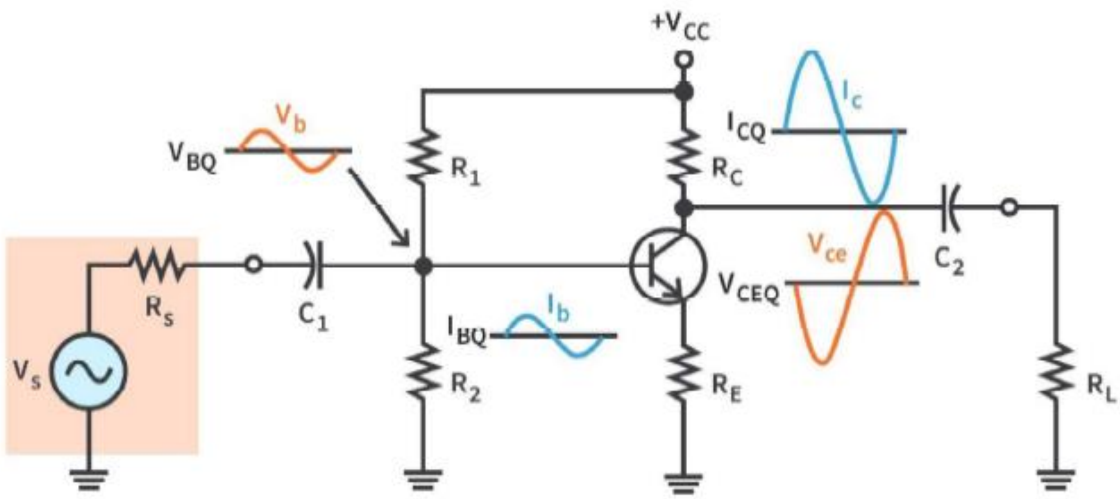
Al-Mustaqbal University
College of Engineering and Technologies
Medical Instrumentation Technique Engineering Department
Class: 2nd
Subject: Electronic Circuits
Lecturer: Dr. Rami Qays Malik
Lecture: 11- Small-Signal Amplifier

Small-Signal Amplifier



The basic construction, appearance, and characteristics of the transistor were introduced in Chapter 3 .We now begin to examine the ac response of the BJT amplifier by reviewing the *models* most frequently used to represent the transistor in the sinusoidal ac domain.

One of our first concerns in the sinusoidal ac analysis of transistor networks is the magnitude of the input signal. It will determine whether *small-signal* or *large-signal* techniques should be applied. There is no set dividing line between the two, but the application—and the magnitude of the variables of interest relative to the scales of the device characteristics will usually make it quite clear which method is appropriate. The small-signal technique is introduced in this Lecture.

There are three models commonly used in the small-signal ac analysis of transistor networks: the ***re*** **model, the hybrid p model, and the hybrid equivalent model**.

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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 steps1 and 2

4. Redrawing the network in a more convenient and logical form

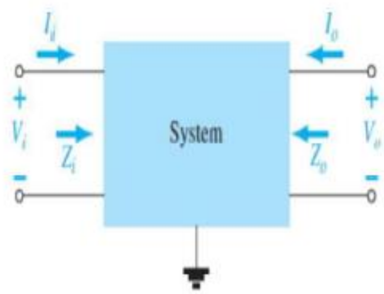


FIG. 5.5
Defining the important parameters of any system.

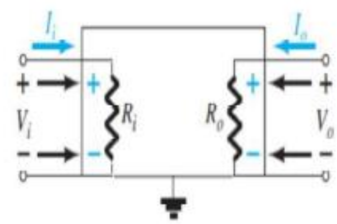
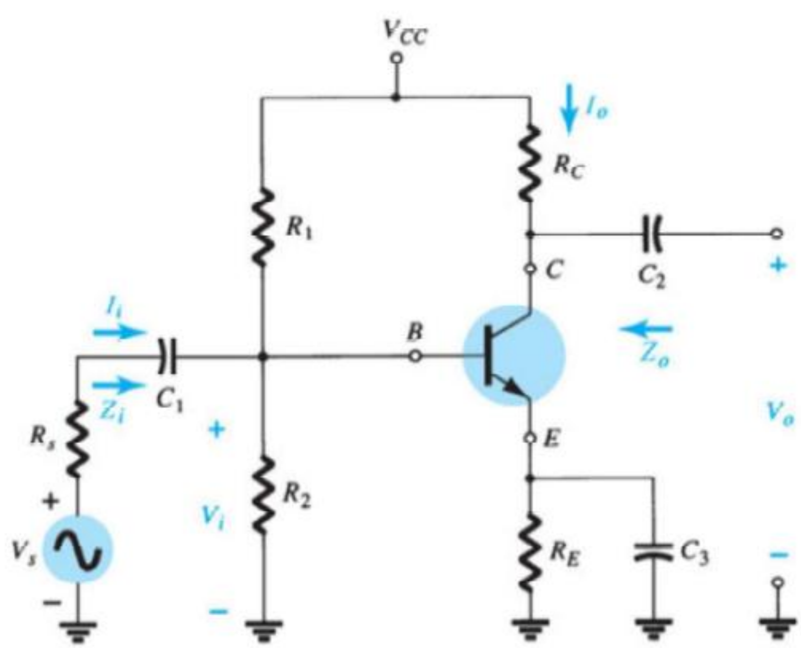


