CHAPTER 7

Transistor Amplifiers

- After completing this chapter you will learn
  1. How to use MOSFET as amplifier
  2. How to model the linear operation of the transistor around the Q point using an equivalent circuit (small signal model)
  3. The three basic amplifier configuration

- In saturation, the MOSFET acts as a voltage controlled current source

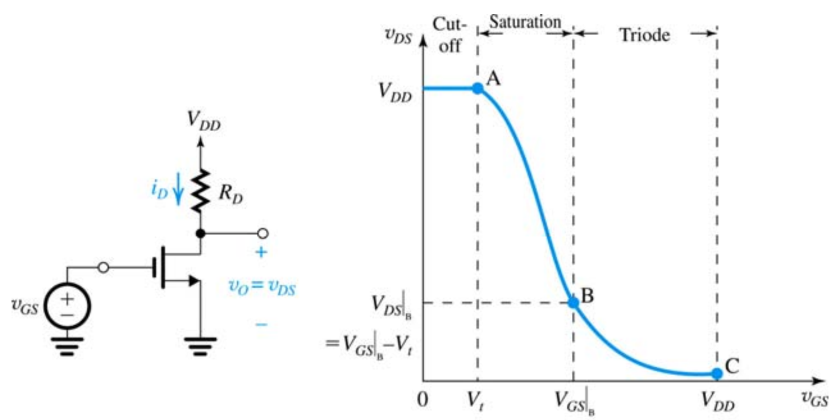
$$i_D = \frac{1}{2} k_n' \left(\frac{W}{L} \right) V_{ov}^2 (1 + \lambda v_{DS})$$

- Non-linear
- If the current (i_D) flows in a resistive load, output voltage is proportional to i_D.

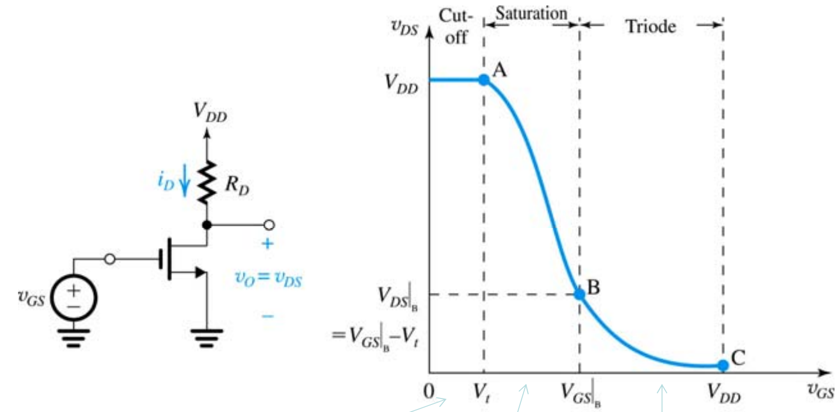
MOSFET as an amplifier

$v_o = v_{DS} = V_{DD} - i_D R_D$

Later, we will discuss small signal equivalent circuit



(a) (b)



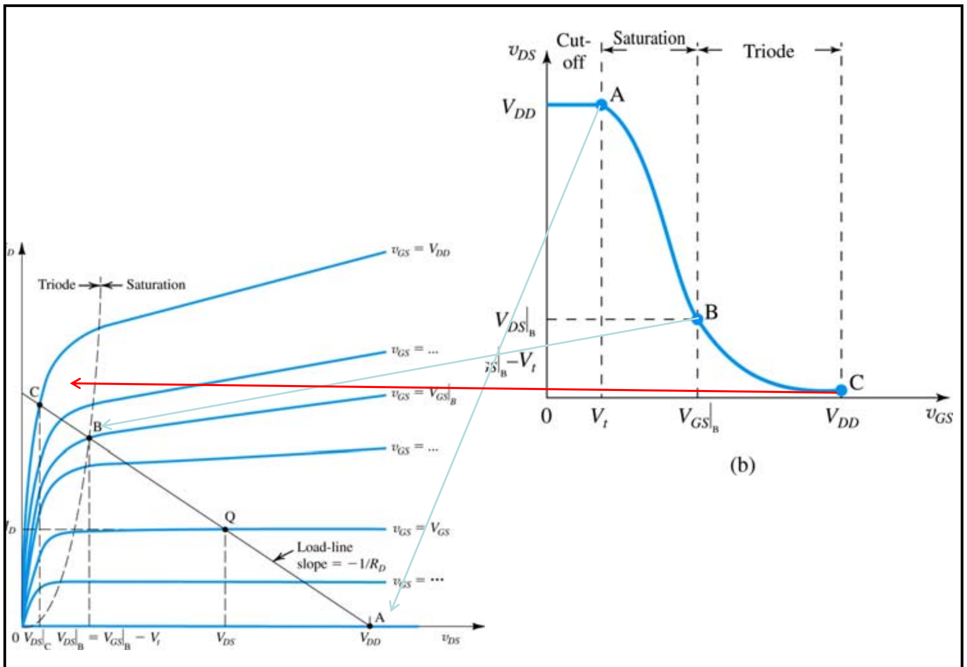
(a)

