IMPORTANT: Besides your calculator and the sheets you use for calculations you are only allowed to have an A4 sized "copy sheet" during this exam. Notes, problems and alike are not permitted. Please submit your "copy sheet" along with your solutions. You may get your "copy sheet" back after your solutions have been graded. ***Do not forget to write down units and convert units carefully!***

ELE222E INTRODUCTION TO ELECTRONICS (20521)
Midterm Exam #2 ✎ 19 April 2010 ⏲ 11.30-13.30

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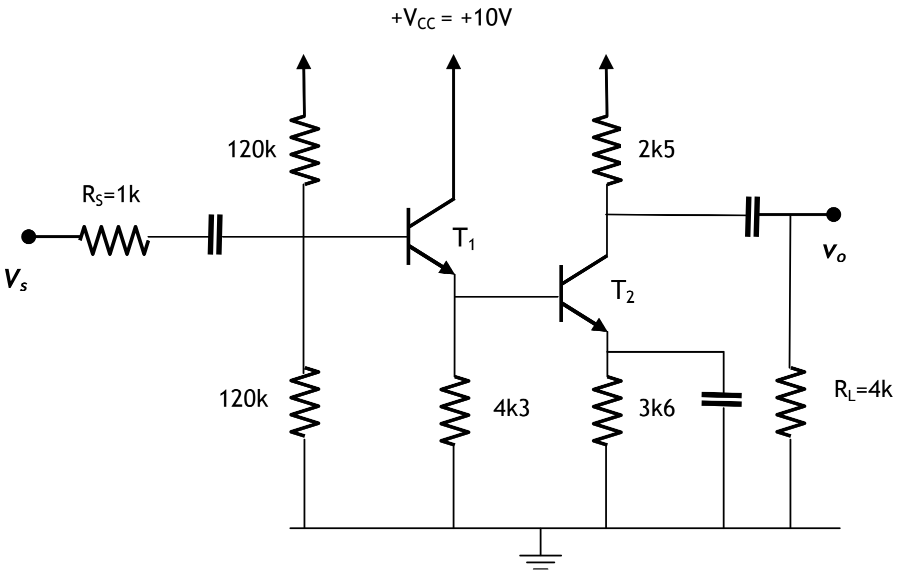
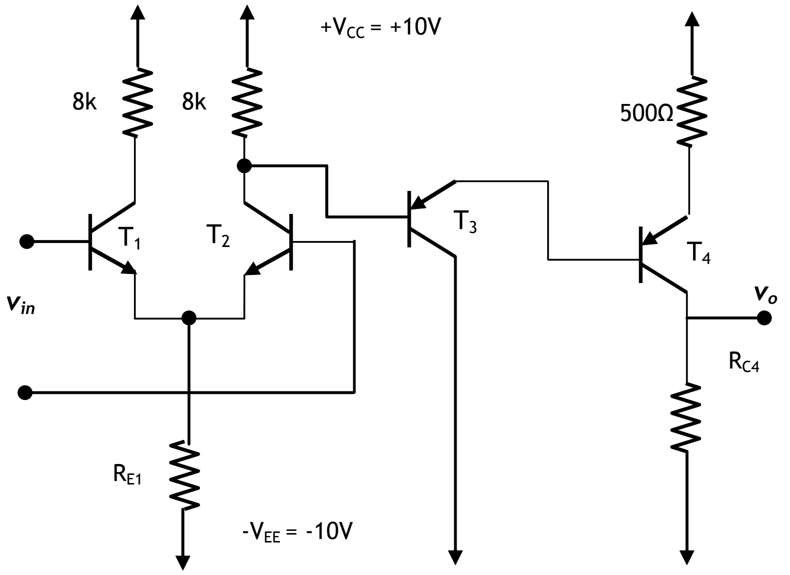
1. Assuming all capacitors are ideal, study the two stage circuit below for $ß = h_{FE} = h_{fe} = 150$, $h_{oe} = h_{re} = 0$, $V_T = 25$ mV, and $|V_{BE}| = 0{,}6$ V. Find collector currents, voltage gain $\mathbf{v_o/v_s}$, $\mathbf{r_i}$, and $\mathbf{r_o}$.



