BJT Small-Signal Analysis

Semiconductor Devices and Circuits

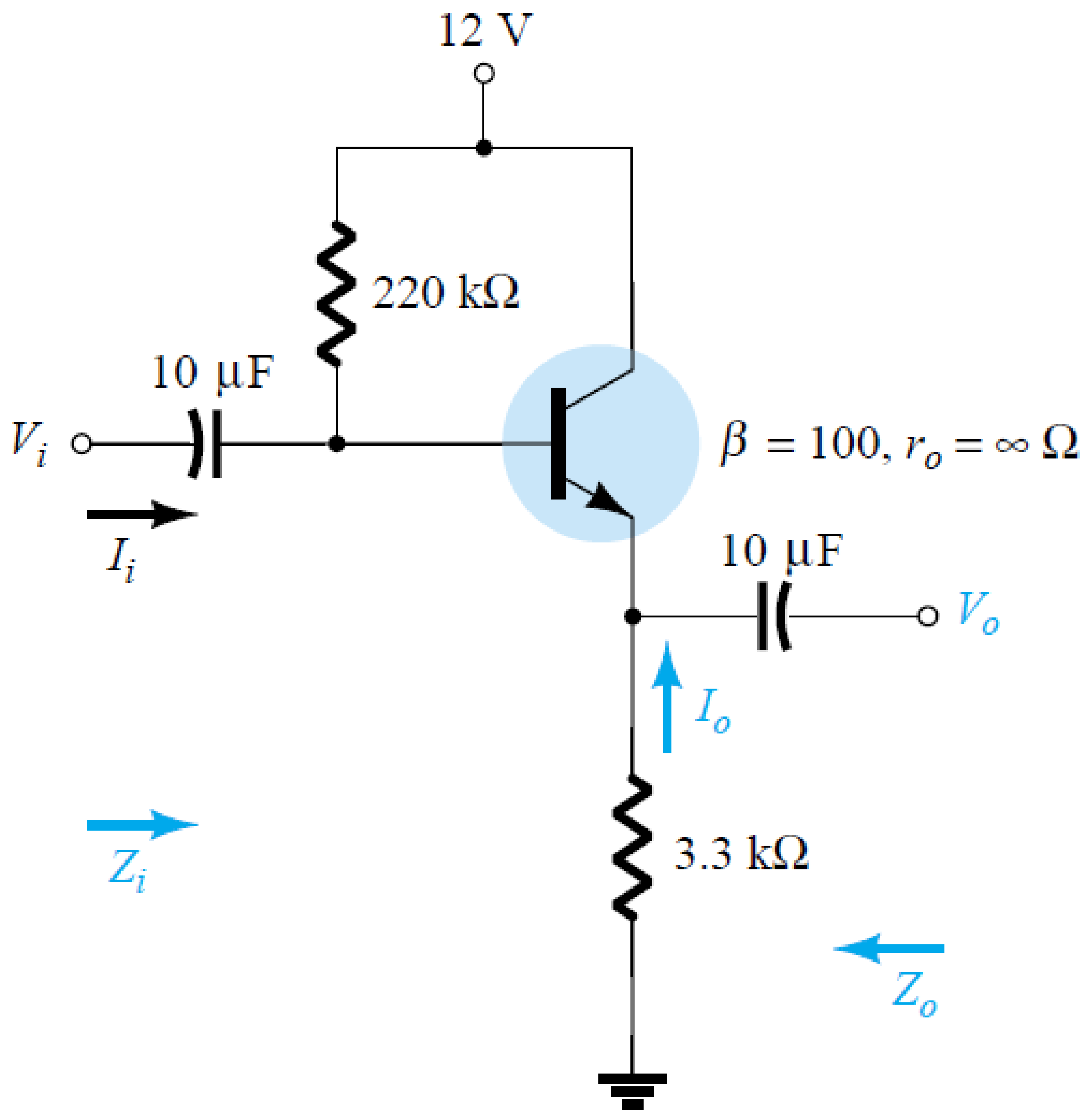
(ECE 181302)

4^{th} January 2022

Example

- Determine:

(a) r_e.
(b) Z_i.
(c) Z_o.
(d) A_v.
(e) A_i.



