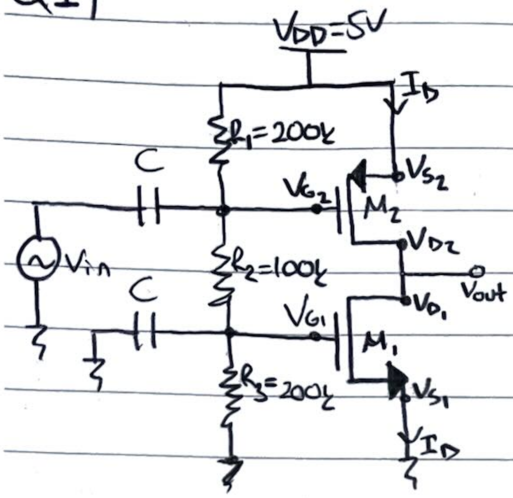
EMRE UNCU 22003884 HW2 / /

Q1)



a) $V_{G_2} = \frac{(200k+100k) \cdot 5V}{200k+100k+200k} = 3V$, $V_{G_1} = \frac{200k \cdot 5V}{200k+100k+200k} = 2V$

$V_{S_1} = 0V$ $\quad V_{G_1} = 2V \quad V_{D_1} = V_{out}$

$V_{GS_1} = 2V \quad V_{DS_1} = V_{out}$

$V_{S_2} = 5V \quad V_{G_2} = 3V \quad V_{D_2} = V_{out}$

$V_{SG_2} = 2V \quad V_{SD_2} = 5 - V_{out}$

Assume SAT for M_1	Assume SAT for M_2
$I_D = K_n(V_{GS_1} - V_{tn})^2(1+\lambda_1 V_{DS_1})$	$I_D = K_p(V_{SG_2} - \lvert V_{tp}\rvert)^2(1+\lambda_2 V_{SD_2})$
$I_D = 0.25(2-1)^2(1+0.02V_{out})$ ①	$I_D = 0.25(2-1)^2(1+0.01(5-V_{out}))$ ②

$\cancel{0.25}(\cancel{1}+0.02V_{out}) = \cancel{0.25}(\cancel{1}+0.01(5-V_{out}))$ by ① = ②

$2V_{out} = 5 - V_{out} \Rightarrow V_{out} = 5/3$

$V_{DS_1} = V_{out} \Rightarrow \boxed{V_{DS_1} = 1.67V}$ $\quad\quad$ $V_{SD_2} = 5 - V_{out} \Rightarrow \boxed{V_{SD_2} = 3.33V}$

SAT $\rightarrow$ $V_{GS_1} > V_{tn} \Rightarrow 2V > 1V$ ✓

$V_{DS_1} \geq V_{GS_1} - V_{tn} \Rightarrow 1.67V > 1V$ ✓

SAT $\rightarrow$ $V_{SG_2} > \lvert V_{tp}\rvert \Rightarrow 2V > 1V$ ✓

$V_{SD_2} \geq V_{SG_2} - \lvert V_{tp}\rvert \Rightarrow 3.33V > 1V$ ✓

$I_D = 0.25(1+0.02 \cdot 1.67) \Rightarrow \boxed{I_D = 0.26mA}$

$g_{m_1} = 2\sqrt{K_n \cdot I_D} = 2\sqrt{0.25 \cdot 0.26}$ $\quad\quad$ $g_{m_2} = 2\sqrt{K_p \cdot I_D} = 2\sqrt{0.25 \cdot 0.26}$

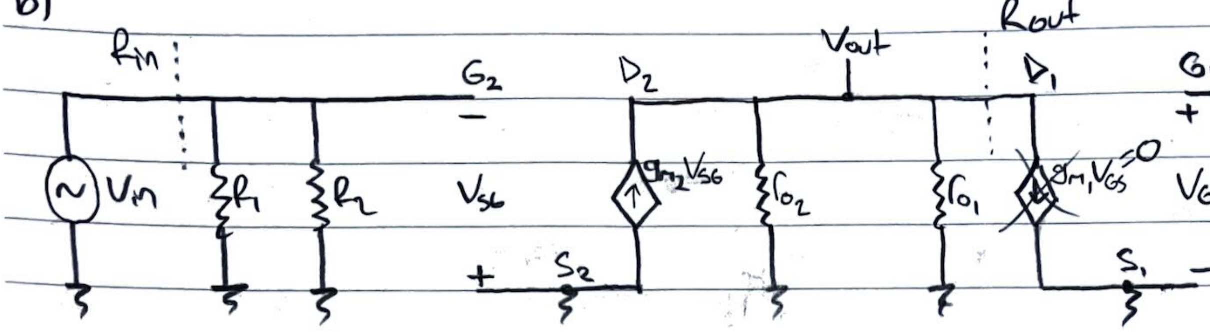
$\boxed{g_{m_1} = 0.51 \ mA/V}$ $\quad\quad$ $\boxed{g_{m_2} = 0.51 \ mA/V}$

