ULD_BETA	Square of characteristic length of lateral channel doping profile	1.00E-12	m^2
ULD_THETA	Offset voltage in threshold voltage	-0.2	V
VFBCV	Flat-band voltage parameter for CAPMOD=0 only	-1V	V
VOFFCV	CV parameter in VGSTEFF CV for weak to strong inversion	0	V

Table 42-12 Temperature Effects Parameters

Parameter Name	Description	Default Value	Unit
AT	Temperature coefficient for saturation	3.30E+04	m/sec

Parameter Name	Description	Default Value	Unit
CTH0	Thermal capacitance per unit width	0	m/(w*sec)
KT1	temperature coefficient of threshold voltage	-0.11	v
KT2	body bias coefficient of threshold voltage temperature effect	0.022	
KT1L	channel length dependence of the temperature coefficient of threshold voltage	0	Vm
PRT	Temperature coefficient for RDSW	0	
PTE	Temperature coefficient of drift region	0	
RTH0	Thermal resistance per unit width	0	mc/w
UA1	Temperature coefficient for UA	4.31E-09	m/v
UB1	temperature coefficient for UB	-7.61E-18	m^2/V^2
UC1	temperature coefficient for UC	-5.60E-11	m/V^2
UTE	Mobility temperature exponent	-1.5	

Table 42-13 dW and dL Parameters

Parameter Name	Description	Default Value	Unit
LDRIFT	Drift region length	3.00E-06	m
LL	Coefficient of length dependence for length offset	0	m^{Lln}
LLC	Coefficient of length dependence for CV channel length offset	0	m^{Lln}
LLN	Power of length dependence of length offset	1	
LMAX	Maximum channel length	1	m

Parameter Name	Description	Default Value	Unit
LMIN	Minimum channel length	0	m
LOV	Overlap region length	1.00E-07	m
LREF	Related to binning	1.00E+20	m
LW	Coefficient of width dependence for length offset	0	m^{Lwn}
LWC	Coefficient of width dependence for CV channel length offset	0	m^{Lwn}
LWL	Coefficient of length and width cross term for length offset	0	$m^{Lwn+Lln}$
LWLC	Coefficient of length and width dependence for CV channel length offset	0	$m^{Lwn+Lln}$
LWN	Power of width dependence of length offset	1	
SCALE	Instance scale factor	1	
SCALEM	Model parameter scale factor		
WL	Coefficient of length dependence for width offset	0	m^{Wln}
WLC	Coefficient of length dependence for CV channel width offset	0	m^{Wln}
WLN	Power of length dependence of width offset	1	
WMAX	Maximum channel width	1	m
WMIN	Minimum channel width	0	m
WOV	Overlap region width	5.00E-07	m
WREF	Related to binning	1.00E+20	m
WTH0	Width scaling factor for thermal resistance	0	
WW	Coefficient of width dependence for width offset	0	m^{Wwn}

Parameter Name	Description	Default Value	Unit
WWC	Coefficient of width dependence for CV channel width offset	0	m^{Wwn}
WWL	Coefficient of length and width cross term for width offset	0	$m^{Wwn+Wln}$
WWLC	Coefficient of length and width dependence for CV channel width	0	$m^{Wwn+Wln}$
WWN	Power of width dependence of width offset		

Table 42-14 Capacitance Parameters

Parameter Name	Description	Default Value	Unit
CGBO	Gate-bulk overlap capacitance	0	F/m
CGDO	Gate-drain overlap capacitance		F/m
CGSO	Gate-source overlap capacitance		F/m
Vth0ov	Threshold voltage at Vbs=0 for the overlap region	0.7	V
K1ov	First order body effect coefficient for the overlap region	0.5	$V^{0.5}$
Nov	Doping concentration in the overlap region	1.7e17	1/cm
Noffov	Transition parameter for the overlap region	1	
Qminvov	Smooth coefficient for inversion charge in the overlap region	0	V
Voffcvov	Overlap region CV parameter in the Vgsteff calculation for weak to strong inversion	0	V
Qmacov	Smooth coefficient for accumulation charge in the overlap region	0.02	V^2

Parameter Name	Description	Default Value	Unit
Delvfbcv	Flatband voltage shift due to overlap region coupling	0	V
K1cv	Capacitance body effect coefficient	0.5	$V^{0.5}$
K1ovw	Width dependent of body effect coefficient for overlap region	0	$V^{0.5}m$
K1cvw	Width dependent of body effect coefficient for capacitance model	0	$V^{0.5}m$
Vth0ovw	Width dependent of threshold voltage for overlap region	0	Vm
Qminv	Smooth coefficient for inversion charge in channel region	0	$V^{0.5}m$
Partov	Smooth coefficient for accumulation charge in overlap region	0	$V^{0.5}m$

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Distributed Components

This chapter describes component statements for the following components:

Microstrip Line (msline)

This is a microstrip line based on the equations of Hammerstad and Jensen. The model contains a thickness correction to the width and frequency dependent permittivity and characteristic impedance. The dispersion equations are those of Kirschning and Jansen.

This device is supported within altergroups.

Sample Instance Statement:

tl1 (in 0 out 0) msline l=0.15 w=0.01 h=0.01

Sample Instance Statement

```
tl1 (in 0 out 0) msline l=0.15 w=0.01 h=0.01
```

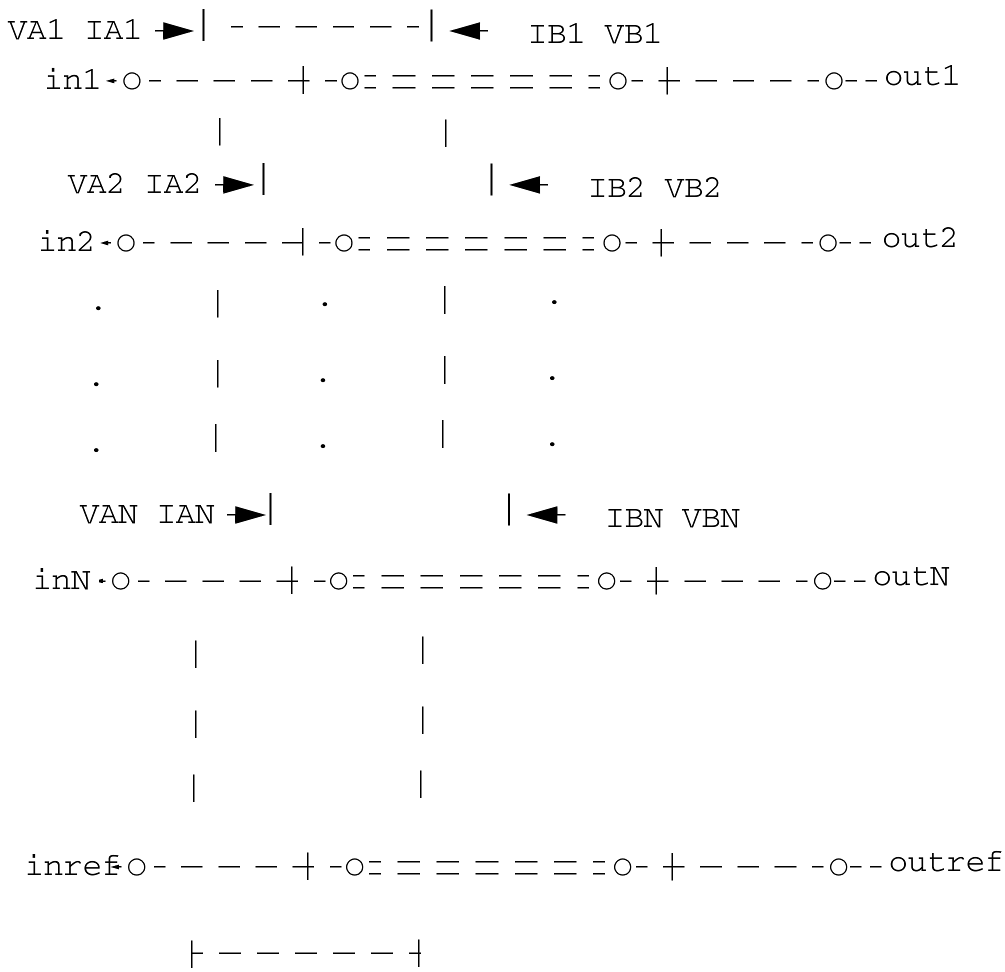
Instance Definition

```
Name  t1  b1  t2  b2 msline parameter=value ...
```

Instance Parameters

1	`l=0 m`	Length.
2	`w (m)`	Width.
3	`h (m)`	Substrate height.
4	`t=0 m`	Conductor thickness.
5	`eps=1`	Substrate permittivity relative to a vacuum.
6	`m=1`	Multiplicity factor.
7	`fmax=10e9 Hz`	Maximum signal frequency.

Multi-Conductor Transmission Line (mtline)



A multi-conductor transmission line (MTLINE) is characterized by constant RLGC matrices or frequency dependent RLGC data. An MTLINE can have as many conductors as there are as described in the input. However, there must be at least two conductors with one conductor used as reference to define terminal voltages. The reference conductor can be ground. The order of the conductors is the same as the order of the data in the input.

All of the conductors are assumed to have the same length, and to be uniform along the length.

MTLINE takes five different types of input: per-unit-length constant RLGC matrices, per-unit-length frequency dependent RLGC data, 2-D field solver geometry and material property information, S-parameter data, or the old single-conductor TLINE parameters. These inputs are explained below.

All transmission line parameters (other than conductor length) can be provided through an instance line or model line. When a particular parameter is provided on both the instance and the model lines, the value on the instance line takes higher priority.

Constant RLGC Matrices

For narrow band applications, transmission line characteristics very often are assumed to be constant over the frequency of interest. The input to MTLINE are per-unit-length resistance (R), inductance (L), conductance (G), and capacitance (C) matrices, and they are usually generated by a third-party field solver. Because these matrices are generally symmetric, MTLINE accepts both full matrix description and lower half matrix description.

For example, to describe the resistance matrix of a four conductor line system:

```
    [ 50 10 1  ]
R = [ 10 50 10 ] Ohm/meter
    [ 1  10 50 ]
```

The following two model descriptions are equivalent:

```
model line mtline
+ r=[ 50 10 1
+     10 50 10
+     1  10 50 ]
+ ...
model line mtline
+ r=[ 50
+     10 50
+     1  10 50 ]
+ ...
```

In the past, the only information available to describe a transmission line system was constant RLGC matrices based on the narrow band assumption. Some approximation has been used in an effort to extend the model to better cover frequency dependent effects, such as skin effect and dielectric loss effect, in wide band applications.

The following simplified equation can be used to model skin effect together with the constant RLGC matrices

R(f) = r + sqrt(f) * (1 + j) * `rskin`,

and the following equation can be used to model dielectric loss effect together with the constant RLGC matrices

G(f) = g + f * `gdloss`,

where f stands for frequency, or

G(f) = g + f * `gdloss` / sqrt(1 + (f/`fgdloss`)^2)

if the fgdloss parameter is specified to limit the dielectric loss effect at higher frequencies.

User should be aware that these are overly simplified versions of the actual frequency dependent effects. And particularly the dielectric loss effect equation of G(f) often results in non-physical models, and it could lead to a very inaccurate model over the frequency of interest.

To accurately model frequency-dependent effects, the user needs to provide true frequency-dependent RLGC data, or use MTLINEs internal 2-D field solver to generate the frequency-dependent model.

Frequency-Dependent RLGC Data

Frequency dependent RLGC data are described in a data file through parameter `file`. The frequency axis can be scaled with the `scale` parameter. The frequencies in the data file are then multiplied by `scale` before the simulator uses them. The default scale factor is unity.

An example data file is listed below:

```
; Comments: rl.dat

FORMAT FREQ:  R1:1 R2:1 R2:2

          L1:1 L2:1 L2:2

0.001e+9:    4.444 0.000383 4.444

          4.565 0.3545   4.565

0.010e+9:    4.447 0.003834 4.447

          4.565 0.3545   4.565
```

```
0.100e+9      4.476 0.03834  4.476

              4.565 0.3545   4.565

1.000e+9      4.762 0.3834   4.762

              3.103 0.2357   3.103

10.00e+9      13.96 1.082    13.96

              2.718 0.2058   2.718

100.0e+9      56.88 3.294    56.88

              2.531 0.1866   2.531

; end of file rl.dat
```

Note that lines starting with `;` are interpreted as comment lines. The data file has a format section, and a data section. In addition, both full matrix and lower half matrix descriptions are accepted.

The user can mix the constant RLGC parameters with frequency-dependent RLGC data. When a particular parameter (R, L, G or C) is provided in both constant matrices and frequency-dependent data file, the constant matrix is the first choice of input. If only one frequency point is provided in the `file`, the RLGC data are assumed to be constant over the frequency of interest.

When providing the frequency-dependent RLGC data, one should always try to provide accurate and sufficient data points. There should be data points to cover low-frequency characteristics, and there should be enough data points to capture the changing nature in the high-frequency range. A rule of thumb is that the lowest frequency point should be down to 1kHz, and there should be at least 5 points per decade, particularly in the high-frequency range where RLGC data tends to change rapidly.

2-D Field Solver Information

MTLINE directly supports a built-in 2-D field solver, it has the same modeling engine as the standalone LMG (Line Model Generator) utility. The output of the 2-D field solver is RLGC data, which can be stored for re-use through the `file` parameter. This makes the actual RLGC model generation a one-time cost, given the field solver input is unchanged.

Line Configuration (`linetype`)

MTLINE supports four interconnect line configurations: microstrip line, strip line, coplanar waveguide, and substrate lossy line.

Model Type (`modeltype`)

For each line configuration, you can choose between three model types. In the lossless model, the internal inductance of the conductor is disregarded by setting the frequency value high; 50 GHz for cases without substrate loss and 15 GHz for cases with substrate loss, and ignoring the value of `fmax`. For the narrow band model, the RLGC data is calculated at frequency `fmax` and assumed to be constant over the frequency of interest. The third choice is the wideband model where true frequency dependent RLGC data is calculated over the frequency of interest. For most applications, you should choose the wideband model as it provides the best model accuracy.

Ground Plane (`numgnd`)

For microstrip line, the number of ground planes is fixed to 1, at the bottom of the 2-D interconnect cross section.

For strip line, the number of ground planes is fixed to 2, at both the bottom and top of the 2-D interconnect cross section.

For coplanar waveguide and substrate lossy line, the number of ground planes can be 1 or 2, at the bottom and top of the 2-D interconnect cross section. For coplanar waveguide, you can also specify 0 ground planes because there will be two ground strips added automatically to the cross section. The width, height, thickness and spacing of these ground strips can be specified in a similar fashion as conductors are specified.

The `gndthickness` parameter can be used to specify the thickness of the ground plane(s), and the `gndsigma` parameter can be used to specify the ground plane conductivity.

Dielectric Layer (`numlayer`)

Dielectric layers are stacked above the ground plane (when `numgnd=1`), or between the ground planes (when `numgnd=2`). There can be many dielectric layers.

The thickness of the dielectric layer can be provided through the `layerthickness` parameter, and the relative dielectric constant of the dielectric layer can be provided through the `er` parameter. Note that both the `layerthickness` and `er` parameters are of vector type to handle different layer geometries and layer properties. When the number of elements in the vector is less than the number of layers, the value of the last element in the vector will be applied to all of the remaining layers.

A particular dielectric layer can be lossy, and either the loss tangent parameter (tan = sigma/(w*ep0)) or the loss sigma parameter (sigma = tan*w*ep0) can be used. This is decided through the `dlosstype` parameter and the actual loss value(s) is provided through the `dloss` vector parameter.

Signal Line

The signal line conductivity can be specified using parameter `linesigma`.

There can be many signal lines. The geometry of the signal line(s) are decided through parameters `linewidth`, `linethickness`, `lineheight` and `linespace`. The parameter `lineheight` is the distance between the signal line and ground plane at the bottom of the 2-D interconnect cross section. The parameter `linespace` is the distance between the signal lines; it can be negative in order to describe overlapping signal lines.

Intermediate RLGC file (`file`)

The `file` parameter can be used to store the 2-D field solver output, to be used in subsequent simulations. This makes the RLGC model generation a one-time effort.

If the `file` parameter is given, MTLINE will first check the existence of the file. If the `file` does not exist, the RLGC model will be generated by the field solver and the output will be stored in `file`; if the `file` does exist, MTLINE will check if the RLGC data stored in the `file` matches the MTLINE 2-D field solver input. If it does not match, a new set of RLGC data will be generated and the `file` will be over-written. Otherwise, the data will be re-used.

If the `file` parameter is not given, then the RLGC data will be stored in the file `%C.rlgc` after the simulation.

S-Parameter Data File

MTLINE also supports S-parameter data file input describing a transmission line system using the `file` parameter. MTLINE will convert the frequency dependent S-parameter to frequency dependent RLGC data and store the results in the file `%C.rlgc` for reuse in subsequent simulations.

If the `file` parameter corresponds to S-parameter data, MTLINE will first check the existence of the file `%C.rlgc` to determine if the S-to-RLGC extraction has been performed in a previous simulation.

The S-parameter data file formats supported include Touchstone, Spectre and Citi.

The physical length of the line must also be specified using the `len` parameter.

The ordering of the S-parameter input file should be in the format of input ports followed by the output ports of the transmission line system, or Pin1, Pin2, Pin3, ..., Pout1, Pout2, Pout3, ...

The Old TLINE Parameters

MTLINE directly supports the old single-conductor TLINE parameters, in a way to ease customer migration, as MTLINE has a more accurate and robust modeling algorithm.

Due to a name conflict, the TLINE parameter `r` has been renamed to `seriesr` in MTLINE, and the TLINE parameter `g` has been renamed to `shuntg` in MTLINE.

In addition, note that the terminal maps between TLINE and MTLINE are different. The following TLINE syntax

Name (t1 b1 t2 b2) tline <parameter=value> ...

should be mapped to the following MTLINE syntax

Name (t1 t2 b1 b2) mtline <parameter=value> ...

For a detailed explanation of TLINE parameters, please refer to the TLINE help page (spectre -h tline).

This device is not supported within altergroup.

Sample Instance Statement

```
x1 (a1 b1 a2 b2 0 0) mtline len=0.01
+ r=[ 0.3
+     0.0 0.3 ]
+ c=[ 0.35p
+    -0.03p 0.35p ]
```

Sample Model Statement

model mtmodel mtline

```
+ r=[ 0.3
+     0.0 0.3 ]
+ c=[ 0.35p
+    -0.03p 0.35p ]
```

model mtmodel mtline

```
+ r=[ 0.3 0.0
+     0.0 0.3 ]
+ c=[ 0.35p -0.03p
+    -0.03p  0.35p ]
```

model mtmodel mtline

```
+ c=[ 0.35p
+    -0.03p 0.35p ]
+ file="rl.data" scale=1
```

Instance Definition

```
Name  in1  out1  in2  [out2] ... ModelName parameter=value ...
Name  in1  out1  in2  [out2] ... mtline parameter=value ...
```

The last two terminals will be used as refin and refout respectively.

Instance Parameters

1 `len=0.01 m` Physical length of line.

2 `m=1` Multiplicity factor.

RLGC data parameters

3 `r=[...] Ω/m` Resistance matrix per unit length.

4 `l=[...] H/m` Inductance matrix per unit length.

5 `g=[...] S/m` Conductor matrix per unit length.

6 `c=[...] F/m` Capacitance matrix per unit length.

7 `rskin=[...] Ω/m √Hz`
Skin effect resistance matrix per unit length.

8 `gdloss=[...] S/m Hz` Dielectric loss conductance matrix per unit length.

9 `fgdloss (Hz)` Dielectric loss cut-off frequency.

10 `file` RLGC data file that contains the frequency dependent RLGC data or S-parameter data file.

11 `freqscale=1` Frequency scale factor for frequency dependent RLGC data and S-parameter data.

2-D Field Solver parameters

12 `linetype=sublossline`
Transmission line type.
Possible values are `microstrip`, `stripline`, `coplanar`, or `sublossline`.

13 `modeltype=wideband`
Model type.
Possible values are `lossless`, `narrowband` or `wideband`.

14 `numlayer` Number of dielectric layers.

15 `numgnd` Number of ground planes.

16 `er=[...]` Relative dielectric constant.

17 `layerthickness=[...] m`Dielectric layer thickness.

18 `dlosstype=tangent`
Dielectric loss type. Loss value is specified with parameter, dloss.
Possible values are `sigma` or `tangent`.

19 `dloss=[...]` Dielectric layer loss. Can be in terms of dielectric conductivity or tangent loss, determined by parameter, dlosstype.

20 `linewidth=[...] m` Signal line width.

21 `linethickness=[...] m`Signal line thickness.

22 `lineheight=[...] m`Signal line height.

23 `linespace=[...] m` Signal line spacing.

24 `linesigma (S/m)` Signal line conductivity.

25 `gndthickness=[...] m`Ground plane thickness.

26 `gndsigma (S/m)` Ground plane conductivity.

Rational fitting parameters

27 `fmax=2.5e10 Hz`	Maximum signal frequency used to determine the relevant range of rational fitting or used in the 2D field solver.

TLINE-related parameters

28 `z0=50 Ω`	Characteristic impedance of lossless line.
29 `td (s)`	Time delay of a lossless line in seconds, a measure of the electrical length.
30 `f (Hz)`	Reference frequency (used in conjunction to the normalized length to specify electrical length of line).
31 `nl=0.25`	Normalized electrical length in wavelengths at `f` of a lossless line.
32 `vel=1`	Propagation velocity of the line given as a multiple of `c`, the speed of light in free space. (vel <= 1).

TLINE conductor loss parameters

33 `corner=0 Hz`	Corner frequency for skin effect, frequency where skin depth equals the conductors wall thickness.
34 `dcr=0 Ω/m`	DC series resistance per unit length.
35 `fc (Hz)`	Conductor loss measurement frequency (use with `r`, `qc`, or `alphac`).
36 `seriesr=0 Ω/m`	Conductor (series) resistance per unit length at `fc`.
37 `alphac=0 dB/m`	Conductor loss at `fc` (low loss approximation).
38 `qc=∞`	Conductor loss quality factor at `fc` (low loss approximation).

TLINE dielectric loss parameters

39 `fd (Hz)`	Dielectric loss measurement frequency (use with `qd`).
40 `shuntg=0 S/m`	Dielectric (shunt) conductance per unit length.

41 `alphad=0 dB/m` Dielectric loss (low loss approximation).

42 `qd=∞` Dielectric loss quality factor at `fd` (low loss approximation).

Noise parameters

43 `trise (C)` Temperature rise from ambient.

44 `thermalnoise=yes` Thermal noise.
Possible values are `no` or `yes`.

45 `noisemodel` To use the internal thermal noise model, or the externally supplied noise data in the S-parameter data file. The default behavior is to use external data whenever it is available.
Possible values are `internal` or `external`.

Model Definition

model modelName mtline parameter=value ...

Model Parameters

RLGC data parameters

1 `r=[...] Ω/m` Resistance matrix per unit length.

2 `l=[...] H/m` Inductance matrix per unit length.

3 `g=[...] S/m` Conductor matrix per unit length.

4 `c=[...] F/m` Capacitance matrix per unit length.

5 `rskin=[...] Ω/m √Hz`
Skin effect resistance matrix per unit length.

6 `gdloss=[...] S/m Hz` Dielectric loss conductance matrix per unit length.

7 `fgdloss (Hz)` Dielectric loss cut-off frequency.

8 `file` RLGC data file that contains the frequency dependent RLGC data or S-parameter data file.

9 `freqscale=1` Frequency scale factor for frequency dependent RLGC data and S-parameter data.

2-D Field Solver parameters

10 `linetype=sublossline`
Transmission line type.
Possible values are `microstrip`, `stripline`, `coplanar`, or `sublossline`.

11 `modeltype=wideband`
Model type.
Possible values are `lossless`, `narrowband` or `wideband`.

12 `numlayer` Number of dielectric layers.

13 `numgnd=1` Number of ground planes.

14 `er=[...]` Relative dielectric constant.

15 `layerthickness=[...] m`Dielectric layer thickness.

16 `dlosstype=tangent`
Dielectric loss type. Loss value is specified with parameter, dloss.
Possible values are `sigma` or `tangent`.

17 `dloss=[...]` Dielectric layer loss. Can be in terms of dielectric conductivity or tangent loss, determined by parameter, dlosstype.

18 `linewidth=[...] m` Signal line width.

19 `linethickness=[...] m`Signal line thickness.

20 `lineheight=[...] m`Signal line height.

21 `linespace=[...] m` Signal line spacing.

22 `linesigma (S/m)` Signal line conductivity.

23 `gndthickness=[...] m`Ground plane thickness.

24 `gndsigma (S/m)` Ground plane conductivity.

Rational fitting parameters

25 `fmax=2.5e10 Hz` Maximum signal frequency used to determine the relevant range of rational fitting or used in the 2D field solver.

TLINE-related parameters

26 `z0=50 Ω` Characteristic impedance of lossless line.

27 `f (Hz)` Reference frequency (used in conjunction to the normalized length to specify electrical length of line).

28 `vel=1` Propagation velocity of the line given as a multiple of `c`, the speed of light in free space. (vel <= 1).

TLINE conductor loss parameters

29 `corner=0 Hz` Corner frequency for skin effect, frequency where skin depth equals the conductors wall thickness.

30 `dcr=0 Ω/m` DC series resistance per unit length.

31 `fc (Hz)` Conductor loss measurement frequency (use with `r`, `qc`, or `alphac`).

32 `seriesr=0 Ω/m` Conductor (series) resistance per unit length at `fc`.

33 `alphac=0 dB/m` Conductor loss at `fc` (low loss approximation).

34 `qc=∞` Conductor loss quality factor at `fc` (low loss approximation).

TLINE dielectric loss parameters

35 `fd (Hz)` Dielectric loss measurement frequency (use with `qd`).

36 `shuntg=0 S/m` Dielectric (shunt) conductance per unit length.

37 `alphad=0 dB/m` Dielectric loss (low loss approximation).

38 `qd=∞` Dielectric loss quality factor at `fd` (low loss approximation).

Noise parameters

39 `trise=0 C` Default temperature rise from ambient.

40 `thermalnoise=yes` Thermal noise.
Possible values are `no` or `yes`.

41 `noisemodel` To use the internal thermal noise model, or the externally supplied noise data in the S-parameter data file. The default behavior is to use external data whenever it is available.
Possible values are `internal` or `external`.

Important note about rational fitting:

Spectre uses rational fitting algorithm to build a stable model that approximates the desired transmission line characteristics. Maximum signal frequency `fmax` is used to determine the relevant range of rational fitting. The accuracy of the mtline model is solely dependent on how well the rational approximation is over frequency range [`fmin`, `fmax`].

When constant RLGC matrices are provided, 1Hz is used as `fmin` and `fmax` is defaulted to 25GHz. Three times the inverse of rise time in the input signal can be used as a good estimation of `fmax`. When RLGC data file is provided, the lowest frequency point in the data file is used as `fmin`, and the largest frequency point in the data file is used as `fmax`. User should provide sufficient data points to cover both low-frequency and high-frequency for an accurate, stable model.

Modeling frequency dependent effects:

One can model the frequency dependent RLGC matrices by providing the data file using parameter `file`. One should always try to provide accurate and sufficient data to describe the frequency dependent RLGC matrices.

In addition, the following simplified equation can be used to model skin effect with the constant RLGC matrices

R(f) = r + sqrt(f) * (1 + j) * `rskin`,

and the following equation can be used to model dielectric loss with the constant RLGC matrices

G(f) = g + f * `gdloss`,

where f stands for frequency, or

G(f) = g + f * `gdloss` / sqrt(1 + (f/`fgdloss`)^2)

if the fgdloss parameter is specified to limit the dielectric loss effect at higher frequencies. User should be aware of that the equation of G(f) results in a non-physical model, and it could lead to an unstable rational model.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Delay Line (delay)

Sample Instance Statement

dl1(outp outn cntrlp cntrln) delay td=10n gain=1.5

Instance Definition

```
Name  p  n  ps  ns delay parameter=value ...
```

Instance Parameters

1 `td=0.0 s` Time delay.

2 `gain=1` Gain parameter.

3 `m=1` Multiplicity factor.

Operating-Point Parameters

1 `v (V)` Output voltage.

Four Terminal Relay (relay)

The four-terminal relay is a voltage controlled relay tied between terminals `t1` and `t2`. The voltage between terminals `ps` and `ns` controls the relay resistance. The relay resistance varies nonlinearly between `ropen` and `rclosed`, the open relay resistance and closed relay resistance, respectively. These resistance values correspond to control voltages of `vt1` and `vt2` respectively. The four parameters, `vt1`, `vt2`, `ropen`, and `rclosed`, can be instance or model parameters.

As an alternative, you can specify the threshold voltage `vth` and a transition width `trans` rather than specifying `vt1` and `vt2`. These two parameters are then calculated from `vth` and `trans`. If all four parameters are specified, `vth` and `trans` override `vt1` and `vt2`. However, `vt1` and `vt2` values you specify on the instance override any model parameter specifications.

The final model parameter, `hysteresis`, designates a hysteresis with the on voltage shifted from `vth` by an amount `hysteresis` and the off voltage shifted by the same amount in the opposite direction. The direction of shift depends on the sign of `trans` (or the relative magnitudes of `vt1` and `vt2`): if `trans` is positive, the on voltage shifts by `+hysteresis`; if trans is negative (implying that the relay is "normally on"), the on-voltage shifts by `-hysteresis`.

This device is not supported within altergroup.

Operating conductance is calculated from the instance parameters as follows:

When Vc lies between vt1 and vt2,

G = Gmin + (Gmin - Gmax) * [2 * (Vc - vt1)^3

- 3 * (vt2 - vt1) * (Vc - vt1)^2] / (vt2 - vt1)^3

Otherwise, if vt1 < vt2, then

G = Gmin for Vc < vt1 and

G = Gmax for Vc > vt2.

If vt1 > vt2,

G = Gmin for Vc > vt1 and

G = Gmax for Vc < vt2.

where Gmin = 1 / ropen, Gmax = 1 / rclosed, and Vc = V(ps) - V(ns).

Sample Instance Statement

```
rel1 (1 2 ps ns) my_relay ropen=1G rclosed=2
```

Sample Model Statement

```
model my_relay relay vt1=2.5 vt2=5 ropen=100M rclosed=0.1
```

Instance Definition

```
Name  1  2  ps  ns ModelName parameter=value ...
Name  1  2  ps  ns relay parameter=value ...
```

Instance Parameters

1	`vt1 (V)`	Relay resistance is `ropen` at this voltage.
2	`vt2=vt1+1.0 V`	Relay resistance is `rclosed` at this voltage.
3	`ropen=∞ Ω`	Resistance of a fully open relay.
4	`rclosed=1.0 Ω`	Resistance of a fully closed relay.
5	`m=1.0`	Multiplicity factor.
6	`region=off`	Estimated operating region. Spectre outputs number (0-1) in a rawfile. Possible values are `off` or `on`.

Model Definition

```
model modelName relay parameter=value ...
```

Model Parameters

1 `vt1 (V)` Relay resistance is `ropen` at this voltage.

2 `vt2=vt1+1.0 V` Relay resistance is `rclosed` at this voltage.

3 `ropen=∞ Ω`
Resistance of a fully open relay.

4 `rclosed=1.0 Ω` Resistance of a fully closed relay.

5 `hysteresis=0.0 V` Switching Hysteresis.

6 `vth=0.0 V` Threshold Voltage.

7 `trans=0.0 V` Switch Transition Region Width.

Operating-Point Parameters

1 `region=off` Estimated operating region. Spectre outputs number (0-1) in a rawfile.
Possible values are `off` or `on`.

2 `res (Ω)` Relay resistance.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

Linear Two Winding Ideal Transformer (transformer)

Winding 1 connects terminals `t1` and `b1`, and winding 2 connects `t2` and `b2`. The number of turns on windings 1 and 2 are given by `n1` and `n2`, respectively, and `n2` must not be zero. The absolute number of turns of each winding is not important, only the ratio of `n1` to `n2`. Current through winding 1 is computed.

This device is not supported within altergroup.

An ideal transformer is modeled, so it acts as a transformer at DC. Thus

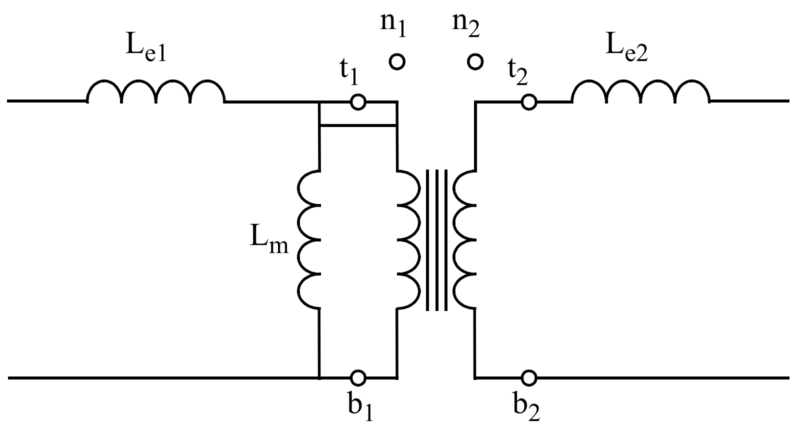
$$\frac{v_1}{v_2} = \frac{t_1}{t_2} = \frac{i_2}{i_1}$$

To model a physical transformer with L_1 and L_2 as the inductance of the windings and *k* as the coupling coefficient, add an inductor $L_m = k.L_1$ in parallel with winding 1 and inductors $L_{e1} = L_1.(1 - k)$ and $L_{e2} = L_2.(1 - k)$ in series with windings 1 and 2, respectively. The turns ratio can be computed with

$$\frac{n_1}{n_2} = \sqrt{\frac{L_1}{L_2}}$$

k can be calculated from the L_1 (the inductance of winding 1 with

$$k = \sqrt{1 - \frac{L_s}{L_1}}$$



Instance Definition

```
Name  t1  b1  t2  b2 transformer parameter=value ...
```

Instance Parameters

1 `n1=1`	Number of turns on winding 1.
2 `n2=1`	Number of turns on winding 2.
3 `m=1`	Multiplicity factor.

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Other Models

This chapter describes component statements for the following models:

High-Voltage MOSFET Model (hvmos)

HV (High-Voltage) MOS transistor model is a deep submicron, high-voltage MOSFET model. It is based on the BSIM3v3 version 3.1. Major enhancements include current-crowding effect at high gate bias, asymmetric source-drain structure, mobility reduction, transconductance reduction under high Vgs at saturation region, forward and reverse mode, self-heating, and more flexible gate-dependent output characteristics. HVMOS can be used for high voltage IC design applications such as Flash memory with asymmetric LDD structures, LCD drivers, CCD, E2PROM and LDMOS applications.

Like BSIM3v3, the HVMOS transistor model also allows the binning option to achieve even higher accuracy. The binning equation is given by

P = P0 + Pl / Leff + Pw / Weff + Pp / (Leff * Weff)

Only the P0 parameters are listed. Pl, Pw, and Pp are not shown but can be recognized. The names of Pl, Pw, and Pp are identical to that of P0 but with a prefix of l, w, and p, respectively. HVMOS transistors require that you use a model statement.

This device is supported within altergroups.

Sample Instance Statement

```
m1 (1 2 0 0) hvnmos w=1.5u l=1u ad=2.6p as=2.6p pd=6.6p ps=6.6p nrd=1.54 nrs=1.54
```

Sample Model Statement

```
model hvnmos hvmos vtho=0.53 w0=2.14e-6 nlx=1.8e-7 nch=2.3e18 xj=0.22e-6 k1=0.48
k2=-0.02 drout=1.1 rsh=10 cgso=2.4e-10 cgdo=2.4e-10
```

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `w (m)` Channel width.

2 `l (m)` Channel length.

3 `as (m^2)` Area of source diffusion.

4 `ad (m^2)` Area of drain diffusion.

5 `ps (m)` Perimeter of source diffusion.

6 `pd (m)` Perimeter of drain diffusion.

7 `nrd (m/m)` Number of squares of drain diffusion.

8 `nrs (m/m)` Number of squares of source diffusion.

9 `ld (m)` Length of drain diffusion region.

10 `ls (m)` Length of source diffusion region.

11 `isnoisy=yes` Should resistor generate noise.
Possible values are `no` or `yes`.

12 `m=1` Multiplicity factor (number of MOSFETs in parallel).

13 `region=triode` Estimated operating region. Spectre outputs number (0-3) in a rawfile.
Possible values are `off`, `triode`, `sat`, or `subth`.

14 `nqsmod` NQS flag.

15 `trise` Temperature rise from ambient.

16 `dtemp` alias of trise.

Model Definition

```
model modelName hvmos parameter=value ...
```

Model Parameters

Device type parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

2 `hvmosver=2.0` HVMOS Model version selector. The available versions are 1.0, 2.0.

Threshold voltage parameters

3 `vtho (V)`	Threshold voltage at zero body bias for long-channel devices. For enhancement-mode devices, vtho > 0 for n-channel and vtho < 0 for p-channel.
4 `k1=0.5 √V`	Body-effect coefficient, default is 0.53 for hvmosver >=2.0 .
5 `k2=-0.0186`	Charge-sharing parameter.
6 `k3=80`	Narrow width coefficient.
7 `k3b=0 1/V`	Narrow width coefficient.
8 `w0=2.5e-6 m`	Narrow width coefficient.
9 `nlx=1.74e-7 m`	Lateral nonuniform doping coefficient.
10 `gamma1=1.0 √V`	Body-effect coefficient near the surface.
11 `gamma2=0 √V`	Body-effect coefficient in the bulk.
12 `vbx=-3 V`	Threshold voltage transition body voltage.
13 `vbm=-3 V`	Maximum applied body voltage.
14 `dvt0=2.2`	First coefficient of short-channel effects.
15 `dvt1=0.53`	Second coefficient of short-channel effects.
16 `dvt2=-0.032 1/V`	Body-bias coefficient of short-channel effects.
17 `a0f=1`	Forward nonuniform depletion width effect coefficient.
18 `a0r=a0f`	Reverse nonuniform depletion width effect coefficient.
19 `b0=0 m`	Bulk charge coefficient due to narrow width effect.
20 `b1=0 m`	Bulk charge coefficient due to narrow width effect.
21 `a1=0`	No-saturation coefficient.

