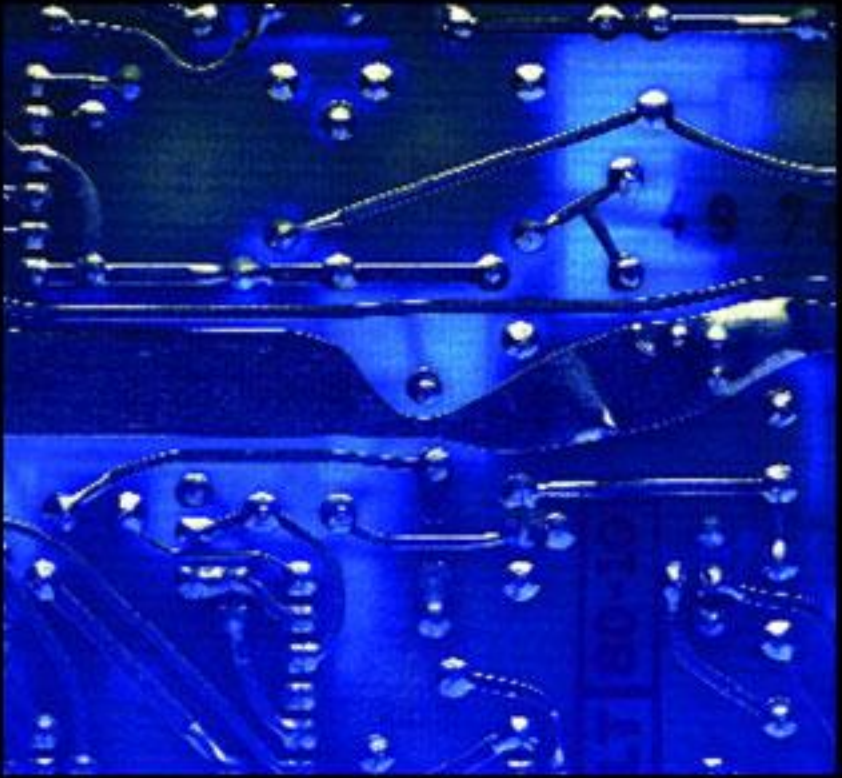
ELECTRONIC DEVICES AND CIRCUIT THEORY

TENTH EDITION



BOYLESTAD

PEARSON

Chapter 5: BJT AC Analysis

Islamic University of Gaza

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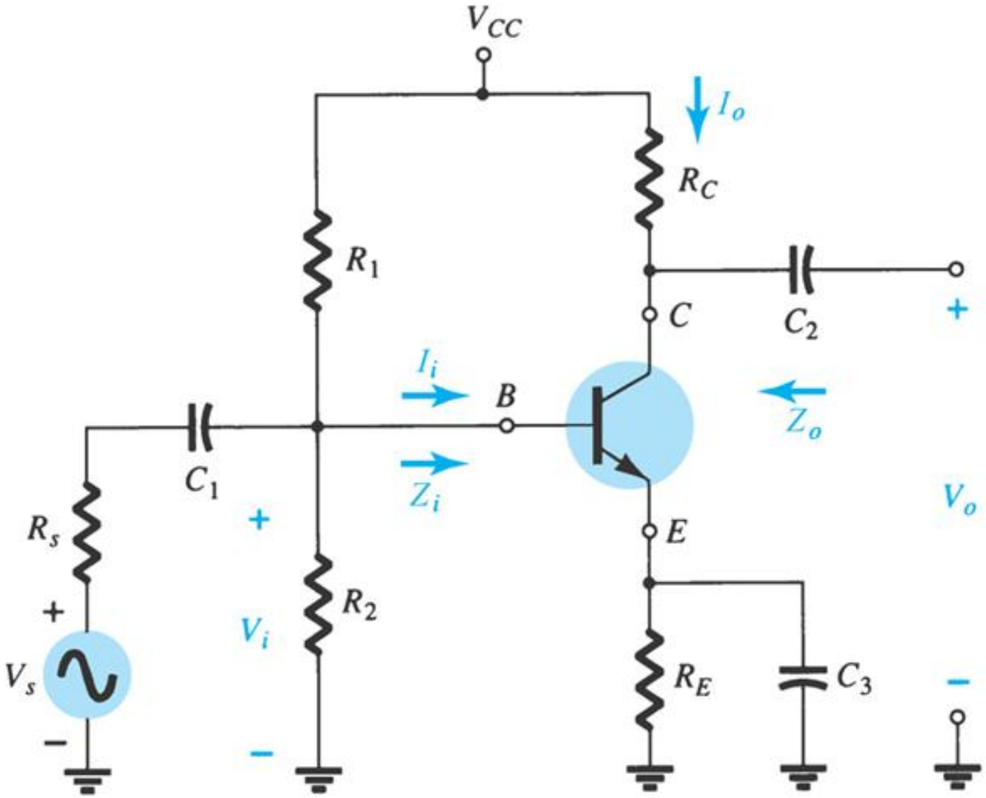
BJT Transistor Modeling

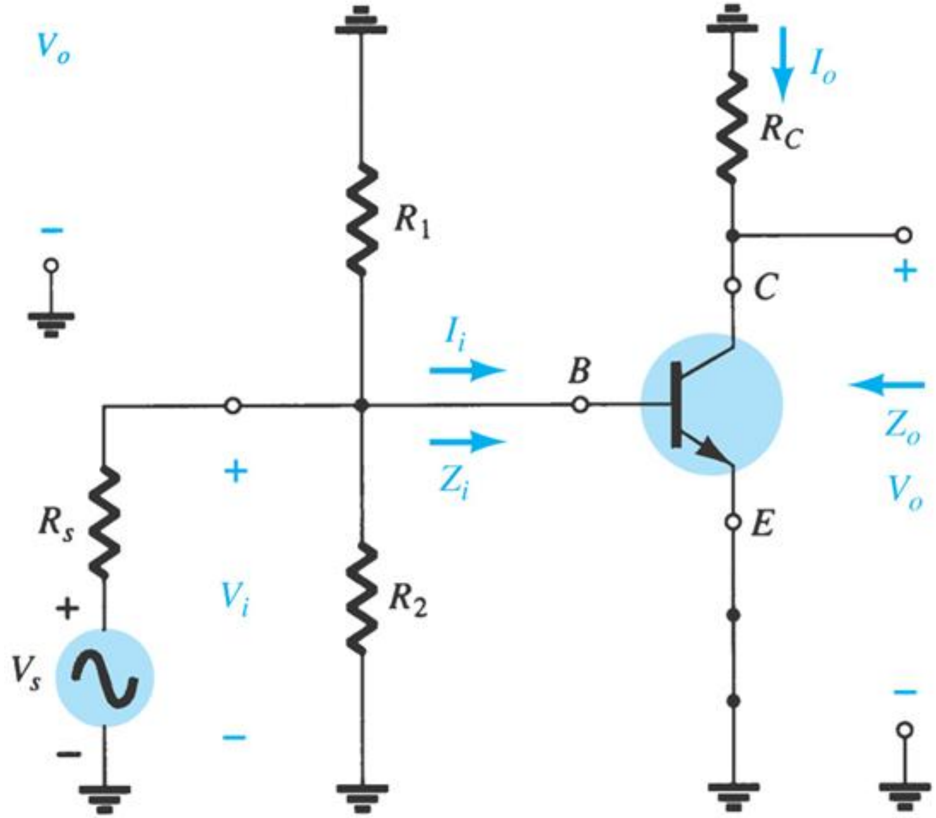
- A model is an equivalent circuit that represents the AC characteristics of the transistor.
- A model uses circuit elements that approximate the behavior of the transistor.
- There are two models commonly used in small signal AC analysis of a transistor:
  - **r_e model**
  - **Hybrid equivalent model**

BJT Transistor Modeling

Capacitors chosen with very small reactance at the frequency of application → replaced by low-resistance or short circuit.

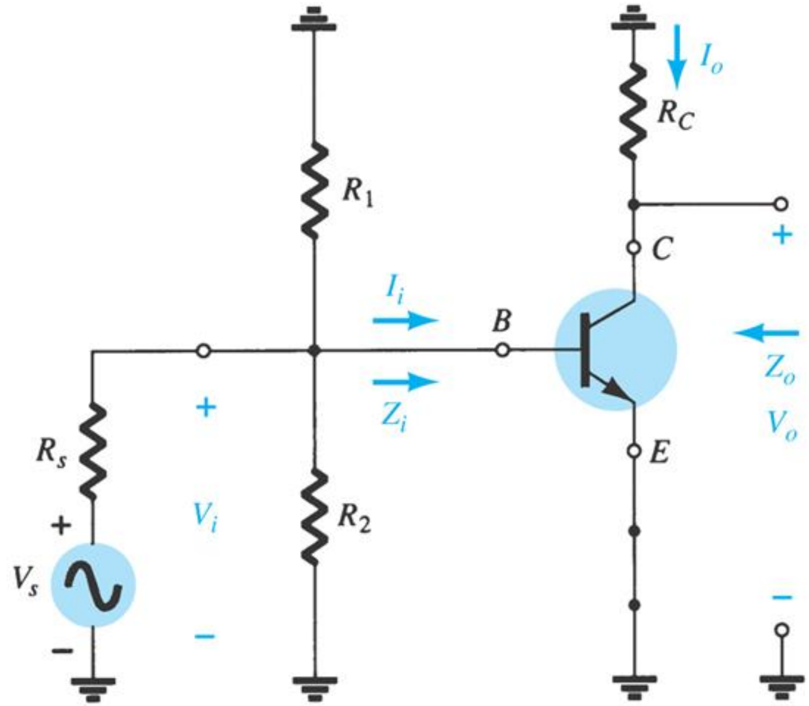


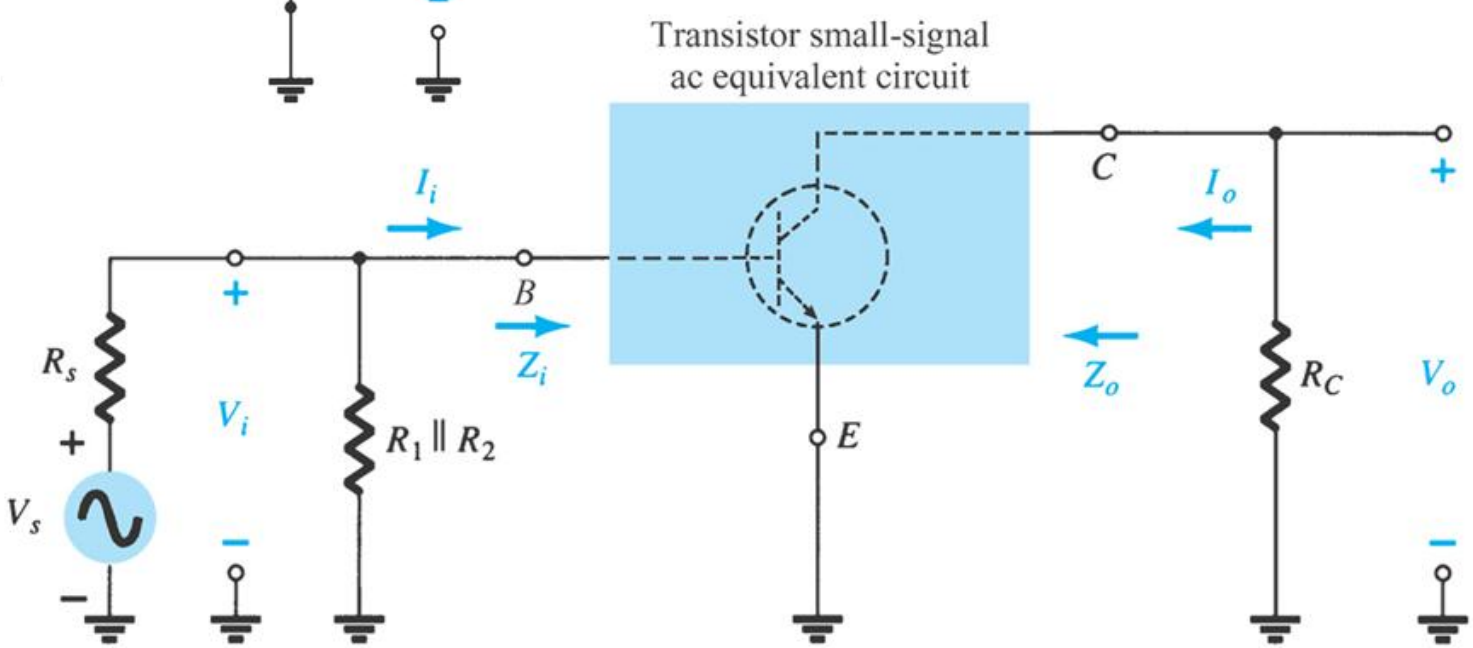
Removal of the dc supply and insertion of the short-circuit equivalent for the capacitors.



