$$\therefore R_1 = \frac{V_{cc} R_B}{V} = 23.94\,K\Omega$$

$$V = \frac{V_{cc} R_2}{R_1 + R_2}$$

$$\Rightarrow \frac{V}{V_{cc}} = \frac{R_2}{R_1 + R_2}$$

$$\Rightarrow 1 - \frac{V}{V_{cc}} = 1 - \frac{R_2}{R_1 + R_2} = \frac{R_1}{R_1 + R_2} = \frac{R_B}{R_2}$$

$$\therefore R_2 = \frac{R_B}{1 - \frac{V}{V_{cc}}} = 12.20\,K\Omega$$

Hybrid or h-parameter Equivalent Circuit :

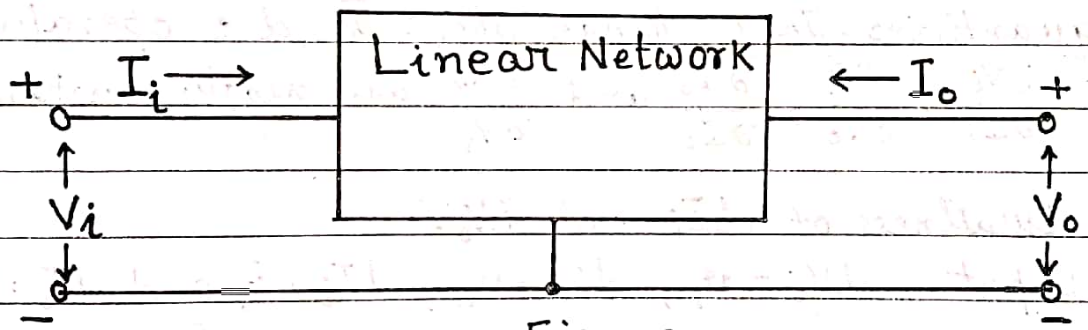

Fig-12

Any network can be represented by a box which has two input terminals and other two output terminals. The behaviour of the network is described by writing the relationships among the voltages and currents as shown in Fig-12.

The four variables are V_i, V_o, I_i and I_o. We consider any two variables are independent variables and the rest two as dependent variables.

We consider I_i and V_o are independent variables

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and I_o and V_i are dependent variables of the network of fig-12.

Therefore,

$$V_i = f_1(I_i, V_o) \quad \text{------} (1)$$

$$I_o = f_2(I_i, V_o) \quad \text{......} (2)$$

Applying Taylor series expansion and neglecting the higher order terms we have

$$dV_i = \frac{\partial V_i}{\partial I_i} dI_i + \frac{\partial V_i}{\partial V_o} dV_o \quad \text{.....} (3)$$

and $$dI_o = \frac{\partial I_o}{\partial I_i} dI_i + \frac{\partial I_o}{\partial V_o} dV_o \quad \text{---} (4)$$

dV_i, dI_o, dI_i and dV_o are very small i.e they are a.c quantities. They change about the d.c operating points. $\frac{\partial V_i}{\partial I_i}$, $\frac{\partial V_i}{\partial V_o}$, $\frac{\partial I_o}{\partial I_i}$ and $\frac{\partial I_o}{\partial V_o}$ are nearly constants due to smallness of dI_i and dV_o.

Let us put $dV_i = v_1$, $dV_o = v_2$, $dI_i = i_1$ and $dI_o = i_2$

$$\frac{\partial V_i}{\partial I_i} = h_{11}, \quad \frac{\partial V_i}{\partial V_o} = h_{12}, \quad \frac{\partial I_o}{\partial I_i} = h_{21} \text{ and } \frac{\partial I_o}{\partial V_o} = h_{22}$$

Thus the equations (3) and (4) become

$$v_1 = h_{11} i_1 + h_{12} v_2 \quad \text{------} (5)$$

and $$i_2 = h_{21} i_1 + h_{22} v_2 \quad \text{......} (6)$$

$$h_{11} = \left.\frac{v_1}{i_1}\right|_{v_2=0}$$ = input impedance when output short-circuited to a.c

$h_{12} = \left.\dfrac{v_1}{v_2}\right|_{i_1=0}$ = reverse voltage gain when input open-circuited to a.c

$h_{21} = \left.\dfrac{i_2}{i_1}\right|_{v_2=0}$ = forward current gain when output short-circuited to a.c

$h_{22} = \left.\dfrac{i_2}{v_2}\right|_{i_1=0}$ = output admittance when input open-circuited to a.c.

