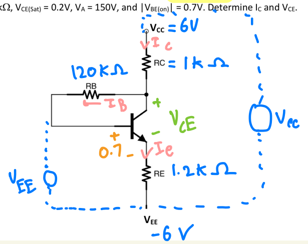
Assignment 1

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}.



$$\alpha = \frac{I_c}{I_E} \qquad \beta = \frac{\alpha}{1-\alpha} = 120.0009196 = \frac{I_c}{I_B}$$

$$V_{CC} - (\beta+1) I_B R_C - I_B R_B - V_{BE} - (\beta+1) I_B R_E - V_{EE} = 0$$

$$V_{CC} - I_B \left[(\beta+1)(R_C + R_E) + R_B \right] - V_{BE} - V_{EE} = 0$$

$$I_B = \frac{V_{CC} - V_{BE} - V_{EE}}{R_B + (\beta+1)(R_C + R_E)} = \frac{6 - 0.7 - (-6)}{120k + (121)(1.2k + 1k)} = 29.2\,\mu A$$

$$\boxed{I_c = \beta I_B = 3.5\,mA}$$

KVL in output loop

$$V_{CC} - I_C R_C - V_{CE} - I_E R_E - V_{EE} = 0$$

$$V_{CC} - I_C (R_C + R_E) - V_{CE} - V_{EE} = 0$$

$$V_{CE} = V_{CC} - I_C (R_C + R_E) - V_{EE}$$

$$= 6 - 3.5mA(1k + 1.2k) - (-6)$$

$$\boxed{V_{CE} = 4.3\,V}$$

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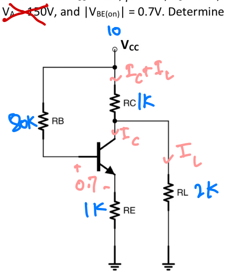
2. Consider the following circuit where V_{CC} = 10V, β = 140, R_C = 1kΩ, R_B = 80kΩ, and R_E = 1kΩ, R_L = 2kΩ, $V_{CE(Sat)}$ = 0.2V, ~~V_A = 150V~~, and $|V_{BE(on)}|$ = 0.7V. Determine I_C and V_{CE}.



Emitter-bias config

$$\beta = \frac{I_c}{I_B} \qquad \alpha = \frac{\beta}{1+\beta} = \frac{140}{141} = 0.9929078014$$

$$\alpha = \frac{I_c}{I_E} \qquad I_c = \alpha I_E$$

$$\beta = \frac{\alpha I_E}{I_B} \Rightarrow I_B = \frac{\alpha I_E}{\beta}$$

KVL:

$$V_{CC} - I_B R_B - V_{BE(on)} - I_E R_E = 0$$

$$V_{CC} - V_{BE} - I_B (R_B + R_E(\beta+1)) = 0$$

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + R_E(\beta+1)} = \frac{10 - 0.7}{80K + 1K(141)} = 42.1\,\mu A$$

$$I_c = (141)(I_B) = 5.94\,mA$$

KVL

$10 - 1000I_1 + 2000I_2 = 0$

$10 = 2000I_1 + 2000(I_1 - (5.9mA))$

$10 = 1000I_1 + 2000I_1 - 11.8$

$I_1 = 7.27mA$

wrong saturation

KVL inner

$10 - 1000I_1 - V_{CE} - 1000I_E = 0$

$V_{CE} = -3.2V$

can't be -ve

Finding V_C, V_B

$10 - 1000I_C = V_C$

$V_C = 4.1V$

$V_B = 10 - 80\mu I_B$

$= 6.6$

forward biased

so $V_E = 5.9V$

∴ $\boxed{V_{CE} = 0.2V}$

$V_{CC} - 1kI_1 - 2uI_2 = 0 \Rightarrow 10uI_1 + 2uI_2$

$I_2 = 5mA - 0.5I_1$ ∴ $I_2 = I_1 - I_C$

$5mA - 0.5I_1 = I_1 - I_C \Rightarrow I_C = 1.5I_1 - 5mA$

$\boxed{I_C = 0.79 mA}$

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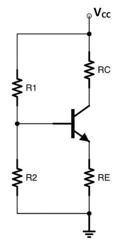
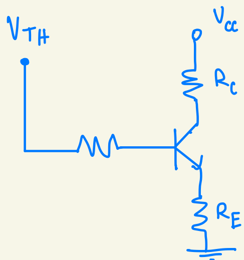
3. Consider the following circuit where $V_{CC} = 14V$, $\beta = 60$, $R_C = 1k\Omega$, $R_1 = 60k\Omega$, $R_2 = 5k\Omega$, $R_E = 0.5k\Omega$, $V_{CE(Sat)} = 0.2V$, $V_A = 150V$, and $|V_{BE(on)}| = 0.7V$. Determine I_C and V_{CE}.

