DC load line

The cut-off point for this line is where $V_{CE}=V_{CC}$. It is also written as V_{CE} (cut-off) saturation point is given by $I_C=V_{CC}/R_L$. It is represented by straight line AQB in Fig.1.

AC load line

The cut-off point is given by $V_{CE(cut\text{-}off)}=V_{CEQ}+I_{CQ}R_{ac}$,where R_{ac} is the ac load resistance. Saturation point is given by $I_{C(sat)} = I_{CQ} + V_{CEQ}/R_{ac}$.

It is represented by straight line CQD in Fig.1. The slope of the ac load line is given by $y=-1/R_{ac}$.

It is seen from Fig. 1 that maximum possible positive signal swing is = $I_{CQ}R_{ac}$.

Similarly, maximum possible negative signal swing is V_{CEQ}.

Example: Draw the dc and ac load lines for the CE circuit shown in fig. below, (a) what is the maximum peak to peak signal that can be obtained?

Solution:

DC load line

$V_{CE(cut\text{-}off)}=V_{CC}=20V$. (point A)

$I_{C(Sat)}=V_{CC}/(R_L+R_E) = 20/5 = 4mA$ (point B).

Hence, AB represents dc load line for the given circuit.

Approximate bias conditions can be quickly found by assuming that I_B is too small to affect the base bias as in fig. below $V_2 = 20 \times 4/(4 + 16) = 4$ V. If we neglect V_{BE}, $V_2= V_E$;

$$I_E = \frac{V_E}{R_E} = \frac{V_2}{R_E} = \frac{4}{2}$$
$$= 2 \text{ mA}$$

Also, $I_C \approx I_E = 2$ mA. Hence, $I_{CQ} = 2$ mA.

AC Load Line

Cut-off point, $V_{CE(cut\text{-}off)} = V_{CEQ} + I_{CQ}R_{ac}$

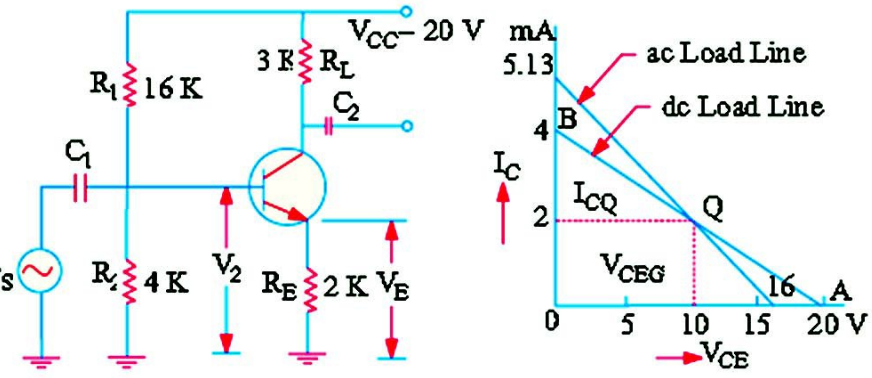
Now, for the given circuit, ac load resistance is $R_{ac} = R_C = 3K$.

Cut-off point = 10 + 2 × 3 = 16 V. Saturation point,

$$I_{c(sat)} = I_{CQ} + \frac{V_{CEQ}}{R_{ac}} = 2 + \frac{10}{3} = 5.13\,\mathrm{mA}$$

Hence, line joining 16-V point and 5.13 mA. Point gives ac load line as shown in Fig. (b). As expected, this line passes through the Q-point.

Now, I_{CQ}. R_{ac} = 2 × 3 = 6 V and V_{CEQ}= 10 V. Taking the smaller quantity, maximum peak output signal = 6 V. Hence, peak-to-peak value = 2 × 6 = 12 V.



(a) (b)

What are h-parameter?

These are four constants which describe the behavior of a two-port linear network. A linear network is one in which resistance, inductances and capacitances remain fixed when voltage across them is changed.

