UNIT III

BJT AMPLIFIERS

BJT h-parameter model

Analysis of transistor amplifier using h-parameter model

CB, CE and CC amplifiers

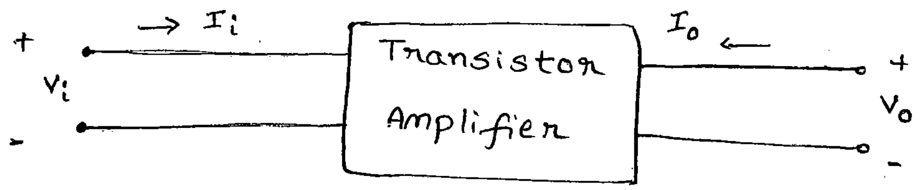
Comparison of CB, CE and CC configurations

Simplified h-parameter model

BJT AMPLIFIERS

H-Parameter Representation of a Transistor

A transistor can be treated as a two-port Network



Here I_i = Input current to the Amplifier

V_i = Input voltage to the Amplifier

I_o = output current of the Amplifier

V_o = output voltage of the Amplifier

Transistor is a current operated device.
Here input voltage V_i and output current I_o are the dependent variables.
Input current I_i and output voltage V_o are Independent variables.

$$V_i = f_1(I_1, V_o)$$

$$I_o = f_2(I_i, V_o)$$

This can be written in the equation form as follows

$$V_i = h_{11} I_i + h_{12} V_o$$

$$I_o = h_{21} I_i + h_{22} V_o$$

The above equation can also be written using alphabetic Notations

$$V_i = h_i I_i + h_r V_o$$

$$I_o = h_f I_i + h_o V_o$$

Definitions of h-parameter:

The parameters in the above equation are defined as follows

$h_{11} = h_i = \left.\frac{V_i}{I_i}\right|_{V_o=0}$ = Input resistance with output short circuited.

$h_{12} = h_r = \left.\frac{V_i}{I_o}\right|_{I_i=0}$ = Reverse voltage transfer ratio with input open circuited.

$h_{21} = h_f = \left.\frac{I_o}{I_i}\right|_{V_o=0}$ = Short circuit forward current gain with output short circuited.

$h_{22} = h_o = \left.\frac{I_o}{V_o}\right|_{I_i=0}$ = output Admittance with input open circuited.

BJT H-parameter Model:

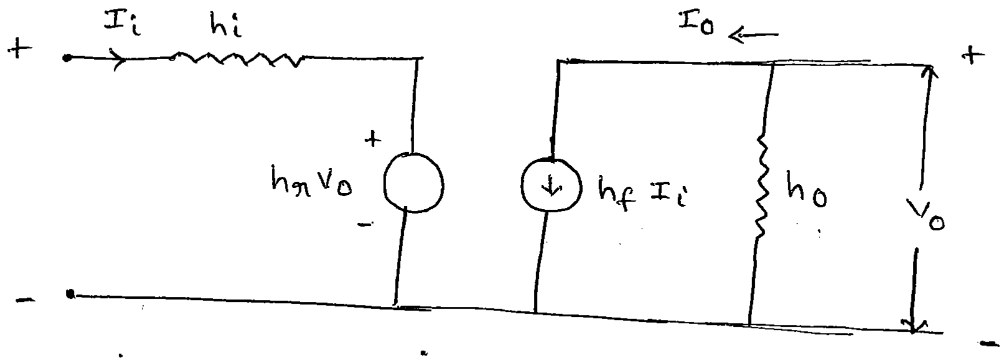
Based on the definition of hybrid parameters the mathematical model for two port networks known as h-parameter model (Hybrid parameter model) can be developed.

The two equations of a transistor is given by

$$V_i = h_i I_i + h_r V_o$$

$$I_o = h_f I_i + h_o V_o$$

Based on above two equations the equivalent circuit or Hybrid Model for transistor can be drawn.



Advantages (or) Benifits of h-parameters

1) Real numbers at audio frequencies
2) Easy to measure
3) can be obtained from the transistor static characteristic curves.
4) convinient to use in circuit analysis and design.
5) Easily convertable from one configuration to other
6) Most of the transistor manufacturers sepecify the h-parameters.

