Tikrit university

Collage of Engineering Shirqat

Department of Electrical Engineering

Second Class

Electronic I

Chapter 4

DC Biasing—BJTs

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4. 5 Voltage-Divider Bias Configuration

In the previous bias configurations, the bias current ICQ and voltage VCEQ were a function of the current gain b of the transistor. However, because b 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 on, or in fact is independent of, the transistor beta. The voltage-divider bias configuration of Fig. 28 is such a network. If analysed on an exact basis, the sensitivity to changes in beta is quite small. If the circuit parameters are properly chosen, the resulting levels of ICQ and VCEQ can be almost totally independent of beta. Recall from previous discussions that a Q-point is defined by a fixed level of ICQ and VCEQ as shown in Fig. 29. The level of IBQ will change with the change in beta, but the operating point on the characteristics defined by ICQ and VCEQ can remain fixed if the proper circuit parameters are employed.

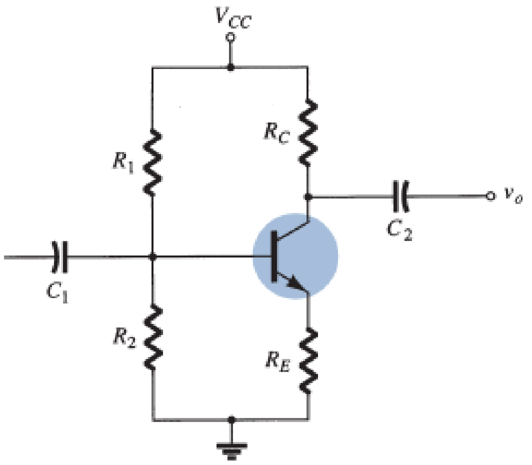


FIG. 28
Voltage-divider bias configuration.

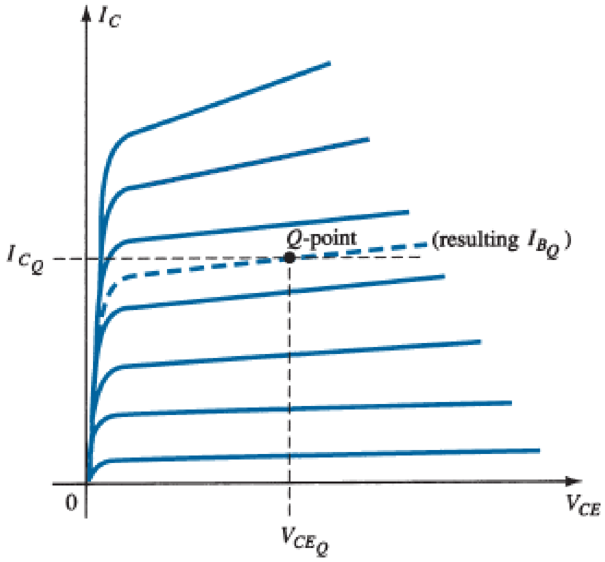


FIG. 29
Defining the Q-point for the voltage-divider bias configuration.

exact analysis

For the dc analysis the network of Fig. 28 can be redrawn as shown in Fig. 30. The input side of the network can then be redrawn as shown in Fig. 31 for the dc analysis.

The Thevenin equivalent network for the network to the left of the base terminal can then be found in the following manner: Rth The voltage source is replaced by a short-circuit equivalent as shown in Fig. 32:

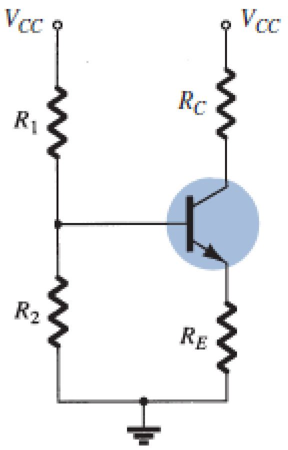
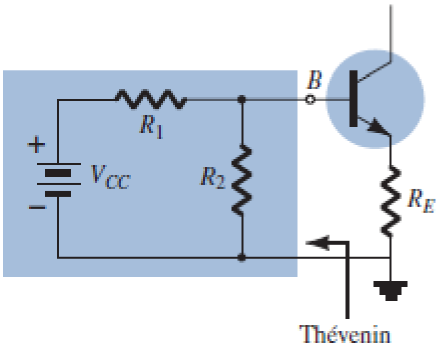


FIG. 30
DC components of the voltage-divider configuration.



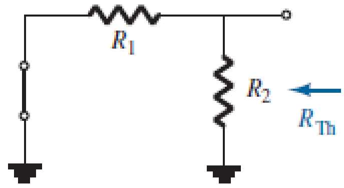


FIG. 32
Determining R_{Th}.

$$\boxed{R_{Th} = R_1 \| R_2} \qquad (28)$$

Eth The voltage source *VCC* is returned to the network and the open-circuit Thevenin voltage of Fig. 33 determined as follows: Applying the voltage-divider rule gives

$$\boxed{E_{Th} = V_{R_2} = \frac{R_2 V_{CC}}{R_1 + R_2}} \qquad (29)$$

The Thevenin network is then redrawn as shown in Fig. 34, and *IBQ* can be determined by first applying Kirchhoff's voltage law in the clockwise direction for the loop indicated:

*E*Th - *IBR*Th - *VBE* - *IERE* = 0

Substituting *IE* = (β + 1)*IB* and solving for *IB* yields

$$\boxed{I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1)R_E}} \qquad (30)$$

Although Eq. (30) initially appears to be 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 (β+1) certainly very similar to Eq. (17). Once

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

$$\boxed{V_{CE} = V_{CC} - I_C(R_C + R_E)} \qquad \textbf{(31)}$$

which is exactly the same as Eq. (19). The remaining equations for *VE*, *VC*, and *VB* are also the same as obtained for the emitter-bias configuration.

EXAMPLE 8 Determine the dc bias voltage V_{CE} and the current I_C for the voltage-divider configuration of Fig. 35.

Solution: Eq. (28):

$$R_{Th} = R_1 \| R_2 = \frac{(39\ \text{k}\Omega)(3.9\ \text{k}\Omega)}{39\ \text{k}\Omega + 3.9\ \text{k}\Omega} = 3.55\ \text{k}\Omega$$

Eq. (29):

$$E_{Th} = \frac{R_2 V_{CC}}{R_1 + R_2} = \frac{(3.9\ \text{k}\Omega)(22\ \text{V})}{39\ \text{k}\Omega + 3.9\ \text{k}\Omega} = 2\ \text{V}$$

Eq. (30):

$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1)R_E} = \frac{2\ \text{V} - 0.7\ \text{V}}{3.55\ \text{k}\Omega + (101)(1.5\ \text{k}\Omega)} = \frac{1.3\ \text{V}}{3.55\ \text{k}\Omega + 151.5\ \text{k}\Omega} = 8.38\ \mu\text{A}$$

$$I_C = \beta I_B = (100)(8.38\ \mu\text{A}) = \mathbf{0.84\ mA}$$

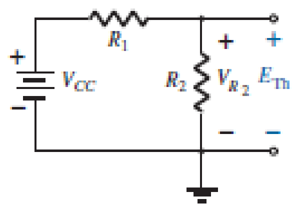


FIG. 33
Determining E_{Th}.

