'Assignment - 03'

Amirun Nahin

ID: 23201416

Sec: 07

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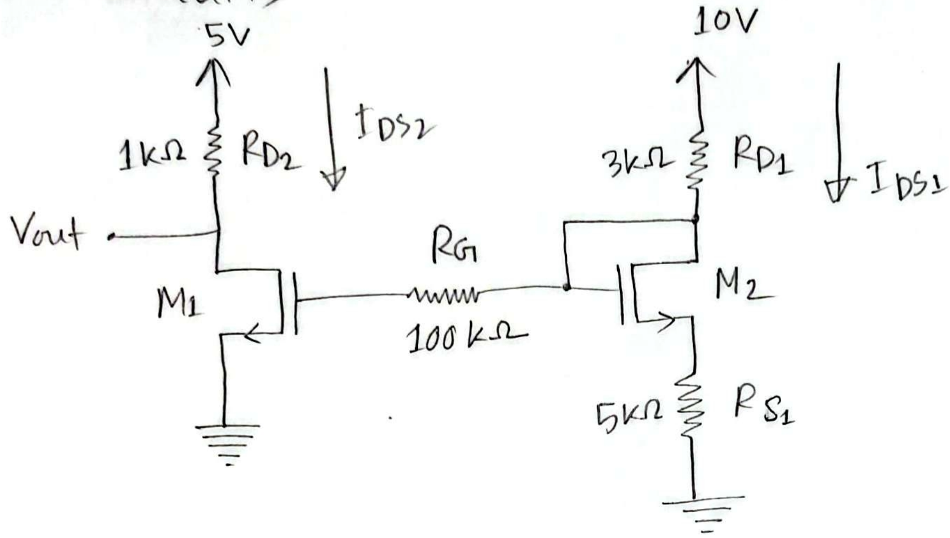
Ans. to the ques. no - 01

(a)

Given circuit,



Here, in M_2 MOSFET, the Gate and Drain are shorted. So, in M_2 MOSFET, $V_{GS} = V_{DS}$. Also, as $I_G = 0$, I_{DS_1} will be the current through M2 MOSFET. Now, to be in saturation mode,

$$V_{DS} \geq V_{ov}$$

$$\Rightarrow V_{DS} \geq V_{GS} - V_T$$

$$\Rightarrow \cancel{V_{DS}} \geq \cancel{V_{DS}} - V_T \quad [\text{as } V_{GS} = V_{DS}]$$

$$\Rightarrow 0 \geq -V_T$$

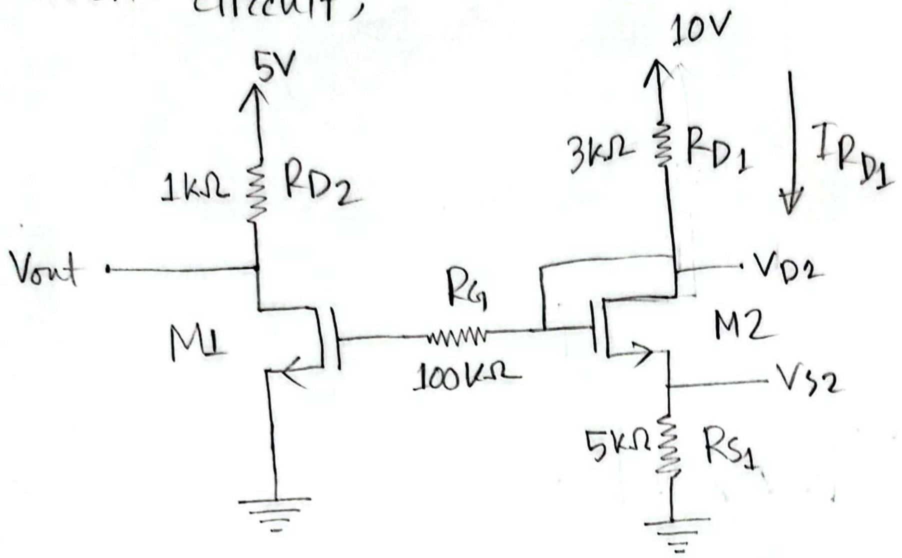
$$\Rightarrow V_T \geq 0 \quad [\text{Multiplying by } (-1)]$$

We see that, to be in saturation mode V_T has to be more than 0. Our given V_T for M2 is 1V.

