10

Single Stage Transistor Amplifiers

INTRODUCTION

In the previous chapter, it was discussed that a properly biased transistor raises the strength of a weak signal and thus acts as an amplifier. Almost all electronic equipments must include means for amplifying electrical signals. For instance, radio receivers amplify very weak signals—sometimes a few millionth of a volt at antenna–until they are strong enough to fill a room with sound. The transducers used in the medical and scientific investigations generate signals in the microvolt (μV) and millivolt (mV) range. These signals must be amplified thousands and millions times before they will be strong enough to operate indicating instruments. Therefore, electronic amplifiers are a constant and important ingredient of electronic systems.

Our purpose here will be to discuss *single stage transistor amplifier*. By a *stage* we mean a single transistor with its bias and auxiliary equipment. It may be emphasised here that a practical amplifier is always a multistage amplifier *i.e.* it has a number of stages of amplification. However, it is profitable to consider the multistage amplifier in terms of single stages that are connected together. In this chapter, we shall confine our attention to single stage transistor amplifiers.

10.1 Single Stage Transistor Amplifier

When only one transistor with associated circuitry is used for amplifying a weak signal, the circuit is known as **single stage transistor amplifier.**

A single stage transistor amplifier has one transistor, bias circuit and other auxiliary components. Although a practical amplifier consists of a number of stages, yet such a complex circuit can be conveniently split up into separate single stages. By analysing carefully only a single stage and using this single stage analysis repeatedly, we can effectively analyse the complex circuit. It follows, therefore, that single stage amplifier analysis is of great value in understanding the practical amplifier circuits.
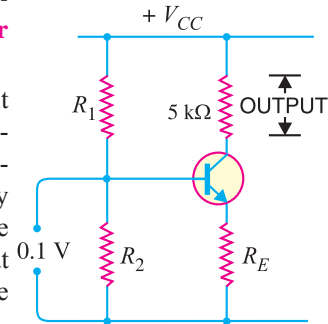

Fig. 10.1

10.2 How Transistor Amplifies ?

Fig. 10.1 shows a single stage transistor amplifier. When a weak a.c. signal is given to the base of transistor, a small base current (which is a.c.) starts flowing. Due to transistor action, a much larger (β times the base current) a.c. current flows through the collector load R_C. As the value of R_C is quite high (usually 4-10 kΩ), therefore, a large voltage appears across R_C. Thus, a weak signal applied in the base circuit appears in amplified form in the collector circuit. It is in this way that a transistor acts as an amplifier.

The action of transistor amplifier can be beautifully explained by referring to Fig. 10.1. Suppose a change of 0.1V in signal voltage produces a change of 2 mA in the collector current. Obviously, a signal of only 0.1V applied to the base will give an output voltage = 2 mA × 5 kΩ = 10V. Thus, the transistor has been able to raise the voltage level of the signal from 0.1V to 10V *i.e.* voltage amplification or stage gain is 100.

10.3 Graphical Demonstration of Transistor Amplifier

The function of transistor as an amplifier can also be explained graphically. Fig. 10.2 shows the output characteristics of a transistor in *CE* configuration. Suppose the zero signal base current is 10 μA *i.e.* this is the base current for which the transistor is biased by the biasing network. When an a.c. signal is applied to the base, it makes the base, say positive in the first half-cycle and negative in the second half-cycle. Therefore, the base and collector currents will increase in the first half-cycle when base-emitter junction is more forward-biased. However, they will decrease in the second half-cycle when the base-emitter junction is less forward biased.
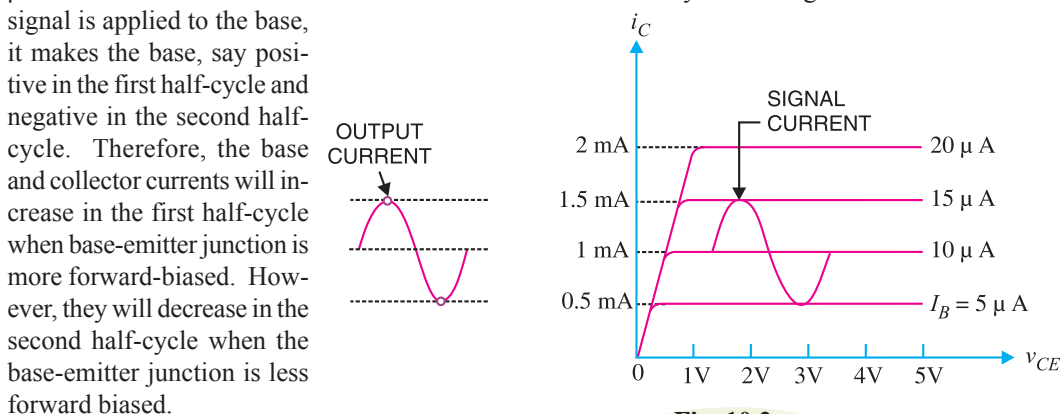
Fig. 10.2

For example, consider a sinusoidal signal which increases or decreases the base current by 5 µA in the two half-cycles of the signal. Referring to Fig. 10.2, it is clear that in the absence of signal, the base current is 10µA and the collector current is 1 mA. However, when the signal is applied in the base circuit, the base current and hence collector current change continuously. In the first half-cycle peak of the signal, the base current increases to 15 µA and the corresponding collector current is 1.5 mA. In the second half-cycle peak, the base current is reduced to 5 µA and the corresponding collector current is 0.5 mA. For other values of the signal, the collector current is inbetween these values *i.e.* 1.5 mA and 0.5 mA.

It is clear from Fig. 10.2 that 10 µA base current variation results in 1mA (1,000 µA) collector current variation *i.e.* by a factor of 100. This large change in collector current flows through collector resistance R_C. The result is that output signal is much larger than the input signal. Thus, the transistor has done amplification.

10.4 Practical Circuit of Transistor Amplifier

It is important to note that a transistor can accomplish faithful amplification only if proper associated circuitry is used with it. Fig. 10.3 shows a practical single stage transistor amplifier. The various circuit elements and their functions are described below :

(*i*) **Biasing circuit.** The resistances R_1, R_2 and R_E form the biasing and stabilisation circuit. The biasing circuit must establish a proper operating point otherwise a part of the negative half-cycle of the signal may be cut off in the output.

(*ii*) **Input capacitor C_{in}.** An electrolytic capacitor C_{in} ($\simeq 10$ µF) is used to couple the signal to the base of the transistor. If it is not used, the signal source resistance will come across R_2 and thus change the bias. The capacitor C_{in} allows only a.c. signal to flow but isolates the signal source from R_2.*
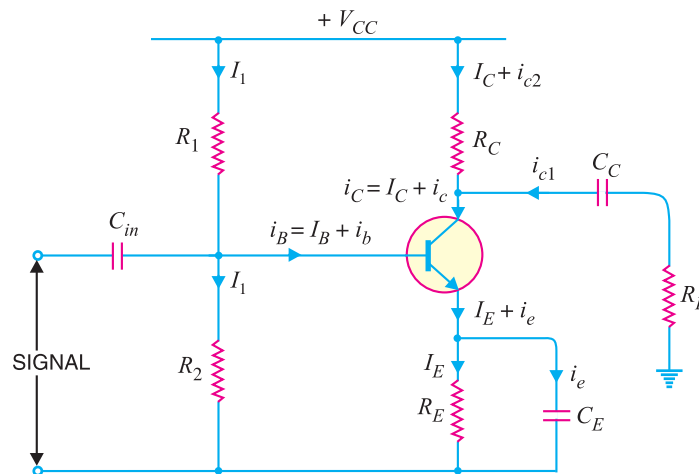

Fig. 10.3

(*iii*) **Emitter bypass capacitor C_E.** An emitter bypass capacitor C_E ($\simeq 100$µF) is used in parallel with R_E to provide a low reactance path to the amplified a.c. signal. If it is not used, then amplified a.c. signal flowing through R_E will cause a voltage drop across it, thereby reducing the output voltage.

(*iv*) **Coupling capacitor C_C.** The coupling capacitor C_C ($\simeq 10$µF) couples one stage of ampli-

* It may be noted that a capacitor offers infinite reactance to d.c. and blocks it completely whereas it allows a.c. to pass through it.

fication to the next stage. If it is not used, the bias conditions of the next stage will be drastically changed due to the shunting effect of R_C. This is because R_C will come in parallel with the upper resistance R_1 of the biasing network of the next stage, thereby altering the biasing conditions of the latter. In short, the coupling capacitor C_C isolates the d.c. of one stage from the next stage, but allows the passage of a.c. signal.

Various circuit currents. It is useful to mention the various currents in the complete amplifier circuit. These are shown in the circuit of Fig. 10.3.

(i) Base current. When no signal is applied in the base circuit, d.c. base current I_B flows due to biasing circuit. When a.c. signal is applied, a.c. base current i_b also flows. Therefore, with the application of signal, total base current i_B is given by:

$$i_B = I_B + i_b$$

(ii) Collector current. When no signal is applied, a d.c. collector current I_C flows due to biasing circuit. When a.c. signal is applied, a.c. collector current i_c also flows. Therefore, the total collector current i_C is given by:

$$i_C = I_C + i_c$$

where $\qquad I_C = \beta I_B = $ zero signal collector current

$$i_c = \beta i_b = \text{collector current due to signal.}$$

(iii) Emitter current. When no signal is applied, a d.c. emitter current I_E flows. With the application of signal, total emitter current i_E is given by :

$$i_E = I_E + i_e$$

It is useful to keep in mind that :

$$I_E = I_B + I_C$$
$$i_e = i_b + i_c$$

Now base current is usually very small, therefore, as a reasonable approximation,

$$I_E \simeq I_C \quad \text{and} \quad i_e \simeq i_c$$

Example 10.1. *What is the role of emitter bypass capacitor C_E in CE amplifier circuit shown in Fig. 10.3 ? Illustrate with a numerical example.*

Solution. The emitter bypass capacitor C_E (See Fig. 10.3) connected in parallel with R_E plays an important role in the circuit. If it is not used, the amplified a.c. signal flowing through R_E will cause a voltage drop across it, thereby reducing the a.c. output voltage and hence the voltage gain of the amplifier.

Let us illustrate the effect of C_E with a numerical example. Suppose $R_E = 1000\Omega$ and capacitive reactance of C_E at the signal frequency is 100Ω (*i.e.* $X_{C_E} = 100\Omega$). Then 10/11 of a.c emitter current will flow through C_E and only 1/11 through R_E. The signal voltage developed across R_E is, therefore, only 1/11 of the voltage which would have been developed if C_E were not present. In practical circuits, the value of C_E is so selected that it almost entirely bypasses the a.c. signal (the name for C_E is obvious). *For all practical purposes, we consider C_E to be a short for a.c. signals.*

Example 10.2. *Select a suitable value for the emitter bypass capacitor in Fig. 10.4 if the amplifier is to operate over a frequency range from 2 kHz to 10 kHz.*

Solution. An amplifier usually handles more than one frequency. Therefore, the value of C_E is so selected that it provides adequate bypassing for the *lowest* of all the frequencies. Then it will also be a good bypass ($X_C \propto 1/f$) for all the higher frequencies. Suppose the minimum frequency to be handled by C_E is f_{min}. Then C_E is considered a good bypass if at f_{min},
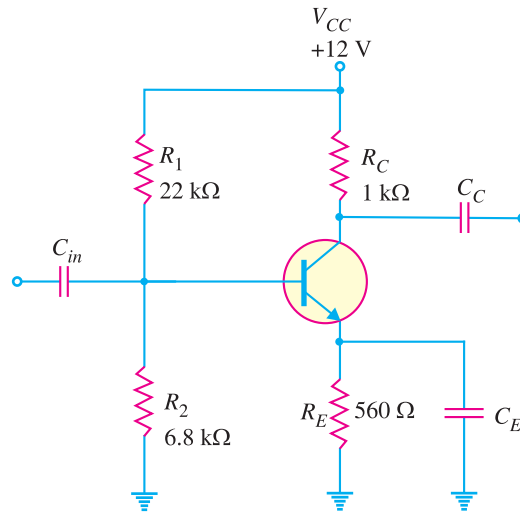
Fig. 10.4

$$X_{C_E} = \frac{R_E}{10}$$

In the given problem, $f_{min} = 2\text{kHz}$; $R_E = 560\Omega$.

$$\therefore \quad 10\ X_{C_E} = 560$$

or $$X_{C_E} = 560/10 = 56\Omega$$

or $$\frac{1}{2\pi\ f_{min}\ C_E} = 56$$

$$\therefore \quad C_E = \frac{1}{2\pi\ f_{min}\ 56} = \frac{1}{2\pi \times (2 \times 10^3) \times 56} = 1.42 \times 10^{-6}\ F = \textbf{1.42 μF}$$

Note. While discussing *CE* amplifier, the reader should be very particular about the role of C_E.

10.5 Phase Reversal

In common emitter connection, when the input signal voltage increases in the positive sense, the output voltage increases in the negative direction and *vice-versa*. In other words, there is a phase difference of 180° between the input and output voltage in *CE* connection. This is called phase reversal.*

The phase difference of 180° between the signal voltage and output voltage in a common emitter amplifier is known as **phase reversal.**

Consider a common emitter amplifier circuit shown in Fig. 10.5. The signal is fed at the input terminals (*i.e.* between base and emitter) and output is taken from collector and emitter end of supply. The total instantaneous output voltage v_{CE} is given by :

$$**v_{CE} = V_{CC} - i_C R_C \quad ...(i)$$

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* This is so if output is taken from collector and emitter end of supply as is always done. However, if the output is taken across R_C, it will be in phase with the input.

** Reactance of C_C (= 10μF) is negligible at ordinary signal frequencies. Therefore, it can be considered a short for the signal.
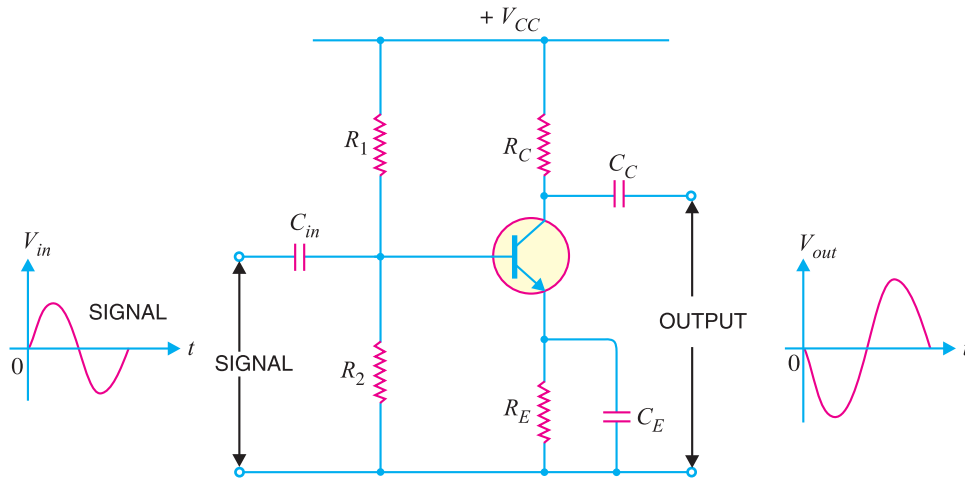
Fig. 10.5

When the signal voltage increases in the positive half-cycle, the base current also increases. The result is that collector current and hence voltage drop $i_C R_C$ increases. As V_{CC} is constant, therefore, output voltage v_{CE} decreases. In other words, as the signal voltage is increasing in the positive half-cycle, the output voltage is increasing in the negative sense *i.e.* output is 180° out of phase with the input. It follows, therefore, that in a common emitter amplifier, the positive half-cycle of the signal appears as amplified negative half-cycle in the output and *vice-versa*. It may be noted that amplification is not affected by this phase reversal.

The fact of phase reversal can be readily proved mathematically. Thus differentiating exp. (*i*), we get,

$$dv_{CE} = 0 - di_c R_C$$

or $$dv_{CE} = -di_c R_C$$

The negative sign shows that output voltage is 180° out of phase with the input signal voltage.

Graphical demonstration. The fact of phase reversal in *CE* connection can be shown graphically with the help of output characteristics and load line (See Fig. 10.6).

In Fig. 10.6, *AB* is the load line. The base current fluctuates between, say ± 5 µA with 10µA as the zero signal base current. From the figure, it is clear that when the base current is maximum in the positive direction, v_{CE} becomes maximum in the negative direction (*point G* in Fig. 10.6). On the other hand, when the base current is maximum in the negative direction, v_{CE} is maximum in the positive sense (*point H* in Fig. 10.6). Thus, the in-
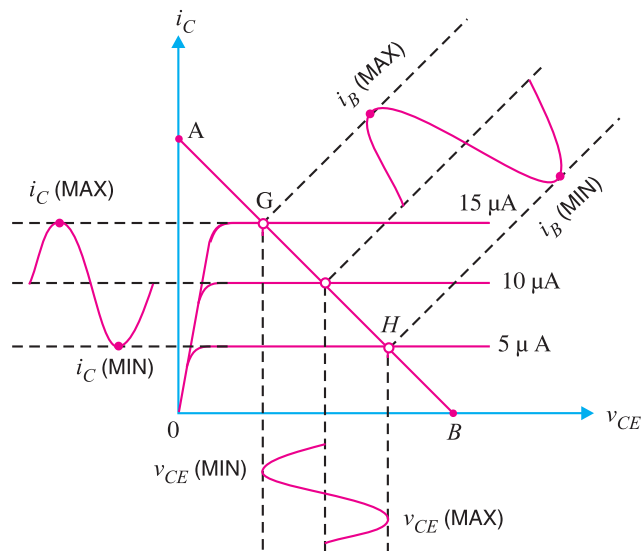

Fig. 10.6

put and output voltages are in *phase opposition* or equivalently, the transistor is said to produce a 180º phase reversal of output voltage *w.r.t.* signal voltage.

