Transistor

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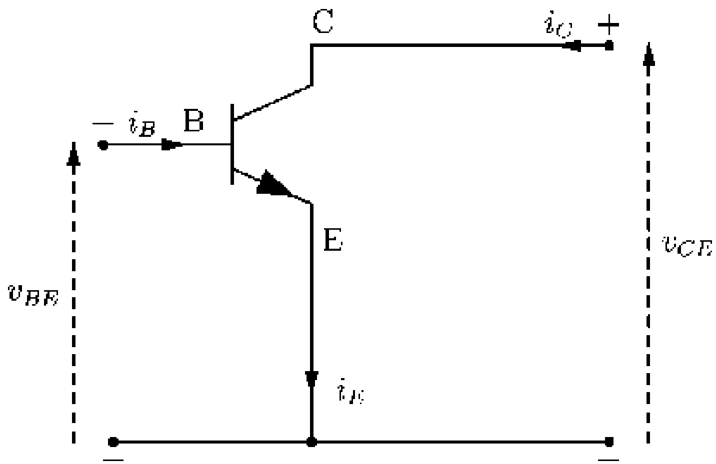
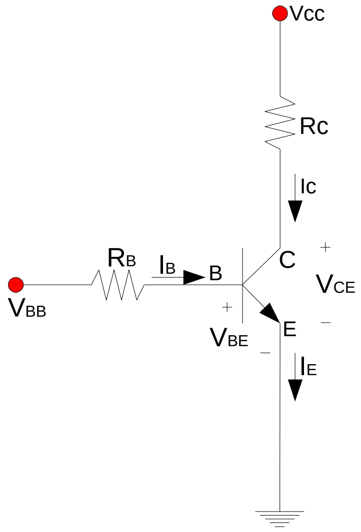
BJT Transistors

- A transistor is a device which acts like a controlled valve. The current flow permitted can be controlled.

- The bipolar junction transistor (BJT) is a three-terminal electronic valve - the output (collector) terminal current-voltage characteristics are controlled by the current injected into the input port (base). The BJT is a semiconductor device constructed from two pn junctions. There are two types of BJT: pnp and npn. Figures 1 and 2 show the circuit symbols and common current and voltage polarities during normal (active) operation.



DC Analiz



$$V_{CC} = R_C * I_C + V_{CE}$$

$$V_{BB} = R_B * I_B + V_{BE}$$

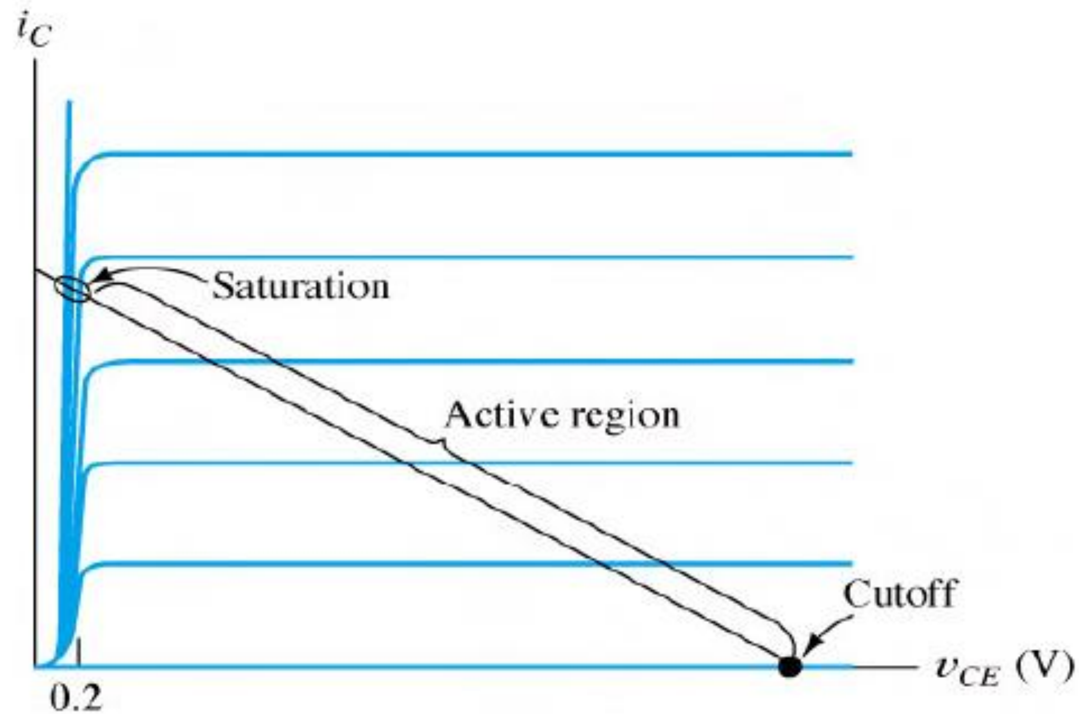
$$I_C = \beta * I_B$$

$$I_{C\,SAT} = \frac{V_{CC}}{R_C}$$

$$I_B = \frac{V_{BB} - V_{BE}}{R_B}$$

$$V_{CE} \le 0\,V \quad ya\ da \quad I_c \ge I_{c\,SAT} \quad ;Saturasyon \quad V_{CE} = 0V \quad Olur.$$

$$I_B \le 0\,A \quad ise \quad ;Kesmede \quad I_B = I_C = 0A \quad Olur.$$



Amplification occurs in the active region. Clipping occurs when the instantaneous operating point enters saturation or cutoff. In saturation, $v_{CE} < 0.2$ V.

- Current Relationship

$$i_E = i_C + i_B$$
$$i_C = \beta i_B$$
$$i_E = (1+\beta) i_B$$
$$i_C = \frac{\beta}{1+\beta} i_E = \alpha i_E$$
$$\alpha = \frac{\beta}{1+\beta}$$
$$\beta = \frac{\alpha}{1-\alpha}$$

- Common Emitter (cont'd)

Base current

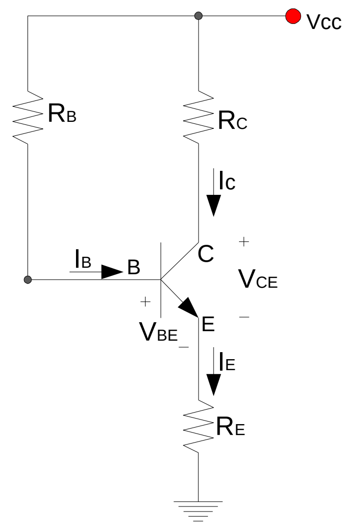
$$I_B = \frac{V_{BB} - V_{BE}(\text{on})}{R_B}$$

C-E Portion

$$I_C = \beta I_B$$
$$V_{CC} = I_C R_C + V_{CE}$$
$$V_{CE} = V_{CC} - I_C R_C$$

Power Dissipation

$$PT = I_B V_{BE}(\text{on}) + I_C V_{CE}$$
$$PT \cong I_C V_{CE}$$



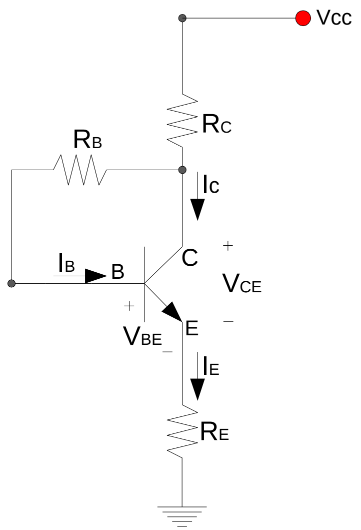
$$V_{CC} = R_C * I_C + V_{CE} + R_E * I_E$$

$$V_{CC} = R_B * I_B + V_{BE} + R_E * I_E$$

$$I_C = \beta * I_B$$

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

$$I_E = I_C + \frac{I_C}{\beta} = (\frac{1+\beta}{\beta}) * I_C$$



$$V_{CC} = R_C * (I_C + I_B) + V_{CE} + R_E * I_E$$

$$V_{CC} = R_C * (I_C + I_B) + R_B * I_B + V_{BE} + R_E * I_E$$

$$I_C = \beta * I_B$$

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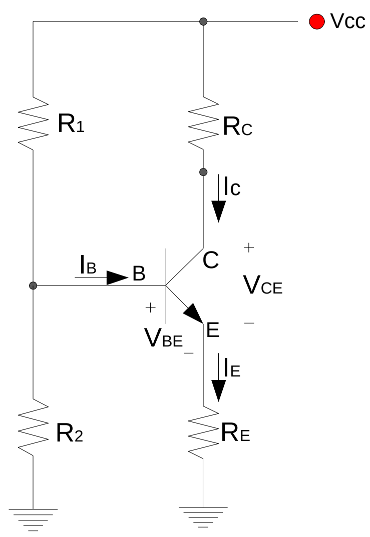
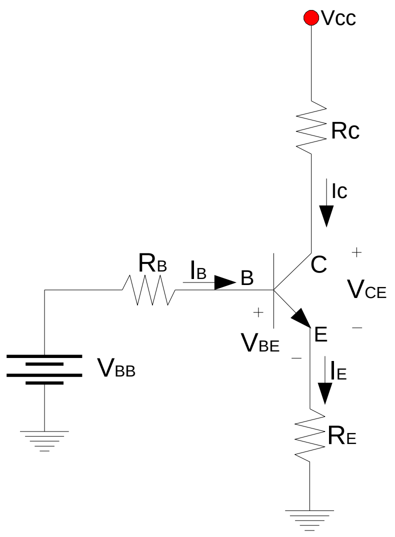




$$V_{BB} = V_{CC} * \frac{R_2}{R_1 + R_2} \qquad R_B = \frac{R_1 * R_2}{R_1 + R_2}$$

