s 6.5: For the circuit in Figure 6.61, $R_E = 2\,k\Omega$ and $R_1 = R_2 = 50\,k\Omega$. Using a PSpice simulation, determine the small-signal voltage gain for (a) $R_L = 50\,\Omega$, (b) $R_L = 200\,\Omega$, (c) $R_L = 500\,\Omega$, and (d) $R_L = 2\,k\Omega$. What can be said about loading effects?

6.7 COMMON-BASE AMPLIFIER

Objective: • Analyze the common-base amplifier and become familiar with the general characteristics of this circuit.

A third amplifier circuit configuration is the **common-base circuit.** To determine the small-signal voltage and current gains, and the input and output impedances, we will use the same hybrid-π equivalent circuit for the transistor that was used previously. The dc analysis of the common-base circuit is essentially the same as for the common-emitter circuit.

6.7.1 Small-Signal Voltage and Current Gains

Figure 6.62 shows the basic common-base circuit, in which the base is at signal ground and the input signal is applied to the emitter. Assume a load is connected to the output through a coupling capacitor C_{C2}.

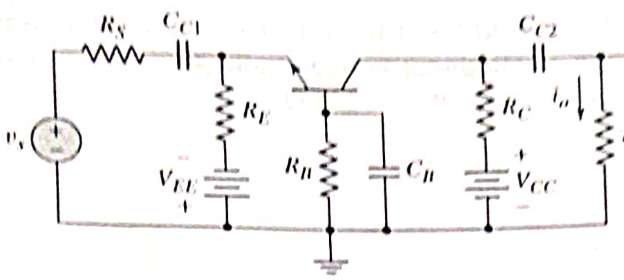

Figure 6.62 Basic common-base circuit. The input signal is applied to the emitter terminal and the output signal is measured at the collector terminal.

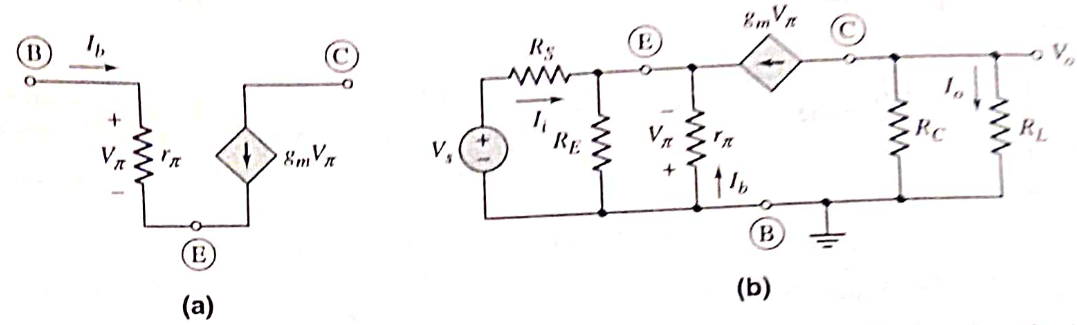

Figure 6.63 (a) Simplified hybrid-π model of the npn transistor and (b) small-signal equivalent circuit of the common-base circuit

Figure 6.63(a) again shows the hybrid-π model of the npn transistor, with the output resistance r_o assumed to be infinite. Figure 6.63(b) shows the small-signal equivalent circuit of the common-base circuit, including the hybrid-π model of the transistor. As a result of the common-base configuration, the hybrid-π model in the small-signal equivalent circuit may look a little strange.

The small signal output voltage is given by

$$V_o = -(g_m V_\pi)(R_C \| R_L) \qquad (6.8$$

Writing a KCL equation at the emitter node, we obtain

$$g_m V_\pi + \frac{V_\pi}{r_\pi} + \frac{V_\pi}{R_E} + \frac{V_s - (-V_\pi)}{R_S} = 0 \qquad (6.$$

Since $\beta = g_m r_\pi$, Equation (6.87) can be written

$$V_\pi \left(\frac{1+\beta}{r_\pi} + \frac{1}{R_E} + \frac{1}{R_S} \right) = -\frac{V_s}{R_S}$$

Then,

$$V_\pi = -\frac{V_s}{R_S} \left[\left(\frac{r_\pi}{1+\beta} \right) \bigg\| R_E \| R_S \right]$$

Substituting Equation (6.89) into (6.86), we find the small-signal voltage gain, as follows:

$$A_v = \frac{V_o}{V_s} = +g_m \left(\frac{R_C \| R_L}{R_S} \right) \left[\left(\frac{r_\pi}{1+\beta} \right) \bigg\| R_E \| R_S \right]$$

We can show that as R_S approaches zero, the small-signal voltage gain becomes

$$A_v = g_m (R_C \| R_L)$$

Figure 6.63(b) can also be used to determine the small-signal current gain. The current gain is defined as $A_i = I_o/I_i$. Writing a KCL equation at the emitter node, we have

$$I_i + \frac{V_\pi}{r_\pi} + g_m V_\pi + \frac{V_\pi}{R_E} = 0 \tag{6.92}$$

Solving for V_π, we obtain

$$V_\pi = -I_i\left[\left(\frac{r_\pi}{1+\beta}\right)\middle\| R_E\right] \tag{6.93}$$

