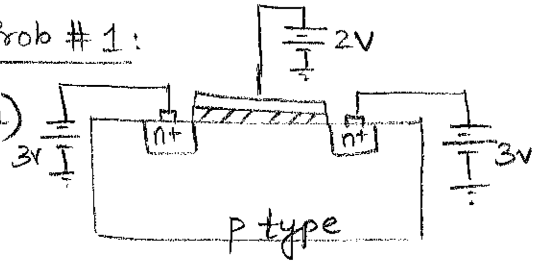
Prob # 1:

a)

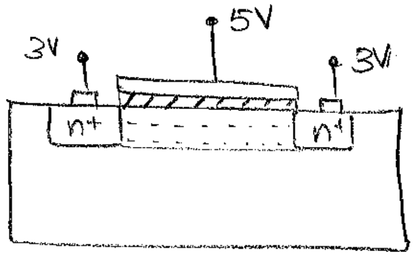


$V_S = 3V, V_G = 2V, V_D = 3V$

$\Rightarrow V_{GS} = -1V < V_t \Rightarrow$ cut off

$\Rightarrow i_D = 0A$

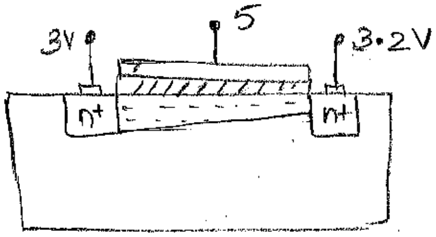
b) $V_S = 3V, V_G = 5V, V_D = 3V$



$V_{GS} > V_t \Rightarrow$ channel created

$V_{DS} = 0V \Rightarrow i_D = 0A$

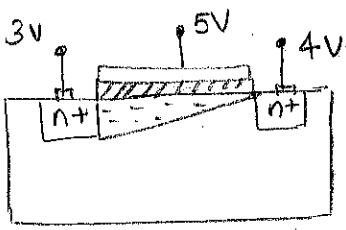
c) $V_S = 3V, V_G = 5V, V_D = 3.2V$



$V_{GS} > V_t$ & $V_{DS} > 0 \Rightarrow$ Triode

$\Rightarrow i_D = \mu_n C_{ox} \frac{W}{L}\left[(V_{GS} - V_t) V_{DS} - \frac{V_{DS}^2}{2}\right]$