- To find r_e do the dc analysis:

$$\text{(a)}\quad I_B = \frac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E}$$

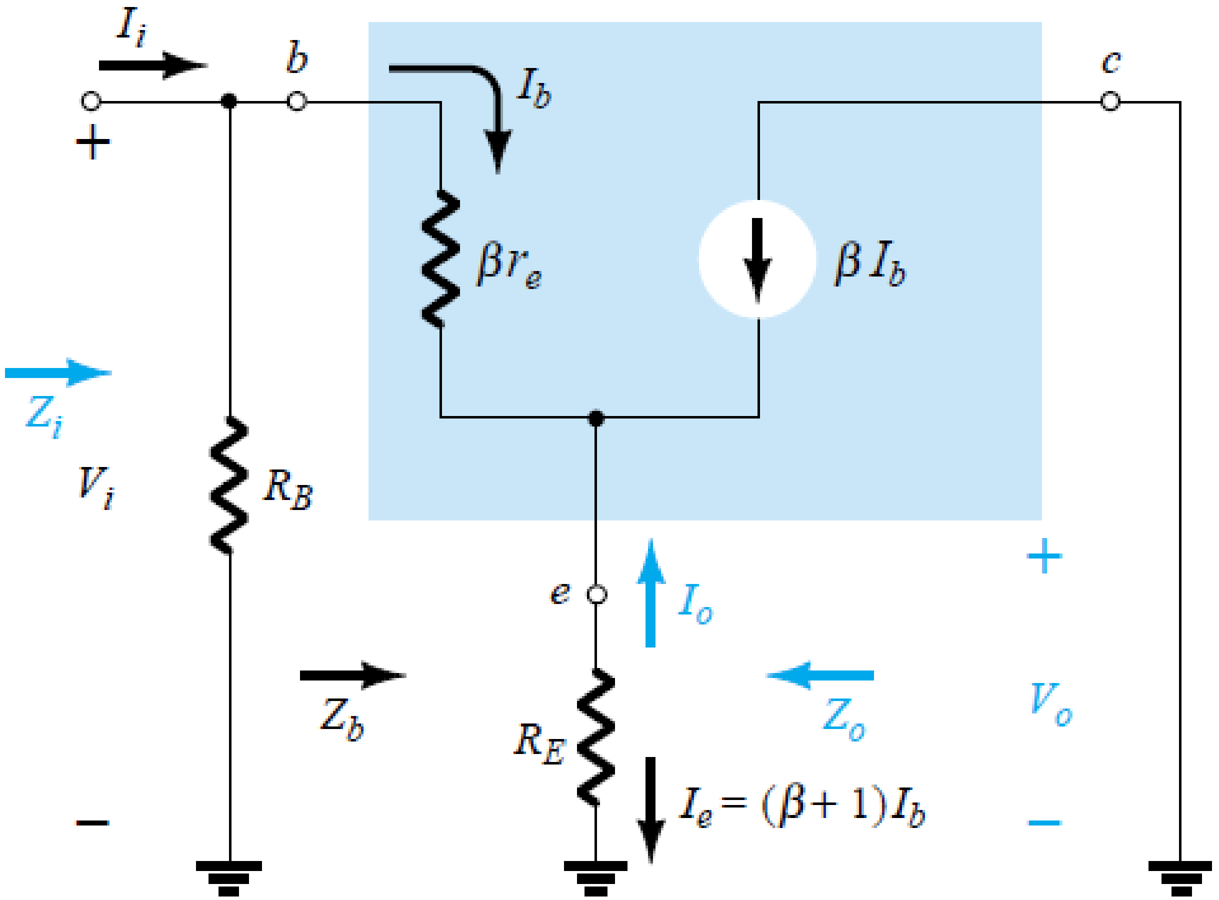
$$= \frac{12\text{ V} - 0.7\text{ V}}{220\text{ k}\Omega + (101)3.3\text{ k}\Omega} = 20.42\ \mu\text{A}$$

$$I_E = (\beta + 1)I_B$$

$$= (101)(20.42\ \mu\text{A}) = 2.062\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{2.062\text{ mA}} = \mathbf{12.61\ \Omega}$$

- Do the ac analysis:
- Substituting the *re* equivalent circuit into the ac equivalent network



- Applying Kirchhoff's voltage law to the input side:

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

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

and the input impedance looking into the network to the right of R_B is

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

$$= (100)(12.61\ \Omega) + (101)(3.3\ \text{k}\Omega)$$

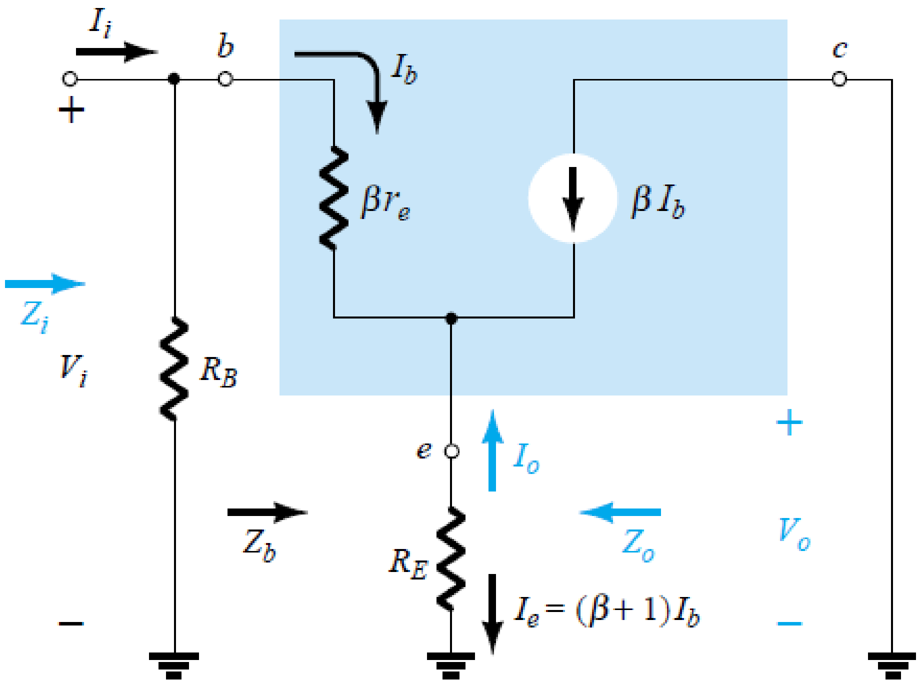
$$= 1.261\ \text{k}\Omega + 333.3\ \text{k}\Omega$$

