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CHAPTER 59

TRANSISTOR EQUIVALENT CIRCUITS AND MODELS

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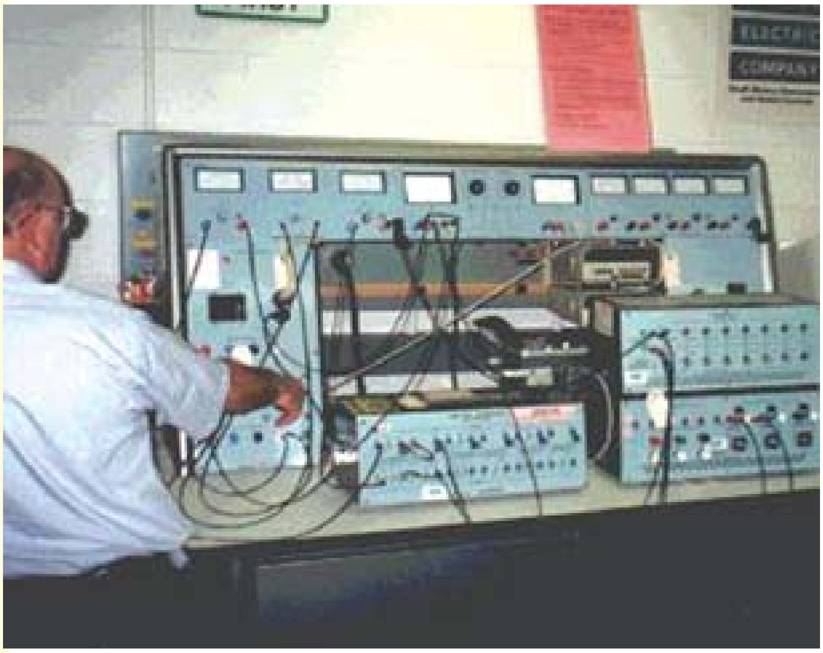

Generalised hybrid parameter equivalent circuit

59.1. General

We will begin by idealizing a transistor with the help of simple approximations that will retain its essential features while discarding its less important qualities. These approximations will help us to ***analyse transistor circuits easily and rapidly.***

We will discuss only the ***small signal*** equivalent circuits in this chapter. Small signal operation is that in which the ac input signal voltages and currents are in the order of ± 10 per cent of *Q*-point voltages and currents.

There are two prominent schools of thought today regarding the equivalent circuit to be substituted for the transistor. The two approaches make use of

(*a*) four *h*-parameters of the transistor and the values of circuit components,

(*b*) the beta (β) of the transistor and the values of the circuit components.

Since long, industrial and educational institutions have heavily relied on the hybrid parameters because they produce more accurate results in the analysis of amplifier circuits. In fact, hybrid-parameter equivalent circuit continues to be popular even to-day. But their use is beset with the following difficulties :

1. The values of *h*-parameters are not so readily or easily available.
2. Their values vary considerably with individual transistors ***even of the same type number.***
3. Their values are limited to a particular set of operating conditions for reasonably accurate results.

The second method which employs transistor beta and resistance values is gaining more popularity of late. It has the following advantages :

1. The required values are easily available;
2. The procedure followed is simple and easy to understand;
3. The results obtained are quite accurate for the study of amplifier circuit characteristics.

To begin with, we will consider the second method first.

59.2. DC Equivalent Circuit

(*a*) CB Circuit

In an ideal transistor, α = 1 which means that $I_C = I_E$.

The emitter diode acts like any ***forward-biased ideal diode.*** However, due to transistor action, collector diode acts as a ***current source.*** In other words, for the purpose of drawing dc equivalent circuit, we can view an ideal transistor as nothing more than a rectifier diode in emitter and a current source in collector. In the dc equivalent circuit of Fig. 59.1 (*b*), current arrow always points in the direction of conventional current.

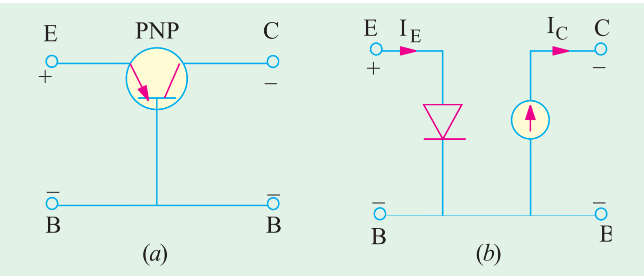

Fig. 59.1

As per the polarities of transistor terminals (Art. 59.3) shown in Fig. 59.1 (*a*), emitter current flow from *E* to *B* and collector current from *B* to *C*.

The dc equivalent circuit shown in Fig. 59.2 for an *NPN* transistor is exactly similar except that direction of current flow is opposite.

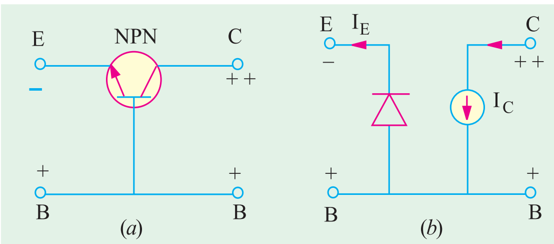

Fig. 59.2

(*b*) CE Circuit

Fig. 59.3 shows the dc equivalent circuit of an *NPN* transistor when connected in the *CE* configuration. Direction of current flow can be easily found by remembering the transistor polarity rule given in Art 59.3. In an ideal *CE* transistor, we disregard leakage current and take a.c beta equal to dc beta.

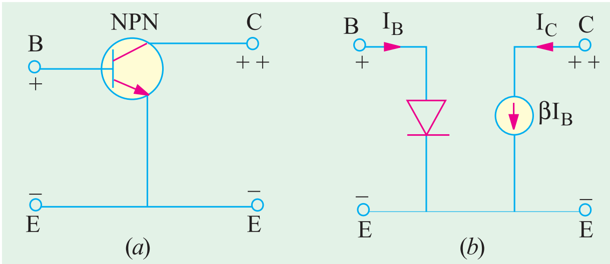

Fig. 59.3

59.3. AC Equivalent Circuit

(*a*) CB Circuit

In the case of ***small* input** ac signals, the emitter ***diode does not rectify,*** instead it offers resistance called ac ***resistance.*** As usual, collector diode acts as a current source.

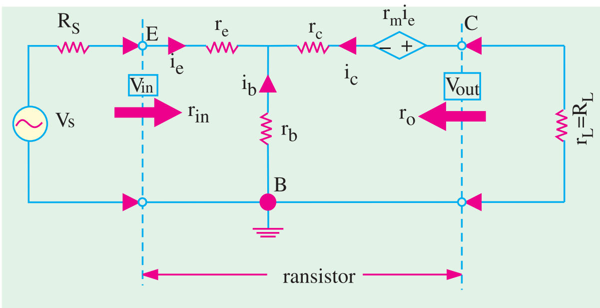

Fig. 59.4

Fig. 59.4 shows the ac equivalent circuit of a transistor connected in the *CB* configuration.* Here, ac resistance offered by the emitter diode is

r_{ac} = junction resistance (r_j) + base-spreading resistance (r_B)**

$$= r_j \qquad r_B \text{ is negligible}$$

$$= \frac{25 \text{ mV}}{I_E}$$

— where I_E is dc emitter current in mA

It is written as r_e' signifying junction resistance of the emitter *i.e.* a.c resistance looking into the emitter.

$$r_e' \quad \frac{25 \text{ mV}}{I_E}$$

Hence, the a.c equivalent circuit of a *CB* circuit becomes as shown in Fig. 59.5. Since changes in collector current are almost equal to changes in emitter current, $\Delta i_c = \Delta i_e$.

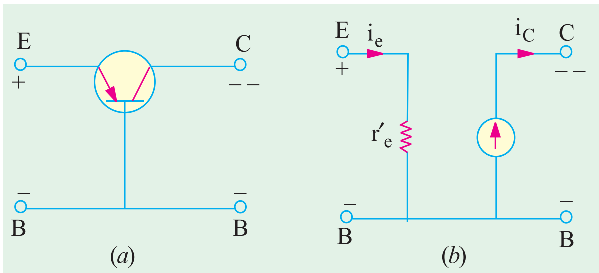

Fig. 59.5

(*b*) CE Circuit

Fig. 59.6 (*a*) shows the equivalent circuit when an *NPN* transistor has been connected in the *CE* configuration.

The a.c resistance ***looking into the base is***

$$r_{ac} \quad \frac{25 \text{ mV}}{I_B}$$ — d.c current is I_B not I_E

---

* This circuit is valid both for *PNP* as well as *NPN* transistors because difference in the direction of ac current does not matter.

** Also called bulk-resistance.

$$\frac{25\,\text{mV}}{I_C\,/}\;,\;\frac{25\,\text{mV}}{I_C}$$

$$,\;\frac{25\,\text{mV}}{I_E}\quad r_e'$$

Strictly speaking,

$r_{ac} = (1 + \beta)\, r' \cong \beta\, r_e'$ — Art 7.24

The a.c collector current is β times the base current *i.e.*, $i_c = \beta\, i_b$.

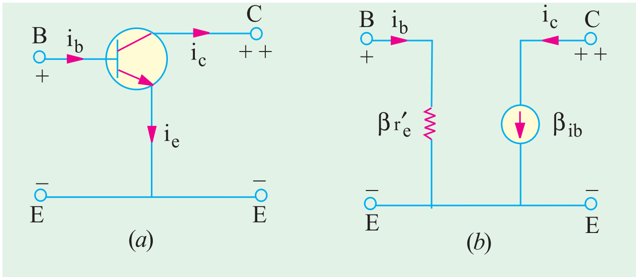

Fig. 59.6

59.4. Equivalent Circuit of a CB Amplifier

In Fig. 59.7 (*a*) is shown the circuit of a common-base amplifier. As seen, emitter is forward-biased by $-V_{EE}$ and collector is reverse-biased by $+ V_{CC}$. The a.c signal source voltage υ_s drives the emitter. It produces small fluctuations in transistor voltage and currents in the output circuit. It will be seen that ac output voltage is amplified because it is more than V_s.

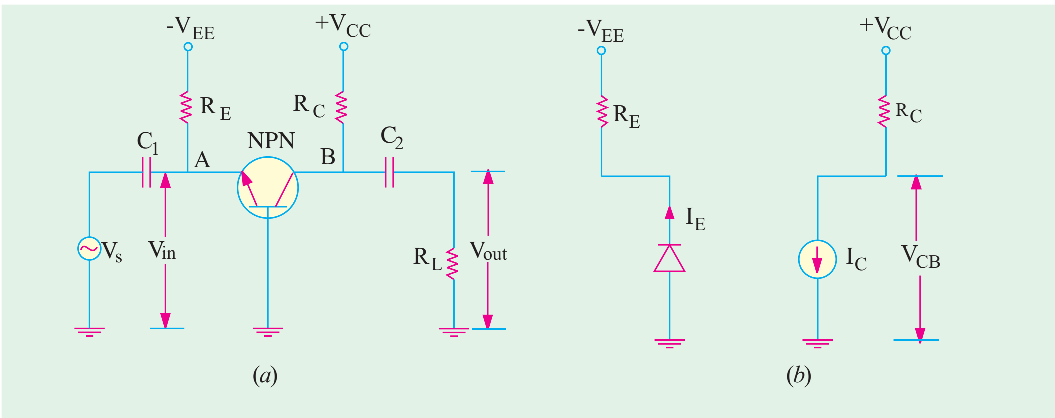

Fig. 59.7

(*a*) DC Equivalent Circuit

For drawing dc equivalent circuit, following procedure should be adopted :

(*i*) short all ac sources *i.e.* reduce them to zero,

(*ii*) open all capacitors because they block dc.

If we do this, then as seen from Fig. 59.7 (*a*), neither emitter current can pass through C_1 nor collector current can pass through C_2. These currents are confined to their respective resistances R_E and R_C (earlier we had been designating it as resistance R_L).

Here, $I_C \cong I_E$ and $V_{CB} = V_{CC} - I_C R_L$

Hence, the dc equivalent circuit becomes as shown in Fig. 59.7 (*b*).

(*b*) AC Equivalent Circuit

For drawing ac equivalent circuit, following procedure is adopted :

(*i*) all dc sources are shorted *i.e.* they are treated as ac ground,

(*ii*) all coupling capacitors like C_1 and C_2 in Fig. 59.7 (*a*) are shorted and

(*iii*) emitter diode is replaced by its a.c resistance $r_{ac} = r_e'$

$$r_e' \quad \frac{25\,\text{mV}}{I_E}$$

where I_E is dc emitter current in mA.

As seen by the input a.c signal, it has to feed R_E and r_e' in parallel [Fig. 59.8 (*a*)]. As looked from point A in Fig. 59.7 (*a*), R_E is grounded through V_{EE} which has been shorted and r_e' is grounded *via* the base.

Similarly, collector has to feed R_C and R_L which are connected in parallel across it *i.e* at point *B* in Fig. 59.7 (*a*). The ac signal in collector sees an output load resistance of $r_L = R_C \parallel R_L$.

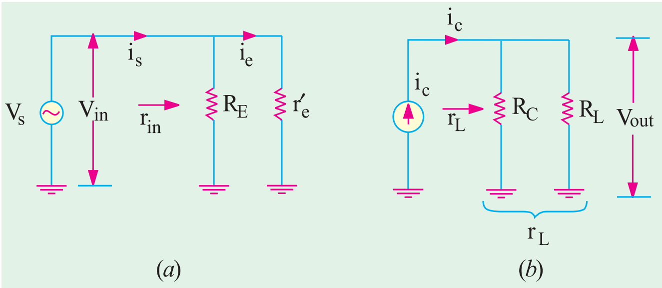

Fig. 59.8

Hence, ac equivalent circuit is as shown in Fig. 59.8 (*b*). Here, collector diode itself has been shown as a current source.

Following two points are worth noting :

(*i*) changes in collector signal current are very nearly equal to changes in emitter signal current. Hence, $\Delta i_c \cong \Delta i_e$.,

(*ii*) directions of ac currents shown in the circuit diagram are those which correspond to positive half-cycle of the a.c input voltage. That is why i_c is shown flowing upwards in Fig. 59.8 (*b*).

(*c*) Principal Operating Characteristics

1. Input Resistance

As seen from Fig. 59.8 (*a*), the input resistance of the circuit (or stage) is given by

$$r_{in} \quad R_E \parallel r_e' \quad \frac{r_e' R_E}{R_E \quad r_e'}$$

In practice, R_E is always much greater than r_e' so that parallel combination $R_E \parallel r_e' \cong r_e'$

$\therefore \; r_{in} \cong = r_e'$ input resistance of the emitter diode

2. AC Load Resistance

The collector load as seen by output ac signal consists of a parallel combination of R_L and R_C. This has already been designated as r_L.

$\therefore \qquad r_L = R_L \parallel R_C$

It should be carefully noted that it is the output resistance ***as seen by collector and not the ac output resistance when looking into the collector.***

Note. In case, R_L has not been connected, then $r_L = R_C$ (Ex. 59.1)

3. Current Gain

It is given by the ratio $A_i \quad \frac{i_c}{i_e}$

4. Voltage Gain

It is given by the ratio

$$A_v \quad \frac{V_{out}}{V_{in}}$$

Now, V_{in}* $= i_e \, r_{in} = (1 + \beta) \, i_b \, . \, r_{in}$

$V_{out} = i_c \, r_L = \beta i_b \, r_L$

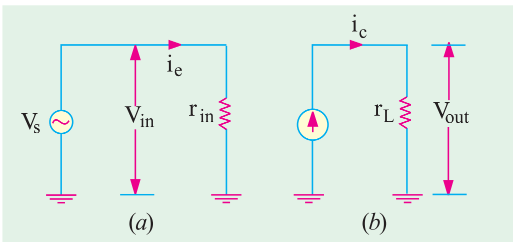

Fig. 59.9

* Here, V_{in} equals υ_s because there is no internal resistance of the source. In case it is there, the two will not be equal (Art 59.5).

$$\therefore \quad A_v \quad \frac{i_b\, r_L}{(1 \quad)\, i_b\, r_{in}}$$

Taking the ratio β / (1 + β) as unity, $A_V \quad \frac{r_L}{r_{in}} \quad \frac{r_L}{r'_e}$

5. Power Gain

$$A_p = \quad A_v . A_i$$

When expressed in decibels, it is written as $G_p = 10 \log_{10} A_p\, dB$.

When expressed in terms of r_{in} and r_L, the a.c equivalent circuit becomes as shown in Fig. 59.9.

Example 59.1. *For the single-stage CB amplifier shown in Fig. 59.10 (a), find r_{in}, r_L, A_i, A_υ and A_p. What would be the rms value of the signal voltage across the load if v_s has an rms value of 1.5 mV? Assume silicon material and transistor α = 0.98.* **(Electronics-II, Madras Univ.)**

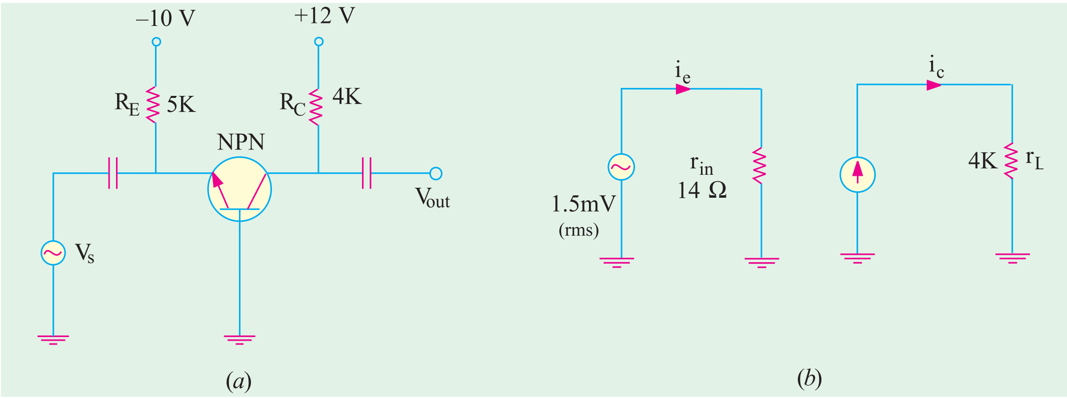

Fig. 59.10

Solution. For finding , let us first find I_E.

$$I_E \quad \frac{V_{EE} \quad V_{BE}}{R_E} \quad \frac{10 \quad 0.7}{5K} \quad 1.86\,\text{mA}$$

$$r'_e \quad \frac{25\,\text{mV}}{I_E\ \text{mA}} \quad \frac{25}{1.86} \quad 14$$

(*i*) $r_{in} = r'_e \,||\, R_E = 14\,\Omega \,||\, 5\text{ K} \cong$ **14 Ω** **(*ii*)** $r_L = R_C =$ **4 K**

The ac equivalent circuit becomes as shown in Fig. 59.10 (*b*).

