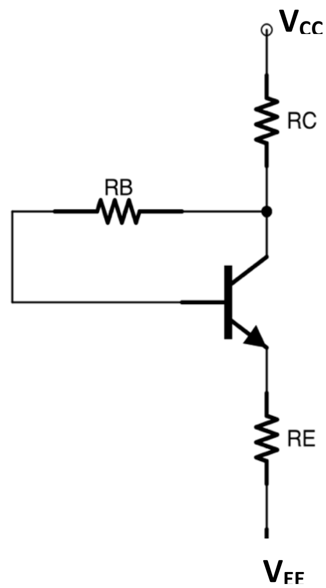
Assignment #1
ENEL469

1. Consider the following circuit where V_{CC} = 6V, V_{EE} = - 6V, α = 0.9917356, R_C = 1kΩ, R_B = 120kΩ, R_E = 1.2kΩ, $V_{CE(Sat)}$ = 0.2V, V_A = 150V, and $|V_{BE(on)}|$ = 0.7V. Determine I_C and V_{CE}.



Soln:

Here, $\beta = \alpha/(1 - \alpha) = 120$

By KVL, $6 + 6 = I_E \times R_C + I_B \times R_B + V_{BE(on)} + I_E \times R_E$

Or, $12 = (\beta + 1) \times I_B \times R_C + I_B \times R_B + 0.7 + (\beta + 1) \times I_B \times R_E$

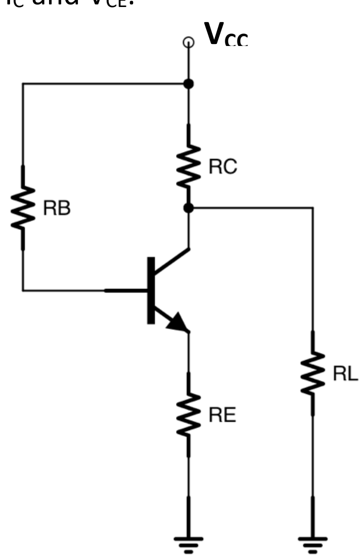
Or, $I_B = 29.26\ \mu A$

Thus, $I_C = I_B \times \beta = 3.51$ mA

By KVL, $V_{CE} = I_B \times R_B + V_{BE(on)}$

Or, $V_{CE} = 4.21$ V

2. Consider the following circuit where V_{CC} = 10V, β = 140, R_C = 1kΩ, R_B = 80kΩ, and R_E = 1kΩ, R_L = 2kΩ, $V_{CE(Sat)}$ = 0.2V, V_A = 150V, and $|V_{BE(on)}|$ = 0.7V. Determine I_C and V_{CE}.



Soln:

By KVL, $V_{CC} = I_B \times R_B + V_{BE(on)} + (\beta + 1) \times I_B \times R_E$

Or, $I_B = 42.08\ \mu A$

Thus, $I_C = I_B \times \beta = 5.93$ mA

Here, the current in R_C will satisfy, $I_{RC} = I_C + I_{RL}$

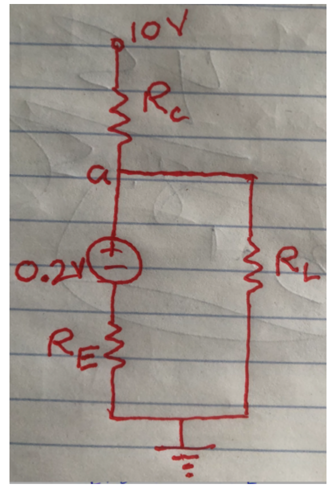
Thus, $I_{RC} < I_C$

Even considering, $I_{RC} = I_C$, V_{CE} becomes, V_{CE} = - 1.86 V.

The above value indicates that the BJT is operating in saturation.

Thus, $V_{CE} = 0.2$ V

To find the collector current let's assume $I_C \approx I_E$ for simplicity. Thus, we can consider the following equivalent circuit.