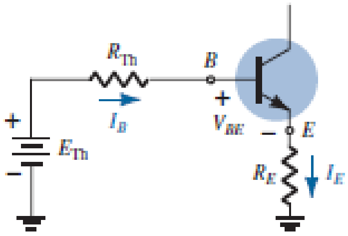


FIG. 34
Inserting the Thévenin equivalent circuit.

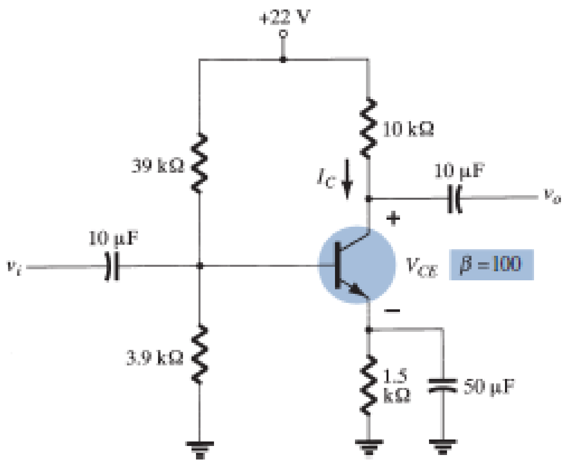


FIG. 35
Beta-stabilized circuit for Example 8.

Eq. (31):

$$V_{CE} = V_{CC} - I_C(R_C + R_E) = 22\ \text{V} - (0.84\ \text{mA})(10\ \text{k}\Omega + 1.5\ \text{k}\Omega) = 22\ \text{V} - 9.66\ \text{V} = \mathbf{12.34\ V}$$

approximate analysis

The input section of the voltage-divider configuration can be represented by the network of Fig. 36. The resistance *Ri* is the equivalent resistance between base and ground for the transistor with an emitter resistor *RE*. Recall from Section 4 [Eq. (18)] that the reflected resistance between base and emitter is defined by $R_i = (\beta + 1) R_E$. If *Ri* is much larger than the resistance *R*2, the current *IB* 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 *IB* is essentially 0 A compared to *I*1 or *I*2, then $I_1 = I_2$, and *R*1 and *R*2 can be considered series elements. The voltage across *R*2, which is actually the base voltage, can be

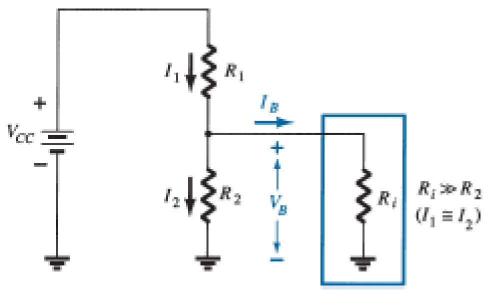


FIG. 36
Partial-bias circuit for calculating the approximate base voltage V_B.

determined using the voltage-divider rule (hence the name for the configuration). That is,

$$\boxed{V_B = \frac{R_2 V_{CC}}{R_1 + R_2}} \qquad (32)$$

Because $R_i = (\beta + 1) R_E \approx \beta R_E$ the condition that will define whether the approximate approach can be applied is

$$\boxed{\beta R_E \geq 10 R_2} \qquad (33)$$

In other words, if β times the value of *RE* is at least 10 times the value of *R*2, the approximate approach can be applied with a high degree of accuracy. Once *VB* is determined, the level of *VE* can be calculated from

$$\boxed{V_E = V_B - V_{BE}} \qquad (34)$$

and the emitter current can be determined from

$$\boxed{I_E = \frac{V_E}{R_E}} \qquad \textbf{(35)}$$

And $\boxed{I_{C_Q} \cong I_E}$ **(36)**

The collector-to-emitter voltage is determined by

VCE = VCC - ICRC – IERE

but because *IE* ≈ *IC*,

$$\boxed{V_{CE_Q} = V_{CC} - I_C(R_C + R_E)} \qquad \textbf{(37)}$$

Note in the sequence of calculations from Eq. (33) through Eq. (37) that b does not appear and *IB* was not calculated. The *Q*-point (as determined by *ICQ* and *VCEQ*) is therefore independent of the value of β.

EXAMPLE 9 Repeat the analysis of Fig. 35 using the approximate technique, and compare solutions for I_{C_Q} and V_{CE_Q}.

Solution: Testing:

$$\begin{aligned} \beta R_E &\geq 10R_2 \\ (100)(1.5\ \text{k}\Omega) &\geq 10(3.9\ \text{k}\Omega) \\ 150\ \text{k}\Omega &\geq 39\ \text{k}\Omega\ (\textit{satisfied}) \end{aligned}$$

Eq. (32):
$$\begin{aligned} V_B &= \frac{R_2 V_{CC}}{R_1 + R_2} \\ &= \frac{(3.9\ \text{k}\Omega)(22\ \text{V})}{39\ \text{k}\Omega + 3.9\ \text{k}\Omega} \\ &= 2\ \text{V} \end{aligned}$$

Eq. (34):
$$\begin{aligned} V_E &= V_B - V_{BE} \\ &= 2\ \text{V} - 0.7\ \text{V} \\ &= 1.3\ \text{V} \end{aligned}$$

$$I_{CQ} \cong I_E = \frac{V_E}{R_E} = \frac{1.3\ \text{V}}{1.5\ \text{k}\Omega} = \mathbf{0.867\ mA}$$

compared to 0.84 mA with the exact analysis. Finally,

$$\begin{aligned} V_{CE_Q} &= V_{CC} - I_C(R_C + R_E) \\ &= 22\text{ V} - (0.867\text{ mA})(10\text{ kV} + 1.5\text{ k}\Omega) \\ &= 22\text{ V} - 9.97\text{ V} \\ &= \mathbf{12.03\text{ V}} \end{aligned}$$

EXAMPLE 10 Repeat the exact analysis of Example 8 if β is reduced to 50, and compare solutions for I_{C_Q} and V_{CE_Q}.

Solution: This example is not a comparison of exact versus approximate methods, but a testing of how much the Q-point will move if the level of β is cut in half. R_{Th} and E_{Th} are the same:

$$R_{\text{Th}} = 3.55\text{ k}\Omega, \qquad E_{\text{Th}} = 2\text{ V}$$

$$\begin{aligned} I_B &= \frac{E_{\text{Th}} - V_{BE}}{R_{\text{Th}} + (\beta + 1)R_E} \\ &= \frac{2\text{ V} - 0.7\text{ V}}{3.55\text{ k}\Omega + (51)(1.5\text{ k}\Omega)} = \frac{1.3\text{ V}}{3.55\text{ k}\Omega + 76.5\text{ k}\Omega} \\ &= 16.24\ \mu\text{A} \\ I_{C_Q} &= \beta I_B \\ &= (50)(16.24\ \mu\text{A}) \\ &= \mathbf{0.81\text{ mA}} \\ V_{CE_Q} &= V_{CC} - I_C(R_C + R_E) \\ &= 22\text{ V} - (0.81\text{ mA})(10\text{ k}\Omega + 1.5\text{ k}\Omega) \\ &= \mathbf{12.69\text{ V}} \end{aligned}$$

Tabulating the results, we have:

Effect of β variation on the response of the voltage-divider configuration of Fig. 35.

