BJT AC Analysis

Equivalent Circuits

Text Book

Electronic Devices and Circuit Theory

by R Boylestad and L Nashelsky

Ac analysis steps

In summary, therefore, the ac equivalent of a network is obtained by:

1. *Setting all dc sources to zero and replacing them by a short-circuit equivalent*
2. *Replacing all capacitors by a short-circuit equivalent*
3. *Removing all elements bypassed by the short-circuit equivalents introduced by steps 1 and 2*
4. *Redrawing the network in a more convenient and logical form*

In the sections to follow, the r_e and hybrid equivalent circuits will be introduced to complete the ac analysis of the network of Fig. 7.5.

Ac analysis: Common-emitter

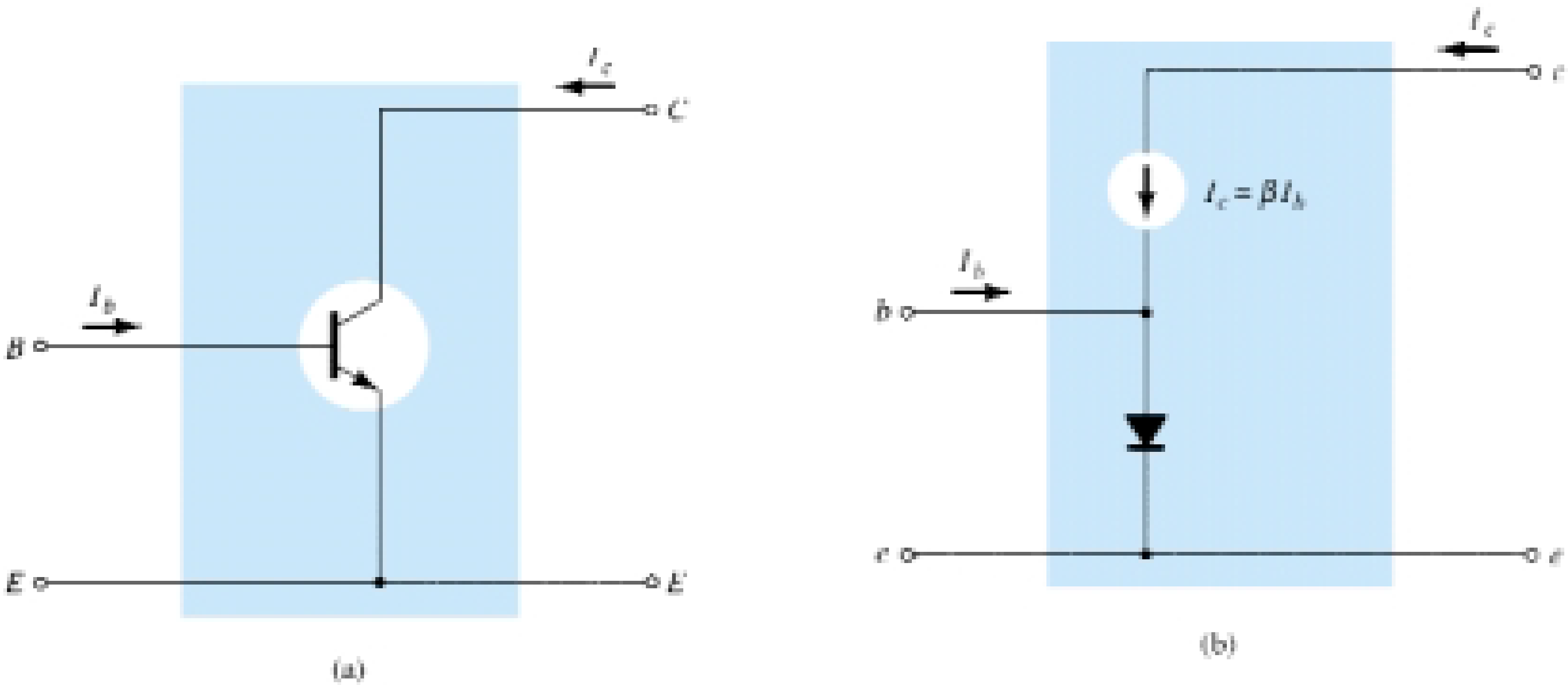


Figure 7.21 (a) Common-emitter BJT transistor; (b) approximate model for the configuration

$$\boxed{I_c = \beta I_b}$$

The current through the diode is therefore determined by

$$I_e = I_c + I_b = \beta I_b + I_b$$

and

$$\boxed{I_e = (\beta + 1)I_b}$$

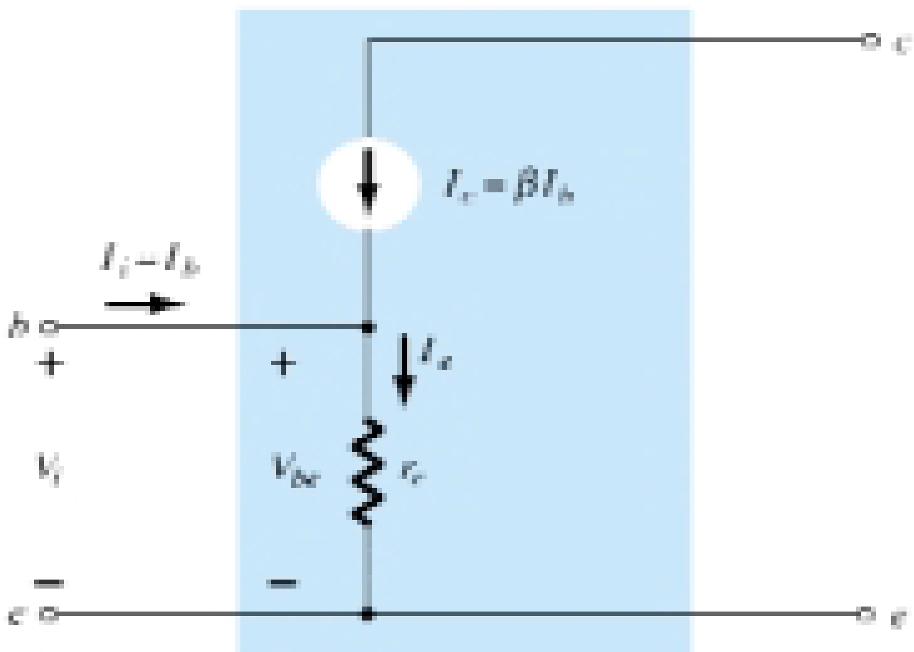
Ac analysis: Common-Emitter

$$\boxed{I_c \cong \beta I_b}$$

The input impedance is determined by the following ratio:

$$Z_i = \frac{V_i}{I_i} = \frac{V_{be}}{I_b}$$

$$V_i = V_{be} = I_e r_e \cong \beta I_b r_e$$



$$Z_i = \frac{V_{be}}{I_b} \cong \frac{\beta I_b r_e}{I_b}$$

$$\boxed{Z_i \cong \beta r_e}_{CE}$$

Ac analysis: Common-Emitter

For the output impedance, the characteristics of interest are the output set of Fig. 7.24. Note that the slope of the curves increases with increase in collector current. The steeper the slope, the less the level of output impedance (Z_o). The r_e model of Fig. 7.21 does not include an output impedance, but if available from a graphical analysis or from data sheets, it can be included as shown in Fig. 7.25.