By KCL (nodal analysis)

$$\frac{V_a - 10}{R_C} + \frac{V_a - 0.2}{R_E} + \frac{V_a}{R_L} = 0$$

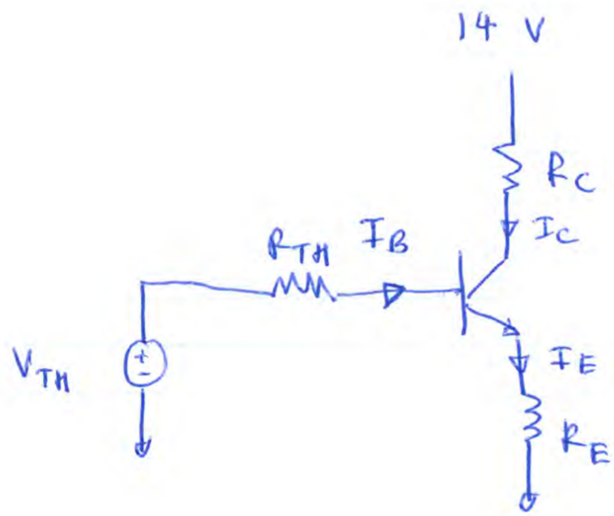
$$\frac{V_a - 10}{1000} + \frac{V_a - 0.2}{1000} + \frac{V_a}{2000} = 0$$

Or, $V_a = 4.08$ V

Thus, $I_C \approx I_E = (V_a - 0.2)/1000$

Or, $I_C = 3.88$ mA

3. Consider the following circuit where $V_{CC} = 14$V, $\beta = 60$, $R_C = 1\text{k}\Omega$, $R_1 = 60\text{k}\Omega$, $R_2 = 5\text{k}\Omega$, $R_E = 0.5\text{k}\Omega$, $V_{CE(Sat)} = 0.2$V, $V_A = 150$V, and $|V_{BE(on)}| = 0.7$V. Determine I_C and V_{CE}.



$$V_{TH} = \frac{V_{CC} \times R_2}{R_1 + R_2} = \frac{5}{65} \times 14 = \frac{14}{13} = 1.0769\text{V}$$

$$R_{TH} = \frac{R_1 R_2}{R_1 + R_2} = \frac{60 \times 10^3 \times 5 \times 10^3}{65 \times 10^3} = 4615.4\ \Omega$$

$V_B = V_{TH} - I_B R_{TH} = V_{BE} + I_E R_E$

~~$V_{TH} - I_B R_{TH}$~~ Let assume operation ~~at~~ in active region.

$V_{TH} - I_B R_{TH} = V_{BE} + (\beta+1) I_B R_E$

$1.0769 - I_B \times 4615.4 = 0.7 + (60+1) I_B \times 500$

$I_B = 10.7338 \times 10^{-6}$ A

$I_C = \beta I_B = 60 I_B = 644.03 \times 10^{-6}$ A

$I_E = (\beta+1) I_B = 61 I_B = 654.76 \times 10^{-6}$ A

$V_E = 500 \times I_E = 0.327$ V

$V_C = 14 - 1000 \times I_C = 13.356$ V

$V_{CE} = V_C - V_E = 13.029$ V $> V_{CE(sat)}$

$V_B = V_E + V_{BE} = 1.027$ V

$V_{CB} = V_C - V_B = 12.329$ V > 0

this confirms that the transistor operates in active region.

4. Consider the following circuit where V_{CC} = 8V, β = 150, R_C = 4kΩ, R_1 = 68kΩ, R_2 = 8kΩ, $V_{CE(Sat)}$ = 0.2V, V_A = 200V, and $|V_{BE(on)}|$ = 0.7V. Determine I_C and V_{CE}.

