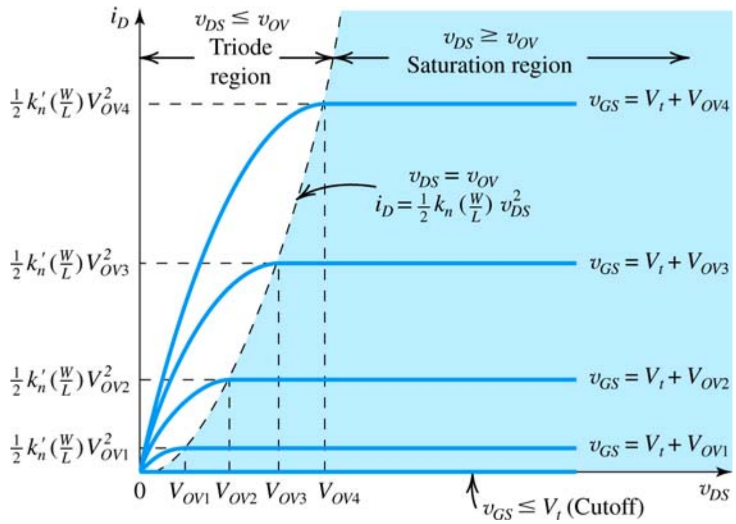

Figure 5.13 The i_D–v_{DS} characteristics for an enhancement-type NMOS transistor.

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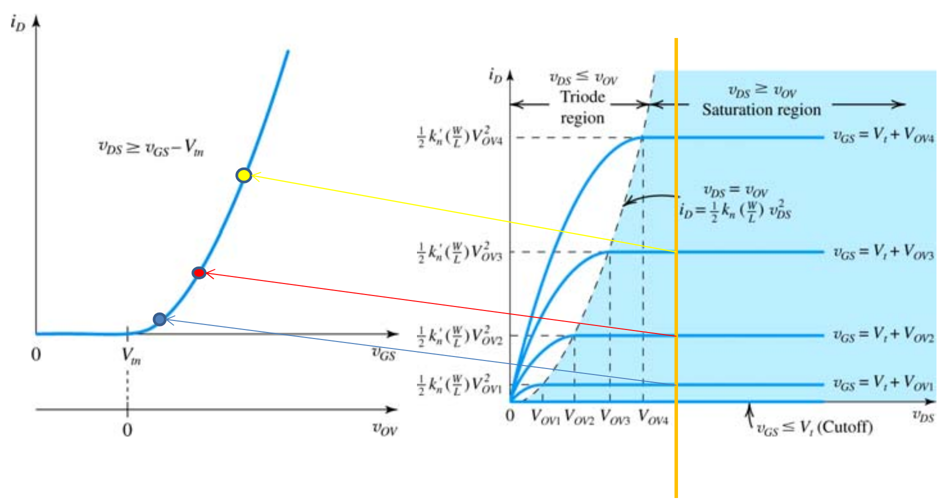

Figure 5.14 The i_D–v_{GS} characteristic of an NMOS transistor operating in the saturation region. The i_D–v_{OV} characteristic can be obtained by simply re-labelling the horizontal axis; that is, shifting the origin to the point $v_{GS} = V_{tn}$.

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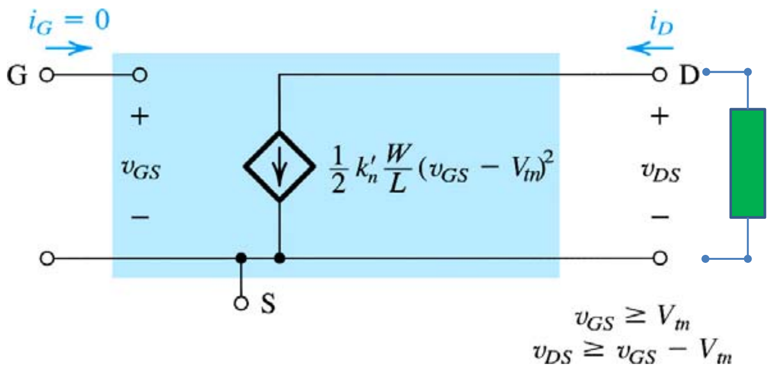
Large Signal Equivalent Circuit