d) $V_S = 3V, V_G = 5V, V_D = 4V$



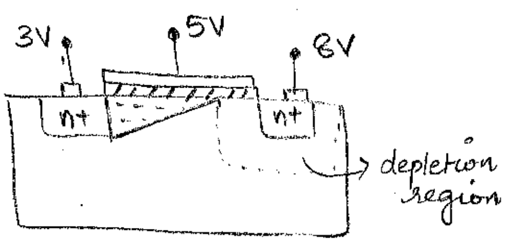
$V_{GS} - V_t = 2 - 1 = 1V$

$V_{DS} = 1V$

$V_{DS} = V_{GS} - V_t \Rightarrow$ pinch off

$\Rightarrow i_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_t)^2$

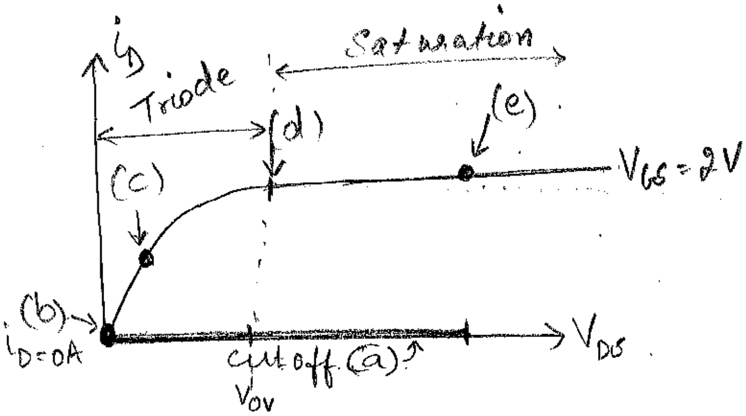
e) $V_S = 3V, V_G = 5V, V_D = 8V$



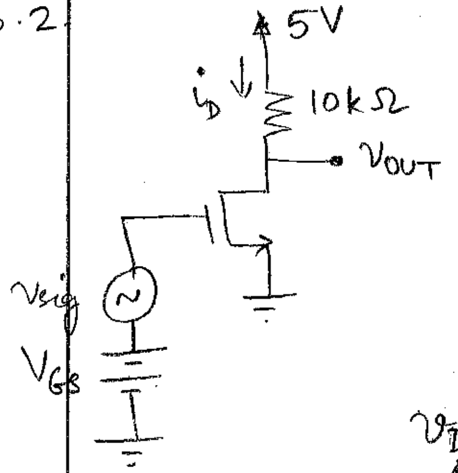
$V_{DS} > V_{GS} - V_t$

$\Rightarrow$ saturation

$\Rightarrow i_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_t)^2 (1 + \lambda V_{DS})$