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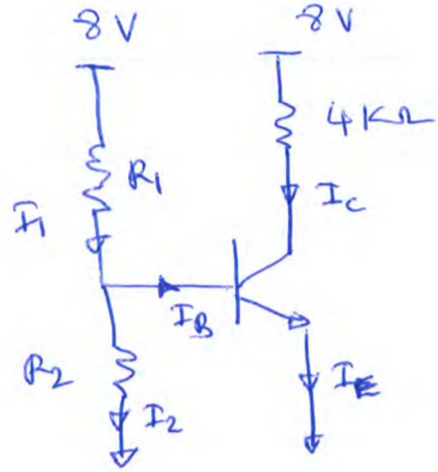


$R_1 = 68 k\Omega$
$R_2 = 8 k\Omega$

$$V_{BE} = 0.7 = I_2 \times 8 \times 10^3$$

$$I_2 = 87.5 \times 10^{-6} \text{ A}$$

$$8 = I_1 R_1 + I_2 R_2$$

$$I_1 = \frac{8 - I_2 R_2}{R_1}$$

$$I_1 = \frac{7.3}{68 \times 10^3} = 107.35 \times 10^{-6} \text{ A}$$

$$I_1 = I_2 + I_B$$

$$I_B = I_1 - I_2 = 19.85 \times 10^{-6} \text{ A}$$

if the circuit operates in active region

$$I_C = \beta I_B = 150 \times 19.85 \times 10^{-6}$$
$$= 2977.94 \times 10^{-6} \text{ A}$$

$$V_{CE} = V_C - V_E = V_C = 8 - 4000 \times I_C$$
$$= -3.91 < 0$$

Since

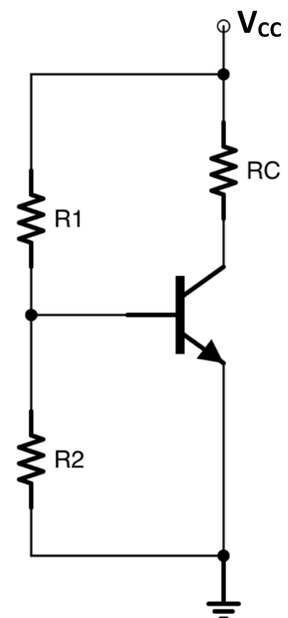
$V_{CE} < 0$ ~~so~~ our assumption was wrong.

this circuit is in saturation.

$$V_{CE} = 0.2\,V = V_C \Rightarrow 8 - 4000\, I_C$$

$$\therefore I_C = 1.95 \times 10^{-3}\ A$$

5. Consider the following circuit where $V_{CC} = 12V$, $\beta = 60$, $R_C = 2k\Omega$, $R_1 = 45k\Omega$, $R_2 = 4k\Omega$, $V_{CE(Sat)} = 0.2V$, $V_A = 200V$, and $|V_{BE(on)}| = 0.7V$. Assume that the maximum and minimum base currents are $I_{B(max)} = 150\mu A$ and $I_{B(min)} = 5\mu A$. Determine:
   a) The maximum and minimum values of R_C, satisfy the base current limits and the transistor operates in the active region. Assume all other values remain unchanged.
   b) The maximum and minimum values of R_2, satisfy the base current limits and the transistor operates in the active region. Assume all other values remain unchanged.
   c) The maximum and minimum values of R_1, satisfy the base current limits and the transistor operates in the active region. Assume all other values remain unchanged.



Soln:

With the given values, $I_{R2} = 175\ \mu A$ and $I_{R1} = 251.1\ \mu A$

Thus, $I_B = 251.1 - 175.0 = 76.1\ \mu A$

And, $I_C = 4.57$ mA

a) If we change R_C only, the base current will not change

Thus, $R_{C(max)} = (V_{CC} - V_{CE,sat})/I_C$

Or, $R_{C(max)} = 11.8/4.57$ mA

Or, $R_{C(max)} = 2.58\ k\Omega$

And $R_{C(min)} = 0\ \Omega$

b) If we change R_2 only (but not to zero), the base current will change but I_{R1} will remain unchanged.

With $R_C = 2\ k\Omega$, the maximum collector current is

$I_{C(max)} = (V_{CC} - V_{CE,sat})/R_C$

Or, $I_{C(max)} = 5.9$ mA

Thus, $I_{B(max)} = 98.33\ \mu A$. This indicates that for active region operation, the maximum base current should be $98.33\ \mu A$.

