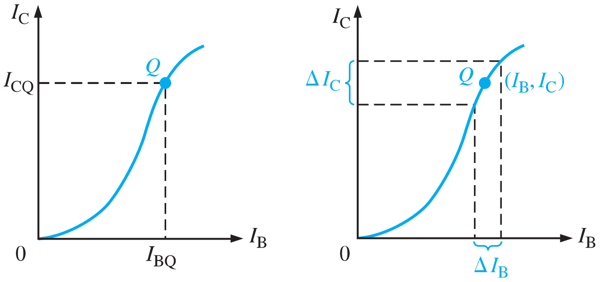
Comparison of the AC Beta (β_{ac}) to the DC Beta (β_{DC})

For a typical transistor, a graph of I_C versus I_B is nonlinear, as shown in Figure 6–7(a). If you pick a Q-point on the curve and cause the base current to vary an amount ΔI_B, then the collector current will vary an amount ΔI_C as shown in part (b). At different points on the nonlinear curve, the ratio $\Delta I_C/\Delta I_B$ will be different, and it may also differ from the I_C/I_B ratio at the Q-point. Since $\beta_{DC} = I_C/I_B$ and $\beta_{ac} = \Delta I_C/\Delta I_B$, the values of these two quantities can differ slightly.



(a) $\beta_{DC} = I_C/I_B$ at Q-point

(b) $\beta_{ac} = \Delta I_C/\Delta I_B$

FIGURE 6–7

I_C-versus-I_B curve illustrates the difference between $\beta_{DC} = I_C/I_B$ and $\beta_{ac} = \Delta I_C/\Delta I_B$.

h Parameters

A manufacturer's datasheet typically specifies *h* (hybrid) parameters (h_i, h_r, h_f, and h_o) because they are relatively easy to measure.

The four basic ac *h* parameters and their descriptions are given in Table 6–2. Each of the four *h* parameters carries a second subscript letter to designate the common-emitter (*e*), common-base (*b*), or common-collector (*c*) amplifier configuration, as listed in Table 6–3. The term *common* refers to one of the three terminals (E, B, or C) that is referenced to ac ground for both input and output signals. The characteristics of each of these three BJT amplifier configurations are covered later in this chapter.

h PARAMETER	DESCRIPTION	CONDITION
h_i	Input impedance (resistance)	Output shorted
h_r	Voltage feedback ratio	Input open
h_f	Forward current gain	Output shorted
h_o	Output admittance (conductance)	Input open

TABLE 6–2

Basic ac *h* parameters.

CONFIGURATION	*h* PARAMETERS
Common-Emitter	h_{ie}, h_{re}, h_{fe}, h_{oe}
Common-Base	h_{ib}, h_{rb}, h_{fb}, h_{ob}
Common-Collector	h_{ic}, h_{rc}, h_{fc}, h_{oc}

TABLE 6–3

Subscripts of *h* parameters for each of the three amplifier configurations.

Relationships of *h* Parameters and *r* Parameters

The ac current ratios, α_{ac} and β_{ac}, convert directly from *h* parameters as follows:

$$\alpha_{ac} = h_{fb}$$
$$\beta_{ac} = h_{fe}$$

Because datasheets often provide only common-emitter h parameters, the following formulas show how to convert them to r parameters. We will use r parameters throughout the text because they are easier to apply and more practical.

$$r'_e = \frac{h_{re}}{h_{oe}}$$

$$r'_c = \frac{h_{re} + 1}{h_{oe}}$$

$$r'_b = h_{ie} - \frac{h_{re}}{h_{oe}}(1 + h_{fe})$$

SECTION 6–2 CHECKUP

1. Define each of the parameters: α_{ac}, β_{ac}, r'_e, r'_b, and r'_c.
2. Which h parameter is equivalent to β_{ac}?
3. If $I_E = 15$ mA, what is the approximate value of r'_e?

