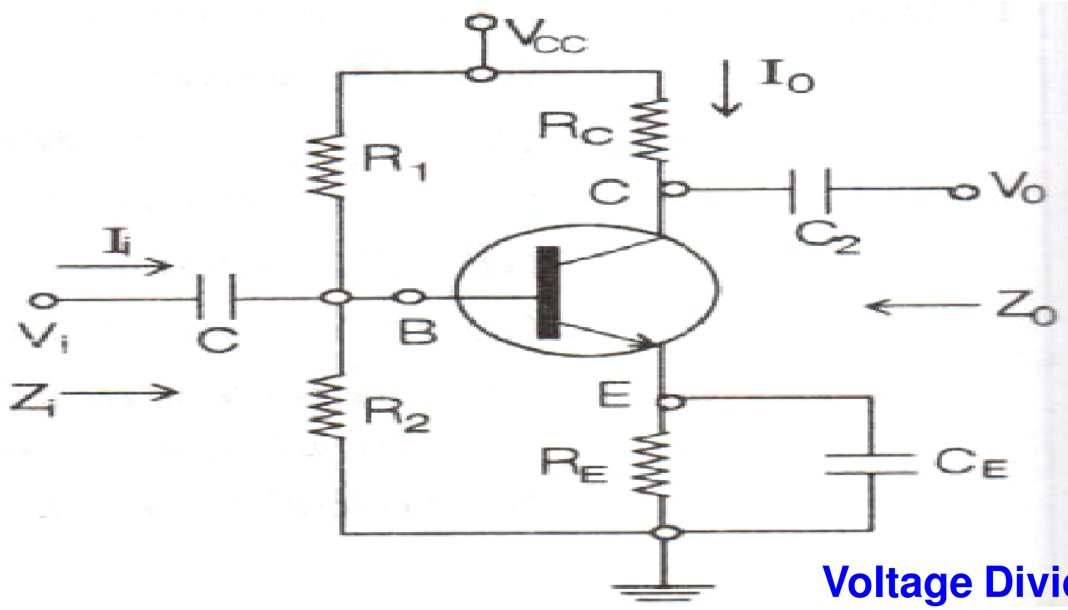
Small Signal Analysis of BJTs Single Stage Amplifier

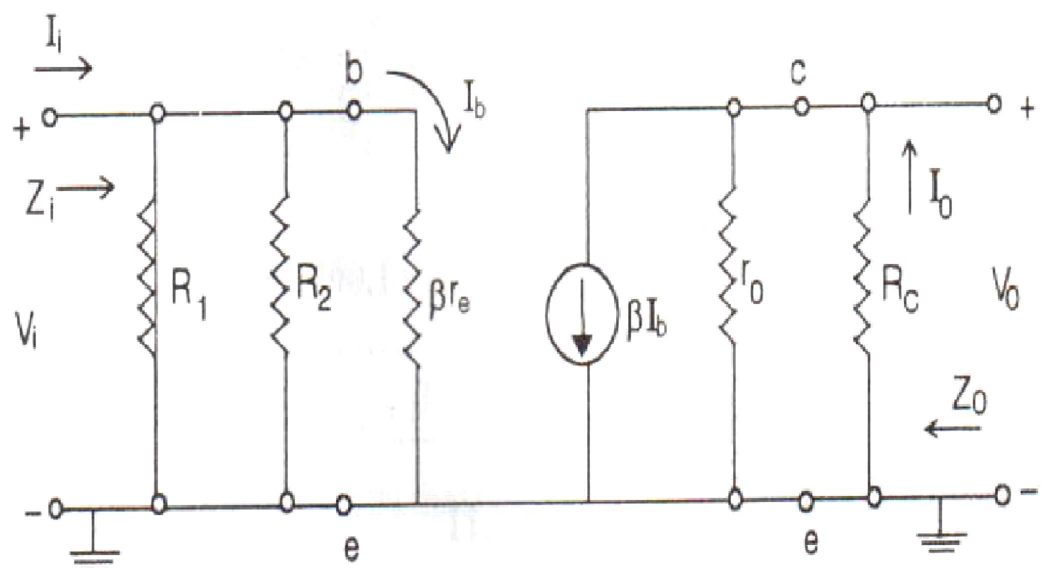
Voltage Divider Circuit



Voltage-divider bias is the most widely used type of bias circuit. Only one power supply is needed and voltage-divider bias is more stable (β independent) than other bias types. For this reason it will be the primary focus for study.