β	I_{C_Q} (mA)	V_{CE_Q} (V)
100	0.84 mA	12.34 V
50	0.81 mA	12.69 V

The results clearly show the relative insensitivity of the circuit to the change in b. Even though β is drastically cut in half, from 100 to 50, the levels of ICQ and VCEQ are essentially the same

EXAMPLE 11 Determine the levels of I_{C_Q} and V_{CE_Q} for the voltage-divider configuration of Fig. 37 using the exact and approximate techniques and compare solutions. In this case, the conditions of Eq. (33) *will not be satisfied* and the results will reveal the difference in solution if the criterion of Eq. (33) is ignored.

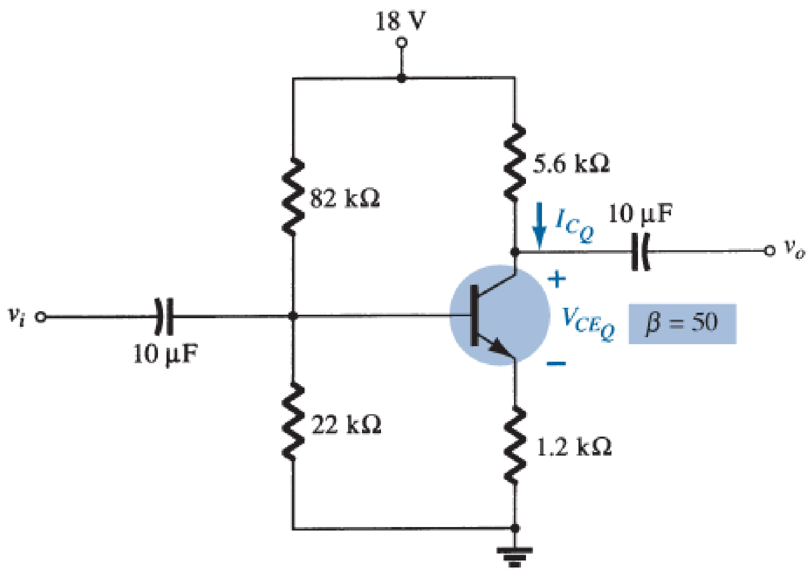


FIG. 37
Voltage-divider configuration for Example 11.

Solution: Exact analysis:

Eq. (33):

$$\beta R_E \geq 10R_2$$
$$(50)(1.2\text{ k}\Omega) \geq 10(22\text{ k}\Omega)$$
$$60\text{ k}\Omega \ngeq 220\text{ k}\Omega \text{ (\textit{not satisfied})}$$
$$R_{Th} = R_1 \| R_2 = 82\text{ k}\Omega \| 22\text{ k}\Omega = 17.35\text{ k}\Omega$$
$$E_{Th} = \frac{R_2 V_{CC}}{R_1 + R_2} = \frac{22\text{ k}\Omega(18\text{ V})}{82\text{ k}\Omega + 22\text{ k}\Omega} = 3.81\text{ V}$$
$$I_B = \frac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1)R_E} = \frac{3.81\text{ V} - 0.7\text{ V}}{17.35\text{ k}\Omega + (51)(1.2\text{ k}\Omega)} = \frac{3.11\text{ V}}{78.55\text{ k}\Omega} = 39.6\ \mu\text{A}$$
$$I_{C_Q} = \beta I_B = (50)(39.6\ \mu\text{A}) = \mathbf{1.98\text{ mA}}$$
$$\begin{aligned} V_{CE_Q} &= V_{CC} - I_C(R_C + R_E) \\ &= 18\text{ V} - (1.98\text{ mA})(5.6\text{ k}\Omega + 1.2\text{ k}\Omega) \\ &= \mathbf{4.54\text{ V}} \end{aligned}$$

Approximate analysis:

$$V_B = E_{Th} = 3.81\text{ V}$$
$$V_E = V_B - V_{BE} = 3.81\text{ V} - 0.7\text{ V} = 3.11\text{ V}$$
$$I_{C_Q} \cong I_E = \frac{V_E}{R_E} = \frac{3.11\text{ V}}{1.2\text{ k}\Omega} = \mathbf{2.59\text{ mA}}$$
$$\begin{aligned} V_{CE_Q} &= V_{CC} - I_C(R_C + R_E) \\ &= 18\text{ V} - (2.59\text{ mA})(5.6\text{ k}\Omega + 1.2\text{ k}\Omega) \\ &= \mathbf{3.88\text{ V}} \end{aligned}$$

Transistor Saturation

The output collector–emitter circuit for the voltage-divider configuration has the same appearance as the emitter-biased circuit analysed in Section 4. The resulting equation for the saturation current (when *VCE* is set to 0 V on the schematic) is therefore the same as obtained for the emitter-biased configuration. That is,

$$I_{C_{sat}} = I_{C_{max}} = \frac{V_{CC}}{R_C + R_E} \tag{38}$$

Load-Line analysis

The similarities with the output circuit of the emitter-biased configuration result in the same intersections for the load line of the voltage-divider configuration. The load line will therefore, have the same appearance as that of Fig. 25, with

$$I_C = \left.\frac{V_{CC}}{R_C + R_E}\right|_{V_{CE}=0\text{ V}} \tag{39}$$

$$V_{CE} = V_{CC}\Big|_{I_C=0\text{ mA}} \tag{40}$$

The level of *IB* is of course determined by a different equation for the voltage-divider bias and the emitter-bias configurations.

6.4 Collector Feedback Configuration

An improved level of stability can also be obtained by introducing a feedback path from collector to base as shown in Fig. 38. Although the Q-point is not totally independent of beta (even under approximate conditions), the sensitivity to changes in beta or temperature variations are normally less than encountered for the fixed-bias or emitter-biased configurations. The analysis will again be performed by first analysing the base–emitter loop, with the results then applied to the collector–emitter loop.

base–emitter Loop Figure 39 shows the base–emitter loop for the voltage feedback configuration. Writing Kirchhoff's voltage law around the indicated loop in the clockwise direction will result in

VCC - ICRC - IBRF - VBE - IERE = 0

It is important to note that the current through RC is not IC, but IC (where IC^{-} = IC + IB). However, the level of IC and IC^{-} far exceeds the usual level of IB, and the approximation $IC^{-}\approx$ IC is normally employed. Substituting $IC^{-}\approx$ IC = βIB and IE ≈ IC results in

VCC - βIBRC - IBRF - VBE - βIBRE = 0

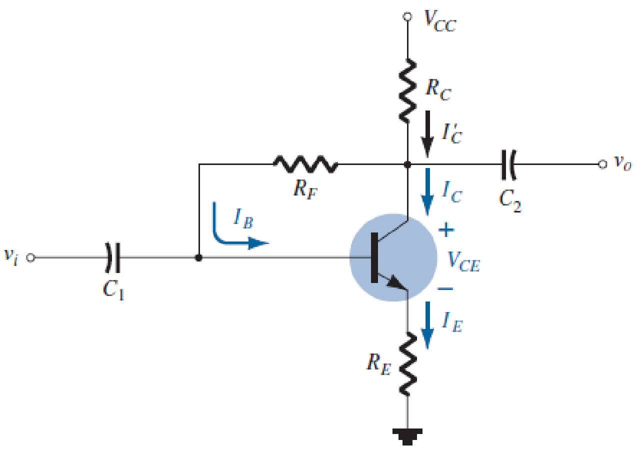


FIG. 38
DC bias circuit with voltage feedback.