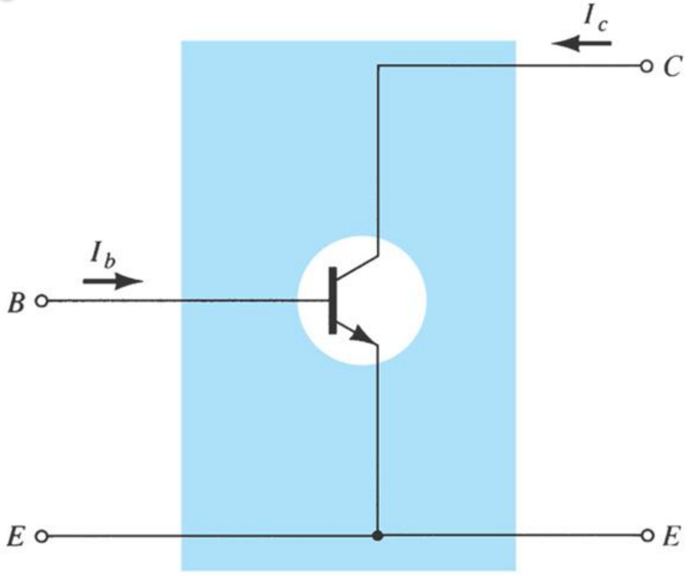
BJT Transistor Modeling

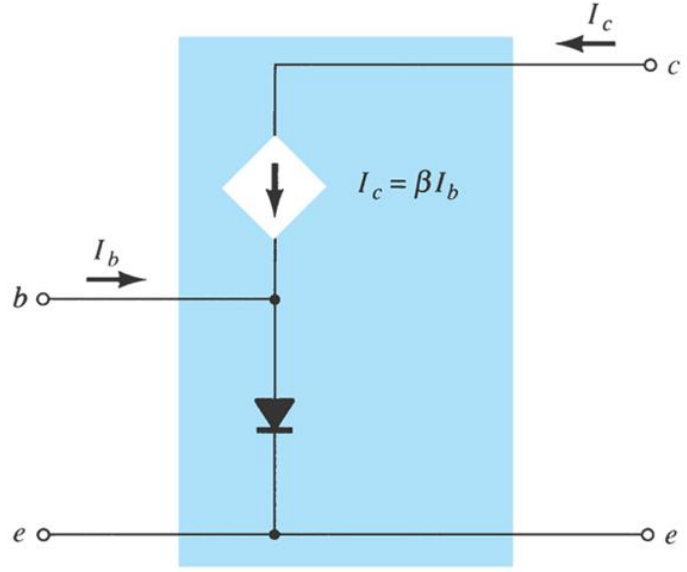
Circuit redrawn for small-signal ac analysis





The r_e Transistor Model Common Emitter Configuration



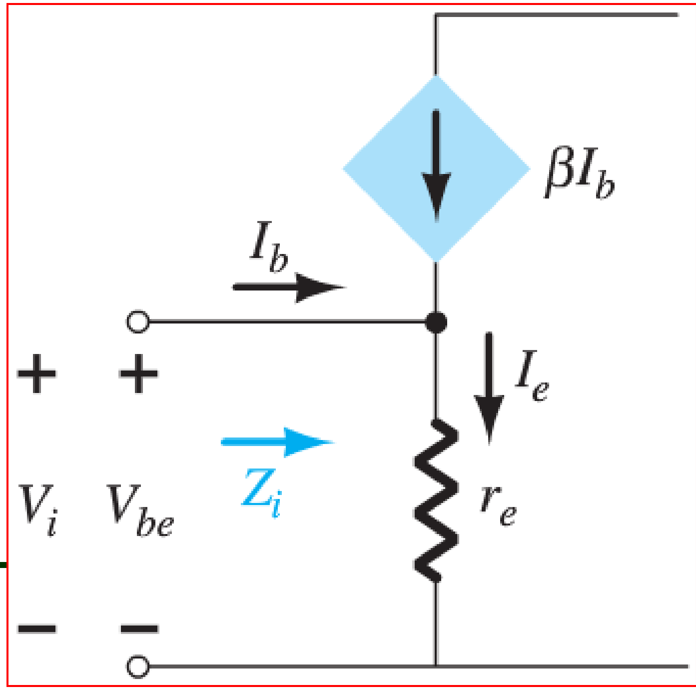


$$Z_i = \frac{V_i}{I_b} = \frac{V_{be}}{I_b}$$

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

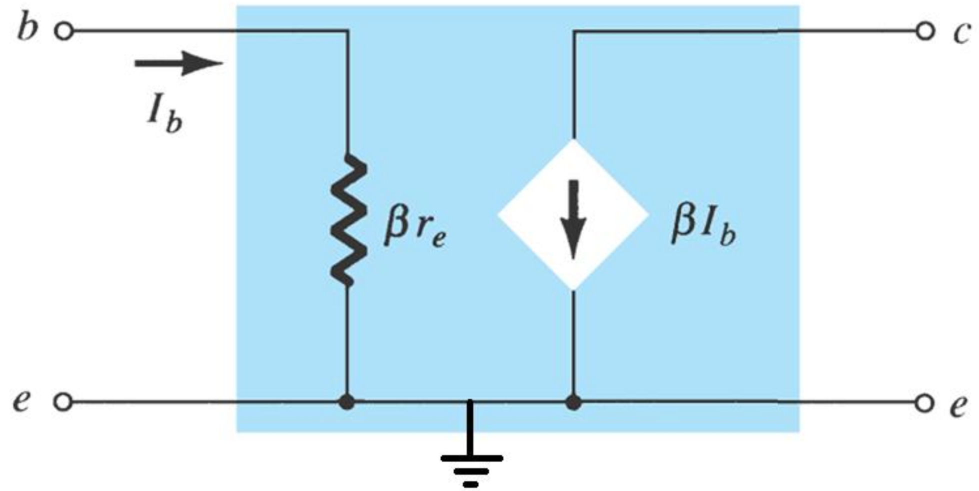
$$= (\beta + 1) I_b r_e$$

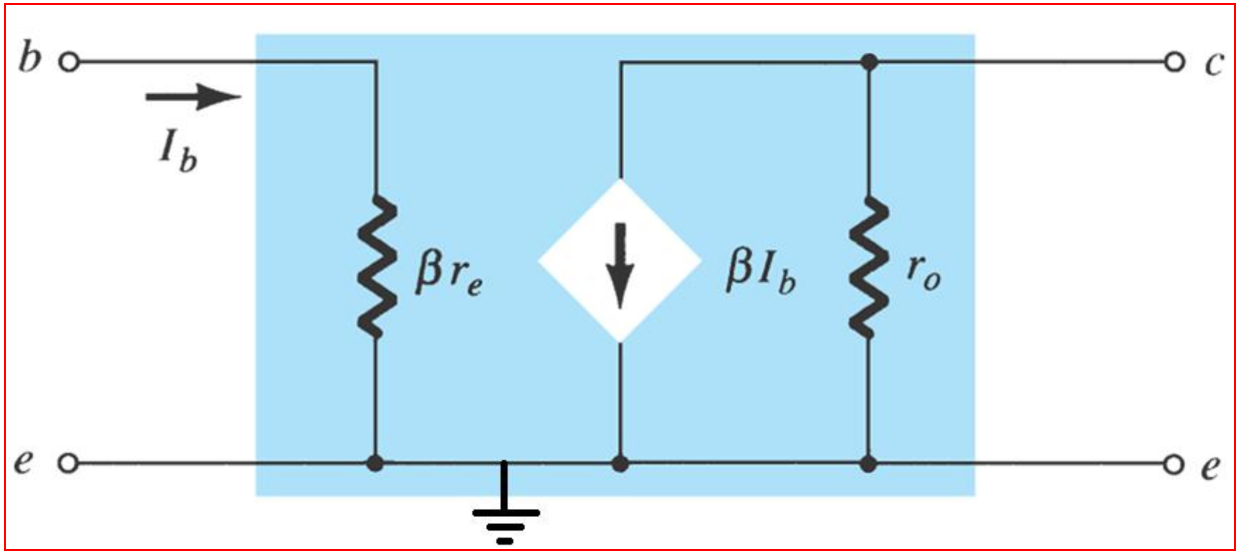
$$Z_i = \frac{V_{be}}{I_b} = \frac{(\beta + 1) I_b r_e}{I_b} = (\beta + 1) r_e \simeq \beta r_e$$