The load current is given by

$$I_o = -(g_m V_\pi)\left(\frac{R_C}{R_C + R_L}\right) \tag{6.94}$$

Combining Equations (6.93) and (6.94), we obtain an expression for the small-signal current gain, as follows:

$$A_i = \frac{I_o}{I_i} = g_m\left(\frac{R_C}{R_C + R_L}\right)\left[\left(\frac{r_\pi}{1+\beta}\right)\middle\| R_E\right] \tag{6.95}$$

If we take the limit as R_E approaches infinity and R_L approaches zero, then the current gain becomes the short-circuit current gain given by

$$A_{io} = \frac{g_m r_\pi}{1+\beta} = \frac{\beta}{1+\beta} = \alpha \tag{6.96}$$

where α is the common-base current gain of the transistor.

Equations (6.90) and (6.96) indicate that, for the common-base circuit, the small-signal voltage gain is usually greater than 1 and the small-signal current gain is slightly less than 1. However, we still have a small-signal power gain. The applications of a common-base circuit take advantage of the input and output resistance characteristics.

6.7.2 Input and Output Impedance

Figure 6.64 shows the small-signal equivalent circuit of the common-base configuration looking into the emitter. In this circuit, for convenience only, we have reversed the polarity of the control voltage, which reverses the direction of the dependent current source.

The input resistance looking into the emitter is defined as

$$R_{ie} = \frac{V_\pi}{I_i} \tag{6.97}$$

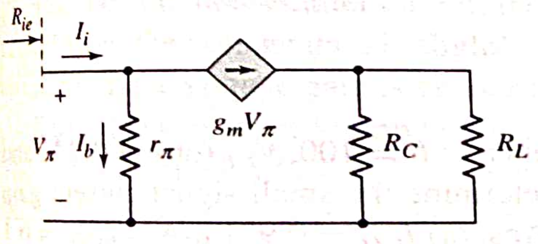

Figure 6.64 Common-base equivalent circuit for input resistance calculations

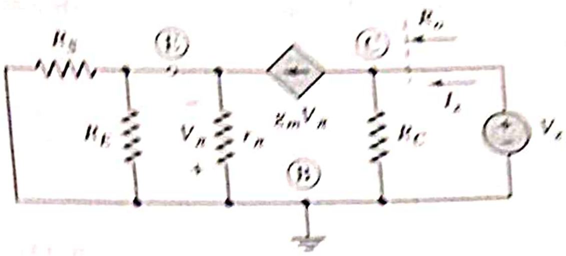

Figure 6.65 Common-base equivalent circuit for output resistance calculations

If we write a KCL equation at the input, we obtain

$$I_i = I_b + g_m V_\pi = \frac{V_\pi}{r_\pi} + g_m V_\pi = V_\pi\left(\frac{1+\beta}{r_\pi}\right) \tag{6.98}$$

Therefore,

$$R_{ie} = \frac{V_\pi}{I_i} = \frac{r_\pi}{1+\beta} \equiv r_e \tag{6.99}$$

The resistance looking into the emitter, with the base grounded, is usually defined as r_e and is quite small, as already shown in the analysis of the emitter-follower circuit. When the input signal is a current source, a small input resistance is desirable.

Figure 6.65 shows the circuit used to calculate the output resistance. The independent source v_s has been set equal to zero. Writing a KCL equation at the emitter, we find

$$g_m V_\pi + \frac{V_\pi}{r_\pi} + \frac{V_\pi}{R_E} + \frac{V_\pi}{R_S} = 0 \tag{6.100}$$

This implies that $V_\pi = 0$, which means that the independent source $g_m V_\pi$ is also zero. Consequently, the output resistance looking back into the output terminals is then

$$R_o = R_C \tag{6.101}$$

Because we have assumed r_o is infinite, the output resistance looking back into the collector terminal is essentially infinite, which means that the common-base circuit looks almost like an ideal current source. The circuit is also referred to as a **current buffer.**

Discussion

The common-base circuit is very useful when the input signal is a current. We will see this type of application when we discuss the cascode circuit in Section 6.9.