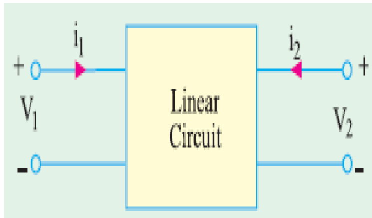


Fig.1

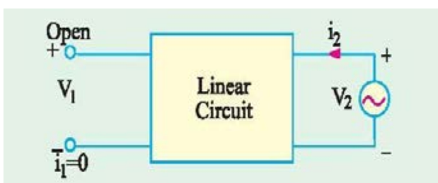
Consider an unknown linear network contained in a black box as shown in Fig. 1. As a matter of convention, currents flowing into the box are taken positive whereas those flowing out of it are considered negative.

Similarly, voltages are positive from the upper to the lower terminals and negative the other way around. The electrical behavior of such a circuit can be described with the help of four hybrid parameters or constants designated as h_{11}, h_{12}, h_{21}, h_{22}.

In this type of double-number subscripts, it is implied that the first variable is always divided by the other. The subscript 1 refers to quantities on the input side and 2 to the quantities on the output side. The letter 'h' has come from the word hybrid which mixture of distinctly different items. These constants are hybrid because they have different units. Out of the four h-parameters, two are found by short-circuiting the output terminals 2-2 and the other two by open-circuiting the input terminals 1-1 of the circuit.

(a) Finding h_{11} and h_{21} from Short-Circuit Test

As shown in Fig. , the output terminals have been shorted so that $v_2 = 0$, because no voltage can exist on a short.



The linear circuit within the box is driven by an input voltage v_1. It produces an input current i_1 whose magnitude depends on the type of circuit within the box.

$$h_{11} \quad \frac{V_1}{i_2} \qquad \text{— output shorted}$$

$$h_{21} \quad \frac{i_2}{i_1} \qquad \text{— output shorted}$$

These two constants are known as forward parameters. The constant h_{11} represents input impedance with output shorted and has the unit of ohm. The constant h_{21} represents current gain of the circuit with output shorted and has no unit since it is the ratio of two similar quantities.

The voltages and currents of such a two-port network are related by the following sets of equations or V/I relations

$$V_1 = h_{11} i_1 + h_{12} V_2$$
$$i_2 = h_{21} i_1 + h_{22} V_2$$

Here, the hare constants for a given circuit but change if the circuit is changed. Knowledge of parameters enables us to find the voltages and currents with the help of the above two equations.

(b) Finding h_{12} and h_{22} from Open-circuit Test

As shown in Fig.3 , the input terminals are open so that $i_1 = 0$ but there does appear a voltage v_1 across them. The output terminals are driven by an ac voltage v_2 which sets up current i_2.

$$h_{12} \quad \frac{V_1}{V_2} \qquad \text{— input open}$$

$$h_{22} \quad \frac{i_2}{V_2} \qquad \text{— input open}$$

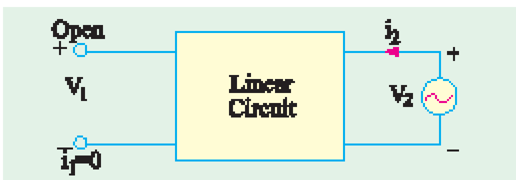


Fig.3

As seen, h_{12} represents voltage gain (not forward gain which is v_2 / v_1). Hence, it has no units. The constant h_{22} represents admittance (which is reverse of resistance) and has the unit of mho or Siemens, s.

It is actually the admittance looking into the output terminals with input terminals open. Generally, these two constants are also referred to as reverse parameters.

Summary of *h*-parameters

h_{11} = input impedance
h_{21} = forward current gain — with output shorted

h_{12} = reverse voltage gain
h = output admittance — with input open

The h-parameter Notation for Transistors

While using h-parameters for transistor circuits, their numerical subscripts are replaced by the first letters for defining them.

$h_{11} = h_i$ = input impedance
$h_{21} = h_f$ = forward current gain — output shorted

$h_{12} = h_r$ = reverse voltage gain
$h_{22} = h_0$ = output admittance — input open

A second subscript is added to the above parameters to indicate the particular configuration. For example, for CE connection, the four parameters are written as h_{ie}, h_{fe}, h_{re}, h_{oe}. Similarly, for CB connection, these are written as h_{ib}, h_{fb}, h_{rb} and for CC connection as h_{ic}, h_{fc}, h_{rc} and h_{oc}

The h-parameters of an Ideal CB Transistor

A CB-connected transistor has been shown in Fig.4 (a), connected in a black box. Fig.4 (b) gives its equivalent circuit. It should be noted that no external biasing resistors or any signal source has been shown connected to the transistor.