HINT: While calculating collector currents you will obtain 2 loop equations with 2 unknowns!

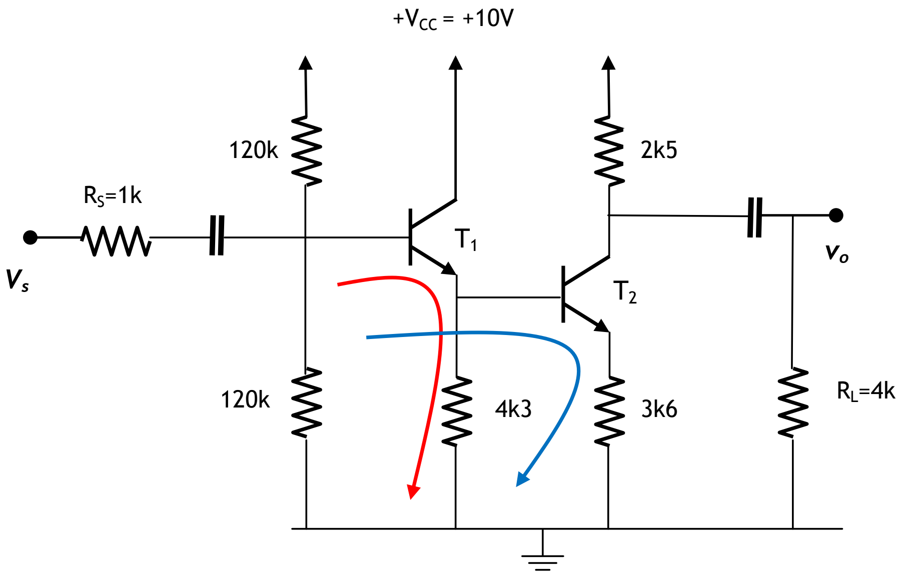
2. Now that you studied Problem 1, analyze the circuit below for $ß = h_{FE} = h_{fe} = 100$, $V_T = 25$ mV, $h_{oe} = h_{re} = 0$, and $|V_{BE}| = 0{,}6$ V. Find the value of R_{C4} such that, $I_{C1} = I_{C2} = 0{,}5$ mA, and the voltage swing at the output (V_o) is symmetric. If you design a current mirror that will provide the current to the first stage you may earn 10 bonus points.
Calculate voltage gain $\mathbf{v_o/v_{in}}$, $\mathbf{r_i}$, $\mathbf{r_o}$, and finally CMRR of the first stage. (60 points)



GOOD LUCK! 40+60 points total!

SOLUTIONS:

1. With ideal capacitors load and source resistors are isolated for biasing purposes. Thus using Thevenin Eq. circuit: R_{BB} = 60K, V_{BB} = 5V and



Red loop: $V_{BB} = R_{BB} I_{B1} + V_{BE1} + 4k3(I_{E1} - I_{B2})$

Blue loop: $V_{BB} = R_{BB} I_{B1} + V_{BE1} + V_{BE2} + 3k6 \cdot I_{E2}$

From blue loop:
$$V_{BB} = R_{BB} I_{B1} + 0{,}6V + 0{,}6V + 3k6(1+\beta) I_{B2}$$
$$\Rightarrow I_{B2} = \frac{V_{BB} - R_{BB} I_{B1} - 1{,}2V}{3k6(1+\beta)}$$

