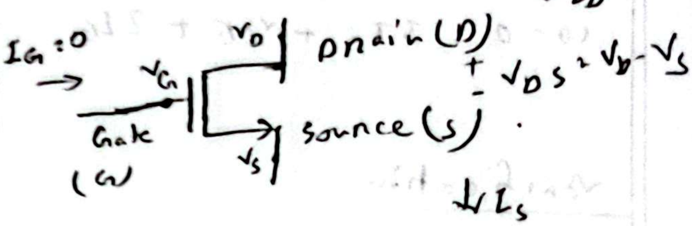
MosFET

~~S model (switch mode) (Ideal model)~~

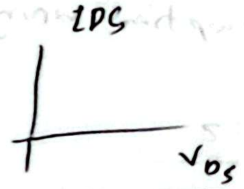
$V_{GS} = V_G - V_S$

i. $V_{GS} \geq V_T$ (ON)

ii. $V_{GS} < V_T$ (OFF)



$I_{DS} = I_D = I_S$



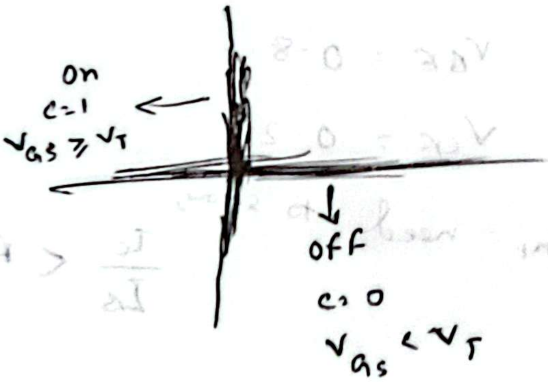
S model (switch model) (Ideal model)

→ $C = 0$, $V_{GS} < V_T$ (OFF)

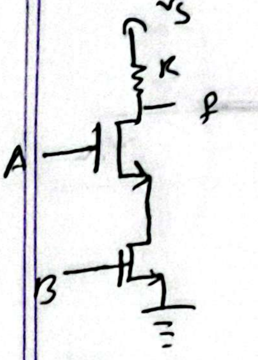
D, S $\downarrow I_{DS} = 0$

→ $C = 1$, $V_{GS} \geq V_T$ (ON)

D, S $\downarrow I$. $V_{DS} = 0$

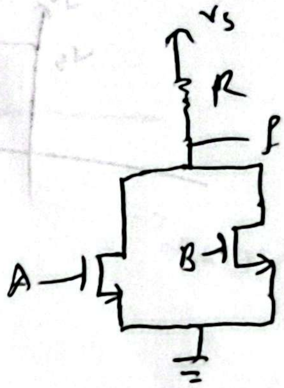


NAND - 2



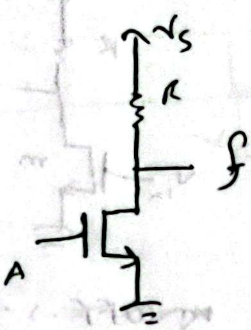
$f = \overline{AB}$

NOT - 2



$f = \overline{A+B}$

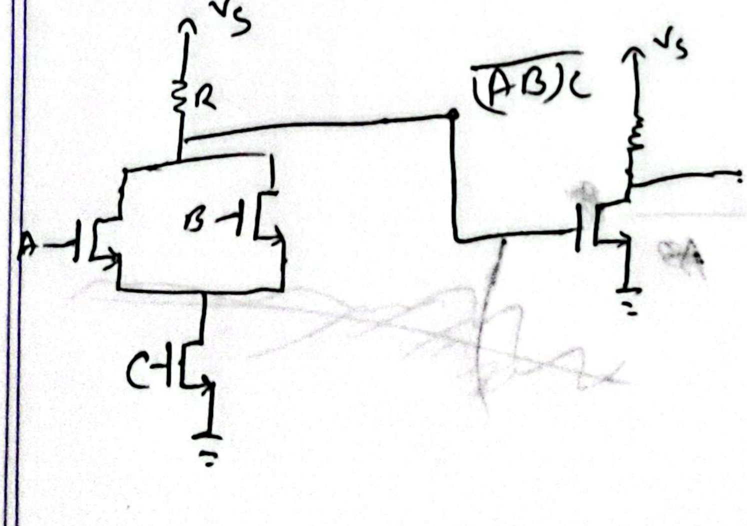
NOT Gate (Inverter)



