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.***

ELE222E INTRODUCTION TO ELECTRONICS (11245)

Midterm Examination #2 13 December 2011 13.30-15.30

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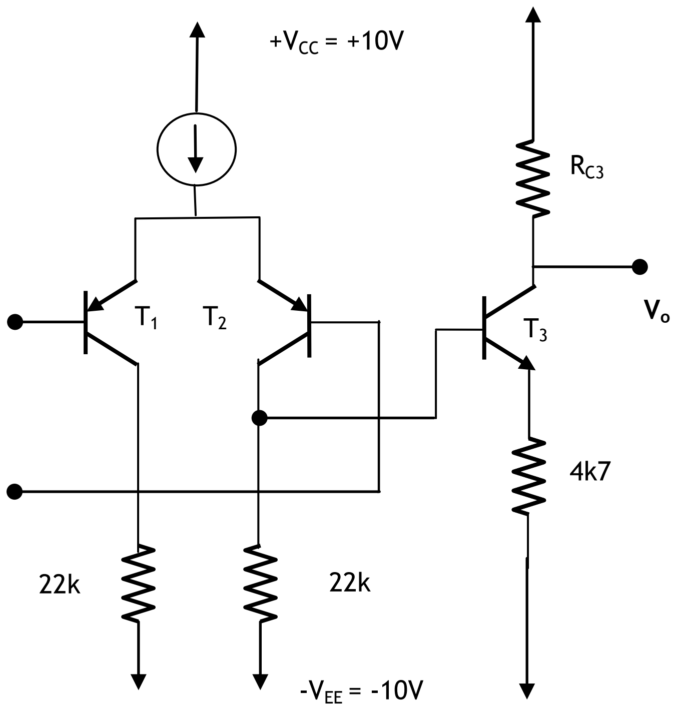


1. In the first midterm exam you had to study DC characteristics of the 2-stage BJT amplifier circuit shown on the left with V_T = 25 mV, $|V_{BE}|$ = 0,6 V, h_{FE} = 200 for all three transistors.

   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. For the circuit shown on the right, transistor parameters for T_1 and T_2 are $V_{A1} = V_{A2} = \infty$, V_T = 25 mV, $|V_{BE}|$ = 0,6 V, and $h_{fe1} = h_{fe2} = h_{FE1} = h_{FE2} = h_{fe} = h_{FE} = \beta = 100$.

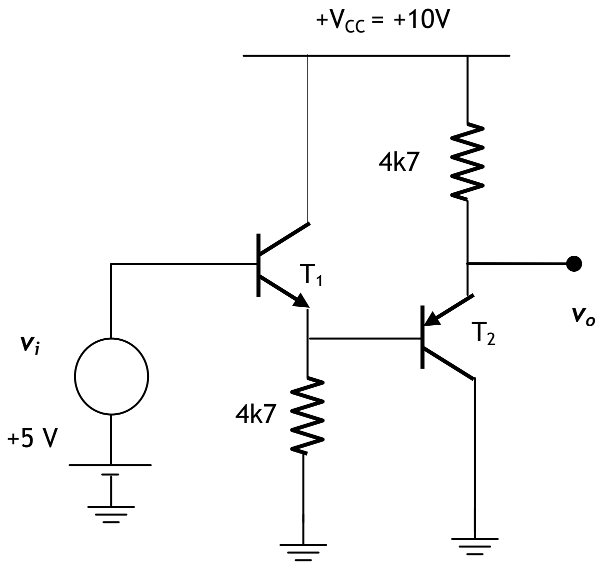
   a. Determine the DC collector current for each BJT. (15 points)

   b. What can you say about the DC level at the output? (5 points)

   c. Find the small signal voltage gain. (15 points)

   d. Determine the input and output resistances. (15 points)

   THIS IS <u>NOT</u> A DARLINGTON CIRCUIT.



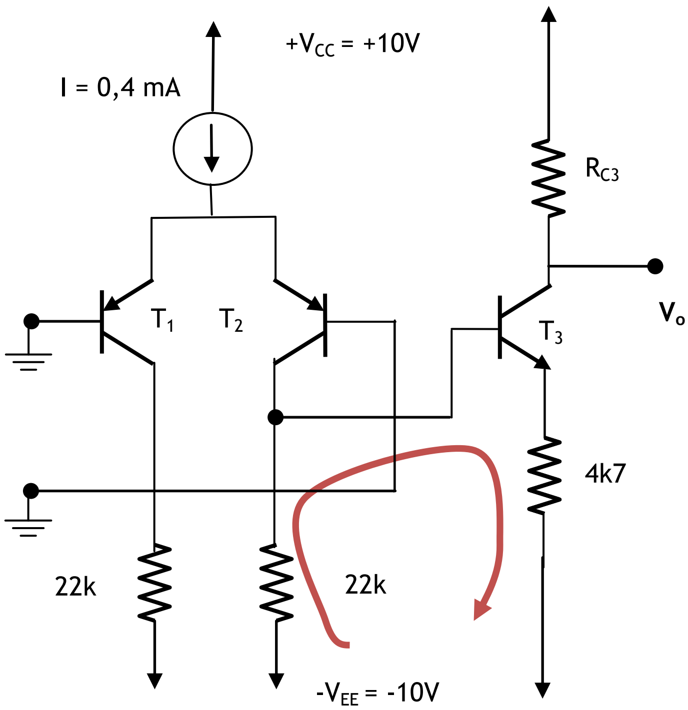
GOOD LUCK!

