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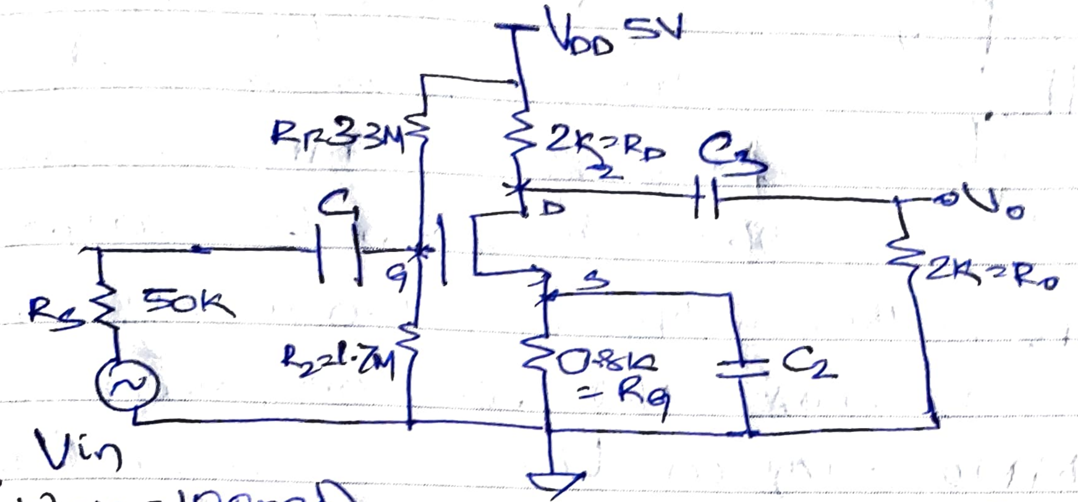
Assignment - 4

1)



Vin

($\omega_{min} = 100 \frac{rad}{s}$)

$\mu_n C_{ox} = 500 \mu A V^{-2}$

$V_T = 0.7V$

$I_{DS} = 1mA$

As we can see I_{DS} is 1mA, we get

$V_S = 0.8k \times 1mA = 0.8V$

$V_D = 5 - 2k \times 1m = 3V$

$\Rightarrow \boxed{V_{DS} = 2.2V}$

And assuming the d.c biasing is done properly, we get

$V_G = 5V \times \frac{1.7M}{1.7M + 3.3M} = 1.7V$ $\boxed{V_G = 1.7V}$

$\Rightarrow V_{GS} = 1.7V - 0.8V$

$\boxed{V_{GS} = 0.9V}$

$\Rightarrow V_{GS} - V_T = 0.9 - 0.7$
$= 0.2V$

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As the $V_{GS}-V_T < V_{DS}$, the MOS is in saturation and

$$I_{DS} = \frac{\mu_n C_{ox} W}{2L}(V_{GS}-V_T)^2$$

$$1mA = 500\mu \times \frac{W}{2L} \times \frac{1}{25}$$

$$\Rightarrow \boxed{\frac{W}{L} = 100}$$

(b) For C_1, the $R_{eff_1} = R_S + (R_1 \| R_2)$

$\Rightarrow R_{eff_1} \times C_1 \gg \frac{1}{\omega_{min}}$ $\Rightarrow R_{eff_1} C_1 = \frac{10 \times 2\pi}{\omega_{min}}$

$$\Rightarrow C_1 = \frac{10 \times 2\pi}{\omega_{min}(R_{eff_1})} = \frac{10 \times 2\pi}{(100)(1172)(1000)}$$

$$= \frac{2\pi}{1172} \times 10^{-4} = 0.000853 \times 10^{-4} \times 2\pi$$

$$= 2\pi \times 85.3\,nF = 535.95\,nF$$

For C_2, the $R_{eff_2} = R_G$

$$\Rightarrow C_2 = \frac{10 \times 2\pi}{\omega_{min} R_{eff_2}} = \frac{10 \times 2\pi}{(100)(0.8k)} = \frac{2\pi}{8}\,mF = 0.125\,mF \times 2\pi$$

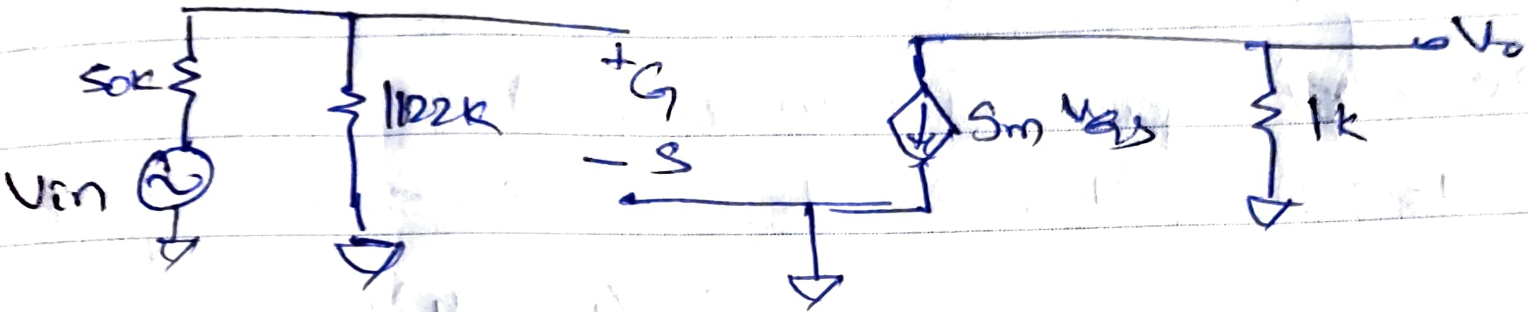
$$= 125\,\mu F \times 2\pi = 785.398\,\mu F$$

