BENHA UNIVERSITY
FACULTY OF ENGINEERING AT SHOUBRA

ECE-312
Electronic Circuits (A)

Lecture #4
BJT Modeling and r_e Transistor Model (small signal analysis)

Instructor:
Dr. Ahmad El-Banna

OCTOBER 2014

Remember ! Lectures List

Week#1
- Lec#1: **Introduction and Basic Concepts**

Week#2
- Lec#2: **BJT Review**
- Lec#3: **BJT Biasing Circuits**

Week#3
- Lec#4: **BJT Modeling and r_e Transistor Model**
- Lec#5: **Hybrid Equivalent Model**

Week#4
- Lec#6: **BJT Small-Signal Analysis**
- Lec#7: **Systems Approach**

Week#5
- Lec#8: **General Frequency Considerations**
- Lec#9: **BJT Low Frequency Response**

Week#6
- Lec#10: **BJT High Frequency Response**
- Lec#11: **Multistage Frequency Effects and Square-Wave Testing**

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- Lec#7: **Systems Approach**

Merged in two lectures only ☺

Week#5
- Lec#6: **General Frequency Considerations**
- Lec#7: **BJT Low Frequency Response**

Week#6
- Lec#8: **BJT High Frequency Response**
- Lec#9: **Multistage Frequency Effects and Square-Wave Testing**

Agenda

- Amplification in the AC Domain
- BJT transistor Modeling
- The r_e Transistor Model (small signal analysis)
- Effect of R_L and R_s (System approach)
- Determining the Current Gain
- Summary Table

AMPLIFICATION IN THE AC DOMAIN

Amplification in the AC Domain

$\eta = P_o/P_i$ cannot be greater than 1.

In fact, a *conversion efficiency* is defined by $\eta = P_{o(\mathrm{ac})}/P_{i(\mathrm{dc})}$, where $P_{o(\mathrm{ac})}$ is the ac power to the load and $P_{i(\mathrm{dc})}$ is the dc power supplied.

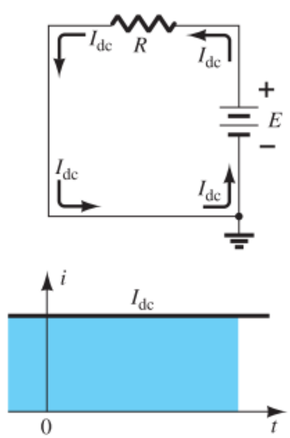


FIG. 5.1
Steady current established by a dc supply.

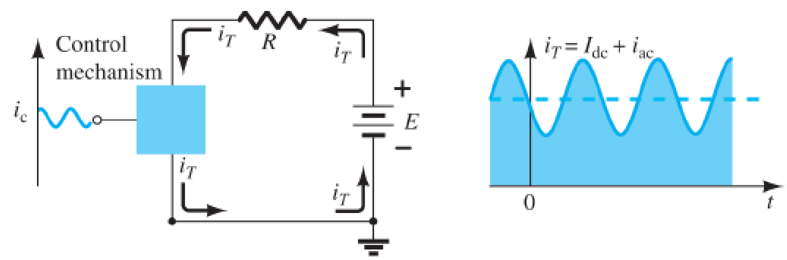


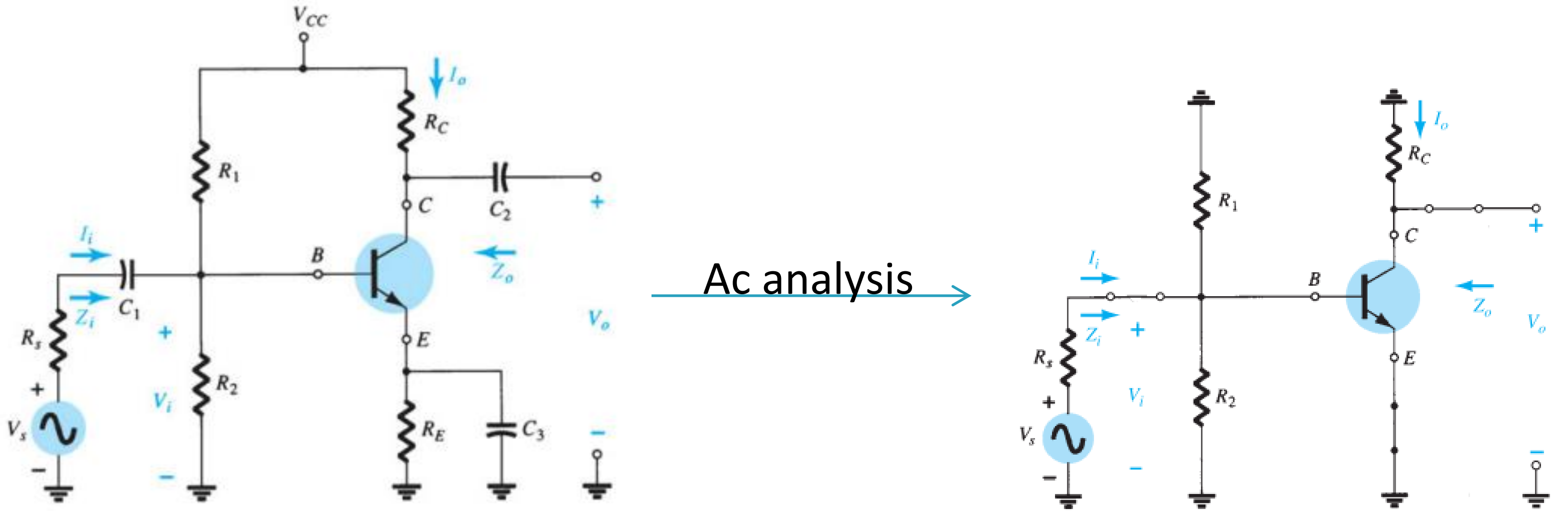
FIG. 5.2
Effect of a control element on the steady-state flow of the electrical system of Fig. 5.1.

- 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.

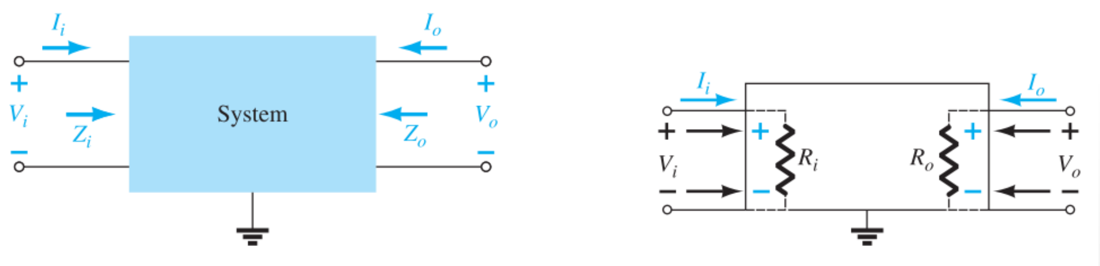
BJT TRANSISTOR MODELING

BJT Transistor Modeling

- A model is a combination of circuit elements, properly chosen, that best approximates the actual behavior of a semiconductor device under specific operating conditions.



