Electronic Devices

Final Term
Lecture - 02

Reference book:

Electronic Devices and Circuit Theory (Chapter-5)

Robert L. Boylestad and L. Nashelsky , (11th Edition)

COMMON-EMITTER VOLTAGE-DIVIDER BIAS

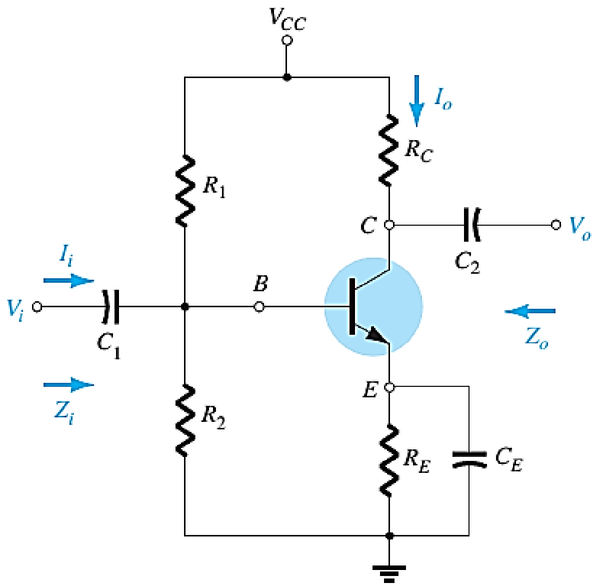


FIG. 5.26
Voltage-divider bias configuration.

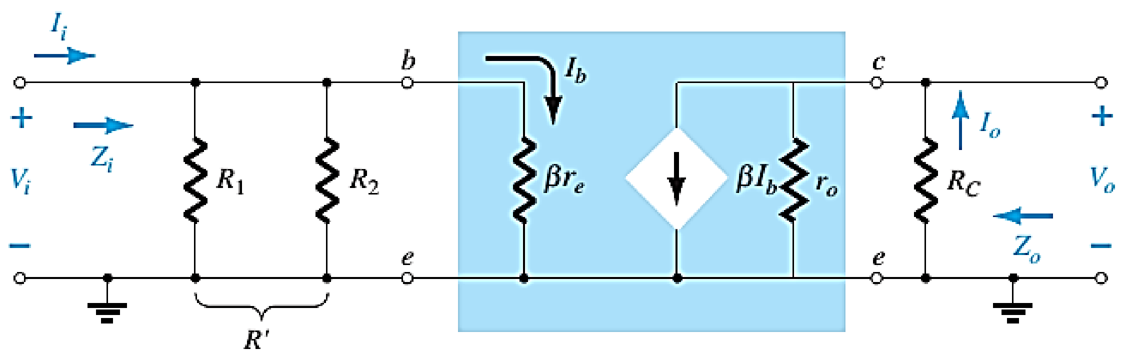
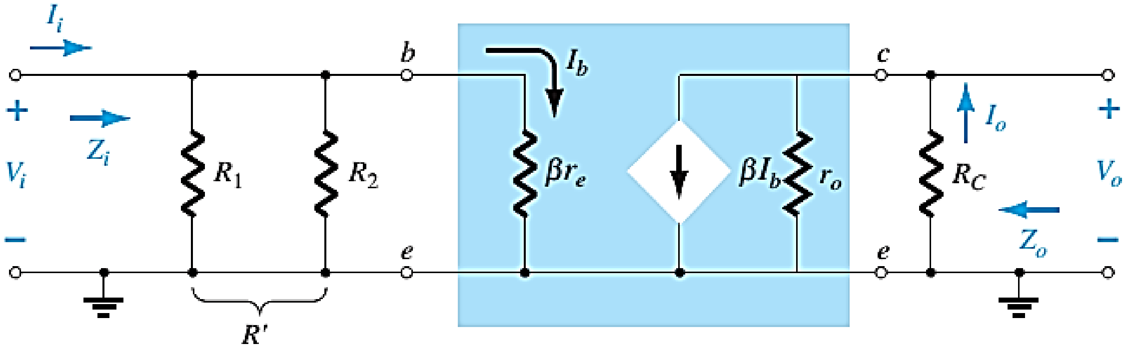


FIG. 5.27
Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 5.26.

COMMON-EMITTER VOLTAGE-DIVIDER BIAS



INPUT IMPEDANCE, Z_i

$$R' = R_1 \| R_2$$

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

OUTPUT IMPEDANCE, Z_o

$$Z_o = R_C \| r_o$$

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

VOLTAGE GAIN, A_v

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

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

EXAMPLE

- **EXAMPLE 5.2:** For the network of Fig. 5.28 :
- Determine $\boldsymbol{r_e}$, $\boldsymbol{Z_i}$, $\boldsymbol{Z_o}$ (with $\boldsymbol{r_o = \infty}$), $\boldsymbol{A_v}$ (with $\boldsymbol{r_o = \infty}$) and Repeat with $\boldsymbol{r_o = 50\ k\Omega}$.