H parameter Model for CE Configuration

let us consider the common emitter configuration shown in figure below. The Variables I_b, I_c, V_b and V_c represent total instantaneous corrents and Voltages.

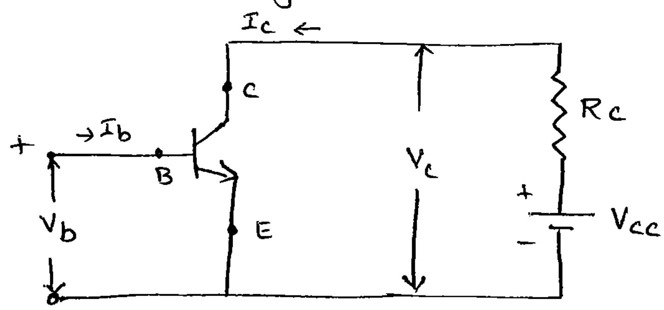
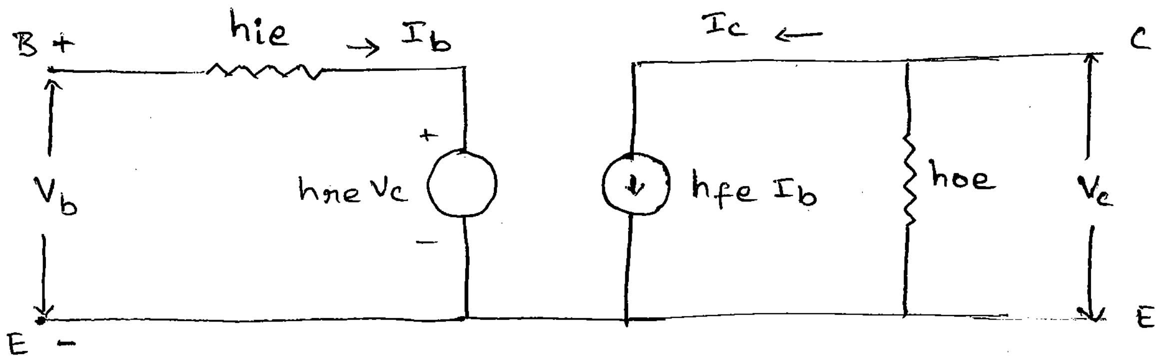


Fig: simple common emitter configuration

Here I_b - Input current V_b - Input voltage

I_c - output current V_c - output voltage

h- parameter model for common emitter configuration is shown in figure below.



$$V_b = h_{ie} I_b + h_{re} V_c$$

$$I_c = h_{fe} I_b + h_{oe} V_c$$

where
$$h_{ie} = \left.\frac{\Delta V_B}{\Delta I_B}\right|_{V_c = \text{constant}} = \left.\frac{V_b}{i_b}\right|_{V_c = \text{constant}}$$

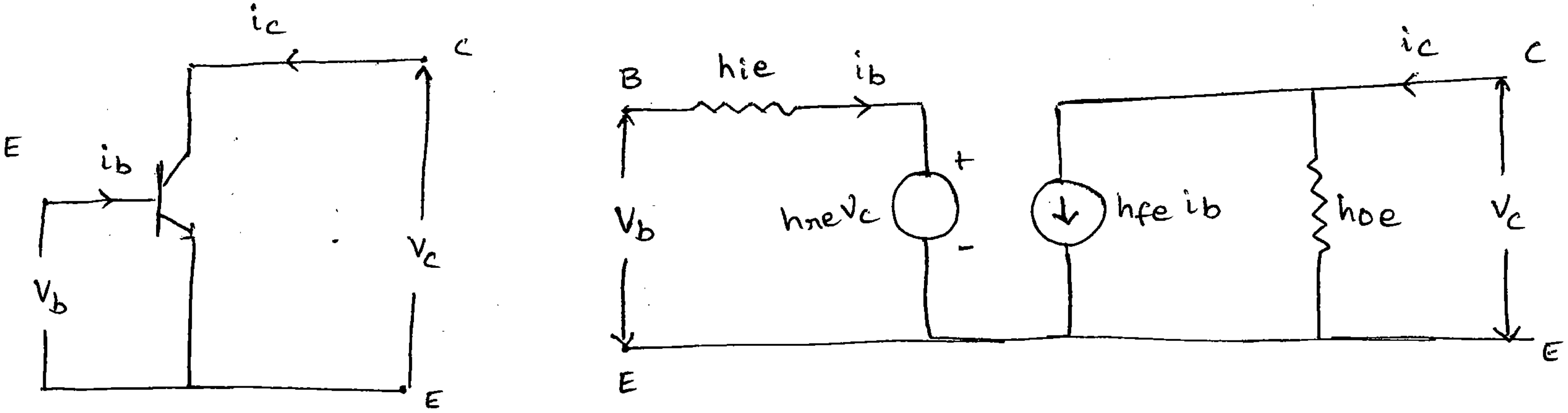
$$h_{re} = \left.\frac{\Delta V_B}{\Delta V_c}\right|_{I_B = \text{constant}} = \left.\frac{V_b}{V_c}\right|_{i_b = \text{constant}}$$

