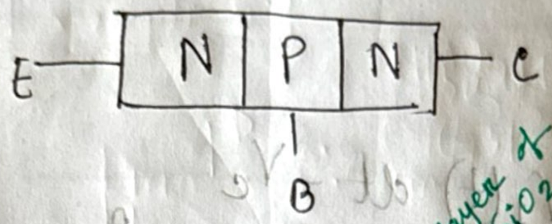
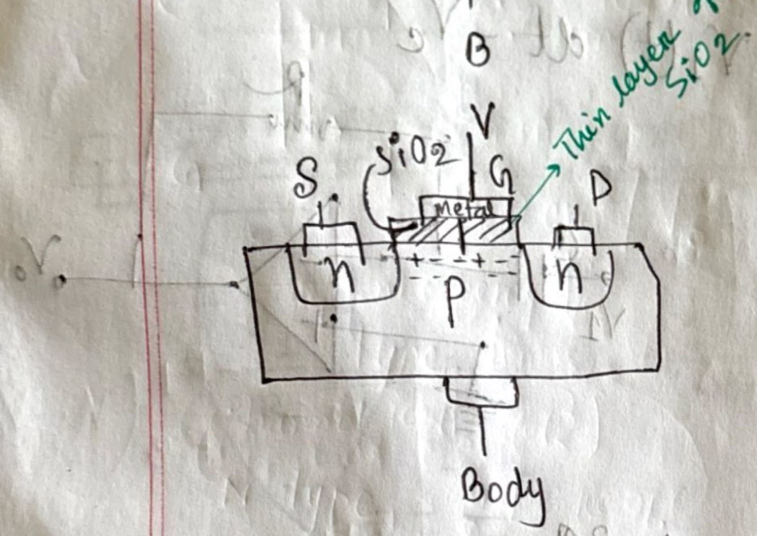
C.W
24/12/2024

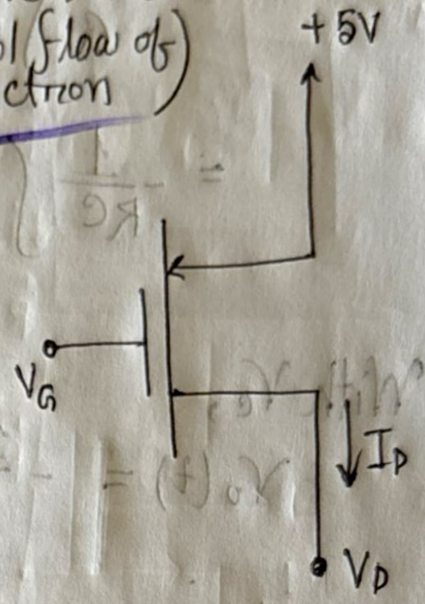
Metal oxide semiconductor field effect transistor

MOSFET → Active Device (control flow of electron)

~~NPN~~







G ⇒ Gate
D ⇒ Drain
S ⇒ Source

- MOSFET → Voltage Driven Device
  Metal Oxide Semiconductor Field effect Transistor
- SiO_2 এর একটা capacitance থাকে।
- Channel তৈরি থাকলে Channel off করাবো, Depletion Type MOSFE বলে তৈরি channel কে,
- আর যদি channel তৈরী থাকে না, তাকে Enhence Type MOSFET. যেখানে Channel তৈরি করতে হবে।

MOSFET

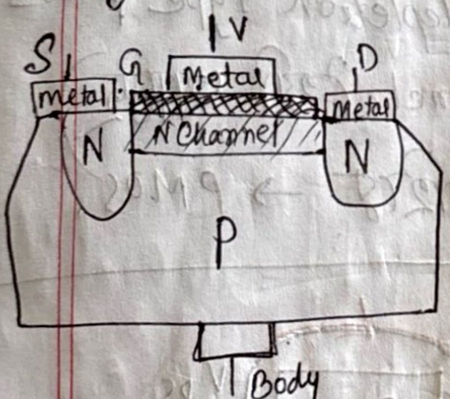
Enhencement Type — Channel তৈরী করে নিতে হবে