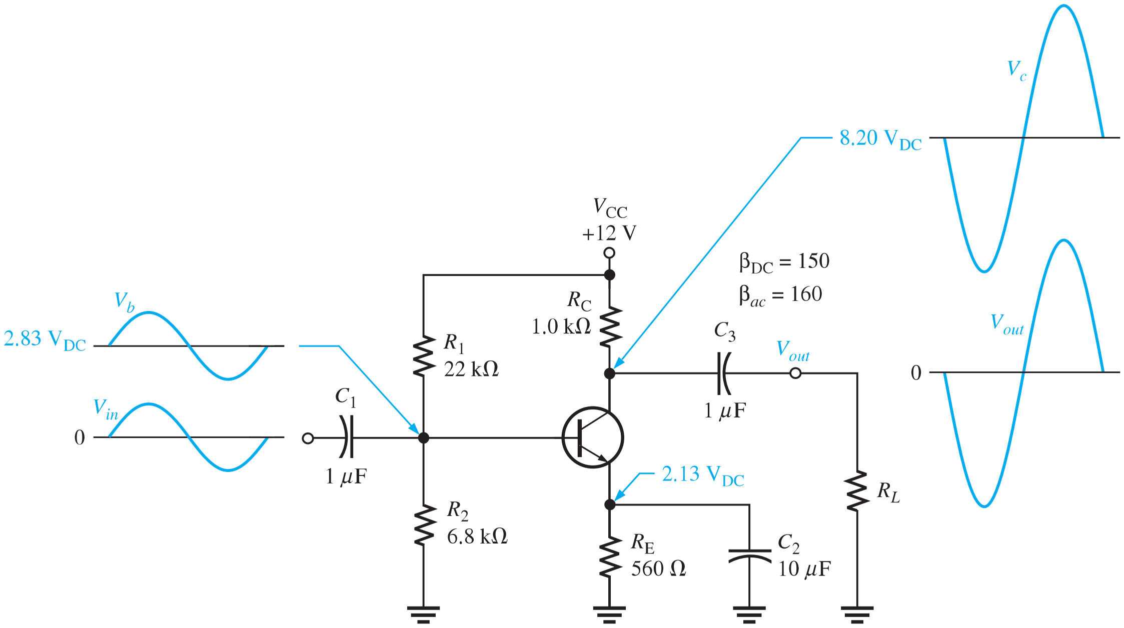
6–3 THE COMMON-EMITTER AMPLIFIER

As you have learned, a BJT can be represented in an ac model circuit. Three amplifier configurations are the common-emitter, the common-base, and the common-collector. The common-emitter (CE) configuration has the emitter as the common terminal, or ground, to an ac signal. CE amplifiers exhibit high voltage gain and high current gain. The common-collector and common-base configurations are covered in the sections 6–4 and 6–5.

After completing this section, you should be able to

- **Describe and analyze the operation of common-emitter amplifiers**
- Discuss a common-emitter amplifier with voltage-divider bias
  - Show input and output signals ◆ Discuss phase inversion
- Perform a dc analysis
  - Represent the amplifier by its dc equivalent circuit
- Perform an ac analysis
  - Represent the amplifier by its ac equivalent circuit ◆ Define *ac ground* ◆ Discuss the voltage at the base ◆ Discuss the input resistance at the base and the output resistance
- Analyze the amplifier for voltage gain
  - Define *attenuation* ◆ Define *bypass capacitor* ◆ Describe the effect of an emitter bypass capacitor on voltage gain ◆ Discuss voltage gain without a bypass capacitor ◆ Explain the effect of a load on voltage gain
- Discuss the stability of the voltage gain
  - Define *stability* ◆ Explain the purpose of swamping r'_e and the effect on input resistance
- Determine current gain and power gain

Figure 6–8 shows a **common-emitter** amplifier with voltage-divider bias and coupling capacitors C_1 and C_3 on the input and output and a bypass capacitor, C_2, from emitter to ground. The input signal, V_{in}, is capacitively coupled to the base terminal, the output signal, V_{out}, is capacitively coupled from the collector to the load. The amplified output is 180° out of phase with the input. Because the ac signal is applied to the base terminal as



▲ **FIGURE 6–8**

A common-emitter amplifier.

the input and taken from the collector terminal as the output, the emitter is common to both the input and output signals. There is no signal at the emitter because the bypass capacitor effectively shorts the emitter to ground at the signal frequency. All amplifiers have a combination of both ac and dc operation, which must be considered, but keep in mind that the common-emitter designation refers to the ac operation.

Phase Inversion The output signal is 180° out of phase with the input signal. As the input signal voltage changes, it causes the ac base current to change, resulting in a change in the collector current from its Q-point value. If the base current increases, the collector current increases above its Q-point value, causing an increase in the voltage drop across R_C. This increase in the voltage across R_C means that the voltage at the collector decreases from its Q-point. So, any change in input signal voltage results in an opposite change in collector signal voltage, which is a phase inversion.

DC Analysis

To analyze the amplifier in Figure 6–8, the dc bias values must first be determined. To do this, a dc equivalent circuit is developed by removing the coupling and bypass capacitors because they appear open as far as the dc bias is concerned. This also removes the load resistor and signal source. The dc equivalent circuit is shown in Figure 6–9.

Theveninizing the bias circuit and applying Kirchhoff's voltage law to the base-emitter circuit,

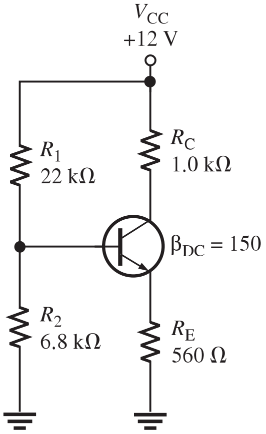
$$R_{TH} = \frac{R_1R_2}{R_1 + R_2} = \frac{(6.8\text{ k}\Omega)(22\text{ k}\Omega)}{6.8\text{ k}\Omega + 22\text{ k}\Omega} = 5.19\text{ k}\Omega$$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{6.8\text{ k}\Omega}{6.8\text{ k}\Omega + 22\text{ k}\Omega}\right)12\text{ V} = 2.83\text{ V}$$

$$I_E = \frac{V_{TH} - V_{BE}}{R_E + R_{TH}/\beta_{DC}} = \frac{2.83\text{ V} - 0.7\text{ V}}{560\ \Omega + 34.6\ \Omega} = 3.58\text{ mA}$$

$$I_C \cong I_E = 3.58\text{ mA}$$

$$V_E = I_ER_E = (3.58\text{ mA})(560\ \Omega) = 2\text{ V}$$



▲ **FIGURE 6–9**

DC equivalent circuit for the amplifier in Figure 6–8.

$$V_B = V_E + 0.7\text{ V} = 2.7\text{ V}$$
$$V_C = V_{CC} - I_C R_C = 12\text{ V} - (3.58\text{ mA})(1.0\text{ k}\Omega) = 8.42\text{ V}$$
$$V_{CE} = V_C - V_E = 8.42\text{ V} - 2\text{ V} = 6.42\text{ V}$$