$$h_{fe} = \left.\frac{\Delta I_c}{\Delta I_B}\right|_{V_c = \text{constant}} = \left.\frac{i_c}{i_b}\right|_{V_c = \text{constant}}$$

$$h_{oe} = \left.\frac{\Delta I_c}{\Delta V_c}\right|_{I_B = \text{constant}} = \left.\frac{i_c}{V_c}\right|_{i_b = \text{constant}}$$

Hybrid model for the transistor in three different configurations

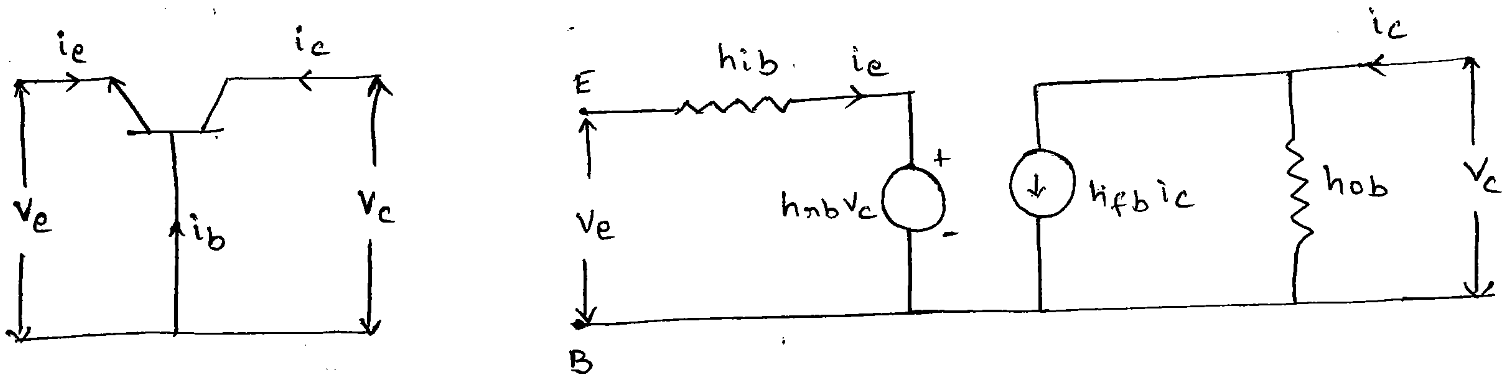
CE



$V_b = h_{ie}\, i_b + h_{re}\, V_c$

$i_c = h_{fe}\, i_b + h_{oe}\, v_c$

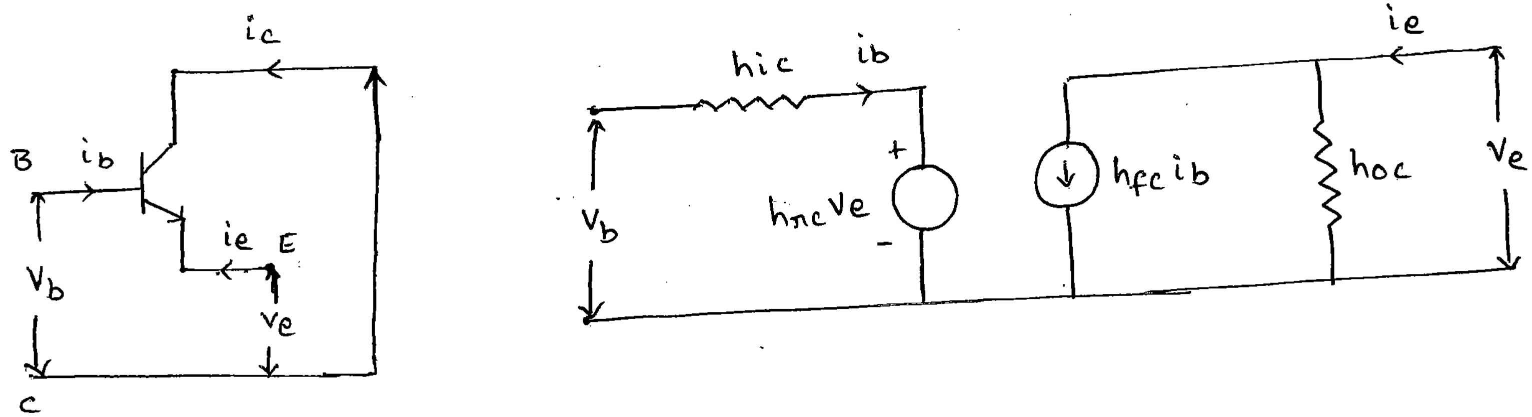
CB



$V_e = h_{ib}\, i_e + h_{rb}\, V_c$

$i_c = h_{fb}\, i_e + h_{ob}\, i_c$

CC