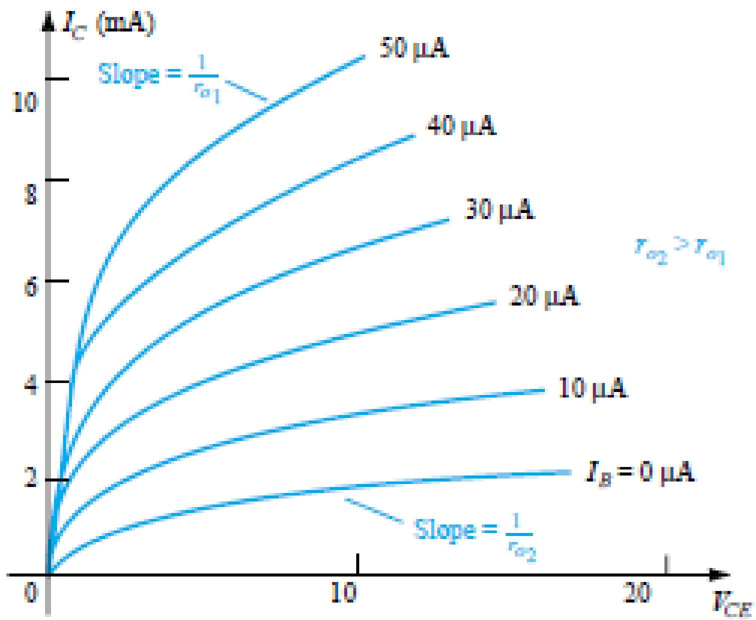


Figure 7.24 Defining r_o for the common-emitter configuration.

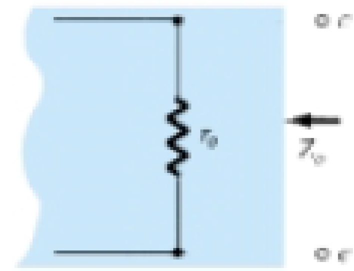


Figure 7.25 Including r_o in the transistor equivalent circuit.

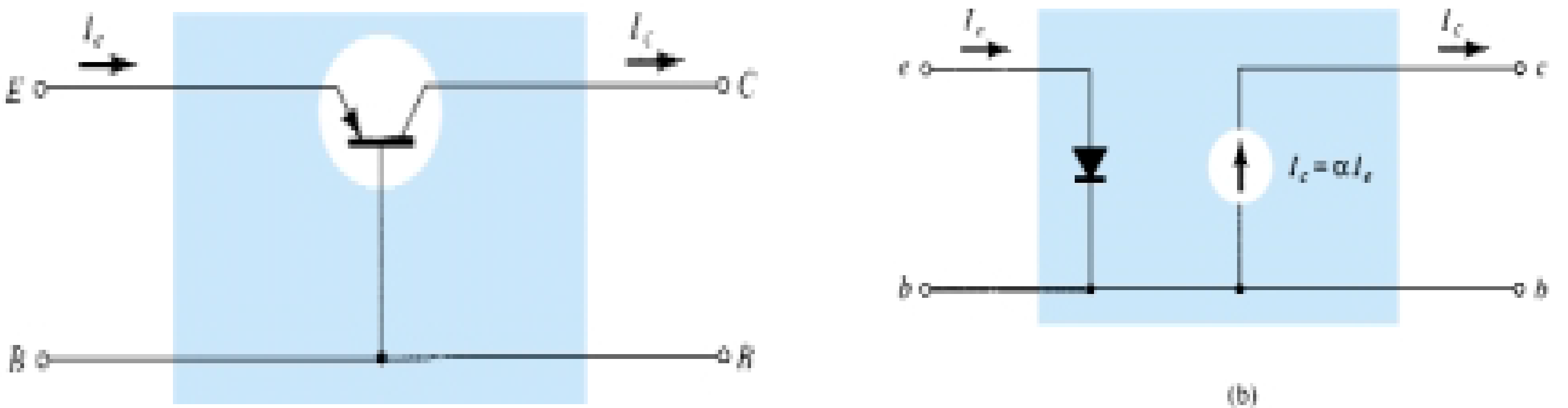
For the common-emitter configuration, typical values of Z_o are in the range of 40 to 50 kΩ.

For the model of Fig. 7.25, if the applied signal is set to zero, the current I_c is 0 A and the output impedance is

$$\boxed{Z_o = r_o}_{CE} \quad (7.20)$$

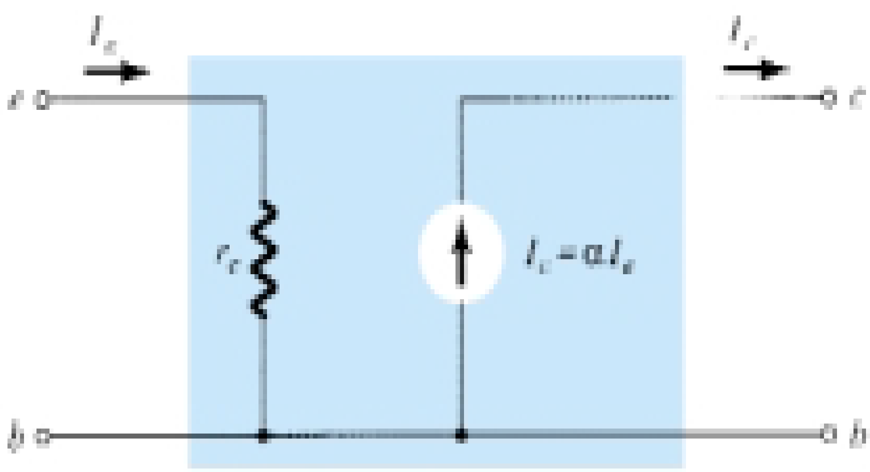
That means, output looks open circuit results in to consider an output impedance. Here, r_0 is chosen as example.

Ac analysis: Common-Base



(a)

Figure 7.16 (a) Common-base BJT transistor; (b) r_e model for the configuration



$$r_e = \frac{26\ \text{mV}}{I_E}$$

Ac analysis: Common-Base

Due to the isolation that exists between input and output circuits of Fig. 7.17, it should be fairly obvious that the input impedance Z_i for the common-base configuration of a transistor is simply r_e. That is,

$$\boxed{Z_i = r_e}_{CB} \tag{7.12}$$

For the common-base configuration, typical values of Z_i range from a few ohms to a maximum of about 50 Ω.

For the output impedance, if we set the signal to zero, then $I_e = 0$ A and $I_c = \alpha I_e = \alpha(0\text{ A}) = 0$ A, resulting in an open-circuit equivalence at the output terminals. The result is that for the model of Fig. 7.17,

$$\boxed{Z_o \cong \infty\ \Omega}_{CB} \tag{7.13}$$

Ac analysis: Common-Base

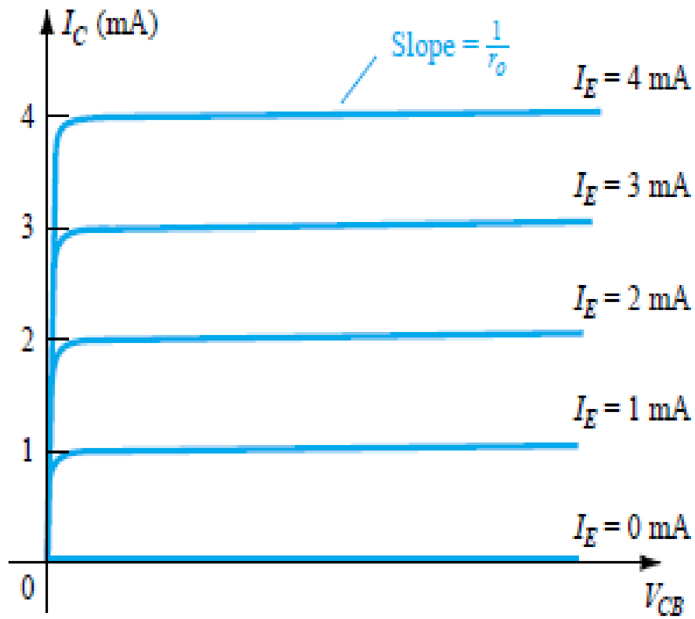


Figure 7.18 Defining Z_o.

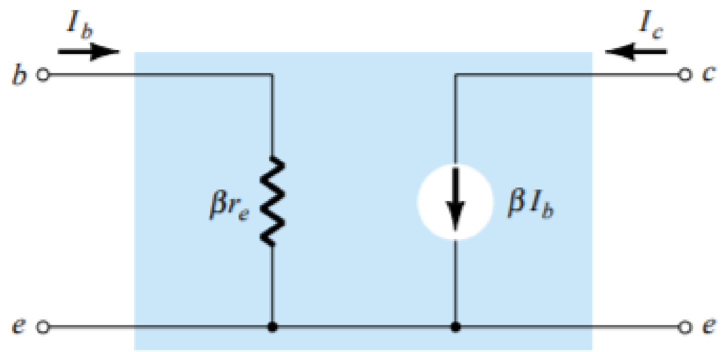
In general, for the common-base configuration the input impedance is relatively small and the output impedance quite high.

