Biasing BJT Circuits

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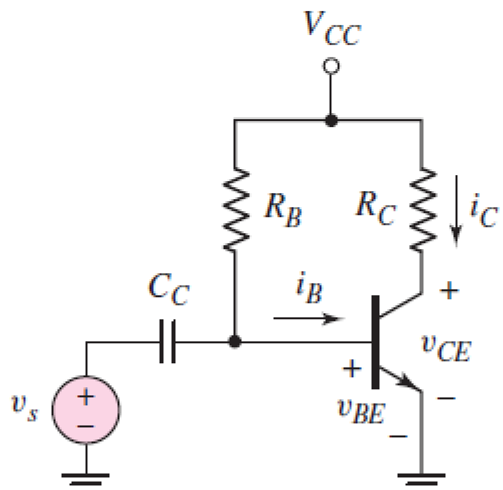
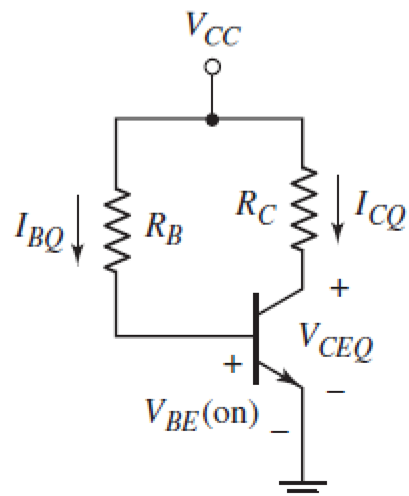
Single Base Resistor Biasing

- Common-emitter circuit with a single bias resistor in the base and dc equivalent circuit

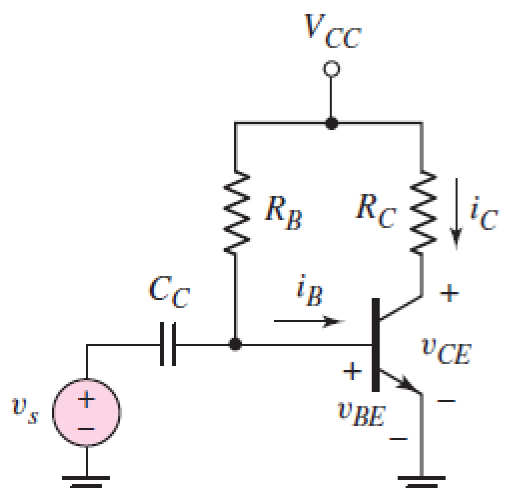


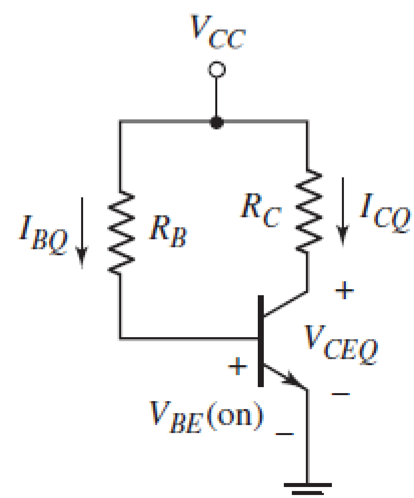


- Quiescent base current is established through the resistor R_B
- The **coupling capacitor** C_C acts as an open circuit to dc
  – Isolating the signal source from the dc base current
- **Q-point** values are indicated by the additional subscript **Q**