Therefore, M2 MOSFET will operate in saturation mode.

(b)

Given circuit,



$V_T = 1V$ (for both)

for M1,

$K_1 = 0.5\ mA/V^2$

for M2,

$K_2 = 2\ mA/V^2$

for M2 MOSFET; assumming saturation,

$$I_{RD_1} = \frac{1}{2} \times K_2 \times (V_{ov})^2$$

$$I_{RD_1} = \frac{1}{\cancel{2}} \times \cancel{2} \times (V_{GS2} - V_T)^2$$

$$I_{RD_1} = (V_{G} - V_{S2} - V_T)^2 \quad \text{——— (i)}$$

Again,

$$I_{RD_1} = \frac{10 - V_{D2}}{3} \quad \text{——— (ii)}$$

$$I_{RD_1} = \frac{V_{S2} - 0}{5}$$

$$= \frac{V_{S2}}{5} \quad \text{——— (iii)}$$

from (ii) and (iii)

$$\frac{10 - V_{D2}}{3} = \frac{V_{S2}}{5}$$

$$\Rightarrow 50 - 5V_{D2} = 3V_{S2}$$

$$\Rightarrow 5V_{D2} = 50 - 3V_{S2}$$

$$\Rightarrow V_{D2} = \frac{50 - 3V_{S2}}{5} \quad \text{——— (iv)}$$

Now, we can see that, Gate and Drain are shorted in M2 MOSFET. So,

$$V_G = V_{D2}$$

also, as $I_G = 0$ through R_G, both MOSFET has same V_G.

Now, from (iv)

$$V_G = \frac{50 - 3V_{S2}}{5}$$

and, from (ii) and (iii)

$$\frac{V_{S2}}{5} = \left(\frac{50 - 3V_{S2}}{5} - V_{S2} - V_T \right)^2$$

$$\Rightarrow \frac{V_{S2}}{5} = \left(\frac{50 - 3V_{S2} - 5V_{S2} - 1}{5} \right)^2$$

$$\Rightarrow 5V_{S2} = (-8V_{S2} + 45)^2$$

$$\Rightarrow 5V_{S2} = 64V_{S2}^2 - 720V_{S2} + 2025$$

$$\Rightarrow 64V_{S2}^2 - 725V_{S2} + 2025 = 0$$

$$\therefore V_{S2} = 6.33V, 5V$$

Taking $V_{S2} = 5V$ as to V_{GS} to be more, we need less value of V_{S2}.

So,

$$V_G = \frac{50-(3\times5)}{5}$$

$$= 7\,V$$

from (i),

$$I_{RD1} = (7-5-1)^2$$

$$= 1\,mA$$

Verify,

$$\text{as } V_{DS} = V_{GS}$$

$$\therefore V_{DS} = V_G - V_{S2}$$

$$= 7-5$$

$$= 2\,V$$

since, $V_{DS} > V_T$; saturation mode assumption is right.

Now, for M2 MOSFET,

the V_G is the same as M1. So, $V_G = 7V$. and $V_{S1} = 0V$.

Assuming saturation,

$$I_{RD2} = \frac{1}{2} \times k_1 \times (V_{ov})^2$$

$$\Rightarrow I_{RD2} = \frac{1}{2} \times 0.5 \times (V_{GS2} - V_t)^2$$

$$\Rightarrow I_{RD_2} = \frac{1}{4} \times (V_{G} - V_{S1} - V_T)^2$$

$$= \frac{1}{4} \times (7 - 0 - 1)^2$$

$$= 9 \text{ mA}$$

Again,

$$I_{RD_2} = \frac{5 - V_{out}}{1}$$

$$\Rightarrow 9 = 5 - V_{out}$$

$$\Rightarrow V_{out} = -4 \text{ V}$$

verify,

$$V_{DS} = V_D - V_{S1}$$

$$= V_{out} - V_{S1}$$

$$= -4 - 0$$

$$= -4$$

since, $V_{DS} < V_T$; assumption is wrong.