In actuality:

For the common-base configuration, typical values of Z_o are in the megohm range.

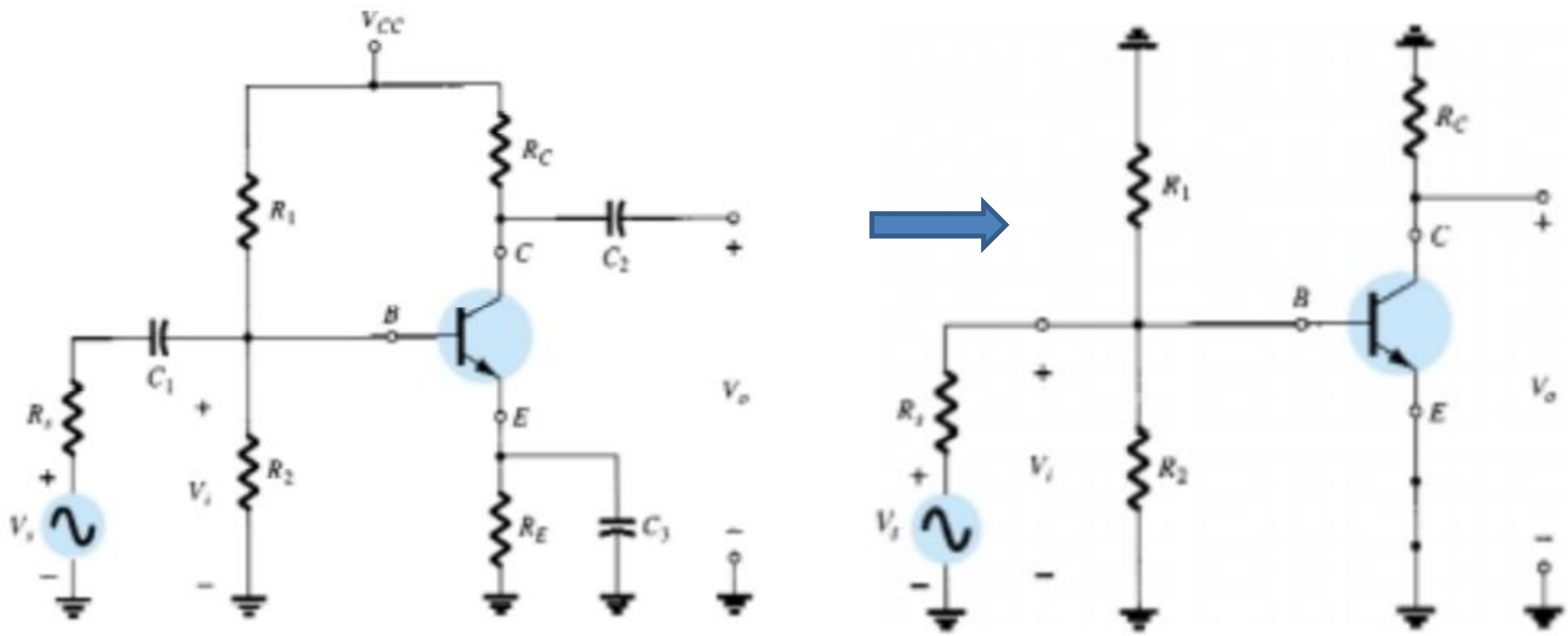
Ac analysis

1. Deactivate (grounded) dc sources in the circuit.
2. Replace coupling and bypass capacitors by short circuit equivalent.
3. Redraw the circuit (optional),
4. Replace the transistor by its ac model.