Prob. 2



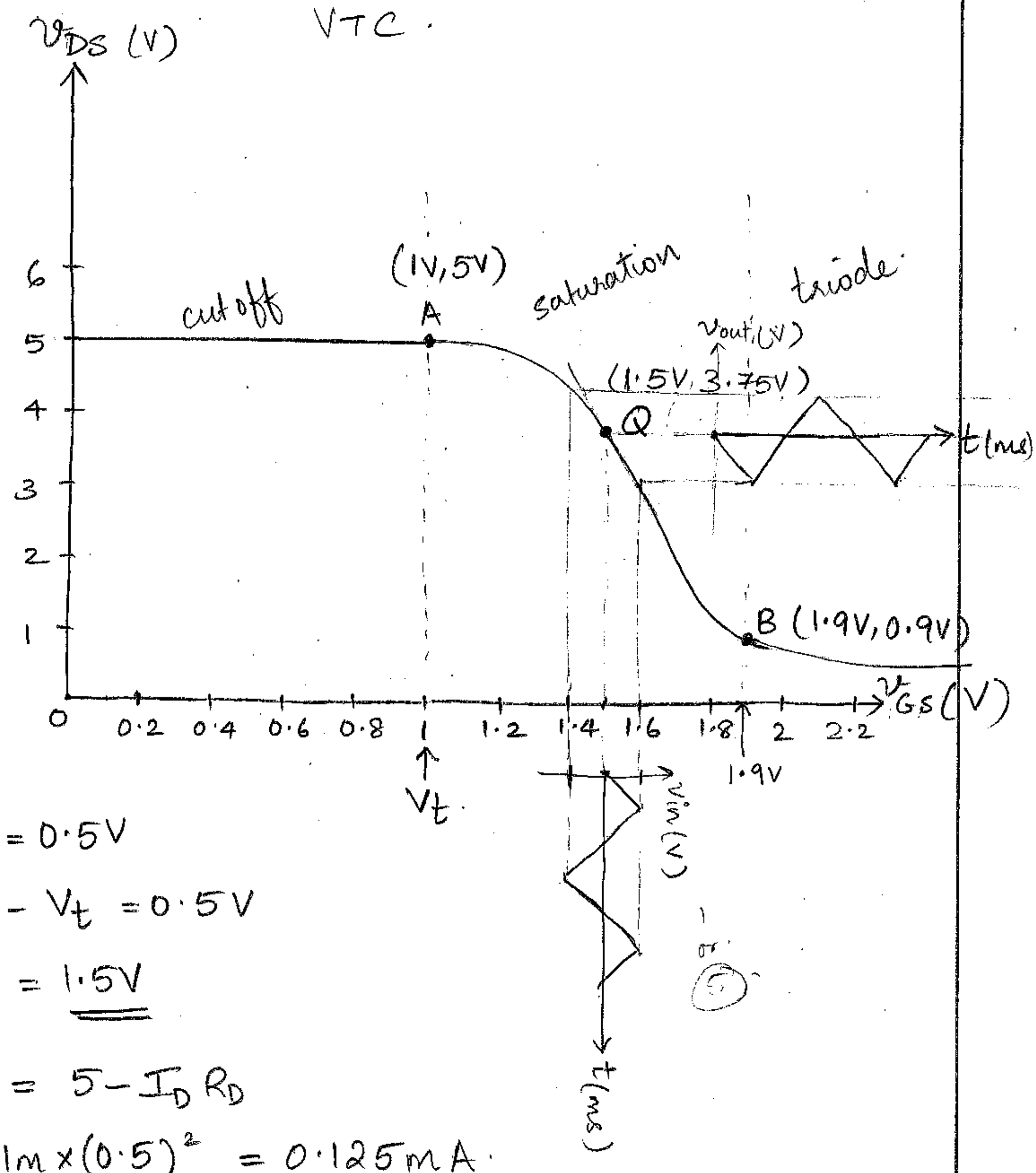
$k_n = 1mA/V^2$

$V_t = 1V$

$(V_{GS}, V_{DS})|_{pinchoff} = (1.9V, 0.9V)$

2 or

(5pts)



attempt ①

Q pt $\Rightarrow V_{OV} = 0.5V$

$\Rightarrow V_{GS} - V_t = 0.5V$

(2) $\Rightarrow V_{GS} = \underline{\underline{1.5V}}$

$V_{DS} = 5 - I_D R_D$

$I_D = \frac{1}{2} \times 1m \times (0.5)^2 = \underline{0.125 mA}$

$\Rightarrow V_{DS} = 5 - 0.125m \times 10k$

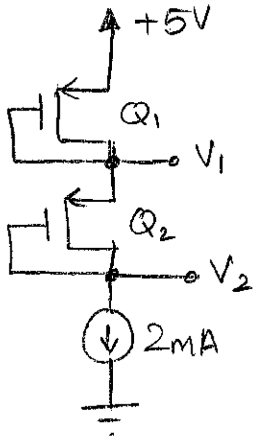
(2) $= \underline{\underline{3.75V}}$

1 or (5) max o/p swing allowed $\Rightarrow$ +ve swing $= 5 - 3.75V = 1.25V$

−ve swing $= 3.75 - 0.9 = 2.85V$

∴ max. allowed swing $= \boxed{1.25V}$

Prob. 3. I. | | 6 min | 3/10



$V_t = 1V$
$k_p = 4mA/V^2$
$\lambda = 0$.

attempt = 1

Both transistors are in saturation:

$\Rightarrow I_D = \frac{1}{2} k_p (V_{ov})^2$.

$I_D = 2mA$.

$V_{ov_1} = V_{SG_1} - V_t = 5 - V_1 - 1 = 4 - V_1$

$V_{ov_2} = V_{SG_2} - V_t = V_1 - V_2 - 1$.

$\Rightarrow 2m = \frac{1}{2} \times 4m \times (V_{ov_1})^2$

$\Rightarrow (V_{ov})^2 = 1$

$\Rightarrow V_{ov} = \pm 1$ $\quad |V_{ov}| = V_{SG} - V_t$ has to be +ve.

2 $\Rightarrow V_{ov} = +1$.

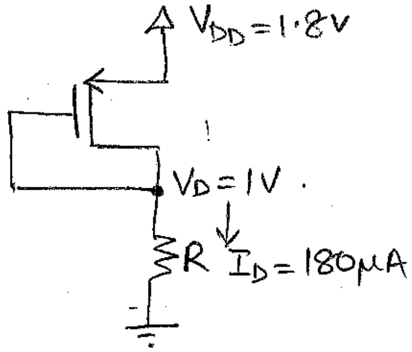
3 $\Rightarrow 4 - V_1 = 1 \Rightarrow \underline{\underline{V_1 = 3V}}$

$\Rightarrow V_{ov_2} = 3 - V_2 - 1 = 2 - V_2$.