AC Analysis

To analyze the ac signal operation of an amplifier, an ac equivalent circuit is developed as follows:

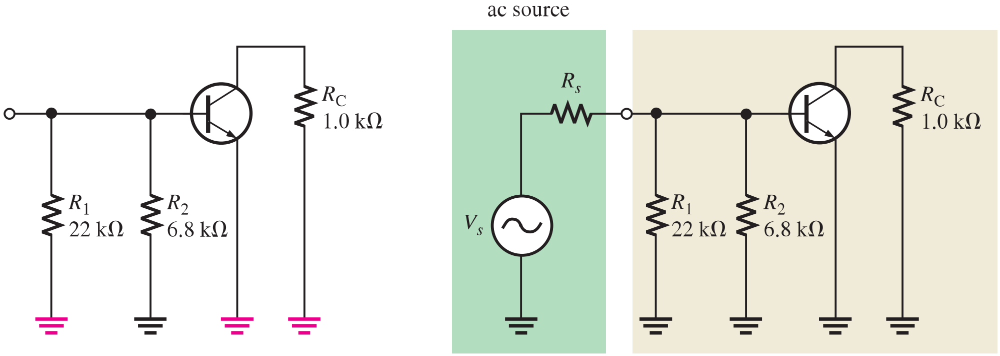
1. The capacitors C_1, C_2, and C_3 are replaced by effective shorts because their values are selected so that X_C is negligible at the signal frequency and can be considered to be 0 Ω.
2. The dc source is replaced by ground.

A dc voltage source has an internal resistance of near 0 Ω because it holds a constant voltage independent of the load (within limits); no ac voltage can be developed across it so it appears as an ac short. This is why a dc source is called an **ac ground**.

The ac equivalent circuit for the common-emitter amplifier in Figure 6–8 is shown in Figure 6–10(a). Notice that both R_C and R_1 have one end connected to ac ground (red) because, in the actual circuit, they are connected to V_{CC} which is, in effect, ac ground.

▶ FIGURE 6–10

AC equivalent circuit for the amplifier in Figure 6–8.



(a) Without an input signal voltage
(AC ground is shown in red.)

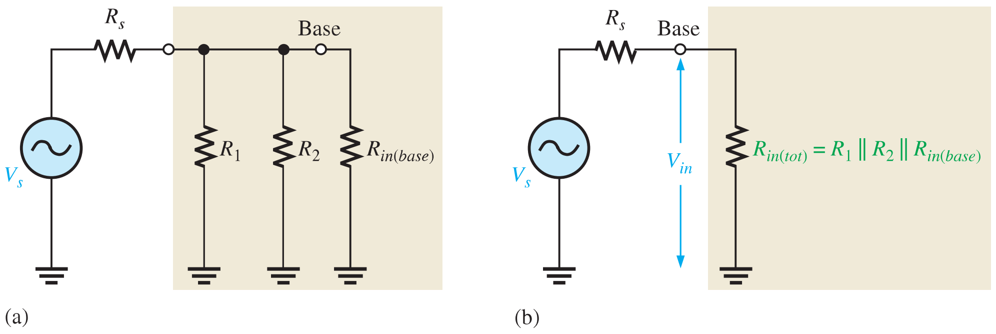
(b) With an input signal voltage

In ac analysis, the ac ground and the actual ground are treated as the same point electrically. The amplifier in Figure 6–8 is called a common-emitter amplifier because the bypass capacitor C_2 keeps the emitter at ac ground. Ground is the common point in the circuit.

Signal (AC) Voltage at the Base An ac voltage source, V_s, is shown connected to the input in Figure 6–10(b). If the internal resistance of the ac source is 0 Ω, then all of the source voltage appears at the base terminal. If, however, the ac source has a nonzero internal resistance, then three factors must be taken into account in determining the actual signal voltage at the base. These are the *source resistance* (R_s), the *bias resistance* ($R_1 \| R_2$), and the *ac input resistance* at the base of the transistor ($R_{in(base)}$). This is illustrated in Figure 6–11(a) and is simplified by combining R_1, R_2, and $R_{in(base)}$ in parallel to get the total **input resistance**, $R_{in(tot)}$, which is the resistance "seen" by an ac source connected to the input, as shown in Figure 6–11(b). A high value of input resistance is desirable so that the amplifier will not excessively load the signal source. This is opposite to the requirement for a stable Q-point, which requires smaller resistors. The conflicting requirement for high input resistance and stable biasing is but one of the many trade-offs that must be considered when choosing components for a circuit. The total input resistance is expressed by the following formula:

Equation 6–2

$$R_{in(tot)} = R_1 \| R_2 \| R_{in(base)}$$



◀ **FIGURE 6–11**

AC equivalent of the base circuit.

As you can see in the figure, the source voltage, V_s, is divided down by R_s (source resistance) and $R_{in(tot)}$ so that the signal voltage at the base of the transistor is found by the voltage-divider formula as follows:

$$V_b = \left(\frac{R_{in(tot)}}{R_s + R_{in(tot)}}\right)V_s$$

If $R_s \ll R_{in(tot)}$, then $V_b \cong V_s$ where V_b is the input voltage, V_{in}, to the amplifier.