(*iii*) $A_i = \alpha =$ **0.98** **(*iv*)** $A_v \quad \frac{r_L}{r_{in}} \quad \frac{r_L}{r'_e} \quad \frac{4K}{14}$ **286**

(*v*) $A_p = A_i A_v = 0.98 \times 286 = 280$ $G_p = 10 \log_{10} 280 =$ **24.5 dB**

Output ac voltage = A_v × input voltage

$\therefore \quad V_{out} = A_v \times V_{in} = 286 \times 1.5 = 429\text{ mV} =$ **0.429 V**

Example 59.2. *For the CB amplifier circuit shown in Fig. 59.11 (a), find*
(*i*) *stage r_{in}* **(*ii*)** *r_L* **(*iii*)** *a.c output voltage V_{out}* **(*iv*)** *voltage gain A_v.*
Take V_{BE} = 0.7 V.

Solution. $I_E = (20 - 0.7)/30\text{ K} = 0.64\text{ mA}$; $r'_e = 25/0.64 = 39\,\Omega$

(*i*) stage $r_{in} = r'_e \,||\, R_E' = 39\Omega \,||\, 30\text{ K} \cong 39\,\Omega$

(*ii*) $r_L = R_L \,||\, R_C = 30\text{ K} \,||\, 15\text{ K} =$ **10 K**

The amplifier circuit alongwith its ac equivalent circuit is shown in Fig. 59.11.

(iii) We will first find the value of n_{out} as a drop across $r_L = R_C \| R_L$. For that purpose, we will employ rms values.

Now, $$i_e \quad \frac{V_{in}}{r_{in}} \quad \frac{V_s}{r_{in}} \quad \frac{1.6}{3.9} \quad 0.04 \text{ mA}^*$$

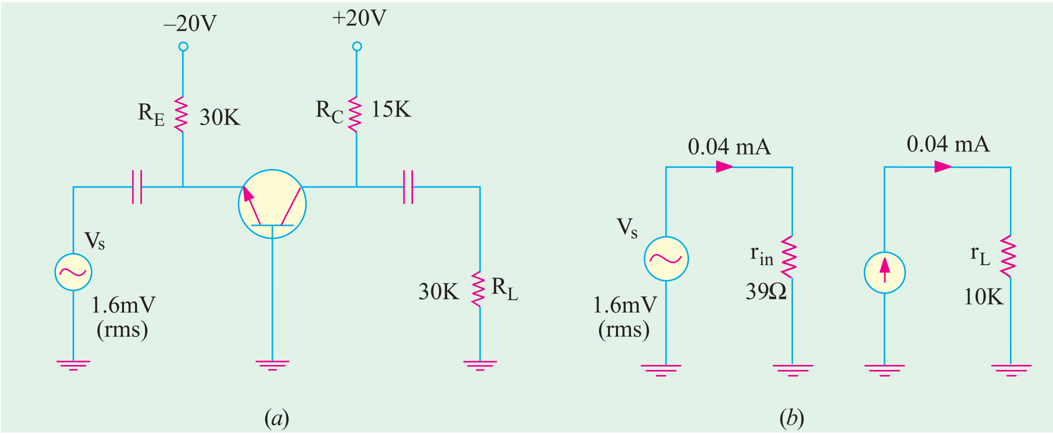

Fig. 59.11

$$i_c = i_e = 0.04 \text{ mA} \; ; \; V_{out} = i_c \, r_L = 0.04 \times 10 \text{ K} = 0.4 \text{ V}$$

(iv) $$A_v \quad \frac{r_L}{r_{in}} \quad \frac{r_L}{r_e'} \quad \frac{r_L}{r_e'} \quad \frac{10 \text{ K}}{39} \quad \mathbf{250}$$

The rms value of ac output voltage may be found with the help of A_v.

Now, $$A_v \quad \frac{V_{out}}{V_{in}} \qquad V_{out} \quad A_v . V_{in} \quad 250 \quad 1.6 \quad 400 \text{ mV} \quad \mathbf{0.4 \ V}$$

59.5. Effect of Source Resistance R_s on Voltage Gain

The voltage gain for the *CB* amplifier circuit has so far been calculated on the assumption that the resistance R_S of the ac signal source is negligible. The voltage gain will decrease as R_S increases because more and more of V_S will drop on R_S rather than on r_{in} and so will not appear in the output.

The basic circuit is shown in Fig. 59.12 where R_S is the internal resistance of the ac signal source.

The ac equivalent circuit is shown in Fig. 59.13 (*a*). Here, R_S is in series with $(r_e' \| R_E)$. The input ac signal voltage v_S drops on these two series resistors. Obviously, V_{in} is the drop across $r_e' \| R_E$ and is less than V_S. Using Proportional Voltage Formula,

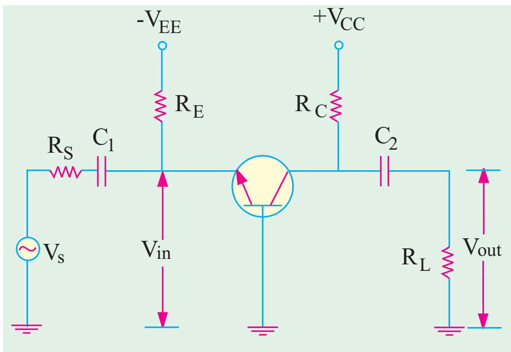

Fig. 59.12

* Strictly speaking, it is not i_e but i_s . a small part of the ac source current goes through R_E = 30 K and the balance (major part) goes through parallel resistance r_e'. However, if we neglect current through 30 K, then $i_e = i_s$

$$V_{in} \quad V_s \frac{r_e' \,||\, R_E}{R_s \quad r_e' \,||\, R_E}$$

In practice, $R_E >> r_e'$, so that $r_e' \,||\, R_E \cong r_e'$

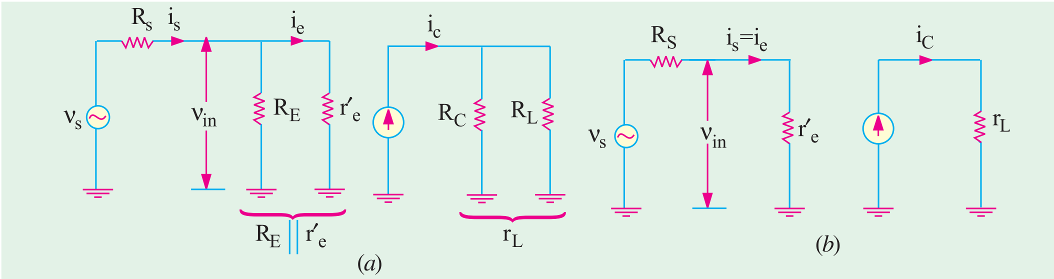

Fig. 59.13

$$\therefore \qquad V_{in} \quad V_s \frac{r_e'}{R_s \quad r_e'} \qquad \frac{V_s}{1 \quad \dfrac{R_s}{r_e'}}$$

As R_S increases in comparison to r_e', the ratio R_S / r_e' increases thereby making v_{in} increasingly less than V_s.

Moreover, as seen from the source, input resistance is

$$R_S + r_e' \,//\, R_E \cong R_S + R_e' \qquad \therefore \quad \frac{V_{out}}{V_s} \quad \frac{r_L}{(R_S \quad r_e')} \quad \frac{r_L}{R_S} \qquad \text{— if } R_S >> r_e'$$

Making R_S much larger than r_e' is called swamping out the emitter diode. This makes voltage gain independent of r_e' and hence the particular transistor is used. The above gain is different from the voltage gain considered from emitter to collector which is

$$\frac{V_{out}}{V_{in}} \quad \frac{r_L}{r_{in}} \quad \frac{r_L}{r'_e}$$

Example. 59.3. *In the CB amplifier circuit of Fig. 59.14, find*

(a) *voltage gain from source to output* **(b)** *voltage gain from emitter to output*

(c) *approximate value of V_{in}* **(Electronics-I, Patna Univ.)**

Solution. (a) The voltage gain from source to output is given by

$$\frac{V_{out}}{V_S} \quad \frac{r_L}{(R_S \quad r_e')}$$

$r_L = R_C \,||\, R_L = 10\text{ K} \,||\, 2\text{M}$

$\cong 10\text{ K}$; $I_E = 25/25\text{ K} = 1\text{ mA}$

$r_e' = 25/1 = 25\ \Omega$

$$\frac{V_{out}}{V_s} \quad \frac{10\text{ K}}{(1\text{K} \quad 26 \quad)} \quad \mathbf{10} \qquad ...(i)$$

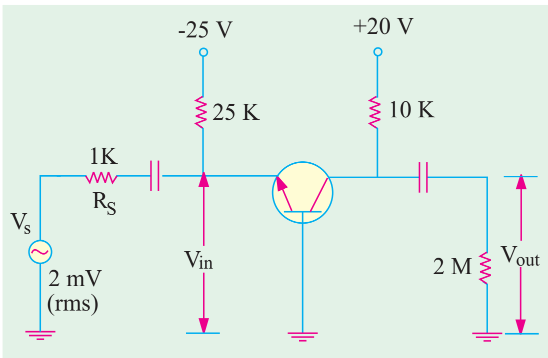

Fig. 59.14

(b) The voltage gain from emitter to output is

$$\frac{V_{out}}{V_s} \quad \frac{r_L}{r_{in}}$$

Now, $r_{in} = R_E // r_e' = 25\text{ K} \parallel 25\ \Omega \cong 25\ \Omega$ $\qquad \therefore \quad \frac{V_{out}}{V_S} \quad \frac{10K}{25}$ **400** ...(*ii*)

(*c*) The value of V_{in} may be found by the following two ways :

(*i*) As seen from Eq. (*ii*) above, $V_{in} = \frac{V_{out}}{400}$, Now, from Eq. (*i*) above, we have

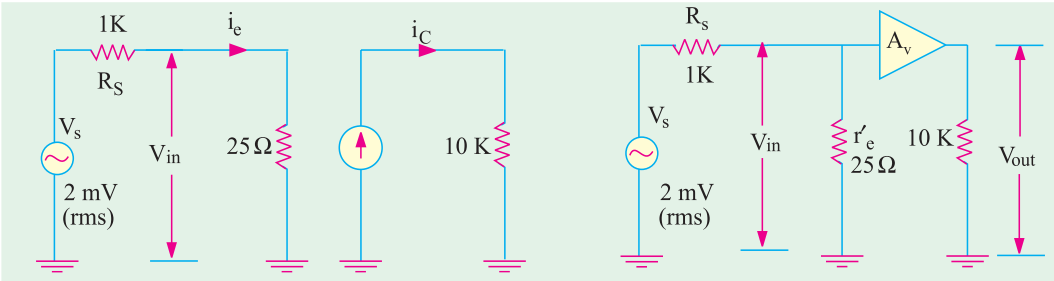

Fig. 59.15

$V_{out} = 10\ V_s = 10 \times 2 = 20\text{ mV}$ $\qquad \therefore \quad V_{in} \quad \frac{20}{400} \quad 10^3$ **50μV**

(*ii*) As seen from the ac equivalent circuit of the amplifier (Fig. 59.15), V_s is dropped proportionally on the two series resistances R_S and r_e' (strictly speaking $r_e' \parallel R_E$). The drop across r_{in} is called V_{in}.

$$\therefore \quad V_{in} \quad V_s \frac{r_e'}{R_s \quad r_e'} \quad 2\,mV \frac{25}{1000 \quad 25} \quad \mathbf{50\mu V}$$

59.6. Equivalent Circuit of a CE Amplifier

Consider the simple *CE* amplifier circuit of Fig. 59.16 (*a*) in which base bias has been employed.

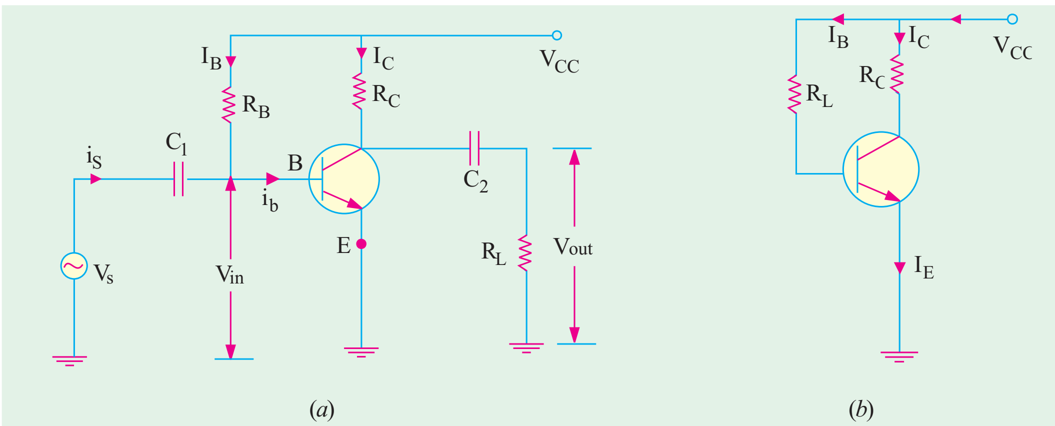

Fig. 59.16

(*a*) DC Equivalent Circuit

Fog drawing the dc equivalent circuit, same procedure is adopted as given in Art. 59.2. It is shown in Fig. 59.16 (*b*).

$$\text{As seen,} \quad I_B \quad \frac{V_{CC} \quad V_{BE}}{R_B} \quad \frac{V_{CC}}{R_B}\ ;\ I_C = \beta \,.\, I_B\ ;\ I_E \cong I_C \cong \beta I_B$$

(*b*) AC Equivalent Circuit

Let us now analyse the ac equivalent circuit given in Fig. 59.17.

As proved in Art. 59.3, the ac resistance as seen by the input signal when looking into the base is = $\beta\, r_e'$. It may be called $r_{in(base)}$ to distinguish it from r_{in} which is resistance of the ***CE stage*** as shown in Fig. 59.17 (*a*).

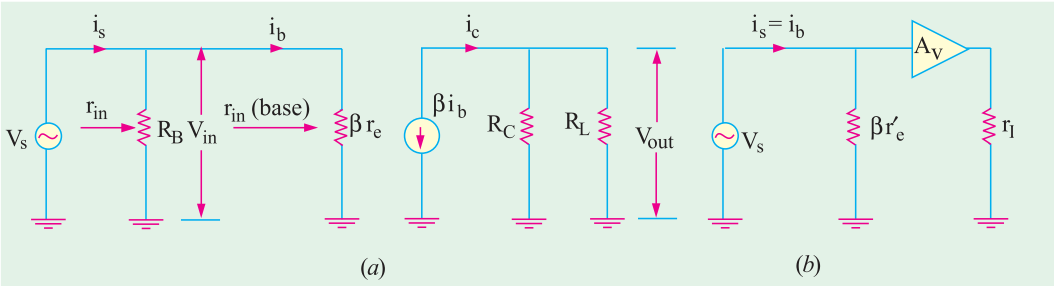

Fig. 59.17

It may be noted that in the absence of ac voltage source resistance R_S, whole of V_s acts across R_B as well as $\beta\, r_e'$ because the two are connected in parallel across it.

Another point worth noting is that major part of source current is passes through $\beta\, r_e'$ and an extremely small part (= v_s/R_B) passes through R_S. Since R_B is usually very large, current passing through it can be easily neglected. Hence, as shown in Fig. 59.17 (*b*), $i_b = i_s$.

(*c*) Principal Operating Characteristics

1. Input Resistance

As seen from Fig. 59.17, input resistance of the *stage* is

$$r_{in} = R_B // \beta\, r_e' \cong \beta\, r_e' \qquad R_B >> \beta\, r_e'$$

= input resistance of the base

$$r_{in(stage)} = r_{in(base)}$$

2. AC Load Resistance. $r_L = R_C \,||\, R_L$

3. Current Gain. $A_i \quad \dfrac{i_c}{i_b}$

4. Voltage gain. The voltage gain of the stage or circuit is $A_v \quad \dfrac{v_{out}}{v_{in}}$

Now, $\quad v_{in} \quad i_b \quad r_e' \qquad$ and $\qquad v_{out} \quad i_c \,.\, r_L \quad i_b r_L$

$$\therefore \quad A_v \quad \frac{i_b r_L}{i_b r_e'} \quad \frac{r_L}{r_e} \qquad \text{— if } R_B >> \beta\, r_s'$$

5. Power Gain. $A_p = A_i \,.\, A_v$ and $G_p = 10 \log_{10} A_v\, dB$

Example. 59.4. *If in the CE circuit of Fig. 59.16 (a), V_{CC} = 20 V, R_C = 10 K, R_B = 1 M, R_L = 1 M, v_s = 2mV and β = 50, find* (*i*) i_b and i_c (*ii*) r_{in} (*iii*) r_L (*iv*) A_n (*v*) A_p and G_p.