22 `a2=1` No-saturation coefficient.

23 `ags=0` F/m^2 V Gate-bias dependence of Abulk.

24 `ketaf=-0.047 1/V` Body-bias coefficient for non-uniform depletion width effect.

25 `ketar=ketaf 1/V` Reverse body-bias coefficient for non-uniform depletion width effect.

Process parameters

26 `nsub=6e16` cm^{-3} Substrate doping concentration.

27 `nch=1.7e17` cm^{-3} Peak channel doping concentration.

28 `xj=0.15e-6 m` Source/drain junction depth.

29 `lint=0 m` Lateral diffusion for one side.

30 `wint=0 m` Width reduction for one side.

31 `ll=0 m` Length dependence of delta L.

32 `lln=1` Length exponent of delta L.

33 `lw=0 m` Width dependence of delta L.

34 `lwn=1` Width exponent of delta L.

35 `lwl=0` m^2 Area dependence of delta L.

36 `lmin=0 m` The minimum channel length for which the model is still valid.

37 `lmax=1 m` The maximum channel length for which the model is still valid.

38 `wl=0 m` Length dependence of delta W.

39 `wln=1` Length exponent of delta W.

40 `ww=0 m` Width dependence of delta W.

41 `wwn=1` Width exponent of delta W.

42 `wwl=0 m`^{2}	Area dependence of delta W.
43 `wmin=0 m`	The minimum channel width for which the model is still valid.
44 `wmax=1 m`	The maximum channel width for which the model is still valid.
45 `dwg=0 m/v`	Gate-bias dependence of channel width.
46 `dwb=0 m/√v`	Body-bias dependence of channel width.
47 `tox=1.5e-8 m`	Gate oxide thickness.
48 `xt=1.55e-7 m`	Doping depth.
49 `rd0=0 Ω`	Fixed drain resistance.
50 `rs0=0 Ω`	Fixed source resistance.
51 `rdw=0 Ω µm`	Width dependence of drain resistance.
52 `rsw=0 Ω µm`	Width dependence of source resistance.
53 `rdsw=0 Ω µm`	Width dependence of drain-source resistance.
54 `prwb=0 1/√v`	Body-effect coefficient for Rds.
55 `prwg=0 1/√v`	Gate-effect coefficient for Rds.
56 `wr=1`	Width offset for parasitic resistance.
57 `binunit=2`	Bin parameter unit selector. 1 for microns and 2 for meters.

Mobility parameters

58 `mobmod=1`	Mobility model selector.
59 `u0f=670 cm`^{2}`/V s`	Forward low-field surface mobility at `tnom`. Default is 250 for PMOS.
60 `u0r=u0f cm`^{2}`/V s`	Reverse low-field surface mobility at `tnom`.
61 `vsatf=8e4 m/s`	Forward carrier saturation velocity at `tnom`.

62 `dvsatf=0 m/s` Forward gate-bias dependence of saturation velocity.

63 `dvsatbf=0 m/s` Forward body-bias dependence of saturation velocity.

64 `vsatr=vsatf m/s` Reverse carrier saturation velocity at `tnom`.

65 `dvsatr=dvsatf m/s` Reverse gate-bias dependence of saturation velocity.

66 `dvsatbr=dvsatbf m/s`
Reverse body-bias dependence of saturation velocity.

67 `uaf=2.25e-9 m/v` Forward first-order mobility reduction coefficient.

68 `ubf=5.87e-19` m^2/v^2
Forward second-order mobility reduction coefficient.

69 `ucf=-4.65e-11` m/v^2
Forward body-bias dependence of mobility. Default is -0.046 and unit is 1/V for mobmod=3.

70 `udf=0` m/v^2 Forward source-resistance dependence of mobility.

71 `uar=uaf m/v` Reverse first-order mobility reduction coefficient.

72 `ubr=ubf` m^2/v^2 Reverse second-order mobility reduction coefficient.

73 `ucr=ucf` m/v^2 Reverse body-bias dependence of mobility.

74 `udr=udf` m/v^2 Reverse source-resistance dependence of mobility.

Output resistance parameters

75 `drout=0.56` DIBL effect on output resistance coefficient.

76 `pclmf=1.3` Forward channel length modulation coefficient.

77 `pclmr=pclmf` Reverse channel length modulation coefficient.

78 `pdiblc1f=0.39` Forward first coefficient of drain-induced barrier lowering.

79 `pdiblc1r=pdiblc1f`
Reverse first coefficient of drain-induced barrier lowering.

80 `pdiblc2f=8.6e-3` Forward second coefficient of drain-induced barrier lowering.

81 `pdiblc2r=pdiblc2f`
Reverse second coefficient of drain-induced barrier lowering.

82 `pdiblcbf=0 1/V` Body-effect coefficient for DIBL.

83 `pdiblcbr=pdiblcbf 1/V`
Reverse body-effect coefficient for DIBL.

84 `pscbe1f=4.24e8 V/m`
First coefficient of substrate current body effect.

85 `pscbe2f=1e-5 m/v` Second coefficient of substrate current body effect.

86 `pscbeg=0 V/m` Third coefficient of substrate current body effect.

87 `pscbe1r=pscbe1f V/m`
Reverse first coefficient of substrate current body effect.

88 `pscbe2r=pscbe2f m/v`
Reverse second coefficient of substrate current body effect.

89 `pvag=0` Gate-dependence of Early voltage.

90 `pclmgf=0` Forward gate dependence of Vaclm.

91 `pclmgr=pclmgf` Reverse gate dependence of Vaclm.

92 `pclmbf=0` Forward body dependence of Vaclm.

93 `pclmbr=pclmbf` Reverse body dependence of Vaclm.

94 `pdiblgf=0` Forward gate dependence of Vadibl.

95 `pdiblgr=pdiblgf` Reverse gate dependence of Vadibl.

96 `delta=0.01 V` Effective drain voltage smoothing parameter.

Subthreshold parameters

97 `cdsc=2.4e-4` F/m^2 Source/drain and channel coupling capacitance.

98 `cdscb=0 F/m2 V` Body-bias dependence of `cdsc`.

99 `cdscd=0 F/m2 V` Drain-bias dependence of `cdsc`.

100 `nfactor=1` Subthreshold swing coefficient.

101 `cit=0 F` Interface trap parameter for subthreshold swing.

102 `voff=-0.08 V` Threshold voltage offset.

103 `dsub=drout` DIBL effect in subthreshold region.

104 `eta0f=0.08` DIBL coefficient subthreshold region.

105 `etabf=-0.07 1/V` Body-bias dependence of `et0`.

106 `eta0r=eta0f` Reverse DIBL coefficient subthreshold region.

107 `etabr=etabf 1/V` Body-bias dependence of `eta0r`.

Substrate current parameters

108 `alpha0=0 m/v` Substrate current impact ionization coefficient.

109 `alpha1=0 1/V` substrate current model parameter.

110 `beta0=30 1/V` Substrate current impact ionization exponent.

Parasitic resistance parameters

111 `rsh=0 Ω/sqr` Drain diffusion sheet resistance.

112 `rshs=0 Ω/sqr` Source diffusion sheet resistance.

113 `rs=0 Ω` Source resistance.

114 `rd=0 Ω` Drain resistance.

115 `lgcs=0 m` Gate-to-contact length of source side.

116 `lgcd=0 m` Gate-to-contact length of drain side.

117 `rsc=0 Ω` Source contact resistance.

118 `rdc=0 Ω` Drain contact resistance.

119 `rss=0 Ω m` Scalable source resistance.

120 `rdd=0 Ω m` Scalable drain resistance.

121 `sc=∞ m` Spacing between contacts.

122 `ldif=0 m` Lateral diffusion beyond the gate.

123 `hdif=0 m` Length of heavily doped diffusion .

124 `minr=0.1 Ω` Minimum source/drain resistance.

Junction diode model parameters

125 `js` (A/m^2) Bulk junction reverse saturation current density.

126 `jsw=0 A/m` Sidewall junction reverse saturation current density.

127 `is=1e-14 A` Bulk junction reverse saturation current.

128 `n=1` Junction emission coefficient.

129 `nj=1` alias of n.

130 `dskip=yes` Use simple piece-wise linear model for diode currents below 0.1*`iabstol`.
Possible values are `no` or `yes`.

131 `imelt=`imax' A` Explosion current, default is 0.1 for hvmosver >=2.0.

132 `ijth=`imax` A` Junction threshold current.

133 `jmelt=`jmax' A/m'`^{2}
Explosion current density.

Overlap capacitance parameters

134 `cgso (F/m)` Gate-source overlap capacitance.

135 `cgdo (F/m)`	Gate-drain overlap capacitance.
136 `cgbo (F/m)`	Gate-bulk overlap capacitance.
137 `meto=0 m`	Metal overlap in fringing field.
138 `cgsl=0 F/m`	Gate-source overlap capacitance in LDD region.
139 `cgdl=0 F/m`	Gate-drain overlap capacitance in LDD region.
140 `ckappa=0.6`	Overlap capacitance fitting parameter.
141 `deltaacc=0.1 V`	Capacitance smoothing parameter.

Junction capacitance model parameters

142 `cbs=0 F`	Bulk-source zero-bias junction capacitance.
143 `cbd=0 F`	Bulk-drain zero-bias junction capacitance.
144 `cj=5e-4` F/m^2	Zero-bias junction bottom capacitance density.
145 `mj=1/2`	Bulk junction bottom grading coefficient.
146 `pb=0.8 V`	Bulk junction built-in potential, default is 1.0 for hvmosver >=2.0.
147 `fc=0.5`	Forward-bias depletion capacitance threshold.
148 `cjsw=5e-10 F/m`	Zero-bias junction sidewall capacitance density.
149 `mjsw=1/3`	Bulk junction sidewall grading coefficient.
150 `pbsw=0.8 V`	Side-wall junction built-in potential, default is 1.0 for hvmosver >=2.0.
151 `fcsw=0.5`	Side-wall forward-bias depletion capacitance threshold.
152 `cjswg=cjsw F/m`	Zero-bias gate-side junction capacitance density.
153 `mjswg=mjsw`	Gate-side junction grading coefficient.
154 `pbswg=pbsw V`	Gate-side junction built-in potential.

Charge model selection parameters

155 `capmod=2` Intrinsic charge model.

156 `nqsmod=0` Non-quasi static model selector. Set to 1 to turn on nqs.

157 `dwc=wint m` Delta W for capacitance model.

158 `dlc=lint m` Delta L for capacitance model.

159 `clc=1e-7 m` Intrinsic capacitance fitting parameter.

160 `cle=0.6` Intrinsic capacitance fitting parameter.

161 `cf (F/m)` Fringe capacitance parameter.

162 `a0cvf=a0f` A0 for C-V calculation.

163 `a0cvr=a0r` Reverse A0 for C-V calculation.

164 `qgvd0f=1` Cgd fitting parameter.

165 `qgvd0r=qgvd0f` Reverse Cgd fitting parameter.

166 `elm=5` Elmore constant of the channel.

167 `vfbcv=-1` Flat-band voltage for capmod=0.

168 `acde=0.5 1/V` Exponential coefficient for finite charge thickness.

169 `moin=15 1/V` Coefficient for Vgs dependent surface potential.

170 `xpart=0` Drain/source channel charge partition in saturation for BSIM charge model, use 0.0 for 40/60, 0.5 for 50/50, or 1.0 for 0/100.

Default instance parameters

171 `w=5e-6 m` Default channel width.

172 `l=5e-6 m` Default channel length.

173 `as=0` m^2 Default area of source diffusion.

174 `ad=0 m`^{2}	Default area of drain diffusion.
175 `ps=0 m`	Default perimeter of source diffusion.
176 `pd=0 m`	Default perimeter of drain diffusion.
177 `nrd=0 m/m`	Default number of squares of drain diffusion.
178 `nrs=0 m/m`	Default number of squares of source diffusion.
179 `xw=0 m`	Width variation due to masking and etching.
180 `xl=0 m`	Length variation due to masking and etching.

Temperature effects parameters

181 `tnom (C)`	Parameters measurement temperature. Default set by `options`.
182 `trise=0 C`	Temperature rise from ambient.
183 `tlev=0`	DC temperature selector.
184 `tlevc=0`	AC temperature selector.
185 `eg=1.12452 V`	Energy band gap.
186 `gap1=7.02e-4 V/C`	Band gap temperature coefficient.
187 `gap2=1108 C`	Band gap temperature offset.
188 `kt1=-0.11 V`	Temperature coefficient for threshold voltage.
189 `kt1l=0 v m`	Temperature coefficient for threshold voltage.
190 `kt2=0.022`	Temperature coefficient for threshold voltage.
191 `atf=3.3e4 m/s`	Temperature coefficient for `vsatf`.
192 `atr=atf m/s`	Temperature coefficient for `vsatr`.
193 `at1f=0 m/s`	Temperature coefficient for `dvsatf`.
194 `at1r=at1f m/s`	Temperature coefficient for `dvsatr`.

195 `ua1f=4.31e-9 m/v` Temperature coefficient for `uaf`.

196 `ub1f=-7.61e-18` m^2/v^2
Temperature coefficient for `ubf`.

197 `uc1f=-5.5e-11` m/v^2
Temperature coefficient for `ucf`. Default is -0.056 for mobmod=3.

198 `ud1f=0` m/v^2 Temperature coefficient for `udf`.

199 `ua1r=ua1f m/v` Temperature coefficient for `uar`.

200 `ub1r=ub1f` m^2/v^2 Temperature coefficient for `ubr`.

201 `uc1r=uc1f` m/v^2 Temperature coefficient for `ucr`.

202 `ud1r=0` m/v^2 Temperature coefficient for `udr`.

203 `rth=0` Ω Self-heating thermal resistance.

204 `rthg=0 1/V` Gate-effect coefficient for Rth.

205 `rthb=0` $1/\sqrt{v}$ Body-effect coefficient for Rth.

206 `prt=0` Ω Temperature coefficient for Rds.

207 `trs=0 1/C` Temperature parameter for source resistance.

208 `trd=0 1/C` Temperature parameter for drain resistance.

209 `ute=-1.5` Mobility temperature exponent.

210 `xti=3` Saturation current temperature exponent.

211 `ptc=0 V/C` Surface potential temperature coefficient.

212 `tcv=0 V/C` Threshold voltage temperature coefficient.

213 `pta=0 V/C` Junction potential temperature coefficient.

214 `tpb=0 V/C` Junction potential temperature coefficient.

215 `ptp=0 V/C` Sidewall junction potential temperature coefficient.

216 `tpbsw=0 V/C`	Sidewall junction potential temperature coefficient.
217 `cta=0 1/C`	Junction capacitance temperature coefficient.
218 `tcj=0 1/C`	Junction capacitance temperature coefficient.
219 `ctp=0 1/C`	Sidewall junction capacitance temperature coefficient.
220 `tcjsw=0 1/C`	Sidewall junction capacitance temperature coefficient.
221 `tcjswg=0 1/C`	Temperature coefficient for `cjswg`.
222 `tpbswg=0 V/C`	Temperature coefficient for `pbswg`.

Noise model parameters

223 `noimod=1`	Noise model selector.
224 `kf=0`	Flicker (1/f) noise coefficient.
225 `em=4.1e7 V/m`	Maximum electric field.
226 `af=1`	Flicker (1/f) noise exponent.
227 `ef=1`	Flicker (1/f) noise frequency exponent.
228 `noia=1e20`	Oxide trap density coefficient. Default is 9.9e18 for pmos.
229 `noib=5e4`	Oxide trap density coefficient. Default is 2.4e3 for pmos.
230 `noic=-1.4e-8`	Oxide trap density coefficient. Default is 1.4e-8 for pmos. Default is -1.4-12 for hvmosver >=2.0.

Operating region warning control parameters

231 `alarm=none`	Forbidden operating region. Possible values are `none`, `off`, `triode`, `sat`, `subth`, or `rev`.
232 `imax=1 A`	Maximum allowable current, default is 0.1 for hvmosver >=2.0 .
233 `jmax=1e8 A/m`^{2}	Maximum allowable current density.

234 `bvj=∞ V` Junction reverse breakdown voltage.

235 `vbox=1e9 tox V` Oxide breakdown voltage.

Length dependent parameters (Not listed)

Width dependent parameters (Not listed)

Cross-term dependent parameters (Not listed)

The `imax` (`jmax`) parameter is used to aid convergence and prevent numerical overflow. The junction characteristics of the FET are accurately modeled for current (density) up to `imax` (`jmax`). For currents (density) above `imax` (`jmax`), the junction is modeled as a linear resistor and a warning is printed.

Output Parameters

1 `weff (m)` Effective channel width.

2 `leff (m)` Effective channel length.

3 `rseff (Ω)` Effective source resistance.

4 `rdeff (Ω)` Effective drain resistance.

Operating-Point Parameters

1 `type=n` Transistor type.
Possible values are `n` or `p`.

2 `region=triode` Estimated operating region. Spectre outputs number (0-3) in a rawfile.
Possible values are `off`, `triode`, `sat`, or `subth`.

3 `reversed` Reverse mode indicator.
Possible values are `no` or `yes`.

4 `ids (A)` Resistive drain-to-source current.

5 `vgs (V)` Gate-source voltage.

6 `vds (V)`	Drain-source voltage.
7 `vbs (V)`	Bulk-source voltage.
8 `vth (V)`	Threshold voltage.
9 `vdsat (V)`	Drain-source saturation voltage.
10 `gm (S)`	Common-source transconductance.
11 `gds (S)`	Common-source output conductance.
12 `gmbs (S)`	Body-transconductance.
13 `betaeff` (A/V^2)	Effective `beta`.
14 `cjd (F)`	Drain-bulk junction capacitance.
15 `cjs (F)`	Source-bulk junction capacitance.
16 `cgg (F)`	Cgg.
17 `cgd (F)`	Cgd.
18 `cgc (F)`	Cgc.
19 `cgs (F)`	Cgs.
20 `cgb (F)`	Cgb.
21 `cdg (F)`	Cdg.
22 `cdd (F)`	Cdd.
23 `cds (F)`	Cds.
24 `cdb (F)`	Cdb.
25 `csg (F)`	Csg.
26 `csd (F)`	Csd.
27 `css (F)`	Css.

28 `csb (F)` Csb.

29 `cbg (F)` Cbg.

30 `cbd (F)` Cbd.

31 `cbs (F)` Cbs.

32 `cbb (F)` Cbb.

33 `ron (Ω)` On-resistance.

34 `id (A)` Resistive drain current.

35 `ibulk (A)` Resistive bulk current.

36 `pwr (W)` Power at op point.

37 `gmoverid (1/V)` Gm/Ids.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

MISN Field Effect Transistor (misnan)

Cadence plans to stop supporting this model and recommends that it no longer be used.

The MISN model is formulated in terms of solutions for the boundary surface potentials of the channel and has the inherent property of continuous modeling. It is an inhouse MOSFET model of NORTEL. The MISN model requires a model statement.

This device is not supported within altergroup.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.sun4v/cmi/lib/5.0.doc/libnortel_sh.so

Sample Instance Statement:

mn1 (1 2 0 0) nch w=1.5u l=1u ad=2.6p as=2.6p pd=6.6p ps=6.6p

Sample Model Statement:

model nch misnan type=n cox=4.4e-6 dop=2e17 phi=-0.43 xj=0.23 scrat=1.4 mu=400 rws=250 is=0.98e-13 cjgo=2e-13 noimdl=1

Instance Definition

```
Name  d  g  s  b ModelName parameter=value ...
```

Instance Parameters

1 `w=1e-5 m` Channel width.

2 `l=3e-6 m` Channel length.

3 `as=3e-11` m^2 Area of source diffusion.

4 `ad=3e-11` m^2 Area of drain diffusion.

5 `ps=2.6e-5 m` Perimeter of source diffusion.

6 `pd=2.6e-5 m` Perimeter of drain diffusion.

7 `m=1` Multiplicity factor (number of MOSFETs in parallel).

8 `region=triode` Estimated DC operating region, used as a convergence aid. Possible values are `off`, `triode`, `sat`, or `subthresh`.

Model Definition

```
model modelName misnan parameter=value ...
```

Model Parameters

Intrinsic MOS parameters

1 `type=n` Transistor gender.
Possible values are `n` or `p`.

2 `cox=4.309e-7 F/cm`^{2}
Gate oxide cap per unit area.

3 `dop=1.665e17 cm`$^{-3}$
Substrate doping. Default = 2.58e17 for pmos.

4 `phi=-0.55 V` Gate Fermi potential.

5 `qss=-5.078e-8 Coul/cm`^{2}
Effective gate oxide charge per unit area. Default = 1.05e-8 for pmos.

6 `dopldd=3.2e17 cm`$^{-3}$
LDD region doping concentration. Default = 3.2e19 for pmos.

Geometry parameters

7 `lvar=0 µm` Gate length correction.

8 `wvar=0 µm`	Gate width correction.
9 `dls=0.0273 µm`	Sideway diffusion length of source region. Default = 0.037 for pmos.
10 `dld=0.0273 µm`	Sideway diffusion length of drain region. Default = 0.037 for pmos.
11 `dl=0.07 µm`	Sideways diffusion length of S/D regions. Default = 0.04 for pmos.
12 `dw=0.032 µm`	Electrical channel width correction. Default = 0.018 for pmos.

Threshold voltage parameters

13 `xj=0.24 µm`	Source/drain-to-substrate junction depth. Default = 0.31 for pmos.
14 `scrat=1.5`	Short channel threshold voltage ratio. Default = 0.7 for pmos.
15 `scind=1.45`	Short channel threshold voltage index. Default = 1.42 for pmos.
16 `ncrat=0.17`	Narrow channel threshold voltage ratio. Default = 0.095 for pmos.
17 `athp=7.5`	Factor controlling peak magnitude effect. Default = 3.5 for pmos.
18 `athl=2e4 1/cm`	Factor controlling channel length dependence effect. Default = 4e4 for pmos.
19 `athb=-1.7e-3`	Factor controlling substrate bias dependence effect. Default = -6e-3.

Mobility parameters

20 `mu=577` cm^2`/V s`	Low-field carrier mobility. Default = 120 for pmos.
21 `mutxp=1.72`	Temperature coefficient for the carrier mobility. Default = 1.01 for pmos.
22 `kg=1.4e-7 cm/V`	Gate field factor. Default = 1.685e-7.
23 `v0=3.21e7 cm/s`	Scattering limited velocity. Default = 2.45e7.

24 `v0txp=-6.3`	Temp coefficient for scattering limited velocity. Default = -5 for pmos.
25 `find=1.25`	Field mobility index factor. Default = 1.9 for pmos.
26 `gfc=9.1e-10`	Gate voltage dependence of enhanced gate-field scattering. Default = 1.05e-10 for pmos.
27 `gfcm=3e-5`	Drain voltage dependence of enhanced gate-field scattering. Default = 2.3e-3 for pmos.
28 `gfmb=1.45e-3`	Factor controlling substrate bias dependence of enhanced gate-field scattering. Default 3.3e-3 for pmos.
29 `csf=1.06e-11`	Drain voltage dependence of coulomb scattering. Default = 1.35e-12 for pmos.
30 `csfb=1.61e-3`	Body voltage dependence of coulomb scattering. Default = 8.5e-3 for pmos.

Saturation parameters

31 `dprat=15`	Drain region/channel doping ration. Default = 2 for pmos.
32 `satpr=0.2`	Saturation region shaping factor. Default = 1.0 for pmos.
33 `sbdr=0.3535534`	Primary parameter controlling the onset of saturation.
34 `sadr=5`	Secondary parameter controlling the onset of saturation.

Capacitance parameters

35 `sccf=0.25`	Inner fringing factor for the N+ S/D.

Extrinsic parameters

36 `rws=480` Ω µm	Source series resistance. Default = 1180 for pmos.
37 `rwd=480` Ω µm	Drain series resistance. Default = 1180 for pmos.

38 `rsd=-1 Ω µm` Drain/source series resistance. Negative value for asymmetrical devices.

39 `rgsh=0 Ω µm` Gate series resistance.

40 `wtgf=0.28 µm` Width of transition from gate to field oxide under poly.

41 `cpts=5.7e-9 F/cm`^{2}
Poly-to-substrate capacitance per unit area.

42 `cgfrs=1e-12 F/cm` Gate-source overlap fringing field capacitance.

43 `cgfrd=1e-12 F/cm` Gate-drain overlap fringing field capacitance.

44 `cgfr=1.36e-12 F/cm`
Gate overlap fringing field capacitance.

Junction parameters

45 `is=1.02e-12 A/cm`^{2}
Sat current per unit area of S/D region-injection component. Default = 9.21e-13 for pmos.

46 `isg=1e-20 A/cm` Sat current per unit length of gate oxide periphery-injection component. Default = 1.17e-20.

47 `isf=1e-20 A/cm` Sat current per unit length of field oxide periphery-injection component. Default = 1.17e-20.

48 `ig=1.31e-10 A/cm`^{2}
Sat current per unit area of S/D region-generation component. Default = 8.27e-10.

49 `igg=6.99e-14 A/cm` Sat current per unit length of gate oxide periphery-generation/ recombination component. Default = 6.47e-14.

50 `igf=6.99e-14 A/cm` Sat current per unit length of field oxide periphery-generation/ recombination component. Default = 6.47e-14.

51 `cjo=9.39e-8 F/cm`^{2}
Zero bias junction capacitance per unit area. Default = 1.273e-7 for pmos.

52 `ena=0.387` Junction capacitance coefficient for the area component. Default = 0.472 for pmos.

53 `cjgo=2.085e-12 F/cm`
Zero bias junction cap per unit length of gate oxide periphery. Default = 1.864e-12 for pmos.

54 `eng=0.322` Junction cap coefficient for gate oxide periphery component. Default = 0.334 for pmos.

55 `cjfo=3.037e-12 F/cm`
Zero bias junction cap per unit length of field oxide periphery. Default = 3.077e-12 for pmos.

56 `enf=0.322` Junction cap coefficient for field oxide periphery component. Default = 0.334 for pmos.

Noise parameters

57 `noimdl=1` Noise model selector.

58 `nt=1.6e10` cm^{-2} Surface trap density. Default = 4e9 for pmos.

59 `nttx=-4` Surface trap density temperature coefficient.

60 `fidx=0.85` Flicker noise frequency coefficient.

61 `beta=1` Thermal noise proportional constant.

62 `sgma=3e-16` Capture cross section. Default = 3e-15 for pmos.

63 `xtau=1e-8` 1/E depth.

64 `wbar=1` Barrier height for tunneling. Default = 4 for pmos.

65 `dept=3e-7` Depth of trap distribution.

Operating-Point Parameters

1 `vgs (V)` Gate-source voltage.

2 `vds (V)` Drain-source voltage.

3 `vbs (V)` Bulk-source voltage.

4 `id (A)` Drain current.

5 `vth (V)` Threshold voltage.

6 `vdsat (V)` Drain-source saturation voltage.

7 `gm (S)` Common-source transconductance.

8 `gd (S)` Common-source output conductance.

9 `gs (S)` Body-transconductance.

10 `gmb (S)` Body transconductance.

11 `gjs (S)` Drain-bulk junction conductance.

12 `ibs (A)` Drain-bulk junction current.

13 `gjd (S)` Source-bulk junction conductance.

14 `ibd (A)` Source-bulk junction current.

15 `qgg (Coul)` Gate charge.

16 `qss (Coul)` Source charge.

17 `qdd (Coul)` Drain charge.

18 `qbb (Coul)` Bulk charge.

19 `cgg (F)` Cgg.

20 `cgs (F)` Cgs.

21 `cgd (F)` Cgd.

22 `cgb (F)` Cgb.

23 `csg (F)` Csg.

24 `css (F)` Css.

25 `csd (F)` Csd.

26 `csb (F)` Csb.

27 `cdg (F)` Cdg.

28 `cds (F)` Cds.

29 `cdd (F)` Cdd.

30 `cdb (F)` Cdb.

31 `cbg (F)` Cbg.

32 `cbs (F)` Cbs.

33 `cbd (F)` Cbd.

34 `cbb (F)` Cbb.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

ad I-4	csd OP-25	ibd OP-14	region I-8
as I-3	csf M-29	ibs OP-12	rgsh M-39
athb M-19	csfb M-30	id OP-4	rsd M-38
athl M-18	csg OP-23	ig M-48	rwd M-37
athp M-17	css OP-24	igf M-50	rws M-36
beta M-61	dept M-65	igg M-49	sadr M-34
cbb OP-34	dl M-11	is M-45	satpr M-32

Diffusion Resistor Model (rdiff)

The rdiff model is a diffusion resistor model, which accurately models the temperature, applied bias and back-bias dependencies of NWell, N+, and P+ resistors. It is described in the paper MODEL FOR DIFFUSION RESISTORS (NWell, N+, P+) USED IN CMOS IC DESIGNS by M.J.B.Bolt, FASELEC Process Development Group, PDG-93029, Modified 3rd May 1995.

Some extensions to that description are applied:

Appropriate model and instance parameter default values are used.

No clipping of parameters is performed. Parameter values are checked for validity. If invalid parameter values occur, the job is aborted with an error message.

For exact inverse behavior of the model in case of Vh less than Vl, the setting of Vbl=abs(Vb-Vl) is replaced by Vbl=min(abs(Vb-Vh),abs(Vb-Vl)). Additionally, the direction of Ih is inverted in this case.

Note: In noise analysis, rdiff instances will not generate any contribution, since there are no noise sources included in the rdiff model.

(c) Philips Electronics N.V. 1993, 1995

This device is supported within altergroups.

This device is dynamically loaded from the shared object /vobs/spectre_dev/tools.lnx86/cmi/lib/5.0.doc/libphilips_sh.so

Sample Instance Statement

```
r2 (1 2 0) rdsn l=9u w=2u nb=0 m=1
```

Sample Model Statement

```
model rdsn rdiff level=1 tr=27 dta=0 rshr=2.5e3 wtol=0.22u rint=3.5u swvp=13.4u
power=2 tcr1=1.5e-3 tcr2=1e-5 vpr=40
```

Instance Definition

```
Name  h  l  [b] ModelName parameter=value ...
```

Instance Parameters

1 `l=1.0 scale m`	Drawn length of resistor. Must be greater than zero. Scale set by option scale.
2 `w=1.0 scale m`	Drawn width of resistor. Must be greater than zero. Scale set by option scale.
3 `nb=0.0`	Number of bends in the resistor. Must be greater or equal zero.
4 `m=1.0`	Multiplicity factor. Must be greater than zero.

Model Definition

```
model modelName rdiff parameter=value ...
```

Model Parameters

1 `level=1.0`	`Level` of this model. Must be 1.
2 `tr (C)`	Reference temperature. Default set by option `tnom`.
3 `tref (C)`	Alias of `tr`. Default set by option `tnom`.
4 `tnom (C)`	Alias of `tr`. Default set by option `tnom`.
5 `dta=0 K`	Temperature offset of the device.
6 `trise=0 K`	Alias of dta.
7 `rshr=1.0e+3 Ω/sqr`	Sheet resistance at reference temperature. Must be greater than zero.
8 `wtol=0.0 m`	Offset between the drawn and effective resistor width.
9 `tcr1=0.0 1/K`	Linear temperature coefficient of the resistor.
10 `tcr2=0.0` $1/K^2$	Quadratic temperature coefficient of the resistor.
11 `vpr=100.0 V`	Reference Pinch-off voltage.
12 `swvp=0.0 V/m`	Coefficient of the width dependence of `vp`.

13 `power=1.5` Voltage exponent. Must be greater than zero.

14 `vdr=1.0 V` Diffusion voltage at reference temperature.

15 `rint=0.0 Ω m` Interface resistance at reference temperature.

16 `tcrint1=0.0 1/K` Linear temperature coefficient of the interface resistor.

Output Parameters

1 `vd (V)` Diffusion voltage. Must be greater than zero.

2 `rsh (Ω/sqr)` Sheet resistance. Must be greater than zero.

3 `vp (V)` Pinch-off voltage. Must be greater than zero.

4 `r0 (Ω)` Zero bias resistance. Must be greater than zero.

Operating-Point Parameters

1 `vhl (V)` Absolute value of the applied bias across the resistor.

2 `vbl (V)` Absolute value of the back-bias across the resistor.

3 `ih (A)` DC current into the resistor.

4 `r (Ω)` Actual resistance value.

5 `pwr (W)` Power.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

45

BSIM-CMG

This chapter contains the following information about the BSIM-CMG model:

Model Overview

BSIM-CMG is a SPICE compact model for modeling the electrical characteristics of common gate MG structures, developed by UC Berkeley.

Physical surface potential-based formulations are derived for both intrinsic and extrinsic models with finite body doping. The surface potentials at the source and drain ends are solved analytically with poly-depletion and quantum mechanical effects. The effect of finite body doping is captured through a perturbation approach. The analytic surface potential solution agrees with 2-D device simulation results well. If the channel doping concentration is low enough to be neglected, computational efficiency can be further improved by setting `COREMOD = 1`.

All the important MG transistor behaviors are captured by this model. Volume inversion is included in the solution of the Poisson's equation, hence the subsequent I-V formulation automatically captures the volume inversion effect. Analysis of the electrostatic potential in the body of MG MOSFETs provided the model equation for the short channel effects (SCE). The extra electrostatic control from the end-gates (top/bottom gates) (triple or quadruple-gate) is also captured in the short channel model.

Users can specify the MG structure of interest via a geometry mode selector (`GEOMOD`, `DG = 0`, `TG = 1`, `QG = 2`, `CG = 3`). Hybrid-surface-orientation mobility, corner-induced effective width reduction, and end-channel-enhanced electrostatic control are considered to address the physics of tri-gate (TG) and quadruple-gate (QG) devices.

BSIM-CMG provides the flexibility to model devices with novel materials. This includes parameters for non-silicon channel devices and High-K/ Metal-gate stack.

Other important effects, such as, mobility degradation, velocity saturation, velocity overshoot, series resistance, channel length modulation, quantum mechanical effects, gate tunneling current, gate-induced-drain-leakage, temperature effects, channel thermal noise, flicker noise, noise associated with device parasitics, and parasitic capacitance, are also incorporated in the model.

BSIM-CMG has been verified with industrial experimental data. The model is continuous and symmetric at `Vds = 0`. This physics-based model is scalable and predictive over a wide range of device parameters.

BSIM-CMG Model Equations

Bias Independent Calculations

Physical constants

Physical quantities in BSIM-CMG are in M.K.S units unless specified otherwise.

$$q = 1.6 \times 10^{-19}$$

$$\varepsilon_0 = 8.8542 \times 10^{-12}$$

$$h = 1.05457 \times 10^{-34}$$

$$m_e = 9.11 \times 10^{-31}$$

$$\varepsilon_{sub} = EPSRSUB \cdot \varepsilon_0$$

$$\varepsilon_{ox} = EPSROX \cdot \varepsilon_0$$

$$C_{ox} = \frac{3.9 \cdot \varepsilon_0}{EOT}$$

$$C_{si} = \frac{\varepsilon_{sub}}{TFIN}$$

$$\varepsilon_{ratio} = \frac{EPSRSUB}{3.9}$$

Effective Channel Width, Channel Length and Fin Number

$$\Delta L = LINT + \frac{LL}{(L + XL)^{LLN}}$$

$$\Delta LCV = DLC + \frac{LLC}{(L + XL)^{LLN}}$$

$$L_{eff} = L + XL + -2\Delta L$$

$$L_{eff,\,CV} = L + XL + -2\Delta LCV$$

If BULKMOD=1 and CAPMOD=1 then

$$L_{eff,\,CV,\,acc} = L_{eff,\,CV} - DLCACC$$

If GEOMOD=0 then

$$W_{eff0} = 2 \cdot HFIN - DELTAW$$

$$W_{eff,\,CV0} = 2 \cdot HFIN - DELTAWCV$$

If GEOMOD=1 then

$$W_{eff0} = 2 \cdot HFIN + FECH \cdot TFIN - DELTAW$$

$$W_{eff,\,CV0} = 2 \cdot HFIN + FECH \cdot TFIN - DELTAWCV$$

If GEOMOD=2 then

$$W_{eff0} = 2 \cdot HFIN + 2 \cdot FECH \cdot TFIN - DELTAW$$

$$W_{eff,\,CV0} = 2 \cdot HFIN + 2 \cdot FECH \cdot TFIN - DELTAWCV$$

If GEOMOD=3 then

$$R = \frac{D}{2}$$

$$W_{eff0} = \pi \cdot D - DELTAW$$

$$W_{eff,\,CV0} = \pi \cdot D - DELTAWCV$$

$$NFINtotal = NFIN \times NF$$

Quantum Mechanical Effects

The following bias-independent calculations are for the threshold voltage shift and bias dependence of inversion charge centroid due to quantum mechanical confinement.

If GEOMOD=0 then

$$MTcen = 1 + AQMTCEN \cdot \exp\left(-\frac{TFIN}{BQMTCEN}\right)$$

$$T_{cen0} = TFIN \cdot MTcen$$

If GEOMOD=1 then

$$MTcen = 1 + AQMTCEN \cdot \exp\left(-\frac{min(HFIN, TFIN)}{BQMTCEN}\right)$$

$$T_{cen0} = min(HFIN, TFIN) \cdot MTcen$$

If GEOMOD=2 then

$$MTcen = 1 + AQMTCEN \cdot \exp\left(-\frac{min(HFIN, TFIN)}{BQMTCEN}\right)$$

$$T_{cen0} = min(HFIN, TFIN) \cdot MTcen$$

If GEOMOD=3 then

$$MTcen = 1 + AQMTCEN \cdot \exp\left(-\frac{R}{BQMTCEN}\right)$$

$$T_{cen0} = R \cdot MTcen$$

Binning Calculations

For given L and NFIN, each model parameter $PARAM_i$ is calculated as a function of PARAM, a length dependent term, LPARAM, a number of fin per finger(NFIN) dependent term, NPARAM, product L x NFIN term, and PPARAM:

$$PARAM_i = PARAM + \frac{1.0e^{-6}}{L_{eff} + DLBIN} \cdot LPARAM + \frac{1.0}{NFIN} \cdot NPARAM + \frac{1.0e^{-6}}{(L_{eff} + DLBIN) \cdot NFIN} \cdot PPARAM$$

Terminal Voltages

Terminal Voltages and V_{dsx} Calculation

$$V_{gs} = V_g - V_s$$

$$V_{gd} = V_g - V_d$$

$$V_{gb} = V_g - V_b$$

$$V_{ds} = V_d - V_s$$

$$V_{dsx} = \sqrt{v_{ds}^2 + 0.01} - 0.1$$

Short Channel Effects

Weighting Function for Forward and Reverse Mode

$$T0 = \tanh(0.6*q*V_{ds}/kT)$$

$$Wf = 0.5 + 0.5T0$$

$$Wr = 0.5 - 0.5T0$$

Asymmetric Parameters

If `ASYMMOD=1`then

$$CDSCDa = CDSCDi*\mathrm{Wf} + CDSCDRi*\mathrm{Wr}$$

$$ETAa = ETA0i*\mathrm{Wf} + ETA0Ri*\mathrm{Wr}$$

$$PDIBL1a = PDIBL1i*\mathrm{Wf} + PDIBL1Ri*\mathrm{Wr}$$

$$PTWGa = PTWG(T)*\mathrm{Wf} + PTWGR(T)*\mathrm{Wr}$$

$$VSAT1a = VSAT1(T)*\mathrm{Wf} + VSAT1R(T)*\mathrm{Wr}$$

$$RSDRa = RSDR(T)*\mathrm{Wf} + RSDRR(T)*\mathrm{Wr}$$

$$RDDRa = RDDR(T)*\mathrm{Wf} + RDDRR(T)*\mathrm{Wr}$$

Else

All above `PARAMa=PARAM` and reverse mode parameter `PAPAMR` are ignored.

