ECE 321C
Electronic Circuits

Lec. 3: BJT Modeling and re Transistor Model (small signal analysis)

Instructor

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Agenda

- Amplification in the AC Domain
- BJT transistor Modeling
- The r_e Transistor Model (small signal analysis)

Amplification in the AC Domain

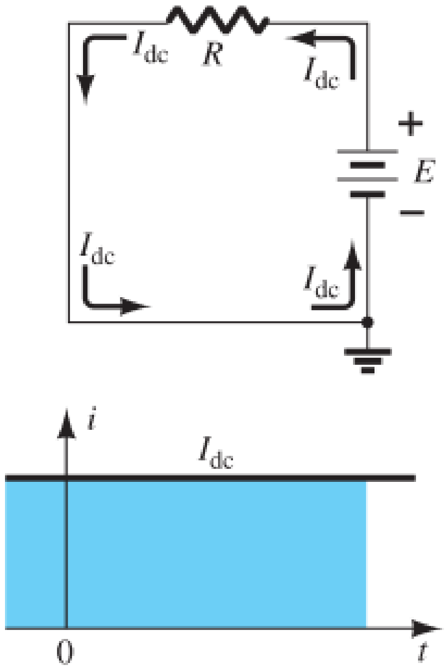


FIG. 5.1

Steady current established by a dc supply.

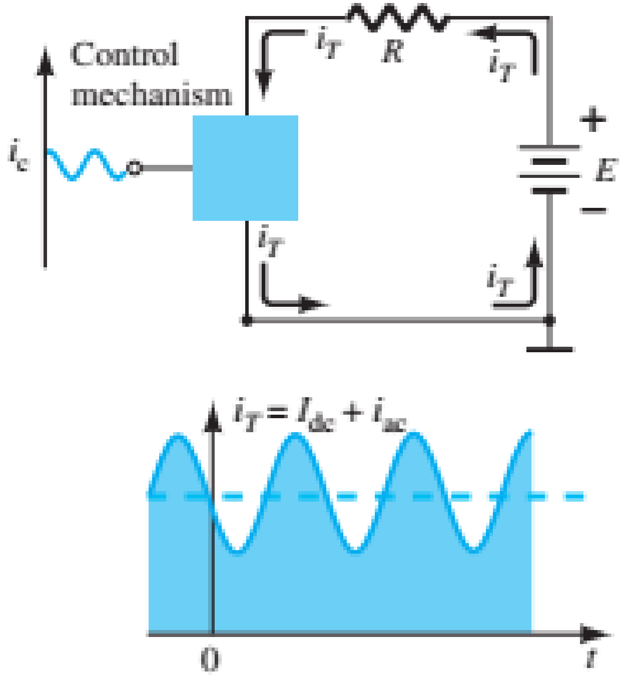


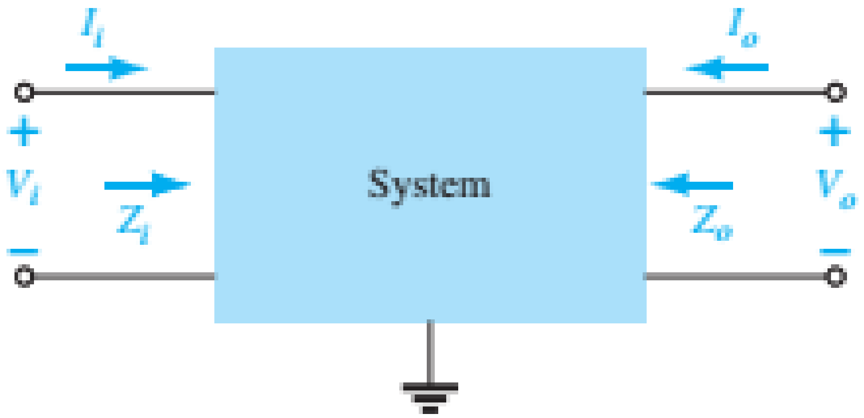
FIG. 5.2

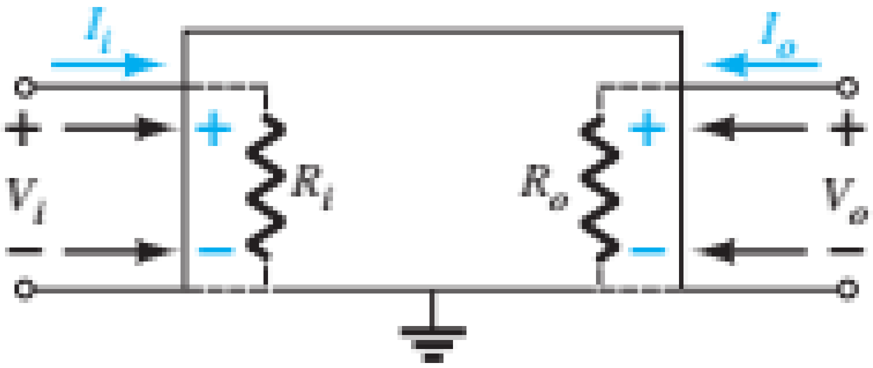
Effect of a control element on the steady-state flow of the electrical system of Fig. 5.1.

The superposition theorem is applicable for the analysis and design of the DC and AC components of a BJT network, permitting the separation of the analysis of the dc and ac responses of the system.