(Basic Electronics, Bombay Univ. 1991)

Solution. I_B = 20/1 M = 20 μA ; $\qquad I_C = \beta\, I_B$ = 50 × 20 mA = 1 mA

r_e' = 25 mV/1 mA = 25 Ω ; $\qquad r_{in(base)} = \beta r_e'$ = 50 × 20 = 1250 Ω

(*i*) As seen from Fig. 59.17 (*a*), ac base current is given by

$$i_b \quad \frac{v_s}{r_{in(base)}} \quad \frac{2\,\text{mV}}{1250} \quad \mathbf{1.6\mu A} \; ; \; i_c = \beta i_b = 50 \times 1.6 = \mathbf{80\mu A}$$

(*ii*) stage $r_{in} = R_B // \beta r_e'$ = 1 M || 1250 Ω ≅ **1250 Ω**

(*iii*) $r_L = R_L \,||\, R_C$ = 1 M || 10 K ≅ **10 K** *(iv)* $A_v \quad \frac{r_v}{r'_e} \quad \frac{r_L}{r'_e} \quad \frac{10\text{ K}}{25}$ **400**

(v) $A_p = A_i \cdot A_v = 50 \times 400 = 20{,}000$; $G_p = 10 \log_{10} 20{,}000 =$ **43 dB**

Example 59.5. *In the CE amplifier circuit of Fig. 59.18 employing emitter feedback, find :*
(i) r_{in} *(ii)* r_L *(iii)* A_v *(iv)* A_p and *(v)* G_p
Take transistor $\beta = 100$. *How will these values change if emitter bypass capacitor is removed ?*
(Electronics—II, Madras Univ.)

Solution. It should be carefully noted that emitter bypass capacitor *C* provides ***ac ground*** to the signal *i.e.* it shorts out R_E to ground so far as ***ac signal is concerned.*** However, it plays its normal role so far as dc quantities are concerned.

Hence, the ac equivalent circuit of the amplifier becomes as shown in Fig. 59.19.

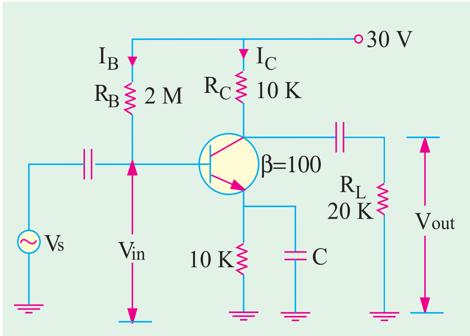

Fig. 59.18

Now, $I_B \quad \frac{V_{CC}}{R_B \quad R_E} \quad \frac{30}{2\text{M} \quad 100 \quad 10\text{K}}$

$= 10\ \mu\text{A}$; $I_C = \beta\, I_B$

$= 100 \times 10\text{ mA} = 1\text{ mA}$

$I_E \cong I_C = 1\text{ mA}$, $r_e' = 25/1 =$ **25 Ω ;**

$\beta\, r_e' = 100 \times 25 =$ **2500 Ω**

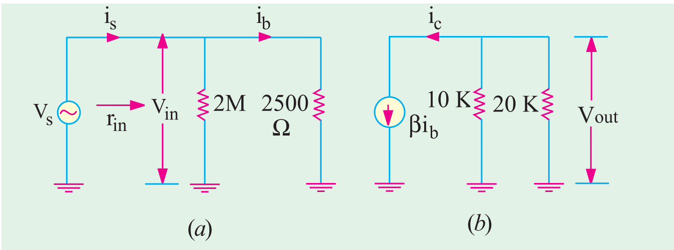

Fig. 59.19

(i) As seen from Fig. 59.19

$r_{in} = R_B \,||\, \text{b}\, r_e'$

$= 2\text{M} \,||\, 2500\ \Omega \cong$ **2500Ω**

(ii) $r_L = R_C \,||\, R_L = 10\text{ K} \,||\, 20\text{ K}$

$=$ **6.67 K**

(iii) $A_V \quad \frac{V_{out}}{V_{in}} \quad \frac{r_L}{r_e'}$

$\frac{6.67\text{ K}}{25}$ **267**

(iv) $A_p = A_i \cdot A_v = 100 \times 267 =$ **26,700** ; $G_p = 10 \log_{10} 26{,}700 =$ **44.3 dB**

When Emitter Bypass Capacitor is Removed

When bypass capacitor is removed, ac ground is removed. Now, the ac signal will have to pass through R_E also. According to β-rule of Art. 57.24, the total emitter resistance referred to base will become $(1 + \beta)\,(r_e' + R_E) \cong \beta\,(r_e' + R_E)$ because r_e' is in series with R_E as shown in Fig. 59.20 (*a*).

Now, the ac equivalent circuit becomes as shown in Fig. 59.20 (*b*).

Stage $r_{in} = R_B \,||\, \beta\,(r'_e + R_E) \cong R_B \,||\, \beta\, R_E$

It is so because R_E is much greater than r_e'.

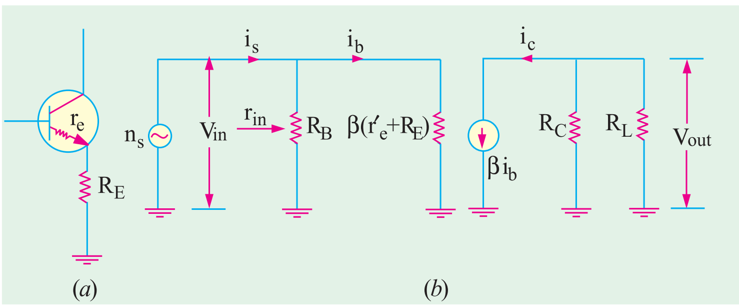

Fig. 59.20

(i) $r_e' = 25\ \Omega$ — as before

$\therefore$ $\beta(r_e' + R_E) \cong \beta R_E = 100 \times 10\text{ K} = 1\text{ M}$

$\therefore$ $r_{in} = R_B \,||\, \beta R_E = 2\text{ M} \,||\, 1\text{M}$

$= \frac{2}{3}\text{M} = $ **666.7 K** — much greater than before

(ii) r_L = **6.67 K** — it remains unchanged

(iii) $V_{in} = i_b \beta\, (r_e' + R_E)$; $V_{out} = i_c \cdot r_L = \beta\, i_b r_L$

$\therefore$ $A_v \quad \frac{V_{out}}{V_{in}} \quad \frac{i_b r_L}{i_b \cdot\ (r_e' \quad R_E)} \quad \frac{r_L}{(r_e' \quad R_E)} \quad \frac{r_L}{R_E}$

$\frac{6.67\text{ K}}{10\text{ K}}$ **0.667** —reduced drastically

(iv) $A_p = A_i A_v = 100 \times 0.667 =$ **66.7** — reduced considerably

It is seen that by removing bypass capacitor, ***excessive degeneration has occurred in the amplifier circuit.***

Example 59.6. *For the circuit shown in Fig. 59.21, compute* ***(i)*** $r_{in\,(base)}$ ***(ii)*** V_{out} ***(iii)*** A_v ***(iv)*** r_{in}. *Neglect* V_{BE} *and take* $\beta = 200$.

Solution. It may be noted that voltage divider bias has been used in the circuit.

$V_2 \quad \frac{15}{15 \quad 45} \quad 30 \quad 7.5\text{ V}$

$V_E = V_2 - V_{BE} \cong V_2 = 7.5\text{ V}$

$I_E = 7.5/7.5\text{ K} = 1\text{ mA}$

$r_e' = 25\text{ mV}/1\text{ mA} = 25\Omega$

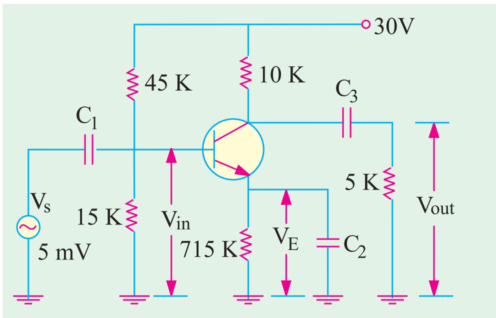

Fig. 59.21

The ac equivalent circuit is shown in Fig. 59.22. Since dc souce is shorted, 45 K, resistor is ac grounded. On the input side, three resistance become paralleled across v_s *i.e.* *(i)* 15 K *(ii)* 45 K and *(iii)* $\beta\, r_e'$ or $r_{in(base)}$.

Capacitor C_2 ac grounds the emitter resistance R_E, so does C_2 to 5 K and V_{CC} to 10 K.

(i) $r_{in(base)} = \beta\, r_e' = 200 \times 25 =$ **5 K** *(ii)* $i_b = 5\text{ mV}/5\text{K} = 1\ \mu\text{A}$

(Obviously, i_b is not the current which leaves the source but that part of the source current is which enters the base). Now, collector load resistance is $i_c = \beta\, i_b = 200 \times 1 = 200\ \ \mu\text{A} = 0.2\text{ A}$

$r_L = 10\text{ K} \,||\, 5\text{ K} = 10/3\text{ K} = 3.33\text{ K},\ V_{out} = i_c r_L = 0.2 \times 3.33 =$ **0.667 V**

(iii) $A_v \quad \frac{V_{out}}{V_{in}} \quad \frac{0.667\text{ V}}{5\text{ m V}}$ **133**

or $A_v \quad \frac{r_L}{r_e'} \quad \frac{3.33\text{ K}}{25} \quad 133$

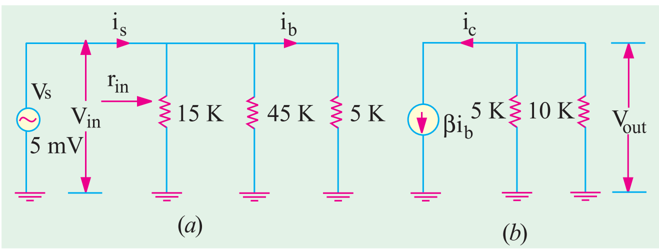

Fig. 59.22

(iv) r_{in} means the input ac resistance as seen from the source *i.e.* from point *A* in Fig. 59.22. It is different from $r_{in(base)}$. Obviously, r_{in} is equal to the equivalent resistance of three resistances connected in parallel. $r_{in} = 15\text{ K} \,||\, 45\text{ K} \,||\, 5\text{ K} = 3.54\text{ K}$.

Example 59.7. *For the CE amplifier circuit of Fig. 59.23, find out (i) r_{in} (ii) r_L (iii) A_v (iv) A_p and (v) V_{out}. Take transistor β = 50 and R_S = 0.* **(Applied Electronics-II, Punjab Univ. 1992)**

Solution.

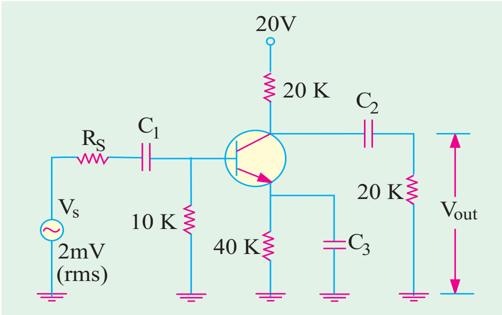

Fig. 59.23

$$I_E \quad \frac{V_{EE}}{R_E} \quad \frac{20}{40} \quad 0.5\text{ mA}$$

$r_e' = 25/0.5 = 50\ \Omega$

$\beta r_e' = 50 \times 50 = 2500\ \Omega$

(*i*) $r_{in} = 10\text{ K} \parallel 2500\ \Omega =$ **2000 Ω**

(*ii*) $r_L = 20\text{ K} \parallel 20\text{ K} =$ **10 K**

(*iii*) $A_v \quad \frac{r_L}{r_e'} \quad \frac{10\,K}{50} \quad$ **200**

(*iv*) $A_p = A_v \,.\, A_i$

$= 200 \times 50 = 10{,}000$

$G_p = 10 \log 10\ 10000 =$ **40 dB**

(*v*) $V_{out} = A_v \times V_{in} = 20 \times 2 =$ **40 mV (r.m.s.)**

Since R_S is zero, whole of v_s appears across the diode base.

Example 59.8. *For the single-stage CE amplifier circuit of Fig. 59.24, find approximate value of (i) r_{in} (ii) r_L (iii) A_v (iv) A_p and G_p. Take transistor β = 100. Use $r_e' = 50\ mV/I_E$.* **(Electronics-II, Gujarat Univ. 1991)**

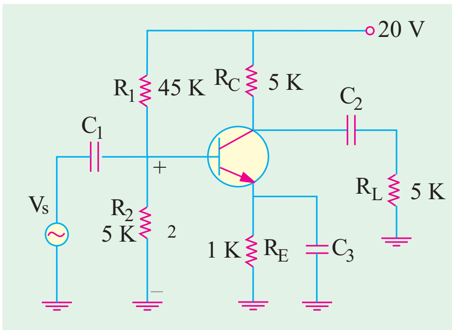

Fig. 59.24

Solution. $\quad V_2 \quad 20 \quad \frac{5}{5 \quad 45} \quad 2\text{ V};$

$$I_E \quad \frac{V_2}{R_E} \quad \frac{2}{1} \quad 2\text{ mA}$$

$r_e' = 50/2 = 25\ \Omega$;

$\beta r_e' = 25 \times 100 = 2.5\text{ K}$

(*i*) $r_{in} = R_1 \parallel R_2 \parallel \beta r_e' = 45 \parallel 5 \parallel 2.5 =$ **1.6 K**

(*ii*) $r_L = 5\text{ K} \parallel 5\text{ K} = 2.5\text{ K}$

(*iii*) $A_v \quad \frac{r_L}{r_e} \quad \frac{2.5\text{ K}}{25} \quad$ **100**

(*iv*) $A_P = A_v \,.\, A_i = 100 \times 100 =$ **10,000**

(*v*) $G_p = 10 \log_{10} 10{,}000 =$ **40 dB**

Note. R_E did not come into picture because it was ac grounded by the bypass capacitor C_3.

Example 59.9. *Find the approximate values of the quantities of Ex. 59.8 in case bypass capacitor C_3 in Fig. 59.24 is removed.*

Solution. (*i*) In this case,

$$r_{in} = R_1 \parallel R_2 \parallel \beta\,(r_e' + R_E) = 45\text{ K} \parallel 5\text{ K} \parallel 100\ (25 + 1\text{ K})$$

$$\cong 45\text{ K} \parallel 5\text{ K} \parallel 100\text{ K} \ = \textbf{5 K}$$

(*ii*) $r_L = 2.5\text{ K}$ — as before

(*iii*) $A_v \quad \frac{r_L}{(r_e' \quad R_E)} \quad \frac{r_L}{r_E} \quad \frac{2.5\text{ K}}{1\text{ K}} \quad$ **2.5**

(Please note the reduction)

(*iv*) $A_p = 100 \times 2.5 =$ **250**

(*v*) $G_p = 10 \log_{10} 250 =$ **24 dB**

59.7. Effect of Source Resistance R_s

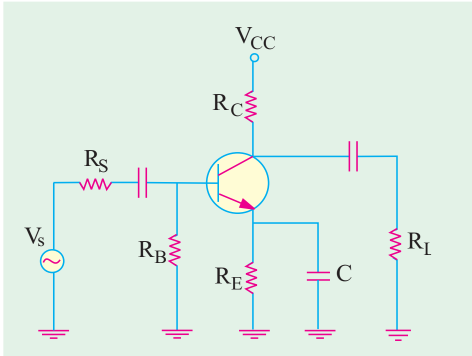

Fig. 59.25

Greater the internal resistance of the ac signal source, greater the internal voltage drop and hence lesser the value of V_{in} because

$$V_{in} = V_s \quad \text{– drop across } R_S.$$

Consider the CE circuit shown in Fig. 59.25 whose ac equivalent circuit is shown in Fig. 59.26.

As seen from Fig. 59.26, on the input side, R_S is in series with $R_B \,||\, \beta\, r_E'$. Hence, V_S is divided between them in the direct ratio of their resistances.

If R_S is much less than $R_B \,||\, \beta r_e'$, then

$$V_{in} \cong V_s$$

The voltage gain from base to output is still given by $\dfrac{V_{out}}{V_{in}} \quad \dfrac{r_L}{r_e'}$

If, in any question, V_s is given, we will first find out how much of it appears across the base as v_{in}. Then, for determining V_{out}, we will simply multipy this V_{in} by the voltage gain.

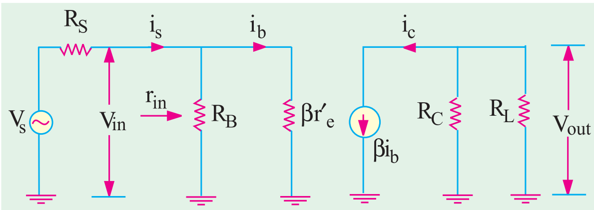

Fig. 59.26

Example 59.10. *In the CE amplifier circuit of Fig. 59.27, find the rms signal output voltage when R_S is* **(a)** *100 Ω and* **(b)** *3 K. Take b = 50.*

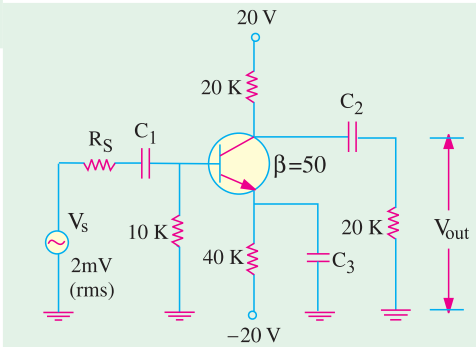

Fig. 59.27

Solution. This circuit is similar to that shown if Fig. 59.23 except for the addition of R_S.