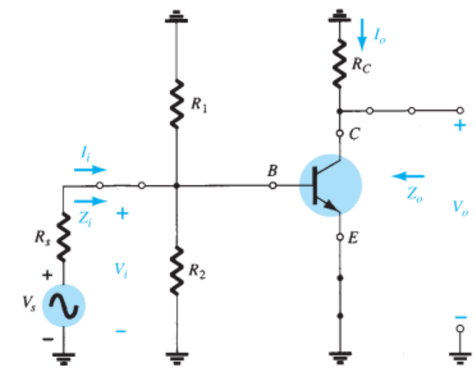
- Defining the important parameters of any system.

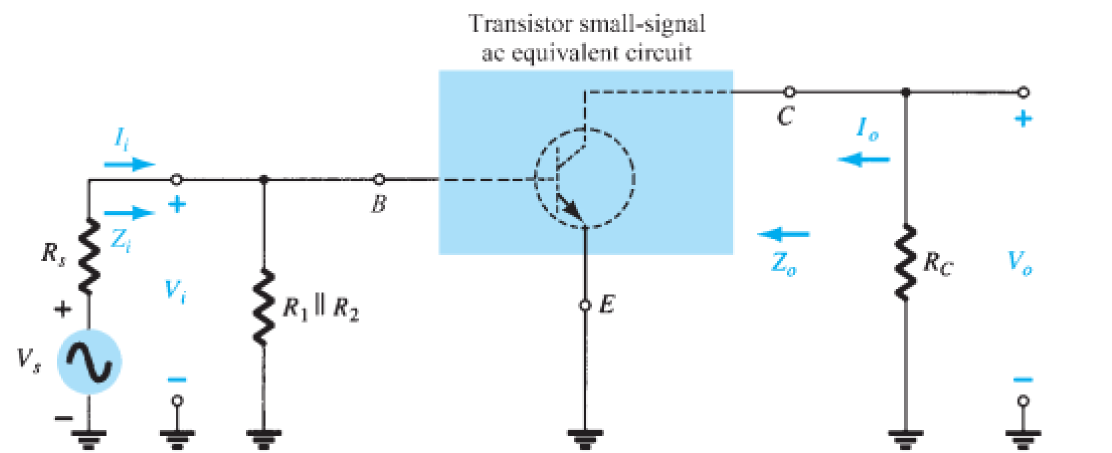


BJT Transistor Modeling

- 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





- Common Emitter Configuration
- Common Base Configuration
- Common Collector Configuration
- r_e Model in Different Bias Circuits

THE r_e TRANSISTOR MODEL

The r_e Transistor Model (CE)

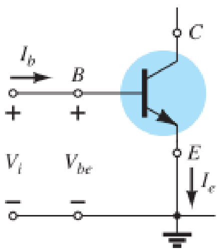


FIG. 5.8
Finding the input equivalent circuit for a BJT transistor.

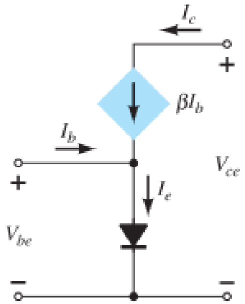


FIG. 5.12
BJT equivalent circuit.

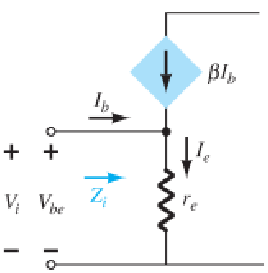


FIG. 5.13
Defining the level of Z_i.

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

$$V_{be} = I_e r_e = (I_c + I_b) r_e = (\beta I_b + I_b) r_e$$
$$= (\beta + 1) I_b r_e$$

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

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

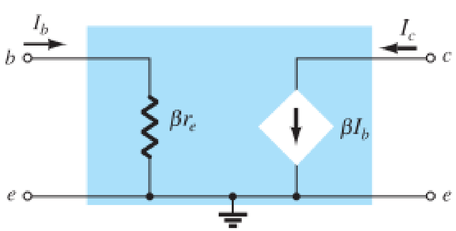


FIG. 5.14
Improved BJT equivalent circuit.

Early Voltage

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

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

$$\text{Slope} = \frac{\Delta y}{\Delta x} = \frac{\Delta I_C}{\Delta V_{CE}} = \frac{1}{r_o}$$

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

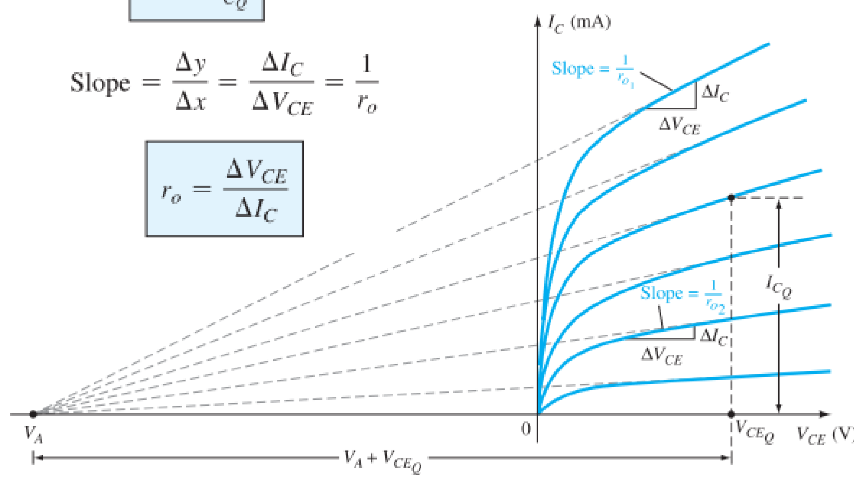


FIG. 5.15
Defining the Early voltage and the output impedance of a transistor.

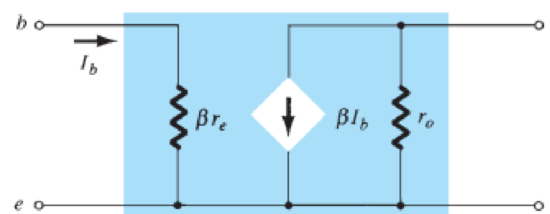


FIG. 5.16
r_e model for the common-emitter transistor configuration including effects of r_o.