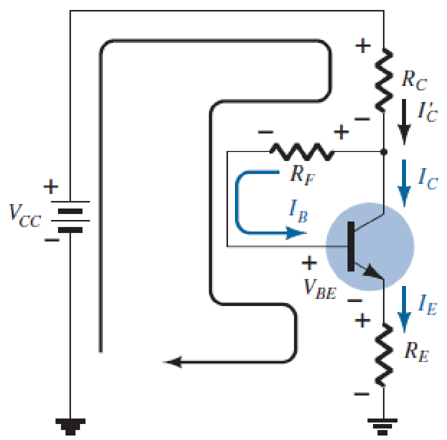


FIG. 39
Base–emitter loop for the network of Fig. 38.

Gathering terms, we have

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

and solving for I_B yields

$$\boxed{I_B = \frac{V_{CC} - V_{BE}}{R_F + \beta(R_C + R_E)}} \qquad \textbf{(41)}$$

Collector–emitter Loop

The collector–emitter loop for the network of Fig. 38 is provided in Fig. 40. Applying Kirchhoff's voltage law around the indicated loop in the clockwise direction results in

$$IERE + VCE + IC^{-}RC - VCC = 0$$

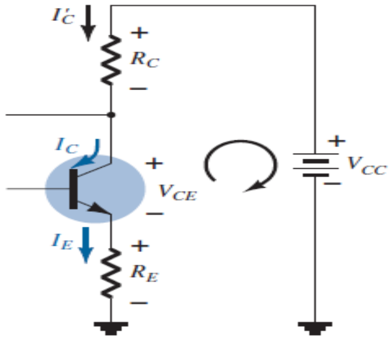


FIG. 40
Collector–emitter loop for the network of Fig. 38.

Because $I_C' \cong I_C$ and $I_E \cong I_C$, we have

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

and

$$\boxed{V_{CE} = V_{CC} - I_C(R_C + R_E)} \qquad (42)$$

which is exactly as obtained for the emitter-bias and voltage-divider bias configurations.

EXAMPLE 12 Determine the quiescent levels of I_{C_Q} and V_{CE_Q} for the network of Fig. 41.

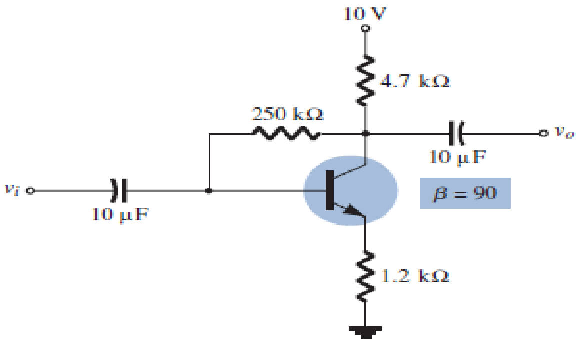


FIG. 41
Network for Example 12.

Solution: Eq. (41):

$$I_B = \frac{V_{CC} - V_{BE}}{R_F + \beta(R_C + R_E)}$$
$$= \frac{10\text{ V} - 0.7\text{ V}}{250\text{ k}\Omega + (90)(4.7\text{ k}\Omega + 1.2\text{ k}\Omega)}$$
$$= \frac{9.3\text{ V}}{250\text{ k}\Omega + 531\text{ k}\Omega} = \frac{9.3\text{ V}}{781\text{ k}\Omega}$$
$$= 11.91\ \mu\text{A}$$
$$I_{C_Q} = \beta I_B = (90)(11.91\ \mu\text{A})$$
$$= \mathbf{1.07\text{ mA}}$$
$$V_{CE_Q} = V_{CC} - I_C(R_C + R_E)$$
$$= 10\text{ V} - (1.07\text{ mA})(4.7\text{ k}\Omega + 1.2\text{ k}\Omega)$$
$$= 10\text{ V} - 6.31\text{ V}$$
$$= \mathbf{3.69\text{ V}}$$

EXAMPLE 14 Determine the dc level of I_B and V_C for the network of Fig. 42.

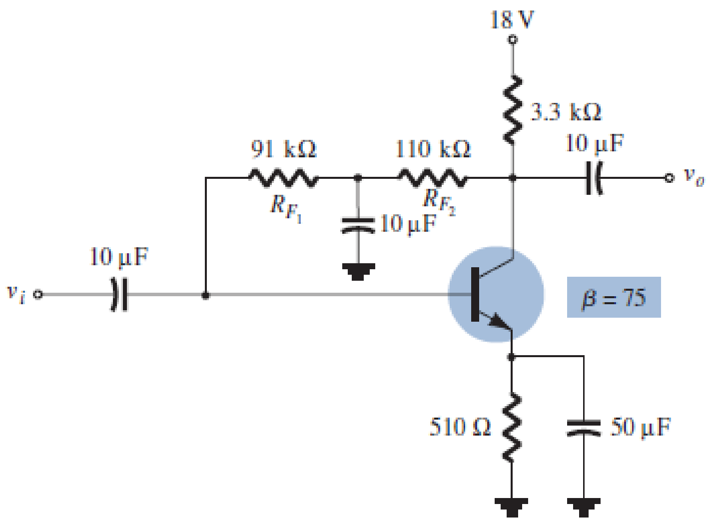


FIG. 42
Network for Example 14.

Solution: In this case, the base resistance for the dc analysis is composed of two resistors with a capacitor connected from their junction to ground. For the dc mode, the capacitor assumes the open-circuit equivalence, and $R_B = R_{F_1} + R_{F_2}$.

Solving for I_B gives

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)}$$
$$= \frac{18\text{ V} - 0.7\text{ V}}{(91\text{ k}\Omega + 110\text{ k}\Omega) + (75)(3.3\text{ k}\Omega + 0.51\text{ k}\Omega)}$$
$$= \frac{17.3\text{ V}}{201\text{ k}\Omega + 285.75\text{ k}\Omega} = \frac{17.3\text{ V}}{486.75\text{ k}\Omega}$$
$$= \mathbf{35.5\ \mu A}$$

$$I_C = \beta I_B$$
$$= (75)(35.5\ \mu\text{A})$$
$$= 2.66\text{ mA}$$
$$V_C = V_{CC} - I_C' R_C \cong V_{CC} - I_C R_C$$
$$= 18\text{ V} - (2.66\text{ mA})(3.3\text{ k}\Omega)$$
$$= 18\text{ V} - 8.78\text{ V}$$
$$= \mathbf{9.22\ V}$$

Saturation Conditions

Using the approximation $IC^{-} = IC$, we find that the equation for the saturation current is the

same as obtained for the voltage-divider and emitter-bias configurations. That is,

$$\boxed{I_{C_{sat}} = I_{C_{max}} = \frac{V_{CC}}{R_C + R_E}} \qquad (43)$$

Load-Line analysis

Continuing with the approximation $IC^{-} = IC$ results in the same load line defined for the voltage-divider and emitter-biased configurations. The level of *IBQ* is defined by the chosen bias configuration.