Note. No phase reversal of voltage occurs in common base and common collector amplifier. The a.c. output voltage is in phase with the a.c. input signal. For all three amplifier configurations; input and output currents are in phase.

Example 10.3. *Illustrate the phenomenon of phase reversal in CE amplifier assuming typical circuit values.*

Solution. In every type of amplifier, the input and output currents are in phase. However, common emitter amplifier has the unique property that input and output voltages are 180° out of phase, even though the input and output currents are in phase. This point is illustrated in Fig. 10.7. Here it is assumed that Q-point value of $I_B = 10$ µA, ac signal peak value is 5 µA and $\beta = 100$. This means that input current varies by 5 µA both above and below a 10 µA dc level. At any instant, the output current will be 100 times the input current at that instant. Thus when the input current is 10 µA, output current is $i_C = 100 \times 10$ µA = 1 mA. However, when the input current is 15 µA, then output current is $i_C = 100 \times 15$ µA = 1.5 mA and so on. Note that input and output currents are in phase.
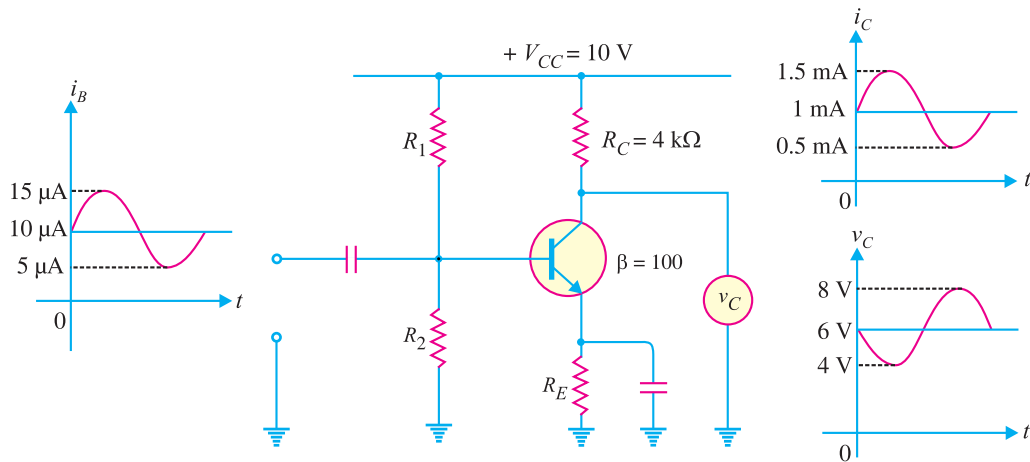

Fig. 10.7

The output voltage, $v_C = V_{CC} - i_C R_C$

(*i*) When signal current is zero (*i.e.*, in the absence of signal), $i_C = 1$ mA.

∴ $\qquad v_C = V_{CC} - i_C R_C = 10\text{ V} - 1\text{ mA} \times 4\text{ k}\Omega = 6\text{V}$

(*ii*) When signal reaches positive peak value, $i_C = 1.5$ mA.

∴ $\qquad v_C = V_{CC} - i_C R_C = 10\text{ V} - 1.5\text{ mA} \times 4\text{ k}\Omega = 4\text{ V}$

Note that as i_C increases from 1mA to 1.5 mA, v_C decreases from 6V to 4V. Clearly, output voltage is 180° out of phase from the input voltage as shown in Fig. 10.7.

(*iii*) When signal reaches negative peak, $i_C = 0.5$ mA.

∴ $\qquad v_C = V_{CC} - i_C R_C = 10\text{ V} - 0.5\text{ mA} \times 4\text{ k}\Omega = 8\text{ V}$

Note that as i_C decreases from 1.5 mA to 0.5 mA, v_C increases from 4 V to 8 V. Clearly, output voltage is 180° out of phase from the input voltage. The following points may be noted carefully about *CE* amplifier :

(*a*) The input voltage and input current are in phase.

(*b*) Since the input current and output current are in phase, input voltage and output current are in phase.

(*c*) Output current is 180° out of phase with the output voltage (v_C). *Therefore, input voltage and output voltage are 180° out of phase.*

10.6 Input/Output Phase Relationships

The following points regarding the input / output phase relationships between currents and voltages for the various transistor configurations may be noted :

(*i*) *For every amplifier type (CE, CB and CC), the input and output currents are in phase.* When the input current decreases, the output current also decreases and vice-versa.

(*ii*) *Remember that common emitter (CE) circuit is the **only configuration** that has input and output voltages 180° out of phase.*

(*iii*) For both common base (*CB*) and common collector (*CC*) circuits, the input and output voltages are in phase. If the input voltage decreases, the output voltage also decreases and vice-versa.

10.7 D.C. And A.C. Equivalent Circuits

In a transistor amplifier, both d.c. and a.c. conditions prevail. The d.c. sources set up d.c. currents and voltages whereas the a.c. source (*i.e.* signal) produces fluctuations in the transistor currents and voltages. Therefore, a simple way to analyse the action of a transistor is to split the analysis into two parts *viz.* a d.c. analysis and an a.c. analysis. In the d.c. analysis, we consider all the d.c. sources at the same time and work out the d.c. currents and voltages in the circuit. On the other hand, for a.c. analysis, we consider all the a.c. sources at the same time and work out the a.c. currents and voltages. By adding the d.c. and a.c. currents and voltages, we get the total currents and voltages in the circuit. For example, consider the amplifier circuit shown in Fig. 10.8. This circuit can be easily analysed by splitting it into *d.c. equivalent circuit* and *a.c equivalent circuit.*
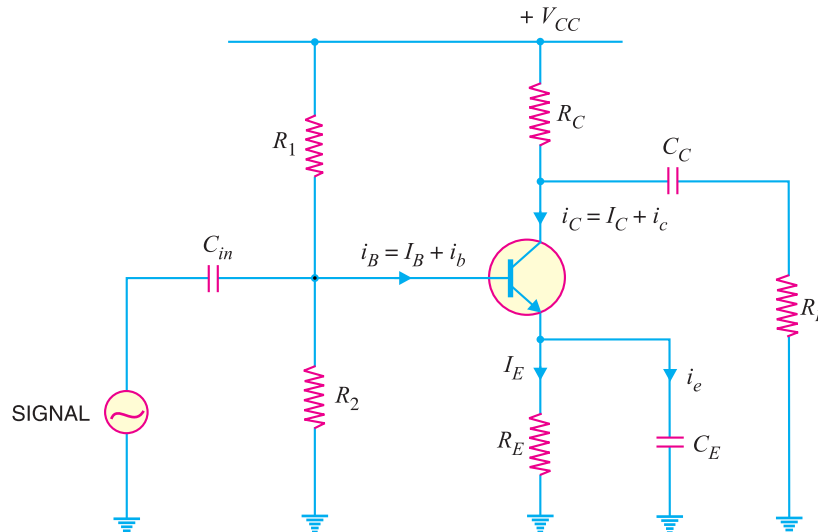

Fig. 10.8

(*i*) **D. C. equivalent circuit.** In the d.c. equivalent circuit of a transistor amplifier, only d.c. conditions are to be considered *i.e.* it is presumed that no signal is applied. As direct current cannot flow through a capacitor, therefore, *all the capacitors look like open circuits in the d.c. equivalent circuit.* It follows, therefore, that in order to draw the equivalent d.c. circuit, the following two steps are applied to the transistor circuit :

(*a*) Reduce all a.c. sources to zero.

(*b*) Open all the capacitors.

Applying these two steps to the circuit shown in Fig. 10.8, we get the d.c. equivalent circuit shown in Fig. 10.9. We can easily calculate the d.c. currents and voltages from this circuit.

(**ii**) **A.C. equivalent circuit.** In the a.c. equivalent circuit of a transistor amplifier, only a.c. conditions are to be considered. Obviously, the d.c. voltage is not important for such a circuit and may be considered zero. The capacitors are generally used to couple or bypass the a.c. signal. The designer intentionally selects capacitors that are large enough to appear as *short* circuits to the a.c. signal. It follows, therefore, that in order to draw the a.c. equivalent circuit, the following two steps are applied to the transistor circuit :

(**a**) Reduce all d.c. sources to zero (*i.e.* $V_{CC} = 0$).

(**b**) Short all the capacitors.

Fig. 10.9

Applying these two steps to the circuit shown in Fig. 10.8, we get the a.c. *equivalent circuit shown in Fig. 10.10. We can easily calculate the a.c. currents and voltages from this circuit.
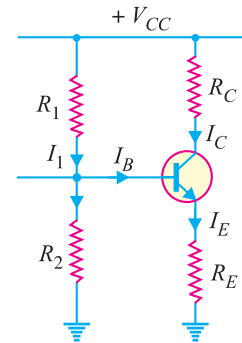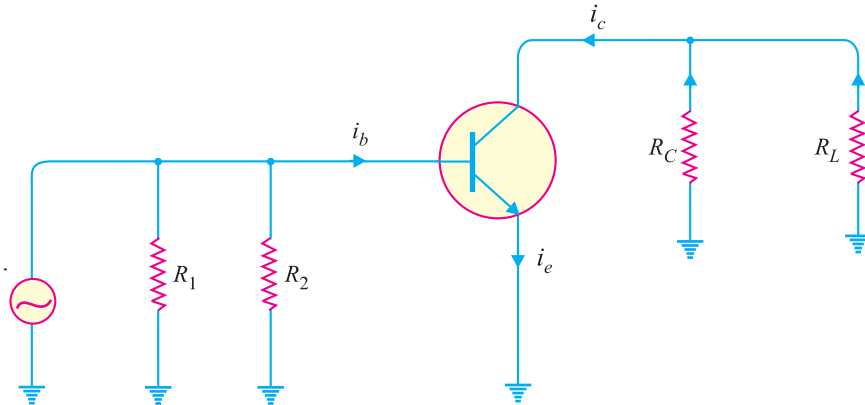
Fig. 10.10

It may be seen that total current in any branch is the sum of d.c. and a.c. currents through that branch. Similarly, the total voltage across any branch is the sum of d.c. and a.c. voltages across that branch.

Example 10.4. *For the transistor amplifier circuit shown in Fig. 10.8, determine :*

 (i)   d.c. load and a.c. load

(ii)   maximum collector-emitter voltage and collector current under d.c. conditions

(iii)   maximum collector-emitter voltage and collector current when a.c. signal is applied

Solution. Refer back to the transistor amplifier circuit shown in Fig. 10.8.

(**i**)   The d.c. load for the transistor is Thevenin's equivalent resistance as seen by the collector and emitter terminals. Thus referring to the d.c. equivalent circuit shown in Fig. 10.9, Thevenin's equivalent resistance can be found by shorting the voltage source (*i.e.* V_{CC}) as shown in Fig. 10.11. Because a voltage source looks like a short, it will bypass all other resistances except R_C and R_E which will appear in series. Consequently, transistor amplifier will see a d.c. load of $R_C + R_E$ *i.e*

*   Note that R_1 is also in parallel with transistor input so far as signal is concerned. Since R_1 is connected from the base lead to V_{CC} and V_{CC} is at "ac ground", R_1 is effectively connected from the base lead to ground as far as signal is concerned.

d.c. load $=$ $\mathbf{R_C + R_E}$

Referring to the a.c. equivalent circuit shown in Fig. 10.10, it is clear that as far as a.c. signal is concerned, resistance R_C appears in parallel with R_L. In other words, transistor amplifier sees an a.c. load equal to $R_C \| R_L$ i.e.

a.c. load, $R_{AC} = R_C \| R_L$

$$= \frac{R_C R_L}{R_C + R_L}$$

(ii) Referring to d.c. equivalent circuit of Fig. 10.9,

Fig. 10.11

$$V_{CC} = V_{CE} + I_C (R_C + R_E)$$

The maximum value of V_{CE} will occur when there is no collector current i.e. $I_C = 0$.

∴   Maximum $V_{CE} = \mathbf{V_{CC}}$

The maximum collector current will flow when $V_{CE} = 0$.

∴   Maximum $I_C = \dfrac{\mathbf{V_{CC}}}{\mathbf{R_C + R_E}}$

(iii) When no signal is applied, V_{CE} and I_C are the collector-emitter voltage and collector current respectively. When a.c. signal is applied, it causes changes to take place above and below the operating point Q (i.e. V_{CE} and I_C).

Maximum collector current due to a.c. signal = *I_C

∴   Maximum positive swing of a.c. collector-emitter voltage

$$= I_C \times R_{AC}$$

Total maximum collector-emitter voltage

$$= V_{CE} + I_C R_{AC}$$

Maximum positive swing of a.c. collector current

$$= V_{CE}/R_{AC}$$

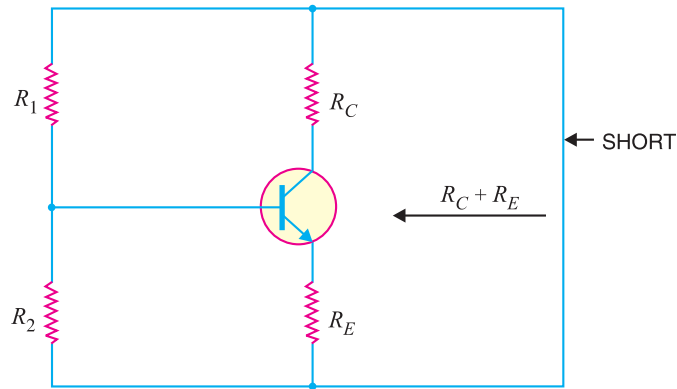∴   Total maximum collector current

$$= I_C + V_{CE}/R_{AC}$$

10.8 Load Line Analysis

The output characteristics are determined experimentally and indicate the relation between V_{CE} and I_C. However, the same information can be obtained in a much simpler way by representing the mathematical relation between I_C and V_{CE} graphically. As discussed before, the relationship between V_{CE} and I_C is linear so that it can be represented by a straight line on the output characteristics. This is known as a *load line*. The points lying on the load line give the possible values of V_{CE} and I_C in the output circuit. As in a transistor circuit both d.c. and a.c. conditions exist, therefore, there are two types of load lines, namely ; d.c. load line and a.c. load line. The former determines the locus of I_C and V_{CE} in the zero signal conditions and the latter shows these values when the signal is applied.

(i) **d.c. load line.** *It is the line on the output characteristics of a transistor circuit which gives the values of I_C and V_{CE} corresponding to zero signal or d.c. conditions.*

* *

*   For faithful amplification.

Consider the transistor amplifier shown in Fig. 10.12. In the absence of signal, d.c. conditions prevail in the circuit as shown in Fig. 10.13 (*i*). Referring to this circuit and applying Kirchhoff's voltage law,

$$V_{CE} = V_{CC} - I_C R_C - I_E R_E$$

or
$$V_{CE} = V_{CC} - I_C (R_C + R_E) \qquad \qquad ...(i)$$
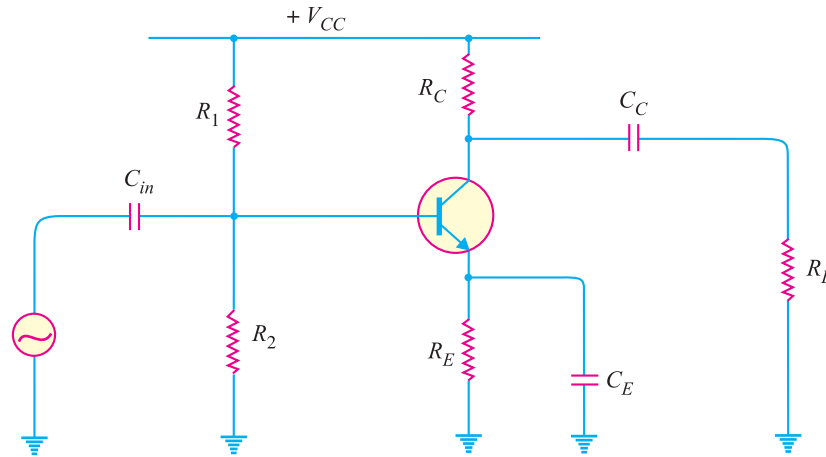$$(\because I_E \simeq I_C)$$

Fig. 10.12

As for a given circuit, V_{CC} and $(R_C + R_E)$ are constant, therefore, it is a first degree *equation and can be represented by a straight line on the output characteristics. This is known as *d.c. load line* and determines the loci of V_{CE} and I_C points in the zero signal conditions. The d.c. load line can be readily plotted by locating two *end points* of the straight line.