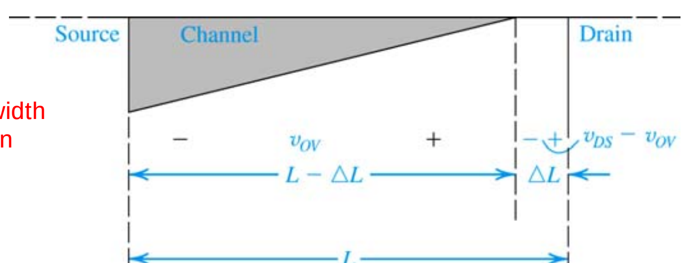
Operating in Saturation

Ideal, back to this point later

Figure 5.15 Large-signal equivalent-circuit model of an *n*-channel MOSFET operating in the saturation

Finite Output Resistance

Channel width modulation



- As v_{DS} increases, the channel *pinch off* moves away from the drain (L gets smaller).
- Voltage across the channel remains v_{ov}
- A voltage drop of $v_{DS} - v_{ov}$ appears across the small depletion region
- This voltage accelerates the electrons that reach the drain (increases current)

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

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

$$r_o = \left[\frac{\partial i_D}{\partial v_{DS}}\right]^{-1}_{v_{GS}\ \text{constant}}$$

$$r_o = \left[\lambda \frac{k_n'}{2}\frac{W}{L}(V_{GS}-V_t)^2\right]^{-1}$$

$$r_o = \frac{1}{\lambda I_D} = \frac{V_A}{I_D}$$

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

$i_D = 0$ when $v_{DS} = -1/\lambda = -V_A$

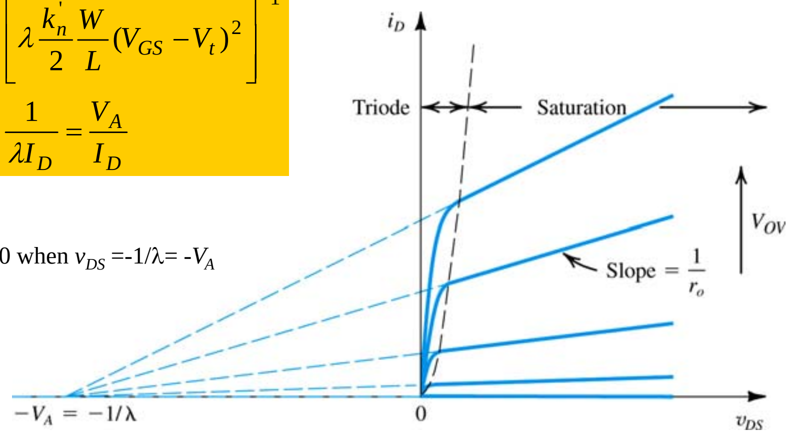


Figure 5.17 Effect of v_{DS} on i_D in the saturation region. The MOSFET parameter V_A depends on the process technology and, for a given process, is proportional to the channel length L.

Large Signal Equivalent Circuit

More realistic equivalent circuit

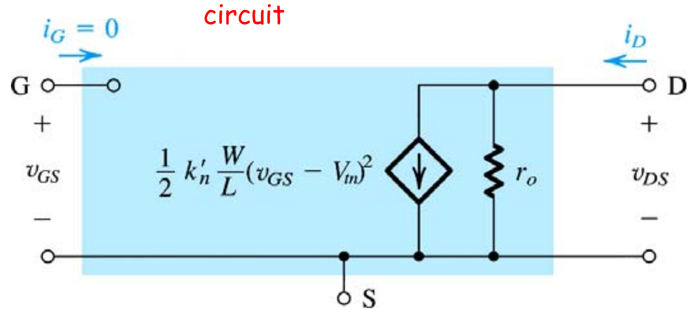
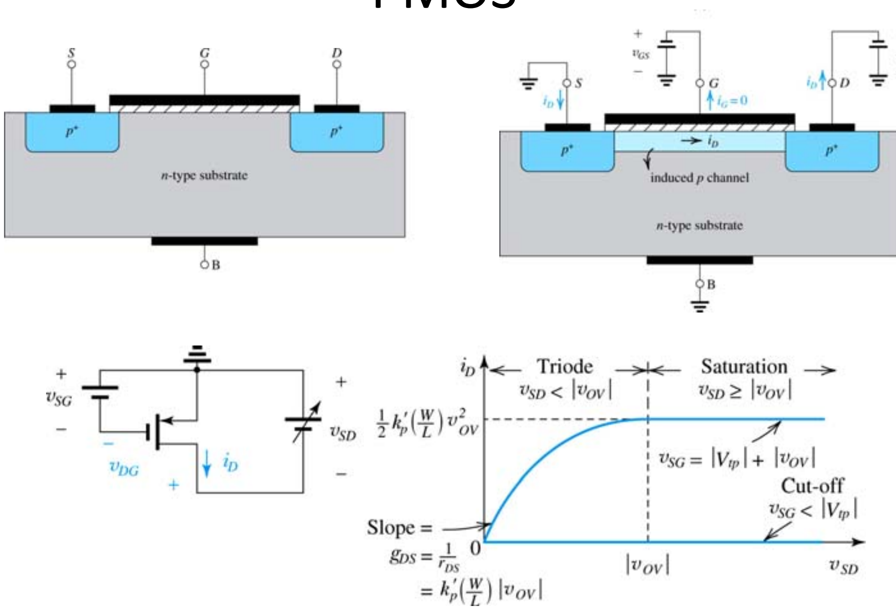