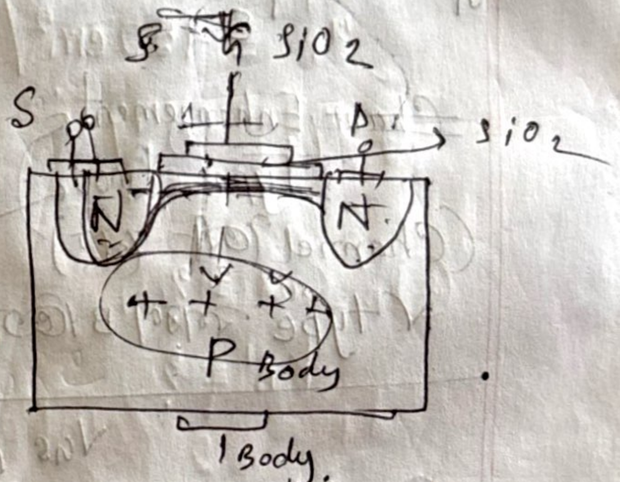
- N-type
- P-type

Depletion type — MOSFET এ Channel তৈরী এ থাকে

- N-type
- P-type

Enhencement type N-MOS





Gate SiO2 { t_{ox} → oxide thickness; C_{ox} → " Capacitance }

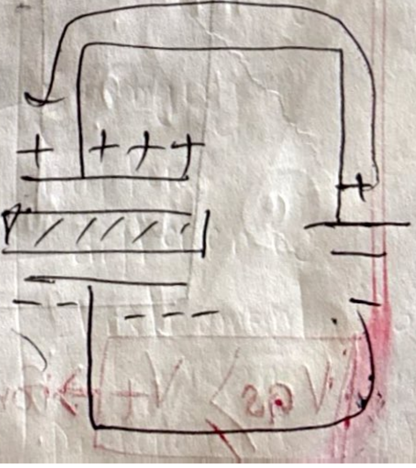
ε_0 → Permitivity

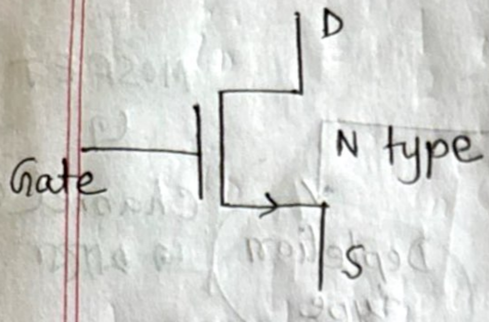
μ → Permiability

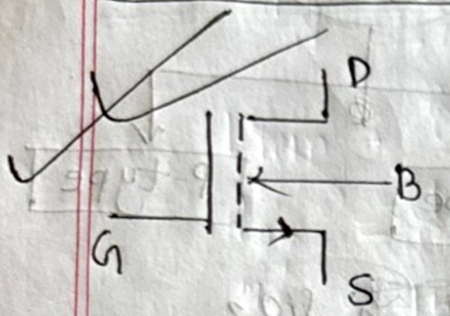
Metal → Polysilicone

L → Channel Length

W → Channel width

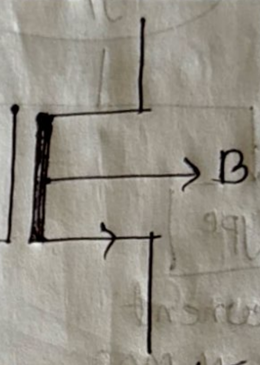




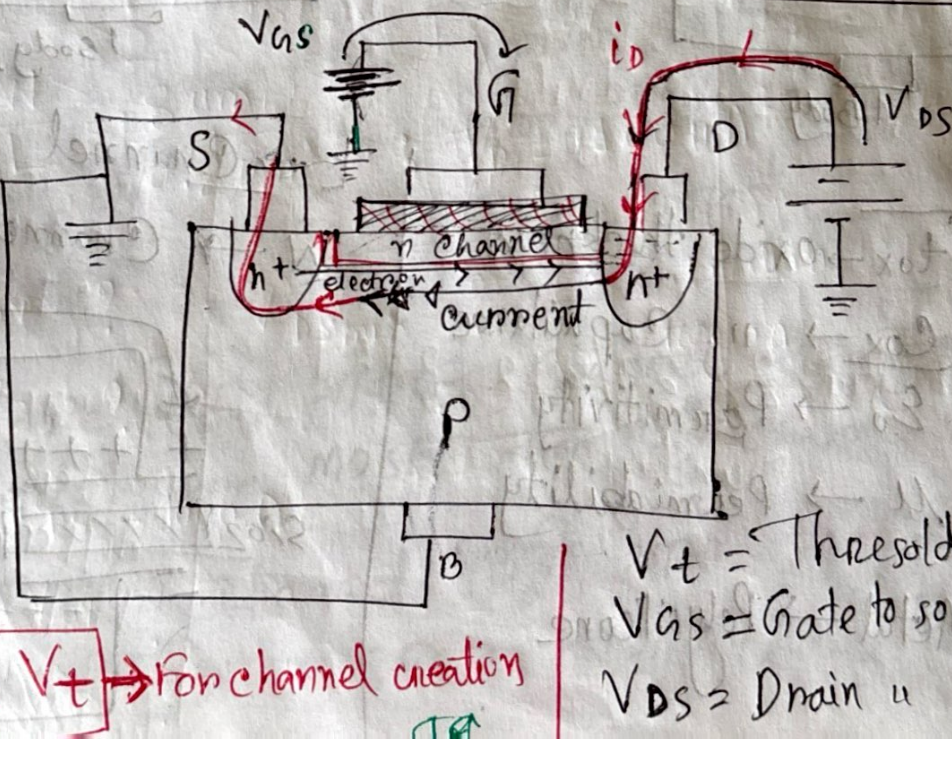


usually

~~Chant~~ Enheneement Type Nmos
(Channel তৈরী নেই)
N type কারণ B ভিতরে



depletion Type PMOS
(Channel তৈরী আছে)
B বাইরে → PMOS



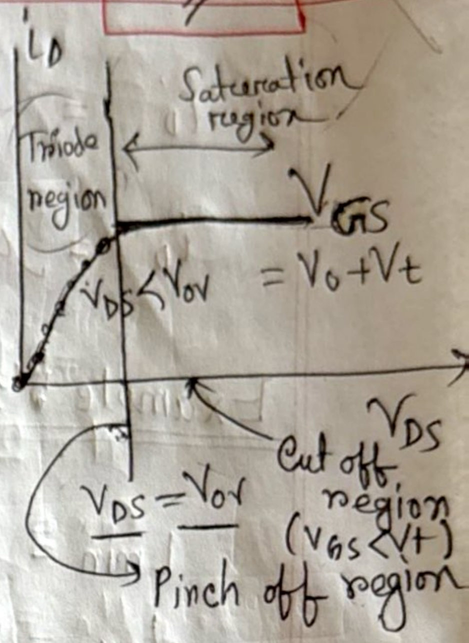
$V_{GS} > V_t$ → For channel creation

V_t = Thresold Voltage
V_{GS} = Gate to source voltage
V_{DS} = Drain " " "

$V_{ov} \rightarrow$ Overdrive Voltage

$$\boxed{V_{ov} = V_{GS} - V_t}$$

$\boxed{V_{DS} \gg V_{ov}}$



$$\boxed{C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}}$$ in F/m^2 unit

$\varepsilon_{ox} \rightarrow$ permiability SiO_2 3.45×10^{-11}

$$i_D = \begin{cases} \text{triode: } (\mu_n C_{ox}) \frac{W}{L} \left(V_{ov} - \frac{1}{2} V_{DS}\right) V_{DS} & [\text{if } V_{DS} < V_{ov}] \\ \text{Saturation: } \frac{1}{2} (\mu_n C_{ox}) \frac{W}{L} V_{ov}^2 \end{cases}$$

$\mu_n C_{ox} = K_n'$ (MOSFET Transfere Characteristics)

Slide: 5:2:2 (ছবি)

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

Overdrive V_{ov} channel কে বড় করার জন্য ফলে current দ্রুত পাস হয়

$V_{tn} \rightarrow$ n type thresold voltage
$V_{pn} \rightarrow$ p " " "

minimum value of V_{GS} required to conduct channel between drain

C.W
29/12/2024

$$i_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)V_{ov}^2 \quad [\text{When, } V_{DS} \geq V_{ov}]$$

$$i_D = \mu_n C_{ox}\left(\frac{W}{L}\right)\left(V_{ov} - \frac{1}{2}V_{DS}\right)V_{DS} \quad [\text{When } V_{DS} < V_{ov}]$$

Example 5.1 NMOS

$L_{min} = 0.4\mu m$

$t_{ox} = 8nm$

$\mu_n = 450\, cm^2/Vs$

$V_t = 0.7\,V$

(a) $C_{ox} = ?$

$K_n' = ?$

(b) $\frac{W}{L} = \frac{8\mu m}{0.8\mu m}$; $I_D = 100\mu A$

$V_{ov} = ?$ $\quad V_{DSmin} = ?$

$V_{GS} = ?$

Saturation region

(c) $r_{DS} = 1000\Omega$

$V_{ov} = ?$

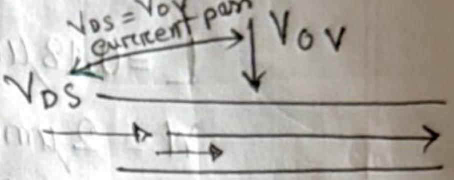
$V_{GS} = ?$

ধ্রুবক value permitivity of SiO2

Answer: (a) $C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}} = \frac{3.45 \times 10^{-11}}{8 \times 10^{-9}} = 4.32 \times 10^{-3}\ F/m$

$\therefore K_n' = \mu_n C_{ox} = 450\,(cm^2/V) \times 4.3 \times 10^{-3}$

$= 194\ \mu A/V^2$



(b) For saturation region,

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

$\Rightarrow 100\,\mu A = \frac{1}{2}(194\,\mu A/V^2) \times \left(\frac{8\,\mu m}{0.8\,\mu m}\right) \times V_{ov}^2$

$\therefore V_{ov} = 0.32\,V = V_{DS\,min}$

$V_{GS} = V_{ov} + V_t = 0.32 + 0.7 = 1.02\,V$

$V_{DS} = V_{ov}$, Saturation region এ থেকে, current pass হবে।

(c) $r_{DS} = \frac{V_{DS}}{I_D}$ $= \cancel{0\ 100\mu A}$

$\Rightarrow 1000 = \frac{1}{K_n'\left(\frac{W}{L}\right) V_{ov}} = \frac{1}{194 \times \left(\frac{8}{0.8}\right) \times V_{ov}}$

$\therefore V_{ov} = 0.52\,V$

$\therefore V_{GS} = V_{ov} + V_t$

$= 0.52 + 0.7 = 1.22\,V$

$\times$ $\mu_n C_{ox}$

Example 5.2 NMOS Homework

(a) Given,

$L = 0.18 \mu m$

$W = 2 \mu m$

$C_{ox} = 8.6 fF/\mu m^2$

$\mu_n = 450 \, cm^2/Vs$

$V_{tn} = 0.5V$

(a) $V_{GS} = ?$ $V_{DS} = ?$ Saturation region

$I_D = 100 \mu A$

$I_D = \boxed{\frac{1}{2} \mu_n C_{ox} \left(\frac{W}{L}\right) V_{ov}^2} \rightarrow \frac{1}{2} K_n V_{ov}^2$ ও লেখা যায়

$K_n = \mu_n C_{ox} \left(\frac{W}{L}\right) = 4.3 \, mA/V^2$

$K_n' = \mu_n C_{ox}$

~~= 450~~

$= 450 \times 10^{-4} \times 8.6 \times 10^{-4} \times 10^{12} \, \mu A/V^2$

$= 387 \, \mu A/V^2$

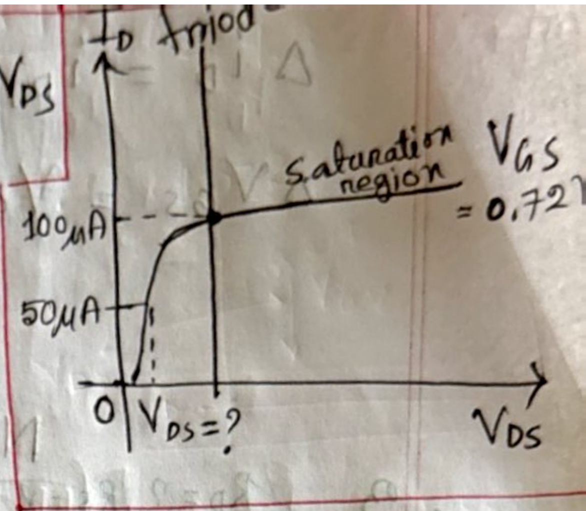
$\Rightarrow 100 = \frac{1}{2} \times 450 \times 8.6 \left(\frac{2}{0.18}\right) V_{ov}^2$

unit গুলো ঠিক করে নিতে হবে

$\Rightarrow V_{ov} = 0.22V$

$V_{GS} = V_{ov} + V_t = 0.22 + 0.5$
$= 0.72V$

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



$\Rightarrow I_D = k_n \left[V_{OV} - \frac{1}{2}V_{DS}\right]V_{DS}$

$\Rightarrow 50 = 4.3\,mA/V^2 \left[0.22V_{DS} - \frac{1}{2}V_{DS}^2\right]$

$\Rightarrow V_{DS}^2 - 0.44V_{DS} + 0.023 = 0$

$\therefore V_{DS} = 0.06V$; ~~$V_{DS} = 0.39V$~~ ✗

এই value টা নিবো

কারণ $V_{OV} = 0.22V$

(c) $V_{DS} = 0.3V$
$V_{GS} = 0.7 \pm 0.1\,V$
$i_D = ??$

$\left.\right\}$ Saturation

$i_D = \frac{1}{2}\boxed{\mu_n C_{ox}\left(\frac{W}{L}\right)}V_{OV}^2$

$= \frac{1}{2}k_n V_{OV}^2 \longrightarrow V_{GS} = 0.7\,V$

$i_{D_1} = \frac{1}{2}k_n V_{OV}^2 \longrightarrow V_{GS_1} = 0.7 + 0.1$

$i_{D_2} = \frac{1}{2}k_n V_{OV}^2 \longrightarrow V_{GS_2} = 0.7 - 0.1$

$V_{GS} = V_G - V_S$

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

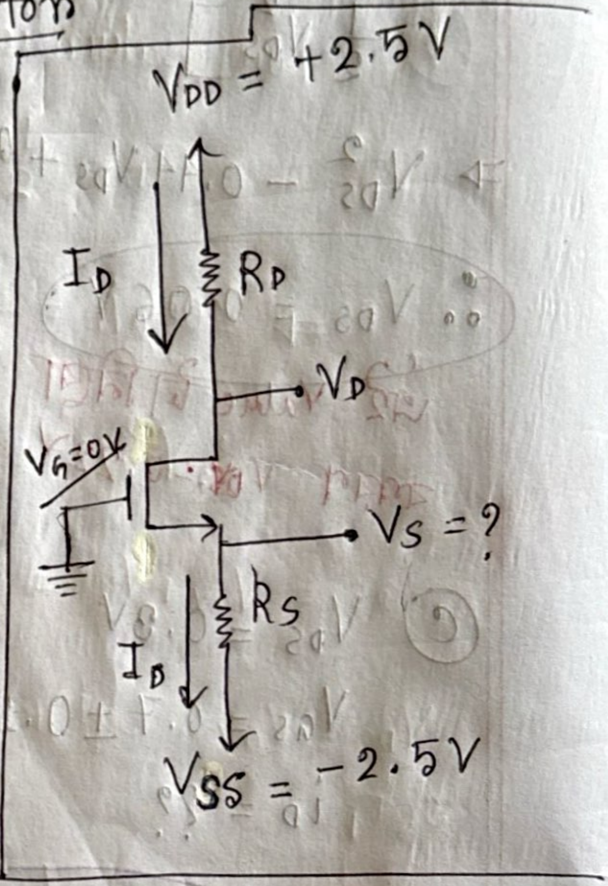
$V_{GS} = V_G - V_S$
$= 0 - V_S$
$V_{GS} = -V_S$

