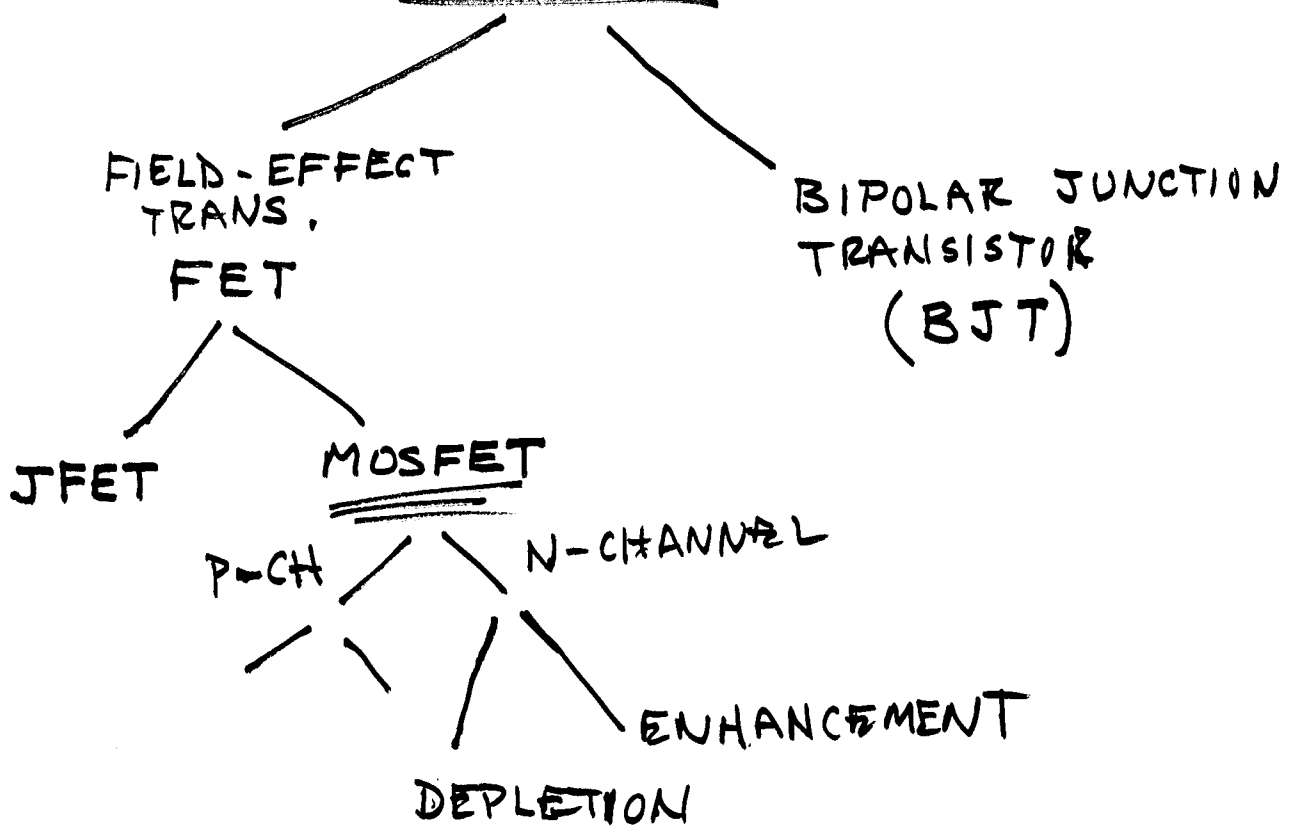
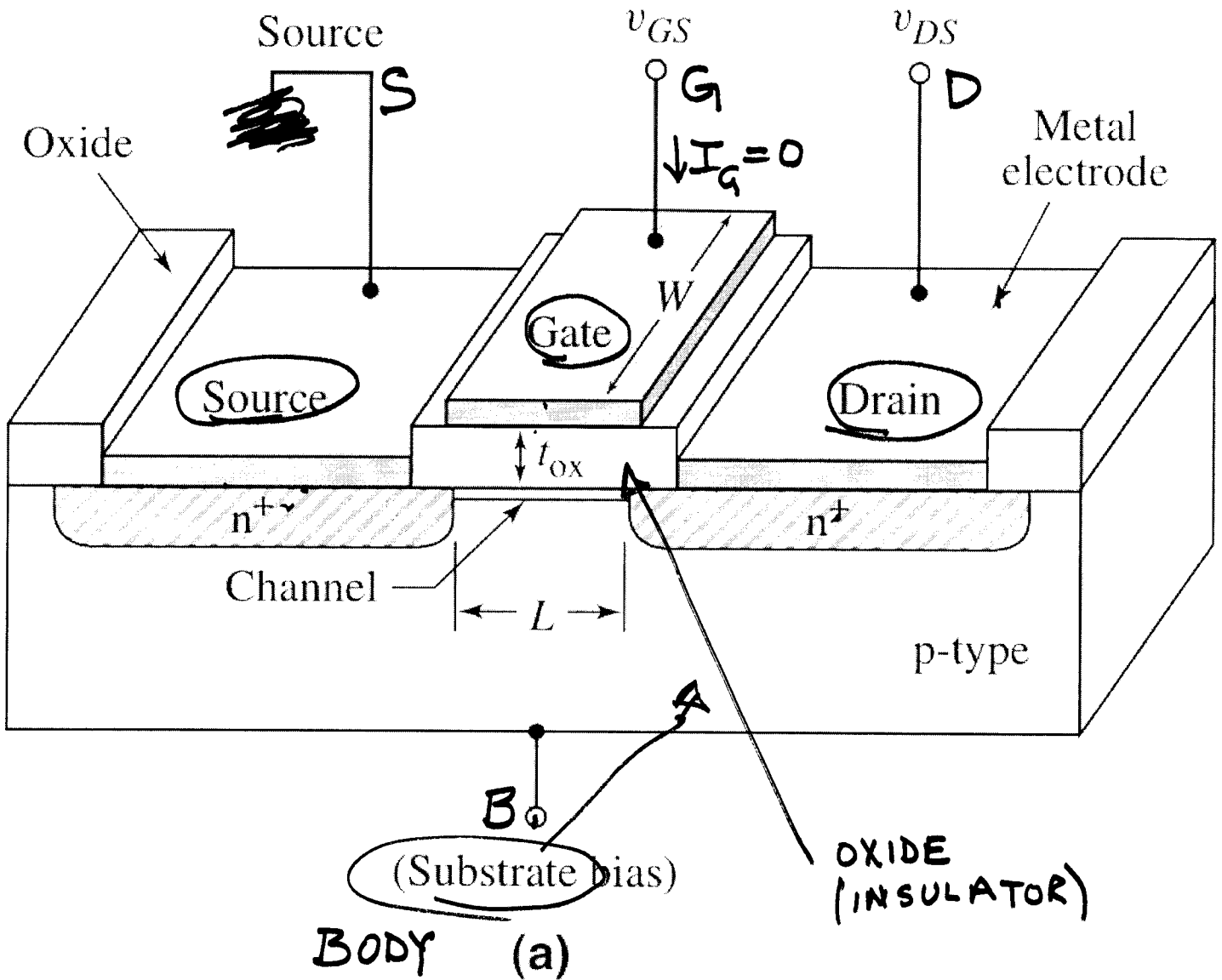
