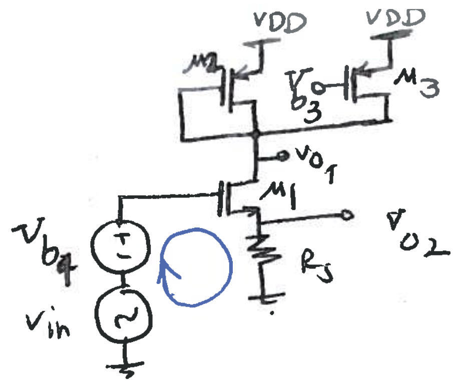
Assignment 2

1)



$\lambda = \gamma = 0$, $V_{DD} = 3^V$, $V_{b_3} = 1.9^V$

$V_{tn} = .5^V$, $V_{tp} = -.6^V$, $K'_n = \mu_n C_{ox} = 200 \frac{\mu A}{V^2}$

$(\frac{W}{L})_1 = 40$, $K'_p = \mu_p C_{ox} = 100 \frac{\mu A}{V^2}$, $(\frac{W}{L})_2 = 40$

$(\frac{W}{L})_3 = 40$, $R_S = 50\,\Omega$

All Trans. are in <u>Saturation</u>

a) if $I_1 = 1\,mA \Rightarrow V_{b_1} = ?$

Solution: KVL around loop 1.

$$\begin{cases} V_{b_1} = V_{gs_1} + R_S I_1 \Rightarrow V_{b_1} = 1^V + \frac{50}{1000}^{k\Omega} \times 1^{mA} = 1.05^V \\ I_1 = \frac{1}{2} k'_n (\frac{W}{L})_1 (V_{gs_1} - V_{tn})^2 \Rightarrow 1 = \frac{1}{2} \times .2 \times 40 \times (V_{gs_1} - .5)^2 \Rightarrow V_{gs_1} = 1^V \end{cases}$$

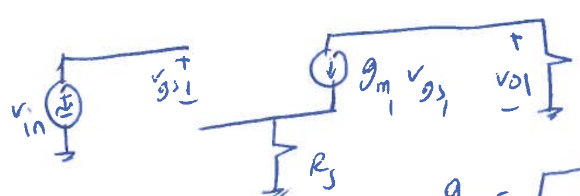
$$\boxed{V_{b_1} = 1.05V}$$

b) $A_{V_1} = \frac{V_{O1}}{V_{in}} = ?$

The Impedance seen from the drain of Transistor M_2 is: $\frac{1}{g_{m_2}}$ and That of M_3 is <u>infinity</u>

So, the parallel Combination of M_2 and M_3 is $\boxed{\frac{1}{g_{m_2}}}$

Using small signal model of M_1



$$A_{V_1} = \frac{V_{O1}}{V_{in}} = \frac{\frac{1}{g_{m_2}} \times g_{m_1}}{1 + g_{m_1} R_S} =$$

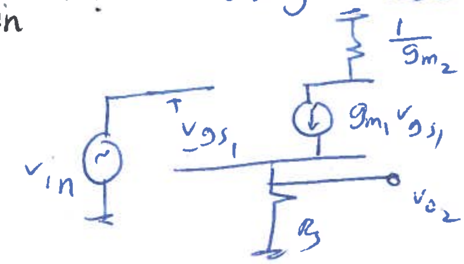
$$g_{m_1} = \sqrt{2 \times .2 \times 40 \times 1} = 4\,m\mho$$

$$g_{m_2} = \sqrt{2 \times .1 \times 40 \times I_{d_2}} = 2\,m\mho$$

$$I_{d_2} = 1 - \frac{1}{2} \times .1 \times 40 \times (V_{DD} - 1.9 - .6)^2 = .5\,mA$$

$$\Rightarrow A_{V_1} = \frac{4 \times 1/2}{1 + (4 \times \frac{50}{1000})} = 1.67\ (\frac{V}{V})$$

c) $A_{v_2} = \frac{v_{o2}}{v_{in}} = ?$ Using small signal model below:



$\Rightarrow A_{v_2} = \frac{v_{o2}}{v_{in}} = \frac{g_{m_1} R_S}{1 + g_{m_1} R_S}$

$A_{v_2} = \frac{4 \times \frac{50}{1000}}{1 + (4 \times \frac{50}{1000})} \approx .17 \ (V/V)$

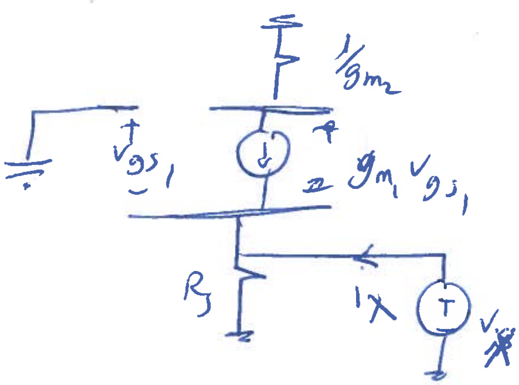
d) output impedance ~~A~~ seen at the output node V_{o_1}.