Design Example

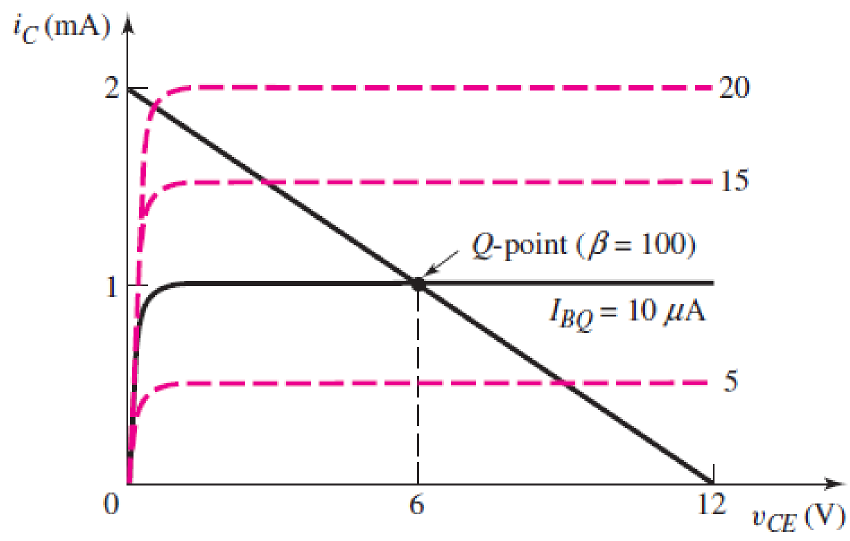
- **Design** a circuit with a single-base resistor to meet a set of specifications.
- Specifications: The circuit is to be biased with V_{CC} = +12 V. The transistor quiescent values are to be I_{CQ} = 1 mA and V_{CEQ} = 6 V





Solution

- Collector resistor $R_C = \dfrac{V_{CC} - V_{CEQ}}{I_{CQ}} = \dfrac{12 - 6}{1} = 6\,\text{k}\Omega$
- Base current $I_{BQ} = \dfrac{I_{CQ}}{\beta} = \dfrac{1\text{ mA}}{100} \Rightarrow 10\,\mu\text{A}$
- Base resistor $R_B = \dfrac{V_{CC} - V_{BE}(\text{on})}{I_{BO}} = \dfrac{12 - 0.7}{10\,\mu\text{A}} = 1.13\,\text{M}\Omega$
- The transistor characteristics, load line, and *Q*-point for this set of conditions



Effect of **β** variation

- Assume
  - The resistor values are fixed
  - **The designed resistor values are available**
- The base current

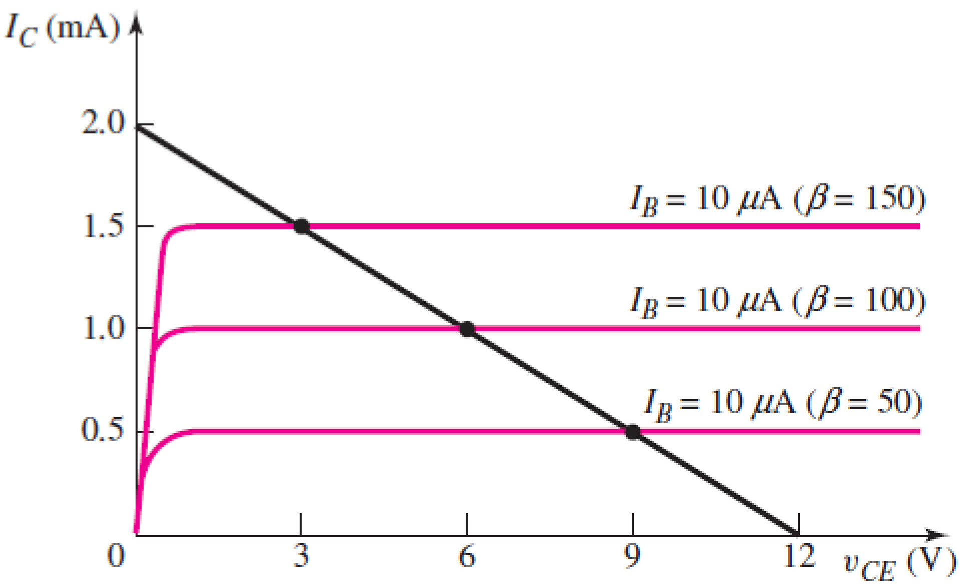
$$I_{BQ} = \frac{V_{CC} - V_{BE}(\text{on})}{R_B} = \frac{12 - 0.7}{1.13\ \text{M}\Omega} = 10\ \mu\text{A}\ \ \text{(unchanged)}$$