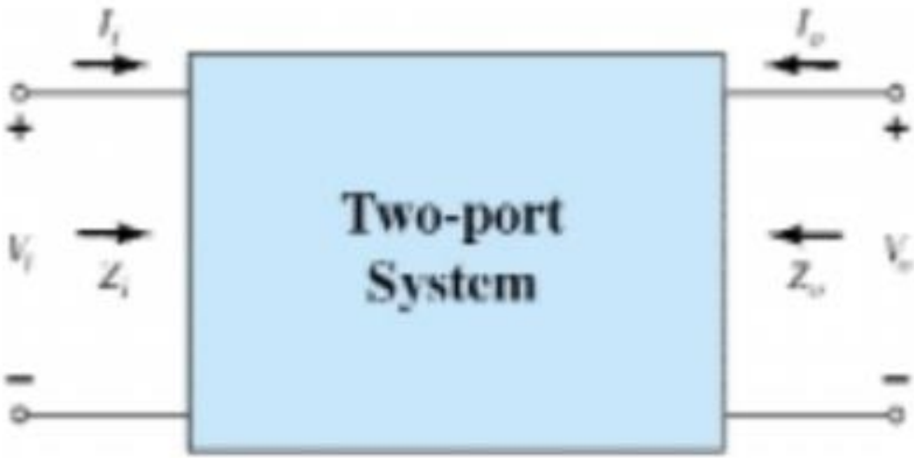


r_e model

Ac analysis and Transistor models



Parameters of importance



$$\boxed{Z_i = \frac{V_i}{I_i}}$$

$$\boxed{Z_o = \frac{V_o}{I_o}}$$

$$\boxed{A_v = \frac{V_o}{V_i}}$$

$$\boxed{A_i = \frac{I_o}{I_i}}$$

Redrawing the circuit

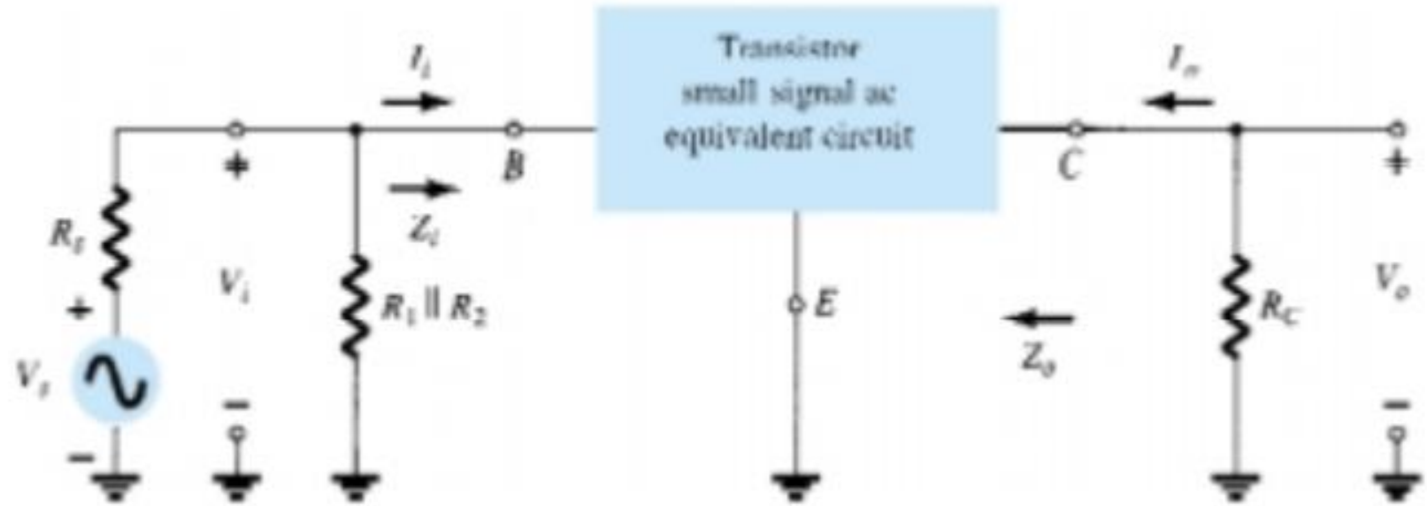
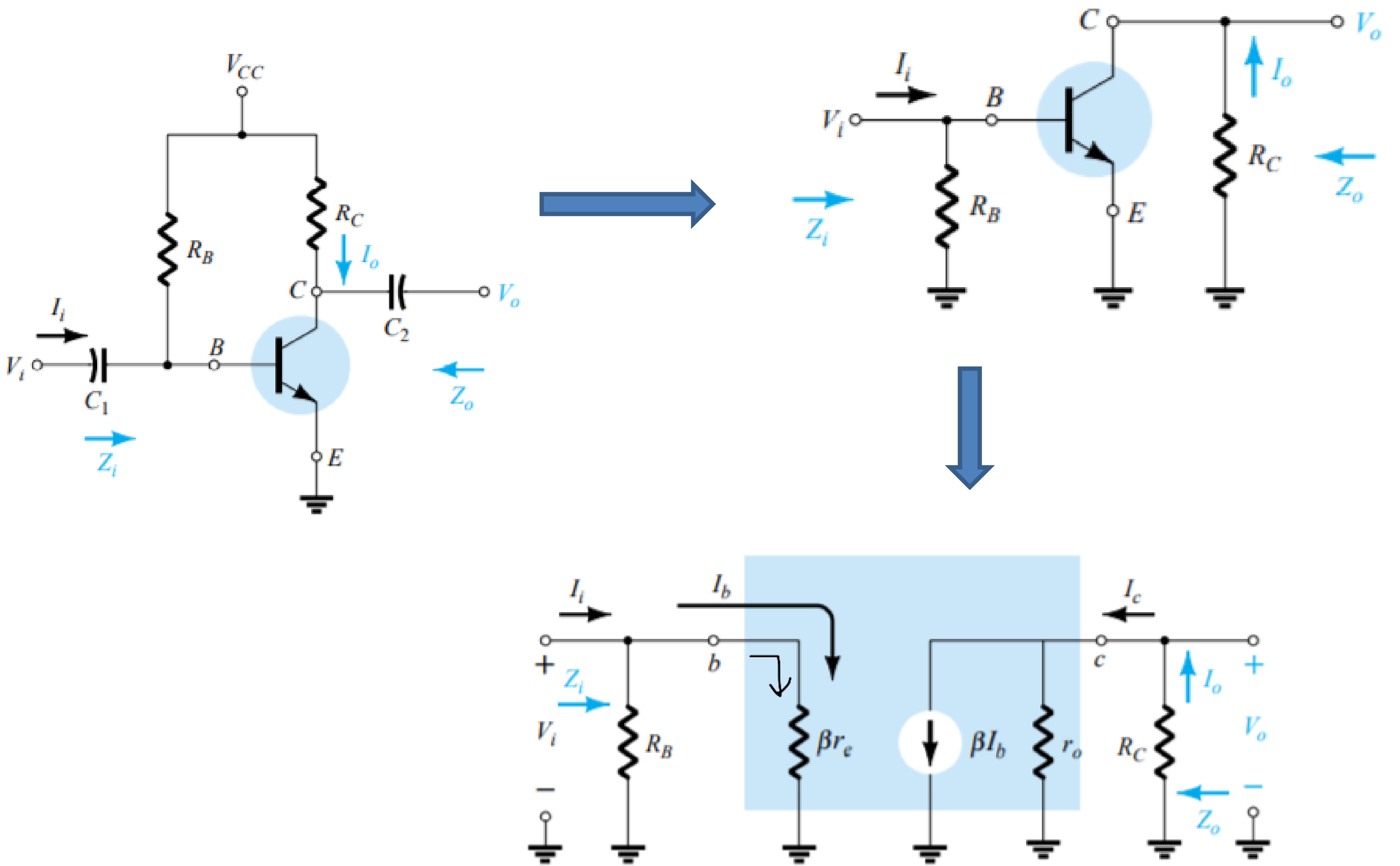


Figure 7.5 Circuit of Fig. 7.4 redrawn for small-signal ac analysis.

Fixed bias amplifier



Ac circuit parameters

Voltage gain:

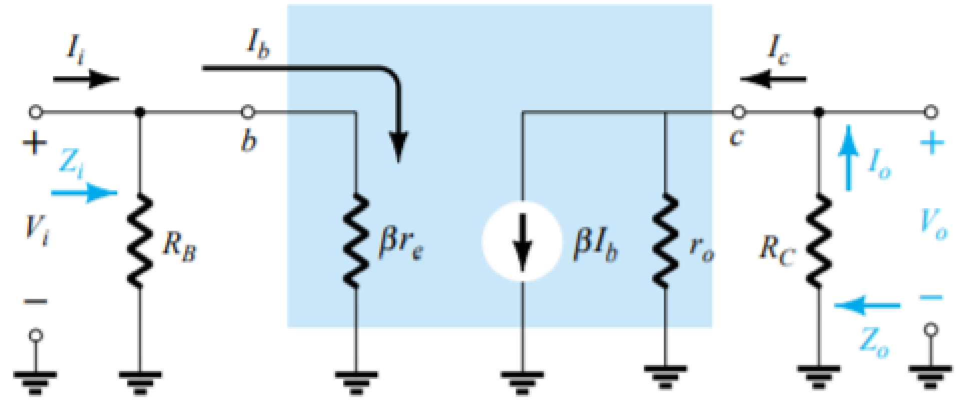
$$V_o = -\beta I_b (R_C \| r_o)$$

$$I_b = \frac{V_i}{\beta r_c}$$

$$V_o = -\beta\left(\frac{V_i}{\beta_{r_e}}\right)(R_C \| r_o)$$

$$\boxed{A_v = \frac{V_o}{V_i} = -\frac{(R_C \| r_o)}{r_e}}$$

$$\boxed{A_v = -\frac{R_C}{r_e}}_{r_o \geq 10R_C}$$



Input Impedance,

$$Z_i = R_B \| \beta r_e \quad \Omega$$

Output Impedance,

$$Z_0 = R_C \| r_0 \approx R_C \quad \Omega$$

Current gain:

$$A_i = \beta$$

Output ac signal swing

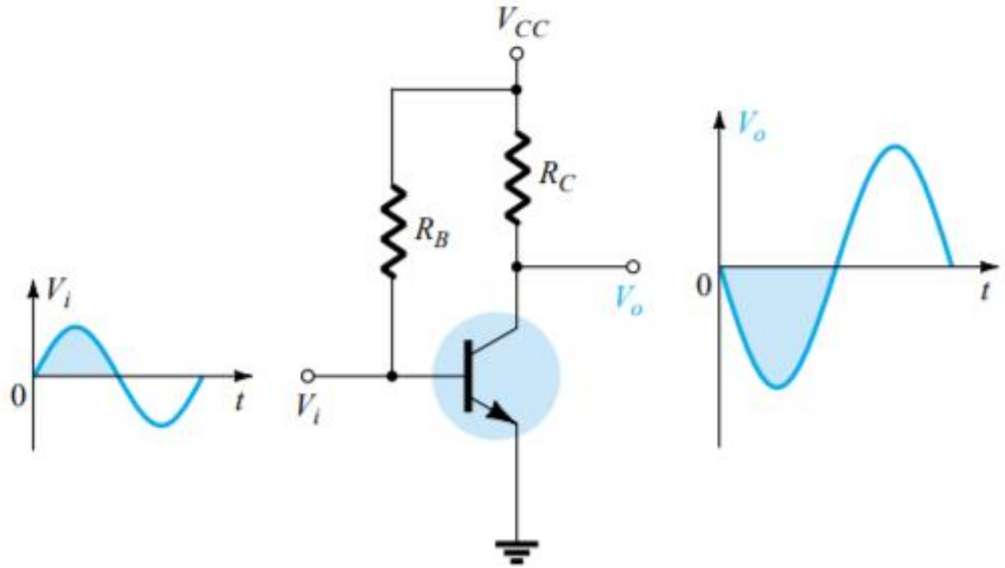
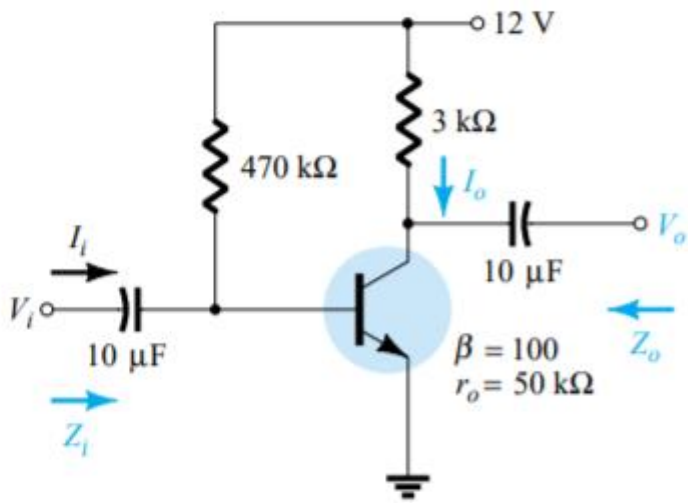


Figure 8.5 Demonstrating the 180° phase shift between input and output waveforms.

