1. For the n-channel MOSFET as shown in Fig. 1 has $K_n = 0.2$ mA/V^2 and $V_{Th} = 1$ V. Given that $V_{DD} = 10$ V and $R_D = 1$ kΩ. Find (a) the region operation, (b) V_{GS} (c) V_{DS} and (d) i_D.

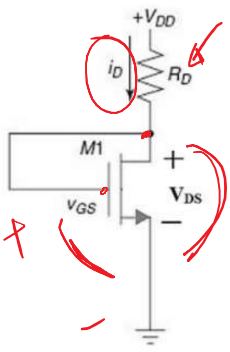


Fig. 1

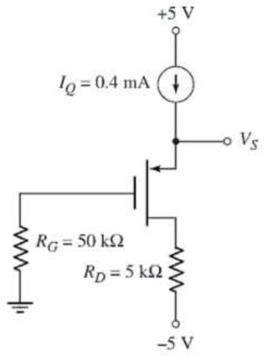


Fig. 2

① Here,

$V_{DS} = V_{GS} > V_{GS} - V_{Th}$

So, MOSFET is in saturation. — ⓐ

$i_D = K_n (V_{GS} - V_{Th})^2 = 0.2\times10^{-3}(V_{GS}-1)^2$

$i_D = \frac{V_{DD}-V_{DS}}{R_D} = \frac{V_{DD}-V_{GS}}{1\,K}$ equate

Page-1

$\therefore 0.2\times10^{-3}(V_{GS}-1)^2 = \frac{10-V_{GS}}{1\,K}$

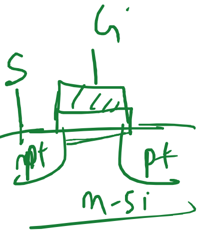
$\therefore V_{GS} = 5.66,\ -8.66$ V.

$V_{GS} < 0$, not possible, So, $V_{GS} = 5.66$ V. — ⓑ

$V_{DS} = 5.66$ V. — ⓒ

$i_D = \frac{V_{DD}-V_{DS}}{R_D} = \frac{10-5.66}{1K} = 4.34$ mA. — ⓓ

$V_G = -1.5V$ $V_G = -1V$ $V_G = 0$



$V_{th} = -0.8$ V

p-MOS

2. For the circuit in Figure 2, the p-channel transistor has threshold voltage (V_{Th}) = −0.8 V and $K_p = 200$ μA/V^2. Determine V_S and V_{SD}.

②

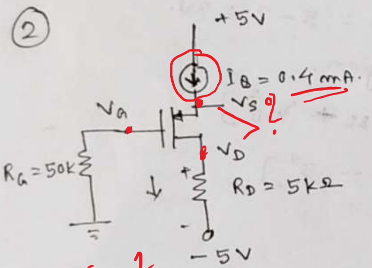


Fig.2

$V_G = 0$

Let us assume, the MOSFET is in saturation

$V_{SG} = V_S - V_G = V_S - 0$

$V_{SG} = V_S$

$I_Q = I_D = K_p(V_{SG} + V_{Th})^2$

$\therefore 0.4 = 200\times10^{-3}\times(V_S - 0.8)^2$

$\therefore V_S = 2.214$ V.

$V_{SD} = V_S - V_D$.

$V_D = -5 + I_Q\cdot R_D$

$= -5 + 0.4\times5$

$\therefore V_{SD} = V_S - V_D = 2.214 - (-3)$

$V_{SD} = 5.214$ V.

V_{SG} $|V_{GS} - V_{Th}|$

$V_D = -5 + I_D \cdot R_D$

$= -5 + 0.4 \times 5$

$V_D = -3\,V.$

$\therefore V_{SD} = V_S - V_D = 2.214 - (-3)$

$\boxed{V_{SD} = 5.214\,V.}$

$V_{SD(sat)} = V_{SG} + V_{Th}$

$= 2.214 - 0.8$

$= 1.414\,V.$

as, $V_{SD} > V_{SD}(sat)$.

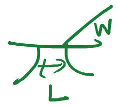
So, MOSFET is saturation as assumed.

V_{SG} $(V_{GS} - V_{Th})$ overdrive

$V_{SG} + V_{Th}$

$V_{SG} - (V_{Th})$

3. A particular n-channel MOSFET has parameters $V_{Th} = 0.6$ V, $L = 0.8$ μm, $t_{ox} = 200$ Å, and $\mu_n = 600$ cm^2/V–s. A drain current of $I_D = 1.2$ mA is required when the device is biased in the saturation region at $V_{GS} = 3$ V. Determine the required channel width of the device.



③ n-ch device

$V_{Th} = 0.6\,V$ $\quad L = 0.8\,\mu m$ $\quad V_{GS} = 3\,V.$ $\quad I_D = 1.2\,mA.$

$t_{ox} = 200\,Å$ $\quad \mu_n = 600\,cm^2/V\text{-}s.$

In saturation, $I_D = K_n (V_{GS} - V_{Th})^2$ $\quad$ 'K_n'

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

$\therefore 1.2 = \frac{1}{2} \times 600 \times \frac{\epsilon_{ox}}{t_{ox}} \times \frac{W}{0.8 \times 10^{-4}} (3 - 0.6)^2$;

$\frac{\epsilon_{ox}}{t_{ox}} = \frac{8.854 \times 10^{-14} \times 3.9}{200 \times 10^{-8}} = 1.726 \times 10^{-7}$ F/cm^2

$\therefore 1.2 = 300 \times 1.726 \times 10^{-7} \times \frac{W}{0.8 \times 10^{-4}} \times 5.76$

I in mA.