BJT Transistor Modeling$_{1/2}$

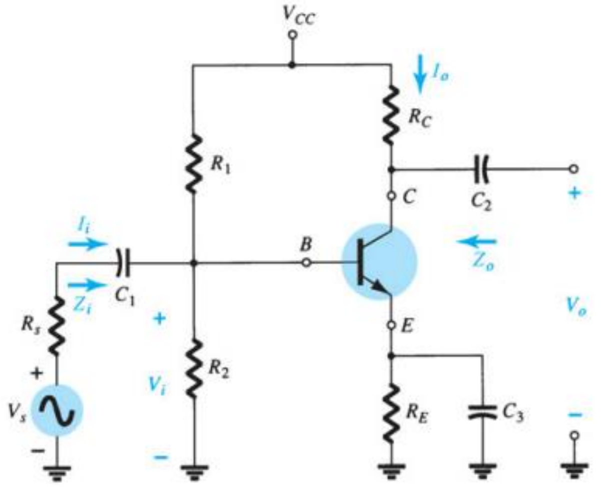
- A model is a combination of circuit elements, properly chosen, that best approximates the actual behavior of a semiconductor device under specific operating conditions.
- Any electronic system has some important parameters have to be determined
  - Input and Output Voltage
  - Input and Output Impedance
  - Input and Output Current

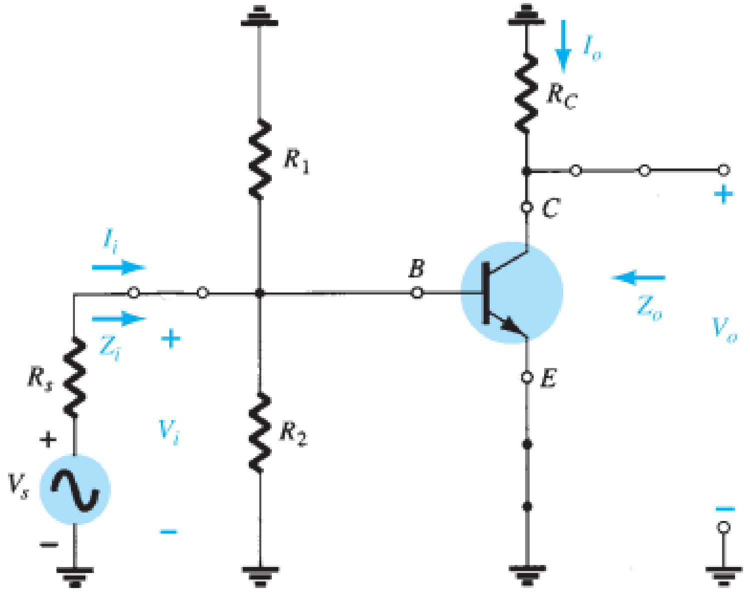


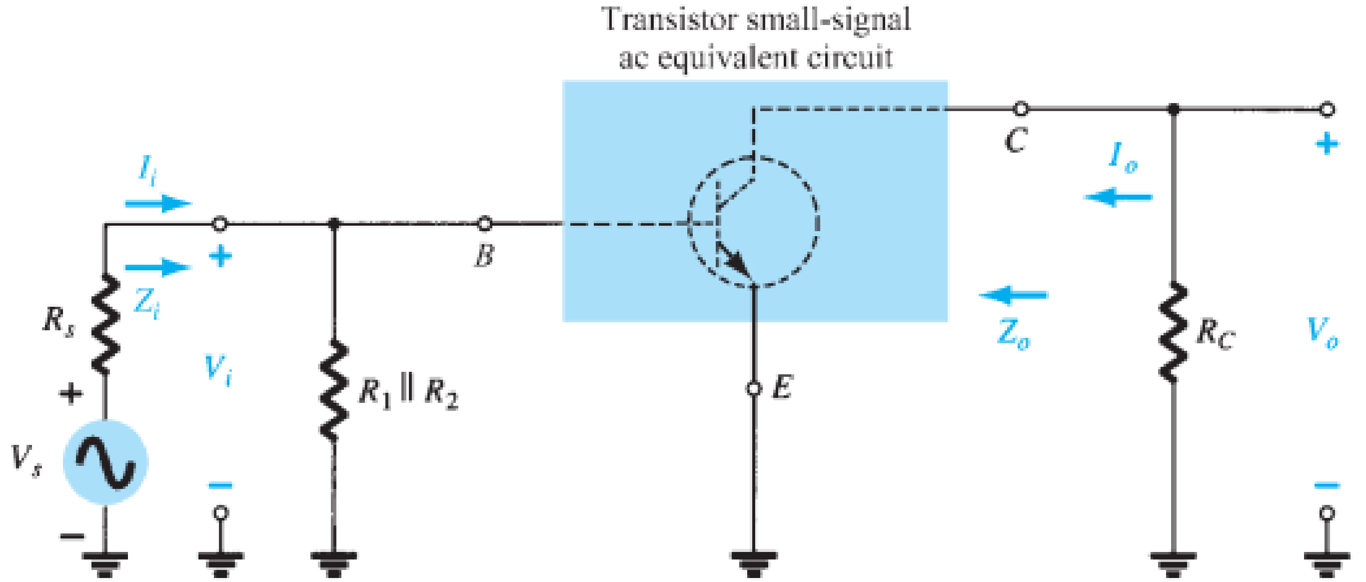


BJT Transistor Modeling$_{2/2}$

- The ac equivalent of a transistor 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







The r_e Transistor Model (CE)$_{1/4}$

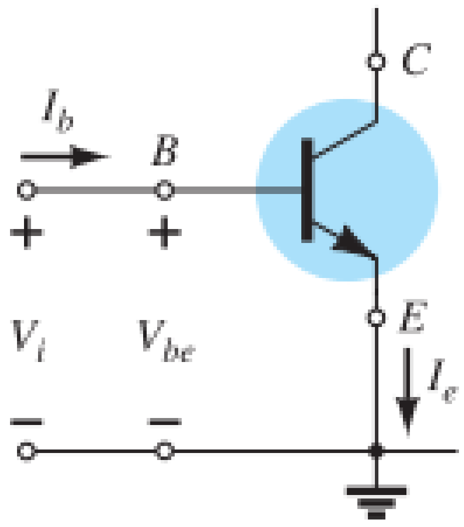


FIG. 5.8
Finding the input equivalent circuit for a BJT transistor.