These h coefficients are known as hybrid or h-parameters. Thus the a.c equivalent circuit of the network (Fig-12) can be drawn with help of equations ⑤ and ⑥. It is shown in Fig-13.

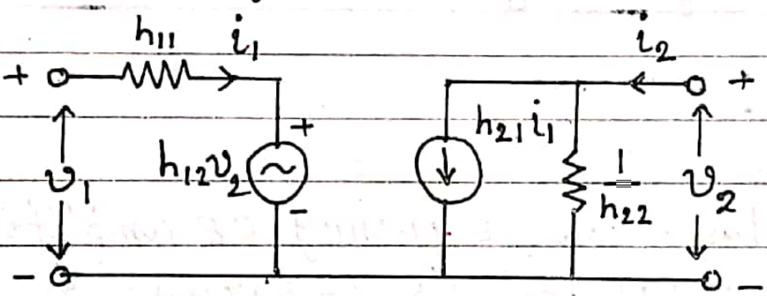
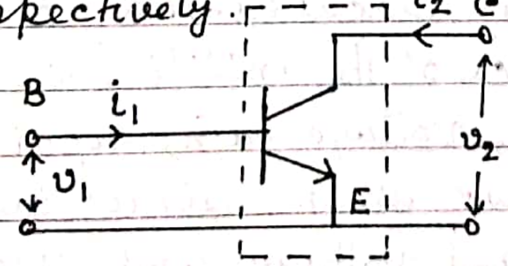


Fig-13.

Transistor h-parameter Model:-

To indicate a specific mode of connection subscripts like e, b or c is attached to the h-parameters. The circuit of CE mode of a n-p-n transistor and its h-parameter equivalent circuit are shown in Fig-14(a) and 14(b) respectively.

Fig-14(a)



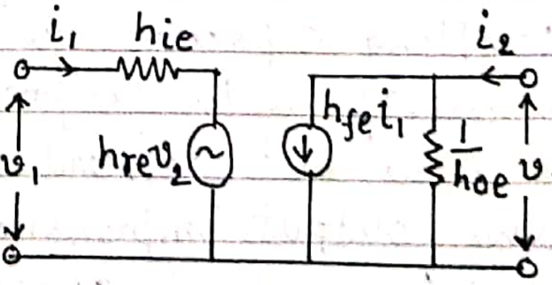


Fig-14(b)

(32)

Similar equations like (5) and (6) can be written for transistor circuit in CE mode connection and are given by

$$v_1 = h_{ie} i_1 + h_{re} v_2 \quad \text{------- (7)}$$

and $$i_2 = h_{fe} i_1 + h_{oe} v_2 \quad \text{------- (8)}$$

This h-parameter model for transistor is valid for low frequency operation because at low frequency the effects of various junction capacitances are negligible.

Analysis of a single stage CE-Amplifier using Hybrid Model:

A simple single-stage low frequency CE amplifier is shown in Fig-15(a) and its h-parameter equivalent circuit is shown in Fig-15(b). R_L is the load resistance connected at the output circuit. R_s is the internal resistance of the signal source v_s. To analyse the performance of the amplifier analytically the a.c equivalent h-parameter circuit (Fig-15(b)) is very useful. Since we are interested in a.c quantities only, the d.c sources and the coupling capacitors are short circuited. Now to understand the performance of the amplifier we are to find out current gain, voltage gain, input and output impedances. We assume sinusoidal variations for the current and voltage and use r.m.s values of the a.c quantities for analysis.