Voltage Divider Bias Configuration

Note the absence of RE due to the low impedance shorting effect of the bypass capacitor, CE. That is at the frequency of operation, the reactance of the capacitor is so small compared to RE that it is treated as short circuit across RE.



AC Equivalent Circuit Configuration

Parallel combination of resistor

$$R' = R_1 \parallel R_2 = \frac{R_1 R_2}{R_1 + R_2} \quad (1)$$

Input Impedance

$\mathbf{Z_i}$: From Fig.

$$\boxed{Z_i = R' \parallel \beta r_e} \quad (2)$$

Output Impedance

$\mathbf{Z_o}$: From Fig. with V_i set to 0 V resulting in $I_b = 0 \mu A$ and $\beta I_b = 0$ mA

$$Z_o = R_C \parallel r_o \quad (3)$$

If $r_o \geqslant 10R_C$.

$$\boxed{Z_o \cong R_C} \quad r_o \geqslant 10R_C \quad (4)$$

Voltage gain

$\mathbf{A_v}$: Since R_C and r_o are in parallel

$$V_o = -(\beta I_b)(R_C \parallel r_o) \quad (5)$$

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

$$V_o = \beta \left(\frac{V_i}{\beta r_e} \right) (R_C \parallel r_o) \quad (6)$$

From Eq: (5) and (6)

$$A_v = \frac{V_o}{V_i} = -\frac{R_C \parallel r_o}{r_e} \qquad A_v = \frac{V_o}{V_i} \cong -\frac{R_C}{r_e} \quad r_o \geqslant 10R_C \quad (7)$$

Current gain

Here: $R' = R_1 \parallel R_2 = R_B$

$$\boxed{A_i = \frac{I_o}{I_i} = \frac{\beta R' r_o}{(r_o + R_C)(R' + \beta r_e)}} \qquad (8)$$

For $r_o \geqslant 10R_C$

$$A_i = \frac{I_o}{I_i} \cong \frac{\beta R' r_o}{r_o (R' + \beta r_e)} \qquad (9)$$

and

$$A_i = \frac{I_o}{I_i} \cong \frac{\beta R'}{R' + \beta r_e} \quad r_o \geqslant 10R_C \qquad (10)$$

And if $R' \geqslant 10\beta r_e$,

$$A_i = \frac{I_o}{I_i} = \frac{\beta R'}{R'}$$

and

$$\boxed{A_i = \frac{I_o}{I_i} \cong \beta} \quad r_o \geqslant 10R_C, R' \geqslant 10\beta r_e, \qquad (11)$$