The r_e Transistor Model Common Emitter Configuration

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





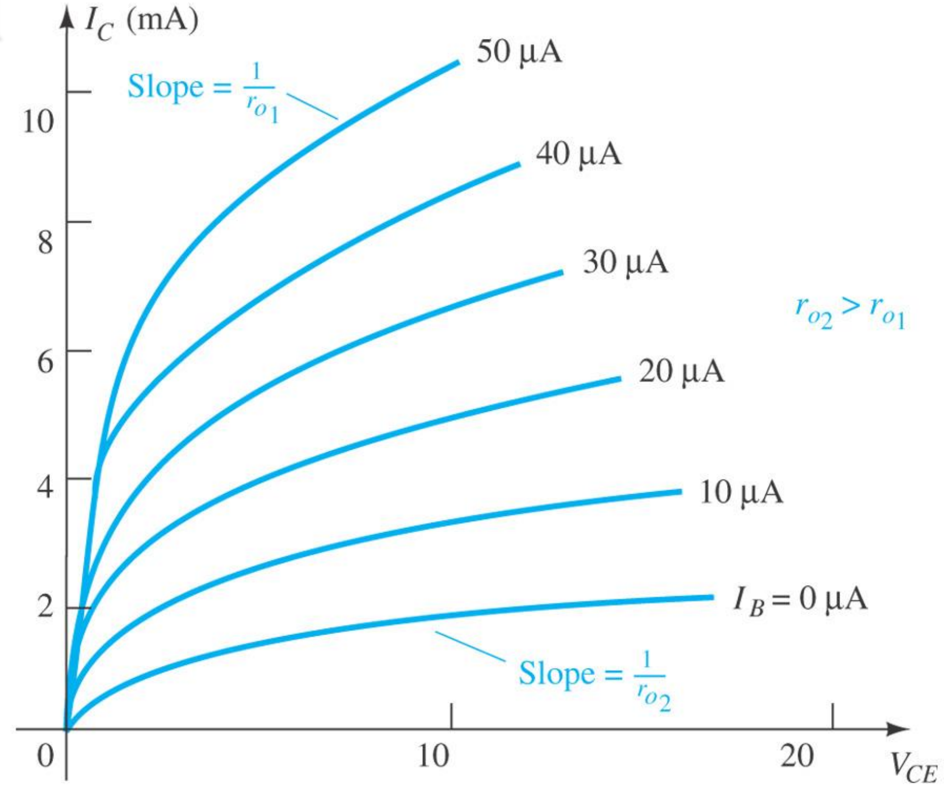
The r_e Transistor Model

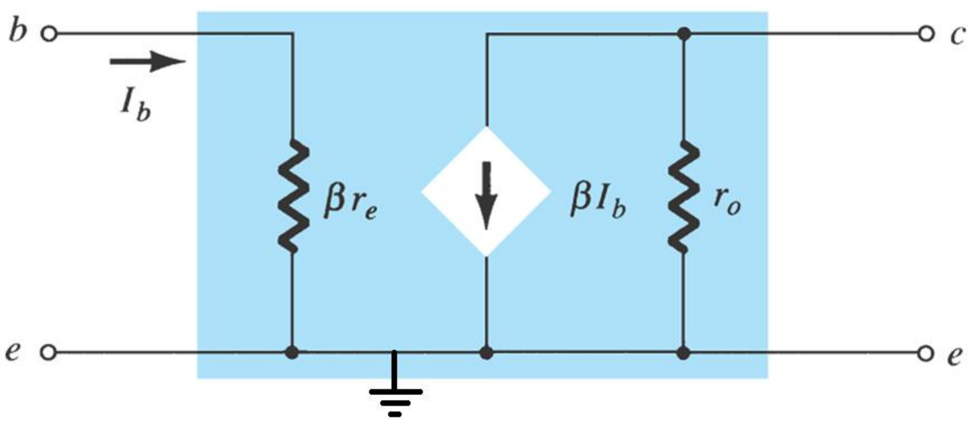
Common Emitter Configuration

$$slope = \frac{\Delta I_C}{\Delta V_{CE}} = \frac{1}{r_0}$$

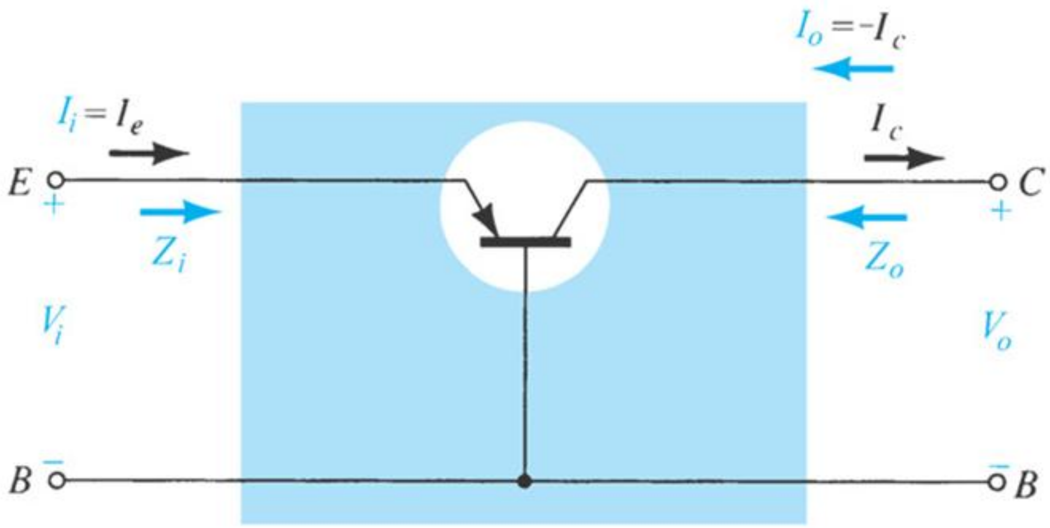
$$r_0 = \frac{\Delta V_{CE}}{\Delta I_C}$$

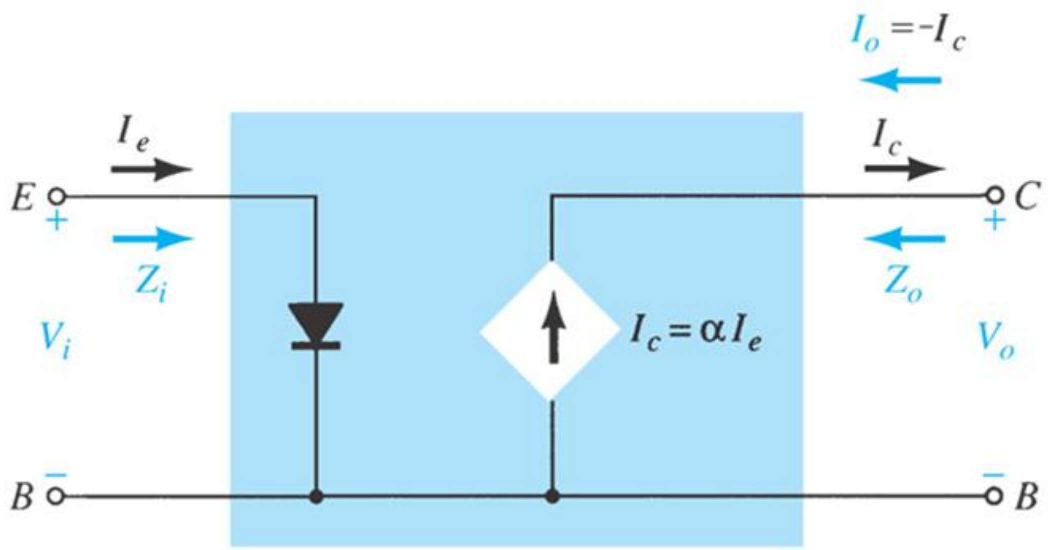
The output resistance *r* is typically in the range of 40 kΩ to 50 kΩ