$r_{o_1} = \frac{1}{\lambda_1 \cdot I_D} = \frac{1}{0.02 \cdot 0.26}$ $\quad\quad$ $r_{o_2} = \frac{1}{\lambda_2 \cdot I_D} = \frac{1}{0.01 \cdot 0.26}$

$\boxed{r_{o_1} = 193.57 \ k\Omega}$ $\quad\quad$ $\boxed{r_{o_2} = 387.15 \ k\Omega}$

λ_1 and $\lambda_2 \neq 0$ for $I_D \neq 0$

b)



$V_{in} = -V_{SG}$

$V_{out} = g_{m_2}V_{SG}(r_{o_1}//r_{o_2})$

$A_V = \frac{V_{out}}{V_{in}} = \frac{g_{m_2}\cancel{V_{SG}}(r_{o_1}//r_{o_2})}{-\cancel{V_{SG}}}$

$A_V = -g_{m_2}\left(\frac{r_{o_1} \cdot r_{o_2}}{r_{o_1}+r_{o_2}}\right) = -\overset{(m)}{0{,}51}\left(\frac{\overset{(k)}{193{,}57} \cdot \overset{(k)}{387{,}15}}{193{,}57+387{,}15}\right)$

$\boxed{A_V = \frac{V_{out}}{V_{in}} = -65{,}82}$

c) $R_{in} = R_1 // R_2$

$R_{in} = \frac{200.100}{200+100} \Rightarrow \boxed{R_{in} = 66.67k\Omega}$

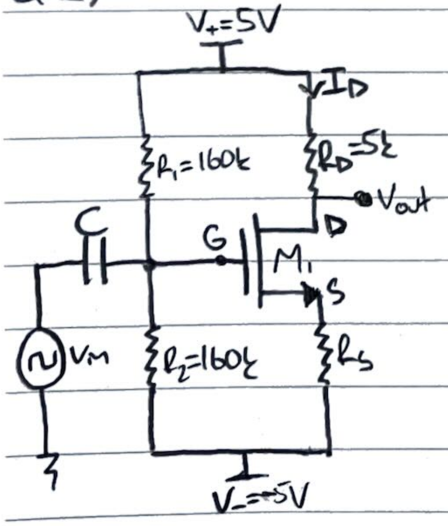
R_{out} $V_{in} \to$ short $\to V_{SG} = 0V$

$g_{m_2}V_{SG} = 0 \to$ open $I_D = 0$

$R_{out} = r_{o_2} // r_{o_2}$

$R_{out} = \frac{193{,}57 \cdot 387{,}15}{193{,}57+387{,}15} \Rightarrow \boxed{R_{out} = 129.05k\Omega}$

Q2)



a) $V_G = (5+(-5)) \cdot \frac{160}{160+160} = 0V$ $\quad V_D = V_{out} = 5 - I_D R_D$

$V_S = -5 + I_D R_S$ $\quad V_{GS} = 5 - I_D R_S$ $\quad V_{DS} = 10 - I_D R_D - I_D R_S$

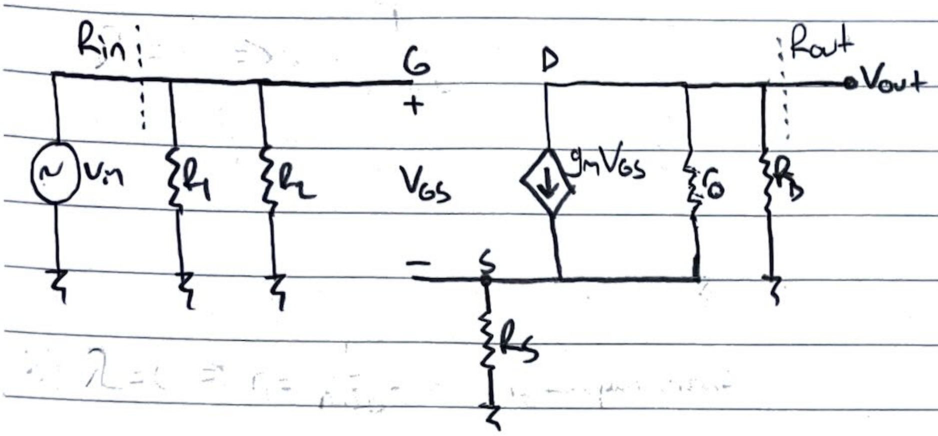
Assume M_1 in SAT $\quad I_D = K_n(V_{GS} - V_{TN})^2$