$V_b = h_{ic}\, i_b + h_{rc}\, V_e$

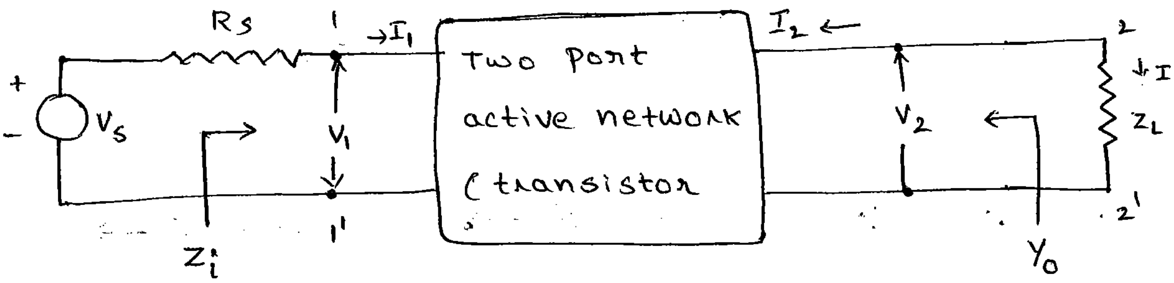
$i_e = h_{fc}\, i_b + h_{oc}\, V_e$

Typical h-parameter values for a transistor

Parameter	CE	CC	CB
h_i	$1100\,\Omega$	$1100\,\Omega$	$22\,\Omega$
h_r	2.5×10^{-4}	1	3×10^{-4}
h_f	50	-51	-0.98
h_o	$25\,\mu A/V$	$25\,\mu A/V$	$0.49\,\mu A/V$

Analysis of a transistor amplifier circuit using h-parameter model.

A transistor amplifier can be constructed by connecting an external load and signal source as indicated in figure below. and biasing the transistor properly.



The hybrid parameter model for above network is shown in figure below.