(*i*)   (*ii*)

Fig. 10.13
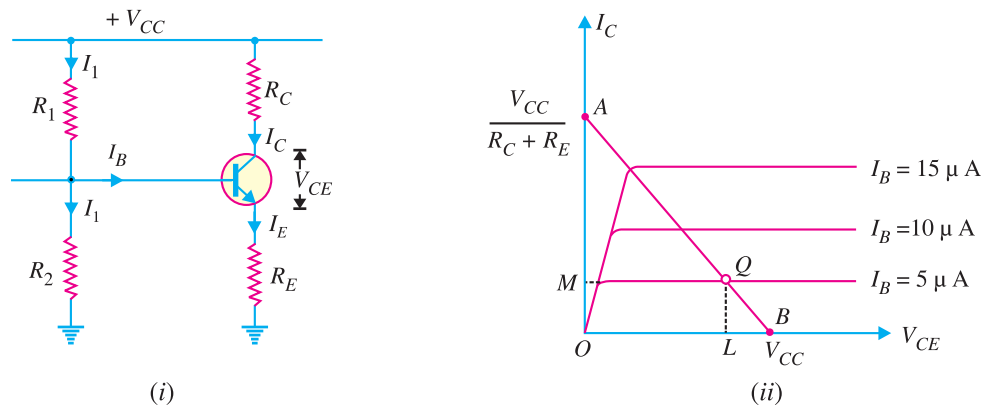
The value of V_{CE} will be maximum when $I_C = 0$. Therefore, by putting $I_C = 0$ in exp. (*i*), we get,

$$\text{Max. } V_{CE} = V_{CC}$$

This locates the first point B ($OB = V_{CC}$) of the d.c. load line.

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*   This equation is known as **load line equation** since it relates the collector-emitter voltage (V_{CE}) to the collector current (I_C) flowing through the load.

The value of I_C will be maximum when $V_{CE} = 0$.

$$\therefore \qquad\qquad \text{Max. } I_C = \frac{V_{CC}}{R_C + R_E}$$

This locates the second point A ($OA = V_{CC}/R_C + R_E$) of the d.c. load line. By joining points A and B, d.c. load line AB is constructed [See Fig. 10.13 (*ii*)].

Alternatively. The two end points of the d.c. load line can also be determined in another way.

$$V_{CE} + I_C (R_C + R_E) = V_{CC}$$

Dividing throughout by V_{CC}, we have,

$$\frac{V_{CE}}{V_{CC}} + \frac{I_C}{(V_{CC}/R_C + R_E)} = 1 \qquad\qquad ...(i)$$

The equation of a line having intercepts a and b on x-axis and y-axis respectively is given by ;

$$\frac{x}{a} + \frac{y}{b} = 1 \qquad\qquad ...(ii)$$

Comparing eqs. (*i*) and (*ii*), we have,

$$\text{Intercept on } x\text{-axis} = V_{CC}$$

$$\text{Intercept on } y\text{-axis} = \frac{V_{CC}}{R_C + R_E}$$

With the construction of d.c. load line on the output characteristics, we get the complete information about the output circuit of transistor amplifier in the zero signal conditions. All the points showing zero signal I_C and V_{CE} will obviously lie on the d.c. load line. At the same time I_C and V_{CE} conditions in the circuit are also represented by the output characteristics. Therefore, actual operating conditions in the circuit will be represented by the point where d.c. load line intersects the base current curve under study. Thus, referring to Fig. 10.13 (*ii*), if $I_B = 5$ µA is set by the biasing circuit, then Q (*i.e.* intersection of 5 µA curve and load line) is the operating point.

(*ii*) **a.c. load line.** *This is the line on the output characteristics of a transistor circuit which gives the values of i_C and v_{CE} when signal is applied.*

Referring back to the transistor amplifier shown in Fig. 10.12, its a.c. equivalent circuit as far as output circuit is concerned is as shown in Fig. 10.14 (*i*). To add a.c. load line to the output characteristics, we again require two end points–one maximum collector-emitter voltage point and the other maximum collector current point. Under the application of a.c. signal, these values are (refer to example 10.4) :

Max. collector-emitter voltage $= V_{CE} + I_C R_{AC}$. This locates the point C of the a.c. load line on the collector-emitter voltage axis.
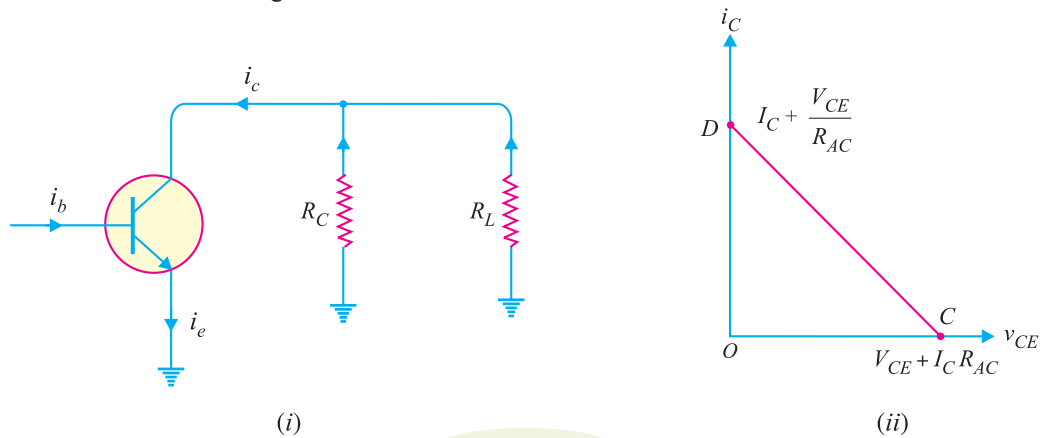

Fig. 10.14

Maximum collector current $= I_C + \dfrac{V_{CE}}{R_{AC}}$

where $R_{AC} = R_C \| R_L = \dfrac{R_C\,R_L}{R_C + R_L}$

This locates the point *D* of a.c. load line on the collector-current axis. By joining points *C* and *D*, the a.c.load line *CD* is constructed [See Fig. 10.14 (*ii*)].

Example 10.5. *For the transistor amplifier shown in Fig. 10.15, $R_1 = 10\ k\Omega$, $R_2 = 5\ k\Omega$, $R_C = 1\ k\Omega$, $R_E = 2\ k\Omega$ and $R_L = 1\ k\Omega$.*

(i) Draw d.c. load line (ii) Determine the operating point (iii) Draw a.c. load line.
Assume $V_{BE} = 0.7\ V$.

Solution. (*i*) **d.c. load line :**

To draw d.c. load line, we require two end points *viz* maximum V_{CE} point and maximum I_C point.

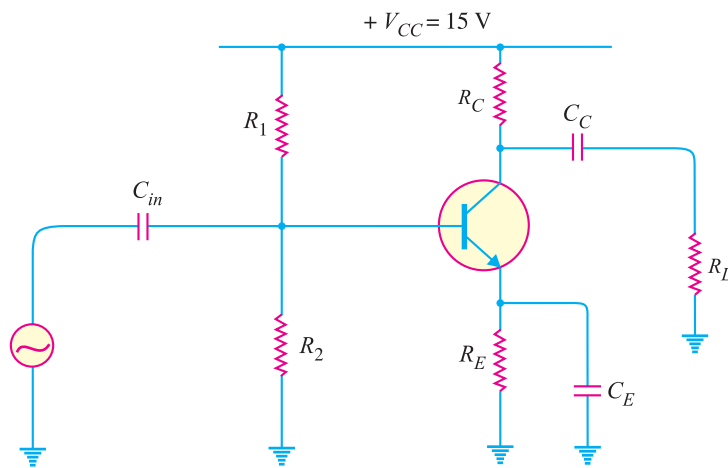**Fig. 10.15**

Maximum $V_{CE} = V_{CC} = 15$ V [See Art. 10.8]

This locates the point *B* (*OB*=15 V) of the d.c. load line.

$$\text{Maximum } I_C = \frac{V_{CC}}{R_C + R_E} = \frac{15\,V}{(1+2)\ k\Omega} = 5\ mA \qquad \text{[See Art. 10.8]}$$

This locates the point *A* (*OA* = 5 mA) of the d.c. load line. Fig. 10.16 (*i*) shows the d.c. load line *AB*.

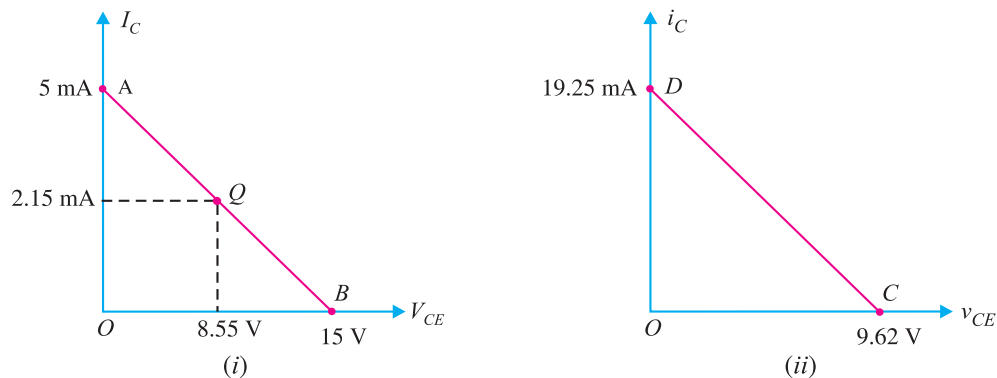**Fig. 10.16**

(*ii*) **Operating point Q.** The voltage across R_2 (= 5 kΩ) is *5 V *i.e.* V_2 = 5 V.

$$\text{Now} \quad V_2 = V_{BE} + I_E R_E$$

$$\therefore \qquad I_E = \frac{V_2 - V_{BE}}{R_E} = \frac{(5 - 0.7) \, V}{2 \, k\Omega} = 2.15 \, mA$$

$$\therefore \qquad I_C = I_E = 2.15 \, mA$$

$$\text{Now} \quad V_{CE} = V_{CC} - I_C (R_C + R_E) = 15 - 2.15 \, mA \times 3 \, k\Omega$$

$$= 8.55 \, V$$

$\therefore$ Operating point *Q* is **8.55 V, 2.15 mA.** This is shown on the d.c. load line.

(*iii*) **a.c. load line.** To draw a.c. load line, we require two end points *viz*. maximum collector-emitter voltage point and maximum collector current point when signal is applied.

$$\text{a.c. load,} \quad R_{AC} = R_C \, || \, R_L = \frac{1 \times 1}{1 + 1} = 0.5 \, k\Omega$$

$\therefore$ Maximum collector-emitter voltage

$$= V_{CE} + I_C R_{AC} \qquad [\text{See example 10.4}]$$

$$= 8.55 + 2.15 \, mA \times 0.5 \, k\Omega = 9.62 \, \text{volts}$$

This locates the point *C* (*OC* = 9.62 V) on the v_{CE} axis.

$$\text{Maximum collector current} \quad = I_C + V_{CE}/R_{AC}$$

$$= 2.15 + (8.55 \, V/0.5 \, k\Omega) = 19.25 \, mA$$

This locates the point *D* (*OD* = 19.25mA) on the i_C axis. By joining points *C* and *D*, a.c. load line *CD* is constructed [See Fig. 10.16 (*ii*)].

> **Example 10.6.** *In the transistor amplifier shown in Fig. 10.15, R_C = 10 kΩ, R_L = 30 kΩ and V_{CC} = 20V. The values R_1 and R_2 are such so as to fix the operating point at 10V, 1mA. Draw the d.c. and a.c. load lines. Assume R_E is negligible.*

Solution. d.c. load line. For drawing d.c. load line, two end points *viz.* maximum V_{CE} point and maximum I_C point are needed. Maximum V_{CE} = 20 V. This locates the point *B* (*OB* = 20V) of the d.c. load line on the V_{CE} axis.

$$\text{Maximum } I_C = \frac{V_{CC}}{R_C + R_E} = \frac{20 \, V}{10 \, k\Omega} = 2 \, mA$$

This locates the point *A* (*OA* = 2 mA) on the I_C axis. By joining points *A* and *B*, the d.c. load line *AB* is constructed (See Fig. 10.17).

a.c. load line. To draw a.c. load line, we require two end points *viz* maximum collector-emitter voltage point and maximum collector current point when signal is applied.

$$\text{a.c. load,} \quad R_{AC} = R_C \, || \, R_L = \frac{10 \times 30}{10 + 30} = 7.5 \, k\Omega$$

Maximum collector-emitter voltage

$$= V_{CE} + I_C R_{AC}$$

$$= 10 + 1 \, mA \times 7.5 \, k\Omega = 10 + 7.5 = 17.5 \, V$$

This locates the point *D* (*OD* = 17.5 V) on the v_{CE} axis.

$$\text{Maximum collector current} \quad = I_C + V_{CE}/R_{AC}$$

$$= 1 \, mA + 10 \, V/7.5 \, k\Omega = 1 \, mA + 1.33 \, mA = 2.33 \, mA$$

- -

* Voltage across series combination of R_1 and R_2 is 15 V. Applying voltage divider theorem, voltage across R_2 = 5 V.

This locates the point C ($OC = 2.33$ mA) on the i_C axis. By joining points C and D, a.c. load line CD is constructed (See Fig. 10.17).
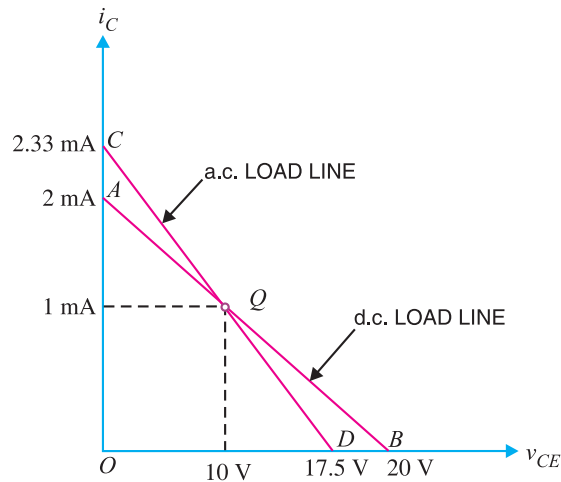

Fig. 10.17

Comments. The reader may see that the operating point lies on both a.c. and d.c. load lines. It is not surprising because signal is a.c. and it becomes zero after every half-cycle. When the signal is zero, we have the exact d.c. conditions. Therefore, key point to keep in mind is that the point of intersection of d.c. and a.c. load lines is the operating point Q.

Example 10.7. *In a transistor amplifier, the operating point Q is fixed at 8V, 1mA. When a.c. signal is applied, the collector current and collector-emitter voltage change about this point. During the positive peak of signal, $i_C = 1.5$ mA and $v_{CE} = 7$ V and during negative peak, $i_C = 0.5$mA and v_{CE} = 9V. Show this phenomenon with the help of a.c. load line.*

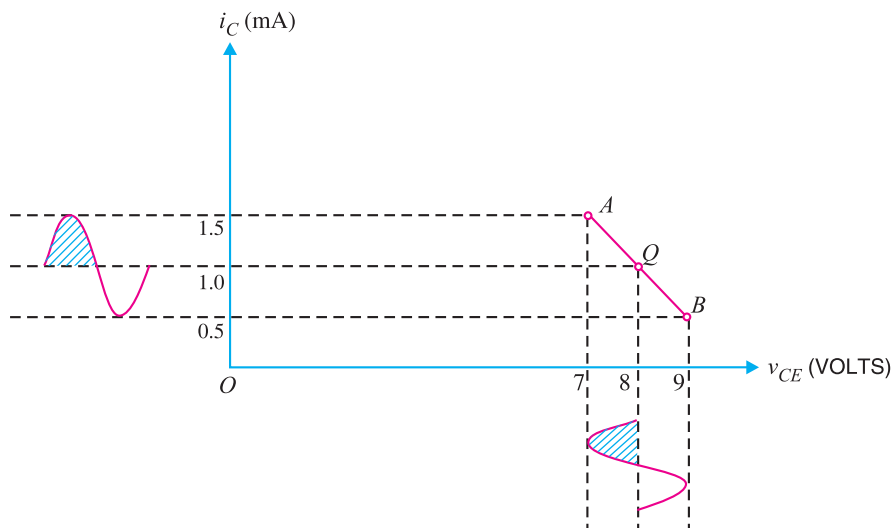**Fig. 10.18**

Solution. Fig. 10.18 shows the whole process. When no signal is applied, $v_{CE} = 8$ V and $i_C =$ 1mA. This is represented by the operating point Q on the a.c. load line. During the positive half-cycle of a.c. signal, i_C swings from 1 mA to 1.5 mA and v_{CE} swings from 8 V to 7 V. This is represented by point A on the a.c. load line. During the negative half-cycle of the signal, i_C swings from 1 mA to 0.5 mA and v_{CE} swings from 8 V to 9 V. This is represented by the point B on the a.c. load line.