Input Resistance at the Base To develop an expression for the ac input resistance looking in at the base, use the simplified *r*-parameter model of the transistor. Figure 6–12 shows the transistor model connected to the external collector resistor, R_C. The input resistance looking in at the base is

$$R_{in(base)} = \frac{V_{in}}{I_{in}} = \frac{V_b}{I_b}$$

The base voltage is

$$V_b = I_e r'_e$$

and since $I_e \cong I_c$,

$$I_b \cong \frac{I_e}{\beta_{ac}}$$

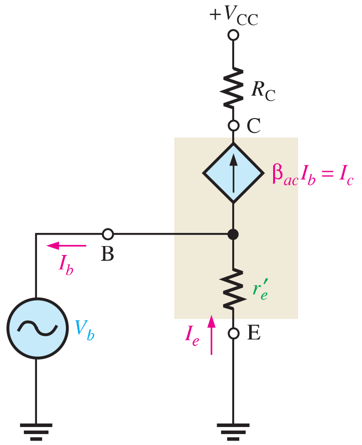
Substituting for V_b and I_b,

$$R_{in(base)} = \frac{V_b}{I_b} = \frac{I_e r'_e}{I_e/\beta_{ac}}$$

Cancelling I_e,

$$\boldsymbol{R_{in(base)} = \beta_{ac} r'_e}$$

Equation 6–3



▲ **FIGURE 6–12**

r-parameter transistor model (inside shaded block) connected to external circuit.

Output Resistance The **output resistance** of the common-emitter amplifier is the resistance looking in at the collector and is approximately equal to the collector resistor.

$$\boldsymbol{R_{out} \cong R_C}$$

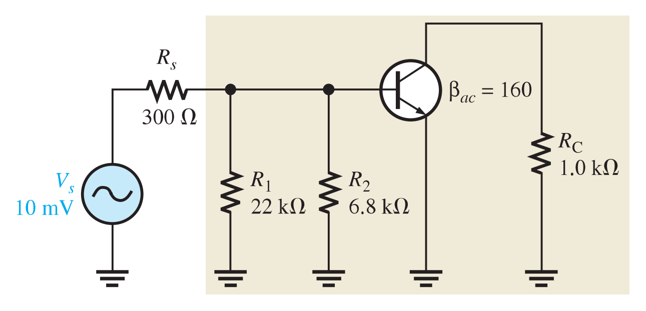
Equation 6–4

Actually, $R_{out} = R_C \parallel r'_c$, but since the internal ac collector resistance of the transistor, r'_c, is typically much larger than R_C, the approximation is usually valid.

EXAMPLE 6–3

Determine the signal voltage at the base of the transistor in Figure 6–13. This circuit is the ac equivalent of the amplifier in Figure 6–8 with a 10 mV rms, 300 Ω signal source. I_E was previously found to be 3.80 mA.

▶ FIGURE 6–13



Solution First, determine the ac emitter resistance.

$$r'_e \cong \frac{25\text{ mV}}{I_E} = \frac{25\text{ mV}}{3.80\text{ mA}} = 6.58\ \Omega$$

Then,

$$R_{in(base)} = \beta_{ac} r'_e = 160(6.58\ \Omega) = 1.05\text{ k}\Omega$$

Next, determine the total input resistance viewed from the source.

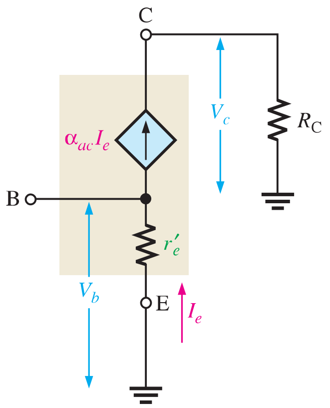
$$R_{in(tot)} = R_1 \| R_2 \| R_{in(base)} = \frac{1}{\frac{1}{22\text{ k}\Omega} + \frac{1}{6.8\text{ k}\Omega} + \frac{1}{1.05\text{ k}\Omega}} = 873\ \Omega$$

The source voltage is divided down by R_s and $R_{in(tot)}$, so the signal voltage at the base is the voltage across $R_{in(tot)}$.

$$V_b = \left(\frac{R_{in(tot)}}{R_s + R_{in(tot)}}\right)V_s = \left(\frac{873\ \Omega}{1173\ \Omega}\right)10\text{ mV} = \mathbf{7.44\ mV}$$

As you can see, there is significant attenuation (reduction) of the source voltage due to the source resistance and amplifier's input resistance combining to act as a voltage divider.

Related Problem Determine the signal voltage at the base of Figure 6–13 if the source resistance is 75 Ω and another transistor with an ac beta of 200 is used.



▲ FIGURE 6–14

Model circuit for obtaining ac voltage gain.

Voltage Gain

The ac voltage gain expression for the common-emitter amplifier is developed using the model circuit in Figure 6–14. The gain is the ratio of ac output voltage at the collector (V_c) to ac input voltage at the base (V_b).

$$A_v = \frac{V_{out}}{V_{in}} = \frac{V_c}{V_b}$$

Notice in the figure that $V_c = \alpha_{ac} I_e R_C \cong I_e R_C$ and $V_b = I_e r'_e$. Therefore,

$$A_v = \frac{I_e R_C}{I_e r'_e}$$

The I_e terms cancel, so

Equation 6–5

$$\boldsymbol{A_v = \frac{R_C}{r'_e}}$$

Equation 6–5 is the voltage gain from base to collector. To get the overall gain of the amplifier from the source voltage to collector, the attenuation of the input circuit must be included.

