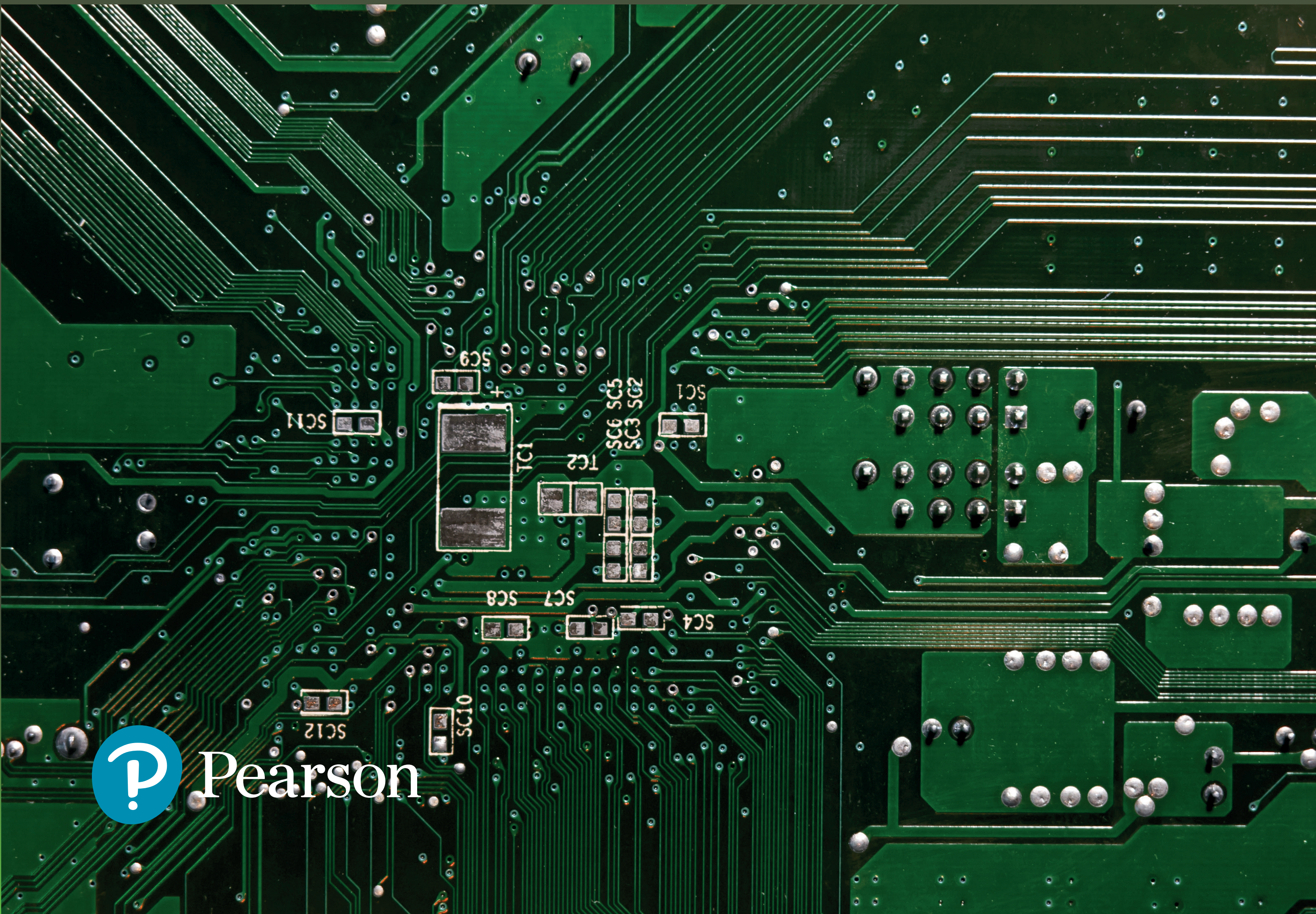
GLOBAL EDITION

Electronic Devices

Conventional Current Version

TENTH EDITION

Thomas L. Floyd



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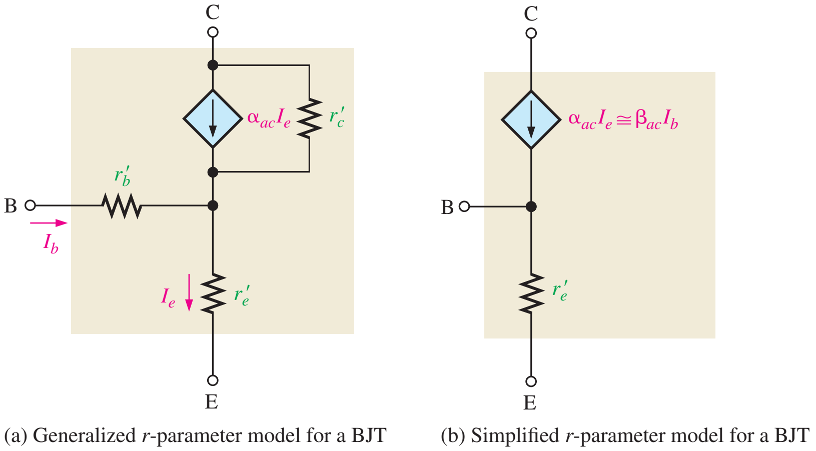


▲ FIGURE 6–5

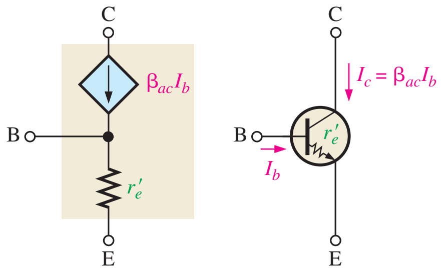
r-parameter transistor model.

small enough to neglect, so it can generally be replaced by a short. The ac collector resistance (r'_c) is usually several hundred kilohms and can approximately be replaced by an open. The resulting simplified *r*-parameter equivalent circuit is shown in Figure 6–5(b).

The interpretation of this model circuit in terms of a transistor's ac operation is as follows: A resistance (r'_e) appears between the emitter and base terminals. This is the resistance "seen" looking into the emitter of a forward-biased transistor. The collector effectively acts as a dependent current source of $\alpha_{ac}I_e$ or, equivalently, $\beta_{ac}I_b$, represented by the diamond-shaped symbol. These factors are shown with a transistor symbol in Figure 6–6.

▶ FIGURE 6–6

Relation of transistor symbol to *r*-parameter model.



Determining r'_e by a Formula

For amplifier analysis, the ac emitter resistance, r'_e, is the most important of the *r* parameters. To calculate the approximate value of r'_e, you can use Equation 6–1, which is derived assuming an abrupt junction between the *n* and *p* regions. It is also temperature dependent and is based on an ambient temperature of 20°C.

Equation 6–1

$$r'_e \cong \frac{25\text{ mV}}{I_E}$$

The numerator will be slightly larger for higher temperatures or transistors with a gradual (instead of an abrupt) junction. Although these cases will yield slightly different results, most designs are not critically dependent on the value of r'_e, and you will generally obtain excellent agreement with actual circuits using the equation as given. The derivation for Equation 6–1 can be found in "Derivations of Selected Equations" at www.pearsonglobaleditions.com/Floyd.

EXAMPLE 6–3 Determine the r'_e of a transistor that is operating with a dc emitter current of 2 mA.