As an option,

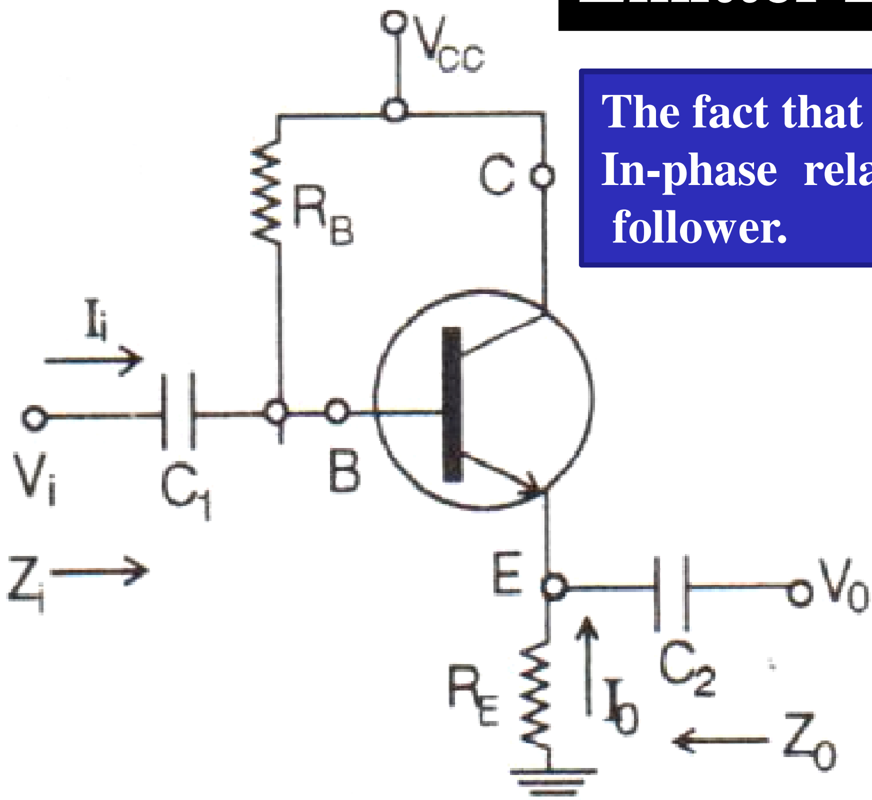
$$\boxed{A_i = -A_v \frac{Z_i}{R_C}} \qquad (12)$$

EMITTER FOLLOWER CONFIGURATION

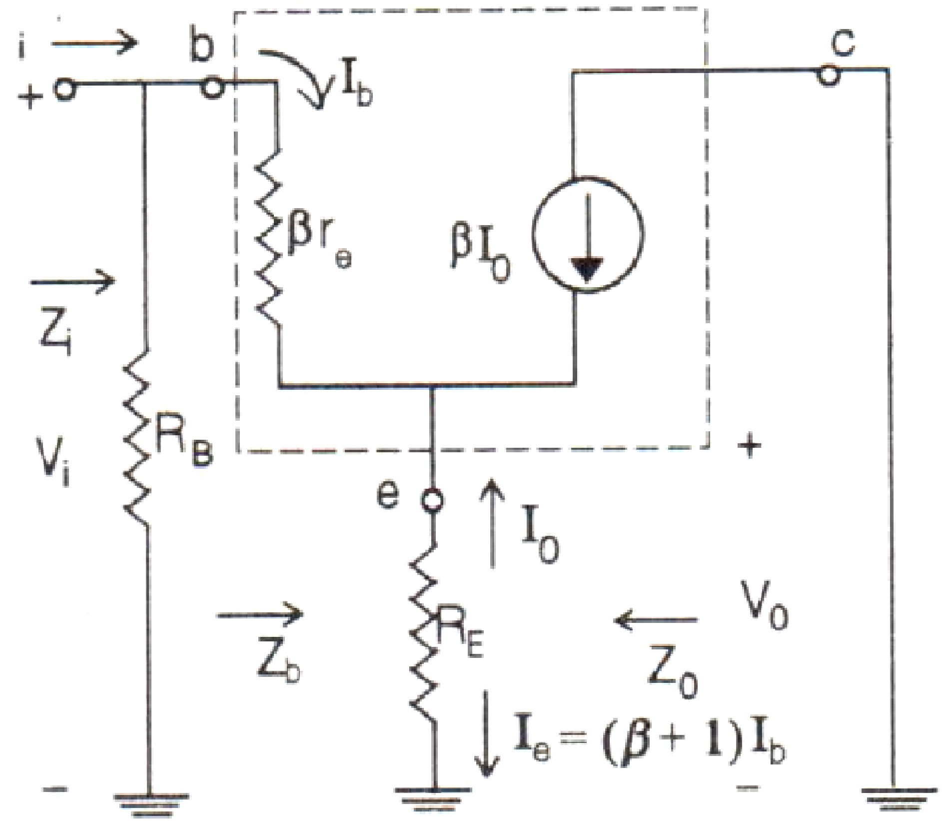
- Emitter follower is a **common collector** transistor configuration.
  (When output taken from the emitter terminal of the transistor is known as emitter follower)
- Emitter follower can be designed by simply **short circuit RC** and **remove bypass capacitor** in RC coupled amplifier.
- Emitter follower gives **high input impedance** and **low output impedance**.
- Emitter follower can be used as **buffer**.
- Emitter follower is also known as **voltage follower**.
- The emitter follower configuration frequently used for impedance matching