Because $\lambda = 0$ and therefore r_o of all transistors is moving towards ∞,

According to point (a), the impedance seen at node V_{o_1} is $\boxed{\frac{1}{g_{m_2}} = .5 \ k\Omega}$

e) output impedance seen at the node V_{o_2}:

Using model below:



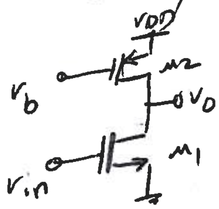
$R_{o_1} = \frac{V_x}{I_x} = R_S \parallel \frac{1}{g_{m_1}}$

$R_{o_1} = 50\Omega \parallel 250\Omega = \underline{41.67\Omega}$

2) Designing a Common_Source amplifier:

$V_{DD}=3^V$, $P_{dc_{total}} = 1.5^{mW}$, $V_{out_{p-p}} = 2.5^V$, $A_v = 40$, $L = 4^{um}$, $V_{out_{dc}} = 1.5^V$

$\lambda_{p,n} = .1\,V^{-1}$, $\gamma = 0$, $V_{tn} = -V_{tp} = .5^V$, $k_n' = .2\,\frac{mA}{V^2}$, $k_p' = .1\,\frac{mA}{V^2}$



find V_b, dc level of input, W_1, W_2 and $A_v = \frac{v_o}{v_{in}}$

Solution: $\begin{cases} V_{out_{p-p}} = V_{DD} - V_{ov_2} - V_{ov_1} = 2.5 \\ V_{dc_{out}} = \dfrac{V_{ov_1} + V_{DD} - V_{ov_2}}{2} = 1.5 \end{cases} \Rightarrow \boxed{V_{ov_1} = V_{ov_2} = .25^V}$

$P_{dc_t} = 1.5^{mW} = V_{DD} \times I \Rightarrow \boxed{I = \frac{1.5}{3} = .5^{mA}}$

$\boxed{r_{o_1} = r_{o_2} = \frac{1}{\lambda I} = \frac{1}{.1 \times .5} = 20^{k\Omega}}$

$|A_v| = g_{m_1} \times (r_{o_1} \| r_{o_2}) = g_{m_1} \times (20^{k\Omega} \| 20^{k\Omega}) \Rightarrow 40 = 10 \times g_{m_1} \Rightarrow \boxed{g_{m_1} = 4^{mU}}$

$g_{m_1} = \sqrt{2 \times .2 \times \left(\frac{W}{L}\right)_1 \times .5^{mA}} = 4 \Rightarrow \left(\frac{W}{L}\right)_1 = 80 \Rightarrow \boxed{W_1 = 32^{um}}$

Dc level of input: $V_{dc_1} = ? \Rightarrow .5^{mA} = \frac{1}{2} k_n' \times \left(\frac{W}{L}\right)_1 (V_{gs_1} - V_{tn})^2$

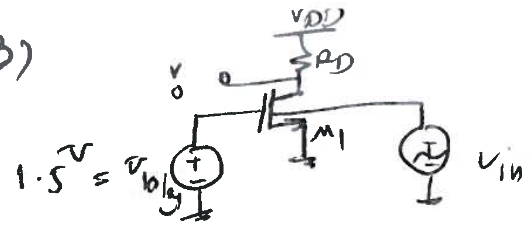
$\Rightarrow \boxed{V_{gs_1} = V_{dc_1} = .75^V}$

$V_{ov_2} = .25^V \Rightarrow \overset{.5^{mA}}{I_D} = \frac{1}{2} \overset{.1\,mA/V^2}{k_p'} \left(\frac{W}{L}\right)_2 (V_{ov_2})^2 \Rightarrow \left(\frac{W}{L}\right)_2 =$ 160 => W2=64um

$\boxed{V_{bias} = V_{DD} - V_{sg_2} = V_{DD} - V_{ov_2} - |V_{tp}| = 2.25^V}$

This is an inverting amplifier whose gain by design has a magnitude of 40V/V so the gain will be -40V/V.

3)



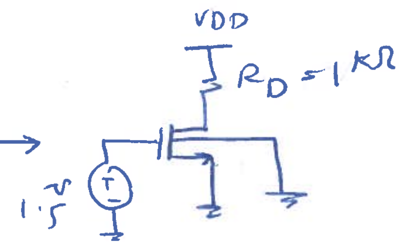
$\lambda = 0$

$\eta = .2$, $V_{tn} = .5^{V}$, $k'_n = .1 \frac{mA}{V^2}$ $R_D = 1\,k\Omega$

$(W/L)_n = 20$, $V_{DD} = 3^{V}$

a) operating region of M_1 ?

