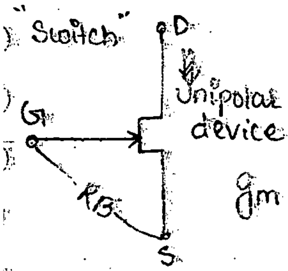
MOSFET

FET

"Switch"

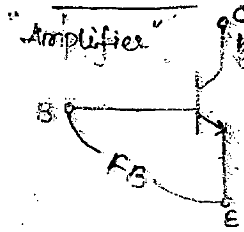


$$(I_D)_Q = 1mA$$

$$g_m = \frac{-2I_{DSS}}{V_P}\left[1 - \frac{(V_{GS})_Q}{V_P}\right]$$

BJT

"Amplifier"

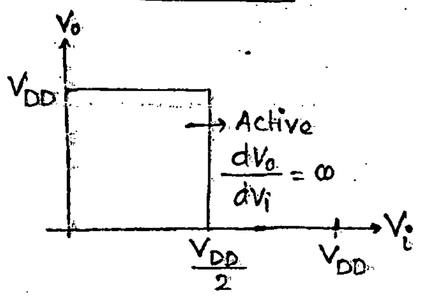


$$g_m = \frac{(I_C)_Q}{V_T} = \frac{1mA}{25mV} = 40mS$$

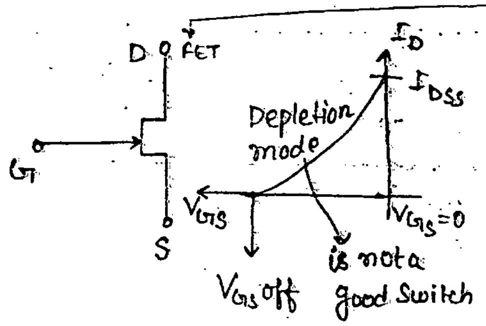
$(I_C)_Q = 1mA$

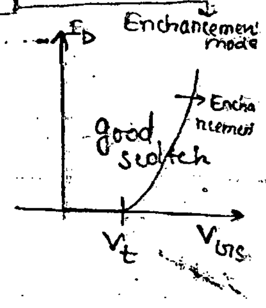
$$\boxed{g_{m\,FET} \leq 10\, g_{m\,BJT}}$$

Ideal Switch (inverter)



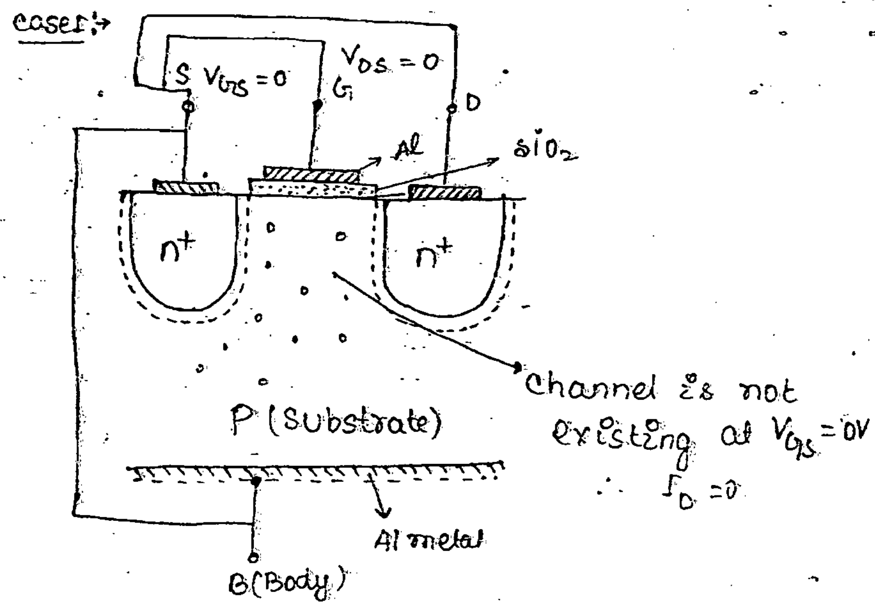
MOSFET





☐ N CHANNEL ENCHANCEMENT MOSFET (NMOS)