Now, assumming Triode,

$$I_{RD_2} = K \times \left(V_{OV} - \frac{V_{DS}}{2}\right) V_{DS}.$$

$$\Rightarrow I_{RD_2} = 0.5 \times \left(V_G - V_{S1} - V_T - \frac{V_{DS}}{2}\right) V_{DS}$$

$$\Rightarrow I_{RD_2} = 0.5 \times \left(7 - 0 - 1 - \frac{V_{out} - V_{S1}}{2}\right) \times (V_{out} - V_{S1})$$

$$\Rightarrow I_{RD_2} = 0.5 \times \left(6 - \frac{V_{out}}{2}\right) \times V_{out}$$

$$\Rightarrow I_{RD_2} = 0.5 \times \frac{(12 - V_{out})}{2} \times V_{out}$$

$$\Rightarrow I_{RD_2} = \frac{12V_{out} - V_{out}^2}{4} \text{ ——— (i)}$$

Again,

$$I_{RD_2} = \frac{5 - V_{out}}{1}$$

$$\Rightarrow I_{RD_2} = 5 - V_{out} \text{ ——— (ii)}$$

from (i) and (ii),

$$5 - V_{out} = \frac{12V_{out} - V_{out}^2}{4}$$

$$\Rightarrow 20 - 4V_{out} = 12V_{out} - V_{out}^2$$

$$\Rightarrow V_{out}^2 - 16V_{out} + 20 = 0$$

$$\therefore V_{out} = 14.633\text{ V}, \; 1.366\text{ V}$$

Verify, let $V_{out} = 1.366$ V

So,

$$V_{DS} = V_D - V_{S1}$$
$$= V_{out} - V_{S1}$$
$$= 1.336 - 0$$
$$= 1.336\text{ V}$$

$$V_{OV} = V_{GS} - V_T$$
$$= V_G - V_{S1} - V_T$$
$$= 7 - 0 - 1$$
$$= 6\text{ V}$$

Since, $V_{DS} < V_T$; Triode mode assumption is right.