FIG. 5.6
Demonstrating the reason for the defined directions and polarities.



re model:

The re model for the CE, CB, and CC BJT transistor configurations will now be introduced with a short description of why each is a good approximation to the actual behavior of a BJT transistor.

Common-Emitter Configuration

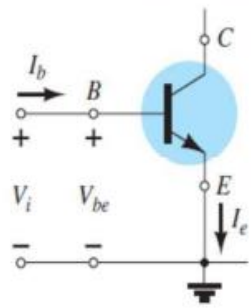


FIG. 5.8
Finding the input equivalent circuit for a BJT transistor.

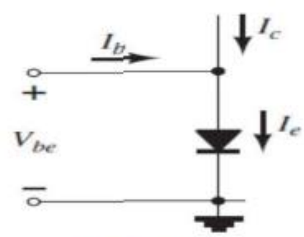


FIG. 5.10
Equivalent circuit for the input side of a BJT transistor.

Now, for the input side: $Z_i = \dfrac{V_i}{I_b} = \dfrac{V_{be}}{I_b}$

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

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

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

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

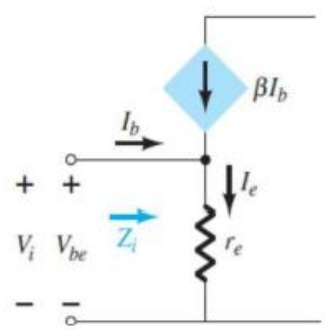


FIG. 5.13
Defining the level of Z_i.

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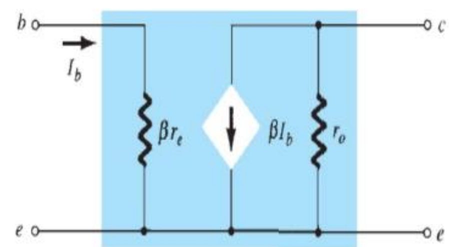
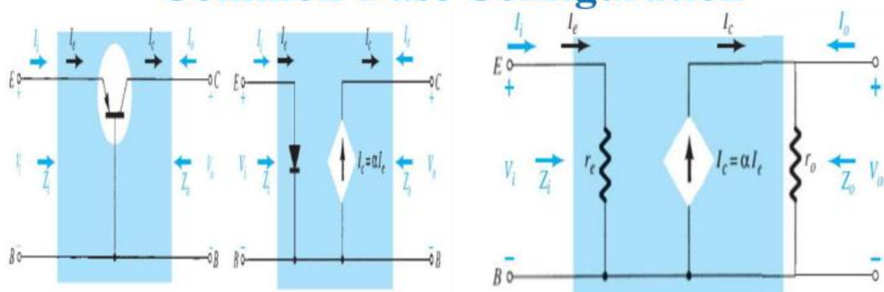
output impedance

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

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



Common-Base Configuration



COMMON-EMITTER FIXED-BIAS CONFIGURATION

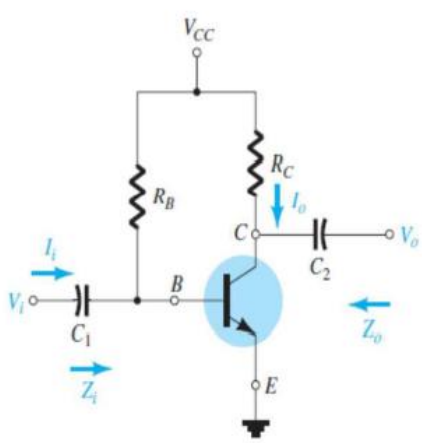


FIG. 5.20
Common-emitter fixed-bias configuration.