$\therefore 1.2 = 3.728 \times W$
mA.

$W = 3.218\,\mu m.$

$C_{ox} = \frac{\epsilon_{ox}}{t_{ox}} = \frac{\epsilon_{SiO_2} \epsilon_0}{t_{ox}}$

$\epsilon_0 = 8.854 \times 10^{-14}$

$\epsilon_r = 3.9$

$\epsilon_{SiO_2} = 3.9$

Si MOSFET $\epsilon_{SiO_2} = 3.9$

SiO_2

4. For a p-channel enhancement-mode MOSFET, the parameters are $K_P = 2$ mA/V^2 and $V_{TP} = -0.5$ V. The gate is at ground potential, and the source terminals is at +5 V. Determine I_D when the drain terminal voltage is: (a) $V_D = 0$ V, (b) $V_D = 2$ V, (c) $V_D = 4$ V, and (d) $V_D = 5$ V.

Enhancement mode MOSFET

PMOS, $V_{Th} < 0$

NMOS, $V_{Th} > 0$

④ P-channel enhancement mode MOSFET. (P-2)

$K_P = 2\,mA/V^2$

$V_{TP} = (-)0.5\,V$ $\quad$ Gate (G) terminal is grounded.

Source (S) " " at +5 V.

~~$V_{SD} = V_{SG}$~~

$V_G = 0$, $V_S = 5\,V$. $\therefore V_{SG} = 5\,V.$

$\boxed{V_{SD(sat)}} = V_{SG} + V_{TP} = 5 - 0.5 = 4.5\,V$

(i) when, $V_D = 0$, $V_{SD} = 5\,V > 4.5\,V$, biased in saturation

So, $I_D = K_P (V_{SG} + V_{TP})^2$

$= 2 \times 10^{-3} (5 - 0.5)^2$

$I_D = 40.5\,mA.$

(ii) When, $V_D = 2\,V$, $V_{SD} = V_S - V_D = 5 - 2 = 3\,V.$

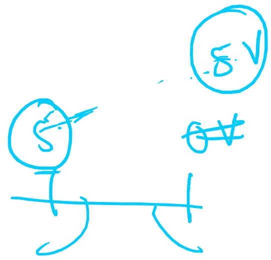
So, MOSFET is in triode region.

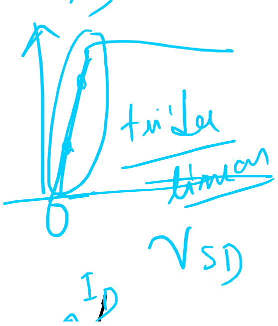
$I_D = K_P [2 (V_{SG} + V_{TP}) V_{SD} - V_{SD}^2]$

$= 2 \times 10^{-3} [2 (5 - 0.5) 3 - 3^2]$

$I_D = 36\,mA.$

(iii) when $V_D = 4\,V$ ... MOSFET in triode region.





$I_D = 36$ mA.

(iii) When $V_D = 4$ V, $V_{SD} = 1$ V. , so, MOSFET in triode region.

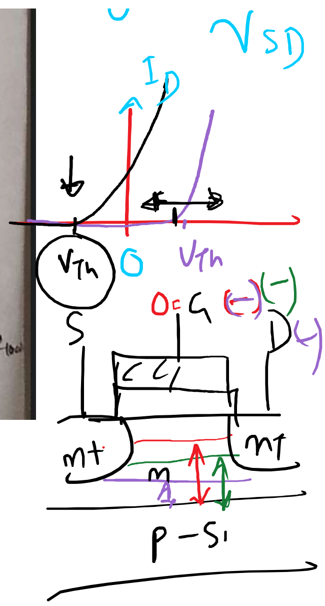
$I_D = k_p[2(V_{SG}+V_{TP})V_{SD} - V_{SD}^2]$

$= 2\times10^{-3}[2(5-0.5)1 - 1]$

$= 16$ mA

(iv) When, $V_D = 5$ V., $V_{SD} = 0$ V. , so, no drain current will flow

∴ $I_D = 0$.



5. In the circuit shown in Fig. 3, the transistor parameters are $V_{Th} = 0.8$ V and $K_n = 0.5$ mA/V^2. Calculate (i) Drain current I_D, (ii) Gate-source voltage (V_{GS}), and (iii) Drain-source voltage (V_{DS}).

6. The transistors (M_1 & M_2) in the circuit shown in Fig. 4 have parameters $V_{Th} = 0.4$ V and $K_n' = 120$ µA/V^2. (a) If the width-to-length ratios of M_1 and M_2 are $(W/L)_1 = (W/L)_2 = 30$, determine V_{GS1}, V_{GS2}, V_O, and I_D. (b) Repeat part (a) if the width-to-length ratios are changed to $(W/L)_1 = 30$ and $(W/L)_2 = 15$.