The following points may be noted :

(i) When a.c. signal is applied, the collector current and collector-emitter voltage variations take place about the operating point Q.

(ii) When a.c. signal is applied, operating point moves along the a.c. load line. In other words, at any instant of a.c. signal, the co-ordinates of collector current and collector-emitter voltage are on the a.c. load line.

10.9 Voltage Gain

The basic function of an amplifier is to raise the strength of an a.c. input signal. The voltage gain of the amplifier is the ratio of a.c. output voltage to the a.c. input signal voltage. Therefore, in order to find the voltage gain, we should consider only the a.c. currents and voltages in the circuit. For this purpose, we should look at the a.c. equivalent circuit of transistor amplifier. For facility of reference, the a.c. equivalent circuit of transistor amplifier is redrawn in Fig. 10.19.
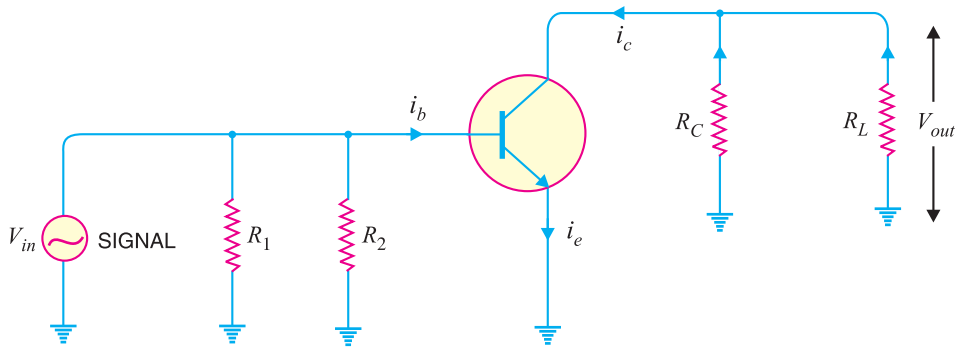
Fig. 10.19

It is clear that as far as a.c. signal is concerned, load R_C appears in parallel with R_L. Therefore, effective load for a.c. is given by :

$$\text{a.c. load, } R_{AC} = R_C \| R_L = \frac{R_C \times R_L}{R_C + R_L}$$

$$\text{Output voltage, } V_{out} = i_c R_{AC}$$

$$\text{Input voltage, } V_{in} = i_b R_{in}$$

$$\therefore \qquad \text{Voltage gain, } A_v = V_{out}/V_{in}$$

$$= \frac{i_c R_{AC}}{i_b R_{in}} = \beta \times \frac{R_{AC}}{R_{in}} \qquad \left(\because \frac{i_c}{i_b} = \beta \right)$$

Incidentally, power gain is given by;

$$A_p = \frac{i_c^2 R_{AC}}{i_b^2 R_{in}} = \beta^2 \times \frac{R_{AC}}{R_{in}}$$

Example 10.8. *In the circuit shown in Fig. 10.20, find the voltage gain. Given that* $\beta = 60$ *and input resistance* $R_{in} = 1 \ k\Omega$.
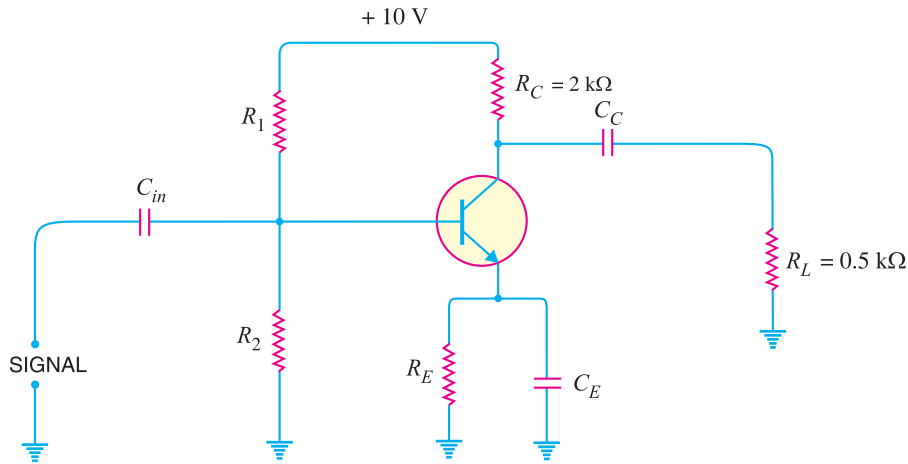

Fig. 10.20

Solution. So far as voltage gain of the circuit is concerned, we need only R_{AC}, β and R_{in}.

Effective load, $R_{AC} = R_C \| R_L$

$$= \frac{R_C \times R_L}{R_C + R_L} = \frac{2 \times 0.5}{2 + 0.5} = 0.4 \ k\Omega$$

∴ Voltage gain $= \beta \times \dfrac{R_{AC}}{R_{in}} = \dfrac{60 \times 0.4 \ k\Omega}{1 \ k\Omega} = \mathbf{24}$

Example 10.9. *In the circuit shown in Fig. 10.20, if* $R_C = 10 \ k\Omega$, $R_L = 10 \ k\Omega$, $R_{in} = 2.5 \ k\Omega$, $\beta = 100$, *find the output voltage for an input voltage of 1mV r.m.s.*

Solution. Effective load, $R_{AC} = \dfrac{R_C \times R_L}{R_C + R_L} = \dfrac{10 \times 10}{10 + 10} = 5 \ k\Omega$

Voltage gain $= \beta \times \dfrac{R_{AC}}{R_{in}} = 100 \times \dfrac{5 \ k\Omega}{2.5 \ k\Omega} = 200$

or $\dfrac{V_{out}}{V_{in}} = 200$

∴ $V_{out} = 200 \times V_{in} = 200 \times 1 \ mV = \mathbf{200 \ mV}$

Example 10.10. *In a transistor amplifier, when the signal changes by 0.02V, the base current changes by 10 μA and collector current by 1mA. If collector load* $R_C = 5 \ k\Omega$ *and* $R_L = 10 \ k\Omega$, *find: (i) current gain (ii) input impedance (iii) a.c. load (iv) voltage gain (v) power gain.*

Solution. $\Delta I_B = 10 \ \mu A$, $\Delta I_C = 1mA$, $\Delta V_{BE} = 0.02 \ V$, $R_C = 5 \ k\Omega$, $R_L = 10 \ k\Omega$

(i) Current gain, $\beta = \dfrac{\Delta I_C}{\Delta I_B} = \dfrac{1 \ mA}{10 \ \mu A} = \mathbf{100}$

(ii) Input impedance, $R_{in} = \dfrac{\Delta V_{BE}}{\Delta I_B} = \dfrac{0.02\,V}{10\,\mu A} = \textbf{2 k}\boldsymbol{\Omega}$

(iii) a.c. load, $R_{AC} = \dfrac{R_C \times R_L}{R_C + R_L} = \dfrac{5 \times 10}{5 + 10} = \textbf{3.3 k}\boldsymbol{\Omega}$

(iv) Voltage gain, $A_v = \beta \times \dfrac{R_{AC}}{R_{in}} = 100 \times \dfrac{3.3}{2} = \textbf{165}$

(v) Power gain, $A_p = $ current gain $\times$ voltage gain $= 100 \times 165 = \textbf{16500}$

Example 10.11. *In Fig. 10.21, the transistor has* $\beta = 50$. *Find the output voltage if input resistance* $R_{in} = 0.5\,k\Omega$.
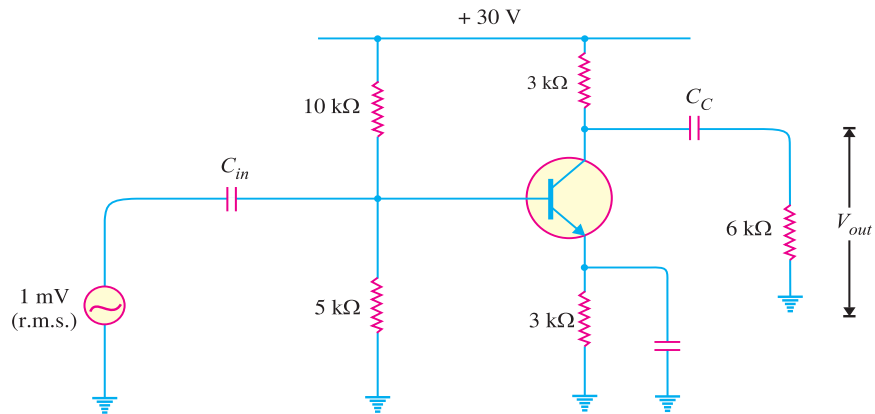
Fig. 10.21

Solution. $\beta = 50, \quad R_{in} = 0.5\,k\Omega$

a.c. load, $R_{AC} = R_C \| R_L = \dfrac{R_C \times R_L}{R_C + R_L} = \dfrac{3 \times 6}{3 + 6} = 2\,k\Omega$

$\therefore$ Voltage gain $= \beta \times R_{AC}/R_{in} = 50 \times 2/0.5 = 200$

or $\dfrac{V_{out}}{V_{in}} = 200$

$\therefore$ Output voltage, $V_{out} = 200 \times V_{in} = 200 \times (1\,mV) = \textbf{200 mV}$

Example 10.12. *Fig. 10.22 shows a transistor circuit. The manufacturer of the circuit shows that collector potential is to be + 6V. The voltage measured at point B by a technician is found to be + 4V. Is the circuit operating properly ?*

Solution. The voltage at point B is equal to the voltage across R_1. Now total voltage V_T across the series combination of R_1 and R_2 is 6 V. Therefore, using voltage divider method, we have,

$$V_B = \text{Voltage across } R_1$$

$$= \dfrac{R_1}{R_1 + R_2} \times V_T = \dfrac{1}{1 + 2} \times 6 = 2\,V$$

Fig. 10.22

The circuit is not operating properly. It is because the voltage at point *B* should be 2 *V* instead of 4 *V*.
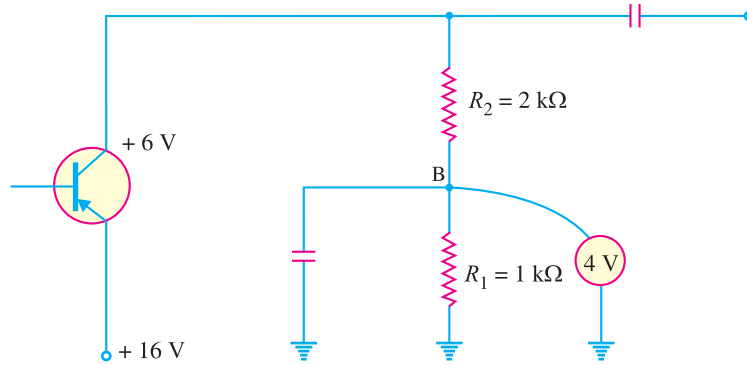
10.10 A.C. Emitter Resistance

The ac or dynamic resistance of emitter-base junction diode of a transistor is called ac emitter resistance. It is defined as the change in base-emitter voltage divided by change in corresponding emitter current [See Fig. 10.23] *i.e.*

Fig. 10.23

$$R_{ac} = \frac{\Delta V_{BE}}{\Delta I_E}$$

For instance, suppose an ac base voltage change of 1 mV produces an ac emitter current change of 50 μA. Then emitter diode has an ac resistance of

$$R_{ac} = \frac{1\,mV}{50\,\mu A} = 20\,\Omega$$
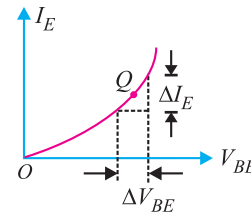
10.11 Formula For AC Emitter Resistance

It can be shown mathematically that the ac resistance of emitter diode is given by ;

$$R_{ac} = \frac{25\,mV}{I_E}$$

where I_E = dc emitter current (= V_E/R_E) at Q point

Note the significance of this formula. It implies that ac emitter resistance can be found simply by substituting the quiescent value of emitter current into the equation. There is no need to have the characteristics available. It is important to keep in mind that this formula is accurate only for small signal operation. It is a usual practice to represent ac emitter resistance by r_e'.

∴ $$r_e' = \frac{25\,mV}{I_E}$$

The subscript *e* indicates emitter. The lower case *r* is used to indicate an ac resistance. The prime shows that it is an internal resistance.

Example 10.13. *Determine the ac emitter resistance for the transistor circuit shown in Fig. 10.24.*

Fig. 10.24

Solution. Voltage across R_2, V_2 = $\dfrac{V_{CC}}{R_1 + R_2} \times R_2$ = $\dfrac{10}{40+10} \times 10$ = 2 V

Voltage across R_E, V_E = $V_2 - V_{BE}$ = $2 - 0.7$ = 1.3 V

Emitter current, I_E = $\dfrac{V_E}{R_E}$ = $\dfrac{1.3\,V}{2\,k\Omega}$ = 0.65 mA

∴   *AC* emitter resistance, r_e' = $\dfrac{25\,mV}{I_E}$ = $\dfrac{25\,mV}{0.65\,mA}$ = **38.46Ω**

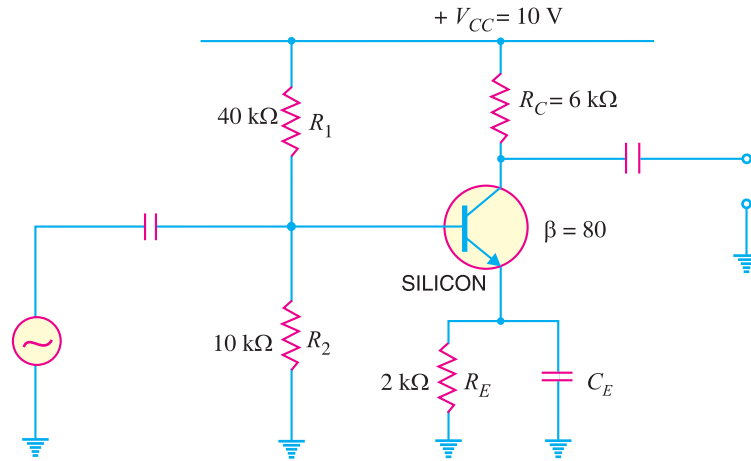## 10.12 Voltage Gain of CE Amplifier

The voltage gain (A_v) of an amplifier is equal to a.c. output voltage (v_{out}) divided by a.c. input voltage (v_{in}) *i.e.* $A_v = v_{out}/v_{in}$. We have already seen that voltage gain of a *CE* amplifier is given by;

Voltage gain, A_v = $\beta \times \dfrac{R_C}{R_{in}}$ ... for unloaded amplifier

= $\beta \times \dfrac{R_{AC}}{R_{in}}$ ... for loaded amplifier

Remember that $R_{AC} = R_C \| R_L$

The above formula for A_v can be used if we know the values of R_C (or R_{AC}), β and R_{in}. Generally, all these values are not known. In that case, we can find the value of A_v in terms of *total a.c. collector resistance* and *total a.c. emitter resistance*. For the circuit shown in Fig. 10.25 (*with C_E connected across R_E*), it can be proved that the voltage gain is given by ;

Voltage gain, A_v = $\dfrac{R_C}{r_e'}$ ... for unloaded amplifier

= $\dfrac{R_{AC}}{r_e'}$ ... for loaded amplifier

10.13 Voltage Gain of Unloaded *CE* Amplifier

Fig. 10.25 shows the circuit of unloaded *CE* amplifier (*i.e.* no load R_L is connected to the circuit).

