Electronic Engineering
COM121

Assist. Prof.

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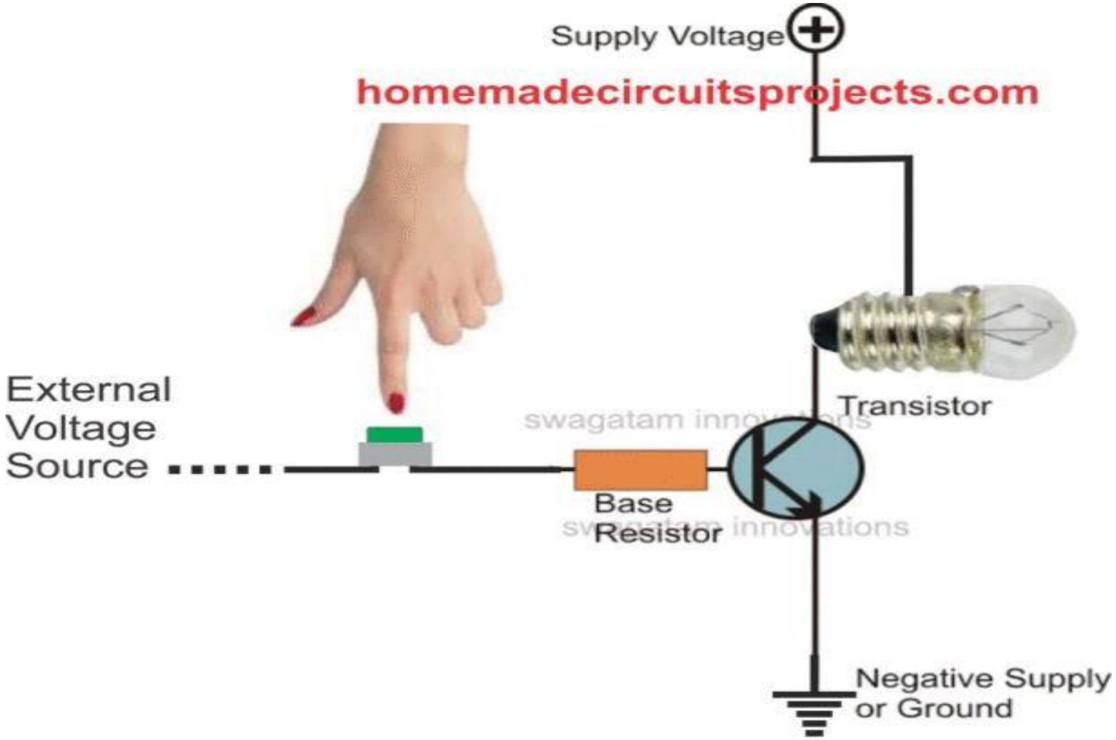
Introduction

- ***Amplifiers:*** **transistors biased in the flat-part of the I-V curves**

– **BJT: forward-active region**

– **MOSFET: saturation region**

- **In these regions, transistors can provide high voltage, current and power gains**



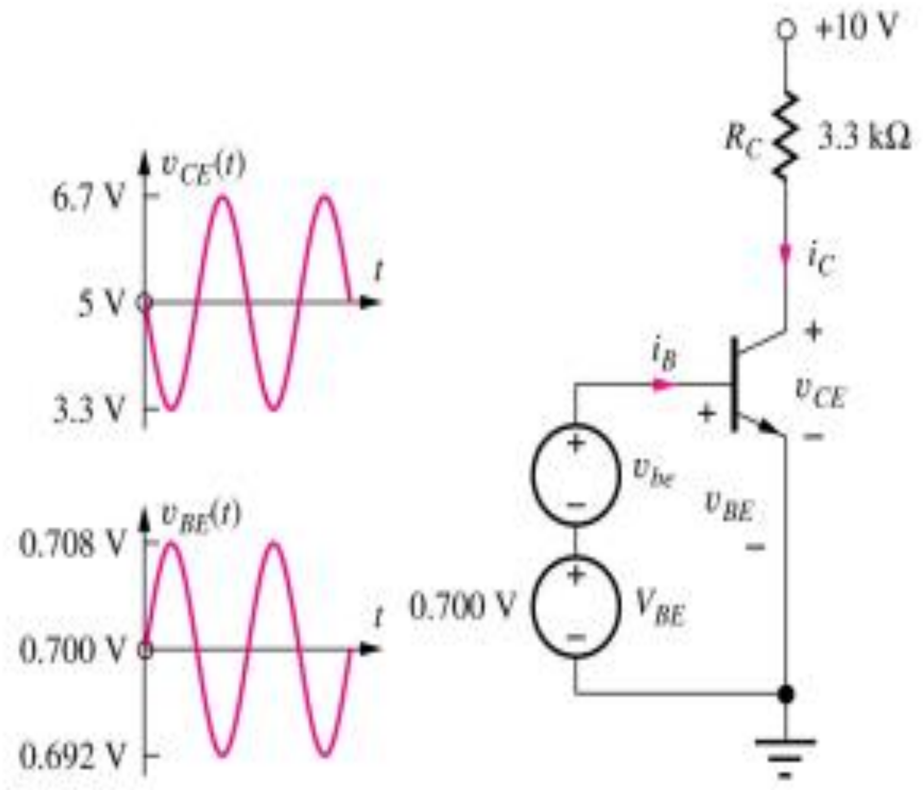
- The BJT is biased in the active region by dc voltage source *VBE*.
- Total base-emitter voltage is:

$$V_{-BE} = V_{-BE} + v_{-be}$$

- Collector-emitter voltage is:

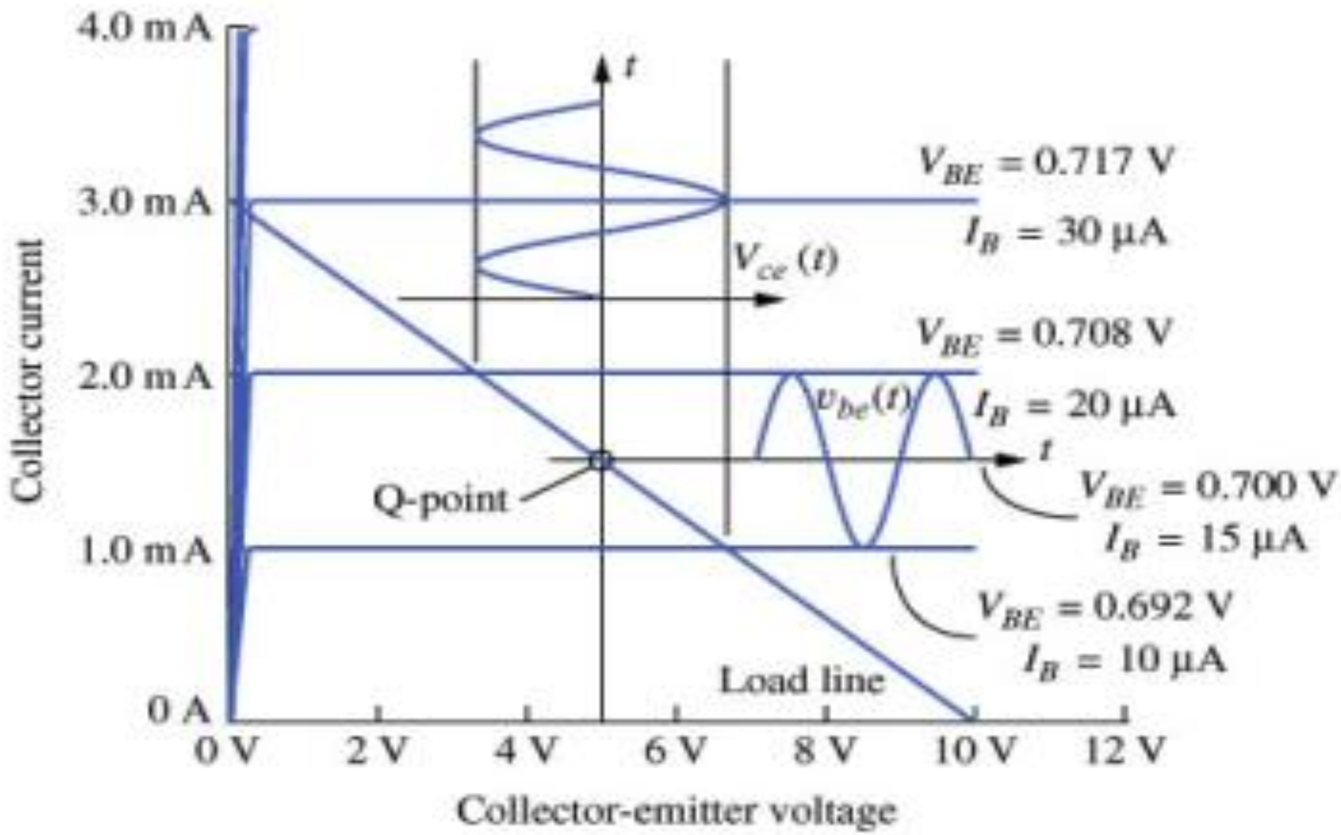
$$V_{CE} = VCC - i_C R_C$$

$$Ic = \beta \, I_B$$



Transistor BJT Amplifier Concept

➢ There are 180° phase shift between the input and output signals.



