MECH 368 – ELECTRONICS FOR MECHANICAL ENGINEERS

ASSIGNMENT #4
(10.2, 10.3, 10.5, 10.6, 10.32)

Problem 10.2

Solution:

Known quantities:
Transistor type and operating characteristics:

(a) npn, V_{BE} = 0.8 V and V_{CE} = 0.4 V
(b) npn, V_{CB} = 1.4 V and V_{CE} = 2.1 V
(c) pnp, V_{CB} = 0.9 V and V_{CE} = 0.4 V
(d) npn, V_{BE} = - 1.2 V and V_{CB} = 0.6 V

Find: The region of operation for each transistor.

Analysis:

(a) Since V_{BE} = 0.8 V, the BE junction is forward-biased. $V_{CB} = V_{CE} + V_{EB}$ = - 0.4 V. Thus, the CB junction is forward-biased. Therefore, the transistor is in the saturation region.
(b) $V_{BE} = V_{BC} + V_{CE}$ = 0.7 V. The BE junction is forward-biased.
V_{CB} = 1.4 V. The CB junction is reverse-biased. Therefore, the transistor is in the active region.
(c) V_{CB} = 0.9 V for a pnp transistor implies that the CB junction is forward-biased.
$V_{BE} = V_{BC} – V_{CE}$ = - 1.3 V. The BE junction is forward-biased. Therefore, the transistor is in the saturation region.
(d) With V_{BE} = - 1.2 V, the BE junction is reverse-biased.
V_{CB} = - 0.6 V. The CB junction is reverse-biased. Therefore, the transistor is in the cutoff region.

Problem 10.3

Solution:

Known quantities: The circuit of Figure P10.3. $\beta = \frac{I_C}{I_B} = 100$.

Find:
The operating point and the state of the transistor.

Analysis:

$V_{BE} = 0.6\text{ V}$ and the BE junction is forward biased.

$$I_B = \frac{V_{CC} - V_{BE}}{R_1 + (\beta + 1)R_E} = \frac{12 - 0.6}{820 + (101)(0.910)} = 12.5\,\mu\text{A}$$

$$I_C = \beta \cdot I_B = 1.25\text{mA}$$

Writing KVL around the right-hand side of the circuit:

$$-V_{CC} + I_C R_C + V_{CE} + I_E R_E = 0 \quad \Rightarrow \quad \begin{aligned} V_{CE} &= V_{CC} - I_C R_C - (I_B + I_C)R_E \\ &= 12 - (1.25)(2.2) - (0.0125 + 1.25)(0.910) \\ &= 8.10\text{ V} \end{aligned}$$

$$V_{CB} = V_{CE} - V_{BE} = 8.10 - 0.6 = 7.50\text{ V}$$

Since the BE junction is forward biased and the BC junction is reverse biased, and also (extra information) $V_{CE} > V_{BE} \Rightarrow$ The transistor is in the active region.

Problem 10.5

Solution:

Known quantities:
The circuit of Figure P10.5, assuming the BJT has $V_\gamma = 0.6\,\mathrm{V}$.

Find:
The emitter current and the collector-base voltage.

Analysis: ***NOTE: The voltage source on the right of the circuit should be of opposite polarity.***

Applying KVL to the right-hand side of the circuit, $I_E = \left(\frac{15 - V_{BE}}{30000}\right) = \frac{15-0.6}{30000} = 520\,\mu\mathrm{A}$

Then, on the left-hand side, assuming $\beta >> 1$:

$$-10 + I_C R_C + V_{CB} = 0 \qquad \Rightarrow \qquad \begin{aligned} V_{CB} &= 10 - I_C \cdot R_C \\ &= 10 - (-520)\cdot(15)\cdot 10^{-3} \\ &= 17.8\,\mathrm{V} \end{aligned}$$

Problem 10.6

Solution:

Known quantities:

The circuit of Figure P10.6, assuming the BJT has $V_\gamma = 0.6\,\mathrm{V}$ and $\beta = \frac{I_C}{I_B} = 150$.

Find:
The operating point and the state of the transistor.