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, we obtain

$$V_B = \frac{R_2}{R_1 + R_2}V_{CC} = \frac{(8.2\ \text{k}\Omega)(22\ \text{V})}{56\ \text{k}\Omega + 8.2\ \text{k}\Omega} = 2.81\ \text{V}$$
$$V_E = V_B - V_{BE} = 2.81\ \text{V} - 0.7\ \text{V} = 2.11\ \text{V}$$
$$I_E = \frac{V_E}{R_E} = \frac{2.11\ \text{V}}{1.5\ \text{k}\Omega} = 1.41\ \text{mA}$$
$$r_e = \frac{26\ \text{mV}}{I_E} = \frac{26\ \text{mV}}{1.41\ \text{mA}} = \mathbf{18.44\ \Omega}$$

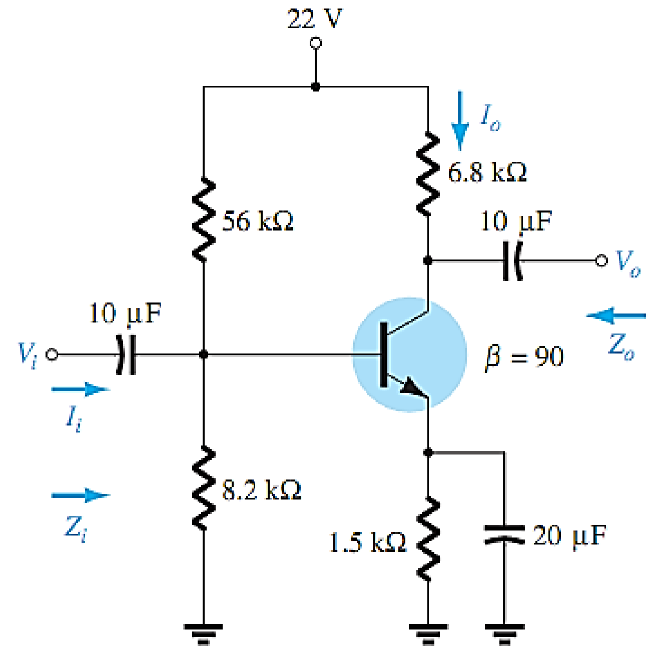
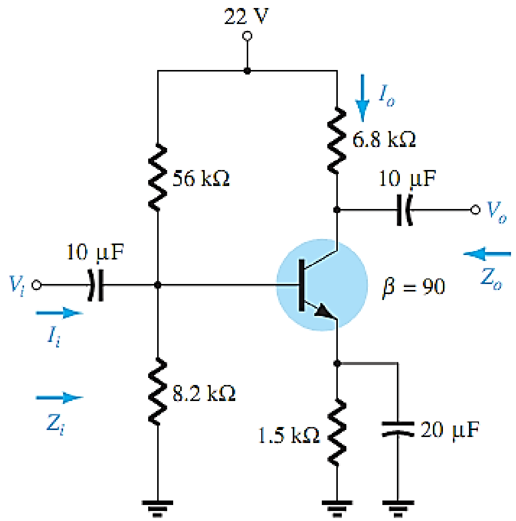


FIG. 5.28
Example 5.2.

EXAMPLE Contd.



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. $A_v = -\dfrac{R_C}{r_e} = -\dfrac{6.8\ \text{k}\Omega}{18.44\ \Omega} = \mathbf{-368.76}$

e. $Z_i = \mathbf{1.35\ k\Omega}$

$$Z_o = R_C \| r_o = 6.8\ \text{k}\Omega \| 50\ \text{k}\Omega = \mathbf{5.98\ k\Omega} \text{ vs. } 6.8\ \text{k}\Omega$$

$$A_v = -\frac{R_C \| r_o}{r_e} = -\frac{5.98\ \text{k}\Omega}{18.44\ \Omega} = \mathbf{-324.3} \text{ vs. } -368.76$$

There was a measurable difference in the results for Z_o and A_v, because the condition $r_o \geq 10R_C$ was *not* satisfied.