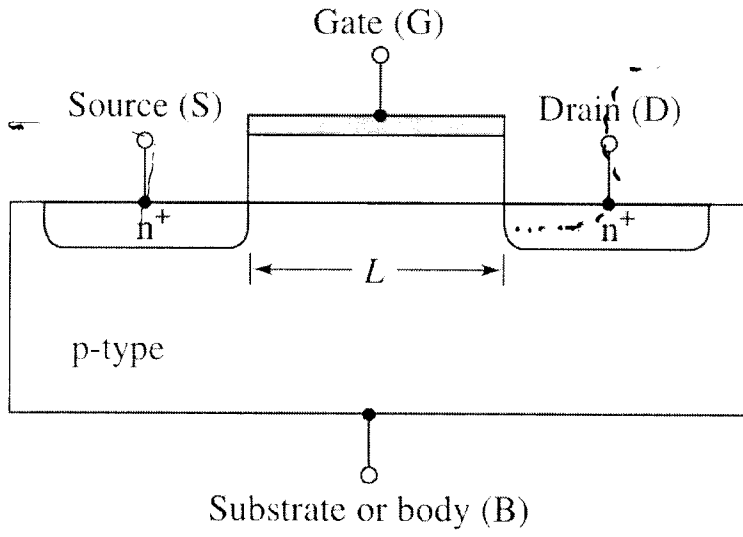