Vt Roll-off, DIBL, and Subthreshold Slope Degradation

$$\Delta V_{th,\,SCE} = -\frac{0.5 \cdot DVT0_i}{\cosh\left(DVT1_i \cdot \frac{Leff}{\lambda}\right) - 1} \cdot (V_{bi} - \Psi_{st})$$

$$\Delta V_{th,\,DIBL} = -\frac{0.5 \cdot ETA0}{\cosh\left(DSUB_i \cdot \frac{Leff}{\lambda}\right) - 1} \cdot V_{dsx}$$

$$V_{th,\,RSCE} = K1RSCE_i \cdot \left[\sqrt{1 + \frac{LPE0_i}{Leff}} - 1\right] \cdot \sqrt{\Psi_{st}}$$

$$\Delta V_{th,\,all} = \Delta V_{th,\,SCE} + \Delta V_{th,\,DIBL} + \Delta V_{th,\,RSCE} + \Delta V_{th,\,temp}$$

$$V_{gsfb} = V_{gs} - \Delta q\Phi - \Delta V_{th,\,all} - DVTHSHIFT$$

Surface Potential Calculation

Surface potentials at the source and drain ends are derived from the Poisson's equation with a perturbation method and computed using the Householder's cubic iteration method. Perturbation allows accurate modeling of finite body doping.

When the body is lightly-doped, a simplified surface potential algorithm can be activated by setting `COREMOD=1` to enhance computational efficiency.

Drain Saturation Voltage

Electric Field Calculations

Electric Field is in MV/cm

If GEOMOD is not equal to 3 then

$$E_{effs} = 10^{-8} \cdot \left(\frac{q_{bs} + \eta \cdot q_{is}}{\varepsilon_{ratio} \cdot EOT}\right)$$

Drain Saturation Voltage (V_{dsat}) Calculations

$$D_{mobs} = \begin{cases} 1 + UA(T) \cdot (E_{effs})^{EU} + \dfrac{UD(T)}{\left(\dfrac{1}{2} \cdot \left(1 + \dfrac{q_{is}}{q_{im,\,th}}\right)\right)^{UCS(T)}} & \textbf{BULKMOD=0} \\ 1 + (UA(T) + UC(T) \cdot V_{eseff}) \cdot (E_{effs})^{EU} + \dfrac{UD(T)}{\left(\dfrac{1}{2} \cdot \left(1 + \dfrac{q_{is}}{q_{im,\,th}}\right)\right)^{UCS(T)}} & \textbf{BULKMOD=1} \end{cases}$$

$$D_{mobs} = \frac{D_{mobs}}{U0MULT}$$

If RDSMOD=0 then

$$R_{ds,\,s} = frac1(W_{eff0}(\mu m))^{WR_i} \cdot \left(RDSWMIN(T) + \frac{RDSW(T)}{1 + PRWG_i \cdot q_{is}}\right)$$

If RDSMOD=1 then

$$R_{ds,\,s} = 0$$

$$E_{sat} = \frac{2 \cdot VSAT(T)}{\mu o(T)/D_{mobs}}$$

$$E_{satL} = E_{sat} \cdot L_{eff}$$

If $R_{ds,s}$=0 then

$$V_{dsat} = \frac{E_{satL} \cdot KSATIV_i \cdot \left(V_{gsfbeff} - \Psi_s + 2\frac{kT}{q}\right)}{E_{satL} + KSATIV_i \cdot \left(V_{gsfbeff} - \Psi_s + 2\frac{kT}{q}\right)}$$

Else

$$WVC_{ox} = W_{eff0} \cdot V_{SAT}(T) \cdot C_{ox}$$

$$T_a = 2 \cdot WVC_{ox} \cdot R_{ds,s}$$

$$T_b = KSATIV_i \cdot (V_{gsfbeff} - \varphi_s + 2kT/q) \cdot (1 + 3 \cdot WVC_{ox} \cdot R_{ds,s}) + E_{satL}$$

$$T_c = KSATIV_i \cdot (V_{gsfbeff} - \varphi_s + 2kT/q) \cdot (E_{satL} + T_a \cdot KSATIV_i \cdot (V_{gsfbeff} - \varphi_s + 2kT/q))$$

$$V_{dsat} = \frac{\left(T_b - \sqrt{T_b^{\ 2} - 2T_aT_c}\right)}{T_a}$$

$$V_{dseff} = \frac{Vds}{\left(1 + \left(\frac{V_{ds}}{V_{dsat}}\right)^{MEXP(T)}\right)^{1/MEXP(T)}}$$

Average Potential and Charge

$$\Delta\Psi = \Psi_d - \Psi_s$$

$$q_{ba} = q_{bs}$$

If GEOMOD is not equal to 3 then

If $NGATE_i$>0 then

$$T_{polyd} = \sqrt{1 + \frac{V_{gsfbeff} - \Psi_d}{V_{poly0}}} - 1$$

$$V_{polyd} = V_{poly0} \cdot T^2{}_{polyd}$$

else

V_{polyd}=0

$$q_{id} = \begin{cases} V_{gsfbeff} - \Psi_d - q_{bm} - V_{polyd} & ifCOREMOD = 0 \\ V_{gsfbeff} - \Psi_d - V_{polyd} & ifCOREMOD = 1 \end{cases}$$

$$q_{ia} = 0.5 \cdot (q_{is} + q_{id})$$
$$\Delta q_i = q_{is} - q_{id}$$

Quantum Mechanical Effects

Charge Centroid Calculation

$$T4 = \frac{q_{im} + ETAQM \cdot q_{bm}}{QM0}$$

$$T5 = 1 + T4^{ALPHAQM}$$

$$T_{cen} = \frac{T_{cen0}}{T5}$$

Effective Width Model

If GEOMOD=0 then

$$W_{eff} = W_{eff0}$$
$$W_{eff,\,CV} = W_{eff,\,CV0}$$

If GEOMOD=1 then

$$W_{eff} = W_{eff0} - 4 \cdot QMTCENIV_i \cdot T_{cen}$$
$$W_{ef,\,CV} = W_{eff,\,CV0} - 4 \cdot QMTCENCV_i \cdot T_{cen}$$

If GEOMOD=2

$$W_{eff} = W_{eff0} - 8 \cdot QMTCENIV_i \cdot T_{cen}$$

$$W_{ef,\,CV} = W_{eff,\,CV0} - 8 \cdot QMTCENCV_i \cdot T_{cen}$$

If GEOMOD=3 then

$$W_{eff} = W_{eff0} - 2\pi \cdot QMTCENIV_i \cdot T_{cen}$$

$$W_{eff,\,CV} = W_{eff0,\,CV0} - 2\pi \cdot QMTCENCV_i \cdot T_{cen}$$

Effective Oxide Thickness/Effective Capacitance

If $QMTCENCV_i$ is not equal to 0 then

$$C_{ox,\,eff} = \begin{cases} \dfrac{3.9 \cdot \varepsilon_0}{TOXP\dfrac{3.9}{EPSROX} + T_{cen}\dfrac{QMTCENCV_i}{\varepsilon_{ratio}}} & GEOMOD \neq 3 \\ \dfrac{3.9 \cdot \varepsilon_0}{R \cdot \left[\dfrac{1}{\varepsilon_{ratio}} 1n\left(\dfrac{R}{R - T_{cen}}\right) + \dfrac{3.9}{EPSROX} 1n\left(1 + \dfrac{T_{oxp}}{R}\right)\right]} & GEOMOD = 3 \end{cases}$$

Charge Centroid Calculation for Accumulation

$$C_{ox,\,acc} = \begin{cases} \dfrac{3.9 \cdot \varepsilon_0}{TOXP\dfrac{3.9}{EPSROX} + \dfrac{T_{cen0}}{T6}\dfrac{QMTCENCVA_i}{\varepsilon_{ratio}}} & GEOMOD \neq 3 \\ \dfrac{3.9 \cdot \varepsilon_0}{R \cdot \left[\dfrac{1}{\varepsilon_{ratio}} 1n\left(\dfrac{R}{R - T_{cen0}/T6}\right) + \dfrac{3.9}{EPSROX} 1n\left(1 + \dfrac{T_{oxp}}{R}\right)\right]} & GEOMOD = 3 \end{cases}$$

If QMTCENCVi=0 then

$$C_{ox \cdot eff} = C_{ox}$$

$$C_{ox \cdot acc} = \frac{3.9 \cdot \varepsilon_0}{EOTACC}$$

Mobility Degradation and Series Resistance

Mobility Degradation

$$\eta = \begin{cases} \frac{1}{2} \cdot ETAMOB_i & NMOS \\ \frac{1}{3} \cdot ETAMOB_i & PMOS \end{cases}$$

$$E_{effa} = 10^{-8} \cdot \left(\frac{q_{ba} + \eta \cdot q_{ia}}{\varepsilon_{ratio} \cdot EOT}\right)$$

$$D_{mob} = \begin{cases} 1 + UA(T) \cdot (E_{effa})^{EU} + \dfrac{UD(T)}{\left(\frac{1}{2} \cdot \left(1 + \frac{q_{ia}}{q_{ba}}\right)\right)^{UCS(T)}} & \textbf{BULKMOD=0} \\ 1 + (UA(T) + UC(T) \cdot V_{eseff}) \cdot (E_{effa})^{EU} + \dfrac{UD(T)}{\left(\frac{1}{2} \cdot \left(1 + \frac{q_{ia}}{q_{ba}}\right)\right)^{UCS(T)}} & \textbf{BULKMOD=1} \end{cases}$$

$$D_{mob} = \frac{D_{mob}}{U0MULT}$$

Lateral Non-uniform Doping Model

$$M_{nud} = \exp\left(-\frac{K0_i}{K0SI_i \cdot q_{ia} + 2.0 \cdot \frac{nkT}{q}}\right)$$

Body Effect Model

$$V_{esx} = V_{es} - 0.5 \cdot (V_{ds} - V_{dsx})$$

$$V_{eseff} = min(V_{esx}, 0.95 \cdot PHIBE_i)$$

$$dVth_{BE} = \sqrt{PHIBE_i - V_{eseff}} - \sqrt{PHIBE_i}$$

$$M_{ob} = \exp\left(-dVth_{BE}\frac{K1_i + K1SAT_i \cdot V_{dsx}}{K0SI_i \cdot q_{ia} + 2.0 \cdot \frac{nkT}{q}}\right)$$

Output Conductance

Channel Length Modulation

$$C_{clm} = \begin{cases} PCLM_i \cdot (1 + PCLMG_i \cdot q_{ia}) & for \quad PCLMG > 0 \\ \dfrac{1}{\dfrac{1}{PCLM_i} - PCLMG_i \cdot q_{ia}} & for \quad PCLMG < 0 \end{cases}$$

$$M_{clm} = 1 + \frac{1}{C_{clm}} 1n\left[1 + \frac{V_{ds} - V_{dseff}}{V_{ASAT} + E_{satL}}\right] \cdot C_{clm}$$

Output Conductance due to DBL

$$PVAG_{factor} = \begin{cases} 1 + PVAG_i \cdot \dfrac{q_{ia}}{E_{sat}L_{eff}} & for \quad PVAG_i > 0 \\ \dfrac{1}{1 - PVAG_i \cdot \dfrac{q_{ia}}{E_{sat}L_{eff}}} & for \quad PVAG_i < 0 \end{cases}$$

$$\theta_{rout} = \frac{0.5 \cdot PDIBL1_a}{\cosh\left(DROUT_i \cdot \frac{L_{eff}}{\lambda}\right) - 1} + PDIBL2_i$$

$$V_{ADIBL} = \frac{q_{ia} + 2kT/q}{\theta_{rout}} \cdot \left(1 - \frac{V_{dsat}}{V_{dsat} + q_{ia} + 2kT/q}\right) \cdot PVAG_{factor}$$

$$M_{oc} = \left(1 + \frac{V_{ds} - V_{dseff}}{V_{ADIBL}}\right) \cdot M_{clm}$$

Velocity Saturation

Current Degradation Due to Velocity Saturation

$$E_{sat1} = \frac{2 \cdot VSAT1_a \cdot D_{mob}}{\mu_0(T)}$$

$$\delta_{vsat} = DELTAVSAT_i$$

$$D_{vsat} = \frac{1 + \left(\delta_{vsat} + \left(\frac{\Delta q_i}{E_{sat1}L_{eff}}\right)^{PSAT(L)}\right)^{\frac{1}{PSAT(L)}}}{1 + (\delta_{vsat})^{\frac{1}{PSAT(L)}}} + \frac{1}{2} \cdot PTWG_a \cdot q_{ia} \cdot \Delta\varphi^2$$

Non-Saturation Effect

$$T_0 = max\left[\left(A1_i + \frac{A2_i}{q_{ia} + 2.0 \cdot \frac{nkT}{q}}\right) \cdot \Delta q_i^2, -1\right]$$

$$N_{sat} = \frac{1 + \sqrt{1 + T0}}{2}$$

$$D_{vsat} = D_{vsat} \cdot N_{sat}$$

Drain Current Model

$$I_{ds} = IDS0MULT \cdot \mu_0(T) \cdot C_{ox} \cdot \frac{W_{eff}}{L_{eff}} \cdot i_{ds0} \cdot \frac{M_{oc}M_{ob}M_{nud}}{D_{vsat}D_r D_{mob}} \times NFIN_{total}$$

Intrinsic Capacitance Model

Channel Length Modulation

$$M_{clm,\,CV} = 1 + \frac{1}{PCLMCV} 1n\left[1 + \frac{V_{ds} - V_{dseff}}{V_{dsat} + E_{satCVL}}\right] \cdot PCLMCV$$

$$I_{ds,CV} = T1 \cdot \frac{M_{clm,cv}}{D_{r,CV}}$$

Intrinsic (Normalized) Charge

$$q_b = q_{bs}$$

$$q_g = \left[q_{ia} + T0 \cdot \frac{\Delta q^2{}_i}{12 \cdot i_{ds,CV}}\right] \cdot \frac{1}{M_{clm,CV}} + (M_{clm,CV} - 1) \cdot qid$$

$$q_d = \left[0.5 \cdot q_{ia} - \frac{\Delta q_i}{12} \cdot \left(1 - T1\frac{\Delta q_i}{30 \cdot i_{ds,CV}} - T2\frac{\Delta q^2{}_i}{1260 \cdot i^2{}_{ds,CV}}\right)\right] \cdot \frac{1}{M^2{}_{clm,CV}} + \left[M_{clm,CV} - \frac{1}{M_{clm,CV}}\right] \cdot q_{id}$$

Accumulation Charge

If GEOMOD=3 then

$$q_{0,acc} = \frac{2 \cdot kT \cdot r1_{acc}}{q}$$

Terminal Charges

For GEOMOD not equal to 3

$$q_{i,acc} = V_{gsfbeff,ac} - \frac{2kT}{q}[1n(\beta)] - 1n(\cos(\beta)) + F_{1.acc}$$

For GEOMOD=3

$$q_{i,acc} = q_{0,acc} \cdot g$$

Terminal Charges

$$Q_{g,\,intrinsic} = NFIN_{total} \cdot C_{ox,\,eff} \cdot W_{eff,\,CV} \cdot L_{eff,\,CV} \cdot (q_g)$$

$$Q_{d,\,intrinsic} = NFIN_{total} \cdot C_{ox,\,eff} \cdot W_{eff,\,CV} \cdot L_{eff,\,CV} \cdot (-q_d)$$

$$Q_{b,\,intrinsic} = NFIN_{total} \cdot C_{ox,\,eff} \cdot W_{eff,\,CV} \cdot L_{eff,\,CV} \cdot (-q_b)$$

$$Q_{s,\,intrinsic} = -Q_{g,\,intrinsic} - Q_{d,\,intrinsic} - Q_{b,\,intrinsic}$$

$$Q_{g,\,acc} = NFIN_{total} \cdot C_{ox,\,acc} \cdot W_{eff,\,CV0} \cdot L_{eff,\,CV} \cdot (-q_{i,\,acc})$$

$$Q_{b,\,acc} = NFIN_{total} \cdot C_{ox,\,acc} \cdot W_{eff,\,CV0} \cdot L_{eff,\,CV} \cdot (-q_{i,\,acc})$$

Parasitic resistances and capacitance models

BSIM-CMG models the parasitic source/drain resistance in two components: a bias dependent extension resistance and a bias independent diffusion resistance. Parasitic gate resistance is modeled as well.

RDSMOD=0 (Internal)

$$R_{source} = R_{s,\,geo}$$

$$R_{drain} = R_{d,\,geo}$$

$$R_{ds} = \frac{1}{NFIN_{total} \cdot W_{eff0}^{WR_i}} \cdot \left(RDSWMIN(T) + \frac{RDSW(T)}{1 + PRWG_i \cdot q_{ia}}\right)$$

$$D_r = 1.0 + NFIN_{total} \cdot \mu_0(T) \cdot C_{ox} \cdot \frac{W_{eff}}{L_{eff}} \cdot \frac{i_{ds0}}{\Delta q_i} \cdot \frac{Rd_s}{D_{vsat} \cdot D_{mob}}$$

RDSMOD=1 (External)

$$R_{source} = \frac{1}{\frac{W_{eff0}}{WR_i} \times NFIN_{total}} \cdot \left(RSWMIN(T) + \frac{RSW(T)}{1 + PRWG_i \cdot V_{gs,eff}}\right) + R_{s,geo}$$

$$R_{drain} = \frac{1}{\frac{W_{eff0}}{WR_i} \times NFIN_{total}} \cdot \left(RSWMIN(T) + \frac{RSW(T)}{1 + PRWG_i \cdot V_{gd,eff}}\right) + R_{d,geo}$$

$R_{s,geo}$ and $R_{d,geo}$ are the source and drain diffusion resistances, described as follows:

Sheet Resistance Model

RGEOMOD = 0 (sheet resistance model)

$$R_{s,geo} = NRS \cdot RSHS$$

$$R_{d,geo} = NRD \cdot RSHD$$

Diffusion Resistance Model for Variability Modeling

RGEOMOD=1

$$R_{s,geo} = R_{dgeo} = \frac{R_{rsd} + R_{ext}}{NF} \cdot \begin{bmatrix} RGEOA + RGEOB \times TFIN + RGEOC \times FPITCH + \\ RGEOD \times LRSD + RGEOE \times HEPI \end{bmatrix}$$

Gate Electrode Resistance Model

$$R_{geltd} = \begin{cases} \dfrac{RGEXT + RGFIN \cdot NFIN}{3 \cdot NF} & for\ \ NGCON = 1 \\ \dfrac{RGEXT + RGFIN \cdot NFIN}{12 \cdot NF} & for\ \ NGCON = 2 \end{cases}$$

Bias-dependent Overlap Capacitance Model

The bias-dependent overlap capacitance model in BSIM-CMG is adopted from BSIM4 for CGEOMOD = 0 and CGEOMOD = 2. The overlap charge is given by:

$$\frac{Q_{gs,\,ov}}{NFIN_{total}\cdot W_{effCV}} = CGSO\cdot V_{gs} + CGSL\cdot\left[V_{gs} - V_{fbsd} - V_{gs,\,overlap} - \frac{CKAPPAS}{2}X\left(\sqrt{1-\frac{4V_{gs,\,overlap}}{CKAPPAS}}-1\right)\right]$$

$$\frac{Q_{gd,\,ov}}{NFIN_{total}\cdot W_{effCV}} = CGDO\cdot V_{gd} + CGDL\cdot\left[V_{gd} - V_{fbsd} - V_{gd,\,overlap} - \frac{CKAPPAD}{2}X\left(\sqrt{1-\frac{4V_{gd,\,overlap}}{CKAPPAD}}-1\right)\right]$$

Substrate Parasitics

$$C_{sbox} = C_{box}\cdot ASEO + C_{box,\,sw}\cdot(PSEO - FPITCH\times NFINtotal)$$

$$C_{dbox} = C_{box}\cdot ADEO + C_{box,\,sw}\cdot(PDEO - FPITCH\times NFINtotal)$$

$$C_{box,\,sw} = CSDESW\cdot 1n\left(1+\frac{HFIN}{EOTBOX}\right)$$

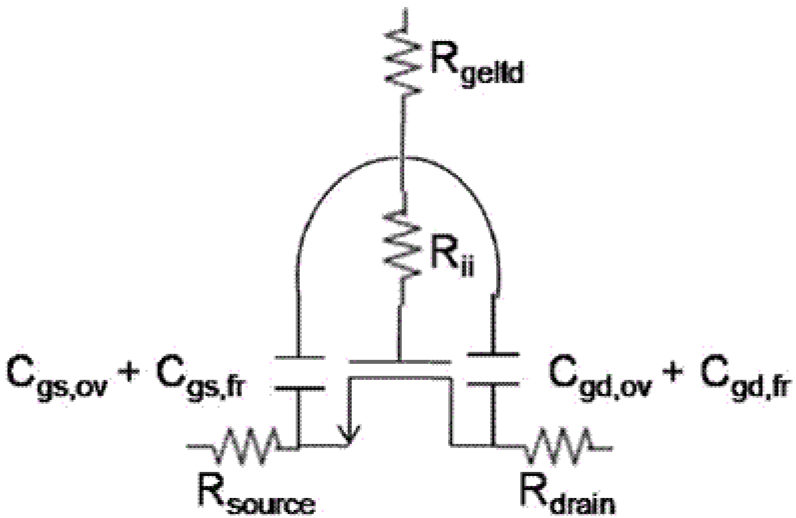
$$C_{ge,\,overlap,\,1} = (CGBO\cdot NF + NGCON + CGBN\cdot NFIN_{total})\cdot L_{eff,\,CV}$$

Fringe Capacitances and Capacitance Model Selectors

CGEOMOD=0

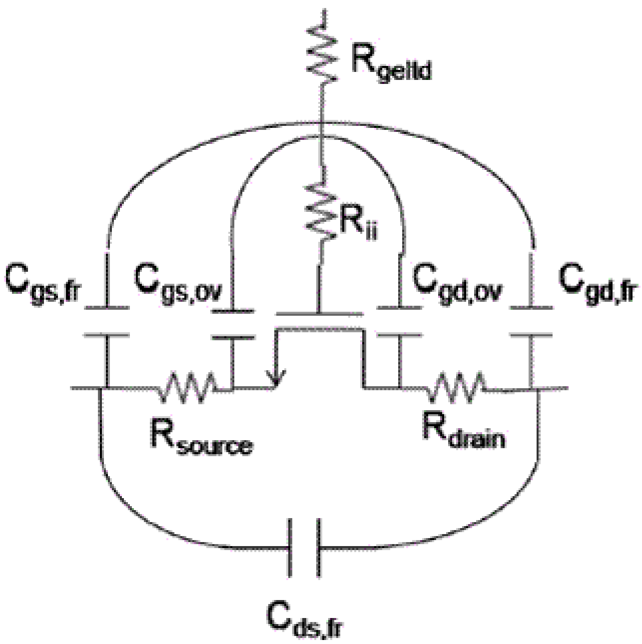
$$C_{gs,fr} = NFIN_{total} \cdot W_{eff,CV} \cdot CFS_i$$

$$C_{gd,fr} = NFIN_{total} \cdot W_{eff,CV} \cdot CFD_i$$



R-C network for CGEOMOD=0, NQSMOD=1, RGATEMOD=1 and RDSMOD=1.

If NQSMOD, RGATEMOD or RDSMOD is 0, then the corresponding resistances become 0 and the nodes collapse.



R-C network for CGEOMOD=1, NQSMOD=1, RGATEMOD=1 andRDSMOD=1.

If NQSMOD, RGATEMOD or RDSMOD is 0, then the corresponding resistances become 0 and the nodes collapse.

CGEOMOD = 1

$$C_{gs,\,ov} = COVS_i$$
$$C_{gd,\,ov} = COVD_i$$
$$C_{gs,fr} = CGSP$$
$$C_{gd,fr} = CGDP$$
$$C_{ds,fr} = CDSP$$

In CGEOMOD=2

$$C_{fr,\,top} = C_{fringe,\,2D}(H_g, H_{rsd}, LRSD) \times TFIN \times NFIN$$

$$C_{fr,\,side} = 2 \times C_{fringe,\,2D}(W_g, T_{rsd}, LRSD) \times HFIN \times NFIN$$

$$C_{corner} = \frac{\varepsilon_{sp}}{LSP} \cdot [A_{corner} \times HFIN + ARSDEND + ASILIEND]$$

$$C_{fr,\,geo} = \begin{array}{c}(C_{corner} + C_{fr,\,top} + CGEOE \cdot C_{fr,\,side}) \times NF \;\; \mathrm{x} \\ [CGEOA + CGEOB \cdot TFIN + CGEOC \cdot FPITCH + CGEOD \cdot LRSD]\end{array}$$

$$C_{fr,\,top} = \left\{3.467 \times 10^{-11} \cdot 1n\left(\frac{EPSRSP \cdot 10^{-7}}{3.9 \cdot LSP}\right) + 0.942 \cdot H_{rsd} \cdot \frac{\varepsilon_{sp}}{LSP}\right\} \cdot ([TFIN + (FPITCH - TFIN) \cdot CRATIO] \cdot NFIN)$$

CGEOMOD=0/1/2

$$C_{ds,\,fr} = CDSP$$

Impact Ionization and GIDL/GISL Model

Impact Ionization Current

I_{ii} can be switched off by setting IIMOD = 0

Case: IIMOD = 1

$$Iii = \frac{ALPHA0_i + ALPHA1_i \cdot L_{eff}}{L_{eff}}(V_{ds} - V_{dseff}) \cdot e^{\frac{BETA0(T)}{V_{ds} - V_{dseff}}} \cdot Ids$$

Case: IIMOD=2

$$I_{ii} = ALPHAII_i \cdot I_{ds} \cdot \exp\left(\frac{V_{diff}}{BETAII2_i + BETAII1_i V_{diff} + BETAII0_i V^2{}_{diff}}\right)$$

Gate-Induced-Drain/Source-Leakage Current

GIDL/GISL are calculated only for GIDLMOD = 1

$$T0 = \frac{AGIDL_i \cdot W_{eff0} \cdot \frac{V_{ds} - V_{fgs} - EGIDL_i + V_{fbsd}}{\varepsilon_{ratio} \cdot EOT} \times \exp\left(-\frac{\varepsilon_{ratio} \cdot EOT \cdot BGIDL(T)}{V_{ds} - V_{gs} - EGIDL_i + V_{fbsd}}\right) \text{ x}}{NFIN_{total}}$$

$$I_{gidl} = \begin{cases} T0 \cdot \dfrac{{V_{de}}^3}{CGIDL + {V_{de}}^3} & BULKMOD = 1 \\ T0 \cdot V_{ds} & \text{BULKMOD=0} \end{cases}$$

$$T1 = \frac{AGISL_i \cdot W_{eff0} \cdot \left(\frac{-V_{ds} - V_{gd} - EGISL_i + V_{fbsd}}{\varepsilon_{ratio} \cdot EOT}\right)^{PGISL_i} \times \exp\left(-\frac{\varepsilon_{ratio} \cdot EOT \cdot BGIDL(T)}{-V_{ds} - V_{gd} - EGIDL_i + V_{fbsd}}\right)}{NIFN_{total}}$$

$$I_{gisl} = \begin{cases} T1 \cdot \dfrac{{V_{se}}^3}{CGISL + {V_{se}}^3} & BULKMOD = 1 \\ T1 \cdot V_{ds} & \text{BULKMOD=0} \end{cases}$$

Gate Tunneling Current

Gate to body current I_{gbinv} and I_{gbacc} is calculated only if IGBMOD = 1

$$I_{gbinv} = \begin{array}{l} W_{eff0} \cdot L_{eff} \cdot A \cdot T_{ox,\,ratio} \cdot V_{ge} \cdot V_{aux,\,igbinv} \cdot I_{gtemp} \times NFIN_{total} \cdot \\ \exp(-B \cdot TOXP \cdot (AIGBINV_i - BIGBINV_i \cdot q_{ia})) \cdot (1 + CIGBINV_i \cdot q_{ia}) \end{array}$$

$$I_{gbacc} = \begin{array}{l} W_{eff0} \cdot L_{eff} \cdot A \cdot T_{ox,\,ratio} \cdot V_{ge} \cdot V_{aux,\,igbacc} \cdot I_{gtemp} \times NFIN_{total} \cdot \\ \exp(-B \cdot TOXP \cdot (AIGBINV_i - BIGBINV_i \cdot V_{oxacc})) \cdot (1 + CIGBINV_i \cdot V_{oxacc}) \end{array}$$

Gate to channel current I_{gc} is calculated only for IGCMOD = 1.

$$I_{gcs0} = \begin{array}{l} W_{eff0} \cdot L_{eff} \cdot A \cdot T_{ox,\,ratio} \cdot I_{gtemp} \times NFIN_{total} \cdot T0 \\ \cdot \exp(-B \cdot TOXP \cdot (AIGC_i - BIGC_i \cdot V_{oxm})) \cdot (1 + CIGC_i \cdot V_{oxm}) \end{array}$$

$$I_{gcs} = I_{gc0} \cdot \frac{PIGCD_i \cdot V_{dseffx} + \exp(PIGCD_i \cdot V_{dseffx}) - 1.0 + 1.0e-4}{PIGCD_i^{\,2} \cdot V^2{}_{dseffx} + 2.0e-4}$$

$$I_{gcd} = I_{gc0} \cdot \frac{1.0 - (PIGCD_i \cdot V_{dseffx} + 1.0) + \exp(-PIGCD_i \cdot V_{dseffx}) + 1.0e-4}{PIGCD_i^{\,2} \cdot V^2{}_{dseffx} + 2.0e-4}$$

Gate to source/drain current I_{gs}, I_{gd} are calculated only for IGCMOD = 1

$$i_{gsd,\,mult} = I_{gtemp} \cdot \frac{W_{eff0} \cdot A}{(TOXP \cdot POXEDGE_i)^2} \left(\frac{TOXREF}{(TOXP \cdot POXEDGE_i)^2} \right)^{NTOXi}$$

$$I_{gs} = \begin{array}{l} i_{gsd,\,mult} \cdot DLCIGS \cdot V'_{gs} \mathrm{X}\ NFIN_{total} \cdot \\ \exp(\, -B \cdot TOXP \cdot POXEDGE_i \cdot (AIGS_i - BIGS_i \cdot V'_{gs}) \cdot (1 + CIGS_i \cdot V'_{gs})) \end{array}$$

$$I_{gd} = \begin{array}{l} i_{gsd,mult} \cdot DLCIGD \cdot V_{gd} \cdot V'_{gd} \mathrm{X}\, NFIN_{total} \cdot \\ \exp(-B \cdot TOXP \cdot POXEDGE_i \cdot (AIGS_i - BIGS_i \cdot V'_{gd}) \cdot (1 + CIGS_i \cdot V'_{gd})) \end{array}$$

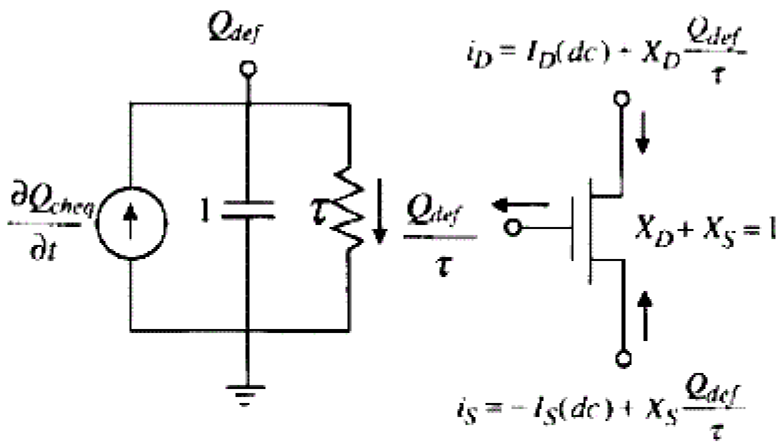
Non Quasi-static Models

This version offers three different non quasi-static (NQS) models. Each of these can be turned on/off using the NQSMOD switch. Setting NQSMOD = 0 turns off all NQS models and switches to plain quasi-static calculations.

Gate Resistance Model (NQSMOD = 1)

$$I_{dovVds} = \mu_0(T) C_{ox} \frac{W_{eff}}{L_{eff}} q_{ia} \frac{M_{oc}}{G_{vsat}}$$

$$\frac{1}{R_{ii}} = \frac{NF}{NFIN} \cdot XRCRG1_i \cdot \left(I_{dovVds} + XRCRG2 \cdot \frac{\mu_{eff} C_{oxe} W_{eff} kT}{qL_{eff}} \right)$$



R-C network for calculating deficient charge Q_{def} and the instantaneous charge, Q_{def}/τ is used in place of the quasi-static charges.

Charge Deficit Model (NQSMOD = 2)

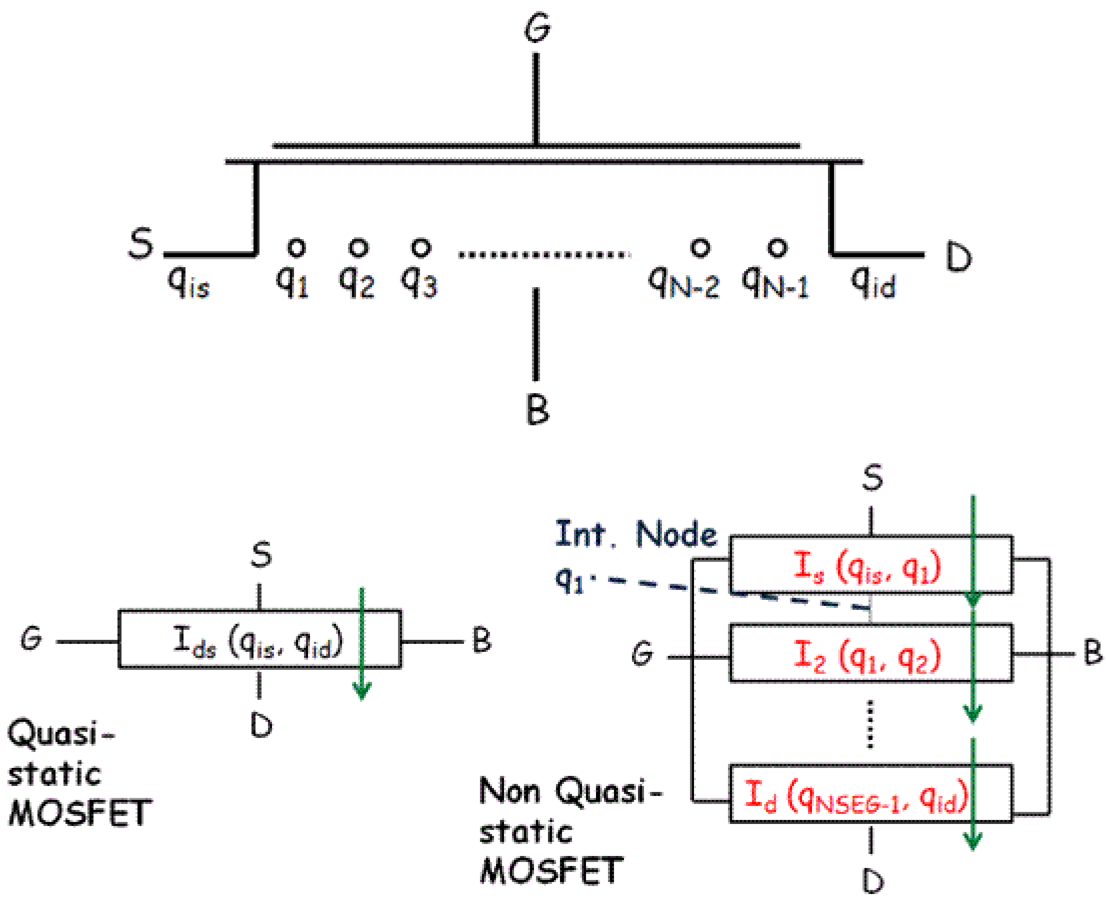
$$X_{d,\,part} = \frac{q_d}{q_g}$$

$$I_{dovVds} = \mu_0(T)C_{ox}\frac{W_{eff}}{L_{eff}}q_{ia}\frac{M_{oc}}{D_{vsat}}$$

$$\frac{1}{R_{ii}} = \frac{NF}{NFIN} \cdot XRCRG1_i \cdot \left(I_{dovVds} + XRCRG2 \cdot \frac{\mu_{eff}C_{oxe}W_{eff}kT}{qL_{eff}}\right)$$

$$\frac{1}{\tau} = \frac{1}{R_{ii} \cdot C_{ox} \cdot W_{eff} \cdot L_{eff}}$$

Charge Segmentation Model (NQSMOD = 3)



A N-segment charge-segmented MOSFET with N-1 internal nodes.

Note: This model is not supported for COREMOD = 1 && GEOMOD not equal to 3. That is, for double gate and likes together with the simplified surface potential solution.