$f = \overline{A}$

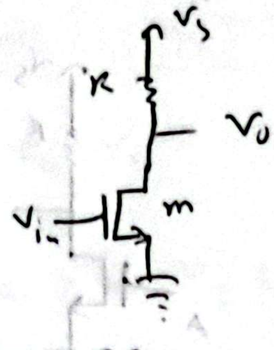
Yn-1 :

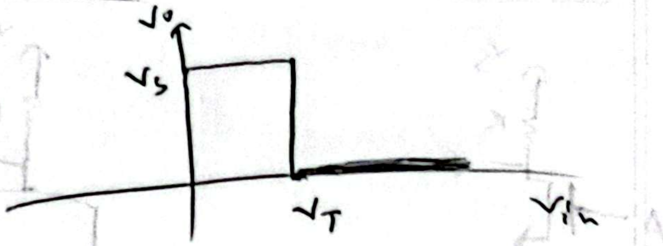
$f = (A+B)C$



$\overline{\overline{(A+B)C}} = (A+B)C$

VTC of Inverter (NOT Gate)



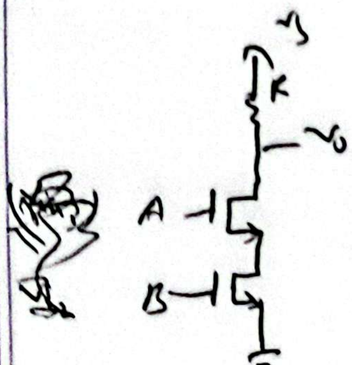


m = OFF →.