COMMON-EMITTER EMITTER-BIAS CONFIGURATION: UNBYPASSED R_E

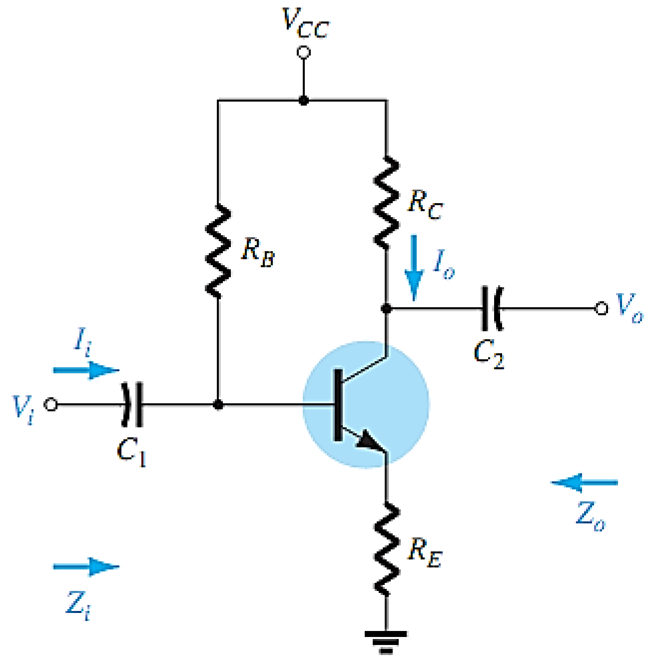


FIG. 5.29
CE emitter-bias configuration.

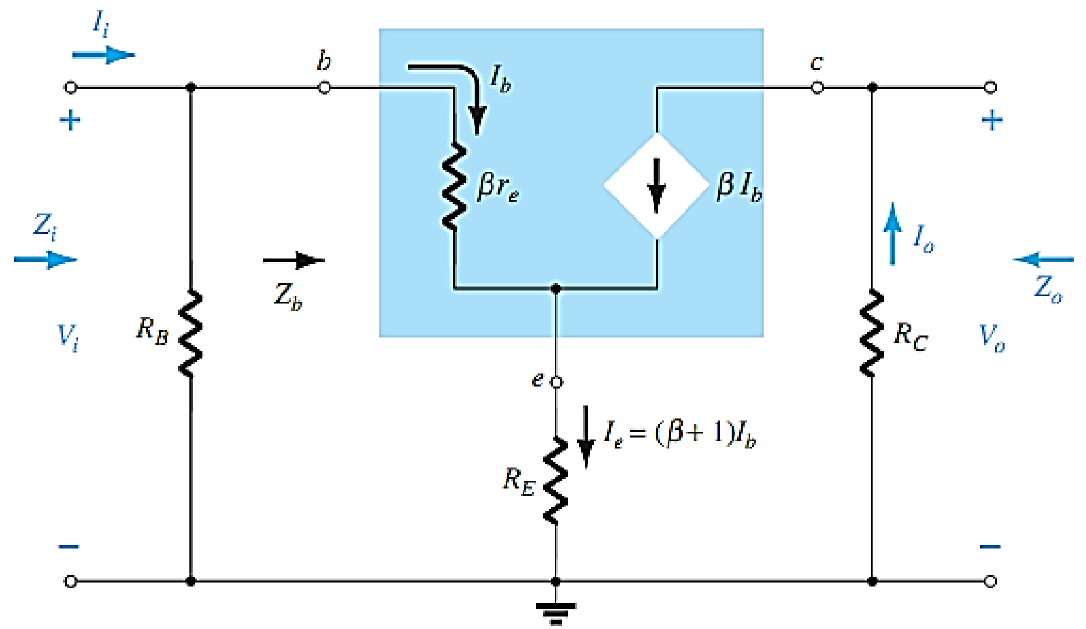


FIG. 5.30
Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 5.29.

IMPEDANCE CALCULATION

INPUT IMPEDANCE, Z_i

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

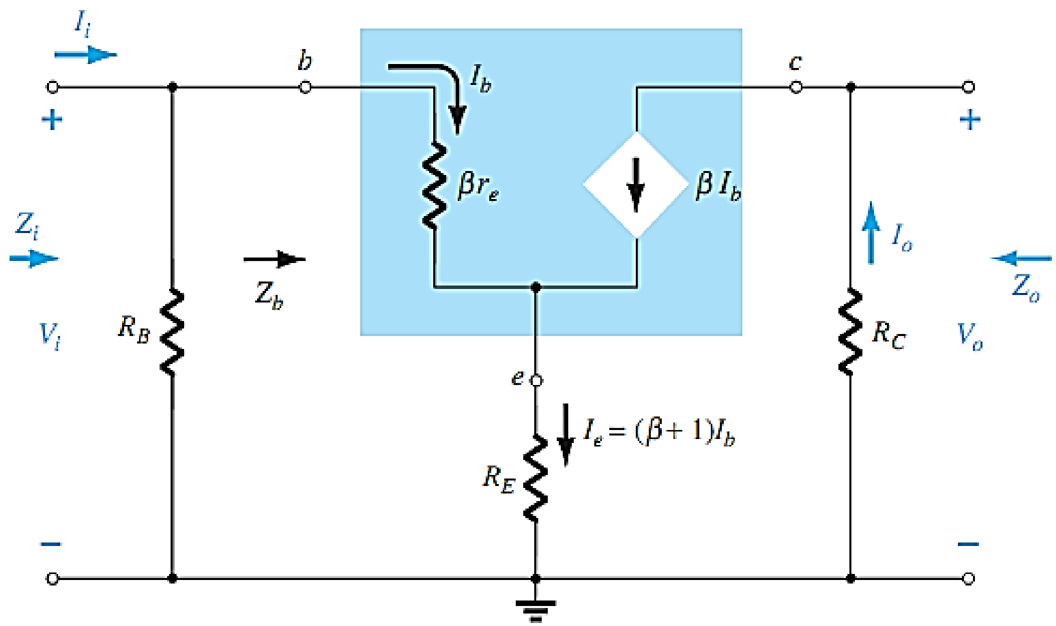
$$= I_b \beta r_e + (\beta + 1) I_b R_E$$