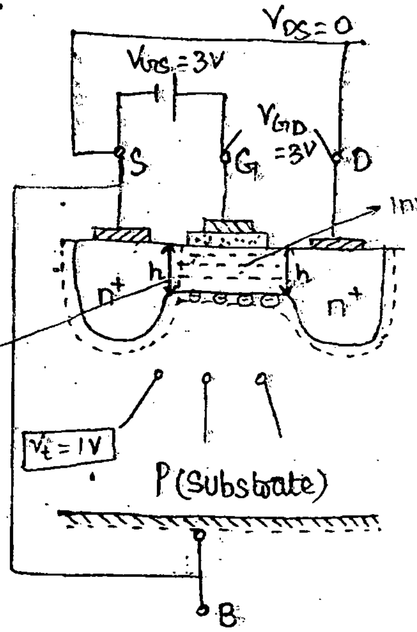
case I :→

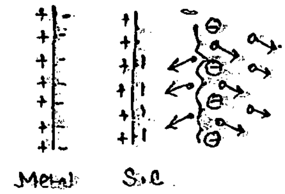


channel is not existing at $V_{GS} = 0V$

$\therefore I_D = 0$

Case II :-





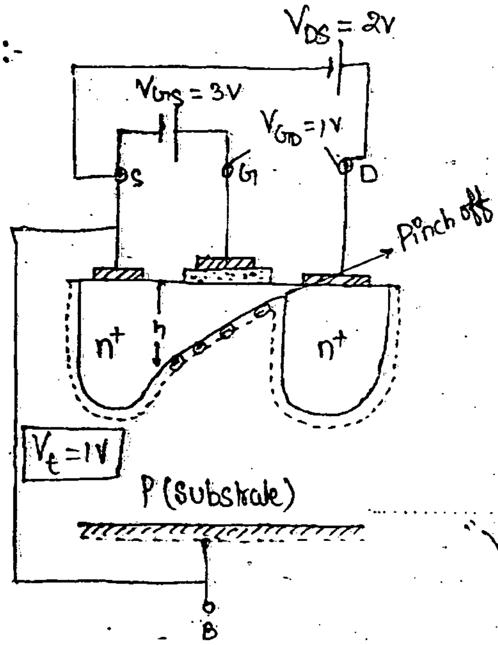
V_t = Thermal Voltage

It is the minimum V_{GS} Voltage where the conducting channel will be formed. V_t (0.5 to 1 V)

$\boxed{\{V_{GS} - V_t\}}$ → Effective Voltage 'OR' Over drive Voltage.

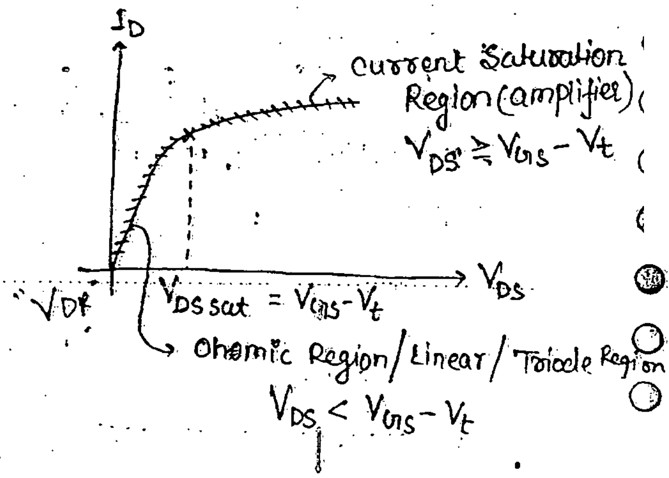
$$V_{GD} = V_{GS} - V_{DS}$$
$$= 3 - 0$$
$$= 3V$$