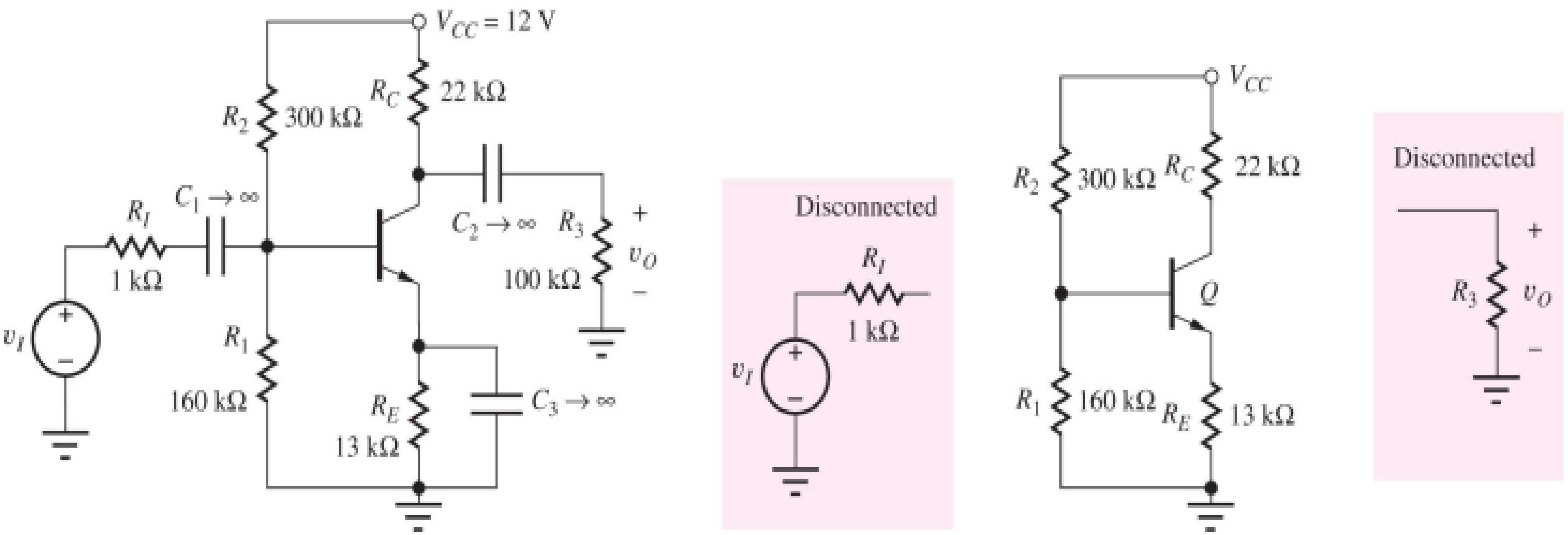
Transistor Amplifiers Dc and Ac

Two Step Analysis:

- **DC analysis:**
  - Find dc equivalent circuit by replacing all capacitors by open circuits and inductors by short circuits.
  - Find Q-point from dc equivalent circuit by using appropriate large-signal transistor model.
- **AC analysis:**
  - Find ac equivalent circuit by replacing all capacitors by short circuits, inductors by open circuits, dc voltage sources by ground connections and dc current sources by open circuits.
  - Replace transistor by its small-signal model
  - Use small-signal ac equivalent to analyze ac characteristics of amplifier.

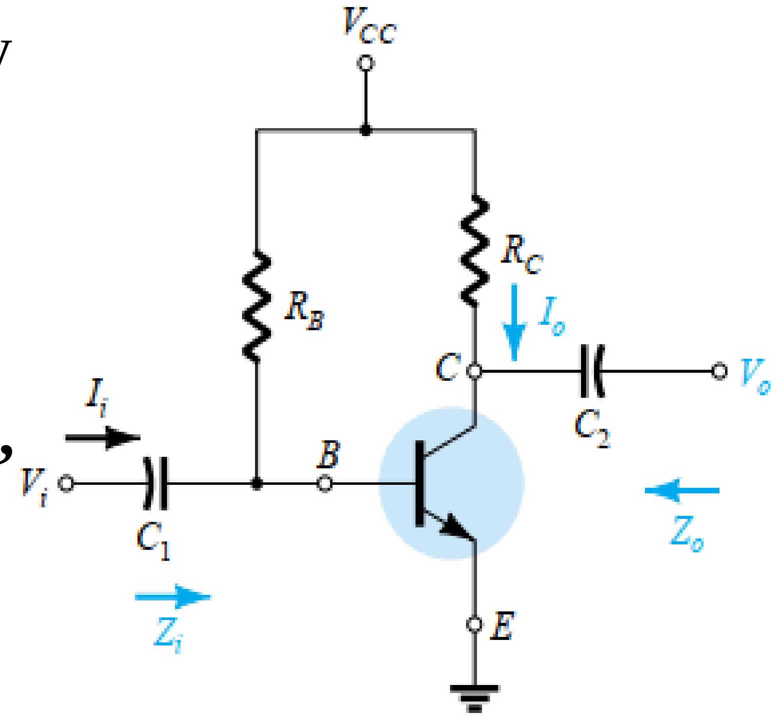
Transistor dc Equivalent Circuit

All capacitors in the original amplifier circuit are replaced by open circuits, disconnecting v_I, R_I, and R_3 from circuit.



Common-emitter Fixed-bias Configuration

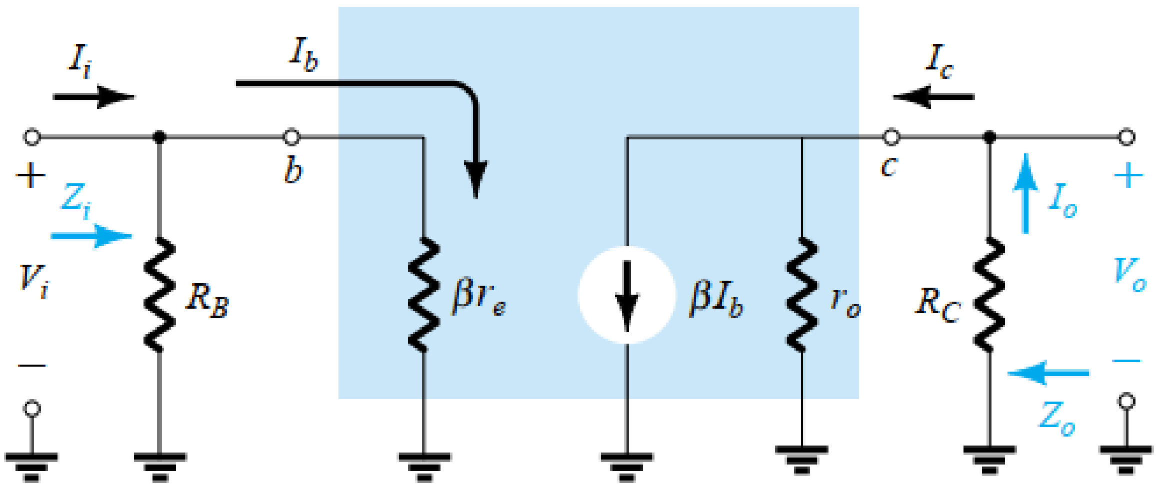
- The small-signal ac analysis begins by removing the dc effects of V_{CC} .
- Blocking capacitors **C_1 and C_2 by short-circuit** equivalents, resulting in the network of Fig.
- Important network parameters $\boldsymbol{Zi, Zo}$, $\boldsymbol{Ii}$, **and** $\boldsymbol{Io}$**.**
- **β, ro**:is typically obtained from a specification sheet .
- **re** :determined from a dc analysis of the system.



$$\boxed{Z_i = R_B \| \beta r_e} \quad \text{ohms}$$

R_B is greater than r_e by more than a factor of 10

$$\boxed{Z_i \cong \beta r_e}_{R_B \geq 10\beta r_e} \quad \text{ohms}$$

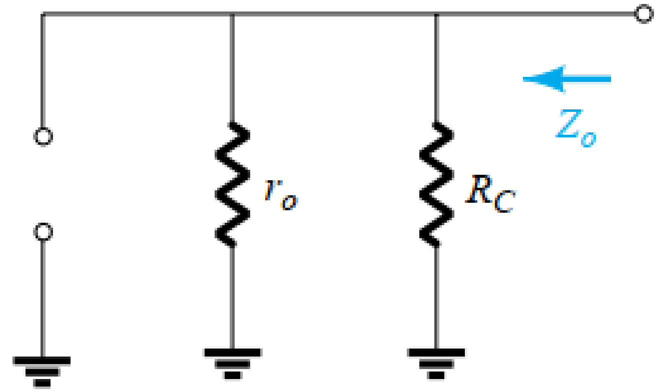


Common-emitter Fixed-bias Configuration

$$\boxed{Z_o = R_C \| r_o}$$ ohms

If $r_0 \geq 10\ R_c$, the approximation $R_C//r_o \cong R_c$ is frequently applied.