# TRANSISTORS

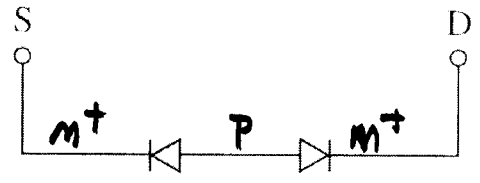


# MOSFETS

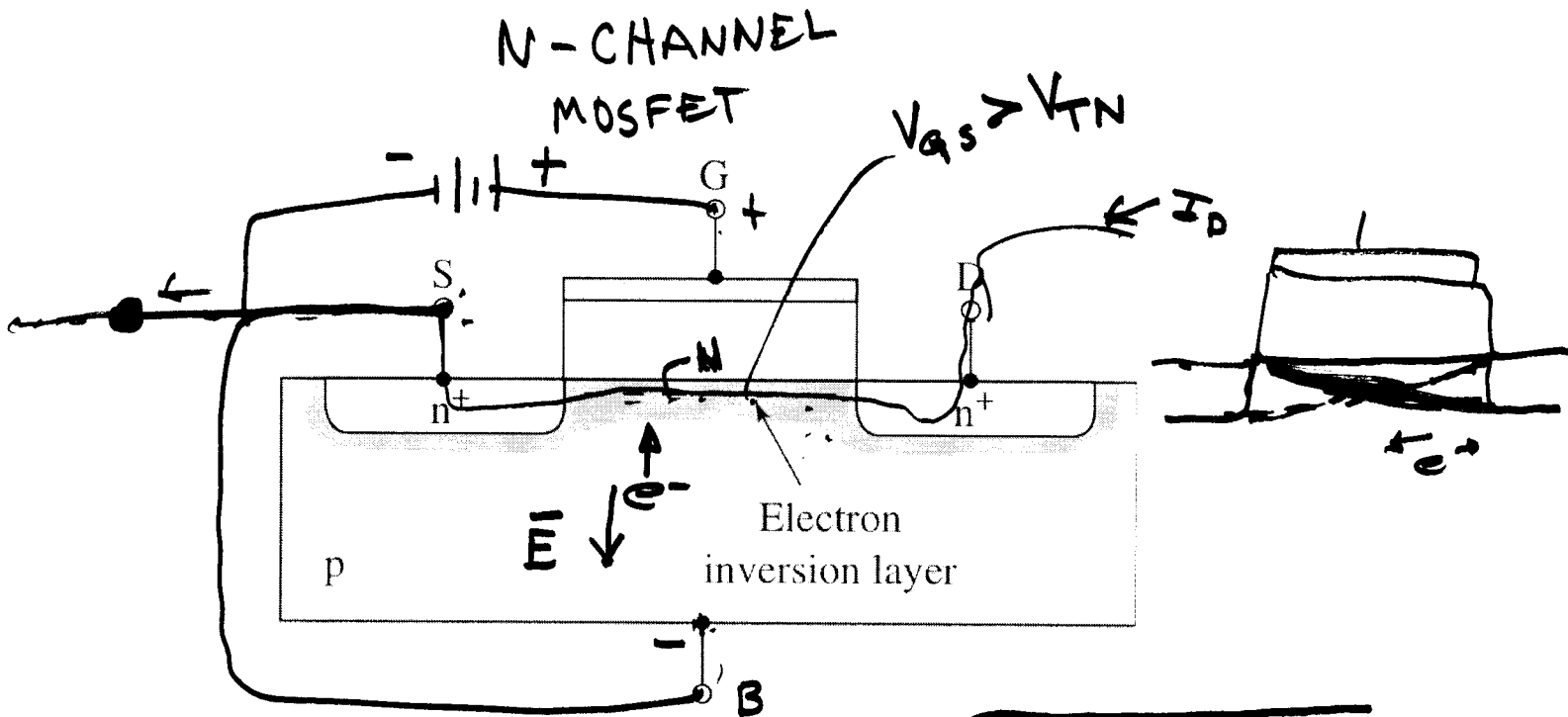




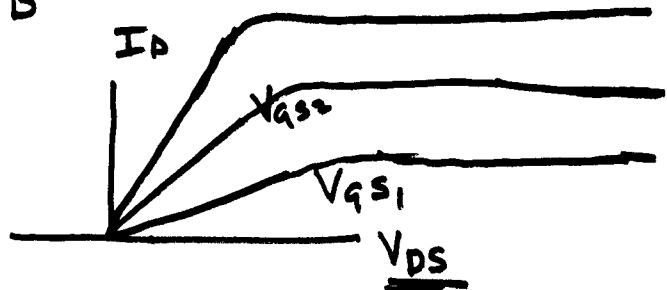
(a)