If $V_{out} = 0 \Rightarrow V_D = 0 = 5 - I_D.5 \Rightarrow I_D = 1mA$

$I_D = 0{,}25(5 - 1.R_S - 1)^2 = 1 \Rightarrow \boxed{R_S = 2k\Omega}$

SAT $\to$ $V_{GS} > V_{TN}$ $\Rightarrow 5 - 1.2 = 3V > 1V$ ✓

$V_{DS} \geq V_{GS} - V_{TN} \Rightarrow 10 - 1.5 - 1.2 = 3V \geq 5 - 1.2 - 1 = 2V$ ✓



$$g_m = 2\sqrt{K_n I_D} = 2\sqrt{0.25 \cdot 1}$$

$$g_m = 1 \text{ mA/V}$$

b) $\lambda = 0 \Rightarrow r_o = \frac{1}{\lambda I_D} = \infty \Rightarrow r_o$ is open circuit

$$V_{in} = V_{GS} + (g_m V_{GS}) R_S \quad , \quad V_{out} = -(g_m V_{GS}) R_D$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{-V_{GS} \cdot g_m \cdot R_D}{V_{GS}(1 + g_m \cdot R_S)} = \frac{-g_m R_D}{1 + g_m R_S} = \frac{-5}{3} \Rightarrow \boxed{A_V = -1.67}$$

c) $r_o = \frac{1}{\lambda I_D} = \frac{1}{0{,}01 \cdot 1} = 100k\,\Omega$ $\qquad V_G = V_{in} \qquad V_{GS} = V_{in} - V_S$

KCL @ S

$$0 = \frac{V_S}{R_S} - g_m \overset{(V_{in} - V_S)}{V_{GS}} + \frac{V_S - V_{out}}{r_o} \Rightarrow V_S\left(\frac{1}{R_S} + g_m + \frac{1}{r_o}\right) = g_m V_{in} + \frac{V_{out}}{r_o} \quad (1)$$

KCL @ D

$$g_m \overset{(V_{in} - V_S)}{V_{GS}} + \frac{V_{out} - V_S}{r_o} + \frac{V_{out}}{R_D} = 0 \Rightarrow V_S\left(\frac{1}{r_o} + g_m\right) = g_m V_{in} + V_{out}\left(\frac{1}{r_o} + \frac{1}{R_D}\right) \quad (2)$$

Using (1) and (2)

$$\frac{(1)}{(2)} = \frac{\frac{1}{R_S} + g_m + \frac{1}{r_o}}{\frac{1}{r_o} + g_m} = \frac{g_m V_{in} + \frac{V_{out}}{r_o}}{g_m V_{in} + V_{out}\left(\frac{1}{r_o} + \frac{1}{R_D}\right)}$$

$$g_m V_{in}\left(\frac{1}{r_o} + g_m\right) + \frac{V_{out}}{r_o}\left(\frac{1}{r_o} + g_m\right) = g_m V_{in}\left(\frac{1}{R_S} + g_m + \frac{1}{r_o}\right) + V_{out}\left(\frac{1}{R_D} + \frac{1}{r_o}\right)\left(\frac{1}{R_S} + g_m + \frac{1}{r_o}\right)$$

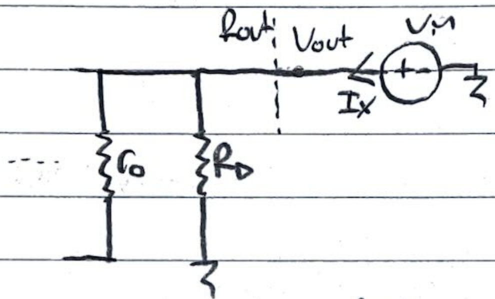
$$V_{out}\left(\frac{1}{r_o}\left(\frac{1}{r_o} + g_m\right) - \left(\frac{1}{r_o} + \frac{1}{R_D}\right)\left(\frac{1}{R_S} + g_m + \frac{1}{r_o}\right)\right) = -V_{in}\left(g_m\left(\frac{1}{R_S} + g_m + \frac{1}{r_o}\right) - g_m\left(\frac{1}{r_o} + g_m\right)\right)$$

$$\frac{V_{out}}{V_{in}} = \frac{g_m\left(\frac{1}{R_S}+g_m+\frac{1}{r_o}-\frac{1}{r_o}-g_m\right)}{\frac{1}{r_o}\left(\frac{1}{r_o}+g_m\right)-\left(\frac{1}{r_o}+\frac{1}{R_D}\right)\left(\frac{1}{R_S}+g_m+\frac{1}{r_o}\right)} \underset{\lambda \to 0}{\overset{\underset{r_o \to \infty}{\text{Lim}}}{\Rightarrow}} \; \frac{1}{r_o}=0 \quad \frac{V_{out}}{V_{in}} = \frac{-g_m\left(\frac{1}{R_S}\right)}{\frac{1}{R_D}\left(\frac{1}{R_S}+g_m\right)} = \underbrace{\frac{-g_m R_D}{1+g_m R_S}}_{\text{Same as part b}}$$

d) $R_{in} = \dfrac{R_1 \cdot R_2}{R_1+R_2} \Rightarrow \boxed{R_{in} = 80k\Omega}$

for Rout

$V_G = 0V$



$R_{out} = \dfrac{V_{in}}{I_x}$

KCL @ S

$$\frac{V_S}{R_S} + g_m \overset{(V_G-V_S)}{V_{GS}} + \frac{V_S - \overset{(V_x)}{V_{out}}}{r_o} = 0 \Rightarrow V_S = V_x\left(\frac{1}{r_o}\right)\left(\frac{1}{R_S}+g_m+\frac{1}{r_o}\right)^{-1}$$