$$= 334.56\ \text{k}\Omega \cong \beta R_E$$

$$Z_i = R_B \| Z_b = 220\ \text{k}\Omega \| 334.56\ \text{k}\Omega$$

$$= \mathbf{132.72\ k\Omega}$$

- To find Zo;



$$I_b = \frac{V_i}{Z_b}$$

and

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

Substituting for Z_b gives

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

or

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

but

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

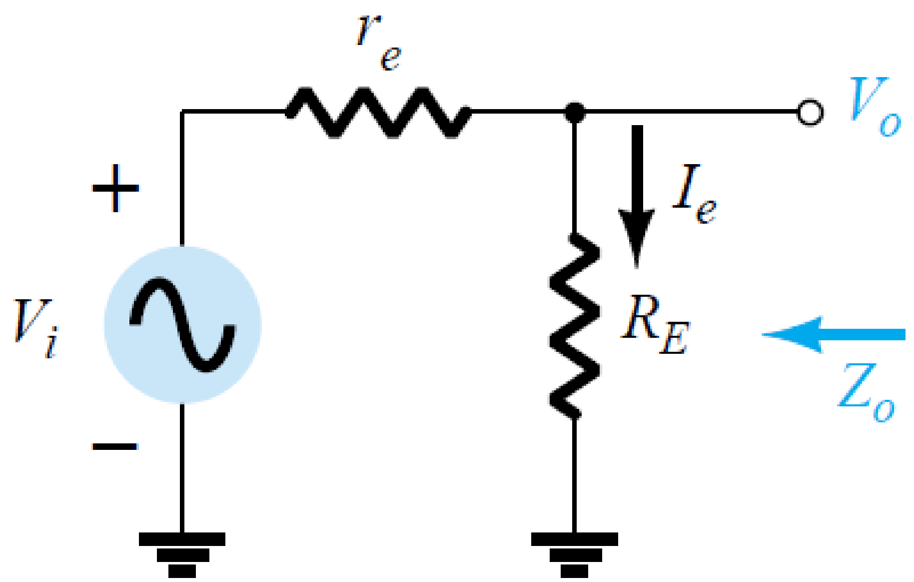
and

$$\frac{\beta r_e}{\beta + 1} \cong \frac{\beta r_e}{\beta} = r_e$$

so that

$$\boxed{I_e \cong \frac{V_i}{r_e + R_E}}$$

- To determine *Zo*, *Vi* is set to zero:



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

$$\text{(c)}\quad Z_o = R_E \| r_e = 3.3\ \text{k}\Omega \| 12.61\ \Omega$$
$$= \mathbf{12.56\ \Omega} \cong r_e$$

• Voltage gain and current gain:

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

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

$$\text{(d)}\quad A_v = \frac{V_o}{V_i} = \frac{R_E}{R_E + r_e} = \frac{3.3\ \text{k}\Omega}{3.3\ \text{k}\Omega + 12.61\ \Omega}$$

$$= \mathbf{0.996} \cong 1$$

- Current gain:

$$I_b = \frac{R_B I_i}{R_B + Z_b}$$

or $$\frac{I_b}{I_i} = \frac{R_B}{R_B + Z_b}$$

and $$I_o = -I_e = -(\beta + 1)I_b$$

or $$\frac{I_o}{I_b} = -(\beta + 1)$$

so that $$A_i = \frac{I_o}{I_i} = \frac{I_o}{I_b}\frac{I_b}{I_i}$$

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

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

$$\boxed{A_i \cong -\frac{\beta R_B}{R_B + Z_b}}$$

or $$\boxed{A_i = -A_v \frac{Z_i}{R_E}}$$

(e) $$A_i \cong -\frac{\beta R_B}{R_B + Z_b} = -\frac{(100)(220\ \text{k}\Omega)}{220\ \text{k}\Omega + 334.56\ \text{k}\Omega} = \mathbf{-39.67}$$

References:

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