Example-1



(a) DC analysis:

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{12\text{ V} - 0.7\text{ V}}{470\text{ k}\Omega} = 24.04\ \mu\text{A}$$

$$I_E = (\beta + 1)I_B = (101)(24.04\ \mu\text{A}) = 2.428\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{2.428\text{ mA}} = \mathbf{10.71\ \Omega}$$

(b) $\beta r_e = (100)(10.71\ \Omega) = 1.071\text{ k}\Omega$

$Z_i = R_B \| \beta r_e = 470\text{ k}\Omega \| 1.071\text{ k}\Omega = \mathbf{1.069\text{ k}\Omega}$

(c) $Z_o = R_C = \mathbf{3\text{ k}\Omega}$

(d) $A_v = -\dfrac{R_C}{r_e} = -\dfrac{3\text{ k}\Omega}{10.71\ \Omega} = \mathbf{-280.11}$

(e) Since $R_B \geq 10\beta r_e (470\text{ k}\Omega > 10.71\text{ k}\Omega)$

$A_i \cong \beta = \mathbf{100}$

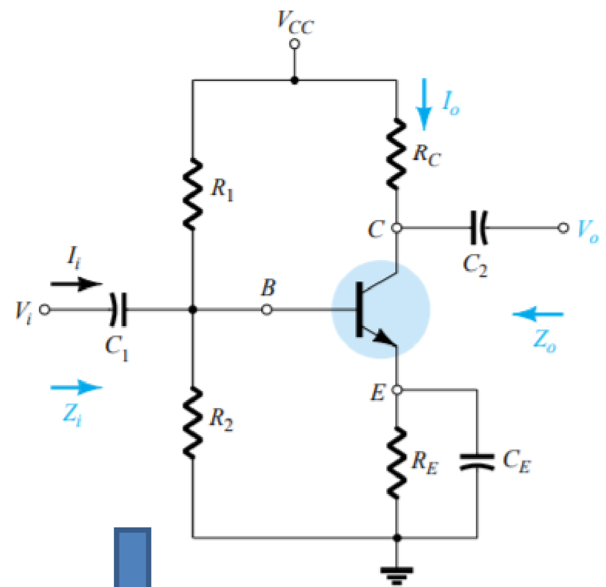
Voltage divider bias

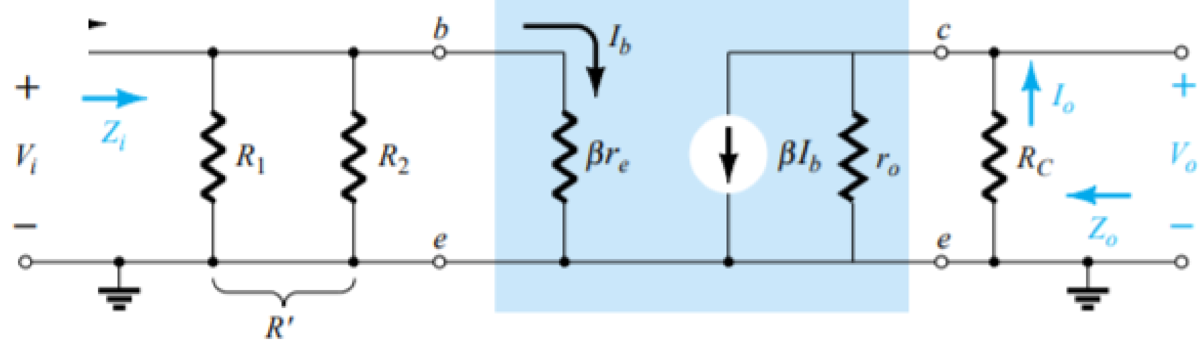
$$R' = R_1 \| R_2 = \frac{R_1 R_2}{R_1 + R_2}$$

$$Z_i = R' \| \beta r_e$$

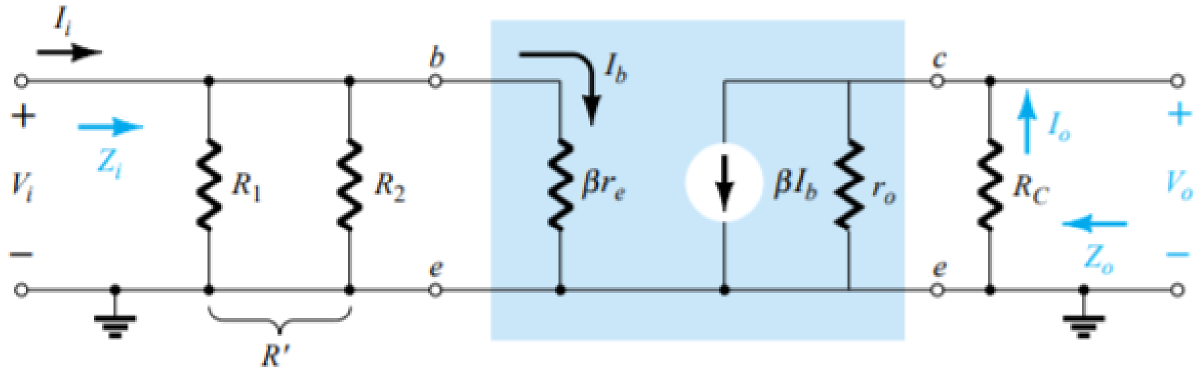
$$Z_o = R_C \| r_o$$

$$Z_o \cong R_C \quad _{r_o \geq 10 R_C}$$





Voltage and current gain



$$V_o = -(\beta I_b)(R_C \| r_o)$$

$$I_b = \frac{V_i}{\beta r_e}$$

$$V_o = -\beta \left(\frac{V_i}{\beta r_e}\right)(R_C \| r_o)$$

$$\boxed{A_v = \frac{V_o}{V_i} = \frac{-R_C \| r_o}{r_e}}$$

$$\boxed{A_v = \frac{V_o}{V_i} \cong -\frac{R_C}{r_e}}_{r_o \geq 10R_C}$$

Current gain:

$$A_i = \beta$$

Phase relationship:

180° phase shift between V_o and V_i.