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

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

$$Z_b \cong \beta R_E \qquad for \;\; R_E \gg r_e$$

$$Z_i = R_B || Z_b$$



OUTPUT IMPEDANCE, Z_o

$$Z_o = R_C$$

GAIN CALCULATIONS

VOLTAGE GAIN, A_v

$$V_o = -I_oR_C = -\beta I_bR_C = -\beta(\frac{V_i}{Z_b})\,R_C$$

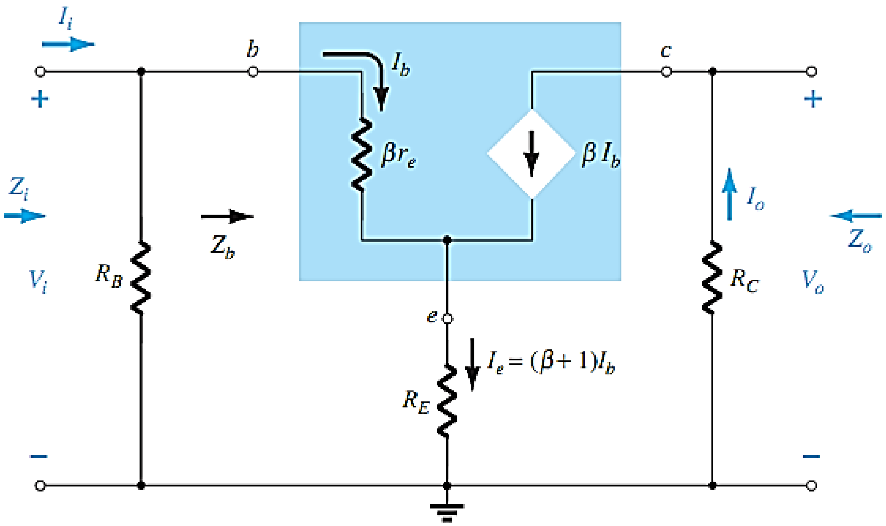
$$A_v = \frac{V_o}{V_i} = -\frac{\beta R_C}{Z_b}$$

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

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

$$For\ the\ approximation \quad Z_b \cong \beta R_E$$

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



The negative sign in gain equations reveals 180° phase shift between input and output waveforms.

COMMON-EMITTER EMITTER-BIAS CONFIGURATION: BYPASSED R_E

Bypassed

If R_E is bypassed by an emitter capacitor C_E, the complete r_e equivalent model can be substituted, resulting in the same equivalent network as Fig. 5.22. Equations of slide no. 13 are therefore applicable.

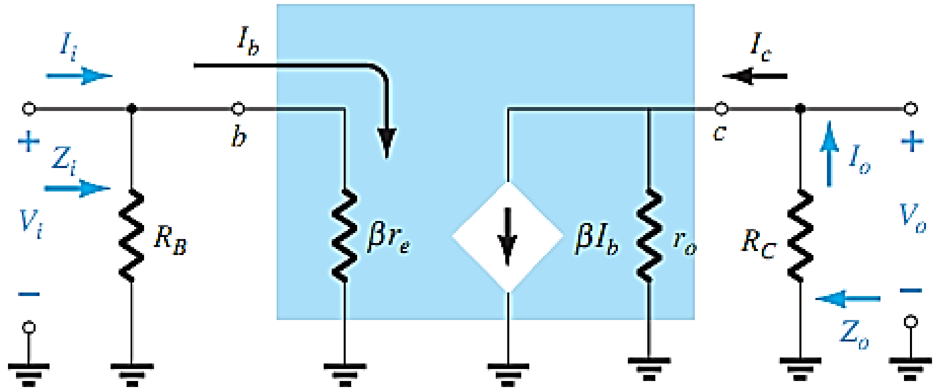


FIG. 5.22
Substituting the r_e model into the network of Fig. 5.21.