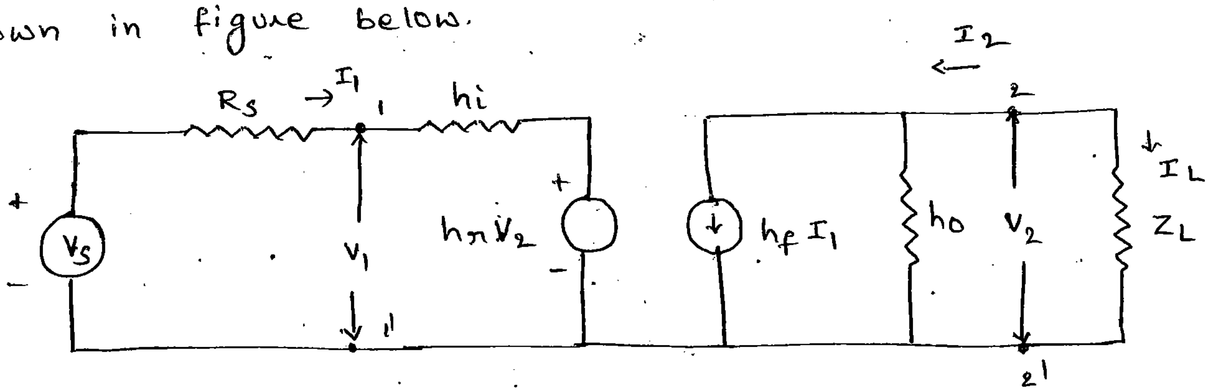


Fig: Transistor hybrid parameter model.

1) Current Gain (or) Current Amplification A_i :

For a transistor amplifier the current gain A_I is defined as the ratio of output current to input current.

$$A_I = \frac{I_L}{I_1} = \frac{-I_2}{I_1}$$

From the circuit $I_2 = h_f I_1 + h_o V_2 \longrightarrow ①$

$$V_2 = I_L Z_L = -I_2 Z_L \longrightarrow ②$$

Sub ② in ①

$$I_2 = h_f I_1 - I_2 Z_L h_o$$

$$I_2 + I_2 Z_L h_o = h_f I_1$$

$$I_2 (1 + Z_L h_o) = h_f I_1 \Rightarrow \frac{I_2}{I_1} = \frac{h_f}{1 + Z_L h_o}$$

$$\boxed{A_I = \frac{-I_2}{I_1} = \frac{-h_f}{1 + Z_L h_o}}$$

	CE	CB	CC
A_I	$\frac{-h_{fe}}{1 + Z_L h_{oe}}$	$\frac{-h_{fb}}{1 + Z_L h_{ob}}$	$\frac{-h_{fc}}{1 + Z_L h_{oc}}$

2) Input Impedance Z_i

In the circuit R_s is the signal source resistance. The impedance seen when looking in to the amplifier terminals $(1, 1')$ is the amplifier input impedance Z_i

$$Z_i = \frac{V_1}{I_1}$$

From figure $V_1 = h_i I_1 + h_r V_2$

So $$Z_i = \frac{h_i I_1 + h_r V_2}{I_1} = h_i + h_r \frac{V_2}{I_1} \longrightarrow (1)$$

$$V_2 = -I_2 Z_L = A_I I_1 Z_L \qquad \left[\because A_I = \frac{-I_2}{I_1}\right]$$

$(1) \Rightarrow$ $$Z_i = h_i + h_r \frac{A_I I_1 Z_L}{I_1}$$

$$Z_i = h_i + h_r A_I Z_L$$

$$Z_i = h_i - h_r Z_L \frac{h_f}{1 + h_o Z_L} \qquad \left[\because A_I = \frac{-h_f}{1 + h_o Z_L}\right]$$

$$Z_i = h_i - \frac{h_f h_r}{\frac{1}{Z_L} + h_o}$$

$$Z_i = h_i - \frac{h_f h_r}{Y_L + h_o} \qquad \left[\because Y_L = \frac{1}{Z_L}\right]$$

	CE	CB	CC
Z_i	$h_{ie} - \frac{h_{fe} h_{re}}{Y_L + h_{oe}}$	$h_{ib} - \frac{h_{fb} h_{rb}}{Y_L + h_{ob}}$	$h_{ic} - \frac{h_{fc} h_{rc}}{Y_L + h_{oc}}$

3) Voltage gain (A_V) :

