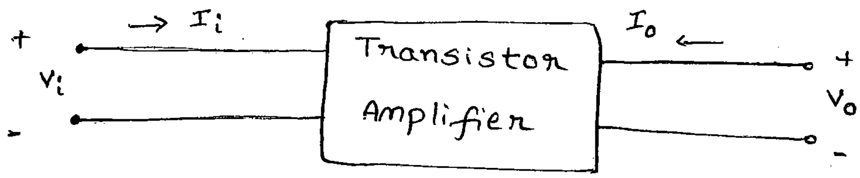
BJT AMPLIFIERS

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.

$h_{12} = h_r = \left.\frac{V_i}{V_o}\right|_{I_i=0}$ = 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:

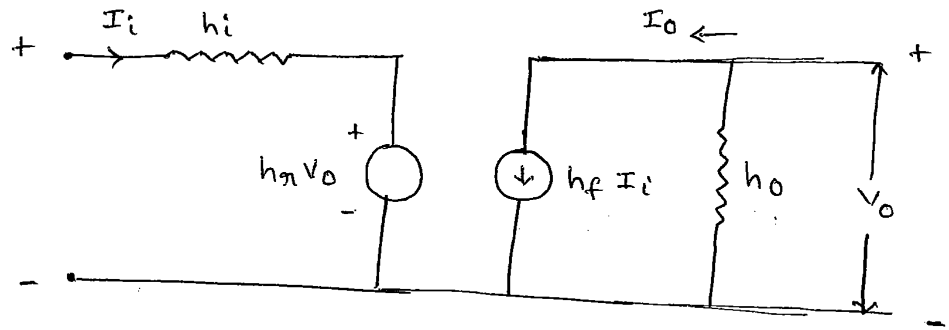
Based on the definition of hybrid parameters the mathematical model for two port networks known as h-parameter model (Hybrid parameter model) can be developed.

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 conventable 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.

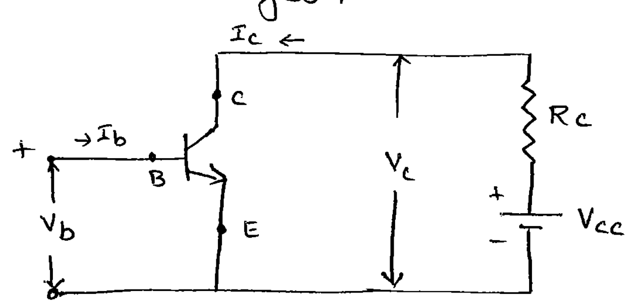
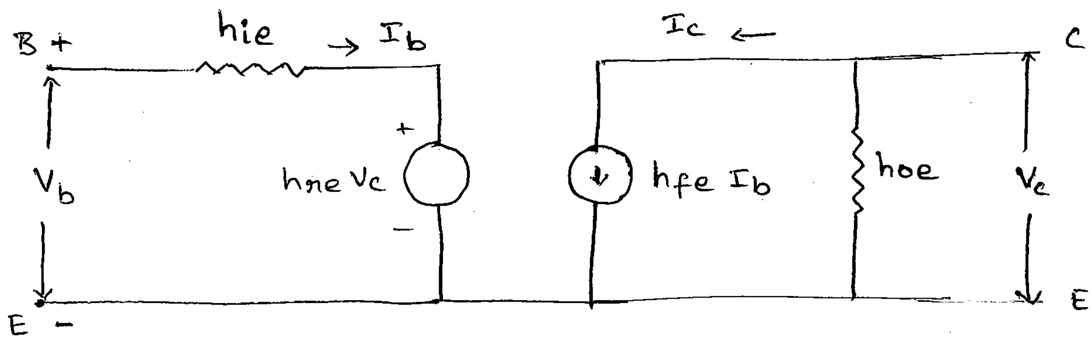