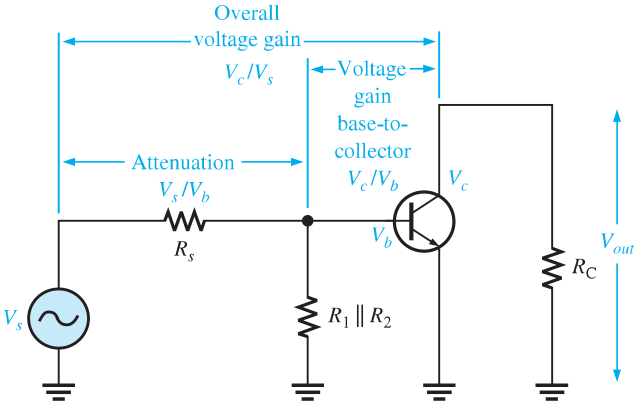
Attenuation is the reduction in signal voltage as it passes through a circuit and corresponds to a gain of less than 1. For example, if the signal amplitude is reduced by half, the attenuation is 2, which can be expressed as a gain of 0.5 because gain is the reciprocal of attenuation. Suppose a source produces a 10 mV input signal and the source resistance combined with the load resistance results in a 2 mV output signal. In this case, the attenuation is 10 mV/2 mV = 5. That is, the input signal is reduced by a factor of 5. This can be expressed in terms of gain as 1/5 = 0.2.

Assume that the amplifier in Figure 6–15 has a voltage gain from base to collector of A_v and the attenuation from the source to the base is V_s/V_b. This attenuation is produced by the source resistance and total input resistance of the amplifier acting as a voltage divider and can be expressed as

$$\text{Attenuation} = \frac{V_s}{V_b} = \frac{R_s + R_{in(tot)}}{R_{in(tot)}}$$

The overall voltage gain of the amplifier, A'_v, is the voltage gain from base to collector, V_c/V_b, times the reciprocal of the attenuation, V_b/V_s.

$$A'_v = \left(\frac{V_c}{V_b}\right)\left(\frac{V_b}{V_s}\right) = \frac{V_c}{V_s}$$



▲ FIGURE 6–15

Base circuit attenuation and overall voltage gain.

Effect of the Emitter Bypass Capacitor on Voltage Gain The emitter **bypass capacitor**, which is C_2 in Figure 6–8, provides an effective short to the ac signal around the emitter resistor, thus keeping the emitter at ac ground, as you have seen. With the bypass capacitor, the gain of a given amplifier is maximum and equal to R_C/r'_e.

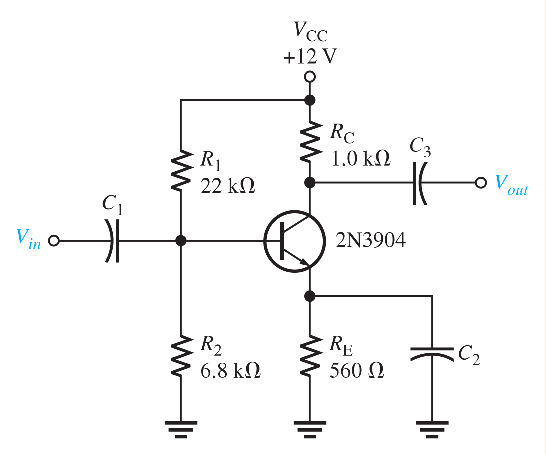
The value of the bypass capacitor must be large enough so that its reactance over the frequency range of the amplifier is very small (ideally 0 Ω) compared to R_E. A good rule-of-thumb is that the capacitive reactance, X_C, of the bypass capacitor should be at least 10 times smaller than R_E at the minimum frequency for which the amplifier must operate.

$$10X_C \leq R_E$$

EXAMPLE 6–4

Select a minimum value for the emitter bypass capacitor, C_2, in Figure 6–16 if the amplifier must operate over a frequency range from 200 Hz to 10 kHz.

▶ FIGURE 6–16



Solution The X_C of the bypass capacitor, C_2, should be at least ten times less than R_E.

$$X_{C2} = \frac{R_E}{10} = \frac{560\ \Omega}{10} = 56\ \Omega$$

Determine the capacitance value at the minimum frequency of 200 Hz as follows:

$$C_2 = \frac{1}{2\pi f X_{C2}} = \frac{1}{2\pi(200\ \text{Hz})(56\ \Omega)} = \mathbf{14.2\ \mu F}$$

This is the minimum value for the bypass capacitor for this circuit. You can always use a larger value, although cost and physical size may impose limitations.

Related Problem If the minimum frequency is reduced to 100 Hz, what value of bypass capacitor must you use?

Voltage Gain Without the Bypass Capacitor To see how the bypass capacitor affects ac voltage gain, let's remove it from the circuit in Figure 6–16 and compare voltage gains.

Without the bypass capacitor, the emitter is no longer at ac ground. Instead, R_E is seen by the ac signal between the emitter and ground and effectively adds to r'_e in the voltage gain formula.

Equation 6–6

$$\boldsymbol{A_v = \frac{R_C}{r'_e + R_E}}$$

The effect of R_E is to decrease the ac voltage gain.

EXAMPLE 6–5

Calculate the base-to-collector voltage gain of the amplifier in Figure 6–16 both without and with an emitter bypass capacitor if there is no load resistor.