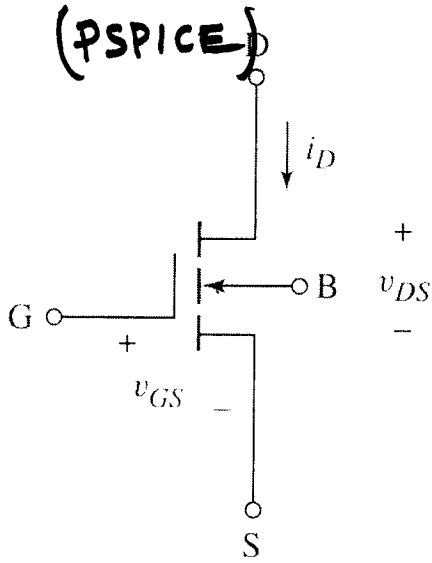
(b)



SMALL  $V_{GS}$



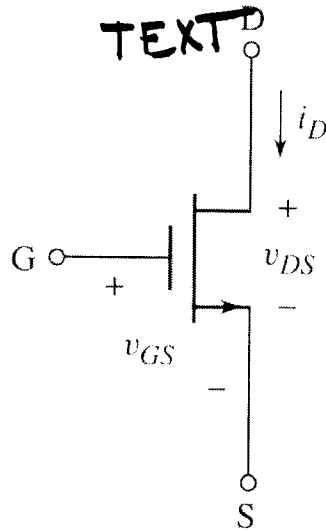
FORMAL  
(PSPICE)



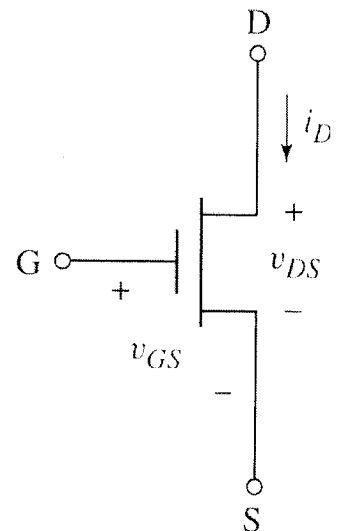
(a)