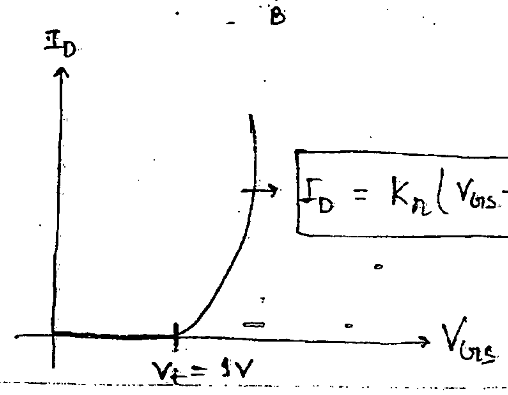
Case III :-



$V_{GD} = V_{GS} - V_{DS} = 3-2 = 1V = V_t$

$V_{GD} = V_{GS} - V_{DS} = 3 - 100mV \simeq 3V$





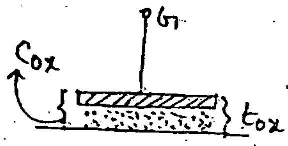
$\boxed{I_D = K_n (V_{GS} - V_t)^2}$ → Transfer characteristic

V-I CHARACTERISTICS OF NMOS.

$$\boxed{I_D = \mu_n C_{ox}\left(\frac{W}{L}\right)\left\{(V_{GS}-V_t)V_{DS} - \frac{1}{2}V_{DS}^2\right\}}$$

Where,

μ_n = Mobility of Electron



$$\boxed{C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}}$$

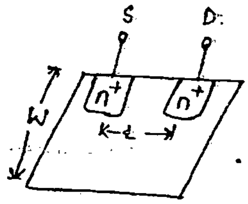
C_{ox} = Capacitance of oxide layer per unit area.

$\epsilon_{ox} = 3.9\epsilon_0$

$= 3.9 \times 8.85 \times 10^{-12}\ F/m.$

$\epsilon_{ox} = 3.45 \times 10^{-11}\ F/m$

$\left(\frac{W}{L}\right)$ = Aspect Ratio



$\{V_{GS} - V_t\}$ = Effective Voltage (or) over drive voltage.

V_{DS} = Drain to Source voltage.

<u>Triode Region</u> :- $V_{DS} < V_{GS} - V_t$

$$I_D = \mu_n C_{ox}\left(\frac{W}{L}\right)\left\{(V_{GS}-V_t)V_{DS} - \frac{1}{2}V_{DS}^2\right\}$$

V_{DS} (mv) Ohmic Region

$$\boxed{I_D = \mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS}-V_t)V_{DS}}$$

$$\boxed{R_{DS} = \frac{V_{DS}}{I_D} = \frac{1}{\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{GS}-V_t)}}$$

<u>current Saturation</u> (Amplifier)

$V_{DS} \geq V_{GS} - V_t$ $\quad I_D = \underbrace{\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)}_{K_n}(V_{GS}-V_t)^2$

K_n (Trans conductance parameter) mA/V^2

$$\boxed{I_D = K_n (V_{GS} - V_t)^2} \rightarrow \text{Transfer characteristics eq}^n.$$

JFET

$$I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2$$

$\rightarrow$ Transfer Ch. eq^n

Depletion NMOS :-

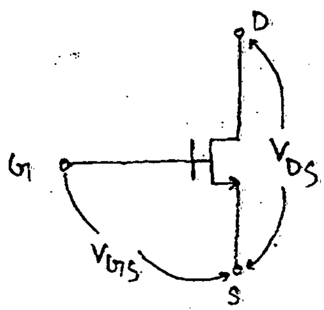
$$I_D = \frac{1}{2}\mu_n C_{ox} \frac{W}{L} V_t^2 \left[\frac{V_{GS}}{V_t} - 1\right]^2$$

