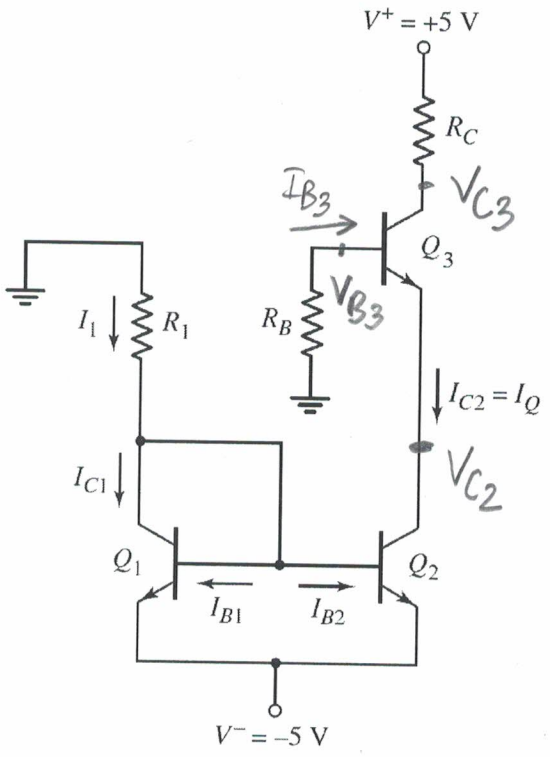
Practice Problem Set # 4

ENEL 469

1. Consider the circuit shown below where all the transistors are identical and, $R_1 = 10\ k\Omega$, $R_B = 100\ k\Omega$, $R_C = 2\ k\Omega$, $\beta = 50$, $V_{BE(ON)} = 0.7\ V$ and $VA = \infty$. Find I_{B1}, I_{B2}, I_{B3}, V_{CE2}, and V_{CE3}. Do not ignore base currents.



Solution:

$$I_1 = \frac{0 - V_{BE(ON)} - V^-}{R_1} = \frac{-0.7 - (-5)}{10k} = 0.43\,mA$$

$$I_{C2} = \frac{I_1}{1 + 2/\beta} = \frac{0.43\,mA}{1 + 2/50} = 0.413\,mA$$

$$\therefore \boxed{I_{B1} = I_{B2} = \frac{I_{C2}}{\beta} = 8.27\,\mu A}$$

$$I_{C3} = I_{C2} \cdot \frac{\beta}{\beta + 1} = 0.405\,mA \; ; \; \boxed{I_{B3} = \frac{I_{C3}}{\beta} = 8.1\,\mu A}$$

$\therefore V_{B_3} = -I_{B_3} R_B = -0.81\,V$

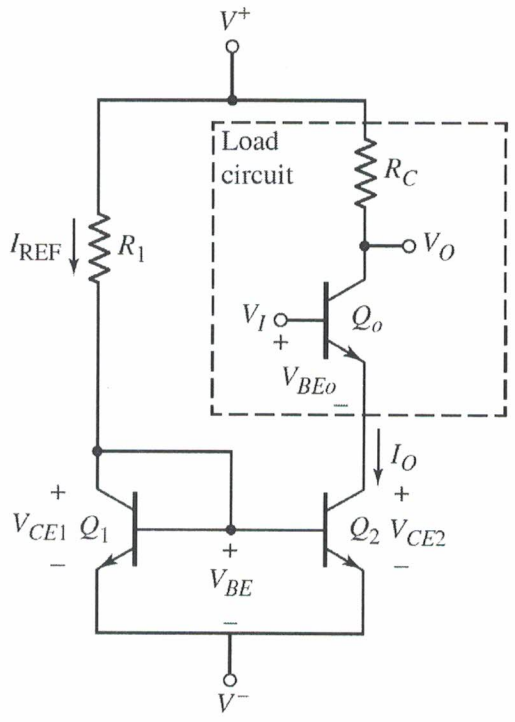
$\therefore V_{C_2} = V_{B_3} - 0.7 = -0.81 - 0.7 = -1.51\,V$

$\therefore \boxed{V_{CE_2} = V_{C_2} - V_{E_2} = -1.51 - (-5) = 3.49\,V}$

$V_{C_3} = 5 - I_{C_3} R_C = 4.19\,V$

$\therefore \boxed{V_{CE_3} = V_{C_3} - V_{E_3} = 4.19 - (-1.51) = 5.7\,V}$

2. Consider the following circuit with the parameters: $V^+ = 5$ V, $V^- = -5$ V, $R_1 = 9.3$ kΩ, $\beta = 50$, $V_{BE(ON)} = 0.7$ V, and $V_A = 80$ V. Determine the change in I_0 as V_{CE2} changes from 0.7 V to 5V.