As found in Ex. 9.8, $r_e' = 50\ \Omega$,

$$\beta r_e' = 2500\ \Omega.$$

$$\therefore \qquad R_B \,||\, \beta r_e' = 10\ \text{K} \,||\, 22500\ \Omega = 2000\ \Omega$$

(*a*) When R_S = 100 Ω

In this case, 2 mV are dropped across a series combination of 100 Ω and 2000 Ω. Drop over 100 Ω is negligible as compared to that on 2000 Ω. Hence, it can be presumed that $V_s = V_{in} = 2\text{mV}$. We have already found that $A_v = 200$.

$$\therefore \qquad V_{out} = A_v \times V_{in} = 200 \times 2 = \textbf{400 mV (rms)}$$

(*b*) When R_S = 3 K

In this case, drop across $R_B \,||\, \beta r_e' = 2$ K is $V_{in} \quad V_{in} \dfrac{R_B \,||\, r_e'}{R_s \quad (R_B \,||\, r_e')} \quad 2 \quad \dfrac{2}{3 \quad 2} \quad 0.8\ \text{mV}$

$$\therefore \qquad V_{out} = 200 \times 0.8 = \textbf{160 mV}$$

Obviously, as R_S is increased, V_{out} is decreased.

59.8. Equivalent Circuit of a CC Amplifier

We will consider the two-supply emitter-bias circuit shown in Fig. 59.28 (*a*) in which the collector is placed at ac (not dc) ground. The ac input signal is coupled into the base and output signal is taken out of the emitter. This circuit is also called **emitter follower circuit** because the emitter signal ***follows the signal at the base both in magnitude and phase.***

(a) DC Equivalent Circuit

It is drawn in the usual way by opening all the capacitors and shorting all ac sources. It is shown in Fig. 59.28 (*b*).

$$I_E \quad \frac{V_{EE} \quad V_{BE}}{R_E \quad R_B /} \quad \frac{V_{BE}}{R_E}$$

(*b*) AC Equivalent Circuit

It is obtained by shorting all ac sources and capacitors and is shown in Fig. 59.29.

(*c*) Principal Operating Characteristics

1. Input Resistance

The input resistance of the *CC* stage is given by the parallel combination of R_S and $r_{in(base)}$. Now, $r_{in(base)}$ is the input resistance looking into the base. It is found to be equal to $(1 + \beta)(r_e' + r_L) \cong \beta\, r_L$ *i.e.* β times the ac load seen by the emitter.

$\therefore \; r_{in}$ or $r_{in(stage)} = R_B \,||\, r_{in(base)}$

$= R_B \,||\, \beta\,(r_e' + r_L) \cong \beta\,(r_e' + r_L)$ — when R_B is very large

$\cong \beta r_L$ — when $r_e' << r_L$

$= \beta R_E$ — if $R_L = 0$

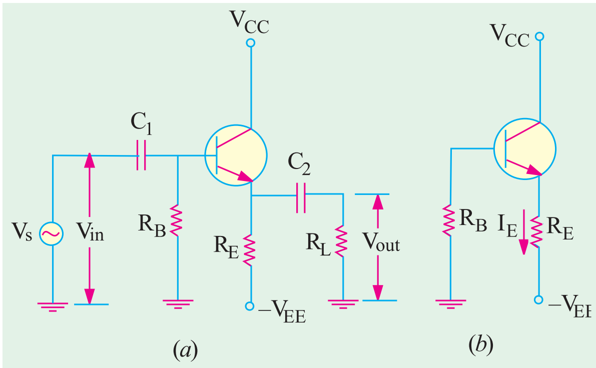

Fig. 59.28

2. AC Load Resistance : $r_L = R_E \,||\, R_L$

It is the ac output resistance as seen by the emitter (and not the one when looking into the emitter).

3. Current Gain. $A_i \quad \frac{i_e}{i_b} \quad (1 \quad)$

4. Voltage Gain. $V_{in} = i_b \,.\, r_{in} = i_b \,.\, \beta\,(r_e' + r_L)$:

$V_{out} = i.e \,.\, r_L = \beta i_b \,.\, r_L$

$$A_v \quad \frac{V_{out}}{V_{in}} \quad \frac{i_b\, r_L}{i_b \,.\, (r_e' \quad r_L)} \quad \frac{r_L}{r_e' \quad r_L} \quad \frac{r_L}{r_L} \quad 1$$

— if $r_e' << r_L$

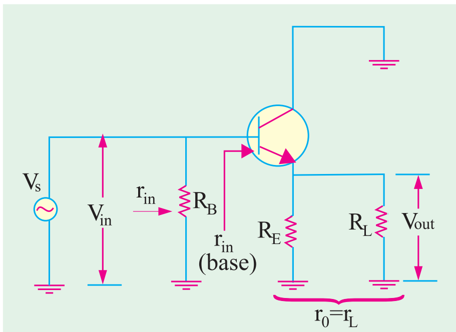

Fig. 59.29

It means that output signal from emitter has the **same magnitude** as the input signal at the base.

5. Power Gain $A_p = A_v \,.\, A_i = 1 \times (1 + \beta) = (1 + \beta) \cong \beta$

$G_p = 10 \log_{10} A_p$ dB

It would be noted from above that main usefulness of the emitter follower is to **step up the impedance level** *i.e.* it transforms load impedance to a much higher value. It does not increase the signal voltage. Hence, primary application of emitter follower or *CC* stage is as an impedance matching device. It offers a higher impedance at the input terminals *i.e.* r_{in} and a low output impedance (r_L) ***– something opposite of typical basic transistor amplifier.***

Another point worth keeping in mind is that the above formulas are not exact because we have used ideal transistor approximations. However, these formulas do help in rapidly grasping the essential features of an emitter follower. Moreover, they are adequate for preliminary analysis and design.

Example. 59.11. *For the emitter follower shown in Fig. 59.30, find*
(i) r_{in} *or* $r_{in(stage)}$ *(ii)* r_L *(iii)* A_v *(iv)* A_p. *Take transistor* $\beta = 50$.
(Electronics, Delhi Univ.)

Solution. $I_E = 20/20 = 1$ mA

$r_e' = 25/1 = 25\ \Omega$

$r_L = R_E \| R_L = 20 \| 5 = 4$ K

$r_{in(base)} = \beta(r_e' + r_L) \cong \beta\, r_L = 50 \times 4 = 200$ K

$\therefore$ (r_e' of 25 Ω has been neglected as compared to r_L of 4 K)

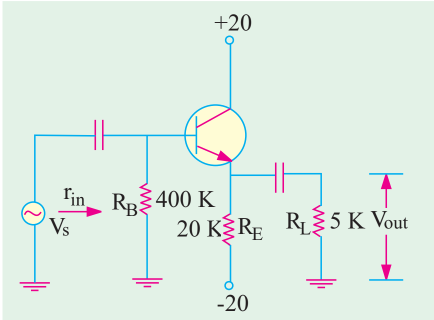

Fig. 59.30

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

$= 400\text{ K} \| 200\text{ K}$

$=$ **133.3 K**

(ii) $r_L = 20\text{ K} \| 5\text{ K} =$ **4 K**

(iii) $A_v \cong 1$ since r_e' is negligible as compared to r_L. If it is not, then A_v could be even less than 1.

(iv) $A_p = A_i \cdot A_v \;\; \beta \times 1 = \beta = 50$; $G_p = 10 \log_{10} 50 =$ **17 dB**

Example 59.12. *For the beta-stabilized emitter follower circuit of Fig. 59.31, find*
(i) $r_{in(base)}$ *(ii)* r_{in} or $r_{in(stage)}$ *(iii)* r_L and *(iv)* A_v. Take transistor $\beta = 100$.
(Electronics Technology, Mysore Univ.)

Solution. $V_2 \quad V_{CC}\dfrac{R_2}{R_1 \quad R_2} \quad 20 \quad \dfrac{10}{40} \quad 5\text{ V}$

$I_E \quad \dfrac{V_2}{R_E} \quad \dfrac{5}{5} \quad 1\text{ mA}$

$r_e' = 25/1 = 25\ \Omega$

$r_L = 5 \| 5 = 2.5$ K

(i) $r_{in(base)} = \beta\,(r_e' + r_L)$

$= 100\,(25 + 2500) =$ **250 K**

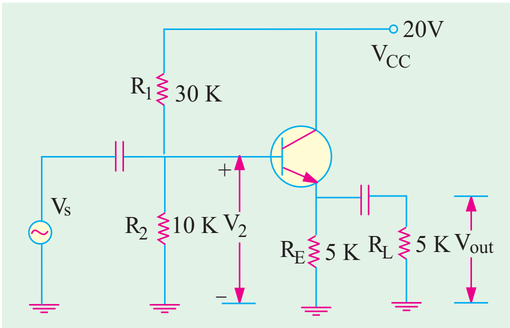

Fig. 59.31

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

$r_{in(base)} = 30\text{K} \| 10\text{ K} \| 250\text{ K} \cong 8$ K

(iii) $r_L = 5\text{ K} \| 5\text{ K} =$ **2.5 K**

(iv) $A_p = A_i \cdot A_v \cong 1 \times \beta = 100$; $G_p = 100 \log_{10} 100 =$ **20dB**

Example 59.13. *For the CE circuit of Fig. 59.32, find*
(i) r_{in} or $r_{in(stage)}$ *(ii)* A_v *(iii)* A_p. Take transistor $\beta = 200$

Solution . $I_E = 20/20 = 1$ mA $\;\; r_e' = 25/1 = 25\ \Omega$

$r_L = 20\text{ K} \| 50\ \Omega = 50\ \Omega$

$r_{in(base)} = \beta\,(r_e' + r_L) = 200\,(25 + 50) = 15$ K;

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

$= 100\text{ K} \| 15\text{ K} =$ **13 K**

(ii) Since r_e' is not negligible as compared to r_L, we will use the expression

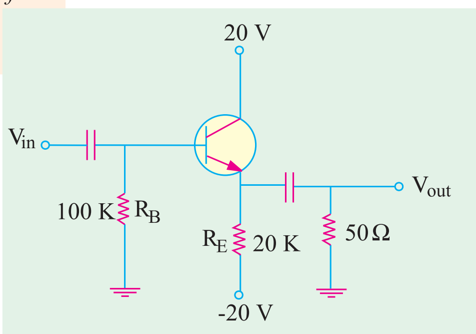

Fig. 59.32

$$A_v \quad \frac{r_L}{r_e' \quad r_L} \quad \frac{50}{25 \quad 50} \quad \mathbf{0.667}$$

(iii) $A_p = A_v \cdot A_i = 0.667 \times 200 =$ **133.3**

59.9. Small-signal Low-frequency Model or Representation

Although many transistor representations or models have been suggested and widely used, the equivalent *T*-model is the easiest to understand because, in this representation, component parts retain their identity in all configurations leading to rapid appreciation of a given network.

59.10. T-Model

Such models are not in common use today because they do not take into account any gain between input and output.

(*a*) CB Circuit

In Fig. 59.33 is shown the low-frequency *T*-equivalent circuit of a transistor connected in *CB* configuration. It utilizes *T*- or *r*-parameters. All these parameters are ac parameters and are measured under open-circuit conditions. Here, r_e represents the ac resistance of the forward-biased emitter-base junction. Its value is

$$r_e \quad \frac{25\,\text{mV}}{I_E} \qquad \text{— for Ge}$$

$$\frac{50\,\text{mV}}{I_E} \qquad \text{— for Si}$$

This resistance is fairly small and depends on I_E. Also, r_c represents the ac resistance of the reverse-biased *C/B* junction. It is of the order of a few MΩ. Finally, r_b represents the resistance of the base region which is common to both junctions. Its value depends on the degree of doping. Usually, r_b is larger than r_e but much smaller than r_c.

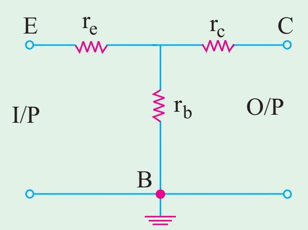

Fig. 59.33

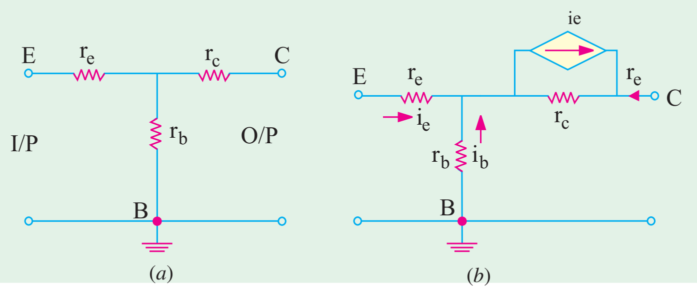

Fig. 59.34

However, circuit shown in Fig. 59.34 (*a*) is not complete because it does not illustrate the forward current transfer ratio. Since current in the output of a transistor depends on the current at the input, a dependent current-generator in parallel with r_c must be included as shown in Fig. 59.34 (*b*). As it is the usual practice, all currents are shown flowing inwards even though some of them may actually be flowing in the opposite direction.

The current generator may be replaced by a voltage generator with the help of Thevenin's theorem as shown in Fig. 59.35 (*a*). In that case, the *T*-equivalent circuit becomes as shown in Fig. 59.35 (*b*). The generator has a voltage of $\alpha i_e r_c = r_{in} i_e$ where $r_{in} = \alpha r_e$.

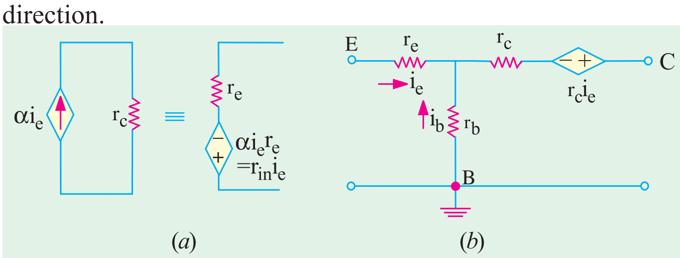

Fig. 59.35

Typical values of different parameters are :

$r_e = 25$ to $50\ \Omega$; $r_b = 100$ to $1000\ \Omega$; $r_c = 1$ MΩ

(b) CE Circuit

The T-equivalent circuit for such a configuration is shown in Fig. 59.36. Whereas circuit shown in Fig. 59.36 contains a parallel current-generator that shown in Fig. 59.37 contains a series-voltage generator.

(c) CC Circuit

The T-equivalent circuit for such a configuration is shown in Fig. 59.38.

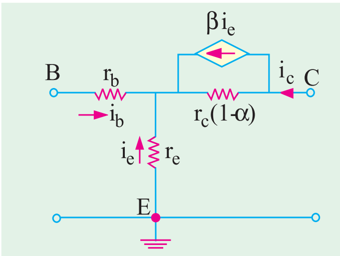

Fig. 59.36

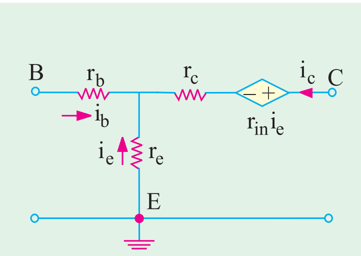

Fig. 59.37

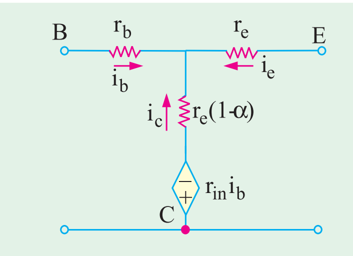

Fig. 59.38

59.11. Formulas for T-Equivalent of a CB Circuit

In Fig. 59.39 is shown a small-signal low-frequency T-equivalent circuit for CB configuration. The ac input signal source has a resistance of R_S and voltage of V_s.

Of course, dc biasing circuit has been omitted and only ac equivalent shown. The approximate expressions for input and output resistance and voltage and current gains as derived by applying KVL to the input and output loops are given below without derivation :

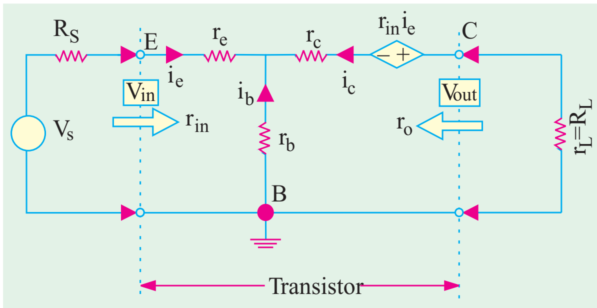

Fig. 59.39

1. $r_{in} \quad r_e \quad r_b\,(1 \quad) \quad r_e \quad \dfrac{r_b}{(1 \quad)} \quad r_e \quad r_b \quad \dfrac{r_c\,(1 \quad) \quad R_L}{r_c \quad r_L}$

2. $r_o \quad r_c \quad \dfrac{r_b r_c}{r_e \quad r_b \quad R_S}$

3. $A_i = \alpha$

4. $A_v \quad \dfrac{v_{out}}{v_{in}} \quad \dfrac{R_L}{r_e \quad r_b\,(1 \quad)}$

$A_v \quad \dfrac{V_{out}}{V_{in}} \quad \dfrac{R_L}{(r_e \quad R_s) \quad r_b\,(1 \quad)} \quad \dfrac{R_L}{(r_e \quad R_s)}$

5. $A_P = A_i \,.\, A_v$

$\dfrac{^2 R_L}{(r_e \quad r_b\,(1 \quad)}$ — no source resistance

$\dfrac{^2 R_L}{(r_e \quad R_s) \quad r_b\,(1 \quad)}$ — with source resistance

$G_p = 10 \log_{10} A_p$

59.12. Formulas for T-Equivalent of a CE Circuit

The low-frequency small-signal *T*-equivalent circuit for such a configuration is shown in Fig. 59.40.