Emitter Follower Configuration

The fact that Vo "follows" the magnitude of Vi with an In-phase relationship accounts for the terminology emitter follower.



Emitter Follower Configuration



R_o Equivalent Circuit for AC Equivalent Network

Input Impedance:

$\mathbf{Z_i}$ **:** The input impedance is determined in the same manner as described

$$Z_i = R_B \parallel Z_b \tag{1}$$

with

$$Z_b = \beta r_e + (\beta + 1)R_E \tag{2}$$

or

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

and

$$Z_b \cong \beta R_E \tag{3}$$

Output Impedance:

$\mathbf{Z_o}$ **:** The output impedance is best described by first writing the equation for the current Ib :

$$I_b = \frac{V_i}{Z_b} \tag{4}$$

and then multiplying by $(\beta + 1)$ to establish I_e. That is,

$$I_e = (\beta + 1)I_b = (\beta + 1)\,\frac{V_i}{Z_b} \tag{5}$$

Substituting for Z_b gives

$$I_e = \frac{(\beta + 1)V_i}{\beta r_e + (\beta + 1)R_E} \tag{6}$$

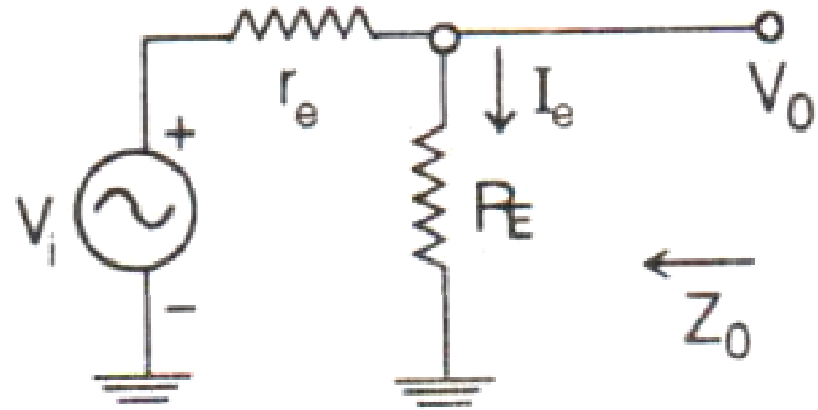
or
$$I_e = \frac{V_i}{[\beta r_e/(\beta+1)] + R_E} \tag{7}$$

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

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

so that
$$I_e \cong \frac{V_i}{r_e + R_E}$$

If we now construct the network defined by Eq.