Finally, from (i),

$$I_{RD_2} = \frac{12 V_{out} - V_{out}^2}{4}$$

$$= \frac{12 \times (1.336) - (1.336)^2}{4}$$

$$= 3.56 \text{ mA}$$

So, We get,

$V_{out} = 1.336$ V

$I_{RD1} = 1$ mA

$I_{RD2} = 3.56$ mA

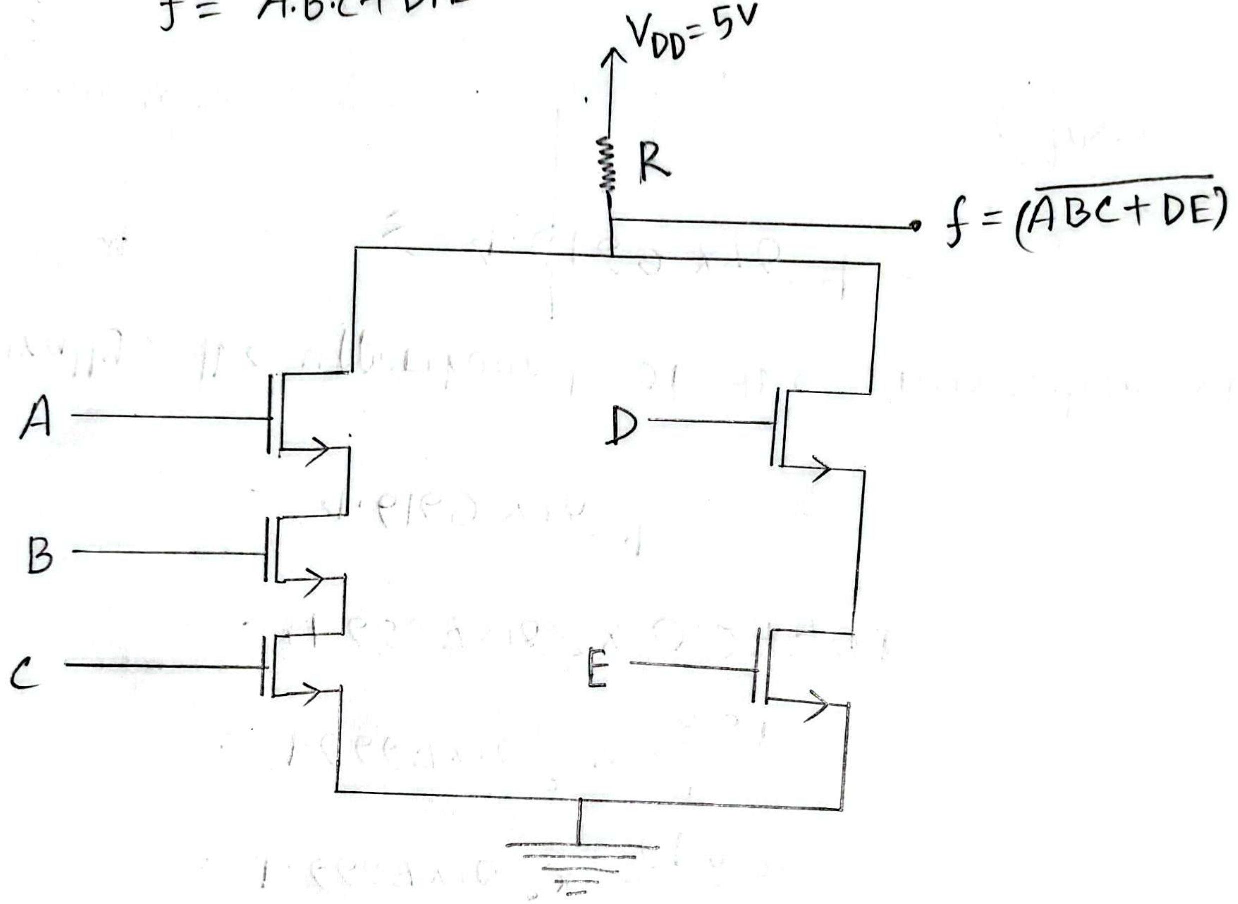
(Ans.)

Ans. to the que. no-02

(i)