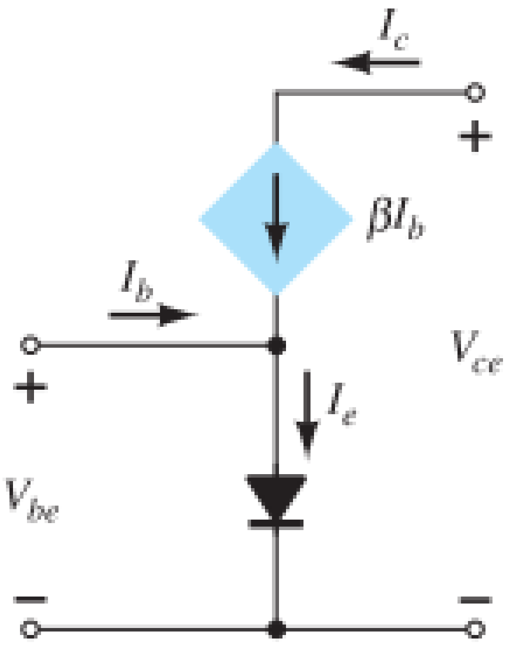


FIG. 5.12
BJT equivalent circuit.

The r_e Transistor Model (CE) 2/4

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

$$V_{be} = I_e r_e = (I_c + I_b) r_e = (\beta I_b + I_b) r_e$$

$$= (\beta + 1) I_b r_e$$

$$Z_i = \frac{V_{be}}{I_b} = \frac{(\beta + 1) I_b r_e}{I_b}$$

$$\boxed{Z_i = (\beta + 1) r_e \cong \beta r_e}$$

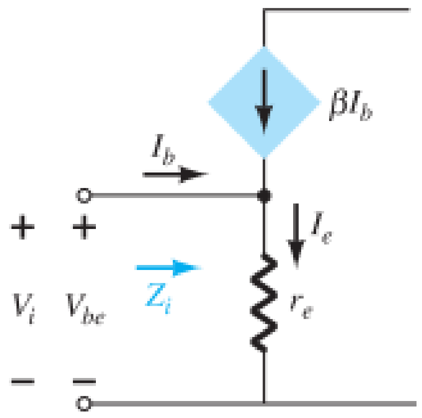


FIG. 5.13
Defining the level of Z_i.

$$r_e = 26\,\text{mV}/I_E$$

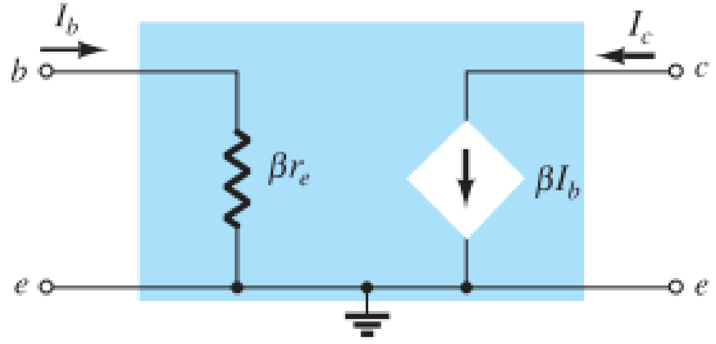


FIG. 5.14
Improved BJT equivalent circuit.