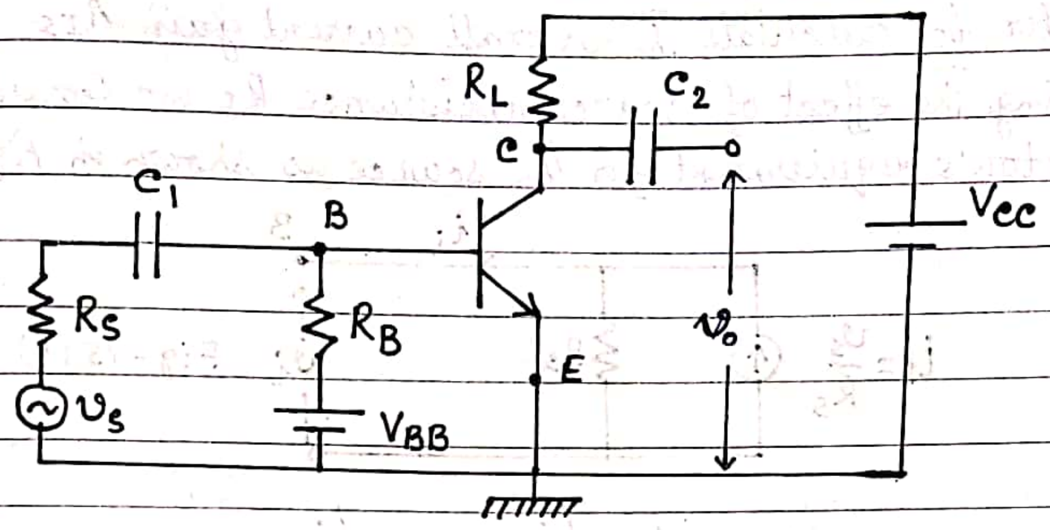


Fig-15(a)

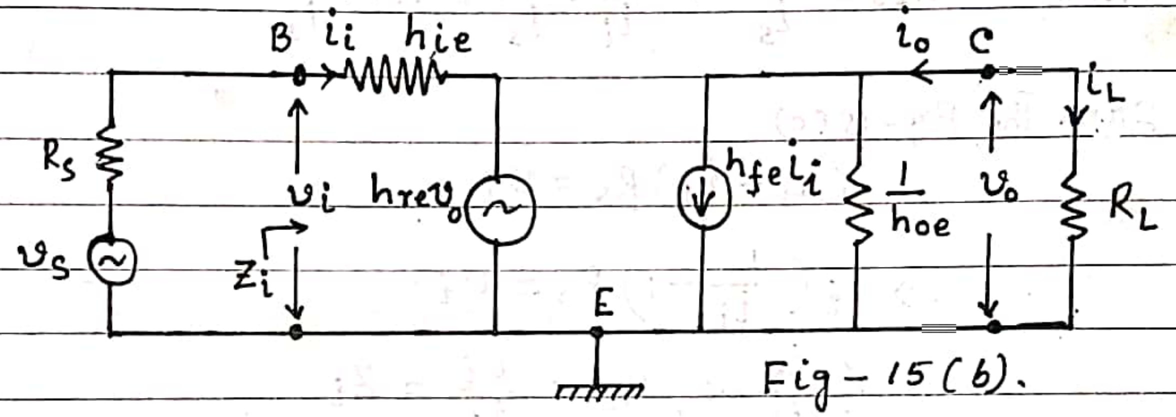


Fig-15(b).

Current Gain (A_I):

The current gain is defined as the ratio of the output current to the input current i.e

$$A_I = \frac{i_o}{i_i} = -\frac{i_L}{i_i} \qquad \text{-------(9)}$$

On the basis of the circuit of Fig-15(b) we have

$$i_o = h_{fe}i_i + h_{oe}v_o \qquad \text{-------(10)}$$

and $v_o = -i_o R_L$ -------(11)

Therefore, $i_o = h_{fe}i_i - h_{oe}R_L i_o$

(34) $\Rightarrow \quad A_I = -\frac{i_o}{i_i} = -\frac{h_{fe}}{1 + h_{oe}R_L}$ ....(12)

In order to calculate the overall current gain A_{Is} including the effect of source resistance R_s we consider the Norton's equivalent for the source as shown in fig-15(c)