- Base current for this circuit configuration is independent of **β**
- Collector current $I_{CQ} = \beta I_{BQ}$
- The load line is fixed. However, the *Q*-point will change
- $V_{CEQ} = V_{CC} - I_{CQ} R_C$

β	**50**	**100**	**150**
Q-point values	$I_{CQ} = 0.50$ mA $V_{CEQ} = 9$ V	$I_{CQ} = 1$ mA $V_{CEQ} = 6$ V	$I_{CQ} = 1.5$ mA $V_{CEQ} = 3$ V

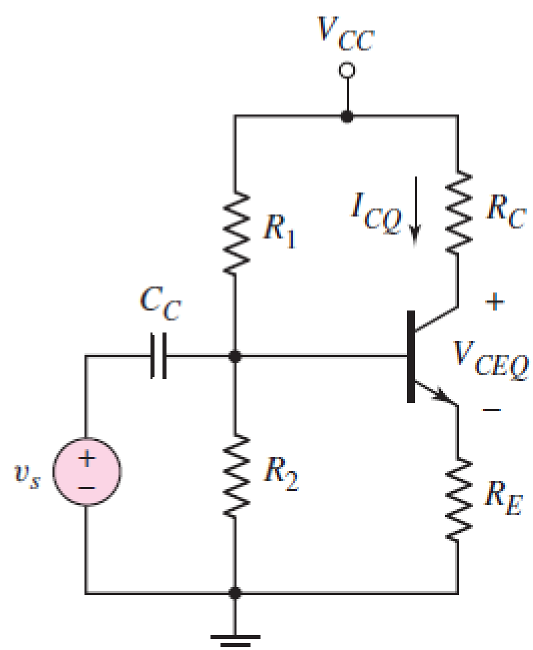
Solution

- With a single base resistor, the Q-point is not stabilized against variations in **β**
- As **β** changes, the Q-point varies significantly
- Value of 1.13 MΩ for R_B will establish the required base current
- This **resistance is too large to be used in integrated circuits**



Voltage Divider Biasing and Bias Stability

- The single bias resistor R_B in single Base Resistor Biasing circuit is replaced by a pair of resistors R1 and R2, and an emitter resistor R_E is added
- The ac signal is coupled to the base of the transistor through the coupling capacitor $\mathbf{C_C}$ (**acts as an open circuit to dc**)