The r_e Transistor Model (CE) 3/4

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

$$r_o \cong \frac{V_A}{I_{C_Q}}$$

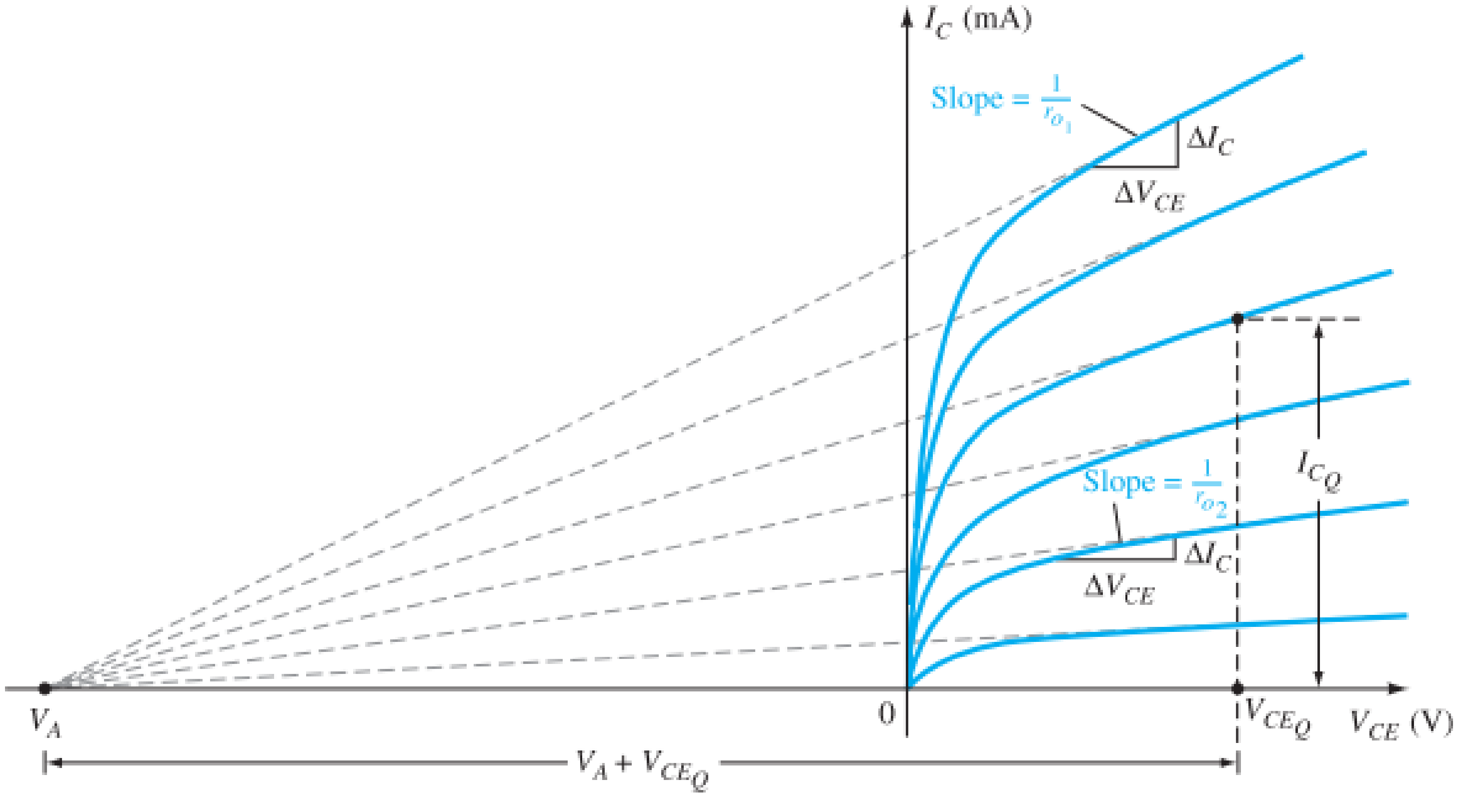


FIG. 5.15
Defining the Early voltage and the output impedance of a transistor.

The r_e Transistor Model (CE) $_{4/4}$

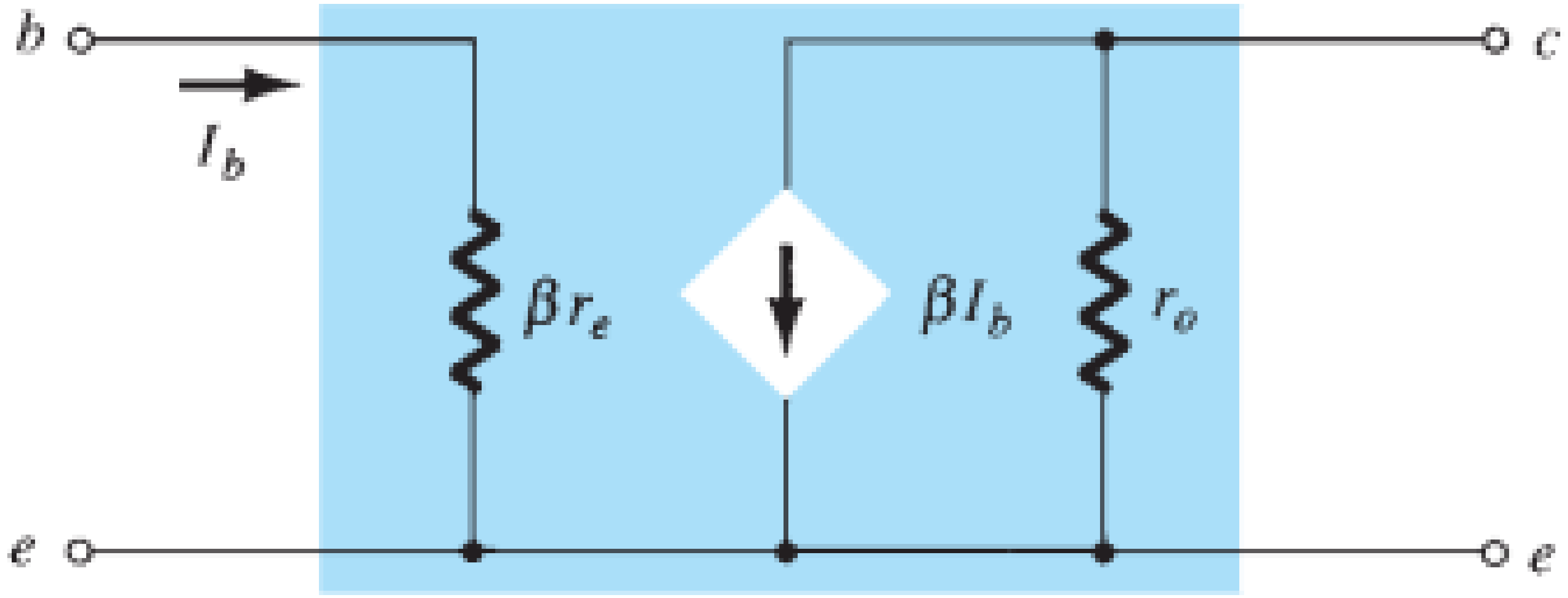


FIG. 5.16

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

C.E. Voltage-Divider Bias$_{1/2}$

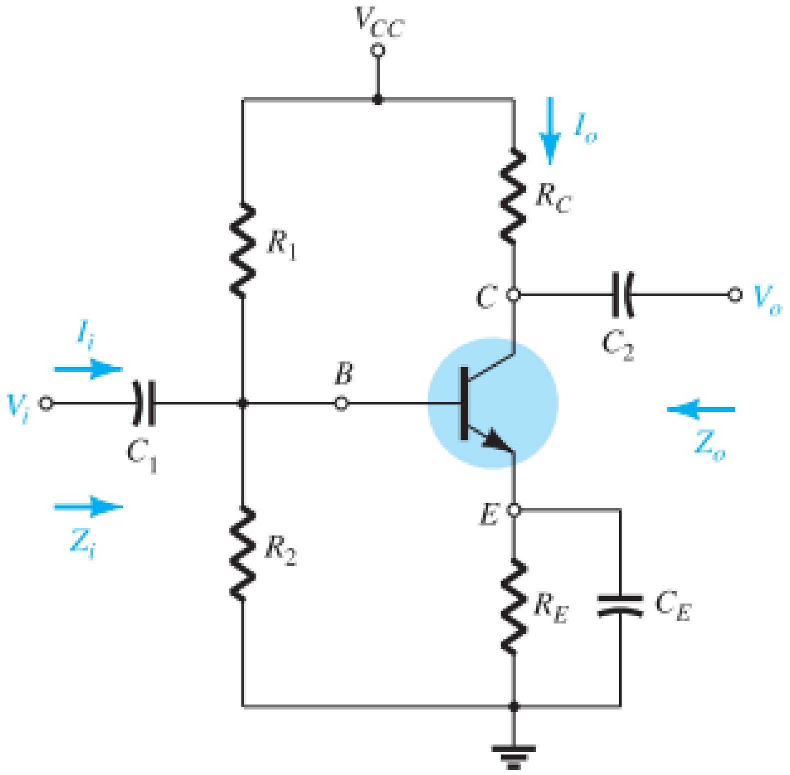


FIG. 5.26
Voltage-divider bias configuration.