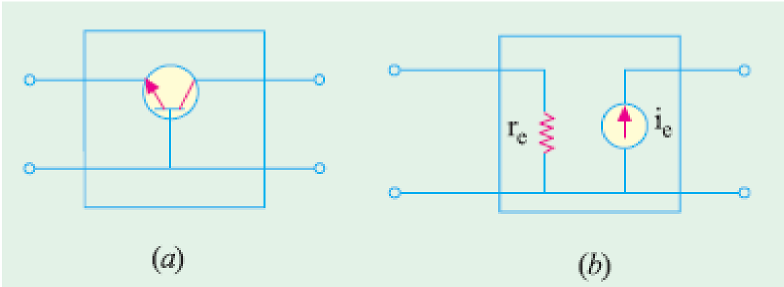


Fig. 4

(i) Forward Parameters

The two forward h-parameters can be found from the circuit of Fig.4 (a) where a short has been put across the output. The input impedance is simply r_e.

$$h_{ib} = r_e$$

The output current equals the input current i.e. Since it flows out of the box, it is taken as negative. The forward current gain is

$$h_{fb} \quad \frac{-i_e}{i_e} \quad 1$$

(It also called the ac α of the CB circuit.)

(ii) Reverse Parameters

The two reverse parameters can be found from the circuit diagram of Fig. (b). When input terminals are open, there can be no ac emitter current. It means that ac current source (inside the box) has a value of zero and so appears as an 'open'.

Because of this open, no voltage can appear across input terminals, however, large V_2 may be. Hence, V_1=0.

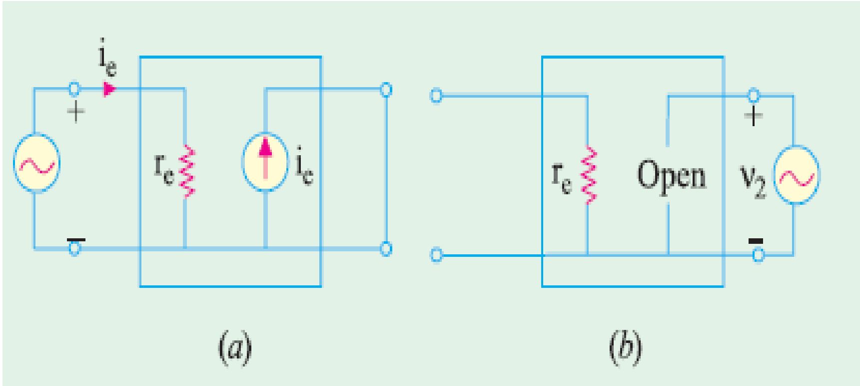


Fig.

$$\therefore \qquad h_{rb} \quad \frac{v_1}{v_2} \quad \frac{0}{v_2} \quad 0$$

Similarly, the impedance, looking into the output terminals is infinite. Consequently, its admittance (= 1/∞) is zero.

$$\therefore \qquad h_{ob} = 0$$

The four h-parameters of an ideal transistor connected in CB configuration are;

$$h_{ib} = r_e \quad ; \qquad h_{fb} = -1, \quad h_{rb} = 0 \; ; \quad h_{ob} = 0$$

The equivalent hybrid circuit is shown in Fig. 5.

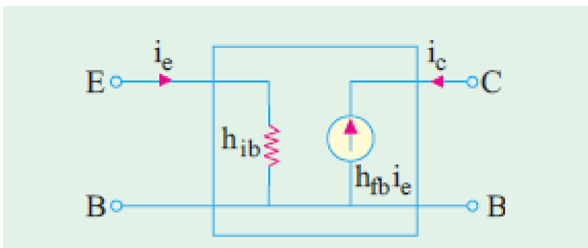


Fig. 5.