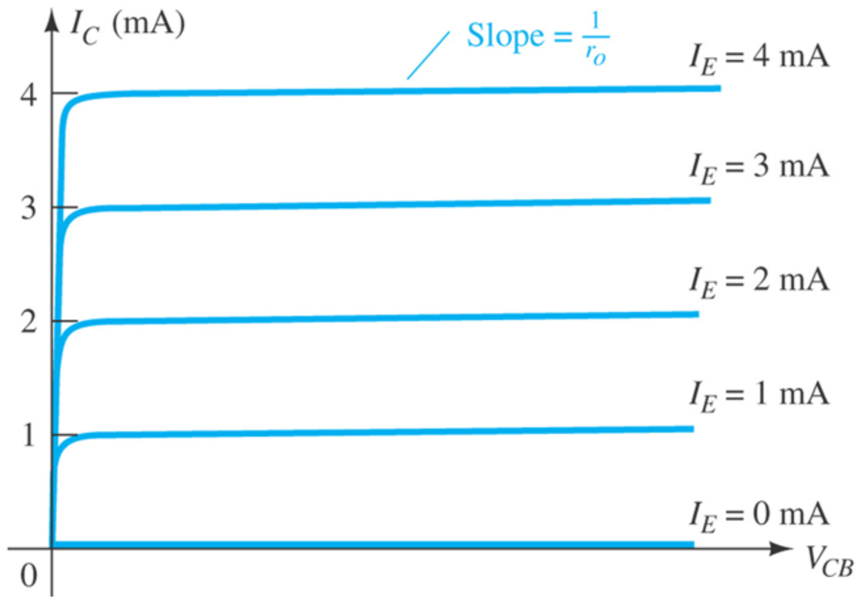


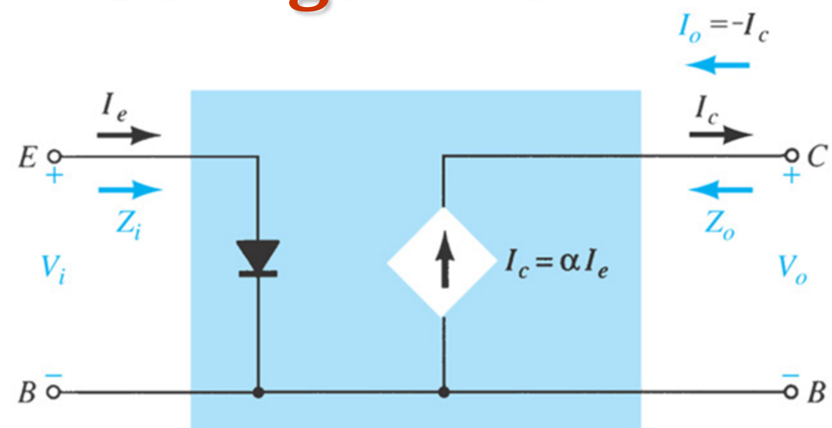
Common-Base Configuration





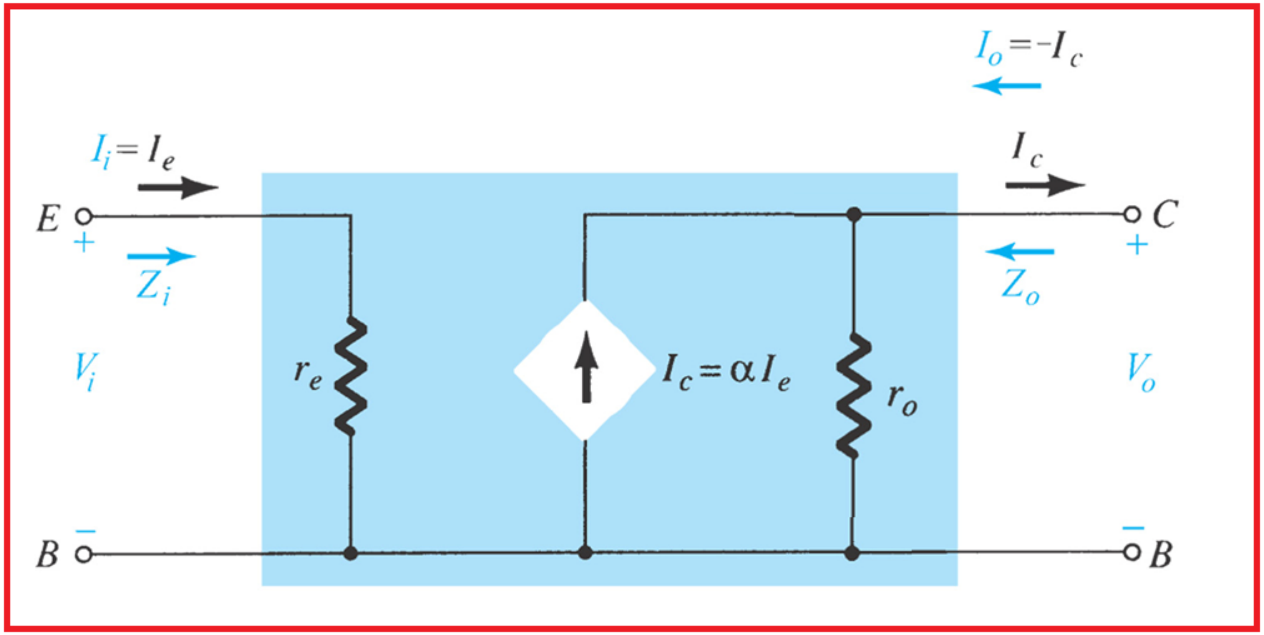
Common-Base Configuration



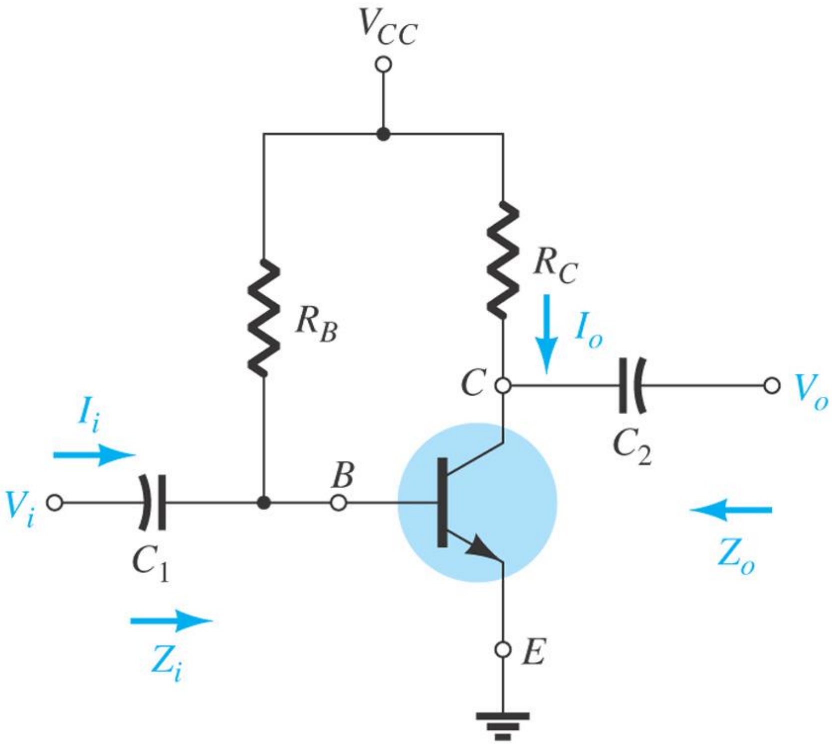


The output resistance r_0 is quite high. typically extend into the megaohm range.

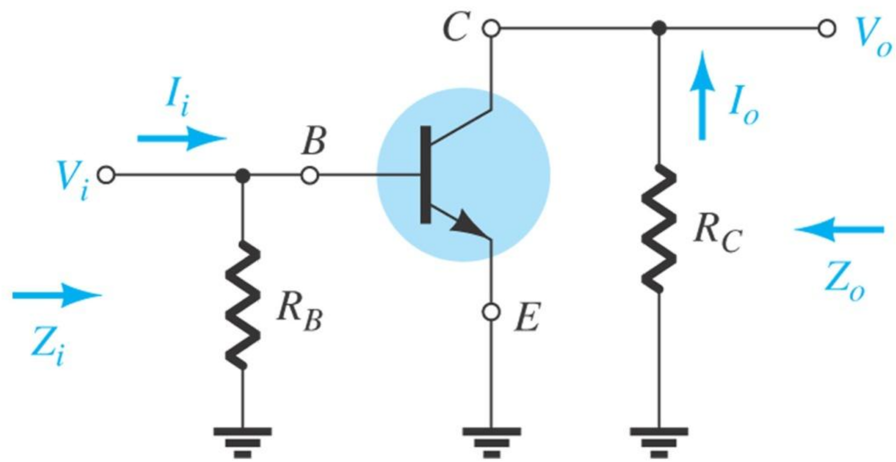
Common Base r_e equivalent circuit



Common Emitter Fixed Bias Configuration

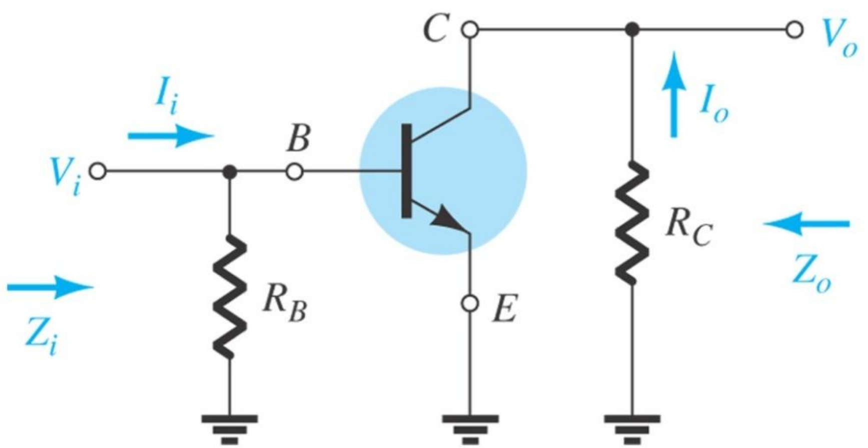


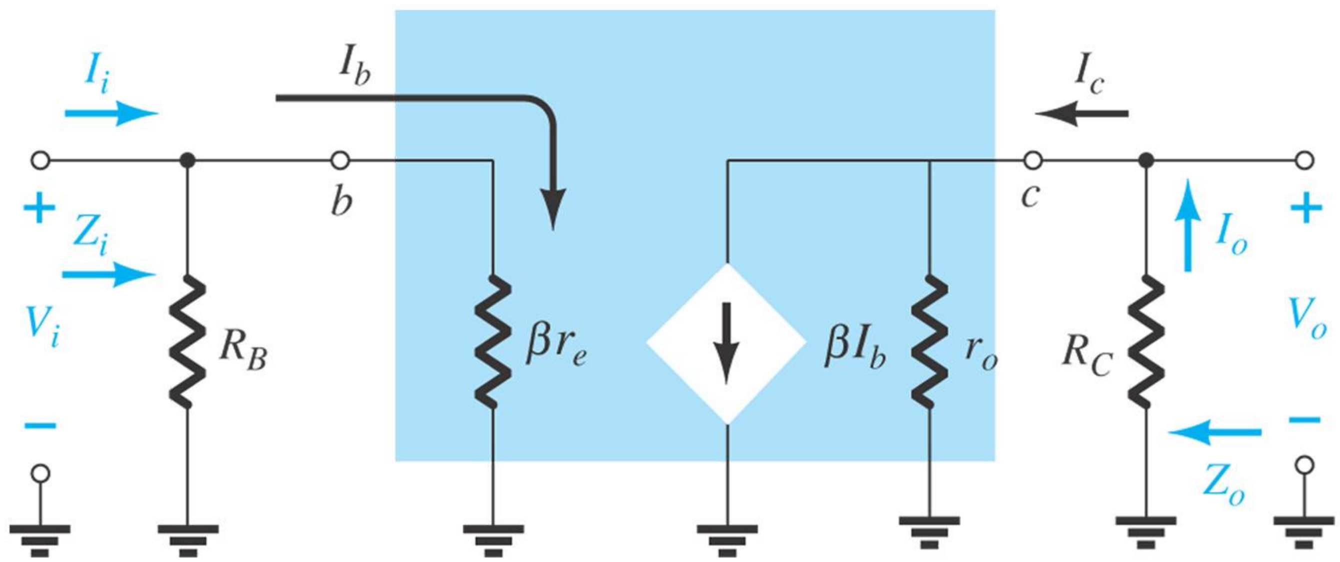
Common-emitter fixed-bias configuration.



Network after the removal of the effects of V_{CC}, C_1 and C_2.

Common Emitter Fixed Bias Configuration





Substituting the r_e model into the network.

Common Emitter Fixed Bias Configuration

Input impedance:

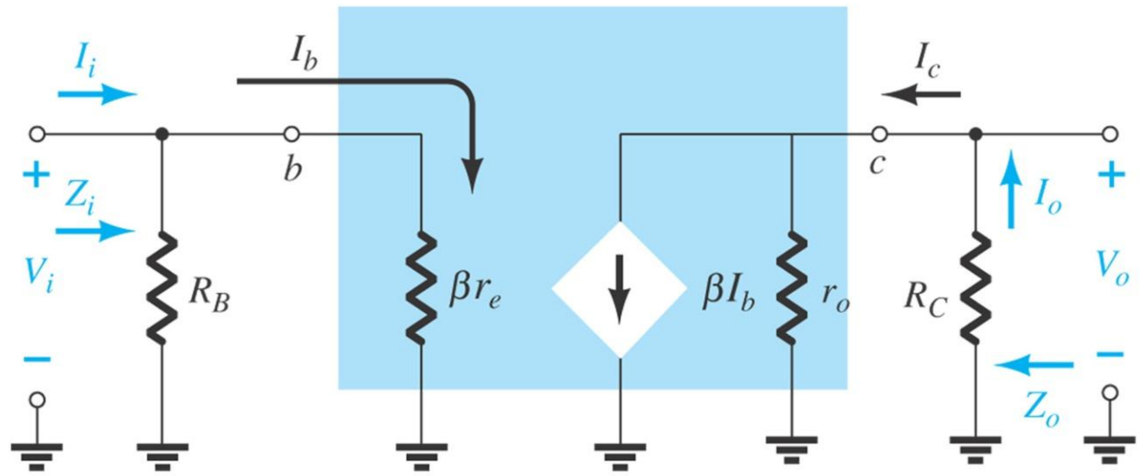
$$Z_i = R_B \,||\, \beta r_e$$

$$Z_i \cong \beta r_e \Big|_{R_E \geq 10\beta r_e}$$

Output impedance:

$$Z_o = R_C \,||\, r_o$$

$$Z_o \cong R_C \Big|_{r_o \geq 10R_C}$$



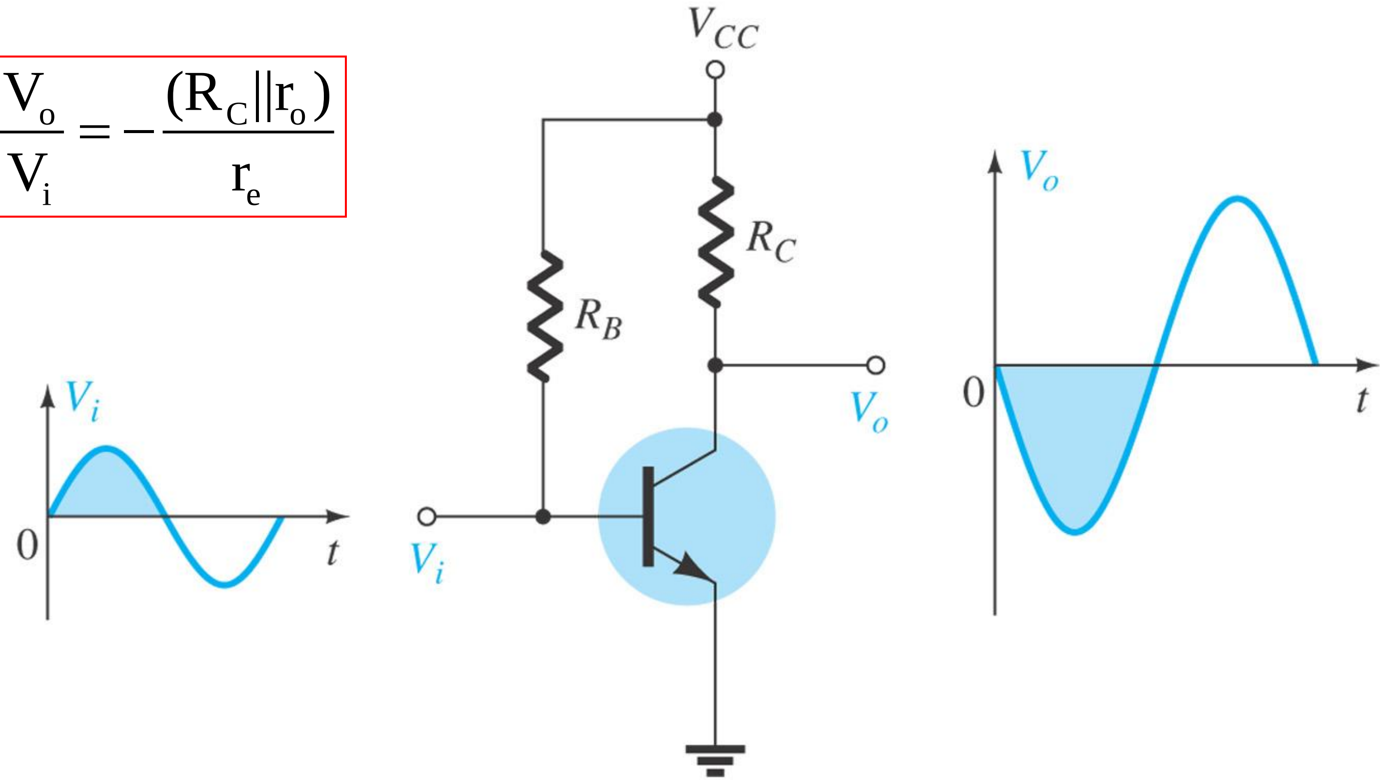
Voltage gain:

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

$$A_v = \frac{V_o}{V_i} = -\frac{(R_C || r_o)}{r_e} \;,\; A_v = -\frac{R_C}{r_e} \Big|_{r_o \geq 10R_C}$$

Common Emitter Fixed Bias Configuration

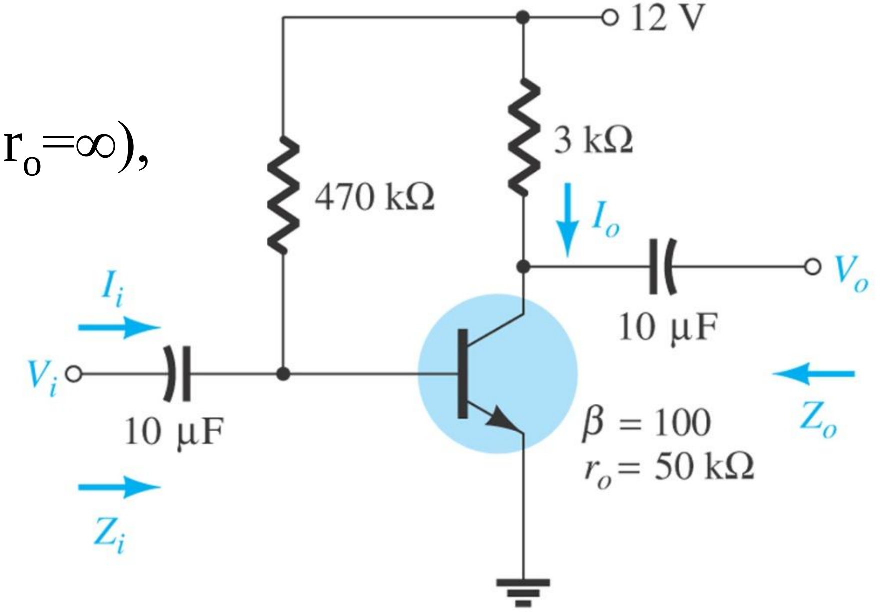
$$A_v = \frac{V_o}{V_i} = -\frac{(R_C \| r_o)}{r_e}$$



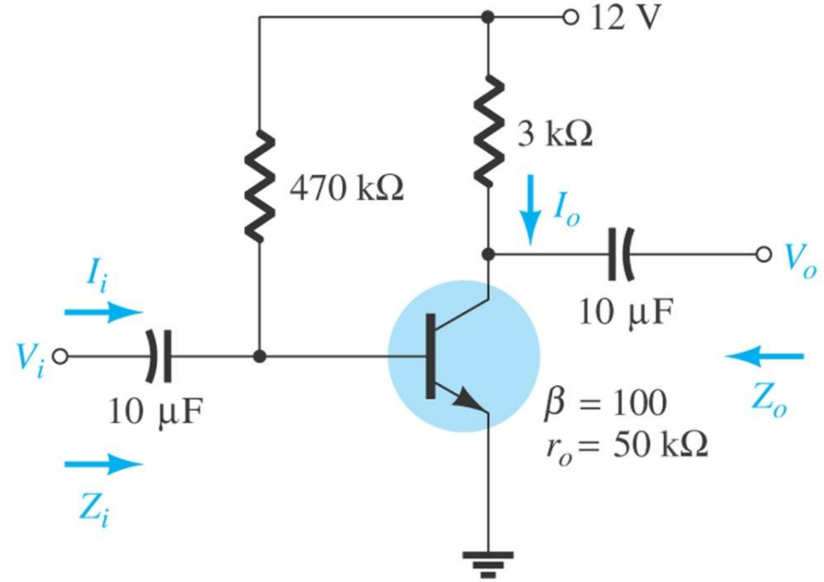
Demonstrating the 180° phase shift between input and output waveforms.

Example 5.1

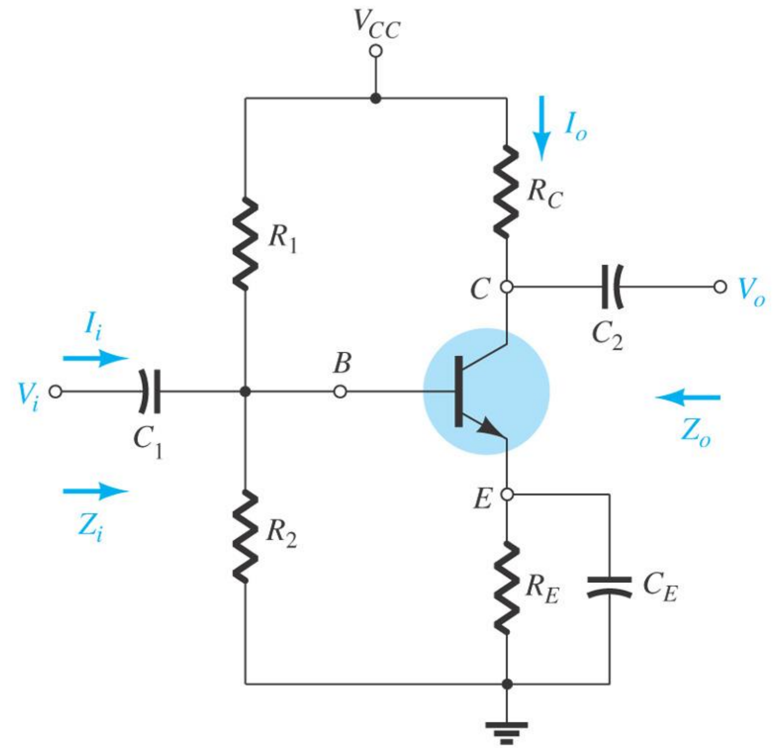
Determine r_e, Z_i (with $r_o=\infty$), Z_o (with $r_o=\infty$), A_v (with $r_o=\infty$).
Repeat with $r_o=50\ k\Omega$.

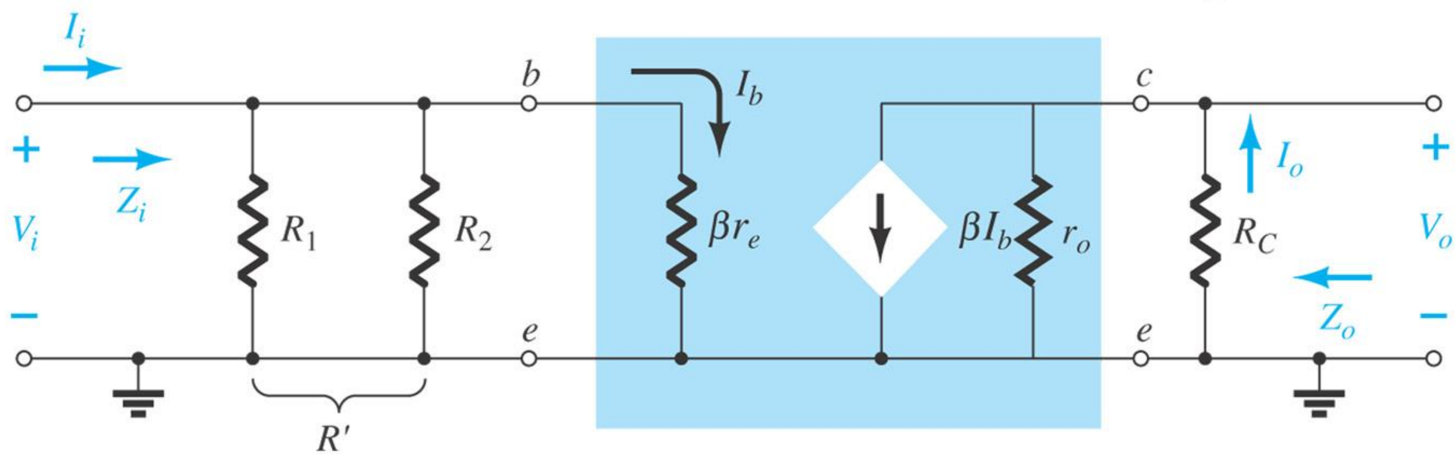


Example 5.1 - Solution



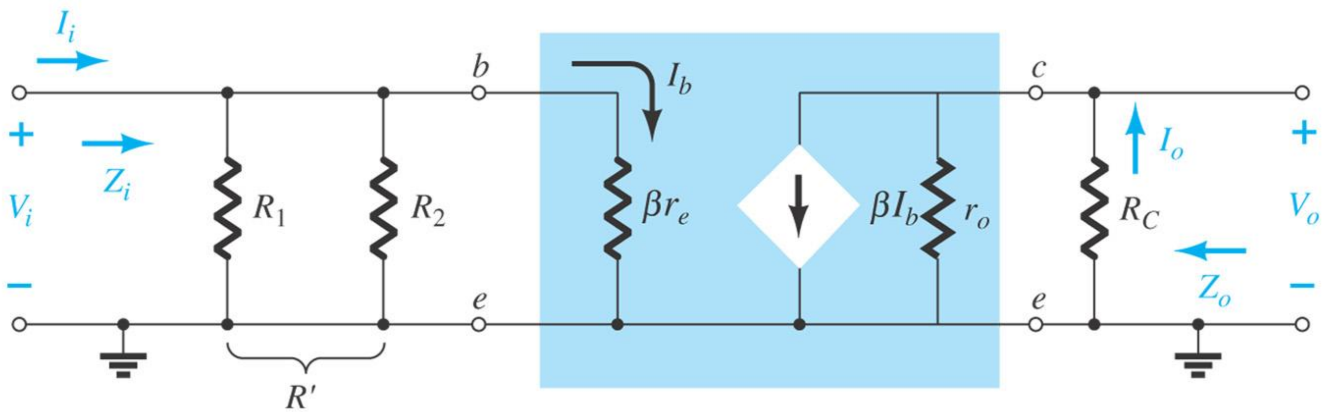
Common-Emitter Voltage-Divider Bias





r_e model requires you to determine β, r_e, and r_o.