Insert I_{B2} into red loop:

$$V_{BB} = R_{BB} I_{B1} + 0{,}6V + 4k3 \cdot I_{E1} - 4k3 \cdot \frac{V_{BB} - R_{BB} I_{B1} - 1{,}2V}{3k6(1+\beta)}$$

$$\Rightarrow V_{BB} - 0{,}6V + 4k3 \cdot \frac{V_{BB} - 1{,}2V}{3k6(1+\beta)} = R_{BB} I_{B1} + 4k3 \cdot I_{E1} + 4k3 \frac{R_{BB} I_{B1}}{3k6(1+\beta)}$$

$$\Rightarrow I_{B1} = \frac{V_{BB} - 0{,}6V + 4k3 \cdot \frac{V_{BB} - 1{,}2V}{3k6(1+\beta)}}{R_{BB} + 4k3(1+\beta) + 4k3 \frac{R_{BB}}{3k6(1+\beta)}} = \frac{5V - 0{,}6V + 4k3 \cdot \frac{5V - 1{,}2V}{3k6(1+150)}}{60k + 4k3(1+\beta) + 4k3 \frac{60k}{3k6(1+150)}} = 7{,}33\mu A$$

$$\Rightarrow \underline{\underline{I_{C1} = 0{,}94mA}} \Rightarrow \underline{\underline{r_{e1} = 26{,}7\Omega}}$$

$$\Rightarrow I_{B2} = \frac{V_{BB} - R_{BB} I_{B1} - 1{,}2V}{3k6(1+\beta)}$$

Insert this value into $I_{B2} = \dfrac{5V - 60k \cdot 7{,}33\mu A - 1{,}2V}{3k6(1+150)} = 6{,}18\mu A$

$$\Rightarrow \underline{\underline{I_{C2} = 0{,}95mA}} \Rightarrow \underline{\underline{r_{e2} = 26{,}4\Omega}}$$

Now we can do AC analysis:

$$Gain = \frac{v_o}{v_s} = \frac{v_o}{v_{b2}} \cdot \frac{v_{b2}}{v_{b1}} \cdot \frac{v_{b1}}{v_s} = \left(-\frac{R_{C2}'}{R_{e2}+r_{e2}}\right)\left(\frac{R_{e1}}{R_{e1}+r_{e1}}\right)\left(\frac{r_i'}{r_i'+R_s}\right)$$

Where

$$\begin{aligned}
r_i' &= R_{BB} \parallel r_i \\
r_i &= h_{fe}(r_{e1}+R_{e1}) \\
R_{e1} &= R_{E1} \parallel r_{i2} \\
r_{i2} &= h_{fe} r_{e2} = 150 \cdot 27\Omega = 3k97 \\
R_{e1} &= R_{E1} \parallel r_{i2} = 2k06 \\
R_{C2}' &= R_{C2} \parallel R_L = 2k5 \parallel 4k = 1k54
\end{aligned}$$

Realize that R_{E2} is shunted.

$$r_i = h_{fe}(r_{e1}+R_{e1}) = 150(27\Omega + 2k08) = \underline{\underline{314k}}$$

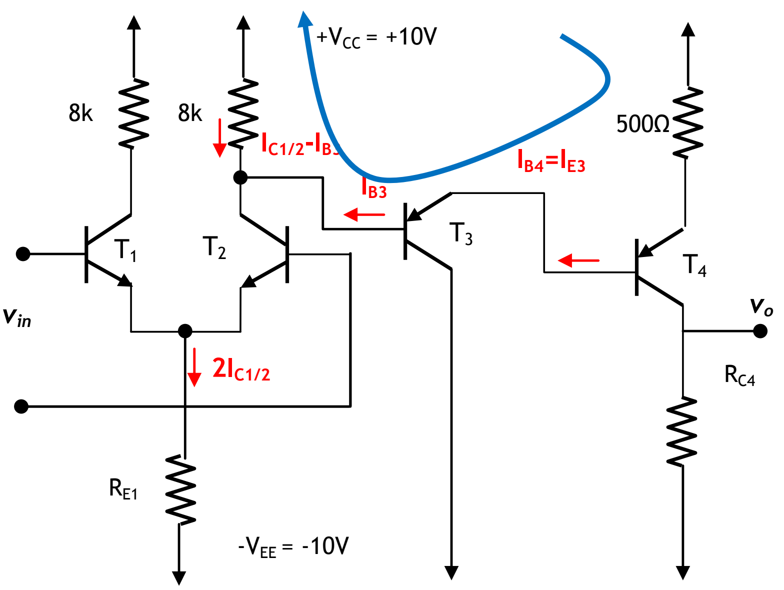
Thus $r_i' = R_{BB} \parallel r_i = 60k \parallel 316k = \underline{\underline{50k4}}$