EXAMPLE 15 Given the network of Fig. 43 and the BJT characteristics of Fig. 44.

a. Draw the load line for the network on the characteristics.
b. Determine the dc beta in the center region of the characteristics. Define the chosen point as the Q-point.
c. Using the dc beta calculated in part b, find the dc value of I_B.
d. Find I_{C_Q} and I_{CE_Q}.

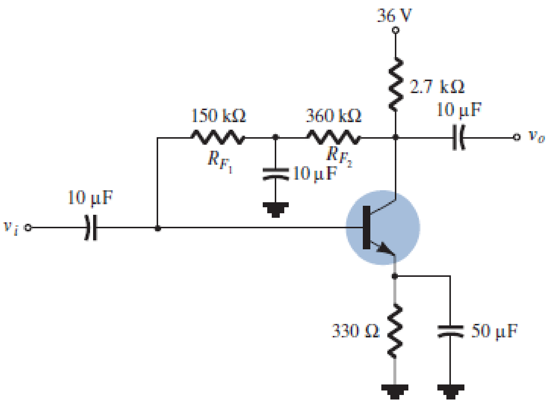


FIG. 43
Network for Example 15.

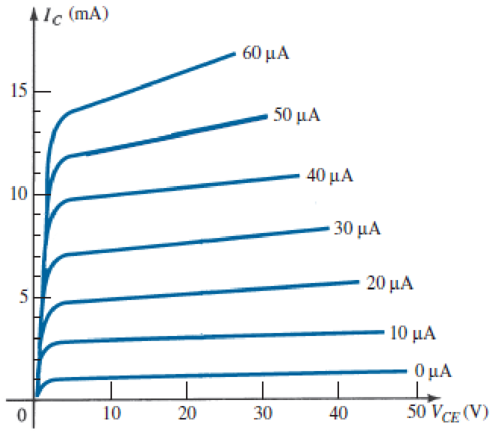


FIG. 44
BJT characteristics.

Solution:

a. The load line is drawn on Fig. 45 as determined by the following intersections:

$$V_{CE} = 0\text{ V}: I_C = \frac{V_{CC}}{R_C + R_E} = \frac{36\text{ V}}{2.7\text{ k}\Omega + 330\ \Omega} = \mathbf{11.88\ mA}$$

$$I_C = 0\text{ mA}: V_{CE} = V_{CC} = \mathbf{36\ V}$$

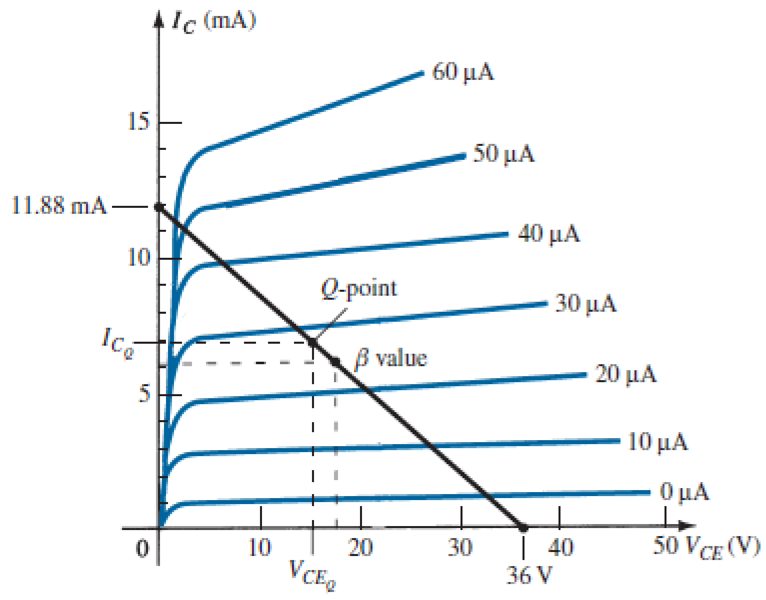


FIG. 45
Defining the Q-point for the voltage-divider bias configuration of Fig. 43.

b. The dc beta was determined using $I_B = 25\ \mu A$ and V_{CE} about 17 V.

$$\beta \cong \frac{I_{C_Q}}{I_{B_Q}} = \frac{6.2\ \text{mA}}{25\ \mu\text{A}} = \mathbf{248}$$

c. Using Eq. 41:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta(R_C + R_E)} = \frac{36\ \text{V} - 0.7\ \text{V}}{510\ \text{k}\Omega + 248(2.7\ \text{k}\Omega + 330\ \Omega)}$$

$$= \frac{35.3\ \text{V}}{510\ \text{k}\Omega + 751.44\ \text{k}\Omega}$$

and $I_B = \dfrac{35.3\ \text{V}}{1.261\ \text{M}\Omega} = \mathbf{28\ \mu A}$

d. From Fig. 45 the quiescent values are

$I_{C_Q} \cong$ **6.9 mA** and $V_{CE_Q} \cong$ **15 V**

7.4 Emitter-Follower Configuration

The previous sections introduced configurations in which the output voltage is typically taken off the collector terminal of the BJT. This section will examine a configuration where the output is taken off the emitter terminal as shown in Fig. 46. The configuration of Fig. 46 is not the only one where the output can be taken off the emitter terminal. In fact, any of the configurations just described can be used so long as there is a resistor in the emitter leg.

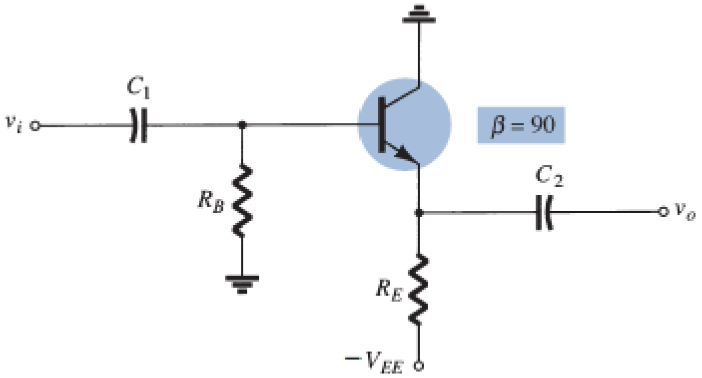


FIG. 46
Common-collecter (emitter-follower) configuration.

The dc equivalent of the network of Fig. 46 appears in Fig. 47
Applying Kirchhoff's voltage rule to the input circuit will result in

$$-I_B R_B - V_{BE} - I_E R_E + V_{EE} = 0$$

and using $I_E = (\beta + 1)I_B$

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

so that

$$\boxed{I_B = \frac{V_{EE} - V_{BE}}{R_B + (\beta + 1)R_E}} \qquad (44)$$

For the output network, an application of Kirchhoff's voltage law will result in

$$-V_{CE} - I_E R_E + V_{EE} = 0$$

and

$$\boxed{V_{CE} = V_{EE} - I_E R_E} \qquad (45)$$

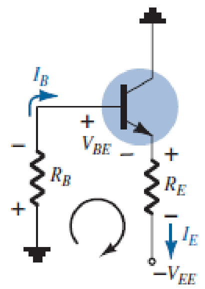


FIG. 47
dc equivalent of Fig. 46.