2.5 V

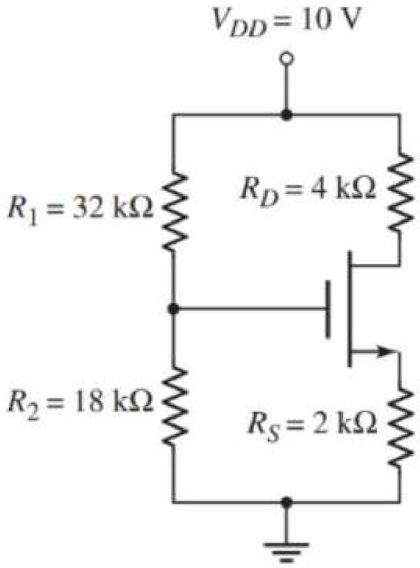


Fig. 3

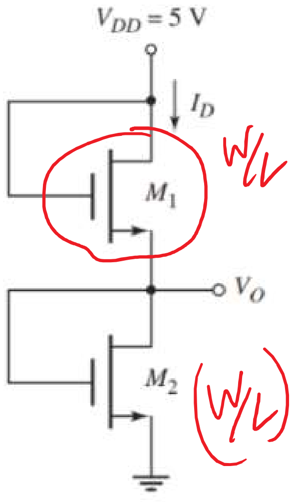
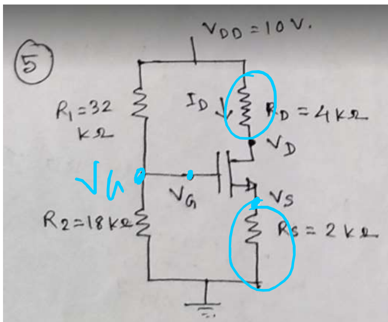


Fig. 4

(5)



$V_G = V_{DD} \times \frac{R_2}{R_1+R_2} = 10 \times \frac{18}{18+32}$

$= 3.6$ V.

Assuming the MOSFET is in saturation.

$I_D = k_n(V_{GS}-V_{Th})^2$

$= 0.5\times10^{-3}\times(V_{GS}-0.8)^2$ — (1)

Again, $I_D = \frac{V_S}{R_S} = \frac{V_G - V_{GS}}{R_S}$

$I_D = \frac{3.6 - V_{GS}}{R_S}$ — (2) ; $[V_G - V_{GS} = V_G - V_G + V_S = V_S]$

∴ From (1) & (2),

$0.5\times10^{-3}\times(V_{GS}-0.8)^2 = \frac{3.6 - V_{GS}}{2\times10^3}$

$V_S = V_G - V_{GS}$
$= V_G - (V_G - V_S)$
$= V_G - V_G + V_S$
$= V_S$

∴ $V_{GS}^2 - 1.6V_{GS} + 0.64 = 3.6 - V_{GS}$

∴ $V_{GS}^2 - 0.6V_{GS} - 2.96 = 0$.

(P-3)

$I_D = \frac{V_S}{R_S}$

$I_D = \frac{V_S}{R_S}$

(P-3)

$\therefore V_{GS}^2 - 1.6V_{GS} + 0.64 = 3.6 - V_{GS}$

$\therefore V_{GS}^2 - 0.6V_{GS} - 2.96 = 0$

$\therefore V_{GS} = \frac{0.6 \pm \sqrt{(0.6)^2 + 4\times(2.96)}}{2}$

$V_{GS} = 2.046$ V. — (ii)

$\frac{V_S}{R_S} = I_D = \frac{V_G - V_{GS}}{R_S} = \frac{3.6 - 2.046}{2} = 0.777$ mA. — (i)

$V_{DS} = V_{DD} - I_D(R_D + R_S)$

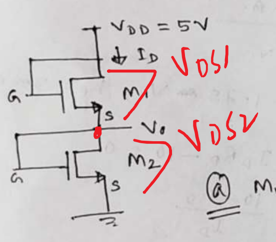
$= 10 - 0.777 \times (4+2)$

$V_{DS} = 5.338$ V. ------ (iii)

$V_{DS(sat)} = V_{GS} - V_{Th} = 2.046 - 0.8 = 1.246$ V.

$V_{DS} > V_{DS(sat)}$, So, MOSFET is in saturation. (our assumption is correct)

(6)



$V_{Th} = 0.4$ V

$k_n' = 120\,\mu A/V^2$

$\therefore \mu_n C_{ox} = 120\,\mu A/V^2$

$\left(\frac{W_1}{L_1}\right) = \left(\frac{W_2}{L_2}\right) = 30$

(a) M_1 and M_2 are in saturation as $V_{DS} > V_{DS(sat)}$

[$V_{GS} = V_{DS}$, $V_{DS(sat)} = V_{GS} - V_{Th}$]

Same current is flowing through both transistors.