The r_e Transistor Model (CB)

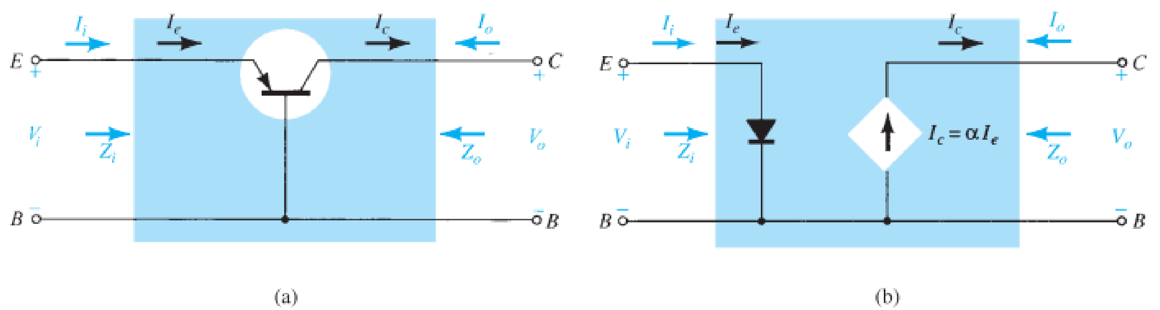


FIG. 5.17

(a) Common-base BJT transistor; (b) equivalent circuit for configuration of (a).

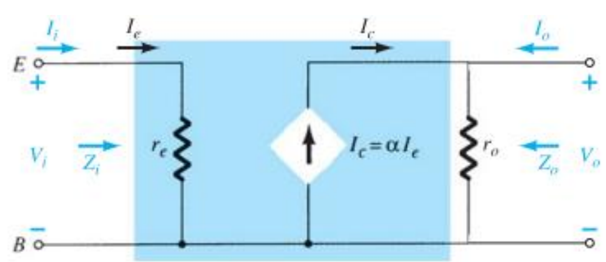


FIG. 5.18

Common base r_e equivalent circuit.

The r_e Transistor Model (CC)

- For the common-collector configuration, the model defined for the common-emitter configuration of is normally applied rather than defining a model for the common-collector configuration.

npn versus pnp

- The dc analysis of *npn* and *pnp* configurations is quite different in the sense that the currents will have opposite directions and the voltages opposite polarities.
- However, for an ac analysis where the signal will progress between positive and negative values, the ac equivalent circuit will be the same.

C.E. Fixed Bias Configuration

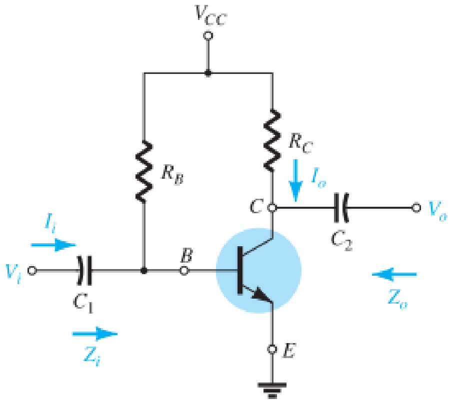


FIG. 5.20
Common-emitter fixed-bias configuration.

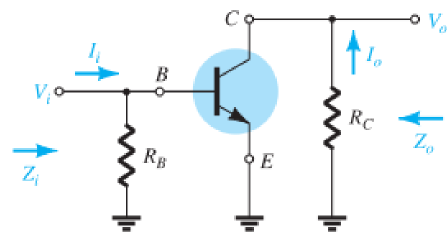


FIG. 5.21
Network of Fig. 5.20 following the removal of the effects of V_{CC}, C_1, and C_2.

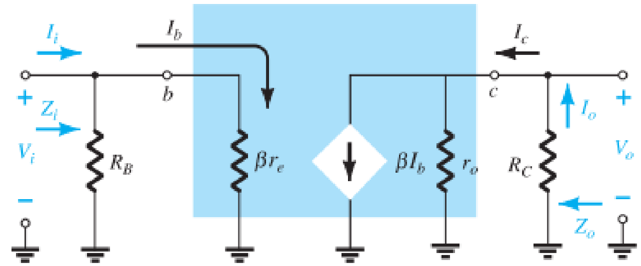


FIG. 5.22
Substituting the r_e model into the network of Fig. 5.21.

Phase Relationship

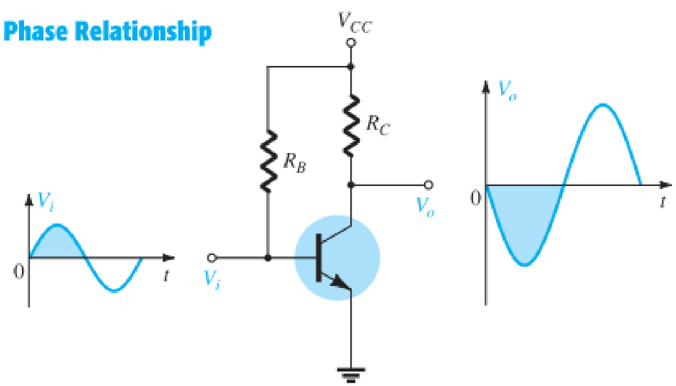


FIG. 5.24
Demonstrating the 180° phase shift between input and output waveforms.

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

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

$$Z_o = R_C \| r_o \quad \text{ohms}$$

$$Z_o \cong R_C \quad r_o \geq 10R_C$$

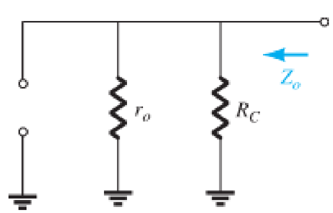


FIG. 5.23
Determining Z_o for the network of Fig. 5.22.

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

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

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

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

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

Voltage-Divider Bias

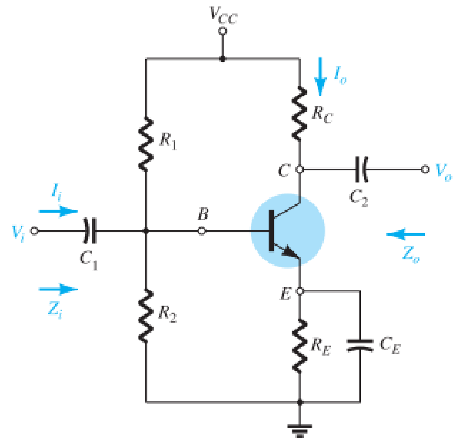


FIG. 5.26
Voltage-divider bias configuration.