SHORTHAND

TEXT

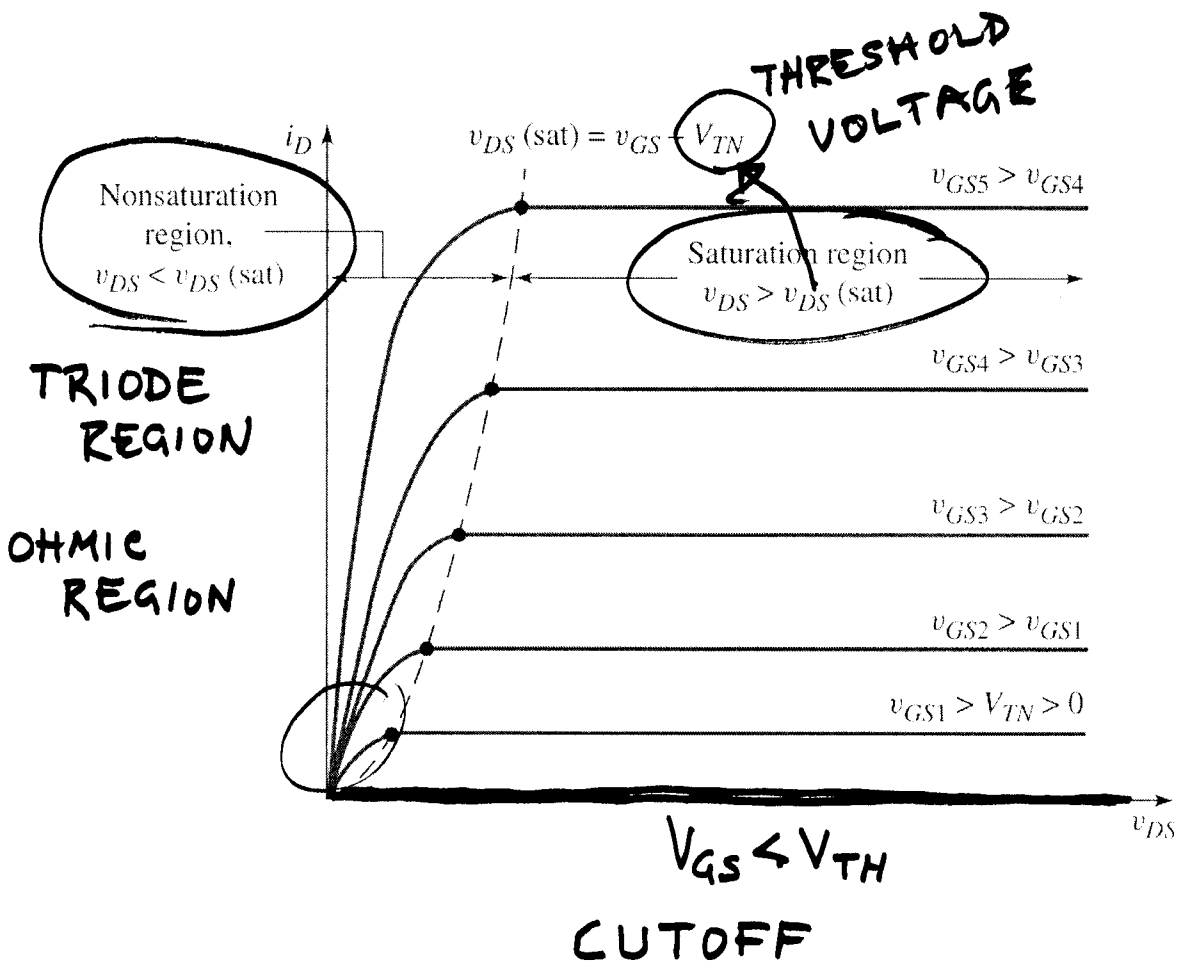


(b)



(c)

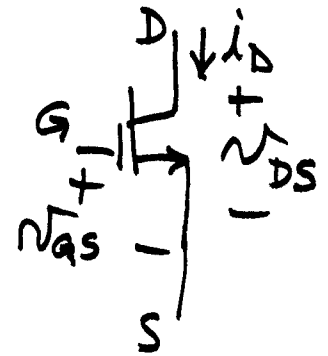
N-CHANNEL  
ENHANCEMENT  
MOSFET



## TRIODE REGION ( $V_{DS} < V_{GS} - V_{TN}$ )

$$i_D = K_n \left[ 2(v_{GS} - V_{TN})v_{DS} - v_{DS}^2 \right]$$

↳ THRESHOLD



where

$$K_n = \frac{\mu_n C_{ox}}{2} \left( \frac{W}{L} \right) = \frac{k'_n}{2} \left( \frac{W}{L} \right)$$

