NOTES:

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

SOLUTION:

Problem 1:

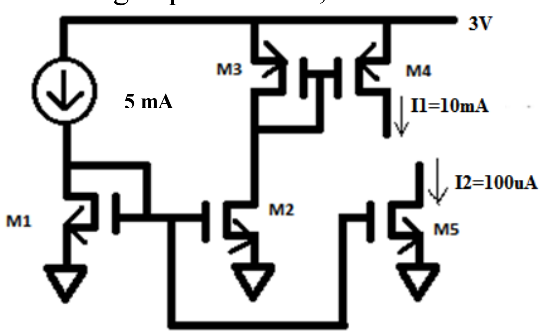
This is two current mirrors =

$$I_{out} = \frac{(W2/L2)}{(W1/L1)} * \frac{(W4/L4)}{(W3/L3)} * I_{in} = \frac{(4/1)}{(5/1)} * \frac{(5/1)}{(20/2)} 250\mu A = \frac{4}{5} * \frac{1}{2} * 250\mu$$

$I_{out} = 100\mu A$

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 100μA sinking current and M_1, M_2, M_3, and M_4 to create the 10mA sourcing current

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 $\frac{W_5}{L_5} = \frac{100\mu A}{5mA} = 0.02$.

So I will use $W_5 = 1\mu$ and $L_5 = 50\mu$.

We then want to convert 5 mA to 1 mA, or times 1/5 . So I will use:

$W_2 = L_2 = 1\mu, \quad W_3 = 20\ \mu, L_3 = 1\mu, \quad W_4 = 4\ \mu, L_4 = 1\mu$

b) $I_1 = \frac{\mu_p C_{ox} W_4}{2L_4}(|V_{GS}| - |V_T|)^2 = 1\ mA$

$$\frac{70 * 10^{-6} * 4}{2 * 1}(|V_{GS}| - |V_T|)^2 = 1\ mA$$

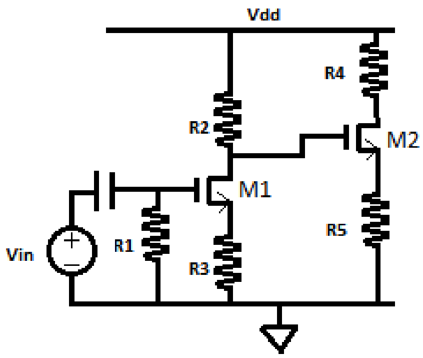
$$|V_{GS}| - |V_T| = \sqrt{\frac{2 * 1 * 1mA}{70 * 10^{-6} * 2}} = 2.67\ V$$

$|V_{DS}| > |V_{GS}| - |V_T| \rightarrow V_{drainMax} = V_{DD} - (|V_{GS}| - |V_T|) = 0.327\ V$ to ensure saturation.

This answer is very design dependent, it could also be negative.

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

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

$$A_V = A_{V1} * A_{V2} = \frac{R_2 R_4}{R_3 R_5}$$

We can set,

$R_2 = 5k\Omega$

$R_3 = 2k\Omega$

$R_4 = R_L = 2k\Omega$

$R_5 = 1k\Omega$

$$A_V = \frac{5 * 2}{2 * 1} = 5\ V/V$$

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 to any value between 100K and 200K,

$R_1 = 150k\Omega$

Problem 4:

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

$$M = \frac{10 - 0.5}{2 - 0.5} * \frac{4}{4}$$

$$A_I = 6.33\ A/A$$

Problem 5:

a) $V_{01} = I_3 R_2 = \frac{A_3}{A_2} \beta I_{BQ1} R_2$

$$V_{01} = \frac{A_3}{A_2} * \beta * \left(\frac{V_{DD} - 0.6}{R_1}\right) * \left(\frac{A_1}{A_1 + A_4}\right) * R_2$$

$$V_{02} = I_6 R_3 = \frac{\frac{W_6}{L_6}}{\frac{W_5}{L_5}} * I_{Q4} * R_3$$

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

b)