voltage divider w/ Emitter resistor



* Thevenin Equivalent *



$R_B = R_1 // R_2$

$\approx 4615.38465\ \Omega$

$I = \frac{V_{cc}}{R_1 + R_2}$

$V_{TH} = I_2R = \frac{R_2 V_{cc}}{R_1 + R_2}$

$I = \frac{5k \cdot 14}{65k} = 1.077$

$\approx 1.1V$

KVL input

$I_B = \frac{V_{TH} - V_{BE}}{R_{TH} + R_c(\beta+1)} = \frac{1.1 - 0.7}{4615 + 500(61)} = 11.4\mu A$

$I_C = \beta I_B = 60 \cdot 11.4\mu A = 0.68\ mA$

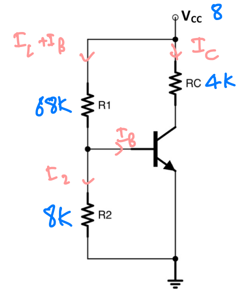
Output KVL

$V_{cc} - I_C R_C - V_{CE} - I_C R_E = 0$

$V_{CE} = V_{cc} - I_C(R_C + R_E)$

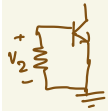
$= 12.98\ V$

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



By KVL:

$$8 - (I_2 + I_B)R_1 - I_2 R_2 = 0$$



$V_2 = 0.7$ $\therefore V_2 = I_2 R_2$

$$I_2 = \frac{V_2}{R_2} = \frac{0.7}{8000} = 8.75 \times 10^{-5} A$$

$$8 - I_2 R_1 - I_B R_1 - I_2 R_2 = 0$$

$$\hookrightarrow I_B = (8 - I_2 R_1 - I_2 R_2)/R_1$$
$$= 1.985 \times 10^{-5} A$$

$$I_C = \beta I_B = 2.978 \times 10^{-3} A$$

$$V_C = 8 - I_C R_C = 8 - (2.978 \times 10^{-3})\,4000 = -3.912V$$ not possible

$$\therefore \boxed{V_{CE(SAT)} = 0.2V}$$

By KVL:

$$8 - I_C R_C - 0.2 = 0 \longrightarrow I_C = \frac{7.8}{R_C}$$

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

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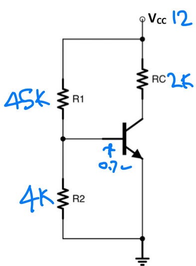
5. Consider the following circuit where $V_{CC} = 12V$, $\beta = 60$, $R_C = 2k\Omega$, $R_1 = 45k\Omega$, $R_2 = 4k\Omega$, $V_{CE(Sat)} = 0.2V$, ~~$V_A = 200V$~~, and $|V_{BE(on)}| = 0.7V$. Assume that the maximum and minimum base currents are $I_{B(max)} = 150\mu A$ and $I_{B(min)} = 5\mu A$. Determine:

a) The maximum and minimum values of R_C, which satisfies the base current limits. Assume all other values remain unchanged

b) The maximum and minimum values of R_2, which satisfies the base current limits. Assume all other values remain unchanged

c) The maximum and minimum values of R_1, which satisfies the base current limits. Assume all other values remain unchanged



$$I_B = (V_{CC} - 0.7)/R_1 - (0.7/R_2)$$
$$= 7.611 \times 10^{-5} A$$

$$I_C = \beta I_B = 4.567 \times 10^{-3} A$$

$$I_2 = \frac{0.7}{4000} = 1.75 \times 10^{-4} A$$

$$I_1 = \frac{(12 - 0.7)}{4500} = 2.511 \times 10^{-4} A$$

$$V_{CE} = V_{CE} - \beta \times I_B \times R_C = 12 - (60)(7.611 \times 10^{-5})(2000)$$
$$= 2.867V$$

$$V_1 = I_1 R_1 = (2.511 \times 10^{-4})(45{,}000) = 11.2995V$$

(a)

$$I_C = \beta I_B \quad \therefore I_{C(min)} = 60(5 \times 10^{-6}) = 3 \times 10^{-4} A$$

$$I_{C(max)} = 60(150 \times 10^{-6}) = 9 \times 10^{-3} A$$

By KVL:

$$V_{CC} - I_C R_C - V_{CE} = 0 \longrightarrow R_C = \frac{V_{CC} - V_{CE}}{I_C} = R_C$$

$$\therefore R_{C(max)} = \frac{12 - 2.867}{9 \times 10^{-3}} = 13{,}014.56\ \Omega$$

$$R_{C(min)} = \frac{12 - 2.867}{3 \times 10^{-4}} = 390{,}436.67\ \Omega$$

(b) $R_2 = \frac{V_2}{I_2}$

$$I_2 = I_1 - I_B$$

$$I_{2(max)} = (2.511 \times 10^{-4}) - (5 \times 10^{-6}) = 2.46 \times 10^{-4}\ A$$

$$I_{2(min)} = (2.511 \times 10^{-4}) - (150 \times 10^{-6}) = 1.011 \times 10^{-4}\ A$$

$$R_{2(min)} = \frac{0.7}{2.461 \times 10^{-4}} = 28\cancel{4}44.372\ \Omega$$

$$R_{2(max)} = \frac{0.7}{1.011 \times 10^{-4}} = 6923.838\ \Omega$$

(c) $I_1 = I_2 + I_B$

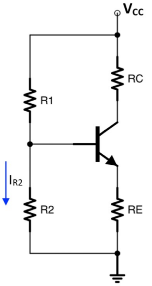
$$I_{1(max)} = 1.75 \times 10^{-4} + 9 \times 10^{-3} = 9.175 \times 10^{-3}$$