3 $\Rightarrow 2 - V_2 = 1 \Rightarrow V_2 = \underline{\underline{1V}}$

$\Rightarrow$ equal drop across Q_1 & Q_2 which makes sense because they have same I_D and hence same V_{ov}. $\Rightarrow$ same V_{GS} $\Rightarrow$ same V_{DS}!

attempt =(1)



$V_t = -0.5V \Rightarrow |V_t| = 0.5V$

$\mu_p C_{ox} = 100\ \mu A/V^2$

$L = 0.18\mu m$

$W = ?$

(3) $R = \frac{1V}{180\mu} = \underline{\underline{5.55k\Omega}}$

transistor is in saturation $\Rightarrow$

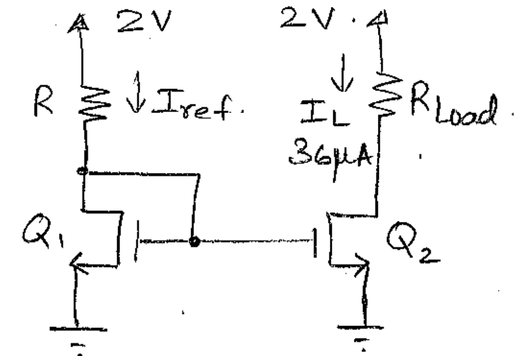
(3) $I_D = \frac{1}{2} \mu_p C_{ox} \frac{W}{L} (V_{SG} - V_t)^2$

$\Rightarrow 180\mu = \frac{1}{2} \times 100\mu \times \frac{W}{0.18\mu} (1.8 - 1 - 0.5)^2$

$\Rightarrow 180 = \frac{1}{2} \times 100 \times \frac{W}{0.18\mu} (0.3)^2$

(3) $\Rightarrow W = \underline{\underline{7.2\mu m}}$

attempt = 1



$I_L = 36\mu A$

$V_t = 0.5V$

$\mu_n C_{ox} = 0.4 mA/V^2$

$\frac{W}{L} = \frac{0.36\mu}{0.18\mu}$

since both transistors are matched and
$V_{GS_1} = V_{GS_2} \Rightarrow I_{ref} = I_L$.

$\Rightarrow I_{ref} = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS_1} - V_t)^2$

$\Rightarrow 36\mu \;\; \frac{1}{2} \times 0.4m \times 2 \; (V_{GS_1} - 0.5)^2$

$\Rightarrow V_{GS_1} - 0.5 = \sqrt{0.09}$

(3) $\Rightarrow V_{GS_1} = 0.3 + 0.5 = \underline{\underline{0.8V}}$

$V_{GS_1} = V_{DS_1} = V_{GS_2}$

(2) $V_{DS_1} = 0.8V \Rightarrow V_D = 0.8V \Rightarrow R = \frac{2 - 0.8}{36\mu} = \underline{\underline{33.3 k\Omega}}$

R_{load} max $\Rightarrow$ Q_2 operates at verge of sat & triode.