The ratio of output voltage V_2 to input voltage gives the voltage gain of the transistor

$$A_V = \frac{V_2}{V_1}$$

Substituting $V_2 = -I_2 Z_L = A_I I_1 Z_L$

$$\Rightarrow A_V = \frac{A_I I_1 Z_L}{V_1} = \frac{A_I Z_L}{V_1/I_1} = \frac{A_I Z_L}{Z_i}$$

	CE	CB	CC
A_V	$\frac{A_I Z_L}{Z_i}$	$\frac{A_I Z_L}{Z_i}$	$\frac{A_I Z_L}{Z_i}$

4) **Output Admittance (Y_o) :**

$$Y_o = \frac{I_2}{V_2} \quad \text{with} \quad V_s = 0 \quad \text{and} \quad R_L = \infty$$

From the circuit $\quad I_2 = h_f I_1 + h_o V_2$

Dividing by V_2, $\quad \frac{I_2}{V_2} = h_f \frac{I_1}{V_2} + h_o \longrightarrow (1)$

With $V_s = 0$, by KVL in input circuit

$$R_s I_1 + h_i I_1 + h_r V_2 = 0$$

$$I_1 (R_s + h_i) + h_r V_2 = 0$$

Hence $\quad \frac{I_1}{V_2} = \frac{-h_r}{R_s + h_i}$

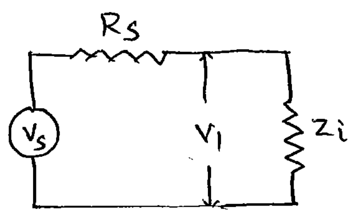
Now Eq (1) $\Rightarrow \quad \frac{I_2}{V_2} = \frac{-h_f h_r}{R_s + h_i} + h_o$

$$\Rightarrow \quad Y_o = h_o - \frac{h_f h_r}{R_s + h_i}$$

	CE	CB	CC
Y_o	$h_{oe} - \frac{h_{fe} h_{re}}{R_s + h_{ie}}$	$h_{ob} - \frac{h_{fb} h_{rb}}{R_s + h_{ib}}$	$h_{oc} - \frac{h_{fc} h_{rc}}{R_s + h_{ic}}$

5) **Voltage gain (A_{vs}) (Including source) :**

$$A_{vs} = \frac{V_2}{V_s} = \frac{V_2}{V_1} \frac{V_1}{V_s} \Rightarrow A_{vs} = A_v \frac{V_1}{V_s}$$



$$V_1 = \frac{V_s Z_i}{R_s + Z_i} \Rightarrow \frac{V_1}{V_s} = \frac{Z_i}{R_s + Z_i}$$

Now $\quad A_{vs} = \frac{A_v Z_i}{R_s + Z_i}$

$$A_{VS} = \frac{A_I R_L}{Z_i} \times \frac{Z_i}{R_s + Z_i} = \frac{A_I R_L}{R_s + Z_i}$$

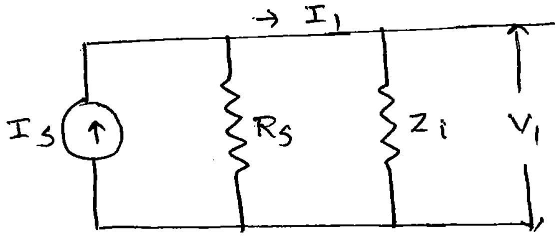
If $R_s = 0$ then $A_{VS} = \frac{A_I R_L}{Z_i} = A_V$.

6) Current Amplification (A_{IS})

$$A_{IS} = \frac{-I_2}{I_s} = \frac{-I_2}{I_1} \cdot \frac{I_1}{I_s} = A_I \frac{I_1}{I_s}$$

The modified input circuit using Norton's equivalent circuit for the source for the calculation of A_{IS}

$$A_{IS} = A_I \frac{R_s}{R_s + Z_i}$$



$$A_{VS} = \frac{A_{IS} Z_L}{R_s}$$

⇒ In CE configuration

Current Gain $A_I = \frac{-h_{fe}}{1 + h_{oe} Z_L}$ $[Z_L = R_L]$

Input Impedance $Z_i = h_{ie} - \frac{h_{fe} h_{re}}{Y_L + h_{oe}}$ $[Y_L = \frac{1}{Z_L} = \frac{1}{R_L}$