Solution From Example 6–3, $r'_e = 6.58\ \Omega$ for this same amplifier. Without C_2, the gain is

$$A_v = \frac{R_C}{r'_e + R_E} = \frac{1.0\ \text{k}\Omega}{567\ \Omega} = \mathbf{1.76}$$

With C_2, the gain is

$$A_v = \frac{R_C}{r'_e} = \frac{1.0\text{ k}\Omega}{6.58\ \Omega} = \mathbf{152}$$

As you can see, the bypass capacitor makes quite a difference.

Related Problem Determine the base-to-collector voltage gain in Figure 6–16 with R_E bypassed, for the following circuit values: $R_C = 1.8\text{ k}\Omega$, $R_E = 1.0\text{ k}\Omega$, $R_1 = 33\text{ k}\Omega$, and $R_2 = 6.8\text{ k}\Omega$.

Effect of a Load on the Voltage Gain A **load** is the amount of current drawn from the output of an amplifier or other circuit through a load resistance. When a resistor, R_L, is connected to the output through the coupling capacitor C_3, as shown in Figure 6–17(a), it creates a load on the circuit. The collector resistance at the signal frequency is effectively R_C in parallel with R_L. Remember, the upper end of R_C is effectively at ac ground. The ac equivalent circuit is shown in Figure 6–17(b). The total ac collector resistance is

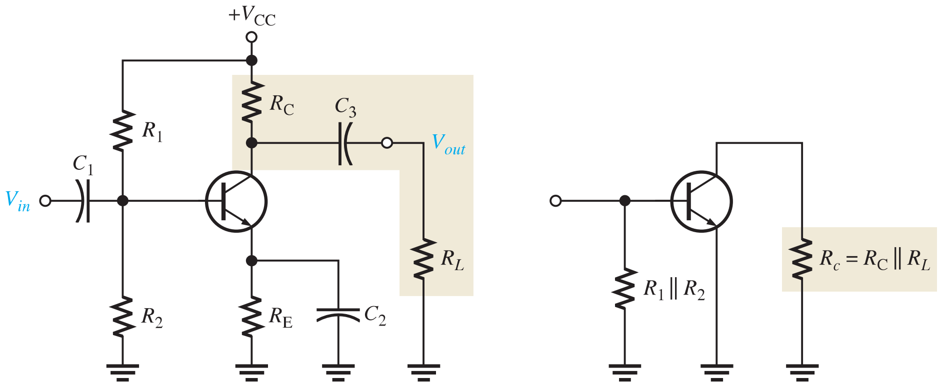
$$R_c = \frac{R_C R_L}{R_C + R_L}$$

Replacing R_C with R_c in the voltage gain expression gives

$$\boldsymbol{A_v = \frac{R_c}{r'_e}}$$

Equation 6–7

When $R_c < R_C$ because of R_L, the voltage gain is reduced. However, if $R_L \gg R_C$, then $R_c \cong R_C$ and the load has very little effect on the gain.



(a) Complete amplifier

(b) AC equivalent ($X_{C1} = X_{C2} = X_{C3} = 0$)

▲ FIGURE 6–17

A common-emitter amplifier with an ac (capacitively) coupled load.

EXAMPLE 6–6

Calculate the base-to-collector voltage gain of the amplifier in Figure 6–16 when a load resistance of 5 kΩ is connected to the output. The emitter is effectively bypassed and $r'_e = 6.58\ \Omega$.

Solution The ac collector resistance is

$$R_c = \frac{R_C R_L}{R_C + R_L} = \frac{(1.0\text{ k}\Omega)(5\text{ k}\Omega)}{6\text{ k}\Omega} = 833\ \Omega$$

Therefore,

$$A_v = \frac{R_c}{r'_e} = \frac{833\ \Omega}{6.58\ \Omega} = \mathbf{127}$$

The unloaded gain was found to be 152 in Example 6–5.

Related Problem Determine the base-to-collector voltage gain in Figure 6–16 when a 10 kΩ load resistance is connected from collector to ground. Change the resistance values as follows: $R_C = 1.8\ \text{k}\Omega$, $R_E = 1.0\ \text{k}\Omega$, $R_1 = 33\ \text{k}\Omega$, and $R_2 = 6.8\ \text{k}\Omega$. The emitter resistor is effectively bypassed and $r'_e = 18.5\ \Omega$.

Stability of the Voltage Gain

Stability is a measure of how well an amplifier maintains its design values over changes in temperature or for a transistor with a different β. Although bypassing R_E does produce the maximum voltage gain, there is a stability problem because the ac voltage gain is dependent on r'_e since $A_v = R_C/r'_e$. Also, r'_e depends on I_E and on temperature. This causes the gain to be unstable over changes in temperature because when r'_e increases, the gain decreases and vice versa.

With no bypass capacitor, the gain is decreased because R_E is now in the ac circuit ($A_v = R_C/(r'_e + R_E)$). However, with R_E unbypassed, the gain is much less dependent on r'_e. If $R_E \gg r'_e$, the gain is essentially independent of r'_e because

$$A_v \cong \frac{R_C}{R_E}$$

Swamping r'_e to Stabilize the Voltage Gain *Swamping* is a method used to minimize the effect of r'_e without reducing the voltage gain to its minimum value. This method "swamps" out the effect of r'_e on the voltage gain. Swamping is, in effect, a compromise between having a bypass capacitor across R_E and having no bypass capacitor at all.