For C_3, the $R_{eff_3} = R_O + R_D$

$$\Rightarrow C_3 = \frac{10 \times 2\pi}{\omega_{min} R_{eff_3}} = \frac{10 \times 2\pi}{100(4k)} = 0.25 \times 10^{-4} \times 2\pi$$

$$= 25\,\mu F \times 2\pi = 157.0796\,\mu F$$

1) c) Incremental Picture:



$$V_{GS} = V_{in}\frac{1122k}{1172k} = \frac{1122}{1172}V_{in}$$

$$V_o = -g_m V_{GS} \times 1k$$

$$\Rightarrow \frac{V_o}{V_{in}} = -g_m \times \frac{1122}{1172} \times 1k$$

And $g_m = \mu_n C_{ox}\frac{W}{L}(V_{GS}-V_T) = \frac{2 I_{DS}}{V_{GS}-V_T}$

$I_{DS} = 1mA \quad V_{GS}-V_T = 0.2V \quad \Rightarrow g_m = \frac{2\times 1m}{0.2} = 10^{-2}$

$$\Rightarrow \frac{V_o}{V_{in}} = -\frac{10^{-2}\times 1122\times 10^{3}}{1172} = -9.57$$

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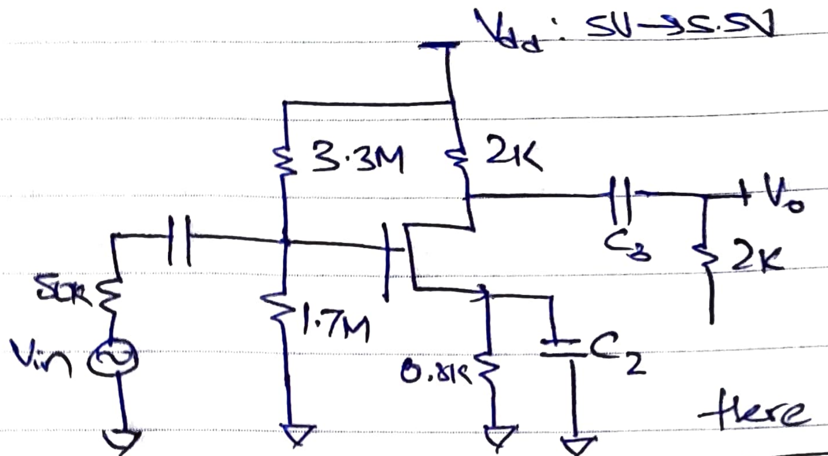
1) d) V_{DD} is changed to 5.5V. New gain:



$\mu_n C_{ox} = 500 \frac{\mu A}{V^2}$

$\frac{W}{L} = 100$

$\beta = \mu_n C_{ox} \frac{W}{L}$

$= 5\times10^{-2} \frac{A}{V^2}$

there $V_G = 5.5 \times \frac{1.7}{5}$

$\Rightarrow \boxed{V_G = 1.87V}$

The gain we found has expression:

Gain $= -g_m V_{GS} (R_D \| R_L)$

And $I_{ds} = \frac{V_s}{R}$; $I_{ds} = \frac{\beta}{2}(\underbrace{V_{GS}}_{\underbrace{V_G - V_S}_{1.87}} - \underset{0.7}{V_T})^2$

$\Rightarrow \frac{V_s}{0.8\times10^3} = \frac{5\times10^{-2}}{2}(1.17 - V_s)^2$

On solving quadratic we get $V_s = 0.9518$ (or) 1.438

but MOS is in saturation so $\boxed{V_s = 0.9518V}$

Then $g_m = \beta(V_{GS} - V_T)$

$= 500\times10^{-6} \times 100 (1.17 - 0.95)$

$= 1.1\times10^{-2}$

Gain: $-g_m V_{GS} \cdot 1K = -10.12$

So the gain increases from 9.5 to 10.12

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1) e) Now V_T Changed from 0.7V to 0.8V

Then we have $V_G = 5 \times \frac{1.7}{5} = 1.7V$

$V_s = I_{ds}(0.8k)$

And $I_{ds} = \beta (V_{GS} - V_T)$

$\Rightarrow \frac{V_s}{0.8k} = \frac{500 \times 10^{-6} \times 100}{2} (1.7 - V_s - 0.8)^2$

$\Rightarrow V_s = 20(0.9 - V_s)^2$

$\Rightarrow (20) V_s^2 - (20 \times 1.8 + 1) V_s + 20(0.9)^2 = 0$

$\Rightarrow V_s = 1.113 / 0.711$, but if $V_s = 1.113$, $V_{GS} - V_T < 0$

$\Rightarrow V_s = 0.71139$, $g_m = \beta(V_{GS} - V_T)$

Then $g_m = 0.945 \times 10^{-2}$

Then gain $= -g_m V_{GS} \times 1k$

$= -(0.945) \times 10^{-2} \times 0.9866 \times 10^{3}$

$= -9.3423$

Hence the |gain| has reduced from 9.58 to 9.34.