Given,

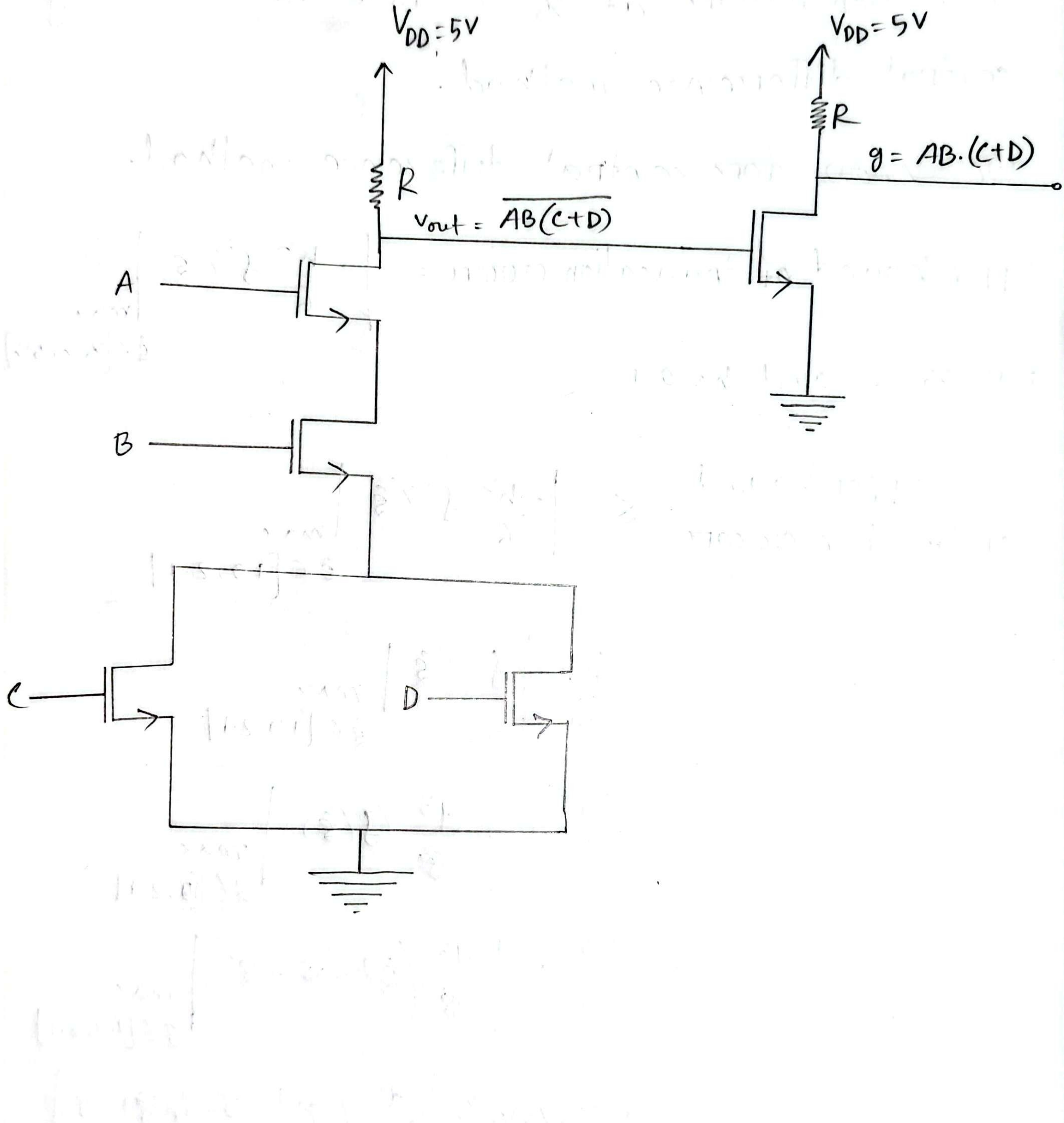
$f = \overline{A.B.C + D.E}$



(ii)

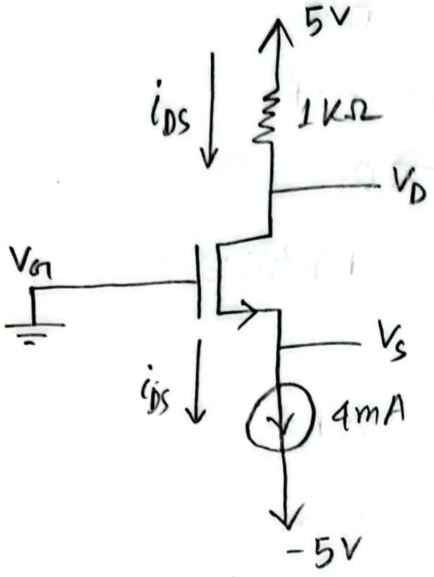
Given,

$$g = A \cdot B \cdot (C+D)$$



Ans. to the ques. no-03

Given,



$V_T = 1V$

$K = 4mA/V^2$

$i_{DS} = 4mA$

Assuming Saturation,

here, $i_{DS} = 4mA$. So,

$$i_{DS} = \frac{1}{2} K_n' \frac{W}{L} \cdot (V_{OV})^2$$

$$\Rightarrow 4 = \frac{1}{2} \times 4 \times (V_{GS} - V_T)^2$$

$$\Rightarrow 4 = 2 \times (V_G - V_S - V_T)^2$$

$$\Rightarrow 4 = 2 \times (0 - V_S - 1)^2$$

$$\Rightarrow 2 = (-V_S - 1)^2$$

$$\Rightarrow \sqrt{2} = -V_S - 1$$

$$\Rightarrow V_S = -1 - \sqrt{2}$$

$$\Rightarrow V_S = -2.414 \text{ V}$$

Now,

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

$$\Rightarrow 4 = \frac{5 - V_D}{1}$$

$$\Rightarrow 4 = 5 - V_D$$

$$\Rightarrow V_D = 5 - 4$$

$$\Rightarrow V_D = 1V$$

Verify,

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

$$= 1 + 2.414$$

$$= 3.414\ V$$

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

$$= V_G - V_S - V_T$$

$$= 0 + 2.414 - 1$$

$$= 1.414\ V$$

$$\therefore V_{DS} > V_{OV}$$

So, assumption is right.