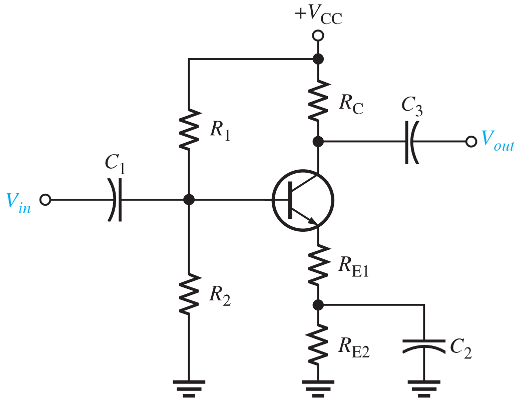
In a swamped amplifier, R_E is partially bypassed so that a reasonable gain can be achieved, and the effect of r'_e on the gain is greatly reduced or eliminated. The total external emitter resistance, R_E, is formed with two separate emitter resistors, R_{E1} and R_{E2}, as indicated in Figure 6–18. One of the resistors, R_{E2}, is bypassed and the other is not.

Both resistors ($R_{E1} + R_{E2}$) affect the dc bias while only R_{E1} affects the ac voltage gain.

$$A_v = \frac{R_C}{r'_e + R_{E1}}$$

▶ FIGURE 6–18

A swamped amplifier uses a partially bypassed emitter resistance to minimize the effect of r'_e on the gain in order to achieve gain stability.



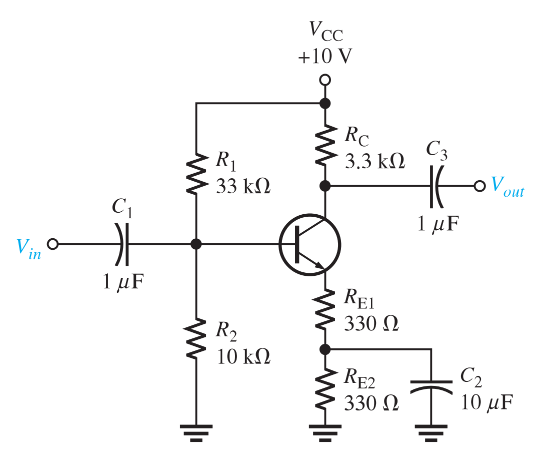
If R_{E1} is at least ten times larger than r'_e, then the effect of r'_e is minimized and the approximate voltage gain for the swamped amplifier is

$$A_v \cong \frac{R_C}{R_{E1}}$$ **Equation 6–8**

EXAMPLE 6–7

Determine the voltage gain of the swamped amplifier in Figure 6–19. Assume that the bypass capacitor has a negligible reactance for the frequency at which the amplifier is operated. Assume $r'_e = 20\ \Omega$.

▶ FIGURE 6–19



Solution R_{E2} is bypassed by C_2. R_{E1} is more than ten times r'_e so the approximate voltage gain is

$$A_v \cong \frac{R_C}{R_{E1}} = \frac{3.3\ \text{k}\Omega}{330\ \Omega} = \mathbf{10}$$

Related Problem What would be the voltage gain without C_2? What would be the voltage gain with C_2 bypassing both R_{E1} and R_{E2}?

The Effect of Swamping on the Amplifier's Input Resistance The ac input resistance, looking in at the base of a common-emitter amplifier with R_E completely bypassed, is $R_{in} = \beta_{ac}r'_e$. When the emitter resistance is partially bypassed, the portion of the resistance that is unbypassed is seen by the ac signal and results in an increase in the ac input resistance by appearing in series with r'_e. The formula is

$$R_{in(base)} = \beta_{ac}(r'_e + R_{E1})$$ **Equation 6–9**

EXAMPLE 6–8

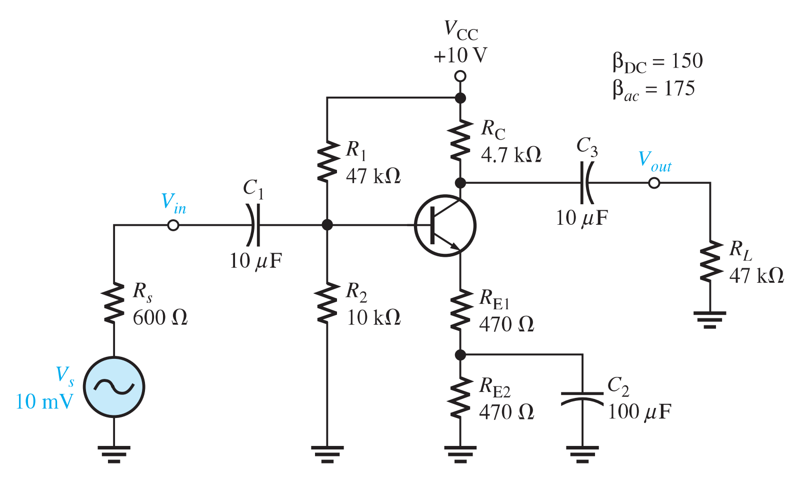
For the amplifier in Figure 6–20,

(a) Determine the dc collector voltage.

(b) Determine the ac collector voltage.

(c) Draw the total collector voltage waveform and the total output voltage waveform.

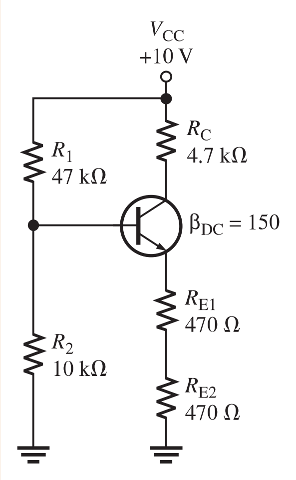
FIGURE 6–20



Solution **(a)** Determine the dc bias values using the dc equivalent circuit in Figure 6–21.