(b)

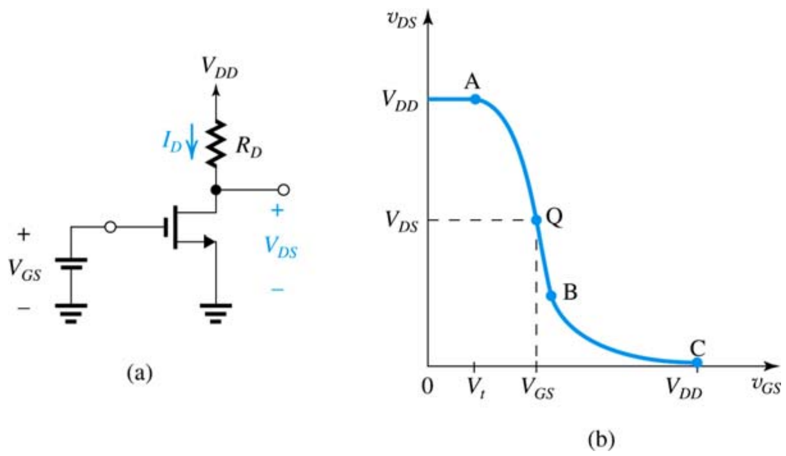
$v_{gs} < V_t$ cut off

v_{gs} increases when $v_{DS} = v_{GS} - V_t$ →Triode

v_{gs} increases when reaches V_t MOSFET is ON
Since initially v_{DS} is high (no drop on R_D) $v_{DS} > v_{GS} - V_t$ →Saturation



(b)



(a) (b)

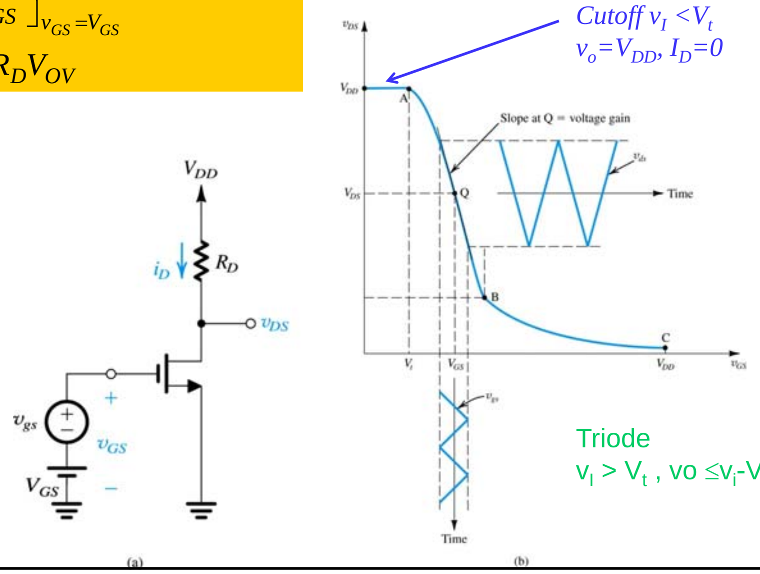
$$v_{DS} = V_{DD} - 1/2\, k_n R_D (v_{GS} - V_t)^2$$