$$V_{CC} = R_C * I_C + V_{CE} + R_E * I_E$$

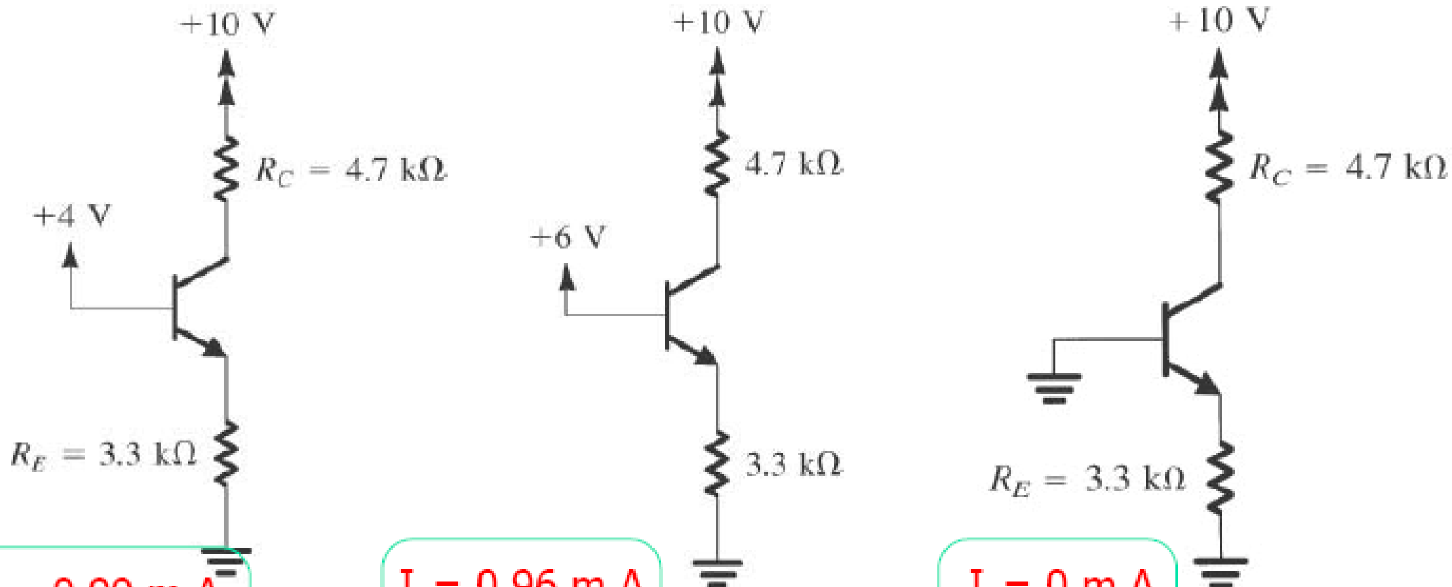
$$V_{BB} = R_B * I_B + V_{BE} + R_E * I_E$$

$$I_C = \beta * I_B$$

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

$$I_E = I_C + \frac{I_C}{\beta} = (\frac{1+\beta}{\beta}) * I_C$$

Calculate the transistor operating point (I_C , V_{CE}) in the following circuits assuming β=100, V_{BE} = 0.7V and V_{CEsat} = 0.2 V. What is the region of operation?

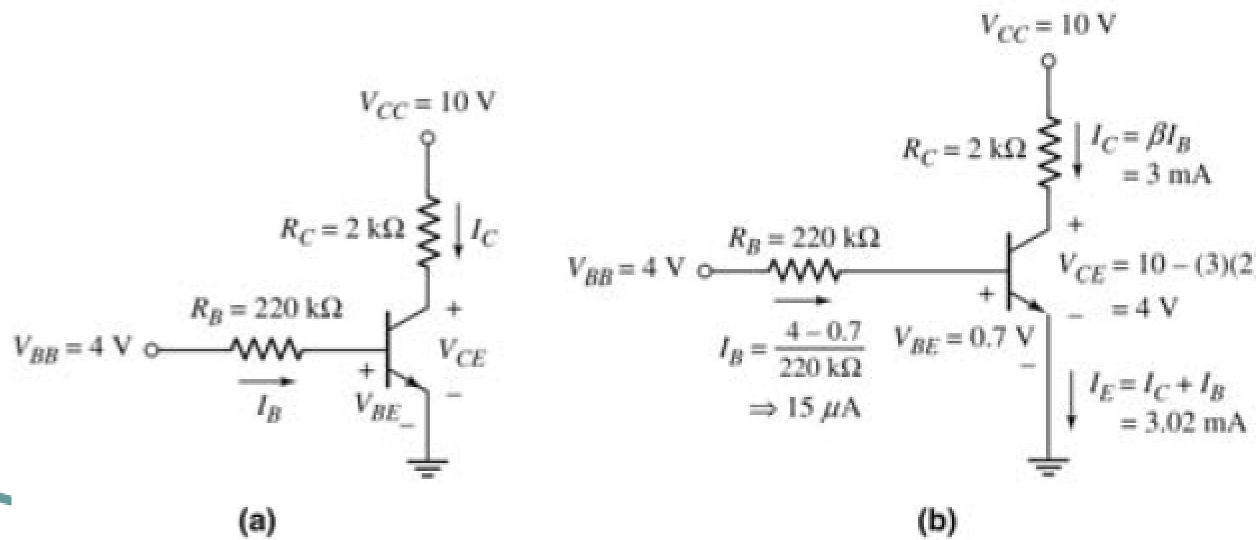


I_C= 0.99 m.A
V_{CE}= 2 V
Active

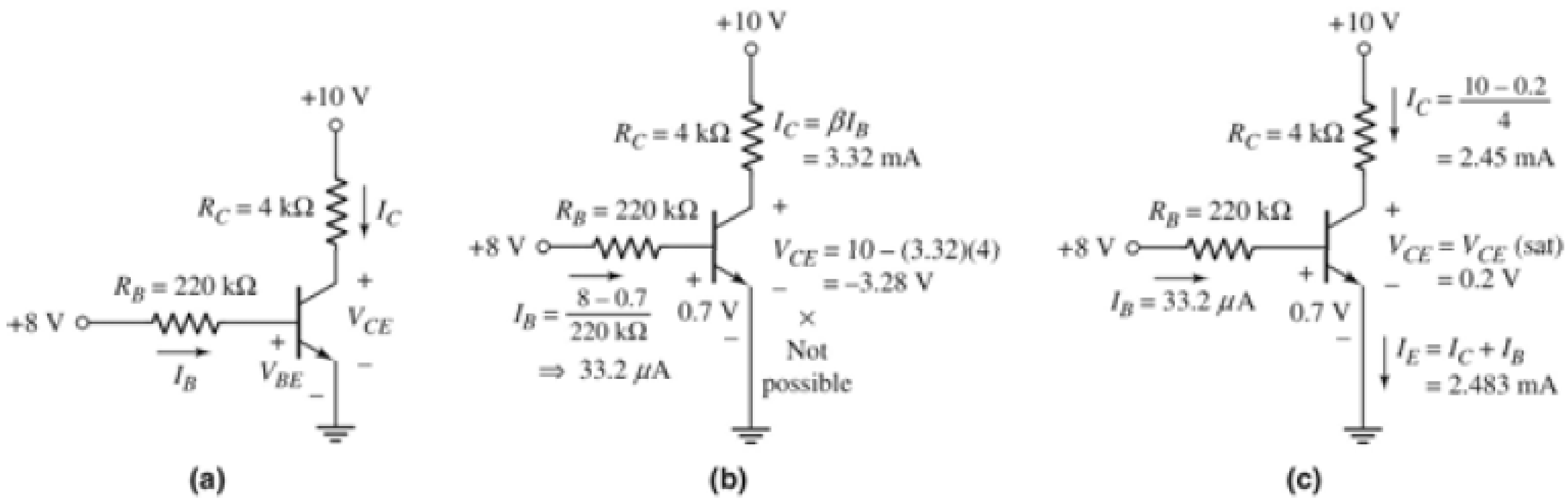
I_C= 0.96 m.A
V_{CE}= 0.2 V
Saturation

I_C= 0 m.A
V_{CE}= 10 V
Cut-Off

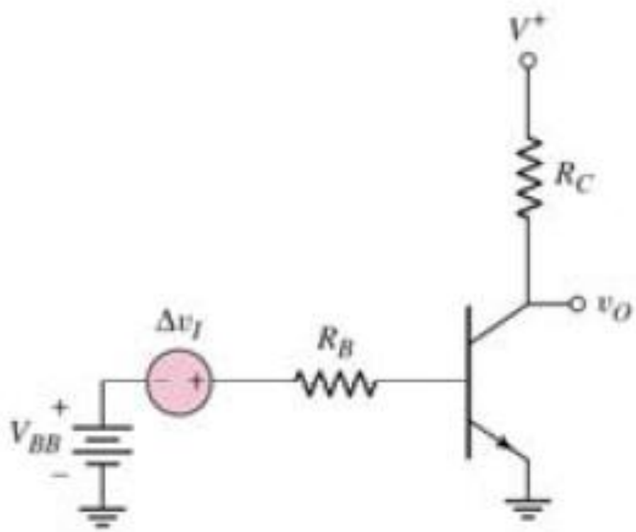
Example: Calculate the base, collector, and emitter curents and the C-E voltage for a common-emitter circuit. Calculate the transistor power dissipation.



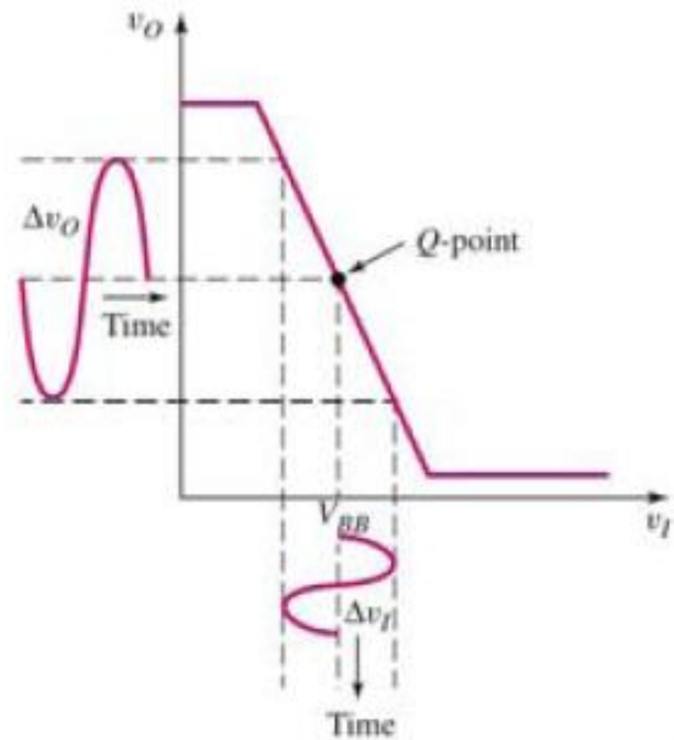
Example: Calculate the currents and voltages in a circuit when the transistor is driven into saturation. Assume $\beta = 100$, $V_{BE}(\text{on}) = 0.7$ V, and $V_{CE}(\text{sat}) = 0.2$ V.