$\therefore k_n(V_{GS_1} - V_{Th})^2 = k_n(V_{GS_2} - V_{Th})^2$

$\therefore \cancel{\tfrac{1}{2}}\cancel{k_n'}\cancel{\left(\tfrac{W}{L}\right)_1}(V_{GS1} - V_{Th})^2 = \cancel{\tfrac{1}{2}}\cancel{k_n'}\cancel{\left(\tfrac{W}{L}\right)_2}(V_{GS} - V_{Th})^2$

$I_D = \frac{1}{2}k_n'\left(\frac{W}{L}\right)_2(V_{GS2} - V_{Th})^2$

$= \frac{1}{2} \times 120 \times 10^{-6} \times 30(2.5 - 0.4)^2$

$= 7.938$ mA.

$\therefore V_{GS1} = V_{GS2}$ $\quad V_{Th}$ same for M_1 & M_2

$V_{DS1} + V_{DS2} = 5$V.

$V_{GS} = V_{DS}$

$\therefore V_{GS1} + V_{GS2} = 5$V ; [as $V_G = V_D$].

$2V_{GS1} = 5$V.

$\therefore V_{GS1} = 2.5$V. $= V_{GS2} = V_o$

(b) $\left(\frac{W}{L}\right)_1 = 30$; $\left(\frac{W}{L}\right)_2 = 15$

$\frac{1}{2}k_n'\left(\frac{W_1}{L_1}\right)(V_{GS1} - V_{Th})^2 = \frac{1}{2}k_n'\left(\frac{W_2}{L_2}\right)(V_{GS2} - V_{Th})^2$

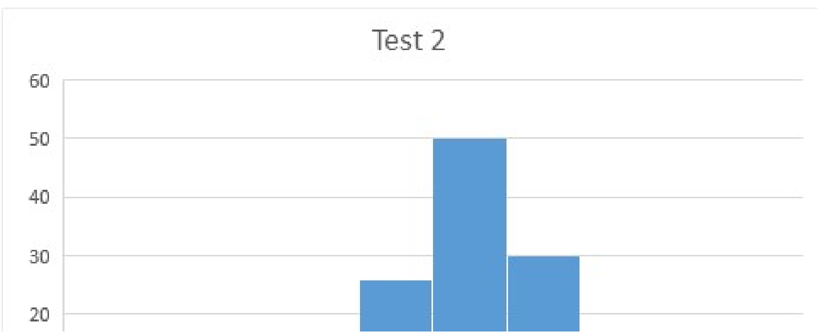
$30(V_{GS1} - V_{Th})^2 = 15(V_{GS2} - V_{Th})^2$

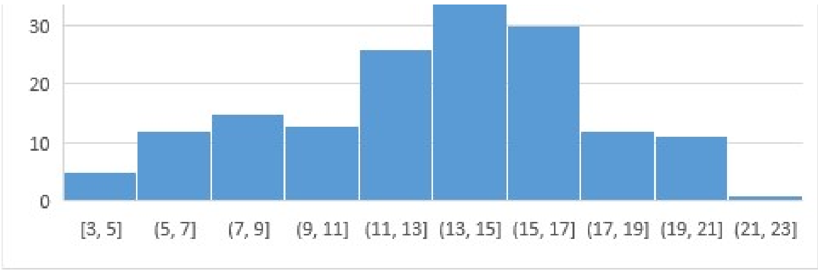
$1.414V_{GS1} - 1.414V_{Th} = V_{GS2} - V_{Th} = V_{DS2} - V_{Th} = 5 - V_{GS1} - V_{Th}$

$\therefore 2.414V_{GS1} = 5 + 0.414V_{Th} = 5.1656$

$\therefore V_{GS1} = 2.139$ V. $\quad \therefore V_{GS2} = 2.86$ V. $(5 - V_{GS1})$

Find I_D.





7. In the circuit shown in Fig. 5, find the value of R_S and R_D when V_D = -3 V and I_D = 0.5 mA. The transistor parameters are given as $K_p' = 30$ $\mu A/V^2$, W/L = 20 and V_{Th} = -1.2 V.