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



$$V_o = -\beta I_b (R_C \| r_o) \qquad I_b = \frac{V_i}{\beta r_c}$$

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

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

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

A**$_i$:** The current gain is determined in the following manner: Applying the current-divider rule to the input and output circuits,

$$I_o = \frac{(r_o)(\beta I_b)}{r_o + R_C} \quad \text{and} \quad \frac{I_o}{I_b} = \frac{r_o\beta}{r_o + R_C}$$

$$A_i = \frac{I_o}{I_i} = \left(\frac{I_o}{I_b}\right)\left(\frac{I_b}{I_i}\right) = \left(\frac{r_o\beta}{r_o + R_C}\right)\left(\frac{R_B}{R_B + \beta r_e}\right)$$

$$\boxed{A_i = \frac{I_o}{I_i} = \frac{\beta R_B r_o}{(r_o + R_C)(R_B + \beta r_e)}}$$

If $r_0 \geq 10\, R_c$ and $R_\mathrm{B} \geq 10\, \beta r_e$

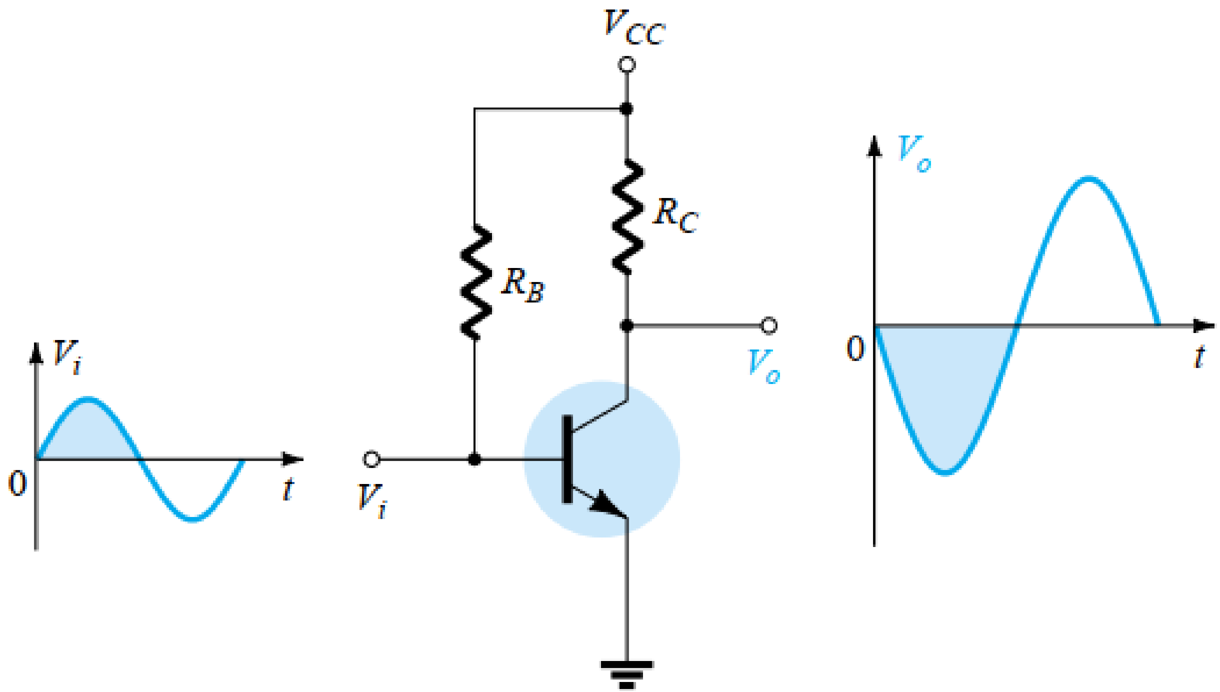
$$A_i = \frac{I_o}{I_i} \cong \frac{\beta R_B r_o}{(r_o)(R_B)}$$

$$\boxed{A_i \cong \beta}$$

$$\boxed{A_i = -A_v \frac{Z_i}{R_C}}$$

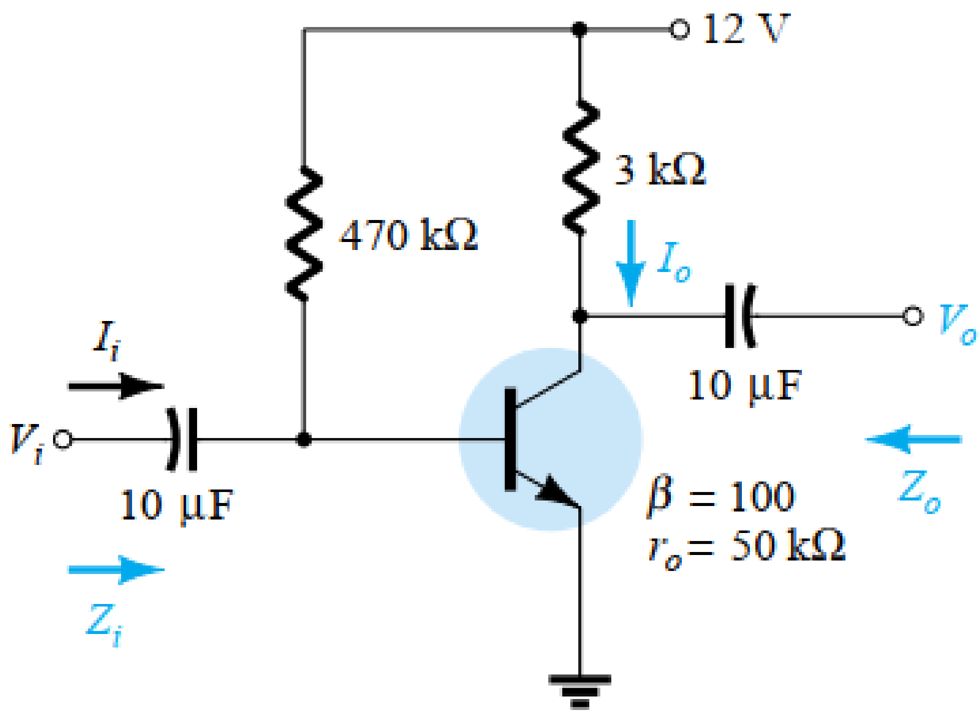
$r_o \geq 10 R_C,\ R_B \geq 10\beta r_e$

Phase Relationship: The negative sign in the resulting equation for A_v reveals that a 180° phase shift occurs between the input and output signals, as shown in Fig



Example

(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) Find A_i (with $r_o = \infty\ \Omega$).
(f) Repeat parts (c) through (e) including $r_o = 50\ \text{k}\Omega$ in all calculations and compare results.



Example

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

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

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

Example

(f) $Z_o = r_o \| R_C = 50\ \text{k}\Omega \| 3\ \text{k}\Omega = \mathbf{2.83\ k\Omega}$ vs. $3\ \text{k}\Omega$

$$A_v = -\frac{r_o \| R_C}{r_e} = \frac{2.83\ \text{k}\Omega}{10.71\ \Omega} = \mathbf{-264.24} \text{ vs. } -280.11$$

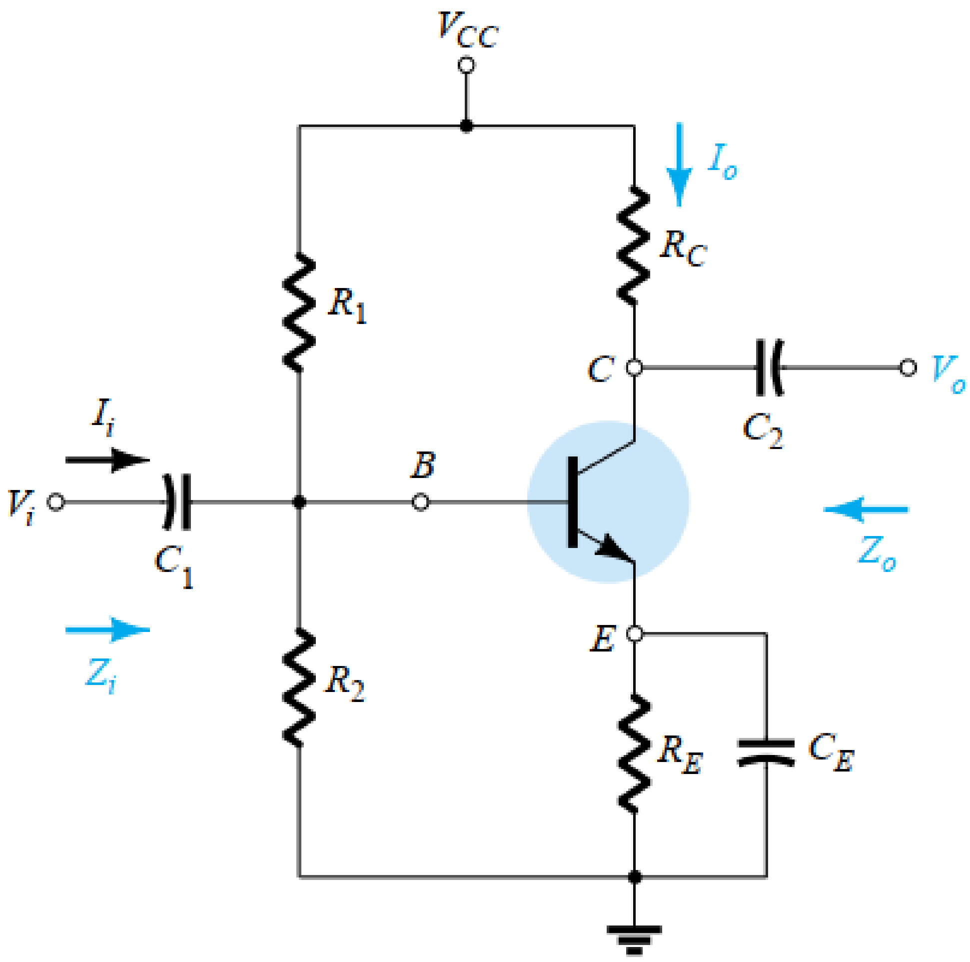
$$A_i = \frac{\beta R_B r_o}{(r_o + R_C)(R_B + \beta r_e)} = \frac{(100)(470\ \text{k}\Omega)(50\ \text{k}\Omega)}{(50\ \text{k}\Omega + 3\ \text{k}\Omega)(470\ \text{k}\Omega + 1.071\ \text{k}\Omega)}$$

$$= \mathbf{94.13} \text{ vs. } 100$$

As a check:

$$A_i = -A_v \frac{Z_i}{R_C} = \frac{-(-264.24)(1.069\ \text{k}\Omega)}{3\ \text{k}\Omega} = \mathbf{94.16}$$