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:

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

$$\frac{v_o}{v_i} = \frac{v_o}{v_{b3}} \cdot \frac{v_{b3}}{v_i} = -\frac{R_{C3}}{r_{e3} + R_{e3}} \cdot \frac{22k \parallel r_{i3}}{2r_{e1/2}} \quad \text{with} \quad \begin{cases} r_{e3} = \dfrac{V_T}{I_{C3}} = \dfrac{25mV}{0{,}782mA} = \underline{\underline{32\Omega}} \\ r_{e1/2} = \dfrac{V_T}{I_{C1/2}} = \dfrac{25mV}{0{,}199mA} = \underline{\underline{125{,}6\Omega}} \\ r_{i3} = h_{fe}(r_{e3} + R_{e3}) = 200(32 + 4k7) = \underline{\underline{946k}} \end{cases}$$

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

$CMRR = 20\log_{10}\left|\frac{A_d}{A_c}\right| = 20\log_{10}\left|\frac{2R_{E1/2}+r_{e1/2}}{r_{e1/2}}\right|$ 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. Now you have an interesting circuit that resembles Darlington, but it is NOT. Still we can easily see that $V_I = V_{B1} = 5V \Rightarrow V_{B2} = 5V - 0{,}6V = 4{,}4V \Rightarrow \underline{\underline{V_0 = 5V = V_I}}$, that is the input and output DC levels are the same. Checking Problem 1b, we realize that $\underline{\underline{V_0 = 5V}}$ makes sure that waveform distortion at the output V_o is minimum and symmetrical, because it is exactly at the midpoint of the entire range of $0 \to 10V$!

$$V_0 = 5V \Rightarrow I_{E2} = \frac{V_{CC}-V_0}{4k7} = \frac{5V}{4k7} = 1{,}06mA \Rightarrow I_{C2} = \frac{h_{fe}}{h_{fe}+1} I_{E2} = \underline{\underline{1{,}05mA}}$$

$$V_{E1} = V_{B1} - V_{BE} = (I_{E1}+I_{B2})4k7 = 4{,}4V$$

$$I_{E1} = \frac{V_{E1}}{4k7} - I_{B2} = \frac{4{,}4V}{4k7} - 10\mu A = 0{,}926mA \Rightarrow I_{C1} = \frac{h_{fe}}{h_{fe}+1} I_{E1} = \underline{\underline{0{,}916mA}}$$

with
$$\begin{cases} r_{e2} = \dfrac{V_T}{I_{C2}} = \dfrac{25mV}{1{,}05mA} = \underline{\underline{23{,}74\Omega}} \Rightarrow r_{i2} = h_{fe}(r_{e2}+R_{e2}) = 100(23{,}74+4k7) = \underline{\underline{473k}} \\ r_{e1} = \dfrac{V_T}{I_{C1}} = \dfrac{25mV}{0{,}916mA} = \underline{\underline{27{,}28\Omega}} \Rightarrow r_{i1} = h_{fe}(r_{e1}+R_{e1}) = 100(27{,}28+4k7 \parallel r_{i2}) = \underline{\underline{468k}} \end{cases}$$

Therefore

$$\frac{v_o}{v_i} = \frac{v_o}{v_{b2}} \cdot \frac{v_{b2}}{v_i} = \frac{R_{e2}}{r_{e2}+R_{e2}} \cdot \frac{R_{e1}}{r_{e1}+R_{e1}} = \frac{4k7}{4k7+23{,}74} \cdot \frac{4k7 \parallel r_{i2}}{4k7 \parallel r_{i2}+27{,}28} = 0{,}995 * 0{,}994 = \underline{\underline{0{,}989}}$$

Obviously, $r_i = r_{i1} = h_{fe}(r_{e1}+R_{e1}) = 100(27{,}28+4k7 \parallel r_{i2}) = \underline{\underline{468k}}$

$r_o = R_{e2} \parallel \left[r_{e2} + \frac{R_S}{h_{fe}}\right] = 4k7 \parallel \left[23{,}74\Omega + \frac{r_{o1}}{100}\right]$ with $r_{o1} = R_{e1} \parallel \left[r_{e1} + \frac{R_S}{h_{fe}}\right] = 4k7 \parallel 27{,}28\Omega = \underline{\underline{27{,}12\Omega}}$

Thus $r_o = 4k7 \parallel \left[23{,}74\Omega + \frac{27{,}12\Omega}{100}\right] = \underline{\underline{23{,}88\Omega}}$