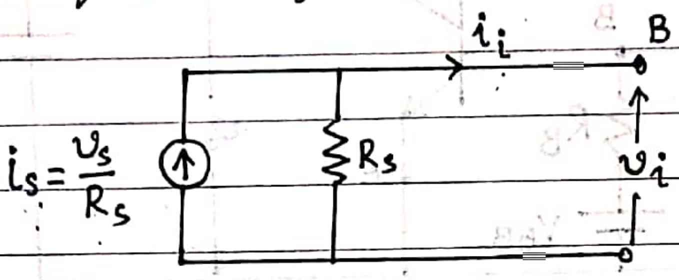


Fig-15(c)

Now $\quad A_{Is} = \frac{i_L}{i_s} = -\frac{i_o}{i_i} \cdot \frac{i_i}{i_s} = A_I \cdot \frac{i_i}{i_s}$ ....(13)

From the fig-15(c)

$$(i_s - i_i) R_s = v_i$$

$$\Rightarrow i_i\left(\frac{i_s}{i_i} - 1\right) R_s = v_i$$

$$\Rightarrow \left(\frac{i_s}{i_i} - 1\right) R_s = \frac{v_i}{i_i} = Z_i$$

$$\Rightarrow \frac{i_i}{i_s} = \frac{R_s}{Z_i + R_s} \quad \text{------(14)}$$

From the equations (13) and (14) we get

$$A_{Is} = A_I \cdot \frac{R_s}{Z_i + R_s} = \frac{A_I}{1 + \frac{Z_i}{R_s}} \quad \text{---(15)}$$

For an ideal current source $R_s = \infty$ $\therefore$ $A_{Is} \rightarrow A_I$.

Input impedance (Z_i):

Input impedance is defined as the ratio of the input voltage to the input current i.e

$$Z_i = \frac{v_i}{i_i}$$

Now from the circuit of fig-15(b) we have

$$v_i = h_{ie} i_i + h_{re} v_o \quad \text{------}(16)$$

and $$v_o = -i_o R_L = A_I i_i R_L \quad \text{------}(17)$$

From the equations (16) and (17) we get

$$v_i = h_{ie} i_i + h_{re} A_I i_i R_L.$$

Therefore

$$Z_i = \frac{v_i}{i_i} = h_{ie} + h_{re} R_L A_I \quad \text{------}(18)$$

using eqn (12) we get

$$Z_i = h_{ie} - \frac{h_{re} h_{fe}}{h_{oe} + \frac{1}{R_L}} \quad \text{------}(19)$$

It is to be noted that Z_i depends on the load resistance R_L.

Voltage Gain (A_v):

The internal voltage gain of the amplifier is defined as the ratio of the output voltage v_o to the input voltage v_i i.e

$$A_v = \frac{v_o}{v_i}$$

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using the equation (17) we get

$$A_V = \frac{A_I R_L i_i}{v_i} = \frac{A_I R_L}{Z_i} = -\frac{\frac{h_{fe}}{1+h_{oe}R_L}\cdot R_L}{Z_i}$$

$$\Rightarrow A_V = -\frac{h_{fe}R_L}{1+h_{oe}R_L}\cdot\frac{1}{Z_i} \quad \cdots\cdots(20)$$

$$\Rightarrow A_V = -\frac{h_{fe}R_L}{1+h_{oe}R_L}\cdot\frac{1}{h_{ie}+h_{re}A_I R_L}$$

$$\Rightarrow A_V = -\frac{h_{fe}R_L}{1+h_{oe}R_L}\cdot\frac{1}{h_{ie}-\frac{h_{fe}h_{re}R_L}{1+h_{oe}R_L}}$$

$$\Rightarrow A_V = -\frac{h_{fe}R_L}{1+h_{oe}R_L}\cdot\frac{1+h_{oe}R_L}{h_{ie}+(h_{ie}h_{oe}-h_{fe}h_{re})R_L}$$

$$\Rightarrow A_V = -\frac{h_{fe}R_L}{h_{ie}+\Delta_h R_L} \quad \cdots\cdots\cdots\cdots(21)$$

