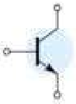
as shown in Fig. 4.24. Different levels of I_{B_Q} will, of course, move the Q-point up or down the load line.

4.5 VOLTAGE-DIVIDER BIAS

In the previous bias configurations the bias current I_{C_Q} and voltage V_{CE_Q} were a function of the current gain (β) of the transistor. However, since β is temperature sensitive, especially for silicon transistors, and the actual value of beta is usually not well defined, it would be desirable to develop a bias circuit that is less dependent, or in



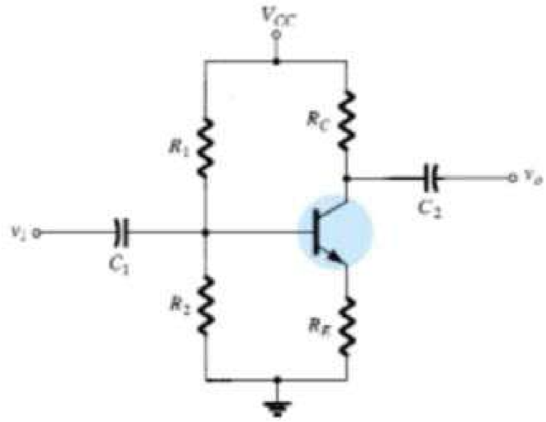


Figure 4.25 Voltage-divider bias configuration.

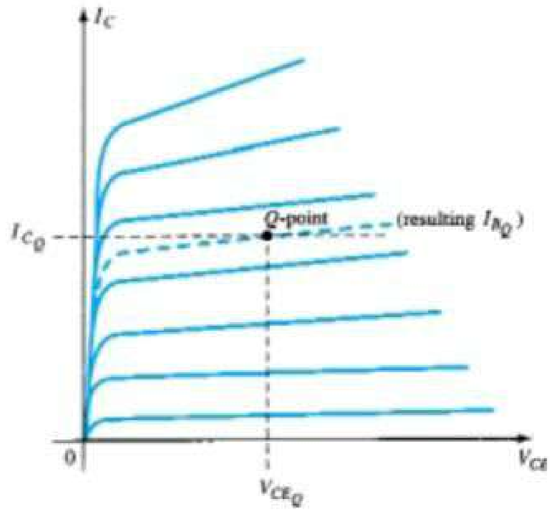


Figure 4.26 Defining the Q-point for the voltage-divider bias configuration.

fact, independent of the transistor beta. The voltage-divider bias configuration of Fig. 4.25 is such a network. If analyzed on an exact basis the sensitivity to changes in beta is quite small. If the circuit parameters are properly chosen, the resulting levels of I_{C_Q} and V_{CE_Q} can be almost totally independent of beta. Recall from previous discussions that a Q-point is defined by a fixed level of I_{C_Q} and V_{CE_Q} as shown in Fig. 4.26. The level of I_{B_Q} will change with the change in beta, but the operating point on the characteristics defined by I_{C_Q} and V_{CE_Q} can remain fixed if the proper circuit parameters are employed.

As noted above, there are two methods that can be applied to analyze the voltage-divider configuration. The reason for the choice of names for this configuration will become obvious in the analysis to follow. The first to be demonstrated is the *exact method* that can be applied to *any* voltage-divider configuration. The second is referred to as the *approximate method* and can be applied only if specific conditions are satisfied. The approximate approach permits a more direct analysis with a savings in time and energy. It is also particularly helpful in the design mode to be described in a later section. All in all, the approximate approach can be applied to the majority of situations and therefore should be examined with the same interest as the exact method.

Exact Analysis

The input side of the network of Fig. 4.25 can be redrawn as shown in Fig. 4.27 for the dc analysis. The Thévenin equivalent network for the network to the left of the base terminal can then be found in the following manner:

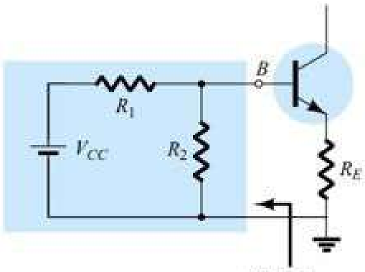
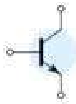


Figure 4.27 Redrawing the input side of the network of Fig. 4.25.