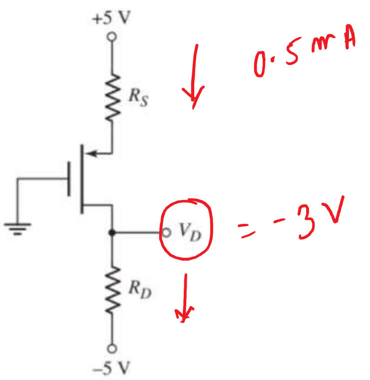
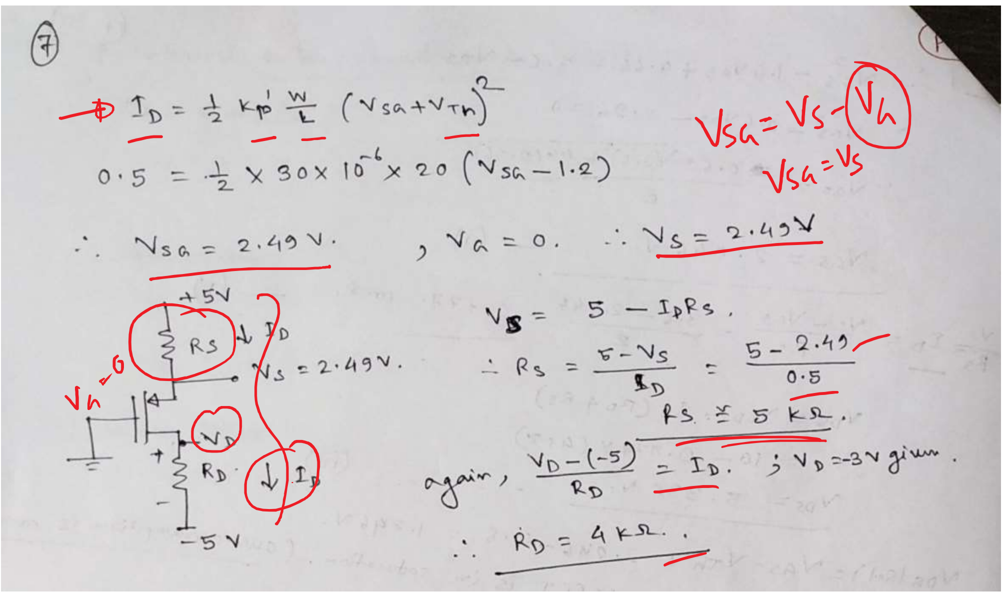


Fig. 5


(7)

$I_D = \frac{1}{2} k_p' \frac{W}{L} (V_{SG}+V_{Th})^2$

$V_{SG} = V_S - V_{th}$

$V_{SG} = V_S$

$0.5 = \frac{1}{2} \times 30 \times 10^{-6} \times 20 \, (V_{SG} - 1.2)$

$\therefore V_{SG} = 2.49$ V. , $V_G = 0$. $\therefore V_S = 2.49$ V

$V_S = 5 - I_D R_S$.

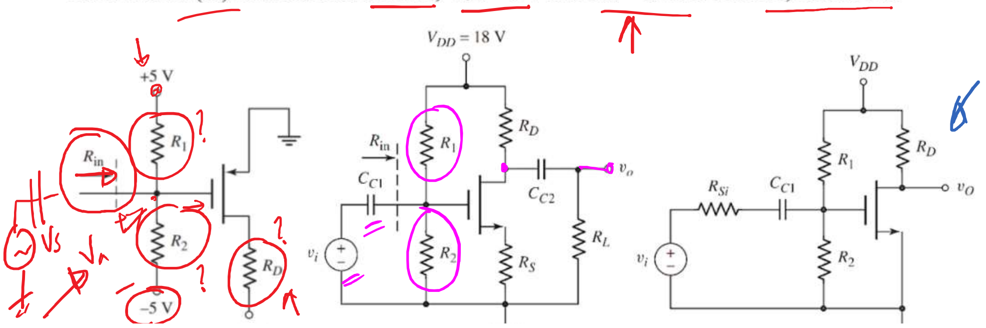
$\therefore R_S = \frac{5 - V_S}{I_D} = \frac{5 - 2.49}{0.5}$

$R_S \simeq 5$ kΩ.

again, $\frac{V_D - (-5)}{R_D} = I_D$. ; $V_D = -3$ V given.

$\therefore R_D = 4$ kΩ.

8. The circuit shown in Fig. 6 have transistor parameters $V_{Th} = -1.75$ V and $K_p = 3$ mA/V^2. The drain current (I_D) in the circuit is 5 mA, V_{SD} = 6 V and R_{in} = 80 kΩ. Find R_1, R_2 and R_D.



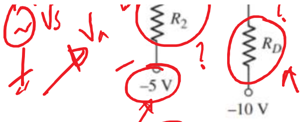
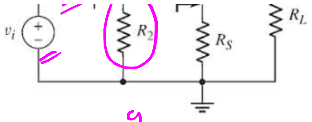


Fig. 6



Q-9

Fig. 7

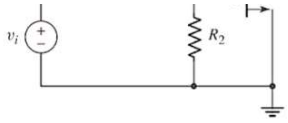
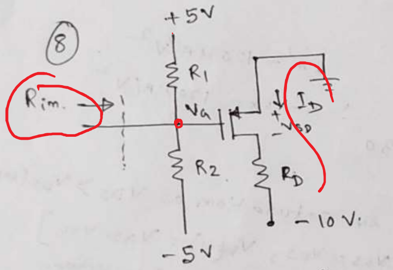


Fig. 8

(8)



$I_D = 5\,mA.$

$V_{SD} = 6\,V.$

$V_{Th} = -1.75\,V$, $k_p = 3\,mA/V^2.$

$+V_{SD} + I_D R_D - 10 = 0.$

$\therefore R_D = \dfrac{10 - V_{SD}}{I_D}$

$R_D = \dfrac{10 - 6}{5\,mA} = 800\,\Omega.$

$R_{im} = 80\,k\Omega = \dfrac{R_1 R_2}{R_1 + R_2}$ —(1)

$V_G = -5 + (5-(-5)) \times \dfrac{R_2}{R_1+R_2}$

$V_G = -5 + 10\,\dfrac{R_2}{R_1+R_2}$ —(2)