Solution:

$$I_{ref} = \frac{V^+ - V_{BE(ON)} - V^-}{R_1} = 1\,mA$$

For $V_{CE_2} = 0.7\,V$, Q_1 and Q_2 are identically biased.

$$\therefore I_0 = \frac{I_{ref}}{1 + 2/\beta} = 0.962\,mA$$

$$\therefore r_0 = \frac{V_A}{I_0} = 83.2\,k\Omega$$

Now, the change in load current is determined from:

$$\frac{dI_o}{dV_{CE_2}} = \frac{1}{r_o}$$

$$\Rightarrow dI_o = \frac{1}{r_o} dV_{CE_2}$$

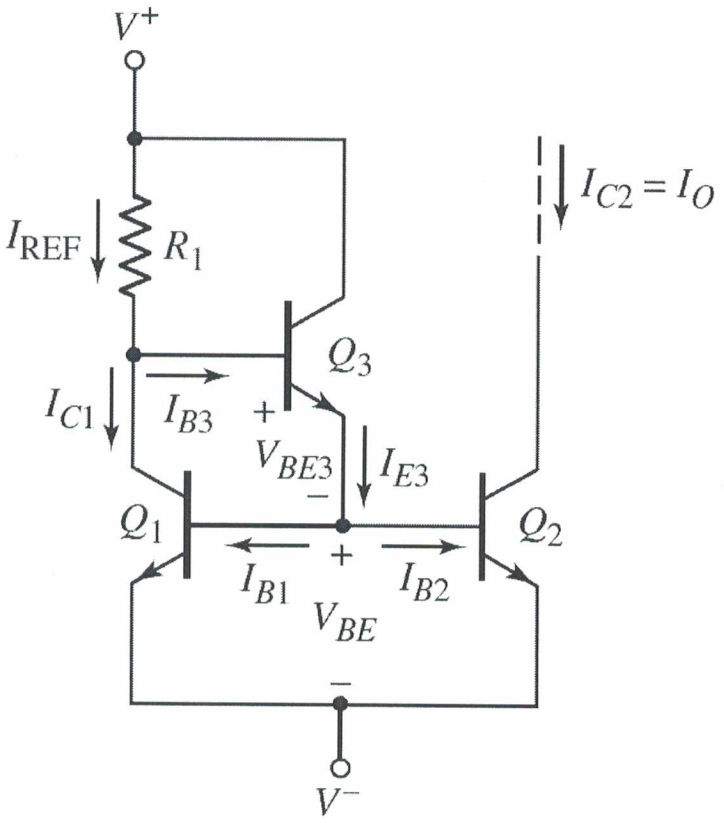
$$= \frac{1}{83.2k} (5 - 0.7)$$

$$= 0.052\,mA$$

∴ The change in I_o as V_{CE_2} changes from 0.7V to 5V is: 0.052 mA

∴ Percent change in I_o: $\frac{dI_o}{I_o} = \frac{0.052}{0.962} = 5.4\%$

3. Consider the circuit shown below having the parameters: $V^+ = 3$ V, $V^- = -3$ V, and $R_1 = 30\ k\Omega$. The parameters of the transistors Q_1 and Q_2 are $V_{BE1,2(on)} = 0.7$ V and $\beta = 120$. The parameters of the transistor Q_3 are $V_{BE3\,(on)} = 0.6$ V and $\beta_3 = 80$. Assume $V_A = \infty$ for all three transistors. Determine the value of each current indicated in the circuit.



$$I_{ref} = \frac{V^+ - V^- - V_{BE_3(ON)} - V_{BE_{1,2}(ON)}}{R_1}$$

$$= \frac{6 - 0.7 - 0.6}{80k} = 0.157\ mA$$

$$\therefore I_{ref} = I_{C_1} + I_{B_3} = I_{C_1} + \frac{I_{E_3}}{\beta_3 + 1} = I_{C_1} + \frac{1}{\beta_3 + 1}\left(I_{B_1} + I_{B_2}\right)$$

$$= I_{C_1} + \frac{1}{\beta_3 + 1} \cdot \frac{2 I_{C_1}}{\beta} = I_{C_1}\left(1 + \frac{2}{\beta\beta_3 + \beta}\right)$$

