BJT Transistor Modeling

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BJT Transistor Modeling

- A model is a combination of circuit elements, properly chosen, that best approximates the actual behavior of a semiconductor device under specific operating conditions.

- Once the ac equivalent circuit is determined, the schematic symbol for the device can be replaced by this equivalent circuit and the basic methods of circuit analysis applied to determine the desired quantities of the network.

- There are two models commonly used in small signal AC analysis of a transistor:
  - r_e model
  - Hybrid equivalent model

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The dc levels were simply important for determining the proper Q-point of operation. Once determined, the dc levels can be ignored in the ac analysis of the network. In addition, the coupling capacitors C1 and C2 and bypass capacitor C3 were chosen to have a very small reactance at the frequency of application.

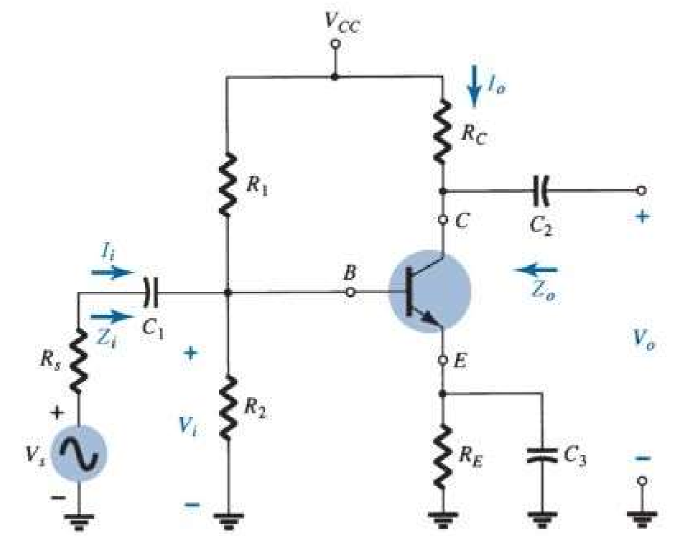

FIG. 3
Transistor circuit under examination in this introductory discussion.

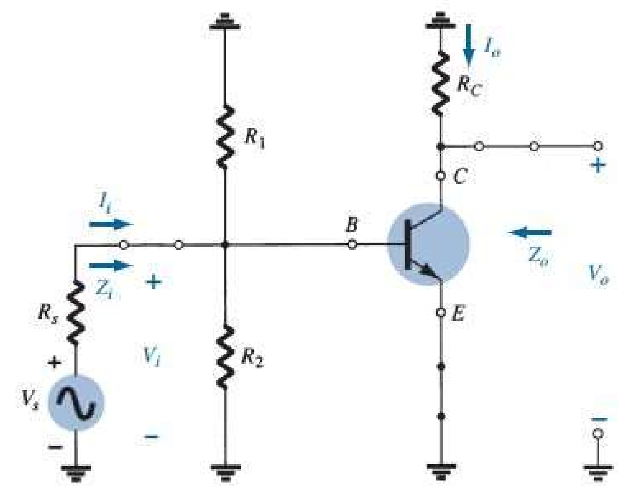

FIG. 4
The network of Fig. 3 following removal of the dc supply and insertion of the short-circuit equivalent for the capacitors.