$\Delta i_D = i_{D1} - i_{D2}$

$\Delta V_{GS} = V_{GS1} - V_{GS2}$

NMOS Transistor

Ex-5.3 $R_D = ?,\ R_S = ?$



$\therefore R_D = \dfrac{V_{DD} - V_D}{I_D}$

$= \dfrac{2.5 - 0.5}{0.4} = 5k\Omega$

$\therefore I_D = \frac{1}{2}(\mu_n C_{ox})\left(\frac{W}{L}\right)V_{ov}^2$

$\Rightarrow 0.4mA = \frac{1}{2}(100)\left(\frac{32}{1}\right)V_{ov}^2$

$\Rightarrow V_{ov} = 0.015V$

$\therefore V_{GS} = 0.5 + 0.7 = 1.2V$

$V_{ov} = V_{GS} - V_t$
$\Rightarrow V_{GS} = V_{ov} + V_t$

$-V_{GS} = V_S$

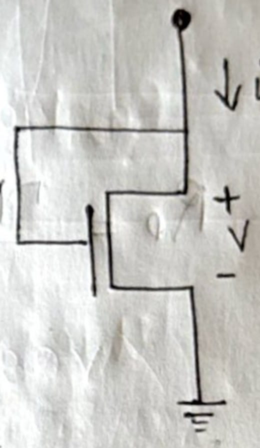
$\therefore V_S = -1.2V$

$V_{GS} = V_G - V_S$
$= 0 - V_S$
$\therefore V_S = -V_{GS}$

$\therefore R_S = \dfrac{-1.2V - (-2.5)}{0.4mA} = 3.25\ k\Omega$

Example-5.4

Find I-V relationship of the resulting two terminal device in terms of MOSFET parameter $K_n = K_n'\left(\frac{W}{L}\right)$ and V_{tn}



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

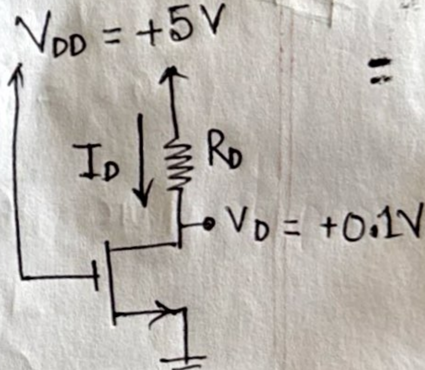
$$= V - V_t$$

$$i = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)(V - V_t)^2$$

Example-5.5

triode region এ কাজ করবো

effective resistance $R_{DS} = ?$



$k_n = 1\,mA/V^2$

$V_{tn} = 1V$

$V_{GS} = 5V$

~~$I_D = \frac{1}{2} \times 1 \times V_{OV}^2$~~

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

Wrong Ans

$$R_{DS} = \frac{V_{DS}}{I_{DS}} = \frac{\cancel{\ \ }}{\cancel{\frac{1}{2}} k_n \cancel{V_{OV}^2}}$$

$$= 2k\Omega$$

$$R_D = \frac{V_{DD} - V_D}{I_D}$$

$$= 9.8k\Omega$$

$$V_{ov} = V_{GS} - V_{tn} = 5 - 1 = 4V$$

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

$$=$$

$$R_D = \frac{V_{DD} - V_D}{I_D} = \frac{5 - 0.1}{\quad}$$

Ex:

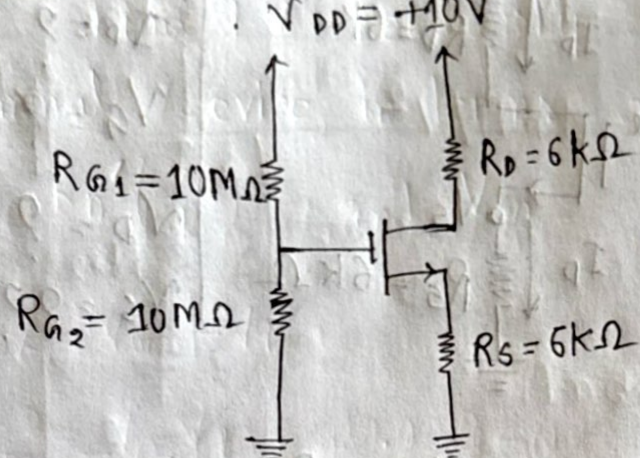
31/12/24

Example-5.6

31/12/2024

MOSFET

Problem:



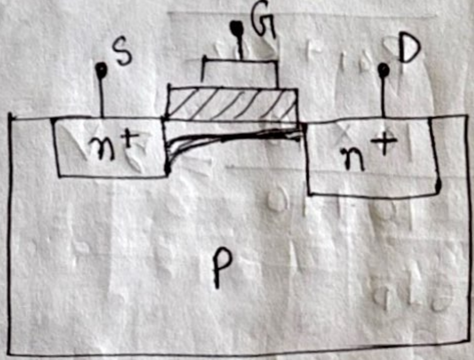
$I_D = ?$

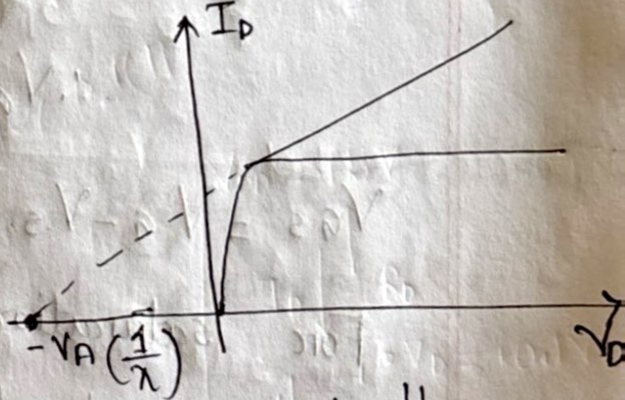
$V_G = ?$

$V_D = ?$

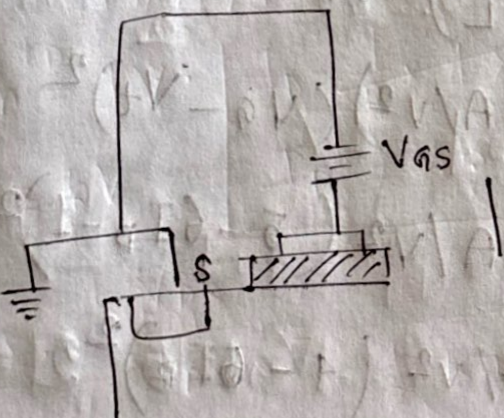
$V_S = ?$

Theory

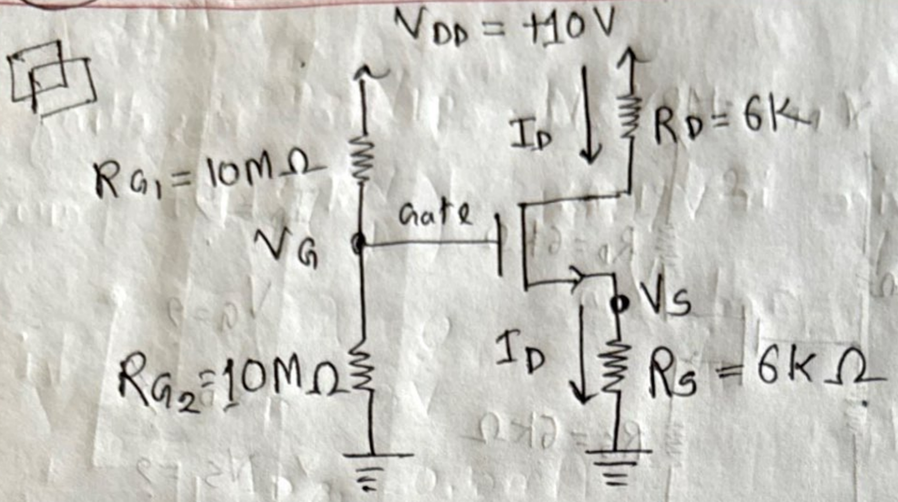




Channel length modulation effect



Example 5.6 Slide



$I_D = ?$

$V_G = ?$

$V_D = ?$

$V_S = ??$

Using VDR, $V_G = \dfrac{V_{DD} \times R_{G_2}}{R_{G_1} + R_{G_2}}$

$$\therefore V_G = \frac{10 \times 10}{10 + 10} = 5V$$

$V_{GS} = V_G - V_S = 5 - 6I_D$

For saturation region,

$$I_D = \frac{1}{2} K_n' \left(\frac{W}{L}\right) V_{ov}^2$$

$$\Rightarrow I_D = \frac{1}{2} \times (1mA/V^2)(V_G - V_t)^2$$

$$\Rightarrow I_D = \frac{1}{2} \times 1mA/V^2 (5 - 6I_D - 1)^2$$

$$\Rightarrow I_D = \frac{1}{2} \times 1mA/V^2 (4 - 6I_D)^2$$

$$\Rightarrow I_D = \frac{1}{2} \times (1mA/V^2)(16 - 48I_D + 36I_D^2)$$

$$\Rightarrow I_D = 2 \times (1mA/V^2)(9I_D^2 - 12I_D + 4)$$

$\Rightarrow I_D = \cancel{2 \times (1mA/V^2)}$ $18I_D^2 - 25I_D + 8 = 0$

$\boxed{\therefore I_D = 0.89mA \quad | \quad I_D = 0.5mA}$

$\cancel{V_{GS}}$: $V_S = 6I_D$ $= 6 \times 0.89$ $= 5.34V$ $V_{GS} = 5 - 5.34$ $= -0.34V$	$V_S = 6I_D$ $= 6 \times 0.5$ $= 3V$ (Ans) $V_{GS} = 5 - 3 = 2V$

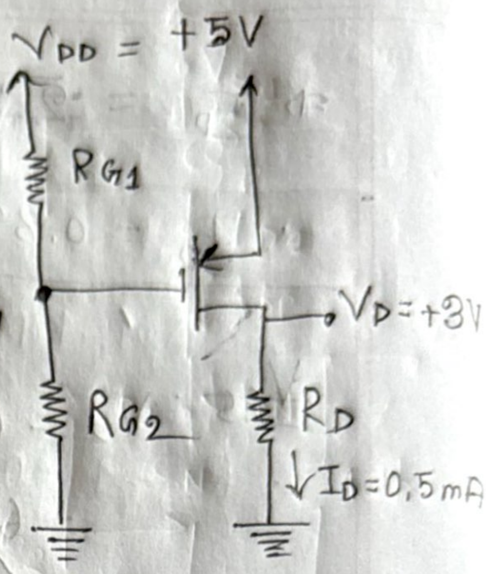
NMOS এ gate এর Voltage negative হবে না, not approriate.
তাই, $I_D = 0.89mA$ is

So, $I_D = 0.5mA$.

$V_D = 10 - 6I_D$ $= 10 - (6 \times 0.5)$ $= 10 - 3$ $= 7V$ (Ans)	$V_{DS} = V_D - V_S$ $= 7 - 3$ $= 4V$ (Ans)

PMOS এ Gate এর নিচে

Example - 5.7



given, $V_{tp} = 1V$

$k_p'\left(\frac{W}{L}\right) = 1 mA/V^2$

$\lambda = 0$

$V_D = 3V$

$I_D = 0.5 mA$

Let, $R_{G1} = 2 K\Omega$

$R_{G2} = 3 K\Omega$

$\cancel{\text{Let } V_G = \left|\frac{V_{DD}\times R_{G2}}{R_{G1}+R_{G2}}\right| = \left|\frac{5\times 3}{3+2}\right|}$

For saturation region, $I_D = \frac{1}{2} K_n V_{ov}^2$

$$\Rightarrow 0.5 mA = \frac{1}{2}(1mA/V^2) V_{ov}^2$$

$$\therefore |V_{ov}| = 1V$$

$\cancel{V_{GS}} = V_{SG} = |V_{ov}| + |V_{tp}| = 1+1 = 2V$

$\because V_{SG} = V_S - V_G$ $\qquad \therefore |V_G| = |5 - 2| = |+3V|$

$\cancel{\therefore |V_G| = 3V}$

$$\boxed{\therefore R_D = \frac{V_D - 0}{I_D} = \frac{+3V}{0.5mA} = 6 K\Omega}$$

$$|V_{D\,max}| = |3+1| = |4V|$$

$$R_{D\,max} = \frac{4}{0.5} = 8k\Omega$$

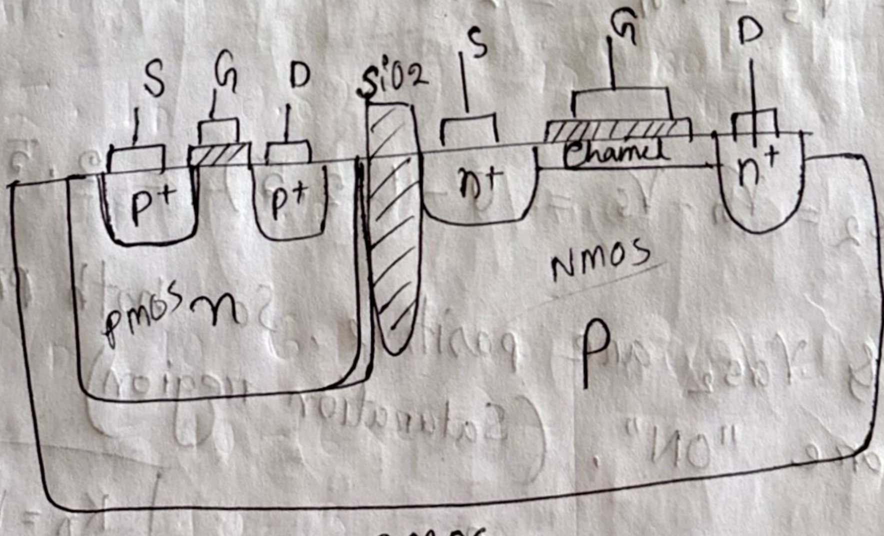
Note: * PMOS এ Gate এর নিচের R Gate এর উপরের R এর চেয়ে বড় হবে। $\boxed{P \rightarrow R_{G_2} \geq R_{G_1}}$

* NMOS এ $\boxed{R_{G_1} \geq R_{G_2}}$

Exercise 5.8

C-MOS (Complementary MOS)

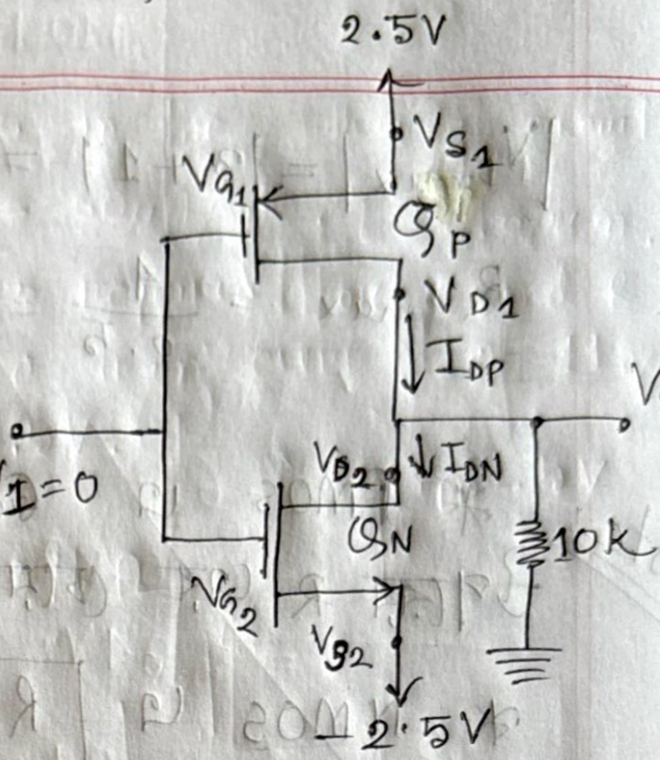
• PMOS ও NMOS এর Cascade



CMOS

$V_1 = 0,\ +2.5,\ -2.5$

When $V_1 = 0$,



$V_{G_1} = 0V$

$V_{G_2} = 0V$

$V_{S_1} = 2.5V$

~~$V_{SG} =$~~

$I_D = \frac{1}{2} K_n' \left(\frac{W_p}{L_p}\right) V_{ov}^2$

$= \frac{1}{2} \times (1mA/V^2)$

For Pmos

$V_{SG_1} = V_S - V_G = 2.5 - 0 = 2.5V$

For NMOS,

$V_{GS_2} = V_G - V_S = 0 - (-2.5) = 2.5V$

$\therefore V_{SG_1}$ & V_{GS_2} are positive, So both pmos & NMOS are "ON". (Saturation region)

$K_n = K_n'\left(\frac{W_n}{L_n}\right) = k_p'\left(\frac{W_p}{L_p}\right) = 1mA/V^2$

$V_{tn} = -V_{tp} = 1V$

$I_D = I_{DP} = I_{DN} = \frac{1}{2} K_n V_{ov}^2$

Saturation region current same

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

$= \frac{1}{2} \times 1 \times (2.5 - 1)^2$

$\therefore I_D = 1.125\ mA$

Again,

For $V_I = 2.5V$

for PMOS

$V_{SG} = V_S - V_G$

$= 2.5 - 2.5$

$= 0V$

for NMOS

$V_{GS} = 0V$

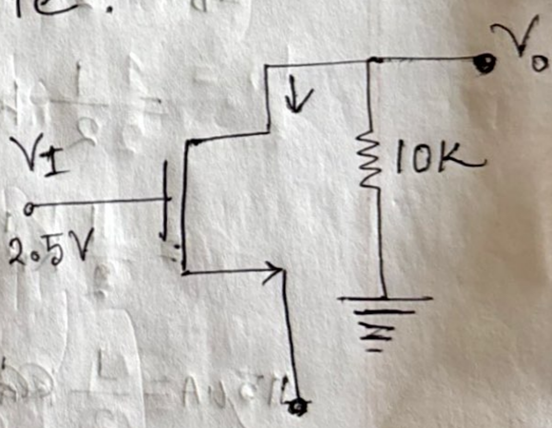
$V_{GS} = V_G - V_S$

$= 2.5 - (-2.5)$

$= 5V$

$\therefore$ NMOS is in "ON" state.