$$A_v = \left[\frac{dv_{DS}}{dv_{GS}}\right]_{v_{GS}=V_{GS}}$$

$$A_v = -k_n R_D V_{OV}$$

Saturation
$v_I > V_t$, $v_o \geq V_I - V_t$

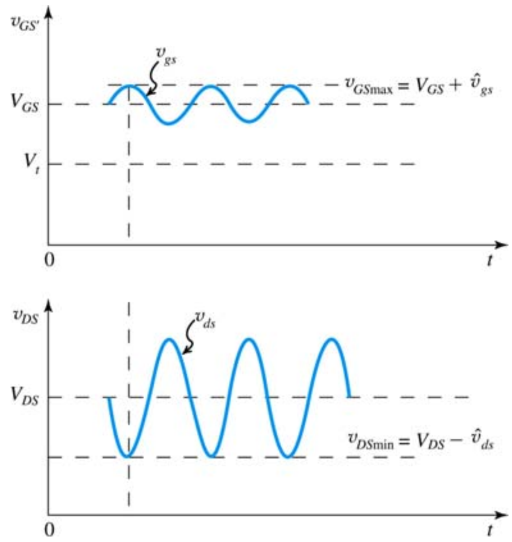
Cutoff $v_I < V_t$
$v_o = V_{DD}$, $I_D = 0$

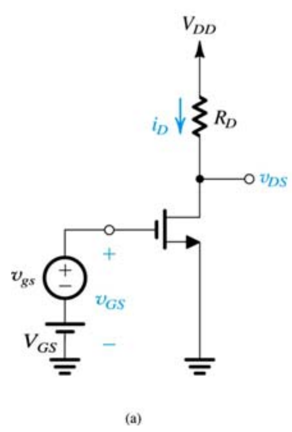


(a) (b)

Triode
$v_I > V_t$, vo $\leq v_i - V_t$

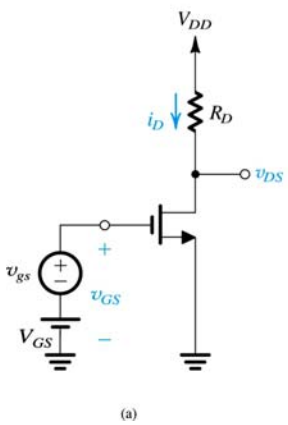
$$V_{DS} = V_{DD} - 1/2\, k_n R_D (v_{GS} - V_t)^2$$
$$v_{GS}(t) = V_{GS} + v_{gs}(t)$$





2 Designs for a gain of 10
1. Changing R_D while keeping V_{OV} constant
2. Changing V_{OV} while keeping R_D constant

V_t=0.4V, V_{DD}=1.8V, V_{GS}=0.6V, K_n'=0.4mA/V_2, W/L=10, R_D = 17.5KΩ



a) For v_{gs}=0 find V_{ov}, I_D, and A_v
b) What is the max symmetrical signal swing allowed at the drain, and v_{gs}

V_t=0.4V, V_{DD}=1.8V, V_{GS}=0.6V, K_n'=0.4mA/V_2, W/L=10, R_D = 17.5KΩ

VTC by Graphical Analysis

- Not used in circuit analysis, used only to illustrate for gaining a greater insight into circuit operation.
- From elementary circuit theory we have
- $V_{DD} = i_D R_D + v_{DS}$
- That represents a line with a slope of -1/RD
- The transistor operates on a point along that line.

