4.4 EMITTER-STABILIZED BIAS CIRCUIT

The dc bias network of Fig. 4.17 contains an emitter resistor to improve the stability level over that of the fixed-bias configuration. The improved stability will be demonstrated through a numerical example later in the section. The analysis will be performed by first examining the base–emitter loop and then using the results to investigate the collector–emitter loop.

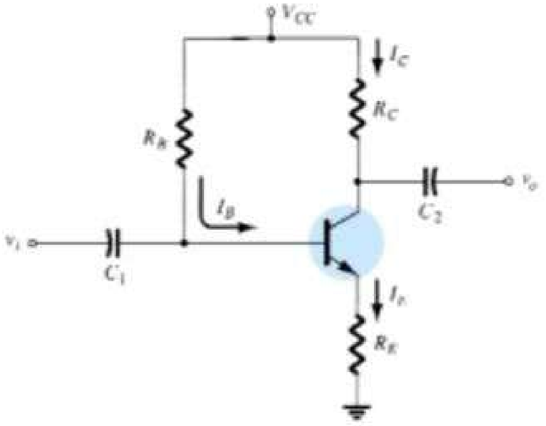


Figure 4.17 BJT bias circuit with emitter resistor.

Base–Emitter Loop

The base–emitter loop of the network of Fig. 4.17 can be redrawn as shown in Fig. 4.18. Writing Kirchhoff's voltage law around the indicated loop in the clockwise direction will result in the following equation:

$$+V_{CC} - I_B R_B - V_{BE} - I_E R_E = 0 \tag{4.15}$$

Recall from Chapter 3 that

$$I_E = (\beta + 1)I_B \tag{4.16}$$

Substituting for I_E in Eq. (4.15) will result in

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

Grouping terms will then provide the following:

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

Multiplying through by (-1) we have

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

with

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

and solving for I_B gives

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} \tag{4.17}$$

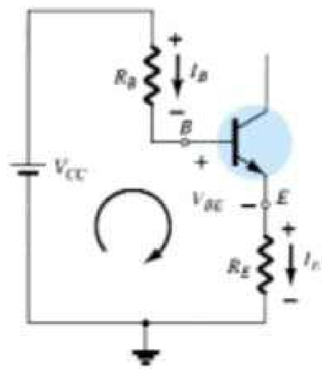


Figure 4.18 Base–emitter loop.

Note that the only difference between this equation for I_B and that obtained for the fixed-bias configuration is the term $(\beta + 1)R_E$.

There is an interesting result that can be derived from Eq. (4.17) if the equation is used to sketch a series network that would result in the same equation. Such is

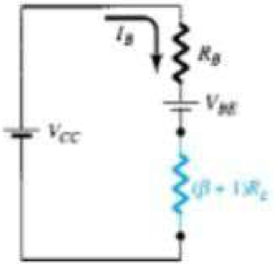


Figure 4.19 Network derived from Eq. (4.17).

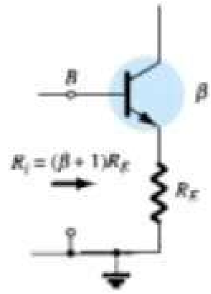


Figure 4.20 Reflected impedance level of R_E.

the case for the network of Fig. 4.19. Solving for the current I_B will result in the same equation obtained above. Note that aside from the base-to-emitter voltage V_{BE}, the resistor R_E is *reflected* back to the input base circuit by a factor $(\beta + 1)$. In other words, the emitter resistor, which is part of the collector–emitter loop, "appears as" $(\beta + 1)R_E$ in the base–emitter loop. Since β is typically 50 or more, the emitter resistor appears to be a great deal larger in the base circuit. In general, therefore, for the configuration of Fig. 4.20,

$$R_i = (\beta + 1)R_E \tag{4.18}$$

Equation (4.18) is one that will prove useful in the analysis to follow. In fact, it provides a fairly easy way to remember Eq. (4.17). Using Ohm's law, we know that the current through a system is the voltage divided by the resistance of the circuit. For the base–emitter circuit the net voltage is $V_{CC} - V_{BE}$. The resistance levels are R_B plus R_E reflected by $(\beta + 1)$. The result is Eq. (4.17).

Collector–Emitter Loop

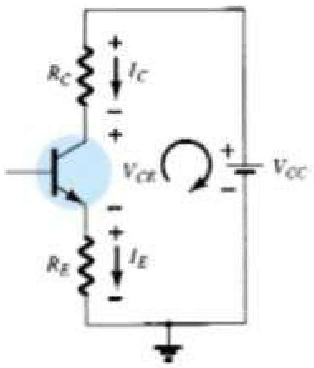


Figure 4.21 Collector–emitter loop.

The collector–emitter loop is redrawn in Fig. 4.21. Writing Kirchhoff's voltage law for the indicated loop in the clockwise direction will result in

$$+I_ER_E + V_{CE} + I_CR_C - V_{CC} = 0$$

Substituting $I_E \cong I_C$ and grouping terms gives

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

and

$$V_{CE} = V_{CC} - I_C(R_C + R_E) \tag{4.19}$$

The single-subscript voltage V_E is the voltage from emitter to ground and is determined by

$$V_E = I_ER_E \tag{4.20}$$

while the voltage from collector to ground can be determined from

$$V_{CE} = V_C - V_E$$

and

$$V_C = V_{CE} + V_E \tag{4.21}$$

or

$$V_C = V_{CC} - I_CR_C \tag{4.22}$$

The voltage at the base with respect to ground can be determined from

$$V_B = V_{CC} - I_BR_B \tag{4.23}$$

or

$$V_B = V_{BE} + V_E \tag{4.24}$$

For the emitter bias network of Fig. 4.22, determine:

EXAMPLE 4.4

(a) I_B.
(b) I_C.
(c) V_{CE}.
(d) V_C.
(e) V_E.
(f) V_B.
(g) V_{BC}.