But in triode region.



$I_{D_N} = K_n\left(V_{OV} - \frac{1}{2}V_{DS}\right)V_{DS}$

$\approx K_n V_{OV} V_{DS}$ (Approx)

$= \ldots\ldots$

Again, for $V_I = -2.5$

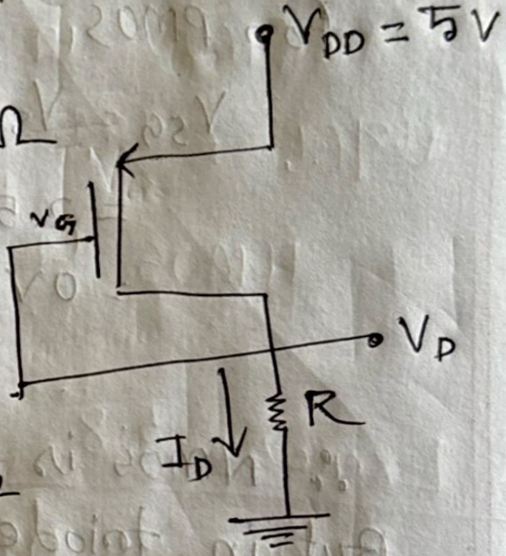
PMOS will be "ON"

I_{DP}

We apply V_{GS} to create channel

$V_{DS} \rightarrow$ Max current হওয়া পর্যন্ত

The PMOS transistor in the following circuit has $V_t = -0.7\,V$, $\mu_p C_{ox} = 60\,\mu A/V^2$, $L = 0.8\,\mu m$ and $\lambda = 0$. Find the values required for W and R in order to establish a drain current of $115\,\mu A$ and a voltage V_D of $3.5\,V$.



$$R = \frac{V_D}{I_D} = \frac{3.5\,V}{115\,\mu A} = 30.434\,k\Omega$$

For saturation region,

$$I_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right) V_{ov}^2$$

$$= \frac{1}{2} k_n' \left(\frac{W}{L}\right) (V_{GS} - V_t)^2$$

$$= \frac{1}{2} k_n' \left(\frac{W}{L}\right) \left((V_{DD} - V_D) - V_t\right)^2 \quad \Big| \; V_{GS} = V_{DD} - V_D$$

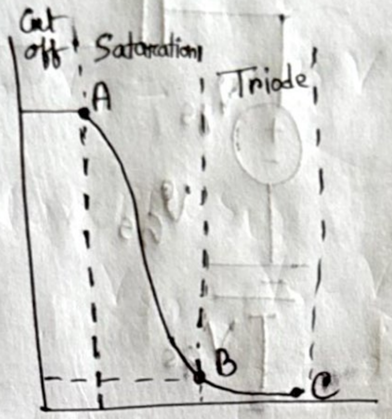
$$115\,\mu A = \frac{1}{2} \times 60\,\mu A/V^2 \left(\frac{W}{0.8\,\mu m}\right) (1.5 - 0.7)^2$$

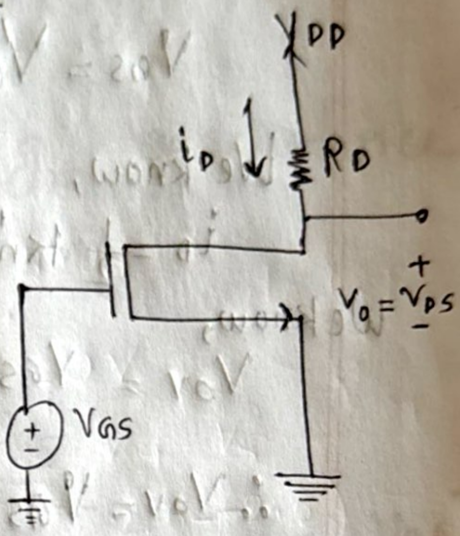
$$\therefore W = 4.79\,\mu m$$

Hello!

c.w
07/01/2024

5.4.2 Voltage transfer circuit

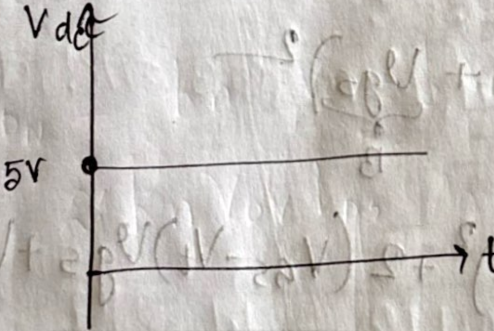


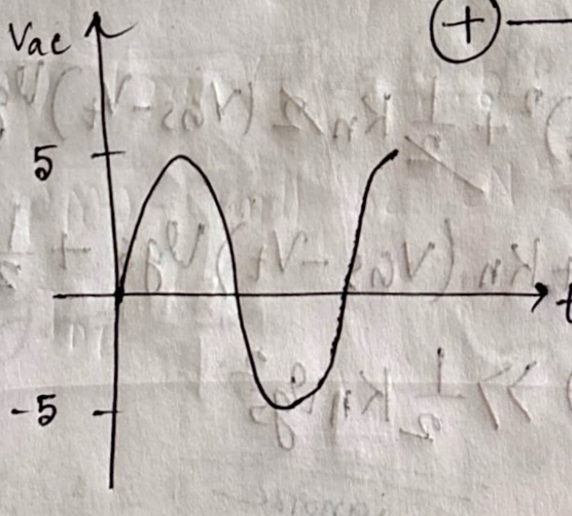


A = Pinch off region

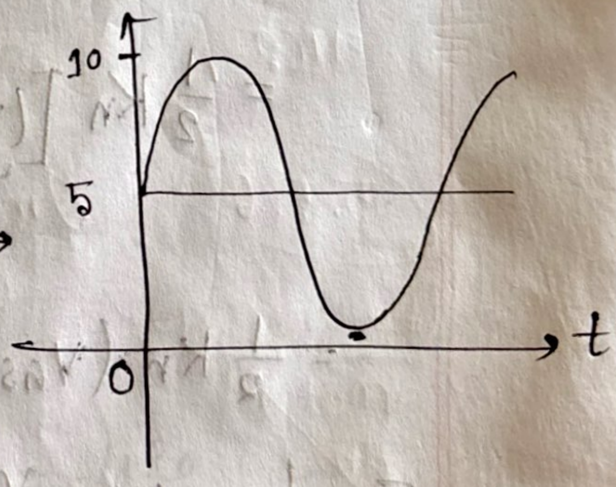
B = " " "

$\boxed{\text{Slide}}$

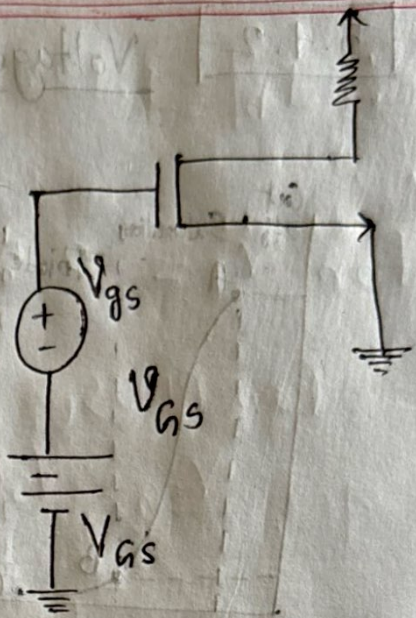




+ $\xrightarrow{\text{দুটো যোগ}}$



Thresold ও DC তে থাকে



$$v_{GS} = V_{GS} + v_{gs}$$

We know,

$$i_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right) V_{ov}^2$$

We know,

$$V_{ov} = v_{GS} - V_t$$

$$\therefore V_{ov} = V_{GS} + \cancel{v} V_t$$

$$= (V_{GS} + v_{gs} - V_t) \xrightarrow{} \text{Thresold.}$$

$$i_D = \frac{1}{2} k_n (V_{GS} + v_{gs} - V_t)^2$$

$$= \frac{1}{2} k_n (\underbrace{V_{GS} - V_t}_{A} + \underbrace{v_{gs}}_{B})^2$$

$$= \frac{1}{2} k_n \underbrace{\left[(V_{GS} - V_t)^2 + 2(V_{GS} - V_t) v_{gs} + v_{gs}^2\right]}_{A^2 + 2AB + B^2}$$

$$= \frac{1}{2} k_n (V_{GS} - V_t)^2 + \frac{1}{\cancel{2}} k_n \cancel{2} (V_{GS} - V_t) v_{gs} + \frac{1}{2} k_n v_{gs}^2$$

$$= \frac{1}{2} k_n (V_{GS} - V_t)^2 + k_n (V_{GS} - V_t) v_{gs} + \frac{1}{2} k_n v_{gs}^2$$