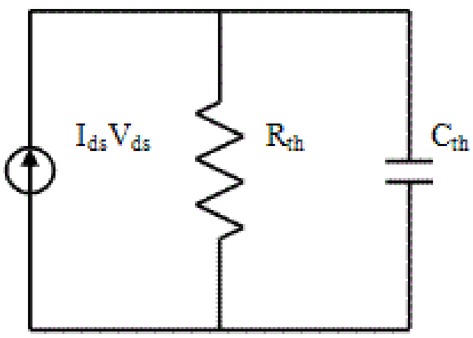
Generation-recombination Component

$$I_{ds,\,gen} = HFIN \cdot TFIN \cdot (L_{eff} - LINTIGEN) \cdot (AIGEN_i \cdot V_{ds} + BIGEN_i \cdot V^3{}_{ds}) \cdot \exp\left[\frac{qE_g}{NTGEN_i \cdot kT}\left(\frac{T}{TNOM} - 1\right)\right] \times NFIN_{total}$$

Junction Current and Capacitances

The junction current and capacitances are only calculated for bulk multi-gate devices (BULKMOD = 1).

Self-heating Model



Thermal resistance and capacitance calculations:

$$\frac{1}{R_{th}} = G_{th} = \frac{WTH0 + FPITCH + NFIN_{total}}{RTH0}$$

$$C_{th} = C_{TH0} + (WTH0 + FPITCH \cdot NFIN_{total})$$

Noise Models

Noise models in BSIM-CMG are based on BSIM4. The following table lists the origin of each noise model:

Model in BSIM-CMG105.0 alpha	**Origin**
Flicker noise model	BSIM4 Unified Model (FNOIMOD=1)
Thermal noise	BSIM4 TNOIMOD=0
Gate current shot noise	BSIM4 gate current noise
Noise associated with parasitic resistances	BSIM4 parasitic resistance noise

Flicker Noise Model

$$S_{si} = \frac{kTq^2\mu_{eff}I_{ds}}{C_{oxe}L^2{}_{eff,noif}{}^{EF} \cdot 10^{10}} \cdot FN1 + \frac{kTI^2{}_{ds}\Delta L_{clm}}{W_{eff} \cdot NFIN_{total} \cdot L^2{}_{eff,noif}{}^{EF} \cdot 10^{10}} \cdot FN2$$

$$S_{wi} = \frac{NOIA \cdot kT \cdot I^2{}_{ds}}{W_{eff} \cdot NFIN_{total} \cdot L^2{}_{eff,noif}{}^{EF} \cdot 10^{10} \cdot N^{*2}}$$

$$S_{id,flicker} = \frac{S_{wi}S_{si}}{S_{wi} + S_{si}}$$

Thermal noise model (TNOIMOD = 0)

$$Q_{inv} = |Q_{s,intrinsic} + Q_{d,intrinsic}| \times NFIN_{total}$$

$$\overline{i^2{}_d} = \begin{cases} NTNOI \cdot \dfrac{4kT\Delta f}{R_{ds} + \dfrac{L^2{}_{eff}}{\mu_{eff}Q_{inv}}} & if \quad RDSMOD = 0 \\ NTNOI \cdot \dfrac{4kT\Delta f}{L^2{}_{eff}} \cdot \mu_{eff}Q_{inv} & if \quad RDSMOD = 1 \end{cases}$$

Gate Current Shot Noise

$$\overline{i^2{}_{gs}} = 2q(I_{gcs} + I_{gs})$$

$$\overline{i^2{}_{gd}} = 2q(I_{gcd} + I_{gd})$$

$$\overline{i^2{}_{gb}} = 2qI_{gbinv}$$

Resistor Noise

The noise associated with each parasitic resistors in BSIM-CMG is calculated.

If RDSMOD = 1 then

$$\frac{\overline{i^2_{RS}}}{\Delta f} = 4kT \cdot \frac{1}{R_{source}}$$

$$\frac{\overline{i^2_{RD}}}{\Delta f} = 4kT \cdot \frac{1}{R_{drain}}$$

If RGATEMOD = 1 then

$$\frac{\overline{i^2_{RG}}}{\Delta f} = 4kT \cdot \frac{1}{R_{geltd}}$$

Model Version Update

Version 105.02 Update

- Added binning along NFIN for all the binnable parameters
- Introduced Gate-to-Substrate Bias dependent parasitic capacitance through parameters CGBL and CKAPPA (both binned)
- Introduced a second-step-junction to S-B and D-B diodes through parameters SJS, MJS2, SJSWS, MJSWS2, SJSWGS, MJSWGS2?SJD, MJD2, SJSWD, MJSWD2, SJSWGD, MJSWGD2
- Source/Drain Junction Tunneling Currents have been introduced (Refer to the BSIM4 model for equations, parameters and binning)

Version 105.03 update

- PCLMG, VASAT, ETAMOB have been added to the list of binnable parameters.
- DVTSHIFT parameter introduced as a handle to create Vth shift.

- All older mobility models replaced with one single new mobility model. The new mobility model uses UA, EU, UD and UCS parameters from MOBMOD=0 of 105.02 release if MOBMOD=1 is used from the previous version.
- New velocity saturation (Ion degradation) model. Parameters VSAT1 (binned), DELTAVSAT replace old parameter THETASAT. This change is not backward compatible.
- RDSMOD=0 implementation changed for better accuracy.
- CLM Model modified to prevent cross-correlation of binning parameters.
- Igb accumulation component added for IGBMOD=1. Available for both BULKMOD=0 and 1.
- Vds asymmetric function changed for better higher order derivative predictivity.
- Accumulation side charge centroid incorporated for better fitting of accumulation capacitance.
- Old parameter ALPHAQM replaced by PQM for the inversion side charge centroid equation.
- Definition of TNOM changed from Kelvin to Celsius to be consistent with BSIM4/ BSIMSOI.

Version 105.031 update

- Limited the exponential function in TANH(x) definition
- GIDL Current Model modified for zero current at zero bias.
- Gate Current Model modified, as follows:
  - Default values of `BIGBINV`, `AIGBACC`, `BIGBACC`, `NIGBACC` changed
  - Gate-to-Channel Current, Igcs/Igcd. Partition function implemented with parameter PIGCD (Binned)
  - Gate Edge Leakage Igs changed
  - Gate Edge Leakage Igd changed
- Removed CLM effect in Charge Model due to wrong implementation.
- Fixed discontinuity in implementation at PCLMG=0 for CLM Model

Version 105.04 update

- Inbuilt tanh() function used instead of ((exp(x) - exp(-(x))) / (exp(x) + exp(-(x))))
- GIDL Current Model modified. New parameter PGIDL/PGISL introduced.
- Gate Current Model modified. Equations around BSIM4 parameters NTOX (binned) and TOXREF added
- CLM Model modified.
  - Fixed discontinuity in implementation at PCLMG=0 for CLM Model
  - CLM Model for I-V Modified.
- Parameter VASAT removed. The old equation was known to case unphysical wiggles.
- ETAMOB binning corrected and linear temperature dependence added with new parameter EMOBT
- Velocity Saturation Model for better Id,sat and Gm,sat fitting
- Parameters DELTAVSAT, DVTSHIFT and KT1 are now binned
- CGEOMOD=0 case; removed QM effects in Fringe Caps
- Drain-to-Source Fringe Cap now available for all CGEOMOD
- Introduced DLCACC parameter for accumulation region capacitance (CAPMOD=1 and BULKMOD=1)
- Velocity Saturation Model for Short Channel C-V introduced. New parameter VSATCV (binned) added
- CLM Model for C-V Modified.
  - MclmCV factor simplified. Parameters VASATCV and PCLMGCV removed
  - Corrected the wrong implementation of in the charge equations
  - For NQSMOD=3, a simple change has been made
- Added relevant equations for Short Channel CV.
- Parameter NFIN has been converted from integer to real to enable optimization
- Gate-to-Substrate Overlap cap scalability corrected. New parameter CGBN introduced.
- Temperature Dependence for Subthreshold Swing enhanced with new parameter TSS (binned)

- RDSMOD=1 enhanced to capture quasi-saturation / current crowding for high voltage devices. New parameters RSDR, RDDR, PRSDR, PRDDR introduced and new equations added. Temperature dependence through TRSDR and TRDDR parameters
- Asymmetric Model - ASYMMOD Switch.
  - In order to model highly asymmetric devices, seven parameters identified in the model and their reverse mode equivalents created. These parameters are: CDSCDR, ETA0R, PDIBL1R, PTWGR, VSAT1R, RSDRR, and RDDRR (Original parameters + 'R' in the end)
  - Additional parameter PRWG split into PRWGS and PRWGD for source and drain side in RDSMOD=1
- Some cosmetic changes to Impact Ionization model (especially IIMOD=1), implementing smooth functions
- Body Effect for BULKMOD=1. New parameters introduced: PHIBE, K1, K1ST, K1SAT.
- Removed nVtm in the poly-depletion correction term.
- Changed the value of q from 1.6e-19 to 1.60219e-19 (Coulombs)
- Quantum Mechanical Effects
  - Introduced new parameter QMTCENCVA (binned) to replace QMTCENCV for the accumulation region capacitance;
  - Some bug fixes done for variable 'Tcen' calculations in both inversion and accumulation region
- Introduced Non-saturation effect with new parameters A1 and A2. To be used to improve Id,sat and Gm,sat fitting.
- Lateral NUD Model introduced to create IV-CV Vth shift.

Version 106.0.0 update

BSIMCMG 106.0.0 is the first standard model for FinFETs. It is based on the version 105.031. Following are the changes from its base version:

- Used built-in hyperbolic functions instead of macros
- Added more significant digits to definition of electronic charge
- Fixed usage of parameter "CIT" in noise model

- Clamped phib and vbi to positive. Current expressions can be negative with SHMOD=1 at high temperature
- Fixed some typo bugs

Version 106.1.0 update

BSIMCMG 106.1.0 is the second standard model for FinFETs. It is based on the version 105.04. Following are the changes from its base version:

- The definitions of the physical intrinsic capacitances, CEDI and CEEI have been corrected
- Gate resistance model has been corrected
- Vfbsd equation for poly and metal gates has been changed
- For `_BINNABLE_` parameters, the bounds are now applied to the "Effective PARAM" (PARAM_i) instead of the root term (PARAM). These include K0SI, DSUB, DVT1, PSAT, and PHIBE.
- The effects of mobility, series resistances, and velocity saturation degradation terms on C-V calculations have been commented out for now (a roll back to BSIM-CMG105.031) to investigate those terms more carefully.
- Effective Channel Length equation has been changed
- Coulomb scattering term has been changed for correct weak-inversion ID-VG slop/behavior
- Threshold voltage definition has been introduced
- Temperature dependence of gate tunneling current has been introduced
- Temperature dependence of the body effect model, lateral non-uniform doping model, and non-saturation effect model has been introduced
- The temperature effect on U0 now affects UTL
- Temperature and length dependence of the impact ionization current has been introduced
- The oxide thickness TOXG is now used in the gate tunneling current, instead of physical oxide thickness TOXP.
- The impact of series resistance on C-V model has been introduced. To enhance the fitting accuracy, a new parameter (correction factor) RCVFAC has been introduced and used in equation for RDSMOD=0.

- To accurately capture the transition region between subthreshold and strong inversion in I-V when a forward body bias is taken into account,a new model parameter K1SI has been introduced and used in Mob.
- The value of Is (Id) at accumulation region has been clamped at the fixed value of 1.0E-15. In this version, a new model parameter IMIN has been introduced to specify this value.
- NQSMOD=3 hsa been disabled to perform an offline study
- A more careful examination of the C-V model derivation revealed that 1) dividing the term idscv by Dmob_cv and Dr_CV and 2) multiplying it by MclmCV were implementation mistakes. This has been corrected.
- To enhance the fitting accuracy, two new parameters DELTAVSATCV and PSATCV have been introduced in Dvsat and CV
- When the argument x is too huge, the built-in cosh(x) could cause arithmetic point error due to overflow. To protect the code, for x > 40, 0.5/(cosh(x)-1) has been replaced by exp(-x).
- Gate-induced source and drain leakage current equations have been changed

Version 107.0.0 update

BSIMCMG 107.0.0 is the third standard model for FinFETs. It is based on the version 105.04. Following are the changes from its previous version 106.1.0:

- Lower `COVS`, `COVD;` defaults to 0 from 25pF.
- For `CGEOMOD=1` only, `GEO1SW=1` now enables the parameters `COVS`, `COVD`, `CGSP`, and `CGDP` to be in F per fin per gate-finger per unit channel width. The default value of the `GEO1SW` switch is zero.
- New NFIN scaling equations have been added for the following parameters: `PHIG`, `CDSC`, `CDSCD`, `CDSCDR`, `NBODY`, `VSAT`, `VSAT1`, `VSAT1R`, `ETA0`, and `U0`.
- The length scaling of SCE and SS has been decoupled. The new binnable parameter `DVT1SS` has been introduced.
- Temperature dependence of DIBL coefficient and Reverse-mode DIBL coefficient has been added. Two new parameters `TETA0` and `TETA0R` have been introduced.
- Long channel DIBL, also called Drain-Induced Vth Shift (DITS) has been added. Two new parameters `DVTP0` and `DVTP1` have been added.

- The average charge weighing factor has been added through the new parameter `CHARGEWF`.
- Support for the length dependence of the `Gate` workfunction has been added. A new parameters `PHIGL` has been added.
- To be consistent with SOI, RTH and CTH equations in the self-heating sub-model have been updated.
- The initial guess for the surface potential calculation has been improved. The model is now infinitely scalable with respect to `TFIN` and `NBODY` without any clamping on `NBODY`.

Component Statements

This device is supported within altergroups.

Instance Definition

Name d g s e ModelName parameter=value ...

Instance Parameters

1	`m=1.0`	Multiplicity factor (number of FINFETs in parallel).
2	`l=(30 1.0e-9)`	Designed Gate Length.
3	`d=(40 1.0e-9)`	Diameter of the cylinder (GEOMOD=3).
4	`tfin=(15 1.0e-9)`	Body (Fin) thickness.
5	`fpitch=(80 1.0e-9)`	Fin pitch.
6	`nf=1`	Number of fingers.
7	`nfin=1.0`	Number of fins per finger.
8	`ngcon=1`	number of gate contact (1 or 2 sided).
9	`aseo=0`	Source to substrate overlap area through oxide.

10 `adeo=0`	Drain to substrate overlap area through oxide.
11 `pseo=0`	Perimeter of source to substrate overlap region.
12 `pdeo=0`	Perimeter of drain to substrate overlap region.
13 `asej=0`	Source junction area (BULKMOD=1).
14 `adej=0`	Drain junction area (BULKMOD=1).
15 `psej=0`	Source to substrate PN junction perimeter (BULKMOD=1).
16 `pdej=0`	Drain to substrate PN junction perimeter (BULKMOD=1).
17 `cgsp=0.0`	Constant gate-to-source fringe capacitance (CGEOMOD=1).
18 `cgdp=0.0`	Constant gate-to-drain fringe capacitance (CGEOMOD=1).
19 `cdsp=0.0`	Constant drain-to-source fringe capacitance (All CGEOMOD).
20 `nrs=0.0`	Number of source diffusion squares.
21 `nrd=0.0`	Number of drain diffusion squares.
22 `lrsd=(30 1.0e-9)`	Length of the source/drain.
23 `rsc=0.0`	Source contact resistance.
24 `rdc=0.0`	Drain contact resistance.
25 `dtemp=0`	Variability in Device Temperature.
26 `trise=0`	Variability in Device Temperature.
27 `delvtrand=0`	Variability in Vth.
28 `u0mult=1`	Variability in carrier mobility.
29 `ids0mult=1`	Variability in Drain current for misc. reasons.
30 `isnoisy=1`	Should device generate noise.

Model Definition

model modelName bsimcmg parameter=value ...

Model Parameters

1 `version=105.03` The available versions are 105.01, 105.02, 105.03, 105.031, 105.04, 106.0, 106.1 and 107.0..

2 `binunit=1` Bin parameter unit selector. 1 for microns and 2 for meters.

3 `l=(30 1.0e-9)` Designed Gate Length.

4 `d=(40 1.0e-9)` Diameter of the cylinder (GEOMOD=3).

5 `tfin=(15 1.0e-9)` Body (Fin) thickness.

6 `fpitch=(80 1.0e-9)`
Fin pitch.

7 `nfin=1` Number of fins per finger.

8 `ngcon=1` number of gate contact (1 or 2 sided).

9 `aseo=0` Source to substrate overlap area through oxide.

10 `adeo=0` Drain to substrate overlap area through oxide.

11 `pseo=0` Perimeter of source to substrate overlap region.

12 `pdeo=0` Perimeter of drain to substrate overlap region.

13 `asej=0` Source junction area (BULKMOD=1).

14 `adej=0` Drain junction area (BULKMOD=1).

15 `psej=0` Source to substrate PN junction perimeter (BULKMOD=1).

16 `pdej=0` Drain to substrate PN junction perimeter (BULKMOD=1).

17 `cgsp=0.0` Constant gate-to-source fringe capacitance (CGEOMOD=1).

18 `cgdp=0.0` Constant gate-to-drain fringe capacitance (CGEOMOD=1).

19 `cdsp=0.0`	Constant drain-to-source fringe capacitance (CGEOMOD=1).
20 `nrs=0.0`	Number of source diffusion squares.
21 `nrd=0.0`	Number of source diffusion squares.
22 `lrsd=(30 1.0e-9)`	Length of the source/drain.
23 `delvtrand=0`	Variability in Vth.
24 `u0mult=1`	Variability in carrier mobility.
25 `ids0mult=1`	Variability in Drain current for misc. reasons.
26 `xl=0`	L offset for channel length due to mask/etch effect.
27 `type=n`	Device doping type. p|0: ptype, n|1: ntype. Possible values are `p` and `n`.
28 `devtype=n`	Device doping type(the same usage as type). p|0: ptype, n|1: ntype. Possible values are `p` and `n`.
29 `bulkmod=0`	0: SOI multi-gate, 1: Bulk multi-gate.
30 `coremod=0`	0: Default surface potential algorithm, 1: Simplified (efficient) surface potential algorithm.
31 `geomod=1`	structure selector. 0: Double gate, 1: Triple gate, 2: Quadruple gate, 3: Cylindrical gate.
32 `mobmod=0`	0: BSIM4-based mobility model, 1: PSP-based mobility model.
33 `rdsmod=0`	Internal s/d resistance model, 1: External s/d resistance model.
34 `asymmod=0`	0: Asymmetry Model turned off - forward mode parameters used, 1: Asymmetry Model turned on.
35 `igcmod=0`	0: Turn off Igc, Igs and Igd, 1: Turn on Igc, Igs and Igd.
36 `igbmod=0`	0: Turn off Igb, 1: Turn on Igb.
37 `gidlmod=0`	0: Turn off GIDL/GISL current, 1: Turn on GIDL/GISL current.

38 `iimod=0`	0: No impact ionization current, 1: BSIM4-based model, 2: BSIMSOI-based model.
39 `nqsmod=0`	0: NQS models turned off, 1: NQS gate resistance / gi node turned on, 2: NQS charge deficit model (BSIM4) / q node turned on, 3: //NQS charge segmentation model / Nseg nodes turned on.
40 `shmod=0`	0: No self-heating, 1: Self-heating turned on.
41 `rgatemod=0`	0: Gate electrode resistance / ge node turned off, 1: Gate electrode resistance / ge node turned on.
42 `rgeomod=0`	Geometry-dependent source/drain resistance. 0: RSH-based, 1: Holistic.
43 `cgeomod=0`	Geometry dependent parasitic capacitance,model selector.
44 `capmod=0`	0: No accumulation capacitance, 1: Accumulation capacitance included. Available only for BULKMOD = 1.
45 `lint=0`	Length reduction parameter (dopant diffusion effect).
46 `ll=0`	Length reduction parameter (dopant diffusion effect).
47 `lln=1`	Length reduction parameter (dopant diffusion effect).
48 `dlc=0`	Delta L for C-V model.
49 `dlcacc=0`	Delta L for C-V model in accumulation region (CAPMOD=1, BULKMOD=1).
50 `dlbin=0`	Delta L for Binning.
51 `llc=0`	Length reduction parameter (dopant diffusion effect).
52 `eot=(1.0 1.0e-9)`	equivalent oxide thickness in meters.
53 `toxp=(1.2 1.0e-9)`	physical oxide thickness in meter.

54 `eotbox=(140 1.0e-9)`
equivalent oxide thickness of the buried oxide (SOI FinFET) or STI (bulk FinFET) in meters.

55 `hfin=(30 1.0e-9)` Fin height in meters.

56 `fech=1` End-channel factor, for different orientation/shape.

57 `deltaw=0` Change of effective width due to shape of fin/cylinder.

58 `fechcv=1` CV end-channel factor, for different orientaion/shape.

59 `deltawcv=0` CV change of effective width due to shape of fin/cylinder.

60 `nbody=1e22` channel (body) doping.

61 `nsd=2e26` Source/drain active doping concentration in m-3.

62 `phig=4.61` Gate workfunction, eV.

63 `epsrox=3.9` Relative dielectric constant of the gate dielectric.

64 `epsrsub=11.9` Relative dielectric constant of the channel material.

65 `easub=4.05` Electron affinity of substrate, eV.

66 `ni0sub=1.1e16` Intrinsic carrier constant at 300.15K, m-3.

67 `bg0sub=1.12` Band gap of substrate at 300.15K, eV.

68 `nc0sub=2.86e25` Conduction band density of states, m-3.

69 `ngate=0.0` Parameter for Poly Gate Doping. For metal gate please set NGATE = 0.

70 `cit=0.0` parameter for interface trap.

71 `cdsc=7e-3` coupling capacitance between S/D and channel.

72 `cdscd=7e-3` drain-bias sensitivity of CDS.

73 `cdscdr=7e-3` Reverse-mode drain-bais sensitivity of CDSC (Experimental).

74 `dvt0=0.0` SCE exponent coefficient, after binning should be in (0:inf).

75 `dvt1=0.60` SCE exponent coefficient.

76 `phin=0.05` Nonuniform vertical doping effect on surface potential, V.

77 `eta0=0.60` DIBL coefficient.

78 `eta0r=0.60` Reverse-mode DIBL coefficient (Experimental).

79 `dsub=1.06` DIBL exponent coefficient.

80 `k1rsce=0.0` K1 for reverse short channel effect calculation.

81 `lpe0=(5.0 1.0e-9)`
Equivalent length of pocket region at zero bias.

82 `dvtshift=0` Vth shift handle.

83 `k0=0.0` Lateral NUD voltage parameter, V.

84 `k0si=1.0` Correction factor for strong inversion, used in Mnud, after binnig should be from (0:inf).

85 `phibe=0.7` Body effect voltage parameter, V, after binnig should be from [0.2:1.2].

86 `k1=0.0` Body effect coefficient for sub-threshold region.

87 `k1si=1.0` Correction factor for strong inversion, used in Mob.

88 `k1sat=0.0` Correction factor for K1 in saturation (high Vds).

89 `dvtb=0.60` Body effect roll-off coefficient.

90 `lpeb=0.0` Lateral non-uniform doping effect on K1.

91 `qmfactor=0.0` Prefactor + switch for QM Vth correction.

92 `qmtceniv=0.0` Prefactor + switch for QM Width correction for IV.

93 `qmtcencv=0.0` Prefactor + switch for QM Width and Toxeff correction for CV.

94 `qmtcencva=0.0`	Prefactor + switch for QM Width and Toxeff correction for CV (accumulation region).
95 `aqmtcen=0.0`	Parameter for Geometric dependence of Tcen on R/TFIN/HFIN.
96 `bqmtcen=12.0e-9`	Parameter for Geometric dependence of Tcen on R/TFIN/HFIN.
97 `etaqm=0.54`	Bulk charge coefficient for Tcen.
98 `qm0=1.00e-3`	Knee-Point for Tcen in inversion(Charge normalized to Cox).
99 `pqm=0.66`	Slope of normalized Tcen in inversion.
100 `qm0acc=1.00e-3`	Knee-Point for Tcen in accumulation (Charge normalized to Cox).
101 `pqmacc=0.66`	Slope of normalized Tcen in accumulation.
102 `alphaqm=0.66`	Slope of normalized Tcen in strong inversion/accumulation.
103 `vsat=85000`	Saturation Velocity m/s.
104 `avsat=0.0`	Length dependence of VSAT.
105 `bvsat=100.0e-9`	Length dependence of VSAT.
106 `vsat1=85000`	Velocity Saturation parameter for I_on degradation - forward mode.
107 `vsat1r=85000`	Velocity Saturation parameter for I_on degradation - reverse mode.
108 `avsat1=0.0`	
109 `bvsat1=100.0e-9`	
110 `deltavsat=1.0`	
111 `psat=2.0`	Velocity saturation exponent for C-V.
112 `apsat=0.0`	
113 `bpsat=1.0`	

114 `ksativ=1.0`	parameter for long channel Vdsat.
115 `vsatcv=85000`	Velocity Saturation parameter for CV.
116 `avsatcv=0.0`	
117 `bvsatcv=100.0e-9`	
118 `mexp=4`	Smoothing function factor for Vdsat.
119 `amexp=0.0`	Length dependence of MEXP.
120 `bmexp=1.0`	Length dependence of MEXP.
121 `ptwg=0.0`	Gmsat degradation parameter - forward mode.
122 `ptwgr=0.0`	Gmsat degradation parameter - reverse mode.
123 `aptwg=0.0`	Length dependence of PTWG.
124 `bptwg=100.0e-9`	Length dependence of PTWG.
125 `thetasat=2.0`	Velocity saturation parameter.
126 `athetasat=0.0`	Length dependence of THETASAT.
127 `bthetasat=100.0e-9`	Length dependence of THETASAT.
128 `u0=0.03`	Shared: low-field mobility (m^2/V-s).
129 `etamob=2.0`	Effective field parameter.
130 `up=0`	Shared: Mobility L coefficient (um^LPA).
131 `lpa=1.0`	Shared: Mobility L power coefficient.
132 `ua=0.3`	MOD0: Mobility reduction coefficient.
133 `aua=0.0`	MOD0: Length dependence of UA.
134 `bua=100.0e-9`	Length dependence of UA.

135 `uc=0.0` Body effect for mobility degradation parameter - BULKMOD=1.

136 `eu=2.5` MOD0: Mobility reduction exponent.

137 `aeu=0.0`

138 `beu=100.0e-9`

139 `ud=0.0` MOD0: Coulomb scattering parameter.

140 `aud=0.0` MOD0: Length dependence of UD.

141 `bud=50.0e-9` Length dependence of UD.

142 `ucs=1.0` MOD0: Coulomb scattering parameter.

143 `mue=1.2` MOD1: Mobility reduction coefficient.

144 `thetamu=1.0` MOD1: Mobility reduction exponent.

145 `athetamu=0.0` MOD1: Length dependence of THETAMU.

146 `bthetamu=100.0e-9`
Length dependence of THETAMU.

147 `cs=0` MOD1: Coulomb scattering parameter.

148 `acs=0.0` MOD1: Length dependence of CS.

149 `bcs=50.0e-9` Length dependence of CS.

150 `pclm=0.013` CLM prefactor.

151 `apclm=0.0` Length dependence of PCLM.

152 `bpclm=100.0e-9` Length dependence of PCLM.

153 `pclmg=0.0` CLM prefactor gate voltage dependence.

154 `vasat=0.2` CLM log dependence parameter.

155 `pclmcv=0.013` CLM parameter for Short Channel CV.

156 `pclmgcv=0.0` CLM prefactor gate voltage dependence.

157 `vasatcv=0.2` CLM log dependence parameter.

158 `a1=0.0` Non-saturation effect parameter for strong inversion region.

159 `a2=0.0` Non-saturation effect parameter for moderate inversion region.

160 `rdswmin=0.0` S/D extension resistance per unit width at high Vgs, ohm(um)^WR.

161 `rdsw=100.0` zero bias S/D extension resistance per unit width, ohm(um)^WR.

162 `ardsw=0.0` Geometrical scaling of RDSW.

163 `brdsw=100.0e-9` Geometrical scaling of RDSW.

164 `rswmin=0.0` Source Resistance for RDSMOD=1.

165 `rsw=50.0` zero bias Source Resistance for RDSMOD=1.

166 `arsw=0.0` Geometrical scaling of RSW.

167 `brsw=100.0e-9` Geometrical scaling of RSW.

168 `rdwmin=0.0` Drain Resistance for RDSMOD=1.

169 `rdw=50.0` zero bias Drain Resistance for RDSMOD=1.

170 `ardw=0.0` Geometrical scaling of RDW.

171 `brdw=100.0e-9` Geometrical scaling of RDW.

172 `prwg=0` gate bias dependence of S/D extension resistance, V-1.

173 `rsdr=0.0` Source side drift resistance parameter - forward mode.

174 `rsdrr=0.0` Source side drift resistance parameter - reverse mode.

175 `rddr=0.0` Drain side drift resistance parameter - forward mode.

176 `rddrr=0.0` Drain side drift resistance parameter - reverse mode.

177 `prsdr=1.0` Source side quasi-saturation parameter.

178 `prddr=1.0` Drain side quasi-saturation parameter.

179 `prwgs=0.0` Gate bias dependence of source extension resistance, Units:V^-1.

180 `prwgd=0.0` Gate bias dependence of drain extension resistance, Units:V^-1.

181 `wr=1.0` W dependence parameter of S/D extension resistance.

182 `trsdr=0.0`

183 `trddr=0.0`

184 `rgext=0.0` Effective gate electrode external resistance.

185 `rgfin=1.0e-3` Effective gate electrode per finger per fin resistance.

186 `rshs=0.0` Source-side sheet resistance.

187 `rshd=0.0` Drain-side sheet resistance.

188 `hepi=(10.0 1.0e-9)`
Height of the raised source/drain on top of the fin.

189 `tsili=(10.0 1.0e-9)`
Thickness of the silicide on top of the raised source/drain.

190 `rhoc=1.0e-12` Contact resistivity at the silicon/silicide interface.

191 `rhorsd=1.0` Average resistivity of silicon in the raised source/drain region.

192 `rhoext=1.0` Average resistivity of silicon in the fin extension region.

193 `cratio=0.5` Ratio of the corner area filled with silicon to the total corner area.

194 `deltaprsd=0.0` Change in silicon/silicide interface length due to non-rectangular epi.

195 `sdterm=0` Indicator fo whether the source/drain are terminated with silicide.

196 `lsp=(6 1.0e-9)` Thickness of the gate sidewall spacer.

197 `ldg=5.0e-9` Lateral diffusion gradient in the fin extension region.

198 `epsrsp=3.9` Relative dielectric constant of the spacer.

199 `tgate=(30.0 1.0e-9)`
Gate height on top of the hard mask.

200 `tmask=(30.0 1.0e-9)`
Height of hard mask on top of the fin.

201 `asiliend=0.0` Extra silicide cross sectional area at the two ends of the FinFET.

202 `arsdend=0.0` Extra raised source/drain cross sectional area at the two ends of the FiinFET.

203 `prsdend=0.0` Extra silicon/silicide interface perimeter at the two ends of the FinFET.

204 `nsde=2e25` Source/drain active doping concentration at Leff edge.

205 `rgeoa=1.0` Fitting parameter for RGEOMOD=1.

206 `rgeob=0.0` Fitting parameter for RGEOMOD=1.

207 `rgeoc=0.0` Fitting parameter for RGEOMOD=1.

208 `rgeod=0.0` Fitting parameter for RGEOMOD=1.

209 `rgeoe=0.0` Fitting parameter for RGEOMOD=1.

210 `cgeoa=1.0` Fitting parameter for CGEOMOD=2.

211 `cgeob=0.0` Fitting parameter for CGEOMOD=2.

212 `cgeoc=0.0` Fitting parameter for CGEOMOD=2.

213 `cgeod=0.0` Fitting parameter for CGEOMOD=2.

214 `cgeoe=1.0` Fitting parameter for CGEOMOD=2.

215 `pdibl1=1.30` DIBL Output Conductance parameter - forward mode.

216 `pdibl1r=1.30` DIBL Output Conductance parameter - reverse mode.

217 `pdibl2=2.0e-4` DIBL Output Conductance parameter.

218 `drout=1.06` L dependence of DIBL effect on Rout.

219 `pvag=1.0` Vg dependence on early voltage.

220 `aigbinv=1.11e-2` parameter for Igb in inversion.

221 `bigbinv=9.49e-4` parameter for Igb in inversion.

222 `cigbinv=6.00e-3` parameter for Igb in inversion.

223 `eigbinv=1.1` parameter for Igb in inversion.

224 `nigbinv=3.0` parameter for Igb in inversion.

225 `aigbacc=1.36e-2` parameter for Igb in accumulation.

226 `bigbacc=1.71e-3` parameter for Igb in accumulation.

227 `cigbacc=7.5e-2` parameter for Igb in accumulation.

228 `nigbacc=1.0` parameter for Igb in accumulation.

229 `aigc=1.36e-2` parameter for Igc in inversion.

230 `bigc=1.71e-3` parameter for Igc in inversion.

231 `cigc=0.075` parameter for Igc in inversion.

232 `nigc=1.0` parameter for Igc in inversion.

233 `pigcd=1.0` parameter for Igc partition.

234 `dlcigs=0` Delta L for Igs model.

235 `aigs=1.36e-2` parameter for Igs in inversion.

236 `bigs=1.71e-3` parameter for Igs in inversion.

237 `cigs=0.075` parameter for Igs in inversion.

238 `dlcigd=0` Delta L for Igd model.

239 `aigd=1.36e-2` parameter for Igd in inversion.

240 `bigd=1.71e-3` parameter for Igd in inversion.

241 `cigd=0.075` parameter for Igd in inversion.

242 `toxref=(1.2 1.0e-9)`
Target tox value [m].

243 `ntox=1.0` Exponent for Tox ratio.

244 `poxedge=1.0` Factor for the gate edge Tox.

245 `agisl=(6.055 1.0e-12)`
pre-exponential coeff. for GISL in mho.

246 `bgisl=0.3e9` exponential coeff. for GISL in V/m.

247 `cgisl=0.5` parameter for body-effect of GISL in V^3.

248 `egisl=0.2` band bending parameter for GISL in V.

249 `pgisl=1.0` parameter for body-bias effect on GISL.

250 `agidl=(6.055 1.0e-12)`
pre-exponential coeff. for GIDL in mho.

251 `bgidl=0.3e9` exponential coeff. for GIDL in V/m.

252 `cgidl=0.5` parameter for body-effect of GIDL in V^3.

253 `egidl=0.2` band bending parameter for GIDL in V.

254 `pgidl=1.0` parameter for body-bias effect on GIDL.

255 `alpha0=0.0` first parameter of Iii, m/V.

256 `alpha1=0.0` L scaling parameter of Iii, 1/V.

257 `beta0=0.0` Vds dependent parameter of Iii, 1/V.

258 `alphaii=0.0` Pre-exponential Constant of Iii.

259 `betaii0=0.0` Vds dependent parameter of Iii, 1/V.

260 `betaii1=0.0` Vds dependent parameter of Iii.

261 `betaii2=0.1` Vds dependent parameter of Iii, V.

262 `esatii=1.0e7` Saturation channel E-Field for Iii, V/m.

263 `lii=0.5E-9` Channel length dependent parameter of Iii, V-m.

264 `sii0=0.5` Vgs dependent parameter of Iii, 1/V.

265 `sii1=0.1` 1st Vgs dependent parameter of Iii, 1/V.

266 `sii2=0.0` 2nd Vgs dependent parameter of Iii.

267 `siid=0.0` 3rd Vds dependent parameter of Iii, 1/V.

268 `eotacc=(1.0 1.0e-9)`
equivalent oxide thickness for accumulation region in meters.

269 `delvfbacc=0.0` Change in Flatband Voltage; Vfb_accumulation-Vfb_inversion.

270 `cfs=2.5e-11` Outer Fringe Cap (source side).

271 `cfd=2.5e-11` Outer Fringe Cap (drain side).

272 `covs=2.5e-11` Constant g/s overlap capacitance.

273 `covd=2.5e-11` Constant g/d overlap capacitance.

274 `cgso=0.0` Non LDD region source-gate overlap capacitance per unit channel width.

275 `cgdo=0.0` Non LDD region drain-gate overlap capacitance per unit channel width.

276 `cgsl=0.0` Overlap capacitance between gate and lightly-doped source region(for GEOMOD = 0, 2).

277 `cgdl=0.0` Overlap capacitance between gate and lightly-doped drain region(for GEOMOD = 0, 2).

278 `ckappas=0.6`	Coefficient of bias-dependent overlap capacitance for the source side(for CGEOMOD = 0, 2).
279 `ckappad=0.6`	Coefficient of bias-dependent overlap capacitance for the drain side(for CGEOMOD = 0, 2).
280 `cgbo=0.0`	Gate to substrate overlap cap per unit channel length per finger per NGCON.
281 `cgbn=0.0`	Gate to substrate overlap cap per unit channel length per fin per finger.
282 `cgbl=0.0`	Bias dependent component of Gate to substrate overlap cap per unit channel length per fin per finger.
283 `ckappab=0.6`	Coefficient for gate to substrate bias-dependent overlap capacitance(for BULKMOD = 1).
284 `csdesw=0.0`	Coefficient for source/drain to substrate sidewall cap.
285 `cjs=5.0e-4`	Unit area source-side junction capacitance at zero bias.
286 `cjd=5.0e-4`	Unit area drain-side junction capacitance at zero bias.
287 `cjsws=5.0e-10`	Unit length source-side sidewall junction capacitance at zero bias.
288 `cjswd=5.0e-10`	Unit length drain-side sidewall junction capacitance at zero bias.
289 `cjswgs=0.0`	Unit length source-side gate sidewall junction capacitance at zero bias.
290 `cjswgd=0.0`	Unit length drain-side gate sidewall junction capacitance at zero bias.
291 `pbs=1.0`	Source-side bulk junction built-in potential.
292 `pbd=1.0`	Drain-side bulk junction built-in potential.
293 `pbsws=1.0`	Built-in potential for Source-side sidewall junction capacitance.
294 `pbswd=1.0`	Built-in potential for Drain-side sidewall junction capacitance.