$I_D = k_p (V_{SG} + V_{Th})^2$

$\therefore 5 = 3(V_{SG} - 1.75)^2$

$\therefore V_{SG} = 3.04$

$V_S - V_G = 3.04$; $V_S = 0.$

$V_G = -3.04\,V.$

From (2)

$-3.04 = -5 + 10\,\dfrac{R_2}{R_1+R_2}$

$\therefore 1.96 = 10\left(\dfrac{R_1R_2}{R_1+R_2}\right)\cdot\dfrac{1}{R_1}$

$\therefore 1.96 = 10 \times 80 \cdot \dfrac{1}{R_1}$ From (1)

$\therefore R_1 = \dfrac{10 \times 80}{1.96}$

$R_1 = 408.16\,k\Omega.$

From, (1), $R_2 = 99.4\,k\Omega.$

(9) P-5

$g_m = 2\sqrt{k_n I_{DQ}}$

$2.2 = 2\sqrt{k_n (6)}$

$\therefore k_n = 0.202\,mA/V^2$

$g_m = 2.2\,mA/V$

$I_{DQ} = 6\,mA.$

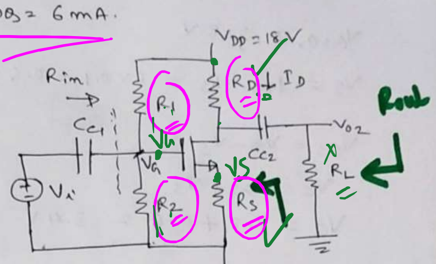
$V_{GSQ} = 2.8\,V.$

$V_{DSQ} = 10\,V.$

$g_m = 2.2\,mA/V$

$\lambda = 0$, $R_L = 1\,k\Omega$

$A_v = -1$, $R_{in} = 100\,k\Omega$



k_n, V_{Th}.

$I_{DQ} = k_n (V_{GSQ} - V_{Th})^2$

$\therefore 6 = 0.202\,(2.8 - V_{Th})^2$

$\therefore V_{Th} = -2.65\,V$

$V_{DD} = I_{DQ}(R_D + R_S) + V_{DSQ}$

$\therefore V_{DSQ} = V_{DD} - I_{DQ}(R_D + R_S)$

$V_{DSQ} = 18 - 6(R_D + R_S) = 10\,V$ (given).

$R_D + R_S = 1.33\,k\Omega$ —(1)

given that, $A_v = -1$

$R_D + R_S = 1.33\ k\Omega$ — (1)

given that, $A_v = -1$

$v_i = v_{gs} + g_m v_{gs} R_s$.

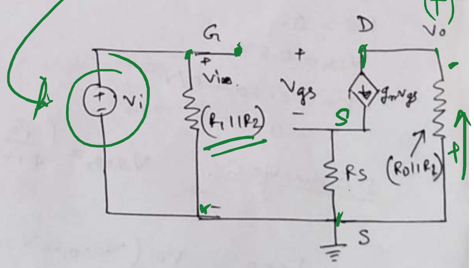
$v_{gs} = \dfrac{v_i}{1 + g_m R_s}$

$v_o = -g_m v_{gs} (R_D \| R_L)$

$v_o = -g_m \dfrac{v_i}{1 + g_m R_s} (R_D \| R_L)$

$\therefore v_o = -\dfrac{g_m (R_D \| R_L)}{1 + g_m R_s} v_i$

$\therefore \dfrac{v_o}{v_i} = A_v = -\dfrac{g_m (R_D \| R_L)}{1 + g_m R_s} = -1$ — (2)



$g_m (R_D \| R_L) = 1 + g_m R_s$; substitute $R_s = 1.33 - R_D$ from (1).

$\therefore g_m (R_D \| R_L) = 1 + g_m (1.33 - R_D)$

$\therefore g_m (R_D \| R_L) = 1 + g_m (1.33 - R_D)$ from (1).

g_m, R_L, known, Find R_D

$2.2 R_D^2 + 0.47 R_D - 3.93 = 0$

$R_D = 1.23\ k\Omega$; neglect the (−) value.

$R_s = 1.33 - 1.23 = 0.1\ k\Omega$

Rin value given, $R_{in} = (R_1 \| R_2) = \dfrac{R_1 \times R_2}{R_1 + R_2} = 100\ k\Omega$. — (3)

(P-6)

$V_{GSQ} = 2.8\ V$

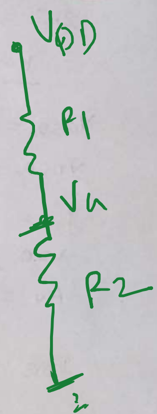
$V_S = I_{DQ} \cdot R_s = 6 \times 0.1 = 0.6\ V$.

$V_{GS} = V_G - V_S$

$\therefore V_G = V_{GS} + V_S$.