Analysis:
First, determine the Thèvenin equivalent of the circuit connected to the base:

$$V_{BB} = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{15}{62+15}\cdot 18 = 3.506\,\mathrm{V}$$

$$R_{BB} = R_1 \| R_2 = \frac{62\cdot 15}{62+15} = 12.08\,\mathrm{k\Omega}$$

Then, applying KVL to the left-hand side of the circuit, we have: $-V_{BB} + I_B R_{BB} + V_{BE} + I_E R_E = 0$

But $I_E = (\beta + 1)\cdot I_B$, so the last equation becomes:

$$V_{BB} = I_B R_{BB} + V_{BE} + (\beta+1) I_B R_E \qquad \Rightarrow \qquad V_{BB} - V_{BE} = I_B\left[R_{BB} + (\beta+1)R_E\right]$$

$$I_B = \frac{V_{BB} - V_{BE}}{\left[R_{BB} + (1+\beta)\cdot R_E\right]} = \frac{3.506 - 0.600}{12080 + 151\cdot 1200} = 15.04\,\mu\mathrm{A}$$

$$I_C = \beta \cdot I_B = 2.256\,\mathrm{mA}$$

Applying KVL to the right-hand side,

$$V_{CE} = V_{CC} - \beta \cdot I_B R_C - (\beta+1) \cdot I_B R_B$$

$$-V_{CC} + I_C R_C + V_{CE} + I_E R_E = 0 \quad \Rightarrow \quad = 18 - 150 \cdot 15.04 \cdot 3.3 \cdot 10^{-3} - 151 \cdot 15.04 \cdot 1.2 \cdot 10^{-3}$$

$$= 7.83\,\text{V}$$

Therefore, $I_{BQ} = 15.04\,\mu\text{A}$, $I_{CQ} = 2.256\,\text{mA}$ and $V_{CEQ} = 7.83\,\text{V}$.
The transistor is in the active linear region.

Problem 10.32

Solution:

Known quantities: For the circuit shown in Figure P10.32:
$V_{CC} = 12\,\text{V}$ $\beta = 130$ $R_1 = 82\,\text{k}\Omega$ $R_2 = 22\,\text{k}\Omega$ $R_E = 0.5\,\text{k}\Omega$ $R_L = 16\Omega$.

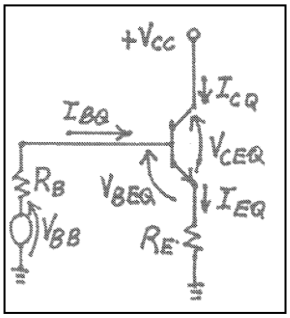
Find:
V_{CEQ} at the DC operating point.

Analysis:
Simplify the circuit by obtaining the Thèvenin equivalent of the biasing network (R_1, R_2, V_{CC}) in the base circuit:

$$\text{VD}: \; V_{BB} = V_{TH} = V_{OC} = \frac{V_{CC}\,R_2}{R_1 + R_2} = \frac{12 \cdot 22}{82 + 22} = 2.538\,\text{V}$$

$$\text{Suppress } V_{CC}: \quad R_B = R_{eq} = \frac{R_1 R_2}{R_1 + R_2} = \frac{82 \cdot 22}{82 + 22} = 17.35\,\text{k}\Omega$$

Redraw the circuit using the Thèvenin equivalent. The "DC blocking" or "AC coupling" capacitors act as open circuits for DC; therefore, the signal source and load can be neglected since this is a DC problem. Specify directions of current and polarities of voltages.



Assume the transistor is operating in its active region. Then, the base-emitter junction is forward biased.

$$V_{BEQ} \approx 700\,\text{mV} \quad [Si] \qquad I_{EQ} = [\,\beta + 1\,]\, I_{BQ}$$

$$\text{KVL}: \; -V_{BB} + I_{BQ} R_B + V_{BEQ} + I_{EQ} R_E = 0$$

$$-V_{BB} + I_{BQ} R_B + V_{BEQ} + [\,\beta + 1\,]\, I_{BQ} R_E = 0$$

$$I_{BQ} = \frac{V_{BB} - V_{BEQ}}{R_B + (\beta+1) \cdot R_E} = \frac{2.538 - 0.7}{17350 + (130+1) \cdot 500} = 22.18\,\mu\text{A}$$

$$I_{EQ} = (\beta + 1)\, I_{BQ} = (130 + 1) \cdot 22.18 \cdot 10^{-6} = 2.906\,\text{mA}$$

$$\text{KVL}: \; -I_{EQ} R_E - V_{CEQ} + V_{CC} = 0$$

$$V_{CEQ} = V_{CC} - I_{EQ} R_E = 12 - 2.906 \cdot 0.5 = 10.55\,\text{V}$$

The collector-emitter voltage is greater than its saturation value (0.3 V for Silicon). Therefore the initial assumption (operation in the active region) was correct and the solution is valid.