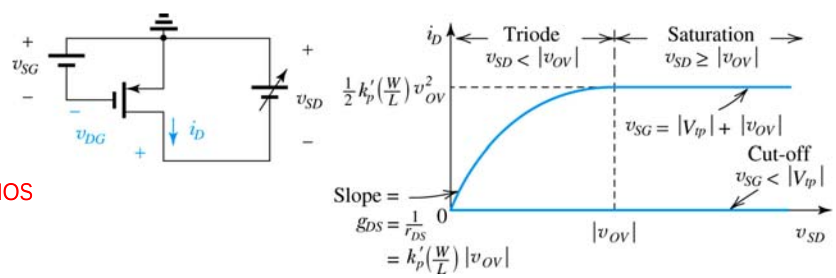
Figure 5.18 Large-signal equivalent circuit model of the n-channel MOSFET in saturation, incorporating the output resistance r_o. The output resistance models the linear dependence of i_D on v_{DS} and is given by Eq. (5.23).

PMOS

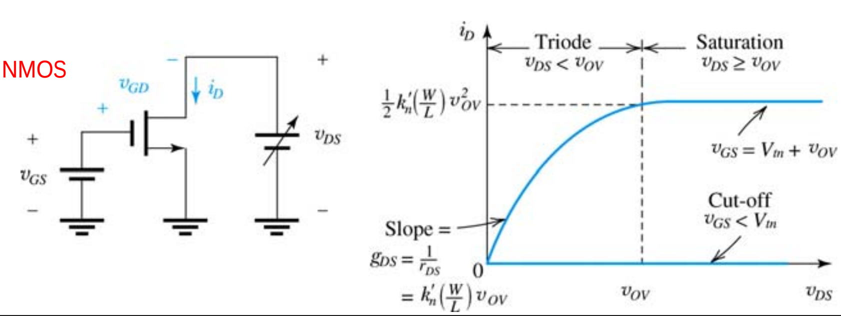


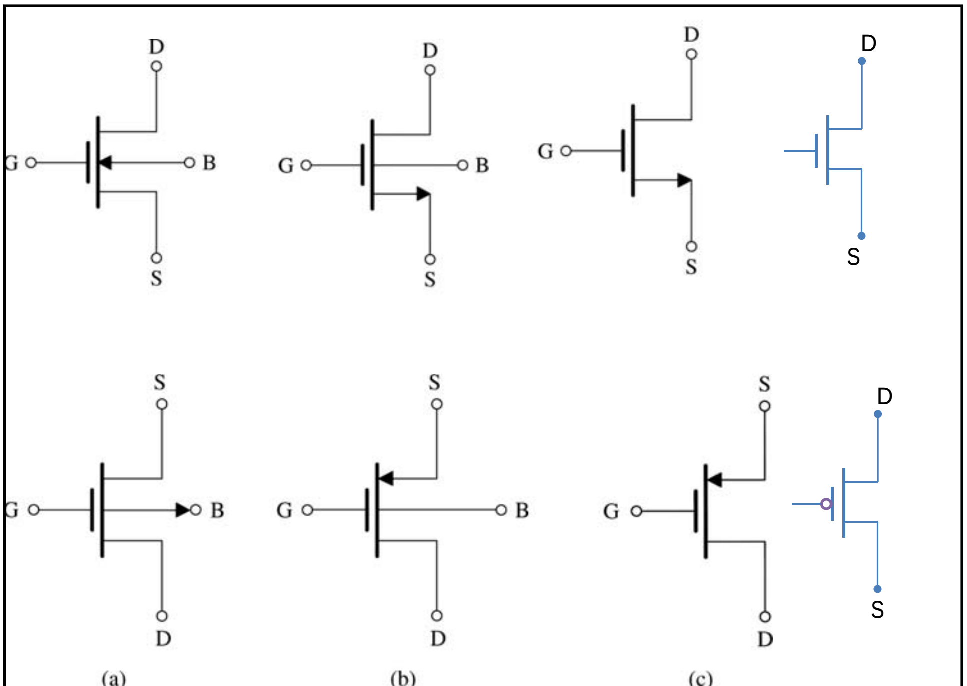
PMOS vs. NMOS

PMOS



NMOS





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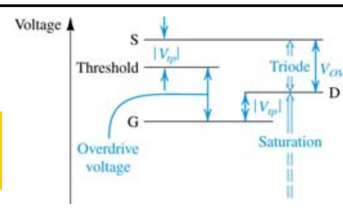