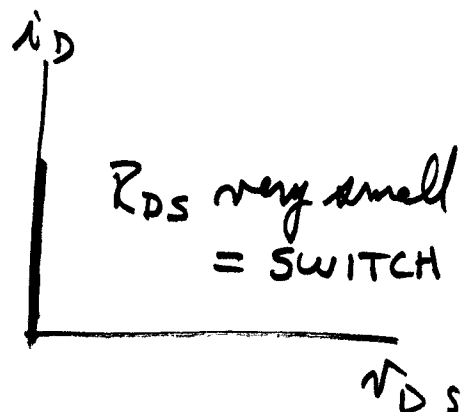
$$k'_n = \mu_n C_{ox} = KP \quad (\text{PSPICE})$$

For small  $v_{DS}$ ,

$$i_D \approx K_n \left[ 2(v_{GS} - V_{TN})v_{DS} \right]$$

$$\frac{i_D}{v_{DS}} = K_n \left[ 2(v_{GS} - V_{TN}) \right] = \frac{1}{R_{DS}}$$

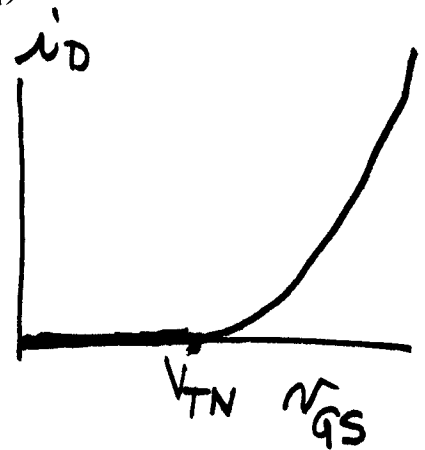
(A voltage-controlled resistor)



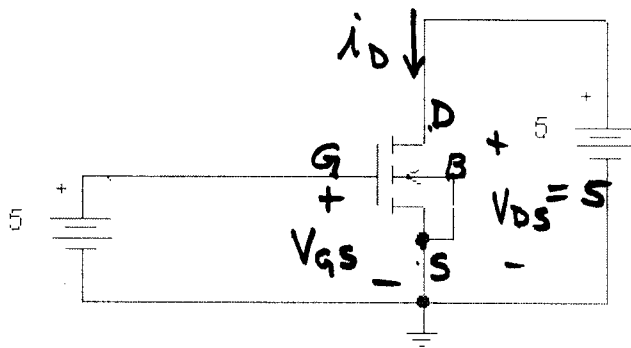
**SATURATION REGION** ( $V_{DS} > V_{GS} - V_{TN}$ )

$$i_D = K_n (v_{GS} - V_{TN})^2$$

$$i_D > 0 \quad \underline{v_{GS} > V_{TN}}$$



**EXAMPLE 1**



$$k'_n = 80 \mu \text{ A/V}^2 \quad V_{TN} = 2 \text{ V.}$$

$$L = 10 \mu \text{ m} \quad W = 100 \mu \text{ m}$$

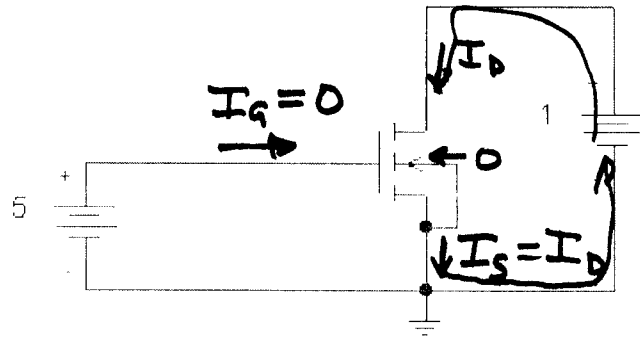
$$K_m = \left( \frac{W}{L} \right) \frac{k'_n}{2} = \frac{100}{10} \left( \frac{80(10)^{-6}}{2} \right) = 0.4 \text{ mA/V}^2$$