$V_{in} < V_T$, m = OFF

$V_{in} \geq V_T$, m = ON

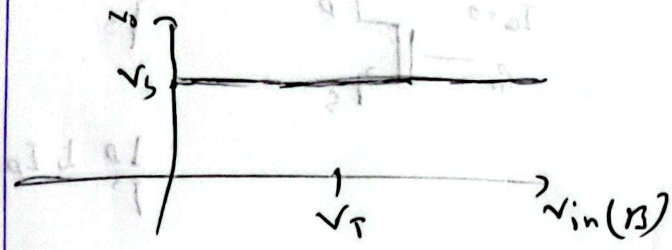
VTC of NAND-2 Gate



$V_0 = \overline{AB}$

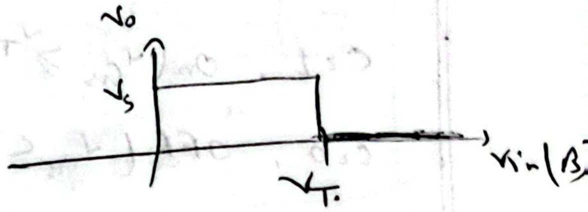
A=0

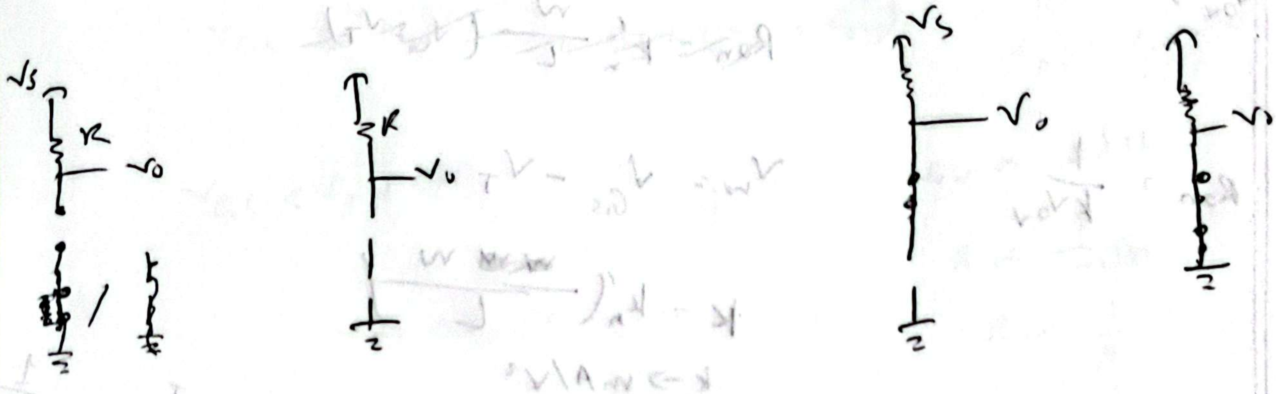
B → Vary



A=1

B → Vary





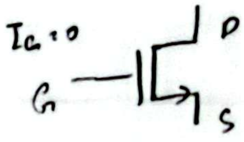
HW → NOR-2,3 Gate

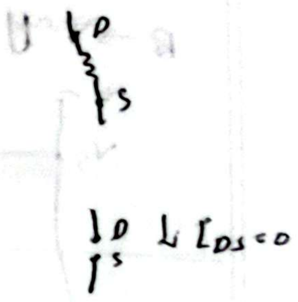
251

SR (switch Resistor) model

$C=1$, On ($V_{GS} \geq V_T$)

$C=0$, OFF ($V_{GS} < V_T$)





V_{ov} → Overdrive voltage

$\cancel{R_{on} = k_n' \frac{W}{L}(V_G - V_T)}$

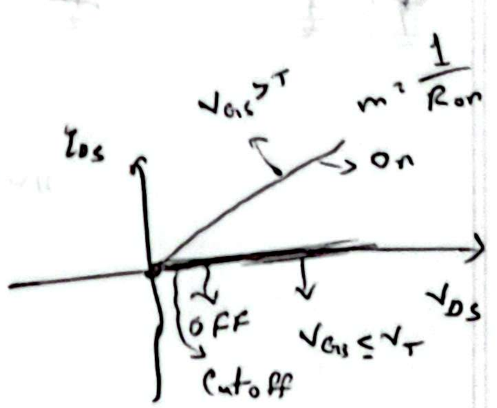
$$R_{on} = \frac{1}{kV_{ov}}$$

$$V_{ov} = V_{GS} - V_T$$

$$k = k_n'\left(\frac{W}{L}\right)$$

$k \rightarrow mA/V^2$

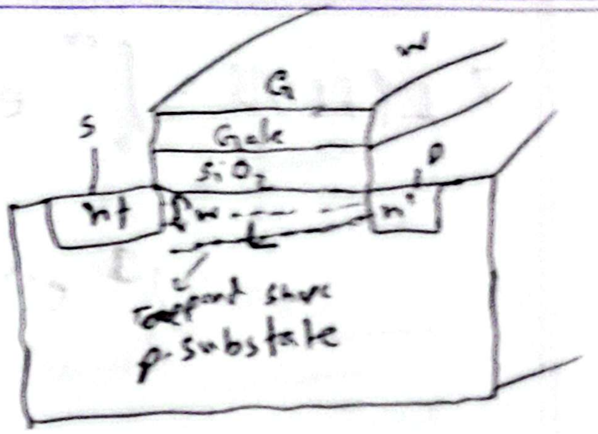
$V_{ov} \propto$ Channel width



SR valid till $\boxed{V_{DS} < V_{ov}}$

Invalid or fails when $V_{DS} \geq V_{ov}$

Working mechanism of Mosfet.