- Amplifier



(a)



(b)

Introduction to BJT Small Signal Analysis

CHAPTER 5

Introduction

- To begin analyze of small-signal AC response of BJT amplifier the knowledge of modeling the transistor is important.
- The input signal will determine whether it’s a small signal (AC) or large signal (DC) analysis.
- The goal when modeling small-signal behavior is to make of a transistor that work for small-signal enough to “keep things linear” (i.e.: not distort too much) [3]
- There are two models commonly used in the small signal analysis:

    a) r_e model

    b) hybrid equivalent model

Introduction

Disadvantage

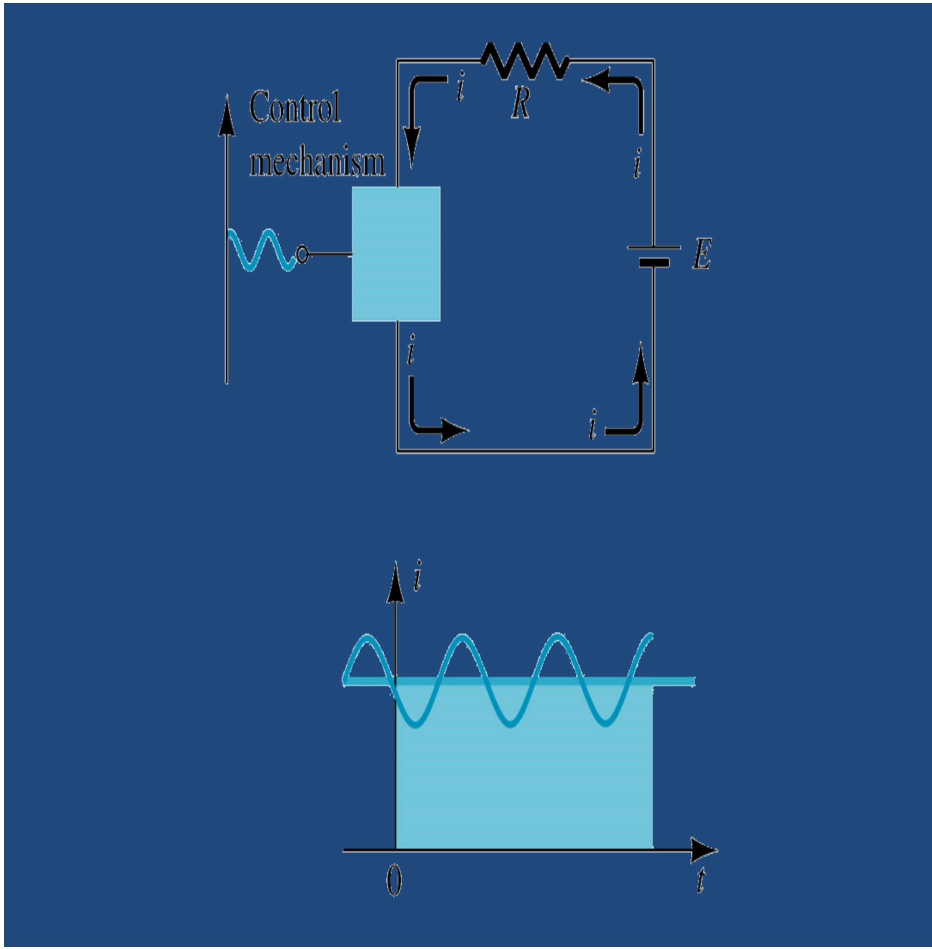
- R_e model
  - Fails to account the output impedance level of device and feedback effect from output to input
- Hybrid equivalent model
  - Limited to specified operating condition in order to obtain accurate result

Amplification in the AC domain

- The transistor can be employed as an amplifying device. That is, the output sinusoidal signal is greater than the input signal or the ac input power is greater than ac input power.
- How the ac power output can be greater than the input ac power?

Amplification in the AC domain

- Conservation; output power of a system cannot be large than its input and the efficiency cannot be greater than 1
- The input dc plays the important role for the amplification to contribute its level to the ac domain where the conversion will become as $\eta = P_{o(ac)}/P_{i(dc)}$



Amplification in the AC domain

- The superposition theorem is applicable for the analysis and design of the dc & ac components of a BJT network, permitting the separation of the analysis of the dc & ac responses of the system.
- In other words, one can make a complete dc analysis of a system before considering the ac response.
- Once the dc analysis is complete, the ac response can be determined using a completely ac analysis.

BJT Transistor Model

- Use equivalent circuit
- Schematic symbol for the device can be replaced by this equivalent circuits.
- Basic methods of circuit analysis is applied.
- DC levels were important to determine the Q-point
- Once determined, the DC level can be ignored in the AC analysis of the network.
- Coupling capacitors & bypass capacitor were chosen to have a very small reactance at the frequency of applications.

BJT Transistor Model

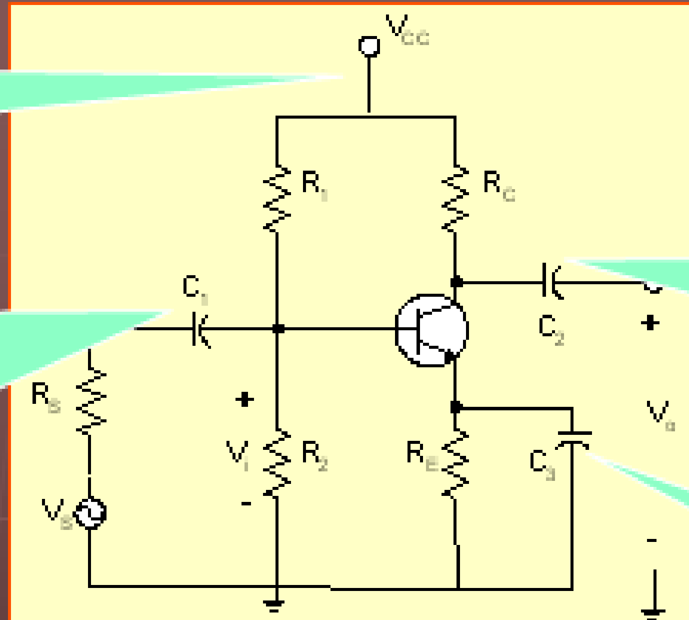
The AC equivalent of a network is

obtained by:

1. Setting all DC sources to zero & replacing them by a short-circuit equivalent.
2. Replacing all capacitors by a short-circuit equivalent.
3. Removing all elements bypassed by short-circuit equivalent.
4. Redrawing the network.

DC supply → "0" potential

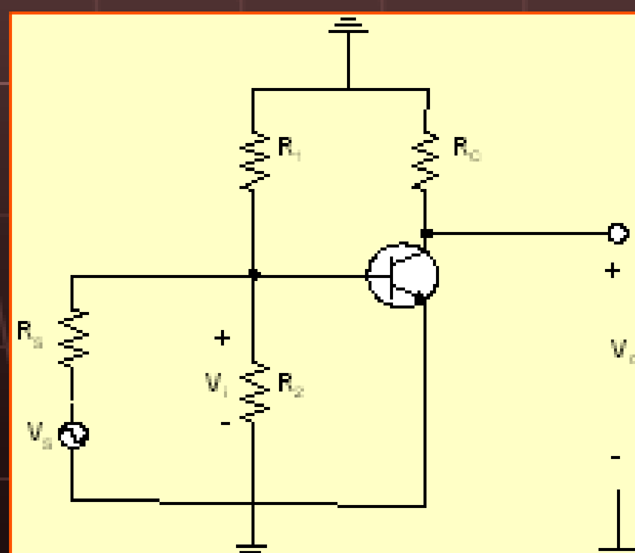
- I/p coupling capacitor → s/c
- Large values
- Block DC and pass AC signal



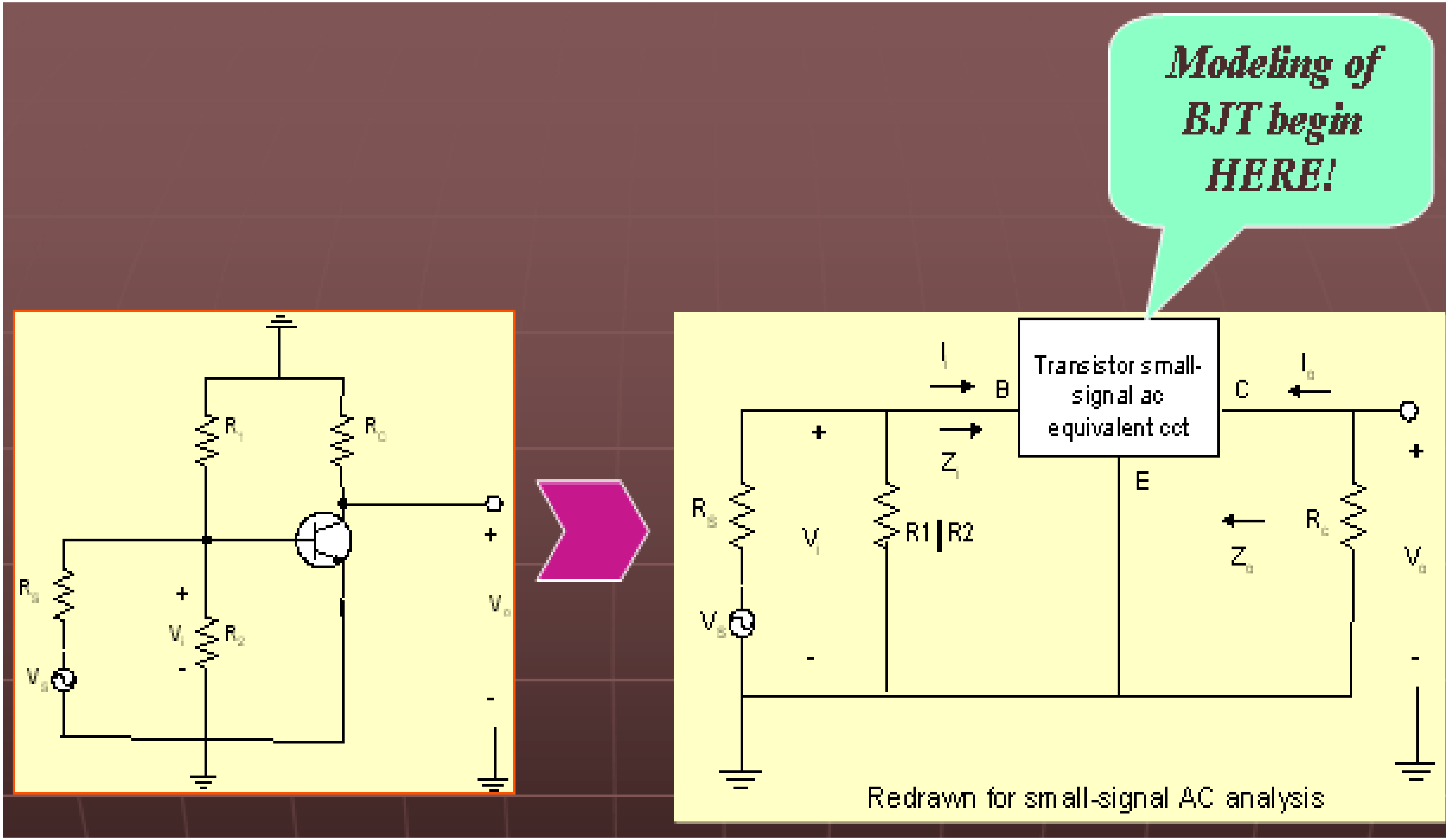
- O/p coupling capacitor → s/c
- Large values
- Block DC and pass AC signal