To determine Z_o, V_i is set to zero and

$$\boxed{\mathbf{Z_0 = R_E \parallel r_e}} \tag{8}$$

Since R_E is typically much greater than *re* the following approximation is often applied :

$$\mathbf{Z \cong r_e} \tag{9}$$

Voltage gain

A_v : Figure can be utilized to determine the voltage gain through an application of the voltage-divider rule :

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

and

$$\boxed{\mathbf{A_v = \frac{V_o}{V_i} = \frac{R_E}{R_E + r_e}}} \qquad (9)$$

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

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

Current gain

A_i : From Fig. ,

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

and

$$I_o = -I_e = -(\beta + 1)I_b \qquad \text{or} \qquad \frac{I_o}{I_b} = -(\beta + 1)$$

so that

$$A_i = \frac{I_o}{I_i} = \frac{I_o}{I_b}\frac{I_b}{I_i} = -(\beta + 1)\frac{R_B}{R_B + Z_b}$$

and since $(\beta + 1) \cong \beta$,

$$\boxed{\mathbf{A_i \cong \frac{\beta R_B}{R_B + Z_b}}} \qquad (10)$$

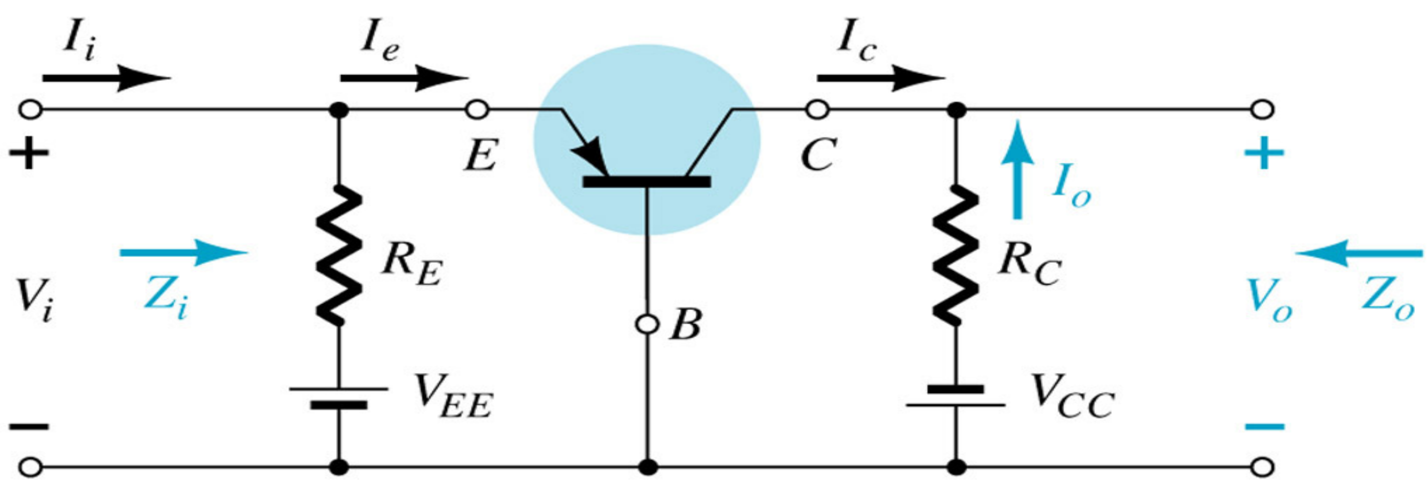
or

$$\boxed{\mathbf{A_i = -A_v \frac{Z_i}{R_E}}} \qquad (11)$$