Note that emitter bypass capacitor C_E is connected in parallel with emitter resistance R_E. The capacitor C_E acts as a *short to the a.c. signal so that it bypasses the a.c. signal to the ground. Therefore, the emitter is effectively at a.c. ground. It is important to note that C_E plays an important role in determining the voltage gain (A_v) of the *CE* amplifier. If it is removed, the voltage gain of the amplifier is greatly reduced (soon you will see the reason for it).
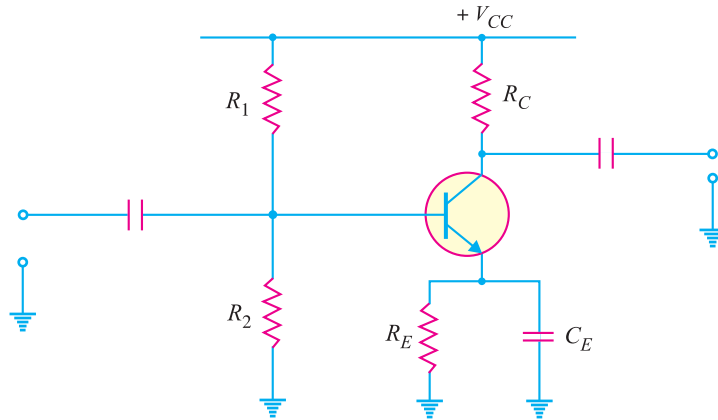

Fig. 10.25

Voltage gain, $A_v = \dfrac{R_C}{r_e'}$

where R_C = ac collector resistance

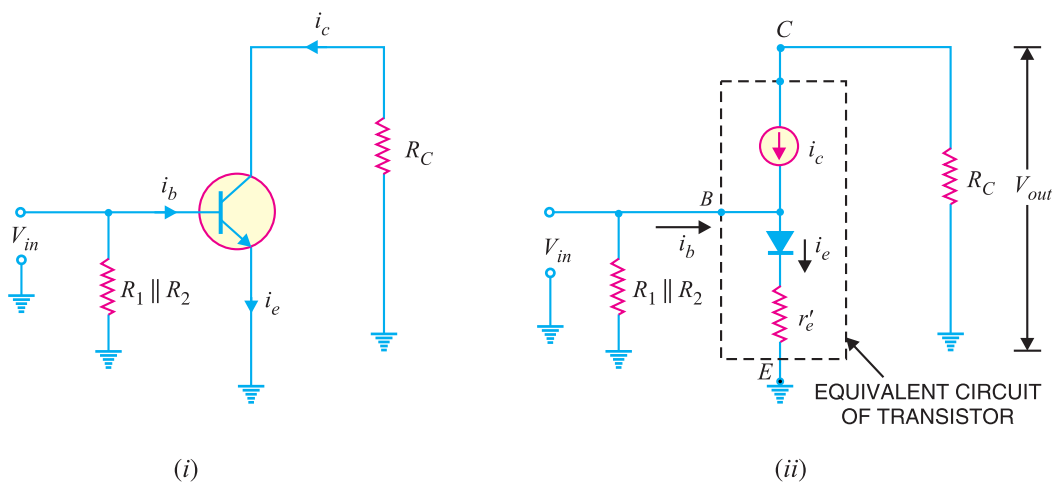r_e' = ac emitter resistance = 25 mV/I_E

(i)   (ii)

Fig. 10.26

* The size of C_E is so selected that it offers negligible reactance to the frequencies handled by the amplifier (See Example 10.2).

Derivation. Fig. 10.25 shows the common emitter amplifier. The ac equivalent circuit of the amplifier is shown in Fig. 10.26. (*i*). Replacing the transistor by its *equivalent circuit, we get the circuit shown in Fig. 10.26 (*ii*). Note that current source is still connected between the collector and base terminals while the diode between the base and emitter terminals. Further, the input current is the base current (i_b) while the output current is still i_c.

Note that input voltage (V_{in}) is applied across the diode and r_e'. Assuming the diode to be ideal (so that it can be replaced by a wire), the *ac* emitter current is given by :

$$i_e = \frac{V_{in}}{r_e'}$$

or

$$V_{in} = i_e r_e' \qquad \text{...(i)}$$

Assuming $i_c = i_e$, we have,

$$V_{out} = i_c R_C = i_e R_C$$

∴ Voltage gain, $A_v = \dfrac{V_{out}}{V_{in}} = \dfrac{i_e R_C}{i_e r_e'} = \dfrac{R_C}{r_e'}$

or

$$A_v = \frac{R_C}{r_e'}$$

where R_C = total a.c. collector resistance

r_e' = total a.c. emitter resistance
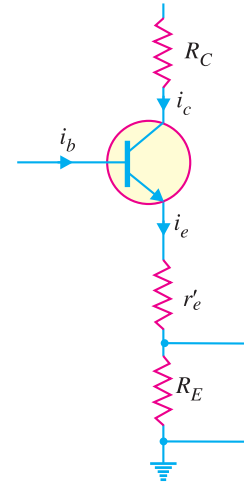
Fig. 10.27

Fig. 10.27 shows the simple a.c. model of *CE* amplifier with C_E connected across R_E. Note that C_E behaves as a short so that R_E is cut out from the emitter circuit for a.c. signal. Therefore, as for as a.c. signal is concerned, the total a.c. emitter resistance is r_e'.

Voltage gain for loaded amplifier. Fig. 10.28 (*i*) shows a part of a.c. equivalent circuit of the

(*i*)   (*ii*)
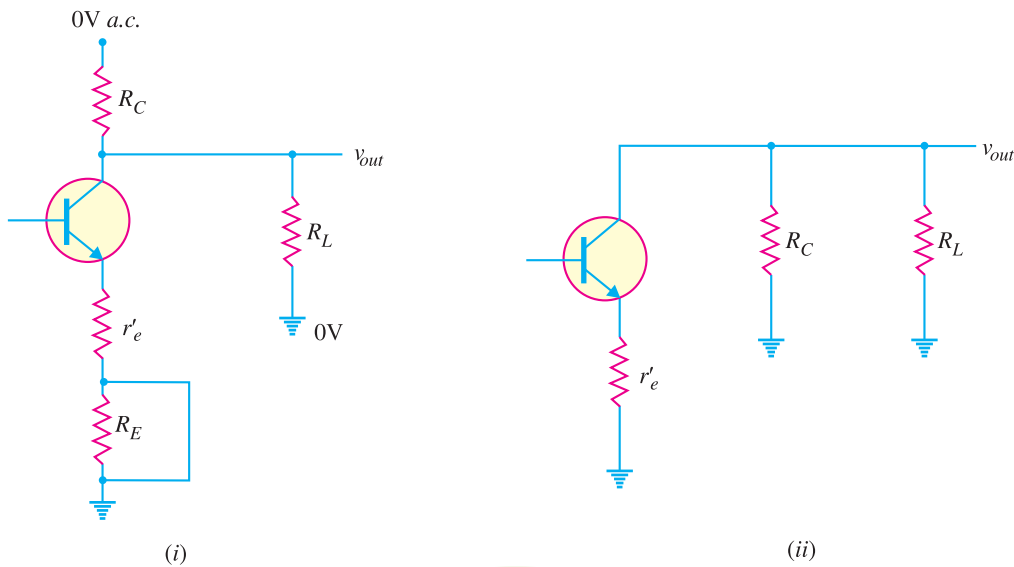
Fig. 10.28

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*   The transistor equivalent circuit contains three components *viz.,*

     (*i*) A resistor r_e' which represents ac emitter resistance.

     (*ii*) A diode which represents the emitter-base junction of the transistor.

     (*iii*) A current source which represents the current being supplied to R_C from the collector of the transistor.

CE amplifier. Note that load R_L is connected to the circuit. Remember that for a.c. analysis, $V_{CC} = 0V$ *i.e.* at ground. Since both R_C and R_L are connected to the collector on one side and ground on the other, the two resistors are in *parallel as shown in Fig. 10.28 (*ii*).

$$\text{Total a.c. collector resistance, } R_{AC} = R_C \| R_L = \frac{R_C R_L}{R_C + R_L}$$

$$\text{Total a.c. emitter resistance} = r'_e$$

$$\therefore \qquad \text{Voltage gain, } A_v = \frac{R_{AC}}{r'_e}$$

10.14 Voltage Gain of *CE* Amplifier Without C_E

When we remove the emitter bypass capacitor from the *CE* amplifier shown in Fig. 10.25, the voltage gain of the circuit is greatly reduced. The reason is simple. Without the emitter bypass capacitor C_E, the emitter is no longer at the ac ground as shown in Fig. 10.29. Therefore, for the a.c. signal, both r'_e and R_E are in series. As a result, the voltage gain of the amplifier becomes :

$$\text{Voltage gain, } A_v = \frac{R_C}{r'_e + R_E} \quad \text{... for unloaded amplifier}$$

$$= \frac{R_{AC}}{r'_e + R_E} \quad \text{... for loaded amplifier}$$

Example 10.14. *For the amplifier circuit shown in Fig. 10.30, find the voltage gain of the amplifier with (i) C_E connected in the circuit (ii) C_E removed from the circuit.*
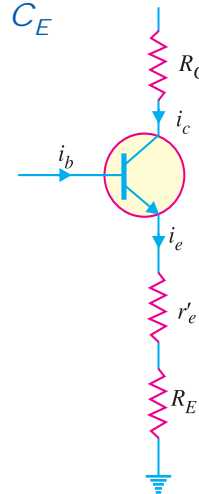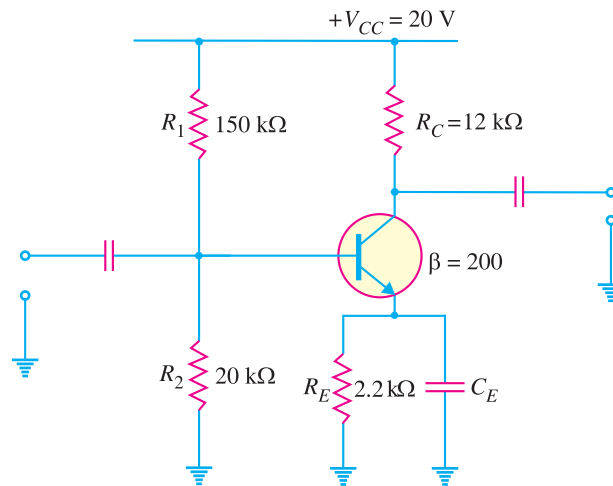

Fig. 10.29

Fig. 10.30

Solution. We shall first find D.C. I_E and hence r'_e.

* Note that C_C behaves as a short for a.c. and is replaced by a wire in the two a.c. circuits.

In order to find D.C. I_E, we shall proceed as under :

$$\text{D.C. voltage across } R_2, V_2 = \frac{V_{CC}}{R_1 + R_2} \times R_2 = \frac{20}{150 + 20} \times 20 = 2.35 \text{ V}$$

$$\text{D.C. voltage across } R_E, V_E = V_2 - V_{BE} = 2.35 - 0.7 = 1.65 \text{ V}$$

$$\therefore \qquad \text{D.C. emitter current, } I_E = \frac{V_E}{R_E} = \frac{1.65 V}{2.2 \text{ k}\Omega} = 0.75 \text{ mA}$$

$$\therefore \qquad \text{AC emitter resistance, } r_e' = \frac{25 \text{ mV}}{I_E} = \frac{25 \text{ mV}}{0.75 \text{ mA}} = 33.3 \text{ }\Omega$$

(i) With C_E connected

$$\text{Voltage gain, } A_v = \frac{R_C}{r_e'} = \frac{12 \text{ k}\Omega}{33.3 \text{ }\Omega} = \textbf{360}$$

(ii) Without C_E

$$\text{Voltage gain, } A_v = \frac{R_C}{r_e' + R_E} = \frac{12 \text{ k}\Omega}{33.3 \text{ }\Omega + 2.2 \text{ k}\Omega} = \textbf{5.38}$$

What a difference the emitter bypass capacitor C_E makes ! With C_E connected, $A_v = 360$ and when C_E is removed, the voltage gain goes down to 5.38.

Example 10.15. *If in the above example, a load of 6 kΩ is connected (with C_E connected) to the collector terminal through a capacitor, what will be the voltage gain of the amplifier?*

Solution. Amplifiers are used to provide ac power to the load. When load R_L is connected to the collector terminal through a capacitor, the total ac resistance of collector changes to :

$$R_{AC} = R_C \| R_L = 12 \text{ k}\Omega \| 6 \text{ k}\Omega = \frac{12 \times 6}{12 + 6} = 4 \text{ k}\Omega$$

The value of ac emitter resistance remains the same.

$$\therefore \qquad \text{Voltage gain, } A_v = \frac{R_{AC}}{r_e'} = \frac{4 \text{ k}\Omega}{33.3 \text{ }\Omega} = \textbf{120}$$

Thus voltage gain of the amplifier is reduced from 360 to 120 when load is connected to the circuit.

Comments. This example shows the fact that voltage gain of the amplifier is *reduced* when load is connected to it. Conversely, if the load is removed from an amplifier, the voltage gain will *increase*. If a load goes open circuit, the effect will be the same as removing the load entirely. Thus the primary symptom of an open load in an amplifier is an *increase* in the voltage gain of the circuit.

Example 10.16. *For the circuit shown in Fig. 10.31, find (i) a.c. emitter resistance (ii) voltage gain (iii) d.c. voltage across both capacitors.*

Solution.

(i) In order to find a.c. emitter resistance r_e', we shall first find D.C. emitter current I_E. To find I_E, we proceed as under :

$$\text{D.C. voltage across } R_2, V_2 = \frac{V_{CC}}{R_1 + R_2} \times R_2 = \frac{9}{240 + 30} \times 30 = 1V$$

$$\text{D.C. voltage across } R_E, V_E = V_2 - V_{BE} = 1V - 0.7V = 0.3V$$

$$\therefore \qquad \text{D.C. emitter current, } I_E = \frac{V_E}{R_E} = \frac{0.3V}{3 \text{ k}\Omega} = 0.1 \text{ mA}$$

$$\text{Now} \qquad \text{A.C. emitter resistance, } r_e' = \frac{25 \text{ mV}}{I_E} = \frac{25mV}{0.1 \text{ mA}} = \textbf{250Ω}$$

$+V_{CC} = +9$ V

R_1 240 kΩ R_C 20 kΩ

C_{in} V_2

V_E

R_2 30 kΩ R_E 3 kΩ C_E
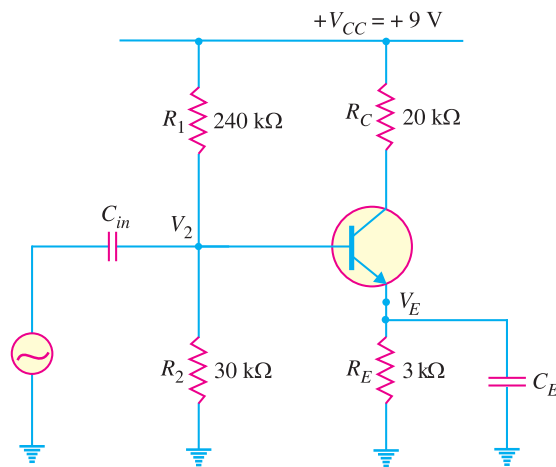
Fig. 10.31

(*ii*)   Voltage gain, $A_v = \dfrac{R_C}{r'_e} = \dfrac{20 \text{ k}\Omega}{250 \ \Omega} = \mathbf{80}$

(*iii*) The d.c. voltage across input capacitor is equal to the d.c. voltage at the base of the transistor which is $V_2 = \mathbf{1V}$. Therefore, d.c. voltage across C_{in} is **1V.**

Similarly, d.c. voltage across C_E = d.c voltage at the emitter = $V_E = \mathbf{0.3V.}$

Example 10.17. *For the circuit shown in Fig. 10.32, find (i) the d.c. bias levels (ii) d.c. voltages across the capacitors (iii) a.c. emitter resistance (iv) voltage gain and (v) state of the transistor.*

$V_{CC} = +15$ V

40 kΩ R_1 2 kΩ R_C C_C

V_C

C_{in} V_2

v_{in} β = 100 $R_L = 1$ kΩ

V_E

10 kΩ R_2 R_E 1 kΩ C_E
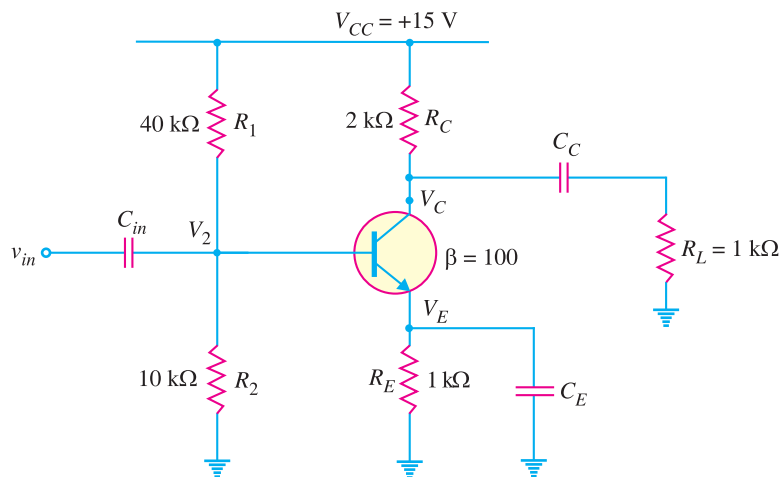
Fig. 10.32

Solution.

(*i*)   **D.C. bias levels.** The d.c. bias levels mean various d.c. currents and d.c. voltages.

D.C. Voltage across R_2, $V_2 = \dfrac{V_{CC}}{R_1 + R_2} \times R_2 = \dfrac{15}{40+10} \, 10 = 3\text{V}$

∴   D.C. base voltage = $V_2 = \mathbf{3V}$

D.C. voltage across R_E, $V_E = V_2 - V_{BE} = 3\text{V} - 0.7\text{V} = \mathbf{2.3V}$

D.C. emitter current, $I_E = \dfrac{V_E}{R_E} = \dfrac{2.3\text{V}}{1 \text{ k}\Omega} = \mathbf{2.3 \text{ mA}}$

$$\text{D.C. collector current, } I_C = I_E = \textbf{2.3 mA}$$
$$\text{D.C. base current, } I_B = I_C/\beta = 2.3 \text{ mA}/100 = \textbf{0.023 mA}$$
$$\text{D.C. collector voltage, } V_C = V_{CC} - I_C R_C$$
$$= 15V - 2.3 \text{ mA} \times 2 \text{ k}\Omega = \textbf{10.4V}$$

Therefore, all d.c. bias levels stand calculated.