For $I_{B(min)} = 5\ \mu A$, $R_{2(min)}$ has to be

$R_{2(min)} = V_{BE(on)}/[I_{R1} - I_{B(min)}]$

Or, $R_{2(min)} = 0.7/(251.1\ \mu A - 5\ \mu A)$

Or, $R_{2(min)} = 2.84\ k\Omega$

For $I_{B(max)} = 98.33\ \mu A$, $R_{2(max)}$ has to be (i.e., active region operation)

$R_{2(max)} = V_{BE(on)}/[I_{R1} - I_{B(max)}]$

Or, $R_{2(max)} = 0.7/(251.1\ \mu A - 98.33\ \mu A)$

Or, $R_{2(max)} = 4.58\ k\Omega$

For $I_{B(max)} = 150\ \mu A$, $R_{2(max)}$ has to be (the transistor is in saturation though)

$R_{2(max)} = V_{BE(on)}/[I_{R1} - I_{B(max)}]$

Or, $R_{2(max)} = 0.7/(251.1\ \mu A - 150\ \mu A)$

Or, $R_{2(max)} = 6.92\ k\Omega$

c) If we change R_1 only, the base current will change but I_{R2} will remain unchanged.

With $R_C = 2\ k\Omega$, the maximum collector current is

$I_{C(max)} = (V_{CC} - V_{CE,sat})/R_C$

Or, $I_{C(max)} = 5.9$ mA

Thus, $I_{B(max)} = 98.33\ \mu A$. This indicates that for active region operation, the maximum base current should be $98.33\ \mu A$.

Also, with $R_2 = 4\ k\Omega$ (given value), $I_{R2} = 0.7/4000 = 175\ \mu A$

For $I_{B(min)} = 5\ \mu A$, $R_{1(max)}$ has to be

$R_{1(max)} = [V_{CC} - V_{BE(on)}] / [I_{R2} + I_{B(min)}]$

Or, $R_{1(max)} = 62.78\ k\Omega$

For $I_{B(max)} = 98.33\ \mu A$, $R_{1(min)}$ has to be (i.e., active region operation)

$R_{1(min)} = [V_{CC} - V_{BE(on)}] / [I_{R2} + I_{B(max)}]$

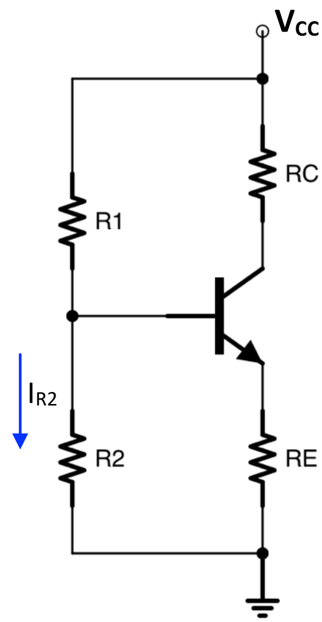
Or, $R_{1(min)} = 41.34\ k\Omega$

For $I_{B(max)} = 150\ \mu A$, $R_{1(min)}$ has to be (the transistor is in saturation though)

$R_{1(min)} = [V_{CC} - V_{BE(on)}] / [I_{R2} + I_{B(max)}]$

Or, $R_{1(min)} = 34.77\ k\Omega$

6. Consider the following circuit where $V_{CC} = 20V$, $\beta = 100$, $V_{CE(Sat)} = 0.2V$, $V_A = 230V$, $|V_{BE(on)}| = 0.7V$. Design the circuit (Determine R_1, R_2, R_C, and R_E) so that the transistor operates at $V_{CE} = 6V$ and $I_C = 2.5mA$. Given that $R_C = R_E$ and $I_{R2} = 2I_B$.