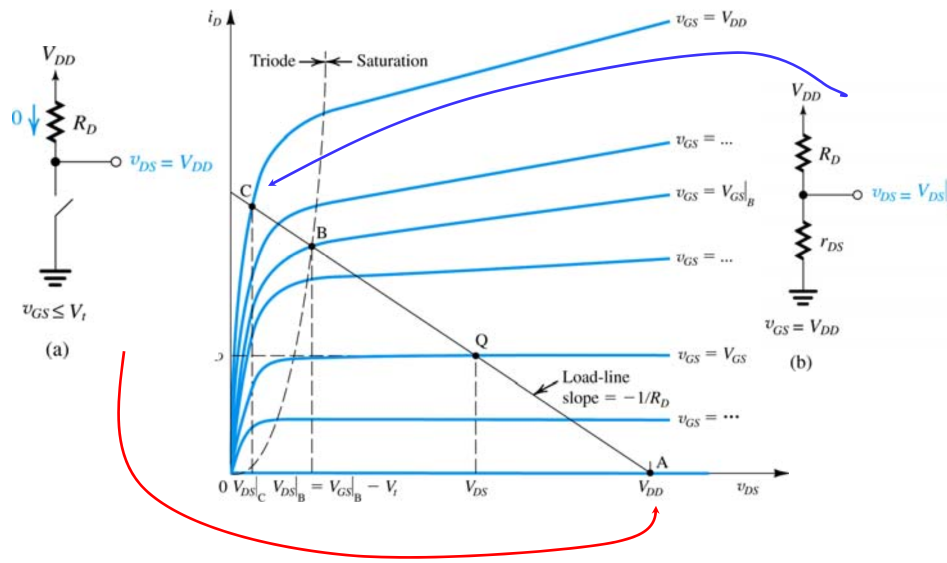
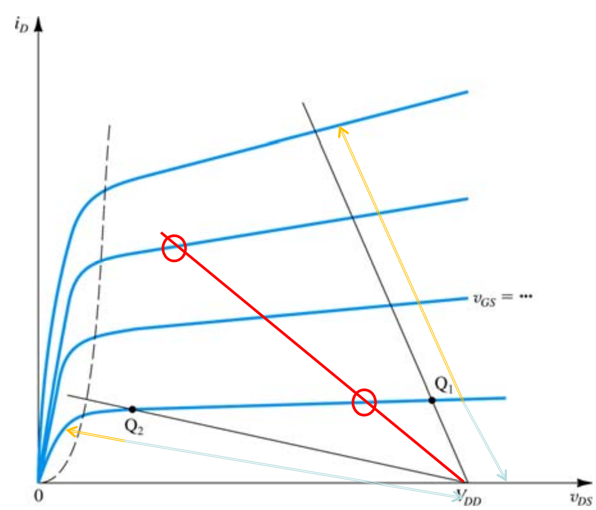
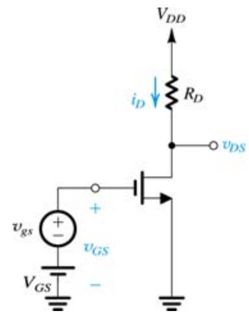


Figure 5.31 Graphical construction to determine the voltage transfer characteristic of the amplifier in Fig. 5.29(a).



Small Signal Operations



- The signal v_{gs} is superimposed on V_{GS}
- $v_{GS} = V_{GS} + v_{gs}$
- $I_D = \frac{1}{2} k_n V^2{}_{OV}$
- $i_D = \frac{1}{2} k_n (V_{OV} + v_{gs})^2$

$$i_D = \frac{1}{2} k_n V_{OV}^2 + k_n V_{OV} v_{gs} + \frac{1}{2} k_n v_{gs}^2$$

Small Signal Operation

- To minimize the nonlinear part

$$\frac{1}{2} k_n v_{gs}^2 << k_n V_{OV} v_{gs}$$

$$v_{gs} << 2V_{OV}$$

- $i_D \approx I_D + i_d$

$$v_{DS} = V_{DD} - i_D R_D$$

$$v_{DS} = V_{DD} - (I_D + i_D) R_D$$

$$v_{DS} = V_{DS} - i_d R_D$$

Small Signal Operation

Assuming small

$$i_D = \frac{1}{2}k_n V_{OV}^2 + k_n V_{OV} v_{gs} + \frac{1}{2}k_n v_{gs}^2$$

$$i_d = k_n V_{OV} v_{gs}$$

$$g_m = \frac{i_d}{v_{gs}} = k_n V_{OV}$$

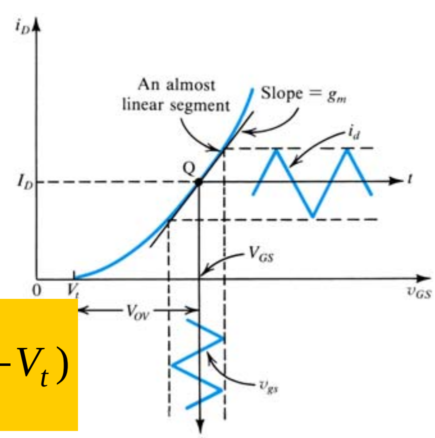
$$g_m = \left.\frac{\partial i_D}{\partial v_{GS}}\right|_{v_{GS}=V_{GS}}$$