The approximate expressions for various resistances and gains as found by applying *KVL* to the input and output loops are given below :

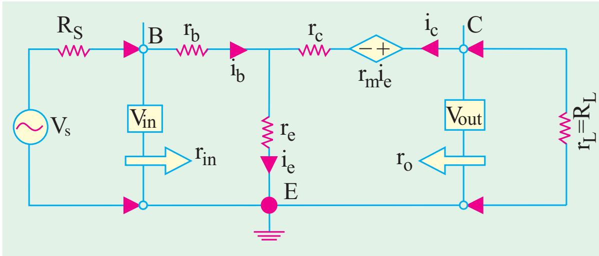

Fig. 59.40

1. $r_{in} \quad r_b \quad \frac{r_e}{((1\quad)}$

$= r_b + (1+\beta) r_e$

2. $r_o \quad r_e\,(1 \quad) \quad \frac{r_e r_e}{r_b \quad r_e \quad R_S}$ **3.** $A_i = \beta \quad (1\quad)$

4. $A_v \quad \frac{V_{out}}{V_{in}} \quad \frac{R_L}{r_e \quad r_b\,(1\quad)}$ $A_{vs} \quad \frac{V_{out}}{V_s} \quad \frac{R_L}{r_e \quad (r_b \quad R_s)\,(1\quad)}$

5. $A_p = A_v.A_i \quad \frac{{}^2 R_L}{(1\quad)[(r_e \quad r_b\,(1\quad)]} \quad \frac{{}^2 R_L}{(1\quad)[(r_e \quad (r_b \quad R_S)\,(1\quad)]}$

59.13. Formulas for T-Equivalent of a CC Circuit

The low-frequency *T*-equivalent circuit for such a configuration is shown in Fig. 59.41. The approximate expressions for various resistances and gains are given below :

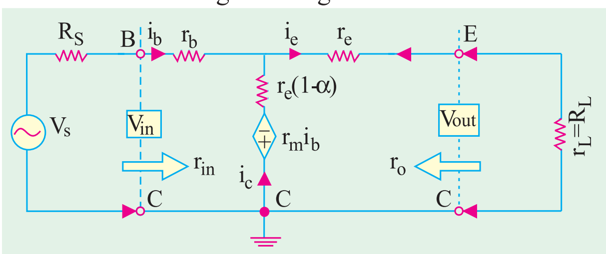

Fig. 59.41

1. $r_{in} \quad \frac{R_L}{1} \quad (1\quad)R_L$

2. $r_v = r_e + (1-\alpha)\,(r_b + R_S)$

$r_e \quad \frac{(r_b \quad R_S)}{(1\quad)}$

3. $A_i \quad \frac{1}{(1\quad)} \quad (1\quad)$

4. $A_n = 1$

5. $A_p \quad \frac{1}{(1\quad)} \quad (1\quad) \quad G_p = 10A_p$ dB

Example 59.14. *A junction transistor has $r_e = 50\ \Omega$, $r_b = 1$ K, $r_c = 1$M and $\alpha = 0.98$. It is used in common-base circuit with a load resistance of 10 K. Calculate the current , voltage and power gains and the input resistance.* **(Applied Electronics, Punjab Univ. 1993)**

Solution. ***(i)*** $A_i = \alpha = 0.98$

(ii) $A_v \quad \frac{R_L}{r_e \quad r_b\,(1\quad)} \quad \frac{0.98 \quad 10,000}{50 \quad 1000\,(1-0.98)}$ **140** ***(iii)*** $A_p = A_v \cdot A_i = 140 \times 0.98 = 137$

(iv) $r_{in} = r_e + r_b(1-\alpha) = 50 + 1000\,(1-0.98) = $ **70 Ω**

Example 59.15. *A P-N-P junction transistor is used as a voltage amplifier in the grounded-base circuit with a load resistance being 300 K and the internal resistance of the original source being 200 Ω.*

Derive an expression for the voltage gain of the amplifier and calculate its magnitude if the transistor T-network parameters are : $r_e = 18\ \Omega$, $r_b = 700\ \Omega$, $r_c = 1$ M and $r_m = 976$ K.

(Applied Electronics and Circuits, Grad. I.E.T.E.)

Solution. Here, $r_m = \alpha (r_c + r_b) \cong \alpha r_c$ $\quad \therefore \alpha = r_m / r_c = 976\ K / 1000\ K = 0.976$

$$A_v \quad \frac{V_2}{V_1} \quad \frac{R_L}{r_c \quad r(1 \quad)} \quad \frac{0.976 \quad 300 \quad 10^3}{18 \quad 700(1-0.976)} \quad \mathbf{8,410}$$

$$A_{vg} \quad \frac{V_2}{Vg} \quad \frac{R_L}{R_G \quad r_c \quad r_b(1 \quad)} \quad \frac{0.976 \quad 300 \quad 10^3}{200 \quad 18 \quad 700(1-0.976)} \quad \mathbf{1247}$$

Example 59.16. *Calculate the input and output resistance, overall current, voltage and power gains for a CE connected transistor having following r-parameters :*

$r_b = 30\ \Omega$, $r_e = 400\ \Omega$, $r_c = 0.75$ M, $\alpha = 0.95$, $R_L = 10$ K and $R_S = 400\ \Omega$

Also, calculate the power gain in decibels.

(Electronics Technology, Bangalore Univ. 1999)

Solution. (*i*) $r_{in} \quad r_b \quad \frac{r_e}{(1- \quad)} \quad 30 \quad \frac{400}{(1-0.95)} \quad \mathbf{8030\ \Omega}$

(*ii*) $r_o \quad r_e(1 \quad) \quad \frac{r_c r_e}{r_b \quad r_c \quad R_S}$

$$750,000(1-0.95) \quad \frac{0.95 \quad 750,000 \quad 400}{(30 \quad 400 \quad 400)} \quad 380,870 \quad \mathbf{0.38\ M}$$

(*iii*) $A_i \quad \frac{\quad}{1} \quad \frac{0.95}{(1 \quad 0.95)} \quad 19$

(*iv*) $A \quad \frac{R_L}{r_e \quad (r_b \quad R_s)(1 \quad)} \quad \frac{0.95 \times 10 \times 10^3}{400 + (30 + 400) \times 0.05} = \mathbf{22.5}$

(*v*) $A_p = A_v \cdot A_i = 22.5 \times 19 =$ **427.5**

Power gain in decibels, $G_p = 10 \log_{10} 427.5 =$ **26.3 dB**

59.14. What are h-parameters ?

These are ***four*** constants which describe the behaviour 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.

Consider an unknown linear network contained in a black box as shown in Fig. 59.42. As a matter of convention, currents flowing into the box are taken positive whereas those flowing out of it are considered negative.

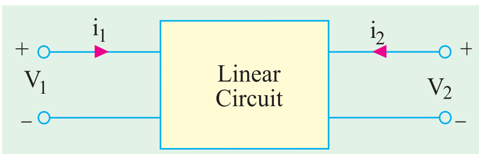

Fig. 59.42

Similarly, voltages are positive from the upper to the lower terminals and negative the other way around. The electrical behaviour 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 means ***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. 59.43, 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.

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

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

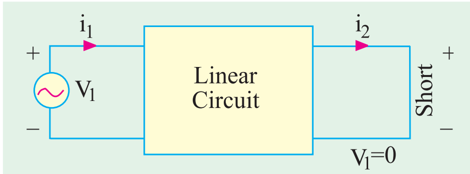

Fig. 59.43

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*)

$i_2 = h_{21}\, i_1 + h_{22}\, V_2$ ... (*ii*)

Here, the h_s are constants for a given circuit but change if the circuit is changed. Knowlege 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. 59.44, 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.

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

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

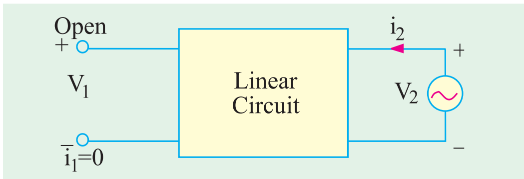

Fig. 59.44

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	with output shorted
h_{21}	=	forward current gain	
h_{12}	=	reverse voltage gain	with input open
h_{22}	=	output admittance	

59.15. Input Impedance of a Two Port Network

Consider the two-port linear network shown in Fig. 59.45 which has a load resistance r_L across its output terminals. The voltage source V_1 on the input side drives the circuit and sets up current i_1. As seen, $Z_{in} = V_1 / i_1$. Substituting the value of V_1 from Eq. (*i*) of Art. 59.14, we get

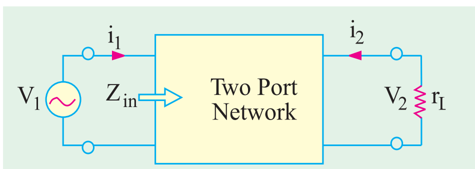

Fig. 59.45

$$Z_{in} \quad \frac{V_1}{i_1} \quad \frac{h_{11} i_1 \quad h_{12} v_2}{i_1}$$

$$h_{11} \quad \frac{h_{12} V_2}{i_1} \qquad \text{... }(i)$$

As seen from Fig. 59.45 above $i_2 = -\,v_2 / R_L$*
Substituting this value of I_2 in Eq. (*ii*) of Art 59.14, we have

$$\frac{-v_2}{R_L} \quad h_{22}\, i_1 \quad h_{22} v_2 \quad \text{or} \quad \frac{v_2}{i_1} \quad \frac{h_{21}}{h_{22} \quad 1/R_L}$$

Substituting this value in Eq. (*i*) above, we have

$$Z_{in} \quad h_{11} \quad \frac{h_{12}\,.h_{21}}{h_{22} \quad 1/R_L}$$

59.16. Voltage Gain of a Two Port Network

The voltage gain of such a circuit (Fig. 59.45) is $A_v = v_2 / v_1$. Now $v_1 = i_1 . Z_{in}$. Hence, $A_v = v_2 / i_1 . Z_{in}$.

Substituting the value of v_2 / i_1 as found earlier in Art. 59.15, we get

$$A_v \quad \frac{h_{21}}{Z_{in}(h_{22} \quad 1/R_L)}$$

Example. 59.17. *Find the h-parameters of the circuit shown in Fig. 59.46 (a).*

Solution. First of all, let us find the forward parameters *hu* and h_{21}. For that purpose, a short is put across the output terminals as shown in Fig. 59.46 (*b*).

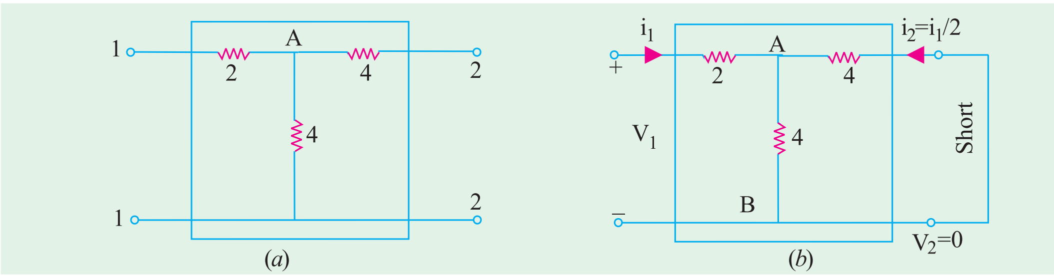

Fig. 59.46

(*i*) The input impedance of the network as viewed from input terminals is
$h_{11} = 2 + 4 \,||\, 4 = $ **4 Ω**

(*ii*) As seen from Fig. 9.46 (*b*), input current i_1 divides into two equal parts at point A. The output current $i_2 = -\,i_1/2$ (negative sign has been taken because actually it is flowing out of the box).

$$\therefore \quad h_{21} \quad \frac{i_2}{i_1} \quad \frac{-i_1/2}{i_1} \quad \frac{1}{2} \quad \mathbf{-\,0.5}$$

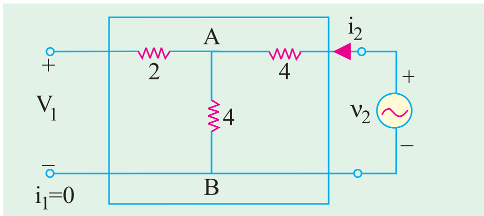

Fig. 59.47

(*iii*) Now, for finding reverse parameters, we will keep input terminals open and apply v_2 across output terminals as shown in Fig. 59.47. It will produce a current i_2 which will produce equal drops across the two 4 Ω resistors. The voltage which appears across input terminals as v_1 is the drop across the vertical 4 Ω resistor connected at point A. Hence, $v_1 = v_2 / 2$.

$$\therefore \quad h_{12} \quad \frac{v_1}{v_2} \quad \frac{v_2/2}{v_2} \quad \mathbf{0.5}$$

* The negative sign is used because actual load current is opposite to that shown in figure.

The input impedance of the network when viewed from output terminals with input terminals open is = 4 + 4 = 8 Ω.

$\therefore$ $h_{22} = 1/8 =$ **0.125 Siemens (*i.e.* mho)**

Hence, for the network shown in Fig. 59.46 (*a*), the *h*-parameters are as under :

$h_{11} = 4\ \Omega$ $\quad h_{21} = -0.5$ $\quad h_{12} = 0.5$ and $\quad h_{22} = 0.125$ S

59.17. 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 ⎤ output shorted
$h_{21} = h_f$ = forward current gain ⎦

$h_{12} = h_r$ = 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} $\quad h_{fe}$ $\quad h_{re}$ and $\quad h_{oe}$

Similarly, for *CB* connection, these are written as h_{ib}, h_{fb}, h_{rb}, h_{op} and for *CC* connection as h_{ic}, h_{fc}, h_{rc} and h_{oc}.

59.18. The h-parameters of an Ideal Transistor

As stated earlier, every linear circuit has a set of parameters associated with it, which fully describe its behaviour. When small ac signals are involved, a transistor behaves like a linear device because its output ac signal ***varies directly as the input signal.*** Hence, for small ac signals, each transistor has its own characteristic set of *h*-parameters or constants.

The *h*-parameters depend on a number of factors such as

1. transistor type **2.** configuration **3.** operating point **4.** temperature **5.** frequency

These *h*-parameters can be found experimentally or graphically. The parameters h_i and h_r are determined from input characteristics of the *CE* transistor whereas h_f and h_0 are found from output characteristics.

59.19. The h-parameters of an Ideal CB Transistor

In Fig. 59.48 (*a*), a *CB*-connected transistor has been shown connected in a black box. Fig., 59.48 (*b*) gives its equivalent circuit. It should be noted that no external biassing resistors or any signal source has been shown connected to the transistor.

(*i*) Forward Parameters

The two forward h-parameters can be found from the circuit of Fig. 59.49 (*a*) where a short has been put across the output. The input impedance is simply r_e.

$\therefore$ $\quad h_{ib} = r_e$

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.)

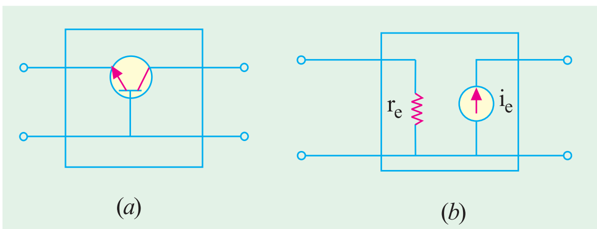

Fig. 59.48

(*ii*) Reverse Parameters

The two reverse parameters can be found from the circuit diagram of Fig. 59.49 (*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, $v_1 = 0$.

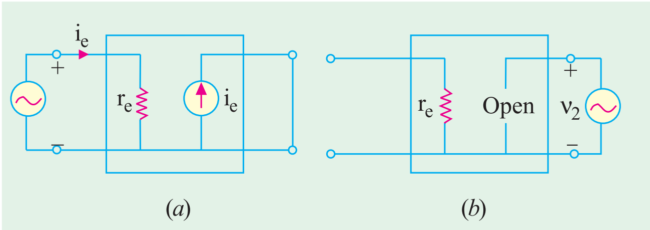

Fig. 59.49

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

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

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

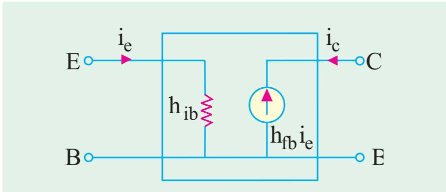

Fig. 59.50

Summary

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. 59.50.

Note. In an actual transistor, h_{rb} and h_{ob} are not zero but have some finite value though extremely small (ranging from 10^{-} to 10^{-6}).

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_{rb} is very small.

59.20. The *h*-parameters of an ideal CE Transistor

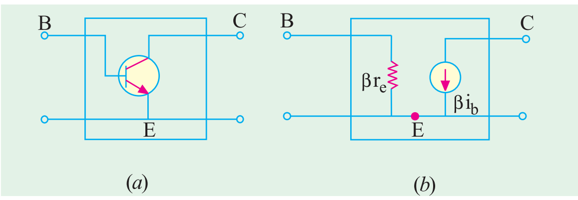

Fig. 59.51

Fig. 59.51 (*a*) shows a *CE*-connected ideal transistor contained in a black box whereas 59.51 (*b*) shows its ac equivalent circuit in terms of its β and resistance values.