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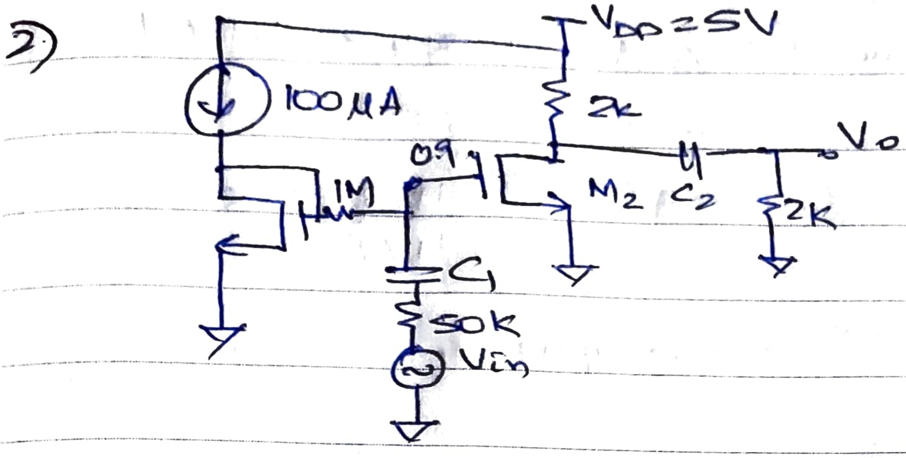
2)



$\mu_n C_{ox} = 500 \mu A V^{-2}$

$V_T = 0.7 V$

$M_2 : I_{ds} = 1 mA$

$\left(\frac{W}{L}\right)_{M_2} = 100$

$\omega_{min} = 100$ rad/s

a) For M_2, $I_{ds} = \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_T)^2$

$\Rightarrow 10^{-3} = 500 \times 10^{-6} \times \frac{100}{2} \times (V_{GS} - 0.7)^2$

$\Rightarrow \frac{1}{5} = V_{GS} - 0.7 \Rightarrow \boxed{V_{GS} = 0.9V}$

And $V_{DS} = 5 - 2K \times 1mA \Rightarrow \boxed{V_{DS} = 3V}$

Now coming M_1, we have $I_{ds} = 100 \mu A$

$\Rightarrow 100 \mu A = \frac{500 \mu}{2} \left(\frac{W}{L}\right)_{M_1} (0.9 - 0.7)^2$

$\Rightarrow \boxed{\left(\frac{W}{L}\right)_{M_1} = 10}$ $\quad V_{GS} = V_{DS} = 0.9 V$

b) For C_2, we can say from incremental picture

$R_{eff} = R_D \| R_L = \frac{2\times 2}{2+2} = 4K$

$\Rightarrow C_2 = \frac{10 \times 2\pi}{\omega_{min} R_{eff}} \Rightarrow \frac{10}{100 \times 4K} \Rightarrow \boxed{25 \mu F} \times 2\pi$

$\Rightarrow C_2 = 157.0796 \mu F$

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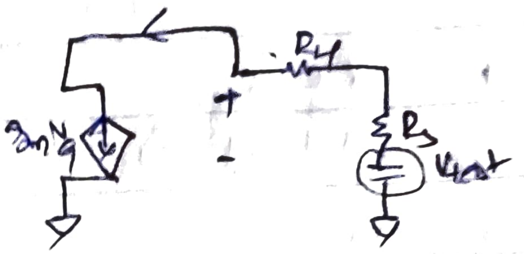
And for C_1,



$$I = \frac{g_m V_{in}}{1+g_m R_4}$$

$$\Rightarrow R_{eff} = \left(\frac{1}{g_m} + R_4\right) + R_s$$

For g_m, we have

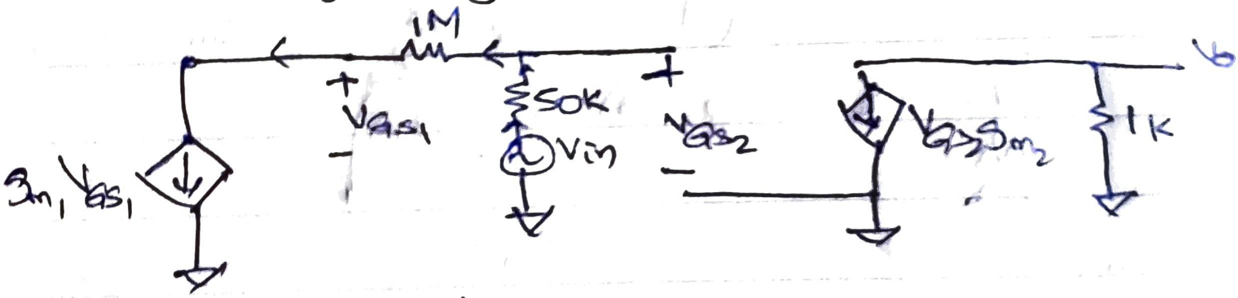
$$g_m = 500\times10^{-3}\times10\times(0.2) = 1m\,\Omega^{-1}$$