Voltage Gain $A_V = A_I \frac{Z_L}{Z_i}$

Output Admittance $Y_o = h_{oe} - \frac{h_{fe} h_{re}}{h_{ie} + R_s}$

⇒ In CB configuration

Current gain $A_I = \frac{-h_{fb}}{1 + h_{ob} Z_L}$

Input Impedance $Z_i = h_{ib} - \frac{h_{fb} h_{rb}}{Y_L + h_{ob}}$

Voltage gain $A_V = A_I \frac{Z_L}{Z_i}$

Output Admittance $Y_o = h_{ob} - \frac{h_{fb} h_{rb}}{h_{ib} + R_s}$

⇒ In CC configuration

Current gain $A_I = \dfrac{-h_{fc}}{1 + h_{oc} Z_L}$

Input Impedance $Z_i = h_{ic} - \dfrac{h_{fc} h_{rc}}{Y_L + h_{oc}}$

Voltage gain $A_V = \dfrac{A_I Z_L}{Z_i}$

Output Admittance $Y_o = h_{oc} - \dfrac{h_{fc} h_{rc}}{h_{ic} + R_s}$

Conversion formulae for hybrid parameters

CB	CC
$h_{ib} = \dfrac{h_{ie}}{1 + h_{fe}}$	$h_{ic} = h_{ie}$
$h_{rb} = \dfrac{h_{ie} h_{oe}}{1 + h_{fe}} - h_{re}$	$h_{rc} = 1$
$h_{fb} = \dfrac{-h_{fe}}{1 + h_{fe}}$	$h_{fc} = -(1 + h_{fe})$
$h_{ob} = \dfrac{h_{oe}}{1 + h_{fe}}$	$h_{oc} = h_{oe}$

1) Characteristics of Common emitter Amplifier

1) Current gain A_I is high for $R_L < 10 K\Omega$
2) The voltage gain is high for normal values of Load resistance R_L
3) The input resistance R_i is medium
4) The output resistance R_o is moderately high

Applications of common emitter amplifier :

1. Of the three configurations CE amplifier alone is capable of providing both voltage gain and current gain.
2. The output resistance R_o and input resistance R_i are moderately high
3. CE amplifier is widely used for Amplification purpose

2) ## Characteristics of Common Base Amplifier :

1. Current gain is less than unity and its magnitude decreases with the increase of load resistance R_L
2. Voltage gain A_v is high for normal values of R_L
3. The input resistance R_i is the lowest of all the three configurations.
4. The output resistance R_o is the highest of all the three configurations.

Applications of common base Amplifier

The CB Amplifier is not commonly used for Amplification purpose. It is used for

1) Matching a very low impedance source.
2) As a non inverting amplifier with voltage gain exceeding unity
3) For driving a high impedance load
4) As a constant current source.

3) ## Characteristics of common collector Amplifier

1. For low value of R_L ($< 10k\Omega$) the current gain A_I is high and almost equal to that of a CE amplifier

2. The voltage gain A_V is less than unity.

3. The input resistance is the highest of all the three configurations.

4. The output resistance is the lowest of all the three configurations.

Applications of common collector Amplifier:

1. The CC Amplifier is widely used as a buffer stage between a high impedance source and low impedance load. (CC Amplifier is called emitter follower)

Comparison of Transistor Amplifier Configurations.

The characteristics of three configurations are summarized in table below. Here the quantities A_I, A_V, R_i, R_o and A_P (Power gain) are calculated for $R_L = R_S = 3\,K\Omega$

Quantity	CB	CC	CE
A_I	0.98	47.5	−46.5
A_V	131	0.989	−131
A_P	128.38	46.98	6091.5
R_i	22.6 Ω	144 KΩ	1065 Ω
R_o	1.72 MΩ	80.5 Ω	45.5 KΩ

Problem: A CE Amplifier is drawn by a voltage souce of Internal resistance $r_s = 800\Omega$ and the load impedance is a resistance $R_L = 1000\Omega$. The h parameters are $h_{ie} = 1k\Omega$, $h_{re} = 2 \times 10^{-4}$, $h_{fe} = 50$ and $h_{oe} = 25\,\mu A/V$, compote the current gain A_I, input resistance R_i, voltage gain A_V, and output resistance R_o using exact analysis and approximate analysis.