(*a*) Forward Parameters

The two forward h-parameters can be found from the circuit of Fig. 59.52 (*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)

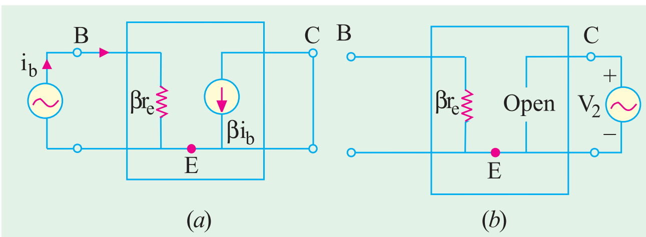

Fig. 59.52

(*b*) Reverse Parameters

These can be found by reference to the circuit of Fig. 59.52 (*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 $i_b = 0$. If $i_b = 0$, then collector current source has zero value and looks like an open. Hence, there can be no v_1 due to this open.

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

Again, the impedance looking into the output terminals is infinite so that conductance is zero.

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

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

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

The hybrid equivalent circuit of such a transistor is shown in Fig. 59.53.

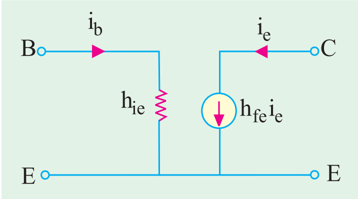

Fig. 59.53

Note. In practice, h_{re} and h_{oe} are not exactly zero but quite small for the same reasons as given in the Note to Art 59.19.

59.21. Approximate Hybrid Equivalent Circuits

So far, we did not take into account the following two factors which exist in an actual transistor (as opposed to an ideal one).

(*i*) because of the transistor's non-unilateral behaviour, there is a 'feedback' of the output voltage into the input voltage. This feedback is represented by a voltage-controlled generator $h_r v_2$ as shown in Fig. 59.54 and 59.55.

By definition, an ideal amplifier is one which responds only to signals applied to its input terminals. It should not do the reverse *i.e.* reproduce at the input any portion of the ac signal applied at the output. Such an ideal one-way device is called a unilateral device. A real transistor cannot be unilateral because of unaviodable interaction between its input and output circuits (after all, it consists of a single piece of a crystal). Therefore, not only its output responds to its input but, to a lesser degree, its input also responds to its output.

(*ii*) even when input circuits is open, there is some effective value of conductanece when looking into the transistor from its output terminals. It is represented by h_0.

We will now draw ***low-frequency small-signal*** hybrid equivalent circuits after taking into account the 'feedback' voltage generator and output admittance.

(*a*) Hybrid CB Circuit

In Fig. 59.54 (*a*) is shown an *NPN* transistor connected in *CB* configuration. Its ac equivalent circuit employing *h*-parameters is shown in Fig. 59.54 (*b*). The *V/I* relations are given by the following two equations.

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

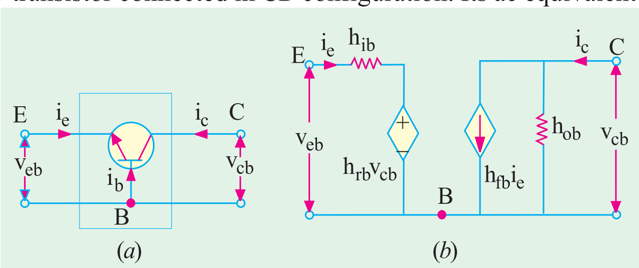

Fig. 59.54

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 in the output terminals must equal the sum of two branch currents.

As per current convention stated earlier (Art. 59.14), collector i_e is shown flowing ***inwards*** though actually this current flows ***outwards*** as shown by the arrow inside the ac current source. Similarly, ac voltage polarities have been taken by considering upper terminal positive and lower one as negative (please remember that the dc biasing rule of Art. 59.12 does not apply here).

It may be noted that no external dc biasing resistor or ac voltage sources have been connected to the equivalent circuit as yet.

Incidentally, it may be noted that the ac equivalent circuit contains a Thevenin's circuit in the input and a Norton's circuit in the output. It is all the more a reason to call it a hybrid equivalent circuit.

(*b*) Hybrid CE Circuit

The hybrid equivalent of the transistor alone when connected in *CE* configuration is shown in Fig. 59.55 (*b*). Its *V/I* characteristics are described by the following two equations.

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

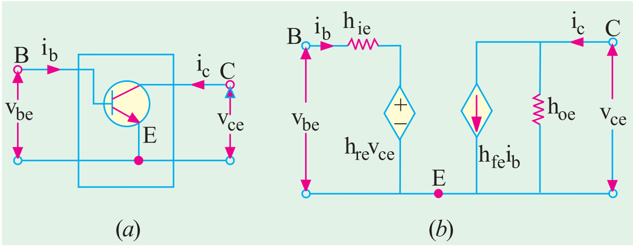

Fig. 59.55

We may connect signal input source across its input terminals and load resistance across output terminals (Art. 59.22).

(*c*) Hybrid CC Circuit

The hybrid equivalent of a transistor alone when connected in *CC* configuration is shown in Fig. 59.56 (*b*). Its *V/I* characteristics are defined by the following two equations :

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

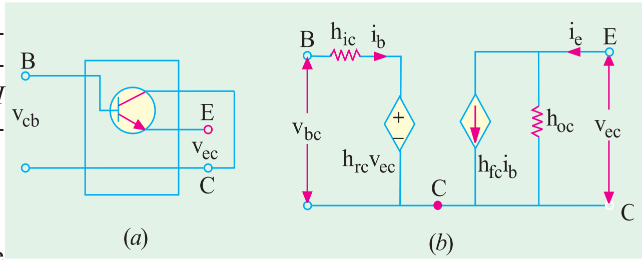

Fig. 59.56

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

59.22. Transistor Amplifier Formulae Using *h*-parameters

As shown in Fig. 59.57, if we add a signal source across input terminals 1-1 of a transistor and a load resistor across its output terminals 2–2, we get a small-signal, low-frequency hybrid model of a transistor amplifier. It is valid for all the three configurations and holds good for all types of load whether a resistance of an impedance. We will now find expressions for its gains and impedances.

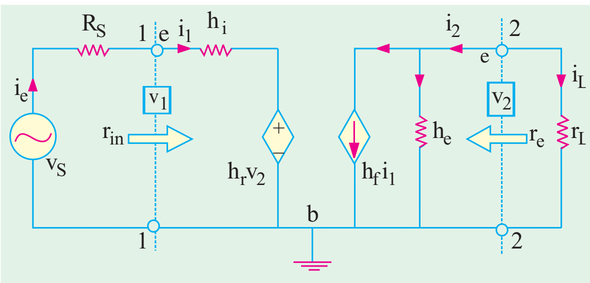

Fig. 59.57

Before undertaking the above derivations, let us consider different components in the hybrid model of Fig. 59.57. The input resistance looks like a resistance (h_i) in series with a voltage generator ($h_r\, v_2$). This generator represents the voltage feed-back from the output to the input circuit. It is known as voltage-controlled generator because its value is determined by v_2 (as h_r is a dimensionless constant). The output circuit also has two components (*i*) h_0 component which represents the conductance as seen from output terminals and (*ii*) the current-controlled generator ($h_f i_1$) which simulates the transistor's ability to amplify. The parameter h_f is a dimensionless constant.

The above model can be described mathematically by using the following two equations :

Input Circuit

v_1 = sum of voltage drops from *a* to *b*

$$= h_i\, i_1 + h_r\, v_2 \qquad \text{...}(i)$$

Output Circuit

i_2 = sum of currents leaving junction *c*

$$= h_f\, i_1 + h_0\, v_2 \qquad \text{...}(ii)$$

Now, $v_2 = -i_2 r_L$. Substituting this value in Eq. (*ii*) above, we have

$$i_2 \quad = h_f i_1 - h_0 i_2 r_L \qquad \text{... (iii)}$$

Eq. (*i*) and (*iii*) can now be used to find various gains of a transistor.

(*i*) Current Gain

It is given by $A_i = i_2/i_1$

Dividing both sides of Eq. (*iii*) by i_1, we get

$$\frac{i_2}{i_1} \quad h_f \quad h_0 \frac{i_2}{i_1} r_L \qquad \text{or} \qquad A_i = h_f - h_0 A_i r_L$$

$$\therefore \qquad A_i \quad \frac{h_f}{1 \quad h_0 r_L}$$

If $\quad r_L = 0$ or $h_0 r_L << 1$, then $A_i = h_f$

Current Gain Taking R_S into Account

The source current is not the transistor input current because i_1 partly flows along R_S and partly along r_{in}.

To illustrate this point, consider the Norton's equivalent of the source (Fig. 59.58). The overall current gain A_{is} is given by

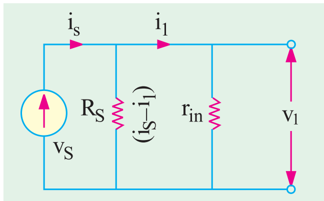

Fig. 59.58

$$A_{is} \quad \frac{i_2}{i_s} \quad \frac{i_2}{i_1} \quad \frac{i_1}{i_s} \qquad A_i \quad \frac{i_1}{i_s}$$

As seen from Fig. 9.58

$$i_1 \quad \frac{i_s \; R_s}{r_{in} \quad R_s} \qquad \text{or} \qquad \frac{i_1}{i_s} \quad \frac{R_s}{r_{in} \quad R_s}$$

$$\therefore \qquad A_{is} \;=\; A_i \,.\, R_S/(r_{in} + R_S)$$

(*ii*) Input Impedance

It is defined as the resistance when looking into the amplifier from its input terminals. Hence, $r_{in} = v_1/i_1$.

From Eq. (*i*) above, we have

$$r_{in} \quad \frac{1}{i_1} \quad \frac{h_i i_1 \quad h_r \quad 2}{i_1} \qquad h_i \qquad h_r \,.\, \frac{2}{i_1}$$

Substituting the value of $v_2 = -i_2 r_L = -A_i\, i_1 r_L$, we get

$$r_{in} \quad h_i \quad h_i A_i r_L \quad h_i \quad \frac{h_f h_r r_L}{1 \quad h_0 r_L} \qquad h_i \quad \frac{h_f h_r}{h_0 \quad 1/r_L}$$

$$\frac{h_i \qquad h r_L}{1 \quad h_0 r_L} \qquad\qquad \text{where} \quad \Delta h = h_i h_0 - h_f h_r$$

$$\cong \; h_i \qquad\qquad - \text{if } h_r \text{ or } r_L \text{ is very small.}$$

It is seen that r_{in} depends on r_L *i.e.* ac resistance of the load across output terminals of the transistor.

(*iii*) Voltage Gain

$A_v = v_2/v_1$. It is also known as the internal voltage gain of the transistor. It is different from $A_{vs} = v_2/v_s$ which is the gain from the source to the output terminals and is known as stage gain or overall gain.

As seen from above, $v_2 = -A_i i_2 r_L$ and $v_1 = i_1 r_{in}$

$$\therefore \quad A_v \quad \frac{\ 2}{1} \quad \frac{i_2\, A_i r_L}{i_L\, r_{in}} \quad A_i \frac{r_L}{r_{in}}$$

$$\frac{h_f}{1 \quad h_0 r_L} \quad \frac{r_L(1 \quad h_0 . r_L)}{h_i \qquad h . r_L} \quad \frac{h_f . r_L}{h_i \qquad h . r_L}$$

$$\frac{h_f r_L}{h_i(1 \quad h_0 r_L) \quad h_f h_r r_L} \qquad h_f \cdot \frac{r_L}{h_i}$$

Overall voltage gain is

$$A_{vs} \quad \frac{v_2}{\ _s} \quad \frac{v_2}{v_1} \frac{v_i}{v_s} \quad A_v \frac{v_i}{v_s}$$

Now, v_s drops over series combination of R_S and r_{in}.

Drop across r_{in} constitutes v_1. Hence, $v_1 = v_s \times r_{in}/(R_S + R_{in})$

$$\therefore \quad \frac{v_1}{v_s} \quad \frac{r_{in}}{(R_S \quad r_{in})} \qquad \text{or} \qquad A_{vs} \quad A_v \frac{r_{in}}{(R_S \quad r_{in})}$$

As seen, if $R_S = 0$, $A_{vs} = A_v$

Value of A_{vs} may also be obtained by adding R_S to h_i in the expression for A_v.

(*iv*) Output Impedance

It is defined as $r_0 \quad \frac{v_2}{i_2}\Big|_{v_s \quad 0}$ or $g_0 \quad \frac{i_2}{v_2}$

Dividing both sides of Eq. (*ii*) by v_2, we get

$$g_0 \quad h_f \cdot \frac{i_2}{v_2} \quad h_0 \qquad \text{..... } (iv)$$

Taking $v_s = 0$ and then applying KVL to the input circuit in Fig. 59.57, we get

$-i_1(h_i + R_S) - h_r v_2 = 0$ or $i_1/v_2 = -h_r/(h_i + R_S)$

Substituting this value in Eq. (*iv*) above, we have

$$g_0 \quad h_0 \cdot \frac{h_f h_r}{(h_i \quad R_S)} \quad \frac{h_o R_S \qquad h}{(h_i \quad R_S)} \qquad \therefore \quad r_o \quad \frac{1}{g_o} \quad \frac{h_i \quad R_S}{h_o R_S \qquad h}$$

It is seen that rin depends on r_L whereas ro depends on R_S.

If R_S is very large (*i.e.* circuit is driven by a current source) or h_r is negligible, then $r_o \cong 1/h_o$.

(*v*) Power Gain

$$A_p \quad \frac{P_2}{P_1} \quad \frac{v_2 i_2}{v_1 i_1} \quad A_v A_i \quad A_i^2 \frac{r_L}{r_{in}}$$

The above formulae are summarized below :

(*i*) $$A_i \quad \frac{h_f}{1 \quad h_o r_L} \quad h_f$$

$$A_i \quad \frac{h_f R_S}{(1 \quad h_o r_L)(r_{in} \quad R_S)} \quad \frac{h_o R_S}{(r_{in} \quad R_S)}$$

(*ii*) $$r_{in} \quad h_i \quad \frac{h_f h_r r_L}{1 \quad h_o r_L} \quad h_i$$

(*iii*) $$A_v \quad \frac{h_f h_r}{h_i \qquad h . r_L} \quad \frac{h_f r_L}{h_i} \ ; \ A_{vs} \quad \frac{h_f r_L}{(h_i \quad R_S)}$$

(*iv*) $r_o \quad \frac{h_i}{h_o R_S} \quad \frac{R_S}{h} \quad \frac{1}{h_o} \quad \frac{h_i / R_S}{h / R_S} \quad \frac{1}{h_o}$

59.23. 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

59.24. Approximate Hybrid Formulas

The approximate hybrid formulas for the three connections are listed below. These are applicable when h_o and h_r are 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

59.25. Common Emitter *h*-parameter Analysis

The *h*-parameter equivalent of the *CE* circuit of Fig. 59.59 (*a*) is shown in Fig. 59.59 (*b*). In Fig. 59.59 (*a*), no emitter resistor has been connected.

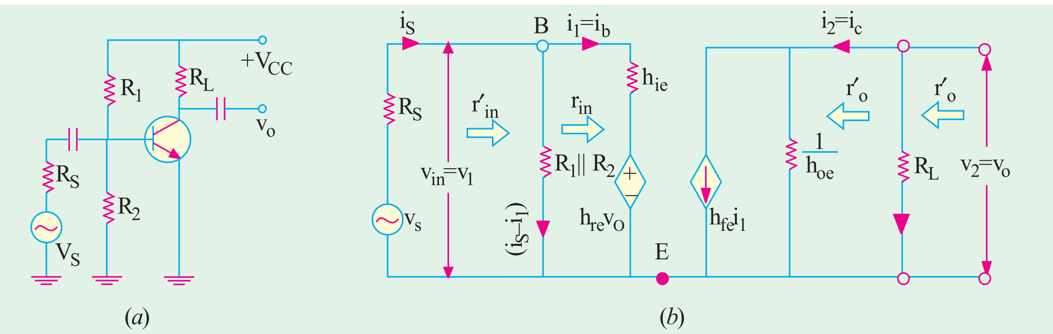

Fig. 59.59

However, Fig. 59.60 shows the *CE* circuit with an emitter resistor R_E.

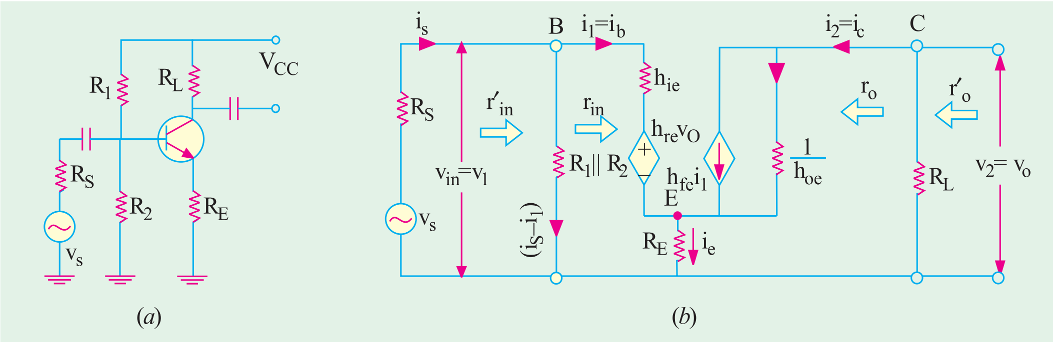

Fig. 59.60

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

1. Input Impedance

When looking into the base-emitter terminals of the transistor, h_{ie} is in series with h_{re} no. For a *CE* circuit, h_{re} is very small so that $h_{re}\, v_0$ is negligible as compared to the drop over h_{ie}. Hence, $r_{in} \cong h_{ie}$.