In reality, output impedance is not infinity but very high so that h_{ob} is extremely small. Similarly, there is some amount of feedback between the output and the input circuits (even when open) though it is very small. Hence, h is very small.

<u>The h--parameters of an ideal CE Transistor</u>

Fig 6 (a) shows a CE-connected ideal transistor contained in a black box where shows its ac equivalent circuit in terms of its β and resistance values.

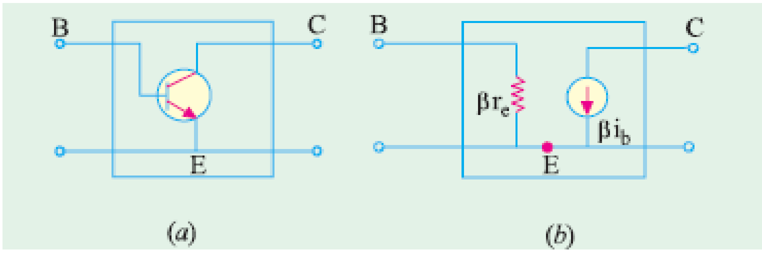


Fig. 6.

(a) Forward Parameters

The two forward h-parameters can be found from the circuit of Fig.7 (a)

Where output has been shorted. Obviously, the input impedance is simply βr_e

$$\therefore \qquad h_{ie} = \beta r_e$$

The forward current gain is given by

$$h_{fe} \quad \frac{i_2}{i_1} \quad \frac{i_b}{i_b}$$

(It is also called the ac beta of the CE circuit)

(b) Reverse Parameters

These can be found by reference to the circuit of Fig.7 (b), where input terminals are open but output terminals are driven by an are voltage source v_2 With input terminals open, there can be no base current so that i_b = o. If i_b= o, then collector current source has zero value i_b and looks like an open. Hence, there can be no v_1 due to this open.

$$\therefore \qquad h_{re} \quad \frac{v_1}{v_2} \quad \frac{0}{v_2} \quad 0$$

Again, the impedance looking into the output terminals is infinite so that conductance is zero $\quad \therefore \qquad h_{oe} = 0 \quad .$

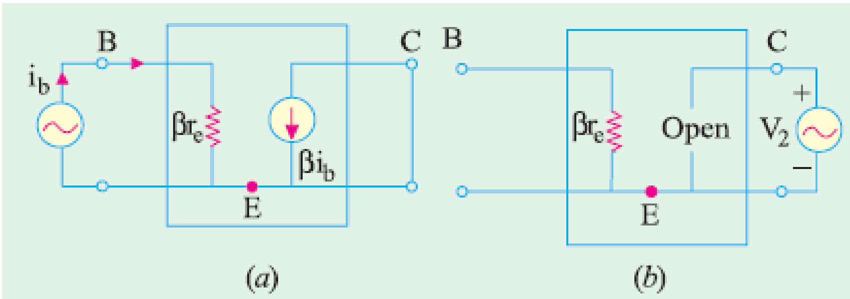


Fig. 7.

Hence, the four h-parameters of an ideal transistor connected in CE transistor are

$$h_{ie} = \beta r_e; \quad h_{fe} = \beta, \quad hr_e = 0; \quad h_{oe} = 0.$$

The hybrid equivalent circuit of such transistor is shown in fig.8.

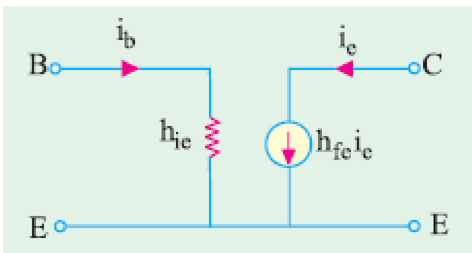


Fig. 8

Approximate Hybrid Equivalent Circuits

(a) Hybrid CB Circuit

In Fig. 9. (a) is shown an NPN transistor connected in CB configuration. Its ac equivalent circuit employing h-parameters is shown in Fig. 9 (b).