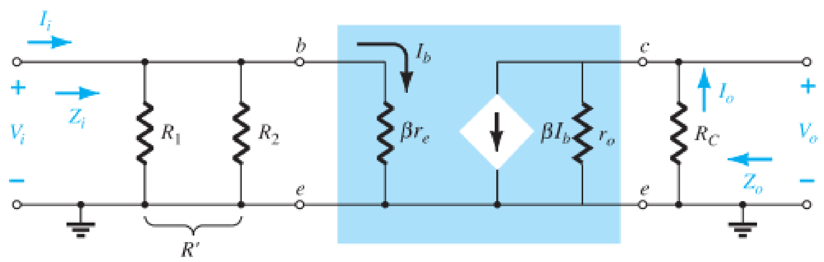


FIG. 5.27
Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 5.26.

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

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

$$Z_o = R_C \| r_o$$

$$Z_o \cong R_C \quad r_o \geq 10 R_C$$

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

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

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

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

180° phase shift

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

C.E. Emitter Bias Configuration

Unbypassed

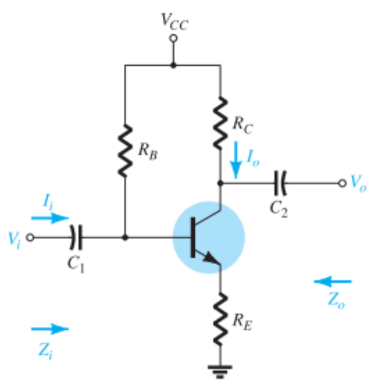


FIG. 5.29
CE emitter-bias configuration.

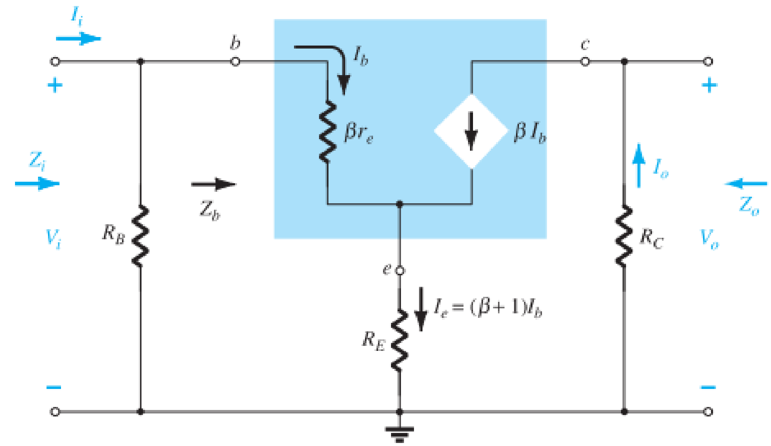


FIG. 5.30
Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 5.29.

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

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

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

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

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

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

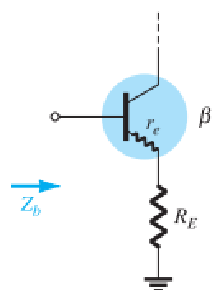


FIG. 5.31
Defining the input impedance of a transistor with an unbypassed emitter resistor.

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

$$\boxed{Z_o = R_C}$$

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

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

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

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

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

$$Z_b \cong \beta R_E$$

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

180° phase shift

C.E. Emitter Bias Configuration..

Effect of r_o

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

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

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

$$Z_b \cong \beta(r_e + R_E) \quad r_o \geq 10(R_C+R_E)$$

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

$r_o \gg r_e$,

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

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

Typically $1/\beta$ and r_e/R_E are less than one with a sum usually less than one.

$$Z_o \cong R_C \quad \text{Any level of } r_o$$

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

$\frac{r_e}{r_o} \ll 1$,

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

$r_o \geq 10R_C$,

$$A_v = \frac{V_o}{V_i} \cong -\frac{\beta R_C}{Z_b} \quad r_o \geq 10R_C$$

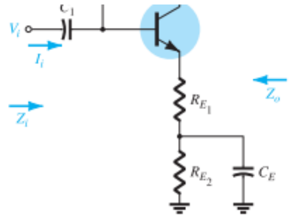


FIG. 5.35
An emitter-bias configuration with a portion of the emitter-bias resistance bypassed in the ac domain.

Bypassed

Same as CE fixed bias config.

Emitter Follower Configuration

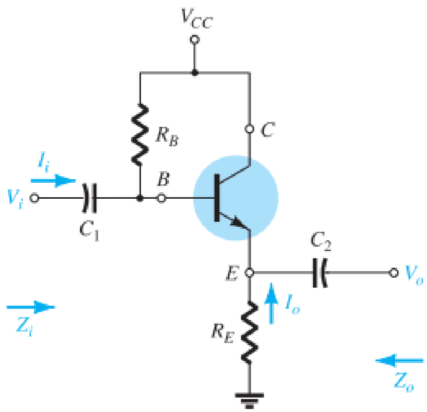


FIG. 5.36
Emitter-follower configuration.

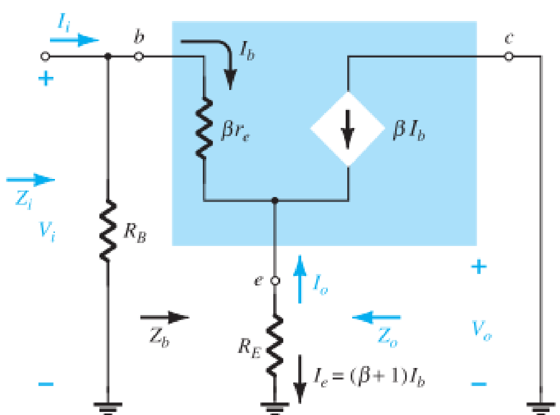


FIG. 5.37
Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 5.36.

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

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

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

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

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

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

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

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

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

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

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

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

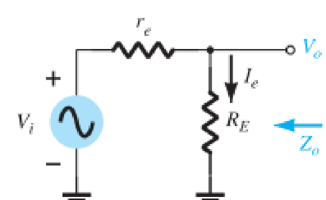


FIG. 5.38
Defining the output impedance for the emitter-follower configuration.

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

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

Because R_E is usually much greater than r_e,

$$R_E + r_e \cong R_E$$

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

in phase

Emitter Follower Configuration..

Effect of r_o

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

$$r_o \geq 10R_E$$

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

$$Z_b \cong \beta(r_e + R_E) \quad r_o \geq 10R_E$$

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

$$Z_o = r_o \| R_E \| r_e$$

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

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

$$A_v \cong \frac{\beta R_E}{Z_b}$$

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

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

$$A_v \cong \frac{R_E}{r_e + R_E} \quad r_o \geq 10R_E$$

Common-Base Configuration

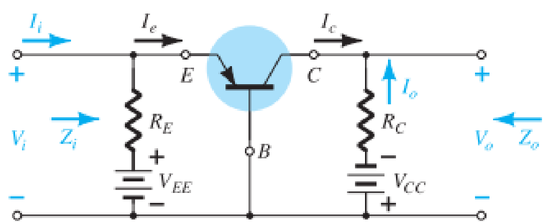


FIG. 5.42
Common-base configuration.