where $\Delta_h = h_{ie}h_{oe} - h_{fe}h_{re}$

The negative sign in equation (21) indicates $180°$ phase difference between input and output voltages in a single stage CE amplifier. The overall voltage gain A_{vs} for the effect of the source resistance R_s is defined by

$$A_{vs} = \frac{v_o}{v_s} = \frac{v_o}{v_i + i_i R_s} = \frac{\frac{v_o}{i_i}}{Z_i + R_s}$$

using equation (17) and (20) we get

$$A_{vs} = \frac{A_I R_L}{Z_i + R_s} = \frac{A_I R_L}{Z_i}\cdot\frac{Z_i}{Z_i+R_s} = A_V\frac{Z_i}{Z_i+R_s} \quad \cdots\cdots(22)$$

For ideal voltage source $R_s = 0$, $A_{vs} \rightarrow A_v$. For practical voltage source $R_s \neq 0$ and $|A_{vs}| < |A_v|$.

Output Impedance (Z_o):

The output impedance of an amplifier is the impedance measured between the output terminals with the input source is replaced by its internal impedance. To obtain the output impedance (Z_o) of an amplifier the voltage source v_s is set to zero, the load R_L to infinity and the output is drawn by a generator v_o. If i_o is the output current drawn then by definition

$$Z_o = \frac{v_o}{i_o} \quad \text{when } v_s = 0 \text{ and } R_L = \infty$$

From the Fig-15(b)

$$v_s = (h_{ie} + R_s) i_i + h_{re} v_o \quad \text{------(23)}$$

$$i_o = h_{fe} i_i + h_{oe} v_o \quad \text{------(24)}$$

Putting $v_s = 0$ and eliminating i_i from equation (23) and (24) we get

$$i_o = \left[h_{oe} - \frac{h_{fe} h_{re}}{h_{ie} + R_s} \right] v_o$$

Therefore,

$$Z_o = \frac{v_o}{i_o} = \frac{1}{h_{oe} - \dfrac{h_{fe} h_{re}}{h_{ie} + R_s}} \quad \text{--------(25)}$$

The output impedance is the function of R_s.

Power Gain (A_P):-

The power gain of the amplifier is defined by the relation

$$A_P = A_V A_I = \frac{h_{fe} R_L}{h_{ie} + \Delta_h R_L} \cdot \frac{h_{fe}}{1 + h_{oe} R_L}$$

$$= \frac{h_{fe}^2 R_L}{(1 + h_{oe} R_L)(h_{ie} + \Delta_h R_L)} \quad \cdots\cdots (26)$$

where $\Delta_h = h_{ie} h_{oe} - h_{fe} h_{re}$ ------(27)

Problem: The transistor CE amplifier of Fig-16(a) has the following set of h-parameters $h_{ie} = 2\,K\Omega$, $h_{fe} = 100$, $h_{re} = 5 \times 10^{-4}$ and $h_{oe} = 2.5 \times 10^{-5}$ mho. Find the voltage gain and a.c input impedance of the stage.