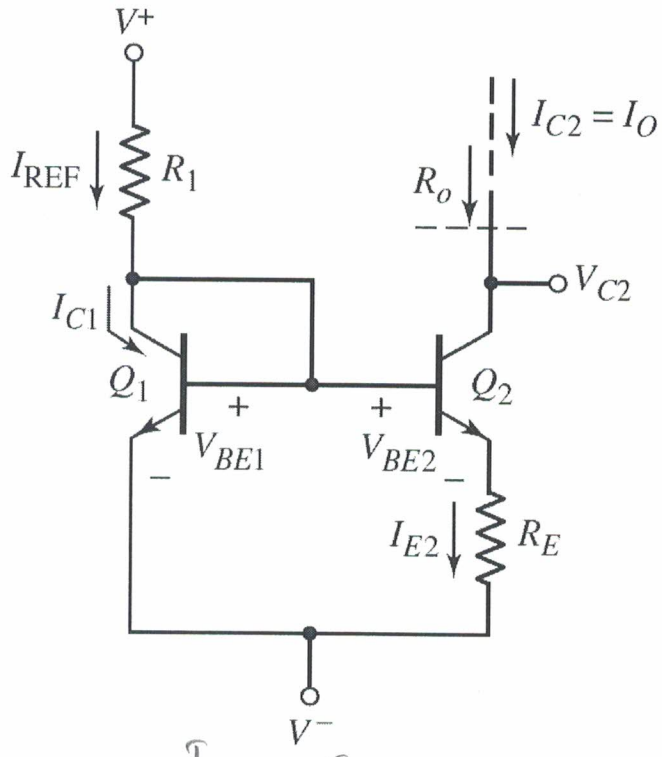
$$\Rightarrow I_{C_1} = I_{ref} \cdot \frac{1}{1 + 2/(\beta + \beta\beta_3)} = 0.156968\ mA = I_{C_2}$$

$$\therefore I_{B_1} = I_{B_2} = \frac{I_{C_1}}{\beta} = 1.31\,\mu A$$

$$\therefore I_{E_3} = 2I_{B_1} = 2I_{B_2} = 2.62\,\mu A$$

$$I_{B_3} = I_{E_3}/(\beta_3 + 1) = 0.0323\,\mu A$$

4. Design a Widlar current source (find the values of R_1 and R_E) as shown in the following figure with the specifications:
Bias voltages: V+ = 5 V, V- = -5 V
Currents: I_{REF} = 1 mA and I_0 = 12 μA.
The transistors Q1 and Q2 are described as V_{BE} = 0.8 V at I_C = 10 mA and β = 50.
Do not ignore base currents.



Solution:

$$I_{ref} = I_{C_1} + \frac{I_{C_1}}{\beta} + \frac{I_{C_2}}{\beta} \Rightarrow I_{C_1} = \frac{I_{ref} - I_{C_2}/\beta}{1 + 1/\beta}$$

$$= 0.98\ mA$$

$$\therefore V_{BE_1} = 0.8 + V_T \ln \frac{0.98mA}{10\ mA}$$

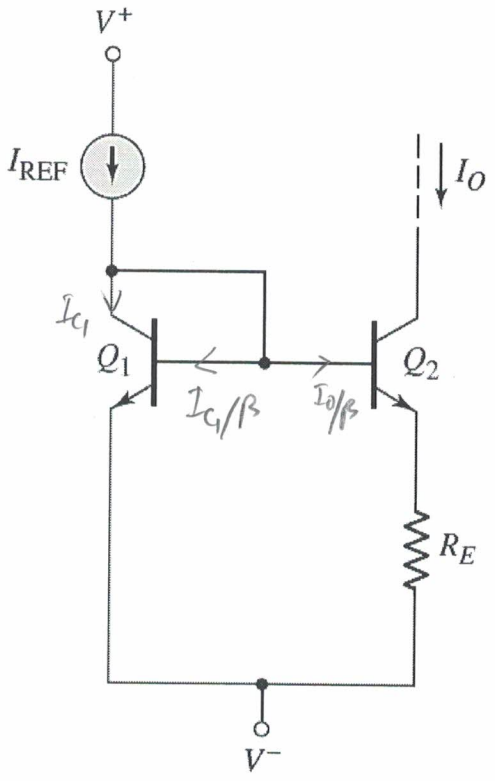
$$= 0.742\ V$$

$$V_{BE_2} = 0.8 + V_T \ln \frac{12MA}{10mA} = 0.632\ V$$

$$\therefore R_1 = \frac{V^+ - V^- - V_{BE_1}}{I_{ref}} = 9.258\ k\Omega ; \quad R_E = \frac{V_{BE_1} - V_{BE_2}}{I_{E_2} = 12.24MA}$$

$$= 8.987\ k\Omega$$

5. In the following circuit assume that $I_{REF} = 120\ \mu A$, $I_{S1} = I_{S2} = 2\times10^{-16}$ A. a) Find V_{BE1}, b) If $I_0 = 50\ \mu A$, determine V_{BE2} and R_E, c) Find I_0 if $R_E = 700\ \Omega$, what is V_{BE2}?