Solution: Given data

$r_s = 800\Omega$, $R_L = 1000\Omega$, $h_{ie} = 1k\Omega$, $h_{re} = 2 \times 10^{-4}$, $h_{fe} = 50$, and $h_{oe} = 25\,\mu A/V$

Exact Analysis:-

Current Gain $A_I = \dfrac{-h_{fe}}{1 + h_{oe} R_L} = -48.78$

Input Resistance $R_i = h_{ie} - \dfrac{h_{fe}\, h_{re}}{h_{oe} + \frac{1}{R_L}} = 990.24\Omega$

Voltage gain $A_V = A_I \dfrac{R_L}{R_i} = -49.26$

Outpot Resistance

$$Y_o = h_{oe} - \frac{h_{fe}\, h_{re}}{h_{ie} + R_s} = 194 \times 10^{-5} \text{ mho}$$

$$R_o = \frac{1}{Y_o} = 51.42\, k\Omega$$

Approximate Analysis:

$$A_I = -h_{fe} = -50$$

$$R_i = h_{ie} = 1\, k\Omega$$

$$A_V = \frac{-h_{fe} R_L}{h_{ie}} = \frac{-50 \times 1000}{1000} = -50$$

$$R_o = \infty$$

Problem: A voltage source of Internal resistance $R_s = 900\,\Omega$ drives a CC amplifier using load resistance $R_L = 2000\,\Omega$. The CE h-parameters are $h_{ie} = 1200\,\Omega$, $h_{re} = 2 \times 10^{-4}$, $h_{fe} = 60$ and $h_{oe} = 25\,\mu A/V$. Compute the current gain A_I, input Resistance R_i, voltage gain A_V, and output resistance R_o using exact analysis and approximate analysis.

Sol Conversion formulae:

$$h_{ic} = h_{ie} = 1200\,\Omega$$

$$h_{fc} = -(1 + h_{fe}) = -(1 + 60) = -61$$

$$h_{rc} = 1$$

$$h_{oc} = h_{oe} = 25\,\mu A/V$$

Exact Analysis:

$$A_I = \frac{-h_{fc}}{1 + h_{oc} R_L} = 58.095$$

$$R_i = h_{ic} - \frac{h_{fc} h_{rc}}{Y_L + h_{oe}} = 117.39\,K\Omega$$

$$A_V = \frac{A_I R_L}{R_i} = 0.9897$$

Output Admittance

$$Y_0 = h_{oc} - \frac{h_{fc} h_{rc}}{h_{ic} + R_S}$$

$$\Rightarrow R_O = \frac{1}{Y_O} = 34.396\,\Omega$$

Approximate Analysis

$$A_I = 1 + h_{fe} = 1 + 60 = 61$$

$$R_i = h_{ie} + (1 + h_{fe}) R_L = 123.2\,K\Omega$$

$$A_V = 1 - \frac{h_{ie}}{R_i} = 0.99$$

$$R_o = \frac{h_{ie} + R_S}{1 + h_{fe}} = 34.43\,\Omega$$

Problem:

For a CB transistor Amplifier driven by a voltage source of internal resistance $R_S = 1200\,\Omega$, the load impedance is a resistor $R_L = 1000\,\Omega$. The h-parameters are $h_{ib} = 22\,\Omega$, $h_{rb} = 3 \times 10^{-4}$, $h_{fb} = -0.98$, $h_{ob} = 0.5\,\mu A/V$. Compute the current gain A_I, Input impedance R_i, voltage gain A_V, overall voltage gain A_{VS}, over all current gain A_{IS}, output impedance R_o and power gain A_p using exact and approximate analysis.

Solution:

Current gain $A_I = \dfrac{-h_{fb}}{1 + h_{ob} R_L} = 0.98$

Input Impedance $R_i = h_{ib} - \dfrac{h_{fb} h_{rb}}{Y_L + h_{ob}} = 22.3\,\Omega$