The V/I relationships are given by the following two equations

$$
\begin{aligned}
v_{eb} &= h_{ib}\, i_e + h_{rb}\, v_{cb} \\
i_e &= h_{fb}\, i_e + h_{ob}\, v_{eb}
\end{aligned}
$$

These equations are self-evident because applied voltage across input terminals must equal the drop over h_{ib} and the generator voltage. Similarly, current i_c the output terminals must equal the sum of two branch currents.

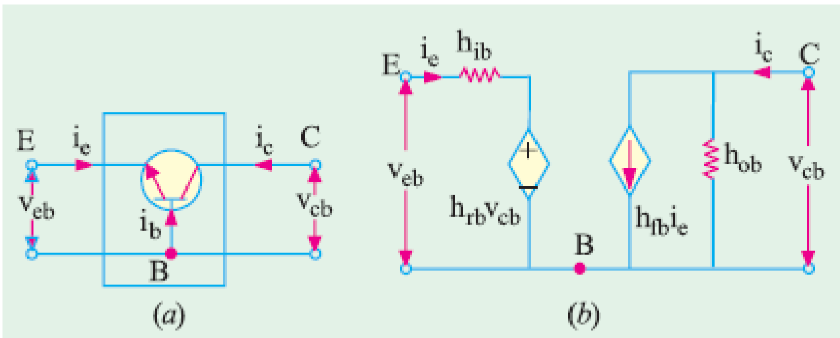


Fig. 9

(b) Hybrid CE Circuit

The hybrid equivalent of the transistor alone when connected in CE configuration is shown in Fig.10 (b). Its V/I characteristics are described by the following two equations.

$$
\begin{aligned}
v_{be} &= h_{ie}\, i_b + h_{re}\, v_{ec} \\
i_e &= h_{fb}\, i_b + h_{oe}\, v_{ec}
\end{aligned}
$$

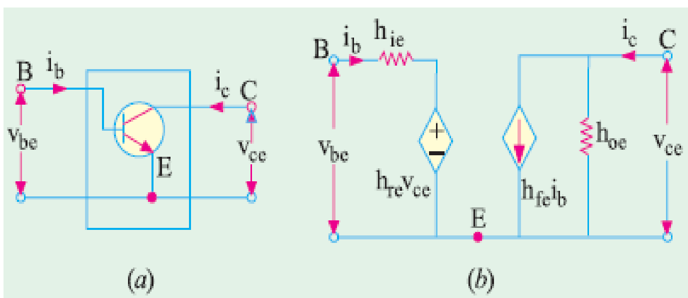


Fig. 10.

(c) Hybrid CC Circuit

The hybrid equivalent of a transistor alone when connected in CC Configuration is shown in Fig.11(b). Its V/I characteristics are defined by the following two equations :

$$v_{be} = h_{ie} i_b + h_{re} v_{ec}$$
$$i_e = h_{fe} i_b + h_{oc} v_{ce}$$

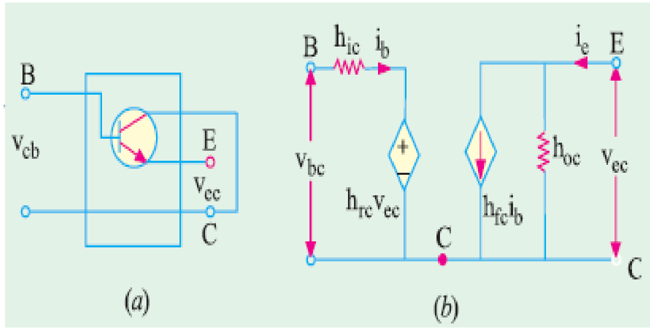


Fig. 11

We may connect signal input source across output terminals BC and load resistance across output terminals EC to get a CC amplifier.

Typical Values of Transistor h-parameters

In the table below are given typical values for each parameter for the broad range of transistors available today in each of the three configurations.

Parameter	*CB*	*CE*	*CC*
h_i	25 Ω	1 K	1 K
h_r	3×10^{-4}	2.5×10^{-4}	≅ 1
h_f	–0.98	50	–50
h_o	0.5×10^{-6}S	25×10^{-6}S	25×10^{-6}S

Approximate Hybrid Formulas

The approximate hybrid formulas for the three connections are listed below. These are applicable when h_o and h_r is very small and R_s is very large. The given values refer to transistor terminals. The values of $r_{in(stage)}$ or r_{in} and $r_{o(stage)}$ will depend on biasing resistors and load resistance respectively.