$V_G = 2.8 + 0.6 = 3.4\ V = V_{DD} \times \dfrac{R_2}{R_1 + R_2}$

$V_G = \dfrac{R_2}{R_1 + R_2} V_{DD}$



$\therefore V_{DD} \times \dfrac{R_1 R_2}{R_1 + R_2} \times \dfrac{1}{R_1} = 3.4$

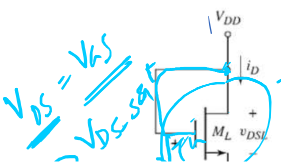
$\therefore 18 \times 100 \times \dfrac{1}{R_1} = 3.4$

$\therefore R_1 = 529\ k\Omega$

from, (3) Find R_2.; $R_2 = 123\ k\Omega$.

10. The parameters of the circuit shown in Fig. 8 are $V_{DD} = 5$ V, $R_1 = 520$ kΩ, $R_2 = 320$ kΩ, $R_D = 10$ kΩ, and $R_{Si} = 0$. Assume transistor parameters of $V_{Th} = 0.8$ V, $K_n = 0.20$ mA/V^2, and $\lambda = 0$. (a) Determine the small-signal transistor parameters g_m and r_o. (b) Find the small-signal voltage gain. (c) Calculate the input and output resistances. (d) Repeat (a) and (b) considering $R_{Si} = 1$ kΩ.

11. Consider the NMOS amplifier with saturated load in Fig. 9. The transistor parameters are $V_{Th\_D} = V_{Th\_L} = 0.6$ V, $k_n' = 100\ \mu A/V^2$, $\lambda = 0$, and $(W/L)_L = 1$. Estimate the W/L ratio of M_D for realizing the overall small-signal voltage gain $|A_v| = 5$.



Please Note: For n-channel MOSFET

$K_n = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}$ is the conduction parameter

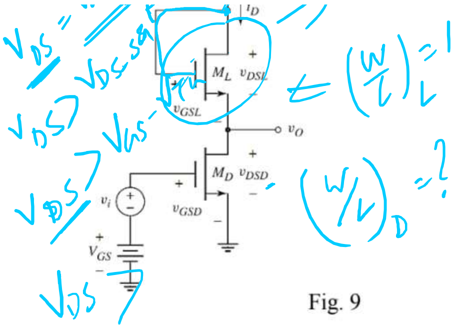


Fig. 9

Please Note: **For n-channel MOSFET**

$K_n = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}$ is the conduction parameter

$K_n = \frac{1}{2}K_n'\frac{W}{L}$

$K_n' = \mu_n C_{ox}$ is the process conduction parameter

(10)

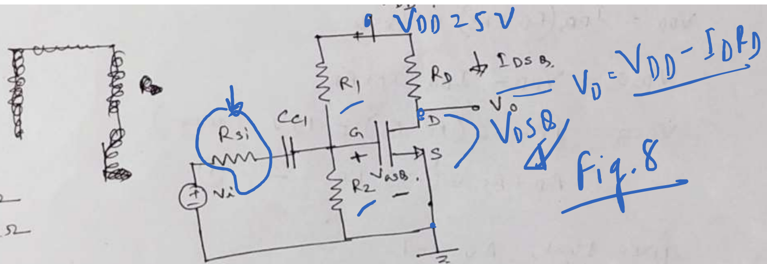


Fig.8

$V_D = V_{DD} - I_D R_D$

$R_1 = 520\ k\Omega$

$R_2 = 320\ k\Omega$

$R_D = 10\ k\Omega$

$R_{si} = 0.$

$V_{Th} = 0.8\ V.$

$k_n = 0.20\ mA/V^2$

$\lambda = 0.$

DC analysis:

$$V_{GSQ} = \left(\frac{R_2}{R_1+R_2}\right) \times V_{DD} = \left(\frac{320}{520+320} \times 5\ V\right)$$

$$= 1.9\ V.$$

$$I_{DSQ} = k_n (V_{GSQ} - V_{Th})^2 = 0.2\ (1.9 - 0.8)^2$$

$$= 0.242\ mA.$$

$$\therefore V_{DSQ} = V_{DD} - I_{DSQ} \cdot R_D$$

$$= 5 - 0.242 \times 10$$

$$= 2.58\ V.$$

$V_{GSQ} - V_{Th} = 1.1$

As, $V_{DSQ} > V_{GSQ} - V_{Th}$, the MOSFET is biased in saturation region.

(a) Small-signal parameter. (P-7)

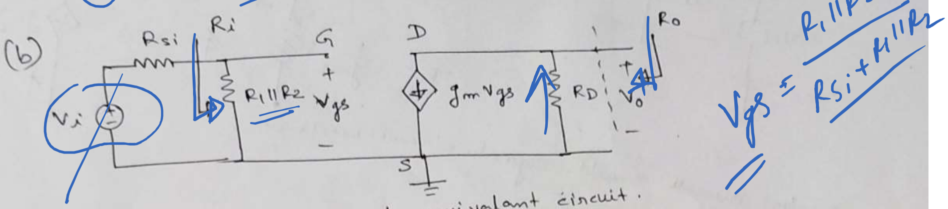
$$g_m = 2\sqrt{k_n I_{DSQ}}$$

$$= 2\sqrt{0.2 \times 0.242}$$

$g_m = 0.44\ mS$

$r_o = \infty$ as $\lambda = 0.$ $\left[r_o = \frac{1}{\lambda I_{DSQ}} \right]$

(b)



Small-signal equivalent circuit.

$$V_{gs} = \frac{R_1 \| R_2}{R_{si} + R_1 \| R_2}$$

$$R_1 \| R_2 = \frac{520 \times 320}{520 \times 320}\ k\Omega$$

$$= 198.09\ k\Omega.$$

$$V_o = -g_m R_D V_{gs}$$

$$V_o = -g_m R_D \times \frac{R_1 \| R_2}{R_{si} + R_1 \| R_2} \times V_i$$

$V_o = -g_m R_D V_{gs}$

$V_o = -g_m R_D \times \frac{R_1 \| R_2}{R_{si} + R_1 \| R_2} \times V_i$ (general expression).