$V_{GS} \geq V_T$, on — Triode ($V_{DS} < V_{OV}$)
— Saturation ($V_{DS} \geq V_{OV}$)

$V_{OV} = V_{GS} - V_T$

$V_{GS} < V_T$, off

$V_{OV} \propto$ width

$R \propto \frac{1}{\text{width}}$

$V_{DS} = V_D - V_S$

$R \propto \frac{1}{A}$

$V_{OV} = V_{GS} - V_T$

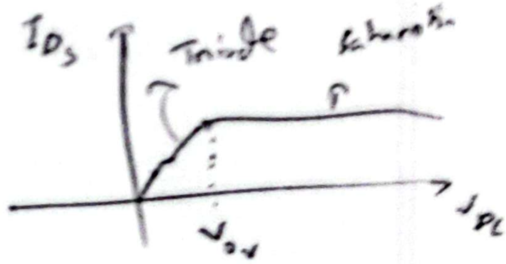
$R \propto \frac{1}{V}$

$= V_G - V_S - V_T$

$R \propto L$

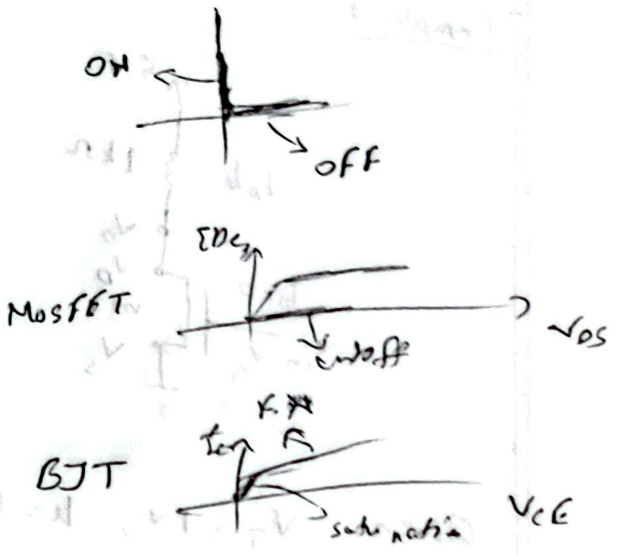
$R \propto \frac{L}{A}$

$= V_G - V_T$



31/8/25

251



Operating Region	Condition	state eqn.
Cutoff	$V_{GS} < V_T$	$I_{DS} = 0$
Triode	$V_{GS} \geq V_T$ $V_{DS} < V_{OV}$	$I_{DS} = K[V_{OV}V_{DS} - \frac{1}{2}V_{DS}]$
Saturation	$V_{GS} \geq V_T$ $V_{DS} \geq V_{OV}$	$I_D = \frac{1}{2} K V_{OV}^2$

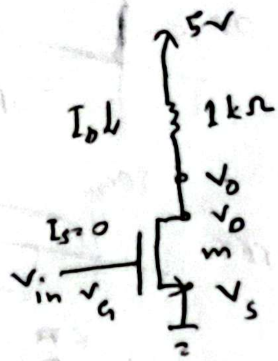
$V_{OV} = V_{GS} - V_T$

$K = K'_n \left(\frac{W}{L}\right)$

↳ unit → mA/V^2

Example-1

saturation,



Given, $V_T = 1V$, $k = 0.5\,mA/V^2$, $v_{in} = 2V$.

saturate I_D and V_o.

Ans.

Assumption-1,

m → saturation

$V_{GS} \geq V_T$

$V_{DS} \geq V_{OV}$

$V_{GS} = V_G - V_S$

$= 2 - 0$

$= 2$

$V_T = 1V$

$V_{DS} = V_D - V_S = V_D$

$V_{ov} = V_{GS} - V_T$

$= 2 - 1$

$= 1$

From equation,

$$I_{DS} = \frac{1}{2} k V_{ov}^2 = \frac{1}{2} \times 0.5 \times (1)^2 = 0.25 \text{ mA} \quad ..(i)$$

Ohms law on $1k\Omega$,

$$I_{DS} = \frac{5 - V_D}{1}$$

$\Rightarrow I_{DS} = 5 - V_D$

$\Rightarrow 0.25 = 5 - V_D$

$\therefore V_D = 4.75$

$V_{DS} = 4.75V$

Verification

$V_{GS} = 2 \geq V_T = 1$ ✓

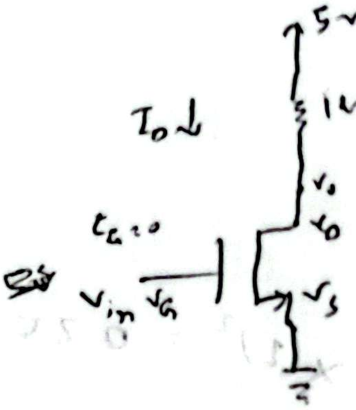
$V_{DS} = 4.75 \geq V_{ov} = 1$ ✓

Assumption is correct

$I_D = 0.25$ mA

$V_{DS} = V_D = 4.75$

Example 2:



$V_T = 1V$

$k = 0.5\ mA/V^2$

$V_{in} = 5v$

~~k = 0.5 mA/v^2~~

I_D and v_o?