Item	CE	CB	CC
r_{in}	h_{ie}	h_{ib}	$h_{ic} + h_{fe}R_L$
ro	$\frac{1}{h_{oc}}$	$\frac{1}{h_{oB}}$	$\frac{h_{ie}}{h_{fc}}$
A_i	$h_{fe} = \beta$	$-h_{fb} \cong 1$	$-h_{fe} \cong \beta$
A_v	$\frac{h_{ie}R_C}{h_{is}}$	$\frac{f_{fb}}{h_{ib}} R_C$	1

Common Emitter h-parameter Analysis

The h-parameter equivalent of the CE circuit of Fig.12 , no emitter resistor has been connected.

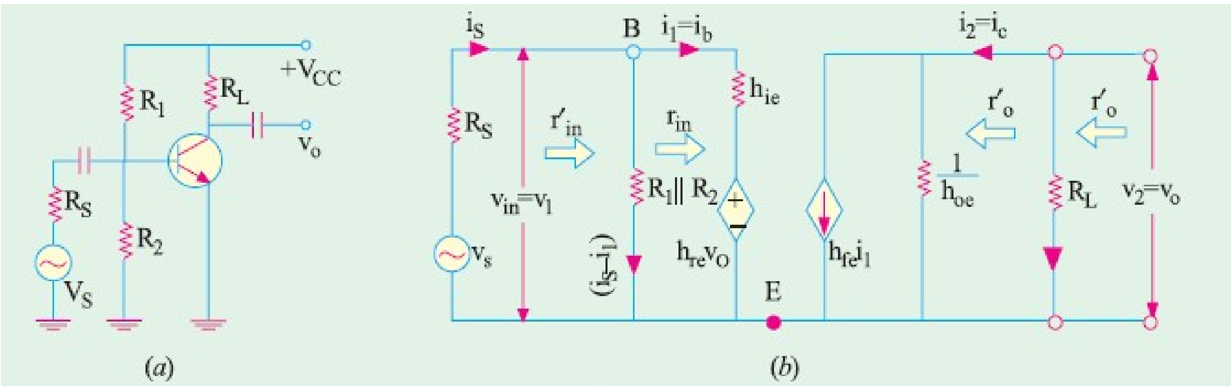


Fig. 12

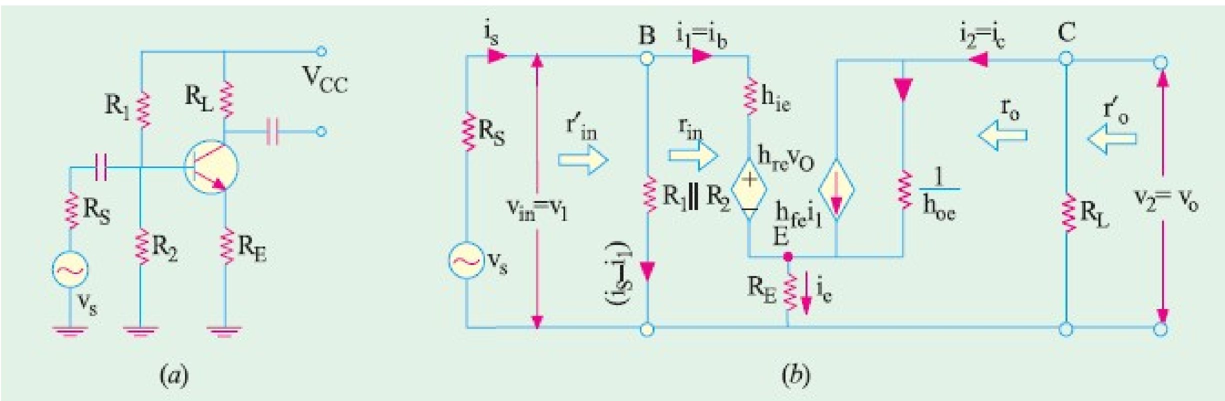


Fig. 13

We will now derive expressions for voltage and current gains for both these circuits.

l. Input Impedance

When looking into the base-emitter terminals of the transistor, h_{ie} in series with h_{re} no. For a CE circuit, h_{re} is very small so that $h_{re}V_o$ is negligible as compared to the drop over h_{ie}. Hence, $r_{in}=h_{ie}$.