$R_1 \| R_2 = \ldots = 198.09\,k\Omega$.

$\therefore \left(\frac{V_o}{V_i}\right) = -g_m R_D \times \frac{R_1 \| R_2}{R_{si} + R_1 \| R_2}$; $R_{si} = 0$ for this case (b).

$A_V = -0.44 \times 10 \times \frac{198.09}{0 + 198.09}$

$A_V = -4.4$.

(c) Input impedance $= R_i = R_1 \| R_2 = 198\,k\Omega$.

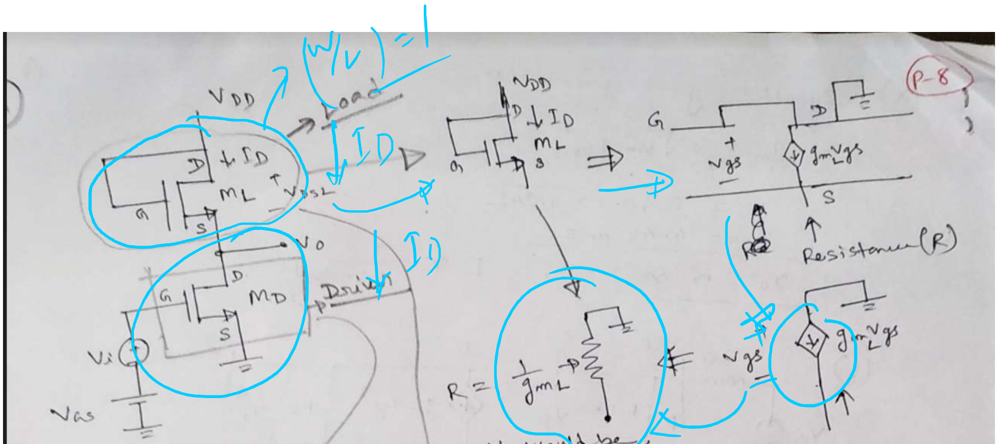
output " $= R_o = R_D = 10\,k\Omega$.

(d) When, $R_{si} = 1\,k\Omega$.

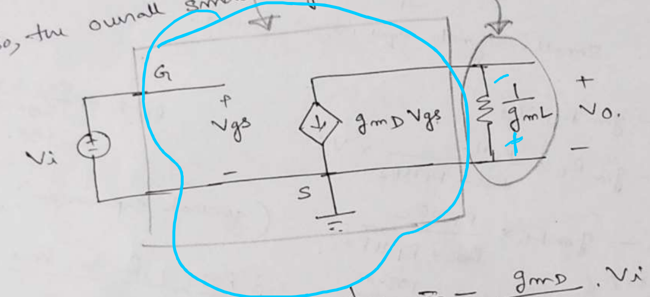
g_m remains unchanged (0.44 mS).

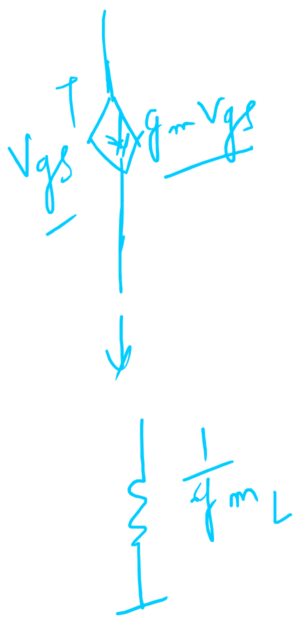
$r_o = \frac{1}{\lambda I_{DSS}} = \frac{1}{0} = \infty$ (unchanged).

gain $A_V = -4.4 \times \frac{198.09}{1 + 198.09} \approx -4.37$.



So, the overall small signal circuit would be,





$V_o = -g_{mD} V_{gs} \cdot \frac{1}{g_{mL}} = -\frac{g_{mD}}{g_{mL}} \cdot V_i$

gain $|A_V| = \frac{g_{mD}}{g_{mL}} = \left|\frac{V_o}{V_i}\right|$

$\frac{g_{mD}}{g_{mL}} = |A_V| = 5$ (given).

$\therefore \frac{\sqrt{k_{mD} I_D}}{\sqrt{k_{mL} I_D}} = 5 \quad \therefore \sqrt{\frac{(W/L)_D}{(W/L)_L}} = 5$

$\therefore \left(\frac{W}{L}\right)_D = 25 \left(\frac{W}{L}\right)_L = 25 \times 1$

$\left(\frac{W}{L}\right)_D = 25$