295 `pbswgs=1.0`	Built-in potential for Source-side gate sidewall junction capacitance.
296 `pbswgd=1.0`	Built-in potential for Drain-side gate sidewall junction capacitance.
297 `mjs=0.5`	Source bottom junction capacitance grading coefficient.
298 `mjd=0.5`	Drain bottom junction capacitance grading coefficient.
299 `mjsws=0.33`	Source sidewall junction capacitance grading coefficient.
300 `mjswd=0.33`	Drain sidewall junction capacitance grading coefficient.
301 `mjswgs=0.33`	Source-side gate sidewall junction capacitance grading coefficient.
302 `mjswgd=0.33`	Drain-side gate sidewall junction capacitance grading coefficient.
303 `sjs=0.0`	Constant for source-side two-step second junction capacitance.
304 `sjd=0.0`	Constant for drain-side two-step second junction capacitance.
305 `sjsws=0.0`	Constant for sidewall two-step second junction capacitance(source-side).
306 `sjswd=0.0`	Constant for sidewall two-step second junction capacitance(drain-side).
307 `sjswgs=0.0`	Constant for gate sidewall two-step second junction capacitance(source-side).
308 `sjswgd=0.0`	Constant for gate sidewall two-step second junction capacitance(drain-side).
309 `mjs2=0.125`	Source bottom two-step second junction capacitance grading coefficient.
310 `mjd2=0.125`	Drain bottom two-step second junction capacitance grading coefficient.
311 `mjsws2=0.083`	Isolation-edge sidewall two-step second junction capacitance grading coefficient(source-side).

312 `mjswd2=0.083`	Isolation-edge sidewall two-step second junction capacitance grading coefficient(drain-side).
313 `mjswgs2=0.083`	Gate-edge sidewall two-step second junction capacitance grading coefficient(source-side).
314 `mjswgd2=0.083`	Gate-edge sidewall two-step second junction capacitance grading coefficient(drain-side).
315 `jss=1.0e-4`	Bottom source junction reverse saturation current density.
316 `jsd=1.0e-4`	Bottom drain junction reverse saturation current density.
317 `jsws=0.0`	Unit length reverse saturation current for sidewall source junction.
318 `jswd=0.0`	Unit length reverse saturation current for sidewall drain junction.
319 `jswgs=0.0`	Unit length reverse saturation current for gate-edge sidewall source junction.
320 `jswgd=0.0`	Unit length reverse saturation current for gate-edge sidewall drain junction.
321 `njs=1.0`	Source junction emission coefficient.
322 `njd=1.0`	Drain junction emission coefficient.
323 `ijthsfwd=0.1`	Forward source diode breakdown limiting current.
324 `ijthdfwd=0.1`	Forward drain diode breakdown limiting current.
325 `ijthsrev=0.1`	Reverse source diode breakdown limiting current.
326 `ijthdrev=0.1`	Reverse drain diode breakdown limiting current.
327 `bvs=10.0`	Source diode breakdown voltage.
328 `bvd=10.0`	Drain diode breakdown voltage.
329 `xjbvs=1.0`	Fitting parameter for source diode breakdown current.
330 `xjbvd=1.0`	Fitting parameter for drain diode breakdown current.

331 `jtss=0.0` Bottom source junction trap-assisted saturation current density.

332 `jtsd=0.0` Bottom drain junction trap-assisted saturation current density.

333 `jtssws=0.0` Unit length trap-assisted saturation current for isolation-edge source side-wall junction.

334 `jtsswd=0.0` Unit length trap-assisted saturation current for isolation-edge drain side-wall junction.

335 `jtsswgs=0.0` Unit length trap-assisted saturation current for gate-edge source sidewall junction.

336 `jtsswgd=0.0` Unit length trap-assisted saturation current for gate-edge drain sidewall junction.

337 `jtweff=0.0` Trap-assisted tunneling current width dependence.

338 `njts=20.0` Non-ideality factor for JTSS.

339 `njtsd=20.0` Non-ideality factor for JTSD.

340 `njtssw=20.0` Non-ideality factor for JTSSWS.

341 `njtsswd=20.0` Non-ideality factor for JTSSWD.

342 `njtsswg=20.0` Non-ideality factor for JTSSWGS.

343 `njtsswgd=20.0` Non-ideality factor for JTSSWGD.

344 `vtss=10.0` Botttom source junction trap-assisted current voltage dependent parameter.

345 `vtsd=10.0` Botttom drain junction trap-assisted current voltage dependent parameter.

346 `vtssws=10.0` Unit length trap-assisted current voltage dependent parameter for isolation-edge source sidewall junction.

347 `vtsswd=10.0` Unit length trap-assisted current voltage dependent parameter for isolation-edge drain sidewall junction.

348 `vtsswgs=10.0`	Unit length trap-assisted current voltage dependent parameter for gate-edge source sidewll junction.
349 `vtsswgd=10.0`	Unit length trap-assisted current voltage dependent parameter for gate-edge drain sidewll junction.
350 `lintigen=0`	Lint for Thermal Generation Current.
351 `ntgen=1.0`	Thermal Generation Current Parameter.
352 `aigen=0`	Thermal Generation Current Parameter.
353 `bigen=0`	Thermal Generation Current Parameter.
354 `xrcrg1=12.0`	Parameter for non quasi-static gate resistance NQSMOD = 1 and NQSMOD = 2.
355 `xrcrg2=1.0`	Parameter for non quasi-static gate resistance NQSMOD = 1 and NQSMOD = 2.
356 `nseg=4`	Number of segments for NQSMOD=3 (3,5 & 10 supported).
357 `ef=1.0`	Flicker Noise frequency exponent.
358 `em=4.1e7`	Flicker noise parameter.
359 `noia=6.250e+39`	Flicker noise parameter.
360 `noib=3.125e+24`	Flicker noise parameter.
361 `noic=8.750e+07`	Flicker noise parameter.
362 `ntnoi=1.0`	Thermal noise parameter.
363 `tnom=27.0`	Temperature at which the model is extracted (Kelvin).
364 `tbgasub=7.02e-4`	Bandgap Temperature Coefficient(eV / degrees).
365 `tbgbsub=1108.0`	Bandgap Temperature Coefficient(degrees).
366 `kt1=0.0`	Vth Temperature Coefficient (V).
367 `kt1l=0.0`	Vth Temperature L Coefficient (m-V).

368 `tss=0.0` SSwing Temperature Coefficient (/ degrees).

369 `ute=0.0` Mobility Temperature Coefficient.

370 `utl=(-1.5e-3)` Mobility Temperature Coefficient.

371 `emobt=0.0`

372 `ua1=1.032e-3` Mobility Temperature Coefficient.

373 `uc1=0.056e-9`

374 `ud1=0.0` Mobility Temperature Coefficient.

375 `ucste=(-4.775e-3)`
Mobility Temperature Coefficient.

376 `stthetamu=1.5` Mobility Temperature Coefficient.

377 `stmue=0.0` Mobility Temperature Coefficient.

378 `stcs=0.0` Mobility Temperature Coefficient.

379 `at=(-1.56e-3)` Saturation Velocity Temperature Coefficient.

380 `tmexp=0.0` Temperature coefficient for Vdseff.

381 `ptwgt=0.004` Temperature dependence of PTWG.

382 `stthetasat=0.0217`
Saturation Velocity Temperature Coefficient.

383 `prt=0.001` Series Resistance Temperature Coefficient.

384 `iit=(-0.5)` Impact Ionization Temperature Dependence, IIMOD=1.

385 `tii=0.0` Impact Ionization Temperature Dependence, IIMOD=2.

386 `tgidl=(-0.003)` GIDL/GISL Temperature Dependence.

387 `igt=2.5` Gate Current Temperature Dependence.

388 `tcj=0.0` Temperature coefficient for CJS/CJD.

389 `tcjsw=0.0`	Temperature coefficient for CJSWS/CJSWD.
390 `tcjswg=0.0`	Temperature coefficient for CJSWGS/CJSWGD.
391 `tpb=0.0`	Temperature coefficient for PBS/PBD.
392 `tpbsw=0.0`	Temperature coefficient for PBSWS/PBSW.
393 `tpbswg=0.0`	Temperature coefficient for PBSWGS/PBSWGD.
394 `xtis=3.0`	Source junction current temperature exponent.
395 `xtid=3.0`	Drain junction current temperature exponent.
396 `xtss=0.02`	Power dependence of JTSS on temperature.
397 `xtsd=0.02`	Power dependence of JTSD on temperature.
398 `xtssws=0.02`	Power dependence of JTSSWS on temperature.
399 `xtsswd=0.02`	Power dependence of JTSSWG on temperature.
400 `xtsswgs=0.02`	Power dependence of JTSSWGS on temperature.
401 `xtsswgd=0.02`	Power dependence of JTSSWGD on temperature.
402 `tnjts=0.0`	Temperature coefficient for NJTS.
403 `tnjtsd=0.0`	Temperature coefficient for NJTSD.
404 `tnjtssw=0.0`	Temperature coefficient for NJTSSW.
405 `tnjtsswd=0.0`	Temperature coefficient for NJTSSWD.
406 `tnjtsswg=0.0`	Temperature coefficient for NJTSSWG.
407 `tnjtsswgd=0.0`	Temperature coefficient for NJTSSWGD.
408 `rth0=0.01`	Thermal resistance for self-heating calculation.
409 `cth0=1.0E-05`	Thermal capacitance for self-heating calculation.
410 `wth0=0.0`	Width-dependence coefficient for self-heating calculation.

411 `toxg=(1.2 1.0e-9)`
oxide thickness for gate current model in meters.

412 `k01=0.0` Temperature dependence of lateral NUD voltage parameter, V.

413 `k0si1=0.0` Temperature dependence of K0SI, 1/K.

414 `k1si1=0.0` Temperature dependence of K1SI, 1/K.

415 `k11=0.0` Temperature dependence of K1.

416 `k1sat1=0.0` Temperature dependence of K1SAT1.

417 `rcvfac=1.0` Series resistance correction factor for CV.

418 `a11=0.0` Temperature dependence of A1.

419 `a21=0.0` Temperature dependence of A2.

420 `aigbinv1=0` parameter for Igb in inversion.

421 `aigbacc1=0` parameter for Igb in accumulation.

422 `aigc1=0` parameter for Igc in inversion.

423 `aigs1=0` parameter for Igs in inversion.

424 `aigd1=0` parameter for Igd in inversion.

425 `alpha01=0.0` Temperature dependence of ALPHA0, m/V/degrees.

426 `alpha11=0.0` Temperature dependence ALPHA1, 1/V/degree.

427 `alphaii0=0.0` first parameter of Iii for IIMOD=2, m/V.

428 `alphaii01=0.0` Temperature dependence of ALPHAII0, m/V/degrees.

429 `alphaii1=0.0` L scaling parameter of Iii for IIMOD=2, 1/V.

430 `alphaii11=0.0` Temperature dependence of ALPHAII1, 1/V/degrees.

431 `imin=1.0E-15` Parameter for Vgs Clamping for inversion region calc. in accumulation.

432 `deltavsatcv=1.0`	
433 `psatcv=2.0`	Velocity saturation exponent for C-V.
434 `apsatcv=0.0`	
435 `bpsatcv=1.0`	
436 `cgeo1sw=0`	For CGEOMOD=1 only, this switch enables the parameters COVS, COVD, CGSP,and CGDP to be in F per fin, per gate-finger, per unit channel width.
437 `nbodyn1=0`	NFIN dependence of channel (body) doping.
438 `nbodyn2=1.0e5`	NFIN dependence of channel (body) doping.
439 `phigl=0`	Length dependence of Gate workfunction, eV/m.
440 `phign1=0`	NFIN dependence of Gate workfunction.
441 `phign2=1.0e5`	NFIN dependence of Gate workfunction.
442 `cdscn1=0`	NFIN dependence of CDSC.
443 `cdscn2=1.0e5`	NFIN dependence of CDSC.
444 `cdscdn1=0`	NFIN dependence of CDSCD.
445 `cdscdn2=1.0e5`	NFIN dependence of CDSCD.
446 `cdscdrn1=0`	NFIN dependence of CDSCD.
447 `cdscdrn2=1.0e-5`	NFIN dependence of CDSCD.
448 `dvt1ss=0.60`	Subthreshold Swing exponent coefficient, after binning should be in (0:inf).
449 `eta0n1=0`	NFIN dependence of ETA0.
450 `eta0n2=1.0e5`	NFIN dependence of ETA0.
451 `teta0=0.0`	Temperature dependence of DIBL coefficient, 1/K.

452 `teta0r=0.0` Temperature dependence of Reverse-mode DIBL coefficient, 1/K.

453 `dvtp0=0` Coefficient for Drain-Induced Vth Shift (DITS).

454 `dvtp1=0` DITS exponent coefficient.

455 `vsatn1=0` NFIN dependence of VSAT.

456 `vsatn2=1.0e5` NFIN dependence of VSAT.

457 `vsat1n1=0` NFIN dependence of VSAT1.

458 `vsat1n2=1.0e-5` NFIN dependence of VSAT1.

459 `vsat1rn1=0` NFIN dependence of VSAT1R.

460 `vsat1rn2=1.0e-5` NFIN dependence of VSAT1R.

461 `mexpr=4`

462 `amexpr=0.0`

463 `bmexpr=1.0`

464 `tmexpr=0.0`

465 `u0n1=0` NFIN dependence of U0.

466 `u0n2=1.0e5` NFIN dependence of U0.

467 `chargewf=0` Average Channel Charge Weighting Factor, +1:source-side, 0:middle, -1:drain-side.

468 `minr=0.001` Ω

469 `compatible=spectre`
compatible parameters.
Possible values are `spectre`, `spice2`, `spice3`, `cdsspice`, `hspice`, `spiceplus`, `eldo`, `sspice`, and `mica`.

470 `vthmod=0` Vth output selector. 'std' outputs model equation Vth. 'vthcc' outputs constant current Vth, and may impact simulation

	performance. The default value is taken from the options parameter 'vthmod'. Possible values are `std` and `vthcc`.
471 `ivth=0.0`	Vth current parameter. The default value is taken from the options parameter 'ivthn' or 'ivthp', depending on the type of the model.
472 `ivthw=0.0`	Width offset for constant current Vth. The default value is taken from the options parameter 'ivthw'.
473 `ivthl=0.0`	Length offset for constant current Vth. The default value is taken from the options parameter 'ivthl'.
474 `ivth_vdsmin=0.05`	Minimum Vds in constant current Vth calculating. The default value is taken from the options parameter 'ivth_vdsmin'.
475 `ffnoiflag=0`	
476 `lnbody=0`	Length dependence of nbody.
477 `nnbody=0`	NFIN dependence of nbody.
478 `pnbody=0`	Cross-term dependence of nbody.
479 `lphig=0`	Length dependence of phig.
480 `nphig=0`	NFIN dependence of phig.
481 `pphig=0`	Cross-term dependence of phig.
482 `lngate=0`	Length dependence of ngate.
483 `nngate=0`	NFIN dependence of ngate.
484 `pngate=0`	Cross-term dependence of ngate.
485 `lcit=0`	Length dependence of cit.
486 `ncit=0`	NFIN dependence of cit.
487 `pcit=0`	Cross-term dependence of cit.

488 `lcdsc=0`	Length dependence of cdsc.
489 `ncdsc=0`	NFIN dependence of cdsc.
490 `pcdsc=0`	Cross-term dependence of cdsc.
491 `lcdscd=0`	Length dependence of cdscd.
492 `ncdscd=0`	NFIN dependence of cdscd.
493 `pcdscd=0`	Cross-term dependence of cdscd.
494 `lcdscdr=0`	Length dependence of cdscdr.
495 `ncdscdr=0`	NFIN dependence of cdscdr.
496 `pcdscdr=0`	Cross-term dependence of cdscdr.
497 `ldvt0=0`	Length dependence of dvt0.
498 `ndvt0=0`	NFIN dependence of dvt0.
499 `pdvt0=0`	Cross-term dependence of dvt0.
500 `ldvt1=0`	Length dependence of dvt1.
501 `ndvt1=0`	NFIN dependence of dvt1.
502 `pdvt1=0`	Cross-term dependence of dvt1.
503 `ldvt1ss=0`	Length dependence of dvt1ss.
504 `ndvt1ss=0`	NFIN dependence of dvt1ss.
505 `pdvt1ss=0`	Cross-term dependence of dvt1ss.
506 `lphin=0`	Length dependence of phin.
507 `nphin=0`	NFIN dependence of phin.
508 `pphin=0`	Cross-term dependence of phin.
509 `leta0=0`	Length dependence of eta0.

510 `neta0=0`	NFIN dependence of eta0.
511 `peta0=0`	Cross-term dependence of eta0.
512 `leta0r=0`	Length dependence of eta0r.
513 `neta0r=0`	NFIN dependence of eta0r.
514 `peta0r=0`	Cross-term dependence of eta0r.
515 `ldsub=0`	Length dependence of dsub.
516 `ndsub=0`	NFIN dependence of dsub.
517 `pdsub=0`	Cross-term dependence of dsub.
518 `lk1rsce=0`	Length dependence of lk1rsce.
519 `nk1rsce=0`	NFIN dependence of lk1rsce.
520 `pk1rsce=0`	Cross-term dependence of lk1rsce.
521 `llpe0=0`	Length dependence of lpe0.
522 `nlpe0=0`	NFIN dependence of lpe0.
523 `plpe0=0`	Cross-term dependence of lpe0.
524 `ldvtshift=0`	Length dependence of dvtshift.
525 `ndvtshift=0`	NFIN dependence of dvtshift.
526 `pdvtshift=0`	Cross-term dependence of dvtshift.
527 `lphibe=0`	Length dependence of phibe.
528 `nphibe=0`	NFIN dependence of phibe.
529 `pphibe=0`	Cross-term dependence of phibe.
530 `lk0=0`	Length dependence of k0.
531 `nk0=0`	NFIN dependence of k0.

532 `pk0=0`	Cross-term dependence of k0.
533 `lk0si=0`	Length dependence of k0si.
534 `nk0si=0`	NFIN dependence of k0si.
535 `pk0si=0`	Cross-term dependence of k0si.
536 `lk1=0`	Length dependence of k1.
537 `nk1=0`	NFIN dependence of k1.
538 `pk1=0`	Cross-term dependence of k1.
539 `lk1si=0`	Length dependence of k1si.
540 `nk1si=0`	NFIN dependence of k1si.
541 `pk1si=0`	Cross-term dependence of k1si.
542 `lk1sat=0`	Length dependence of k1sat.
543 `nk1sat=0`	NFIN dependence of k1sat.
544 `pk1sat=0`	Cross-term dependence of k1sat.
545 `ldvtb=0`	Length dependence of dvtb.
546 `ndvtb=0`	NFIN dependence of dvtb.
547 `pdvtb=0`	Cross-term dependence of dvtb.
548 `llpeb=0`	Length dependence of lpeb.
549 `nlpeb=0`	NFIN dependence of lpeb.
550 `plpeb=0`	Cross-term dependence of lpeb.
551 `lqmfactor=0.0`	Length dependence of qmfactor.
552 `nqmfactor=0.0`	NFIN dependence of qmfactor.
553 `pqmfactor=0.0`	Cross-term dependence of qmfactor.

554 `lqmtceniv=0.0` Length dependence of qmtceniv.

555 `nqmtceniv=0.0` NFIN dependence of qmtceniv.

556 `pqmtceniv=0.0` Cross-term dependence of qmtceniv.

557 `lqmtcencv=0.0` Length dependence of qmtcencv.

558 `nqmtcencv=0.0` NFIN dependence of qmtcencv.

559 `pqmtcencv=0.0` Cross-term dependence of qmtcencv.

560 `lqmtcencva=0.0` Length dependence of qmtcencva.

561 `nqmtcencva=0.0` NFIN dependence of qmtcencva.

562 `pqmtcencva=0.0` Cross-term dependence of qmtcencva.

563 `lvsat=0` Length dependence of vsat.

564 `nvsat=0` NFIN dependence of vsat.

565 `pvsat=0` Cross-term dependence of vsat.

566 `lvsat1=0` Length dependence of vsat1.

567 `nvsat1=0` NFIN dependence of vsat1.

568 `pvsat1=0` Cross-term dependence of vsat1.

569 `lvsat1r=0` Length dependence of vsat1r.

570 `nvsat1r=0` NFIN dependence of vsat1r.

571 `pvsat1r=0` Cross-term dependence of vsat1r.

572 `lpsat=0` Length dependence of psat.

573 `npsat=0` NFIN dependence of psat.

574 `ppsat=0` Cross-term dependence of psat.

575 `ldeltavsat=0` Length dependence of deltavsat.

576 `ndeltavsat=0`	NFIN dependence of ndetavsat.
577 `pdeltavsat=0`	Cross-term dependence of deltavsat.
578 `lksativ=0`	Length dependence of ksativ.
579 `nksativ=0`	NFIN dependence of ksativ.
580 `pksativ=0`	Cross-term dependence of ksativ.
581 `lvsatcv=0`	Length dependence of vsatcv.
582 `nvsatcv=0`	NFIN dependence of vsatcv.
583 `pvsatcv=0`	Cross-term dependence of vsatcv.
584 `lmexp=0`	Length dependence of mexp.
585 `nmexp=0`	NFIN dependence of mexp.
586 `pmexp=0`	Cross-term dependence of mexp.
587 `lmexpr=0`	Length dependence of mexpr.
588 `nmexpr=0`	NFIN dependence of mexpr.
589 `pmexpr=0`	NFIN dependence of mexpr.
590 `lptwg=0.0`	Length dependence of ptwg.
591 `nptwg=0.0`	NFIN dependence of ptwg.
592 `pptwg=0.0`	Cross-term dependence of ptwg.
593 `lptwgr=0.0`	Length dependence of ptwgr.
594 `nptwgr=0.0`	NFIN dependence of ptwgr.
595 `pptwgr=0.0`	Cross-term dependence of ptwgr.
596 `lthetasat=0`	Length dependence of thetasat.
597 `nthetasat=0`	NFIN dependence of thetasat.

598 `pthetasat=0`	Cross-term dependence of thetasat.
599 `lu0=0`	Length dependence of u0.
600 `nu0=0`	NFIN dependence of u0.
601 `pu0=0`	Cross-term dependence of u0.
602 `letamob=0`	Length dependence of letamob.
603 `netamob=0`	NFIN dependence of netamob.
604 `petamob=0`	Cross-term dependence of petamob.
605 `lup=0`	Length dependence of up.
606 `nup=0`	NFIN dependence of up.
607 `pup=0`	Cross-term dependence of up.
608 `lua=0`	Length dependence of ua.
609 `nua=0`	NFIN dependence of ua.
610 `pua=0`	Cross-term dependence of ua.
611 `luc=0`	Length dependence of uc.
612 `nuc=0`	NFIN dependence of uc.
613 `puc=0`	Cross-term dependence of uc.
614 `leu=0`	Length dependence of eu.
615 `neu=0`	NFIN dependence of eu.
616 `peu=0`	Cross-term dependence of eu.
617 `lud=0`	Length dependence of ud.
618 `nud=0`	NFIN dependence of ud.
619 `pud=0`	Cross-term dependence of ud.

620 `lucs=0`	Length dependence of ucs.
621 `nucs=0`	NFIN dependence of ucs.
622 `pucs=0`	Cross-term dependence of ucs.
623 `lmue=0`	Length dependence of mue.
624 `nmue=0`	NFIN dependence of mue.
625 `pmue=0`	Cross-term dependence of mue.
626 `lcs=0`	Length dependence of cs.
627 `ncs=0`	NFIN dependence of cs.
628 `pcs=0`	Cross-term dependence of cs.
629 `lpclm=0`	Length dependence of pclm.
630 `npclm=0`	NFIN dependence of pclm.
631 `ppclm=0`	Cross-term dependence of pclm.
632 `lpclmg=0`	Length dependence of pclmg.
633 `npclmg=0`	Length dependence of nclmg.
634 `ppclmg=0`	Length dependence of pclmg.
635 `lvasat=0`	Length dependence of lvasat.
636 `nvasat=0`	Length dependence of nvasat.
637 `pvasat=0`	Length dependence of pvasat.
638 `lpclmcv=0`	Length dependence of pclmcv.
639 `npclmcv=0`	NFIN dependence of pclmcv.
640 `ppclmcv=0`	Cross-term dependence of pclmcv.
641 `la1=0`	Length dependence of a1.

642 `na1=0` NFIN dependence of a1.

643 `pa1=0` Cross-term dependence of a1.

644 `la2=0` Length dependence of a2.

645 `na2=0` NFIN dependence of a2.

646 `pa2=0` Cross-term dependence of a2.

647 `lrdsw=0` Length dependence of rdsw.

648 `nrdsw=0` NFIN dependence of rdsw.

649 `prdsw=0` Cross-term dependence of rdsw.

650 `lrsw=0.0` Length dependence of rsw.

651 `nrsw=0.0` NFIN dependence of rsw.

652 `prsw=0.0` Cross-term dependence of rsw.

653 `lrdw=0.0` Length dependence of rdw.

654 `nrdw=0.0` NFIN dependence of rdw.

655 `prdw=0.0` Cross-term dependence of rdw.

656 `lprwg=0` Length dependence of prwg.

657 `nprwg=0` NFIN dependence of prwg.

658 `pprwg=0` Cross-term dependence of prwg.

659 `lprwgs=0` Length dependence of prwgs.

660 `nprwgs=0` NFIN dependence of prwgs.

661 `pprwgs=0` Cross-term dependence of prwgs.

662 `lprwgd=0` NFIN dependence of prwgd.

663 `nprwgd=0` NFIN dependence of prwgd.

664 `pprwgd=0`	Cross-term dependence of prwgd.
665 `lwr=0`	Length dependence of wr.
666 `nwr=0`	NFIN dependence of wr .
667 `pwr=0`	Cross-term dependence of wr.
668 `lpdibl1=0`	Length dependence of pdibl1.
669 `npdibl1=0`	NFIN dependence of pdibl1.
670 `ppdibl1=0`	Cross-term dependence of pdibl1.
671 `lpdibl1r=0`	Length dependence of pdibl1r.
672 `npdibl1r=0`	NFIN dependence of pdibl1r.
673 `ppdibl1r=0`	Cross-term dependence of pdibl1r.
674 `lpdibl2=0`	Length dependence of pdibl2.
675 `npdibl2=0`	NFIN dependence of pdibl2.
676 `ppdibl2=0`	Cross-term dependence of pdibl2.
677 `ldrout=0`	Length dependence of drout.
678 `ndrout=0`	NFIN dependence of drout.
679 `pdrout=0`	Cross-term dependence of drout.
680 `lpvag=0`	Length dependence of pvag.
681 `npvag=0`	NFIN dependence of pvag.
682 `ppvag=0`	Cross-term dependence of pvag.
683 `laigbinv=0`	Length dependence of aigbinv.
684 `naigbinv=0`	NFIN dependence of aigbinv.
685 `paigbinv=0`	Cross-term dependence of aigbinv.

686 `lbigbinv=0` Length dependence of bigbinv.

687 `nbigbinv=0` NFIN dependence of bigbinv.

688 `pbigbinv=0` Cross-term dependence of bigbinv.

689 `lcigbinv=0` Length dependence of cigbinv.

690 `ncigbinv=0` NFIN dependence of cigbinv.

691 `pcigbinv=0` Cross-term dependence of cigbinv.

692 `leigbinv=0` Length dependence of eigbinv.

693 `neigbinv=0` NFIN dependence of eigbinv.

694 `peigbinv=0` Cross-term dependence of eigbinv.

695 `lnigbinv=0` Length dependence of nigbinv.

696 `nnigbinv=0` NFIN dependence of nigbinv.

697 `pnigbinv=0` Cross-term dependence of nigbinv.

698 `laigbacc=0` Length dependence of laigbacc.

699 `naigbacc=0` Length dependence of naigbacc.

700 `paigbacc=0` Length dependence of paigbacc.

701 `lbigbacc=0` Length dependence of lbigbacc.

702 `nbigbacc=0` Length dependence of nbigbacc.

703 `pbigbacc=0` Length dependence of pbigbacc.

704 `lcigbacc=0` Length dependence of lcigbacc.

705 `ncigbacc=0` Length dependence of ncigbacc.

706 `pcigbacc=0` Length dependence of pcigbacc.

707 `lnigbacc=0` Length dependence of lnigbacc.

708 `nnigbacc=0`	Length dependence of nnigbacc.
709 `pnigbacc=0`	Length dependence of pnigbacc.
710 `laigc=0`	Length dependence of aigc.
711 `naigc=0`	NFIN dependence of aigc.
712 `paigc=0`	Cross-term dependence of aigc.
713 `lbigc=0`	Length dependence of bigc.
714 `nbigc=0`	NFIN dependence of bigc.
715 `pbigc=0`	Cross-term dependence of bigc.
716 `lcigc=0`	Length dependence of cigc.
717 `ncigc=0`	NFIN dependence of cigc.
718 `pcigc=0`	Cross-term dependence of cigc.
719 `lnigc=0`	Length dependence of nigc.
720 `nnigc=0`	NFIN dependence of nigc.
721 `pnigc=0`	Cross-term dependence of nigc.
722 `lpigcd=0`	Length dependence of pigcd.
723 `npigcd=0`	NFIN dependence of pigcd.
724 `ppigcd=0`	Cross-term dependence of pigcd.
725 `laigs=0`	Length dependence of aigs.
726 `naigs=0`	NFIN dependence of aigs.
727 `paigs=0`	Cross-term dependence of aigs.
728 `lbigs=0`	Length dependence of bigs.
729 `nbigs=0`	NFIN dependence of bigs.

730 `pbigs=0` Cross-term dependence of bigs.

731 `lcigs=0` Length dependence of cigs.

732 `ncigs=0` NFIN dependence of cigs.

733 `pcigs=0` Cross-term dependence of cigs.

734 `laigd=0` Length dependence of aigd.

735 `naigd=0` NFIN dependence of aigd.

736 `paigd=0` Cross-term dependence of aigd.

737 `lbigd=0` Length dependence of bigd.

738 `nbigd=0` NFIN dependence of bigd.

739 `pbigd=0` Cross-term dependence of bigd.

740 `lcigd=0` Length dependence of cigd.

741 `ncigd=0` NFIN dependence of cigd.

742 `pcigd=0` Cross-term dependence of cigd.

743 `lntox=0` Length dependence of ntox.

744 `nntox=0` Length dependence of ntox.

745 `pntox=0` Length dependence of ntox.

746 `lpoxedge=0` Length dependence of poxedge.

747 `npoxedge=0` NFIN dependence of poxedge.

748 `ppoxedge=0` Cross-term dependence of poxedge.

749 `lagidl=0` Length dependence of agidl.

750 `nagidl=0` NFIN dependence of agidl.

751 `pagidl=0` Cross-term dependence of agidl.

752 `lbgidl=0`	Length dependence of bgidl.
753 `nbgidl=0`	NFIN dependence of bgidl.
754 `pbgidl=0`	Cross-term dependence of bgidl.
755 `legidl=0`	Length dependence of egidl.
756 `negidl=0`	NFIN dependence of egidl.
757 `pegidl=0`	Cross-term dependence of egidl.
758 `lcgidl=0`	Length dependence of cgidl.
759 `ncgidl=0`	NFIN dependence of cgidl.
760 `pcgidl=0`	Cross-term dependence of cgidl.
761 `lpgidl=0`	Length dependence of pgidl.
762 `npgidl=0`	Length dependence of pgidl.
763 `ppgidl=0`	Length dependence of pgidl.
764 `lagisl=0`	Length dependence of agisl.
765 `nagisl=0`	NFIN dependence of agisl.
766 `pagisl=0`	Cross-term dependence of agisl.
767 `lbgisl=0`	Length dependence of bgisl.
768 `nbgisl=0`	NFIN dependence of bgisl.
769 `pbgisl=0`	Cross-term dependence of bgisl.
770 `legisl=0`	Length dependence of egisl.
771 `negisl=0`	NFIN dependence of egisl.
772 `pegisl=0`	Cross-term dependence of egisl.
773 `lcgisl=0`	Length dependence of cgisl.

774 `ncgisl=0`	NFIN dependence of cgisl.
775 `pcgisl=0`	Cross-term dependence of cgisl.
776 `lpgisl=0`	Length dependence of pgisl.
777 `npgisl=0`	Length dependence of pgisl.
778 `ppgisl=0`	Length dependence of pgisl.
779 `lalpha0=0.0`	Length dependence of alpha0.
780 `nalpha0=0.0`	NFIN dependence of alpha0.
781 `palpha0=0.0`	Cross-term dependence of alpha0.
782 `lalpha1=0.0`	Length dependence of alpha1.
783 `nalpha1=0.0`	NFIN dependence of alpha1.
784 `palpha1=0.0`	Cross-term dependence of alpha1.
785 `lbeta0=0.0`	Length dependence of beta0.
786 `nbeta0=0.0`	NFIN dependence of beta0.
787 `pbeta0=0.0`	Cross-term dependence of beta0.
788 `lalphaii=0.0`	Length dependence of alphaii.
789 `nalphaii=0.0`	NFIN dependence of alphaii.
790 `palphaii=0.0`	Cross-term dependence of alphaii.
791 `lbetaii0=0.0`	Length dependence of betaii0.
792 `nbetaii0=0.0`	NFIN dependence of betaii0.
793 `pbetaii0=0.0`	Cross-term dependence of betaii0.
794 `lbetaii1=0.0`	Length dependence of betaii1.
795 `nbetaii1=0.0`	NFIN dependence of betaii1.

796 `pbetaii1=0.0` Cross-term dependence of betaii1.

797 `lbetaii2=0.0` Length dependence of betaii2.

798 `nbetaii2=0.0` NFIN dependence of betaii2.

799 `pbetaii2=0.0` Cross-term dependence of betaii2.

800 `lesatii=0.0` Length dependence of esatii.

801 `nesatii=0.0` NFIN dependence of esatii.

802 `pesatii=0.0` Cross-term dependence of esatii.

803 `llii=0.0` Length dependence of lii.

804 `nlii=0.0` NFIN dependence of lii.

805 `plii=0.0` Cross-term dependence of lii.

806 `lsii0=0.0` Length dependence of sii0.

807 `nsii0=0.0` NFIN dependence of sii0.

808 `psii0=0.0` Cross-term dependence of sii0.

809 `lsii1=0.0` Length dependence of sii1.

810 `nsii1=0.0` NFIN dependence of sii1.

811 `psii1=0.0` Cross-term dependence of sii1.

812 `lsii2=0.0` Length dependence of sii2.

813 `nsii2=0.0` NFIN dependence of sii2.

814 `psii2=0.0` Cross-term dependence of sii2.

815 `lsiid=0.0` Length dependence of siid.

816 `nsiid=0.0` NFIN dependence of siid.

817 `psiid=0.0` Cross-term dependence of siid.

818 `lcfs=0.0` Length dependence of cfs.

819 `ncfs=0.0` NFIN dependence of cfs.

820 `pcfs=0.0` Cross-term dependence of cfs.

821 `lcfd=0.0` Length dependence of cfd.

822 `ncfd=0.0` NFIN dependence of cfd.

823 `pcfd=0.0` Cross-term dependence of cfd.

824 `lcovs=0.0` Length dependence of.

825 `ncovs=0.0` NFIN dependence of.

826 `pcovs=0.0` Cross-term dependence of.

827 `lcovd=0.0` Length dependence of covd.

828 `ncovd=0.0` NFIN dependence of covd.

829 `pcovd=0.0` Cross-term dependence of covd.

830 `lcgsl=0.0` Length dependence of cgsl.

831 `ncgsl=0.0` NFIN dependence of cgsl.

832 `pcgsl=0.0` Cross-term dependence of cgsl.

833 `lcgdl=0.0` Length dependence of cgdl.

834 `ncgdl=0.0` NFIN dependence of cgdl.

835 `pcgdl=0.0` Cross-term dependence of cgdl.

836 `lckappas=0.0` Length dependence of ckappas.

837 `nckappas=0.0` NFIN dependence of ckappas.

838 `pckappas=0.0` Cross-term dependence of ckappas.

839 `lckappad=0.0` Length dependence of ckappad.

840 `nckappad=0.0`	NFIN dependence of ckappad.
841 `pckappad=0.0`	Cross-term dependence of ckappad.
842 `lcgbl=0.0`	Length dependence of cgbl.
843 `ncgbl=0.0`	NFIN dependence of cgbl.
844 `pcgbl=0.0`	Cross-term dependence of cgbl.
845 `lckappab=0.0`	Length dependence of ckappab.
846 `nckappab=0.0`	NFIN dependence of ckappab.
847 `pckappab=0.0`	Cross-term dependence of ckappab.
848 `lntgen=0`	Length dependence of ntgen.
849 `nntgen=0`	NFIN dependence of ntgen.
850 `pntgen=0`	Cross-term dependence of ntgen.
851 `laigen=0`	Length dependence of aigen.
852 `naigen=0`	NFIN dependence of aigen.
853 `paigen=0`	Cross-term dependence of aigen.
854 `lbigen=0`	Length dependence of bigen.
855 `nbigen=0`	NFIN dependence of bigen.
856 `pbigen=0`	Cross-term dependence of bigen.
857 `lxrcrg1=0.0`	Length dependence of xrcrg1.
858 `nxrcrg1=0.0`	NFIN dependence of xrcrg1.
859 `pxrcrg1=0.0`	Cross-term dependence of xrcrg1.
860 `lxrcrg2=0.0`	Length dependence of xrcrg2.
861 `nxrcrg2=0.0`	NFIN dependence of xrcrg2.

862 `pxrcrg2=0.0` Cross-term dependence of xrcrg2.

863 `lintnoi=0.0` Length dependence of intnoi.

864 `lute=0.0` Length dependence of ute.

865 `nute=0.0` NFIN dependence of ute.

866 `pute=0.0` Cross-term dependence of ute.

867 `lutl=0.0` Length dependence of utl.

868 `nutl=0.0` NFIN dependence of utl.

869 `putl=0.0` Cross-term dependence of utl.

870 `lemobt=0` Length dependence of emobt.

871 `nemobt=0` NFIN dependence of emobt.

872 `pemobt=0` Cross-term dependence of emobt.

873 `lua1=0.0` Length dependence of ua1.

874 `nua1=0.0` NFIN dependence of ua1.

875 `pua1=0.0` Cross-term dependence of ua1.

876 `luc1=0.0` Length dependence of uc1.