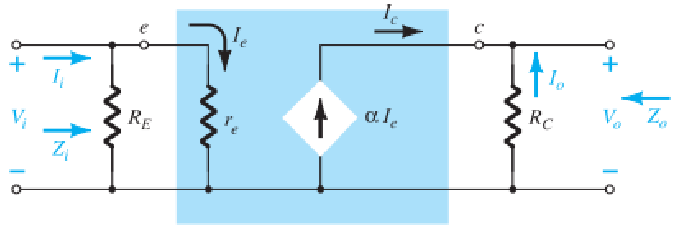


FIG. 5.43
Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 5.44.

$$Z_i = R_E \| r_e$$

$$Z_o = R_C$$

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

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

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

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

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 $r_o \| R_C \cong R_C$.

Collector-Feedback Configuration

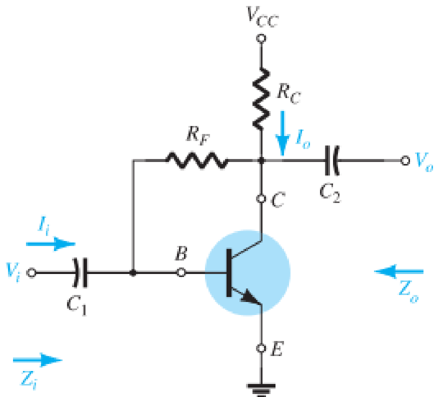


FIG. 5.45
Collector feedback configuration.

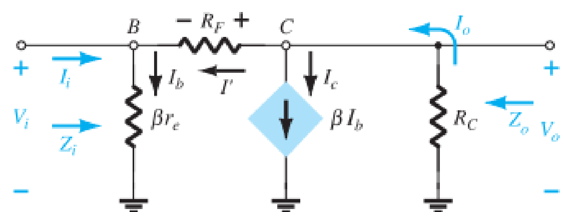


FIG. 5.46
Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 5.45.

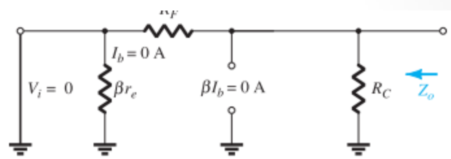


FIG. 5.47
Defining Z_o for the collector feedback configuration.

$$Z_o \cong R_C \| R_F$$

$$I_o = I' + \beta I_b$$

$$I' = \frac{V_o - V_i}{R_F}$$

$$V_o = -I_o R_C = -(I' + \beta I_b)R_C$$

$$V_i = I_b \beta r_e$$

$$I' = -\frac{(I' + \beta I_b)R_C - I_b\beta r_e}{R_F} = -\frac{I'R_C}{R_F} - \frac{\beta I_b R_C}{R_F} - \frac{I_b \beta r_e}{R_F}$$

$$I'\left(1 + \frac{R_C}{R_F}\right) = -\beta I_b \frac{(R_C + r_e)}{R_F}$$

$$I' = -\beta I_b \frac{(R_C + r_e)}{R_C + R_F}$$

$$I_i = I_b - I' = I_b + \beta I_b \frac{(R_C + r_e)}{R_C + R_F}$$

$$I_i = I_b\left(1 + \beta\frac{(R_C + r_e)}{R_C + R_F}\right)$$

$$Z_i = \frac{V_i}{I_i} = \frac{I_b \beta r_e}{I_b\left(1 + \beta\dfrac{(R_C + r_e)}{R_C + R_F}\right)} = \frac{\beta r_e}{1 + \beta\dfrac{(R_C + r_e)}{R_C + R_F}}$$

$R_C \gg r_e$

$$Z_i = \frac{\beta r_e}{1 + \dfrac{\beta R_C}{R_C + R_F}}$$

$$Z_i = \frac{r_e}{\dfrac{1}{\beta} + \dfrac{R_C}{R_C + R_F}}$$

$$V_o = -I_o R_C = -(I' + \beta I_b)R_C$$

$$= -\left(-\beta I_b \frac{(R_C + r_e)}{R_C + R_F} + \beta I_b\right)R_C$$

$$V_o = -\beta I_b\left(1 - \frac{(R_C + r_e)}{R_C + R_F}\right)R_C$$

$$A_v = \frac{V_o}{V_i} = \frac{-\beta I_b\left(1 - \dfrac{(R_C + r_e)}{R_C + R_F}\right)R_C}{\beta r_e I_b}$$

$$= -\left(1 - \frac{(R_C + r_e)}{R_C + R_F}\right)\frac{R_C}{r_e}$$

$$A_v = -\left(1 - \frac{R_C}{R_C + R_F}\right)\frac{R_C}{r_e}$$

$$A_v = -\frac{(R_C + R_F - R_C)}{R_C + R_F}\frac{R_C}{r_e}$$

$$A_v = -\left(\frac{R_F}{R_C + R_F}\right)\frac{R_C}{r_e}$$

$$A_v \cong -\frac{R_C}{r_e}$$

180° phase shift

Collector-Feedback Configuration..

Effect of r_o

$$Z_i = \frac{1 + \dfrac{R_C \| r_o}{R_F}}{\dfrac{1}{\beta r_e} + \dfrac{1}{R_F} + \dfrac{R_C \| r_o}{\beta r_e R_F} + \dfrac{R_C \| r_o}{R_F r_e}}$$

$r_o \geq 10R_C$

$$Z_i = \frac{1 + \dfrac{R_C}{R_F}}{\dfrac{1}{\beta r_e} + \dfrac{1}{R_F} + \dfrac{R_C}{\beta r_e R_F} + \dfrac{R_C}{R_F r_e}} = \frac{r_e\left[1 + \dfrac{R_C}{R_F}\right]}{\dfrac{1}{\beta} + \dfrac{1}{R_F}\left[r_e + \dfrac{R_C}{\beta} + R_C\right]}$$