DC model of structure above →



$V_{sb} = 0 \Rightarrow$ $\boxed{V_{tn} = V_{tn_0} = .5^{V}}$

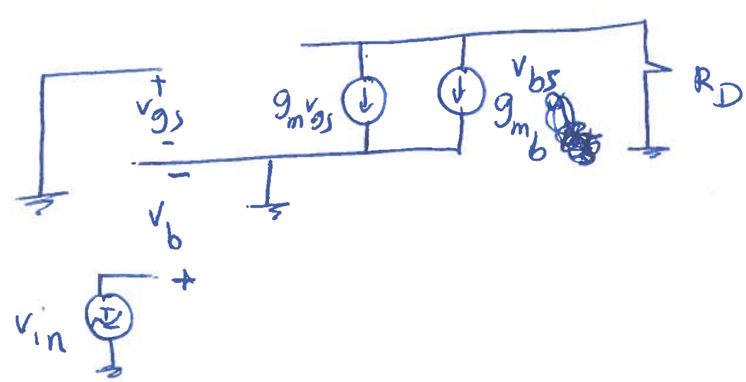
$\boxed{V_{ov} = 1.5 - .5 = 1^{V}}$, $I_D = \frac{1}{2} \times .1 \times 20 \times (1)^2 = 1^{mA}$, $V_{DS_1} = 3^{V} - (1^{k\Omega} \times 1^{mA}) \Rightarrow$

$\boxed{V_{DS_1} = 2^{V}}$

Since $V_{ov} < V_{DS} \Rightarrow M_1$ is in saturation

b) $A_v = \frac{v_{out}}{v_{in}}$ $g_{mb} = \eta g_m$

Using small signal model



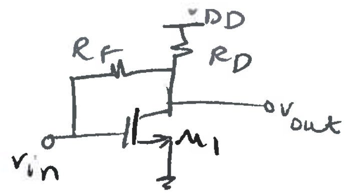
$\rightarrow A_v = -g_{mb} R_D$

$A_v = -\eta g_m R_D$

$\boxed{g_m = \sqrt{2 \times .1 \times 20 \times 1} = 2^{m℧}}$

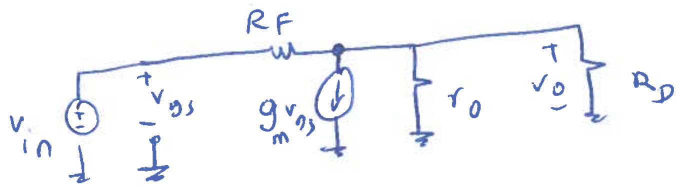
$\Rightarrow A_v = -.2 \times 2 \times 1 = -.4 \left(\frac{V}{V}\right)$

4)



$\lambda \neq 0$

a) $A_v = ?$ Using small signal model:



$v_{gs} = v_{in}$

having a kcl at node V_{out}: $\dfrac{v_o - v_{in}}{R_F} + \dfrac{v_o}{r_o} + \dfrac{v_o}{R_D} + g_m v_{in} = 0$

$$\Rightarrow v_o \left\{ \frac{1}{R_F} + \frac{1}{r_o} + \frac{1}{R_D} \right\} = v_{in} \left\{ \frac{1}{R_F} - g_m \right\} \Rightarrow$$

$$\boxed{A_r = \frac{\frac{1}{R_F} - g_m}{\frac{1}{R_F} + \frac{1}{r_o} + \frac{1}{R_D}}}$$

b) $R_F = ?$ if $A_v = 1$: Using A_v ~~obtained~~ calculated in the last part

$$\frac{1}{R_F} - g_m = \frac{1}{R_F} + \frac{1}{r_o} + \frac{1}{R_D}$$

The only value of RF for which the gain will be one is RF=0 which is a trivial solution that is input and output are shorted. Otherwise, there is no non-zero solution for RF.

c) $R_F = ?$ if $A_v = -1$ $\Rightarrow g_m - \dfrac{1}{R_F} = \dfrac{1}{R_F} + \dfrac{1}{r_o} + \dfrac{1}{R_D} \Rightarrow g_m - \dfrac{1}{r_o} - \dfrac{1}{R_D} = \dfrac{2}{R_F}$

$$\Rightarrow \boxed{R_F = \frac{2}{g_m - \frac{1}{r_o} - \frac{1}{R_D}}}$$

d) for R_F to be realizable : $R_F > 0 \Rightarrow \dfrac{2}{g_m - \frac{1}{r_o} - \frac{1}{R_D}} > 0 \Rightarrow$

$$\boxed{g_m > \frac{1}{r_o} + \frac{1}{R_D}}$$