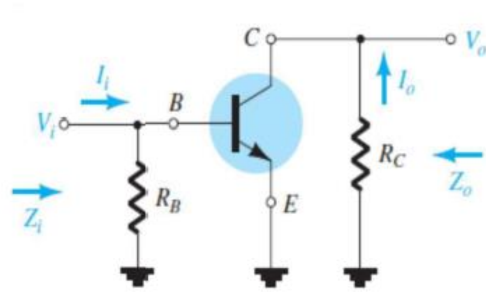


FIG. 5.21
Network of Fig. 5.20 following the removal of the effects of V_{CC}, C_1, and C_2.

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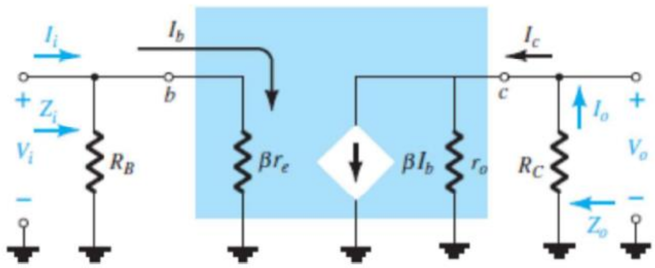
The equivalent network of common-emitter fixed bias can be redrawn as the following



Z_i Figure 5.22 clearly shows that

$$Z_i = R_B \| \beta r_e \quad \text{ohms} \tag{5.5}$$

For the majority of situations R_B is greater than βr_e by more than a factor of 10 (recall from the analysis of parallel elements that the total resistance of two parallel resistors is always less than the smallest and very close to the smallest if one is much larger than the other), permitting the following approximation:

$$Z_i \cong \beta r_e \Big|_{R_B \geq 10\beta r_e} \quad \text{ohms} \tag{5.6}$$

Z_o Recall that the output impedance of any system is defined as the impedance Z_o determined when $V_i = 0$. For Fig. 5.22, when $V_i = 0$, $I_i = I_b = 0$, resulting in an open-circuit equivalence for the current source. The result is the configuration of Fig. 5.23. We have

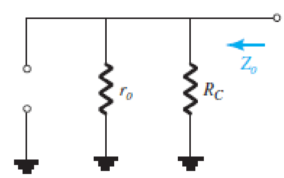


FIG. 5.23
Determining Z_o for the network of Fig. 5.22.

$$Z_o = R_C \| r_o \quad \text{ohms} \tag{5.7}$$

If $r_o \geq 10R_C$, the approximation $R_C \| r_o \cong R_C$ is frequently applied, and

$$Z_o \cong R_C \Big|_{r_o \geq 10R_C} \tag{5.8}$$

A_v The resistors r_o and R_C are in parallel, and

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

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

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

and
$$A_v = \frac{V_o}{V_i} = -\frac{(R_C \| r_o)}{r_e} \tag{5.9}$$

If $r_o \geq 10R_C$, so that the effect of r_o can be ignored,

$$A_v = -\frac{R_C}{r_e} \Big|_{r_o \geq 10R_C} \tag{5.10}$$

Note the explicit absence of β in Eqs. (5.9) and (5.10), although we recognize that β must be utilized to determine r_e.

EXAMPLE 5.1 For the network of Fig. 5.25:

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. Repeat parts (c) and (d) including $r_o = 50\text{ k}\Omega$ in all calculations and compare results.

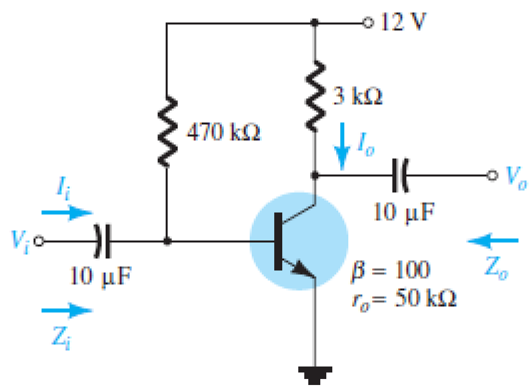


FIG. 5.25
Example 5.1.

