The Common-Emitter Amplifier

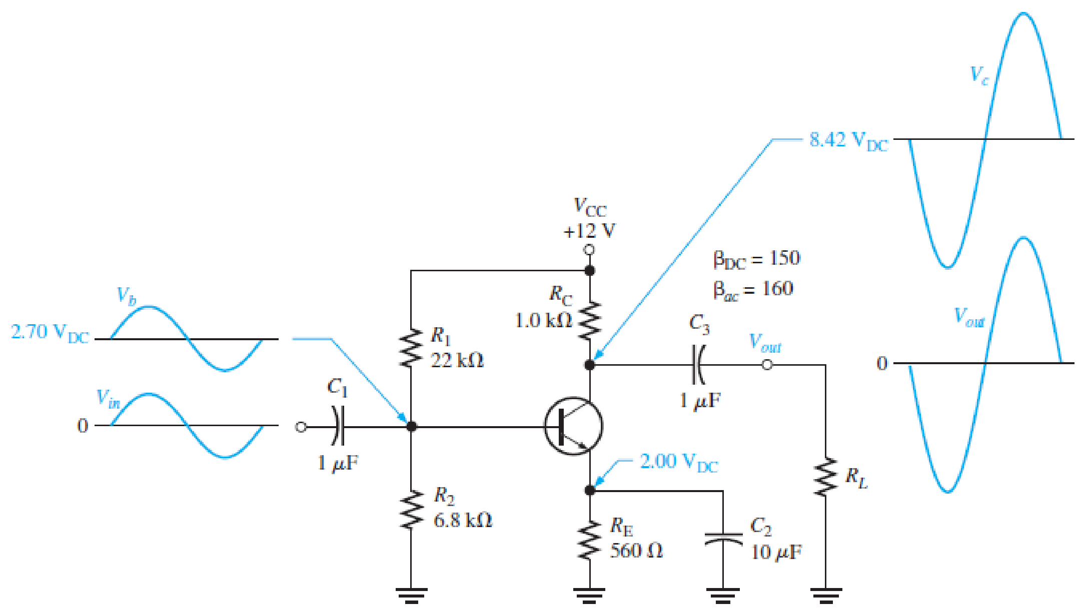


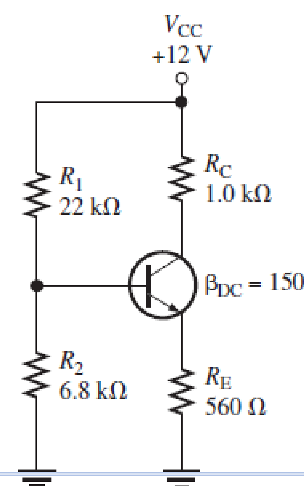
Figure shows a **common-emitter** amplifier with voltage-divider bias and coupling capacitors $C1$ and $C3$ on the input and output and a bypass capacitor, $C2$, from emitter to ground. The input signal, Vin, is capacitive coupled to the base terminal, the output signal, Vout, is capacitive coupled from the collector to the load.

DC Analysis

The dc equivalent circuit is shown in Figure. Theveninizing the bias circuit and applying Kirchhoff's voltage law to the base-emitter circuit

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

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



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

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

$$V_E = I_E R_E = (3.58\ \text{mA})(560\ \Omega) = 2.00\ \text{V}$$

$$V_B = V_E + 0.7\ \text{V} = 2.70\ \text{V}$$

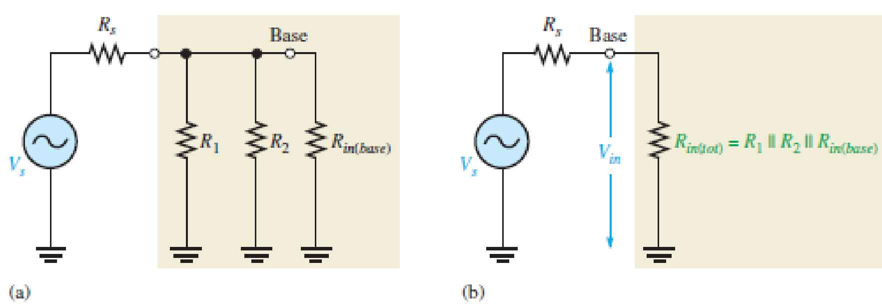
$$V_C = V_{CC} - I_C R_C = 12\ \text{V} - (3.58\ \text{mA})(1.0\ \text{k}\Omega) = 8.42\ \text{V}$$

$$V_{CE} = V_C - V_E = 8.42\ \text{V} - 2.00\ \text{V} = 6.42\ \text{V}$$

AC Analysis

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:

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



As you can see in the figure, the source voltage, Vs, is divided down by Rs (source resistance) and Rin(tot) so that the signal voltage at the base of the transistor is found by the voltage-divider formula as follows:

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

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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 $I_e \cong I_c$,

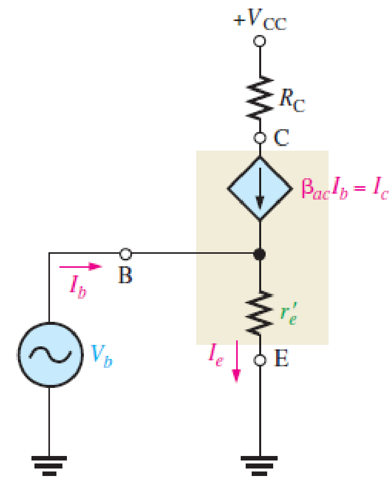
$$I_b \cong \frac{I_e}{\beta_{ac}}$$

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,

$$\mathbf{R_{in(base)} = \beta_{ac} r'_e} \quad \text{Equation 6–3}$$



▲ 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.

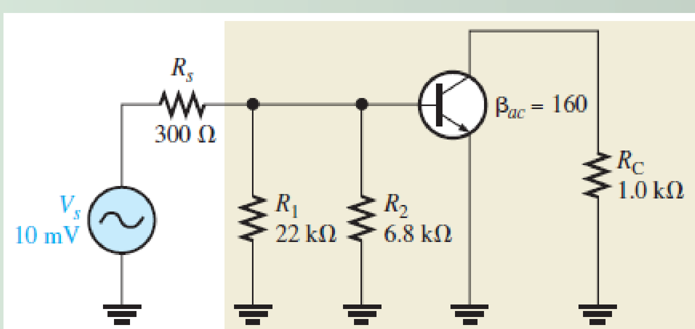
$$\mathbf{R_{out} \cong R_C} \quad \text{Equation 6–4}$$

Actually, $R_{out} = R_C \| r'_c$, 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 6–4

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 3.58 mA.

▶ FIGURE 6–13



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Solution First, determine the ac emitter resistance.

$$r'_e \cong \frac{25\text{ mV}}{I_E} = \frac{25\text{ mV}}{3.58\text{ mA}} = 6.98\ \Omega$$

Then,

$$R_{in(base)} = \beta_{ac} r'_e = 160(6.98\ \Omega) = 1.12\text{ k}\Omega$$

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

$$R_{in(tot)} = R_1 \parallel R_2 \parallel R_{in(base)} = \frac{1}{\frac{1}{22\text{ k}\Omega} + \frac{1}{6.8\text{ k}\Omega} + \frac{1}{1.12\text{ k}\Omega}} = 920\ \Omega$$

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

$$V_b = \left(\frac{R_{in(tot)}}{R_s + R_{in(tot)}}\right)V_s = \left(\frac{920\ \Omega}{1221\ \Omega}\right)10\text{ mV} = \mathbf{7.53\text{ mV}}$$

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.

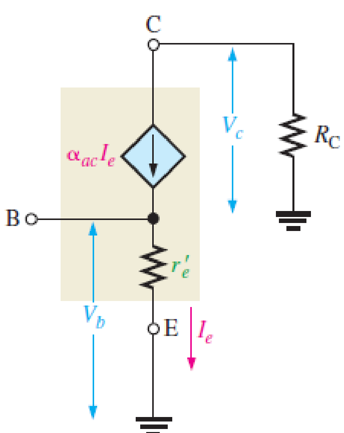

FIGURE 6–14
Model circuit for obtaining ac voltage gain.