Now, consider the circuit of Fig.13. Again ignoring $h_{re}V_o$ we have

$$\begin{aligned} v_1 &= h_{ie}i_b + i_e R_E = h_{ie}\, i_b + (i_b + i)\, R_E \\ &= h_{ie}i_b + i_b R_E + h_{fe}\, i_b R_E \qquad ((\quad i_c \quad h_{fe}i_b) \\ &= i_b\,[h_{ie} + R_E(1 + h_{fe})] \end{aligned}$$

$$\therefore \qquad r_{in} = r_{in(base)} = \frac{v_1}{i_1} \quad \frac{v_1}{i_b} \quad h_{ie} \quad (1 \quad h_{fe})R_E \; *$$

$$r_{in} \text{ or } r_{in(base)} = R_1 \,||\, R_2 \,||\, r_{in(base)}$$

2. Output Impedance

Looking back into the collector and emitter terminals of the transistor in Fig. (12 b), $r_o = 1/h_{oe}$.

As seen, r_o' or $r_{o(stage)} = r_o \,||\, R_L = (1/h_o) \,||\, r_L \qquad (\quad r_L \quad R_L)$

Since $1/h_{oe}$ is typically 1 M or so and R_L is usually much smaller, $r_o' \cong R_L = r_L$

3. Voltage Gain

$$A_v \quad \frac{v_2}{v_1} \quad \frac{v_o}{v_{in}}$$

Now, $\quad v_o = -\,i_c R_L \quad$ and $\qquad v_{in} \cong i_b\, h_{ie}$

$$\therefore \qquad A_v \quad \frac{i_s R_L}{i_b h_{ie}} \quad \frac{i_c}{i_b} \cdot \frac{R_L}{h_{ie}} \quad \frac{h_f R_L}{h_{ie}}$$

Now, consider Fig.13(b). Ignoring $h_{re}v_o$, we have from the input loop of the circuit

$$v_{in} = i_b\,[h_{ie} + R_E(1 + h_{fe})] \qquad \text{–proved above}$$

$$\therefore \qquad A_v \quad \frac{v_o}{v_{in}} \quad \frac{i_c R_L}{i_b[h_{ie} \quad R_E(1 \quad h_{fe})]} \quad \frac{h_{fe}R_L}{h_{fe} \quad (1 \quad h_{fe})R_E}$$

$$\frac{R_L}{R_E} \qquad \text{— if } (1 + h_{fe})\, R_E >> h_{ie}$$

4. Current Gain

$$A_i \quad \frac{i_2}{i_1} \quad \frac{h_{fe}}{1 \quad h_{oe} r_L} \quad h_{fe} \qquad \text{— if } h_{oe}\, r_L << 1$$