$$\Rightarrow R_{eff} = 1K + 50K + 1M \approx 1M$$

$$C_1 = \frac{10\times2\pi}{\omega_m R_{eff}} = \frac{10\times2\pi}{100\times10^{6}} = \boxed{0.1\mu F}\times2\pi$$

$$= 0.628nF$$

c) Small signal gain, the incremental picture is



For M_1 mosfet: $$\frac{V_{in} - V_{GS_1}}{1M + 50k} = g_{m_1} V_{GS_1}$$ $50k << 1M$

$$\Rightarrow V_{in} - V_{GS} = 1M\times g_{m_1} V_{GS_1}$$

$$\Rightarrow V_{GS} = \frac{V_{in}}{1+g_{m_1}(1M)}$$

$$\Rightarrow I = \frac{V_{in} - \frac{V_{in}}{1+g_{m_1}(1M)}}{1M} \quad \Rightarrow I = \frac{g_{m_1}}{1+g_{m_1}(1M)} V_{in}$$

For $V_{GS_2} = V_{in} - 50K\left(\frac{V_{in}\, g_{m_1}}{1+g_{m_1}1M}\right)$

$$= V_{in}\left(1 - \frac{50K\, g_{m_1}}{1+g_{m_1}(1M)}\right)$$

$$V_o = -V_{GS_2}\, g_{m_2}\, 1K$$

$$\Rightarrow \frac{V_o}{V_{in}} = -\left(1 - \frac{50K\, g_{m_1}}{1+g_{m_1}1M}\right) g_{m_2}(1K)$$

For a fair approximation $1+g_{m_1}(1M) \approx g_{m_1}(1M)$

$$\Rightarrow \frac{V_o}{V_{in}} \approx -\left(1 - \frac{50K\, \cancel{g_{m_1}}}{1M\, \cancel{g_{m_1}}}\right) g_{m_2}(1K)$$

$$\approx -\left(1 - \frac{50\times10^3}{10^6}\right) g_{m_2}(1K)$$

$$\Rightarrow \boxed{\frac{V_o}{V_{in}} \approx -(0.95)\, g_{m_2}(1K)}$$

$$g_{m_2} = \frac{2 I_{DS}}{(V_{GS}-V_T)} = \frac{2\times 1mA}{(0.9-0.7)} = \frac{2\times10^{-3}}{2\times10^{-1}} = 10^{-2}\,\mho$$

$$\Rightarrow \frac{V_o}{V_{in}} \approx -(0.95)\,10^{-2}(1K)$$

$$\frac{V_o}{V_{in}} \approx \boxed{-9.5}$$

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2) d) Now it is said V_{DD} : 5V → 5.5V

From the gain formula we brought we have

$$\frac{V_o}{V_{in}} = -\left(1 - \frac{50k\, g_{m_1}}{1+g_m \times 1M}\right) g_{m_2} (1k)$$

$$\approx -(0.95)\, g_{m_2} (1K)$$

And $g_{m_2} = \beta_2 (V_{G_2} - V_{S_2} - V_{T_2})$

$= \beta_2 (V_{G_2} - V_{T_2})$ $(\because V_{S_2} = 0)$

But in M_1 (current mode biased), the I_{ds} and β_1 are unchanged making $V_{GS_2} = V_{G_2}$ to remain same, and as current through 1M is 0A, the $V_{G_1} \approx V_{G_2}$. When V_{G_2} & V_{T_2} remain unchanged, $(I_{ds})_2$ and g_{m_2} a also remain same and so is the gain which is

$$\boxed{\frac{V_o}{V_{in}} \simeq -9.5}$$

When compared to (1), this is different as in (1), the V_G is being directly controlled by voltage driven source divider. But here the current is maintained by a current source and V_G can still remain the same.

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2) c) We have Gain : $-(0.95) g_{m_2} (1K)$

$g_{m_2} = \beta_2 (V_{G_2} - V_{S_2} - V_{T_2})$
$= \beta_2 (V_{G_2} - V_{T_2})$

Case (i): $V_{T_1} \Rightarrow$ 0.7V to 0.8V
V_{T_2} constant 0.7V

In M_1, I_{DS} is maintained to 100 μA, hence

$100\,\mu A = \frac{500 \times 10^{-6} \times 10^{-5}}{2} (V_{G_1} - V_{T_1})^2$

$\Rightarrow 0.2 = V_{G_1} - V_{T_1}$

$\Rightarrow V_{G_1} = 0.2 + V_{T_1} = 0.2 + 0.8$
$= 1V$

And as we saw $V_{G_1} = V_{G_2}$, we get

$g_{m_2} = 500 \times 10^{-6} \times 100 (1 - 0.7)$
$= 5 \times 10^{-2} \times 0.3 = 1.5 \times 10^{-3}$ ℧

Gain $= -10 \times 0.95 \times 1.5 \times 10^{-3} \times 1K$
$= -14.25$

The |Gain| increased from 9.5 to 14.25

Case (ii): $V_{T_1} \Rightarrow$ Const 0.7V ~~V_{T_2} Const~~
$V_{T_2} \Rightarrow$ 0.7V to 0.8V

We still have $V_{G_1} = V_{G_2} = 0.9V$

$\Rightarrow g_{m_2} = \beta_2 (V_{G_2} - V_{T_2})$
$= 5 \times 10^{-2} (0.9 - 0.8)$
$= 5 \times 10^{-2} \times 0.1$

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Gain $:-0.95 \times 5 \times 10^{-3} \times 10^{3} = -4.75$

The |Gain| has reduced from 9.5 to 4.75.