Since, $k_n (V_{GS} - V_t) \gg \underbrace{\frac{1}{2} k_n v_{gs}^2}_{\text{ignore}}$

$$= \underbrace{\frac{1}{2} K_n (V_{GS} - V_t)^2}_{\text{DC } I_D} + \underbrace{K_n (V_{GS} - V_t) v_{gs}}_{i_D(t) \text{ for AC}}$$

MOSFET transconductance $= g_m =$ conductance

$$g_m = \frac{i_D}{V_{DS}}$$

$$= \frac{K_n (V_{GS} - V_t) v_{gs}}{v_{gs}} \quad [V_{DS} \geq v_{gs}]$$

$$\therefore g_m = K_n (V_{GS} - V_t)$$

$$V_{DS} = V_{DD} - i_D R_D$$

$$= V_{DD} - (\underbrace{I_D}_{DC} + \underbrace{i_d}_{AC}) R_D$$

$$= \underbrace{V_{DD} - I_D R_D}_{V_{DS}} - \underbrace{i_d R_D}_{AC}$$

$$= V_{DS} - i_d R_D \rightarrow v_{ds}$$

$v_{ds} = -i_d R_D$

$$g_m = \frac{i_d}{v_{ds}}$$

$$\therefore i_d = g_m v_{ds}$$

$$v_{ds} = -i_d R_D$$

$$\Rightarrow v_{ds} = -(g_m v_{ds}) R_D$$

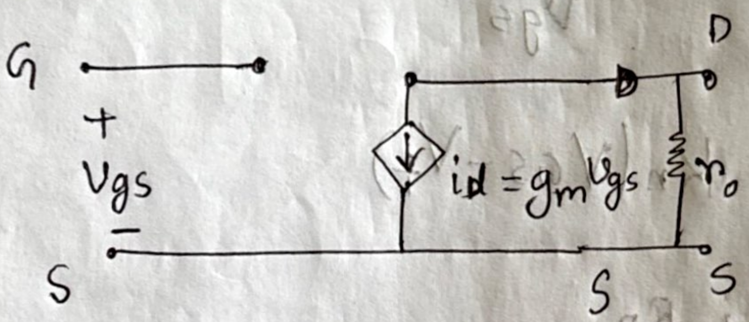
$$\Rightarrow v_{ds} = -g_m v_{gs} R_D$$

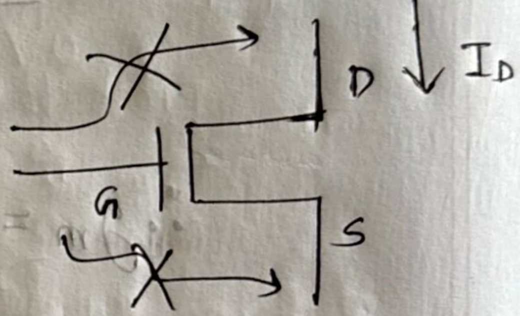
$$\Rightarrow \frac{v_{ds}}{v_{gs}} = -g_m R_D \qquad A_v = \frac{v_o}{v_i}$$

$v_{ds} \rightarrow V_o$, $v_{gs} \rightarrow V_i$

$$\Rightarrow A_v = -g_m R_D$$

Small Signal Eqv Model





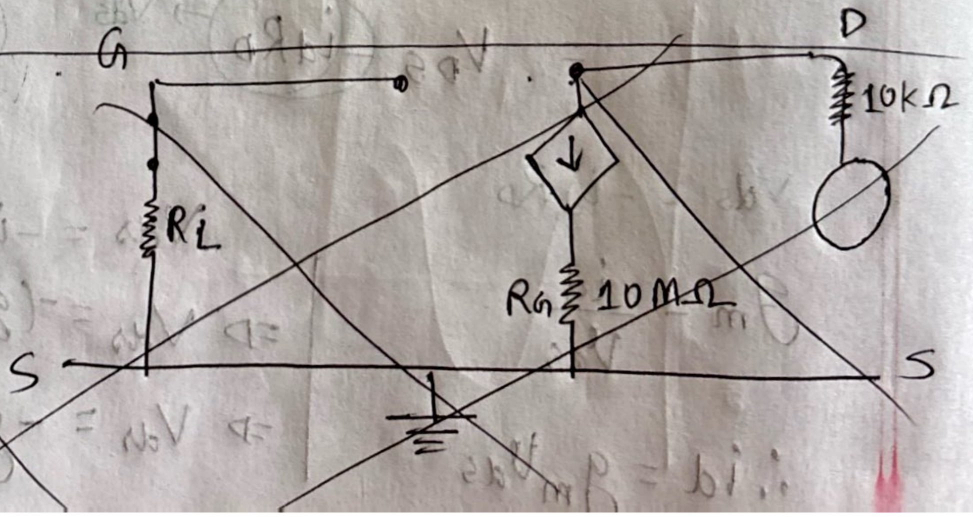
r_o question অনুযায়ী থাকতেও পারে, নাও থাকতে পারে,

5.5.6 g_m এর আরও ২টা সূত্র

Example 5.10

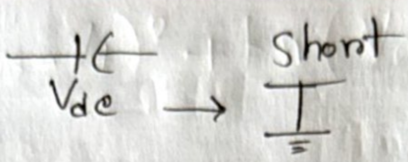
~~model draw from circuit~~

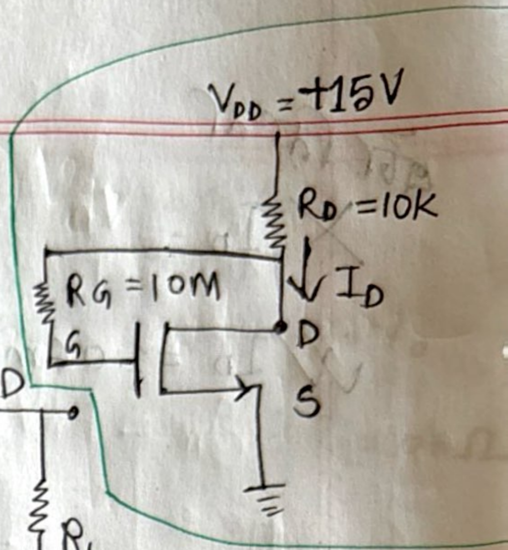
Wrong

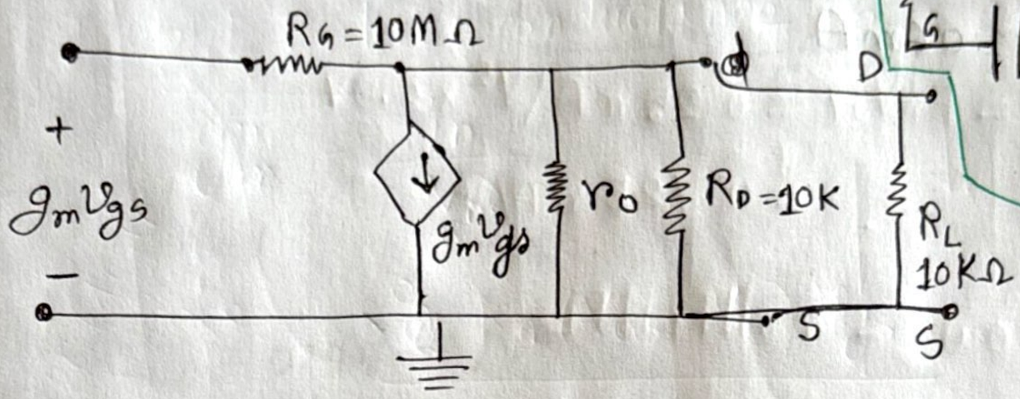


Example 5.10

Small Signal







$$I_D = \frac{V_{DD} - V_D}{R_D} = \frac{15 - }{10K} =$$

DC

$$I_D = \frac{1}{2} K_n V_{ov}^2 = \frac{1}{2} K_n' \left(\frac{W}{L}\right) (V_{GS} - V_t)^2$$

[For saturation region]

$$V_{GS} = V_{DS} = V_{DD} - I_D R_D$$
$$= (15 - 10 I_D)$$

$$I_D = \frac{1}{2} \times 0.25 mA/V^2 \times (15 - 10 I_D - 1.5)^2$$
$$= \frac{1}{2} \times 0.25 mA/V^2 \times (13.5 - 10 I_D)^2$$
$$I_D = 0.125 \times (182.25 - 270 I_D + 100 I_D^2)$$

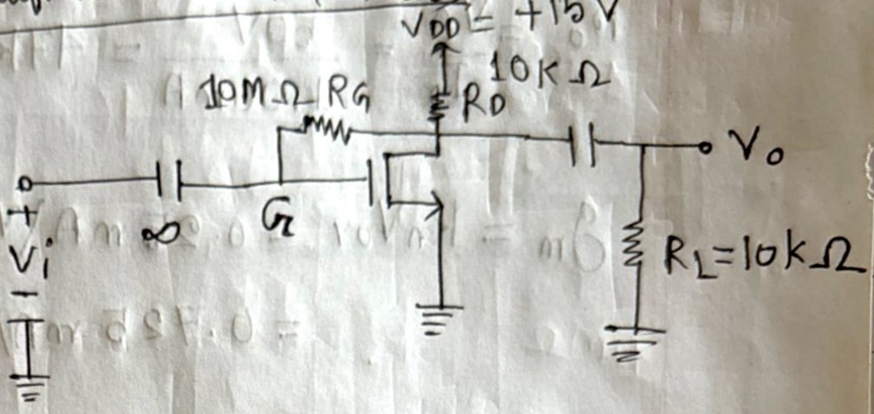
প্রচুর নিয়ম

$I_D =$

$I_D = 1.06\,mA$

12/01/2024

Ex: 5.10 amplifier circuit (slide)



$V_t = 1.5V$

$K_n'\left(\frac{W}{L}\right) = 0.25 mA/V^2$

$V_A = 50V$

(a) Small signal voltage gain = ?