$$A_{is} \quad \frac{h_{fe} \cdot R_1 \| R_2}{r_{in} \quad R_1 \| R_2}$$

5. Power Gain

$$A_p = A_v \times A_i$$

Common Collector h-parameter Analysis

The CC transistor circuit and its h-parameter equivalent are shown in Fig.14

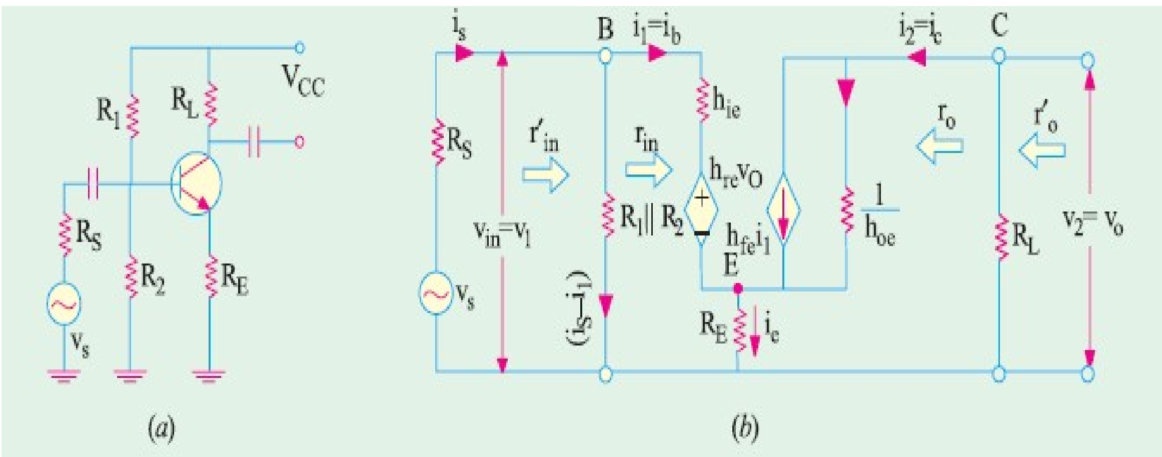


Fig.14

1. Input Impedance

$$v_{in} = i_b h_{ic} + h_{rc} v_o = i_b h_{ic} + v_o = i_b h_{ic} + i_e R_L$$
$$= i_b h_{ic} + h_{fe}\, i_b R_L = i_b (h_{ic} + h_{fe} R_L) \qquad i_c = h_{fe}\, i_b$$

$$\therefore \qquad r_{in} \quad \frac{v_{in}}{i_b} \quad h_{ic} \quad h_{fe} R_L$$

As seen, $r_{in(stage)} = r_{in(base)} \| R_1 \| R_2 = r_{in(base)} \| R_B$ where $R_B = R_1 \| R_2$

2. Output Impedance

$$r_o \quad \frac{v_2}{i_2}\Big|_{v_s} \ 0 \qquad\qquad \frac{v_o}{i_c}\Big|_{v_s} \ 0$$

Now, $\quad i_e \cong i_c = h_{fe}\, i_b = h_{fc}\, i_1$

Since $\quad v_s = 0$, i_b is produced by $h_{rc}\, v_o = v_o$

Hence, considering the input circuit loop, we get

$$i_b \quad \frac{v_0}{h_{ic} \quad (R_S \parallel R_1 \parallel R_2)} \quad \frac{v_0}{h_{ic} \quad R_S \parallel R_B}$$

$$i_c \quad h_{fc}\, i_b \quad \frac{h_{fe}\, v_o}{h_{ic} \quad (R_S \parallel R_B)}$$

where $R_B = R_1 \parallel R_2$

$$\therefore \qquad r_o \quad \frac{V_o}{i_e} \quad \frac{h_{ic} \quad (R_S \parallel R_1 \parallel R_2)}{h_{fe}}$$

Also, r_o' or $\quad r_{o(stage)} = r_o \parallel R_L$

3. Voltage Gain

$$A_v \quad \frac{v_2}{v_1} \quad \frac{v_o}{v_{in}}$$

Now, $\quad v_o = i_e R_L = h_{fe}\, i_b R_L$ and $i_b = (v_{in} - v_o) / h_{ic}$

$$v_o \quad \frac{h_{fe}\, R_L}{h_{ie}} (v_{in} \quad v_o) \qquad \text{or} \qquad v_o \quad 1 \quad \frac{h_{fe} R_L}{h_{ic}} \quad \frac{h_{fe} R_L v_{in}}{h_{ic}}$$

$$\therefore \qquad A_v \quad \frac{v_o}{v_{in}} \quad \frac{h_{fe} R_L / h_{ic}}{1 \quad h_{fe} R_L / h_{ic}} \quad 1$$

4. Current Gain

$$A_i \quad \frac{i_2}{i_1} \quad \frac{i_e}{i_b} \quad h_{fe} \ ; \ A_{is} \quad \frac{h_{fe} R_B}{r_{in} \quad R_B}$$

where $R_B = R_1 \parallel R_2$