Homework 12

Note many problems are design problems and have ∞ solutions, the solution here is one example and I have given reasoning for each decision.

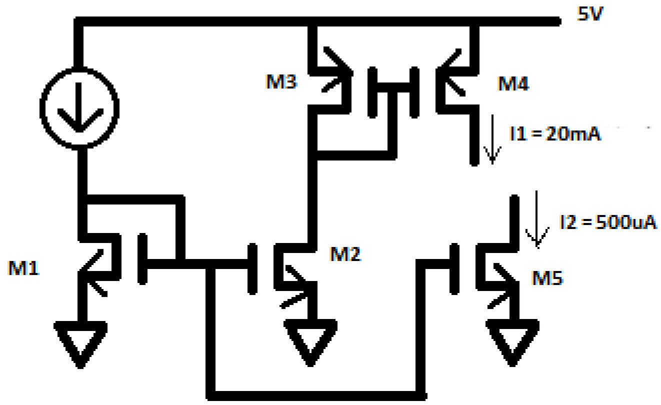
Problem 1)

$$I_{out} = \frac{\frac{40}{2}}{\frac{20}{2}} * \frac{\frac{20}{4}}{\frac{5}{1}} * 50\mu A$$

$I_{out} = 100\mu A$

Problem 2)

One design option is this,



a)

With this we have to choose the sizes of M_1 and M_5 to determine the 500μA sinking current and M_1, M_2, M_3, and M_4 to create the 20mA sourcing current

As we can choose whatever sizes we want, I am going to use $W_1 = L_1 = 1\mu$, so $\frac{W_1}{L_1}$ = 1.

From there I can set M_5, I want $\frac{W_5}{L_5} = \frac{500\mu A}{10mA} = 0.05.$

So I will use $W_5 = 1\mu$ and $L_5 = 20\mu$.

We then want to convert 10mA to 20mA, or times 2.This can be easily done in a single mirror, so I will use,

$M_2 = L_2 = 1\mu$

$M_3 = L_3 = 1\mu$

Then I just need $M_4/L_4 = 2$, so $M_4 = 2\mu, L_4 = 1\mu$

b)

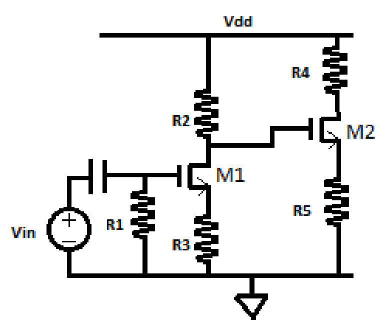
$$I_1 = \frac{\mu_p C_{ox} W_4}{2L_4}(|V_{GS}| - |V_T|)^2 = 20mA$$

$$\frac{33 * 10^{-6} * 2}{2 * 1}(|V_{GS}| - |V_T|)^2 = 20mA$$

$$|V_{GS}| - |V_T| = \sqrt{\frac{2 * 1 * 20mA}{33 * 10^{-6} * 2}} = 24.62V$$

Problem 3)

This design problem has a few parts that make it a bit difficult. First it needs an input impedance of 100k-200kΩ. This seems easy enough, but our basic amplifier structures have ∞ except for the Common Gate design. I am not going to use that design because of a problem with getting the proper R_{in}, so instead I will use two CSwRS amplifiers and an extra resister, because determining the gain of CSwRS amplifiers is the easiest.



The gain of this is fairly easy to calculate, as the second stage is $A_{V2} = -\frac{R_4}{R_5}$ and the first stage is

$$A_{V1} = -\frac{(R_2||R_{in2})}{R_3}, and\ R_{in2} = \infty \rightarrow A_{V1} = -\frac{R_2}{R_3}$$

$$A_V = A_{V1} * A_{V2} = \frac{R_2R_4}{R_3R_5}$$

We can set,

$R_2 = 5k\Omega$

$R_3 = 1k\Omega$

$R_4 = 2k\Omega$

$R_5 = 1k\Omega$

$$A_V = \frac{5 * 2}{1 * 1} = 10$$

Finally we need to create the proper input impedance. The amplifier structure has an $R_{in1} = \infty$, but it is in parallel with R_1