- Bypass capacitor → s/c
- Large values

Voltage-divider configuration under AC analysis

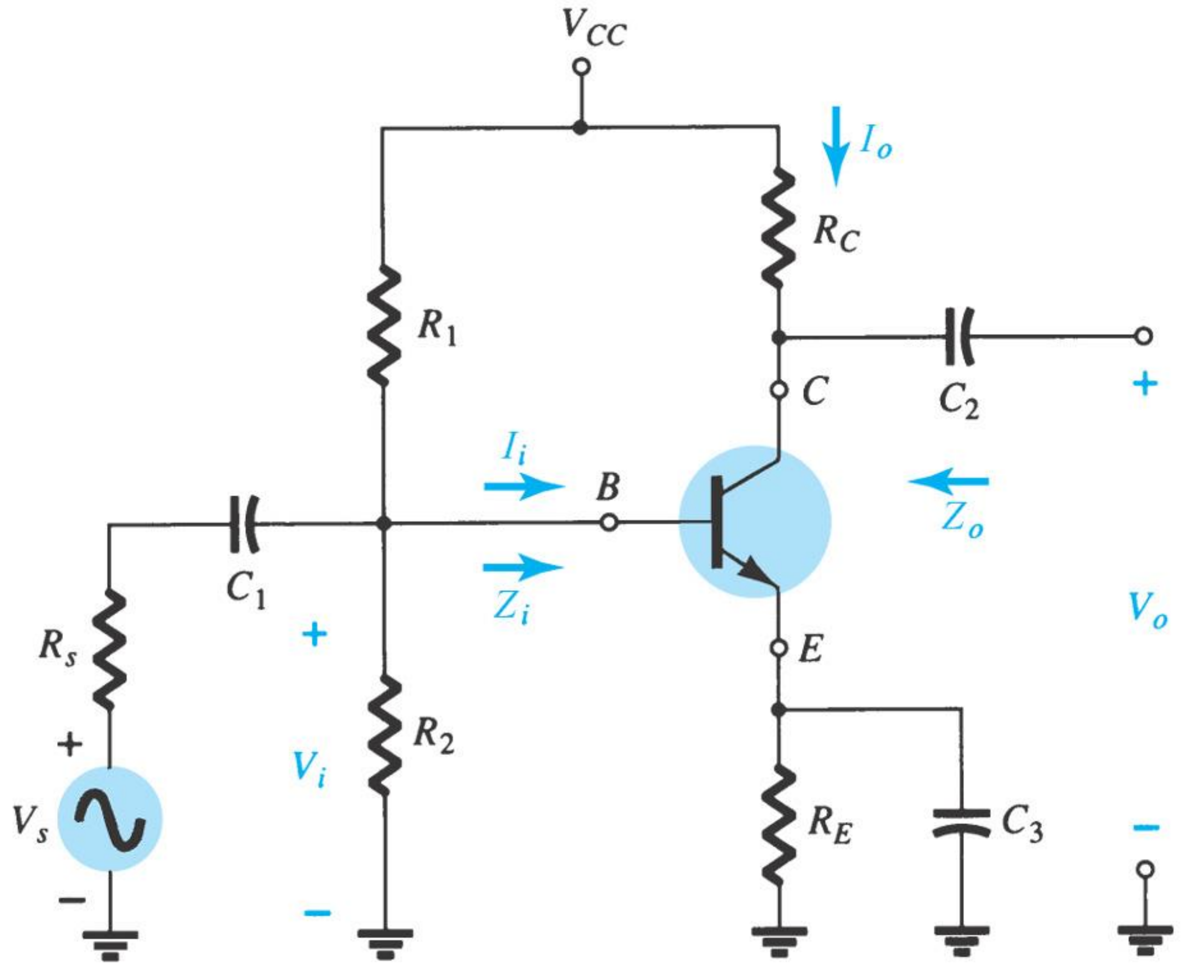


Redraw the voltage-divider configuration after removing dc supply and insert s/c for the capacitors

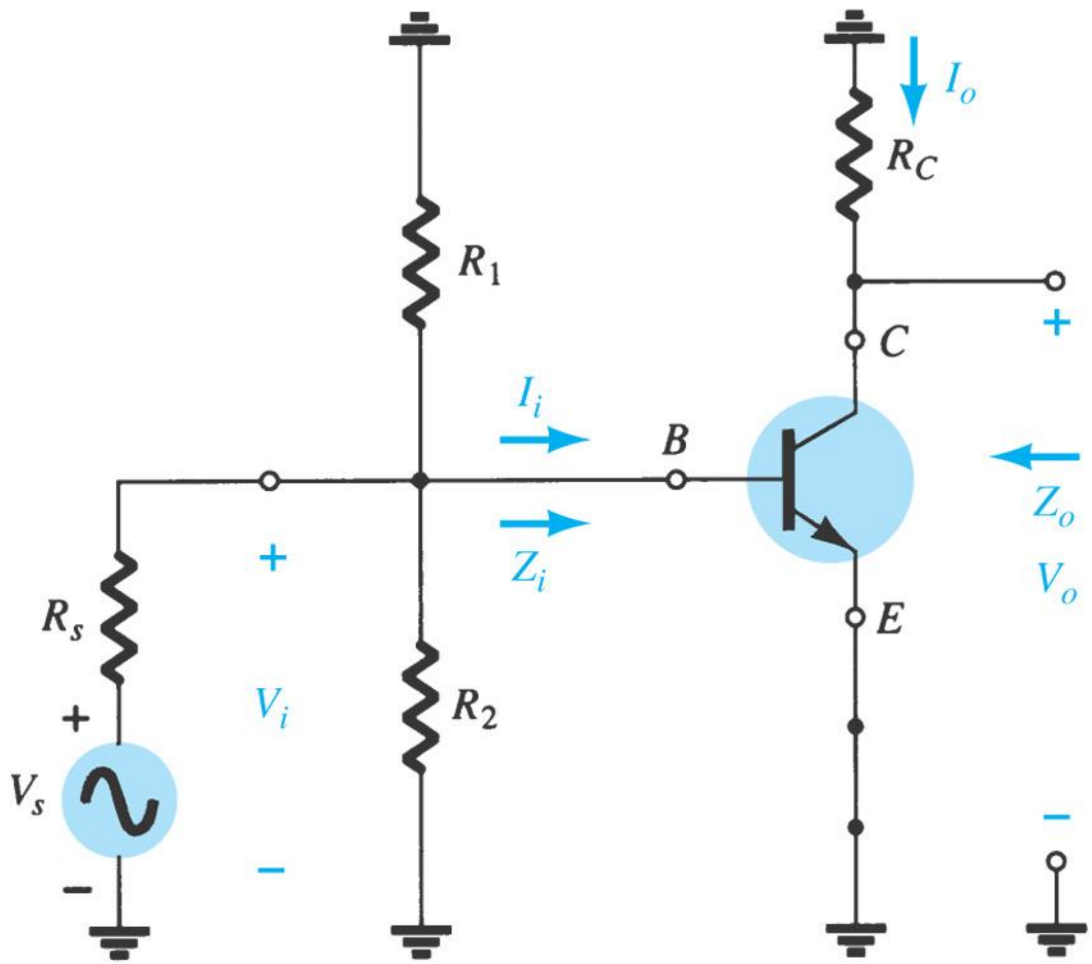


Modeling of BJT begin HERE!
R1
RC
RS
Vi
R2
VS
Vo
Transistor small-signal ac equivalent cct
Ii
B
C
Io
E
Zi
R1 | R2
Zo
Redrawn for small-signal AC analysis