Case C(ii): $V_{T_1} \Rightarrow 0.7V$ to $8V$

$V_{T_2} \Rightarrow 0.7V$ to $8V$

Then from earlier analysis we get

$V_{G_2} = 0.9V + 0.1V \quad \Rightarrow (V_{GT})_2 = 0.2V$

$V_{T_2} = 0.7V + 0.1V$ as before

As $(V_{GT})_2$ remains same, so does g_{m_2}, so does the gain. then $\frac{V_o}{V_{in}} = -9.5$.

→ When Compared to problem (i) the control of source supply voltage has been removed, and swings in gain for small change in threshold voltages are scaling up more.

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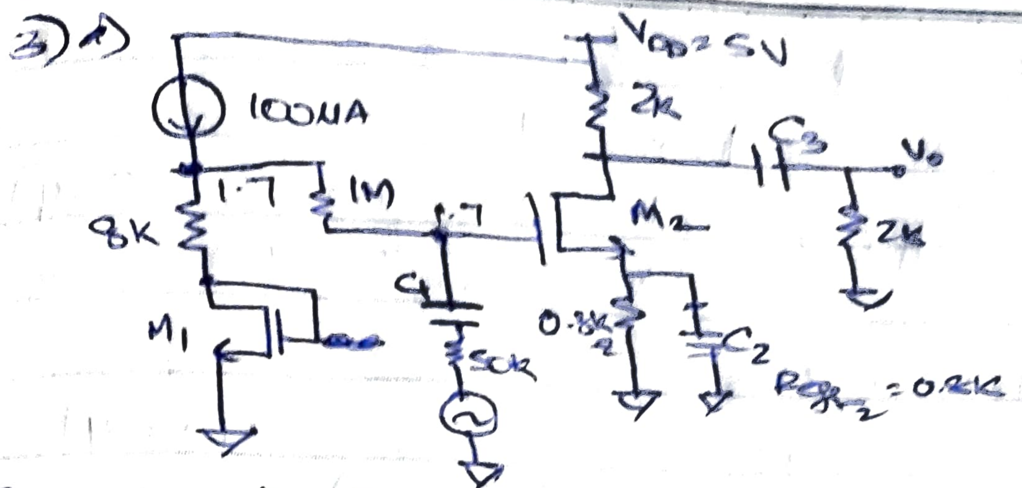
3) a)



$\mu_n C_{ox} = 500 \frac{\mu A}{V^2}$

$V_t = 0.7V$

$M_2 : I_{ds} = 1mA$

$\left(\frac{W}{L}\right)_{M_2} = 100$

$V_{SM_2} = 0.8k \times 1mA$
$= 0.8V$

For M_1, the I_{ds} current can't flow through $R_{High} = 1M$,

so $(V_{DS})_{M_1} = 1.7 - 100\mu \times 8K$
$= 1.7 - 0.8 = 0.9V$

$\boxed{(V_{GS})_{M_1} = (V_{DS})_{M_1} = 0.9V}$

And $100\mu A = \frac{500 \times 10^{-6}}{2} \times \left(\frac{W}{L}\right)_{M_1} \times ((0.9) - 0.7)^2$

$\Rightarrow \boxed{\left(\frac{W}{L}\right)_{M_1} = 10}$

And $((V_{GS})_{M_2} - 0.7)^2 = \frac{2 \times 10^{-3}}{500 \times 10^{-6} \times 100}$

$\Rightarrow (V_{GS})_{M_2} - 0.7 = 0.2$

$\Rightarrow \boxed{(V_{GS})_{M_2} = 0.9}$

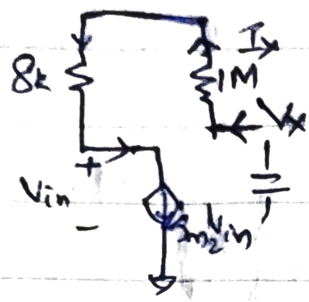
$V_D = 5 - 2K\,(1mA) = 3$

$\boxed{(V_{DS})_{M_2} = 2.2V}$

b) Now for ~~affi~~ effective caps, we can observe that C_3 and C_2 are unaffected by the current source at drain hence remain same.

$\Rightarrow C_2 = \cancel{\ldots} \frac{10 \times 2\pi}{100 \times 0.8 \times 1k} = 785\mu F \qquad C_3 = \cancel{\ldots}\ 157.0796\mu F$