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

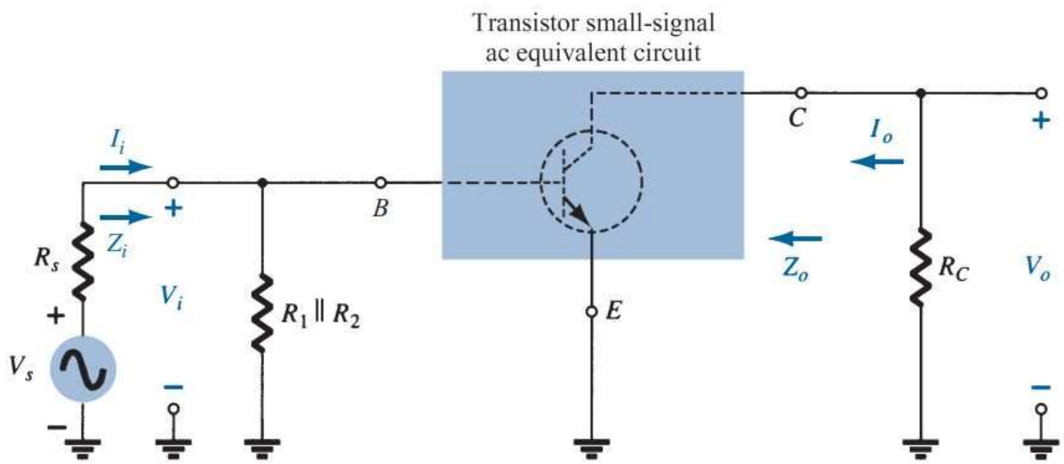

FIG. 7
Circuit of Fig. 4 redrawn for small-signal ac analysis.

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- Voltage Gain
- Current Gain

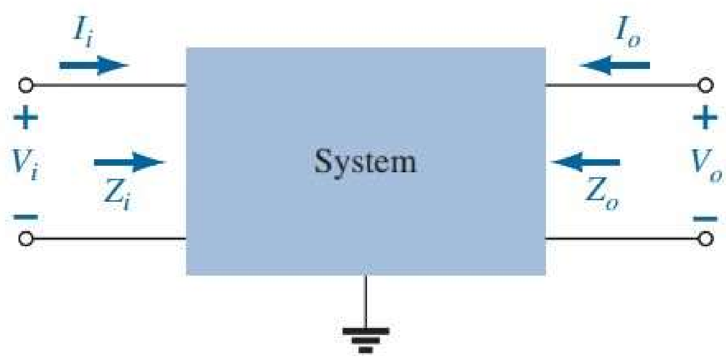

FIG. 5

Defining the important parameters of any system.

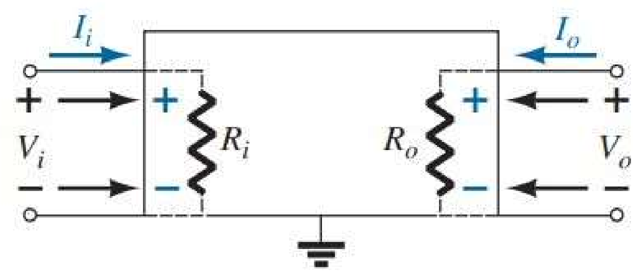

FIG. 6

Demonstrating the reason for the defined directions and polarities.

r_e Model

- Input Equivalent Circuit

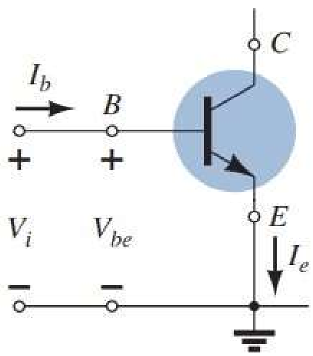

FIG. 8
Finding the input equivalent circuit for a BJT transistor.

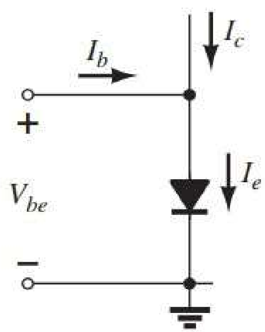

FIG. 10
Equivalent circuit for the input side of a BJT transistor.