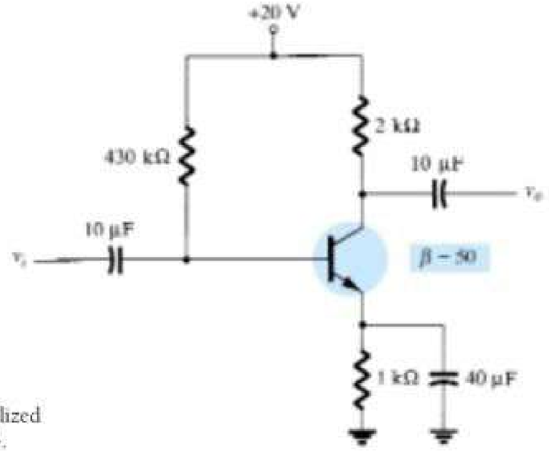


Figure 4.22 Emitter-stabilized bias circuit for Example 4.4.

Solution

(a) Eq. (4.17): $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} = \dfrac{20\text{ V} - 0.7\text{ V}}{430\text{ k}\Omega + (51)(1\text{ k}\Omega)}$

$= \dfrac{19.3\text{ V}}{481\text{ k}\Omega} = \mathbf{40.1\ \mu A}$

(b) $I_C = \beta I_B$

$= (50)(40.1\ \mu\text{A})$

$\cong \mathbf{2.01\ mA}$

(c) Eq. (4.19): $V_{CE} = V_{CC} - I_C(R_C + R_E)$

$= 20\text{ V} - (2.01\text{ mA})(2\text{ k}\Omega + 1\text{ k}\Omega) = 20\text{ V} - 6.03\text{ V}$

$= \mathbf{13.97\ V}$

(d) $V_C = V_{CC} - I_C R_C$

$= 20\text{ V} - (2.01\text{ mA})(2\text{ k}\Omega) = 20\text{ V} - 4.02\text{ V}$

$= \mathbf{15.98\ V}$

(e) $V_E = V_C - V_{CE}$

$= 15.98\text{ V} - 13.97\text{ V}$

$= \mathbf{2.01\ V}$

or $V_E = I_E R_E \cong I_C R_E$

$= (2.01\text{ mA})(1\text{ k}\Omega)$

$= \mathbf{2.01\ V}$

(f) $V_B = V_{BE} + V_E$

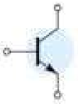
$= 0.7\text{ V} + 2.01\text{ V}$

$= \mathbf{2.71\ V}$

(g) $V_{BC} = V_B - V_C$

$= 2.71\text{ V} - 15.98\text{ V}$

$= \mathbf{-13.27\ V}$ (reverse-biased as required)



Improved Bias Stability

The addition of the emitter resistor to the dc bias of the BJT provides improved stability, that is, the dc bias currents and voltages remain closer to where they were set by the circuit when outside conditions, such as temperature, and transistor beta, change. While a mathematical analysis is provided in Section 4.12, some comparison of the improvement can be obtained as demonstrated by Example 4.5.

EXAMPLE 4.5

Prepare a table and compare the bias voltage and currents of the circuits of Figs. 4.7 and Fig. 4.22 for the given value of $\beta = 50$ and for a new value of $\beta = 100$. Compare the changes in I_C and V_{CE} for the same increase in β.

Solution

Using the results calculated in Example 4.1 and then repeating for a value of $\beta = 100$ yields the following:

β	I_B (μA)	I_C (mA)	V_{CE} (V)
50	47.08	2.35	6.83
100	47.08	4.71	1.64

The BJT collector current is seen to change by 100% due to the 100% change in the value of β. I_B is the same and V_{CE} decreased by 76%.

Using the results calculated in Example 4.4 and then repeating for a value of $\beta = 100$, we have the following:

β	I_B (μA)	I_C (mA)	V_{CE} (V)
50	40.1	2.01	13.97
100	36.3	3.63	9.11

Now the BJT collector current increases by about 81% due to the 100% increase in β. Notice that I_B decreased, helping maintain the value of I_C—or at least reducing the overall change in I_C due to the change in β. The change in V_{CE} has dropped to about 35%. The network of Fig. 4.22 is therefore more stable than that of Fig. 4.7 for the same change in β.

Saturation Level

The collector saturation level or maximum collector current for an emitter-bias design can be determined using the same approach applied to the fixed-bias configuration: Apply a short circuit between the collector–emitter terminals as shown in Fig. 4.23 and calculate the resulting collector current. For Fig. 4.23:

$$I_{C_{sat}} = \frac{V_{CC}}{R_C + R_E} \tag{4.25}$$

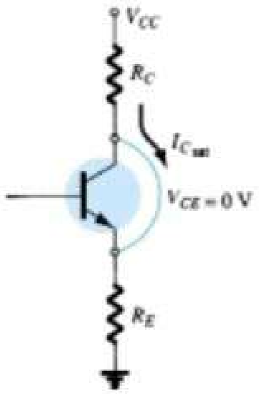


Figure 4.23 Determining $I_{C_{sat}}$ for the emitter-stabilized bias circuit.

The addition of the emitter resistor reduces the collector saturation level below that obtained with a fixed-bias configuration using the same collector resistor.