$R_{in} = R_{in1}||R_1 = R_1$ so we set R_1 between 100K and 200K,

$R_1 = 150k\Omega$

Problem 4)

$$M = \frac{W_2 + 2\Delta w}{W_1 + 2\Delta w} * \frac{L_1}{L_2}$$

$$M = \frac{10 - 0.2}{2 - 0.2} * \frac{4}{4}$$

$$M = 5.44$$

Problem 5)

a)

$$V_{01} = I_3 R_2 = \frac{A_3}{A_2}\beta I_1 R_2$$

$$V_{01} = \left(\frac{V_{DD} - 0.6}{R_1}\right)\beta \frac{A_3}{A_2} * R_2$$

$$V_{02} = I_6 R_3 = \frac{\frac{W_6}{L_6}}{\frac{W_5}{L_5}} * \frac{A_4}{A_1} * \beta I_1 R_3$$

$$V_{02} = \left(\frac{V_{DD} - 0.6}{R_1}\right)\beta * \frac{A_4}{A_1} * \frac{W_6 L_5}{W_5 L_6} R_3$$

b)

$$\left(\frac{10 - 0.6}{60k}\right) * 100 * \frac{25}{100} * R_2 = 3V$$

$$R_2 = 255.3\Omega$$

$$\left(\frac{10 - 0.6}{60k}\right) * 100 * \frac{300}{100} * \frac{16 * 1}{10 * 4} * R_3 = 6V$$

$$R_3 = 319.1\Omega$$

Problem 6)

a)

$$A_{VCC} = -\frac{g_{m1}}{g_{01}}$$

b)

$$A_{VCC} = -\frac{1}{2}\left(\frac{g_{m1}}{g_{01}} * \frac{g_{m2}}{g_{02}}\right)$$

c)

$$A_{VCC} = -\left[\frac{g_{m1}}{g_{01}} * \frac{g_{m2}}{g_{02}}\right]$$

Problem 7

A)

$$A_{V3} = \frac{g_{m5}}{-g_{05} + g_{m6} + g_{06}} \approx -\frac{g_{m5}}{g_{m6}}$$

$$A_{V2} = -\frac{g_{m4}}{g_{m3}} \quad ; \quad A_{V1} = -\frac{g_{m1}}{g_{m2}}$$

$$A_V = A_{V1} A_{V2} A_{V3} = -\frac{g_{m1} g_{m4} g_{m5}}{g_{m2} g_{m3} g_{m6}}$$

B)

$$I_{m1} = I_{m4} = I_{m5} = 500\mu A$$

$$g_m = \frac{2I_{CQ}}{V_{GSQ} - V_T}$$

$$V_{GS2} = V_{TP} + \sqrt{\frac{I_{M1}}{\mu C_{OX}\left(\frac{W_2}{2L_2}\right)}} = 2.5V$$

$$V_{GS3} = V_{TP} + \sqrt{\frac{I_{M4}}{\mu C_{OX}\left(\frac{W_3}{2L_3}\right)}} = 2.5V$$

$$V_{GS6} = V_{TP} + \sqrt{\frac{I_{M5}}{\mu C_{OX}\left(\frac{W_6}{2L_6}\right)}} = 4V$$

$$g_{m1} = \frac{2 * 500\mu}{5 - 0.5} = \frac{1000}{4.5}\frac{\mu A}{V}$$

$$g_{m2} = g_{m3} = g_{m4} = g_{m5} = \frac{2 * 500\mu}{2.5 - 0,.5} = \frac{500\mu A}{V}$$

$$g_{m6} = \frac{2 * 500\mu}{4 - 0.5} = \frac{1000}{3.5}\frac{\mu A}{V}$$

$$A_V = -\frac{g_{m1}}{g_{m2}}\frac{g_{m4}}{g_{m3}}\frac{g_{m5}}{g_{m6}} = -\frac{g_{m1}}{g_{m6}}$$

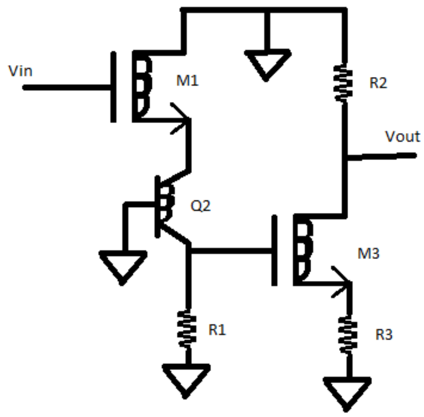
$$A_V = -\frac{3.5}{4.5} = -0.777$$

Problem 8)

$$\frac{V_{out}}{V_A} = -\frac{R_2}{R_3}$$

$$\frac{V_A}{V_{in}} = g_{m2}R_1\left(\frac{g_{m1}}{g_{m1}g_{m2}}\right)$$

$$A_V = \frac{V_{out}}{V_{in}} = \frac{V_{out}}{V_A} * \frac{V_A}{V_{in}} = -\frac{R_2}{R_3}g_{m2}R_1 * \left(\frac{g_{m1}}{g_{m1}+g_{m2}}\right)$$