EXAMPLE

- **<u>EXAMPLE 5.3:</u>** For the network of following Fig, without C_E (unbypassed), determine: $\boldsymbol{r_e}$, $\boldsymbol{Z_i}$, $\boldsymbol{Z_o}$ & $\boldsymbol{A_v}$.

a. DC:

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

$$I_E = (\beta + 1)I_B = (121)(35.89\ \mu\text{A}) = 4.34\text{ mA}$$

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

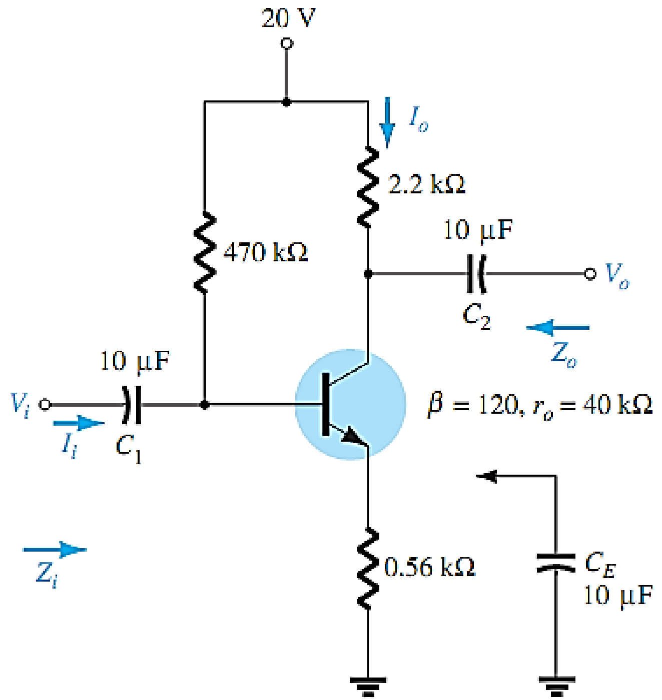


FIG. 5.32
Example 5.3.

EXAMPLE Contd.

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

$$40\ \text{k}\Omega \geq 10(2.2\ \text{k}\Omega + 0.56\ \text{k}\Omega)$$
$$40\ \text{k}\Omega \geq 10(2.76\ \text{k}\Omega) = 27.6\ \text{k}\Omega\ (\textit{satisfied})$$

Therefore,

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

and

$$Z_i = R_B \| Z_b = 470\ \text{k}\Omega \| 67.92\ \text{k}\Omega$$
$$= \mathbf{59.34\ k\Omega}$$

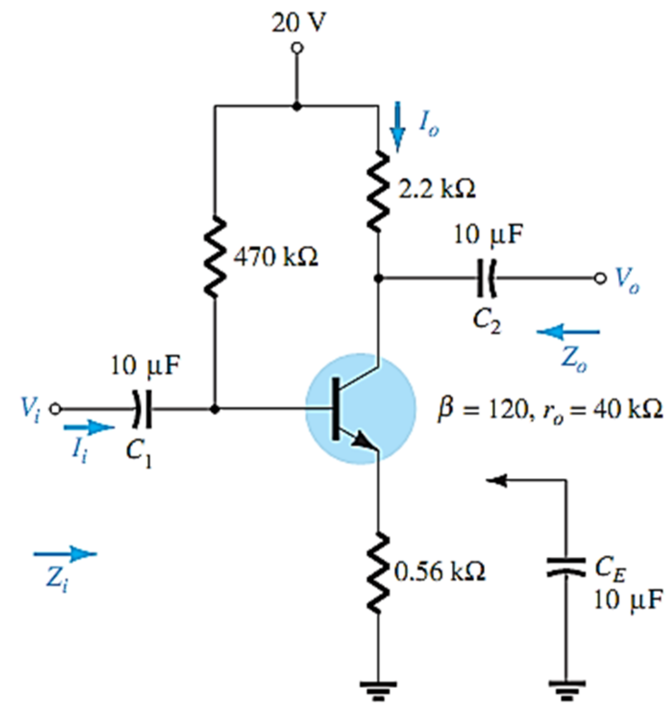


FIG. 5.32
Example 5.3.

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

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

$$A_v = \frac{V_o}{V_i} \cong -\frac{\beta R_C}{Z_b} = -\frac{(120)(2.2\ \text{k}\Omega)}{67.92\ \text{k}\Omega}$$
$$= \mathbf{-3.89}$$

compared to -3.93 using Eq. (5.20): $A_v \cong -R_C/R_E$.