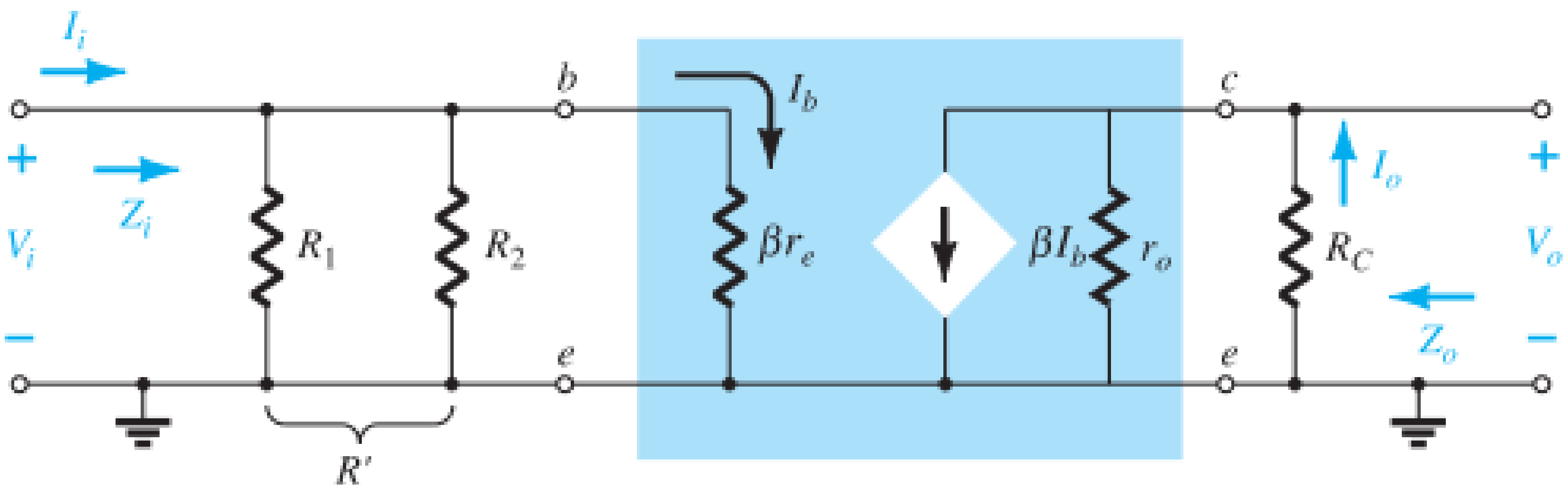


FIG. 5.27
Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 5.26.

C.E. Voltage-Divider Bias$_{2/2}$

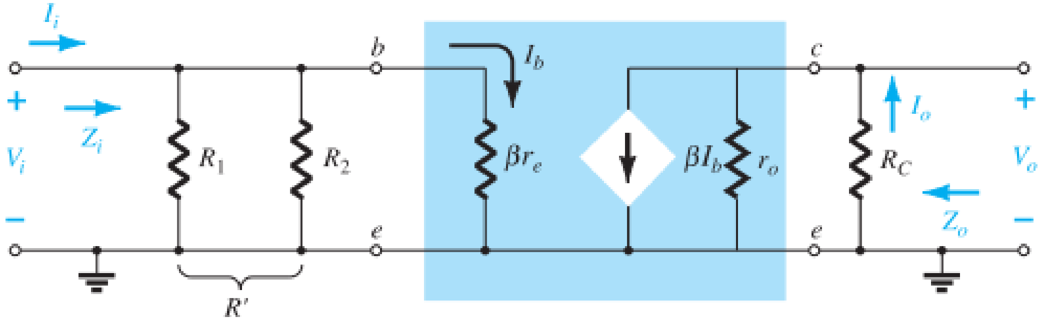


FIG. 5.27
Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 5.26.

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

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

$$Z_o = R_C \| r_o$$

$$Z_o \cong R_C$$

$r_o \geq 10R_C$

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

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

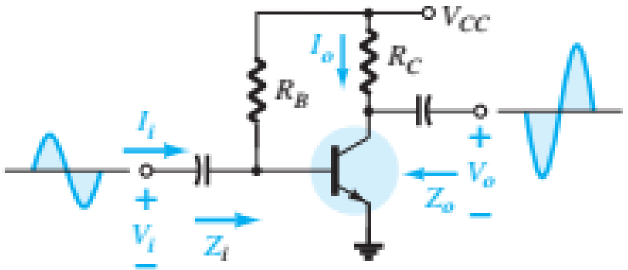
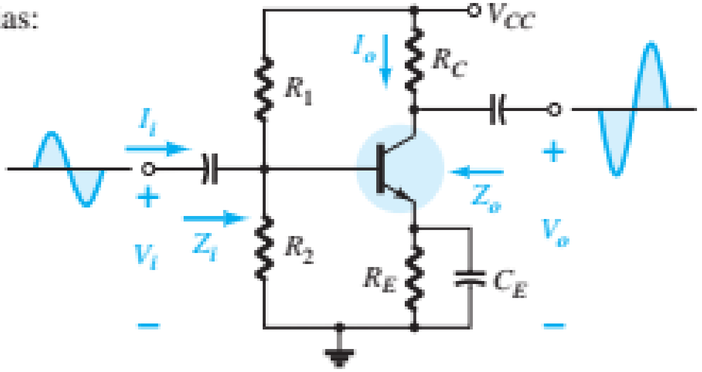
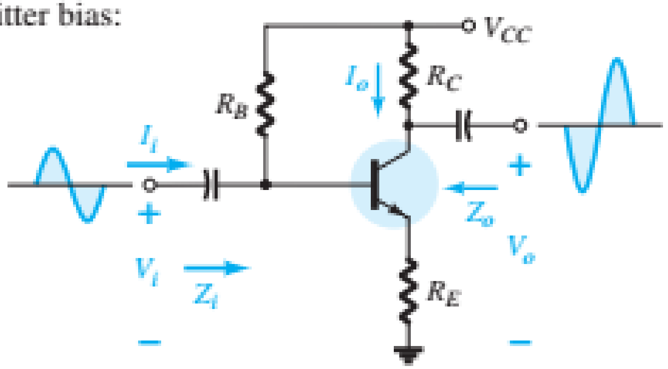
$$V_o = -\beta\left(\frac{V_i}{\beta r_e}\right)(R_C \| r_o)$$