(*ii*) $\quad$ D.C. voltage across C_{in} = V_2 = **3V**

$\qquad$ D.C. voltage across C_E = V_E = **2.3V**

$\qquad$ D.C. voltage across C_C = V_C = **10.4V**

(*iii*) $\quad$ a.c. emitter resistance, $r_e' = \dfrac{25 \text{ mV}}{I_E} = \dfrac{25 \text{ mV}}{2.3 \text{ mA}} = \textbf{10.9}\boldsymbol{\Omega}$

(*iv*) Total a.c. collector resistance is given by ;

$$R_{AC} = R_C \| R_L = \frac{R_C R_L}{R_C + R_L} = \frac{2 \times 1}{2 + 1} = 0.667 \text{ k}\Omega$$

$\therefore \qquad$ Voltage gain, $A_v = \dfrac{R_{AC}}{r_e'} = \dfrac{0.667 \text{ k}\Omega}{10.9 \ \Omega} = \textbf{61.2}$

(*v*) As calculated above, V_C = 10.4V and V_E = 2.3V. Since $V_C > V_E$, the transistor is in **active state.**

Example 10.18. *An amplifier has a voltage gain of 132 and* β = 200. *Determine the power gain and output power of the amplifier if the input power is 60 μW.*

Solution.

$$\text{Power gain, } A_p = \text{current gain} \times \text{voltage gain}$$
$$= \beta \times A_v = 200 \times 132 = \textbf{26400}$$
$$\text{Output power, } P_{out} = A_p \times P_{in} = (26400) \ (60 \ \mu W) = \textbf{1.584 W}$$

Example 10.19. *For the circuit shown in Fig. 10.33, determine (i) the current gain (ii) the voltage gain and (iii) the power gain. Neglect the a.c. emitter resistance for the transistor.*
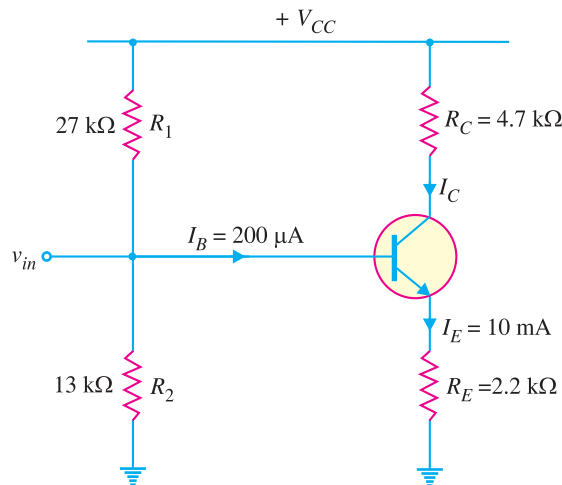

Fig. 10.33

Solution. In most practical circuits, the value of a.c. emitter resistance r_e' for the transistor is generally quite small as compared to R_E and can be neglected in circuit calculations with reasonable accuracy.

(i)
$$I_C = I_E - I_B = 10 \text{ mA} - 200 \text{ μA} = 9.8 \text{ mA}$$

Current gain, $A_i = \beta = \dfrac{I_{out}}{I_{in}} = \dfrac{I_C}{I_B} = \dfrac{9.8 \text{ mA}}{200 \text{ μA}} = \mathbf{49}$

(ii)
Voltage gain, $A_v = \dfrac{R_C}{R_E} = \dfrac{4.7 \text{ kΩ}}{2.2 \text{ kΩ}} = \mathbf{2.14}$

(iii)
Power gain, $A_p = A_i \times A_v = 49 \times 2.14 = \mathbf{105}$

10.15 Input Impedance of *CE* Amplifier

When one CE amplifier is being used to drive another, the input impedance of the second amplifier will serve as the load resistance of the first. Therefore, in order to calculate the voltage gain (A_v) of the first amplifier stage correctly, we must calculate the input impedance of the second stage.

The input impedance of an amplifier can be found by using the ac equivalent circuit of the amplifier as shown in Fig. 10.34.

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

where Z_{in} = input impedance of the amplifier

$Z_{in\,(base)}$ = input impedance of transistor base

Now $Z_{in\,(base)} = {}^*\beta\, r_e'$

Fig. 10.34

The input impedance [Z_{in}] is always less than the input impedance of the base [$Z_{in(base)}$].
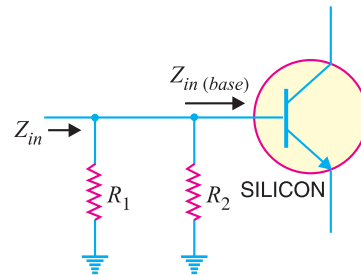
Example 10.20. *Determine the input impedance of the amplifier circuit shown in Fig. 10.35.*
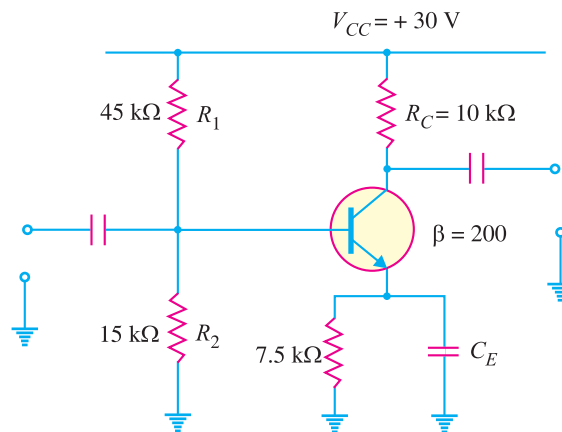
Fig. 10.35

Solution.   Voltage across R_2, $V_2 = \dfrac{V_{CC}}{R_1 + R_2} \times R_2 = \dfrac{30}{45 + 15} \times 15 = 7.5 \text{ V}$

. . . .

* $Z_{in(base)} = \dfrac{V_{in}}{i_b} = \dfrac{i_e\, r_e'}{i_b}$. Since $\dfrac{i_e}{i_b}$ is approximately equal to β, $Z_{in\,(base)} = \beta\, r_e'$.

$$\text{Voltage across } R_E, V_E = V_2 - V_{BE} = 7.5 - 0.7 \simeq 7.5 \text{ V}$$

$$\text{Emitter current, } I_E = \frac{V_E}{R_E} = \frac{7.5 \text{ V}}{7.5 \text{ k}\Omega} = 1 \text{ mA}$$

$$\text{AC emitter resistance, } r'_e = 25 \text{ mV}/I_E = 25 \text{ mV}/1 \text{ mA} = 25 \,\Omega$$

$$Z_{in \,(base)} = \beta \, r'_e = 200 \times 25 = 5 \times 10^3 \,\Omega = 5 \text{ k}\Omega$$

$$\therefore \qquad Z_{in} = R_1 \| R_2 \| Z_{in \,(base)}$$

$$= 45 \text{ k}\Omega \| 15 \text{ k}\Omega \| 5 \text{ k}\Omega = \textbf{3.45 k}\boldsymbol{\Omega}$$

10.16 Voltage Gain Stability

One important consideration for an amplifier is the stability of its voltage gain. An amplifier should have voltage gain values that are stable so that the output of the circuit is predictable under all normal conditions. In a standard *CE* amplifier, the entire d.c. emitter resistance R_E is bypassed by the bypass emitter capacitor C_E. Therefore, the total a.c. emitter resistance is r'_e. The voltage gain of such an amplifier at no-load is given by ;

$$\text{Voltage gain, } A_v = \frac{R_C}{r'_e} \quad \text{where } r'_e = \frac{25 \text{ mV}}{I_E}$$

The voltage gain of a standard *CE* amplifier is quite large. However, the drawback of the circuit is that its voltage gain changes with emitter current I_E, temperature variations and transistor replacement. For example, if emitter current I_E increases, the a.c. emitter resistance r'_e decreases. This changes the voltage gain of the amplifier. Similarly, when the temperature varies or when a transistor is replaced, the a.c. current gain β changes. This will also result in the change in voltage gain. In order to stabilise the voltage gain, the emitter resistance R_E is partially bypassed by C_E. Such an amplifier is called a *swamped amplifier*.

Standard *CE* Amplifier   Swamped Amplifier
(i)   (ii)
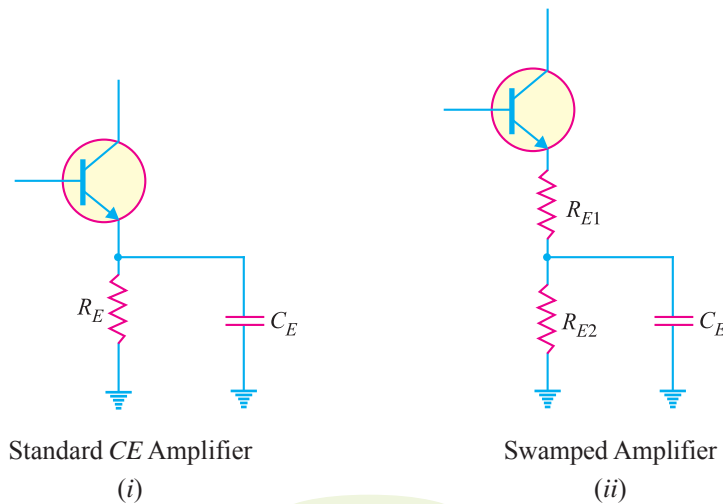
Fig. 10.36

Fig. 10.36 (*i*) shows the emitter leg of a standard *CE* amplifier while Fig. 10.36 (*ii*) shows the emitter leg of swamped amplifier. In swamped amplifier, the resistance R_E is split into two parts *viz.* R_{E1} and R_{E2}. Only R_{E2} is bypassed by C_E while R_{E1} is not.

10.17 Swamped Amplifier

Fig. 10.37 shows the circuit of a swamped amplifier. Note that d.c. emitter resistance R_E is divided into two parts *viz.* R_{E1} and R_{E2}. Only resistance R_{E2} is bypassed by the capacitor C_E while resistance

R_{E1} is not. This method swamps or minimises the effect of r'_e on the voltage gain without reducing the voltage gain too much. Now the total a.c. emitter resistance is $(r'_e + R_{E1})$ instead of r'_e as in a standard *CE* amplifier. Therefore, the voltage gain of a swamped amplifier at no-load becomes :

$$\text{Voltage gain, } A_v = \frac{R_C}{r'_e + R_{E1}}$$
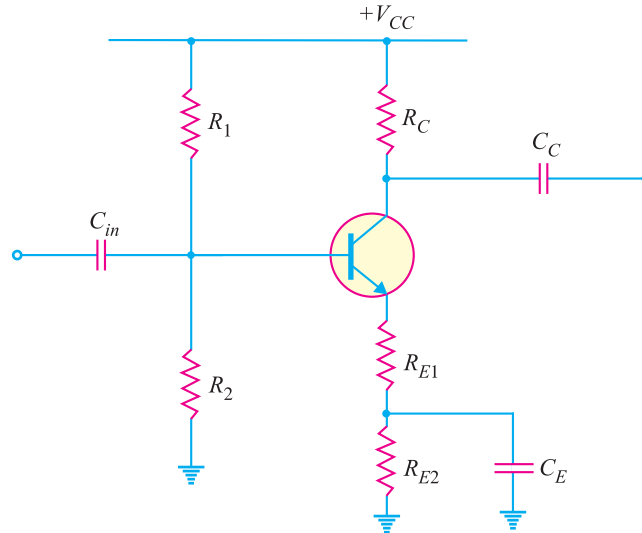
Fig. 10.37

If $R_{E1} \geq 10\ r'_e$, then the effect of r'_e is almost negligible and the voltage gain is given by ;

$$A_v \simeq \frac{R_C}{R_{E1}}$$

Therefore, the voltage gain is essentially independent of r'_e or it is reasonably stabilised.

Effect of swamping on $Z_{in\ (base)}$. The $Z_{in\ (base)}$ with R_E completely bypassed is $Z_{in\ (base)} = \beta\ r'_e$. When the emitter resistance is partially bypassed, the portion of the resistance that is unbypassed (*i.e.* R_{E1}) is seen by the a.c. signal and appears in series with r'_e. Therefore, for swamped amplifier,

$$Z_{in\ (base)} = \beta\ (r'_e + R_{E1})$$

Example 10.21. *Determine the value of voltage gain (A_v) for the swamped amplifier shown in Fig. 10.38. What will be $Z_{in\ (base)}$ for this circuit ?*

Solution. In order to find voltage gain (A_v), we first determine D.C. emitter current I_E and then a.c. emitter resistance r'_e. The value of I_E can be determined as under :

$$\text{D.C. voltage across } R_2, V_2 = \frac{V_{CC}}{R_1 + R_2} \times R_2 = \frac{10}{18 + 4.7} \times 4.7 = 2.1\text{V}$$

$$\text{D.C. voltage across } R_E, V_E = V_2 - V_{BE} = 2.1\text{V} - 0.7\text{V} = 1.4\text{V}$$

$$\text{D.C. emitter current, } I_E = \frac{V_E}{R_{E1} + R_{E2}} = \frac{1.4\text{V}}{300\ \Omega + 900\ \Omega} = 1.16\text{ mA}$$

$$\therefore \quad \text{a.c. emitter resistance, } r'_e = \frac{25\text{ mV}}{I_E} = \frac{25\text{ mV}}{1.16\text{ mA}} = 21.5\Omega$$

$$\text{Voltage gain, } A_v = \frac{R_C}{r'_e + R_{E1}} = \frac{1.5\text{ k}\Omega}{21.5\Omega + 300\ \Omega} = \textbf{4.66}$$

Input impedance of transistor base is given by ;

$$Z_{in\,(base)} = \beta\,(r'_e + R_{E1}) = 150\,(21.5\Omega + 300\Omega) = \textbf{48.22 k}\boldsymbol{\Omega}$$
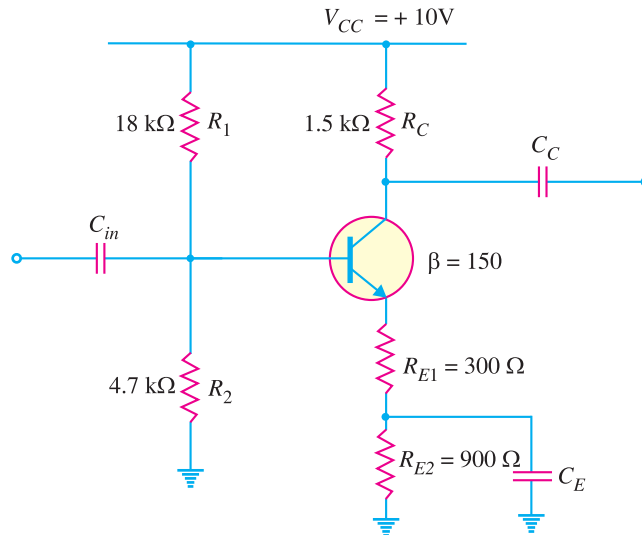
Fig. 10.38

Example 10.22. *Determine the change in voltage gain for the amplifier in example 10.21 when* r'_e *doubles in value.*

Solution.

$$\text{Voltage gain, } A_v = \frac{R_C}{r'_e + R_{E1}}$$

When r'_e doubles, the value of A_v becomes :

$$A_v = \frac{R_C}{2r'_e + R_{E1}} = \frac{1.5\ k\Omega}{2 \times 21.5\ \Omega + 300\ \Omega} = 4.37$$

∴ Change in gain $= 4.66 - 4.37 = 0.29$

Therefore, percentage change from the original value

$$= \frac{4.66 - 4.37}{4.66} \times 100 = \frac{0.29}{4.66} \times 100 = \textbf{6.22\%}\ (\textit{decrease})$$

Consequently, the change in A_v is only 6.22% from the original value. In an amplifier that is not swamped, doubling the value of r'_e would cause the value of A_v to change (decrease) by *50%. Thus the voltage gain (A_v) of the amplifier becomes more stable by swamping the emitter circuit.

Example 10.23. *Fig. 10.39 shows the circuit of a **standard CE amplifier. The emitter circuit of this amplifier is swamped as shown in Fig. 10.40. Find :*

(ii) input impedance of transistor base [i.e. $Z_{in\,(base)}$] for each circuit.

(ii) input impedance (Z_{in}) for each circuit.

. . . .

* Original $A_v = \dfrac{R_C}{r'_e}$; Final $A_v = \dfrac{R_C}{2\,r'_e}$. Obviously, a change of 50% from the original value.