$$V_{DS} = 5, \quad V_{GS} = 5 \quad (\text{saturation})$$

$$i_D = K_n (v_{GS} - V_{TN})^2$$

$$= 0.4 \text{ mA/V}^2 (5 - 2)^2 = 3.6 \text{ mA}$$

## EXAMPLE 2

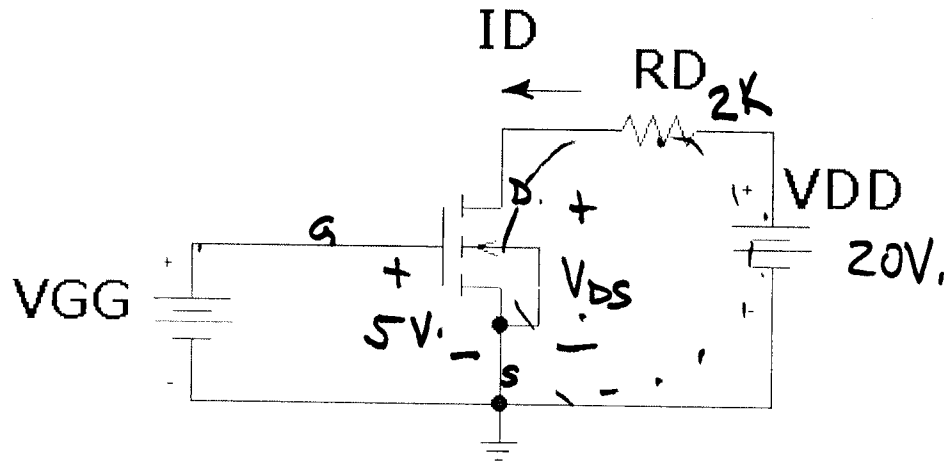


$$V_{DS} = 1, \quad V_{GS} = 5 \quad \text{triode} \quad V_{GS} > V_{TN}$$

$$i_D = K_n [2(v_{GS} - V_{TN})v_{DS} - v_{DS}^2]$$

$$i_D = 0.4 \text{ mA/V}^2 [2(5 - 2)1 - 1^2] = 2 \text{ mA}$$

**MOSFETs: DC operating conditions--  
Determine  $I_D$  and  $V_{DS}$**



$$V_{DS} = V_{DD} - I_D R_D \quad (\text{a load-line equation})$$

$$V_{GS} = V_{GG}$$

**If in Saturation:**  $I_D = K_n (V_{GS} - V_{TN})^2$   
 $V_{DS} > V_{GS} - V_{TN}$

**If in the triode region:**

$$I_D = K_n [2(V_{GS} - V_{TN})V_{DS} - V_{DS}^2]$$

**If in cutoff:**  $I_D = 0$

$$\begin{aligned}
 V_{DD} &= 20 \text{ V.} & V_{GG} &= 5 \text{ V.} & R_D &= 2 \text{ k} \\
 V_{TN} &= 2 \text{ V.} & k_n' &= 80 \mu\text{A/V}^2 \\
 W &= 50 \mu\text{m} & L &= 10 \mu\text{m}
 \end{aligned}$$

$$K_n = 0.2 \text{ mA/V}^2$$

**Saturation, triode, or cutoff?**

**Try saturation:**

$$\begin{aligned}
 I_D &= K_n (V_{GS} - V_{TN})^2 = 0.2 (5 - 2)^2 = 1.8 \text{ mA} \\
 V_{DS} &= V_{DD} - I_D R_D = 20 - 1.8 (2) = 16.4 \text{ V.}
 \end{aligned}$$