Example-2

- Find Z_i, Z_0, A_v and A_i, given $I_{EQ} = 1.41mA$

$$r_e = \frac{26 \text{ mV}}{I_E} = \frac{26 \text{ mV}}{1.41 \text{ mA}} = \mathbf{18.44\ \Omega}$$

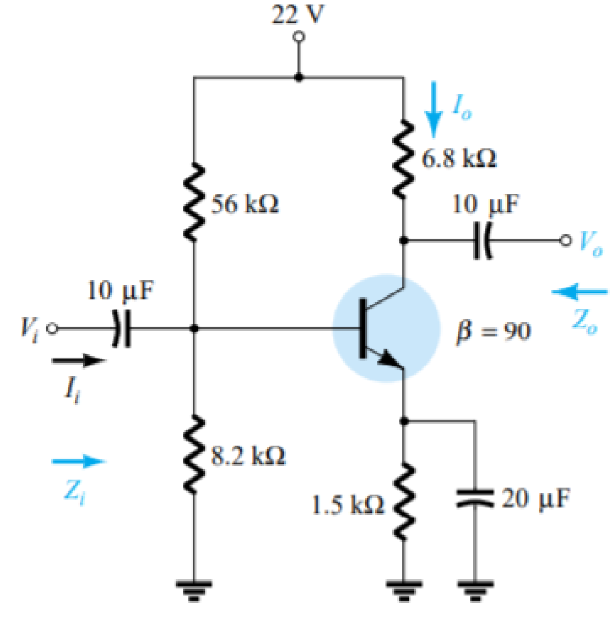
(b) $R' = R_1 \| R_2 = (56 \text{ k}\Omega)\|(8.2 \text{ k}\Omega) = 7.15 \text{ k}\Omega$

$Z_i = R' \| \beta r_e = 7.15 \text{ k}\Omega \| (90)(18.44\ \Omega) = 7.15 \text{ k}\Omega \| 1.66 \text{ k}\Omega$

$= \mathbf{1.35\ k\Omega}$

(c) $Z_o = R_C = \mathbf{6.8\ k\Omega}$

(d) $A_v = -\frac{R_C}{r_e} = -\frac{6.8 \text{ k}\Omega}{18.44\ \Omega} = \mathbf{-368.76}$

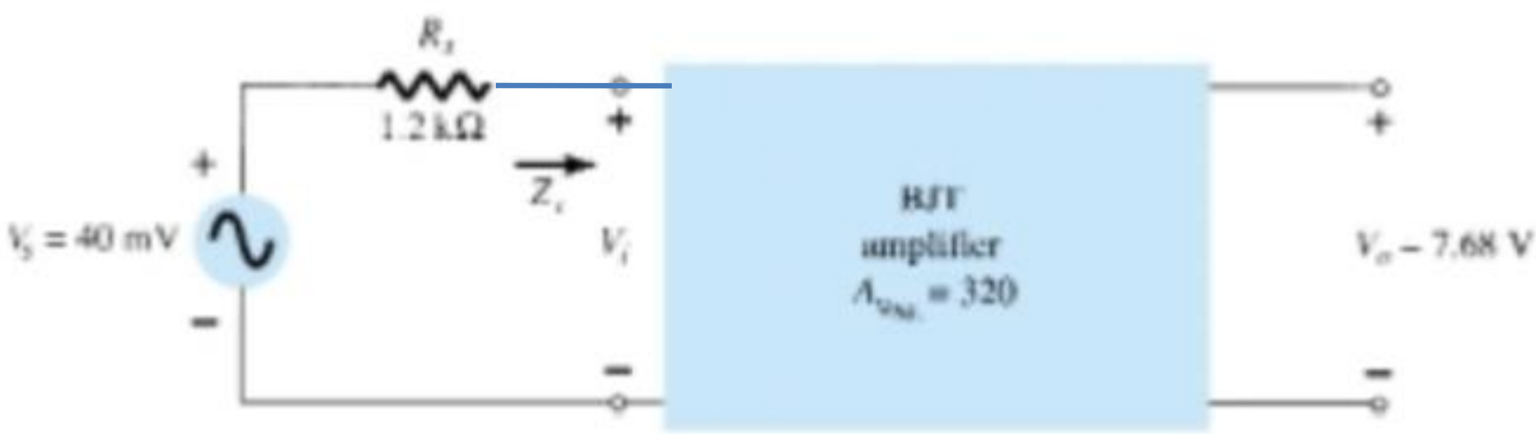


Example-3

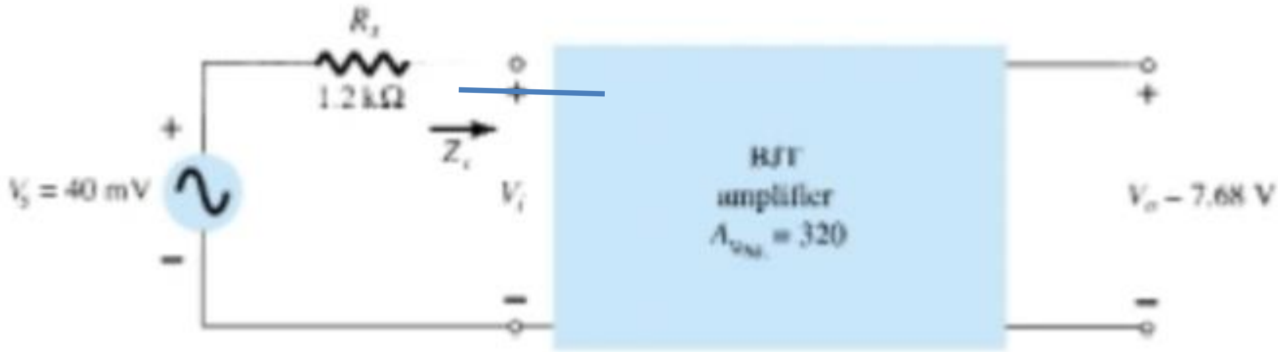
EXAMPLE 7.3

For the BJT amplifier of Fig. 7.14, determine:

(a) V_i.
(b) I_i.
(c) Z_i.
(d) A_{v_s}.



Solution



Solution

(a) $A_{v_{NL}} = \dfrac{V_o}{V_i}$ and $V_i = \dfrac{V_o}{A_{v_{NL}}} = \dfrac{7.68\text{ V}}{320} = \mathbf{24\text{ mV}}$

(b) $I_i = \dfrac{V_s - V_i}{R_s} = \dfrac{40\text{ mV} - 24\text{ mV}}{1.2\text{ k}\Omega} = \mathbf{13.33\ \mu A}$

(c) $Z_i = \dfrac{V_i}{I_i} = \dfrac{24\text{ mV}}{13.33\ \mu\text{A}} = \mathbf{1.8\text{ k}\Omega}$

(d) $$A_{v_s} = \frac{Z_i}{Z_i + R_s} A_{v_{NL}}$$

$$= \frac{1.8\text{ k}\Omega}{1.8\text{ k}\Omega + 1.2\text{ k}\Omega}(320)$$

$$= \mathbf{192}$$

For the system of Fig. 7.13 having a source resistance R_s, the level of V_i would first have to be determined using the voltage-divider rule before the gain V_o/V_s could be calculated. That is,

$$V_i = \frac{Z_i V_s}{Z_i + R_s}$$

with
$$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s}$$

and
$$A_{v_s} = \frac{V_o}{V_s} = \frac{V_i}{V_s} \cdot \frac{V_o}{V_i}$$

so that
$$\boxed{A_{v_s} = \frac{V_o}{V_s} = \frac{Z_i}{Z_i + R_s} A_{v_{NL}}} \qquad (7.8)$$

Unbypassed

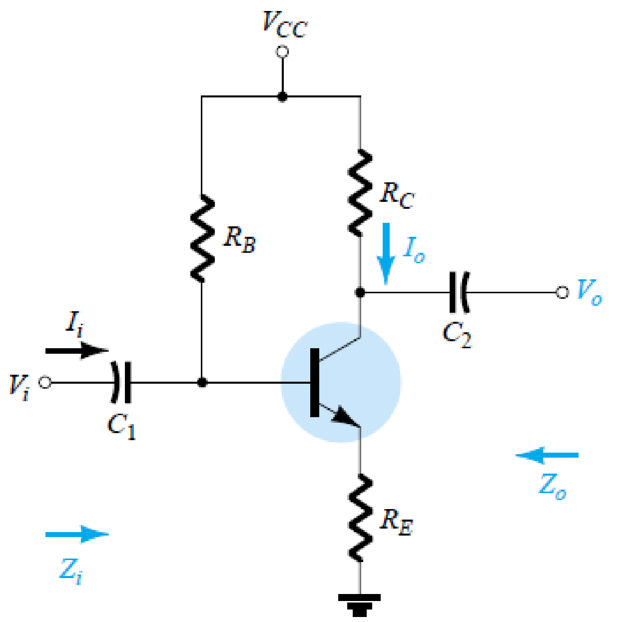


Figure 8.10 CE emitter-bias configuration.