Common-Emitter Voltage-Divider Bias



Input impedance:

$$R' = R_1 \,||\, R_2$$

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

Output impedance:

$$Z_o = R_C \,||\, r_o$$

$$Z_o \cong R_C \Big|_{r_o \geq 10R_C}$$

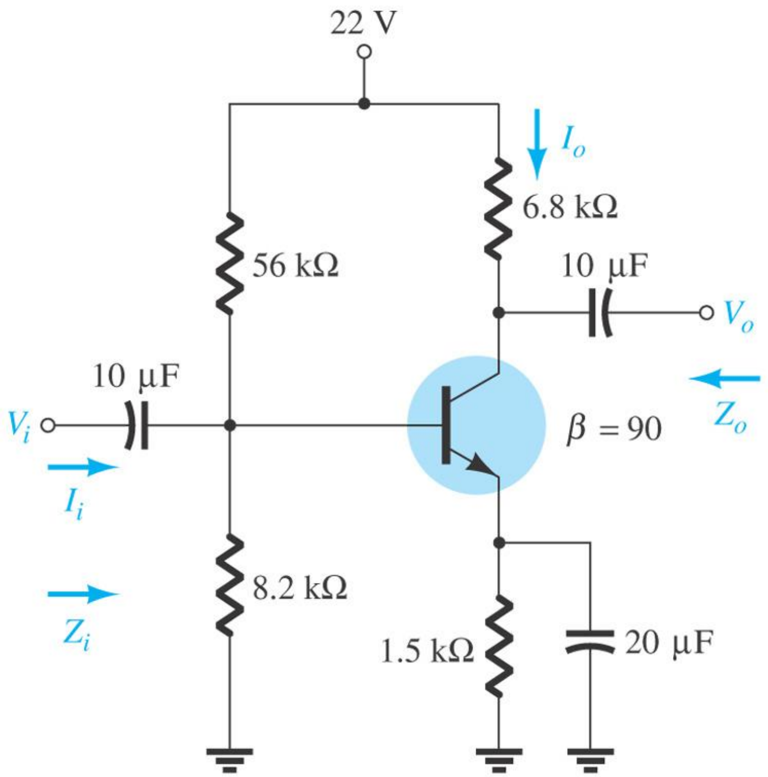
Voltage gain:

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

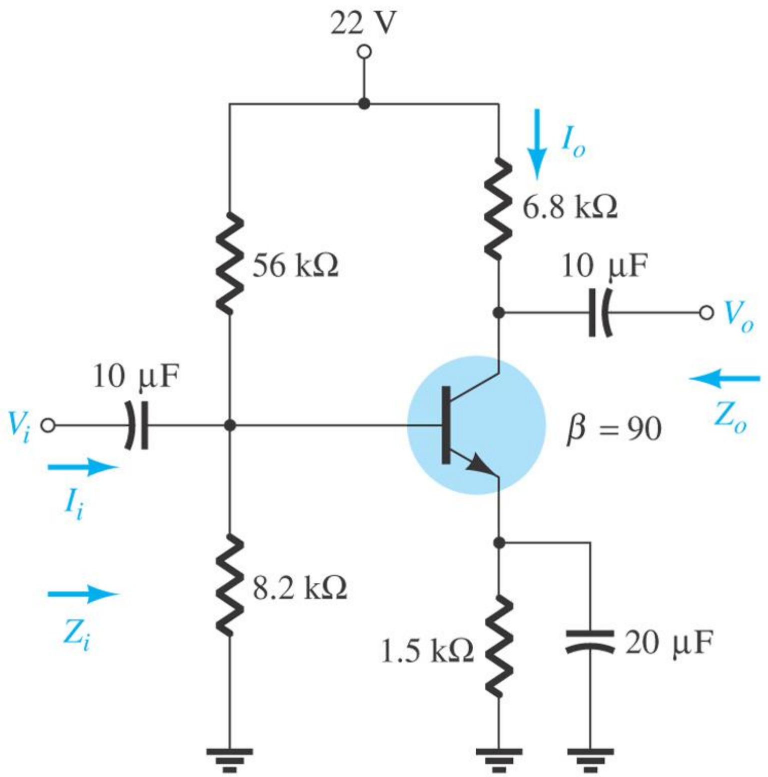
$$A_v = \frac{V_o}{V_i} = -\frac{(R_C||r_o)}{r_e} \quad , \quad A_v = -\frac{R_C}{r_e}\Big|_{r_o \geq 10R_C}$$

Example 5.2

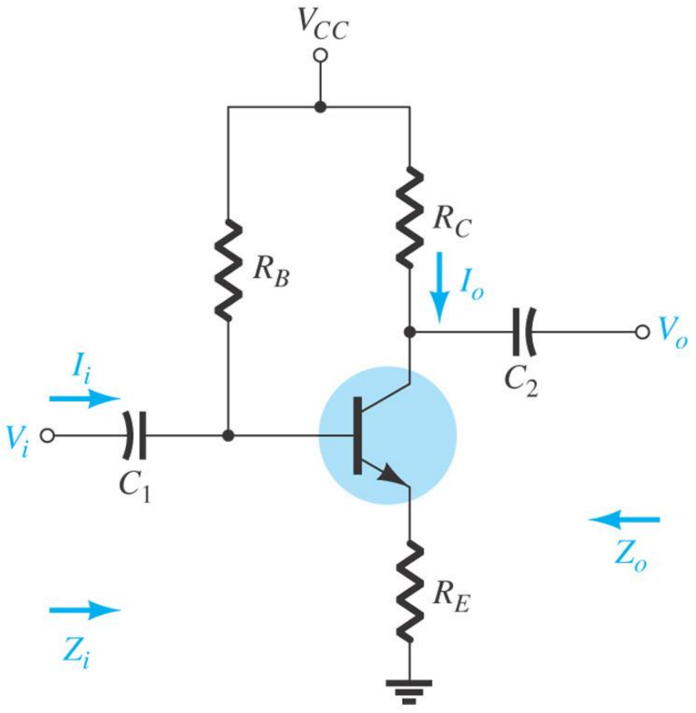
Determine r_e, Z_i , Z_o (with $r_o=\infty$), A_v (with $r_o=\infty$). Repeat with $r_o=50\ k\Omega$.

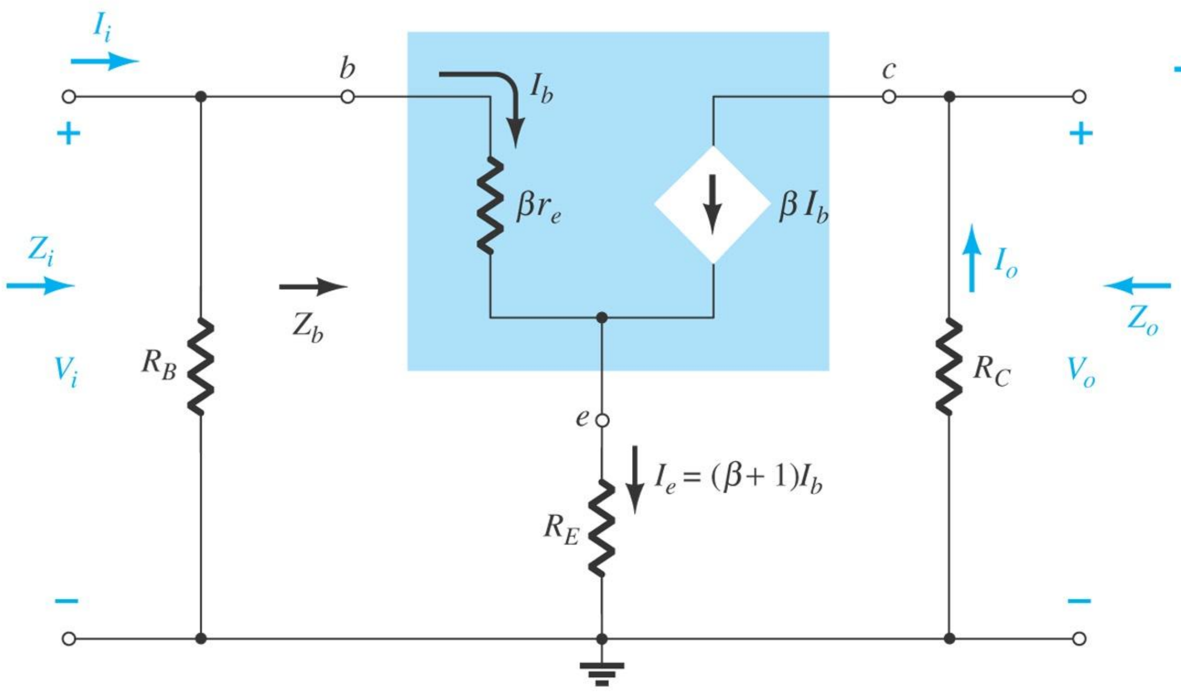


Example 5.2 - Solution



Common-Emitter Emitter-Bias Configuration





Impedance Calculations

Input impedance:

$$V_i = I_b \beta r_e + I_e R_E$$

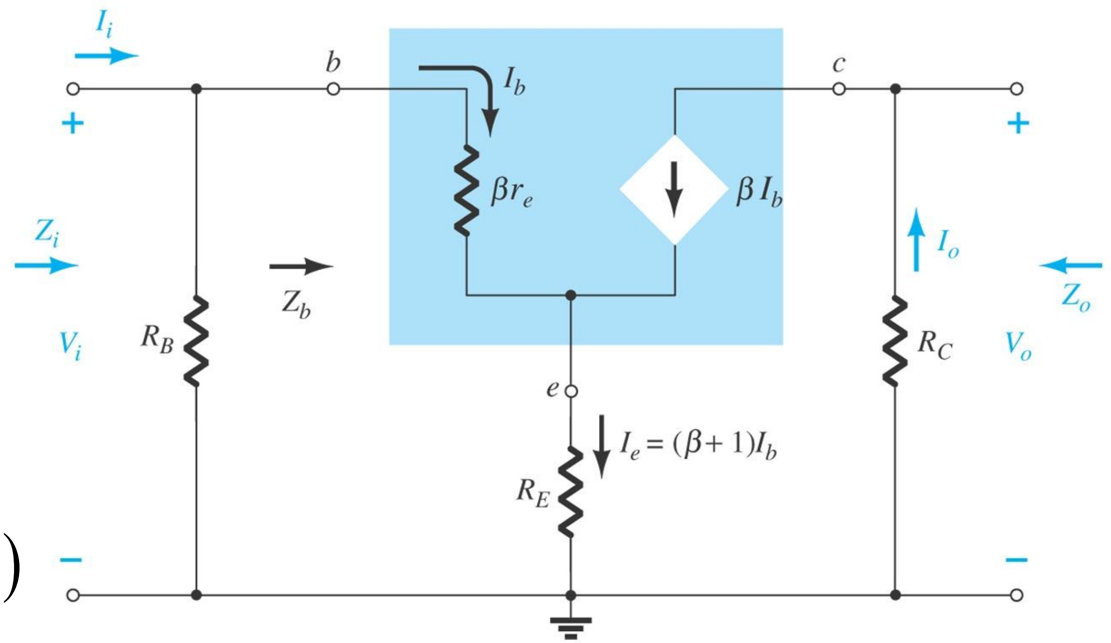
$$V_i = I_b \beta r_e + (\beta + 1) I_b R_E$$