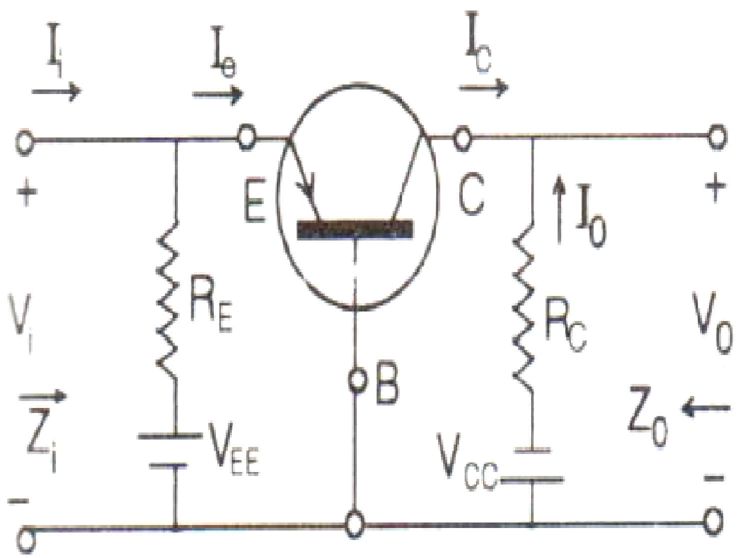
Common-Base (CB) Configuration

The input (V_i) is applied to the emitter and the output (V_o) is from the collector.

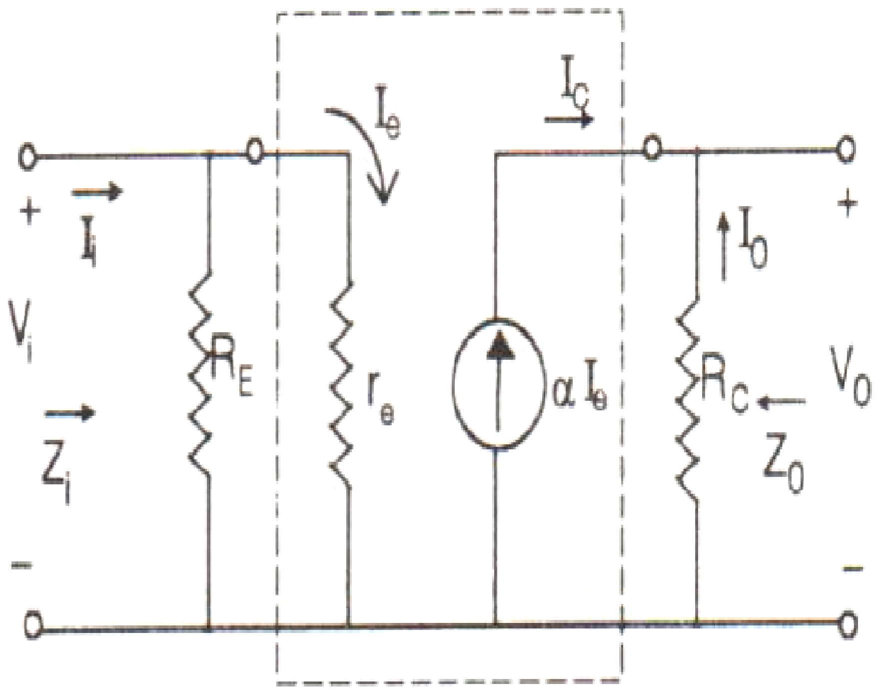
The Common-Base is characterized as having low input impedance and high output impedance with a current gain less than 1 and a very high voltage gain.



Common Base Configuration



CB Configuration



AC Equivalent Circuit

Input Impedance:

Output Impedance:

Z_i : $$Z_i = R_E \parallel r_e \quad (1)$$

Z_o : $$Z_o = R_C \quad (2)$$

Voltage gain:

A_v :

$$V_o = -I_o R_C = -(-I_c)R_C = \alpha I_e R_C \quad (3)$$

with $$I_e = \frac{V_i}{r_e} \quad (4)$$

so that $$V_o = \alpha \left(\frac{V_i}{r_e}\right) R_C \quad (5)$$

and $$A_V = \frac{V_o}{V_i} = \frac{\alpha R_C}{r_e} \cong \frac{R_C}{r_e} \quad (6)$$

Current gain:

A_i : Assuming that $R_E >> r_e$ yields

$$I_e = I_i$$

and $$I_o = -\alpha I_e = -\alpha I_i \quad (7)$$

$$A_i = \frac{I_o}{I_i} = -\alpha \cong -1 \quad (8)$$

Phase Relationship

A CB amplifier configuration has no phase shift between input and output.