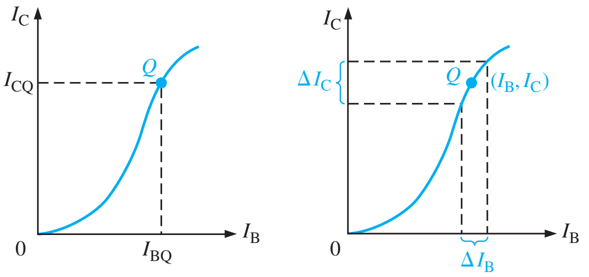
Solution

$$r'_e \cong \frac{25\text{ mV}}{I_E} = \frac{25\text{ mV}}{2\text{ mA}} = \mathbf{12.5\ \Omega}$$

Related Problem What is I_E if $r'_e = 8\ \Omega$?

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

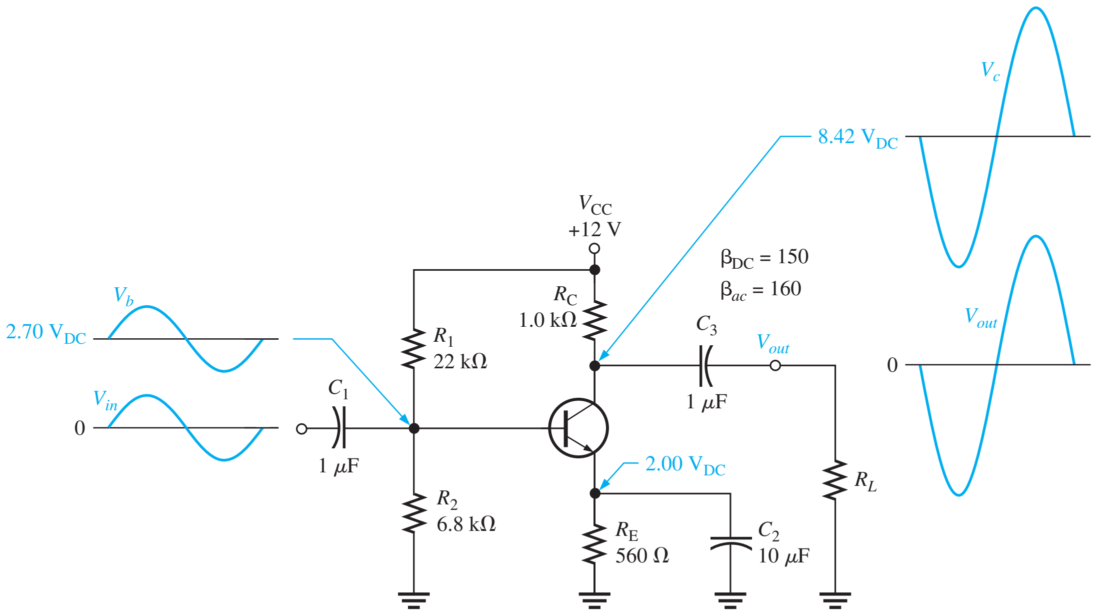
1. Define each of the parameters: α_{ac}, β_{ac}, r'_e, r'_b, r'_c.
2. Which h parameter is equivalent to β_{ac}?
3. If $I_E = 15$ mA, what is the approximate value of r'_e.
4. What is the difference between β_{ac} and β_{DC}?

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

A common-emitter amplifier.

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 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.

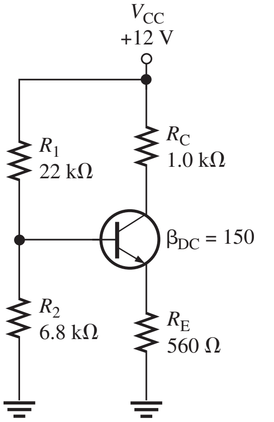
DC Analysis

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,

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

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



▲ FIGURE 6–9

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

$$I_E = \frac{V_{TH} - V_{BE}}{R_E + R_{TH}/\beta_{DC}} = \frac{2.83\text{ V} - 0.7\text{ V}}{560\ \Omega + 34.6\ \Omega} = 3.58\text{ mA}$$
$$I_C \cong I_E = 3.58\text{ mA}$$
$$V_E = I_E R_E = (3.58\text{ mA})(560\ \Omega) = 2.00\text{ V}$$
$$V_B = V_E + 0.7\text{ V} = 2.70\text{ V}$$
$$V_C = V_{CC} - I_C R_C = 12\text{ V} - (3.58\text{ mA})(1.0\text{ k}\Omega) = 8.42\text{ V}$$
$$V_{CE} = V_C - V_E = 8.42\text{ V} - 2.00\text{ V} = 6.42\text{ V}$$