Voltage-Divider Bias

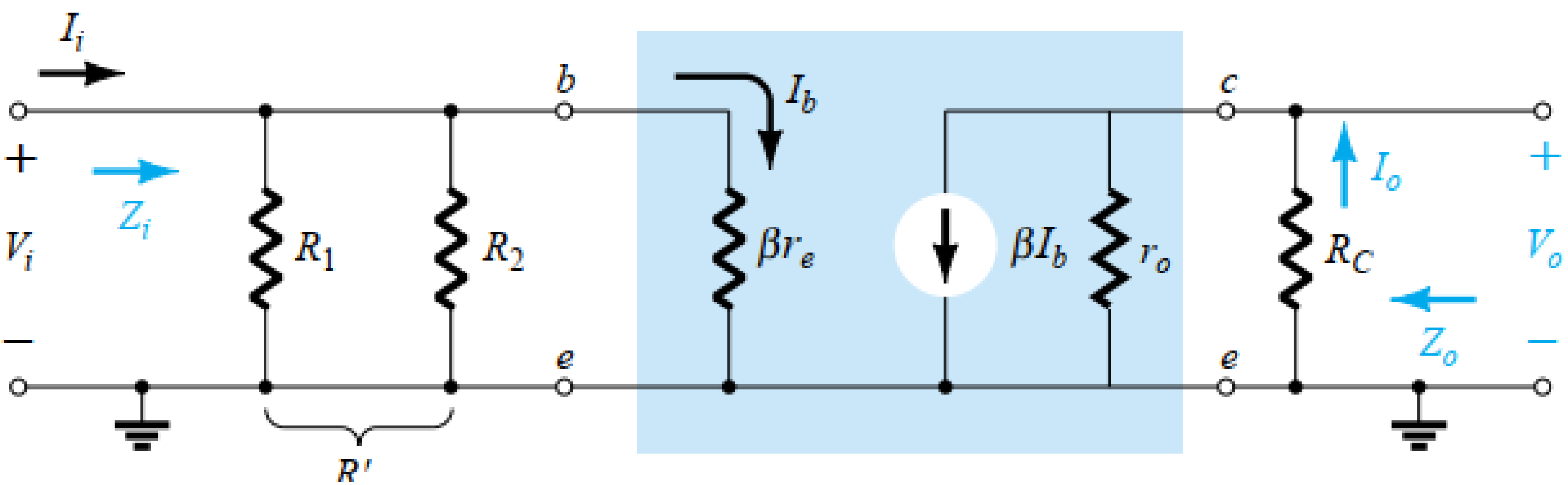


Voltage-Divider Bias

- The absence of R_E due to the low-impedance shorting effect of the bypass capacitor, C_E.

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

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

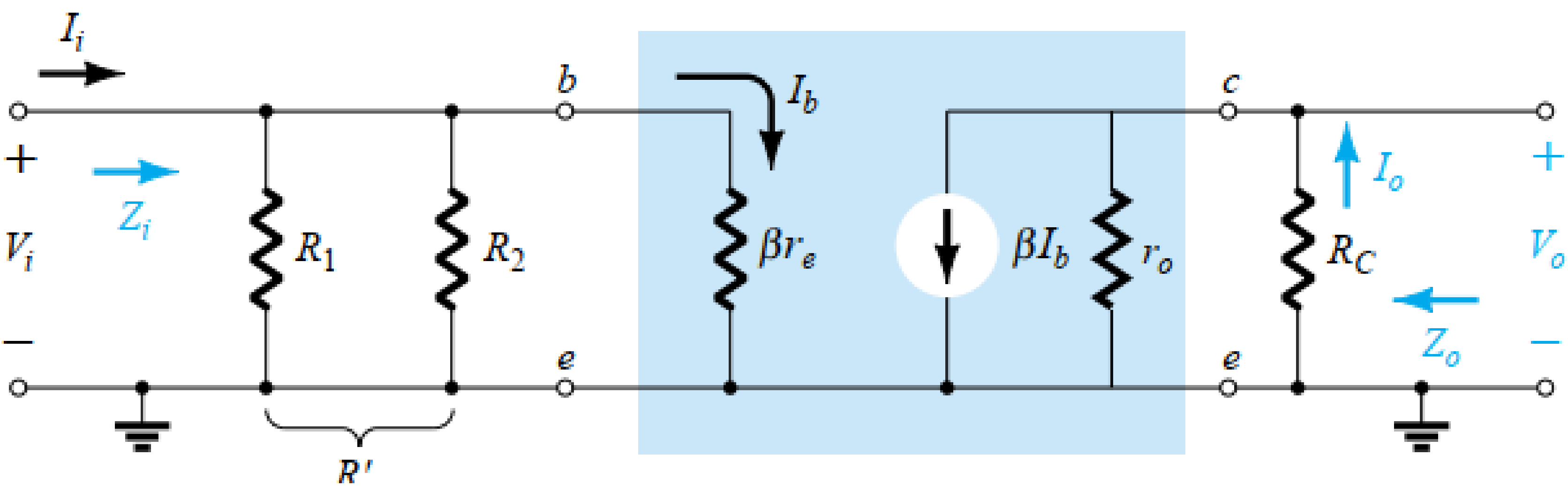


Voltage-Divider Bias

V_i set to 0 V resulting in $I_b = 0$ A and $\beta I_b = 0$ mA

$$\boxed{Z_o = R_C \| r_o}$$

If $r_0 \geq 10\, R_c$ $\Rightarrow$ $\boxed{Z_o \cong R_C}_{r_o \geq 10 R_C}$



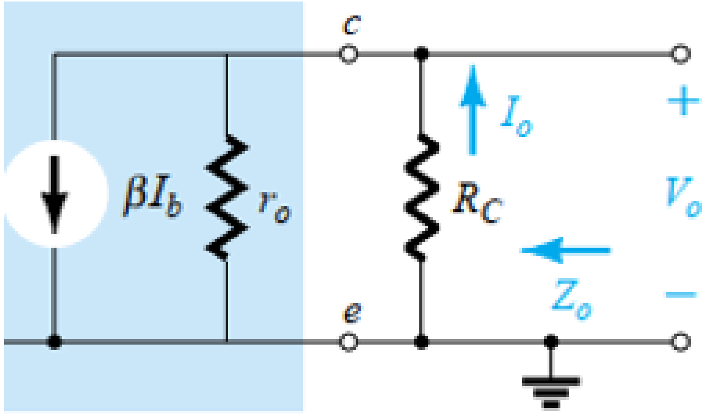
Voltage-Divider Bias

As: $R_C // r_o$

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

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

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



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

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

Voltage-Divider Bias

$$\boxed{A_i = \frac{I_o}{I_i} = \frac{\beta R' r_o}{(r_o + R_C)(R' + \beta r_e)}}$$

If $r_0 \geq 10\, R_c$ $\Rightarrow$ $A_i = \dfrac{I_o}{I_i} \cong \dfrac{\beta R' r_o}{r_o(R' + \beta r_e)}$

$$\boxed{A_i = \frac{I_o}{I_i} \cong \frac{\beta R'}{R' + \beta r_e}}_{r_o \geq 10 R_C}$$