Problem 9)

$$A_V = -\frac{R_2}{R_3}g_{m2}R_1 * \left(\frac{g_{m1}}{g_{m1}+g_{m2}}\right)$$

$$g_{m1} = \frac{2I_{CQ1}}{V_{GS1}-V_{TN}} \quad ; \quad I_{CQ1} = 200\mu + I_{CQ2}$$

$$I_{CQ2} = J_S A_{E_2}\exp\left(\frac{V_{BE}}{V_t}\right) = 10^{-14} * 100 * \exp\left(\frac{0.6}{0.0259}\right) = 0.0115A$$

$$I_{CQ1} = 200\mu + 11.5m = 11.7mA$$

$$g_{m2} = \frac{I_{CQ2}}{V_t} = \frac{0.0115}{0.0259} = \frac{0.444A}{V}$$

$$g_{m1} = \frac{2(0.0117)}{(V_{GS1}-V_{TN})} = \sqrt{2\mu_n C_{ox}\left(\frac{W_1}{L_1}\right)I_{CQ1}} = 3.06 * 10^{-3}$$

$$A_V = -\frac{25000}{12500} * 0.444 * 8000 * \frac{3.06 * 10^{-3}}{3.06 * 10^{-3} + 0.444}$$

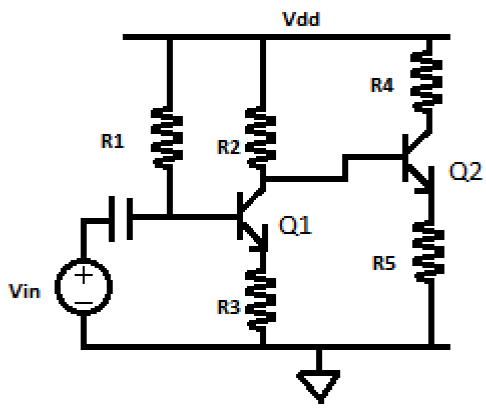
$A_V = -48.6$

Problem 10)

$$A_V = (-g_{m1}R_1) * g_{m3}\left(\frac{1}{g_{m2}}||R_{in4}\right) * \left(-\frac{R_3||R_6}{R_2}\right) \;\; ; \;\; R_{in4} = r_{\pi 4} + \beta R_2$$

Problem 11)

For this problem we have BJTs to create a gain of 40 and input impedance greater than 200k. The load is 1k. The easiest amplifier to create is the CEwRE (Common Emitter with Emitter Resistor), but has the problem of creating a negative gain. So we need two stages of negative gain.



We have to work backwards for this circuit because the input impedance of Q2 (R_{in2}) will affect the gain of Q1. First I will set $V_{dd} = 5V$

R_4 is already determined, as it is the load resistor, $R_4 = 1k\Omega$

We want a total gain of 40, and the gain of the above is $-\frac{R_C}{R_E} = -\frac{R_4}{R_5}$. Therefore if we use $R_5 = 500\Omega$ we get a gain of $A_{V2} = -\frac{1000}{500} = -2$ and need a gain of -20 in the first stage.

The first stage has a gain of $-\dfrac{(R_2||R_{in2})}{R_3}$. $R_{in2} = \beta\left(\dfrac{V_t}{I_{CQ2}} + R_E\right) = 100\left(\dfrac{0.0259}{I_{CQ2}} + 500\Omega\right)$.

$I_{CQ} = \beta I_{B2}, I_{B2} = \dfrac{5V - 0.6 - V_{R5}}{R_2} = \dfrac{V_{R5}}{500}$. We want this small so that the resistance is large.

I am going to set $R_2 = 500k\Omega$. This sets $V_{R5} = 4.39mV$ and $I_B = 8.79\mu A$. $I_C = 100(i_B) = 879\mu A$

$$R_{in2} = 100 * \left(\frac{0.0259}{0.000879} + 500\right) = 52.9k\Omega$$

$R_2||R_{in2} = 47.9k\Omega$, so we want $R_3 = \dfrac{47.9k}{20} 2395\Omega$

$$A_{V1} = -\frac{47900}{1595} \approx -20$$

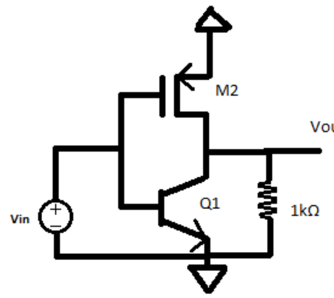
$$A_V = A_{V1} * A_{V2} = -30 * -2 \rightarrow A_V = 40\frac{V}{V}$$