Fig: simple common emitter configuration

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

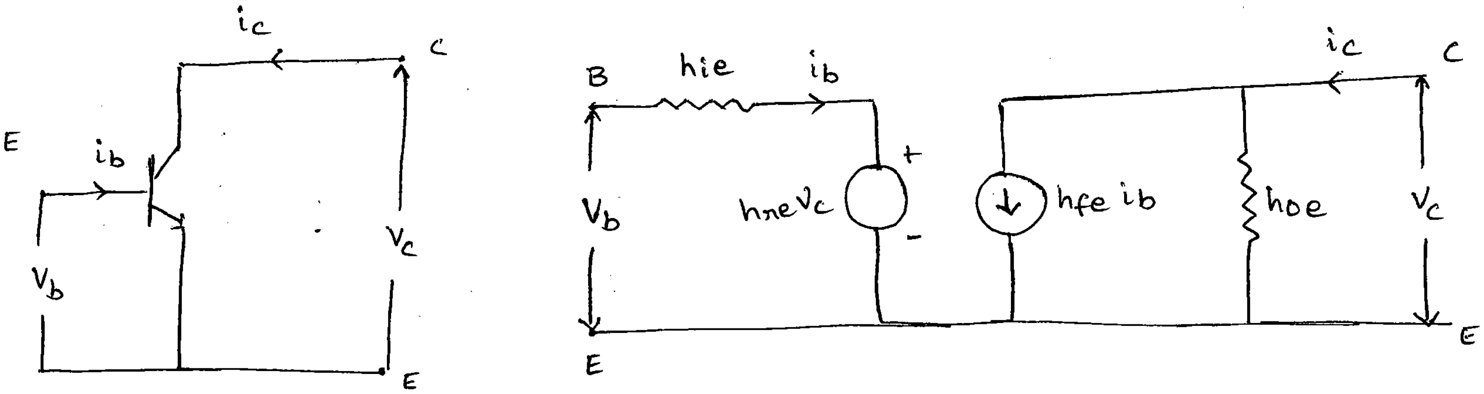
$$h_{re} = \left.\frac{\Delta V_B}{\Delta V_c}\right|_{I_B = \text{constant}} = \left.\frac{V_b}{V_c}\right|_{i_b = \text{constant}}$$