Substitute

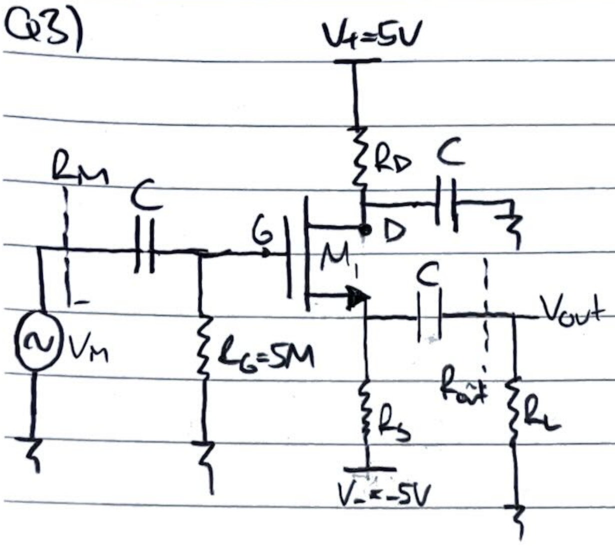
KCL @ D

$$I_x = \frac{\overset{(V_x)}{V_{out}}}{R_D} + g_m \overset{(V_G-V_S)}{V_{GS}} + \frac{\overset{(V_x)}{V_{out}} - V_S}{r_o} \Rightarrow I_x = V_x\left(\frac{1}{R_D}+\frac{1}{r_o}\right) - V_S\left(g_m+\frac{1}{r_o}\right)$$

$$I_x = V_x\left(\frac{1}{R_D}+\frac{1}{r_o}\right) - V_x\left(\frac{1}{r_o}\right)\left(\frac{1}{R_S}+g_m+\frac{1}{r_o}\right)^{-1}\left(g_m+\frac{1}{r_o}\right) = V_x\left(\frac{1}{R_D}+\frac{1}{r_o}-\left(\frac{1}{r_o}\right)\left(\frac{1}{R_S}+g_m+\frac{1}{r_o}\right)^{-1}\left(g_m+\frac{1}{r_o}\right)\right)$$

$$I_x = V_x\left(\frac{1}{5}+\frac{1}{100}-\frac{1}{100}\cdot\left(\frac{1}{2}+1+\frac{1}{100}\right)^{-1}\left(1+\frac{1}{100}\right)\right) \Rightarrow \frac{V_x}{I_x} = \boxed{R_{out} \simeq 5k\Omega}$$

Q3)



a)

Assume M_1 in SAT

$V_G = 0V$ $\quad V_S = -5 + I_D R_S$ $\quad V_D = 5 - I_D R_D$

$V_{GS} = 5 - I_D R_S$ $\quad V_{DS} = 10 - I_D R_S - I_D R_D$

$I_D = K_n (V_{GS} - V_{TN})^2$ $\quad$ If $I_D = 0.2$ and $V_D = 1V$

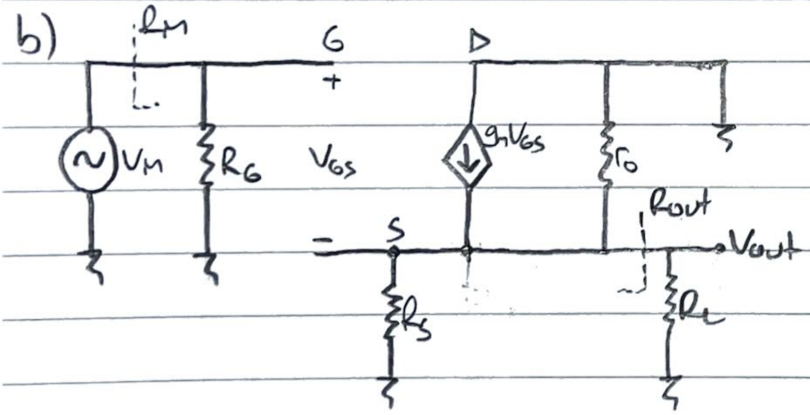
$V_D = 5 - I_D R_D = 5 - 0.2 R_D = 1 \Rightarrow \boxed{R_D = 20k\,\Omega}$

$I_D = K_n (V_{GS} - V_{TN})^2 = 0.5 (V_{GS} - 1)^2 = 0.2 \Rightarrow V_{GS} = 1.63 = 5 - 0.2 R_S \Rightarrow \boxed{R_S = 16.85k\,\Omega}$

SAT $\rightarrow$ $V_{GS} > V_{TN}$ $\quad \Rightarrow 1.63 > 1$ ✓

$V_{DS} \geq V_{GS} - V_{TN}$ $\quad \Rightarrow 2.63 \geq 1.63 - 1$ ✓

b)



$r_o = \frac{1}{\lambda . I_D} = \frac{1}{0.01 . 0.2} \Rightarrow r_o = 500k\,\Omega$