EXAMPLE 16 Determine V_{CE_Q} and I_{E_Q} for the network of Fig. 48.

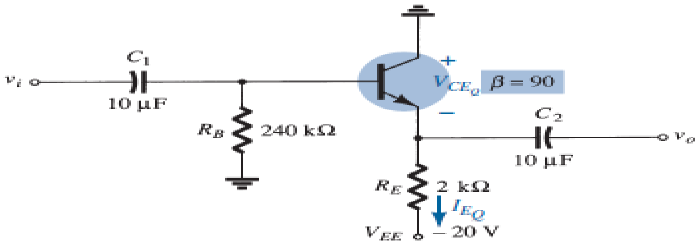


FIG. 48
Example 16.

Solution:

Eq. 44:
$$I_B = \frac{V_{EE} - V_{BE}}{R_B + (\beta + 1)R_E}$$
$$= \frac{20\text{ V} - 0.7\text{ V}}{240\text{ k}\Omega + (90 + 1)2\text{ k}\Omega} = \frac{19.3\text{ V}}{240\text{ k}\Omega + 182\text{ k}\Omega}$$
$$= \frac{19.3\text{ V}}{422\text{ k}\Omega} = 45.73\ \mu\text{A}$$

and Eq. 45:
$$V_{CE_Q} = V_{EE} - I_E R_E$$
$$= V_{EE} - (\beta + 1)I_B R_E$$
$$= 20\text{ V} - (90 + 1)(45.73\ \mu\text{A})(2\text{ k}\Omega)$$
$$= 20\text{ V} - 8.32\text{ V}$$
$$= \mathbf{11.68\text{ V}}$$
$$I_{E_Q} = (\beta + 1)I_B = (91)(45.73\ \mu\text{A})$$
$$= 4.16\text{ mA}$$

8.4 Common-Base Configuration

The common-base configuration is unique in that the applied signal is connected to the emitter terminal and the base is at, or just above, ground potential. It is a fairly popular configuration because in the ac domain it has a very low input impedance, high output impedance, and good gain.

A typical common-base configuration appears in Fig. 49. Note that two supplies are used in this configuration and the base is the common terminal between the input emitter terminal and output collector terminal. The dc equivalent of the input side of Fig. 49 appears in Fig.50.

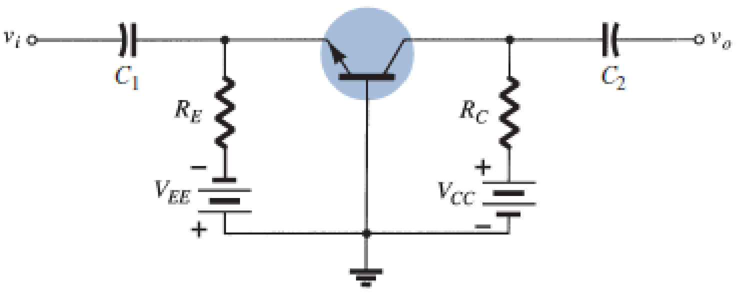


FIG. 49
Common-base configuration

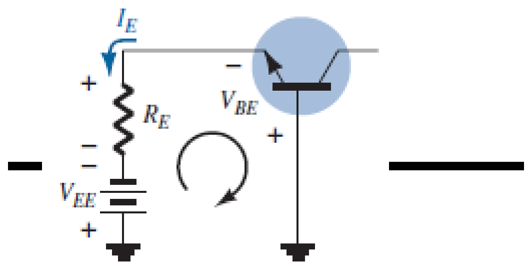


FIG. 50
Input dc equivalent of

Applying Kirchhoff's voltage law will result in

$-V_{EE} + I_E R_E + V_{BE} = 0$

$$I_E = \frac{V_{EE} - V_{BE}}{R_E} \qquad (46)$$

Applying Kirchhoff's voltage law to the entire outside perimeter of the network of Fig. 51 will result in

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

and solving for V_{CE}: $V_{CE} = V_{EE} + V_{CC} - I_E R_E - I_C R_C$

Because $I_E \approx I_C$

$$V_{CE} = V_{EE} + V_{CC} - I_E(R_C + R_E) \qquad (47)$$

The voltage V_{CB} of Fig. 51 can be found by applying Kirchhoff's voltage law to the output loop of Fig 51 to obtain:

$V_{CB} + I_C R_C - V_{CC} = 0$

or $V_{CB} = V_{CC} - I_C R_C$

Using $I_C \approx I_E$

$$V_{CB} = V_{CC} - I_C R_C \qquad (48)$$

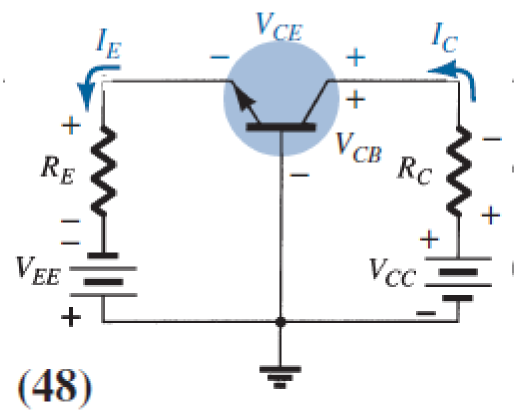


FIG. 51
Determining V_{CE} and V_{CB}.

EXAMPLE 17 Determine the currents I_E and I_B and the voltages V_{CE} and V_{CB} for the common-base configuration of Fig. 52.

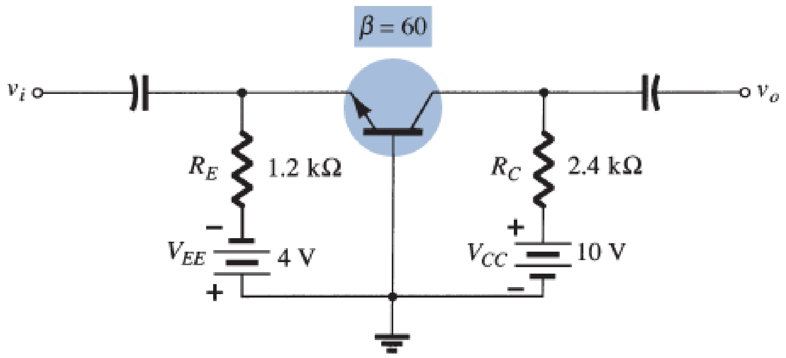


FIG. 52
Example 17.