(b) Input resistance = ? The Largest allowable input signal = ?

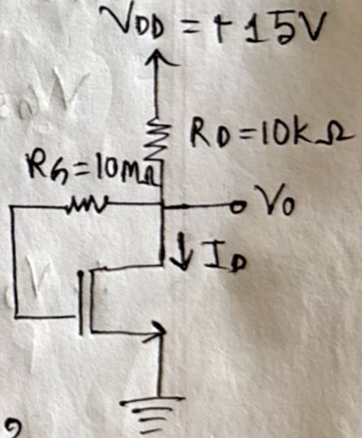


Fig 1

Ans: For saturation region,

$$I_D = \frac{1}{2} k_n'\left(\frac{W}{L}\right) V_{ov}^2$$

$$= \frac{1}{2} \times 0.25 mA/V^2 \times (V_{GS} - V_t)^2$$

$$= \frac{1}{2} \times 0.25 mA/V^2 \times (V_{DD} - I_D R_D - V_t)^2$$

$$\therefore I_D = \frac{1}{2} \times 0.25 mA/V^2 \times (15 - 10 I_D - 1.5)^2$$

$$I_D = 1.06 mA$$

$$r_o = \frac{V_A}{I_D} = \frac{50V}{1.06mA} = 47K\Omega$$

$$g_m = K_n V_{ov} = 0.25\,mA/V^2 \times 2.9V$$
$$= 0.725\,mA/V$$

$$R_{out} = r_o \| R_D \| R_L$$
$$= 47K \| 10K \| 10K$$
$$= 47K \| 5K$$
$$= 4.52K$$

$$A_v = -g_m R_{out} = -0.725 \times 4.52 = -3.3$$

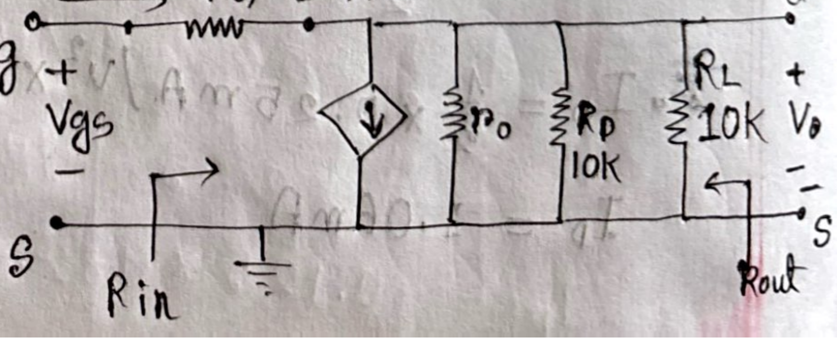
$$V_{GS} = V_{ds} = V_{DD} - I_D R_D$$
$$= 15 - 10 I_D = 4.4V$$

$$\therefore V_{ov} = V_{GS} - V_t$$
$$= 4.4 - 1.5 = 2.9V$$

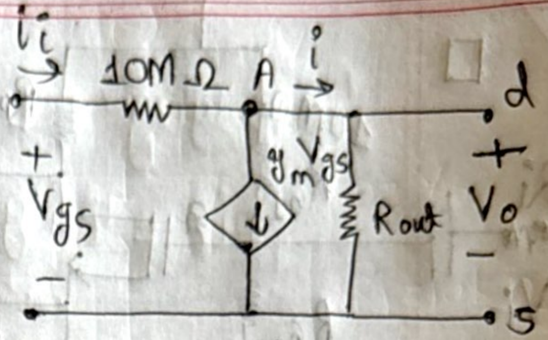
$$r_o = \frac{V_A}{I_D}$$

$$r_o = \frac{V_A' L}{I_D}$$

Small signal model:



Applying KCL at node A



$$i_i = i + g_m V_{gs}$$

$$\Rightarrow i = i_i - g_m V_{gs}$$

$$\Rightarrow i_i = \frac{V_{gs} - V_o}{R_G}$$

$$R_{in} = \frac{V_i}{i_i} = \frac{V_{gs}}{i_i} = \frac{V_{gs}}{\frac{V_{gs}-V_o}{R_G}} = \frac{R_G V_{gs}}{V_{gs}-V_o}$$

$$= \frac{R_G V_{gs}}{V_{gs} - (-A_v V_{gs})}$$

$\frac{V_o}{V_{gs}} = -A_v$

$\Rightarrow V_o = -A_v V_{gs}$

$$= \frac{R_G V_{gs}}{V_{gs}(1+A_v)} = \frac{R_G}{1+A_v}$$

$$\therefore R_{in} = \frac{R_G}{1+A_v} = \frac{10M\Omega}{1+(+3.3)} = \cancel{4.34} \; 2.32k\Omega$$