For C_1, look into the R_{in} picture



$$\frac{V_x - V_{in}}{8k + 1M} = g_m V_{in}$$

$$\Rightarrow V_{in} = \frac{V_x}{1 + g_m(8k+1M)}$$

$$\Rightarrow I_x = \frac{g_m V_x}{1 + g_m(8k+1M)}$$

$$\Rightarrow R_x = \frac{1}{g_m} + 8k + 1M$$

$\therefore$ Eff. resistance : $R_3 = R_x + R_s$

$$= \frac{1}{g_m} + 8k + 1M + 50k$$

Here $g_{m_2} = \frac{500\times10^{-6}\times10}{1}(0.9-0.7) = 5\times10^{-3}\times0.2$

$$= 10^{-3}\ \mho$$

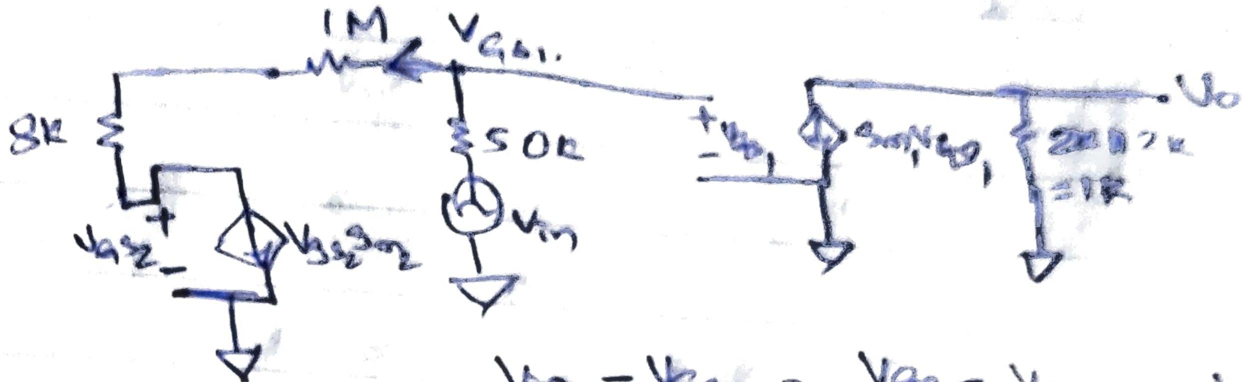
$\Rightarrow R_{eff_3} = 1k + 8k + 1M + 50k = 1M + 59k$

Though R_{eff_3} has increased, the $1M\Omega$ is still dominant and can nearly be approximated to it which results, even C_p to remain same

i.e $C_p = \frac{10\times2\pi}{\text{when } R_{eff_1}} \approx 0.1\mu F \times 2\pi =$

And $g_{m_1} = \frac{500\times10^{-6}\times100}{1}(0.9-0.7)^2 = 10^{-2}\ \mho$

2) c) Incremental Picture :



$$\frac{V_{in} - V_{GS_1}}{50K} = \frac{V_{GS_1} - V_{GS_2}}{1M + 8K} = V_{GS_2} g_{m_2}$$

$\Rightarrow V_{GS_1} = V_{GS_2}\left(1 + g_{m_2}(1M + 8K)\right) \Rightarrow V_{GS_2} = \dfrac{V_{GS_1}}{1 + g_{m_2}(1M+8K)}$

$$\Rightarrow \frac{V_{in} - V_{GS_1}}{50K} = \frac{g_{m_2} V_{GS_1}}{1 + g_{m_2}(1M + 8K)}$$

$$\Rightarrow V_{in} = V_{GS_1}\left(1 + \frac{g_{m_2} 50K}{1 + g_{m_2}(1M + 8K)}\right)$$

$$\Rightarrow V_{GS_1} = \frac{V_{in}}{1 + \dfrac{g_{m_2} 50K}{1 + g_{m_2}(1M + 8K)}}$$

$$V_o = -(1K) g_{m_1} V_{GS_1}$$

$$= -(1K) g_{m_1} \frac{V_{in}}{1 + \dfrac{g_{m_2}(50K)}{1 + g_{m_2}(1M + 8K)}}$$

$$\Rightarrow \frac{V_o}{V_{in}} = \frac{-(1K) g_{m_1}}{1 + \dfrac{g_{m_2}(50K)}{1 + g_{m_2}(1M + 8K)}}$$

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We have $g_{m_2} = 10^{-3}$ and $g_{m_1} = 10^{-2}$. Here we can see that $1 + g_{m_2}(1M+8k) \approx g_{m_2}(1M+8k)$