$V_{out} = V_S$ $\quad V_D = 0V$

$g_m = 2\sqrt{k_n I_D} = 2\sqrt{0.5 . 0.2} \Rightarrow g_m = 0.63 \frac{mA}{V}$

KCL @ S

$$g_m V_{GS} = \frac{\overset{(V_{out})}{V_S}}{R_S} + \frac{\overset{(V_{out})}{V_S}}{r_o} \Rightarrow V_{out} = \frac{g_m V_{GS}}{\frac{1}{r_o} + \frac{1}{R_S}}$$

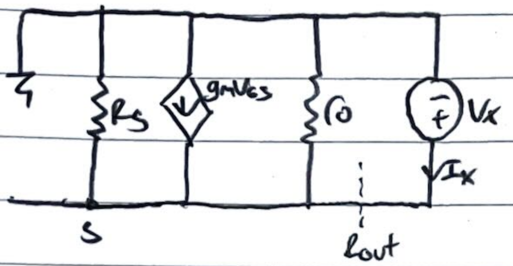
$$V_{in} = V_{GS} + \overset{(V_{out})}{V_S} = V_{GS} + V_{out} \Rightarrow V_{in} = V_{GS} + \frac{g_m V_{GS}}{\frac{1}{r_o} + \frac{1}{R_S}}$$

$$A_v = \frac{V_{out}}{V_{in}} = \frac{\frac{\cancel{V_{GS}}\, g_m}{\frac{1}{r_o} + \frac{1}{R_S}}}{\cancel{V_{GS}}\left(1 + \frac{g_m}{\left(\frac{1}{r_o} + \frac{1}{R_S}\right)}\right)} = \frac{\frac{0.63}{\frac{1}{500} + \frac{1}{16.85}}}{1 + \frac{0.63}{\frac{1}{500} + \frac{1}{16.85}}} \Rightarrow \boxed{A_{voc} = 0.91}$$

c)

$$R_{in} = R_G \Rightarrow \boxed{R_{in} = 5M\Omega}$$

for R_{out} $\quad V_G = 0V \quad V_S = V_x \quad V_{GS} = -V_S = -V_x$

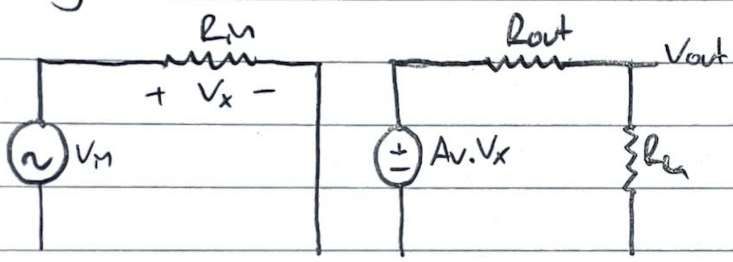


$$I_x = \frac{V_x}{r_o} + \frac{V_x}{R_S} - g_m \overset{(-V_x)}{V_{GS}} = V_x\left(\frac{1}{r_o}+\frac{1}{R_S}+g_m\right)$$

$$R_{out} = \frac{V_x}{I_x} = \frac{1}{\frac{1}{r_o}+\frac{1}{R_S}+g_m} = \frac{1}{\frac{1}{500}+\frac{1}{16.65}+0.63}$$

$$\boxed{R_{out} = 1.45k\Omega}$$

d) Using Black Box Model

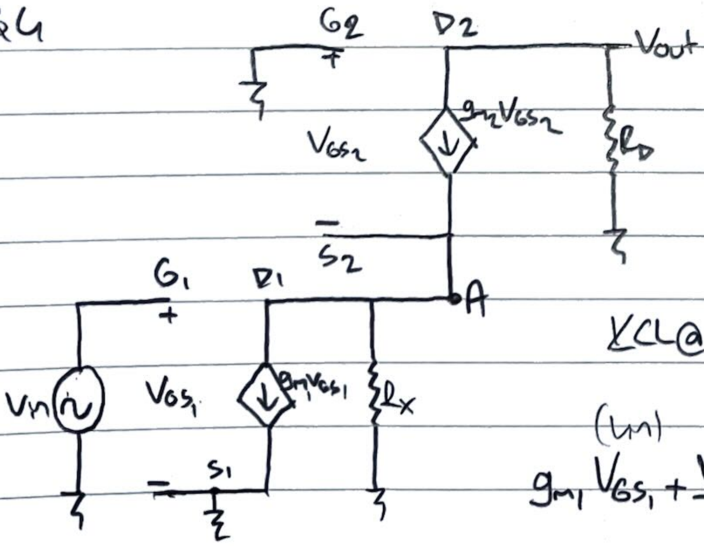


$$V_x = V_{in}$$

$$V_{out} = A_{voc} \cdot \overset{(V_{in})}{V_x} \cdot \frac{R_L}{R_{out}+R_L}$$

$$A_v = \frac{V_{out}}{V_{in}} = 0.91 \cdot \frac{10}{1.45+10} \Rightarrow \boxed{A_v = 0.79}$$