EMITTER-FOLLOWER CONFIGURATION

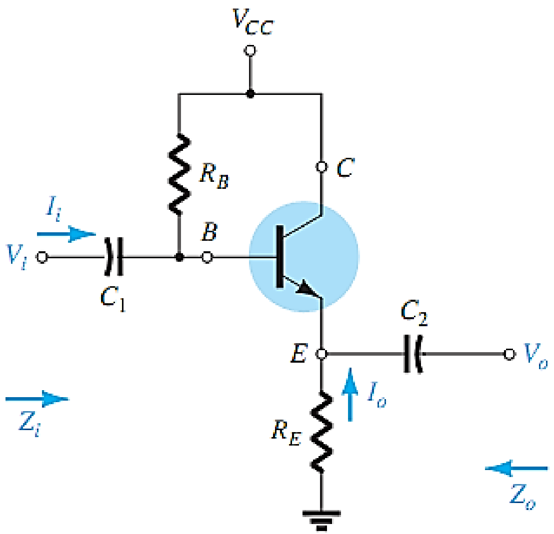


FIG. 5.36
Emitter-follower configuration.

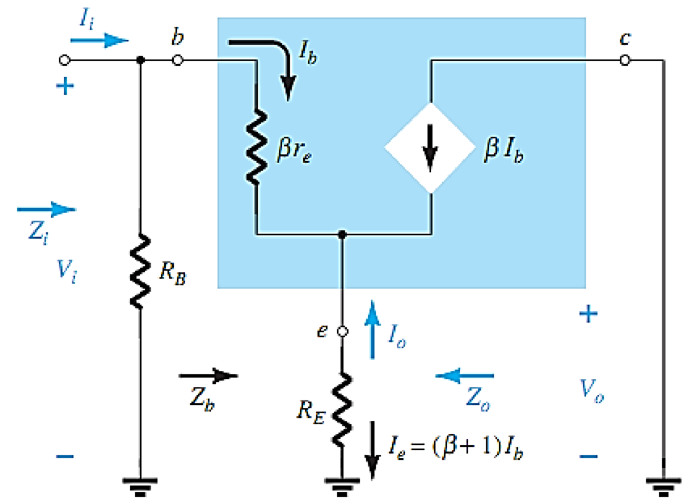


FIG. 5.37
Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 5.36.

- 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

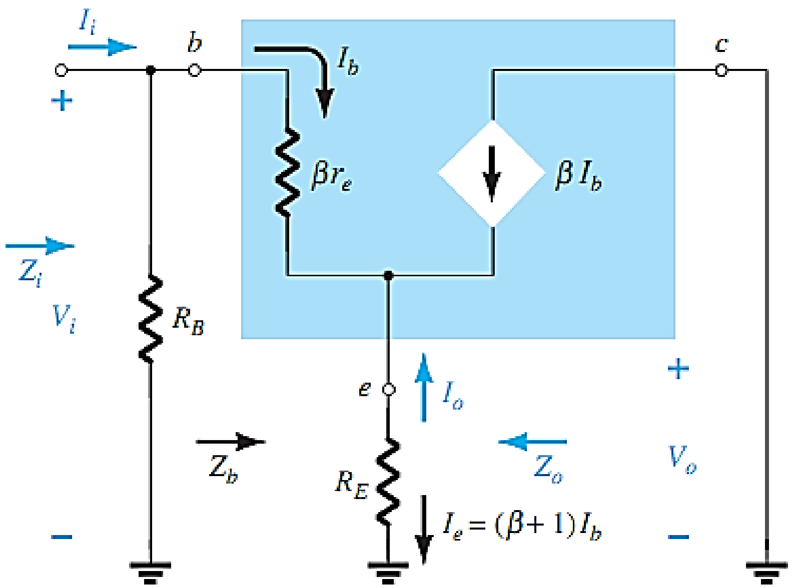
INPUT IMPEDANCE, Z_i

$$Z_i = R_B || Z_b$$

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

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

$$Z_b \cong \beta R_E \qquad for \ \ R_E \gg r_e$$



IMPEDANCE CALCULATIONS

OUTPUT IMPEDANCE, Z_o

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

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

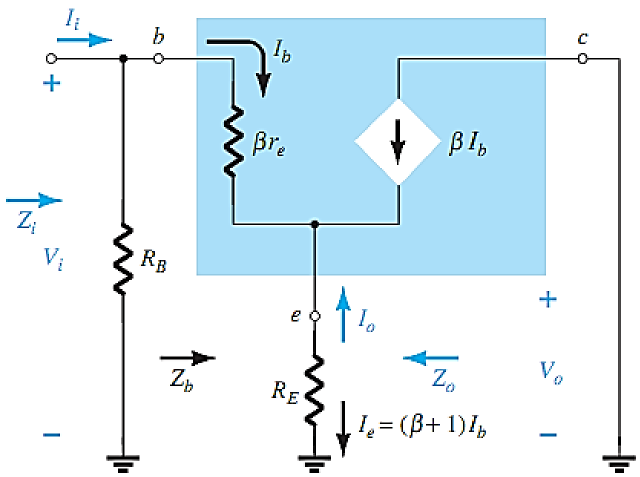
$$I_E = \frac{(\beta+1)V_i}{\beta r_e + (\beta+1)R_E}$$