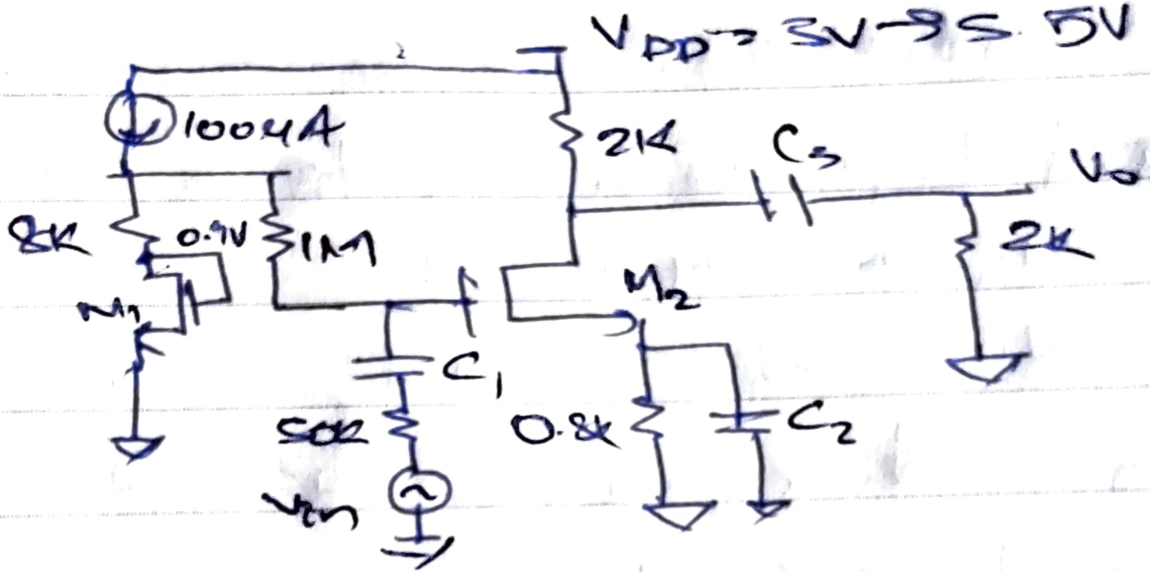
Then,

$$\frac{V_o}{V_{in}} = \frac{-(1K)\, g_{m_1}}{1 + \dfrac{g_{m_2}(500k)}{g_{m_2}(1M+8k)}}$$

$$= -\frac{(10k)(10^{-2})}{1M+8k+500k}(1M+8k) \approx \frac{(1M+8k)(100)}{1M+58k}$$

$$\approx -9.527$$

3) d)



Gain ≈

$$-\frac{(1M+8K)}{1M+58K} \times g_{m2} \times 1K$$

Now V_{DD} is changed from 5V to 5.5V

$\Rightarrow V_{S2} = 0.8K\, I_{ds2}$

$V_{G2} = V_{G1} + 8K \times 100\mu A$

$= 0.9V + 0.8V = 1.7V$

Continue:

3) d) Gain : $-\dfrac{(1M \parallel 8k)}{(1M + 58k)} \times 1k \times \boxed{g_{m_2}}$ → deciding factor

$$g_{m_2} = \beta_2 (V_{GS_2} - V_{T_2}) = \beta_2 (V_{G_2} - V_{S_2} - V_{T_2})$$

Change in gain: $\Delta g_{m_2} = \beta_2 (\Delta V_{G_2} - \Delta V_{S_2})$

$$I_{ds} = \frac{\beta}{2} (V_{G_2} - V_{S_2} - V_{T_2})^2 = \frac{V_{S_2}}{0.8k}$$

$$\Rightarrow \frac{\Delta V_{S_2}}{0.8k} = \frac{\beta}{2} (2) (V_{G_2} - V_{S_2} - V_{T_2}) (\Delta V_{G} - \Delta V_{S_2})$$

But as we saw earlier $\Delta V_{G_2} = 0$ because the current biased MOS maintains the voltage.

$$\Rightarrow \Delta V_{S_2} \left[\frac{1}{0.8k} + \beta (V_{G_2} - V_{S_2} - V_{T_2}) \right] = 0$$

$$\rightarrow \Delta V_{S_2} = 0 \Rightarrow \Delta Gain = 0$$

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Hence gain is same -9.527. This case is very similar to the case (2) problem. Though here there is a resistance 8k on top of M_1, the V_G relative increased from Case (2) but remains constant. And for M_2, the resistance added at source though has dependence on I_{DS}, for V_s, the change in V_s is again driven by change in V_G. So in effect, the new resistance doesn't change the control for V_{DD} on gain.

3) e) Small signal gain:

a) V_{TN_1}: $0.7 \to 0.8V$ and $V_{T,N_2}: 0.7V$

$\therefore$ $I_{ds} = 100\mu A$, then

$\Rightarrow I_{ds_1} = \frac{B_1}{2}(V_{GS_1} - V_{T_1})^2 \Rightarrow 100\mu A = \frac{500\times10^{-6}\times10}{2}(V_{GS_1}-V_{T_1})^2$

$\Rightarrow V_{GS_1} - V_{T_1} = \frac{1}{5} \Rightarrow V_{GS_1} = 0.8 + 0.2 = 1V$

Then $V_{G_2} = V_{GS_1} + 8k\Omega(100\mu A)$

$= 1V + 8\times10^3\times10^{-4} \approx 1.8V$

$V_{S_2} = I_{ds_2}(0.8k)$

$\Rightarrow I_{ds_2} = \frac{B_2}{2}(V_{GS_2} - V_{T_2})^2$

$\Rightarrow \frac{V_{S2}}{0.8k} = \frac{500\times10^{-6}\times100}{2}(V_{G_2} - V_{S_2} - V_{T_2})^2$

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$\Rightarrow V_{S_2} = \frac{0.8 \times 5 \times 10^{2} \times 10^{-6}}{2} (1.8V - 1V_{S_2} - 0.7)^2$

$\Rightarrow V_{S_2} = 20(1.1 - V_{S_2})^2 \rightarrow 20V_{S_2}^2 - (2(20)(1.1)+1)V_2 + 20(1.1)^2 = 0$

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$\Rightarrow V_{S_2} = 1.3608 \text{ or } \boxed{0.8891}$ For saturation purpose.

Then $g_{m_2} = \beta(V_{GS_2} - V_{T_2})$

$= 500 \times 10^{-6} \times 100 (1.8 - 0.8891 - 0.7)$

$= 5 \times 10^{-2} \times 0.210 = 1.054 \times 10^{-2}$

Gain : $-\frac{(1M + 8K)}{(1M + 58K)} \times 1.054 \times 10^{-2} \times 1K = -10.043$

∴ The gain has increased from 9.521 to 10.0418 on increasing V_T of M_1.