Q4



$$V_{G_2} = 0V \quad V_{GS_2} = -V_{S_2} = -V_A$$

$$V_{G_1} = V_{in} \quad V_{GS_1} = V_{G_1} = V_{in}$$

$$V_{out} = -g_{m_2} \overset{(-V_A)}{V_{GS_2}} R_D = g_{m_2} V_A R_D$$

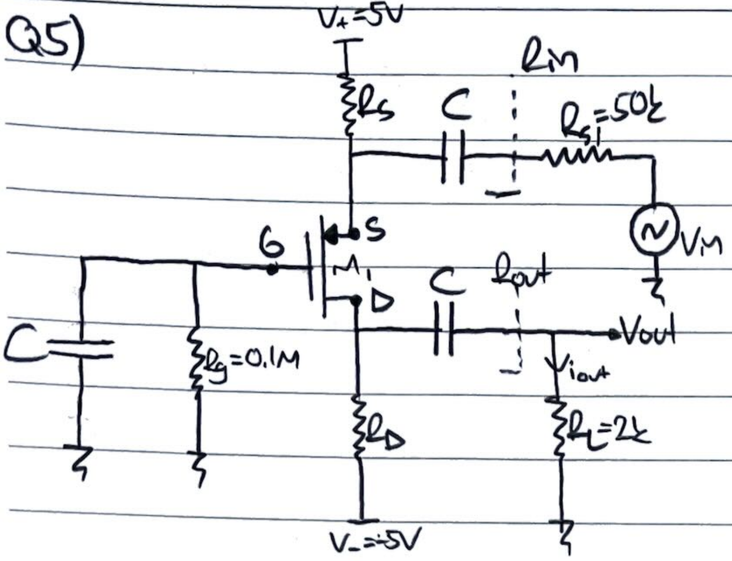
KCL@A

$$g_{m_1} \overset{(V_{in})}{V_{GS_1}} + \frac{V_A}{R_X} - g_{m_2} \overset{(-V_A)}{V_{GS_2}} = g_{m_1} V_{in} + \frac{V_A}{R_X} + g_{m_2} V_A = 0$$

$$V_{in} = \frac{-V_A}{g_{m_1}}\left(\frac{1}{R_X}+g_{m_2}\right)$$

$$A_v = \frac{V_{out}}{V_{in}} = \frac{V_A \cdot g_{m_2} \cdot R_D}{\frac{-V_A}{g_{m_1}}\left(\frac{1}{R_X}+g_{m_2}\right)} \Rightarrow \boxed{A_v = \frac{-g_{m_1} \cdot g_{m_2} \cdot R_D}{\frac{1}{R_X}+g_{m_2}}}$$

Q5)



a)

$V_G = 0V \quad V_S = 5 - I_D R_S \quad V_D = -5 + I_D R_D$

$V_{SG} = 5 - I_D R_S \quad V_{SD} = 10 - I_D R_S - I_D R_D$

Assume M_1 in SAT If $I_D = 0.5$ $V_{SD} = 5V$

$I_D = K_p(V_{SG} - |V_{TP}|)^2 = 0.5(V_{SG} - 1)^2 = 0.5$

2 ~~0~~

$V_{SG} = 5 - I_D R_S = 5 - 0.5 \cdot R_S = 2$

$\boxed{R_S = 6k\,\Omega \quad R_D = 4k\,\Omega}$

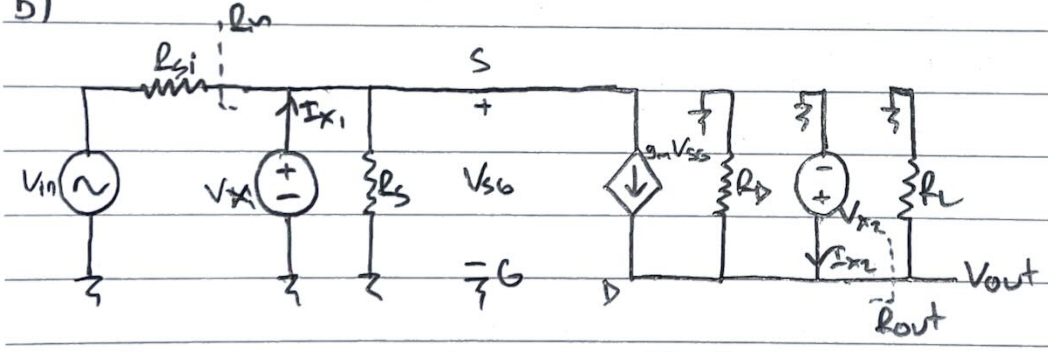
$V_{SD} = 10 - I_D R_S - I_D R_D = 10 - 0.5 \cdot 6 - 0.5 \cdot R_D = 5$

SAT $\rightarrow V_{SG} > |V_{TP}| \quad \Rightarrow 2 > 1$ ✓

$V_{SD} \geq V_{SG} - |V_{TP}| \Rightarrow 5 \geq 2 - 1$ ✓

b)