$$\frac{50}{100} * 100 * \left(\frac{10 - 0.6}{80k}\right) * \frac{100}{100 + 300} * R_2 = 6V$$

$$R_2 = 4.085\ k\Omega$$

$$\frac{16 * 1}{10 * 4} * 100 * \left(\frac{10 - 0.6}{80k}\right) * \frac{300}{100 + 300} * R_3 = 3V$$

$$R_3 = 851\ \Omega$$

Problem 6:

a) $A_{V3} = \frac{g_{m5}}{g_{m5} + g_{m6}}$

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

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

b) $I_{DS1} = I_{DS4} = I_{DS5} = 500\mu A$

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

$$|V_{GS1}| = 2V$$

$$|V_{GS2}| = 1V$$

$|V_{GS3}| = |1.3V - 2V| = 0.7\ V$

$V_{GS4} = 1V$
$V_{GS5} = 1.3V - 0.7V = 0.6\ V$
$V_{GS6} = 0.7V$

$$g_{m1} = \frac{2 * 500\mu}{2 - 0.5} = \frac{1000}{1.5}\frac{\mu A}{V} = 0.667\text{ m}$$
$$g_{m2} = \frac{2*500\mu}{1-0.5} = \frac{1000}{0.5}\frac{\mu A}{V} = 2\text{ m}$$

$$g_{m3} = \frac{2 * 1000\mu}{0.7 - 0.5} = \frac{2000}{0.5}\frac{\mu A}{V} = 10\text{ m}$$

$$g_{m4} = \frac{2 * 500\mu}{1 - 0.5} = \frac{1000}{0.5}\frac{\mu A}{V} = 2\text{ m}$$

$$g_{m5} = \frac{2 * 500\mu}{0.6 - 0.5} = \frac{1000\mu A}{0.1V} = 10\text{ m}$$
$$g_{m6} = \frac{2 * 500\mu}{0.7 - 0.5} = \frac{1000}{0.2}\frac{\mu A}{V} = 5\text{ m}$$
$$A_V = \frac{g_{m1}}{g_{m2}}\frac{g_{m4}}{g_{m3}}\frac{g_{m5}}{g_{m5} + g_{m6}} = \frac{0.667}{2}\frac{2}{10}\frac{10}{10 + 5}$$
$A_V = 0.044\ V/V$

Problem 7:

$$A_{V3} = -\frac{R_2}{R_3}$$
$$A_{V2} = g_{m2}R_1$$
$$A_{V1} = -g_{m1}R_L = -g_{m1}R_{in2} = -\frac{\text{gm}_1}{gm_2}$$
$$A_V = A_{V1}A_{V2}A_{V3}$$

$$A_V = \left(-\frac{\text{gm}_1}{gm_2}\right) * (g_{m2}R_1) * \left(-\frac{R_2}{R_3}\right)$$

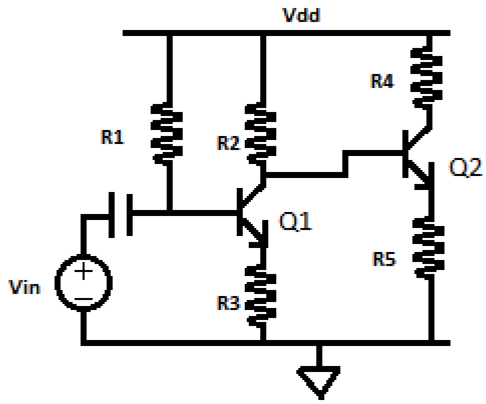
Problem 8:

$$A_{V3} = -\frac{(R_3||R_L)}{R_2}$$
$$R_{inQ4} = \beta\left(\frac{V_t}{I_{CQ\ Q_4}} + R_2\right)$$
$$A_{V2} = -g_{m3}R_C = -g_m\left(R_{in4}||\frac{1}{g_{m2}}\right)$$
$$A_{V1} = -g_{m1}R_C = -g_{m1}R_1$$
$$A_V = A_{V1}A_{V2}A_{V3}$$

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

Problem 9:

For this problem we have BJTs to create a gain of 60 and input impedance greater than 100k. The load is 5k. 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.