Applying $R_C \gg r_e$ and $\dfrac{R_C}{\beta}$,

$$Z_i \cong \frac{r_e\left[1 + \dfrac{R_C}{R_F}\right]}{\dfrac{1}{\beta} + \dfrac{R_C}{R_F}} = \frac{r_e\left[\dfrac{R_F + R_C}{\cancel{R_F}}\right]}{\dfrac{R_F + \beta R_C}{\beta \cancel{R_F}}} = \frac{r_e}{\dfrac{1}{\beta}\left(\dfrac{R_F}{R_F + R_C}\right) + \dfrac{R_C}{R_C + R_F}}$$

but, since R_F typically $\gg R_C$, $R_F + R_C \cong R_F$ and $\dfrac{R_F}{R_F + R_C} = 1$

$$Z_i \cong \frac{r_e}{\dfrac{1}{\beta} + \dfrac{R_C}{R_C + R_F}}$$ $r_o \gg R_C,\ R_F > R_C$

$$Z_o = r_o \| R_C \| R_F$$

For $r_o \geq 10R_C$,

$$Z_o \cong R_C \| R_F$$ $r_o \geq 10R_C$

$$Z_o \cong R_C$$ $r_o \geq 10R_C, R_F \gg R_C$

$$A_v = -\left(\frac{R_F}{R_C \| r_o + R_F}\right)\frac{R_C \| r_o}{r_e}$$

For $r_o \geq 10R_C$,

$$A_v \cong -\left(\frac{R_F}{R_C + R_F}\right)\frac{R_C}{r_e}$$ $r_o \geq 10R_C$

and for $R_F \gg R_C$

$$A_v \cong -\frac{R_C}{r_e}$$ $r_o \geq 10R_C,\ R_F \geq R_C$

Collector DC Feedback Configuration

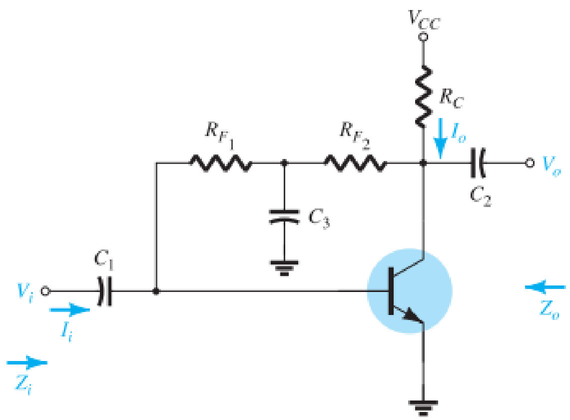


FIG. 5.50
Collector dc feedback configuration.

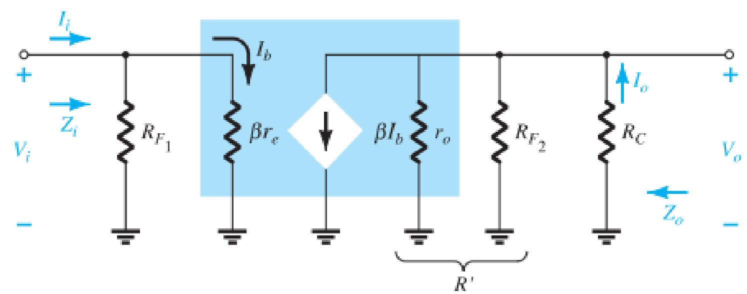


FIG. 5.51
Substituting the r_e equivalent circuit into the ac equivalent network of Fig. 5.50.

$$Z_i = R_{F_1} \| \beta r_e$$

$$Z_o = R_C \| R_{F_2} \| r_o$$

$$Z_o \cong R_C \| R_{F_2} \quad r_o \geq 10R_C$$

$$R' = r_o \| R_{F_2} \| R_C$$

$$V_o = -\beta I_b R'$$

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

$$V_o = -\beta \frac{V_i}{\beta r_e} R'$$

$$A_v = \frac{V_o}{V_i} = -\frac{r_o \| R_{F_2} \| R_C}{r_e}$$

$$A_v = \frac{V_o}{V_i} \cong -\frac{R_{F_2} \| R_C}{r_e} \quad r_o \geq 10R_C$$

180° phase shift

EFFECT OF R_L AND R_S (SYSTEM APPROACH)

Effect of R_L and R_s

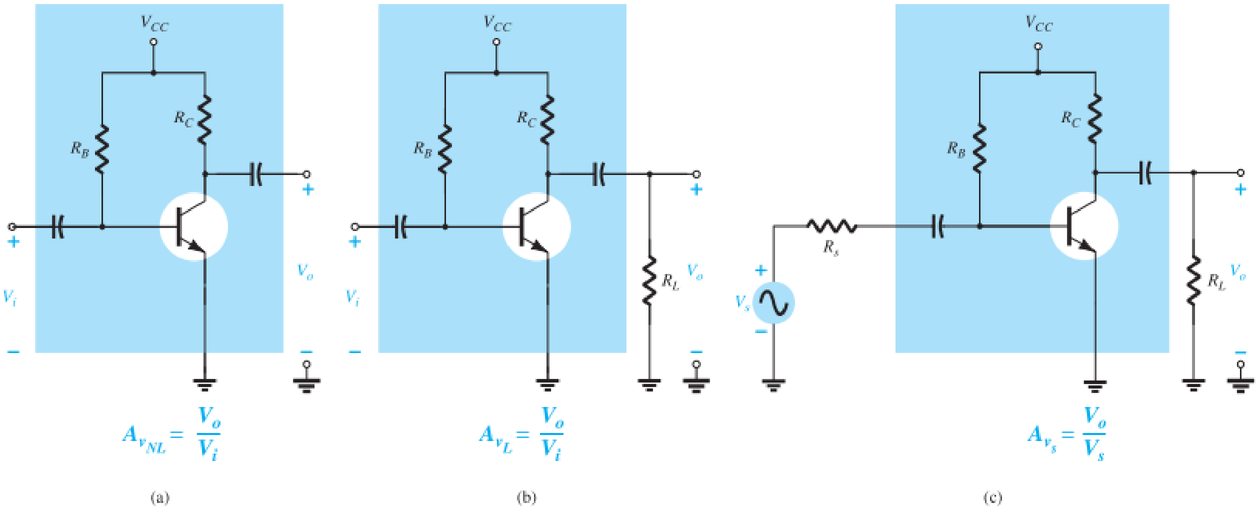


FIG. 5.54
Amplifier configurations: (a) unloaded; (b) loaded; (c) loaded with a source resistance.

$$A_{v_{NL}} = \frac{V_o}{V_i}$$

$$A_{v_L} = \frac{V_o}{V_i} \quad \text{with } R_L$$

$$A_{v_s} = \frac{V_o}{V_s} \quad \text{with } R_L \text{ and } R_s$$

- The loaded voltage gain of an amplifier is always less than the no-load gain.
- The gain obtained with a source resistance in place will always be less than that obtained under loaded or unloaded conditions due to the drop in applied voltage across the source resistance.
- For the same configuration $A_{vNL} > A_{vL} > A_{vs}$.
- For a particular design, the larger the level of R L , the greater is the level of ac gain.
- For a particular amplifier, the smaller the internal resistance of the signal source, the greater is the overall gain.
- For any network that have coupling capacitors, the source and load resistance do not affect the dc biasing levels.