FIGURE 6–21

DC equivalent for the circuit in Figure 6–20.



Apply Thevenin's theorem and Kirchhoff's voltage law to the base-emitter circuit in Figure 6–21.

$$R_{TH} = \frac{R_1R_2}{R_1 + R_2} = \frac{(47\text{ k}\Omega)(10\text{ k}\Omega)}{47\text{ k}\Omega + 10\text{ k}\Omega} = 8.25\text{ k}\Omega$$

$$V_{TH} = \left(\frac{R_2}{R_1 + R_2}\right)V_{CC} = \left(\frac{10\text{ k}\Omega}{47\text{ k}\Omega + 10\text{ k}\Omega}\right)10\text{ V} = 1.75\text{ V}$$

$$I_E = \frac{V_{TH} - V_{BE}}{R_E + R_{TH}/\beta_{DC}} = \frac{1.75\text{ V} - 0.7\text{ V}}{940\ \Omega + 55\ \Omega} = 1.06\text{ mA}$$

$$I_C \cong I_E = 1.06\text{ mA}$$

$$V_E = I_E(R_{E1} + R_{E2}) = (1.06\text{ mA})(940\ \Omega) = 1\text{ V}$$

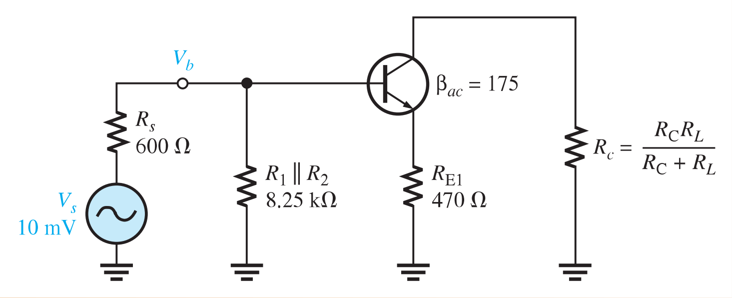
$$V_B = V_E + 0.7\text{ V} = 1\text{ V} - 0.7\text{ V} = 0.3\text{ V}$$

$$V_C = V_{CC} - I_CR_C = 10\text{ V} - (1.06\text{ mA})(4.7\text{ k}\Omega) = \mathbf{5.02\text{ V}}$$

(b) The ac analysis is based on the ac equivalent circuit in Figure 6–22.

FIGURE 6–22

AC equivalent for the circuit in Figure 6–20.



The first thing to do in the ac analysis is calculate r'_e.

$$r'_e \cong \frac{25\text{ mV}}{I_E} = \frac{25\text{ mV}}{1.06\text{ mA}} = 23.6\ \Omega$$

Next, determine the attenuation in the base circuit. Looking from the 600 Ω source, the total R_{in} is

$$R_{in(tot)} = R_1 \parallel R_2 \parallel R_{in(base)}$$
$$R_{in(base)} = \beta_{ac}(r'_e + R_{E1}) = 175(494\ \Omega) = 86.5\text{ k}\Omega$$

Therefore,

$$R_{in(tot)} = 47\text{ k}\Omega \parallel 10\text{ k}\Omega \parallel 86.5\text{ k}\Omega = 7.53\text{ k}\Omega$$

The attenuation from source to base is

$$\text{Attenuation} = \frac{V_s}{V_b} = \frac{R_s + R_{in(tot)}}{R_{in(tot)}} = \frac{600\ \Omega + 7.53\text{ k}\Omega}{7.53\text{ k}\Omega} = 1.08$$

Before A_v can be determined, you must know the ac collector resistance R_c.

$$R_c = \frac{R_C R_L}{R_C + R_L} = \frac{(4.7\text{ k}\Omega)(47\text{ k}\Omega)}{4.7\text{ k}\Omega + 47\text{ k}\Omega} = 4.27\text{ k}\Omega$$

The voltage gain from base to collector is

$$A_v \cong \frac{R_c}{R_{E1}} = \frac{4.27\text{ k}\Omega}{470\ \Omega} = 9.09$$

The overall voltage gain is the reciprocal of the attenuation times the amplifier voltage gain.

$$A'_v = \left(\frac{V_b}{V_s}\right)A_v = (0.93)(9.09) = 8.45$$

The source produces 10 mV rms, so the rms voltage at the collector is

$$V_c = A'_v V_s = (8.45)(10\text{ mV}) = \mathbf{84.5\ mV}$$

(c) The total collector voltage is the signal voltage of 84.5 mV rms riding on a dc level of 4.74 V, as shown in Figure 6–23(a), where approximate peak values are determined as follows:

$$\text{Max } V_{c(p)} = V_C + 1.414\,V_c = 4.74\text{ V} + (84.5\text{ mV})(1.414) = 4.86\text{ V}$$
$$\text{Min } V_{c(p)} = V_C - 1.414\,V_c = 4.74\text{ V} - (84.5\text{ mV})(1.414) = 4.62\text{ V}$$

The coupling capacitor, C_3, keeps the dc level from getting to the output. So, V_{out} is equal to the ac component of the collector voltage ($V_{out(p)} = (84.5\text{ mV})(1.414) = 119\text{ mV}$),