$\Rightarrow V_{DS_2} = V_{GS_2} - V_t$

$= 0.8 - 0.5$

$= \underline{\underline{0.3V}}$

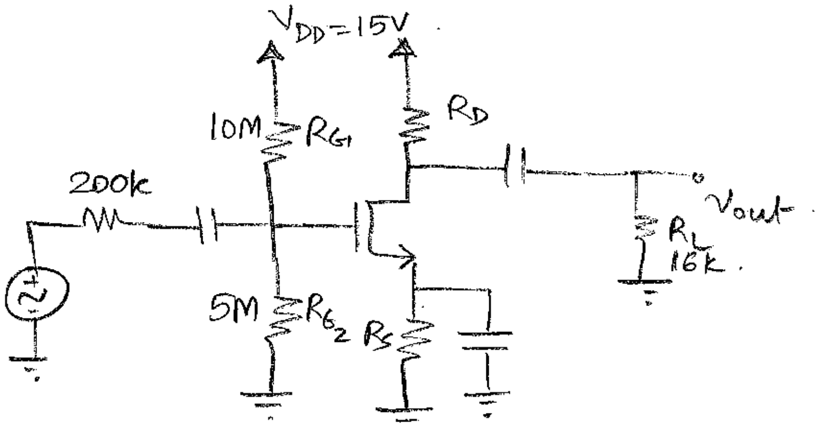
$\Rightarrow V_D = 0.3V$

(3) $\Rightarrow R_{load\,(max)} = \frac{2 - 0.3}{36\mu} = \underline{\underline{47.2 k\Omega}}$

(1) $\Rightarrow$ for saturation operation : $0 < R_{load} \leq \underline{\underline{47.2 k\Omega}}$

P#4:

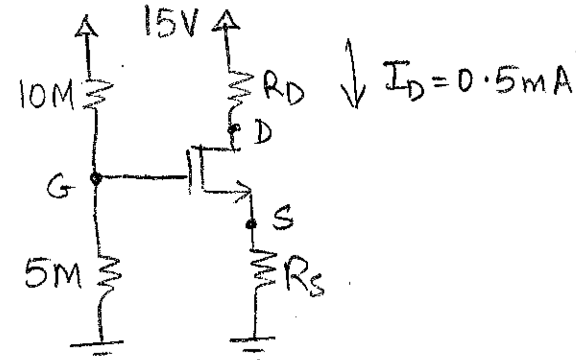
$A_V = -15\ V/V$
$I_D = 0.5mA$ } Design criteria.



$V_t = 1V$
$k_n = 4mA/V^2$
$V_A = 100V$

DC Analysis:

(3)



assume saturation operation 'cos its an amplifier:

$\Rightarrow I_D = \frac{1}{2} k_n (V_{GS} - V_t)^2$

$\Rightarrow 0.5m = \frac{1}{2} \times 4m \times V_{ov}^2$

$\Rightarrow V_{ov} = \pm 0.5V$ for NMOS $V_{ov} \geq 0V$ $(V_{GS} \geq V_t)$ for it to conduct.

$\Rightarrow V_{ov} = +0.5V$.

$\Rightarrow V_{GS} - V_t = 0.5V$

(2) $\Rightarrow V_{GS} = 0.5 + 1 = \underline{1.5V}$ ✓

$V_G = \frac{5}{5+10} \times 15 = 5V$. ✓

$V_{GS} = V_G - V_S$.

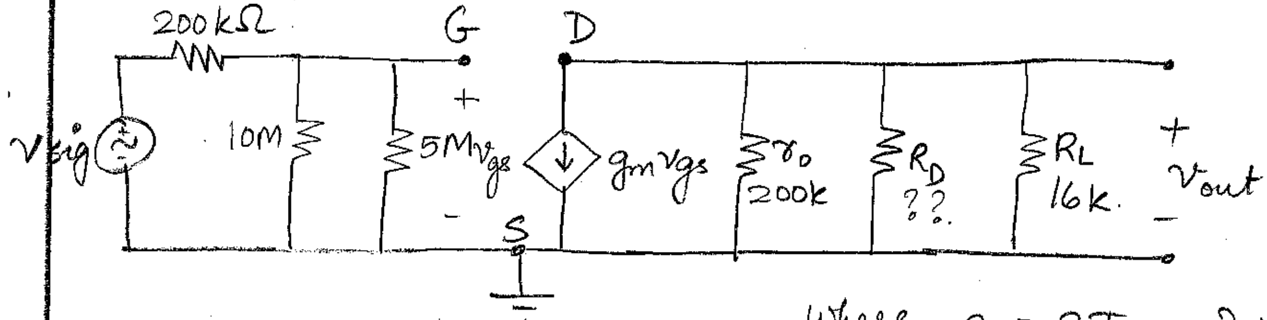
$\Rightarrow V_S = V_G - V_{GS}$
$= 5 - 1.5 = \underline{3.5V}$ ✓

7/10

(3) $\Rightarrow R_S = \dfrac{3.5 - 0}{0.5m} = \underline{\underline{7k\Omega}}$

small signal AC analysis $\Rightarrow$

(3)



where $g_m = \dfrac{2I_D}{V_{OV}} = 2mA/V$. (2)

and $r_o = \dfrac{V_A}{I_D} = 200k\Omega$.