877 `nuc1=0.0` NFIN dependence of uc1.

878 `puc1=0.0` Cross-term dependence of uc1.

879 `lud1=0.0` Length dependence of ud1.

880 `nud1=0.0` NFIN dependence of ud1.

881 `pud1=0.0` Cross-term dependence of ud1.

882 `lucste=0.0` Length dependence of ucste.

883 `nucste=0.0` NFIN dependence of ucste.

884 `pucste=0.0`	Cross-term dependence of ucste.
885 `lptwgt=0`	Length dependence of ptwgt.
886 `nptwgt=0`	NFIN dependence of ptwgt.
887 `pptwgt=0`	Cross-term dependence of ptwgt.
888 `lat=0`	Length dependence of at.
889 `nat=0`	NFIN dependence of at.
890 `pat=0`	Cross-term dependence of at.
891 `lstthetasat=0`	Length dependence of stthetasat.
892 `nstthetasat=0`	NFIN dependence of stthetasat.
893 `pstthetasat=0`	Cross-term dependence of stthetasat.
894 `lprt=0`	Length dependence of prt.
895 `nprt=0`	NFIN dependence of prt.
896 `pprt=0`	Cross-term dependence of prt.
897 `lkt1=0`	Length dependence of kt1.
898 `nkt1=0`	NFIN dependence of kt1.
899 `pkt1=0`	Cross-term dependence of kt1.
900 `ltss=0`	Length dependence of tss.
901 `ntss=0`	NFIN dependence of tss.
902 `ptss=0`	Cross-term dependence of tss.
903 `liit=0`	Length dependence of iit.
904 `niit=0`	NFIN dependence of iit.
905 `piit=0`	Cross-term dependence of iit.

906 `ltii=0.0`	Length dependence of tii.
907 `ntii=0.0`	NFIN dependence of tii.
908 `ptii=0.0`	Cross-term dependence of tii.
909 `ltgidl=0`	Length dependence of tgidl.
910 `ntgidl=0`	NFIN dependence of tgidl.
911 `ptgidl=0`	Cross-term dependence of tgidl.
912 `ligt=0`	Length dependence of igt.
913 `nigt=0`	NFIN dependence of igt.
914 `pigt=0`	Cross-term dependence of igt.
915 `lk01=0`	Length dependence of k01.
916 `nk01=0`	NFIN dependence of k01.
917 `pk01=0`	Cross-term dependence of k01.
918 `lk0si1=0`	Length dependence of k0si1.
919 `nk0si1=0`	NFIN dependence of k0si1.
920 `pk0si1=0`	Cross-term dependence of k0si1.
921 `lk1si1=0`	Length dependence of k1si1.
922 `nk1si1=0`	NFIN dependence of k1si1.
923 `pk1si1=0`	Cross-term dependence of k1si1.
924 `lk11=0`	Length dependence of k11.
925 `nk11=0`	NFIN dependence of k11.
926 `pk11=0`	Cross-term dependence of k11.
927 `lk1sat1=0`	Length dependence of k1sat1.

928 `nk1sat1=0`	NFIN dependence of k1sat1.
929 `pk1sat1=0`	Cross-term dependence of k1sat1.
930 `la11=0`	Length dependence of a11.
931 `na11=0`	NFIN dependence of a11.
932 `pa11=0`	Cross-term dependence of a11.
933 `la21=0`	Length dependence of a21.
934 `na21=0`	NFIN dependence of a21.
935 `pa21=0`	Cross-term dependence of a21.
936 `laigbinv1=0`	Length dependence of aigbinv1.
937 `naigbinv1=0`	NFIN dependence of aigbinv1.
938 `paigbinv1=0`	Cross-term dependence of aigbinv1.
939 `laigbacc1=0`	Length dependence of aigbacc1.
940 `naigbacc1=0`	NFIN dependence of aigbacc1.
941 `paigbacc1=0`	Cross-term dependence of aigbacc1.
942 `laigc1=0`	Length dependence of aigc1.
943 `naigc1=0`	NFIN dependence of aigc1.
944 `paigc1=0`	Cross-term dependence of aigc1.
945 `laigs1=0`	Length dependence of aigs1.
946 `naigs1=0`	NFIN dependence of aigs1.
947 `paigs1=0`	Cross-term dependence of aigs1.
948 `laigd1=0.0`	Length dependence of aigd1.
949 `naigd1=0.0`	NFIN dependence of aigd1.

950 `paigd1=0.0` Cross-term dependence of aigd1.

951 `lalphaii0=0.0` Length dependence of alphaii0.

952 `nalpha=0.0` NFIN dependence of alphaii0.

953 `palphaii0=0.0` Cross-term dependence of alphaii0.

954 `lalphaii1=0.0` Length dependence of alphaii1.

955 `nalphaii1=0.0` NFIN dependence of alphaii1.

956 `palphaii1=0.0` Cross-term dependence of alphaii1.

957 `lpsatcv=0` Length dependence of psatcv.

958 `npsatcv=0` NFIN dependence of psatcv.

959 `ppsatcv=0` Cross-term dependence of psatcv.

960 `ldeltavsatcv=0` Length dependence of deltavsatcv.

961 `ndeltavsatcv=0` NFIN dependence of deltavsatcv.

962 `pdeltavsatcv=0` Cross-term dependence of deltavsatcv.

963 `mvtwl=0.0 V m` Threshold mismatch area dependence.

964 `mvtwl2=0.0 V m^1.5`
Threshold mismatch area square dependence.

965 `mvt0=0.0 V` Threshold mismatch intercept.

966 `mbewl=0.0 m` Beta mismatch area dependence.

967 `mbe0=0.0` Beta mismatch intercept.

968 `mismatchmod=0` Select mismatch mode. The available modes are 0, 1, 2 and 3.

969 `mismatchdist=0.0` Mismatch Distance.

970 `lmin=0.0 m` Minimum channel length for which the model is valid.

971 `lmax=1.0 m` Maximum channel length for which the model is valid.

972 `nfinmin=1` Minimum number of fins per finger.

973 `nfinmax=100000` Maximum number of fins per finger.

Output Parameters

1 `weff` Effective channel width.

2 `leff` Effective channel length.

3 `weffcv` Effective channel width for C-V.

4 `leffcv` Effective channel length for C-V.

5 `_age_is_shared`
NULL.

6 `tempeff (C)` Effective temperature for a single device.

7 `temp_sh (C)` Effective temperature including selfheating temperature.

Operating-Point Parameters

1 `linearity_factor`

2 `ids (A)` Intrinsic drain current (electrical).

3 `gm` Transconductance.

4 `gds` Output conductance.

5 `gmbs` Body transconductance.

6 `rout (O)` Output resistance.

7 `vgs (V)` VGS.

8 `vgd (V)` VGD.

9 `vds (V)`	VDS.
10 `ves (V)`	VES.
11 `vth (V)`	Threshold voltage.
12 `vgt (V)`	Effective gate drive voltage.
13 `vfb (V)`	Flatband voltage.
14 `beta`	Drain current prefactor per fin per finger.
15 `vdssat (V)`	Drain-Source saturation voltage.
16 `pwr (W)`	Power at op point.
17 `ideff (A)`	Total drain current (physical).
18 `iseff (A)`	Total source current (physical).
19 `igtot (A)`	Iotal gate current.
20 `isub (A)`	Substrate current.
21 `idsgen (A)`	Generation-Recombination Current (Physical).
22 `iii (A)`	Impact ionization current.
23 `igidl (A)`	GIDL current (physical).
24 `igisl (A)`	GISL current (physical).
25 `ijsb (A)`	Source-Body junction current (physical).
26 `ijdb (A)`	Drain-Body junction current (physical).
27 `igs (A)`	IGS.
28 `igd (A)`	IGD.
29 `igcs (A)`	IGCS.
30 `igcd (A)`	IGCD.

31 `igbs (A)`	IBGS.
32 `igbd (A)`	IBGD.
33 `igbacc (A)`	IGBACC.
34 `igbinv (A)`	IGBINV.
35 `qgi (C)`	Intrinsic gate charge.
36 `qdi (C)`	Intrinsic drain charge.
37 `qsi (C)`	Intrinsic source charge.
38 `qbi (C)`	Intrinsic body charge.
39 `qg (C)`	Total gate charge.
40 `qd (C)`	Total drain charge.
41 `qs (C)`	Total source charge.
42 `qb (C)`	Total bulk charge.
43 `cggi (F)`	Intrinsic gate capacitance.
44 `cgsi (F)`	Intrinsic gate-to-source capacitance.
45 `cgdi (F)`	Intrinsic gate-to-drain capacitance.
46 `cgei (F)`	Intrinsic gate-to-bulk capacitance.
47 `cdgi (F)`	Intrinsic drain-to-gate capacitance.
48 `cddi (F)`	Intrinsic drain capacitance.
49 `cdsi (F)`	Intrinsic drain-to-source capacitance.
50 `cdei (F)`	Intrinsic drain-to-bulk capacitance.
51 `csgi (F)`	Intrinsic source-to-gate capacitance.
52 `csdi (F)`	Intrinsic source-to-drain capacitance.

53 `cssi (F)`	Intrinsic source capacitance.
54 `csei (F)`	Intrinsic source-to-bulk capacitance.
55 `cegi (F)`	Intrinsic bulk-to-gate capacitance.
56 `cedi (F)`	Intrinsic bulk-to-drain capacitance.
57 `cesi (F)`	Intrinsic bulk-to-drain capacitance.
58 `ceei (F)`	Intrinsic bulk capacitance.
59 `cgg (F)`	Total gate capacitance.
60 `cgs (F)`	Total gate-to-source capacitance.
61 `cgd (F)`	Total gate-to-drain capacitance.
62 `cge (F)`	Total gate-to-bulk capacitance.
63 `cdg (F)`	Total drain-to-gate capacitance.
64 `cdd (F)`	Total drain capacitance.
65 `cds (F)`	Total drain-to-source capacitance.
66 `cde (F)`	Total drain-to-bulk capacitance.
67 `csg (F)`	Total source-to-gate capacitance.
68 `csd (F)`	Total source-to-drain capacitance.
69 `css (F)`	Total source capacitance.
70 `cse (F)`	Total source-to-bulk capacitance.
71 `ceg (F)`	Total bulk-to-gate capacitance.
72 `ced (F)`	Total bulk-to-drain capacitance.
73 `ces (F)`	Total bulk-to-drain capacitance.
74 `cee (F)`	Total bulk capacitance.

75 `cgsext (F)`	Gate-Source overlap + outer fringing capacitance.
76 `cgdext (F)`	Gate-Drain overlap + outer fringing capacitance.
77 `cgbov (F)`	Gate-Body overlap capacitance.
78 `cjst (F)`	Total of junction capacitance and source/drain-body overlap capacitance.
79 `cjdt (F)`	Total of junction capacitance and source/drain-body overlap capacitance.
80 `rsgeo`	External bias independent source resistance.
81 `rdgeo`	External bias independent drain resistance.
82 `cfgeo (C)`	Geometric parasitic cap for cgeomod=1.
83 `para_rs (R)`	Parasitic source resistance.
84 `para_rd (R)`	Parasitic drain resistance.
85 `para_rg (R)`	Parasitic gate electrode resistance.
86 `para_csbox (c)`	Parasitic coupled capacitance between source and substrate.
87 `para_cdbox (c)`	Parasitic coupled capacitance between drain and substrate.
88 `para_cgbox (c)`	Parasitic coupled capacitance between gate and substrate.
89 `para_qgs_ov (c)`	Parasitic overlap capacitance between gate and source.
90 `para_qgd_ov (c)`	Parasitic overlap capacitance between gate and drain.
91 `para_qgs_fr (c)`	Parasitic fringe capacitance between gate and source.
92 `para_qgd_fr (c)`	Parasitice fringe capacitance between gate and drain.

93 `para_qds_fr (c)`
Parasitice fringe capacitance between source and drain.

94 `didsdvg` DIDSDVG.

95 `didsdvs` DIDSDVS.

96 `didsdvd` DIDSDVD.

97 `digsdvg` DIGSDVG.

98 `digsdvs` DIGSDVS.

99 `digsdvd` DIGSDVD.

100 `digddvg` DIGDDVG.

101 `digddvs` DIGDDVS.

102 `digddvd` DIGDDVD.

103 `diiidvg` DIIIDVG.

104 `diiidvs` DIIIDVS.

105 `diiidvd` DIIIDVD.

106 `digidldvg` DIGIDLDVG.

107 `digidldvs` DIGIDLDVS.

108 `digidldvd` DIGIDLDVD.

109 `digisldvg` DIGISLDVG.

110 `digisldvs` DIGISLDVS.

111 `digisldvd` DIGISLDVD.

112 `cgt (F)` CGT.

113 `cst (F)` CST.

114 `cdt (F)`	CDT.
115 `didsdvth`	DIDSDVTH.
116 `digsdvth`	DIGSDVTH.
117 `digddvth`	DIGDDVTH.
118 `diiidvth`	DIIIDVTH.
119 `digidldvth`	DIGIDLDVTH.
120 `digisldvth`	DIGISLDVTH.
121 `dithdvth`	DITHDVTH.
122 `ith (A)`	ITH.
123 `dithdvg`	DITHDVG.
124 `dithdvs`	DITHDVS.
125 `dithdvd`	DITHDVD.
126 `lpoly`	LPOLY.
127 `reversed`	REVERSED. Possible values are `no` and `yes`.
128 `vgst (V)`	Gate-source voltage.
129 `vgdt (V)`	Gate-drain voltage.
130 `vdet (V)`	Drain-bulk voltage.
131 `vget (V)`	Gate-bulk voltage.
132 `vdst (V)`	Drain-source voltage.
133 `vest (V)`	Bulk-source voltage.
134 `_age_vs (V)`	The source terminal voltage.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

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BSIM-IMG

BSIM-IMG is a SPICE compact model for modeling the electrical characteristics of common gate MG structures, developed by UC Berkeley. The latest version is 101.0.

The BSIM-IMG models the independent double-gate structure as a four terminal device, containing the source(s), drain(d), front gate(fg), and back gate(bg) terminals. The two gates (fg, bg) are allowed to have different workfunctions ($\Delta\varphi 1, \Delta\varphi 2$) and dielectric thicknesses (T_{ox1}, T_{ox2}). They can also be biased separately at different voltages.

This chapter contains the following information about the BSIM-IMG model:

Model Overview

Physical surface-potential-based formulations are derived in both intrinsic and extrinsic models of BSIM-IMG. Surface potentials and integrated charge densities at the source and drain ends are obtained by solving the Poisson's equation in a fully-depleted, lightly doped body and calculating with efficient analytical approximations. Since the surface potential equation is derived based on Poisson's equation, the model captures volume inversion effects very well and shows excellent scalability compared with 2D device simulation.

To meet the requirements of future devices, new parameters have been included to model devices consisting of novel materials. This includes parameters for non-silicon channel devices and High-K gate insulators.

The back-gate of a planar double-gate SOI FET is often used for tuning device threshold voltage (V_{TH}). Therefore, the effect of back-gate on V_{TH} must also be addressed by the model. V_{TH} varies with back-gate voltage. When V_{bg} is low, they follow a linear relationship. At large V_{bg}, however, the back-gate effect slows down as a result of back surface accumulation.

Other important effects, such as short channel effects, mobility degradation, velocity saturation, velocity overshoot, series resistance, channel length modulation, quantum mechanical effects, gate tunneling current, gate-induced-drain-leakage, and parasitic capacitance are also incorporated in the model.

The model is continuous and symmetric at `Vds=0`. This physics-based model is scalable and predictive over a wide range of device parameters.

BSIM-IMG Model Equations

Bias Independent Calculations

Physical Constants

Physical quantities in BSIM-IMG are in M.K.S units, unless specified otherwise.

$$q = 1.6 \times 10^{-19}$$

$$\varepsilon_0 = 8.8542 \times 10^{-12}$$

$$k = 1.3787 \times 10^{-23}$$

$$\varepsilon_{si} = EPSRSUB \cdot \varepsilon_0$$

$$\varepsilon_{ox1} = EPSROX1 \cdot \varepsilon_0$$

$$\varepsilon_{ox2} = EPSROX2 \cdot \varepsilon_0$$

$$C_{ox1} = \frac{39 \cdot \varepsilon_0}{EOT1}$$

$$C_{ox2} = \frac{39 \cdot \varepsilon_0}{EOT2}$$

$$C_{si} = \frac{\varepsilon_{si}}{TSI}$$

$$\varepsilon_{ratio} = \frac{EPSRSUB}{3.9}$$

$$V_{tm} = \frac{kT}{q}$$

$$V_{gfb2n} = -1.2$$

Effective Channel Width, Channel Length

$$\Delta L = LINT + \frac{LL}{(L + XL)^{LLN}}$$

$$\Delta LCV = DLC + \frac{LLC}{(L + XL)^{LLN}}$$

$$L_{eff} = L + XL - 2\Delta L$$

$$L_{eff,\,CV} = L + XL - 2\Delta LCV$$

$$W_{eff} = W$$

$$W_{eff,\,CV} = W$$

Binning Calculations

$$PARAM_i = PARAM + \frac{1}{L_{eff}} \cdot LPARAM + \frac{1}{W_{eff}} \cdot WPARAM + \frac{1}{L_{eff} \cdot W_{eff}} \cdot PPARAM$$

Front and Back Gate Workfunction Calculation

$$\Phi_{ref} = \begin{cases} EASUB & for \quad NMOS \\ EASUB + E_g & for \quad PMOS \end{cases}$$

$$\Delta\Phi_1 = devsign \cdot (PHIG1_i - \Phi_{ref})$$

$$\Delta\Phi_2 = devsign \cdot (PHIG2_i - \Phi_{ref})$$

$$\Phi_{sd} = EASUB + \frac{E_g}{2} - devsign \cdot min[\frac{E_g}{2}, \frac{kT}{q} \cdot In\left(\frac{NSD}{ni}\right)]$$

$$V_{fbsd} = devsign \cdot (PHIG1_i - \Phi_{sd})$$

Terminal Voltages and Pre-Conditioning

Terminal Voltages and `Vdsx` Calculation

$$V_{fgs} = V_{fg} - V_s$$

$$V_{fgd} = V_{fg} - V_d$$

$$V_{bgs} = V_{bg} - V_s$$

$$V_{bgd} = V_{bg} - V_d$$

$$V_{ds} = V_d - V_s$$

$$V_{gfb1} = V_{fgs} - \Delta\Phi 1$$

$$V_{gfb2} = V_{bgs} - \Delta\Phi 2$$

$$V_{dsx} = \sqrt{V_{ds}^2 + 0.01} - 0.1$$

Back Gate Biasing Effect

$$Kvbg = KBG0 - \frac{0.5 \cdot KBG1}{\cosh\left(DBG \cdot \frac{Leff}{\lambda}\right)}$$

$$K^{*}vbg = KBG2 + \frac{1}{2}\left[K_{vbg} - KBG2 + \sqrt{(K_{vbg} - KBG2)^{2} + 0.0001}\right]$$

$$V_{gfb2eff} = V_{gfb2n} - symmetryfactor$$

$$\gamma_{0} = -\frac{C_{ox2} \cdot C_{si}}{(C_{ox2} + C_{si}) \cdot C_{ox1}}$$

$$\Delta V_{th,\, vbg} = \gamma_{0} \cdot K^{*}vbg \cdot (V_{gfb2} - V_{gfb2eff})$$

Short Channel Effects

Vt Roll-off

$$\Delta V_{th,SCE} = -\frac{0.5 \cdot DVT0_{i}}{\cosh\left(DVT1 \cdot \frac{Leff}{\lambda}\right) - 1} \cdot (V_{bi} - \Phi_{st})$$

Drain Induced Barrier Lowering (DIBL)

$$\Delta V_{th,DIBL} = -\frac{0.5 \cdot ETA0_{i}}{\cosh\left(DSUB \cdot \frac{Leff}{\lambda}\right) - 1} \cdot V_{dsx}$$

Vt Roll on/off at moderate channel lengths

$$V_{th,\,RSCE} = K1RSCE\left[\sqrt{1+\frac{LPE0}{Leff}}-1\right]\cdot\sqrt{\Psi_{st}}$$

Vt Roll on/off at moderate channel lengths and high V_{ds}

$$\Delta V_{th,\,DSC} = -\frac{DSC0}{DSC1+L_{eff}}\cdot V_{dsx}$$

Body Doping Effects

Body Doping Effect

$$\Delta V_{g,\,NBODY} = -\frac{q\cdot NBODY\cdot TS1}{C_{ox1}}\left[1-\frac{0.5\cdot TSI}{TSI+\varepsilon_{ratio}\cdot EOT2}\right]$$

Drain Saturation Voltage

The drain saturation voltage model is calculated after the source-side surface po-tential (φ_s) has been calculated. Vdseff is subsequently used to compute the drain-sidesurface potential (φ_d).

Electric Field Calculations

$$q_{is} = \frac{Q_{tots}}{C_{ox1}}$$

$$q_{bs} = \frac{q \cdot NBODY \cdot TSI}{C_{ox1}}$$

$$T_2 = \eta_\mu q_{is} + q_{bs} + E_{bs} \cdot \frac{\varepsilon_{si}}{C_{ox1}}$$

$$T_3 = \frac{1}{2}\left(T_2 + \sqrt{{T_2}^2 + 0.001}\right)$$

$$E_{effs} = 10^{-8} \cdot \frac{C_{ox1}}{\varepsilon_{si}} \cdot T_3$$

Calculate the Drain Saturation Voltage

$$D_{mobs} = 1 + (UA(T) + UC(T) \cdot V_{bgs}) \cdot (E_{effs})^{EU} + \frac{UD(T)}{\left(\frac{1}{2}\left(1 + \frac{q_{is}}{q_{ia,\,th}}\right)\right)^{UCS(T)}}$$

$$E_{sat} = \frac{2 \cdot VSAT}{\mu_o D_{mobs}}$$

If D_{rs}=0, then

$$V_{dsat} = \frac{E_{sat}L_{eff} \cdot \left(\frac{Q_{tots}}{C_{ox1} + C_{ox2}}\right)}{E_{sat}L_{eff} + \frac{Q_{tots}}{C_{ox1} + C_{ox2}}}$$

If D_{rs} is not equal to 0, then

$$T6 = KSATIV \cdot \left(\frac{Q_{tots}}{C_{ox1} + C_{ox2}} + 2V_t\right)$$

$$a = 2W \cdot V_{SAT} \cdot C_{ox1} \cdot G_{rs}$$

$$b = T_6 + E_{sat}L_{eff} + 3T_6W_{eff} \cdot V_{SAT} \cdot C_{ox1} \cdot G_{rs}$$

$$c = T_6 \cdot [E_{sat}L_{eff} + T_6 \cdot a]$$

$$V_{dsat} = \frac{b - \sqrt{b^2 - 2ac}}{a}$$

Calculate Average Field, Potential, and Charge

Average Field, Potential, and Charge

$$\varphi_m = \frac{\varphi_{fs} + \varphi_{fd}}{2}$$

$$q_{ia} = \frac{Q_{tots} + Q_{totd}}{2C_{ox1}}$$

$$q_{ba} = \frac{qN_A \cdot TSI}{C_{ox1}}$$

$$E_{ba} = \frac{E_{bs} + E_{bd}}{2}$$

$$\Delta\varphi = \varphi_{fd} - \varphi_{fs}$$

$$\Delta q_i = \frac{Q_{tots} - Q_{totd}}{C_{ox1}}$$

Mobility Degradation

The mobility model is based on the BSIM4 model.

$$\eta = \begin{cases} \frac{1}{2} \cdot ETAMOB & for \quad NMOS \\ \frac{1}{2} \cdot ETAMOB & for \quad PMOS \end{cases}$$

$$T_2 = \eta_\mu q_{ia} + q_{ba} + E_{ba} \cdot \frac{\varepsilon_{si}}{C_{ox1}}$$

$$T_3 = \frac{1}{2}\left(T_2 + \sqrt{T_2^{\ 2} + 0.001}\right)$$

$$E_{effm} = 10^{-8} \cdot \frac{C_{ox1}}{\varepsilon_{si}} \cdot T_3$$

$$D_{mob0} = 1 + (UA(T) + UC(T) \cdot V_{bgs}) \cdot (E_{effm})^{EU} + \frac{UD(T)}{\left(\frac{1}{2}\left(1 + \frac{q_{ia}}{q_{ia,\, th}}\right)\right)^{UCS(T)}}$$

$$D_{mob} = \frac{D_{mob0}}{U0MULT}$$

Output Conductance

Channel Length Modulation

$$C_{clm} = \begin{cases} PCLM \cdot (1 + PCLMG \cdot q_{im}) & for \quad PCLMG > 0 \\ PCLM \div (1 - PCLMG \cdot q_{im}) & for \quad PCLMG < 0 \end{cases}$$

$$M_{clm} = 1 + \frac{1}{C_{clm}} 1n\left[1 + \frac{V_{ds} - V_{dseff}}{VASAT}\right] \cdot C_{clm}$$

Output Conductance due to DIBL

$$PVAG_{factor} = \begin{cases} 1 + PVAG_i \cdot \dfrac{q_{ia}}{E_{sat}L_{eff}} & for \quad PVAG_i > 0 \\ \dfrac{1}{1 - PVAG_i \cdot \dfrac{q_{ia}}{E_{sat}L_{eff}}} & for \quad PVAG_i < 0 \end{cases}$$

$$\theta_{rout} = \frac{0.5 \cdot PDIBL1_i}{\cosh\left(DROUT_i \cdot \frac{L_{eff}}{\lambda}\right) - 1} + PDIBL2_i$$

$$V_{ADIBL} = \frac{q_{im} + 2kT/q}{\theta_{rout}} \cdot \left(1 - \frac{V_{dsat}}{V_{dsat} + q_{ia} + 2kT/q}\right) \cdot PVAG_{factor}$$

$$M_{oc} = \left(1 + \frac{V_{ds} - V_{dseff}}{V_{ADIBL}}\right) \cdot M_{clm}$$

M_{oc} is multiplied to `Ids` in the `_nal` drain current expression.

Veolocity Saturation

Current Degradation Due to Velocity Saturation

The following formulation models the current degradation factor due to velocity saturation in the linear region. It is adopted from the BSIM5 model.

$$E_{sat1} = \frac{2 \cdot VSAT1(T)}{\mu_{eff}}$$

$$\delta_{vsat} = DELTAVSAT$$

$$T_0 = 0.8 + VSATB \cdot V_{bgx}$$

$$X_{sat} = 0.2 + \frac{\left[T_0 + \sqrt{T_0^{\ 2} + 0.01}\right]}{2}$$

$$D_{vsat} = \frac{1 + \sqrt{\delta_{vsat} + \left(\frac{\Delta q_i}{E_{sat1} L_{eff}} \cdot X_{sat}\right)^2}}{1 + \sqrt{\delta_{vsat}}} + \frac{1}{2} \cdot PTWG(T) \cdot q_{ia} \cdot \Delta q_i^2$$

Drain Current Model

$$I_{ds0} = \mu_0 \cdot C_{ox1} \cdot \frac{W_{eff}}{L_{eff}} \cdot i_{ds0} \cdot \frac{M_{oc}}{D_{mob} \cdot D_r \cdot D_{vsat}}$$

C-V Model

Channel Length Modulation

$$C_{clm,CV} = \begin{cases} PCLMCV \cdot (1 + PCLMGCV \cdot q_{im}) & for PCLMGCV > 0 \\ \dfrac{PCLMCV}{1 - PCLMGCV \cdot q_{im}} & for PCLMGCV < 0 \end{cases}$$

$$M_{clm,CV} = 1 + \frac{1}{C_{clm,CV}} 1n1 + \left[\frac{V_{ds} - V_{dseff}}{VASAT} \cdot C_{clm,CV} \right]$$

Assign Variables

$$Q_{fg} = \frac{1}{M_{clm,CV}} \cdot C_{ox1} \cdot W_{eff} \cdot L_{eff} \cdot (q_{fg})$$

$$Q_{bg} = \frac{1}{M_{clm,CV}} \cdot C_{ox1} \cdot W_{eff} \cdot L_{eff} \cdot (q_{bg})$$

$$Q_{d} = \frac{1}{M_{clm,CV}} \cdot C_{ox1} \cdot W_{eff} \cdot L_{eff} \cdot (-q_{d1} - q_{d2})$$

Parasitic Resistance and Capacitance Models

BSIM-IMG models the parasitic source/drain resistance in two components, a bias dependent extension resistance, and a bias independent diffusion resistance.

The parasitic capacitance model in BSIM-MG includes a bias-independent outer fringe capacitance, a bias-dependent inner fringe capacitance, a bias-dependent overlap capacitance, and substrate capacitances.

Bias-dependent Extension Resistance

RDSMOD=0 (Internal)

$$R_{ds} = \frac{1}{NF \cdot W_{eff}^{WR}} \cdot \left(RDSWMIN(T) + \frac{RDSW(T)}{1 + PRWG_i \cdot q_{ia}}\right)$$

RDSMOD=1 (External)

$$R_{source} = \frac{1}{W_{eff0}^{WR} \cdot NF} \cdot \left(RSWMIN(T) + \frac{RSW(T)}{1 + PRWG_i \cdot V_{gs,\,eff}}\right) + R_{s,\,geo}$$

$$R_{drain} = \frac{1}{W_{eff0}^{WR} \cdot NF} \cdot \left(RDWMIN(T) + \frac{RDW(T)}{1 + PRWG_i \cdot V_{gd,\,eff}}\right) + R_{d,\,geo}$$

Bias-independent Diffusion Resistance

$$R_{s,\,geo} = NRD \cdot RSHS$$

$$R_{d,\,geo} = NRD \cdot RSHD$$

Overlap Capacitance Model

$$Q_{fgs,\,ov} = W_{eff,\,CV} \cdot LOVS_i \cdot C_{ox1} \cdot C(ge, s) + W_{eff,\,CV} \cdot CGSL$$

$$\left\{V_{fgs,\,noswap} - V_{fbsd} - V_{fgs,\,ov} - \frac{1}{2} \cdot CKAPPAS \cdot \left[\left(\sqrt{1 - \frac{4V_{gs,\,overlap}}{CKAPPAS}} - 1\right)\right]\right\} \cdot devsign$$

$$Q_{fgd,\,ov} = W_{eff,\,CV} \cdot LOVD_i \cdot C_{ox1} \cdot V(ge, d) + W_{eff,\,CV} \cdot CGDL$$

$$\left\{V_{fgd,\,noswap} - V_{fbsd} - V_{fgd,\,ov} - \frac{1}{2} \cdot CKAPPAS \cdot \left[\left(\sqrt{1 - \frac{4V_{gd,\,overlap}}{CKAPPAD}} - 1\right)\right]\right\} \cdot devsign$$

Outer Fringe Capacitances

$$Q_{fgs,\,of} = W_{eff,\,CV} \cdot CFS \cdot V(ge, s)$$

$$Q_{fgd,\,of} = W_{eff,\,CV} \cdot CFD \cdot V(ge, d)$$

Inner Fringe Capacitance

$$C_{if,factor} = ETACIF \cdot W_{eff,CV} \cdot \frac{2\varepsilon_{si}}{\pi}$$

$$1n\left[\frac{\varepsilon_{ratio} \cdot EOT1 + TSI + \sqrt{L_{un}^{2} + TSI^{2} + 2\varepsilon_{ratio} \cdot EOT1 \cdot TSI}}{L_{un} + \varepsilon_{ratio} \cdot EOT1}\right]$$

$$Q_{fgs,if} = devsign \cdot C_{if,factor} \cdot \left(\psi_{fs} - 0.0 - \frac{1}{2}E_{g}\right)$$

$$Q_{fgd,if} = devsign \cdot C_{if,factor} \cdot \left(\psi_{fd} - V_{ds} - \frac{1}{2}E_{g}\right)$$

Source/drain to Substrate Capacitances

$$C_{sdbgsw0} = CSDBGSW \cdot 1n\left(1 + \frac{TSI}{EOT2}\right)$$

$$Q_{sbg} = [C_{ox2} \cdot AS + (PS - W) \cdot C_{sdbgsw0}] \cdot V(s, bg)$$

$$Q_{dbg} = [C_{ox2} \cdot AD + (PD - W) \cdot C_{sdbgsw0}] \cdot V(d, bg)$$

Impact Ionization and GIDL/GISL Model

Impact Ionization Current

$$Iii = \frac{ALPHA0_{i} + ALPHA1_{i} \cdot L_{eff}}{L_{eff}}(V_{ds} - V_{dseff}) \cdot e^{\frac{-BETA0}{V_{ds} - V_{dseff}}} \cdot Ids$$

Gate-Induced-Drain/Source-Leakage Current

$$I_{gidl} = AGIDL \cdot W_{eff} \cdot \frac{V_{ds} - V_{fgs} - EGIDL + V_{fbsd}}{\varepsilon_{ratio} \cdot EOT1} \times \exp\left(-\frac{\varepsilon_{ratio} \cdot EOT1 \cdot BGIDL(T)}{V_{ds} - V_{fgs} - EGIDL + V_{fbsd}}\right)$$

$$I_{gisl} = AGIDL \cdot W_{eff} \cdot \frac{-V_{ds} - V_{fgd} - EGIDL + V_{fbsd}}{\varepsilon_{ratio} \cdot EOT1} \times \exp\left(-\frac{\varepsilon_{ratio} \cdot EOT1 \cdot BGIDL(T)}{-V_{ds} - V_{fgd} - EGIDL + V_{fbsd}}\right)$$

Gate Tunneling Current

Gate to channel current (I_{gc})

$$I_{gcs} = \frac{W_{eff} \cdot L_{eff} \cdot A}{\left(\frac{EOT1 \cdot EPSROX}{3.9}\right)^2} \cdot V'_{fgs} \cdot V_{auxs}$$

$$\cdot \exp\left(-B \cdot \frac{EOT1 \cdot EPSROX}{3.9} \cdot (AIGC - BIGC \cdot V_{oxm})\right) \cdot (1 + CIGC \cdot V_{oxm})$$

$$I_{gcd} = \frac{W_{eff} \cdot L_{eff} \cdot A}{\left(\frac{EOT1 \cdot EPSROX}{3.9}\right)^2} \cdot V'_{fgd} \cdot V_{auxd}$$

$$\cdot \exp\left(-B \cdot \frac{EOT1 \cdot EPSROX}{3.9} \cdot (AIGC - BIGC \cdot V_{oxm})\right) \cdot (1 + CIGC \cdot V_{oxm})$$

$$I_{gc} = I_{gcs} + I_{gcd}$$

Gate to source/drain current (I_{gs}, I_{gd})

$$I_{gs} = \frac{W_{eff} \cdot DLCIG \cdot A}{\left(EOT \cdot \frac{EPSROX}{3.9} \cdot POXEDGE_i\right)^2} \cdot V_{fgs} \cdot V'_{fgs}$$

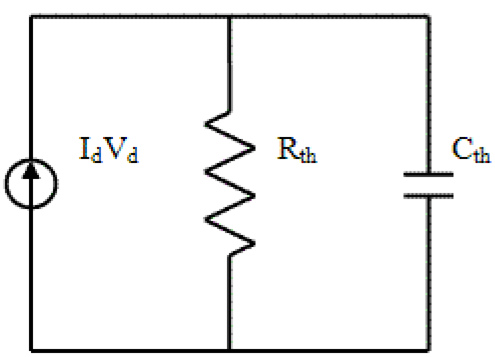
$$\cdot \exp\left(-B \cdot EOT \cdot \frac{EPSROX}{3.9} \cdot POXEDGE_i \cdot (AIGS_i - BIGS_i \cdot V'_{fgs}) \cdot (1 + CIGS_i \cdot V'_{fgs})\right)$$

$$I_{gd} = \frac{W_{eff} \cdot DLCIG \cdot A}{\left(EOT \cdot \frac{EPSROX}{3.9} \cdot POXEDGE_i\right)^2} \cdot V_{fgd} \cdot V'_{fgd}$$

$$\cdot \exp\left(-B \cdot EOT \cdot \frac{EPSROX}{3.9} \cdot POXEDGE_i \cdot (AIGS_i - BIGS_i \cdot V'_{fgd}) \cdot (1 + CIGS_i \cdot V'_{fgd})\right)$$

Self Heating Model

Figure 46-1 R-C network for self-heating calculation



Thermal resistance and capacitance calculations

$$\frac{1}{R_{th}} = G_{th} = \frac{WTH0 + W_{eff} \cdot NF}{RTH0}$$

$$C_{th} = CTH0 \cdot (WTH0 + W_{eff} \cdot NF)$$

Component Statements

Sample Model Statement

```
Model nch bsimimg devtype=1 gidlmod=1 igmod=1 rdsmod=1 nobody=1e22
```

Sample Instance Statement

```
m1 (d fg s bg) nch1=30n w=1u nf=4
```

Instance Definition

```
Name  d  fg  s  bg ModelName parameter=value ...
```

Instance Parameters

1 `exp_cr=80.0` instance parameter

2 `cmi_limexp_method=1.0` instance parameter

3 `cmi_compactable=1.0` instance parameter

4 `m=1.0` Multiplicity factor.

5 `l=(30 1.0e-9)` Designed Gate Length.

6 `w=(1 1.0e-6)` Designed Gate Width.

7 `nf=1` Number of fingers.

8 `as=0.0`	Source area in m^2.
9 `ad=0.0`	Drain area in m^2.
10 `ps=0.0`	Source perimeter in m.
11 `pd=0.0`	Drain perimeter in m.
12 `nrs=0.0`	Number of source diffusion square.
13 `nrd=0.0`	Number of source diffusion squares.
14 `xl=0`	L offset for channel length due to mask/etch effect.
15 `delvtrand=0`	Variability in Vth.
16 `u0mult=1`	Variability in carrier mobility.
17 `ids0mult=1`	Variability in Drain current for misc. reasons.

Model Definition

model modelName bsimimg parameter=value ...

Model Parameters

1 `devtype=1`	Device doping type. 0: ptype, 1: ntype.
2 `rdsmod=0`	0: Internal s/d resistance model; 1: External s/d resistance model.
3 `gidlmod=0`	0: Turn off GIDL/GISL current; 1: Turn on GIDL/GISL current.
4 `igmod=0`	Gate current switcher; 0=turn off, 1=turn on.
5 `lint=0`	Length reduction parameter.
6 `rgatemod=0`	0: Gate electrode resistance / ge node turned off, 1: Gate electrode resistance / ge node turned on.
7 `nqsmod=0`	0: NQS models turned off, 1: NQS gate resistance / gi node turned on.