$g_m = 2\sqrt{0.5 \cdot 0.5} = 1\ mA/V$



$V_G = 0V \quad V_{SG} = V_S$

for Rin, by using $V_{x_1} \Rightarrow R_{in} = V_{x_1}/I_{x_1}$ ignore left side of Rin kill Vin

ignore V_{x_2} source

KCL@S

$$I_{x_1} = \frac{\overset{(V_{x_1})}{V_S}}{R_S} + g_m \overset{(V_{x_1})}{V_{GS}} = V_{x_1}\left(\frac{1}{R_S} + g_m\right) \quad R_{in} = \frac{V_{x_1}}{I_{x_1}} = \frac{1}{\frac{1}{R_S} + g_m} = \frac{1}{\frac{1}{6} + 1} \Rightarrow \boxed{R_{in} = 0.86\,k\Omega}$$

for Rout, by using $V_{x_2} \Rightarrow R_{out} = V_{x_2}/I_{x_2}$ ignore right side of Rout kill Vin $V_{in} = 0$

ignore V_{x_1} source

KCL@D

$$I_{x_2} = \frac{\overset{(V_{x_2})}{V_D}}{R_D} - g_m \overset{(V_S)}{V_{SG}} = \frac{V_{x_2}}{R_D} - g_m V_S$$

KCL@S

$$g_m V_{SG} + \frac{V_S}{R_S} + \frac{V_S}{R_{si}} = 0 \Rightarrow V_S = 0V$$

$$\Rightarrow I_{x_2} = \frac{V_{x_2}}{R_D} \Rightarrow R_{out} = \frac{V_{x_2}}{I_{x_2}} = R_D \Rightarrow \boxed{R_{out} = 4k\,\Omega}$$

c) KCL @ S

$$g_m \overset{(V_S)}{V_{SG}} + \frac{V_S}{R_S} + \frac{V_S - V_{in}}{R_{Si}} = V_S\left(g_m + \frac{1}{R_S} + \frac{1}{R_{Si}}\right) - \frac{V_{in}}{R_{Si}} = V_S\left(1+\frac{1}{6}+\frac{1}{50}\right) - \frac{0.5\cdot 10^{-3}}{50} = 0$$

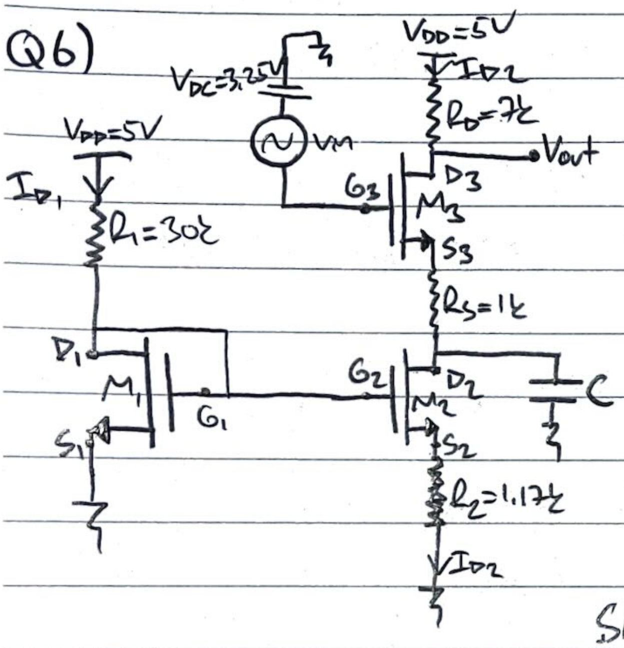
$$V_S = 8.43\cos(\omega t)\,\mu V$$

KCL @ D

$$-g_m \overset{(V_S)}{V_{SG}} + \frac{\overset{i_{out}\cdot R_L}{V_D}}{R_D} + i_{out} = -g_m V_S + \frac{i_{out}\cdot R_L}{R_D} + i_{out} = -1\cdot 8.43\cdot 10^{-6} + i_{out}\cdot\frac{3}{2} = 0$$

$$\boxed{i_{out} = 5.62\cos(\omega t)\,\mu A}$$

Q6)



Assume M_1 in SAT

$V_{G_1} = V_{D_1} = 5 - I_{D_1}R_1$ ✓ $\quad V_{GS_1} = V_{DS_1} = V_{G_1}$

$V_{S_1} = 0V$

$I_{D_1} = K_{n_1}(V_{GS_1} - V_{TN})^2 = K_{n_1}(5 - I_D R_1 - V_{TN})^2$

$I_{D_1} = 0.1(5 - 30I_{D_1} - 1)^2 = 0.1(16 - 240I_{D_1} + 900I_{D_1}^2)$

$I_{D_1} =$
- $\cancel{0.18}\,mA \Rightarrow V_{GS_1} = 5 - 0.18\cdot 30 < V_{TN}$ X
- $0.1\,mA \Rightarrow V_{GS_1} = 5 - 0.1\cdot 30 = 2V$

$I_{D_1} = 0.1\,mA$

SAT M_1 $\rightarrow V_{GS_1} > V_{TN} \Rightarrow 2 > 1$ ✓

$V_{DS_1} \geq V_{GS_1} - V_{TN} \Rightarrow 2 \geq 1$ ✓

$$\boxed{\begin{array}{l} V_{G_1} = 2V \\ V_{D_1} = 2V \\ V_{S_1} = 0V \end{array}}$$