Solution: Eq. 46:

$$I_E = \frac{V_{EE} - V_{BE}}{R_E}$$
$$= \frac{4\text{ V} - 0.7\text{ V}}{1.2\text{ k}\Omega} = \mathbf{2.75\text{ mA}}$$
$$I_B = \frac{I_E}{\beta + 1} = \frac{2.75\text{ mA}}{60 + 1} = \frac{2.75\text{ mA}}{61}$$
$$= \mathbf{45.08\ \mu A}$$

Eq. 47:

$$V_{CE} = V_{EE} + V_{CC} - I_E(R_C + R_E)$$
$$= 4\text{ V} + 10\text{ V} - (2.75\text{ mA})(2.4\text{ k}\Omega + 1.2\text{ k}\Omega)$$
$$= 14\text{ V} - (2.75\text{ mA})(3.6\text{ k}\Omega)$$
$$= 14\text{ V} - 9.9\text{ V}$$
$$= \mathbf{4.1\text{ V}}$$

Eq. 48:

$$V_{CB} = V_{CC} - I_C R_C = V_{CC} - \beta I_B R_C$$
$$= 10\text{ V} - (60)(45.08\ \mu\text{A})(24\text{ k}\Omega)$$
$$= 10\text{ V} - 6.49\text{ V}$$
$$= \mathbf{3.51\text{ V}}$$

9 Miscellaneous Bias Configurations

There are a number of BJT bias configurations that do not match the basic mold of those analysed in the previous sections. In fact, there are variations in design that would require many more pages than is possible in a single publication. However, the primary purpose here is to emphasize those characteristics of the device that permit a dc analysis of the configuration and to establish a general procedure toward the desired solution. For each configuration discussed thus far, the first step has been the derivation of an expression for the base current. Once the base current is known, the collector current and voltage levels of the output circuit can be determined quite directly. This is not to imply that all solutions will take this path, but it does suggest a possible route to follow if a new configuration is encountered. The first example is simply one where the emitter resistor has been dropped from the voltage-feedback configuration of Fig. 38. The analysis is quite similar, but does require dropping *RE* from the applied equation.

EXAMPLE 18 For the network of Fig. 53:

a. Determine I_{C_Q} and V_{CE_Q}.
b. Find V_B, V_C, V_E, and V_{BC}.

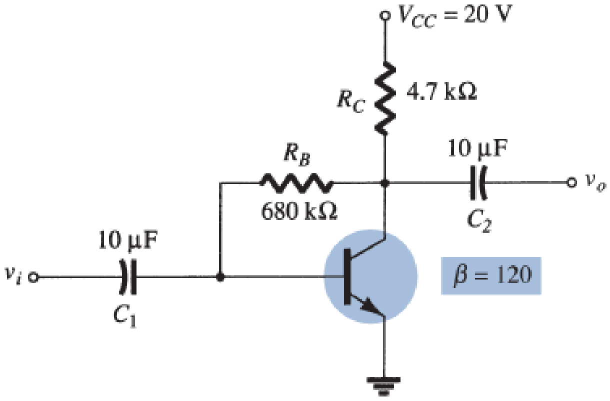


FIG. 53
Collector feedback with $R_E = 0\ \Omega$.

Solution:

a. The absence of R_E reduces the reflection of resistive levels to simply that of R_C, and the equation for I_B reduces to

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta R_C}$$
$$= \frac{20\text{ V} - 0.7\text{ V}}{680\text{ k}\Omega + (120)(4.7\text{ k}\Omega)} = \frac{19.3\text{ V}}{1.244\text{ M}\Omega}$$
$$= \mathbf{15.51\ \mu A}$$
$$I_{C_Q} = \beta I_B = (120)(15.51\ \mu\text{A})$$
$$= \mathbf{1.86\ mA}$$
$$V_{CE_Q} = V_{CC} - I_C R_C$$
$$= 20\text{ V} - (1.86\text{ mA})(4.7\text{ k}\Omega)$$
$$= \mathbf{11.26\ V}$$

b.
$$V_B = V_{BE} = \mathbf{0.7\ V}$$
$$V_C = V_{CE} = \mathbf{11.26\ V}$$
$$V_E = \mathbf{0\ V}$$
$$V_{BC} = V_B - V_C = 0.7\text{ V} - 11.26\text{ V}$$
$$= \mathbf{-10.56\ V}$$

EXAMPLE 19 Determine V_C and V_B for the network of Fig. 54.

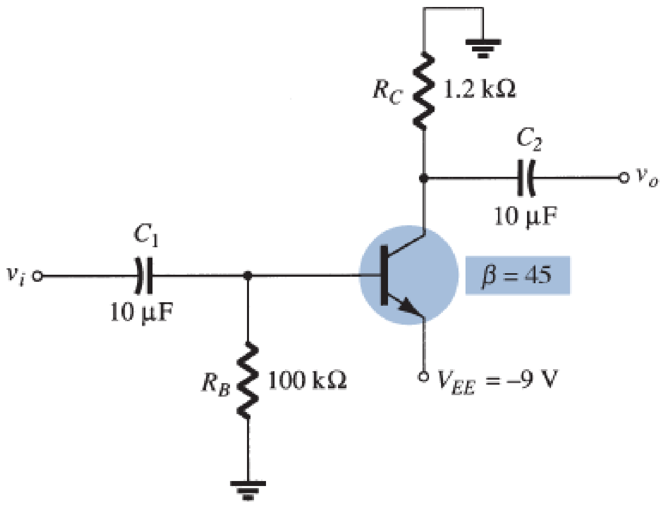


FIG. 54
Example 19.

Solution: Applying Kirchhoff's voltage law in the clockwise direction for the base–emitter loop results in

$$-I_B R_B - V_{BE} + V_{EE} = 0$$

and

$$I_B = \frac{V_{EE} - V_{BE}}{R_B}$$

Substitution yields

$$I_B = \frac{9\text{ V} - 0.7\text{ V}}{100\text{ k}\Omega} = \frac{8.3\text{ V}}{100\text{ k}\Omega} = 83\ \mu\text{A}$$

$$\begin{aligned} I_C &= \beta I_B \\ &= (45)(83\ \mu\text{A}) \\ &= 3.735\text{ mA} \\ V_C &= -I_C R_C \\ &= -(3.735\text{ mA})(1.2\text{ k}\Omega) \\ &= \mathbf{-4.48\ V} \\ V_B &= -I_B R_B \\ &= -(83\ \mu\text{A})(100\text{ k}\Omega) \\ &= \mathbf{-8.3\ V} \end{aligned}$$

EXAMPLE 20 Determine V_C and V_B for the network of Fig. 55.

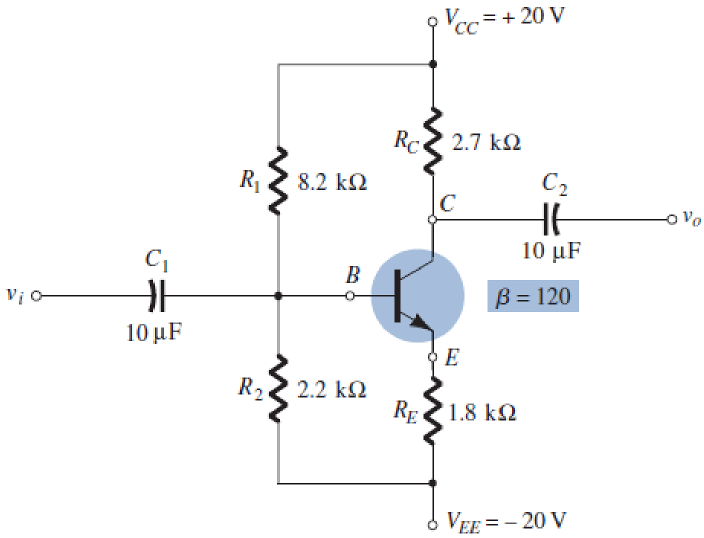


FIG. 55
Example 20.