AC Analysis

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

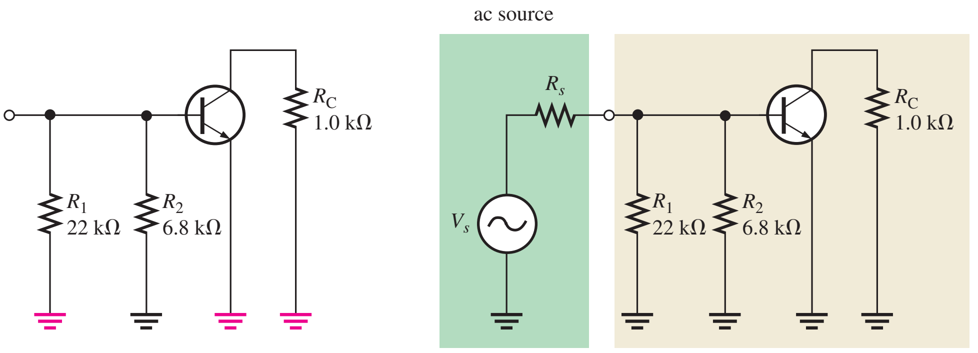
1. The capacitors C_1, C_2, and C_3 are replaced by effective shorts because their values are selected so that X_C is negligible at the signal frequency and can be considered to be 0 Ω.
2. The dc source is replaced by ground.

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.

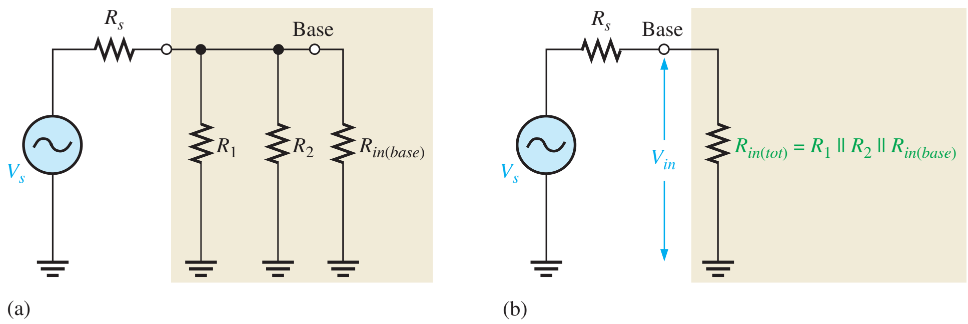


(a) Without an input signal voltage (AC ground is shown in red.)

(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



◀ FIGURE 6–11

AC equivalent of the base circuit.

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:

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

Equation 6–2

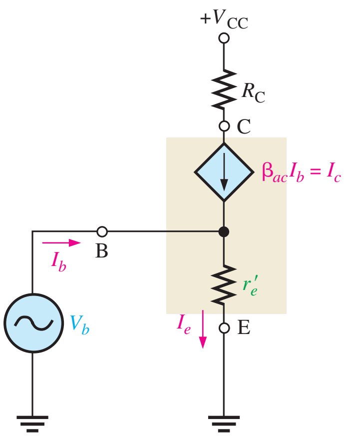
As you can see in the figure, the source voltage, V_s, is divided down by R_s (source resistance) and $R_{in(tot)}$ so that the signal voltage at the base of the transistor is found by the voltage-divider formula as follows:

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

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

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



▲ FIGURE 6–12

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

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

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