Assume M_2 in SAT

$V_{G_2} = V_{G_1} = 2V \quad V_{S_2} = I_{D_2}R_2 \quad V_{GS_2} = 2 - I_{D_2}R_{D_2}$

$I_{D_2} = K_{n_2}(V_{GS_2} - V_{TN})^2 = K_{n_2}(2 - I_{D_2}R_2 - V_{TN})^2 = 0.5(2 - I_{D_2}(1.17) - 1)^2 = 0.68I_{D_2}^2 - 1.17I_{D_2} + \frac{1}{2}$

I_{D_2}
- $\cancel{2.94}\,mA \Rightarrow V_{GS_2} = 2 - 2.94\cdot 1.17 < V_{TN}$ X
- $0.25\,mA \Rightarrow V_{GS_2} = 2 - 0.25\cdot 1.17 = 1.71V$

$$\boxed{\begin{array}{l} V_{S_2} = 0.29V \\ V_{G_2} = 2V \\ V_{D_2} = 1.5V \end{array}} \qquad \boxed{\begin{array}{l} I_{D_1} = 0.1\,mA \\ I_{D_2} = 0.25\,mA \end{array}}$$

Assume M_3 in SAT

$V_{G_3} = 3.25 \quad V_{S_3} = V_{D_2} + I_{D_2}R_S \quad V_{D_3} = 5 - I_{D_2}R_D$

$$\boxed{\begin{array}{l} V_{G_3} = 3.25V \\ V_{D_3} = 3.25V \\ V_{S_3} = 1.75V \end{array}}$$

$V_{GS_3} = 3.25 - V_{D_2} - I_{D_2}R_S \quad V_{DS_3} = 5 - I_{D_2}R_D - V_{D_2} - I_{D_2}R_S$

$I_{D_2} = K_{N_3}(V_{GS_3} - V_{TN})^2 = K_{N_3}(3{,}25 - V_{D_2} - I_{D_2}.R_S - 1)^2 = 1(3{,}25 - V_{D_2} - 0{,}25.1 - 1)^2 = 0{,}25$

$V_{D_2} \rightarrow 2{,}5V \Rightarrow V_{GS_3} = 3{,}25 - 2{,}5 - 0{,}25.1 < 1$ X

$V_{D_2} \rightarrow 1.5V \Rightarrow V_{GS_3} = 3.25 - 1.5 - 0.25.1 = 1.5V$ $\quad V_{S_3} = V_{D_2} + I_{D_2}R_S = 1.75V$

SAT → $V_{GS_2} > V_{TN}$ ⇒ $1{,}71 > 1$ ✓

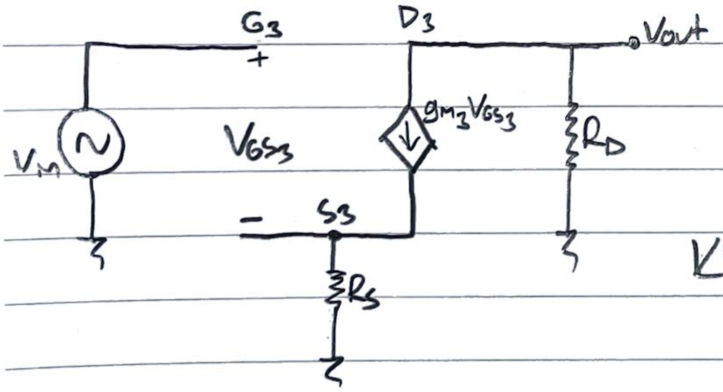
M2 $\quad V_{DS_2} \geq V_{GS_2} - V_{TN} \Rightarrow 1{,}5 - 0{,}29 > 1{,}71 - 1$ ✓

SAT → $V_{GS_3} > V_{TN}$ ⇒ $1{,}5 > 1$ ✓

M3 $\quad V_{DS_3} \geq V_{GS_3} - V_{TN} \Rightarrow 3{,}25 - 1{,}75 > 1{,}5 - 1$ ✓

So, M_1, M_2, and M_3 are in SATURATION

b) In AC, drain of M_2 is ground, due to the short circuit on capacitor. So, M_2 and M_3 can be ignored in small signal analysis equivalent circuit



$g_{m_3} = 2\sqrt{K_{N_3} I_{D_2}} = 2\sqrt{1.\,0{,}25} = 1\ mA/V$

KVL

$V_{in} = V_{GS_3} + g_{m_3} V_{GS_3}.R_S$

KCL @ D_3

$-\frac{V_{out}}{R_D} = g_{m_3} V_{GS_3} \Rightarrow V_{out} = g_{m_3} V_{GS_3} R_D$

$A_V = \frac{V_{out}}{V_{in}} = \frac{-g_{m_3} V_{GS_3} R_D}{V_{GS_3} + g_{m_3} V_{GS_3} R_S} = \frac{-g_{m_3} R_D}{1 + g_{m_3} R_S} = \frac{-1.7}{1 + 1.1} \Rightarrow \boxed{A_V = -3{,}5}$