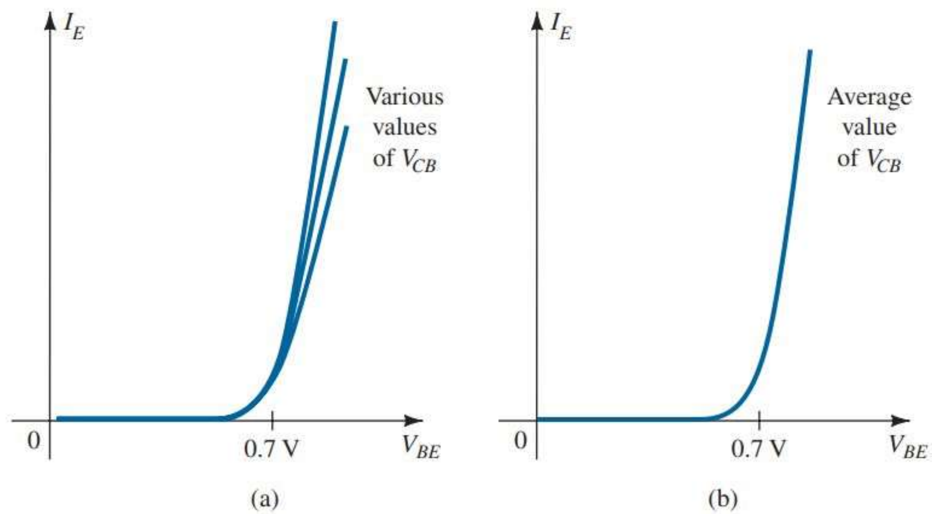

FIG. 9
Defining the average curve for the characteristics of Fig. 9a.

r_e Model

- Equivalent Circuit

It can be improved by first replacing the diode by its equivalent resistance as determined by the level of I_E.

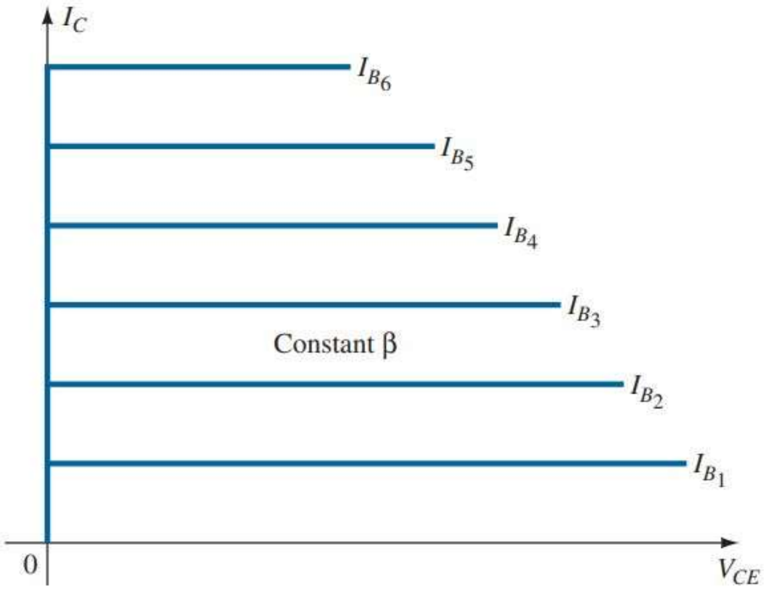

FIG. 11
Constant β characteristics.

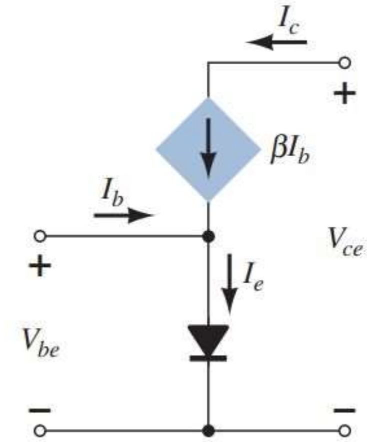

FIG. 12
BJT equivalent circuit.

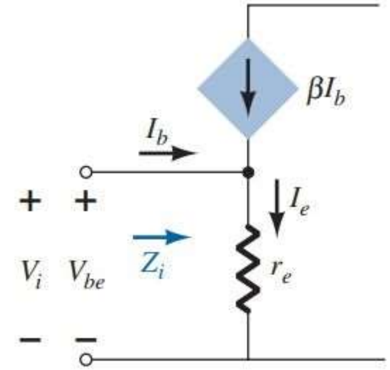

FIG. 13
Defining the level of Z_i.