Now, consider the circuit of Fig. 59.60. Again ignoring $h_{re} v_o$, we have

$$v_1 = h_{ie} i_b + i_e R_E = h_{ie}\, i_b + (i_b + i)\, R_E$$

$$= h_{ie} i_b + i_b\, R_E + h_{fe}\, i_b\, R_E \qquad ((\quad i_c \quad h_{fe} i_b)$$

$$= i_b\, [h_{ie} + R_E\, (1 + h_{fe})]$$

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

r_{in} 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. 59.59 (*b*), $r_o \cong 1/h_{oe}$.

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

$$A_v \quad \frac{v_2}{v_1} \quad \frac{v_o}{v_{in}} \qquad \text{– Fig. 9.59 } (b)$$

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

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

Now, consider Fig. 59.60 (*b*). Ignoring $h_{re}\, v_o$, we have from the input loop of the circuit

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

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

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

* The above result could also be obtained by applying β-rule (Art. 9..24)

In general,

4. Current Gain

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

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

5. Power Gain

$$A_p = A_v \times A_i$$

59.26. Common Collector *h*-parameter Analysis

The *CC* transistor circuit and its *h*-parameter equivalent are shown in Fig. 59.61.

One can make quick approximations of *CC* gains and impedance if one remembers that $h_{re} = 1$ *i.e.* all of v_o is fed back to the input (Art. 59.23).

1. Input Impedance

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

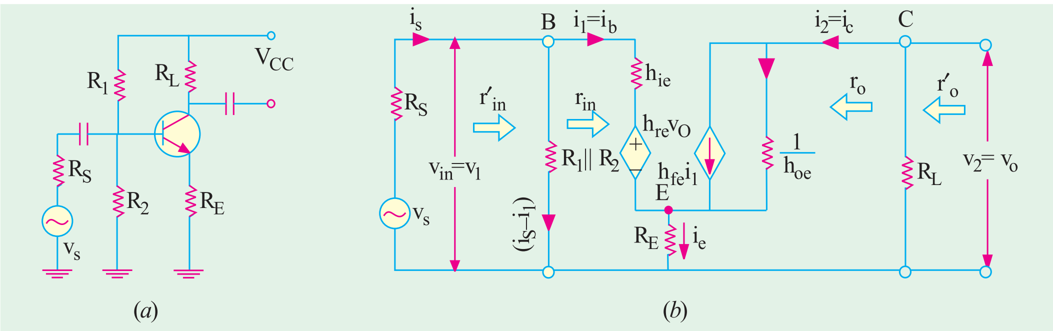

Fig. 59.61

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

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

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

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

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

Hence, considering the input circuit loop, we get

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

$$i_c \quad h_{fc} i_b \quad \frac{h_{fc} v_o}{h_{ic} \quad (R_S || R_B)}$$ where $R_B = R_1 || R_2$

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

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

3. Voltage Gain

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

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

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

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

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 $R_B = R_1 \| R_2$

59.27. Conversion of *h*-parameters

Transistor data sheets generally specify the transistor in terms of its *h*-parameters for *CB* connection *i.e.* h_{ib}, h_{fb}, h_{rb} and h_{ob}. If we want to use the transistor in *CE* or *CC* configuration we will have to convert the given set of parameters into a set of *CE* or *CC* parameters. Approximate conversion formulae are tabulated over leaf :

Table No. 59.2

From CB to CE	*From CE to CB*	*From CE to CC*
$h_{ie} \quad \frac{h_{ib}}{1 \quad h_{fb}}$	$h_{ie} \quad \frac{h_{ie}}{1 \quad h_{fe}}$	$h_{ic} = h_{ic}$
$h_{oe} \quad \frac{h_{ob}}{1 \quad h_{fb}}$	$h_{ob} \quad \frac{h_{oe}}{1 \quad h_{fe}}$	$h_{oc} = h_{oe}$
$h_{fe} \quad \frac{h_{fb}}{1 \quad h_{fb}}$	$h_{fb} \quad \frac{h_{fe}}{1 \quad h_{fe}}$	$h_{fe} = -(1 + h_{fe})$
$h_{re} \quad \frac{h_{ib} h_{ob}}{1 \quad h_{fb}} \quad h_{rb}$	$h_{rb} \quad \frac{h_{ie} h_{oe}}{1 \quad h_{fe}} \quad h_{re}$	$h_{re} = 1 - h_{re} \cong 1$

Example. 59.18. *A transistor used in CB circuit has the following set of parameters.*

$h_{ib} = 36\ \Omega$, $h_{fb} = 0.98$, $h_{rb} = 5 \times 10^{-4}$, $h_{ob} = 10^{-6}$ *Siemens*

With $R_S = 2$ *K and* $R_C = 10$ *K, calculate* **(*i*)** $r_{in(base)}$ **(*ii*)** r_{out} **(*iii*)** A_i and **(*iv*)** A_v.

(Applied Electronics-I; Punjab Univ. 1991)

Solution. Approximate Values

(*i*) $r_{in} = h_{ib} = 36\ \Omega$ **(*ii*)** $r_o \quad \frac{1}{h_{ob}} \quad \frac{1}{10 \quad 6} \quad$ **1M**

(*iii*) $A_i = h_{fb} =$ **– 0.98** **(*iv*)** $A_v \quad \frac{h_{fb}}{h_{ib}} \quad R_C \quad \frac{0.98}{36} \quad 10\text{K}$ **272**

More Accurate Values

(*i*) $r_{in(base)} \quad h_{ib} \quad \frac{h_{rb}h_{fb}}{h_{ob} \quad 1/r_L}$ —Art 9.22

$$= 36 \quad \frac{0.98 \quad 5 \quad 10^{\quad 4}}{10^{\quad 6} \quad 1/10 \quad 10^3}$$ (∴ $r_L = R_C$ since there is no R_L)

$= 36 + 4.9 =$ **40.9 Ω**

It is the input resistance at transistor terminals.

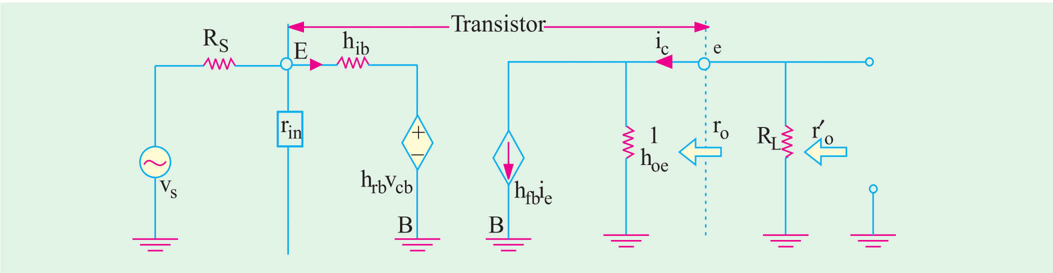

Fig. 59.62

(*ii*) $r_o \quad \frac{h_{ib} \quad R_s}{h_o(h_{ib} \quad R_S) \quad h_{fb}.h_{rb}} \quad \frac{36 \quad 2000}{10^{\quad 6}(36 \quad 2000) \quad (\quad 0.98) \quad 5 \quad 10^{\quad 4}}$ **0.8 M**

It is the output resistance at transistor terminals.

(*iii*) $A_i \quad \frac{h_{fb}}{1 \quad h_{ob}r_L} \quad \frac{0.98}{1 \quad 10^{\quad 6} \quad 10^4}$ **–0.97**

(*iv*) $A_v \quad \frac{h_{fb}r_L}{h_{ib}(1 \quad h_{ob}r_L) \quad h_{fb}\,h_{rb}.r_L}$ ($r_L \quad R_L$)

Here, ac load $r_L = R_L = 10$ K = 104 Ω

$$\therefore \quad A_v \quad \frac{(\quad 0.98) \quad 10^4}{36(1 \quad 10^{\quad 6} \quad 10^4) \quad (\quad 0.98) \quad 5 \quad 10^{\quad 4} \quad 10^4}$$ **249**

Example 59.19. *A transistor used in CE connection (Fig. 59.63) has the following set of h-parameters : h_{ir} = 1 K, h_{fe} = 100, h_{re} = 5 ×10^{-4} and h_{oc} = 2 × 10^{-5} S. With R_S = 2 K and R_C = 5 K, determine* **(*i*)** *r_{in}* **(*ii*)** *r_o* **(*iii*)** *A_i and* **(*iv*)** A_v

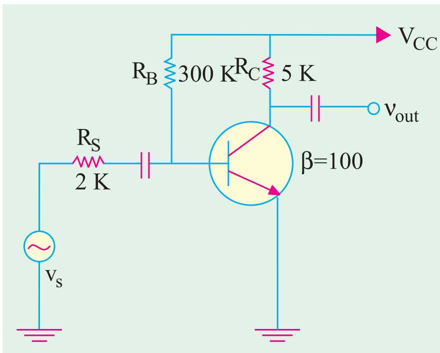

Fig. 59.63

Solution.

(*i*) $r_{in} \quad h_{ie} \quad \frac{h_{fb}r_L}{h_o \quad 1/r_L}$

$$= 1000 \quad \frac{5 \quad 10^{\quad 4} \quad 100}{2 \quad 10^{\quad 5} \quad 1/5 \quad 10^3}$$

= **723 Ω**

(*ii*) $r_o \quad \frac{h_{ie} \quad R_s}{(h_{ie} \quad R_s)h_{oe} \quad h_{fe}.h_{re}} \quad \frac{1000 \quad 2000}{(1000 \quad 2000) \quad 10^{\quad 5} \quad 100 \quad 5 \quad 10^{\quad 4}}$

$= 30{,}000\Omega =$ **0.03 M**

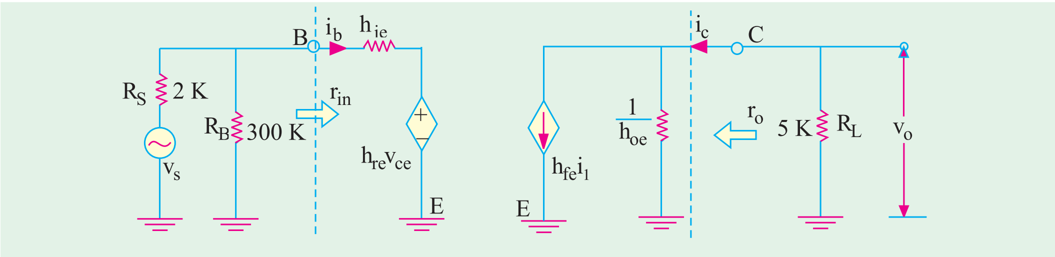

Fig. 59.64

(iii) $A_i \quad \frac{h_{fe}}{1 \quad h_{oe}r_L} \quad \frac{100}{1 \quad 2 \quad 10^{\;5} \quad 5 \quad 10^3}$ **91**

(iv) $A_i \quad \frac{h_{fe}r_L}{(h_{ie} \quad R_s)\,(1 \quad h_{oe}.r_L) \quad h_{fe}h_{re}r_L}$

$$\frac{100 \quad 5 \quad 10^3}{(100 \quad 2000)\,(1 \quad 2 \quad 10^{\;5} \quad 5 \quad 10^3) \quad 100 \quad 5 \quad 10^{\;4} \quad 5 \quad 10^3}$$ **–164**

The negative sign indicates that there is 180° phase shift between the input and output ac signals. Obviously, it is the overall (or circuit) voltage gain and not the voltage gain of the transistor alone.

Example 59.20. *In the CE circuit shown in Fig. 59.65, the transistor parameters are* :

$h_{ie}=2$ K, $h_{fe}=100$, $h_{re} = 5 \times 10^{-4}$, $h_{oe} = 2 \times 10^{-5}$ S

Calculate **(i)** $r_{in(base)}$, **(ii)** $r_{in(stage)}$, **(iii)** r_o, **(iv)** $r_{o(stage)}$, **(v)** A_i and **(vi)** A_v.

(Electronics–1, Karnataka Univ.)

Solution. The hybrid equivalent circuit is shown in Fig. 59.66. We will use the approximate formulas given in Art. 59.24.

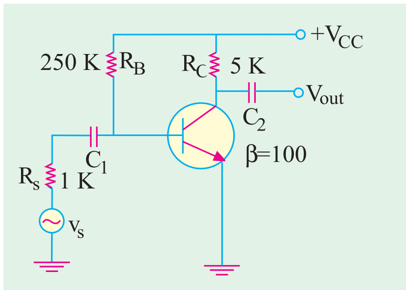

Fig. 59.65

(i) $r_{in(base)} = h_{ie}$ = **2K**

(ii) $r_{in(stage)}$ = 2 K || 250 K = **1.98 K**

(iii) $r_o = 1 / h_{oe} = 1/2 \times 10^{-5}$ = **50 K**

It is the output impedance of the transistor only.

(iv) $r_{o(stage)} = r_o{'}$ = 50 K || 5 K = **4.54 K**

The impedance takes into account the collector load.

(v) $A_i \cong h_{fe} = 100$

(vi) $A_v \quad \frac{h_{fe}r_L}{h_{ie}} \quad \frac{100 \quad 5}{2}$ **–250**

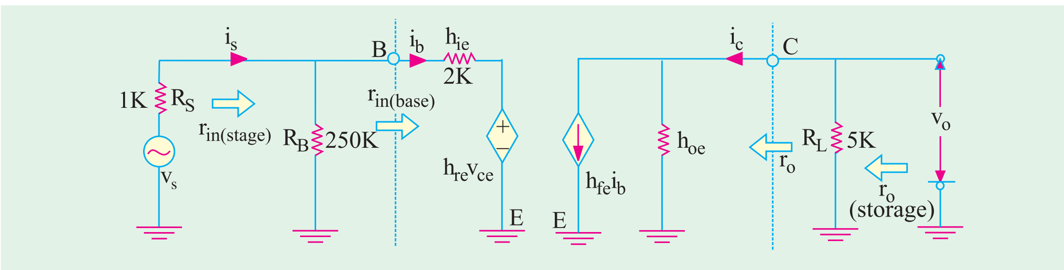

Fig. 59.66

Example 59.21. *Determine the various gains of the circuit of Fig. 59.67 if an emitter resistance of 0.5 K is included in the circuit.* **(Applied Electronics, Punjab Univ. 1991)**

Solution. The *CE* circuit with R_E included is shown in Fig. 59.47. Different performance characteristics of the circuit are as under :

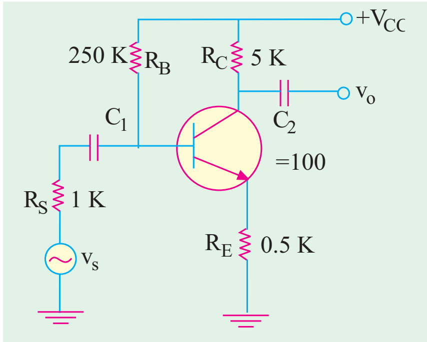

Fig. 59.67

(i) $r_{in(base)}$ h_{ie} (1) R_E

$= 2 + 101 \times 0.5 =$ **52.5 K**

(ii) $r_{in(stage)} = R_B \| r_{in} = 250 \| 52.5$

= **43.3K**

(iii) $r_o = 1/h_{oe} =$ **50 K**

(iv) $r_{o(stage)} = r_o' = 50\text{ K} \| 5\text{ K}$

= **4.54 K**

(v) $A_v = h_{fe} =$ **100**

(vi) A_v $\dfrac{h_{fe} r_L}{h_{ie} \quad (1 \quad) R_E}$ $\dfrac{100 \quad 5}{2 \quad 50.5}$ **–9.5**

The value is reduced from 250 to 9.5.

Example 59.22. *The transistor of Fig. 59.68 has the following set of h-parameters :*

$h_{ie} = 2\text{K}$, $h_{fe} = 50$, $h_{rs} = 4 \times 10^{-4}$, $h_{oe} = 25 \times 10^{-6}$ *Siemens*

Determine **(i)** $r_{in(base)}$ **(ii)** $r_{in(base)}$ **(iii)** r_o **(iv)** $r_{o(stage)}$ and **(v)** A_v.

(Electronics-I, Patna Univ. 1991)

Solution. we will use the formula derived in Art. 59.25.

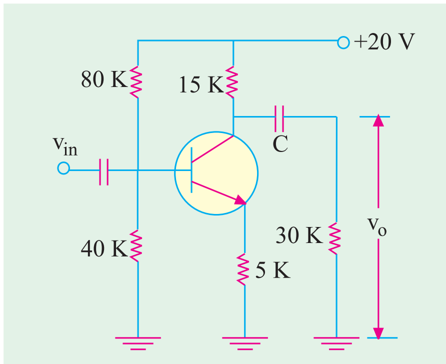

Fig. 59.68

(i) $r_{in(base)}$ h_{ie} (1 h_{fe}) R_E 2 (1 50) 5

= **257 K**

(ii) $r_{in(stage)} = r_{in(base)} \| R_1 \| R_2 = 257 \| 80 \| 40$

= **24 K**

(iii) $r_o = 1/h_{oe} = 1/25 \times 10^{-6} =$ **40 K**

(iv) $r_{o(stage)}$ $= r_o \| r_L$ where $r_L = 15\text{ K} \| 30\text{ K}$

$= 10\text{ K} = 40\text{ K} \| 10 =$ **8 K**

(v) A_v $\dfrac{h_{fe} R_L}{h_{ie} \quad (1 \quad h_{fe}) R_E}$

$\dfrac{50 \quad 10}{257}$ **–2.9**

Example 59.23. *Draw a hybrid small-signal model for a transistor in CE configuration.*

A single source with an open circuit voltage of 1 mV and internal impedance of 600 W is connected to the input of transistor AC 125 in CE configuration. The small-signal parameters measured at $V_{CB} = -5$ *V and* $I_E = 2$ *mA, are as follows :*

$h_{ie} = 1.7$ K, $h_{re} = 6.5 \times 10^{-4}$, $h_{fe} = 125$, $h_{oe} = 80$ µS.