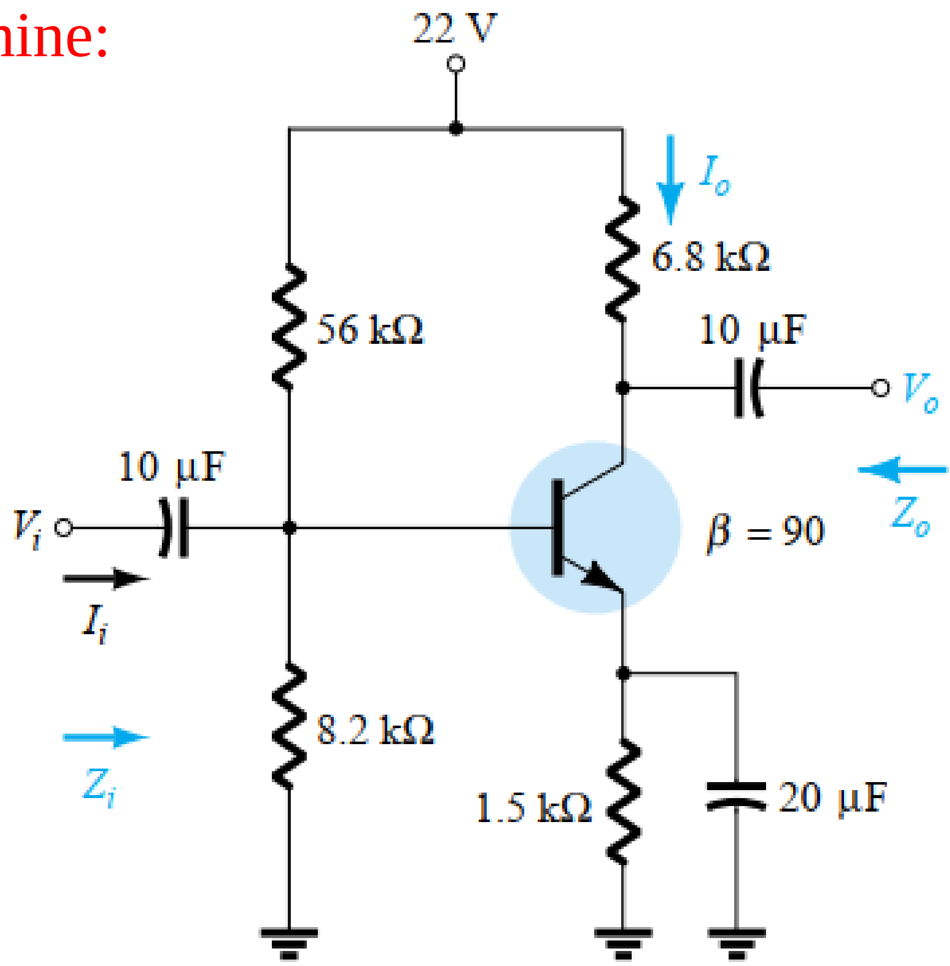
If $R' \geq 10\, \beta r_e$ $\Rightarrow$ $A_i = \dfrac{I_o}{I_i} = \dfrac{\beta R'}{R'}$

$$\boxed{A_i = \frac{I_o}{I_i} \cong \beta}_{r_o \geq 10 R_C,\ R' \geq 10 \beta r_e} \Rightarrow \boxed{A_i = -A_v \frac{Z_i}{R_C}}$$

Example

For the network of Figure, determine:

(a) r_e.
(b) Z_i.
(c) Z_o ($r_o = \infty\ \Omega$).
(d) A_v ($r_o = \infty\ \Omega$).
(e) A_i ($r_o = \infty\ \Omega$).



Example

(a) DC: Testing $\beta R_E > 10R_2$

$$(90)(1.5\ \text{k}\Omega) > 10(8.2\ \text{k}\Omega)$$

$$135\ \text{k}\Omega > 82\ \text{k}\Omega\ (\textit{satisfied})$$

Using the approximate approach,

$$V_B = \frac{R_2}{R_1 + R_2} V_{CC} = \frac{(8.2\ \text{k}\Omega)(22\ \text{V})}{56\ \text{k}\Omega + 8.2\ \text{k}\Omega} = 2.81\ \text{V}$$

$$V_E = V_B - V_{BE} = 2.81\ \text{V} - 0.7\ \text{V} = 2.11\ \text{V}$$

$$I_E = \frac{V_E}{R_E} = \frac{2.11\ \text{V}}{1.5\ \text{k}\Omega} = 1.41\ \text{mA}$$

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

Example

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

(e) The condition $R' \geq 10\beta r_e$ ($7.15\ \text{k}\Omega \geq 10(1.66\ \text{k}\Omega) = 16.6\ \text{k}\Omega$ is *not* satisfied. Therefore,

$$A_i \cong \frac{\beta R'}{R' + \beta r_e} = \frac{(90)(7.15\ \text{k}\Omega)}{7.15\ \text{k}\Omega + 1.66\ \text{k}\Omega} = \mathbf{73.04}$$

CE Emitter-Bias Configuration

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

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

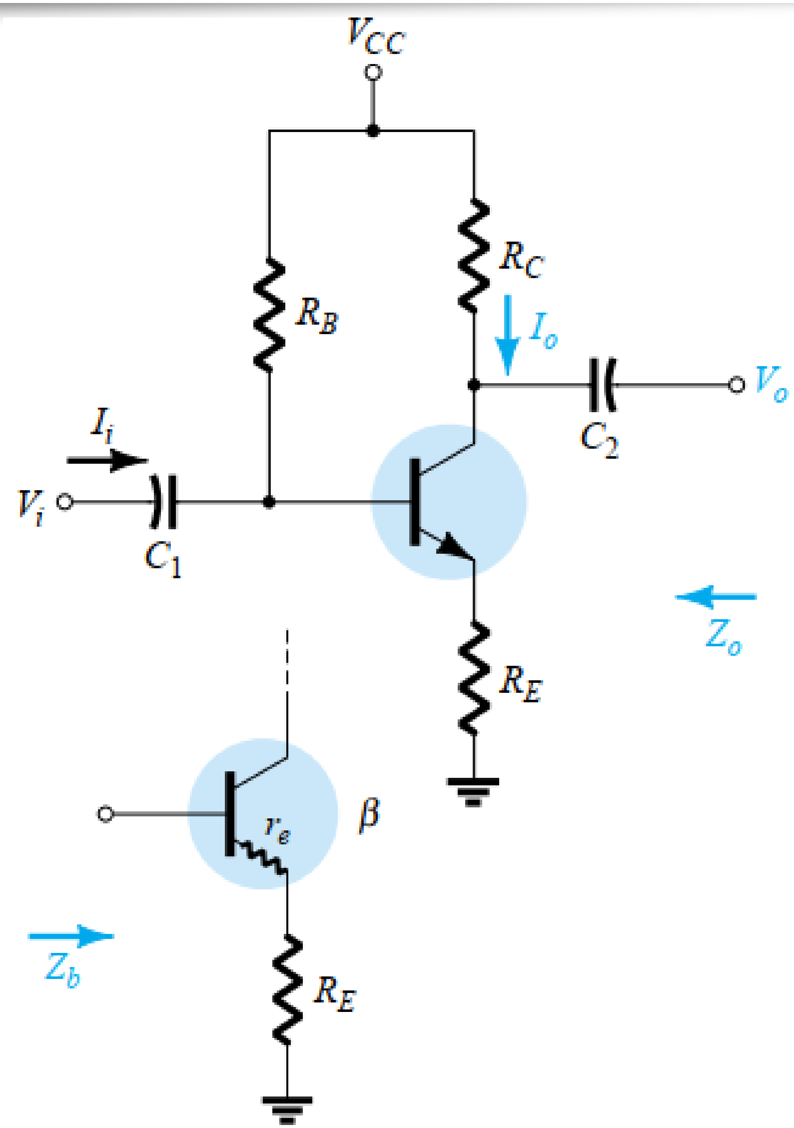
$$Z_b = \frac{V_i}{I_b} = \beta r_e + (\beta + 1)R_E$$

$$\boxed{Z_b = \beta r_e + (\beta + 1)R_E}$$

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

$$\boxed{Z_b \cong \beta(r_e + R_E)}$$

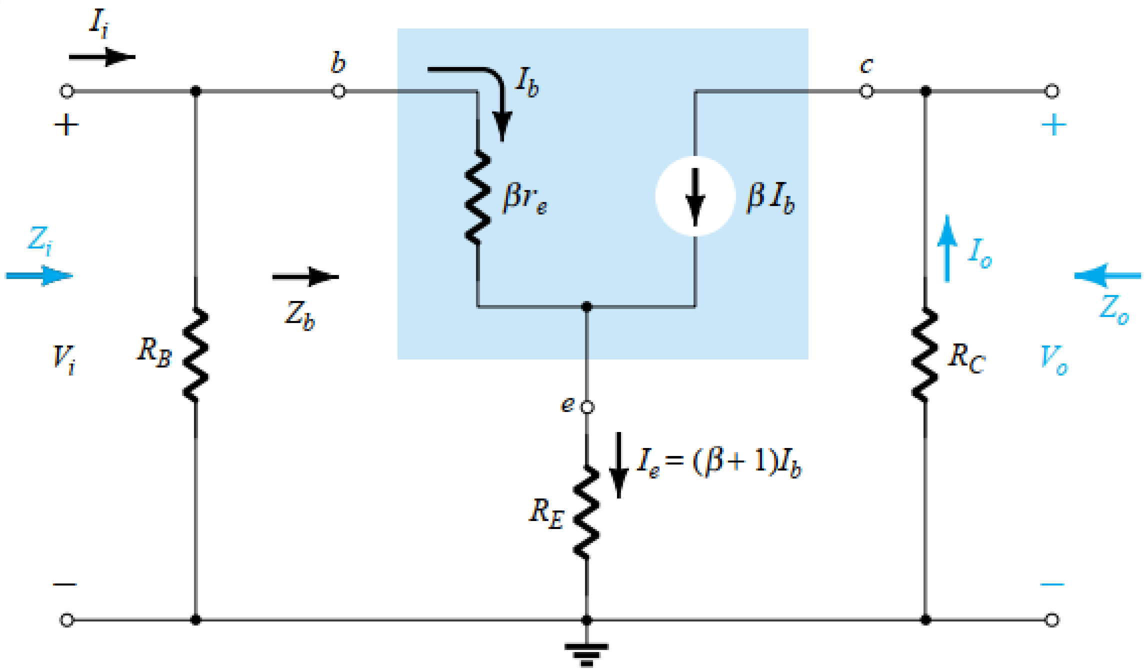
$R_E \gg r_e \Rightarrow \boxed{Z_b \cong \beta R_E}$



CE Emitter-Bias Configuration

$$\boxed{Z_i = R_B \| Z_b}$$

$$\boxed{Z_o = R_C}$$



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

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

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

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

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

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

$$Z_b \cong \beta R_E,$$

CE Emitter-Bias Configuration

To obtain A_i

- Applying the current-divider rule to the input circuit will result in:

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

$$I_o = \beta I_b \qquad \frac{I_o}{I_b} = \beta$$

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

$$= \beta \frac{R_B}{R_B + Z_b}$$

$$\boxed{A_i = \frac{I_o}{I_i} = \frac{\beta R_B}{R_B + Z_b}}$$

$$\boxed{A_i = -A_v \frac{Z_i}{R_C}}$$

Phase relationship: The negative sign in reveals a 180° phase shift between V_o and Vi.