Test Your Understanding

TYU 6.13 For the circuit shown in Figure 6.66, the transistor parameters are: $\beta = 100$, $V_{EB}(\text{on}) = 0.7$ V, and $r_o = \infty$. (a) Calculate the quiescent values of I_{CQ} and V_{ECQ}. (b) Determine the small-signal current gain $A_i = i_o/i_i$. (c) Determine the small-signal voltage gain $A_v = v_o/v_s$. (Ans. (a) $I_{CQ} = 0.921$ mA, $V_{ECQ} = 6$… V (b) $A_i = 0.987$ (c) $A_v = 177$)

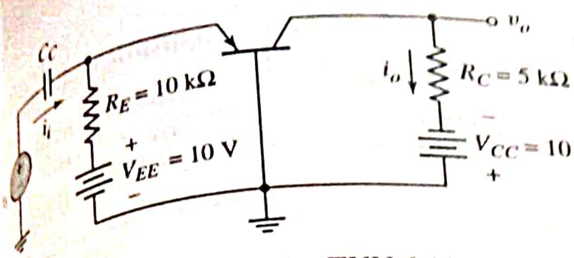

Figure 6.66 Figure for Exercise TYU 6.13

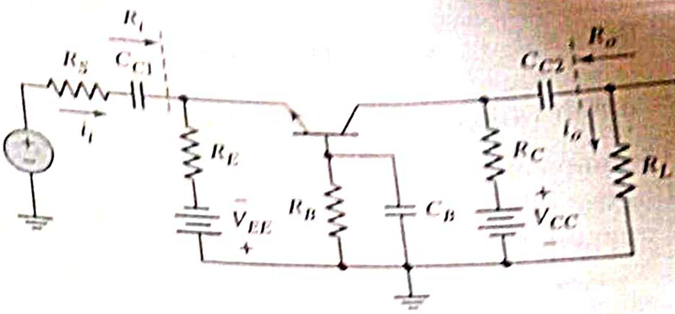

Figure 6.67 Figure for Exercises TYU 6.14 and TYU 6.15

TYU 6.14 For the circuit shown in Figure 6.67, the parameters are: $R_B = 100\ k\Omega$, $R_E = 10\ k\Omega$, $R_C = 10\ k\Omega$, $V_{CC} = V_{EE} = 10$ V, $R_L = 1\ k\Omega$, $R_S = 1\ k\Omega$, $V_{BE}(\text{on}) = 0.7$ V, $\beta = 100$, and $V_A = \infty$. (a) Determine the small-signal transistor parameters g_m, r_π, and r_o. (b) Find the small-signal current gain $A_i = i_o/i_i$ and the small-signal voltage gain $A_v = v_o/v_s$. (c) Determine the input resistance R_i and the output resistance R_o. (Ans. (a) $r_\pi = 3.1\ k\Omega$, $g_m = 32.23$ mA/V, $r_o = \infty$ (b) $A_v = 0.870$, $A_i = 0.90$ (c) $R_i = 30.6\ \Omega$, $R_o = 10\ k\Omega$)

TYU 6.15 For the circuit shown in Figure 6.67, let $R_S = 0$, $C_B = 0$, $R_C = R_L = 2\ k\Omega$, $V_{CC} = V_{EE} = 5$ V, $\beta = 100$, $V_{BE}(\text{on}) = 0.7$ V, and $V_A = \infty$. Design R_E and R_B for a dc quiescent collector current of 1 mA and a small-signal voltage gain of 20. (Ans. $R_B = 2.4\ k\Omega$, $R_E = 4.23\ k\Omega$)

COMPUTER ANALYSIS EXERCISE

PS 6.6: Using a PSpice simulation, verify the common-base circuit design in the Test Your Understanding exercise TYU6.15. Use a standard transistor.

6.8 THE THREE BASIC AMPLIFIERS: SUMMARY AND COMPARISON

Objective: • Compare the general characteristics of the three basic amplifier configurations

The basic small-signal characteristics of the three single-stage amplifier configurations are summari[z]ed in Table 6.4.

For the common-emitter circuit, the voltage and current gains are generally greater than 1. For th[e emit]ter-follower, the voltage gain is slightly less than 1, while the current gain is greater than 1. For the co[mmon-]base circuit, the voltage gain is greater than 1, while the current gain is less than 1.

The input resistance looking into the base terminal of a common-emitter circuit may be in the low [kΩ] range; in an emitter follower, it is generally in the 50 to 100 kΩ range. The input resistance looking [into the] emitter of a common-base circuit is generally on the order of tens of ohms.

The overall input resistance of both the common-emitter and emitter-follower circuits can b[e] affected by the bias circuitry.

Table 6.4 Characteristics of the three BJT amplifier configurations

Configuration	Voltage gain	Current gain	Input resistance	Output resistance
Common emitter	$A_v > 1$	$A_i > 1$	Moderate	Moderate to high
Emitter follower	$A_v \cong 1$	$A_i > 1$	High	Low
Common base	$A_v > 1$	$A_i \cong 1$	Low	Moderate to high

The output resistance of the emitter follower is generally in the range of a few ohms to tens of ohms. In contrast, the output resistance looking into the collector terminal of the common-emitter and common-base circuits is very high. In addition, the output resistance looking back into the output terminal of the common-emitter and common-base circuits is a strong function of the collector resistance. For these circuits, the output resistance can easily drop to a few kilohms.

The characteristics of these single-stage amplifiers will be used in the design of multistage amplifiers.