PMOS

Cut-off

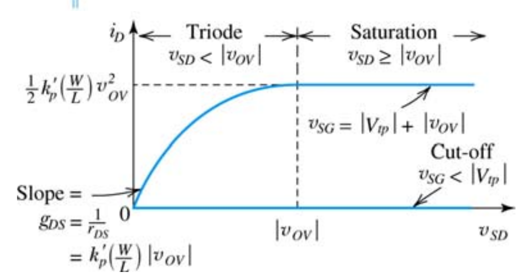
$$v_{SG} < |V_{tp}|$$



Saturation

$$v_{DG} < |V_{tp}|$$

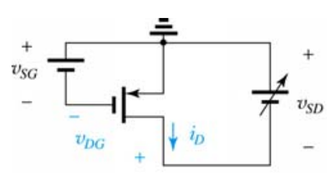
$$v_{SD} > |v_{OV}|$$



Triode

$$v_{DS} < v_{OV}$$

$$v_{GD} > V_t$$



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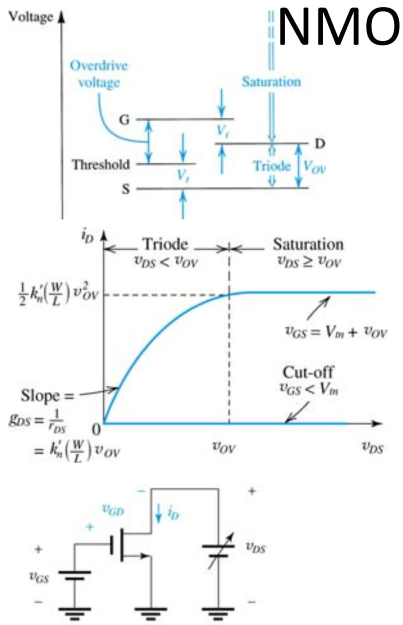
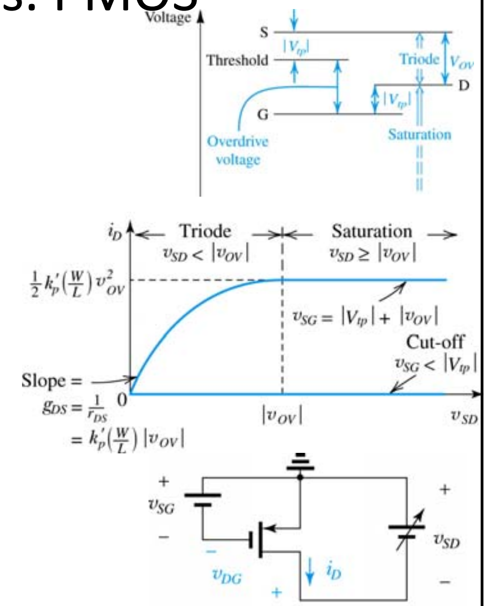
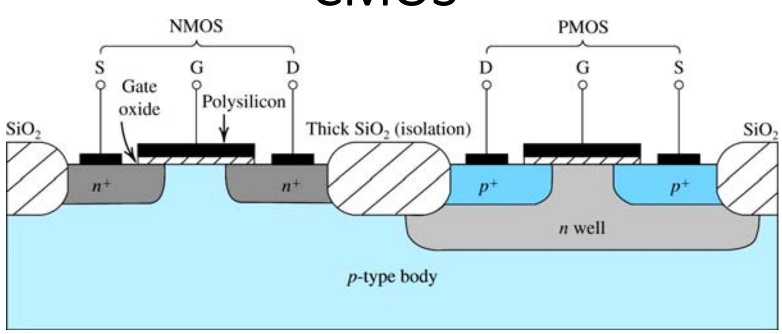
NMOS vs. PMOS