CE Emitter-Bias Configuration

Z_i:

$$Z_b = \beta r_e + \left[\frac{(\beta + 1) + R_C/r_o}{1 + (R_C + R_E)/r_o}\right] R_E$$

Since the ratio R_C/r_o is always much less than $(\beta + 1)$,

$$Z_b \cong \beta r_e + \frac{(\beta + 1) R_E}{1 + (R_C + R_E)/r_o}$$

For $r_o \geq 10(R_C + R_E)$,

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

For $r_o \geq 10(R_C + R_E)$,

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

$$\boxed{Z_b \cong \beta(r_e + R_E)} \quad {}_{r_o \geq 10(R_C + R_E)}$$

CE Emitter-Bias Configuration

Z_o:

$$\boxed{Z_o = R_C \| \left[r_o + \frac{\beta(r_o + r_e)}{1 + \frac{\beta r_e}{R_E}} \right]}$$

$$Z_o \cong R_C \| r_o \left[1 + \frac{\beta}{1 + \frac{\beta r_e}{R_E}} \right]$$

$$Z_o \cong R_C \| r_o \left[1 + \frac{1}{\frac{1}{\beta} + \frac{r_e}{R_E}} \right]$$

$R_E \gg \beta$ and r_o :

$$\boxed{Z_o = R_C}$$

CE Emitter-Bias Configuration

$\boldsymbol{A_v}$:

$$A_v = \frac{V_o}{V_i} = \frac{-\dfrac{\beta R_C}{Z_b}\left[1 + \dfrac{r_e}{r_o}\right] + \dfrac{R_C}{r_o}}{1 + \dfrac{R_C}{r_o}}$$

The ratio $\dfrac{r_e}{r_o} \ll 1$

and

$$A_v = \frac{V_o}{V_i} \cong \frac{-\dfrac{\beta R_C}{Z_b} + \dfrac{R_C}{r_o}}{1 + \dfrac{R_C}{r_o}}$$

For $r_o \geq 10R_C$,

$$A_i = -A_v \frac{Z_i}{R_C}$$

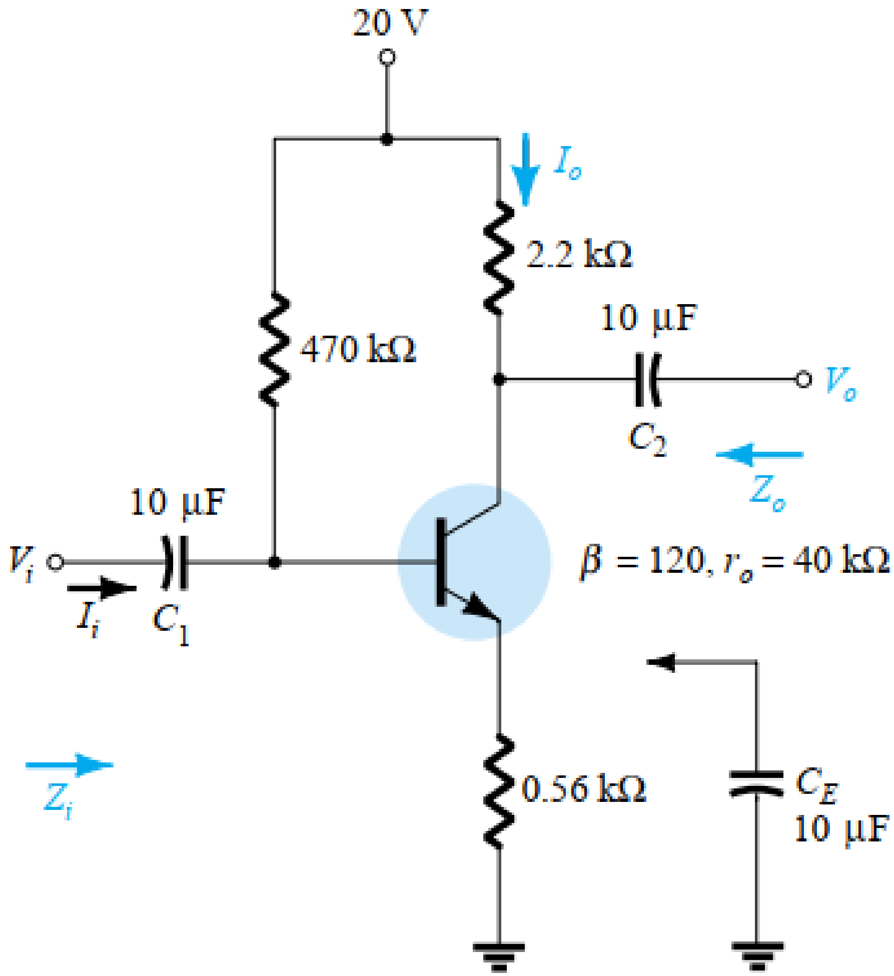
$$A_v = \frac{V_o}{V_i} \cong -\frac{\beta R_C}{Z_b}$$

$r_o \geq 10R_C$

Example

For the network of shown figure, without C_E (un bypassed), determine:

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



Example

(a) DC: $I_B = \dfrac{V_{CC} - V_{BE}}{R_B + (\beta + 1)R_E} = \dfrac{20\text{ V} - 0.7\text{ V}}{470\text{ k}\Omega + (121)0.56\text{ k}\Omega} = 35.89\ \mu\text{A}$

$$I_E = (\beta + 1)I_B = (121)(46.5\ \mu\text{A}) = 4.34\text{ mA}$$

and $r_e = \dfrac{26\text{ mV}}{I_E} = \dfrac{26\text{ mV}}{4.34\text{ mA}} = \mathbf{5.99\ \Omega}$

(b) Testing the condition $r_o \geq 10(R_C + R_E)$,

$$40\text{ k}\Omega \geq 10(2.2\text{ k}\Omega + 0.56\text{ k}\Omega)$$

$$40\text{ k}\Omega \geq 10(2.76\text{ k}\Omega) = 27.6\text{ k}\Omega\ (\textit{satisfied})$$

Therefore,

$$Z_b \cong \beta(r_e + R_E) = 120(5.99\ \Omega + 560\ \Omega)$$
$$= 67.92\text{ k}\Omega$$

and $Z_i = R_B \| Z_b = 470\text{ k}\Omega \| 67.92\text{ k}\Omega$

$$= \mathbf{59.34\text{ k}\Omega}$$

Example

(c) $Z_o = R_C = \mathbf{2.2\ k\Omega}$

(d) $r_o \geq 10R_C$ is satisfied. Therefore,

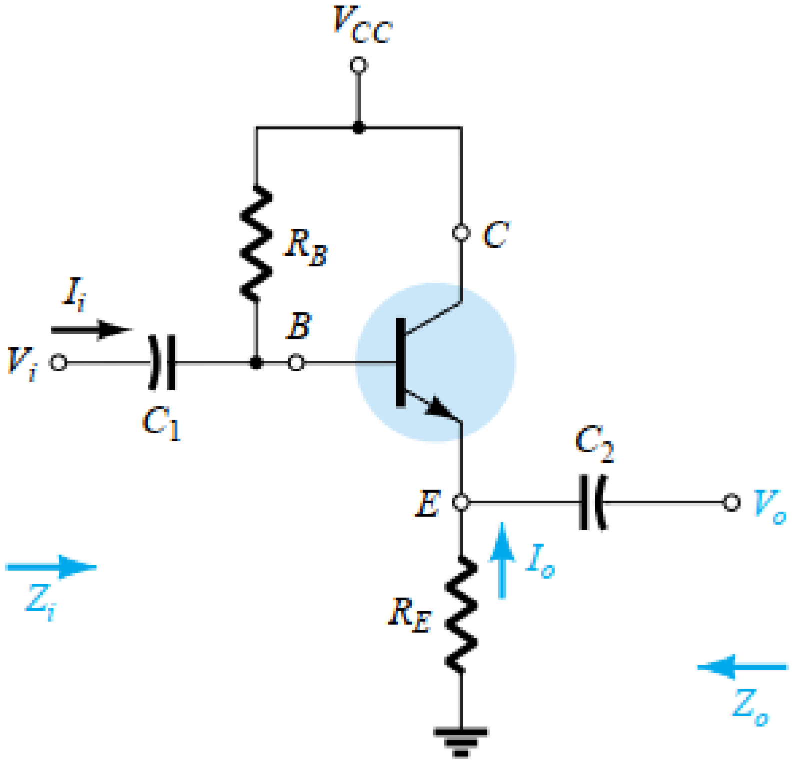
$$A_v = \frac{V_o}{V_i} \cong -\frac{\beta R_C}{Z_b} = -\frac{(120)(2.2\ \text{k}\Omega)}{67.92\ \text{k}\Omega}$$

