Problem 1. (25 points)

Answer the following questions for the circuit shown below. Assume that the value of C for all three capacitors is infinite. All transistors have $\beta = 100$ and possess an infinite Early voltage, $V_A$. Assume that $V_{BE}$ is 700 mV.

(a) Classify the amplifier. Circle one of the following: common-emitter, common-base, common-collector, common-emitter with emitter degeneration.

(b) Determine the DC collector current, $I_C$. You may assume infinite $\beta$ when computing the DC collector current.

$$I_C = \left(\frac{\beta}{\beta + 1}\right) I_E = I_E \quad \text{if} \quad \beta = \infty \Rightarrow I_C = 1 \text{mA}$$

(c) Determine the value of the transconductance, $g_m$.

$$g_m = \frac{I_C}{V_T} = 25 \text{mA} \cdot \frac{\text{mA}}{25 \text{mV}} = 1.38 \text{mS}$$

(d) Determine the value of $r_e$?

$$r_e = \frac{1}{g_m} = \frac{38.6 \text{mS}}{1.38 \text{mS}} = 28.6 \text{K}\Omega$$

(e) What is the small-signal mid-band gain, $A = \frac{V_o}{V_i}$?

$$A = -\frac{g_m R_C}{1 + g_m R_C} = -\frac{(38.6 \text{mS})(1.5K)(47K)}{1 + (38.6 \text{mS})(0.33K)}$$

$$= -\frac{56.1}{1 + 12.7} \approx -4.1$$
Problem 2. (20 points)

Answer the following questions for the circuit shown below. Assume the value of $C$ for both capacitors is infinite. The transistor has $\beta = 150$ and an Early voltage of 200 Volts. Assume $V_{BE}$ is 700 mV.

(a) Classify the amplifier as either common-emitter, common-emitter with emitter degeneration, or common-collector (a.k.a. emitter follower). Circle one!

(b) Determine the DC collector current, $I_C$. You may assume infinite $\beta$ for this calculation.

$$I_C = \frac{V_{TH} - V_{BE}}{R_3} = \frac{5V - 0.7V}{1K} = \sqrt{4.3mA}$$

(c) Determine the $r_0$ of the transistor.

$$r_0 = \frac{V_A}{I_C} = \frac{200V}{4.3mA} \approx \sqrt{46.5K\Omega}$$

(d) Determine the small signal input resistance, $R_{in}$ for the circuit.

$$R_{in} = r_T + (\beta + 1)R_C$$

$$R_{in} = 46.5K\Omega$$

$$R_{in} = \frac{403 + (151)(1220)}{4.3mA} \approx 145K\Omega$$

$$R_{in} = R_1 + (R_2 + R_3) = \sqrt{4.8K\Omega}$$
Problem 3. (20 points)

Answer the following questions for the circuit shown below. Assume infinite $\beta$ and Early Voltage, $V_A$, for all transistors. Also, assume that all transistors are in the active region and assume that the base-emitter voltage (for NPNs), $V_{BE}$, and emitter-base voltage (for PNP$s), $V_{EB}$, is 700 mV.

(a) Determine the DC voltage, $V_z$.

\[
1.7V
\]

(b) Determine the DC current flowing through resistor, $R_1$.

\[
\frac{5 - 0.7}{4.3k} = 1mA
\]

(c) Determine the DC voltage, $V_x$.

\[
5 - 0.7 = 4.3V
\]

(d) Determine the DC voltage, $V_y$.

\[
V_y = 1mA \cdot 1k = 1V
\]
Problem 4. (15 points)

For the circuit shown below assume the transistors are matched. Moreover, assume the $\beta$ of the transistors is infinite and the Early voltage is 125 V.

(a) What kind of current mirror is being used below? Circle one: simple current mirror, Widlar current mirror, cascode current mirror!

(b) Find the value of $R_1$ so that the voltage, $V_x$, is 6 V.

\[
I_0 = \frac{6V}{22k} = 0.272 mA
\]

\[
A_N = \frac{U_T \ln(I_D)}{I_D} = \frac{25.9 mV \ln(0.272)}{272 mA} = 277 \Omega
\]

(c) Determine the small-signal output resistance of the current mirror.

\[
R_0 = R_{01} \left[1 + g_m \left(\frac{R_{\text{in}}}{R_1}\right)\right]
\]

\[
g_m = \frac{I_c}{V_T} = \frac{0.272 mA}{25.9 mV} = 10.5 mV^2/A^2, \quad \frac{R_{\text{in}}}{g_m} = 8
\]

\[
R_{01} = \frac{V_T}{\beta} = \frac{125 V}{0.272 mA} = 460 k\Omega
\]

\[
R_0 = R_{01} \left[1 + \left(10.5 mV^2\right) \left(0.277 k\Omega\right)\right] = 108 M\Omega
\]

\[
\Rightarrow 460 k\Omega
\]
Problem 5. (10 points)

A diode-connected BJT has an emitter current of 1 mA.

(a) Compute the base-emitter voltage if $I_{ES}$ is 3 fA.

$$V_{BE} = V_T \ln \left( \frac{I_E}{I_{ES}} \right) = 25.9 \text{ mV} \cdot \ln \left( \frac{1 \text{ mA}}{3 \text{ fA}} \right)$$

$$V_{BE} = 687 \text{ mV}$$

(b) If the current is reduced to 0.3 mA, what is the new base-emitter voltage?

$$\Delta V_{BE} = V_T \ln \left( \frac{I_{E2}}{I_{E1}} \right)$$

$$\Delta V_{BE} = 25.9 \text{ mV} \cdot \ln \left( \frac{0.3}{1} \right) = -310.2 \text{ mV}$$

$$V_{BE2} = V_{BE1} + \Delta V_{BE} = 656 \text{ mV}$$
Problem 6.  (10 points) GRADUATE STUDENTS ONLY

For the circuit shown below, assume that all transistors have infinite $\beta$ and infinite Early Voltage, $V_A$. Moreover, assume that all transistors are matched. Note the current flowing in the collector of $Q_5$ is $I$.

(a) Please determine the current (in terms of the current, $I$) flowing in the collector of transistor, $Q_4$.

\[ I_4 = I/14 \]

(b) Please determine the voltage across the resistor, $R$. Give your answer in mV.

\[ V_{BE1} = V_{BE2} + V_R \]

\[ V_{BE1} - V_{BE2} = V_R \]

\[ \Delta V_{BE} = V_R \Rightarrow V_T \ln \left[ \frac{I/14}{I/14} \right] \]

\[ 2V_{BE} = V_T \ln \left[ 14 \right] = 25.9 \text{ mV} \cdot \ln(14) \]

\[ \approx 68.4 \text{ mV} \]

Note: \[ \frac{68.4 \text{ mV}}{300K} = 228 \text{ mV/}^\circ \text{C} \]