Ans: Assumption-1, ⇒ saturation

$V_{GS} \geq V_T$

&

$V_{DS} \geq V_{OV}$

$V_G = V_G - V_S = 5 - 0 = 5$

$V_T = 1V$

$V_{DS} = V_D - V_S = V_D - 0 = V_D$

$V_{OV} = V_{GS} - V_T = 5 - 1 = 4V$

From eqn:

$I_{DS} = \frac{1}{2} k (V_{OV})^2$

$= \frac{1}{2} \times 0.5 \times (4)^2$

$= 4\ mA \quad ...(i)$

Ohm's law on 1kΩ,

$I_{DS} = I_D = \frac{5 - V_D}{1}$

$\Rightarrow I_{DS} = 5 - V_D$

$\Rightarrow 4 = 5 - V_D$ [(i)]

$\Rightarrow V_D = 1V$

$V_{DS} = V_D = 1V$

Verification

$V_{GS} = 4V \geq V_T = 1V$ ✓

$V_{DS} = 1V \ngeq V_{OV} = 4V$ ✗

Assumption wrong

Assumption-ii

in Triode

$$\boxed{\begin{matrix} V_{GS} \geq V_T \\ V_{DS} < V_{OV} \end{matrix}}$$

$V_{GS} = V_G - V_S = 5 - 0 = 5$

$V_T = 1$

$V_{DS} = V_D - V_S = V_D - 0 = V_D$

$V_{OV} = V_{GS} - V_T = 5 - 1 = 4$

Form eqn.

$$I_{DS} = k\left[V_{OV} V_{DS} - \frac{1}{2} V_{DS}^2\right]$$

$$\Rightarrow I_{DS} = 0.5\left[4V_D - \frac{1}{2} V_D^2\right]$$

$$\Rightarrow I_{DS} = 2V_D - 0.25\,V_D^2 \;..(i)$$

Ohms law on $1k\Omega$

$$I_{DS} = \frac{5 - V_D}{1}$$

$$\Rightarrow I_D = 5 - V_D \;..(ii)$$

from (i), (ii)

$2V_D - 0.25V_D^2 = 5 - V_D$

$\therefore V_D = 10V \mid V_D = 2V$ ✓

$V_{DS} = V_D = 2V$

Verification:

$V_{GS} = 5 \geq V_T = 1$ ✓

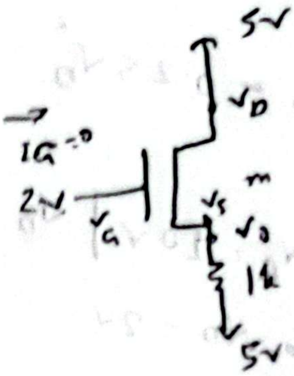
$V_{DS} = 2V < V_{OV} = 4V$ ✓

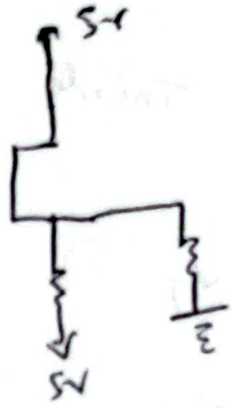
Assumption 2 correct

$I_D = 5 - V_D = 5 - 2 = 3mA$

$V_o = V_D = 2V$

Example-3 :





$V_T = 1V$

$k = 4\,mA/V^2$

calc V_O, I_D

Ans

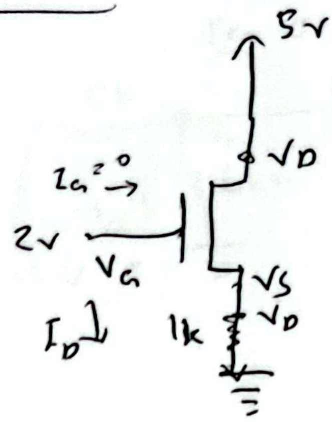
m = cutoff

$I_D = 0$

$V_O = 5V$

no voltage difference

Example-4.