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

$$A_v = \frac{R_C}{r'_e} \qquad \text{Equation 6–5}$$

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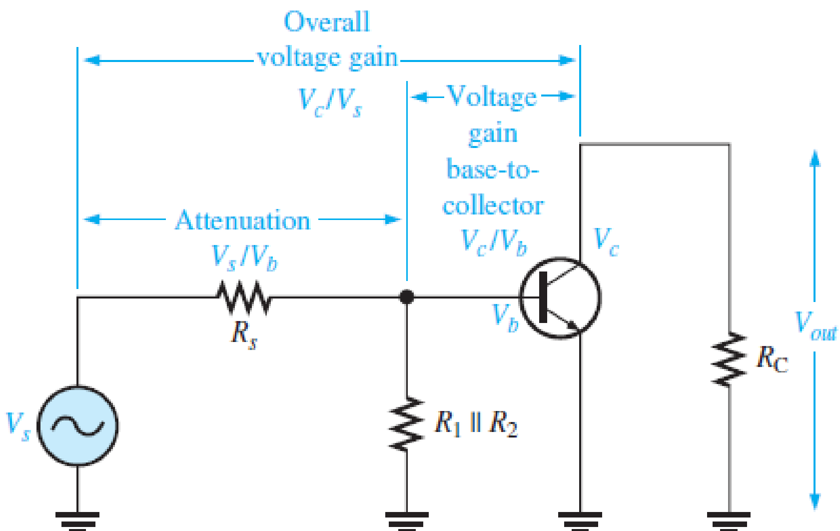
Assume that the amplifier in Figure 6–15 has a voltage gain from base to collector of A_v and the attenuation from the source to the base is V_s/V_b. This attenuation is produced by the source resistance and total input resistance of the amplifier acting as a voltage divider and can be expressed as

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

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.

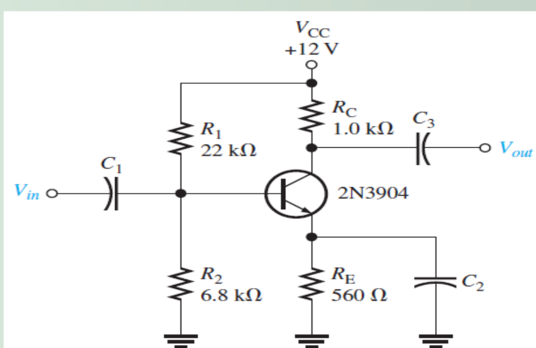
$$A'_v = \left(\frac{V_c}{V_b}\right)\left(\frac{V_b}{V_s}\right) = \frac{V_c}{V_s}$$



EXAMPLE 6–5

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



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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.

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

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

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

EXAMPLE 6–6 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 6–4, $r'_e = 6.98\ \Omega$ 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

$$A_v = \frac{R_C}{r'_e} = \frac{1.0\text{ k}\Omega}{6.98\ \Omega} = \mathbf{143}$$

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

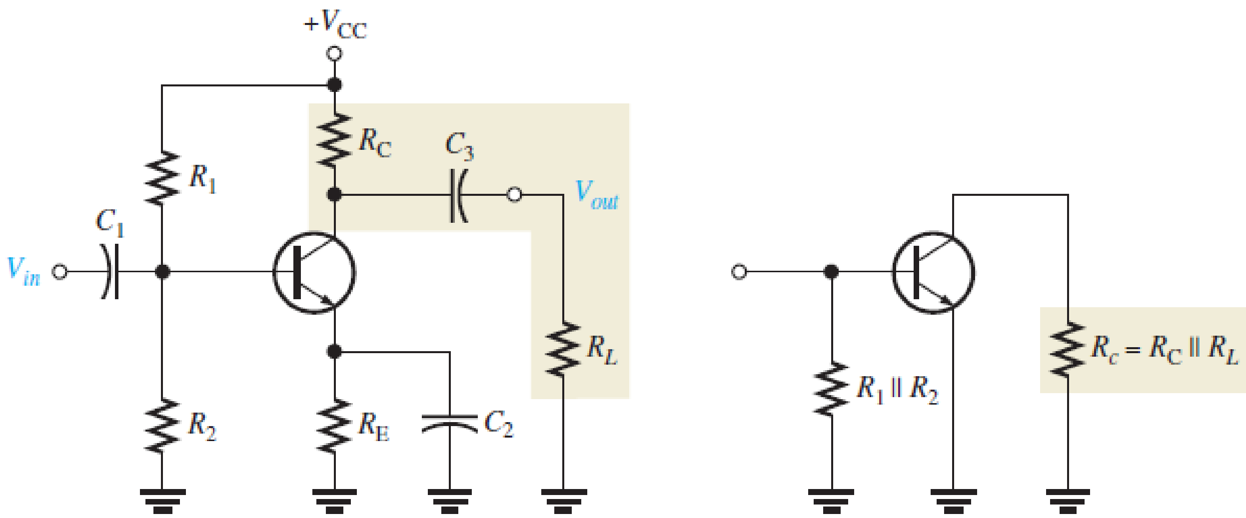
Effect of a Load on the Voltage Gain A **load** is the amount of current drawn from the output of an amplifier or other circuit through a load resistance. When a resistor, R_L, is connected to the output through the coupling capacitor C_3, as shown in Figure 6–17(a), it creates a load on the circuit. 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

$$A_v = \frac{R_c}{r'_e} \qquad \textbf{Equation 6–7}$$

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 ($X_{C1} = X_{C2} = X_{C3} = 0$)