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

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

$To\ determine\ Z_o,\ V_i\ is\ set\ to\ zero$

$Z_o = R_E \,||\, r_e \qquad Z_o = r_e \;\big|_{R_E \gg r_e}$



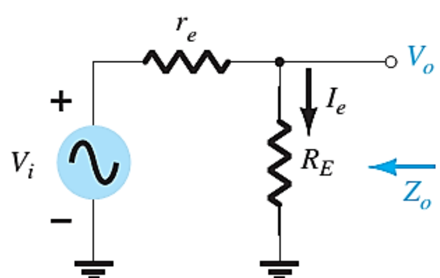


FIG. 5.38
Defining the output impedance for the emitter-follower configuration.

GAIN CALCULATIONS

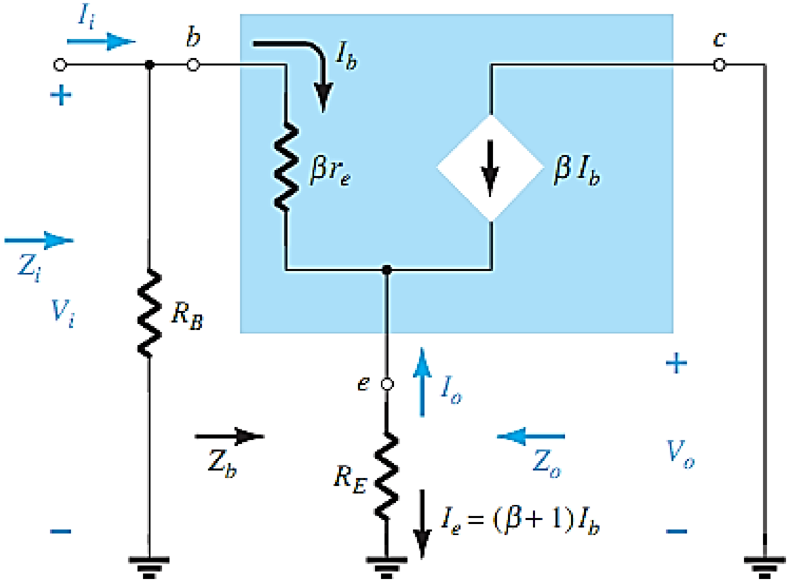
VOLTAGE GAIN, A_v

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

$$when\ r_o \geq 10R_E\ and\ \beta + 1 \cong \beta$$

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

$$A_v = \frac{V_o}{V_i} \cong \frac{\beta R_E}{\beta(r_e + R_E)} \cong \frac{R_E}{(r_e + R_E)}$$



❑ ***See Example 5.7***

COMMON-BASE CONFIGURATION

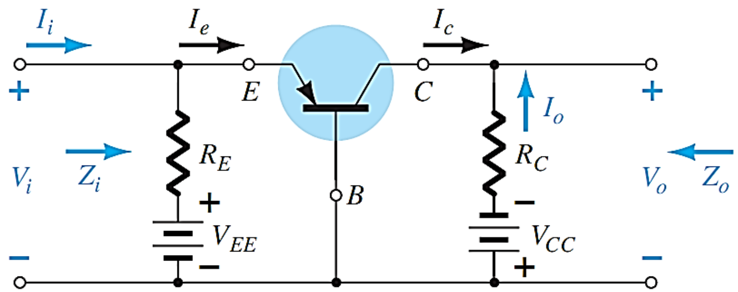


FIG. 5.42
Common-base configuration.