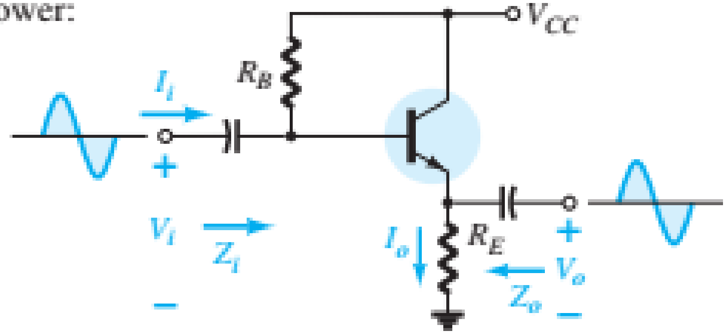
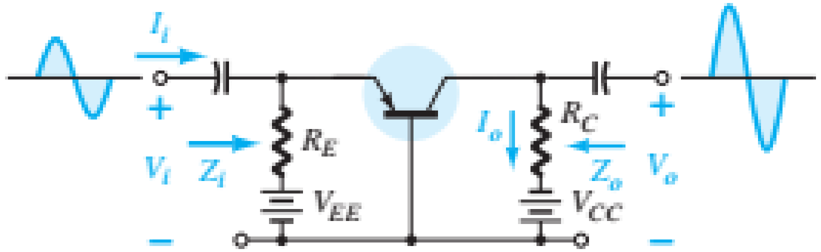
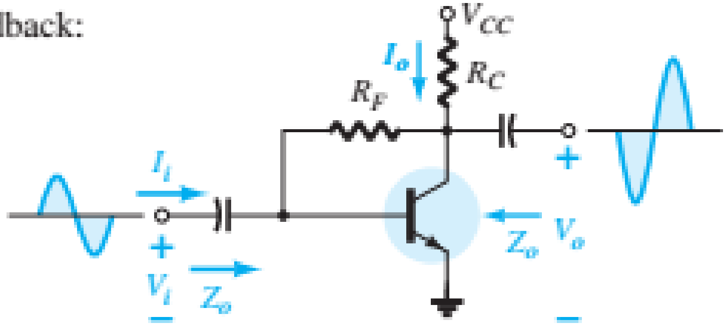
$$A_v = \frac{V_o}{V_i} = \frac{-R_C \| r_o}{r_e}$$

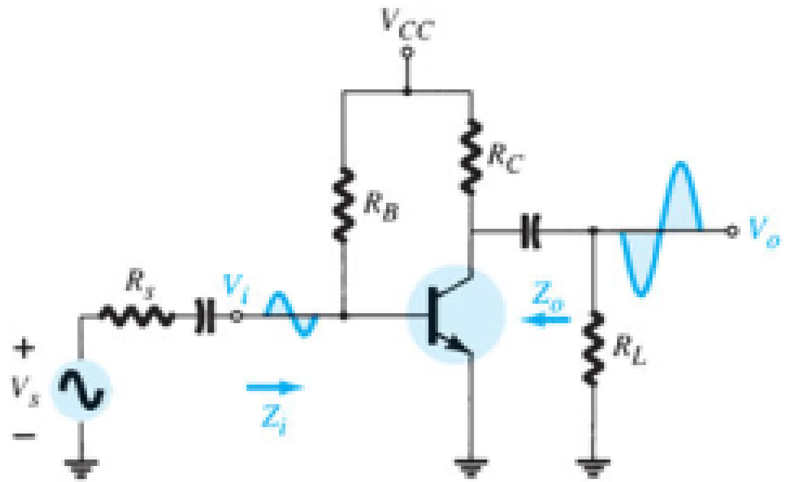
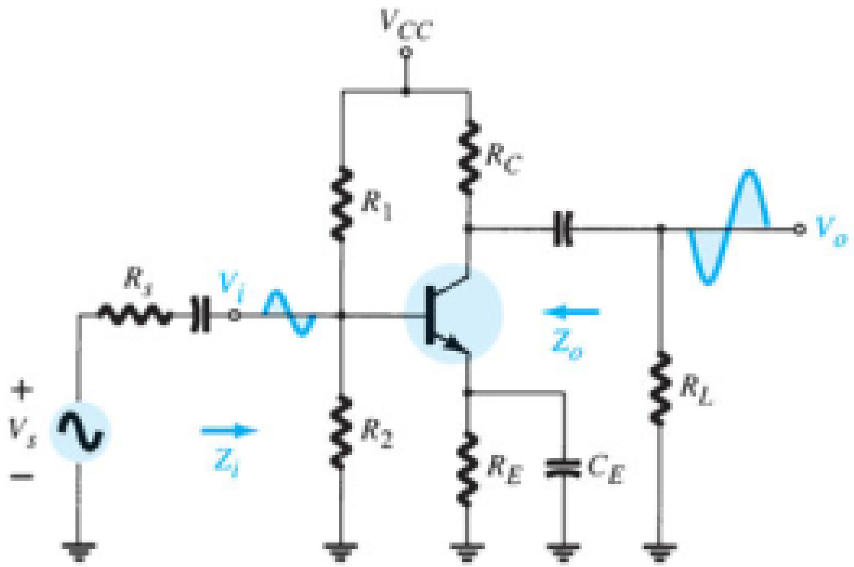
$$A_v = \frac{V_o}{V_i} \cong -\frac{R_C}{r_e}$$