r_e Model

- Equivalent Circuit

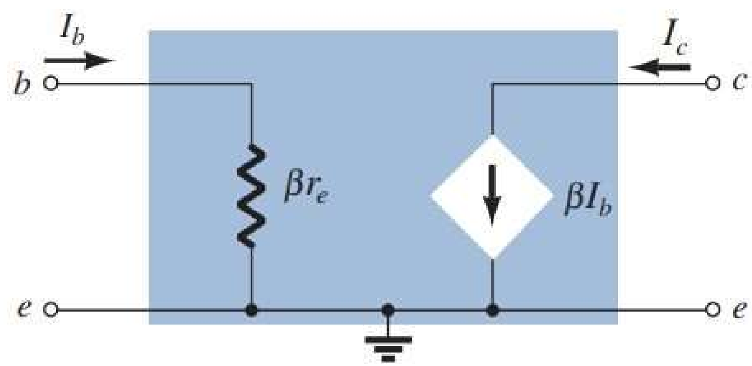

FIG. 14
Improved BJT equivalent circuit.

Early Voltage

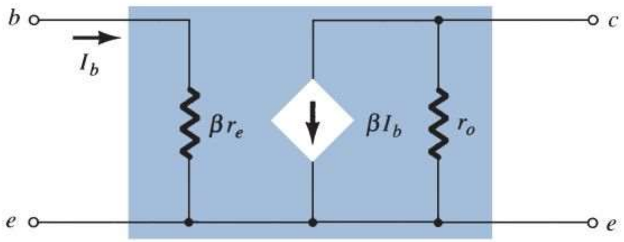

FIG. 16
r_e model for the common-emitter transistor configuration including effects of r_o.

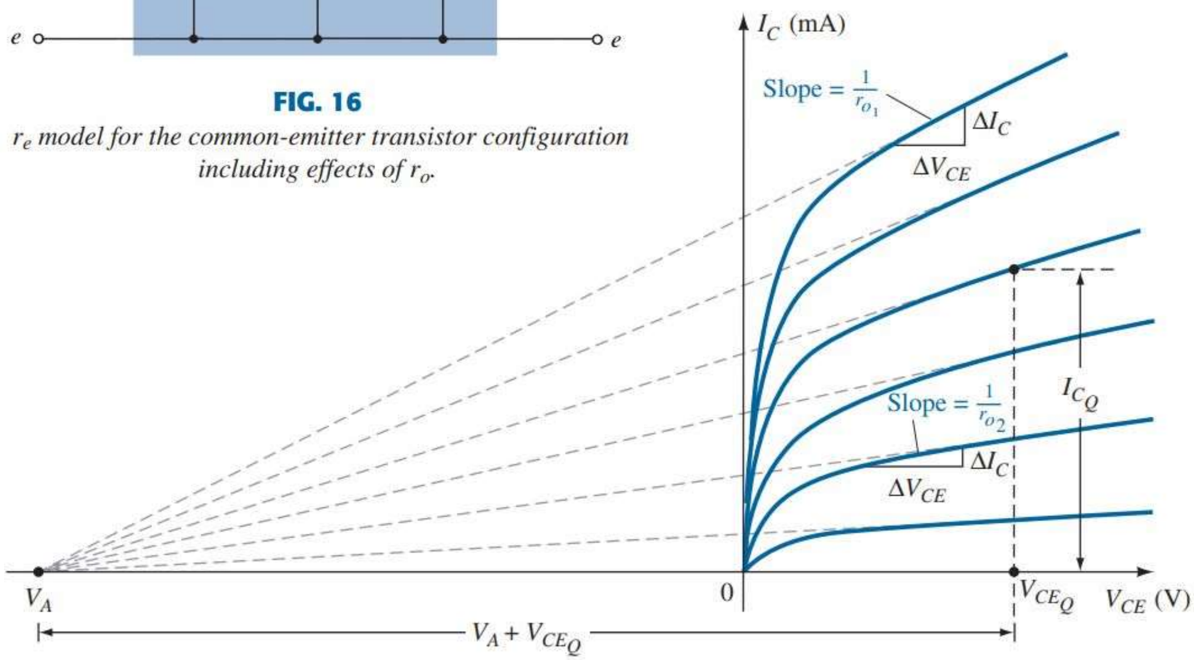

FIG. 15
Defining the Early voltage and the output impedance of a transistor.