8 `shmod=0`	0: No self-heating, 1: Self-heating turned on.
9 `ll=0`	Length reduction parameter.
10 `lln=1`	Length reduction parameter.
11 `llc=0`	Length reduction parameter.
12 `dlc=0`	Delta L for C-V model.
13 `eot1=(1.0 1.0e-9)`	Equivalent front gate dielectric thickness relative to SiO2, (m).
14 `eot2=(140 1.0e-9)`	Equivalent back gate dielectric thickness relative to SiO2, (m).
15 `tsi=(8.0 1.0e-9)`	Body thickness (m).
16 `nbody=1e22`	channel (body) doping.
17 `nsd=2e26`	Source/drain active doping concentration in m-3.
18 `nbg=6.0e22`	Back gate (or substrate) doping (positive means same as body, vice versa.).
19 `easub=4.05`	Electron affinity of substrate, eV.
20 `ni0sub=1.1e16`	Intrinsic carrier constant at 300.15K, m-3.
21 `bg0sub=1.12`	Band gap of substrate at 300.15K, eV.
22 `nc0sub=2.86e25`	Conduction band density of states, m-3.
23 `phig1=4.61`	Front Gate Workfunction, eV.
24 `phig2=5.17`	Back Gate Workfunction, eV.
25 `epsrsub=11.9`	Relative dielectric constant of the channel material.
26 `epsrox1=3.9`	Relative dielectric constant of the front gate dielectric.
27 `epsrox2=3.9`	Relative dielectric constant of the back gate dielectric.

28 `ascl=0.0`

29 `bscl=0.0`

30 `cit=0` parameter for interface trap.

31 `cdsc=0.14` coupling capacitance between S/D and channel.

32 `cdscd=0.14` drain-bias sensitivity of CDSC.

33 `dvt0=19.20` SCE coefficient.

34 `dvt1=0.45` SCE exponent coefficient.

35 `phin=0.045` Nonuniform vertical doping effect on surface potential, V.

36 `eta0=2.00` DIBL coefficient 1.

37 `dsub=0.375` DIBL coefficient 2.

38 `k1rsce=(-0.32)` Vt Roll-off at moderate Lg.

39 `lpe0=8.2e-9` Vt Roll-off at moderate Lg.

40 `dsc0=0.0`

41 `dsc1=1.00e-9`

42 `vsat=85000`

43 `avsat=0.0`

44 `bvsat=100.0e-9`

45 `vsat1=85000`

46 `avsat1=0.0`

47 `bvsat1=100.0e-9`

48 `deltavsat=1.0`

49 `ksativ=1.0`

```
mexp=4
amexp=0.0
bmexp=1.0
ptwg=0.0
aptwg=0.0
bptwg=100.0e-9
at=(-1.56e-3)
tmexp=0.0
ptwgt=0.004
ptwgb=0.0
vsatb=0.0
u0=0.03
etamob=2.0
up=0
lpa=1.0
ua=0.3
aua=0.0
bua=100.0e-9
eu=2.5
aeu=0.0
beu=100.0e-9
uc=0
```

72 `ud=0.0`

73 `aud=0.0`

74 `bud=50.0e-9`

75 `ucs=1.0`

76 `ute=0.0`

77 `utl=(-1.5e-3)`

78 `ua1=1.032e-3`

79 `ud1=0.0`

80 `ucste=(-4.775e-3)`

81 `rdswmin=0.0`

82 `rdsw=100.0`

83 `ardsw=0.0`

84 `brdsw=100.0e-9`

85 `rswmin=0.0`

86 `rsw=50.0`

87 `arsw=0.0`

88 `brsw=100.0e-9`

89 `rdwmin=0.0`

90 `rdw=50.0`

91 `ardw=0.0`

92 `brdw=100.0e-9`

93	`prwg=0`	
94	`prwb=0`	
95	`wr=1.0`	
96	`prt=0.001`	
97	`pdibl1=1.30`	
98	`pdibl2=2.0e-4`	
99	`drout=1.06`	
100	`pvag=1.0`	
101	`pclm=0.013`	
102	`apclm=0.0`	
103	`bpclm=100.0e-9`	
104	`pclmg=0.0`	
105	`vasat=0.2`	
106	`pclmcv=0.013`	
107	`pclmgcv=0.0`	
108	`vasatcv=0.2`	
109	`rshs=0.0`	Source-side sheet resistance.
110	`rshd=0.0`	Drain-side sheet resistance.
111	`aigc=1.36e-2`	parameter for Igc in inversion.
112	`bigc=1.71e-3`	parameter for Igc in inversion.
113	`cigc=0.075`	parameter for Igc in inversion.
114	`nigc=1.0`	parameter for Igc in inversion.

115 `vthigc=0.3`	parameter for Igc in inversion.
116 `aigs=1.36e-2`	parameter for Igs, Igd.
117 `bigs=1.71e-3`	parameter for Igs, Igd.
118 `cigs=0.075`	parameter for Igs, Igd.
119 `poxedge=1`	Factor for the gate edge Tox.
120 `dlcig=0`	Delta L for Igs/Igd model.
121 `agidl=6.055e-12`	pre-exponential coeff. for GIDL in mho.
122 `bgidl=3.0e8`	exponential coeff. for GIDL in V/m.
123 `egidl=0.2`	band bending parameter for GIDL in V.
124 `alpha0=0.0`	first parameter of Iii, m/V.
125 `alpha1=0.0`	L scaling parameter of Iii, 1/V.
126 `beta0=0.0`	Vds dependent parameter of Iii, 1/V.
127 `lovs=0.0`	Overlap length for fg/s fg/d overlap (m).
128 `lovd=0.0`	Overlap length for fg/s fg/d overlap (m).
129 `cfs=0.0`	Outer Fringe Cap (F).
130 `cfd=0.0`	Outer Fringe Cap (F).
131 `cgsl=0.0`	
132 `cgdl=0.0`	
133 `ckappas=0.6`	
134 `ckappad=0.6`	
135 `etacif=1.0`	
136 `csdbgsw=0.0`	Source/drain sidewall fringing capacitance per unit length.

137 `kbg0=1.0`	Length dependence of body factor.
138 `kbg1=0.0`	Length dependence of body factor.
139 `kbg2=(-1.0)`	Length dependence of body factor.
140 `dbg=0.12`	Length dependence of body factor.
141 `tnom=27.0`	Temperature at which the model is extracted (Celcius).
142 `tbgasub=7.02e-4`	Bandgap Temperature Coefficient (eV / degrees).
143 `tbgbsub=1108.0`	Bandgap Temperature Coefficient (degrees).
144 `kt1=0.0`	Vth Temperature Coefficient (V).
145 `kt1l=0.0`	Vth Temperature L Coefficient (m-V).
146 `kt2=0.0`	Vth Temperature Vbg Coefficient (V).
147 `kt3=0.0`	Vth Temperature Vds Coefficient (V).
148 `iit=(-0.5)`	Impact Ionization Temperature Dependence.
149 `tgidl=(-0.003)`	GIDL/GISL Temperature Dependence.
150 `igt=2.5`	Gate Current Temperature Dependence.
151 `rth0=0.01`	Thermal resistance.
152 `cth0=1.0E-05`	Thermal capacitance.
153 `wth0=0.0`	Width dependence coefficient for Rth and Cth.
154 `rdkeep=0`	
155 `rskeep=0`	
156 `lrdsw=0.0`	
157 `wrdsw=0.0`	
158 `prdsw=0.0`	

159 `lrdw=0.0`

160 `wrdw=0.0`

161 `prdw=0.0`

162 `lrsw=0.0`

163 `wrsw=0.0`

164 `prsw=0.0`

165 `lprwg=0.0`

166 `wprwg=0.0`

167 `pprwg=0.0`

168 `lprwb=0.0`

169 `wprwb=0.0`

170 `pprwb=0.0`

171 `lwr=0.0`

172 `wwr=0.0`

173 `pwr=0.0`

174 `lphig1=0.0`

175 `wphig1=0.0`

176 `pphig1=0.0`

177 `lphig2=0.0`

178 `wphig2=0.0`

179 `pphig2=0.0`

180 `lnsd=0.0`

181 `wnsd=0.0`

182 `pnsd=0.0`

183 `lnbody=0.0`

184 `wnbody=0.0`

185 `pnbody=0.0`

186 `lcit=0.0`

187 `wcit=0.0`

188 `pcit=0.0`

189 `lcdsc=0.0`

190 `wcdsc=0.0`

191 `pcdsc=0.0`

192 `lcdscd=0.0`

193 `wcdscd=0.0`

194 `pcdscd=0.0`

195 `ldvt0=0.0`

196 `wdvt0=0.0`

197 `pdvt0=0.0`

198 `ldvt1=0.0`

199 `wdvt1=0.0`

200 `pdvt1=0.0`

201 `lphin=0.0`

202 `wphin=0.0`

```
pphin=0.0
leta0=0.0
weta0=0.0
peta0=0.0
ldsub=0.0
wdsub=0.0
pdsub=0.0
lk1rsce=0.0
wk1rsce=0.0
pk1rsce=0.0
llpe0=0.0
wlpe0=0.0
plpe0=0.0
lmexp=0.0
wmexp=0.0
pmexp=0.0
lptwg=0.0
wptwg=0.0
pptwg=0.0
lptwgt=0.0
wptwgt=0.0
pptwgt=0.0
```

```
lu0=0.0
wu0=0.0
pu0=0.0
lua=0.0
wua=0.0
pua=0.0
luc=0.0
wuc=0.0
puc=0.0
lud=0.0
wud=0.0
pud=0.0
lucs=0.0
wucs=0.0
pucs=0.0
leu=0.0
weu=0.0
peu=0.0
lutl=0.0
wutl=0.0
putl=0.0
lute=0.0
```

```
wute=0.0
pute=0.0
lua1=0.0
wua1=0.0
pua1=0.0
lud1=0.0
wud1=0.0
pud1=0.0
lucste=0.0
wucste=0.0
pucste=0.0
lat=0.0
wat=0.0
pat=0.0
lprt=0.0
wprt=0.0
pprt=0.0
liit=0.0
wiit=0.0
piit=0.0
ltgidl=0.0
wtgidl=0.0
```

269 ptgidl=0.0

270 ligt=0.0

271 wigt=0.0

272 pigt=0.0

273 lpclm=0.0

274 wpclm=0.0

275 ppclm=0.0

276 lpclmcv=0.0

277 wpclmcv=0.0

278 ppclmcv=0.0

279 ldrout=0.0

280 wdrout=0.0

281 pdrout=0.0

282 lpdibl1=0.0

283 wpdibl1=0.0

284 ppdibl1=0.0

285 lpdibl2=0.0

286 wpdibl2=0.0

287 ppdibl2=0.0

288 lpvag=0.0

289 wpvag=0.0

290 ppvag=0.0

291 `lalpha0=0.0`

292 `walpha0=0.0`

293 `palpha0=0.0`

294 `lalpha1=0.0`

295 `walpha1=0.0`

296 `palpha1=0.0`

297 `lbeta0=0.0`

298 `wbeta0=0.0`

299 `pbeta0=0.0`

300 `laigc=0.0`

301 `waigc=0.0`

302 `paigc=0.0`

303 `lbigc=0.0`

304 `wbigc=0.0`

305 `pbigc=0.0`

306 `lcigc=0.0`

307 `wcigc=0.0`

308 `pcigc=0.0`

309 `lnigc=0.0`

310 `wnigc=0.0`

311 `pnigc=0.0`

312 `lagidl=0.0`

```
wagidl=0.0
pagidl=0.0
lbgidl=0.0
wbgidl=0.0
pbgidl=0.0
legidl=0.0
wegidl=0.0
pegidl=0.0
laigs=0.0
waigs=0.0
paigs=0.0
lbigs=0.0
wbigs=0.0
pbigs=0.0
lcigs=0.0
wcigs=0.0
pcigs=0.0
lpoxedge=0.0
wpoxedge=0.0
ppoxedge=0.0
llovs=0.0
wlovs=0.0
```

335 `plovs=0.0`

336 `llovd=0.0`

337 `wlovd=0.0`

338 `plovd=0.0`

339 `lcfs=0.0`

340 `wcfs=0.0`

341 `pcfs=0.0`

342 `lcfd=0.0`

343 `wcfd=0.0`

344 `pcfd=0.0`

345 `lvsat=0.0`

346 `wvsat=0.0`

347 `pvsat=0.0`

348 `lvsat1=0.0`

349 `wvsat1=0.0`

350 `pvsat1=0.0`

351 `lksativ=0.0`

352 `wksativ=0.0`

353 `pksativ=0.0`

354 `lup=0.0`

355 `wup=0.0`

356 `pup=0.0`

Output Parameters

1 `d`

2 `fg`

3 `s`

4 `bg`

5 `di`

6 `si`

7 `ge`

8 `gi`

9 `t`

Operating-Point Parameters

1 `exp_cr=80.0` instance parameter

2 `cmi_limexp_method=1.0` instance parameter

3 `cmi_compactable=1.0` instance parameter

4 `m=1.0` Multiplicity factor.

5 `l=(30 1.0e-9)` Designed Gate Length.

6 `w=(1 1.0e-6)` Designed Gate Width.

7 `nf=1` Number of fingers.

8 `as=0.0` Source area in m^2.

9 `ad=0.0` Drain area in m^2.

10 `ps=0.0` Source perimeter in m.

11 `pd=0.0`	Drain perimeter in m.
12 `nrs=0.0`	Number of source diffusion square.
13 `nrd=0.0`	Number of source diffusion squares.
14 `xl=0`	L offset for channel length due to mask/etch effect.
15 `delvtrand=0`	Variability in Vth.
16 `u0mult=1`	Variability in carrier mobility.
17 `ids0mult=1`	Variability in Drain current for misc. reasons.
18 `op_ids (A)`	
19 `op_qfg (C)`	
20 `op_qbg (C)`	
21 `op_qd (C)`	
22 `op_qs (C)`	
23 `op_ueff`	
24 `op_cfgd (F)`	
25 `op_cfgfg (F)`	
26 `op_cfgs (F)`	
27 `op_cfgbg (F)`	
28 `op_cbgd (F)`	
29 `op_cbgfg (F)`	
30 `op_cbgs (F)`	
31 `op_cbgbg (F)`	
32 `op_cdd (F)`	

33 `op_cdfg (F)`

34 `op_cds (F)`

35 `op_cdbg (F)`

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

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Angelov Model

The Angelov model is an empirical equation-based large signal model that is used for III-V field effect transistors, such as HEMT and MESFET. An enhancement version of Angelov model, which was developed by L.S. Liu, J.G. Ma, and G.I. Ng is also integrated into this model, which improves both model accuracy and convergence. The enhancement version is called as MA (modified Angelov) model, which can be turned on with model parameter `ma_mod=1`.

This chapter contains the following information for the Angelov model:

Ma Model Equation

To activate the Ma model, you need to set the value of the `ma_model` model parameter to `1`.

There are two I_{ds} equations in the Ma model referred to as `idsmo`d=0 and `idsmod=1`.

$$Ids = Ids_1 \cdot Ids_2$$

$$Ids_2 = \tanh(\alpha Vds)(1 + \lambda Vds)$$

For `Idsmod=0` (with Gm compression and $Isat \approx 2Ipk$).

$$Ids_1 = Ipk[1 + \tanh(\Psi_1)]$$

$$\Psi_1 = P_1 \cdot V_{gsp} + P_{21} \cdot Veff^2 p1 + P_{31} \cdot Veff^3 p1 + P_{22} \cdot Veff^2 p2 + P_{32} \cdot Veff^3 p2$$

For `Idsmod=1` (with Gm compression and $Isat \neq 2Ipk$)

$$Ids_1 = Ipk[1 + \tanh(ph_1)] + Ipk' \tanh(ph_2)$$

$$Ipk' = Ipk$$

$$ph_1 = P_1 \cdot Veff_{p1} + P_2 \cdot Veff^2 p1 + P_3 \cdot Veff^3 p1$$

$$ph_2 = P^{'} 1 \cdot Veff_{p2} + P_{22} \cdot Veff^2 p2 + P_{32} \cdot Veff^3 p2$$

$$P_1' = P_1 \cdot Ipk/Ipk'$$

Component Statements

This device is supported within altergroups.

Sample Instance Statement

```
pch (1234) pchmod m=1 trise=20
```

Sample Model Statement

```
model pchmod angelov  idsmod=1 igmod=1 ij=25.92e-9 ipk0=12.17e-3 kf=0.0 klf=0.0
lambda1=1e-3 lambda=71.08e-3 ld=76.3e-12 rc=10.0e3 rcin=100e3 rcmin=1.0 rd=4.122
rg=74.35 rgd=32.54 ri=144.7 rs=6.2 rth=1.09e3 selft=1 tau=1.0e-12 td1=100e-3 td=25
tg=25 tmn=1.0 tnom=25 vjg=374.1e-3 vkn=800.0e-3
```

Instance Definition

```
Name d g s [t] ModelName parameter=value ...
```

Instance Parameters

1	`m=1.0`	Multiplicity factor.
2	`w=1e-6 m`	Gate width, unused but reserved.
3	`ng=1`	Gate fingers, unused but reserved.
4	`mode=1`	Unused but reserved.
5	`noise=1`	Unused but reserved.
6	`trise=0.0 C`	Difference sim. temp and device temp.
7	`temp=27 C`	Device temp only used if Trise is zero.

Model Definition

model modelName angelov parameter=value ...

Model Parameters

1	`type=n`	Channel type parameter, n=NFET p=PFET. Possible values are `n` or `p`.
2	`noimod=1`	Unused but reserved.
3	`selft=0`	Flag for self-heating.

4 `idsmod=0`	Ids Current Model [0:3].
5 `igmod=0`	Select gate diode model [0:1].
6 `capmod=2`	Select cap model [0:2].
7 `ipk0=0.05 A`	Current for max. transconductance Ipk.
8 `vpks=(-0.2) V`	Gate voltage Vpk for max transconductance.
9 `dvpks=0.2 V`	Delta gate voltage at peak gm.
10 `p1=1.0 1/V`	Polynomial coeff P1 for channel current.
11 `p2=0.0` $1/V^2$	Polynomial coeff P2 for channel current.
12 `p3=0.0` $1/V^3$	Polynomial coeff P3 for channel current.
13 `alphar=0.1 1/V`	Saturation parameter alpha_r.
14 `alphas=1.0 1/V`	Saturation parameter alpha.
15 `vkn=0.8 V`	Knee voltage.
16 `lambda=0.0`	Channel length modulation parameter.
17 `lambda1=0.0`	Channel length modulation parameter.
18 `lvg=0.0`	Coeff for channel length modulation parameter
19 `b1=0.0`	Unsaturated coeff B1 for P1.
20 `b2=3.0 1/V`	Saturated coeff B2 for P1.
21 `lsb0=0.0`	Soft breakdown model parameter.
22 `vtr=20.0 V`	Soft breakdown model parameter.
23 `vsb2=0.0 V`	Surface breakdown model parameter.
24 `cds=0 F`	Zero-bias D-S junction capacitance.

25 `cgspi=0.0 F` Gate-source pinch-off capacitance.

26 `cgs0=0.0 F` Gate-source capacitance parameter.

27 `cgdpi=0.0 F` Gate-drain pinch-off capacitance.

28 `cgdpe=0 F` External G-D Capacitor.

29 `cgd0=0.0 F` Gate-drain capacitance parameter Cgdo.

30 `p10=0.0` Polynomial coeff P10 for capacitance.

31 `p11=1.0` Polynomial coeff P11 for capacitance.

32 `p20=0.0` Polynomial coeff P20 for capacitance.

33 `p21=0.2` Polynomial coeff P21 for capacitance.

34 `p30=0.0` Polynomial coeff P30 for capacitance.

35 `p31=0.2` Polynomial coeff P31 for capacitance.

36 `p40=0.0` Polynomial coeff P40 for capacitance.

37 `p41=1.0` Polynomial coeff P41 for capacitance.

38 `p111=0.0` Polynomial coeff P400 for capacitance.

39 `ij=0.00005 A` Gate fwd saturation current.

40 `pg=15.0` Gate current parameter.

41 `ne=1.4` Gate p-n emission coeff.

42 `vjg=0.7 V` Gate current parm.

43 `rg=0.0` Ohm Gate ohmic resistance.

44 `rd=0.0` Ohm Drain ohmic resistance.

45 `ri=0.0` Ohm Input resistance.

46 `rs=0.0` Ohm Source ohmic resistance.

47 `rgd=0` Ohm — Gate resistance.

48 `ld=0 H` — Drain ohmic inductance.

49 `ls=0 H` — Source ohmic inductance.

50 `lg=0 H` — Gate ohmic inductance.

51 `tau=0 s` — Device delay.

52 `rcmin=1.0e3` Ohm — Min value of Rc.

53 `rc=10.0e3` Ohm — R for freq dep output cond.

54 `crf=0.0 F` — C for freq dep output cond.

55 `rcin=100.0e3` Ohm — R for freq dep input cond.

56 `crfin=0.0 F` — C for freq dep input cond.

57 `rth=0.0` Ohm — Thermal resistance.

58 `cth=0.0 F` — Thermal capacitance.

59 `tcipk0=0.0 A/K` — Linear temp coef TIpk for Ipk.

60 `tcp1=0.0 A/K` — Linear temp coef TIpk for Ipk.

61 `tccgs0=0.0` — Linear temp coef Cgs0 parm.

62 `tccgd0=0.0` — Linear temp coef Cgd0 parm.

63 `tclsb0=0.0` — Linear temp coef Lsb0 parm.

64 `tcrc=0.0` — Linear temp coef Rc parm.

65 `tccrf=0.0` — Linear temp coef Crf parm.

66 `noiser=0.5` — Gate noise coeff.

67 `noisep=1.0` — Gate noise coeff.

68 `noisec=0.9` — Gate-drain noise coeff.

69 `fnc=0.0 Hz` Noise corner freq.

70 `kf=0.0` Flicker noise coeff.

71 `af=1.0` Flicker noise exponent.

72 `ffe=1.0` Flicker noise parameter.

73 `tg=25.0 C` Equiv temp.

74 `td=25.0 C` Equiv temp.

75 `td1=0.1 C` Equiv temp.

76 `tmn=1.0` noise fitting coeff.

77 `klf=1.0e14` Flicker noise exponent.

78 `fgr=60.0e3 Hz` G-R freq corner.

79 `np=0.3` flicker noise freq exp.

80 `lw=0.1 mm` effective gate noise width.

81 `tnom=27 C` param meas T.

82 `ma_mod=0` Flag to turn on Ma model.

Operating-Point Parameters

1 `m=1.0` Multiplicity factor.

2 `w=1e-6 m` Gate width, unused but reserved.

3 `ng=1` Gate fingers, unused but reserved.

4 `mode=1` Unused but reserved.

5 `noise=1` Unused but reserved.

6 `trise=0.0 C` Difference sim. temp and device temp.

7 `temp=27 C` Device temp only used if Trise is zero.

8 `ids (A)` Ids.

9 `igs (A)` Igs.

10 `igd (A)` Igd.

11 `qgd (F)` Qgd.

12 `qgs (F)` Qgs.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

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DIODE_CMC Model

The DIODE_CMC model is based on Juncap2 200.3.3 from NXP Semiconductors. It is mainly used to model those diodes that are formed with MOSFETs. Those MOSFETs have source, drain, or well-to-bulk junctions. Geometrically, DIODE_CMC has capacitances and currents of bottom, gate edge, and STI edge contributions.

This chapter contains the following information for the DIODE_CMC model:

Model Version and Development

The current available version for DIODE_CMC is version 1.0.0.

Model Equations

Junction Charge

$$C_{jo} = CJOR \cdot \left(\frac{VBIR}{V_{bi}}\right)^{P}$$

$$V_j = hyp_5(V_{AK}; V_{F,min}, V_{ch})$$

$$Q'_j = \left\{\frac{C_{j0} \cdot V_{bi}}{1-P} \cdot \left[1 - \left(1 - \frac{V_j}{V_{bi}}\right)^{1-P}\right] + a \cdot C_{j0} \cdot (V_{AK} - V_j)\right\}$$

Ideal Current

$$M_{ID} = \left\{\begin{array}{ll} \exp\left(\frac{V_{AK}}{n \cdot \phi_{TD}}\right) & if\ V_{AK} < V_{max} \\ \left(1 + \frac{V_{AK} - VMAX}{n \cdot \phi_{TD}}\right) \cdot \exp\left(\frac{VMAX}{\phi_{TD}}\right) & if\ V_{AK} \geq V_{max} \end{array}\right\}$$

$$I'_D = (M_{ID} - 1) \cdot I_{DSAT}$$

Shockley-Read-Hall current

$$Z_{inv} = \begin{cases} \sqrt{\exp\left(\frac{V_{AK}}{\phi_{TD}}\right)} & if \quad V_{AK} < V_{max} \\ \sqrt{\left(1 + \frac{V_{AK} - VMAX}{\phi_{TD}}\right) \cdot \exp\left(\frac{VMAX}{\phi_{TD}}\right)} & if \quad V_{AK} \geq V_{max} \end{cases}$$

$$Z = \frac{1}{Z_{inv}}$$

$$\Psi^* = \begin{cases} \phi_{TD} \cdot \ln[z + 2 + \sqrt{(z+1) \cdot (z+3)}] & if \quad V_{AK} > 0 \\ -\frac{V_{AK}}{2} + \phi_{TD} \cdot \ln[1 + 2 \cdot z_{inv} + \sqrt{(1 + z_{inv}) \cdot (1 + 3 \cdot z_{inv})}] & if \quad V_{AK} \leq 0 \end{cases}$$

$$V_{j,\,lim} = V_{bi,\,min} - 2 \cdot \Psi^*$$

$$V_{j,\,SRH} = hyp2(V_{AK}; V_{j,\,lim}, \phi_{TD})$$

$$\Delta w_{SRH} = \left(\frac{w_{SRH,\,step}^2 \cdot \ln w_{SRH,\,step}}{1 - w_{SRH,\,step}} + w_{SRH,\,step}\right) \cdot (1 - 2 \cdot P)$$

$$w_{SRH} = w_{SRH,\,step} + \Delta w_{SRH}$$

$$W_{dep} = \frac{XJUN \cdot \varepsilon_{Si}}{CJOR} \cdot \left(\frac{V_{bi} - V_{j,SRH}}{VBIR}\right)^{P}$$

$$I'_{SRH} = CSRH \cdot F_{TD} \cdot (z_{inv} - 1) \cdot w_{SRH} \cdot W_{dep}$$

Trap-Assisted Tunneling Current

$$F_{max} = \frac{V_{bi} - V_{j,SRH}}{W_{dep} \cdot (1-P)}$$

$$m_{eff} = MEFFTAT \cdot m_0$$

$$\Delta E = max\left(\frac{\phi_{GD}}{2}, \phi_{TD}\right)$$

$$a_{TAT} = \frac{\Delta E}{\phi_{TD}}$$

$$b_{TAT} = \sqrt{\frac{32 \cdot m_{eff} \cdot q \cdot \Delta E^3}{3 \cdot h \cdot F_{max}}}$$

$$u'_{max} = \left(\frac{2 \cdot a_{TAT}}{3 \cdot b_{TAT}}\right)^2$$

$$u_{max} = \sqrt{\frac{{u'}^2_{max}}{{u'}^2_{max} + 1}}$$

$$w_{\Gamma} = \left(1 + b_{TAT} \cdot u_{max}^{\frac{3}{2}}\right)^{\frac{P}{P-1}}$$

$$w_{TAT} = \frac{w_{SRH} \cdot w_{\Gamma}}{w_{SRH} + w_{\Gamma}}$$

$$k_{TAT} = \sqrt{\frac{3 \cdot b_{TAT}}{8 \cdot \sqrt{u_{max}}}}$$

$$l_{TAT} = \frac{4 \cdot a_{TAT}}{3 \cdot b_{TAT}} \cdot \sqrt{u_{max}} - u_{max}$$

$$m_{TAT} = \frac{2 \cdot a_{TAT}^{2}}{3 \cdot b_{TAT}} \cdot \sqrt{u_{max}} - a_{TAT} \cdot u_{max} + \frac{b_{TAT}}{2} u_{max}^{3/2}$$

$$erfcapprox(y) = \left\{ \begin{array}{l} terfc = \begin{array}{lll} \dfrac{1}{1 + p_{erfc} \cdot y} & if & y > 0 \\ \dfrac{1}{1 - p_{erfc} \cdot y} & if & y \le 0 \end{array} \\ erfcapprox^{+} = \left(a_{erfc} \cdot t_{erfc} + b_{erfc} \cdot t_{erfc}^{2} + c_{erfc} \cdot t_{erfc}^{3} \right) \cdot \exp(-y^{2}) \\ erfcapprox(y) = \left\{ \begin{array}{lll} erfcapprox^{+} & if & y > 0 \\ 2 - erfcapprox^{+} & if & y \le 0 \end{array} \right\} \end{array} \right\}$$

$$\Gamma_{max} = \frac{a_{TAT} \cdot \exp(m_{TAT}) \cdot erfcapprox[k_{TAT} \cdot (l_{TAT} - 1)] \cdot \sqrt{\pi}}{2 \cdot k_{TAT}}$$

$$I_{TAT} = CTAT \cdot F_{TD} \cdot (z_{inv} - 1) \cdot \Gamma_{max} \cdot w_{TAT} \cdot W_{dep}$$

Band-to-band tunneling current

$$V_{BBT,lim} = min(VBIRBOT, VBIRSTI, VBIRGAT) - \Delta V_{bi}$$

$$V_{BBT} = hyp_2(V_{AK}, V_{BBT,lim}, \phi_{TR})$$

$$W_{dep,r} = \frac{XJUN \cdot \varepsilon_{Si}}{CJOR} \cdot \left(\frac{VBIR - V_{BBT}}{VBIR}\right)$$

$$F_{max,r} = \frac{VBIR - V_{BBT}}{W_{dep,r} \cdot (1 - P)}$$

$$F_{BBT} = FBBTR \cdot [1 + STFBBT \cdot (T_{KD} - T_{KR})]$$

$$I_{BBT} = CBBT \cdot V_{AK} \cdot F_{max,r}^2 \cdot \exp\left(-\frac{F_{BBT}}{F_{max,r}}\right)$$

Avalanche and Breakdown

$$V_{av} = hyp_2(V_{AK};0, \varepsilon_{av})$$

$$f_{stop} = \frac{1}{1 - \alpha_{av}^{PBR}}$$

$$s_f = -f_{stop}^2 \cdot \alpha_{av}^{PBR - 1} \cdot \frac{PBR}{VBR}$$

$$f_{breakdown} = \begin{cases} \dfrac{1}{1 - \left|\dfrac{-V_{av}}{VBR}\right|^{PBR}} & if \quad V_{av} > -\alpha_{av} \cdot VBR \\ f_{stop} + (V_{av} + \alpha_{av} \cdot VBR) \cdot s_f & if \quad V_{av} \le -\alpha_{av} \cdot VBR \end{cases}$$

Total Current

$$I'_j = (I'_D + I'_{SRH} + I'_{TAT} + I'_{BBT}) \cdot f_{breakdown}$$

Thermal Voltage

$$T_{KR} = T_0 + TRJ$$

$$T_{KD} = max(T_0 + temp + subckt\_\text{trise} + TRISE + DTA, T_0 + T_{min})$$

$$\phi_{TR} = \frac{k_B \cdot T_{KR}}{q}$$

$$\phi_{TD} = \frac{k_B \cdot T_{KD}}{q}$$

Band Gap

$$\Delta\phi_{GR} = -\frac{7.02e-4 \cdot T_{KR}^2}{1108.0 + T_{KR}}$$

$$\phi_{GR,bot} = PHIGBOT + \Delta\phi_{GR}$$

$$\phi_{GR,sti} = PHIGSTI + \Delta\phi_{GR}$$

$$\phi_{GR,gat} = PHIGGAT + \Delta\phi_{GR}$$

$$\Delta\phi_{GD} = -\frac{7.02e-4 \cdot T_{KD}^2}{1108.0 + T_{KD}}$$

$$\phi_{GD,bot} = PHIGBOT + \Delta\phi_{GD}$$

$$\phi_{GD,sti} = PHIGSTI + \Delta\phi_{GD}$$

$$\phi_{GD,gat} = PHIGGAT + \Delta\phi_{GD}$$

Intrinsic Carrier Concentration

$$F_{TD,bot} = \left(\frac{T_{KD}}{T_{KR}}\right)^{XTI/2.0} \cdot \exp\left(\frac{\phi_{GR,bot}}{2 \cdot \phi_{TR}} - \frac{\phi_{GD,bot}}{2 \cdot \phi_{TD}}\right)$$

$$F_{TD,sti} = \left(\frac{T_{KD}}{T_{KR}}\right)^{XTI/2.0} \cdot \exp\left(\frac{\phi_{GR,sti}}{2 \cdot \phi_{TR}} - \frac{\phi_{GD,sti}}{2 \cdot \phi_{TD}}\right)$$

$$F_{TD,gat} = \left(\frac{T_{KD}}{T_{KR}}\right)^{XTI/2.0} \cdot \exp\left(\frac{\phi_{GR,gat}}{2 \cdot \phi_{TR}} - \frac{\phi_{GD,gat}}{2 \cdot \phi_{TD}}\right)$$

Saturation Current Density

$$I_{DSAT,bot} = IDSATRBOT \cdot F_{TD,bot}^{2}$$

$$I_{DSAT,sti} = IDSATRSTI \cdot F_{TD,sti}^{2}$$

$$I_{DSAT,gat} = IDSATRGAT \cdot F_{TD,gat}^{2}$$

Determination of Vmax

$$V_{max,bot} = \begin{cases} V_{max,large} & if \quad I_{DSAT,bot} \cdot AB = 0 \\ \phi_{TD} \cdot \ln\left(\frac{IMAX}{I_{DSAT,bot} \cdot AB} + 1\right) & if \quad I_{DSAT,bot} \cdot AB \neq 0 \end{cases}$$

$$V_{max,sti} = \begin{cases} V_{max,large} & if \quad I_{DSAT,sti} \cdot LS = 0 \\ \phi_{TD} \cdot \ln\left(\frac{IMAX}{I_{DSAT,sti} \cdot LS} + 1\right) & if \quad I_{DSAT,sti} \cdot LS \neq 0 \end{cases}$$

$$V_{max,gat} = \begin{cases} V_{max,large} & if \quad I_{DSAT,gat} \cdot LG = 0 \\ \phi_{TD} \cdot \ln\left(\frac{IMAX}{I_{DSAT,gat} \cdot LG} + 1\right) & if \quad I_{DSAT,gat} \cdot LG \neq 0 \end{cases}$$

$$V_{max} = min(V_{max,bot}, V_{max,sti}, V_{max,gat})$$

Built-In Voltages

$$U_{bi,bot} = VBIRBOT \cdot \frac{T_{KD}}{T_{KR}} - 2 \cdot \phi_{TD} \cdot \ln F_{TD,bot}$$

$$V_{bi,bot} = U_{bi,bot} + \phi_{TD} \cdot \ln\left[1 + \exp\left(\frac{V_{bi,low} - U_{bi,bot}}{\phi_{TD}}\right)\right]$$

$$U_{bi,sti} = VBIRSTI \cdot \frac{T_{KD}}{T_{KR}} - 2 \cdot \phi_{TD} \cdot \ln F_{TD,sti}$$

$$V_{bi,\,sti} = U_{bi,\,sti} + \phi_{TD} \cdot \ln\left[1 + \exp\left(\frac{V_{bi,\,low} - U_{bi,\,sti}}{\phi_{TD}}\right)\right]$$

$$U_{bi,\,gat} = VBIRGAT \cdot \frac{T_{KD}}{T_{KR}} - 2 \cdot \phi_{TD} \cdot \ln F_{TD,\,gat}$$

$$V_{bi,\,gat} = U_{bi,\,gat} + \phi_{TD} \cdot \ln\left[1 + \exp\left(\frac{V_{bi,\,low} - U_{bi,\,gat}}{\phi_{TD}}\right)\right]$$

Determination of VF, min and Vch

$$V_{bi,\,min} = min(V_{bi,\,bot}, V_{bi,\,sti}, V_{bi,\,gat})$$

$$V_{F,\,min} = \begin{cases} V_{bi,\,min} \cdot (1 - a^{-1/(PBOT)}) & if \quad V_{bi,\,min} = V_{bi,\,bot} \\ V_{bi,\,min} \cdot (1 - a^{-1/(PSTI)}) & if \quad V_{bi,\,min} = V_{bi,\,sti} \\ V_{bi,\,min} \cdot (1 - a^{-1/(PGAT)}) & if \quad V_{bi,\,min} = V_{bi,\,gat} \end{cases}$$

$$V_{ch} = \varepsilon_{ch} \cdot V_{bi,\,min}$$

Voltage Difference VAK

$$V_{AK} = TYPE \cdot (V_A - V_K)$$

Final Junction Current

$$I_j = TYPE \cdot MULT \cdot (AB \cdot I'_{j,bot} + LS \cdot I'_{j,sti} + LG \cdot I'_{j,gat})$$

Auxiliary Equations

$$hyp_1(x;\varepsilon) = \frac{1}{2} \cdot \left(x + \sqrt{x^2 + 4 \cdot \varepsilon^2}\right)$$

$$hyp_2(x;x_0, \varepsilon) = x - hyp_1(x - x_0, \varepsilon)$$

$$hyp_5(x;x_0, \varepsilon) = x_0 - hyp_1\left(x_0 - x - \frac{\varepsilon^2}{x_0};\varepsilon\right)$$

Component Statements

This device is supported within altergroups

Instance Definition

```
Name  a  k ModelName parameter=value ...
```

Instance Parameters

1	`ab=1E-12 m`^{2}	Junction area.
2	`area=1E-12`	Junction area.
3	`ls=1e-6 m`	STI-edge part of junction perimeter.
4	`pj=1e-6`	STI-edge part of junction perimeter.