~~$V_{GS} \geq V_T$~~

$V_T = 1V$

$k = 4 \; mA/V^2$

Calc V_s, I_D

An

Assumption, m → saturation

$$\boxed{\begin{array}{c} V_{GS} \geq V_T \\ V_{DS} \geq V_T \end{array}}$$

$V_G = V_G - V_S = 2 - V_S$

$V_T = 1V$

$V_{DS} = V_D - V_S = 5 - V_S$

$V_{ov} = V_{GS} - V_T$

$= 2 - V_s - 1$

$= 1 - V_s$

From eqn

$I_{DS} = \frac{1}{2} k (V_{ov})^2$

$\Rightarrow I_{DS} = \frac{1}{2} \times 4 \times (1 - V_s)^2$

$\Rightarrow I_{DS} = 2(1 - 2V_s - V_s^2)$

$\Rightarrow I_{DS} = 2 - 4V_s + 2V_s^2$ ...(i)

Ohms law on 1kΩ

$I_{DS} = \frac{V_s - 0}{1}$

$\Rightarrow I_{DS} = V_s - 0$

$\therefore I_{DS} = V_s$ .. (ii)

(i), (ii),

$2 - 4V_s + 2V_s^2 = V_s$

$\Rightarrow 2V_s^2 - 5V_s + 2 = 0$

$\therefore V_s = 2$ ✗ | $V_s = 0.5$ ✓

Verification:

$V_{GS} = 2 - 0.5V = 1.5V$

$V_T = 1$

$V_{DS} = 5 - V_S = 5 - 0.5 = 4.5V$

$V_o = 1 - V_S = 0.5$

Verification

$V_{GS} \geq V_T$

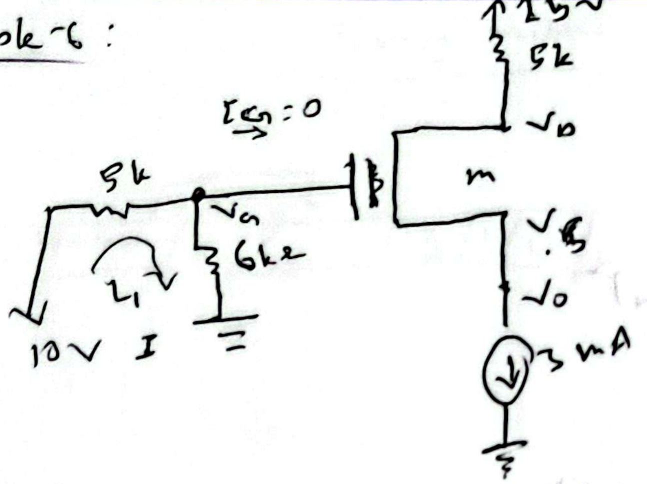
$V_{DS} \geq V_{OV}$

Assumption correct

$V_o = V_D = 0.5V$

$I_D = V_S = 0.5mA$

Example-6 :



Assumpt.