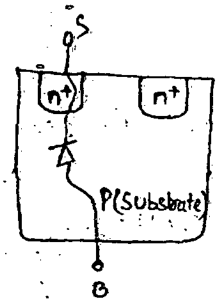
$$I_D = \underbrace{\frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right) V_t^2}_{I_{DSS}} \left[1 - \frac{V_{GS}}{V_t}\right]^2$$

$$\boxed{I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_t}\right]^2}$$

$\rightarrow$ Tr. ch. eq^n of NMOS depletion.

☐ N-MOS





Current Saturation

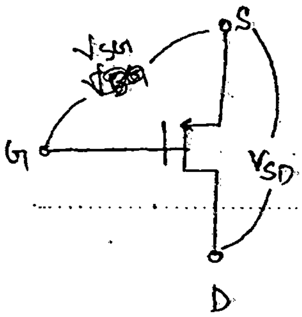
$$I_D = K_n (V_{GS} - V_t)^2$$

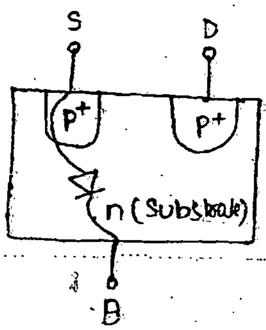
$$K_n = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right).$$

Triode Region

$$I_D = 2K_n \left\{(V_{GS} - V_t) V_{DS} - \frac{1}{2} V_{DS}^2\right\}$$

☐ P-MOS





Current Saturation

$$I_D = K_p (V_{SG} - |V_t|)^2$$

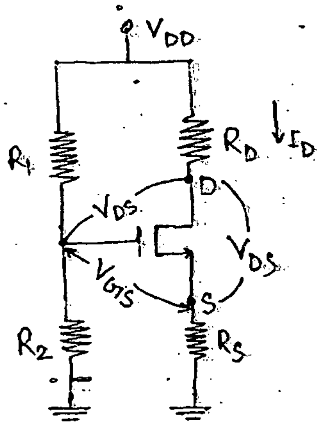
where, $K_p = \frac{1}{2}\mu_p C_{ox}\left(\frac{W}{L}\right)$

Triode Region

$$I_D = 2K_p \left\{V_{SG} - |V_t|\right\} V_{SD} - \frac{1}{2} V_{SD}^2 \right\}$$

MOSFET BIASING.

1. VOLTAGE DIVIDER BIAS.



Current saturation

$V_{DS} > V_{GS} - V_t$

$V_{DS} = V_{GS} + V_{DG}$

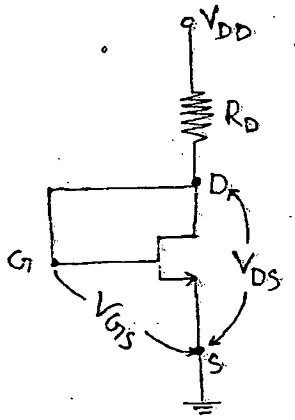
$\boxed{V_{DS} > V_{GS}}$

$I_D = K_n(V_{GS} - V_t)^2$

Assume $(I_D)_Q = 1\,mA$

$(V_{GS})_Q = \sqrt{\dfrac{(I_D)_Q}{K_n}} + V_t$

2. DRAIN TO GATE FEEDBACK BIAS.



$V_{DS} = V_{GS}$

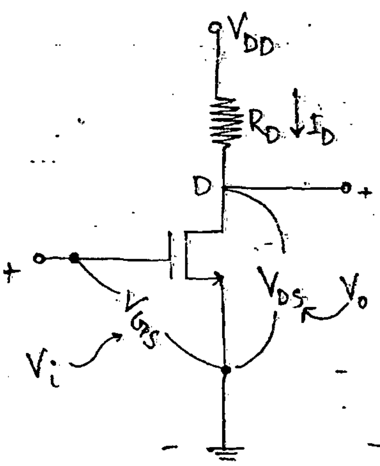
$V_{DS} > V_{GS} - V_t$

$\boxed{(V_{DS})_Q = V_{DD} - (I_D)_Q R_D}$

$\boxed{(V_{GS})_Q = V_{DD} - (I_D)_Q R_D}$

$\boxed{I_D = K_n(V_{GS} - V_t)^2}$

NMOS INVERTER.