$I_{C1} = I_S e^{V_{BE1}/V_T}$

$\Rightarrow V_{BE1} = V_T \ln \frac{I_{C1}}{I_S}$

Solution:

a) Ignoring base currents:

$I_{C1} = I_{ref} = 120\,\mu A$

$\therefore V_{BE1} = V_T \ln \frac{I_{C1}}{I_S} = 0.678V$

b) $I_0 = 50\,\mu A$;

$\therefore V_{BE2} = V_T \ln \frac{I_0}{I_S} = 0.656V$

$\therefore R_E = \frac{V_{BE1} - V_{BE2}}{I_0} = 440\,\Omega$

c) $R_E = 700\Omega$

$$V_{BE_1} - V_{BE_2} = I_O R_E = V_T \ln \frac{I_{ref}}{I_O}$$

By applying trial and error method:

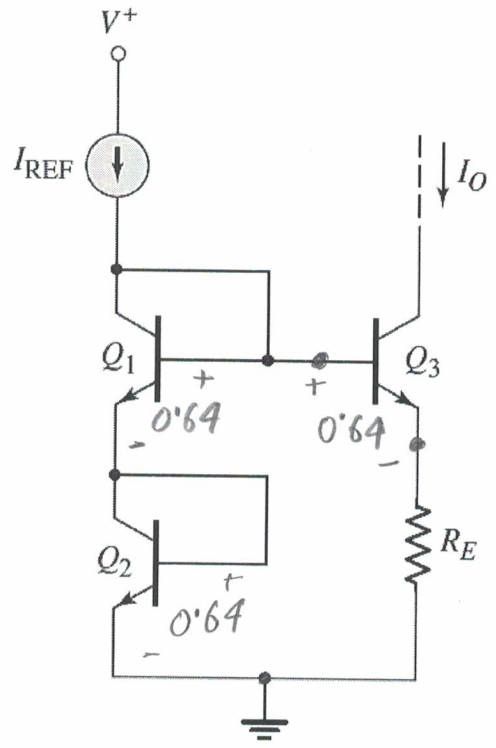
$$I_O = 40\,\mu A$$

$$\therefore V_{BE_2} = V_{BE_1} - I_O R_E$$

$$= 0.678 - 40 \times 10^{-6} \times 700$$

$$= 0.65\,V$$

6. Consider the circuit shown below. Neglect base currents and assume $VA = \infty$. Determine the value of R_E such that $I_O = I_{REF} = 100\ \mu A$. Assume $V_{BE} = 0.7$ V at a collector current of 1 mA.



Solution: $I_O = I_{ref} = 100\mu A = 0.1mA$

V_{BE} at $0.1mA \Rightarrow V_{BE} = 0.7 + V_T \ln \frac{0.1mA}{1mA}$

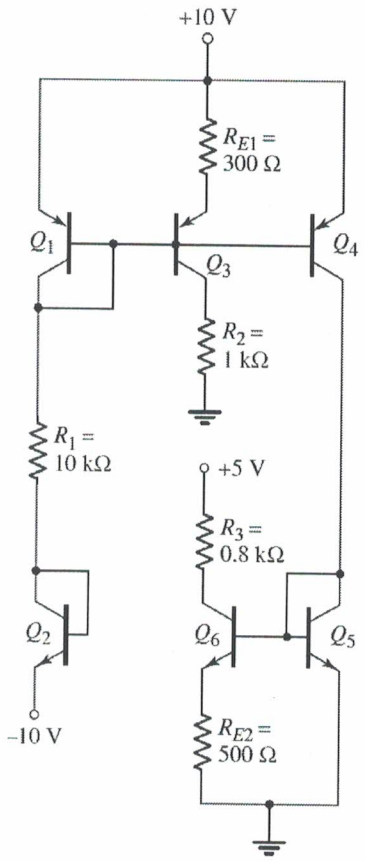
$= 0.64V$

Note that ignoring base current will cause every transistor to draw 0.1mA, thus, $V_{BE} = 0.64$ for all transistors.

$\therefore \quad I_O R_E = V_{BE}$

$\Rightarrow R_E = \frac{V_{BE}}{I_O} = 6.4k\Omega$

7. For the circuit shown in the following figure assume transistor parameters $V_{BE} = V_{EB} = 0.7$ V for all transistors except Q3 and Q6, and let $\beta = \infty$. Find the collector current in each transistor.



Solution: $\beta = \infty$; ignoring base currents.

$$I_{C1} = I_{C2} = \frac{10 - 0.7 - 0.7 - (-10)}{10k} = 1.86\ mA$$

$$I_{C4} = I_{C5} = 1.86\ mA$$

$$I_{C3} R_{E1} = V_{BE1} - V_{BE3} = V_T \ln \frac{I_{C1}}{I_{C3}}$$

By trial and error method:

Students will not be required to do trial and error method in exams

$$I_{C3} = 0.195\ mA$$

Again;

$$I_{C_6} R_{E_2} = V_{BE_5} - V_{BE_6} = V_T \ln \frac{I_{C_5}}{I_{C_6}}$$

By trial and error;

$$I_{C_6} = 0.136\,mA$$

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