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! Cell phones are not allowed and should be placed on the front desk before the exam.***

EHB222E INTRODUCTION TO ELECTRONICS (12137)
Midterm Exam #2 ✎ 5 December 2017 ⌛ 15.30-17.30
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EEF 5302-5202

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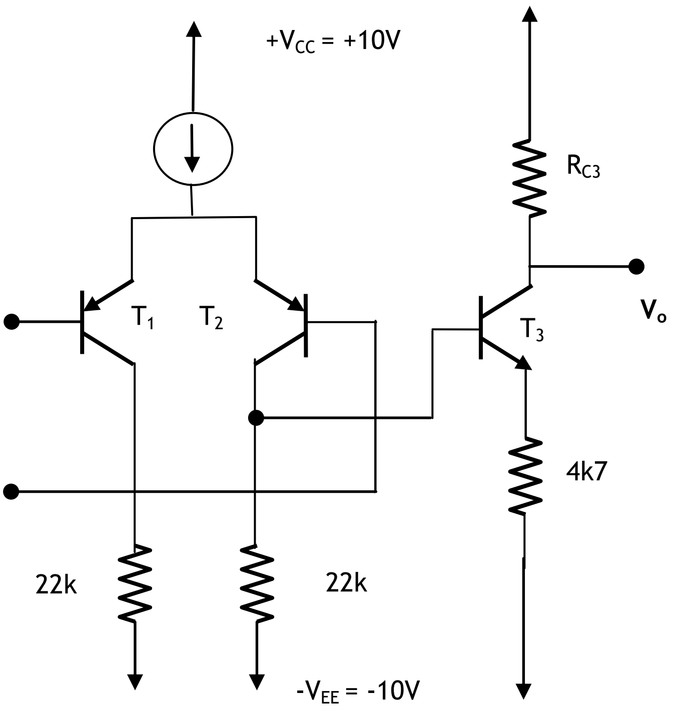
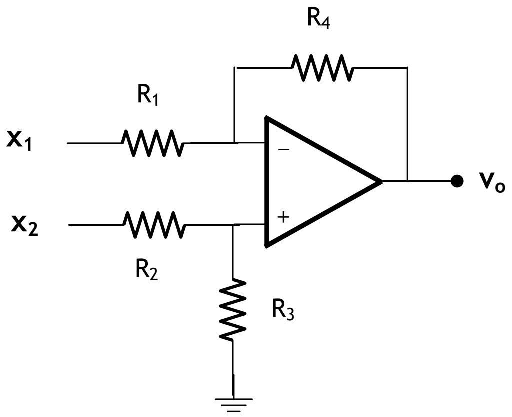
1. Study the 2-stage BJT amplifier circuit shown on the left with V_T = 25 mV, $|V_{BE}|$ = 0,6 V, h_{FE} = 200 for all three transistors. Do NOT forget $h_{oe} = h_{re} = 0$
   a. Design a current source that will provide 0,4 mA biasing current to the differential stage. (10 points)
   b. Choose R_{C3} such that the such that, waveform distortion at the output V_o is minimum and symmetrical. <u>Do NOT neglect</u> base currents. (10 points)
   c. Find the small signal voltage gain of the 2-stage amplifier and the CMRR. (20 points)
   d. Calculate the input and output resistances. (10 points)



2. Analysis/synthesis:
   a. Analyze the OPAMP circuit shown on below right and express $\mathbf{v_o}$ in terms of the resistors R_1, …, R_4, and inputs x_1 and x_2. (25 points)
   b. Taking advantage of the analysis above, design an OPAMP circuit that will realize the function $v_o = 3x_3 - 2x_2 - 5x_1$. Please use meaningful resistor values. (25 points)



BONUS: Who gave these units their names and which country are they from: mV, kW, dB, K. **Each correct answer 2,5 points! Wrong answers -2,5 each!!!!**

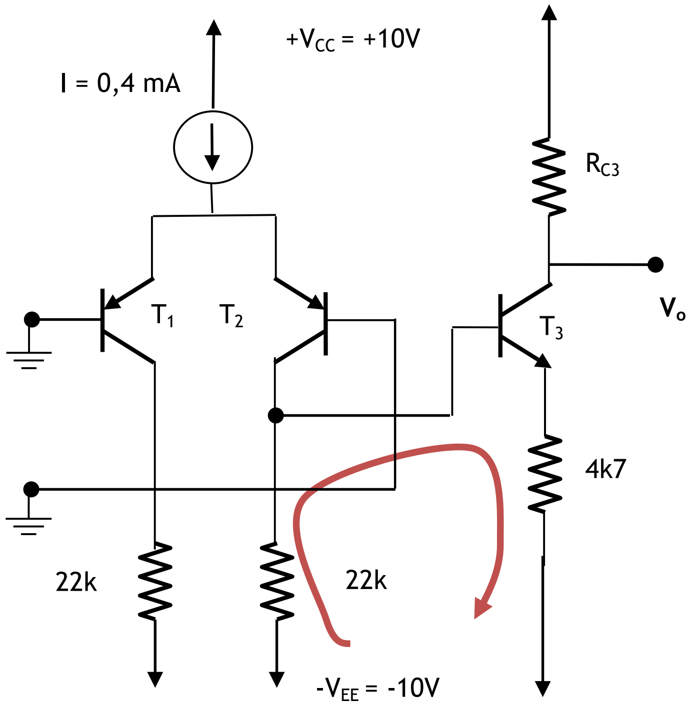
GOOD LUCK

SOLUTIONS

1. This circuit has to be analyzed in parts. You can easily design the current mirror. So this part is left to you like before. If you have trouble check solutions to MT1 of Spring 2011.