$$Z_b = \frac{V_i}{I_b} = \beta r_e + (\beta + 1) R_E$$

$$Z_b \cong \beta r_e + \beta R_E = \beta (r_e + R_E)$$

$$Z_b \cong \beta R_E \quad \text{for } R_E >> r_e$$

$$Z_i = R_B \| Z_b$$



Output impedance:

$$Z_o = R_C$$

Gain Calculations

Voltage gain:

$$V_o = -I_o R_C = -\beta I_b R_C$$

$$V_o = -\beta \left(\frac{V_i}{Z_b} \right) R_C$$

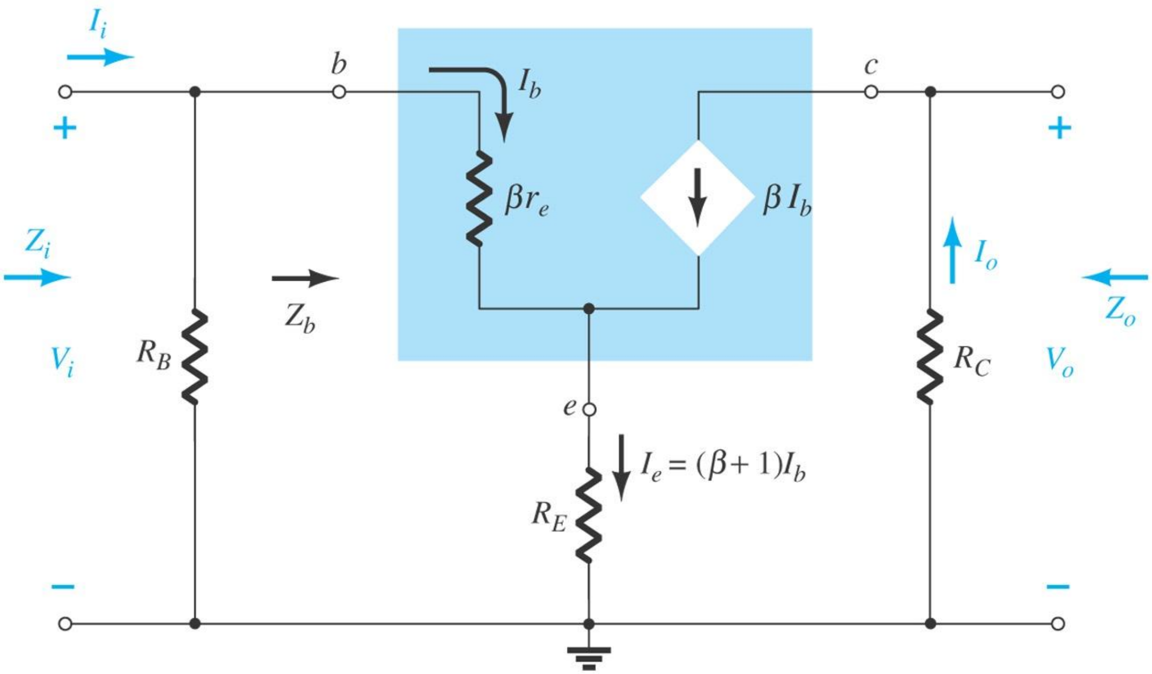
$$A_v = \frac{V_o}{V_i} = -\frac{\beta R_C}{Z_b}$$

substituting $Z_b \cong \beta(r_e + R_E)$

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

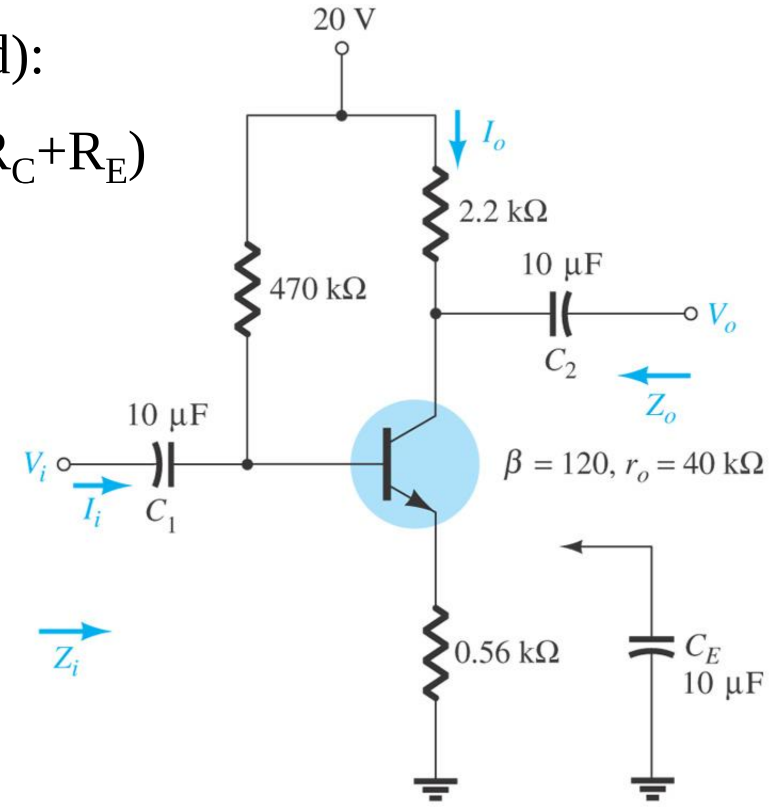
and for the approximation $Z_b \cong \beta R_E$

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

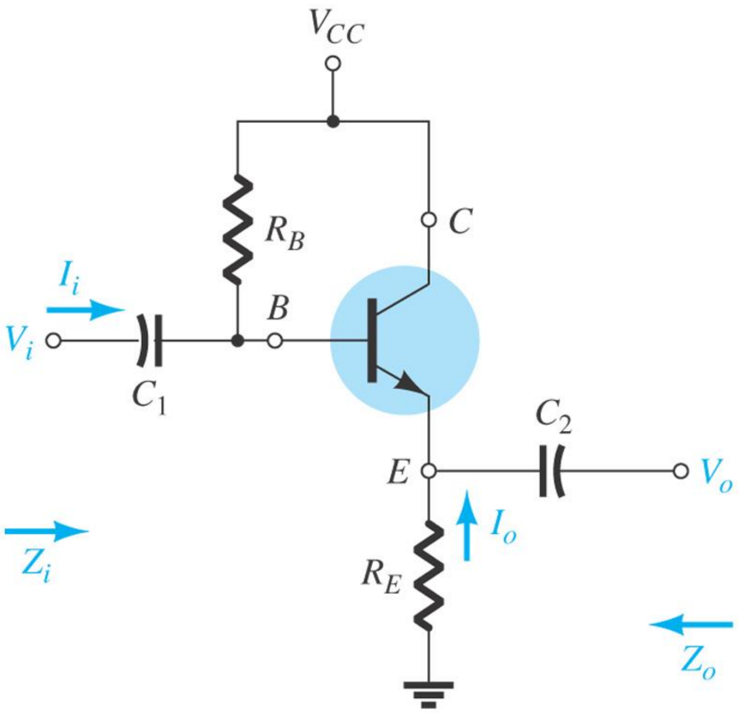


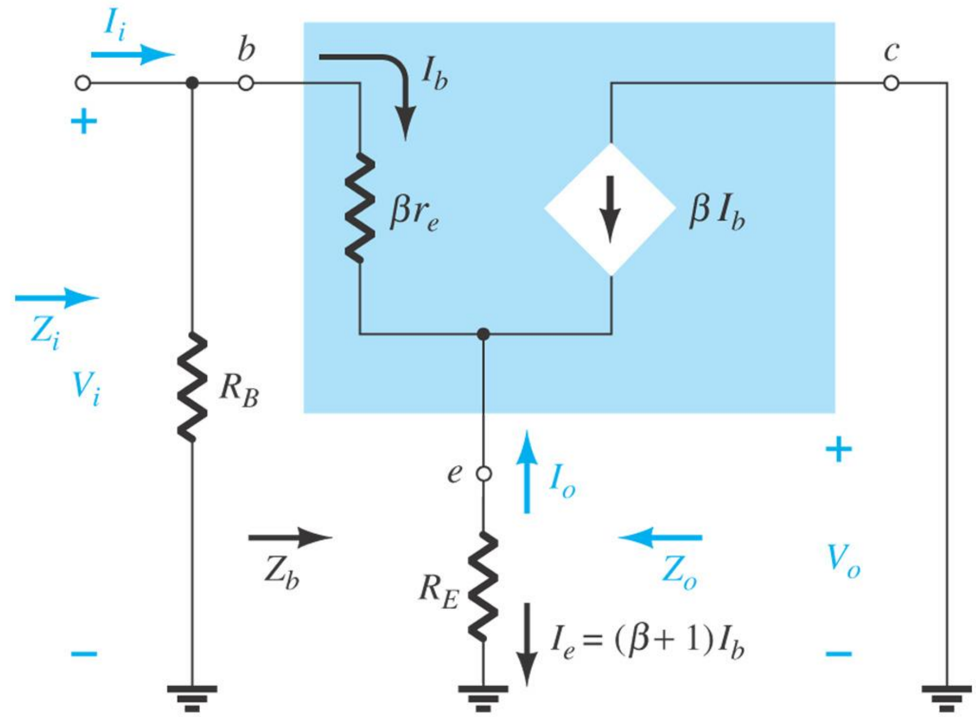
Example 5.3 Without C_E (unbypassed):

Determine r_e, Z_i , Z_o , A_v . ignore r_o for $r_o \geq 10(R_C+R_E)$



Emitter-Follower Configuration





- This is also known as the common-collector configuration.
- The input is applied to the base and the output is taken from the emitter.
- There is no phase shift between input and output.

Impedance Calculations

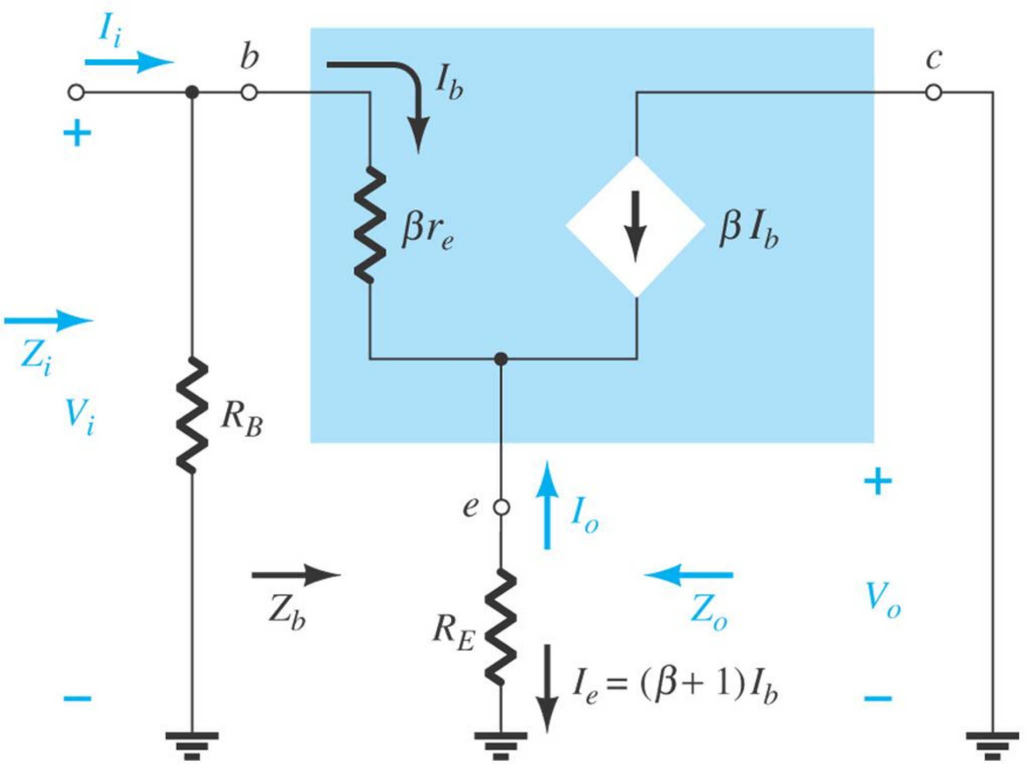
Input impedance:

$$Z_i = R_B \| Z_b$$

$$Z_b = \beta r_e + (\beta + 1)R_E$$

$$Z_b \cong \beta(r_e + R_E)$$

$$Z_b \cong \beta R_E \quad (\text{for } R_E >> r_e)$$



Impedance Calculations

Output impedance:

$$I_b = \frac{V_i}{Z_b} \quad , \; I_e = (\beta+1) I_b$$

$$= (\beta+1) \frac{V_i}{Z_b}$$

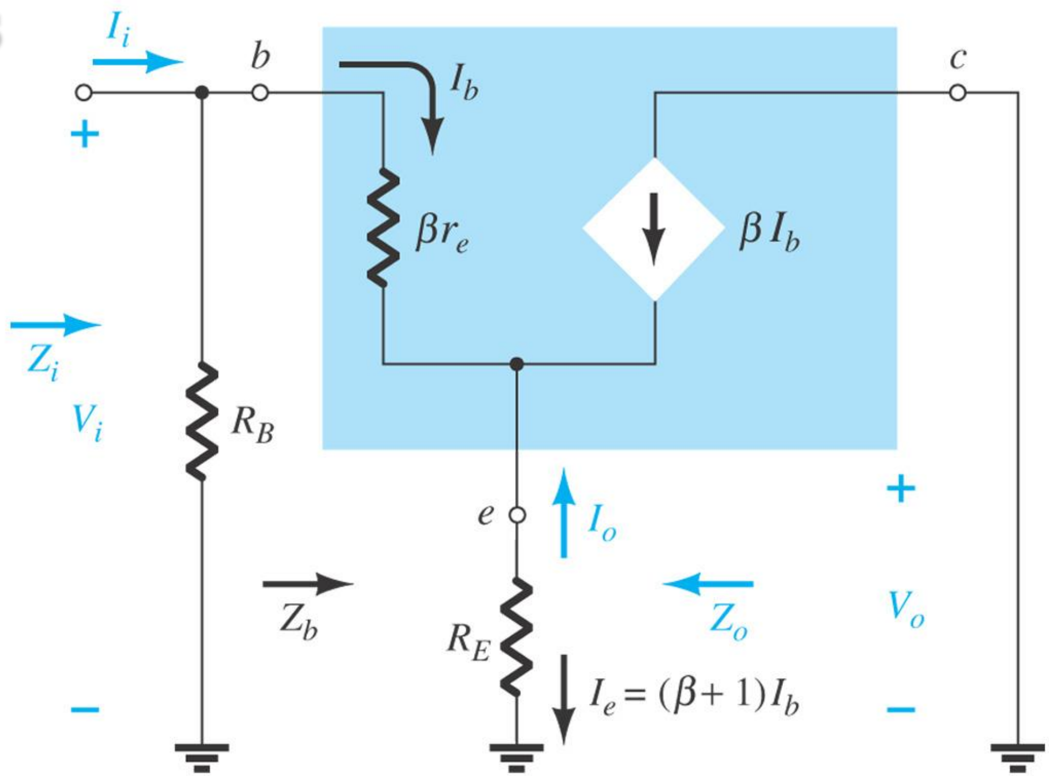
$$I_e = \frac{(\beta+1) V_i}{\beta r_e + (\beta+1) R_E}$$

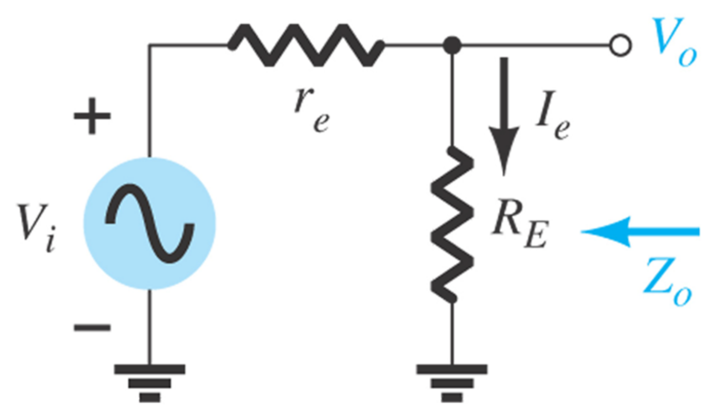
since $(\beta+1) \cong \beta$

$$I_e = \frac{V_i}{r_e + R_E}$$

To determine Z_o, V_i is set to zero

$$Z_o = R_E \| r_e \quad , \qquad Z_o \cong r_e \Big|_{R_E >> r_e}$$





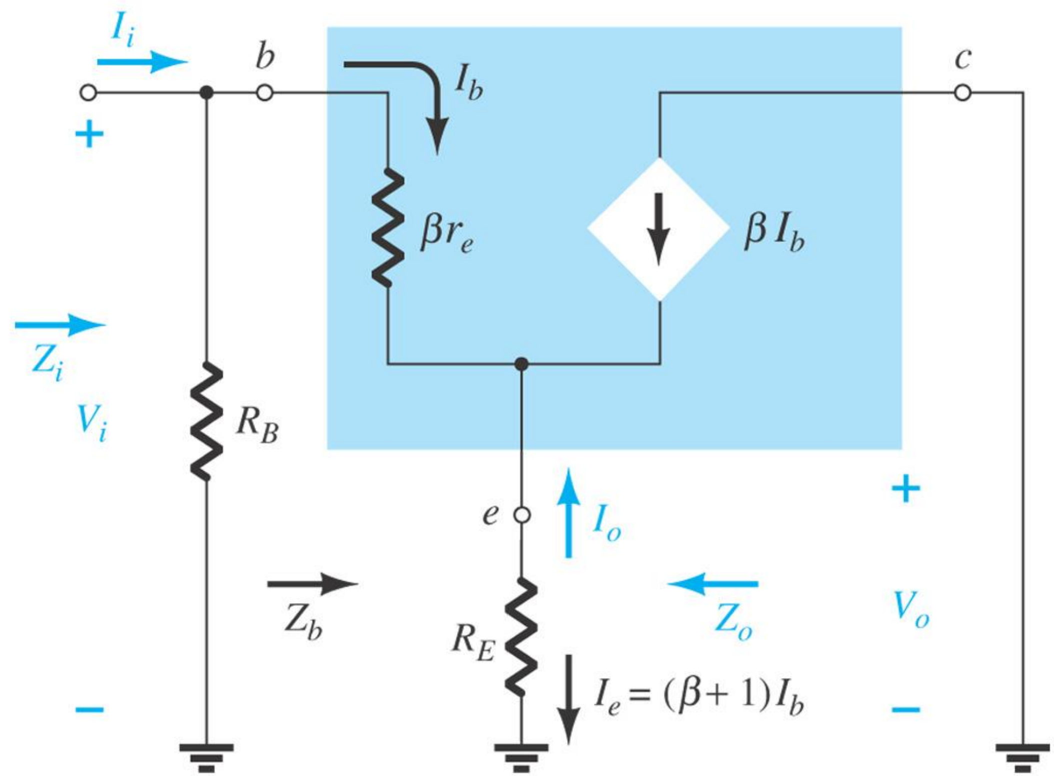
Gain Calculations

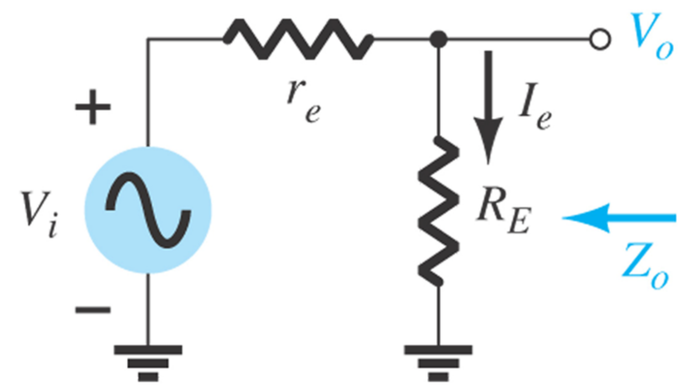
Voltage gain:

$$V_o = \frac{R_E}{R_E + r_e} V_i$$

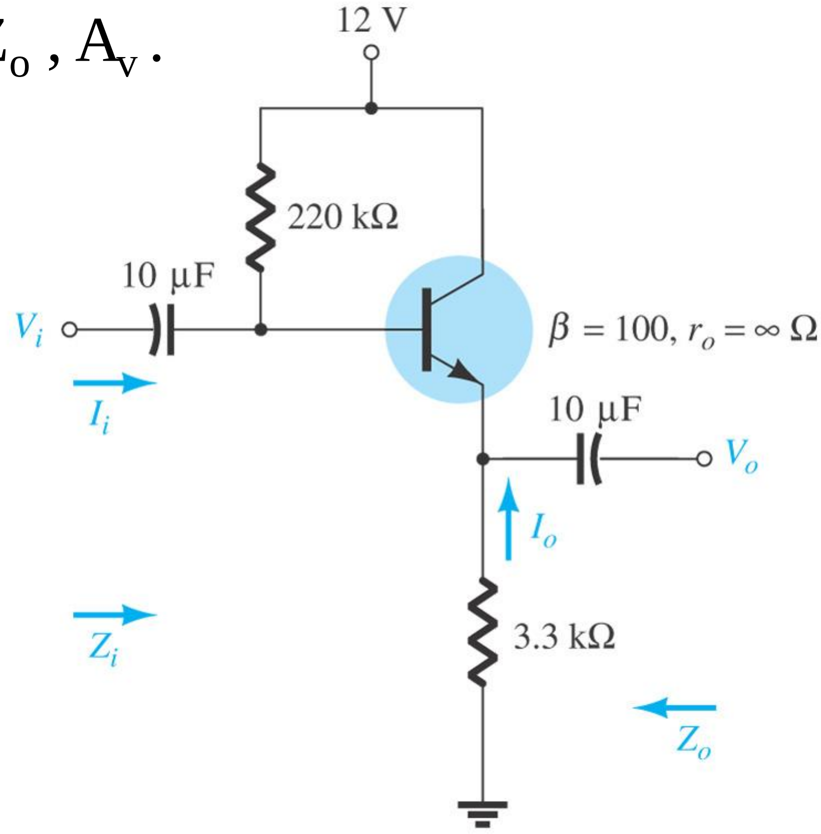
$$A_v = \frac{V_o}{V_i} = \frac{R_E}{R_E + r_e}$$

$$A_v = \frac{V_o}{V_i} \cong 1 \Big|_{R_E >> r_e,\; R_E + r_e \cong R_E}$$





Example 5.7 Determine r_e, Z_i , Z_o , A_v .



Example 5.7 - solution