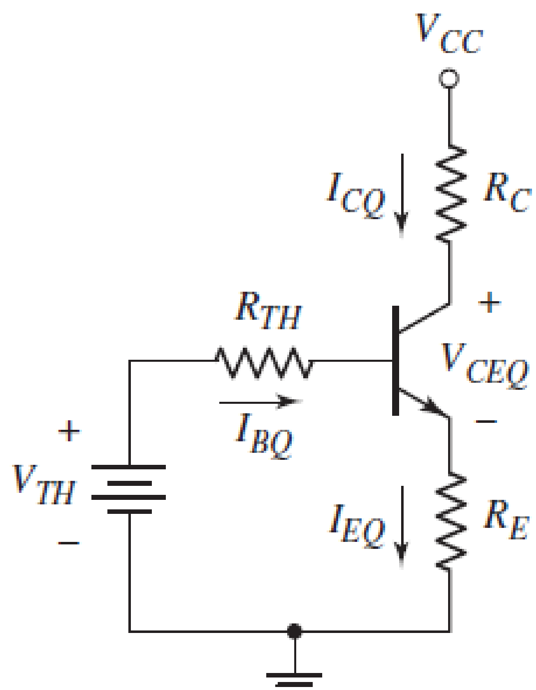


DC circuit with a Thevenin equivalent base circuit

$$V_{TH} = [R_2/(R_1 + R_2)]V_{CC}$$

and the equivalent Thevenin resistance is

$$R_{TH} = R_1 \| R_2$$



Thevenin's Equivalent Circuit

- Applying Kirchhoff's law around the B–E loop

$$V_{TH} = I_{BQ}R_{TH} + V_{BE}(\text{on}) + I_{EQ}R_E$$

- If the transistor is biased in the forward-active mode

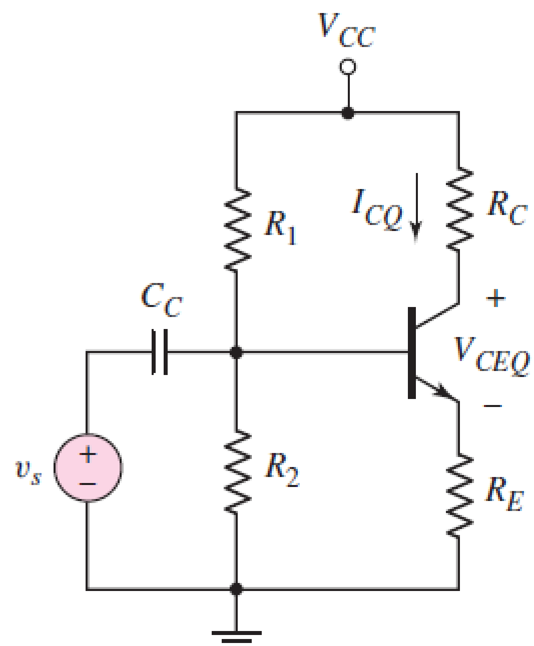
$$I_{EQ} = (1 + \beta)I_{BQ}$$

$$I_{BQ} = \frac{V_{TH} - V_{BE}(\text{on})}{R_{TH} + (1 + \beta)R_E}$$

$$I_{CQ} = \beta I_{BQ} = \frac{\beta(V_{TH} - V_{BE}(\text{on}))}{R_{TH} + (1 + \beta)R_E}$$

Design Example

- Let R_1 = 56 k, R_2 = 12.2 k, R_C = 2 k, R_E = 0.4 k, V_{CC} = 10 V, $V_{BE(on)}$ = 0.7 V, and β = 100
- Analyze a circuit and determine the **change in the *Q*-point** with a variation in β



Solution

$$R_{TH} = R_1 \| R_2 = 56 \| 12.2 = 10.0\,\mathrm{k\Omega}$$

and

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right) \cdot V_{CC} = \left(\frac{12.2}{56 + 12.2}\right)(10) = 1.79\,\mathrm{V}$$

$$I_{BQ} = \frac{V_{TH} - V_{BE}(\mathrm{on})}{R_{TH} + (1+\beta)R_E} = \frac{1.79 - 0.7}{10 + (101)(0.4)} \Rightarrow 21.6\,\mu\mathrm{A}$$

The collector current is

$$I_{CQ} = \beta I_{BQ} = (100)(21.6\,\mu\mathrm{A}) \Rightarrow 2.16\,\mathrm{mA}$$

and the emitter current is

$$I_{EQ} = (1+\beta)I_{BQ} = (101)(21.6\,\mu\mathrm{A}) \Rightarrow 2.18\,\mathrm{mA}$$