R_{Th}: The voltage source is replaced by a short-circuit equivalent as shown in Fig. 4.28.

$$\boxed{R_{Th} = R_1 \| R_2} \tag{4.28}$$

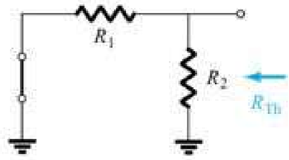


Figure 4.28 Determining R_{Th}.

E_{Th}: The voltage source V_{CC} is returned to the network and the open-circuit Thévenin voltage of Fig. 4.29 determined as follows:

Applying the voltage-divider rule:

$$\boxed{E_{Th} = V_{R_2} = \frac{R_2 V_{CC}}{R_1 + R_2}} \tag{4.29}$$

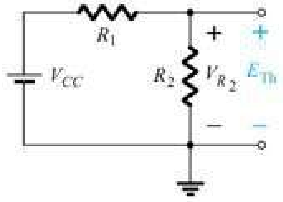


Figure 4.29 Determining E_{Th}.

The Thévenin network is then redrawn as shown in Fig. 4.30, and I_{BQ} can be determined by first applying Kirchhoff's voltage law in the clockwise direction for the loop indicated:

$$E_{Th} - I_B R_{Th} - V_{BE} - I_E R_E = 0$$

Substituting $I_E = (\beta + 1)I_B$ and solving for I_B yields

$$\boxed{I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1)R_E}} \tag{4.30}$$

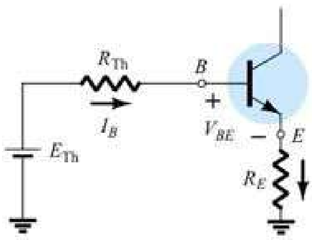


Figure 4.30 Inserting the Thévenin equivalent circuit.

Although Eq. (4.30) initially appears different from those developed earlier, note that the numerator is again a difference of two voltage levels and the denominator is the base resistance plus the emitter resistor reflected by $(\beta + 1)$—certainly very similar to Eq. (4.17).

Once I_B is known, the remaining quantities of the network can be found in the same manner as developed for the emitter-bias configuration. That is,

$$\boxed{V_{CE} = V_{CC} - I_C(R_C + R_E)} \tag{4.31}$$

which is exactly the same as Eq. (4.19). The remaining equations for V_E, V_C, and V_B are also the same as obtained for the emitter-bias configuration.

EXAMPLE 4.7

Determine the dc bias voltage V_{CE} and the current I_C for the voltage-divider configuration of Fig. 4.31.

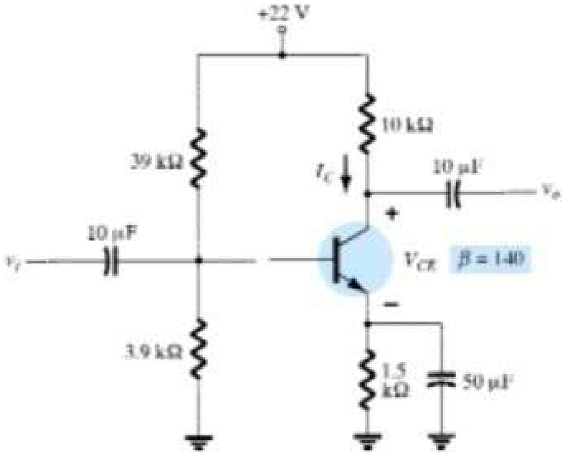


Figure 4.31 Beta-stabilized circuit for Example 4.7.