The input impedance of the system is $100 * \left(\frac{0.0259}{I_{CQ1}} + 957\right)$. $I_{CQ1} = \beta I_{B1}$, we want this really small try

$R_1 = 7M\Omega \rightarrow I_{B1} = 0.628\mu A \rightarrow I_{C1} = 62.8\mu A \rightarrow R_{in1} = 200.7k\Omega$

Problem 12) A)

SS equivalent circuit:



$$A_V = -(g_{m1} + g_{m2}) * \left(1k \left|\left|\frac{1}{g_{01}}\right|\right| \frac{1}{g_{02}}\right)$$

$$I_{DQ} = I_{CQ} = J_s A_E \exp\left(\frac{V_{BE}}{V_t}\right) = 10.5mA$$

$$g_{m2} = \frac{2I_{CQ}}{V_{GS} - V_T} = \frac{2 * 0.0105}{5V - 0.5V} = \frac{0.021}{4.5} = 0.0046667$$

$$g_{m1} = \frac{I_{CQ}}{V_t} = \frac{0.0105}{0.0259} = 0.4054$$

$$g_{01} = \frac{I_{CQ}}{V_{AF}} = \frac{0.0105}{100} = 0.000105$$

$$g_{02} = \lambda I_{DQ} = 0.01 * 0.0105 = 0.000105$$

$$\frac{1}{g_{02}} = \frac{1}{g_{01}} = \frac{1}{0.000105} = 9523.8$$

$$A_V = -(0.4054 + 0.00467) * \left(\frac{1}{\frac{1}{1000} + \frac{1}{9523} + \frac{1}{9523}}\right)$$

$$A_V = -338.9\frac{V}{V}$$

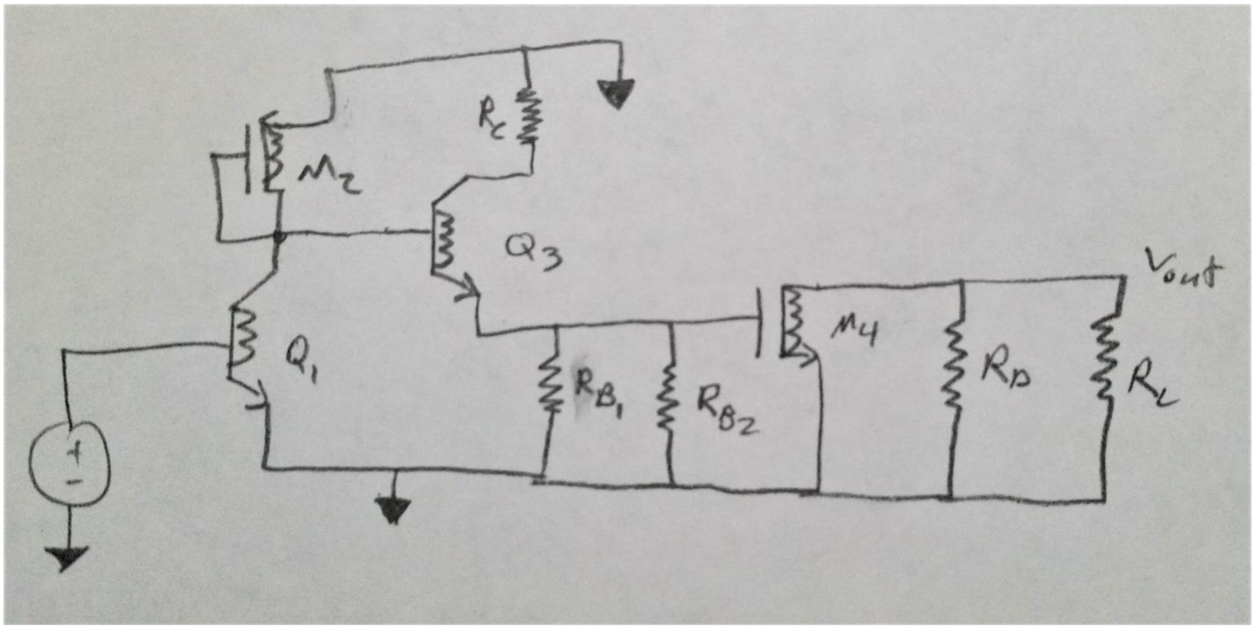
B)

$V_{out} = A_V V_{in}$

$V_{out} = 3.38 \sin(1000t)$

Problem 13

a)



b)

$$A_v = -g_{m1}\left(\frac{1}{g_{m2}}||R_{in3}\right) * g_{m3}\left(\frac{R_c}{R_{B1}||R_{B2}}\right) * -g_{m4}(R_D||R_L)$$