$$r_o = \frac{\Delta V}{\Delta I} = \frac{V_A + V_{CE_Q}}{I_{C_Q}}$$

Common-emitter fixed-bias Configuration

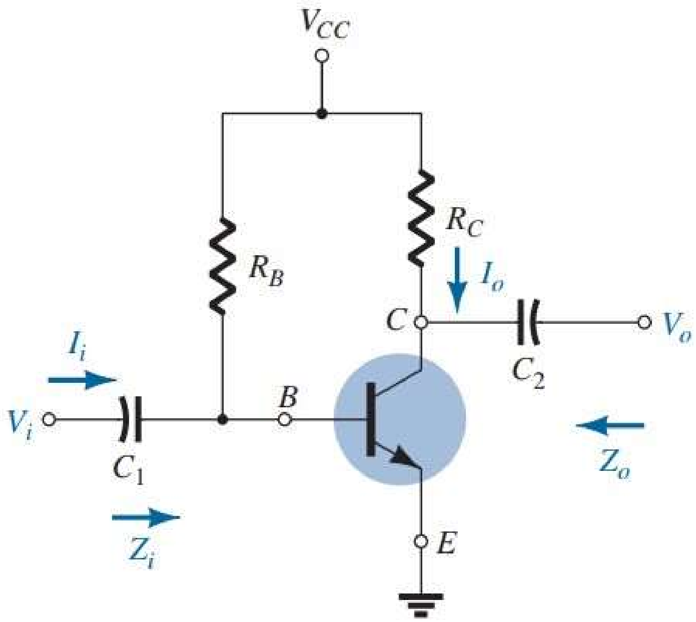

FIG. 20
Common-emitter fixed-bias configuration.

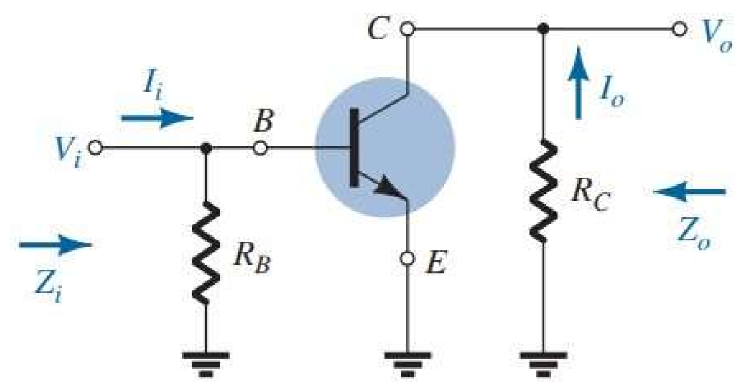

FIG. 21
Network of Fig. 20 following the removal of the effects of V_{CC}, C_1, and C_2.

Common-emitter fixed-bias Configuration

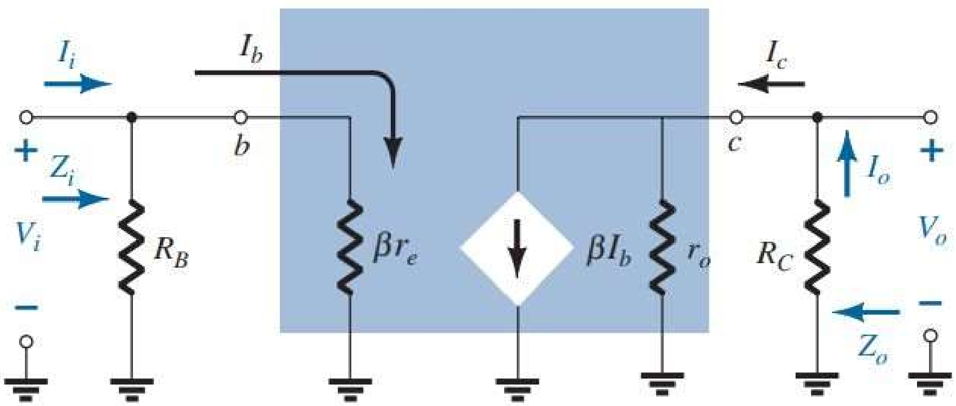

FIG. 22

Substituting the r_e model into the network of Fig. 21.