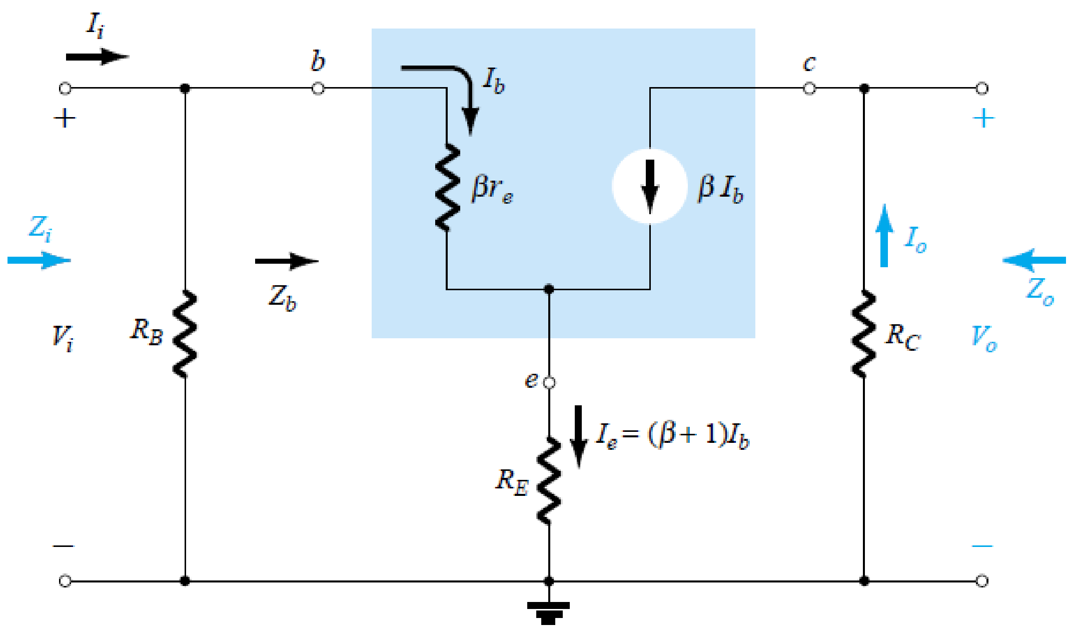


Figure 8.11 Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 8.10.

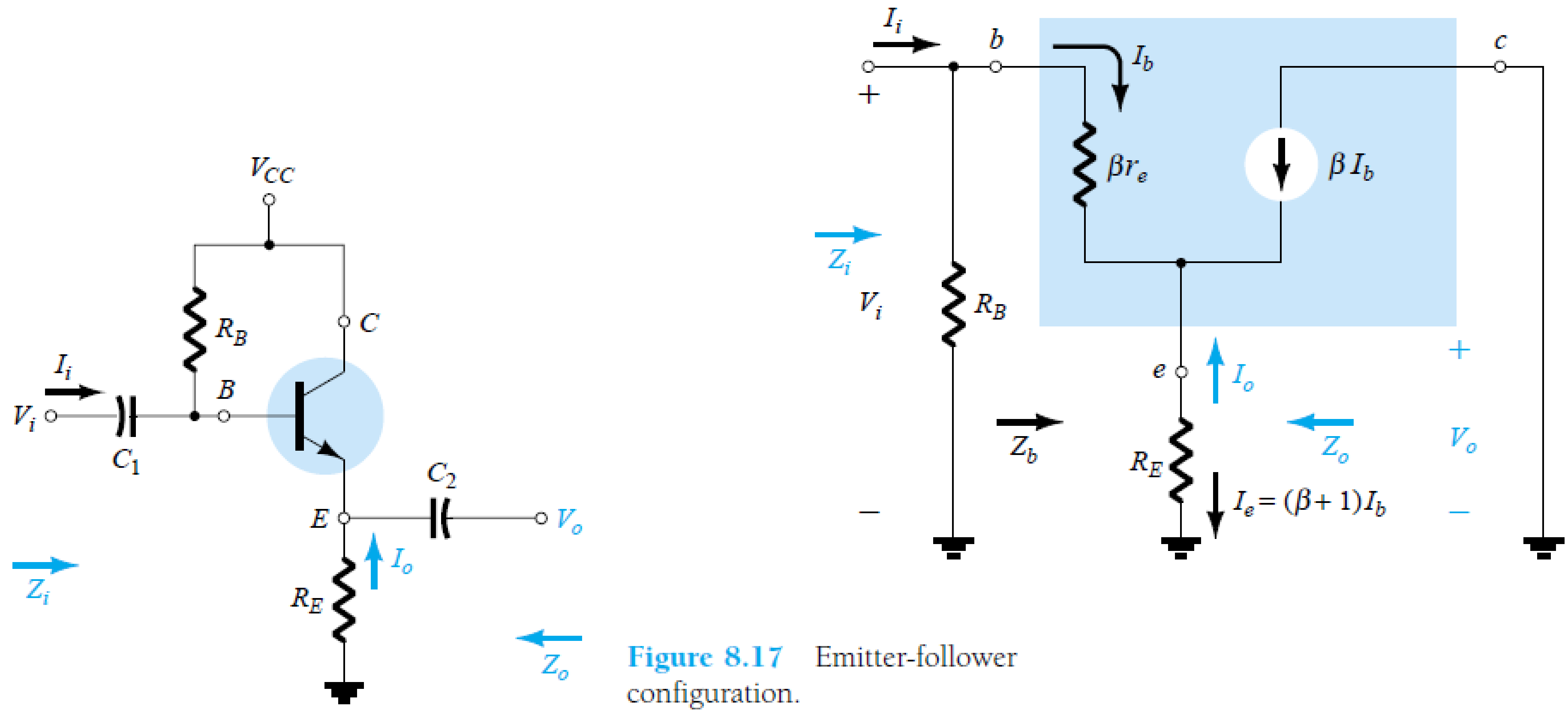


Figure 8.17 Emitter-follower configuration.

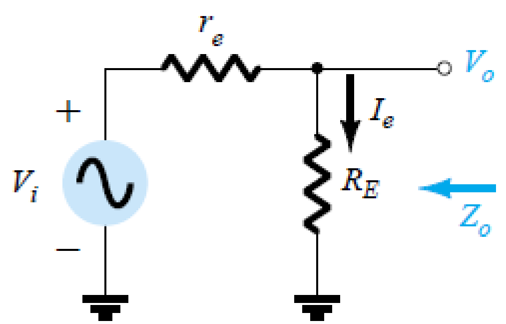


Figure 8.19 Defining the output impedance for the emitter-follower configuration.

To determine Z_o, V_i is set to zero and

$$\boxed{Z_o = R_E \| r_e} \tag{8.42}$$

Since R_E is typically much greater than r_e, the following approximation is often applied:

$$\boxed{Z_o \cong r_e} \tag{8.43}$$

COMMON-BASE CONFIGURATION

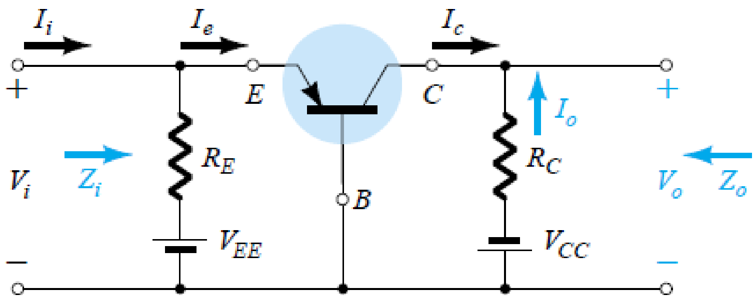


Figure 8.23 Common-base configuration.