Calculate the input and output impedances and signal amplification for a load of 5.6 K. Also, find the value of the signal voltage at the output. **(Electronics-I, Gwalior Univ.)**

Solution. $\Delta h = 1.7 \times 10^3 \times 80 \times 10^{-6} - 125 \times 6.5 \times 10^{-4} = 0.055$

(i) r_{in} $\dfrac{h_{ie} \quad h.R_L}{1 \quad h_{oe} R_L}$ $\dfrac{1700 \quad 5.6 \quad 10^3 \quad 55 \quad 10^{\ 3}}{1 \quad 80 \quad 10^{\ 6} \quad 5.6 \quad 10^3}$ –Art. 59.22

(*ii*) $r_o \quad \dfrac{h_{ie} \quad R_S}{h_{oe}\, R_S \qquad h} \quad \dfrac{1700 \quad 600}{80 \quad 10^{\;6} \quad 600 \quad 0.055} \quad \dfrac{2300}{0.103}$ **22.3 K**

(*iii*) $A_v \quad \dfrac{h_{fe} R_L}{h_{ie} \quad R_L \cdot \ h} \quad \dfrac{125 \quad 5600}{1700 \quad 308}$ **–348.6**

The negative sign merely indicates that there is phase reversal of 180° between the output and input voltages.

Now, 1 mV signal voltage is divided between r_{in} and R_S. The input voltage v_{in} is that which drops over $r_{in} = 1 \times r_{in}/(r_{in} + R_S) = 1 \times 1387/(1387 + 600) = 0.698$ mV

∴ output voltage = –348.6 × 0.698 = **–243.3 mV.**

Example 59.24. *The transistor of Fig. 59.69 has the following set of h-parameters :*

$$h_{ie} = 2\text{ K},\ h_{fe} = 100,\ h_{re} = 5 \times 10^{-4},\ h_{oe} = 2.5 \times 10^{-5}\text{ S}$$

Find the voltage gain and the ac impedance of the stage.

(Electronics-II, Bombay Univ. 1992)

Solution. Using somewhat exact formulas given in Art. 59.22, we have

$$r_{in(base)} \quad h_{ie} \quad \frac{h_{fe} h_{re}}{h_{oe} \quad 1/r_L}$$

Now, collector load

r_L = 10 K || 30 K = 7.5 K

$$\therefore \quad r_{in(base)} \quad 200 \quad \frac{100 \quad 5 \quad 10^{\;4}}{2.5 \quad 10^{\;5} \quad 1/7.5 \quad 10^3}$$

=2000 – 316 = **1684 Ω**

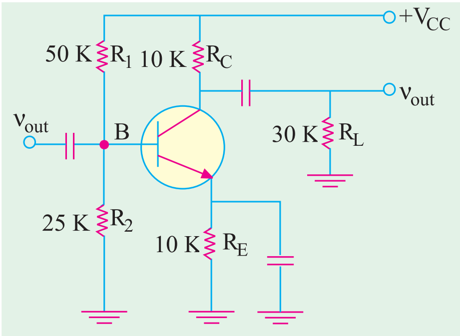

Fig. 59.69

The ac input impedance of the stage *i.e.* impedance when looking into point *B* is

$r_{in(base)} = r_{\text{in(base)}} \,||\, R_1 \,||\, R_2 = 1.684 \,||\, 50 \,||\, 25$ = **1.53K**

$$A_v \quad \frac{h_{fe}}{r_{in(base)}\,(h_{oe} \quad 1/r_L)} \qquad \text{Now,} \quad r_L = 10\text{ K} \,||\, 30\text{ K} = 7.5\text{ K}$$

$$\therefore \quad A_v \quad \frac{100}{0184\,(2.5 \quad 10^{\;5} \quad 1/7500)} \quad \mathbf{-\,375}$$

Obviously, R_E does not come into the ac picture because it is ac grounded by the bypass capacitor.

Example 59.25. *In the CC circuit of Fig. 59.70, the transistor parameter are h_{ic} = 2K and h_{fc} = 100. Calculate the circuit input and output impedance and voltage, current and power gains.*

(Electronic Technology, Bangalore Univ.)

Solution. $r_{in} \cong h_{ic} + h_{fe} R_L = 2 + 100 \times 5 =$ **502 K**

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

= 10 || 10 || 502 = **4.95 K**

$$r_o \quad \frac{h_{ie} \quad (R_s \,||\, R_1 \,||\, R_2)}{h_{fe}}$$

$$\frac{2 \quad (1 \,||\, 10 \,||\, 100)}{100} \quad \mathbf{28.3\ \Omega}$$

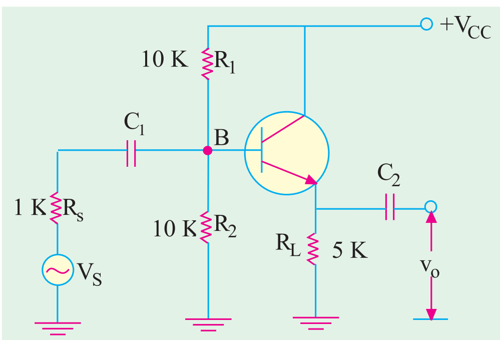

Fig. 59.70

$r_{o(stage)} = r_o \,||\, R_L = 28.3\ \Omega \,||\, 5K$

$= \mathbf{28.1\Omega}$

$A_v \cong 1$ and $A_i = h_{fe} = 100$

Example 59.26. *A transistor with h_{ie} = 1.5 K and h_{fe} = 75 is used in an emitter follower circuit where resistances R_1 and R_2 are used for normal biasing. Calculate **(i)** A_i **(ii)** r_{in} **(iii)** r_o and **(iv)** A_v if R_E = 860 Ω, $R_1 \,||\, R_2$ = 20K and R_S = 1K.* **(Electronic Engg.; Indore Univ. 1992)**

Solution. Let us first convert the given *CE* values of *h*-parameters into their equivalent *CC* values with the help of Table No. 59.2. It is seen that $h_{ic} = h_{ie}$ = 1.5 K and $h_{fc} = (1 + h_{fe})$ = 76.

(i) $A_i = h_{fe} = 76$ *(ii)* $r_{in} = h_{ic} + h_{fc} R_L = 1.5 + 76 \times 0.860 =$ **66.9 K**

(iii) $r_o \quad \frac{h_{ic} \quad (R_s \,||\, R_1 \,||\, R_2)}{h_{fe}} \quad \frac{1.5 \quad 1 \,||\, 20}{76}$ **32.3 Ω** *(iv)* $A_v \cong 1$

Tutorial Problems No. 59.1

1. Using ideal transistor approximations for the single-stage *CB* amplifier of Fig. 59.71, find (*i*) stage r_{in} (*ii*) r_L (*iii*) Avand (*iv*) A_p. Take transistor α = –0.99.
[(*i*) 25 Ω (*ii*) 10 K (*iii*) 400 (*iv*) 396]

2. For the single-stage *CB* amplifier circuit shown in Fig. 59.72, find (*i*) r_{in} (*ii*) r_L (*iii*) A_v and (*iv*) A_p

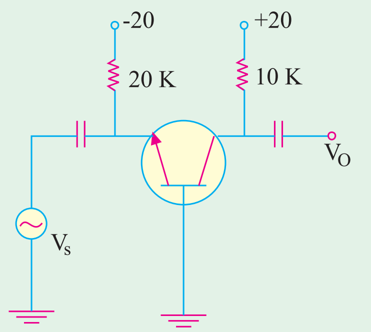

Fig. 59.71

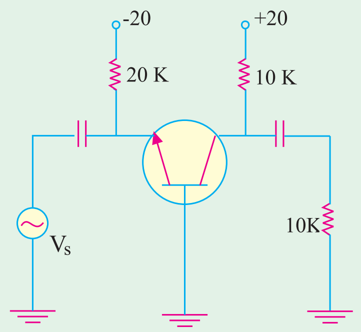

Fig. 59.72

Transistor α = –0.9. Take G_e transistor material. **[(*i*) 25 Ω (*ii*) 5 K (*iii*) 200 (*iv*) 196]**

3. For the *CB* amplifier circuit of Fig. 59.73, find approximate values of

(i) stage r_{in}
(ii) r_L
(iii) $A_v = v_{out} / v_{in}$
(iv) $A_{v\sigma} = v_{out} / v_s$
(v) A_p
(vi) G_p

Take transistor α = –0.98
[(*i*) 25 Ω (*ii*) 5K (*iii*) 200 (*iv*) 22.2 (*v*) 196 (*vi*) 22.9 dB]

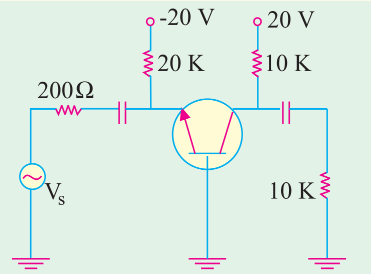

Fig. 59.73

4. Find r_{in}, r_L, A_i, A_v and G_p for the *CE* amplifier shown in Fig. 9.74.
[(*i*) 1250 Ω (*ii*) 5K (*iii*) 50 (*iv*) 200 (*v*) 30 dB]

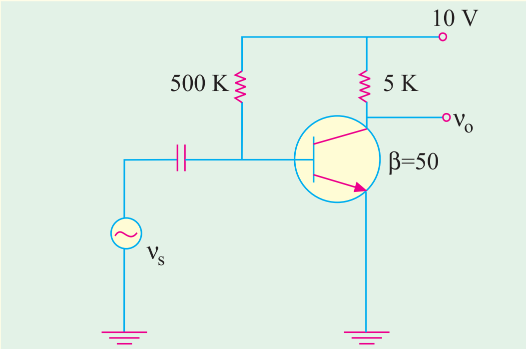

Fig. 59.74

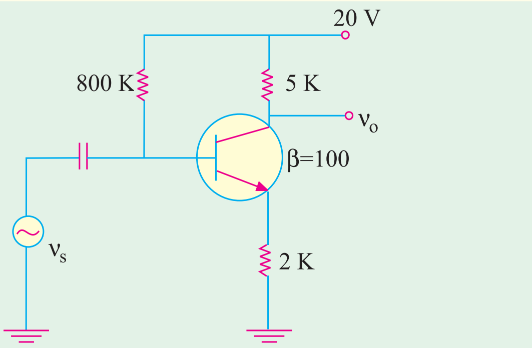

Fig. 59.75

5. For the single-stage *CE* amplifier circuit of Fig. 59.75, find
(*i*) r_{in} (*ii*) r_L (*iii*) A_v (*iv*) A_p and (*v*) G_p
Take β = 100 and use $r_e = 50 \text{ mV}/I_E$. **[(*i*) 160 K (*ii*) 5K (*iii*) 2.5 (*iv*) 250 (*v*) 24 dB]**

6. For the C_E amplifier of Fig. 59.76, find approximate values of
(*i*) r_{in} (*ii*) r_L (*iii*) A_v (*iv*) A_p and G_p.
Take transistor β = 50 and use $r_e = 50 \text{ mV}/I_E$. **[(*i*) 2K (*ii*) 10K (*iii*) 200 (*iv*) 10,000 (*v*) 40 dB]**

7. For the emitter follower circuit shown in Fig. 59.77, find
(*i*) $r_{in(base)}$ (*ii*) $r_{in(stage)}$
(*iii*) stage A_v (*iv*) A_p in decibles
Take β = 100 and use $r_e = 25 \text{ mV}/I_E$. **[(*i*) 10K (*ii*) 9.52K (*iii*) 0.75 (*iv*) 18.75 dB]**

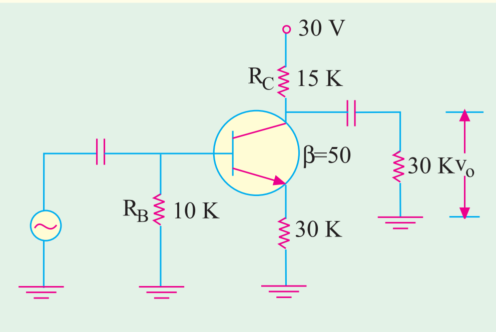

Fig. 59.76

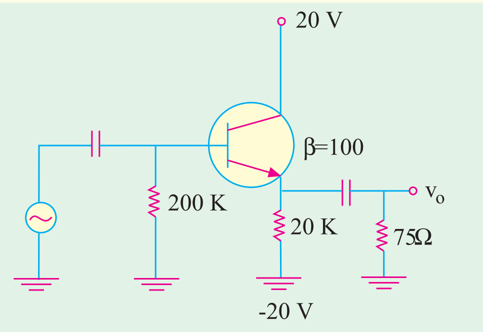

Fig. 59.77

8. An *NPN* silicon transistor is connected as a C_E amplifier with load R_L and a source resistance R_S. The *h*-parameters are :
$h_{ie} = 1.1$ K, $h_{re} = 2.5 \times 10^{-4}$, $h_{fe} = 50$ and $h_{oe} = 25$ μS
If $R_L = 10$K and $R_S = 1$K, find the various gains and input and output impedances.
Derive the relations used.
[$A_i = 40$, $A_{is} = 20$, $r_{in} = 1K$, $A_v = -400$, $A_{vs} = -200$, $r_o = 52.5$ K, $A_p = 16{,}000$, $G_p = 42$ dB]

9. Calculate the gain of a common-emitter transistor amplifier whose hybrid parameters are:
$h_{ie} = 1100$ ohms, $h_{re} = 2.5 \times 10^{-4}$; $h_{fe} = 50$, $h_{oe} = 25$ μS, $R_L = 5$K.
Derive any formula used. ***(–213) (Electronic Engg., Indore Univ.)***

10. A *CE* amplifier has $h_{ie} = 1.1$ K, $h_{fe} = 50$, $h_{re} = 2.5 \times 10^{-4}$; $h_{oe} = 25$ μS, $R_S = R_L = 500$ ohm. Calculate the output impedance and voltage gain.
(Applied Electronics-I, Punjab Univ. Dec.)

11. A junction transistor has the following *h*-parameters $h_{ie} = 2000$ ohm, $h_{re} = 15 \times 10^{-4}$, $h_{fe} = 49$, $h_{oe} = 50$ μS. Determine the current gain, voltage gain, input resistance and output resistance of the *CE* amplifier if the load resistance is 10K and source resistance is 600 ohm. Derive the expressions used.

(Applied Electronics-1, Punjab May)

12. A *CE* amplifier has h_{ie} = 1.1 K, h_{fe} = 50, h_{re} = 2.5 × 10^{-4}, h_{oe} = 25 μS, R_S = R_L = 1K. Calculate the output impedance and voltage gain.

(Applied Electronics-1, Punjab Univ. Dec.)

13. A junction transistor has the following *h*-parameters h_{ie} = 1kW, h_{re} = 1, h_{fe} = –50, h_{oe} = 25mA/V. This transistor is connected to a source of internal resistance 600 ohm and a load of 40 kΩ. Calculate the current gain, voltage gain, input resistance and output resistance of the amplifier. Derive the expressions used.

(Applied Electronics-I, Punjab Univ. June)

14. A transistor connected in CE configuration has following *h*-parameters.

h_{ie} = 1.1 kΩ	h_{re} = 2.5 × 10^{-4}
h_{fe} = 50	h_{oe} = 25 μ Siemens
and	r_s = r_L = 1 kΩ

Calculated current gain, input impedance and voltage gain.

(Electronics Engg. Bangalore Univ. 2001)

OBJECTIVE TESTS – 59

1. In an ac amplifier, larger the internal resistance of the ac signal source
(*a*) greater the overall voltage gain
(*b*) greater the input impedance
(*c*) smaller the current gain
(*d*) smaller the circuit voltage gain.

2. The main use of an emitter follower is as
(*a*) power amplifier
(*b*) impedance matching device
(*c*) low-input impedance circuit
(*d*) follower of base signal.

3. An ideal amplifier is one which
(*a*) has infinite voltage gain
(*b*) responds only to signals at its input terminals
(*c*) has positive feeback
(*d*) gives uniform frequency response.

4. The smallest of the four *h*-parameters of a transistor is
(*a*) h_i (*b*) h_r (*c*) h_o (*d*) h_f

5. The voltage gain of a single-stage *CE* amplifier is increased when
(*a*) its ac load is decreased
(*b*) resistance of signal source is increased
(*c*) emitter resistance R_E is increased.
(*d*) ac load resistance is increased.

6. When emitter bypass capacitor in a *CE* amplifier is removed, its .... is considerably reduced.
(*a*) input resistance
(*b*) output load resistance
(*c*) emitter current
(*d*) voltage gain

7. Unique features of a *CC* amplifier circuit is that it
(*a*) steps up the impedance level
(*b*) does not increase signal voltage
(*c*) acts as an impedance matching device
(*d*) all of the above.

8. The input impedance h_{11} of a network with output shorted is given by the ratio
(*a*) v_1/i_1 (*b*) v_1 / v_2
(*c*) i_2 / i_1 (*d*) i_2 / v_2

9. The *h*-parameters of a transistor depend on its
(*a*) configuration
(*b*) operating point
(*c*) temperature
(*d*) all of the above

10. The output admittance h_0 of an ideal transistor connected in *CB* configuration is .... siemens.
(*a*) 0 (*b*) 1/r
(*c*) $1/\beta r_e$ (*d*) –1.

11. A transistor has h_{fe} = 100, h_{ie} = 5.2 K Ω, and r_{bb} = 0. At room temperature, V_T = 26 mV, the collector current, | I_C | will be.
(*a*) 10 mA (*b*) 5 mA
(*c*) 1 mA (*d*) 0.5 mA

ANSWERS

1. (*d*) **2.** (*b*) **3.** (*b*) **4.** (*c*) **5.** (*d*) **6.** (*d*) **7.** (*d*) **8.** (*a*) **9.** (*d*) **10.** (*a*) **11.** (*a*)

ROUGH WORK