** Remember that in a standard *CE* amplifier, the emitter resistance R_E is completely bypassed by the capacitor C_E.

Fig. 10.39

Fig. 10.40

Solution. Both the circuits have the same value of a.c. emitter resistance r'_e. Therefore, following the standard procedure for finding r'_e gives us a value of *25Ω for both circuits.
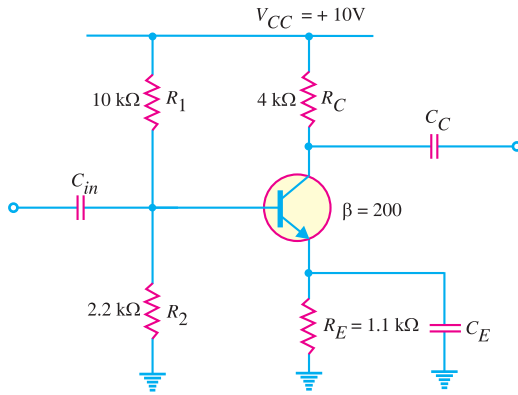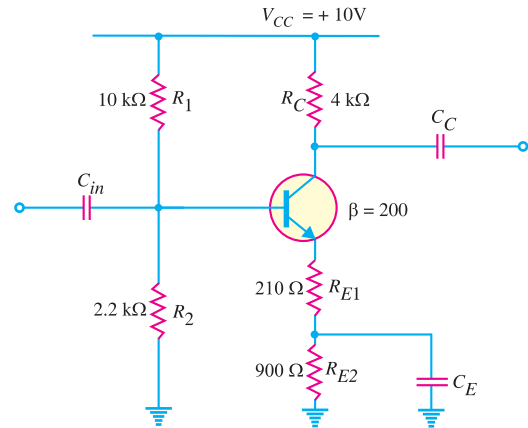
(i) $Z_{in\,(base)}$

For the standard *CE* amplifier shown in Fig. 10.39, we have,

$$Z_{in\,(base)} = \beta r'_e = 200 \times 25\Omega = \textbf{5 k}\boldsymbol{\Omega}$$

For the swamped amplifier shown in Fig. 10.40, we have,

$$Z_{in\,(base)} = \beta\,(r'_e + R_{E1})$$
$$= 200\,(25\Omega + 210\ \Omega) = 47000\Omega = \textbf{47 k}\boldsymbol{\Omega}$$

(ii) Z_{in}

For the standard *CE* amplifier shown in Fig. 10.39, we have,

$$Z_{in} = R_1 \parallel R_2 \parallel Z_{in\,(base)}$$
$$= 10\text{ k}\Omega \parallel 2.2\text{ k}\Omega \parallel 5\text{ k}\Omega = \textbf{1.33 k}\boldsymbol{\Omega}$$

For the swamped amplifier circuit shown in Fig. 10.40, we have,

$$Z_{in} = R_1 \parallel R_2 \parallel Z_{in\,(base)}$$
$$= 10\text{ k}\Omega \parallel 2.2.\text{ k}\Omega \parallel 47\text{ k}\Omega = \textbf{1.74 k}\boldsymbol{\Omega}$$

Note that swamping increases the input impedance (Z_{in}) of the amplifier. This reduces the amplifier's loading effects on a previous stage.

Example 10.24. *Find the voltage gain for both circuits of example 10.23.*

Solution.

For the standard *CE* amplifier shown in Fig. 10.39, the voltage gain (A_v) is given by ;

$$A_v = \frac{R_C}{r'_e} = \frac{4\text{ k}\Omega}{25\ \Omega} = \textbf{160}$$

For the swamped amplifier shown in Fig. 10.40, the voltage gain (A_v) is given by ;

. . . .

* $V_2 = \dfrac{V_{CC}}{R_1 + R_2} \times R_2 = \dfrac{10}{10 + 2.2} \times 2.2 = 1.8\text{V}$; $V_E = V_2 - V_{BE} = 1.8\text{V} - 0.7\text{V} = 1.1\text{V}$

$I_E = \dfrac{V_E}{R_E} = \dfrac{1.1\text{V}}{1.1\text{ k}\Omega} = 1\text{ mA}$ $\therefore$ $r'_e = \dfrac{25\text{ mV}}{I_E} = \dfrac{25\text{ mV}}{1\text{ mA}} = 25\Omega$

$$A_v = \frac{R_C}{r_e' + R_{E1}} = \frac{4 \text{ k}\Omega}{25\ \Omega + 210\ \Omega} = \frac{4 \text{ k}\Omega}{235\ \Omega} = \mathbf{17}$$

The following points may be noted ;

(**i**)   The two circuits are identical for d.c. analysis purposes. Both have a total of 1.1. kΩ d.c. resistance in their emitter circuits.

(**ii**)   For a standard *CE* amplifier, the total a.c. emitter resistance is r_e'. When this amplifier is swamped, the total a.c. emitter resistance is increased to $(r_e' + R_{E1})$.

(**iii**)   Swamping reduces the voltage gain of the amplifier. However, the gain of a swamped amplifier is more stable than that of a comparable standard *CE* amplifier.

10.18 Classification Of Amplifiers

The transistor amplifiers may be classified as to their *usage, frequency capabilities, coupling methods* and *mode of operation.*

(**i**)   ***According to use.***   The classifications of amplifiers as to usage are basically *voltage amplifiers* and *power amplifiers*. The former primarily increases the voltage level of the signal whereas the latter mainly increases the power level of the signal.

(**ii**)   ***According to frequency capabilities.***   According to frequency capabilities, amplifiers are classified as *audio amplifiers, radio frequency amplifiers* etc.   The former are used to amplify the signals lying

Radio amplifiers

in the audio range *i.e.* 20 Hz to 20 kHz whereas the latter are used to amplify signals having very high frequency.

(**iii**)   ***According to coupling methods.***   The output from a single stage amplifier is usually insufficient to meet the practical requirements. Additional amplification is often necessary. To do this, the output of one stage is coupled to the next stage. Depending upon the coupling device used, the amplifiers are classified as *R-C coupled amplifiers, transformer coupled amplifiers* etc.

(**iv**)   ***According to mode of operation.***   The amplifiers are frequently classified according to their mode of operation as *class A, class B* and *class C* amplifiers.   This classification depends on the portion of the input signal cycle during which collector current is expected to flow.   Thus, class *A* amplifier is one in which collector current flows for the entire a.c. signal.   Class *B* amplifier is one in which collector current flows for half-cycle of input a.c. signal.   Finally, class *C* amplifier is one in which collector current flows for less than half-cycle of a.c. signal.

> **Example 10.25.** *What do you understand by following amplifiers:*
>
>   (i)   *Class A voltage amplifier*   (ii) *Audio voltage amplifier*
>
> (iii)   *Class B power amplifier*   (iv) *Class A transformer coupled power amplifier ?*

Solution.   (*i*) Class *A* voltage amplifier means that it raises the voltage level of the signal and its mode of operation is such that collector current flows for the whole input signal.

(**ii**)   Audio voltage amplifier means that it raises the voltage level of audio signal (*i.e.* one having frequency range 20 Hz to 20 kHz) and its mode of operation is class *A*.

(**iii**)   It means that this amplifier raises the power level of the signal and its mode of operation is such that collector current flows for half-cycle of the signal only.

(*iv*) It means that power amplification is being done, coupling is by transformer and mode of operation is class *A*.

10.19 Amplifier Equivalent Circuit

An amplifier can be replaced by an equivalent circuit for the purpose of analysis. Fig. 10.41 (*i*) shows the amplifier circuit while Fig. 10.41 (*ii*) shows its equivalent circuit.

V_1 = input signal voltage to the amplifier
I_1 = input signal current
R_{in} = input resistance of the amplifier
A_0 = voltage gain of the amplifier when no load is connected
I_2 = output current
V_2 = output voltage across load R_L
R_{out} = output resistance of the amplifier
R_L = load resistance
A_v = voltage gain when load R_L is connected

(*i*) (*ii*)
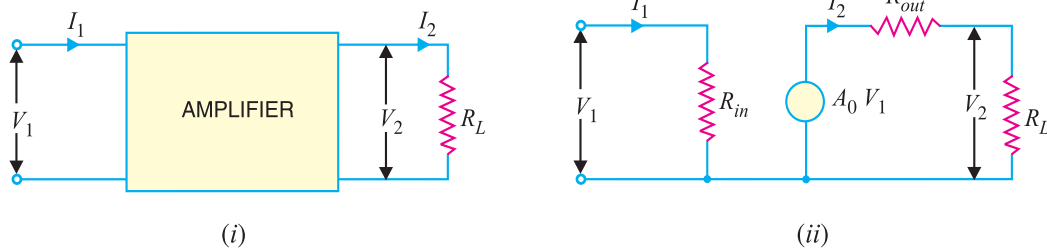
Fig. 10.41

Note that capability of the amplifier to produce voltage gain is represented by the voltage generator A_0V_1. The voltage gain of the loaded amplifier is A_v. Clearly, A_v will be less than A_0 due to voltage drop in R_{out}.

10.20 Equivalent Circuit with Signal Source

If the signal source of voltage E_S and resistance R_S is considered, the amplifier equivalent circuit will be as shown in Fig. 10.42.

Referring to Fig. 10.42, we have,

$$I_1 = \frac{E_S}{R_S + R_{in}}$$

$$\therefore \qquad V_1 = I_1 R_{in} = \frac{E_S R_{in}}{R_S + R_{in}}$$

$$I_2 = \frac{A_0 V_1}{R_{out} + R_L} \qquad \qquad ...(i)$$

$$= \frac{A_0 I_1 R_{in}}{R_{out} + R_L} \qquad \qquad ...(ii)$$

$$\therefore \qquad V_2 = I_2 R_L = \frac{A_0 V_1 R_L}{R_{out} + R_L} \qquad \qquad ...(iii)$$

$$\text{Voltage gain, } A_v = \frac{V_2}{V_1} = \frac{A_0 R_L}{R_{out} + R_L}$$

Fig. 10.42

$$\text{Current gain, } A_i = \frac{I_2}{I_1} = \frac{A_0\, R_{in}}{R_{out} + R_L}$$

$$\text{Power gain, } A_p = \frac{I_2^2\, R_L}{I_1^2\, R_{in}} = \frac{(I_2\, R_L)\, I_2}{(I_1\, R_{in})\, I_1}$$

$$= \frac{V_2\, I_2}{V_1\, I_1} = \left(\frac{V_2}{V_1}\right) \times \left(\frac{I_2}{I_1}\right)$$

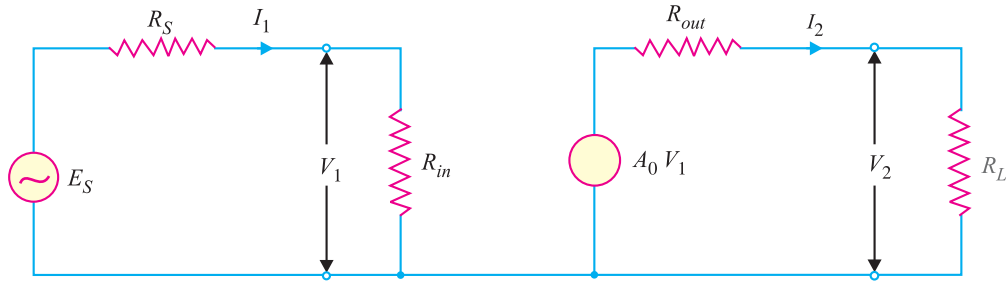$$= A_v \times A_i$$

Note. The use of such an equivalent circuit is restricted to the signal quantities only. Further, in drawing the equivalent circuit, it is assumed that exact linear relationship exists between input and output signals *i.e.* the amplifier produces no waveform distortion.

Example 10.26. *An amplifier has an open circuit voltage gain of 1000, an input resistance of 2 kΩ and an output resistance of 1Ω. Determine the input signal voltage required to produce an output signal current of 0.5A in 4Ω resistor connected across the output terminals.*
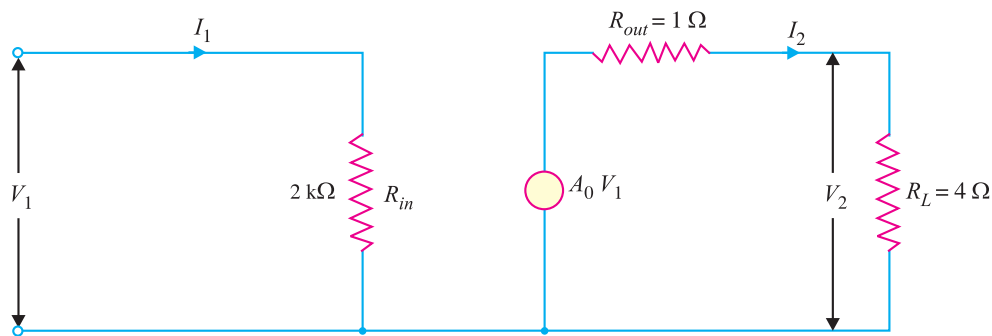

Fig. 10.43

Solution. Fig. 10.43 shows the equivalent circuit of the amplifier. Here $A_0 = 1000$.

$$\frac{I_2}{I_1} = \frac{A_0\, R_{in}}{R_{out} + R_L} \qquad \text{[See Art. 10.20]}$$

$$= \frac{1000 \times 2000}{1 + 4} = 4 \times 10^5$$

$$\therefore \qquad I_1 = \frac{I_2}{4 \times 10^5} = \frac{0.5}{4 \times 10^5} = 1.25 \times 10^{-6}\ \text{A}$$

Now $\qquad V_1 = I_1 R_{in} = (1.25 \times 10^{-6}) \times 2000 = 2.5 \times 10^{-3} \text{ V} = \textbf{2.5 mV}$

Example 10.27. *An amplifier has an open circuit voltage gain of 1000, an output resistance of 15Ω and an input resistance of 7kΩ. It is supplied from a signal source of e.m.f. 10mV and internal resistance 3kΩ. The amplifier feeds a load of 35 Ω. Determine (i) the magnitude of output voltage and (ii) power gain.*
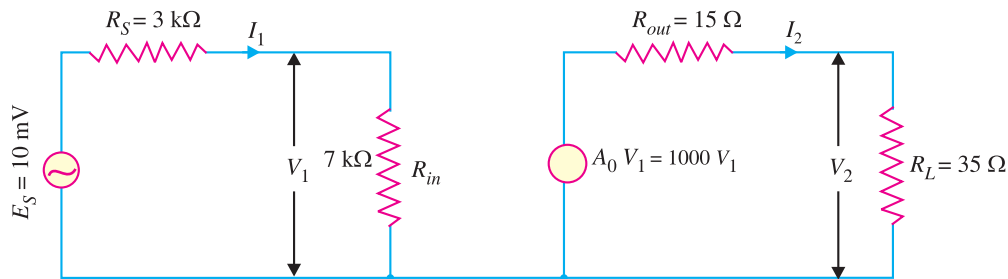
Fig. 10.44

Solution. **(i)** $\qquad I_1 = \dfrac{E_S}{R_S + R_{in}} = \dfrac{10 \times 10^{-3}}{3000 + 7000} = 10^{-6} \text{ A}$

$$V_1 = I_1 R_{in} = 10^{-6} \times 7000 = 7 \times 10^{-3} \text{ V}$$

$$A_v = \frac{V_2}{V_1} = \frac{A_0 R_L}{R_{out} + R_L} = \frac{1000 \times 35}{15 + 35} = 700$$

∴ $\qquad V_2 = 700 \, V_1 = 700 \times 7 \times 10^{-3} = \textbf{4.9 V}$

(ii) $\qquad$ Output power, $P_2 = \dfrac{V_2^2}{R_L} = \dfrac{(4.9)^2}{35} = 0.686 \text{ W}$

$\qquad$ Input power, $P_1 = \dfrac{V_1^2}{R_{in}} = \dfrac{(7 \times 10^{-3})^2}{7000} = 7 \times 10^{-9} \text{ W}$

∴ $\qquad$ Power gain, $A_p = \dfrac{P_2}{P_1} = \dfrac{0.686}{7 \times 10^{-9}} = \textbf{98} \times \textbf{10}^{\textbf{6}}$

Example 10.28. *An amplifier, when loaded by 2 kΩ resistor, has a voltage gain of 80 and a current gain of 120. Determine the necessary signal voltage and current to give an output voltage of 1V. What is the power gain of the amplifier ?*

Solution. $\qquad A_v = \dfrac{V_2}{V_1} = 80$

∴ $\qquad V_1 = V_2/80 = 1/80 = 0.0125 \text{ V} = \textbf{12.5 mV}$

$$A_v = \frac{A_0 R_L}{R_{out} + R_L} \qquad \qquad \text{...[See Art. 10.20]}$$

$$A_i = \frac{A_0 R_{in}}{R_{out} + R_L} \qquad \qquad \text{...[See Art. 10.20]}$$

∴ $\qquad \dfrac{A_v}{A_i} = \dfrac{R_L}{R_{in}}$

or $\qquad \dfrac{80}{120} = \dfrac{2}{R_{in}}$

∴ $\qquad R_{in} = 120 \times 2/80 = 3 \text{ k}\Omega$

Fig. 10.45

$$I_1 = V_1/R_{in} = 12.5 \text{ mV}/3 \text{ k}\Omega = \textbf{4.17 μA}$$
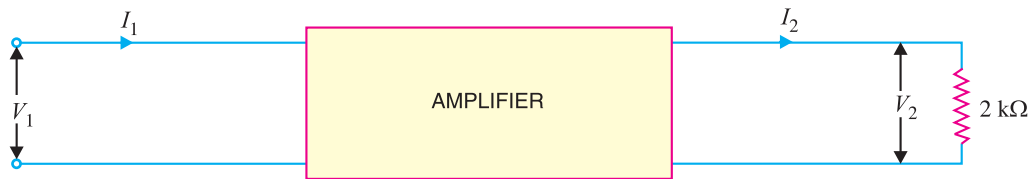$$\text{Power gain} = A_v \times A_i = 80 \times 120 = \textbf{9600}$$

10.21 Gain and Transistor Configurations

We know that the process of raising the strength of an a.c. signal is called amplification and the circuit used to preform this function is called an amplifier. There are three types of gain : *current gain, voltage gain* and *power gain.*

(*i*) The *common emitter (CE) amplifier* exhibits all there types gain . From input to output, current will increase, voltage will increase and power will increase.