$$r_o = R_{C2} = \underline{\underline{2k5}}$$

Finally:

$$\frac{v_o}{v_s} = \left(-\frac{R_{C2}'}{0+r_{e2}}\right)\left(\frac{R_{e1}}{R_{e1}+r_{e1}}\right)\left(\frac{r_i'}{r_i'+R_s}\right) = (-58{,}2)\cdot 0{,}987 \cdot 0{,}981 = \underline{\underline{-56{,}3}}$$

2. Since $I_{C1} = I_{C2} = I_C = 0{,}5$ mA, $R_{E1} = \frac{0 - V_{BE1} - (-10V)}{2I_C} = \frac{9{,}4V}{1mA} = \underline{\underline{9k4}}$



$$500\Omega \cdot I_{E4} + V_{EB4} + V_{EB3} = 8k(I_C - I_{B3})$$
$$500\Omega \cdot I_{B4}(\beta + 1) + V_{EB4} + V_{EB3} = 8k(I_C - I_{B3})$$
$$500\Omega \cdot I_{E3}(\beta + 1) + V_{EB4} + V_{EB3} = 8k(I_C - I_{B3})$$
$$500\Omega \cdot I_{B3}(\beta + 1)(\beta + 1) + V_{EB4} + V_{EB3} = 8k(I_C - I_{B3})$$
$$\Rightarrow I_{B3} = \frac{8kI_C - V_{EB4} - V_{EB3}}{8k + (1+\beta)(1+\beta)500\Omega} = \underline{\underline{550nA}}$$

Blue loop: $\Rightarrow \underline{\underline{I_{C3} = 54{,}8\mu A}}$

$$\Rightarrow r_{e3} = \underline{\underline{456\Omega}}$$
$$\Rightarrow I_{C4} = \beta \cdot I_{B4} = \beta \cdot I_{\hat{E}3} = \underline{\underline{5{,}5mA}}$$
$$\Rightarrow r_{e4} = \underline{\underline{4{,}52\Omega}}$$

$ALSO$

$$r_{e1} = r_{e2} = r_{e1/2} = \frac{25mV}{0{,}5mA} = \underline{\underline{50\Omega}}$$

Now that V_o = 0V should be satisfied: $R_{C4} = \frac{0-(-10V)}{I_{C4}} = \underline{\underline{1k81}}$

AC analysis:

$$Gain = \frac{v_o}{v_{in}} = \frac{v_o}{v_{b4}} \cdot \frac{v_{b4}}{v_{b3}} \cdot \frac{v_{b3}}{v_{in}} = \left(-\frac{R_{C4}}{R_{e4} + r_{e4}}\right)\left(\frac{R_{e3}}{R_{e3} + r_{e3}}\right)\left(\frac{R_C \parallel r_{i3}}{2r_{e1}}\right)$$

Where
$$R_{e3} = r_{i4} = h_{fe}\left(r_{e4} + R_{e4}\right) = \underline{\underline{50k5}}$$
$$r_{i3} = h_{fe}(r_{e3} + R_{e3}) = \underline{\underline{5M}}$$

Also
$$r_i = 2h_{fe} r_{e1/2} = \underline{\underline{10k}}$$
$$r_o = R_{C4} = \underline{\underline{1k81}}$$

$$\frac{v_o}{v_{in}} = \left(-\frac{R_{C4}}{R_{e4} + r_{e4}}\right)\left(\frac{R_{e3}}{R_{e3} + r_{e3}}\right)\left(\frac{R_C \parallel r_{i3}}{2r_{e1}}\right) = -3{,}58 \cdot 0{,}991 \cdot 80 = \underline{\underline{-284}}$$

$$CMRR = 20\log_{10}\left[\frac{2R_{E1} + r_{e1}}{r_{e1}}\right] = 20\log_{10}\left[\frac{2 \cdot 9k4 + 50}{50}\right] = \underline{\underline{51{,}5dB}}$$