**check:  $V_{DS} > V_{GS} - V_{TN}$  ?    yes**

**∴ Saturation**

**If we had tried the triode region,**

$$\begin{aligned}
 I_D &= k_n [2(V_{GS} - V_{TN})V_{DS} - V_{DS}^2] \\
 V_{DS} &= V_{DD} - I_D R_D
 \end{aligned}$$

**Solve simultaneously**

## CHANGE RD TO 10k

$$\begin{aligned} V_{DD} &= 20 \text{ V.} & V_{GG} &= 5 \text{ V.} & R_D &= 10 \text{ k} \\ V_{TN} &= 2 \text{ V.} & k_n' &= 80 \mu\text{A/V}^2 \\ W &= 50 \mu\text{m} & L &= 10 \mu\text{m} \end{aligned}$$

$$K_n = 0.2 \text{ mA/V}^2$$

Try saturation:

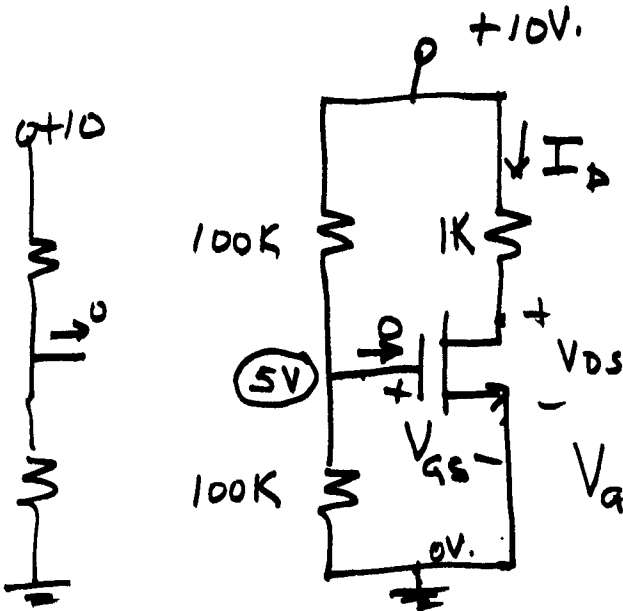
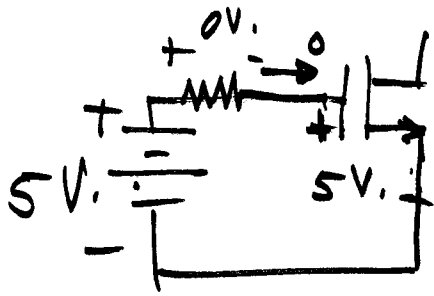
$$\begin{aligned} I_D &= K_n (V_{GS} - V_{TN})^2 = 0.2 (5 - 2)^2 = 1.8 \text{ mA} \\ V_{DS} &= V_{DD} - I_D R_D = 20 - 1.8 (10) = 2 \text{ V.} \end{aligned}$$

check:  $V_{DS} > V_{GS} - V_{TN}$  ?  $2 > 5 - 2$ ? no  
not Saturation, not cutoff,  $\therefore$  triode

triode region:

$$\begin{aligned} I_D &= K_n [2(V_{GS} - V_{TN})V_{DS} - V_{DS}^2] \\ \text{and } V_{DS} &= V_{DD} - I_D R_D \end{aligned}$$

Solution gives  $I_D = 1.75 \text{ mA}$ ,  $V_{DS} = 2.5 \text{ V}$ .



$$K_m = 0.5 \text{ mA/V}^2$$

$$V_{TN} = 3 \text{ V}$$

$$I_D = K_m (V_{GS} - V_{TN})^2$$

$$= (0.5)(5 - 3)^2 = 2 \text{ mA}$$

$$V_{DS} = 10 - I_D \cdot 1 \text{ K}$$

$$= 10 - 2$$

$$10 - (1 \text{ K})(2 \text{ mA}) = 8 \text{ V}$$

$$8 > 5 - 3 \quad \checkmark$$

$$\therefore \text{SAT.}$$