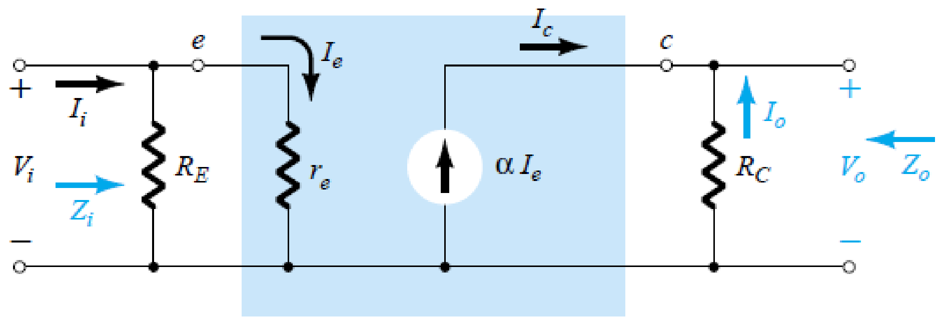


Figure 8.24 Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 8.23.

COLLECTOR FEEDBACK CONFIGURATION

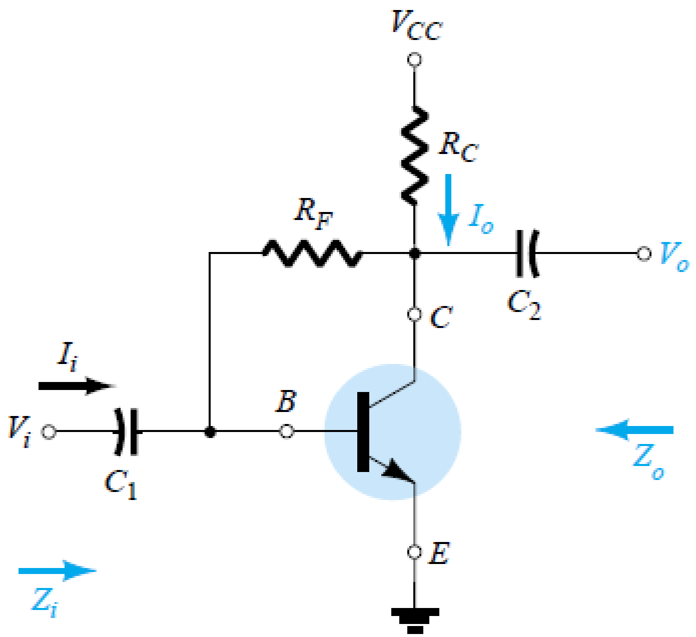


Figure 8.26 Collector feedback configuration.

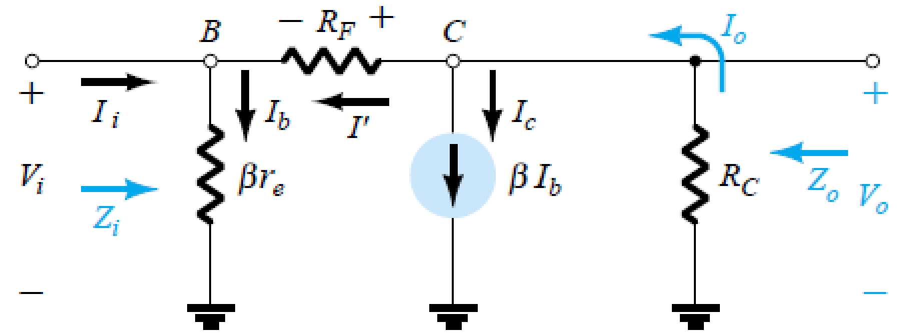


Figure 8.27 Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 8.26.

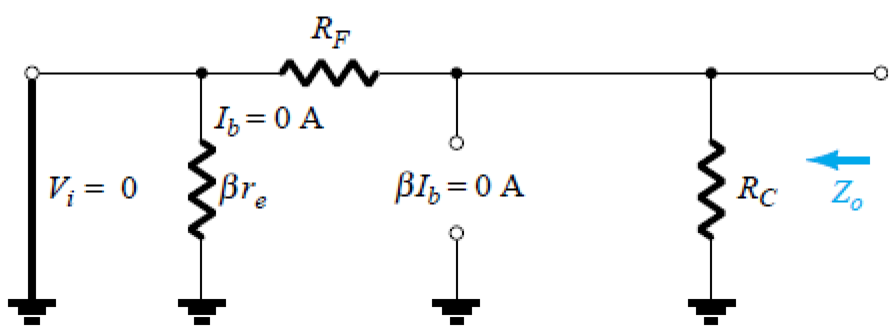


Figure 8.28 Defining Z_o for the collector feedback configuration.

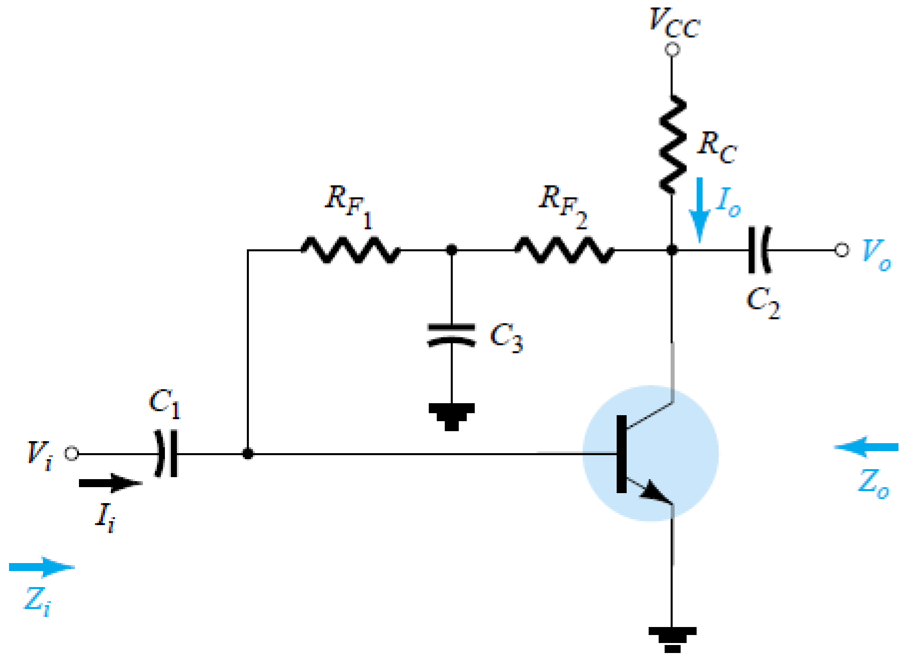


Figure 8.31 Collector dc feedback configuration.

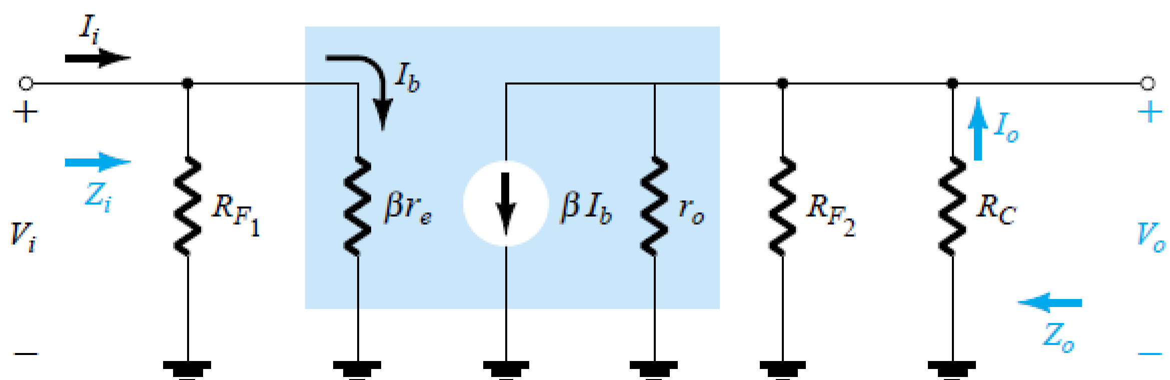


Figure 8.32 Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 8.31.

Practice yourself and send me your feedback, if any.