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

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

Hybrid model for the transistor in three different configurations

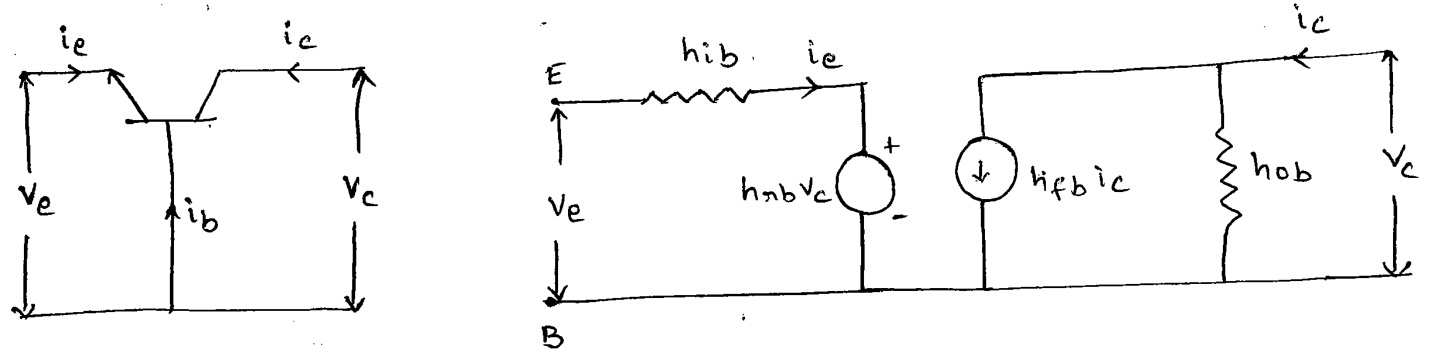
CE



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

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

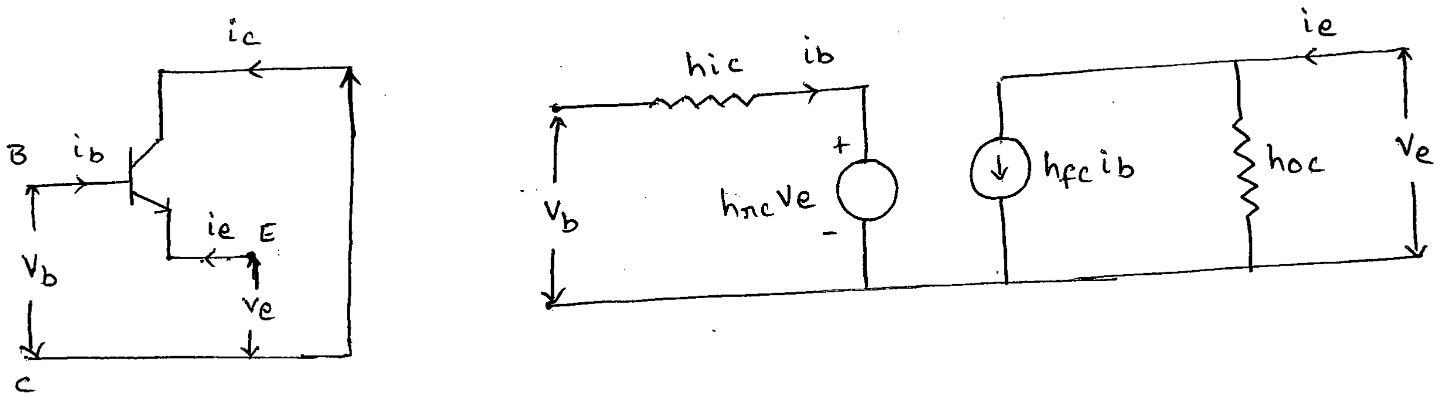
CB



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

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

CC



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

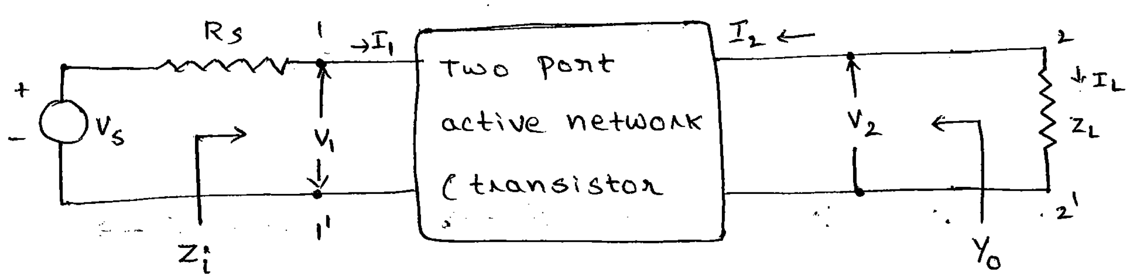
$i_e = h_{fc}\, i_b + h_{oc}\, V_e$

Typical h-parameter values for a transistor

Parameter	CE	CC	CB
h_i	1100 Ω	1100 Ω	22 Ω
h_r	2.5×10^{-4}	1	3×10^{-4}
h_f	50	−51	−0.98
h_o	25 μA/V	25 μA/V	0.49 μA/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.

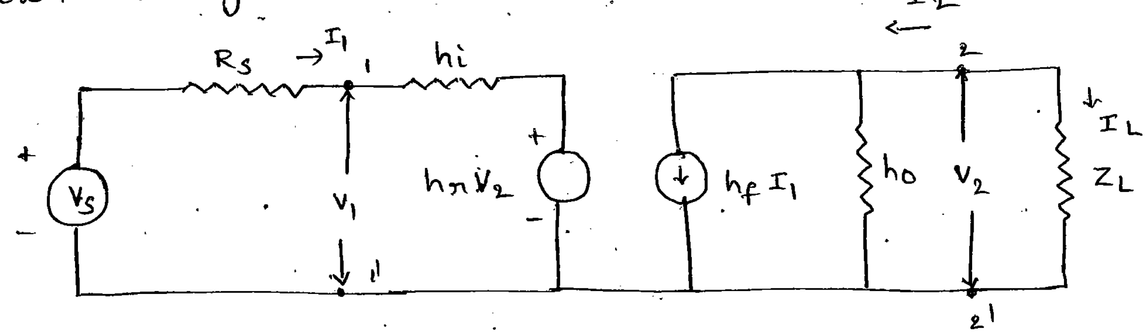


Fig: Transistor hybrid parameter model.

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) <u>Output Admittance</u> (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 $I_2 = h_f I_1 + h_o V_2$

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

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

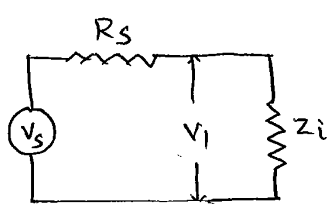
Now Eq (1) $\Rightarrow \frac{I_2}{V_2} = \frac{-h_f h_r}{R_s + h_i} + h_o$

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

	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) <u>Voltage gain</u> (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 $A_{vs} = \frac{A_v Z_i}{R_s + Z_i}$

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

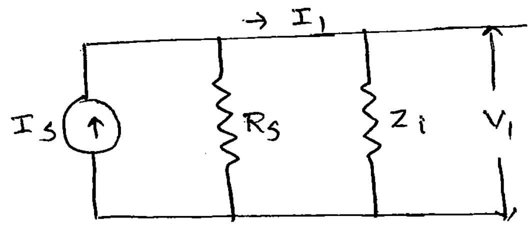
If $R_S = 0$ then $A_{VS} = \frac{A_I R_L}{Z_i} = A_V$.

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

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

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 $Y_o = h_{ob} - \frac{h_{fb} h_{rb}}{h_{ib} + R_S}$