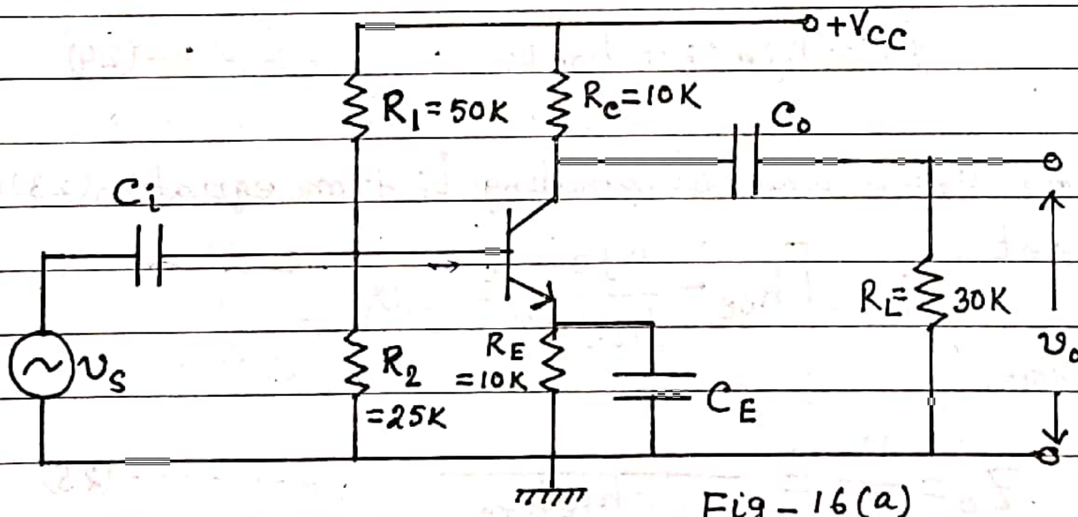

Fig-16(a)

since R_E is connected with by-pass capacitor C_E. So R_E has no role in the small signal a.c h-parameter equivalent circuit for The Calculation of voltage gain or input impedance. The h-parameter a.c equivalent circuit is shown in Fig-16(b)

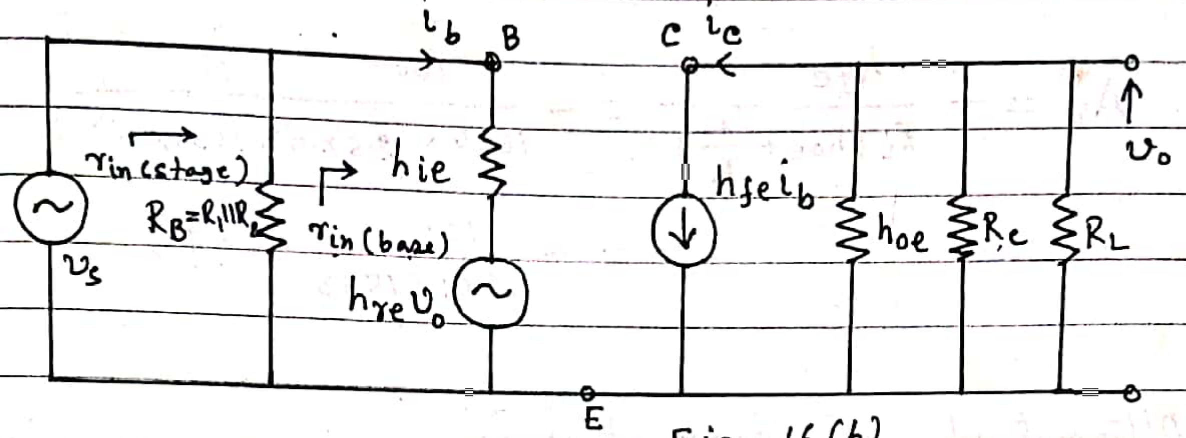

Fig-16(b)

Sol^n:

$$Z_i = r_{in(base)} = h_{ie} - \frac{h_{fe}h_{re}}{h_{oe} + \frac{1}{r_L}}$$

where

$$r_L = \text{Collector Load} = R_c \| R_L = 10K \| 30K = \frac{10 \times 30}{10+30}K = \frac{300}{40}K$$

$$= 7.5K$$

$$\therefore r_{in(base)} = 2000 - \frac{100 \times 5 \times 10^{-4}}{2.5 \times 10^{-5} + \frac{10^{-3}}{7.5}} = 2000 - \frac{100 \times 5 \times 10^{-4}}{10^{-4}(.25 + 1.33)} = 2000 - \frac{500}{1.58}$$

$$= (2000 - 316.5)\Omega$$

$$= 1683.5\,\Omega$$

$$\simeq 1684\,\Omega = 1.684K$$

The a.c input impedance of the stage

$$Z_{in} = r_{in(stage)} = r_{in(base)} \| R_1 \| R_2$$

$$= r_{in(base)} \| R_B$$

$$= \frac{1.684 \times 16.67}{1.684 + 16.67}K$$

$$= 1.53K.$$

$$R_B = \frac{R_1 R_2}{R_1 + R_2} = \frac{50 \times 25}{75}K$$

$$= 16.67K$$