$V_T = 1V$

$k = 5mA/V^2$

Calc V_0, I_D

Ans

Assumption-1, m → saturation

$$\boxed{\begin{array}{c} V_{GS} \geq V_T \\ V_{DS} \geq V_{OV} \end{array}}$$

$V_{GS} = V_G - V_S$

KVL on L_1,

$10 - 0 = 5I + 6I$

$\therefore I = \frac{10}{11}$

Ohms law on 6kΩ,

$\frac{V_G - 0}{6} = I$

$V_G = \frac{6 \times 10}{11}$

$= 5.45V$

$V_{GS} = 5.45 - V_S$

$V_T = 1V$

$V_{DS} = V_D - V_S$

$V_{OV} = V_{GS} - V_T$

$= 5.45 - V_S - 1$

$= 4.45 - V_S$

$I_{DS} = 3$

Ohms law on 5k

$I_{DS} = \frac{15 - V_D}{5}$

$\Rightarrow 3 = \frac{15 - V_D}{5}$

$\therefore V_D = 0$

From eqn

$\therefore I_{DS} = \frac{1}{2} k (V_{ov})^2$

$\Rightarrow 3 = \frac{1}{2} \times 5 \times (V_{ov})^2$

$\Rightarrow 6 = 5(4.45 - V_S)^2$

$\Rightarrow 5[V_S^2 - 2 \times 4.45 V_S + (4.45)^2] = 6$

$V_S = 1 / V_S = 1$

$V_{GS} = 5.45 - 1 = 4.45$

$V_{ov} = 4.45 - 1$

$= 3.45$

$V_{DS} = V_D - V_S = 0 - 1 = -1$

Verification :

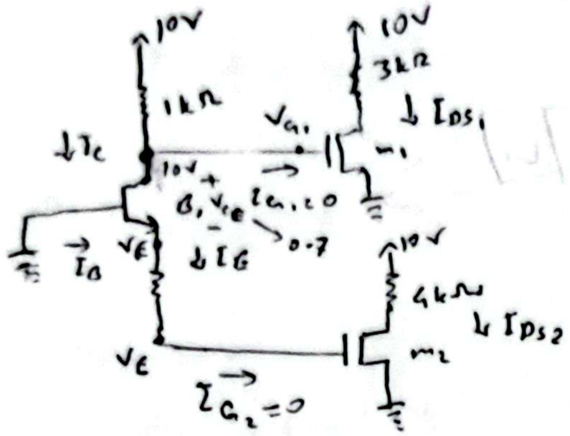
$V_{GS} = 4.45 > V_T$

$V_{DS} = -1 \ngtr V_{ov}$

$\therefore$ Wrong

251

Ex. 1:



$V_T = 1V$

$k = 5mA/V^2$

$\beta = 100$

$\alpha = 0.99$

1. calculate I_C, I_B, I_E
2. calculate I_{DS1}
3. Calculate I_{DS2}

Soln.

1. $B_1 \rightarrow$ Cutoff

~~I_B~~ ~~I_B, I_C~~.

$I_B = I_C = I_E = 0$.

---

3. $V_{CE} = V_C - V_E = 0.7$ [best case]

$0.7 = 10 - V_E$

$\therefore V_E = 9.3$

2. $m_1 \rightarrow$ saturation

$$\boxed{\begin{array}{l} V_{GS} \geq V_T \\ V_{DS} \geq V_{OV} \end{array}}$$

$I_{DS} = \frac{1}{2} k V_{OV}^2$

$V_{GS_1} = V_{G_1} - V_{S_1}$

$= 10 - 0$

$= 10$

$V_T = 1V$

$V_{DS_1} = V_{D_1} - V_{S_1} = V_{D_1} - 0$

$= V_{D_1}$

$V_{OV_1} = V_{G_1} - V_T = 10 - 1 = 9V$

From eqn.

$I_{DS_1} = \frac{1}{2} k (V_{OV_1})^2$

$\Rightarrow I_{DS_1} = \frac{1}{2} \times 5 \times (9)^2 = 202.5mA$

Ohms law on $3k\Omega$

$\Rightarrow I_{DS_1} = \frac{10 - V_{D_1}}{3}$

$\Rightarrow 202.5 = \frac{10 - V_{D_1}}{3}$

$V_{D_1} = 10 - (202.5 \times 3)$

$= -597.5 \text{ mA}$

$V_{DS_1} = V_{D_1} = -597.5 \text{ V}$

Verification:

$V_{GS_1} = 10 \geq V_T = 1V$

$V_{DS_1} = -597.5 \ngeq V_{ov} = 9V$

$\therefore$ Assumption wrong

Assumption 2:

$m \Rightarrow$ Triode

$$\boxed{\begin{array}{c} V_{GS} \geq V_T \\ V_{DS} < V_{OV} \end{array}}$$

$$I_{DS} = k\left[V_{ov} \cdot V_{DS} - \frac{1}{2} V_{DS}^2\right]$$

$V_{GS_1} = V_{G_1} - V_{S_1} = 10 - 0 = 10V$

$V_T = 1V$

$V_{DS_1} = V_{D_1} - V_{S_1} = V_{D_1} - 0$
$= V_{D_1}$

$V_{OV_1} = V_{GS_1} - V_T$
$= 10 - 1 = 9V$

From eqn:

$$I_{DS_1} = k\left[V_{ov_1} V_{DS_1} - \frac{1}{2} V_{DS_1}^2\right]$$

$$I_{DS_1} = 5\left[9V_{D_1} - \frac{1}{2} V_{D_1}^2\right]$$

$$I_{DS_1} = 45 V_{D_1} - 2.5 V_{D_1}^2 \quad \ldots (i)$$

Ohms law on $3k\Omega$

$$I_{DS_1} = \frac{10 - V_{D_1}}{3} \quad \ldots (ii)$$

(i), (ii),

$$\frac{10 - V_{D_1}}{3} = 45 V_{D_1} - 2.5 V_{D_1}^2$$

$V_{D_1} = 18.06V$ × | $V_{D_1} = 0.072V$ ✓

$V_{GS_1} = V_{D_1} = 0.072V$

Verification

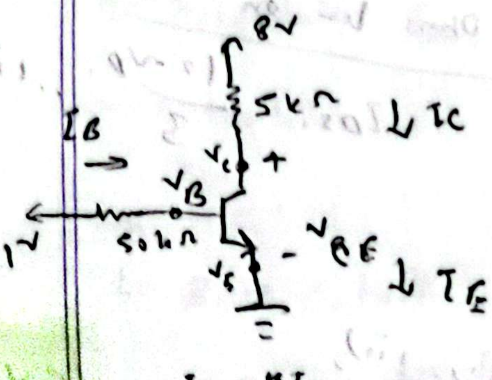
$V_{GS_1} : 10 \geq V_T = 1V$

$V_{DG} = 0.072 < V_{OV} = 5V$

∴ Assumption correct

$I_{DS_1} = \frac{10 - 0.072}{3}$ mA

Ex-2 :



$I_C = \beta I_B$, $I_C = \alpha I_E$

$\beta = 100$

$\alpha = 0.99$

V_{BE} (active) = 0.7

V_{BE} (sat) = 0.8V

V_{CE} (sat) = 0.2V

~~calculate I_B, I_C, I_E?~~

* Calculate I_B, I_C, I_E?

Ans: Assumption-1.

Active

$$\boxed{\begin{array}{c} I_B, I_C, I_E > 0 \\ V_{CE} \geq 0.2V \end{array}}$$

$V_{BE} = 0.7$

$\Rightarrow V_B - V_E = 0.7$

$\Rightarrow V_B - 0 = 0.7$

$V_B = 0.7$

Ohms law on 50kΩ

$\frac{1 - V_B}{50} = I_B$

$I_B = \frac{1 - 0.7}{50} = 0.006$ mA

$I_E = I_B + I_C$

$I_C = \beta I_B = 100 \times 0.006 = 0.6$ mA

$I_E = 0.006 + 0.6 = 0.606$ mA

Ohms law on 5kΩ:

$$I_C = \frac{8 - V_C}{5}$$

$$\Rightarrow 0.6 = \frac{8 - V_C}{5}$$

$$\therefore V_C = 8 - (5 \times 0.6)$$

$$= 5V$$

$$V_{CE} = V_C - V_E$$

$$= 5 - 0$$

$$= 5V$$

Verification

$I_B = 0.006$,

$I_C = 0.6$,

$I_E = 0.606 > 0$

$V_{CE} = 5 > 0.2$

Assumption 1 correct

$I_B = 0.006$ mA

$I_C = 0.6$ mA

$I_E = 0.606$ mA

Ex 3:

$$f = \overline{C \cdot (A+B)} \cdot (A + \overline{B} + C)$$