$$A_V = -g_m R_D$$

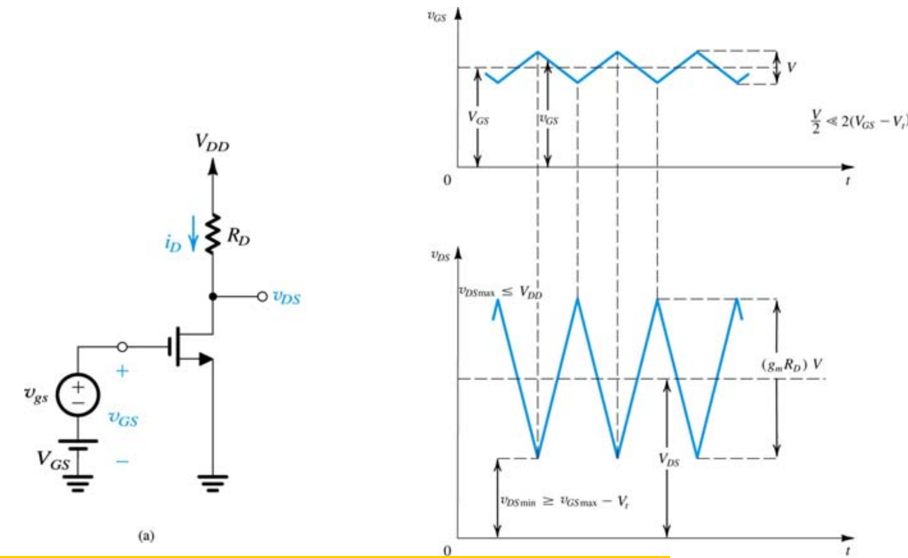
- Transconductance: relates i_d and v_{ds}

Transconductance

- The slope of the i_{DS}-v_{GS} characteristics at the Q point (DC bias point)
- As shown, almost linear.



$$g_m = \frac{i_D}{v_{GS}} = k_n'\left(\frac{W}{L}\right)(V_{GS} - V_t)$$



$$v_D = V_{DD} - R_D i_D = V_{DD} - R_D(I_D + i_d)$$

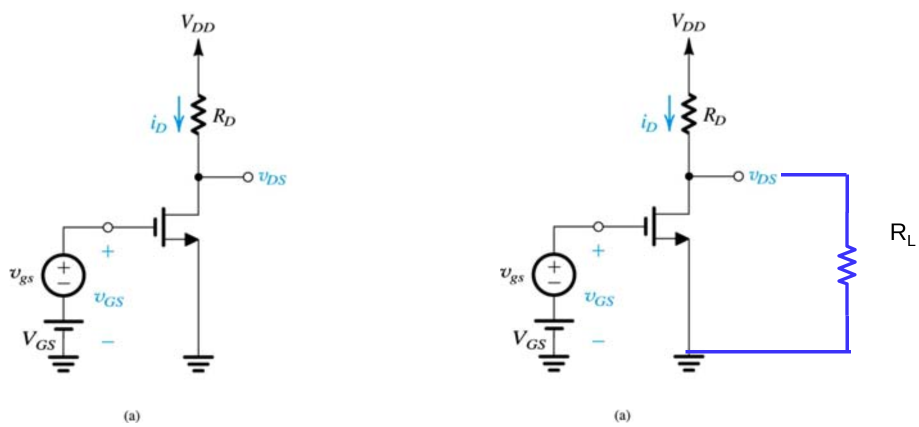
$$v_D = V_D - R_D i_D$$

Separating DC Analysis and Signal Analysis

- Signal quantities are superimposed on DC quantities.
- We can separate DC and AC Analysis.
- The DC Analysis determine the Q Point
- (Bypass) Capacitors are added to prevent disturbing the DC bias (Q point). **WHY?**
- Draw the circuit from the signal point of view
  - DC voltages (current) are short (open)
  - Capacitors are short
  - MOSFET replaced by **small signal equivalent Circuit**

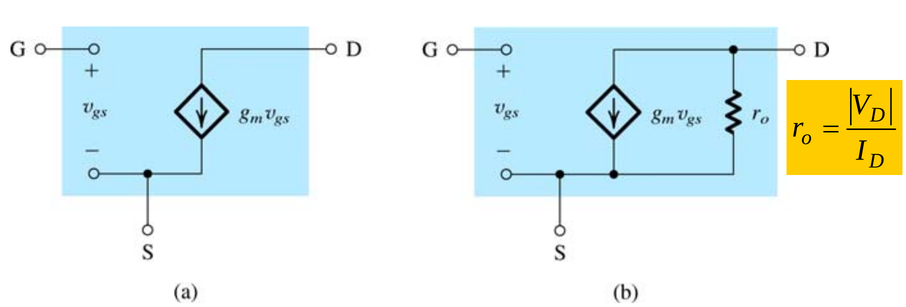
Why Capacitors

- Adding the load



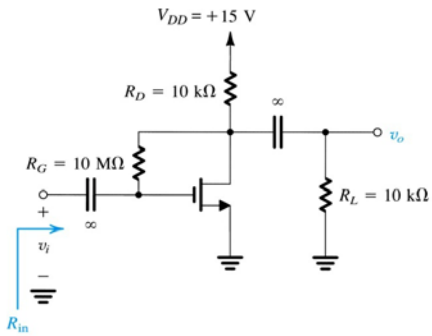
Small Signal Equivalent Circuit

- Represents only time varying component (DC only determine the bias point)
- What is the difference between (a) and (b).