$\boxed{V_o = V_{DD} - I_D R_D}$

When $V_i < V_t$

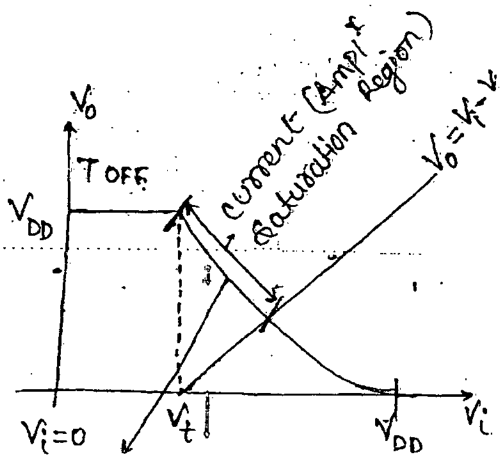
T_{OFF}, $I_D = 0$.

$\boxed{V_o = V_{DD}}$

When $V_i > V_t$

T current saturation

$V_o > V_i - V_t$



$\dfrac{dV_o}{dV_i}$ (less gain)

$$I_D = K_n (V_{GS} - V_t)^2$$
$$= K_n (V_i - V_t)^2$$
$$\boxed{V_0 = V_{DD} - K_n (V_i - V_t)^2 R_D}$$

$$\boxed{V_0 = V_{DD} - 2K_n \left\{ (V_i - V_t)V_0 - \tfrac{1}{2} V_0^2 \right\} R_D}$$

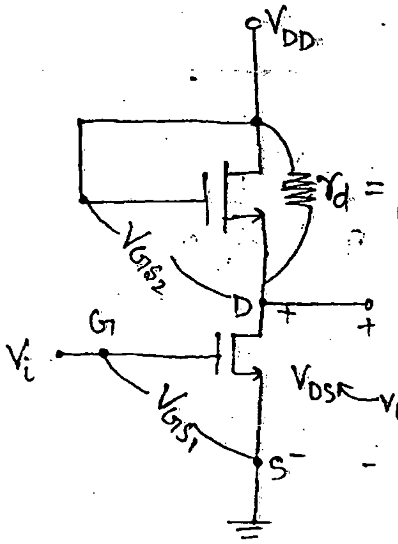
<u>Boundary for Triode Region.</u>

$$V_{DS} = V_{GS} - V_t$$
$$\boxed{V_0 = V_i - V_t}$$

When $V_0 < V_i - V_t$

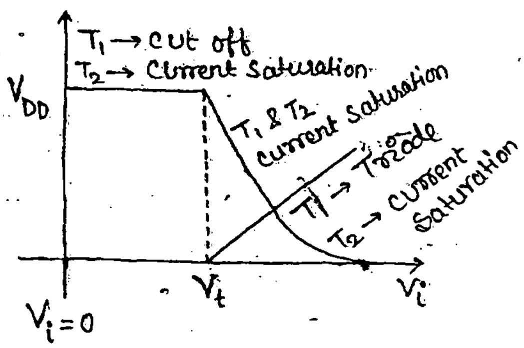
$$I_D = 2K_n \left\{ (V_{GS} - V_t) V_{DS} - \tfrac{1}{2} V_{DS}^2 \right\}$$
$$I_D = 2K_n \left\{ (V_i - V_t) V_0 - \tfrac{1}{2} V_0^2 \right\}$$