$R_D = ?$

given $A_v = -15\ V/V$.

$A_v = \dfrac{v_{out}}{v_{in}}$

$v_{out} = -g_m v_{gs} \cdot (r_o \| R_D \| R_L)$. ✓

$v_{in} = v_{gs}$

$\Rightarrow A_v = -g_m (r_o \| R_D \| R_L)$.

$\Rightarrow -15 = -2(200 \| 16 \| R_D)$.

$\Rightarrow 7.5k = 14.81k \| R_D$.

$\Rightarrow 1/R_D = 1/7.5k - 1/14.81k$

(3) $\Rightarrow R_D = \underline{\underline{15.2k\Omega}}$ ✓

$G_v = \dfrac{v_{out}}{v_{sig}} = \dfrac{v_{out}}{v_{in}} \times \dfrac{v_{in}}{v_{sig}}$

$v_{in} = v_{gs} = \dfrac{3.33M}{3.33M + 0.2M} v_{sig}$ $(10M \| 5M = 3.33M)$

$= \underline{\underline{0.94}}$

(2)

$\Rightarrow G_v = -15 \times 0.94$ ✓

$= \underline{\underline{14.1\ V/V}}$

assumed saturation

→ verify ⇒ $V_{DS} \geq V_{GS} - V_t$.

$$V_{GS} - V_t = V_{OV} = \underline{\underline{0.5V}}.$$

$$V_D = 15 - I_D \cdot R_D$$
$$= 15 - 0.5m \times 15.2k$$
$$= \underline{\underline{7.4V}}.$$

2

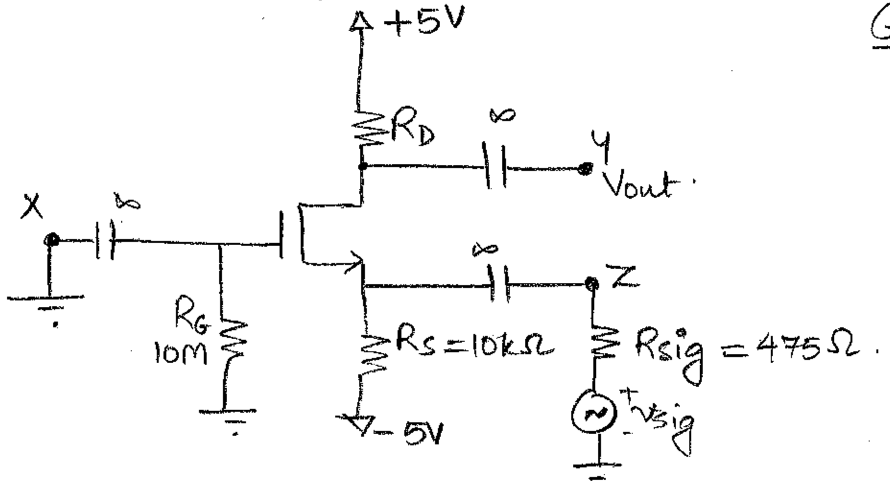
$$V_{DS} = V_D - V_S.$$
$$= 7.4 - 3.5$$
$$= \underline{\underline{3.9V}}. \qquad (3.9V > 0.5V)$$

⇒ V_{DS} is greater than V_{OV}, hence valid assumption.

Exam #2 | | | 9/10

P#5: For impedance matching, we need a CG amplifier where Rin of the amplifier equals Rsig.