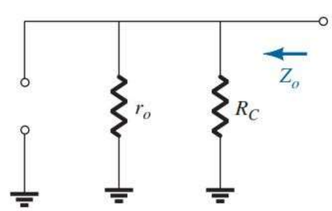

FIG. 23

Determining Z_o for the network of Fig. 22.

Common-emitter fixed-bias Configuration

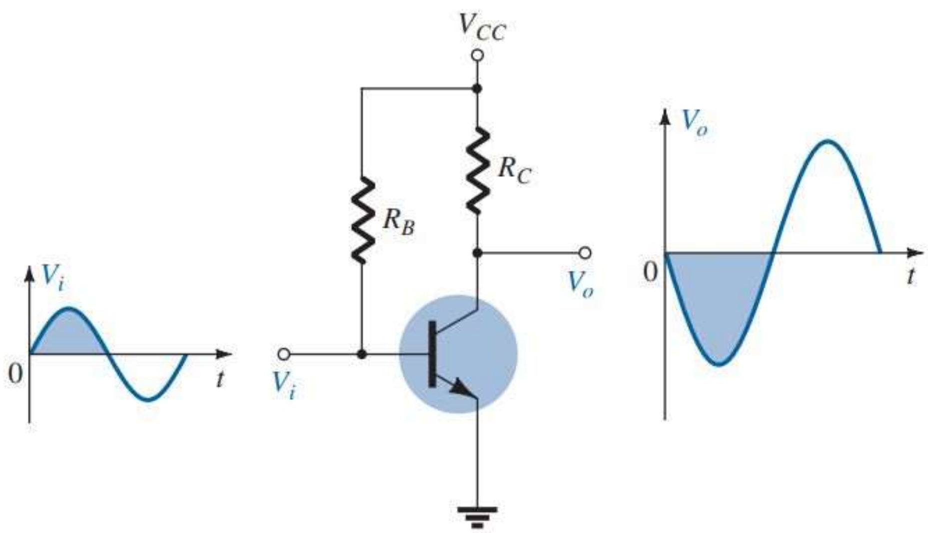

FIG. 24

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

Common-emitter fixed-bias Configuration

EXAMPLE 1 For the network of Fig. 25:

a. Determine r_e.
b. Find Z_i (with $r_o = \infty\,\Omega$).
c. Calculate Z_o (with $r_o = \infty\,\Omega$).
d. Determine A_v (with $r_o = \infty\,\Omega$).
e. Repeat parts (c) and (d) including $r_o = 50\text{ k}\Omega$ in all calculations and compare results.

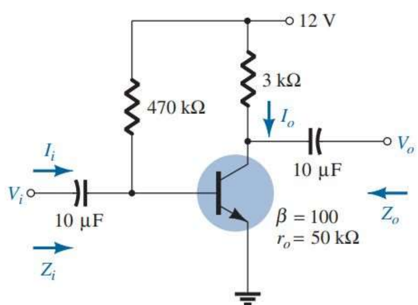

FIG. 25
Example 1.

Voltage-divider Bias

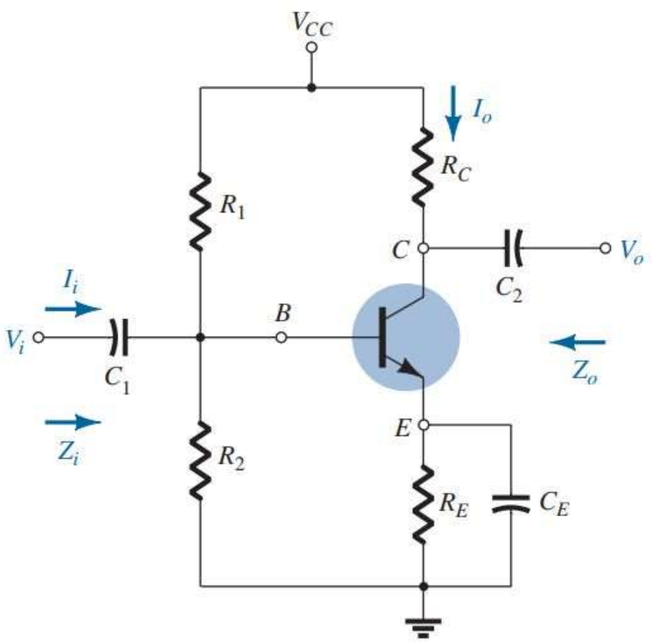

FIG. 26
Voltage-divider bias configuration.