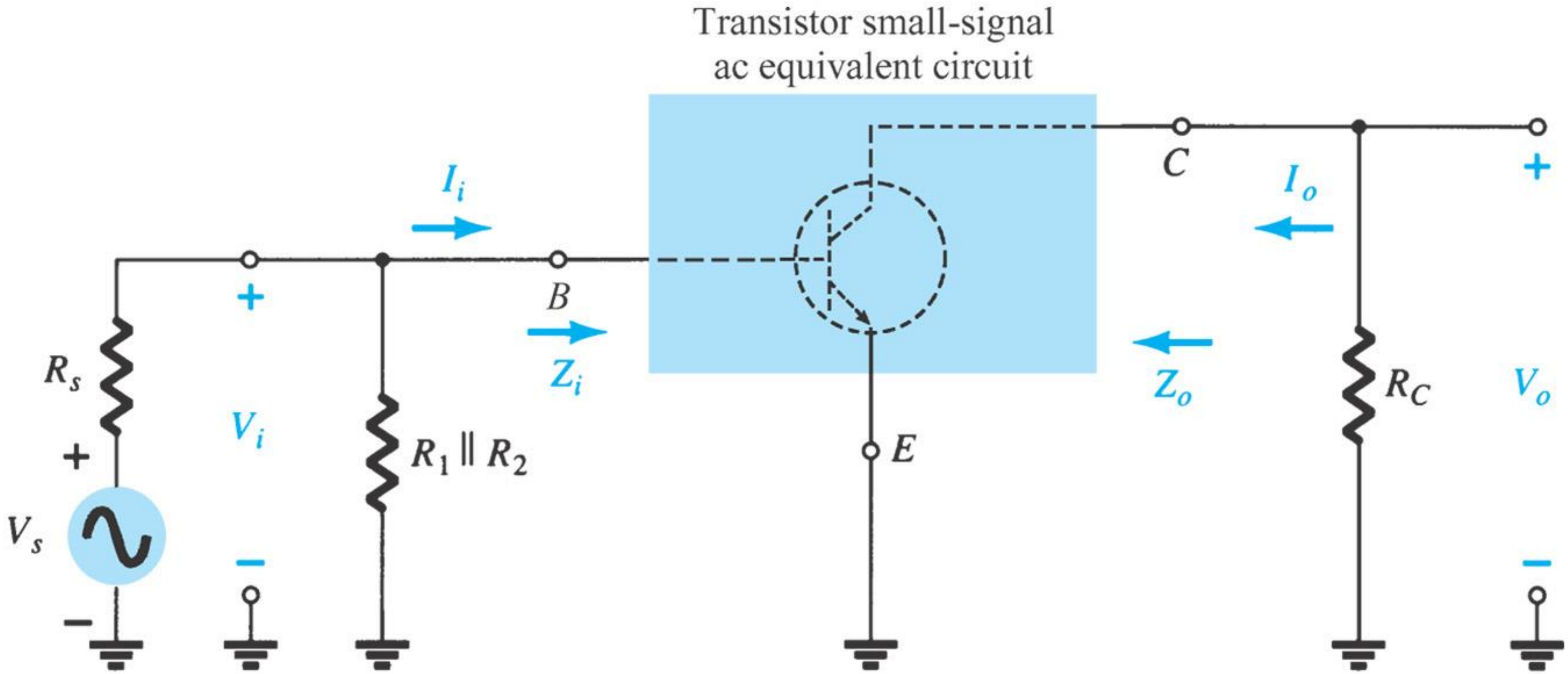
Example



Example



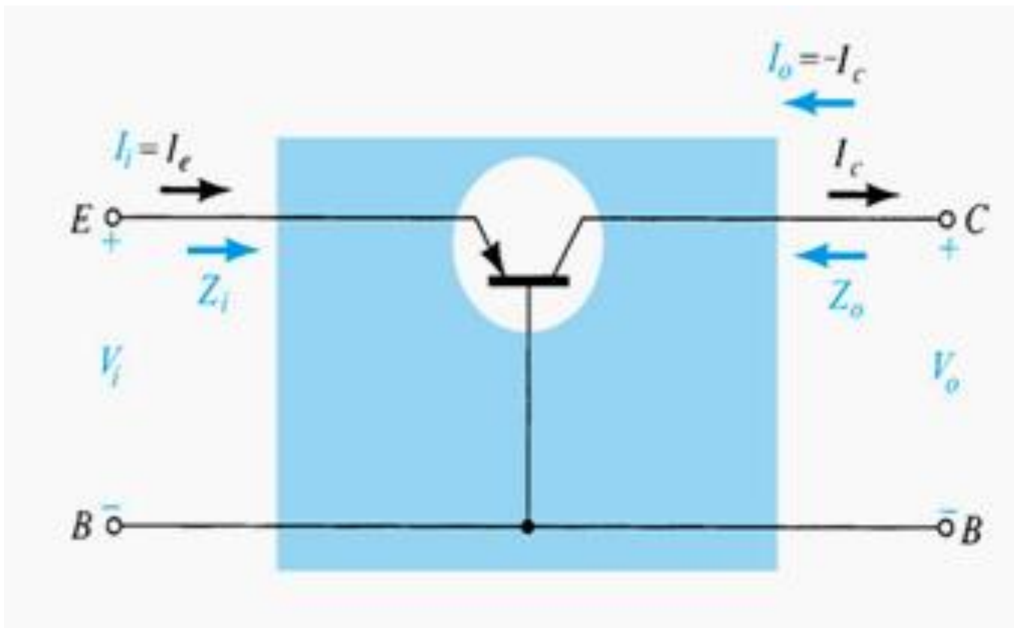
Example



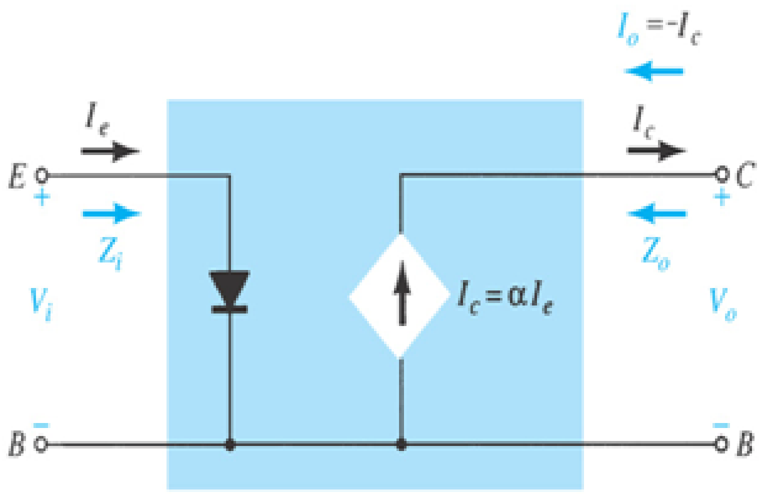
Transistor small-signal
ac equivalent circuit
I_i
B
Z_i
C
I_o
E
Z_o
R_s
+
V_s
−
+
V_i
−
$R_1 \parallel R_2$
R_C
+
V_o
−

The re transistor model

- Common Base PNP Configuration



Common Base PNP Configuration



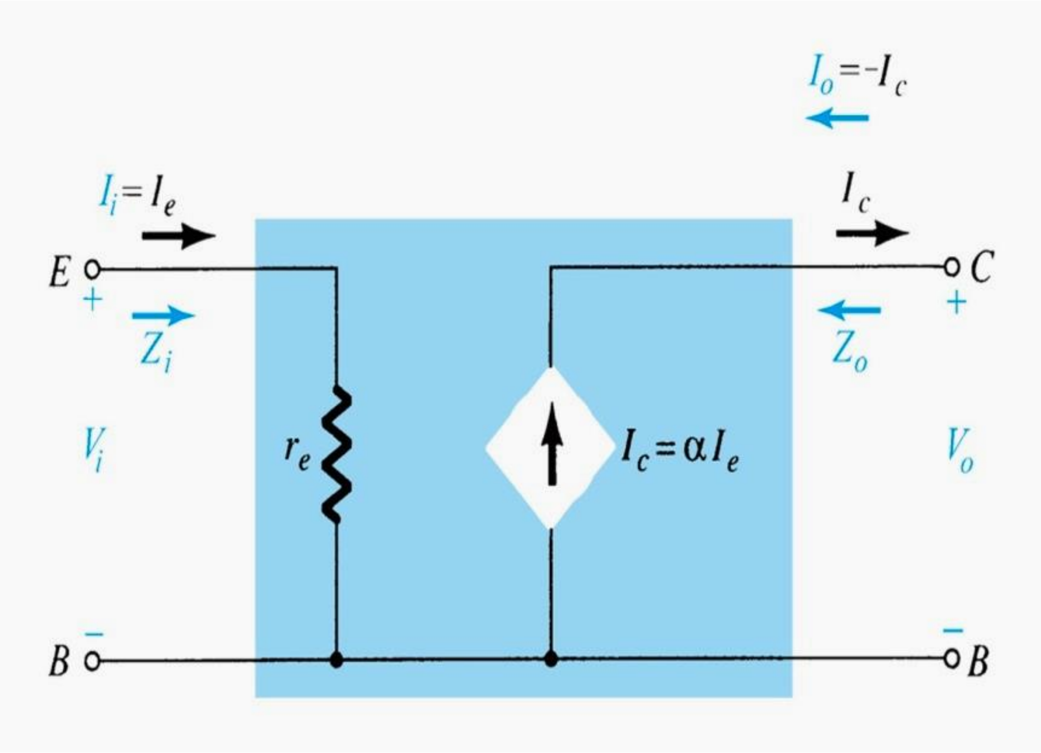
- Transistor is replaced by a single diode between E & B, and control current source between B & C
- Collector current Ic is controlled by the level of emitter current Ie.
- For the ac response the diode can be replaced by its equivalent ac resistance.

Common Base PNP Configuration

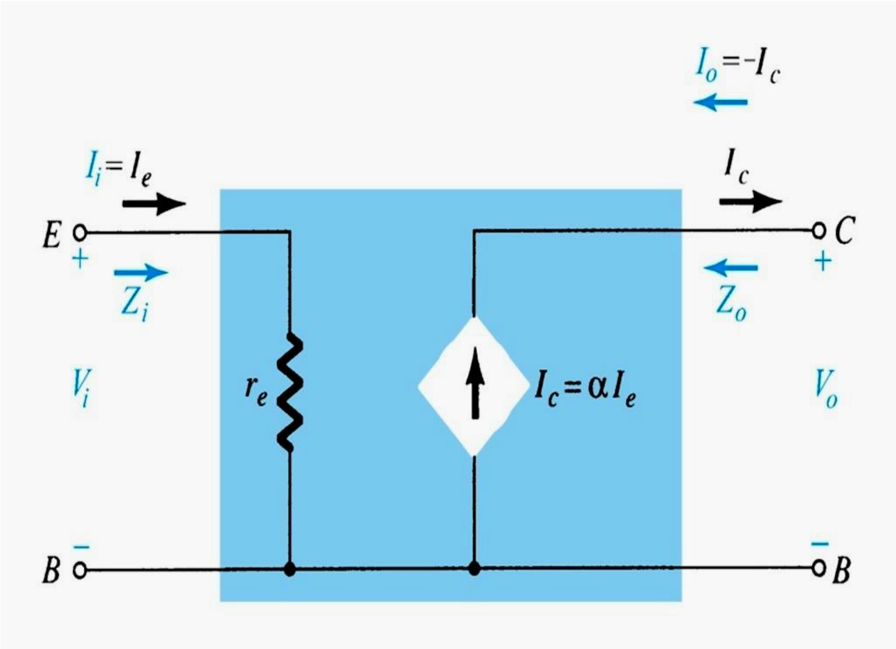
- The ac resistance of a diode can be determined by the equation;

$$re = \frac{26mV}{I_E}$$

Where I_D is the dc current through the diode at the Q-point.



Common Base PNP Configuration



- Input impedance is relatively small and output impedance quite high.