Effect of R_L and R_s ..

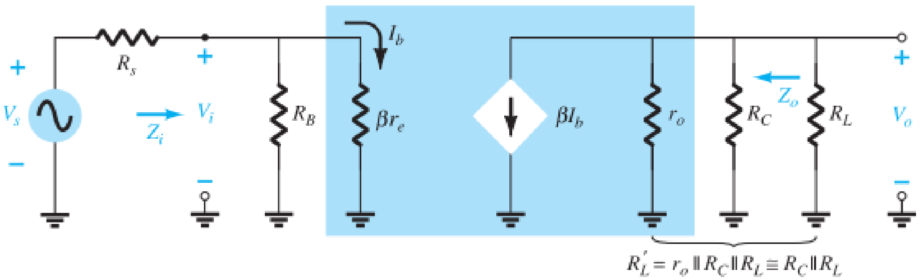


FIG. 5.55
The ac equivalent network for the network of Fig. 5.54c.

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

$$V_i = \frac{Z_i V_s}{Z_i + R_s}$$
$$\frac{V_i}{V_s} = \frac{Z_i}{Z_i + R_s}$$
$$A_{v_S} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_s} = A_{v_L} \frac{Z_i}{Z_i + R_s}$$

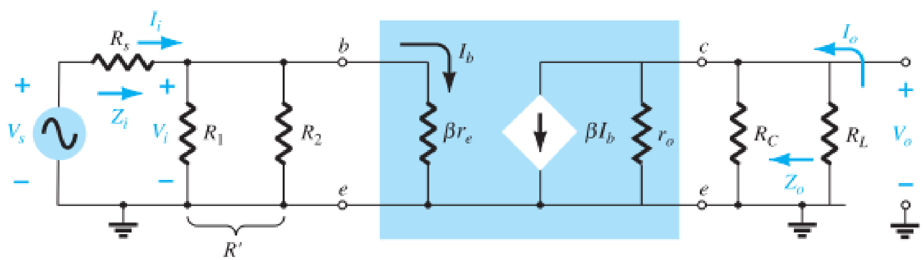
$$A_{v_L} = \frac{V_o}{V_i} = -\frac{R_C \| R_L}{r_e}$$

$$A_{v_S} = \frac{Z_i}{Z_i + R_s} A_{v_L}$$

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

$$Z_o = R_C \| r_o$$

Voltage-divider ct.



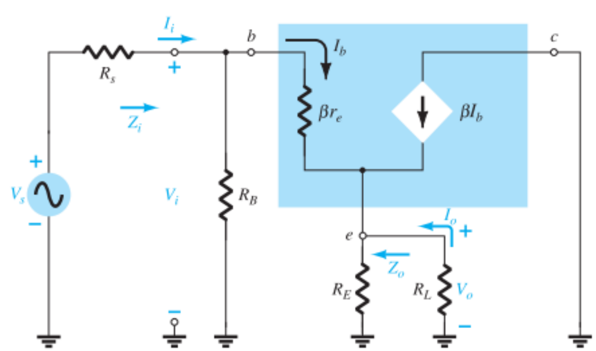
$$A_{v_L} = \frac{V_o}{V_i} = -\frac{R_C \| R_L}{r_e}$$

$$Z_i = R_1 \| R_2 \| \beta r_e$$

$$Z_o = R_C \| r_o$$

$$A_{v_L} = \frac{V_o}{V_i} = \frac{R_E \| R_L}{R_E \| R_L + r_e}$$

Emitter-Follower Ct.



$$Z_i = R_B \| Z_b$$

$$Z_b \cong \beta(R_E \| R_L)$$

$$Z_o \cong r_e$$

DETERMINING THE CURRENT GAIN

Determining the Current gain

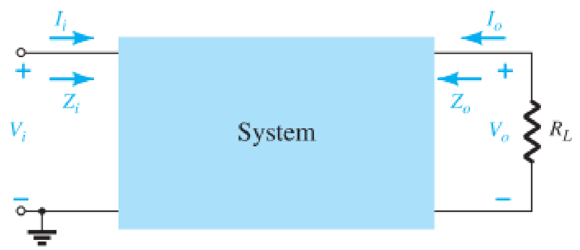


FIG. 5.60
Determining the current gain using the voltage gain.

- For each transistor configuration, the current gain can be determined directly from the voltage gain, the defined load, and the input impedance.

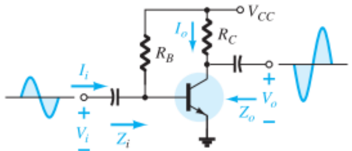
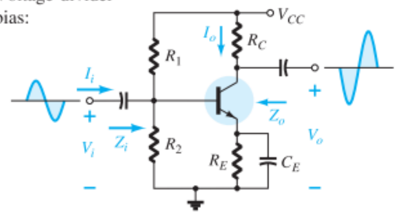
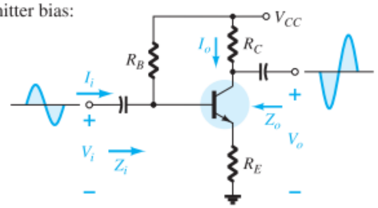
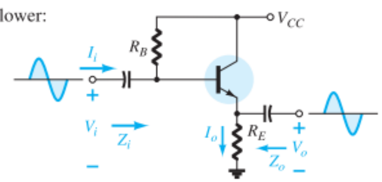
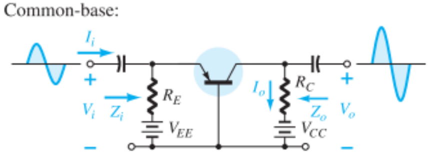
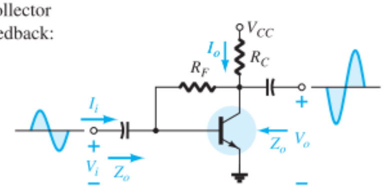
$$A_i = \frac{I_o}{I_i}$$