The quiescent C–E voltage is then

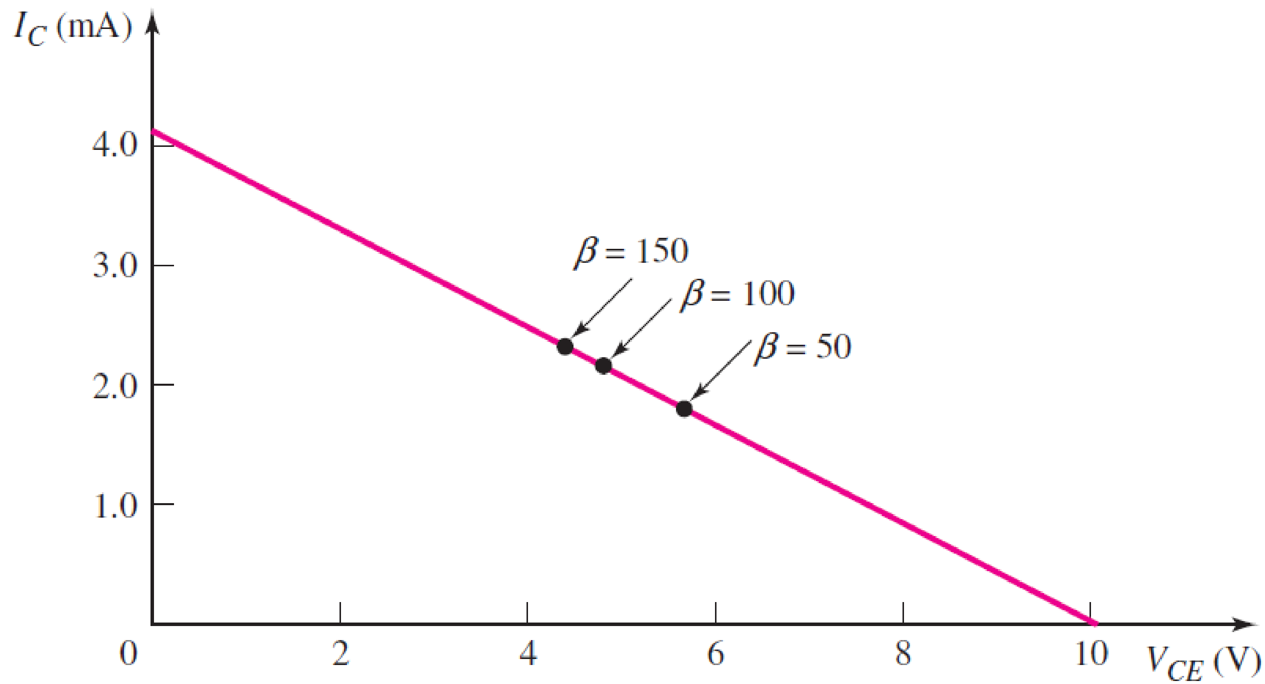
$$V_{CEQ} = V_{CC} - I_{CQ}R_C - I_{EQ}R_E = 10 - (2.16)(2) - (2.18)(0.4) = 4.81\,\mathrm{V}$$

- These results show that the transistor is biased in the active region

Analysis

β	50	100	150
Q-point values	$I_{BQ} = 35.9\ \mu A$ $I_{CQ} = 1.80$ mA $V_{CEQ} = 5.67$ V	$I_{BQ} = 21.6\ \mu A$ $I_{CQ} = 2.16$ mA $V_{CEQ} = 4.81$ V	$I_{BQ} = 15.5\ \mu A$ $I_{CQ} = 2.32$ mA $V_{CEQ} = 4.40$ V

For a **3 : 1 ratio in β**, the collector current and collector–emitter voltage change by only a **1.29 : 1 ratio**



Analysis & Comparison

- The voltage divider circuit of R_1 and R_2 can bias the transistor in its active region using resistor values in **low kilo Ohm** range
- In contrast, single resistor biasing requires a resistor in the **mega ohm range**
- The change in I_{CQ} and V_{CEQ} with a change in **β** has been substantially reduced compared to the change in the single resistor biasing circuit

- Including an emitter resistor R_E
  - Helps to stabilize the Q-point with respect to variations in β
  - Introduces negative feedback,
  - Negative feedback tends to stabilize circuits