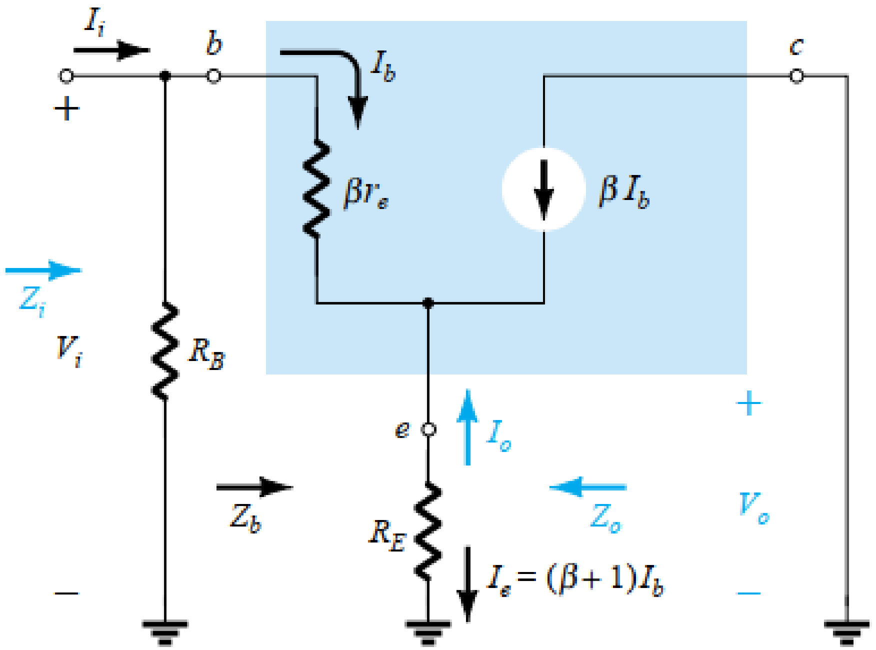
$$= \mathbf{-3.89}$$

(e) $$A_i = -A_v \frac{Z_i}{R_C} = -(-3.89)\left(\frac{59.34\ \text{k}\Omega}{2.2\ \text{k}\Omega}\right)$$

$$= \mathbf{104.92}$$

Emitter-follower Configuration





Emitter-follower Configuration

Z_i:

$$\boxed{Z_i = R_B \| Z_b}$$

$$\boxed{Z_b \cong \beta(r_e + R_E)}$$

$$\boxed{Z_b = \beta r_e + (\beta + 1)R_E}$$

$$\boxed{Z_b \cong \beta R_E}$$

Z_o:

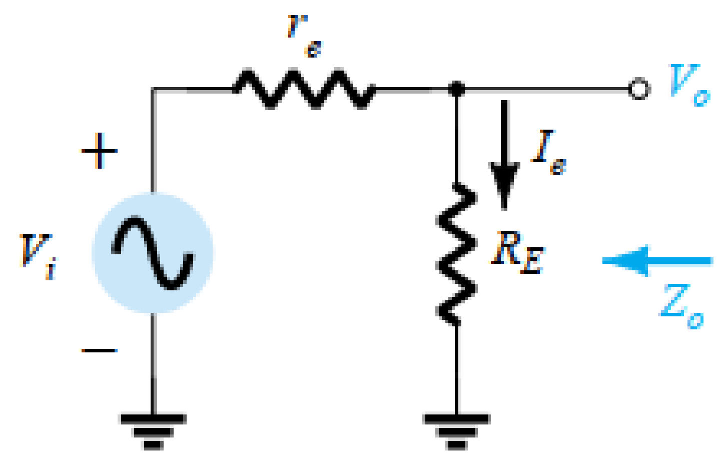
$$I_b = \frac{V_i}{Z_b}$$

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

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

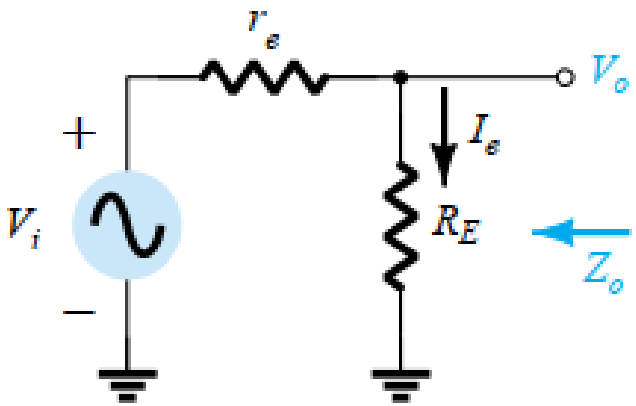
$$I_e = \frac{V_i}{[\beta r_e/(\beta + 1)] + R_E}$$

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



Emitter-follower Configuration

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



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

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

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

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

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

R_E is usually much greater than r_e, $R_E + r_e \cong R_E$

$$\boxed{A_v = \frac{V_o}{V_i} \cong 1}$$

Emitter-follower Configuration

$\boldsymbol{A_i}$:

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

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

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

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

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

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

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

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

Emitter-follower Configuration

Z_o:

$$\boxed{Z_o = r_o \| R_E \| \frac{\beta r_e}{(\beta + 1)}}$$

Using $\beta + 1 \cong \beta$, $\Rightarrow$ $Z_o = r_o \| R_E \| r_e$

$$\boxed{Z_o \cong R_E \| r_e}_{\text{Any } r_o}$$

A_v:

$$\boxed{A_v = \frac{(\beta + 1)R_E/Z_b}{1 + \dfrac{R_E}{r_o}}}$$

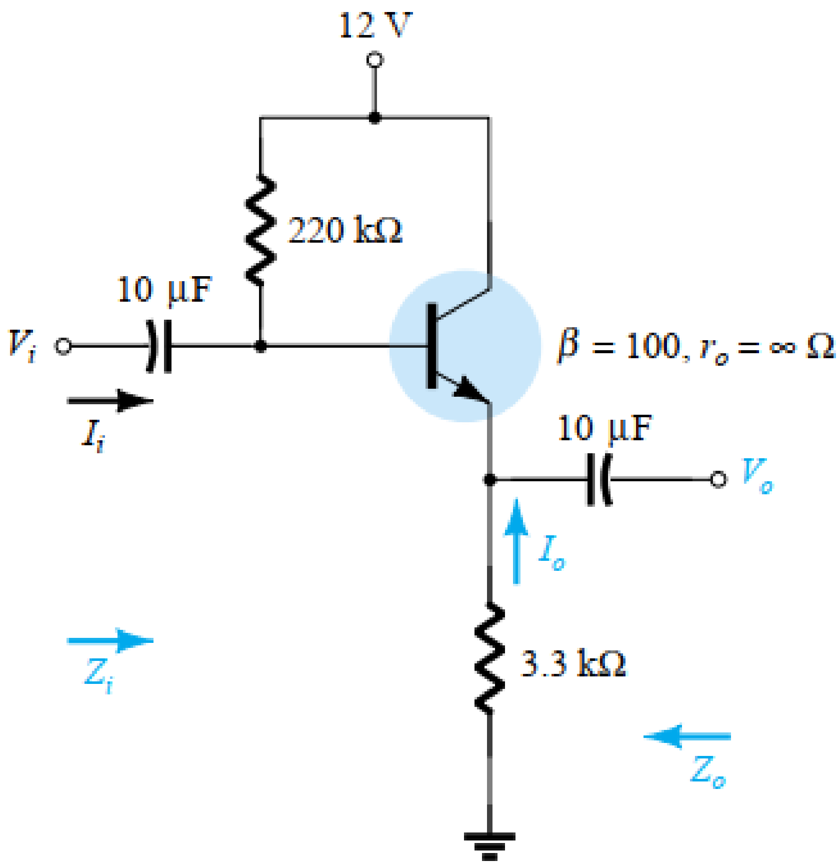
If the condition $r_o \geq 10R_E$ is satisfied and we use the approximation $\beta + 1 \cong \beta$,

$$A_v \cong \frac{\beta R_E}{Z_b} \quad Z_b \cong \beta(r_e + R_E) \quad A_v \cong \frac{\beta R_E}{\beta(r_e + R_E)} \quad \boxed{A_v \cong \frac{R_E}{r_e + R_E}}_{r_o \geq 10R_E}$$

Example

For the emitter-follower network of Figure, determine:

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



Example

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

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

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

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

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

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

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

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

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

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

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

Example

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

$$= \mathbf{12.56\ \Omega} \cong r_e$$

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

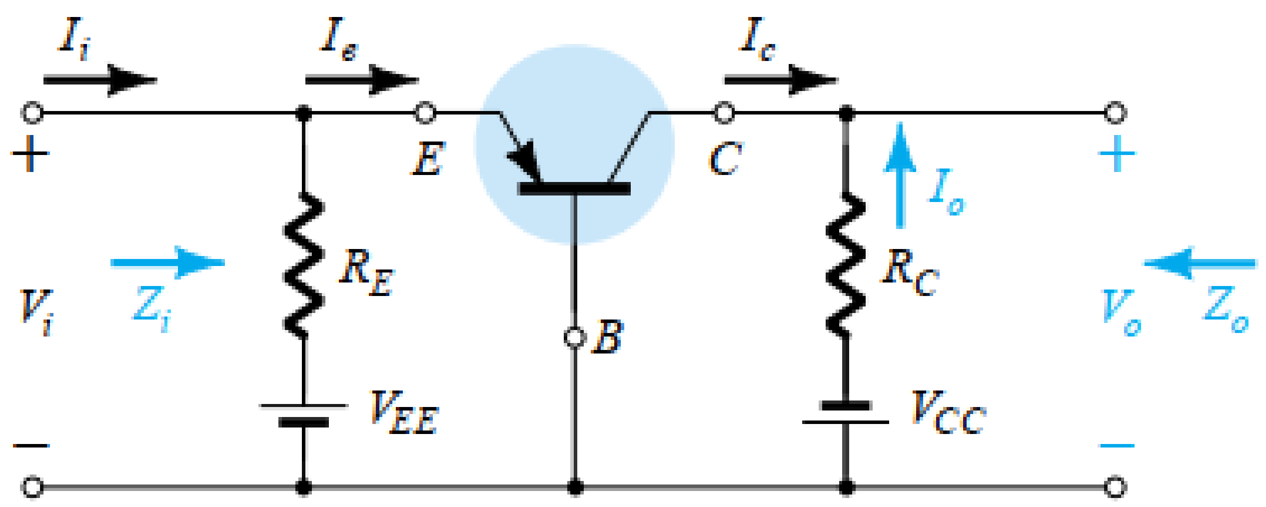
$$= \mathbf{0.996} \cong 1$$

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

$$A_i = -A_v \frac{Z_i}{R_E} = -(0.996)\left(\frac{132.72\ \text{k}\Omega}{3.3\ \text{k}\Omega}\right) = \mathbf{-40.06}$$

Common-base Configuration

- Low input impedance.
- High output impedance.
- Current gain less than 1.
- Voltage gain quite large.



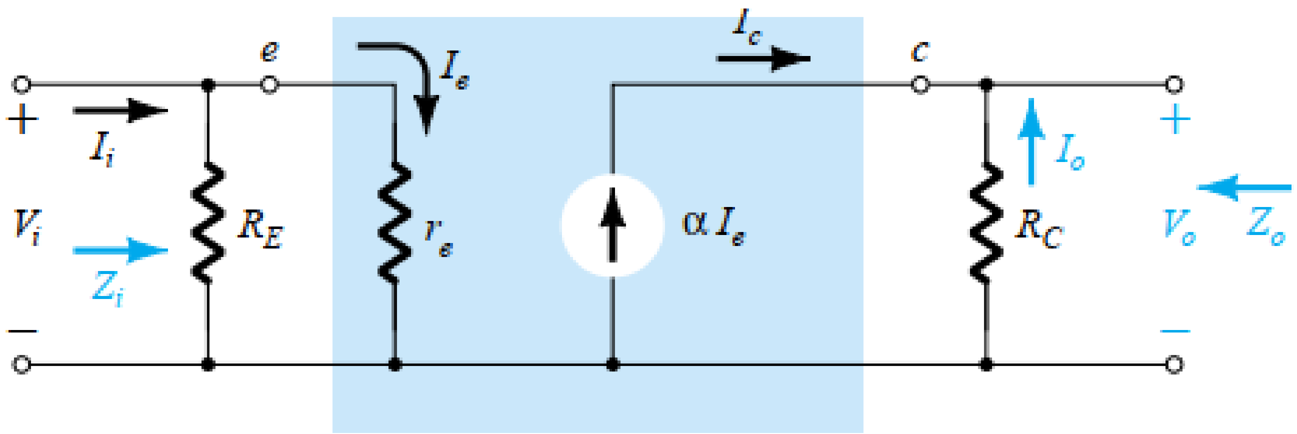
Common-base Configuration

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

$$\boxed{Z_o = R_C}$$

$$V_o = -I_o R_C = -(-I_c)R_C = \alpha I_e R_C \qquad I_e = \frac{V_i}{r_e}$$

$$V_o = \alpha\left(\frac{V_i}{r_e}\right) R_C \Rightarrow \boxed{A_v = \frac{V_o}{V_i} = \frac{\alpha R_C}{r_e} \cong \frac{R_C}{r_e}}$$



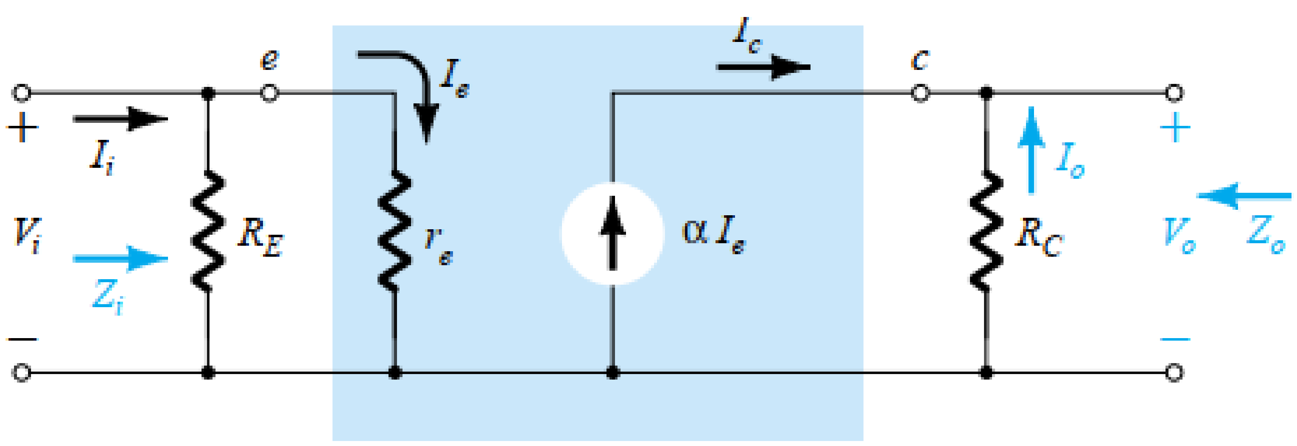
Common-base Configuration

$R_E \gg r_e$

$$I_e = I_i$$

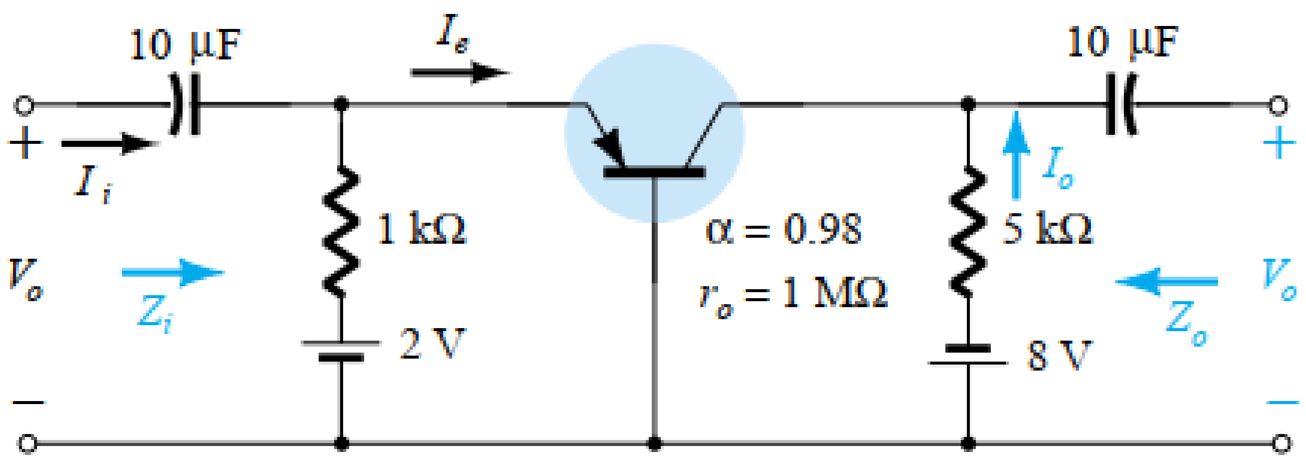
$$I_o = -\alpha I_e = -\alpha I_i$$

$$\boxed{A_i = \frac{I_o}{I_i} = -\alpha \cong -1}$$



For the network of Figure, determine:

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



Example

$$\text{(a)}\quad I_E = \frac{V_{EE} - V_{BE}}{R_E} = \frac{2\text{ V} - 0.7\text{ V}}{1\text{ k}\Omega} = \frac{1.3\text{ V}}{1\text{ k}\Omega} = 1.3\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{I_E} = \frac{26\text{ mV}}{1.3\text{ mA}} = \mathbf{20\ \Omega}$$

$$\text{(b)}\quad Z_i = R_E \| r_e = 1\text{ k}\Omega \| 20\ \Omega$$

$$= \mathbf{19.61\ \Omega} \cong r_e$$

$$\text{(c)}\quad Z_o = R_C = \mathbf{5\ k\Omega}$$

$$\text{(d)}\quad A_v \cong \frac{R_C}{r_e} = \frac{5\text{ k}\Omega}{20\ \Omega} = \mathbf{250}$$

$$\text{(e)}\quad A_i = \mathbf{-0.98} \cong -1$$

THANK YOU