Therefore, the MOSFET is in Saturation mode.

and, $V_S = -2.414\ V$. (Ans.)

Ans. to the ques. no-04

ⓐ

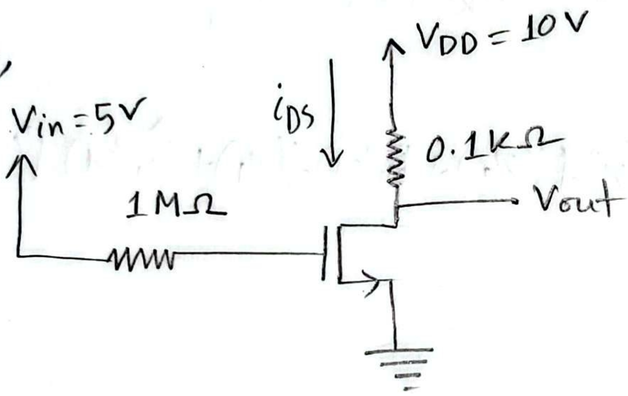
In saturation mode, the MOSFET will have,

$$V_{GS} \geq V_{Tn}$$

and, $V_{DS} \geq V_{ov}$ where, $V_{ov} = V_{GS} - V_{Tn}$

ⓑ

Given,



$V_T = 1V$

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

Assumming saturation,

$$i_{DS} = \frac{1}{2} \times K' \times \frac{W}{L} \times (V_{ov})^2$$

$$= \frac{1}{2} \times 4 \times (V_{GS} - V_T)^2$$

$$= 2 \times (V_G - V_S - V_T)^2$$

$$= 2 \times (5 - 0 - 1)^2$$

$$= 32\ mA$$

so, $i_{DS} = \dfrac{V_{DD} - V_{out}}{0.1}$

$\Rightarrow 32 \times 0.1 = 10 - V_{out}$

$\Rightarrow 3.2 = 10 - V_{out}$

$\Rightarrow V_{out} = 10 - 3.2$

$\Rightarrow V_{out} = 6.8\,V$

Verify,

$V_{GS} = V_G - V_S$

$= 5 - 0$

$= 5V$

$\therefore V_{GS} > V_T$

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

$= V_{out} - V_S$

$= 6.8 - 0$

$= 6.8\,V$

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

$= V_G - V_S - V_T$

$= 5 - 0 - 1$

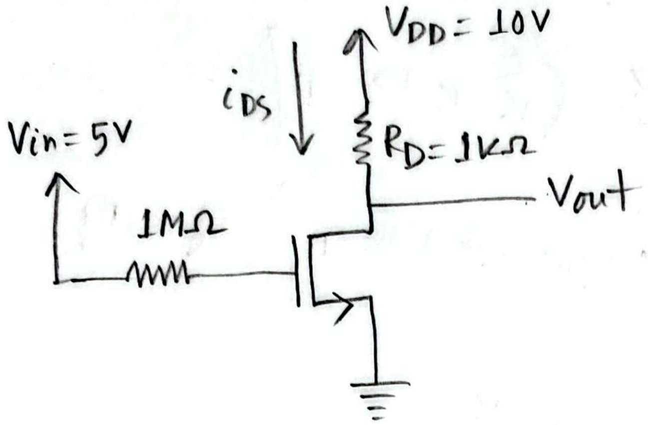
$= 4V$

As, $V_{DS} > V_{ov}$, the assumption is correct and the MOSFET is in saturation mode.

As, we're given logic HIGH as input and got $V_{out} = 6.8V$, which is also logic HIGH, Nirmol was correct. (Ans.)