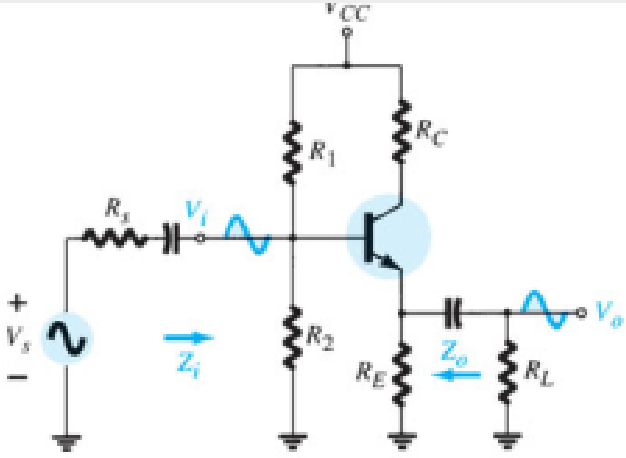
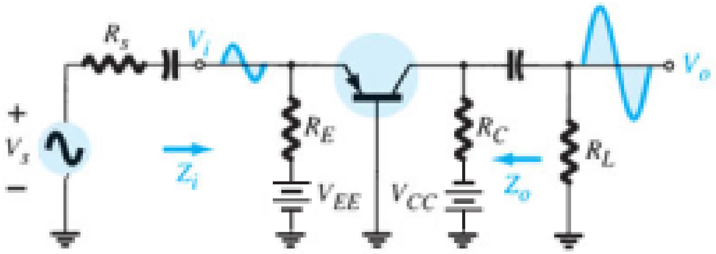
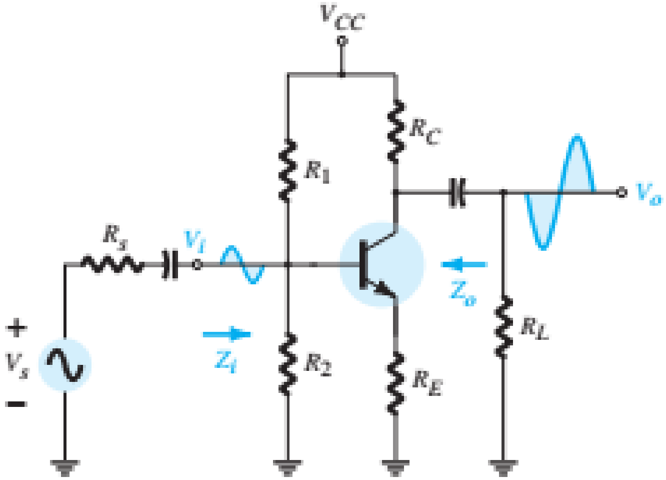
$r_o \geq 10R_C$

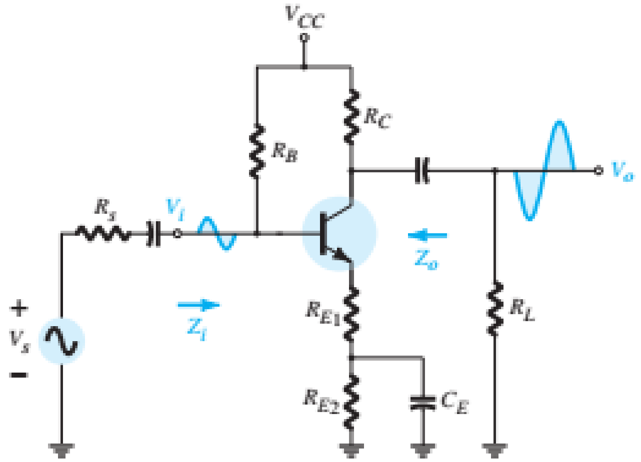
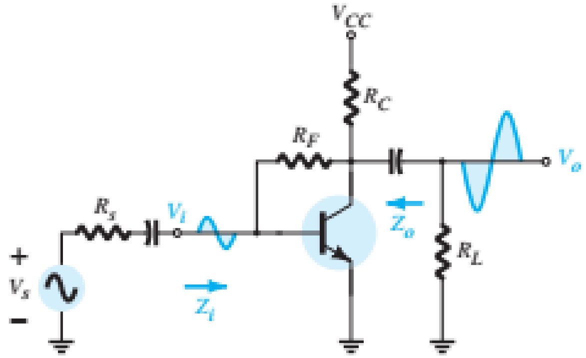
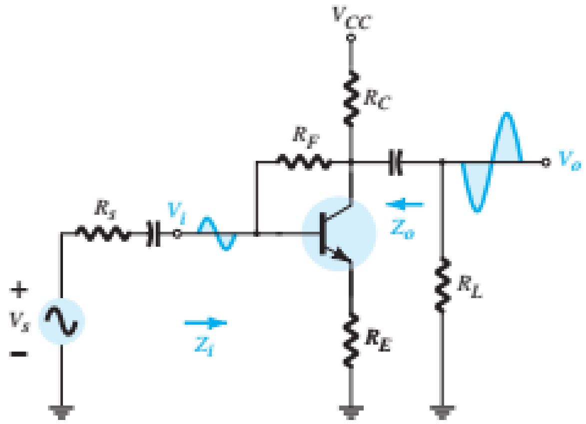
180° phase shift