3) e) b) $V_{T_1} : 0.7V \quad V_{T_2} : 0.8V$

Now again $V_{GS_1} - V_{T_1} = 0.2 \Rightarrow V_{GS} = 0.9V$

$\Rightarrow V_{G_2} = V_{GS_1} + 0.8V = 1.7V$

$V_{S_2} = I_{ds_2}(0.8k)$

$\Rightarrow I_{ds_2} = \frac{\beta_2}{2}(V_{GS_2} - 0.8)^2$

$\Rightarrow V_{S_2} = \frac{20}{\cancel{0.8K \times 500 \times 10^{-2} \times 100}}(\underbrace{1.7 - V_{S_2} - 0.8}_{0.9})^2$

$\Rightarrow V_{S_2} = 20(0.9 - V_{S_2})^2$

$\Rightarrow V_{S_2} = 20(0.9 - V_{S_2})^2$

$\Rightarrow 20(V_{S_2})^2 - \underbrace{(2(20)(0.9)+1)}_{37} V_{S_2} + 20(\underset{0.81}{0.9})^2 = 0$

16.2

$\Rightarrow V_{S_2} = 1.1386$ (or) $\boxed{0.711}$

↳ saturation purpose

$g_{m_2} = 500 \times 10^{-6} \times 100 \times (0.9 - 0.711)$

$= 0.945 \times 10^{-2}$

Gain: $-\left(\frac{1M + 3K}{1M + 58K}\right) g_{m_2}(1k)$

$= -9.0034$

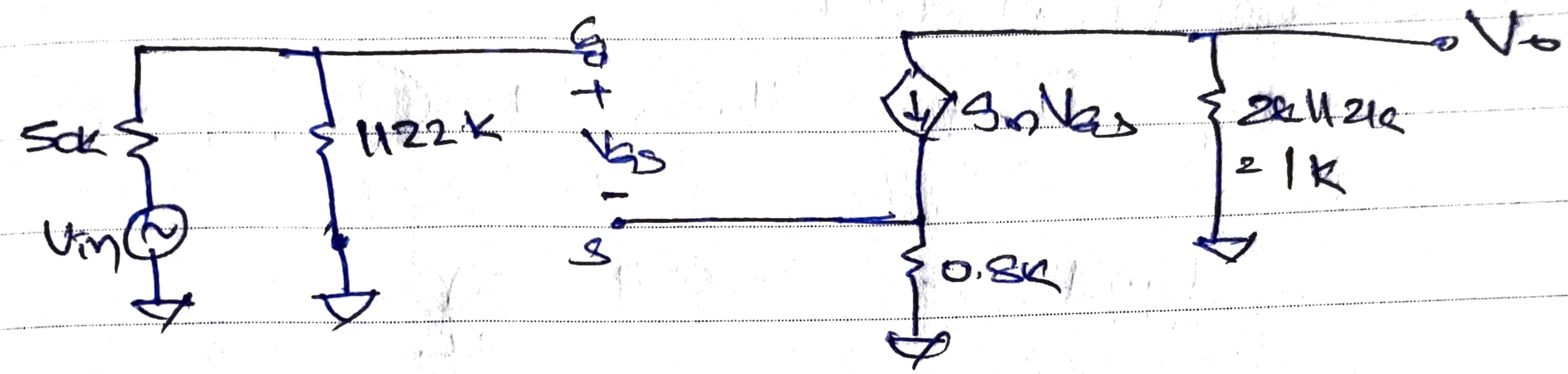
The gain has reduced from 9.52 to 9.0034.

3) c) c) $V_{T_1}: 0.7 \rightarrow 0.8$ $\quad V_{T_2}: 0.7 \rightarrow 0.8$

Then $V_{GS_2} - V_{T_2} \Rightarrow$ will have no difference as V_{T_1} changes V_{G_2} to move from 0.9 to 1V and V_{T_2} change from 0.7 to 0.8 making the effective difference 0.

→ In totality (2) & (3) are almost same, the gate voltage being operated is changed, rest remain the same including comparision from (1) case.

4) Small signal gain, incremental picture is



$$g_m = \frac{\mu_n C_{ox} W}{L} (V_{GS} - V_T)^2 = 500 \times 10^{-6} \times 100 \times 0.2$$

$$= 1 \times 10^{-2}$$

And $V_G = \frac{1122K}{1172K} V_{in}$ and $V_S = 0.8K \times g_m V_{GS}$

$$= 0.8K \times 10^{-2} \times V_{GS}$$

$$V_S = 8 V_{GS}$$

$$\Rightarrow V_{GS} = \frac{1122}{1172} V_{in} - 8 V_{GS} \Rightarrow V_{GS} = \frac{1122}{1172} \times \frac{V_{in}}{9}$$

$$\Rightarrow V_o = -g_m V_{GS} (1k) = -10^{-2} \times \frac{1122}{1172} \times \frac{V_{in}}{9} \times 10^3$$

$$\Rightarrow \frac{V_o}{V_{in}} = -\frac{11220}{1172 \times 9} = -1.063$$