Comments

- Considering the equation

$$I_{CQ} = \beta I_{BQ} = \frac{\beta(V_{TH} - V_{BE}(\text{on}))}{R_{TH} + (1+\beta)R_E}$$

- The design requirement for bias stability is $\mathbf{R_{TH} << (1 + \beta)R_E}$.
- Consequently, the collector current is approximately

$$I_{CQ} \cong \frac{\beta(V_{TH} - V_{BE}(\text{on}))}{(1+\beta)R_E}$$

- Normally, **β >> 1**; therefore, **β** /(1 + **β**) ~= 1, and

$$I_{CQ} \cong \frac{(V_{TH} - V_{BE}(\text{on}))}{R_E}$$

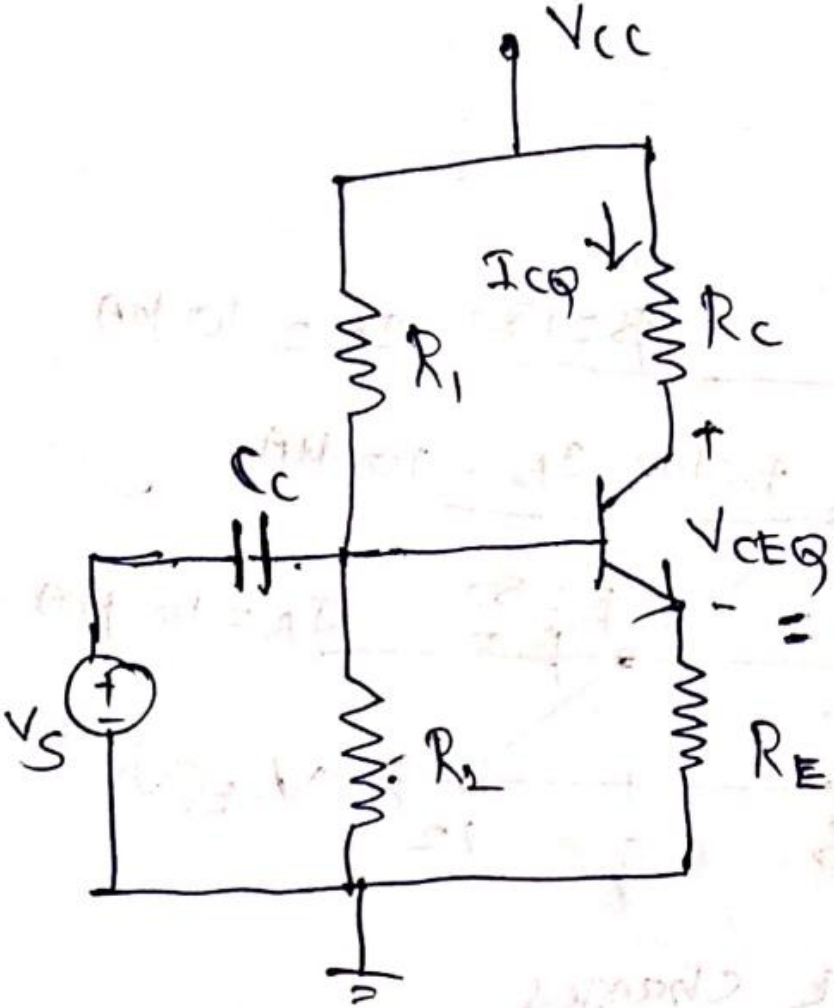
- Now the quiescent collector current is essentially a function of only the dc voltages and the emitter resistance
- Q-point is stabilized against **β** variations

Comments

- However, if R_{TH} is too small, then R_1 and R_2 are small, and excessive power is dissipated in these resistors
- The general rule is that a circuit is considered **bias stable** when

$$R_{TH} \cong 0.1(1 + \beta) R_E$$

Design Example



$V_{CC} = 5\text{ V}$

$R_C = 1\text{ k}\Omega$

choose R_E & determine bias resistor R_1 & R_2 such that the circuit is considered bias stable and that $V_{CEQ} = 3\text{ V}$