Solution: The Thévenin resistance and voltage are determined for the network to the left of the base terminal as shown in Figs. 56 and 57.

R_{Th}

$$R_{Th} = 8.2\ \text{k}\Omega \,\|\, 2.2\ \text{k}\Omega = 1.73\ \text{k}\Omega$$

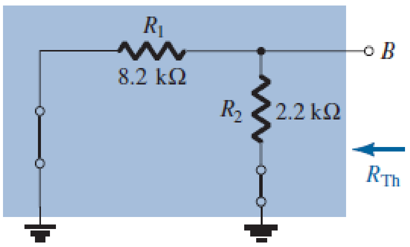


FIG. 56
Determining R_{Th}.

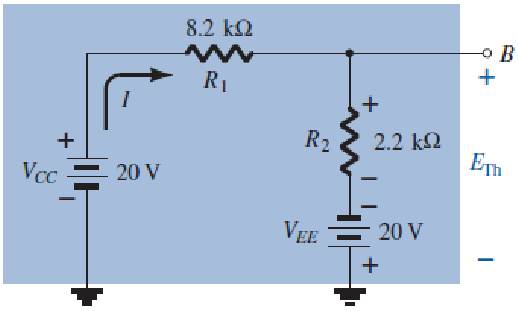


FIG. 57
Determining E_{Th}.

E_{Th}

$$I = \frac{V_{CC} + V_{EE}}{R_1 + R_2} = \frac{20\text{ V} + 20\text{ V}}{8.2\text{ k}\Omega + 2.2\text{ k}\Omega} = \frac{40\text{ V}}{10.4\text{ k}\Omega}$$
$$= 3.85\text{ mA}$$
$$E_{Th} = IR_2 - V_{EE}$$
$$= (3.85\text{ mA})(2.2\text{ k}\Omega) - 20\text{ V}$$
$$= -11.53\text{ V}$$

The network can then be redrawn as shown in Fig. 58, where the application of Kirchhoff's voltage law results in

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

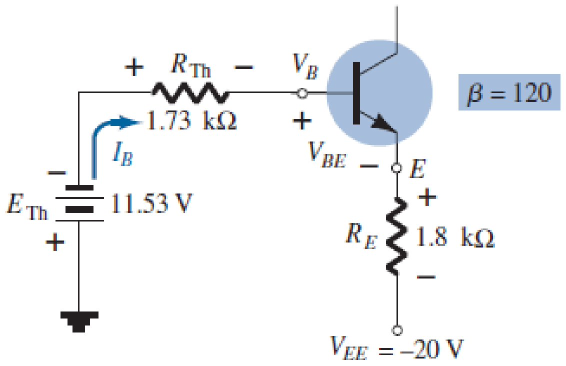


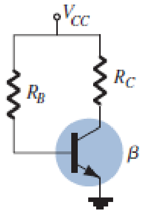
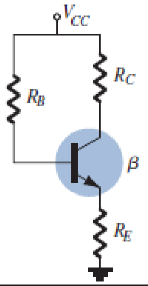
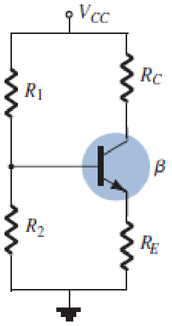
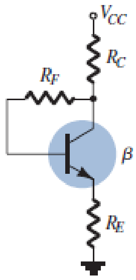
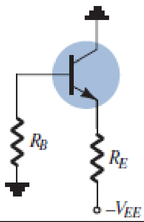
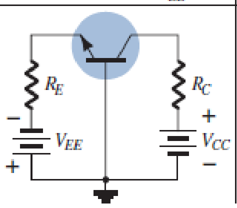
FIG. 58
Substituting the Thévenin equivalent circuit.

Substituting $I_E = (\beta + 1)I_B$ gives

$$V_{EE} - E_{Th} - V_{BE} - (\beta + 1)I_B R_E - I_B R_{Th} = 0$$

and
$$I_B = \frac{V_{EE} - E_{Th} - V_{BE}}{R_{Th} + (\beta + 1)R_E}$$
$$= \frac{20\text{ V} - 11.53\text{ V} - 0.7\text{ V}}{1.73\text{ k}\Omega + (121)(1.8\text{ k}\Omega)}$$
$$= \frac{7.77\text{ V}}{219.53\text{ k}\Omega}$$
$$= 35.39\ \mu\text{A}$$
$$I_C = \beta I_B$$
$$= (120)(35.39\ \mu\text{A})$$
$$= 4.25\text{ mA}$$
$$V_C = V_{CC} - I_C R_C$$
$$= 20\text{ V} - (4.25\text{ mA})(2.7\text{ k}\Omega)$$
$$= \mathbf{8.53\text{ V}}$$
$$V_B = -E_{Th} - I_B R_{Th}$$
$$= -(11.53\text{ V}) - (35.39\ \mu\text{A})(1.73\text{ k}\Omega)$$
$$= \mathbf{-11.59\text{ V}}$$

TABLE 1
BJT Bias Configurations

Type	Configuration	Pertinent Equations
Fixed-bias		$I_B = \dfrac{V_{CC} - V_{BE}}{R_B}$ $I_C = \beta I_B, I_E = (\beta + 1)I_B$ $V_{CE} = V_{CC} - I_C R_C$
Emitter-bias		$I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E}$ $I_C = \beta I_B, I_E = (\beta + 1)I_B$ $R_i = (\beta + 1)R_E$ $V_{CE} = V_{CC} - I_C(R_C + R_E)$
Voltage-divider bias		EXACT: $R_{Th} = R_1 \| R_2, E_{Th} = \dfrac{R_2 V_{CC}}{R_1 + R_2}$ $I_B = \dfrac{E_{Th} - V_{BE}}{R_{Th} + (\beta + 1)R_E}$ $I_C = \beta I_B, I_E = (\beta + 1)I_B$ $V_{CE} = V_{CC} - I_C(R_C + R_E)$ APPROXIMATE: $\beta R_E \geq 10R_2$ $V_B = \dfrac{R_2 V_{CC}}{R_1 + R_2}, V_E = V_B - V_{BE}$ $I_E = \dfrac{V_E}{R_E}, I_B = \dfrac{I_E}{\beta + 1}$ $V_{CE} = V_{CC} - I_C(R_C + R_E)$
Collector-feedback		$I_B = \dfrac{V_{CC} - V_{BE}}{R_F + \beta(R_C + R_E)}$ $I_C = \beta I_B, I_E = (\beta + 1)I_B$ $V_{CE} = V_{CC} - I_C(R_C + R_E)$
Emitter-follower		$I_B = \dfrac{V_{EE} - V_{BE}}{R_B + (\beta + 1)}$ $I_C = \beta I_B, I_E = (\beta + 1)I_B$ $V_{CE} = V_{EE} - I_E R_E$
Common-base		$I_E = \dfrac{V_{EE} - V_{BE}}{R_E}$ $I_B = \dfrac{I_E}{\beta + 1}, I_C = \beta I_B$ $V_{CE} = V_{EE} + V_{CC} - I_E(R_C + R_E)$ $V_{CB} = V_{CC} - I_C R_C$