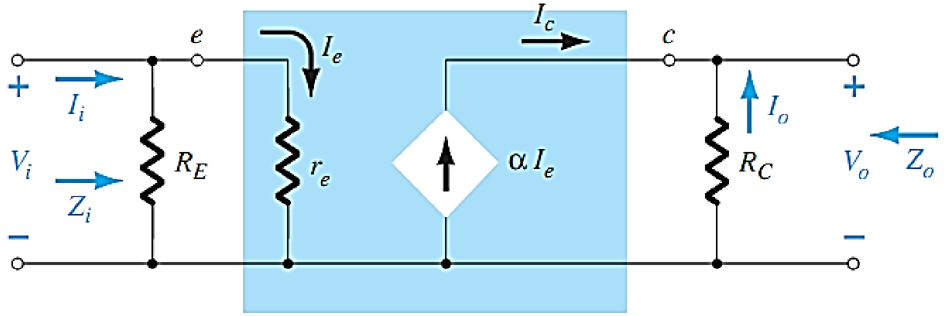
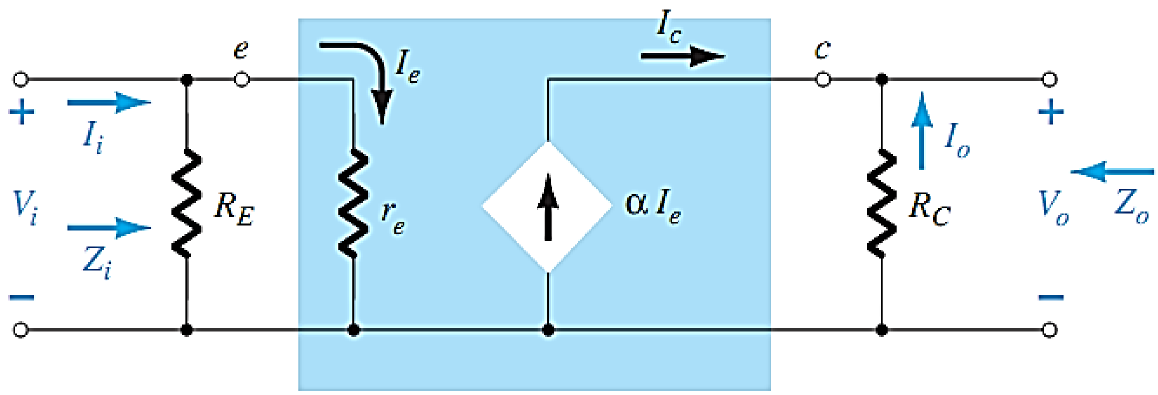


FIG. 5.43
Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 5.44.

- The input is applied to the emitter.
- The output is taken from the collector.
- Low input impedance.
- High output impedance.
- Very high voltage gain.
- No phase shift between input and output.

CALCULATIONS



INPUT IMPEDANCE, Z_i

$$Z_i = R_E \| r_e$$

OUTPUT IMPEDANCE, Z_o

$$Z_o = R_C$$

VOLTAGE GAIN, A_v

$$V_o = -I_o R_C = -(I_C) R_C = \alpha I_e R_C\ ; \quad I_e = \frac{V_i}{r_e}$$

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

CURRENT GAIN, A_i

$$Assuming\ R_E \gg r_e$$

$$I_e = I_i$$

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

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

COMMON-BASE CONFIGURATION

- **Phase Relationship:**

The fact that A_v is a positive number shows that V_o and V_i are in phase for the common-base configuration.

- **Effect of r_o :**

For the common-base configuration, $r_o = 1/h_{ob}$ is typically in the megohm range and sufficiently larger than the parallel resistance R_C to permit the approximation $r_o \,||\, R_C \cong R_C$.

EXAMPLE

- **EXAMPLE 5.8:** For the network of following figure, determine: r_e, Z_i, Z_o, A_v, A_i.

a. $I_E = \dfrac{V_{EE} - V_{BE}}{R_E} = \dfrac{2\text{ V} - 0.7\text{ V}}{1\text{ k}\Omega} = \dfrac{1.3\text{ V}}{1\text{ k}\Omega} = 1.3\text{ mA}$

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

b. $Z_i = R_E \| r_e = 1\text{ k}\Omega \| 20\ \Omega$

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

c. $Z_o = R_C = \mathbf{5\ k\Omega}$

d. $A_v \cong \dfrac{R_C}{r_e} = \dfrac{5\text{ k}\Omega}{20\ \Omega} = \mathbf{250}$

e. $A_i = \mathbf{-0.98} \cong -1$

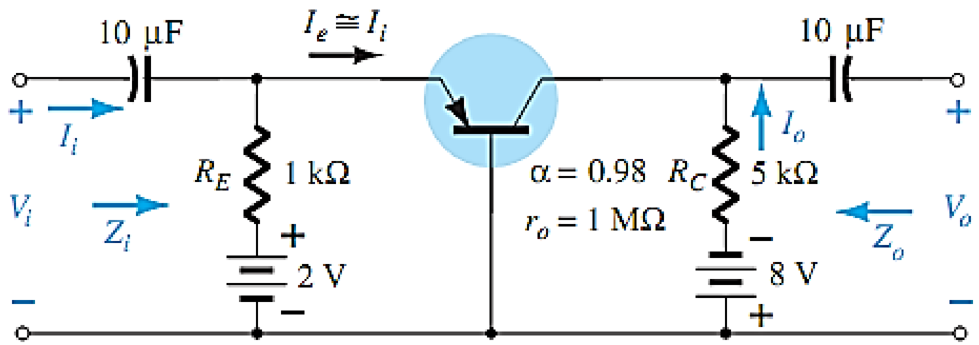


FIG. 5.44
Example 5.8.

End of Lecture-2