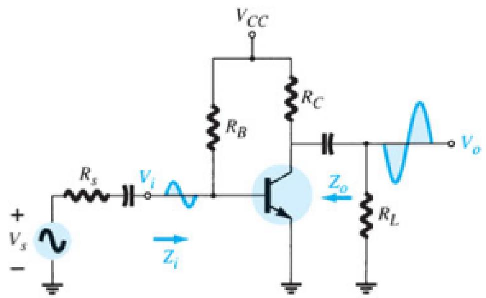
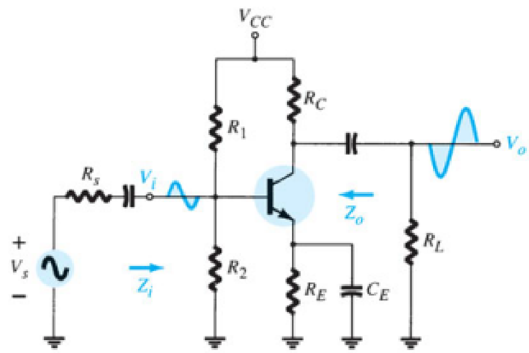
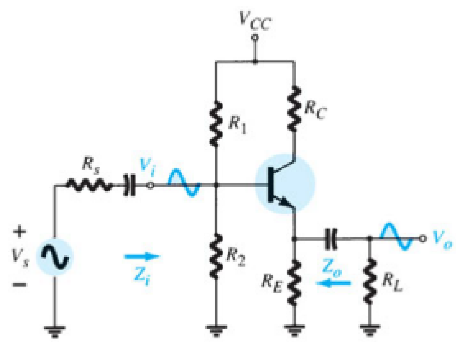
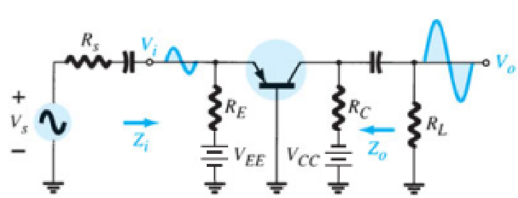
$$I_i = \frac{V_i}{Z_i} \quad \text{and} \quad I_o = -\frac{V_o}{R_L}$$

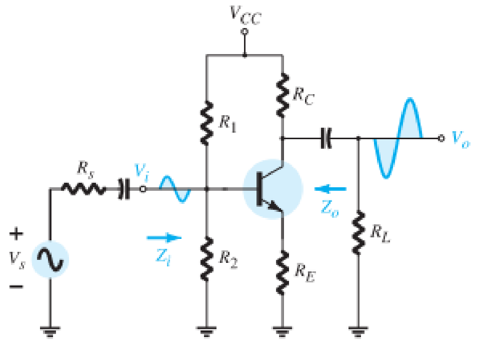
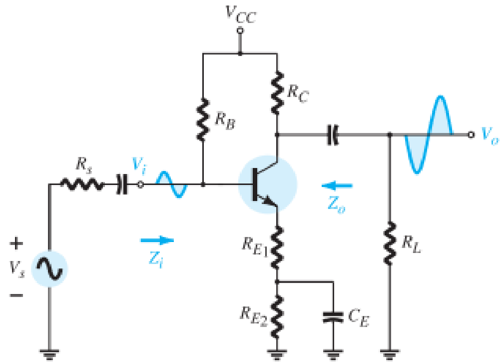
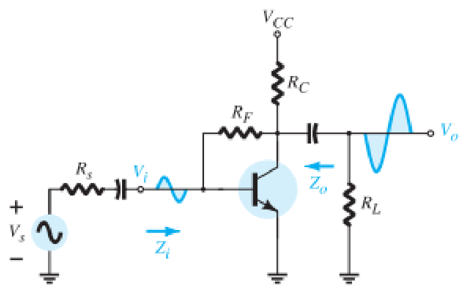
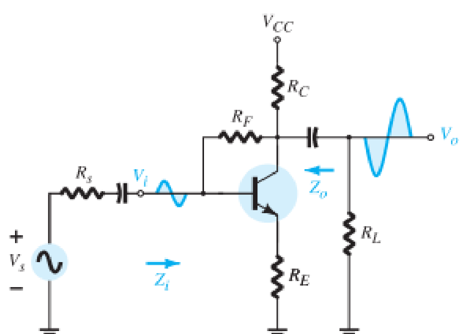
$$A_{i_L} = \frac{I_o}{I_i} = \frac{-\dfrac{V_o}{R_L}}{\dfrac{V_i}{Z_i}} = -\frac{V_o}{V_i} \cdot \frac{Z_i}{R_L}$$

$$\boxed{A_{i_L} = -A_{v_L}\frac{Z_i}{R_L}}$$

SUMMARY TABLE

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) $\cong -\frac{\beta R_B}{R_B + Z_b}$
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 (≅1) $= \frac{R_E}{R_E + r_e}$ $\cong 1$	High (−50) $\cong -\frac{\beta R_B}{R_B + Z_b}$
Common-base: 	Low (20 Ω) $= R_E \| r_e$ $\cong r_e$ $(R_E \gg r_e)$	Medium (2 kΩ) $= R_C$	High (200) $\cong \frac{R_C}{r_e}$	Low (−1) $\cong -1$
Collector feedback: 	Medium (1 kΩ) $= \frac{r_e}{\frac{1}{\beta} + \frac{R_C}{R_F}}$ $(r_o \geq 10R_C)$	Medium (2 kΩ) $\cong R_C \| R_F$ $(r_o \geq 10R_C)$	High (−200) $\cong -\frac{R_C}{r_e}$ $(r_o \geq 10R_C)$ $(R_F \gg R_C)$	High (50) $= \frac{\beta R_F}{R_F + \beta R_C}$ $\cong \frac{R_F}{R_C}$

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

	$\frac{-(R_L \| R_C)}{R_E}$	$R_1 \| R_2 \| \beta(r_e + R_E)$	R_C
	Including r_o: $\frac{-(R_L \| R_C)}{R_E}$	$R_1 \| R_2 \| \beta(r_e + R_e)$	$\cong R_C$
	$\frac{-(R_L \| R_C)}{R_{E_1}}$	$R_B \| \beta(r_e + R_{E_1})$	R_C
	Including r_o: $\frac{-(R_L \| R_C)}{R_{E_1}}$	$R_B \| \beta(r_e + R_E)$	$\cong R_C$
	$\frac{-(R_L \| R_C)}{r_e}$	$\beta r_e \| \frac{R_F}{\|A_v\|}$	R_C
	Including r_o: $\frac{-(R_L \| R_C \| r_o)}{r_e}$	$\beta r_e \| \frac{R_F}{\|A_v\|}$	$R_C \| R_F \| r_o$
	$\frac{-(R_L \| R_C)}{R_E}$	$\beta R_E \| \frac{R_F}{\|A_v\|}$	$\cong R_C \| R_F$
	Including r_o: $\cong \frac{-(R_L \| R_C)}{R_E}$	$\cong \beta R_E \| \frac{R_F}{\|A_v\|}$	$\cong R_C \| R_F$

- For more details, refer to:
  - Chapter 5 at R. Boylestad, **Electronic Devices and Circuit Theory**, 11th edition, Prentice Hall.
- The lecture is available online at:
  - http://bu.edu.eg/staff/ahmad.elbanna-courses/11966
- For inquires, send to:
  - ahmad.elbanna@fes.bu.edu.eg