Soln:

$I_E = I_C \times (\beta+1)/ \beta = 2.525$ mA

By KVL, $V_{CC} = I_C \times R_C + V_{CE} + I_E \times R_E$

Or, $V_{CC} = I_C \times R_C + V_{CE} + I_E \times R_C$

Or, $20 = 2.5\ R_C + 6 + 2.525 \times R_C$

Or, $R_C = 2.786\ k\Omega$

And $R_E = 2.786\ k\Omega$

Here, $I_B = I_C / \beta = 25\ \mu A$

Thus, $I_{R2} = 50\ \mu A$

And, $I_{R1} = 50\ \mu A + 25\ \mu A = 75\ \mu A$

Thus, $R_2 = [V_{BE(on)} + I_E \times R_E] / I_{R2}$

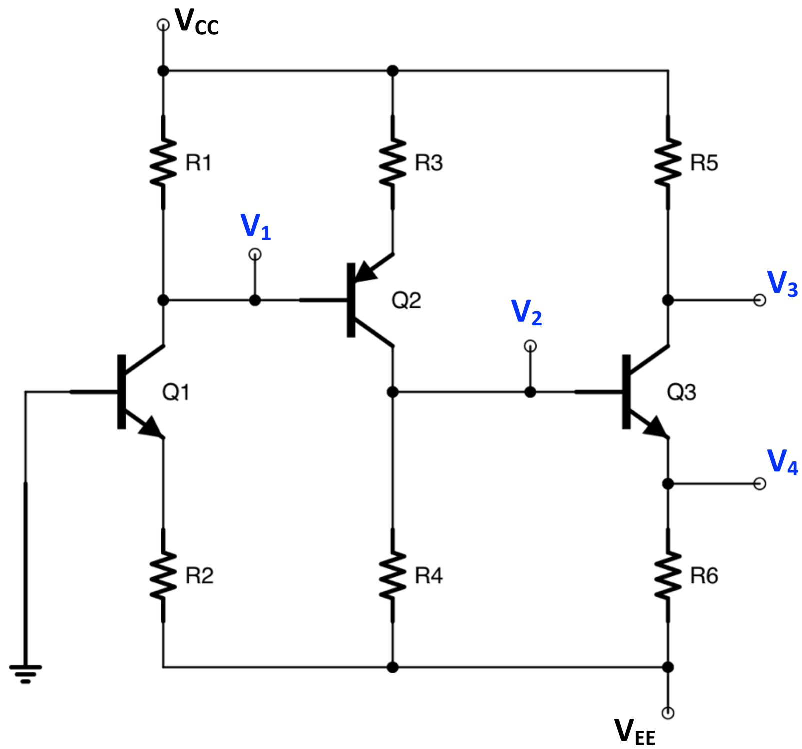
Or, $R_2 = 154.7\ k\Omega$

Also, $R_1 = [V_{CC} - I_{R2} \times R_2] / I_{R1}$

Or, $R_1 = 12.265 / 75\ \mu A$

Or, $R_1 = 163.53\ k\Omega$

7. Design the following circuit so that the transistors operate at I_{C1} = 2mA, I_{C2} = 2mA, I_{C3} = 4mA, V_1 = 2V, V_2 = –3V, and V_3 = 0V. Also given that V_{CC} = 10V, V_{EE} = –10V, $\beta = \infty$ (i.e., ignore base currents), $V_{CE(Sat)}$ = 0.2V, V_A = 300V, and $|V_{BE(on)}|$ = 0.7V.



Soln:

$R_1 = (V_{CC} - V_1) / I_{C1}$

Or, $R_1 = 4\ k\Omega$

Again, $R_2 = (0 - 0.7 - V_{EE}) / I_{E1}$

Or, $R_2 = (0 - 0.7 + 10) / I_{E1}$

Or, $R_2 = 9.3 / 2\ mA$

Or, $R_2 = 4.65\ k\Omega$

Solving for R3

$R_3 = [V_{CC} - V_{B1E2(on)} - V_1] / I_{E2}$

Or, $R_3 = [10 - 0.7 - 2) / 2\ mA$

Or, $R_3 = 3.65\ k\Omega$

Solving for R4

$R_4 = [V_2 - V_{EE}] / I_{C2}$

Or, $R_4 = [-3 + 10) / 2\ mA$

Or, $R_4 = 3.5\ k\Omega$

Solving for R5

$R_5 = [V_{CC} - V_3] / I_{C3}$

Or, $R_5 = 2.5\ k\Omega$

Solving for R6

$R_6 = [V_2 - V_{BE3(on)} - V_{EE}] / I_{E3}$

Or, $R_6 = 6.3/4\ mA$

Or, $R_6 = 1.575\ k\Omega$