5 `perim=1e-6`	STI-edge part of junction perimeter.
6 `lg=0 m`	Gate-edge part of junction perimeter.
7 `mult=1`	Number of devices in parallel.
8 `m=1`	Number of devices in parallel.
9 `trise=0.0`	Temperature rise from the ambient.
10 `diode_region=1.0`	
11 `region=on`	Estimated operating region. Spectre outputs number (0-2) in a rawfile. Possible values are `off`, `on`, and `breakdown`.

Model Definition

```
model modelName diode_cmc parameter=value ...
```

Model Parameters

1 `level=1002`	Model level must be 1002.
2 `version=1`	Model version.
3 `subversion=0`	Model subversion.
4 `revision=0`	Model revision.
5 `type=n`	Type parameter, n reflects n-type, p reflects p-type. Possible values are `n` and `p`.
6 `dta=0 C`	Temperature offset with respect to ambient temperature.
7 `imax=1000 A`	Maximum current up to which forward current behaves exponentially.
8 `trj=21 C`	Reference temperature.
9 `cjorbot=1E-3` Fm^{-2}	Zero-bias capacitance per unit-of-area of bottom component.

10 `cjorsti=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of STI-edge component.

11 `cjorgat=1E-9 Fm^-1`
Zero-bias capacitance per unit-of-length of gate-edge component.

12 `vbirbot=1 V` Built-in voltage at the reference temperature of bottom component.

13 `vbirsti=1 V` Built-in voltage at the reference temperature of STI-edge component.

14 `vbirgat=1 V` Built-in voltage at the reference temperature of gate-edge component.

15 `pbot=0.5` Grading coefficient of bottom component.

16 `psti=0.5` Grading coefficient of STI-edge component.

17 `pgat=0.5` Grading coefficient of gate-edge component.

18 `phigbot=1.16 V` Zero-temperature bandgap voltage of bottom component.

19 `phigsti=1.16 V` Zero-temperature bandgap voltage of STI-edge component.

20 `phiggat=1.16 V` Zero-temperature bandgap voltage of gate-edge component.

21 `idsatrbot=1E-12 Am`$^{-2}$
Saturation current density at the reference temperature of bottom component.

22 `idsatrsti=1E-18 Am^-1`
Saturation current density at the reference temperature of STI-edge component.

23 `idsatrgat=1E-18 Am^-1`
Saturation current density at the reference temperature of gate-edge component.

24 `csrhbot=1E2 Am`$^{-3}$ Shockley-Read-Hall prefactor of bottom component.

25 `csrhsti=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of STI-edge component.

26 `csrhgat=1E-4 Am`$^{-2}$
Shockley-Read-Hall prefactor of gate-edge component.

27 `xjunsti=100E-9 m` Junction depth of STI-edge component.

28 `xjungat=100E-9 m` Junction depth of gate-edge component.

29 `ctatbot=1E2 Am`$^{-3}$ Trap-assisted tunneling prefactor of bottom component.

30 `ctatsti=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of STI-edge component.

31 `ctatgat=1E-4 Am`$^{-2}$
Trap-assisted tunneling prefactor of gate-edge component.

32 `mefftatbot=0.25` Effective mass (in units of m0) for trap-assisted tunneling of bottom component.

33 `mefftatsti=0.25` Effective mass (in units of m0) for trap-assisted tunneling of STI-edge component.

34 `mefftatgat=0.25` Effective mass (in units of m0) for trap-assisted tunneling of gate-edge component.

35 `cbbtbot=1E-12 AV`$^{-3}$
Band-to-band tunneling prefactor of bottom component.

36 `cbbtsti=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of STI-edge component.

37 `cbbtgat=1E-18 AV`$^{-3}$`m`
Band-to-band tunneling prefactor of gate-edge component.

38 `fbbtrbot=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of bottom component.

39 `fbbtrsti=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of STI-edge component.

40 `fbbtrgat=1E9 Vm^-1`
Normalization field at the reference temperature for band-to-band tunneling of gate-edge component.

41 `stfbbtbot=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of bottom component.

42 `stfbbtsti=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of STI-edge component.

43 `stfbbtgat=(-1E-3) K^-1`
Temperature scaling parameter for band-to-band tunneling of gate-edge component.

44 `vbrbot=10 V` Breakdown voltage of bottom component.

45 `vbrsti=10 V` Breakdown voltage of STI-edge component.

46 `vbrgat=10 V` Breakdown voltage of gate-edge component.

47 `pbrbot=4 V` Breakdown onset tuning parameter of bottom component.

48 `pbrsti=4 V` Breakdown onset tuning parameter of STI-edge component.

49 `pbrgat=4 V` Breakdown onset tuning parameter of gate-edge component.

50 `rsbot=0.0 VA^-1m`^{2}
Series resistance per unit-of-area of bottom component.

51 `rssti=0.0 VA^-1m` Series resistance per unit-of-length of STI-edge component.

52 `rsgat=0.0 VA^-1m` Series resistance per unit-of-length of gate-edge component.

53 `rscom=0.0 ohm` Common series resistance, no scaling .

54 `strs=0` Temperature scaling parameter for series resistance.

55 `kf=0` KF parameter for flicker noise.

56 `af=1.0` AF parameter for flicker noise.

57	`tt=0 s`	Transit time.
58	`stvbrbot1=0 1/K`	Temp. co of breakdown voltage bottom component.
59	`stvbrbot2=0 1/K`^{2}	Temp. co of breakdown voltage bottom component.
60	`stvbrsti1=0 1/K`	Temp. co of breakdown voltage STI-edge component.
61	`stvbrsti2=0 1/K`^{2}	Temp. co of breakdown voltage STI-edge component.
62	`stvbrgat1=0 1/K`	Temp. co of breakdown voltage gate-edge component.
63	`stvbrgat2=0 1/K`^{2}	Temp. co of breakdown voltage gate-edge component.
64	`nfabot=1.0`	ideality factor bottom component.
65	`nfasti=1.0`	ideality factor STI-edge component.
66	`nfagat=1.0`	ideality factor gate-edge component.
67	`abmin=0.0 m`^{2}	minimum allowed junction area.
68	`abmax=1.0 m`^{2}	maximum allowed junction area.
69	`lsmin=0.0 m`	minimum allowed junction STI-edge.
70	`lsmax=1.0 m`	maximum allowed junction STI-edge.
71	`lgmin=0.0 m`	minimum allowed junction gate-edge.
72	`lgmax=1.0 m`	maximum allowed junction gate-edge.
73	`tempmin=(-55) C`	minimum allowed junction temp.
74	`tempmax=155 C`	maximum allowed junction temp.
75	`vfmax=0.0 V`	maximum allowed forward junction bias.
76	`vrmax=0.0 V`	maximum allowed reverse junction bias.
77	`pt=3`	Temp. co of saturation current.
78	`xti=3`	Temp. co of saturation current.

79 `scalee=1.0` Scale parameter.

80 `shrink=0` Scale parameter.

81 `swjunexp=0.0` Flag for JUNCAP-express; 0=full model, 1=express model.

82 `vjunref=2.5` Typical maximum junction voltage; usually about 2*VSUP.

83 `fjunq=0.03` Fraction below which junction capacitance components are considered negligible.

Output Parameters

1 `tempeff (C)` Effective temperature for a single device.

Operating-Point Parameters

1 `diode_region=1.0`

2 `region=on` Estimated operating region. Spectre outputs number (0-2) in a rawfile.
Possible values are `off`, `on`, and `breakdown`.

3 `vak (V)` Voltage between anode and cathode excluding the series resistor.

4 `cj (F)` Total source junction capacitance.

5 `cjbot (F)` Junction capacitance (bottom component).

6 `cjgat (F)` Junction capacitance (gate-edge component).

7 `cjsti (F)` Junction capacitance (STI-edge component).

8 `ij (A)` Total source junction current.

9 `ijbot (A)` Junction current (bottom component).

10 `ijgat (A)` Junction current (gate-edge component).

11 `ijsti (A)` Junction current (STI-edge component).

12 `si (A^2/Hz)` Total junction current noise spectral density.

13 `vrs (V)` Voltage across series resistor.

14 `sf (A^2/Hz)` Total junction flicker noise spectral density.

15 `sr (A^2/Hz)` Total series resistor thermal noise spectral density.

16 `rseries (V/A)` Series resistor.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

49

JFET100 Model

JFET100 is a new model developed by TSMC.

Instance Definition

```
Name  d  g  s  e ModelName parameter=value ...
```

Instance Parameters

1	`l=1.0e-6`	Drawn Length.
2	`w=1.0e-6`	Drawn Width.
3	`nf=1.0`	Number of finger.
4	`as=1.0e-12`	Source diffusion area.
5	`ad=as`	Drain diffusion area.
6	`ps=1.0e-6`	Source diffusion perimeter.
7	`pd=ps`	Drain diffusion perimeter.
8	`nrs=1.0`	Number of squares of drain diffusion for resistance calculations.
9	`nrd=nrs`	Number of squares of source diffusion for resistance calculations.
10	`lgs=1.0e-6`	Space of source to gate open.
11	`lgd=lgs`	Space of drain to gate open.
12	`dtemp=0`	Temperature offset.

13 `trise=0` Temperature offset.

14 `m=1` number of devices in parallel.

Model Definition

model modelName jfet100 parameter=value ...

Model Parameters

1 `level=100` Level no. of the JFET model.

2 `version=0.2` version no. of the JFET model.

3 `type=1` Device type: ntype(1), ptype(-1). Possible values are `p` and `n`.

4 `shmod=0` Self-heating mode: off(0), on(1).

5 `capmod=1` Capacitance mode: single depletion capacitor model(0), double depletion capacitor model(1).

6 `cdsmod=0` Capacitance mode: constant cds capacitor model(0), single-step cds capacitor model(1).

7 `resmod=0` Resistance mode: without internal drain resistance(0), with internal drain resistance(1).

8 `betatempmod=1` Temperature dependence mode of BETA.

9 `tlevc=1` Temperature dependence mode of capacitance .

10 `tlev=1` Temperature dependence mode of bandgap evalation.

11 `xl=0.0` Length offset.

12 `dlc=0.0` Length offset in CV evaluation.

13 `xw=0.0` Width offset.

14 `dwc=0.0` Width offset in CV evaluation.

15 `rg=0.0` Gate resistance.

16 `rs=0.0`	Source resistance.
17 `rd=_mpv(RS)`	Drain resistance.
18 `rdis=0.0`	The resistance in series wtih the gate-source diode.
19 `rdid=_mpv(RDIS)`	The resistance in series with the gate-drain diode.
20 `tnom=25.0`	
21 `eg=1.16`	Energy bandgap for the gate-drain and gate-source diode for TLEV=2.
22 `gap1=7.02e-4`	First bandgap correction factor for TLEV=2.
23 `gap2=1108`	Second bandgap correction factor for TLEV=2.
24 `shconst=5.0`	Temperature smoothing constant.
25 `ifwdlimit=0.01`	Limiting current for the forward gate-drain and gate-source diode per Weff.
26 `iss=1.0e-14`	Saturation current of the gate-source diode per unit area.
27 `nsf=5.0`	Emission coefficient of the gate-source diode.
28 `its=1.0e-14`	Tunneling saturation current of the gate-source diode per unit area.
29 `nts=10.0`	Tunneling emission coefficient of the gate-source diode.
30 `vts=10.0`	Trap-assisted voltage dependent parameter of the gate-source diode.
31 `offsets=0.0`	Offset voltage in evaluating tunneling current of the gate-source diode.
32 `isd=_mpv(ISS)`	Saturation current of the gate-drain diode per unit area.
33 `ndf=_mpv(NSF)`	Emission coefficient of the gate-drain diode.
34 `itd=_mpv(ITS)`	Tunneling saturation current of the gate-drain diode per unit area.

35	`ntd=_mpv(NTS)`	Tunneling emission coefficient of the gate-drain diode.
36	`vtd=_mpv(VTS)`	Trap-assisted voltage dependent parameter of the gate-drain diode.
37	`offsetd=_mpv(OFFSETS)`	Offset voltage in evaluating tunneling current of the gate-drain diode.
38	`alpha=2.0`	Saturation factor.
39	`beta=1.0e-4`	Transconductance parameter.
40	`delta=0.0`	Ids feedback parameter.
41	`gamds=0.0`	Drain induced threshold voltage lowering coefficient.
42	`lambda=0.0`	Channel length modulation parameter.
43	`k1=0.0`	Threshold voltage sensitivity to body bias.
44	`nd=0.0`	Drain subthreshold factor.
45	`ng=0.0`	Gate subthreshold factor.
46	`mstar=0.5`	Fitting factor for moderate inversion condition.
47	`subconst=100.0e-3`	Fitting factor for the subthreshold swing.
48	`ucrit=0.0`	Critical field for mobility degradation.
49	`vgexp=2.0`	Gate voltage exponent.
50	`vto=(-2.0)`	Threshold voltage.
51	`voff=0.0`	Offset voltage in subthreshold region.
52	`satexp=3.0`	Drain voltage exponent.
53	`cvto=0.0`	Threshold voltage for CV model.
54	`calpha=4.0e-2`	Saturation factor for CV model.

55	`cgamds=0.0`	Drain induced threshold voltage lowering coefficient for CV model.
56	`ck1=0.0`	Body bias dependence factor for CV model.
57	`cgs=0.0`	Zero-bias gate-source junction capacitance.
58	`cgd=0.0`	Zero-bias gate-drain junction capacitance.
59	`mjs=0.5`	Grading coefficient for gate-source diode.
60	`mjd=_mpv(MJS)`	Grading coefficient for gate-drain diode.
61	`cgd1=0.0`	Zero-bias gate-drain junction capacitance for the second depletion capacitance (only for CAPMOD=1).
62	`cgs1=0.0`	Zero-bias gate-source junction capacitance for the second depletion capacitance (only for CAPMOD=1).
63	`mjs1=0.2`	Grading coefficient for the second depletion gate-source diode (only for CAPMOD=1).
64	`mjd1=_mpv(MJS1)`	Grading coefficient for the second depletion gate-drain diode (only for CAPMOD=1).
65	`pb=0.8`	Gate junction potential.
66	`fc=0.9`	Coefficient for forward-bias depletion capacitance formulas.
67	`cvtd=0.0`	Second threshold voltage for CV model.
68	`calphad=4.0e-2`	Second Saturation factor for CV model.
69	`covs=0.0`	Overlap capacitance between gate and source.
70	`covd=_mpv(COVS)`	Overlap capacitance between gate and drain.
71	`cvtds=0.0`	First switching voltage for the step like drain-source capacitance (only for CDSMOD=1).
72	`cvtds1=0.0`	Second switching voltage for the step like drain-source capacitance (only for CDSMOD=1).

73 `cvtds2=0.0` Third switching voltage for the step like drain-source capacitance (only for CDSMOD=1).

74 `calphads=4.0e-2` First saturation factor for drain-source capacitance (only for CDSMOD=1).

75 `calphads1=4.0e-2` Second saturation factor for drain-source capacitance (only for CDSMOD=1).

76 `calphads2=4.0e-2` Third saturation factor for drain-source capacitance (only for CDSMOD=1).

77 `mjds=0.5` Grading coefficient for the first drain-source capacitance (only for CDSMOD=1).

78 `mjds1=_mpv(MJDS)` Grading coefficient for the second drain-source capacitance (only for CDSMOD=1).

79 `mjds2=_mpv(MJDS1)`
Grading coefficient for the third drain-source capacitance (only for CDSMOD=1).

80 `mjds3=_mpv(MJDS2)`
Grading coefficient for the fourth drain-source capacitance (only for CDSMOD=1).

81 `capds=0.0` Capacitance between drain and source.

82 `capds1=0.0` Zero-bias drain-source capacitance for the second capacitance (only for CDSMOD=1).

83 `capds2=0.0` Zero-bias drain-source capacitance for the third capacitance (only for CDSMOD=1).

84 `capds3=0.0` Zero-bias drain-source capacitance for the fourth capacitance (only for CDSMOD=1).

85 `pbds=0.8` First Drain-source junction potential (only for CDSMOD=1).

86 `pbds1=0.8` Second Drain-source junction potential (only for CDSMOD=1).

87 `pbds2=0.8` Third Drain-source junction potential (only for CDSMOD=1).

88 `fcds=0.9`	Coefficient for forward-bias drain-source capacitance formulas (only for CDSMOD=1).
89 `capsb=0.0`	Capacitance between source and body.
90 `capdb=0.0`	Capacitance between drain and body.
91 `capgb=0.0`	Capacitance between gate and body.
92 `xtis=0.0`	Junction current temperature exponent for gate-source diode.
93 `xtid=_mpv(XTIS)`	Junction current temperature exponent for gate-drain diode.
94 `xts=0.0`	Power dependence of ITS.
95 `tnts=0.0`	Temperature coefficient of NTS.
96 `xtd=_mpv(XTS)`	Power dependence of ITD.
97 `tntd=_mpv(TNTS)`	Temperature coefficient of NTD.
98 `tvto=0.0`	Temperature coefficient of VTO.
99 `tvoff=0.0`	Temperature coefficient of VOFF.
100 `tgamds=0.0`	Temperature coefficient of GAMDS.
101 `tdelta=0.0`	Temperature coefficient of DELTA.
102 `trg1=0.0`	First order temperature cofficient of RG.
103 `trs1=0.0`	First order temperature cofficient of RS.
104 `trd1=_mpv(TRS1)`	First order temperature cofficient of RD.
105 `trg2=0.0`	Second order temperature cofficient of RG.
106 `trs2=0.0`	Second order temperature cofficient of RS.
107 `trd2=_mpv(TRS2)`	Second order temperature cofficient of RD.
108 `trdis1=0.0`	First order temperature cofficient of RDIS.

109 `trdid1=_mpv(TRDIS1)`
First order temperature cofficient of RDID.

110 `trdis2=0.0` Second order temperature cofficient of RDIS.

111 `trdid2=_mpv(TRDIS2)`
Second order temperature cofficient of RDIS.

112 `ctd=0.0` Temperature coefficient of CGD (TLEVC=1).

113 `cts=_mpv(CTD)` Temperature coefficient of CGS (TLEVC=1).

114 `tpb=0.0` Temperature coefficient of PB (TLEVC=1, 2).

115 `tfbex=1.0` Temperature factor for BEX.

116 `bex1=0.0` First order temperature cofficient of mobility exponent.

117 `bex2=0.0` Second order temperature cofficient of mobility exponent.

118 `tfvgexp=1.0` Temperature factor for VGEXP.

119 `vgexpt1=0.0` First order temperature cofficient of gate voltage exponent.

120 `vgexpt2=0.0` Second order temperature cofficient of gate voltage exponent.

121 `tcvto=0.0` Temperature coefficient of CVTO.

122 `tcgamds=0.0` Temperature coefficient of CGAMDS.

123 `tcvtds=0.0` Temperature coefficient of CVTDS (CDSMOD=1).

124 `ctds=0.0` Temperature coefficient of CAPDS and CAPDS1 (CDSMOD=1).

125 `tcvtd=0.0`

126 `tpbds=0.0` Temperature coefficient of PBDS (CDSMOD=1)).

127 `trdv1=0.0` First order temperature cofficient of RDV.

128 `trdv2=0.0` Second order temperature cofficient of RDV.

129 `trdvg1=0.0` First order temperature cofficient of RDVG.

130 `tvdeff1=0.0`	First order temperature cofficient of VDEFF.
131 `tvdmr1=0.0`	First order temperature cofficient of VDMR.
132 `kf=0.0`	Flicker noise coefficient.
133 `af=1.0`	Flicker noise exponent.
134 `ef=1.0`	Flicker noise frequency exponent.
135 `gdsnoi=1.0`	Channel noise coefficient.
136 `rth0=0.01`	Thermal resistance.
137 `cth0=1.0E-05`	Thermal capacitance.
138 `shlimit=(-1.0)`	Limit of temperature change due to self heating; if it is negative, there is no limit. .
139 `wth0=0.0`	Minimum width for thermal.
140 `ls=2.5e-6`	Length of ohmic open at source side.
141 `ld=_mpv(LS)`	Length of ohmic open at drain side.
142 `lfp=1.0e-6`	Source side field plate.
143 `pfp=1.0e-6`	Gate side field plate.
144 `rdv=0.0`	Voltage dependent RD coefficient.
145 `rdvg=0.2`	Gate-bias dependent RD parameter .
146 `vdeff=1.0`	Drain-bias exponent RD parameter.
147 `vdmr=500`	Drain-bias dependent RD parameter.
148 `liss=0.0`	length dependence of iss.
149 `wiss=0.0`	width dependence of iss.
150 `piss=0.0`	cross-term dependence of iss.

151 `lnsf=0.0` length dependence of nsf.

152 `wnsf=0.0` width dependence of nsf.

153 `pnsf=0.0` cross-term dependence of nsf.

154 `lxtis=0.0` length dependence of xtis.

155 `wxtis=0.0` width dependence of xtis.

156 `pxtis=0.0` cross-term dependence of xtis.

157 `lits=0.0` length dependence of its.

158 `wits=0.0` width dependence of its.

159 `pits=0.0` cross-term dependence of its.

160 `lnts=0.0` length dependence of nts.

161 `wnts=0.0` width dependence of nts.

162 `pnts=0.0` cross-term dependence of nts.

163 `lxts=0.0` length dependence of xts.

164 `wxts=0.0` width dependence of xts.

165 `pxts=0.0` cross-term dependence of xts.

166 `lvts=0.0` length dependence of vts.

167 `wvts=0.0` width dependence of vts.

168 `pvts=0.0` cross-term dependence of vts.

169 `ltnts=0.0` length dependence of tnts.

170 `wtnts=0.0` width dependence of tnts.

171 `ptnts=0.0` cross-term dependence of tnts.

172 `lisd=0.0` length dependence of isd.

173 `wisd=0.0` width dependence of isd.

174 `pisd=0.0` cross-term dependence of isd.

175 `lndf=0.0` length dependence of ndf.

176 `wndf=0.0` width dependence of ndf.

177 `pndf=0.0` cross-term dependence of ndf.

178 `lxtid=0.0` length dependence of xtid.

179 `wxtid=0.0` width dependence of xtid.

180 `pxtid=0.0` cross-term dependence of xtid.

181 `litd=0.0` length dependence of itd.

182 `witd=0.0` width dependence of itd.

183 `pitd=0.0` cross-term dependence of itd.

184 `lntd=0.0` length dependence of ntd.

185 `wntd=0.0` width dependence of ntd.

186 `pntd=0.0` cross-term dependence of ntd.

187 `lxtd=0.0` length dependence of xtd.

188 `wxtd=0.0` width dependence of xtd.

189 `pxtd=0.0` cross-term dependence of xtd.

190 `lvtd=0.0` length dependence of vtd.

191 `wvtd=0.0` width dependence of vtd.

192 `pvtd=0.0` cross-term dependence of vtd.

193 `ltntd=0.0` length dependence of tntd.

194 `wtntd=0.0` width dependence of tntd.

195 `ptntd=0.0`	cross-term dependence of tntd.
196 `lalpha=0.0`	length dependence of alpha.
197 `walpha=0.0`	width dependence of alpha.
198 `palpha=0.0`	cross-term dependence of alpha.
199 `lbeta=0.0`	length dependence of beta.
200 `wbeta=0.0`	width dependence of beta.
201 `pbeta=0.0`	cross-term dependence of beta.
202 `ldelta=0.0`	length dependence of delta.
203 `wdelta=0.0`	width dependence of delta.
204 `pdelta=0.0`	cross-term dependence of delta.
205 `lgamds=0.0`	length dependence of gamds.
206 `wgamds=0.0`	width dependence of gamds.
207 `pgamds=0.0`	cross-term dependence of gamds.
208 `llambda=0.0`	length dependence of lambda.
209 `wlambda=0.0`	width dependence of lambda.
210 `plambda=0.0`	cross-term dependence of lambda.
211 `lk1=0.0`	length dependence of k1.
212 `wk1=0.0`	width dependence of k1.
213 `pk1=0.0`	cross-term dependence of k1.
214 `lnd=0.0`	length dependence of nd.
215 `wnd=0.0`	width dependence of nd.
216 `pnd=0.0`	cross-term dependence of nd.

217 `lng=0.0`	length dependence of ng.
218 `wng=0.0`	width dependence of ng.
219 `png=0.0`	cross-term dependence of ng.
220 `lmstar=0.0`	length dependence of mstar.
221 `wmstar=0.0`	width dependence of mstar.
222 `pmstar=0.0`	cross-term dependence of mstar.
223 `lsatexp=0.0`	length dependence of satexp.
224 `wsatexp=0.0`	width dependence of satexp.
225 `psatexp=0.0`	cross-term dependence of satexp.
226 `lucrit=0.0`	length dependence of ucrit.
227 `wucrit=0.0`	width dependence of ucrit.
228 `pucrit=0.0`	cross-term dependence of ucrit.
229 `lvgexp=0.0`	length dependence of vgexp.
230 `wvgexp=0.0`	width dependence of vgexp.
231 `pvgexp=0.0`	cross-term dependence of vgexp.
232 `lvto=0.0`	length dependence of vto.
233 `wvto=0.0`	width dependence of vto.
234 `pvto=0.0`	cross-term dependence of vto.
235 `lvoff=0.0`	length dependence of voff.
236 `wvoff=0.0`	width dependence of voff.
237 `pvoff=0.0`	cross-term dependence of voff.
238 `lrs=0.0`	length dependence of rs.

239 `wrs=0.0`	width dependence of rs.
240 `prs=0.0`	cross-term dependence of rs.
241 `lrd=0.0`	length dependence of rd.
242 `wrd=0.0`	width dependence of rd.
243 `prd=0.0`	cross-term dependence of rd.
244 `lrg=0.0`	length dependence of rg.
245 `wrg=0.0`	width dependence of rg.
246 `prg=0.0`	cross-term dependence of rg.
247 `lrdis=0.0`	length dependence of rdis.
248 `wrdis=0.0`	width dependence of rdis.
249 `prdis=0.0`	cross-term dependence of rdis.
250 `lrdid=0.0`	length dependence of rdid.
251 `wrdid=0.0`	width dependence of rdid.
252 `prdid=0.0`	cross-term dependence of rdid.
253 `lrdv=0.0`	length dependence of rdv.
254 `wrdv=0.0`	width dependence of rdv.
255 `prdv=0.0`	cross-term dependence of rdv.
256 `lrdvg=0.0`	length dependence of rdvg.
257 `wrdvg=0.0`	width dependence of rdvg.
258 `prdvg=0.0`	cross-term dependence of rdvg.
259 `lvdeff=0.0`	length dependence of vdeff.
260 `wvdeff=0.0`	width dependence of vdeff.

261 `pvdeff=0.0` cross-term dependence of vdeff.

262 `lvdmr=0.0` length dependence of vdmr.

263 `wvdmr=0.0` width dependence of vdmr.

264 `pvdmr=0.0` cross-term dependence of vdmr.

265 `ltrdv1=0.0` length dependence of trdv1.

266 `wtrdv1=0.0` width dependence of trdv1.

267 `ptrdv1=0.0` cross-term dependence of trdv1.

268 `ltrdv2=0.0` length dependence of trdv2.

269 `wtrdv2=0.0` width dependence of trdv2.

270 `ptrdv2=0.0` cross-term dependence of trdv2.

271 `ltrdvg1=0.0` length dependence of trdvg1.

272 `wtrdvg1=0.0` width dependence of trdvg1.

273 `ptrdvg1=0.0` cross-term dependence of trdvg1.

274 `ltrdvg2=0.0` length dependence of trdvg2.

275 `wtrdvg2=0.0` width dependence of trdvg2.

276 `ptrdvg2=0.0` cross-term dependence of trdvg2.

277 `ltvdeff1=0.0` length dependence of tvdeff1.

278 `wtvdeff1=0.0` width dependence of tvdeff1.

279 `ptvdeff1=0.0` cross-term dependence of tvdeff1.

280 `ltvdeff2=0.0` length dependence of tvdeff2.

281 `wtvdeff2=0.0` width dependence of tvdeff2.

282 `ptvdeff2=0.0` cross-term dependence of tvdeff2.

283 `ltvdmr1=0.0` length dependence of tvdmr1.

284 `wtvdmr1=0.0` width dependence of tvdmr1.

285 `ptvdmr1=0.0` cross-term dependence of tvdmr1.

286 `ltvdmr2=0.0` length dependence of tvdmr2.

287 `wtvdmr2=0.0` width dependence of tvdmr2.

288 `ptvdmr2=0.0` cross-term dependence of tvdmr2.

289 `lcvto=0.0` length dependence of cvto.

290 `wcvto=0.0` width dependence of cvto.

291 `pcvto=0.0` cross-term dependence of cvto.

292 `lcalpha=0.0` length dependence of calpha.

293 `wcalpha=0.0` width dependence of calpha.

294 `pcalpha=0.0` cross-term dependence of calpha.

295 `lcgamds=0.0` length dependence of cgamds.

296 `wcgamds=0.0` width dependence of cgamds.

297 `pcgamds=0.0` cross-term dependence of cgamds.

298 `lcvtds=0.0` length dependence of cvtds.

299 `wcvtds=0.0` width dependence of cvtds.

300 `pcvtds=0.0` cross-term dependence of cvtds.

301 `lcvtds1=0.0` length dependence of cvtds1.

302 `wcvtds1=0.0` width dependence of cvtds1.

303 `pcvtds1=0.0` cross-term dependence of cvtds1.

304 `lcvtds2=0.0` length dependence of cvtds2.

305 `wcvtds2=0.0` width dependence of cvtds2.

306 `pcvtds2=0.0` cross-term dependence of cvtds2.

307 `lcalphads=0.0` length dependence of calphads.

308 `wcalphads=0.0` width dependence of calphads.

309 `pcalphads=0.0` cross-term dependence of calphads.

310 `lcalphads1=0.0` length dependence of calphads1.

311 `wcalphads1=0.0` width dependence of calphads1.

312 `pcalphads1=0.0` cross-term dependence of calphads1.

313 `lcalphads2=0.0` length dependence of calphads2.

314 `wcalphads2=0.0` width dependence of calphads2.

315 `pcalphads2=0.0` cross-term dependence of calphads2.

316 `lcalphad=0.0` length dependence of calphad.

317 `wcalphad=0.0` width dependence of calphad.

318 `pcalphad=0.0` cross-term dependence of calphad.

319 `ltgamds=0.0` length dependence of tgamds.

320 `wtgamds=0.0` width dependence of tgamds.

321 `ptgamds=0.0` cross-term dependence of tgamds.

322 `ltvto=0.0` length dependence of tvto.

323 `wtvto=0.0` width dependence of tvto.

324 `ptvto=0.0` cross-term dependence of tvto.

325 `ltvoff=0.0` length dependence of tvoff.

326 `wtvoff=0.0` width dependence of tvoff.

327 `ptvoff=0.0`	cross-term dependence of tvoff.
328 `lck1=0.0`	length dependence of ck1.
329 `wck1=0.0`	width dependence of ck1.
330 `pck1=0.0`	cross-term dependence of ck1.
331 `ltcgamds=0.0`	length dependence of tcgamds.
332 `wtcgamds=0.0`	width dependence of tcgamds.
333 `ptcgamds=0.0`	cross-term dependence of tcgamds.
334 `ltcvto=0.0`	length dependence of tcvto.
335 `wtcvto=0.0`	width dependence of tcvto.
336 `ptcvto=0.0`	cross-term dependence of tcvto.
337 `ltcvtd=0.0`	length dependence of tcvtd.
338 `wtcvtd=0.0`	width dependence of tcvtd.
339 `ptcvtd=0.0`	cross-term dependence of tcvtd.
340 `ltcvtds=0.0`	length dependence of tcvtds.
341 `wtcvtds=0.0`	width dependence of tcvtds.
342 `ptcvtds=0.0`	cross-term dependence of tcvtds.
343 `ltrg1=0.0`	length dependence of trg1.
344 `wtrg1=0.0`	width dependence of trg1.
345 `ptrg1=0.0`	cross-term dependence of trg1.
346 `ltrg2=0.0`	length dependence of trg2.
347 `wtrg2=0.0`	width dependence of trg2.
348 `ptrg2=0.0`	cross-term dependence of trg2.

349 `ltrs1=0.0` length dependence of trs1.

350 `wtrs1=0.0` width dependence of trs1.

351 `ptrs1=0.0` cross-term dependence of trs1.

352 `ltrs2=0.0` length dependence of trs2.

353 `wtrs2=0.0` width dependence of trs2.

354 `ptrs2=0.0` cross-term dependence of trs2.

355 `ltrd1=0.0` length dependence of trd1.

356 `wtrd1=0.0` width dependence of trd1.

357 `ptrd1=0.0` cross-term dependence of trd1.

358 `ltrd2=0.0` length dependence of trd2.

359 `wtrd2=0.0` width dependence of trd2.

360 `ptrd2=0.0` cross-term dependence of trd2.

361 `ltrdis1=0.0` length dependence of trdis1.

362 `wtrdis1=0.0` width dependence of trdis1.

363 `ptrdis1=0.0` cross-term dependence of trdis1.

364 `ltrdis2=0.0` length dependence of trdis2.

365 `wtrdis2=0.0` width dependence of trdis2.

366 `ptrdis2=0.0` cross-term dependence of trdis2.

367 `ltrdid1=0.0` length dependence of trdid1.

368 `wtrdid1=0.0` width dependence of trdid1.

369 `ptrdid1=0.0` cross-term dependence of trdid1.

370 `ltrdid2=0.0` length dependence of trdid2.

371 `wtrdid2=0.0` width dependence of trdid2.

372 `ptrdid2=0.0` cross-term dependence of trdid2.

373 `ltpb=0.0` length dependence of tpb.

374 `wtpb=0.0` width dependence of tpb.

375 `ptpb=0.0` cross-term dependence of tpb.

376 `ltpbds=0.0` length dependence of tpbds.

377 `wtpbds=0.0` width dependence of tpbds.

378 `ptpbds=0.0` cross-term dependence of tpbds.

379 `lbex1=0.0` length dependence of bex1.

380 `wbex1=0.0` width dependence of bex1.

381 `pbex1=0.0` cross-term dependence of bex1.

382 `lbex2=0.0` length dependence of bex2.

383 `wbex2=0.0` width dependence of bex2.

384 `pbex2=0.0` cross-term dependence of bex2.

385 `ltdelta=0.0` length dependence of tdelta.

386 `wtdelta=0.0` width dependence of tdelta.

387 `ptdelta=0.0` cross-term dependence of tdelta.

388 `lvgexpt1=0.0` length dependence of vgexpt1.

389 `wvgexpt1=0.0` width dependence of vgexpt1.

390 `pvgexpt1=0.0` cross-term dependence of vgexpt1.

391 `lvgexpt2=0.0` length dependence of vgexpt2.

392 `wvgexpt2=0.0` width dependence of vgexpt2.

393 `pvgexpt2=0.0` cross-term dependence of vgexpt2.

394 `lrth0=0.0` length dependence of rth0.

395 `wrth0=0.0` width dependence of rth0.

396 `prth0=0.0` cross-term dependence of rth0.

397 `lcth0=0.0` length dependence of cth0.

398 `wcth0=0.0` width dependence of cth0.

399 `pcth0=0.0` cross-term dependence of cth0.

400 vds_max=><Font<FTagsm symbol><FLockedNo>><CharBullet><Font<FTag><FLockedNo>><Font<FTagl literals><FLockedNo>><String V
Maximum allowed voltage cross source and drain.

401 vgd_max=><Font<FTagsm symbol><FLockedNo>><CharBullet><Font<FTag><FLockedNo>><Font<FTagl literals><FLockedNo>><String V
Maximum allowed voltage cross gate and drain.

402 vgs_max=><Font<FTagsm symbol><FLockedNo>><CharBullet><Font<FTag><FLockedNo>><Font<FTagl literals><FLockedNo>><String V
Maximum allowed voltage cross gate and source/bulk.

403 vbd_max=><Font<FTagsm symbol><FLockedNo>><CharBullet><Font<FTag><FLockedNo>><Font<FTagl literals><FLockedNo>><String V
Maximum allowed voltage cross source/drain and bulk.

404 `vbs_max=vbd_max V` Maximum allowed voltage cross source and bulk.

405 vgb_max=><Font<FTagsm symbol><FLockedNo>><CharBullet><Font<FTag><FLockedNo>><Font<FTagl

literals><FLockedNo>><String V
Maximum allowed voltage cross gate and bulk.

406 `vgdr_max=vgd_max V`
Maximum allowed reverse voltage cross gate and drain.

407 `vgsr_max=vgs_max V`
Maximum allowed reverse voltage cross gate and source.

408 `vgbr_max=vgb_max V`
Maximum allowed reverse voltage cross gate and bulk.

409 `vbsr_max=vbs_max V`
Maximum allowed reverse voltage cross source and bulk.

410 `vbdr_max=vbd_max V`
Maximum allowed reverse voltage cross source/drain and bulk.

411 `wmax=1.0 m` Maximum channel width for which the model is valid.

412 `wmin=0.0 m` Minimum channel width for which the model is valid.

413 `lmax=1.0 m` Maximum channel length for which the model is valid.

414 `lmin=0.0 m` Minimum channel length for which the model is valid.

Output Parameters

1 `weff` effective channel width.

2 `leff` effective channel length.

3 `weffcv` effective channel width for CV.

4 `leffcv` effective channel length for CV.

5 `meff` Effective multiplicity factor (m-factor).

Operating-Point Parameters

1 `devtemper` device temperature.

2 `ids (A)`	Channel Current.
3 `igs (A)`	Gate-to-source Current.
4 `igd (A)`	Gate-to-drain Current.
5 `vgs (V)`	Voltage difference between the terminals of the gate-source diode for IV evaluation.
6 `vgd (V)`	Voltage difference between the terminals of the gate-drain diode for IV evaluation.
7 `vgscv (V)`	Voltage difference between the terminals of the gate-source diode for CV evaluation.
8 `vgdcv (V)`	Voltage difference between the terminals of the gate-drain diode for CV evaluation.
9 `vth (V)`	Threshold voltage.
10 `gm`	transconductance.
11 `gds`	conductance.
12 `cgd (C)`	intrinsic gate-to-drain capacitance.
13 `cgs (C)`	intrinsic gate-to-drain capacitance.

Parameter Index

In the following index, `I` refers to instance parameters, `M` refers to the model parameters section, `O` refers to the output parameters section, and `OP` refers to the operating point parameters section. The number indicates where to look in the appropriate section to find the description for that parameter. For example, a reference of `M-35` means the 35th model parameter.

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