Solution:

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. $\beta r_e = (100)(10.71\ \Omega) = 1.071\text{ k}\Omega$

$$Z_i = R_B \| \beta r_e = 470\text{ k}\Omega \| 1.071\text{ k}\Omega = \mathbf{1.07\text{ k}\Omega}$$

c. $Z_o = R_C = \mathbf{3\text{ k}\Omega}$

d. $A_v = -\dfrac{R_C}{r_e} = -\dfrac{3\text{ k}\Omega}{10.71\ \Omega} = \mathbf{-280.11}$

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

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

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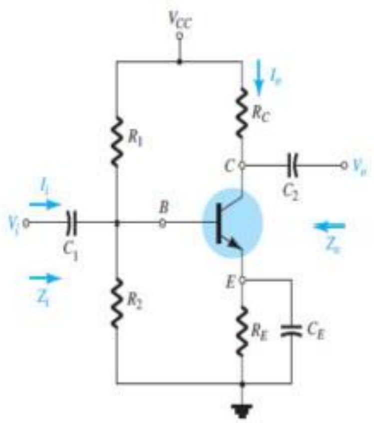
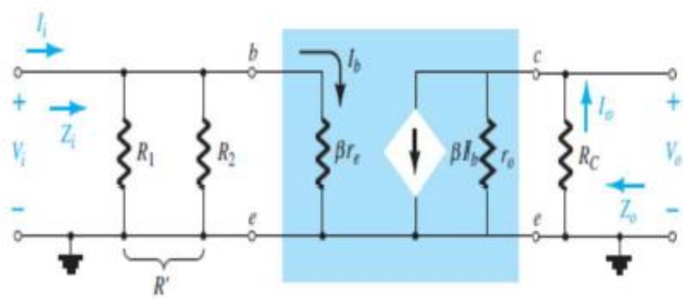
VOLTAGE-DIVIDER BIAS





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

Input impedance

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

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Zo From Fig below with Vi set to 0 V, resulting in Ib = 0 mA and βI_b = 0 mA

$$Z_o = R_C \| r_o \quad (5.13)$$

If $r_o \geq 10R_C$,

$$Z_o \cong R_C \Big|_{r_o \geq 10R_C} \quad (5.14)$$

A_v Because R_C and r_o are in parallel,

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

and

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

so that

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

and

$$A_v = \frac{V_o}{V_i} = \frac{-R_C \| r_o}{r_e} \quad (5.15)$$

which you will note is an exact duplicate of the equation obtained for the fixed-bias configuration.

For $r_o \geq 10R_C$,

$$A_v = \frac{V_o}{V_i} \cong -\frac{R_C}{r_e} \Big|_{r_o \geq 10R_C} \quad (5.16)$$

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EXAMPLE 5.2 For the network of Fig. 5.28, determine:

a. r_e.
b. Z_i.
c. Z_o $(r_o = \infty\,\Omega)$.
d. A_v $(r_o = \infty\,\Omega)$.
e. The parameters of parts (b) through (d) if $r_o = 50\,k\Omega$ and compare results.

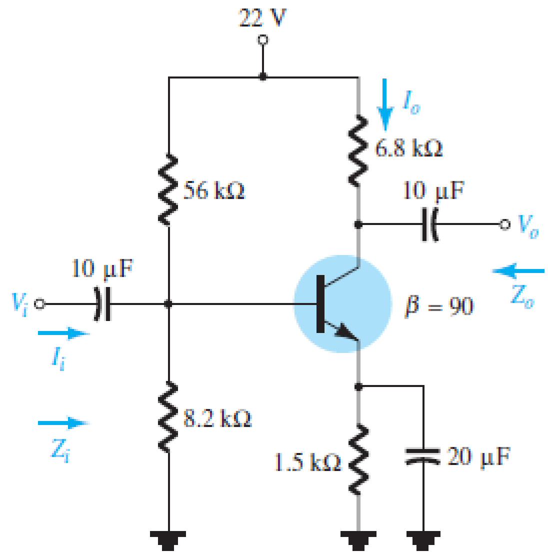

FIG. 5.28
Example 5.2.

Solution:

a. DC: Testing $\beta R_E > 10R_2$,

$$(90)(1.5\,k\Omega) > 10(8.2\,k\Omega)$$

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

Using the approximate approach, we obtain

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

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

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

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

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

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

$A_v = -\dfrac{R_C \| r_o}{r_e} = -\dfrac{5.98\,\text{k}\Omega}{18.44\,\Omega} = \mathbf{-324.3}$ 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.

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