Sat

$V_{DS} \geqslant V_{ov}$

$V_{DS} \geqslant (V_{GS} - V_t)$

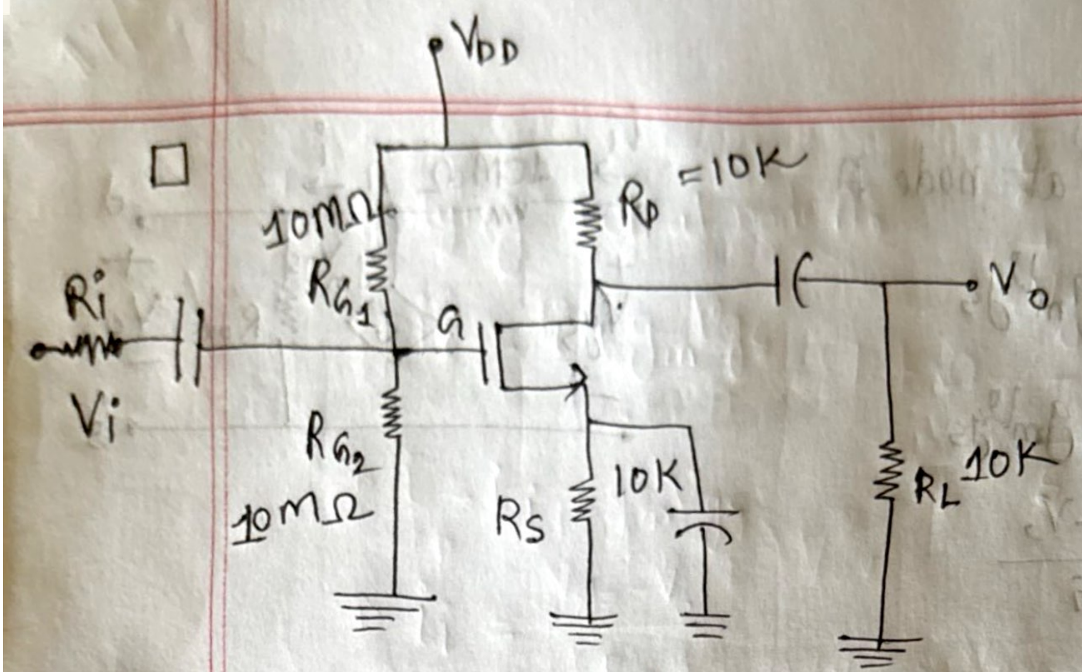
$V_{DS} - A_v \cancel{gs} V_{gs}$

$= V_{GS} - \frac{A_v V_{gs}}{\ldots} - V_i$

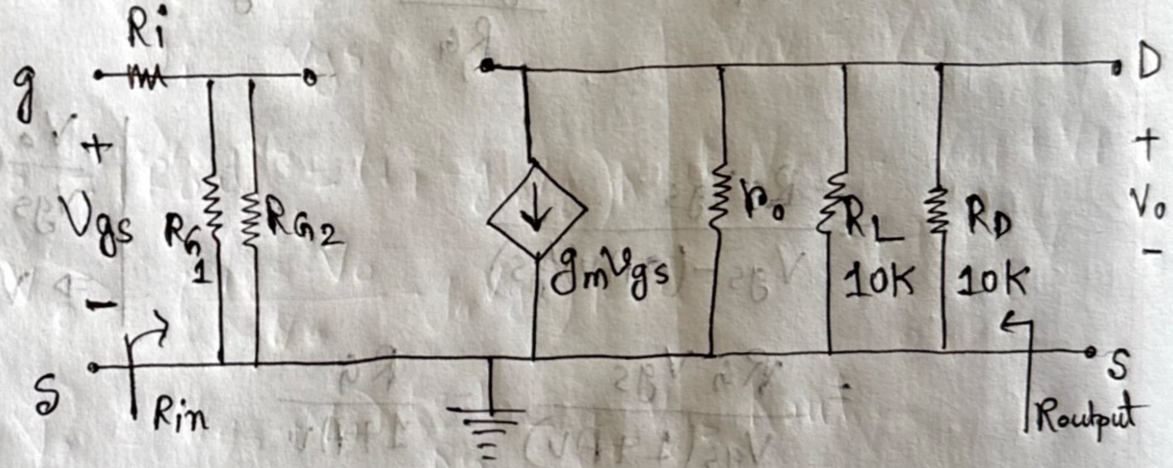
Allowable largest input signal

$$V_i = \frac{V_t}{A_v + 1} = \frac{1.5}{3.3+1} = 0.35V$$

□



Small Signal Model

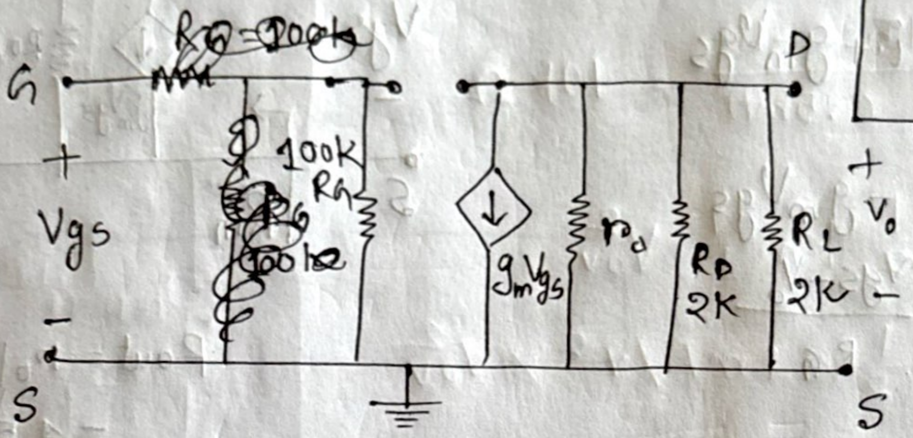


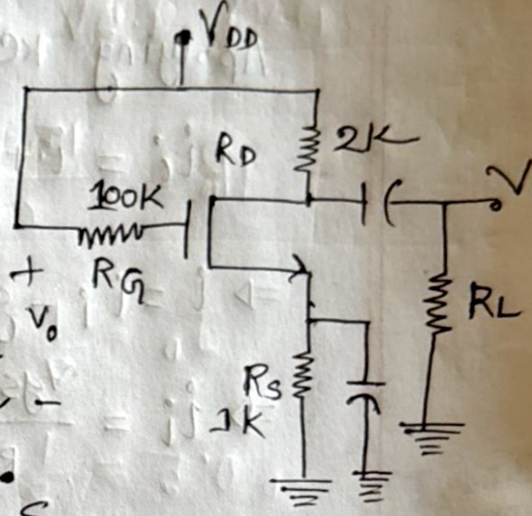
$$R_{input} = R_i + (R_{G_1} \| R_{G_2})$$

$$R_{output} = r_o \| R_D \| R_L$$

$$A_v = -g_m R_{output}$$

□ Rout = ?, Small Signal Model



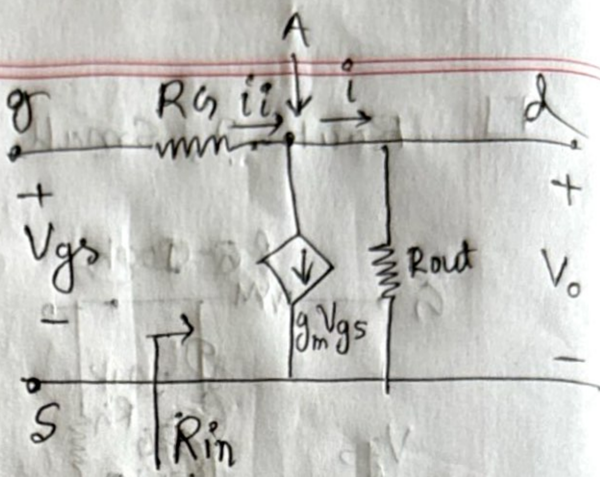


$$R_{out} = r_o \,||\, R_D \,||\, R_L$$

$$= 0.5\,k \,||\, 2\,k \,||\, 2k = 0.33\,K\Omega$$

C.W 14/01/24

Applying KCL at node A,



$$i_i = i + g_m V_{gs}$$

$$\Rightarrow i = i_i - g_m V_{gs}$$

$$\Rightarrow i_i = \frac{V_{gs} - V_o}{R_G}$$

$$R_{out} = r_o \| R_D \| R_L = 4.5\,k\Omega$$

$$A_v = \frac{V_o}{V_i} = \frac{V_o}{V_{gs}}$$

$$V_o = i R_{out} = (i_i - g_m V_{gs}) R_{out}$$

$$\Rightarrow V_o = \left(\frac{V_{gs} - V_o}{R_G} - g_m V_{gs}\right) R_{out}$$

$$\Rightarrow V_o = (V_{gs} - V_o)\frac{R_{out}}{R_G} - g_m V_{gs} R_{out}$$

$$\Rightarrow V_o = V_{gs}\frac{R_{out}}{R_G} - V_o\frac{R_{out}}{R_G} - g_m V_{gs} R_{out}$$

$$\Rightarrow V_o + V_o\frac{R_{out}}{R_G} = V_{gs}\frac{R_{out}}{R_G} - g_m V_{gs} R_{out}$$

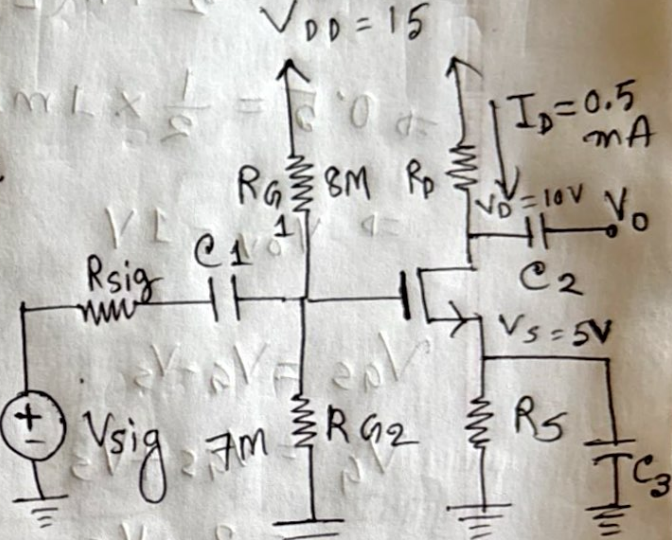
$$\Rightarrow V_o\left(1 + \frac{R_{out}}{R_G}\right) = V_{gs}\left(\frac{R_{out}}{R_G} - g_m R_{out}\right)$$

$$\Rightarrow V_o\left(1 + \frac{R_{out}}{R_G}\right) = V_{gs} g_m R_{out}\left(\frac{1}{R_G g_m} - 1\right)$$

$$\therefore \frac{V_o}{V_{gs}} = \frac{-g_m R_{out}\left(1 - \frac{1}{R_G g_m}\right)}{\left(1 + \frac{R_{out}}{R_G}\right)}$$

$$\therefore A_v = -g_m R_{out}\left(\frac{\left(1 - \frac{1}{R_G g_m}\right)}{\left(1 + \frac{R_{out}}{R_G}\right)}\right)$$

$$\boxed{\therefore A_v \approx -g_m R_{out}}$$



□ ~~#~~ Determine the percentage change in I_D when $K_n'\left(\frac{W}{L}\right)$ remain same but $V_t = 1.5V$

Find Rin and Rout of the small signal model.

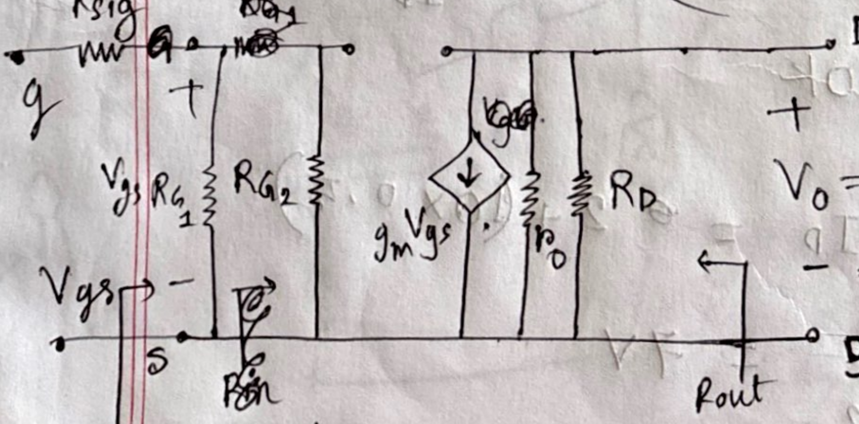
$A_v = -g_m(r_o || R_D)$

$V_t = 1V$

$K_n'\left(\frac{W}{L}\right) = 1\,mA/V^2$

$\lambda = 0$ (Channel length ~~modification~~ modulation)

(2)



$V_o = -g_m V_{gs}(r_o || R_D)$

$R_{in} = R_{G_1} || R_{G_2}$

(1) $V_t = 1.5V$

$$R_D = \frac{15 - 10}{0.5mA} = 10K\Omega$$

$$I_D = \frac{1}{2} K_n'\left(\frac{W}{L}\right) V_{ov}^2$$

$$\Rightarrow 0.5 = \frac{1}{2} \times 1 mA/V^2 \times V_{ov}^2$$

$$\Rightarrow V_{ov} = 1V$$

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

$$\Rightarrow V_{GS} = V_{ov} + V_t$$

$$= (1+1) V$$

$$= 2V$$

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

$$V_G = V_{GS} + V_S$$

$$= 2 + V_S$$

$$= V_{GS} + I_D R_S$$

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

$$R_S = \frac{5}{0.5mA} = 10K$$

$$V_{GS} = V_{GS} + 10 I_D = 2 + (10 \times 0.5)$$

$$V_G = \frac{V_{DD} \times R_{G2}}{R_{G1} + R_{G2}} = 7V$$