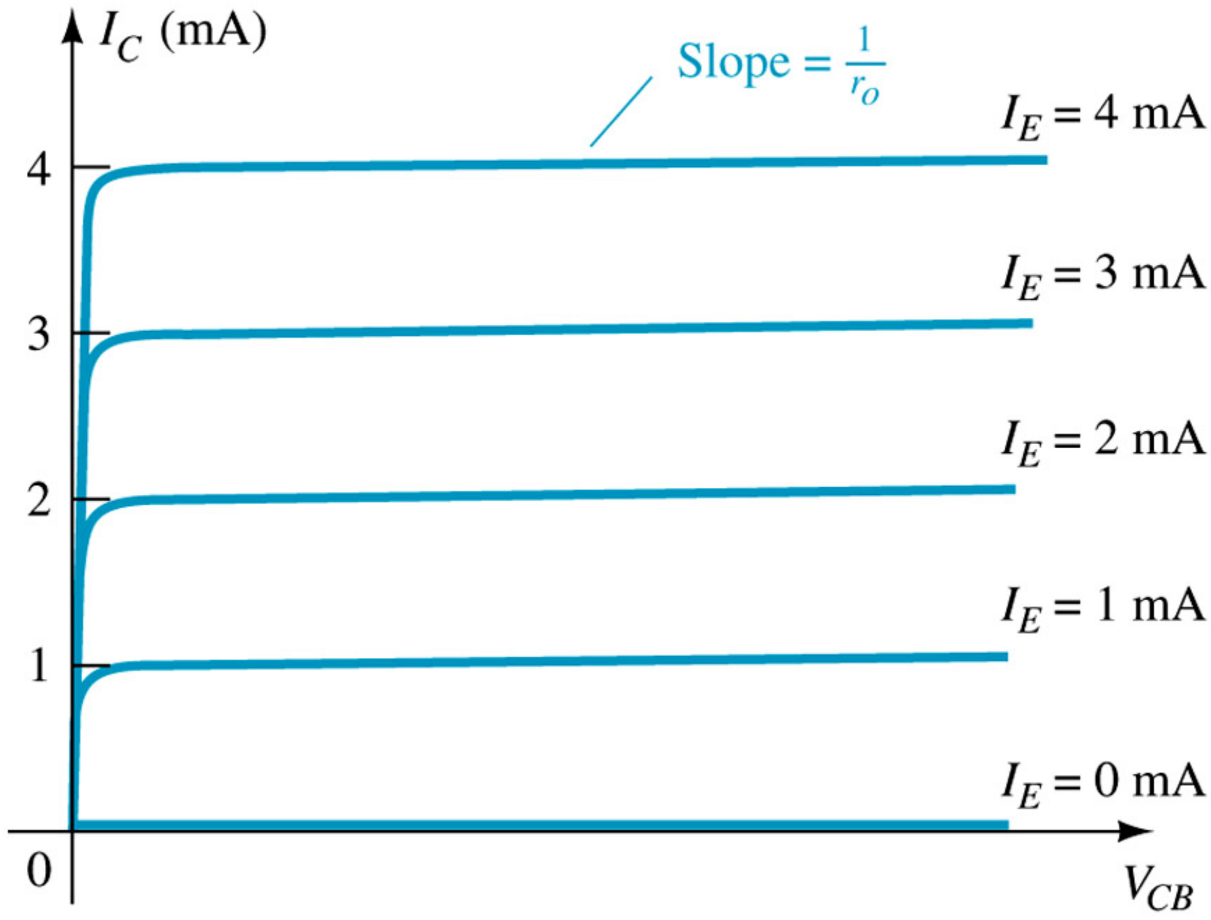
$$Z_i = re_{CB}$$

- range from a few Ω to max 50 Ω

$$Zo = \infty\Omega_{CB}$$

- Typical values are in the M Ω

The common-base characteristics



Voltage Gain

output voltage: $V_o = -I_o R_L$

$$= -(-I_C)R_L$$

$$= \alpha I_e R_L$$

input voltage: $V_i = I_i Z_i$

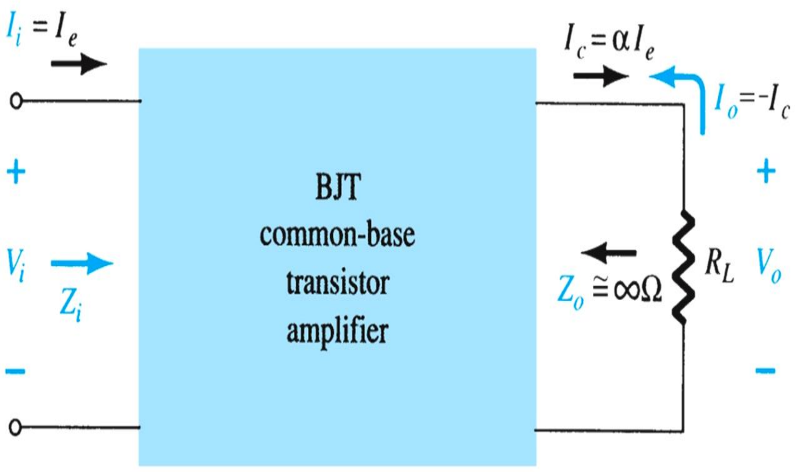
$$= I_e Z_i$$

$$= I_e r_e$$

voltage gain: $A_V = \frac{V_O}{V_i} = \frac{\alpha I_e R_L}{I_e r_e}$

$$= \frac{\alpha R_L}{re}$$

$$\therefore A_V = \frac{R_L}{re}$$

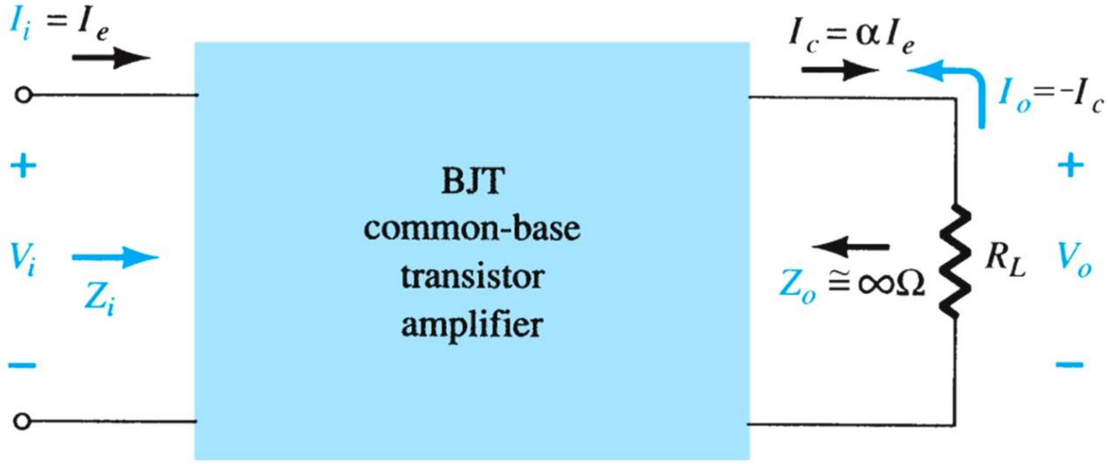


Current Gain

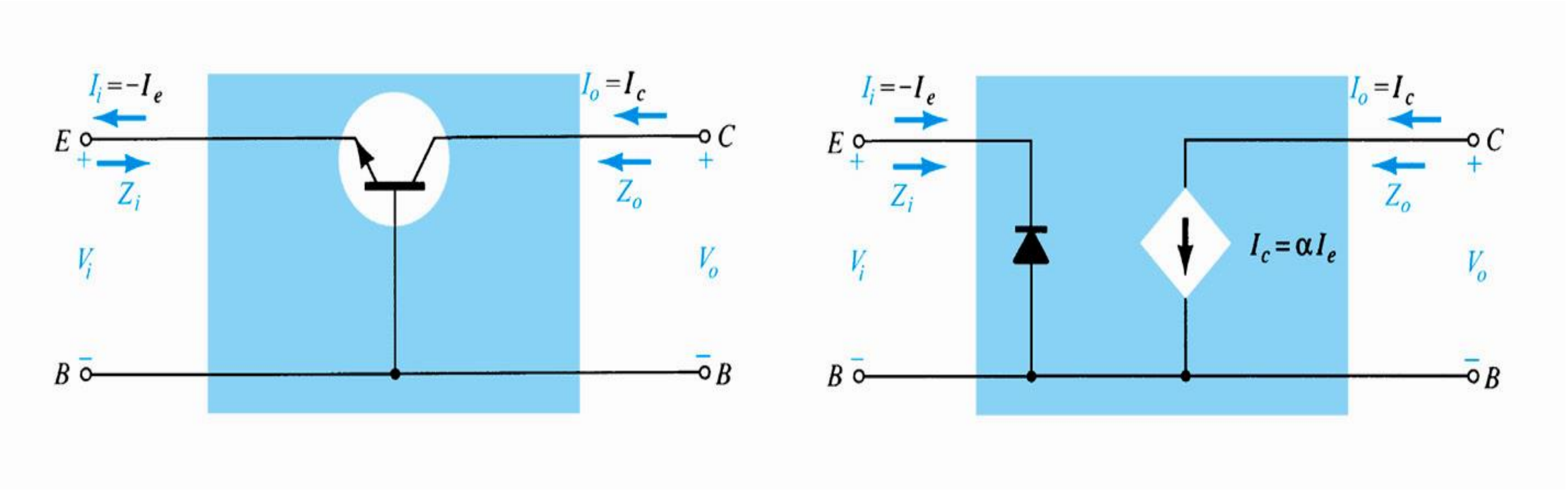
$$A_i = \frac{I_o}{I_i} = \frac{-I_C}{I_e} = \frac{-\alpha I_e}{I_e}$$

$$A_i = -\alpha \cong -1$$

- The fact that the polarity of the V_o as determined by the current I_C is the same as defined by figure below.
- It reveals that V_o and V_i are in phase for the common-base configuration.