(c)

Nirmol changed the value of R_D to $1k\Omega$. So, circuit,



$V_T = 1V$

$K_n = 4\ mA/V^2$

Assumming saturation,

$$i_{DS} = \frac{1}{2} \times K_n' \times \frac{W}{L} \times (V_{ov})^2$$

$$= \frac{1}{2} \times 4 \times (V_{GS} - V_T)^2$$

$$= \frac{1}{2} \times 4 \times (V_G - V_S - V_T)^2$$

$$= 2 \times (5 - 0 - 1)^2$$

$$= 32\ mA$$

So, $\therefore$ $i_{DS} = \frac{V_{DD} - V_{out}}{1}$

$\Rightarrow 32 = 10 - V_{out}$

$\Rightarrow V_{out} = -22V$

Verify, $V_{GS} = V_G - V_S$

$= 5 - 0$

$= 5V$

$\therefore V_{GS} > V_T$

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

$= V_{out} - V_S$

$= -22 - 0$

$= -22\ V$

$\therefore\ V_{ov} = V_{GS} - V_T = V_G - V_S - V_T$

$= 5 - 0 - 1$

$= 4V$

As, $V_{DS} < V_{ov}$, assumption is wrong.

Assuming Triode Mode,

$$i_{DS} = k_n' \cdot \frac{W}{L} \times \left[V_{ov} - \frac{V_{DS}}{2}\right] V_{DS}$$

$$\Rightarrow i_{DS} = 4 \times \left[V_G - V_S - V_T - \frac{(V_D - V_S)}{2}\right](V_D - V_S)$$

$$\Rightarrow i_{DS} = 4 \times \left[5 - 0 - 1 - \frac{(V_D - 0)}{2}\right](V_D - 0)$$

$$\Rightarrow i_{DS} = 4 \times \left(4 - \frac{V_D}{2}\right) V_D$$

$$\Rightarrow i_{DS} = 4 \times \left(\frac{8 - V_{out}}{2}\right) V_{out}$$

$$\Rightarrow i_{DS} = (16 - 2V_{out}) V_{out}$$

$$\Rightarrow i_{DS} = 16 V_{out} - 2V_{out}^2 \text{ ——— (i)}$$

Again,

$$i_{DS} = \frac{V_{DD} - V_{out}}{R_D}$$

$$\Rightarrow i_{DS} = \frac{10 - V_{out}}{1}$$

$$\Rightarrow i_{DS} = 10 - V_{out} \quad \text{——— (ii)}$$

from (i) and (ii)

$$16 V_{out} - 2V_{out}^2 = 10 - V_{out}$$

$$\Rightarrow 2V_{out}^2 - 17 V_{out} + 10 = 0$$

$$\therefore V_{out} = 0.635 \text{ V}$$

Verify,

$$V_{DS} = V_D - V_S$$
$$= V_{out} - V_S$$
$$= 0.635 - 0$$
$$= 0.635 \text{ V}$$

and, $V_{OV} = V_{GS} - V_T$
$$= V_G - V_S - V_T$$
$$= 5 - 0 - 1$$
$$= 4 \text{ V}$$

As $V_{DS} < V_{OV}$; so, assumption is right. So, the MOSFET is in Triode Mode.

Now, As $V_{out} = 0.635$ v which is less than 5v. the output is logic LOW. So, Yes, the inverter was working properly.

(Ans.)

(d)

At the edge of saturation,

$$V_{DS} = V_{ov}$$

Now,

$$V_{ov} = V_{GS} - V_T$$
$$= V_G - V_S - V_T$$
$$= 5 - 0 - 1$$
$$= 4V$$

$$\therefore V_{DS} = 4V$$

$$\Rightarrow V_D - V_S = 4$$

$$\Rightarrow V_D - 0 = 4$$

$$\Rightarrow V_D = 4V$$

Now, at the saturation mode,

$$i_{DS} = \frac{1}{2} \times k_n' \times \frac{W}{L} \times (V_{ov})^2$$
$$= \frac{1}{2} \times 4 \times (4)^2$$
$$= 32 \text{ mA}$$

again,

$$i_{DS} = \frac{V_{DD} - V_{out}}{R_D}$$

$$\Rightarrow R_D = \frac{10 - 6}{32}$$

$$\Rightarrow R_D = 0.1875 \text{ k}\Omega$$

Therefore, for $R_D = 0.1875 \text{ k}\Omega$, the MOSFET operates at the edge of saturation. (Ans.)

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