R_4 is already determined, as it is the load resistor, $R_4 = 5k\Omega$

We want a total gain of 60, 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 $A_{V2} = -\frac{5000}{500} = -10$ and need a gain of -6 in the first stage.

The first stage has gain $= -\frac{(R_2||R_{inQ2})}{R_3}, R_{inQ2} = \beta\left(\frac{V_t}{I_{CQ2}} + R_E\right) = 100\left(\frac{0.0259}{I_{CQ2}} + 500\Omega\right)$.

$I_{CQ} = \beta I_{B2}, I_{B2} = \frac{1.8V - 0.6 - V_{R5}}{R_2} = \frac{V_{R5}}{R_5 * \beta}$

I am going to set $R_2 = 5k\Omega$. This sets $V_{R5} = 1.09$ V and $I_B = 22$ μA. $I_C = 100(i_B) = 2.2$ mA

$R_{in2} = 100 * \left(\frac{0.0259}{0.0022} + 500\right) = 51.18\ k\Omega$

$R_2||R_{in2} = 4.55\ k\Omega$, so we want $R_3 = \frac{4.55\ k}{6} = 757.6\ \Omega$

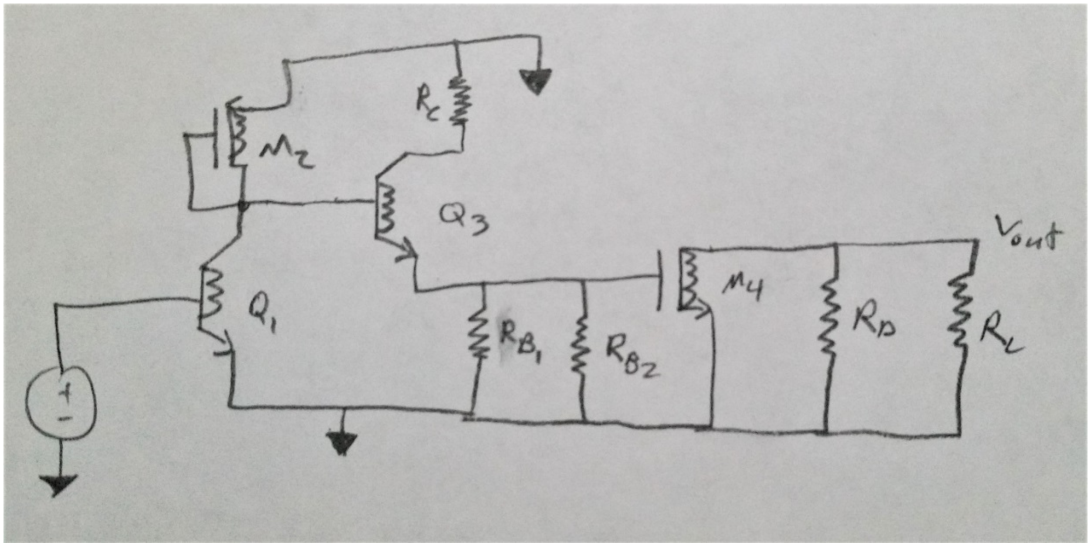
$A_{V1} = -\frac{4.55\ k}{757.6} \approx -6$

$A_V = A_{V1} * A_{V2} = -10 * -6 \rightarrow A_V = 60\frac{V}{V}$

The input impedance of the system is $R1\ ||(100 * \left(\frac{0.0259}{I_{CQ1}} + 757.6\right))$. $I_{CQ1} = \beta I_{B1}$, we want this really small try $R_1 = 200\ k\Omega \rightarrow I_{B1} = 4.35\ \mu A \rightarrow I_{C1} = 0.435\ mA \rightarrow R_{in1} = 58.12\ k\Omega$

Problem 10:

a)



b) $A_v = -g_{m1}(\frac{1}{g_{m2}}||R_{inQ3}) * -\left(\frac{R_C}{R_{B1}||R_{B2}}\right) * -g_{m4}(R_D||R_L)$