Solution

Let $\beta = 120$ $V_{BE(on)} = 0.7\,V$

$I_{CQ} \cong I_{EQ}$

Let $R_E = 0.51\,k\Omega$ (standard value)

$$I_{CQ} = \frac{V_{CC} - V_{CEQ}}{R_C + R_E} = \frac{5-3}{1+0.51} = 1.32 \text{ mA}$$

$$V_{RE} = I_{EQ} \cdot R_E = 1.32\text{m} \times 0.51\text{ K}$$

$$= 0.673 \text{ V}$$

$$I_{BQ} = \frac{I_{CQ}}{\beta} = \frac{1.32\text{m}}{120} = 11 \ \mu\text{A}$$

By Thevenins Eqvt ckt

$$I_{BQ} = \frac{V_{th} - V_{BE(on)}}{R_{th} + (1+\beta).R_E}$$

for bias stable circuit $\cdot R_{th} = 0.1(1+\beta) R_E$

$= 6.17\ k\Omega$

$$I_{BQ} = \frac{V_{th} - 0.7}{6.17 + 121 \times 0.51}$$

$V_{th} = 1.45\ V$

$$V_{th} = V_{cc}\left(\frac{R_2}{R_1+R_2}\right) = 5\left(\frac{R_2}{R_1+R_2}\right)$$

$$\frac{R_2}{R_1+R_2} = 0.29$$

$$R_{th} = \frac{R_1 R_2}{R_1+R_2} = 6.17\ K$$

$$R_1\left(\frac{R_2}{R_1+R_2}\right) = 6.17\ K$$

$$R_1 = \frac{6.17\,K}{0.29} = 21.3\,k\Omega$$

$$R_2 = 8.69\,k\Omega$$

Standard resistor values

$$R_1 = 20\,k\Omega$$

$$R_2 = 8.2\,k\Omega$$

Effect on Q-point ~~variation~~ values with β variation

$$R_1 = 20\ k\Omega$$

$$R_2 = 8.2\ k\Omega$$

$$R_{TH} = R_1 \parallel R_2 = \underline{5.82}\ k\Omega$$

$$V_{TH} = V_{CC}\left(\frac{R_2}{R_1+R_2}\right) = 5\left(\frac{8.2}{20+8.2}\right)$$

$$V_{TH} = \underline{1.454}\ V$$

$$\boxed{I_{BQ} = \frac{V_{TH} - V_{BE(on)}}{R_{TH} + (1+\beta) R_E}}$$

$$\boxed{I_{CQ} = \beta I_{BQ}}$$

$$V_{CEQ} = V_{CC} - I_{CQ} R_C - I_{EQ} R_E$$

$$= V_{CC} - I_{CQ} R_C - \frac{I_{CQ}}{\alpha} R_E$$

$$\boxed{V_{CEQ} = V_{CC} - I_{CQ} \left(R_C - \left(\frac{\beta+1}{\beta} \right) R_E \right)}$$

Analysis

- Collector current changes by only −8.2 percent when changes by a factor of 2 (from 120 to 60), and changes by only +3.0 percent when changes by +50 percent (from 120 to 180)
- The Q-point is now considered to be stabilized against variations in **β**
- Voltage divider resistors R1 and R2 have reasonable values in the kilo ohm range

β	60	120	180
Q-point values	$I_{BQ} = 20.4\ \mu A$ $I_{CQ} = 1.23$ mA $V_{CEQ} = 3.13$ V	$I_{BQ} = 11.2\ \mu A$ $I_{CQ} = 1.34$ mA $V_{CEQ} = 2.97$ V	$I_{BQ} = 7.68\ \mu A$ $I_{CQ} = 1.38$ mA $V_{CEQ} = 2.91$ V

References

- Donald A Neamen, Microelectronics: Circuit Analysis and Design / Edition 4, 2010.