Solution

Eq. (4.28): $R_{Th} = R_1 \| R_2$

$$= \frac{(39\ k\Omega)(3.9\ k\Omega)}{39\ k\Omega + 3.9\ k\Omega} = 3.55\ k\Omega$$

Eq. (4.29): $E_{Th} = \frac{R_2 V_{CC}}{R_1 + R_2}$

$$= \frac{(3.9\ k\Omega)(22\ V)}{39\ k\Omega + 3.9\ k\Omega} = 2\ V$$

Eq. (4.30): $I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1)R_E}$

$$= \frac{2\ V - 0.7\ V}{3.55\ k\Omega + (141)(1.5\ k\Omega)} = \frac{1.3\ V}{3.55\ k\Omega + 211.5\ k\Omega}$$

$$= 6.05\ \mu A$$

$$I_C = \beta I_B$$

$$= (140)(6.05\ \mu A)$$

$$= \mathbf{0.85\ mA}$$

Eq. (4.31): $V_{CE} = V_{CC} - I_C(R_C + R_E)$

$$= 22\ V - (0.85\ mA)(10\ k\Omega + 1.5\ k\Omega)$$

$$= 22\ V - 9.78\ V$$

$$= \mathbf{12.22\ V}$$

Approximate Analysis

The input section of the voltage-divider configuration can be represented by the network of Fig. 4.32. The resistance R_i is the equivalent resistance between base and ground for the transistor with an emitter resistor R_E. Recall from Section 4.4 [Eq. (4.18)] that the reflected resistance between base and emitter is defined by $R_i = (\beta + 1)R_E$. If R_i is much larger than the resistance R_2, the current I_B will be much smaller than I_2 (current always seeks the path of least resistance) and I_2 will be approximately equal to I_1. If we accept the approximation that I_B is essentially zero amperes compared to I_1 or I_2, then $I_1 = I_2$ and R_1 and R_2 can be considered series ele-

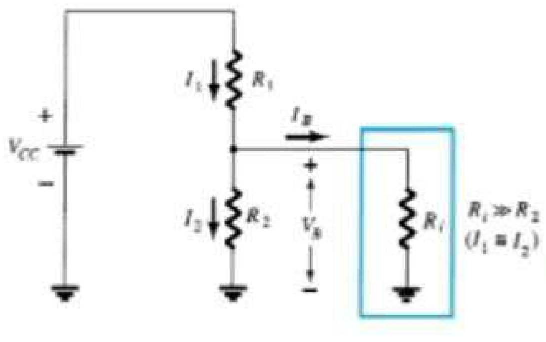


Figure 4.32 Partial-bias circuit for calculating the approximate base voltage V_B.

ments. The voltage across R_2, which is actually the base voltage, can be determined using the voltage-divider rule (hence the name for the configuration). That is,

$$V_B = \frac{R_2 V_{CC}}{R_1 + R_2} \tag{4.32}$$

Since $R_i = (\beta + 1)R_E \cong \beta R_E$ the condition that will define whether the approximate approach can be applied will be the following:

$$\beta R_E \geq 10 R_2 \tag{4.33}$$

In other words, if β times the value of R_E is at least 10 times the value of R_2, the approximate approach can be applied with a high degree of accuracy.

Once V_B is determined, the level of V_E can be calculated from

$$V_E = V_B - V_{BE} \tag{4.34}$$

and the emitter current can be determined from

$$I_E = \frac{V_E}{R_E} \tag{4.35}$$

and

$$I_{C_Q} \cong I_E \tag{4.36}$$

The collector-to-emitter voltage is determined by

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

but since $I_E \cong I_C$,

$$V_{CE_Q} = V_{CC} - I_C(R_C + R_E) \tag{4.37}$$

Note in the sequence of calculations from Eq. (4.33) through Eq. (4.37) that β does not appear and I_B was not calculated. The Q-point (as determined by I_{C_Q} and V_{CE_Q}) is therefore independent of the value of β.

EXAMPLE 4.8

Repeat the analysis of Fig. 4.31 using the approximate technique, and compare solutions for I_{C_Q} and V_{CE_Q}.

Solution

Testing:

$$\beta R_E \geq 10 R_2$$

$$(140)(1.5\ \text{k}\Omega) \geq 10(3.9\ \text{k}\Omega)$$

$$210\ \text{k}\Omega \geq 39\ \text{k}\Omega\ (\textit{satisfied})$$

$$\text{Eq. (4.32):} \quad V_B = \frac{R_2 V_{CC}}{R_1 + R_2}$$

$$= \frac{(3.9\ \text{k}\Omega)(22\ \text{V})}{39\ \text{k}\Omega + 3.9\ \text{k}\Omega}$$

$$= 2\ \text{V}$$