⊡ N MOS INVERTER WITH ACTIVE LOAD (INTEGRATED)



$$r_d = \frac{V_A}{(I_D)_Q} = 1M\Omega.$$

$$A_V = -g_m R_D$$
$$= -g_m r_d$$
$$= -4mS \times 1M\Omega$$
$$= -4000$$



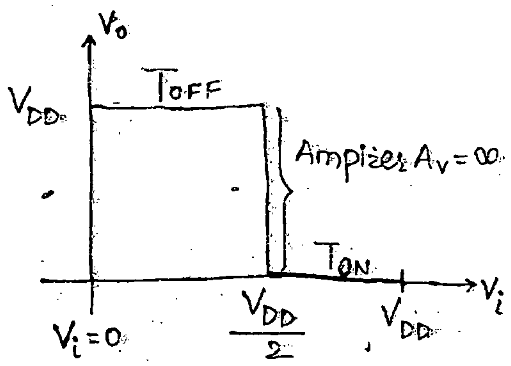
$V_i > V_t$

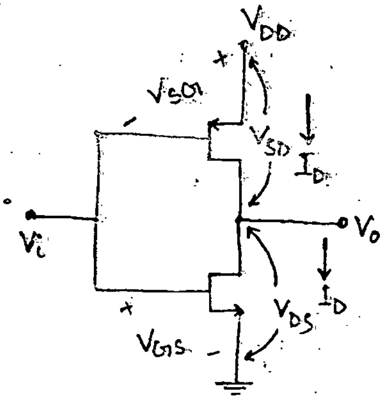
T_1 & T_2 are in current Saturation

$$K_1 (V_{GS_1} - V_t)^2 = K_2 (V_{GS_2} - V_t)^2$$
$$K_1 (V_i - V_t)^2 = K_2 (V_{DD} - V_0 - V_t)^2$$
$$\boxed{V_0 = V_{DD} - V_t - \sqrt{\frac{K_1}{K_2}} (V_i - V_t)}$$

CMOS (COMPLIMENTRY MOS TRANSISTOR)

Ideal Switch (Inverter)





$V_{SD} < V_{SG} - |V_T|$ → Triode

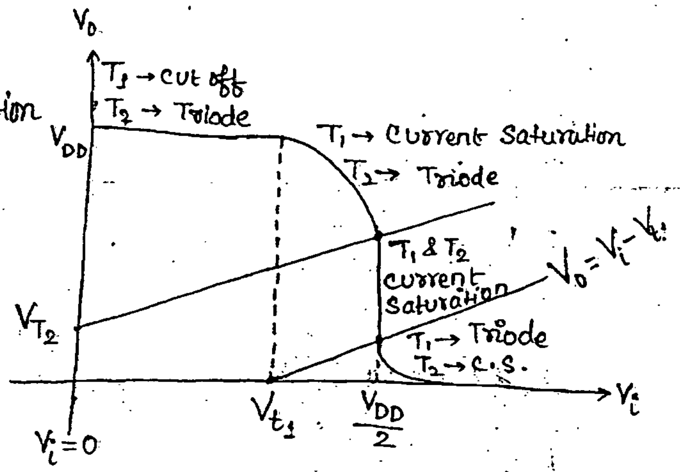
$V_{SD} > V_{SG} - |V_T|$ → Saturation

Boundary for current Saturation

$V_{SD} = V_{SG} - |V_T|$

$\cancel{V_{DD}} - V_o = \cancel{V_{DD}} - V_i - |V_T|$

$\boxed{V_o = V_i + |V_T|}$



$K_1 = K_2$

$V_{t_1} = V_{t_2}$

$\boxed{V_i = \frac{V_{DD}}{2}}$

When T_1 & T_2 are current Saturation

$K_1(V_{GS} - V_{T_1})^2 = K_2(V_{SG} - |V_T|)^2$

$K_1(V_i - V_{T_1}) = K_2(V_{DD} - V_i - |V_T|)$