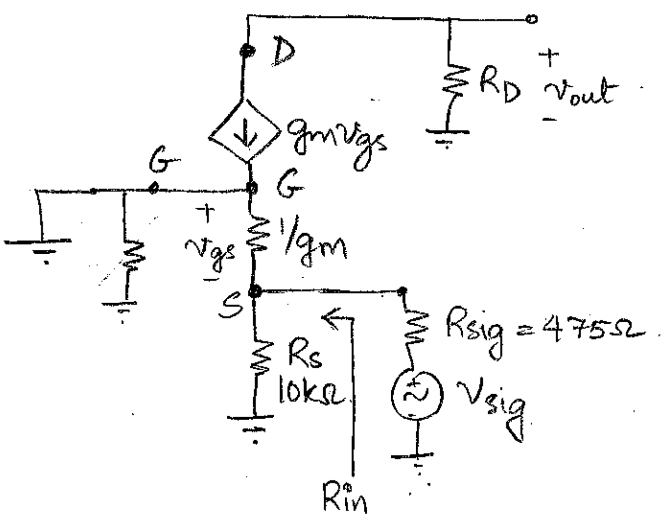
(2pt) CG config ⇒ X = GND, Z = Input, Y = output.



Given:
$V_{OV} = 0.4V$

$V_{DS} = V_{OV} + 0.8V$
$= \underline{1.2V}$

Small signal AC model ⇒



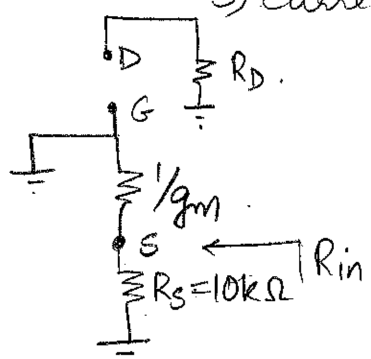
for impedance matching,
$R_{in} = R_{sig} = \cancel{475}\Omega$ 475Ω

(2pt)

(5pt)

To determine Rin: 1) disconnect input signal source.
2) Rin = R b/w S and GND.
3) current source has ∞ resistance.

⇒



$\Rightarrow R_{in} = 1/g_m \,||\, R_s$

$\Rightarrow \frac{1}{475} = g_m + \frac{1}{10000}$

$\Rightarrow g_m = \underline{2 mA/V}$ (3pt)

To find the resistor values, we need the DC bias current, I_D.

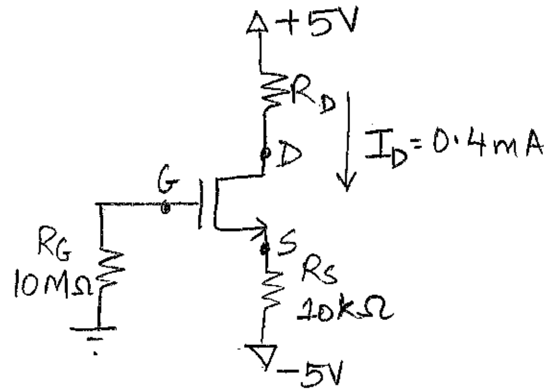
$$g_m = \frac{2I_D}{V_{ov}}$$

$$\Rightarrow 2\,mA/V = \frac{2 \times I_D}{0.4V}$$

(3pt) $\Rightarrow I_D = \underline{\underline{0.4\,mA}}$

Now, perform DC analysis to find the value of R_D.

<u>DC Analysis:</u>



$V_G = 0V$

$V_S = I_D R_S - 5 = (0.4m)(10k) - 5 = -\underline{\underline{1V}}$

$V_{GS} = 1V$ and $V_{ov} = 0.4V$ given.

(3) $V_{DS} = V_{ov} + 0.8V = 1.2V$

$\Rightarrow V_D = 1.2 + V_S$

$= \underline{\underline{0.2V}}$

(2) $R_D = \dfrac{5 - 0.2}{0.4m} = \underline{\underline{12k\Omega}}$ $\Rightarrow R_D \leq \underline{\underline{12k\Omega}}$.

if $R_D > 12k\Omega \Rightarrow V_D < 0.2V$ and the output swing would reduce from $0.8V$.