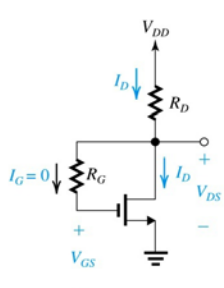
Example

- Find the small signal voltage gain, input resistance, and the largest allowable input signal. V_t=1.5V, k'_n=0.25mA/V^2, VA=50 V.



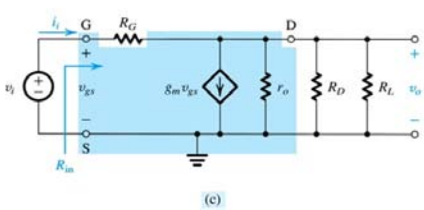
(a)

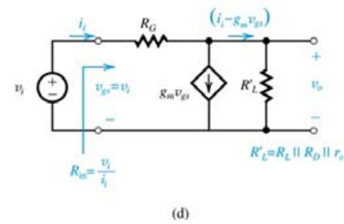
Example cont.



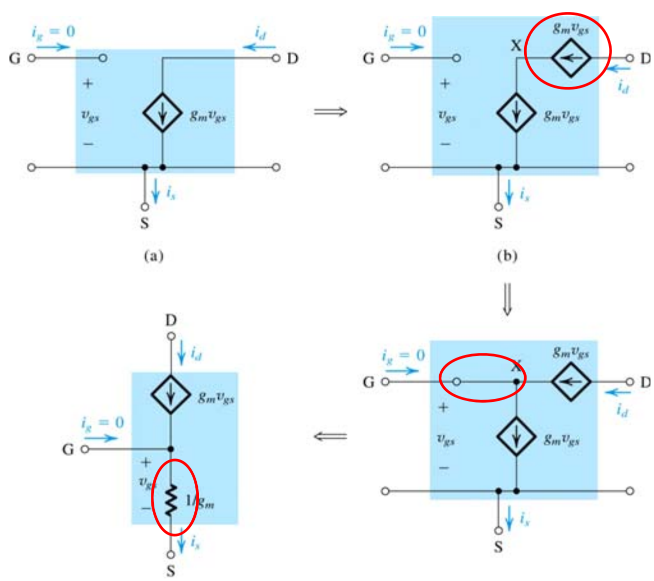
(b)

Example cont.

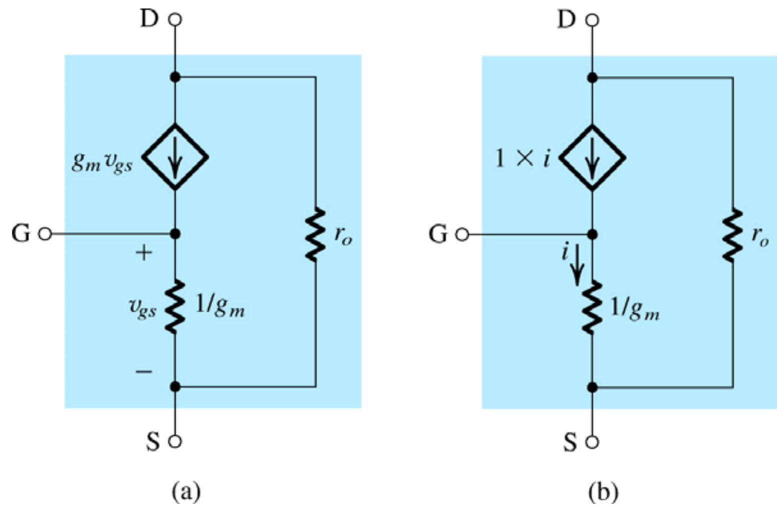




T-Equivalent-Circuit Model



Incorporating r_0



Example

- Assume saturation, find gain and input