   Without neglecting the base currents of the differential (the very first) stage, for $V_i = 0$ V

$$I_{C1} = I_{C2} = \frac{h_{FE}}{h_{FE}+1} \cdot \frac{I_{ref}}{2} = \frac{200}{200+1} \cdot \frac{0{,}4mA}{2} \Rightarrow I_{C1} = I_{C2} = \underline{\underline{0{,}199mA}}$$



Following the brown loop $-(I_{C2} - I_{B3})22k + V_{BE3} + (h_{FE}+1)I_{B3}4k7 = 0$

$$I_{C3} = h_{FE}\frac{22k * I_{C2} - V_{BE3}}{(h_{FE}+1)4k7 + 22k} = 200\frac{22k * 0{,}199mA - 0{,}6V}{(200+1)4k7 + 22k} = \underline{\underline{0{,}782mA}}$$

for waveform distortion at the output V_o to be minimum and symmetrical:

$$V_o = 0V \Rightarrow I_{C3}R_{C3} = V_{CC} = 10V \Rightarrow R_{C3} = \frac{V_{CC} - V_o}{I_{C3}} = \frac{10V}{0{,}782mA} = \underline{\underline{12k8}}$$

$$\frac{v_o}{v_i} = \frac{v_o}{v_{b3}} \cdot \frac{v_{b3}}{v_i} = -\frac{R_{C3}}{r_{e3} + R_{e3}} \cdot \frac{22k \,||\, r_{i3}}{2r_{e1/2}}$$ with

$$\begin{cases} r_{e3} = \dfrac{V_T}{I_{C3}} = \dfrac{25mV}{0{,}782mA} = \underline{\underline{32\Omega}} \\ r_{e1/2} = \dfrac{V_T}{I_{C1/2}} = \dfrac{25mV}{0{,}199mA} = \underline{\underline{125{,}6\Omega}} \\ r_{i3} = h_{fe}(r_{e3} + R_{e3}) = 200(32 + 4k7) = \underline{\underline{946k}} \end{cases}$$

$$\frac{v_o}{v_i} = -\frac{R_{C3}}{r_{e3} + R_{e3}} \cdot \frac{22k \,||\, r_{i3}}{2r_{e1/2}} = -\frac{12k8}{32 + 4k7} \cdot \frac{22k \,||\, 966k2}{2 \cdot 125{,}6} = \underline{\underline{-231{,}5}}$$

$CMRR = 20\log_{10}\left|\dfrac{A_d}{A_c}\right| = 20\log_{10}\left|\dfrac{2R_{E1/2} + r_{e1/2}}{r_{e1/2}}\right|$ since there is no resistor connected to the common emitters of the differential stage, $R_{E1/2} \to \infty \Rightarrow CMRR \to \infty$

As the 2nd stage is a common emitter circuit $r_o = R_{C3} = \underline{\underline{12k8}}$

$r_i = r_{i1/2} = 2h_{fe}r_{e1/2} = \underline{\underline{20k250}}$

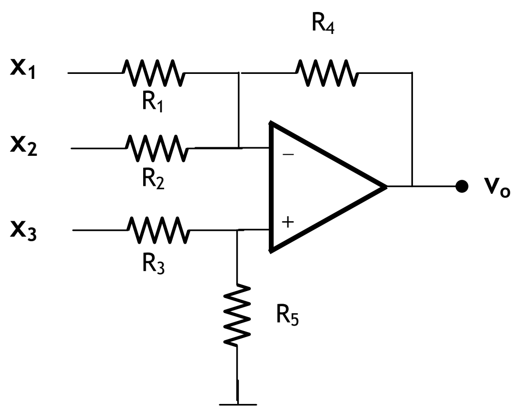
2. The function realized by the given circuit is found from solving

$$\frac{x_1 - v_-}{R_1} = \frac{v_- - v_o}{R_4} \text{ where } v_- = v_+ = \frac{R_3}{R_2 + R_3} x_2$$

➔ $v_o = -\dfrac{R_4}{R_1} x_1 + \dfrac{R_3}{R_2 + R_3} \cdot \left(1 + \dfrac{R_4}{R_1}\right) x_2$

For example, if $\dfrac{R_4}{R_1} = \dfrac{4k}{1k} = 4; \dfrac{R_3}{R_2 + R_3} = \dfrac{2k}{2k + 3k} = \dfrac{2}{5}$ then the circuit realizes the function $v_o = 2x_2 - 4x_1$

In a similar way $v_o = 3x_3 - 2x_2 - 5x_1$ can be realized by the OPAMP circuit below:



Now we have to find the R values

$$\frac{R_4}{R_1} = 5 \Rightarrow \underline{\underline{R_4 = 10k}}, \underline{\underline{R_1 = 2k}}; \frac{R_4}{R_2} = 2 \Rightarrow \underline{\underline{R_2 = 5k}}$$

$$\frac{R_5}{R_3 + R_5}\left(1 + \frac{R_4}{R_1} + \frac{R_4}{R_2}\right) = \frac{R_5}{R_3 + R_5}(1 + 5 + 2) = 3 \Rightarrow \frac{R_5}{R_3 + R_5} = \frac{3}{8} \Rightarrow \underline{\underline{R_5 = 3k}}, \underline{\underline{R_3 = 5k}}$$