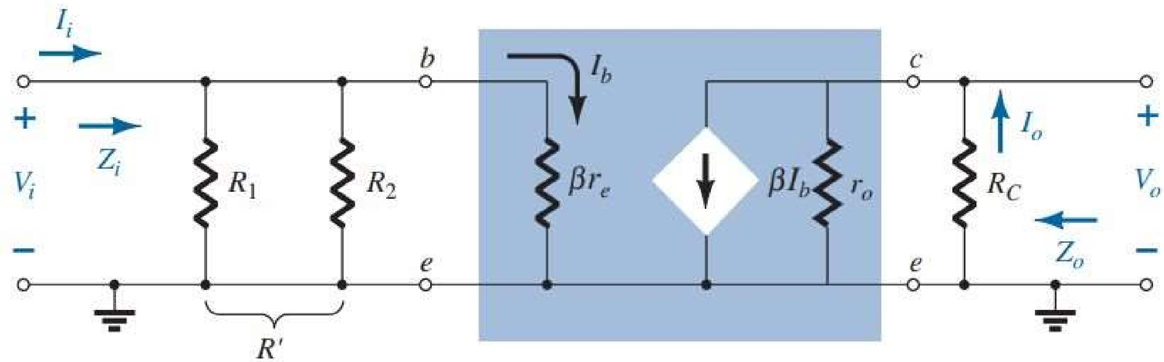

FIG. 27
Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 26.

Voltage-divider Bias

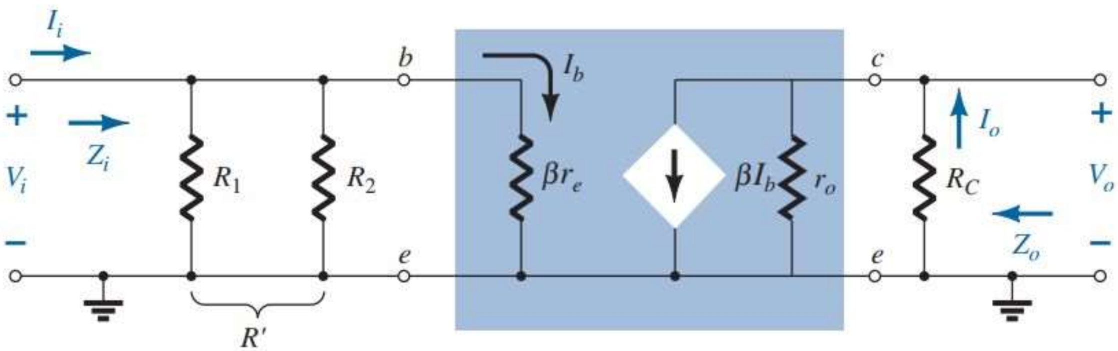

FIG. 27

Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 26.

Voltage-divider Bias

EXAMPLE 2 For the network of Fig. 28, determine:

a. r_e.
b. Z_i.
c. Z_o ($r_o = \infty\,\Omega$).
d. A_v ($r_o = \infty\,\Omega$).
e. The parameters of parts (b) through (d) if $r_o = 50\text{ k}\Omega$ and compare results.

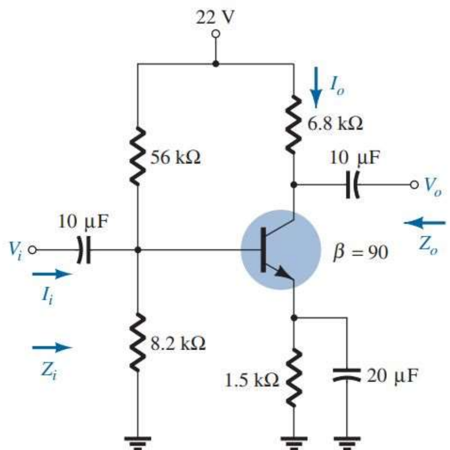

FIG. 28