CMOS



The vast majority of IC's
Small and low power consumption

EXAMPLE

V_{tp} = -1 V, K_p'=60 $\mu A/v^2$, W/L=10

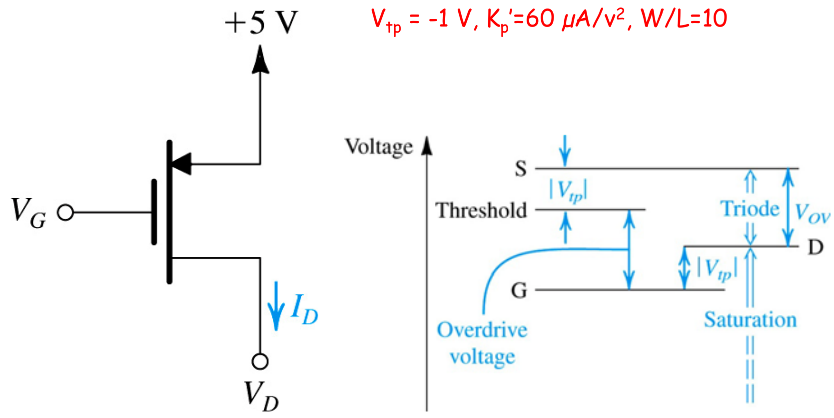


Figure E5.7

Example

- Find R_s and R_d such that
- I_d=0.4 mA, V_D=+0.5 V
- V_t=0.7 V, $\mu_n C_{ox}$=100µA/V^2
- L=1µm, W=32µm.

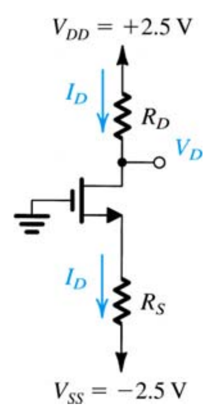
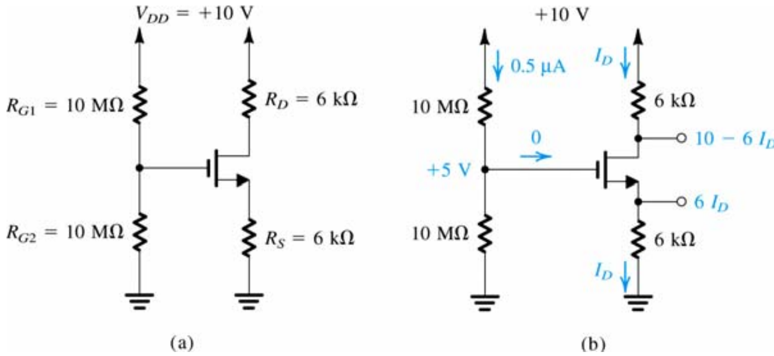


Figure 5.21 Circuit for Example 5.3.



Find the voltages and currents
V_{tn}=1 V, Kn(W/L)=1 mA/V^2

Figure 5.24 (a) Circuit for Example 5.6. (b) The circuit with some of the analysis details shown.

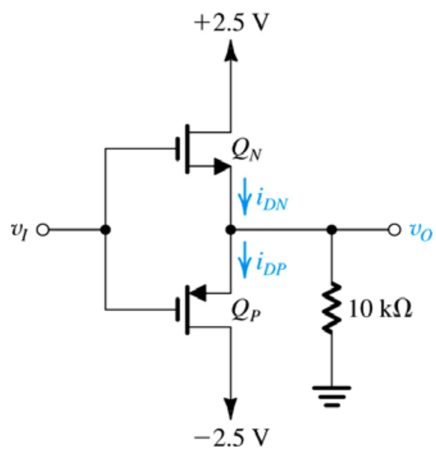


Figure E5.15