Configuration	Z_i	Z_o	A_v	A_i
Fixed-bias: 	Medium (1 kΩ) $= R_B \| \beta r_e$ $\cong \beta r_e$ $(R_B \geq 10\beta r_e)$	Medium (2 kΩ) $= R_C \| r_o$ $\cong R_C$ $(r_o \geq 10R_C)$	High (−200) $= -\frac{(R_C \| r_o)}{r_e}$ $\cong -\frac{R_C}{r_e}$ $(r_o \geq 10R_C)$	High (100) $= \frac{\beta R_B r_o}{(r_o + R_C)(R_B + \beta r_e)}$ $\cong \beta$ $(r_o \geq 10R_C, R_B \geq 10\beta r_e)$
Voltage-divider bias: 	Medium (1 kΩ) $= R_1 \| R_2 \| \beta r_e$	Medium (2 kΩ) $= R_C \| r_o$ $\cong R_C$ $(r_o \geq 10R_C)$	High (−200) $= -\frac{R_C \| r_o}{r_e}$ $\cong -\frac{R_C}{r_e}$ $(r_o \geq 10R_C)$	High (50) $= \frac{\beta(R_1 \| R_2) r_o}{(r_o + R_C)(R_1 \| R_2 + \beta r_e)}$ $\cong \frac{\beta(R_1 \| R_2)}{R_1 \| R_2 + \beta r_e}$ $(r_o \geq 10R_C)$
Unbypassed emitter bias: 	High (100 kΩ) $= R_B \| Z_b$ $Z_b \cong \beta(r_e + R_E)$ $\cong R_B \| \beta R_E$ $(R_E \gg r_e)$	Medium (2 kΩ) $= R_C$ (any level of r_o)	Low (−5) $= -\frac{R_C}{r_e + R_E}$ $\cong -\frac{R_C}{R_E}$ $(R_E \gg r_e)$	High (50) $\cong -\frac{\beta R_B}{R_B + Z_b}$

Configuration	Z_i	Z_o	A_v	A_i
Emitter-follower: 	High (100 kΩ) $= R_B \| Z_b$ $Z_b \cong \beta(r_e + R_E)$ $\cong R_B \| \beta R_E$ $(R_E \gg r_e)$	Low (20 Ω) $= R_E \| r_e$ $\cong r_e$ $(R_E \gg r_e)$	Low ($\cong 1$) $= \dfrac{R_E}{R_E + r_e}$ $\cong 1$	High (−50) $\cong -\dfrac{\beta R_B}{R_B + Z_b}$
Common-base: 	Low (20 Ω) $= R_E \| r_e$ $\cong r_e$ $(R_E \gg r_e)$	Medium (2 kΩ) $= R_C$	High (200) $\cong \dfrac{R_C}{r_e}$	Low (−1) $\cong -1$
Collector feedback: 	Medium (1 kΩ) $= \dfrac{r_e}{\dfrac{1}{\beta} + \dfrac{R_C}{R_F}}$ $(r_o \geq 10R_C)$	Medium (2 kΩ) $\cong R_C \| R_F$ $(r_o \geq 10R_C)$	High (−200) $\cong -\dfrac{R_C}{r_e}$ $(r_o \geq 10R_C)$ $(R_F \gg R_C)$	High (50) $= \dfrac{\beta R_F}{R_F + \beta R_C}$ $\cong \dfrac{R_F}{R_C}$

Configuration	$A_{v_L} = V_o/V_i$	Z_i	Z_o
	$\frac{-(R_L \| R_C)}{r_e}$	$R_B \| \beta r_e$	R_C
	Including r_o: $-\frac{(R_L \| R_C \| r_o)}{r_e}$	$R_B \| \beta r_e$	$R_C \| r_o$
	$\frac{-(R_L \| R_C)}{r_e}$	$R_1 \| R_2 \| \beta r_e$	R_C
	Including r_o: $\frac{-(R_L \| R_C \| r_o)}{r_e}$	$R_1 \| R_2 \| \beta r_e$	$R_C \| r_o$

Configuration	$A_{v_L} = V_o/V_i$	Z_i	Z_o
	$\cong 1$	$R'_E = R_L \| R_E$ $R_1 \| R_2 \| \beta(r_e + R'_E)$	$R'_s = R_s \| R_1 \| R_2$ $R_E \| \left(\frac{R'_s}{\beta} + r_e\right)$
	Including r_o: $\cong 1$	$R_1 \| R_2 \| \beta(r_e + R'_E)$	$R_E \| \left(\frac{R'_s}{\beta} + r_e\right)$
	$\cong \frac{-(R_L \| R_C)}{r_e}$	$R_E \| r_e$	R_C
	Including r_o: $\cong \frac{-(R_L \| R_C \| r_o)}{r_e}$	$R_E \| r_e$	$R_C \| r_o$
	$\frac{-(R_L \| R_C)}{R_E}$	$R_1 \| R_2 \| \beta(r_e + R_E)$	R_C
	Including r_o: $\frac{-(R_L \| R_C)}{R_E}$	$R_1 \| R_2 \| \beta(r_e + R_e)$	$\cong R_C$

Configuration	$A_{v_L} = V_o/V_i$	Z_i	Z_o
	$\frac{-(R_L \parallel R_C)}{R_{E_1}}$	$R_B \parallel \beta(r_e + R_{E_1})$	R_C
	Including r_o: $\frac{-(R_L \parallel R_C)}{R_{E_1}}$	$R_B \parallel \beta(r_e + R_E)$	$\cong R_C$
	$\frac{-(R_L \parallel R_C)}{r_e}$	$\beta r_e \parallel \frac{R_F}{\lvert A_v \rvert}$	R_C
	Including r_o: $\frac{-(R_L \parallel R_C \parallel r_o)}{r_e}$	$\beta r_e \parallel \frac{R_F}{\lvert A_v \rvert}$	$R_C \parallel R_F \parallel r_o$
	$\frac{-(R_L \parallel R_C)}{R_E}$	$\beta R_E \parallel \frac{R_F}{\lvert A_v \rvert}$	$\cong R_C \parallel R_F$
	Including r_o: $\cong \frac{-(R_L \parallel R_C)}{R_E}$	$\cong \beta R_E \parallel \frac{R_F}{\lvert A_v \rvert}$	$\cong R_C \parallel R_F$


Thank You!