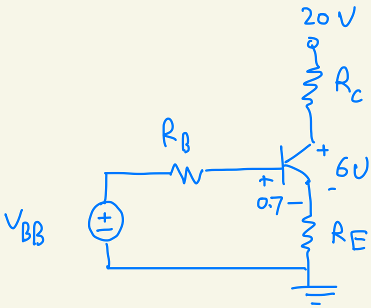
$$I_{2(min)} = 1.75 \times 10^{-4} + 3 \times 10^{-4} = 4.75 \times 10^{-4}$$

$$R_1 = \frac{V_1}{I_1} \longrightarrow R_{1\,max} = \frac{11.2995}{9.175 \times 10^{-3}} = 1231.55\ \Omega$$

$$R_{1\,min} = \frac{11.2995}{4.75 \times 10^{-4}} = 23{,}788.42\ \Omega$$

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 $I_{R2} = 2I_B$.





$$V_{BB} = \frac{V_{CC} R_2}{R_1 + R_2} = \frac{20 R_2}{R_1 + R_2}$$

$$R_B = \frac{R_1 + R_2}{R_1 \times R_2}$$

$$\beta = \frac{I_C}{I_B}$$

$$I_B = \frac{I_C}{\beta} = \frac{2.5\times10^{-3}}{100} = 2.5\times10^{-5} A$$

$$I_E = \frac{I_C(1+\beta)}{\beta} = 2.525\times10^{-3} A$$

By KVL:

$$20 - I_C R_C - 6 - I_E R_E = 0$$

$R_C = R_E$

$$\therefore \quad 14 = R_E (I_C + I_E)$$

$$\boxed{R_E = \frac{14}{I_C + I_E} = R_C = 2786.07\,\Omega}$$

$$I_1 = I_2 + I_B$$

$$I_2 = 2I_B = 5\times10^{-5}$$

$$I_1 = 5\times10^{-5} + 2.5\times10^{-5} = 7.5\times10^{-5} A$$

$$V_2 = 0.7 + V_E = 0.7 + (2.525\times10^{-3})(2786.07) = 7.735 V$$

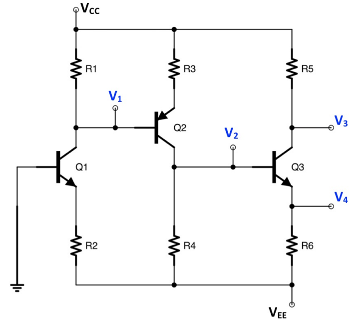
$$\boxed{R_2 = \frac{V_2}{I_2} = \frac{7.735}{5\times10^{-5}} = 154.7 K\Omega}$$

$$\boxed{R_1 = \frac{V_1}{I_1} = \frac{12.265}{7.5\times10^{-5}} = 163.5k\Omega}$$

by KVL:

$$V_{CC} - V_1 - V_2 = 0 \rightarrow V_1 = V_{CC} - V_2 = 20 - 7.735 = 12.265$$

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 current), $V_{CE(Sat)} = 0.2V$, $V_A = 300V$, and $|V_{BE(on)}| = 0.7V$.



$\beta = \infty$, so $I_c = I_E$

$$\boxed{R_1 = \frac{V_{CC} - V_1}{I_{C1}} = \frac{10-2}{2mA} = 4000\ \Omega}$$

$$-V_{BE} - I_{E1} R_2 - (-10V) = 0$$

$$\boxed{R_2 = \frac{10-0.7}{2mA} = 4650\ \Omega}$$

$V_{B2} = 2V$, $V_{C2} = -3V$ $\Rightarrow$ $V_{BC2} = 5V$

F.B

$V_{EC_2} = 0.7 + 5 = 5.7V$

so, $10 - I_{C2} R_3 - 5.7 - 7 - (-10) = 0$

$$\boxed{R_3 = \frac{7.3}{2mA} = 3650\ \Omega}$$

$$\boxed{R_5 = \frac{V_{CC} - V_3}{I_{C3}} = \frac{10}{4mA} = 2500\ \Omega}$$

$$\boxed{R_4 = \frac{V_2 - V_{EE}}{I_{C2}} = \frac{-3-(-10)}{2mA} = 3500\ \Omega}$$

$V_2 = -3$, $V_4 = -3.7V$

$$\boxed{R_6 = \frac{V_4 - V_{EE}}{I_{E3}} = \frac{-3.7-(-10)}{4mA} = 1575\ \Omega}$$