(*ii*) The *common base (CB) amplifier* has voltage gain and power gain but no current gain. Note that the current gain of a *CB* circuit is less than 1.

(*iii*) The *common collector (CC) amplifier* has current gain and power gain but no voltage gain.

It is important to note that the type of gain an amplifier has depends upon the transistor configuration. Consequently, the choice of an amplifier for a given application often depends on the type of gain that is desired. Since *CE* arrangement is widely used (in about 90% applications), we shall be mainly concentrating on this type of circuit.

MULTIPLE-CHOICE QUESTIONS

1. A single stage transistor amplifier contains .... and associated circuitry.
   (*i*) two transistors   (*ii*) one transistor
   (*iii*) three transistors
   (*iv*) none of the above

2. The phase difference between the output and input voltages of a *CE* amplifier is ....
   (*i*) 180°   (*ii*) 0°
   (*iii*) 90°   (*iv*) 270°

3. It is generally desired that a transistor should have .... input impedance.
   (*i*) low   (*ii*) very low
   (*iii*) high   (*iv*) very high

4. When an a.c. signal is applied to an amplifier, the operating point moves along ....
   (*i*) d.c. load line   (*ii*) a.c. load line
   (*iii*) both d.c. and a.c. load lines
   (*iv*) none of the above

5. If the collector supply is 10 V, then collector cut off voltage under d.c. conditions is ....

   (*i*) 20 V   (*ii*) 5 V
   (*iii*) 2 V   (*iv*) 10 V

6. In the zero signal conditions, a transistor sees .... load.
   (*i*) d.c.   (*ii*) a.c.
   (*iii*) both d.c. and a.c
   (*iv*) none of the above

7. The input capacitor in an amplifier is the .... capacitor.
   (*i*) coupling   (*ii*) bypass
   (*iii*) leakage   (*iv*) none of the above

8. The point of intersection of d.c. and a.c. load lines is called ....
   (*i*) saturation point (*ii*) cut off point
   (*iii*) operating point (*iv*) none of the above

9. The slope of a.c. load line is .... that of d.c. load line.
   (*i*) the same as   (*ii*) more than
   (*iii*) less than   (*iv*) none of the above

10. If a transistor amplifier draws 2 mA when

input voltage is 10 V, then its input impedance is ....
   (i) 20 kΩ   (ii) 0.2 kΩ
   (iii) 10 kΩ   (iv) 5 kΩ

11. When a transistor amplifier is operating, the current in any branch is ....
   (i) sum of a.c. and d.c.
   (ii) a.c. only   (iii) d.c. only
   (iv) difference of a.c. and d.c.

12. The purpose of capacitors in a transistor amplifier is to ....
   (i) protect the transistor
   (ii) cool the transistor
   (iii) couple or bypass a.c. component
   (iv) provide biasing

13. In the d.c. equivalent circuit of a transistor amplifier, the capacitors are considered ....
   (i) short   (ii) open
   (iii) partially short (iv) none of the above

14. In a *CE* amplifier, voltage gain $= ..... \times \dfrac{R_{AC}}{R_{in}}$
   (i) α (ii) $(1 + \alpha)$
   (iii) $(1 + \beta)$ (iv) β

15. In practice, the voltage gain of an amplifier is expressed ....
   (i) as volts   (ii) as a number
   (iii) in *db*   (iv) none of the above

16. If the power and current gains of a transistor amplifier are 16500 and 100 respectively, then voltage gain is ....
   (i) 165   (ii) 165×10^4
   (iii) 100   (iv) none of the above

17. If R_C and R_L represent the collector resistance and load resistance respectively in a single stage transistor amplifier, then a.c. load is ....
   (i) $R_L + R_C$ (ii) $R_C \parallel R_L$
   (iii) $R_L - R_C$ (iv) R_C

18. In a *CE* amplifier, the phase difference between voltage across collector load R_C and signal voltage is ....
   (i) 180º   (ii) 270º
   (iii) 90º   (iv) 0º

19. In the a.c. equivalent circuit of a transistor amplifier, the capacitors are considered ....
   (i) short   (ii) open

(iii) partially open   (iv) none of the above

20. In a single stage transistor amplifier, R_C and R_L represent collector resistance and load resistance respectively. The transistor sees a d.c. load of ....
   (i) $R_C + R_L$ (ii) $R_C \parallel R_L$
   (iii) R_L (iv) R_C

21. The purpose of d.c. conditions in a transistor is to ....
   (i) reverse bias the emitter
   (ii) forward bias the collector
   (iii) set up operating point
   (iv) none of the above

22. An amplifier has a power gain of 100. Its *db* gain is........
   (i) 10 *db*   (ii) 20 *db*
   (iii) 40 *db*   (iv) none of the above

23. In order to get more voltage gain from a transistor amplifier, the transistor used should have ....
   (i) thin base   (ii) thin collector
   (iii) wide emitter   (iv) none of the above

24. The purpose of a coupling capacitor in a transistor amplifier is to ....
   (i) increase the output impedance of transistor
   (ii) protect the transistor
   (iii) pass a.c. and block d.c.
   (iv) provide biasing

25. The purpose of emitter capacitor (*i.e.* capacitor across R_E) is to ....
   (i) avoid voltage gain drop
   (ii) forward bias the emitter
   (iii) reduce noise in the amplifier
   (iv) none of the above

26. The ratio of output to input impedance of a *CE* amplifier is ....
   (i) about 1   (ii) low
   (iii) high   (iv) moderate

27. If a transistor amplifier feeds a load of low resistance (*e.g.* speaker), then voltage gain will be ....
   (i) high   (ii) very high
   (iii) moderate   (iv) low

28. If the input capacitor of a transistor amplifier is short-circuited, then ....
   (i) transistor will be destroyed
   (ii) biasing conditions will change

(*iii*) signal will not reach the base

(*iv*) none of the above

29. The radio wave picked up by the receiving antenna is amplified about .... times to have reasonable sound output.

(*i*) 1000　　　　(*ii*) a million

(*iii*) 100　　　　(*iv*) 10000

30. A *CE* amplifier is also called .... circuit.

(*i*) grounded emitter

(*ii*) grounded base

(*iii*) grounded collector

(*iv*) none of the above

31. The d.c. load of a transistor amplifier is generally .... that of a.c. load.

(*i*) the same as　　(*ii*) less than

(*iii*) more than　　(*iv*) none of the above

32. The value of collector load R_C in a transistor amplifier is .... the output impedance of the transistor.

(*i*) the same as　　(*ii*) less than

(*iii*) more than　　(*iv*) none of the above

33. A single stage transistor amplifier with collector load R_C and emitter resistance R_E has a d.c. load of ....

(*i*) R_C　　　　(*ii*) $R_C \parallel R_E$

(*iii*) $R_C - R_E$　　(*iv*) $R_C + R_E$

34. In transistor amplifiers, we generally use .... capacitors.

(*i*) electrolytic　　(*ii*) mica

(*iii*) paper　　　(*iv*) air

35. A single stage transistor amplifier with no load sees an a.c. load of ....

(*i*) $R_C + R_E$　　　(*ii*) R_C

(*iii*) $R_C \parallel R_E$　　　(*iv*) R_C / R_E

36. The output power of a transistor amplifier is more than the input power because the additional power is supplied by ....

(*i*) transistor　　(*ii*) biasing circuit

(*iii*) collector supply V_{CC}

(*iv*) none of the above

37. A transistor converts ....

(*i*) d.c. power into a.c. power

(*ii*) a.c. power into d.c. power

(*iii*) high resistance into low resistance

(*iv*) none of the above

38. A transistor amplifier has high output impedance because ....

(*i*) emitter is heavily doped

(*ii*) collector has reverse bias

(*iii*) collector is wider than emitter or base

(*iv*) none of the above

39. For highest power gain, one would use .... configuration.

(*i*) *CC*　　　　(*ii*) *CB*

(*iii*) *CE*　　　(*iv*) none of the above

40. *CC* configuration is used for impedance matching because its ....

(*i*) input impedance is very high

(*ii*) input impedance is low

(*iii*) output impedance is very low

(*iv*) none of the above

Answers to Multiple-Choice Questions

1. (*ii*)	**2.** (*i*)	**3.** (*iii*)	**4.** (*ii*)	**5.** (*iv*)
6. (*i*)	**7.** (*i*)	**8.** (*iii*)	**9.** (*ii*)	**10.** (*iv*)
11. (*i*)	**12.** (*iii*)	**13.** (*ii*)	**14.** (*iv*)	**15.** (*iii*)
16. (*i*)	**17.** (*ii*)	**18.** (*iv*)	**19.** (*i*)	**20.** (*iv*)
21. (*iii*)	**22.** (*ii*)	**23.** (*i*)	**24.** (*iii*)	**25.** (*i*)
26. (*iv*)	**27.** (*iv*)	**28.** (*ii*)	**29.** (*ii*)	**30.** (*i*)
31. (*iii*)	**32.** (*ii*)	**33.** (*iv*)	**34.** (*i*)	**35.** (*ii*)
36. (*iii*)	**37.** (*i*)	**38.** (*ii*)	**39.** (*iii*)	**40.** (*i*)

Chapter Review Topics

1. What do you understand by single stage transistor amplifiers ?

2. Explain with the help of output characteristics how the variations in base current affect collector current variations. Assume the base current varies sinusoidally.

3. Draw the circuit of a practical single stage transistor amplifier. Explain the function of each component.

4. Show the various currents and voltages in a single stage transistor amplifier.

5. Show that the output voltage of a single stage common emitter transistor amplifier is 180° out of phase with the input voltage.

6. What do you understand by d.c. and a.c. load lines ? How will you construct them on the output characteristics ?

7. Draw the d.c. and a.c. equivalent circuits of a transistor amplifier.

8. Derive an expression for the voltage gain of a transistor amplifier from its a.c. equivalent circuit.

9. Write short notes on the following :

(*i*) phase reversal (*ii*) d.c. and a.c. load lines

(*iii*) operating point (*iv*) classification of amplifiers.

Problems

1. In transistor amplifier, the collector current swings from 2 mA to 5 mA as the base current is changed from 5 µA to 15 µA. Find the current gain. **[300]**

2. A transistor amplifier employs a 4 kΩ as collector load. If the input resistance is 1 kΩ, determine the voltage gain. Given $\beta = 100$, $g_m = 10$ mA/volt and signal voltage = 50 mV. **[1.04]**

3. Fig. 10.46 shows the transistor amplifier. If $R_C = 4$ kΩ, $R_E = 5$ kΩ and $V_{CC} = 30$ V, draw the d.c. load line.
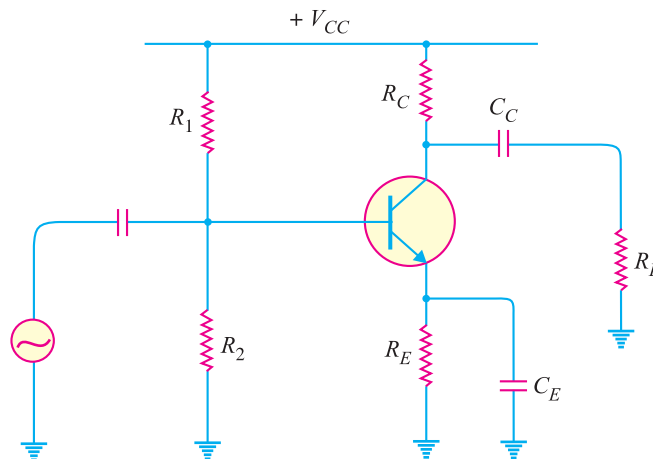
Fig. 10.46

4. Find the operating point for Fig. 10.46, $V_{CC} = 30$ V, $R_1 = 20$ kΩ, $R_2 = 20$ kΩ, $R_C = 4$ kΩ, $R_E = 5$ kΩ. **[13.2V, 1.85mA]**

5. For the circuit shown in Fig. 10.46, find the voltage gain if $\beta = 100$, $R_C = 3$ kΩ, $R_L = 6$ kΩ and $R_{in} = 2$ kΩ. **[100]**

6. In the circuit shown in Fig. 10.46, $V_{CC} = 30$ V, $R_1 = 2$ kΩ, $R_2 = 1$ kΩ, $R_C = 2$ kΩ, $R_L = 2$ kΩ, $R_E = 1$ kΩ. Draw the d.c. and a.c. load lines.

7. A voltage-divider biased circuit has an emitter voltage of 2 V and an emitter resistor of 4.7 kΩ. What is the ac resistance of emitter diode ? **[58.7 Ω]**

8. A transistor amplifier has a dc collector current of 5 mA. What is the ac resistance of the base if $\beta = 200$? **[1000 Ω]**

9. Determine the voltage gain for the amplifier circuit shown in Fig. 10.47.
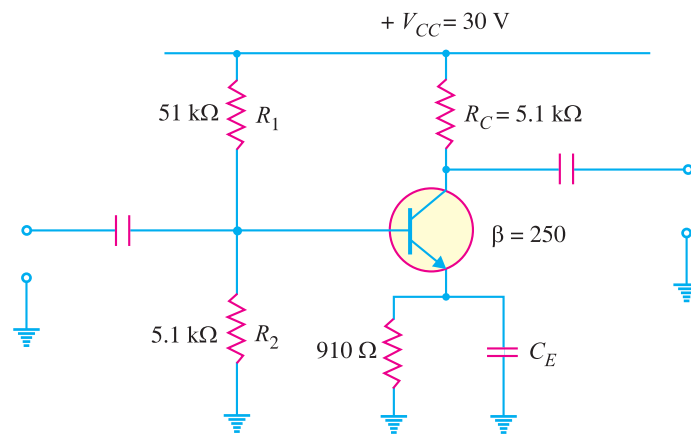
Fig. 10.47

10. What is the input impedance of the amplifier circuit shown in Fig. 10.47 ?   **[1.75 kΩ]**

11. A voltage-divider biased amplifier has the values of $R_1 = 40$ kΩ, $R_2 = 10$ kΩ, $R_C = 6$ kΩ ; $R_E = 2$ kΩ, $V_{CC} = +10$V and $\beta = 80$. Determine the a.c. emitter resistance of the transistor.   **[38.46Ω]**

12. A standard *CE* amplifier has the following values : $V_{CC} = 30$V, $R_1 = 51$ kΩ, $R_2 = 5.1$ kΩ, $R_C = 5.1$ kΩ, $R_E = 910$Ω and $\beta = 250$. Determine the voltage gain of the amplifier.   **[455.4]**

13. A *CE* amplifier has a voltage gain $A_v = 59.1$ and $\beta = 200$. Determine the power gain and output power of the amplifier when input power is 80 µW..   **[11820 ; 945.6 mW]**

14. Determine the voltage gain for the first stage in Fig. 10.48.   **[53.03]**

15. If the value of β for the second stage in Fig. 10.48 is increased to 280, determine the voltage gain of the first amplifier stage.   **[58.08]**
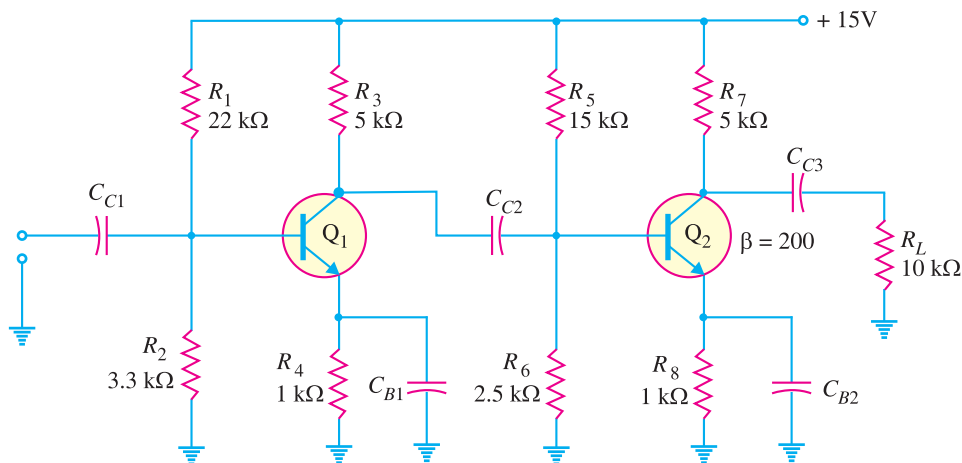

Fig. 10.48

Discussion Questions

1. Does phase reversal affect amplification ?
2. Why does ac load differ from dc load ?
3. What is the importance of load line analysis ?
4. Why is ac load line steeper than dc load line?
5. What is the significance of operating point ?

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