Common Base PNP Configuration

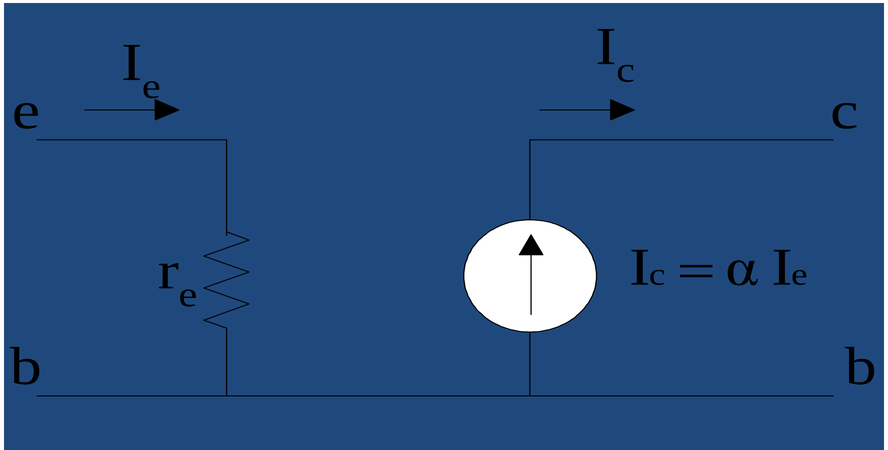


Approximate model for a common-base npn transistor configuration

Example 1: For a common-base configuration in figure below with I_E=4mA, α=0.98 and AC signal of 2mV is applied between the base and emitter terminal:

a) Determine the Z_i b) Calculate A_v if R_L=0.56kΩ

c) Find Z_o and A_i



common-base r_e equivalent cct

Solution:

$$a)\ Z_i = r_e = \frac{26m}{I_E} = \frac{26m}{4m} = \underline{\underline{6.5\Omega}}$$

$$b)\ A_v = \frac{\alpha R_L}{r_e} = \frac{0.98(0.56k)}{6.5} = \underline{\underline{84.43}}$$

$$c)\ Z_o \cong \underline{\underline{\infty\Omega}}$$

$$A_i = \frac{I_o}{I_i} = -\alpha = \underline{\underline{-0.98}}$$

Example 2: For a common-base configuration in previous example with I_e=0.5mA, α=0.98 and AC signal of 10mV is applied, determine:

a) Z_i b) V_o if R_L=1.2kΩ c) A_v d) A_i e) I_b

Solution :

$$a)\ Z_i = \frac{V_i}{I_e} = \frac{10m}{0.5m} = \underline{\underline{20\Omega}}$$

$$b)\ V_o = I_c R_L = \alpha I_e R_L$$
$$= 0.98(0.5m)(1.2k)$$
$$= \underline{\underline{588mV}}$$

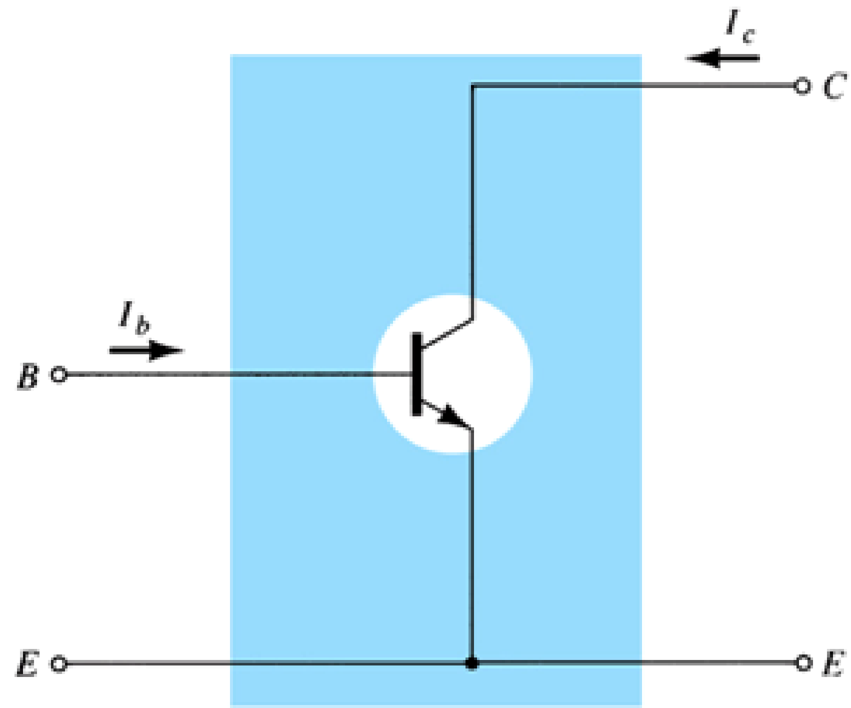
$$c)\ A_v = \frac{V_o}{V_i} = \frac{588m}{10m} = \underline{\underline{58.8}}$$

$$d)\ A_i = -\alpha = \underline{\underline{-0.98}}$$

$$e)\ I_b = I_e - I_c$$
$$= I_e - \alpha I_e$$
$$= 0.5m(1-\alpha)$$
$$= 0.5m(1-0.98)$$
$$= \underline{\underline{10\mu A}}$$

Common Emitter NPN Configuration

- Base and emitter are input terminal
- Collector and emitter are output terminals



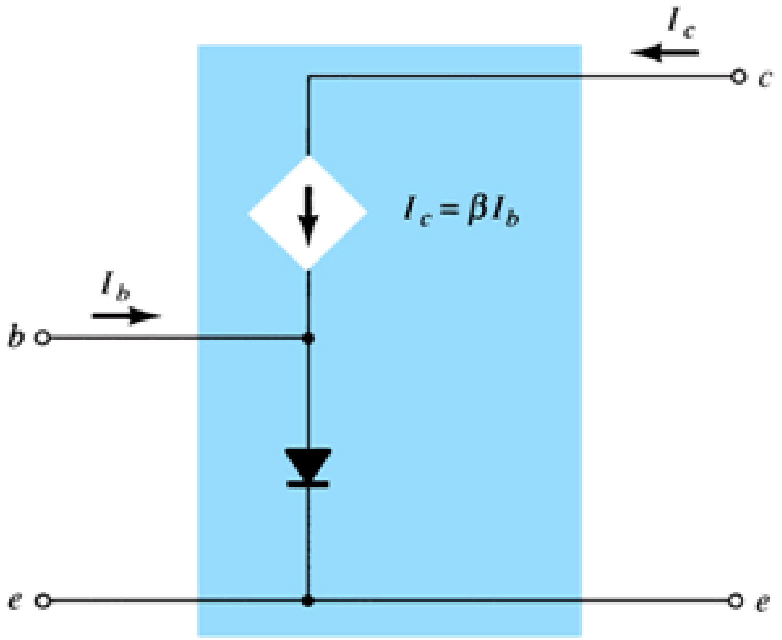
Common Emitter NPN Configuration

- Substitute r_e equivalent circuit

$$I_c = \beta I_b$$

- Current through diode

$$I_e = I_c + I_b = \beta I_b + I_b$$
$$I_e = (\beta + 1) I_b \cong \beta I_b$$



- Input impedance

$$\text{input impedance}: \quad Z_i = \frac{V_i}{I_i} = \frac{V_{be}}{I_b}$$

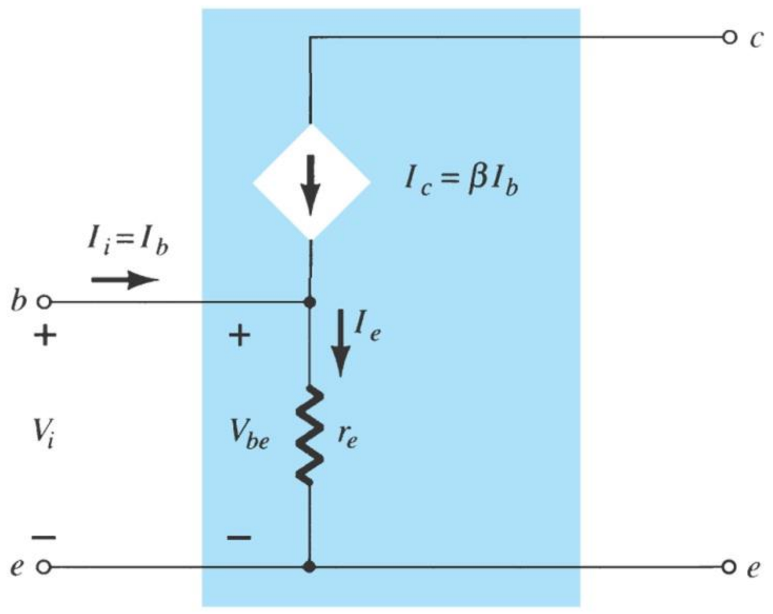
$$\text{input voltage}: \quad V_i = I_e r_e$$

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

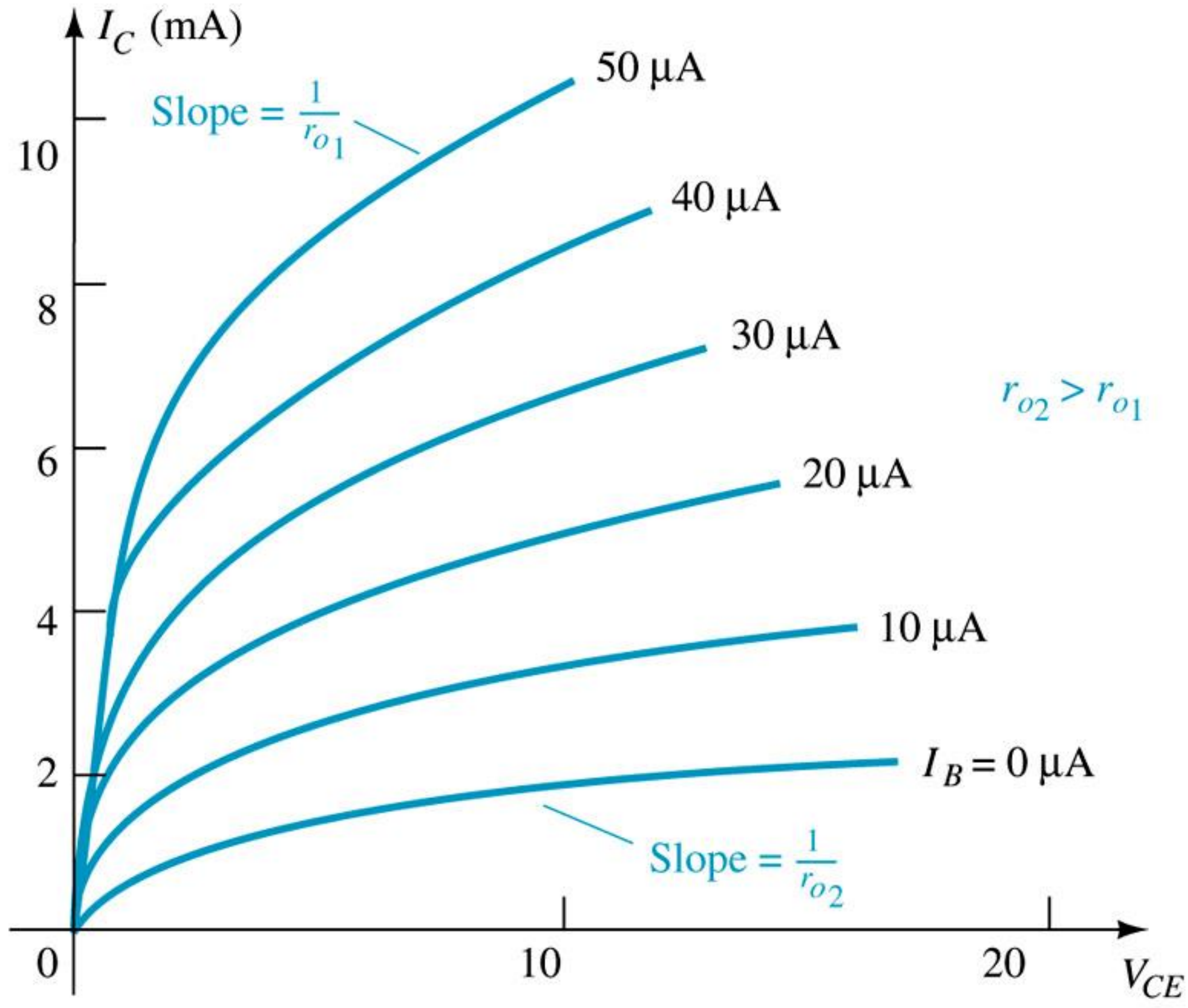
$$\text{so that} \quad Z_i = \frac{(\beta+1) I_b r_e}{I_b}$$

$$\therefore Z_i = (\beta+1) r_e$$

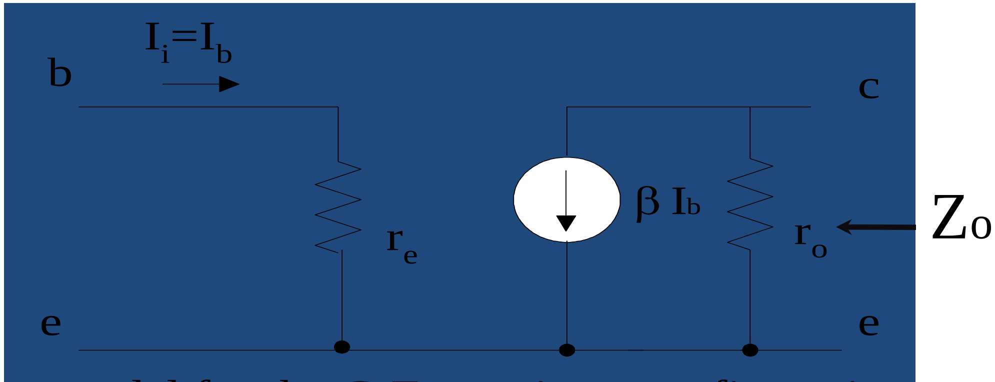
$$\beta \text{ usually greater than } 1; \quad Z_i \cong \beta r_e$$



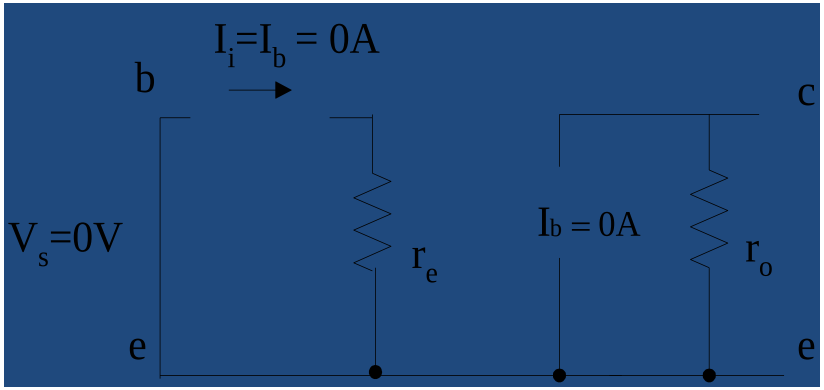
The output graph



Output impedance Z_o



r_e model for the C-E transistor configuration



$$\underline{\underline{Z_o = r_o}}$$

if r_o is ignored thus the

$\underline{\underline{Z_o = \infty\Omega}}$ (open cct, high impedance)

Voltage Gain

output voltage: $V_o = -I_o R_L$

$$V_o = -I_c R_L$$

$$= -\beta I_b R_L$$

input voltage: $V_i = I_i Z_i$

$$= I_b \beta r_e$$

so that $A_V = \dfrac{V_o}{V_i} = \dfrac{-\beta I_b R_L}{I_b \beta r_e}$

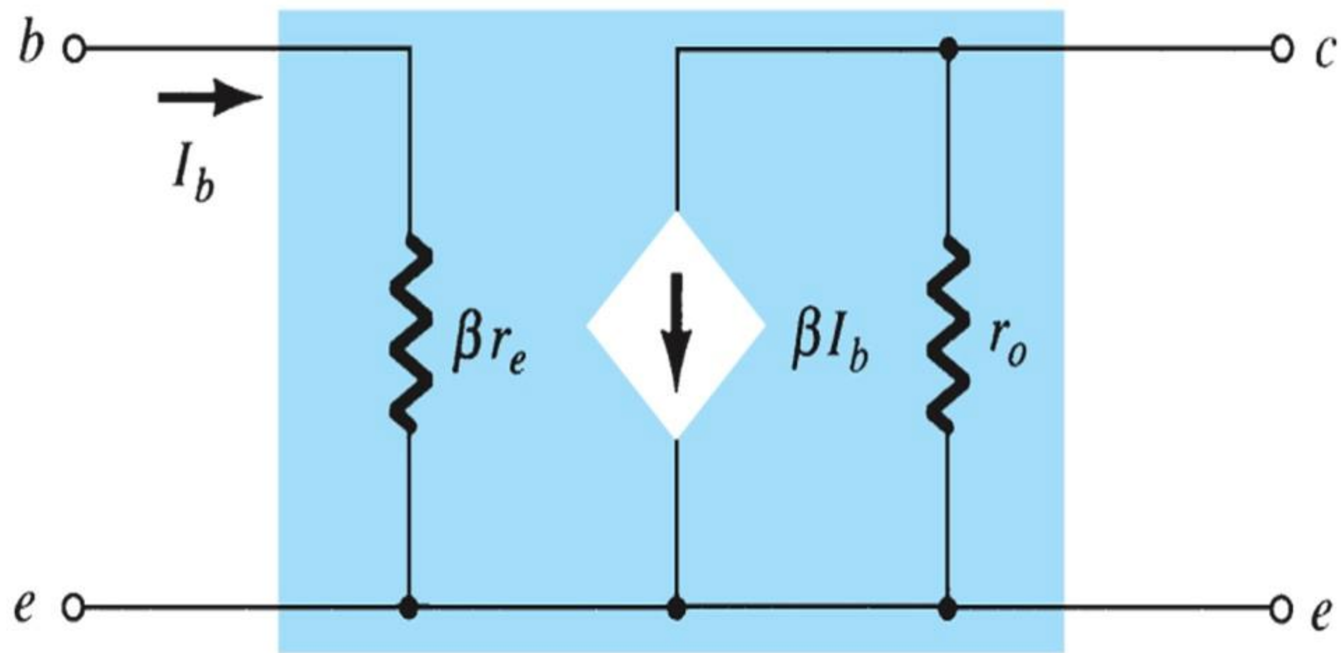
$$\therefore A_V = \frac{-R_L}{r_e}$$

Current Gain

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

$$\therefore A_i = \beta$$

r_e model for common-emitter



Example 3: Given β=120 and $I_{E(dc)}$=3.2mA for a common-emitter configuration with ro= $\propto$ Ω, determine:

a) Z_i b)A_v if a load of 2 kΩ is applied c) A_i with the 2 kΩ load

Solution:

$$a)\ r_e = \frac{26m}{I_E} = \frac{26m}{3.2m} = 8.125\Omega$$

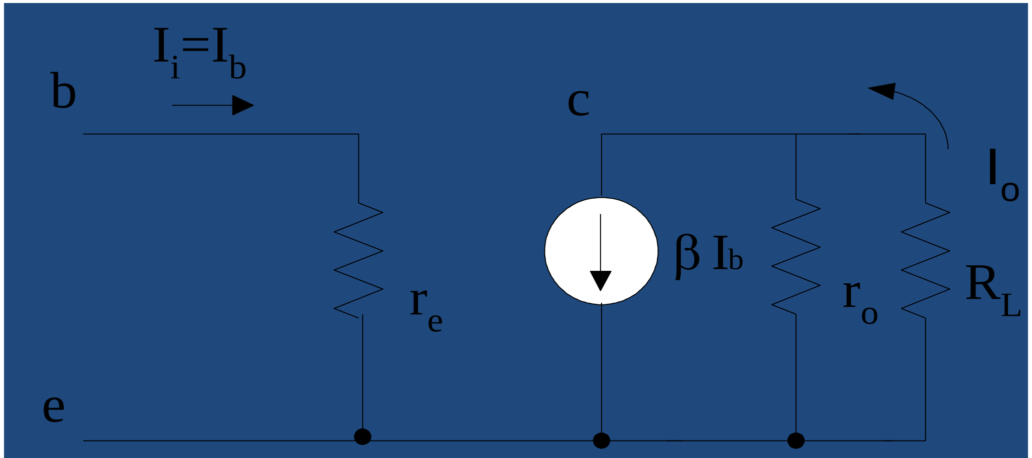
$$Z_i = \beta r_e = 120(8.125) = \underline{\underline{975\Omega}}$$

$$b)A_v = -\frac{R_L}{r_e} = -\frac{2k}{8.125} = \underline{\underline{-246.15}}$$

$$c)\ A_i = \frac{I_o}{I_i} = \beta = \underline{\underline{120}}$$

Example 4: Using the npn common-emitter configuration, determine the following if $\beta=80$, $I_{E(dc)}=2$ mA and $r_o=40$ kΩ

a) Z_i b) A_i if $R_L=1.2\text{k}\ \Omega$ c) Av if $R_L=1.2\text{k}\ \Omega$



r_e model for the C-E transistor configuration

Solution:

$$a)\ r_e = \frac{26m}{I_E} = \frac{26m}{2m} = 13\Omega$$

$$Z_i = \beta r_e = 80(13) = \underline{\underline{1.04k\Omega}}$$

Solution (cont)

$$b)\ A_i = \frac{I_o}{I_i} = \frac{I_L}{I_b}$$

$$I_L = \frac{r_o(\beta I_b)}{r_o + R_L}$$

$$A_i = \frac{\dfrac{r_o(\beta I_b)}{r_o + R_L}}{I_b} = \frac{r_o}{r_o + R_L} \cdot \beta = \frac{40k}{40k + 1.2k}(80)$$

$$= \underline{\underline{77.67}}$$

$$c)\ A_v = -\frac{R_L \| r_o}{r_e} = -\frac{1.2k \| 40k}{13} = \underline{\underline{-89.6}}$$

Common Collector Configuration

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