From exps. (*i*) and (*ii*), it is clear that magnitude of output is the same whether we take output across collector load or terminals 1 and 2. The minus sign in exp. (*ii*) simply indicates the phase reversal. The second method of taking output is used in multistages of amplification.

8.21 Performance of Transistor Amplifier

The performance of a transistor amplifier depends upon input resistance, output resistance, effective collector load, current gain, voltage gain and power gain. As *common emitter connection* is universally adopted, therefore, we shall explain these terms with reference to this mode of connection.

(*i*) **Input resistance.** *It is the ratio of small change in base-emitter voltage (ΔV_{BE}) to the resulting change in base current (ΔI_B) at constant collector-emitter voltage i.e.*

$$\text{Input resistance, } R_i = \frac{\Delta V_{BE}}{\Delta I_B}$$

The value of input resistance is quite small because the input circuit is always forward biased. It ranges from 500 Ω for small low powered transistors to as low as 5 Ω for high powered transistors. In fact, input resistance is the opposition offered by the base-emitter junction to the signal flow. Fig. 8.47 shows the general form of an amplifier. The input voltage V_{BE} causes an input current I_B.

$$\therefore \quad \text{Input resistance, } R_i = \frac{\Delta V_{BE}}{\Delta I_B} = \frac{V_{BE}}{I_B}$$

Thus if the input resistance of an amplifier is 500 Ω and the signal voltage at any instant is 1 V, then,

$$\text{Base current, } i_b = \frac{1\,V}{500\,\Omega} = 2\text{ mA}$$

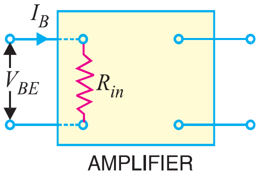


Fig. 8.47

(*ii*) **Output resistance.** *It is the ratio of change in collector-emitter voltage (ΔV_{CE}) to the resulting change in collector current (ΔI_C) at constant base current i.e.*

$$\text{Output resistance, } R_O = \frac{\Delta V_{CE}}{\Delta I_C}$$

The output characteristics reveal that collector current changes very slightly with the change in collector-emitter voltage. Therefore, output resistance of a transistor amplifier is very high– of the order of several hundred kilo-ohms. The physical explanation of high output resistance is that collector-base junction is reverse biased.

(*iii*) **Effective collector load.** *It is the total load as seen by the a.c. collector current.*

In case of single stage amplifiers, the effective collector load is a parallel combination of R_C and R_O as shown in Fig. 8.48 (*i*).

$$\text{Effective collector load, } R_{AC} = R_C \parallel R_O$$

$$= \frac{R_C \times R_O}{R_C + R_O} = {}^*R_C$$

It follows, therefore, that for a single stage amplifier, effective load is equal to collector load R_C.

However, in a multistage amplifier (*i.e.* having more than one amplification stage), the input resistance R_i of the next stage also comes into picture as shown in Fig. 8.48 (*ii*). Therefore, effective collector load becomes parallel combination of R_C, R_O and R_i *i.e.*

$$\text{Effective collector load, } R_{AC} = R_C \parallel R_O \parallel R_i$$

---

* As output resistance R_O is several times R_C, therefore, R_C can be neglected as compared to R_O.

$$R_{AC} = \frac{R_C \times R_O}{R_O} = R_C$$

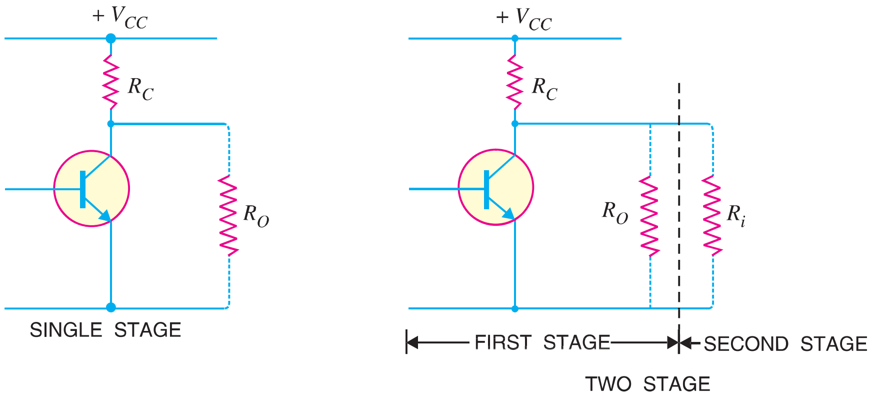
$$= {}^*R_C \parallel R_i = \frac{R_C\, R_i}{R_C + R_i}$$

As input resistance R_i is quite small (25 Ω to 500 Ω), therefore, effective load is reduced.

(iv) Current gain. *It is the ratio of change in collector current* (ΔI_C) *to the change in base current* (ΔI_B) *i.e.*

$$\text{Current gain, } \beta = \frac{\Delta I_C}{\Delta I_B}$$

The value of β ranges from 20 to 500. The current gain indicates that input current becomes β times in the collector circuit.



(i) (ii)

Fig. 8.48

(v) Voltage gain. *It is the ratio of change in output voltage* (ΔV_{CE}) *to the change in input voltage* (ΔV_{BE}) *i.e.*

$$\begin{aligned}\text{Voltage gain, } A_v &= \frac{\Delta V_{CE}}{\Delta V_{BE}}\\ &= \frac{\text{Change in output current} \times \text{effective load}}{\text{Change in input current} \times \text{input resistance}}\\ &= \frac{\Delta I_C \times R_{AC}}{\Delta I_B \times R_i} = \frac{\Delta I_C}{\Delta I_B} \times \frac{R_{AC}}{R_i} = \beta \times \frac{R_{AC}}{R_i}\end{aligned}$$

For single stage, $R_{AC} = R_C$. However, for multistage, $R_{AC} = \dfrac{R_C \times R_i}{R_C + R_i}$ where R_i is the input resistance of the next stage.

(vi) Power gain. *It is the ratio of output signal power to the input signal power i.e.*

$$\begin{aligned}\text{Power gain, } A_p &= \frac{(\Delta I_C)^2 \times R_{AC}}{(\Delta I_B)^2 \times R_i} = \left(\frac{\Delta I_C}{\Delta I_B}\right) \times \frac{\Delta I_C \times R_{AC}}{\Delta I_B \times R_i}\\ &= \text{Current gain} \times \text{Voltage gain}\end{aligned}$$

Example 8.28. *A change of 200 mV in base-emitter voltage causes a change of 100 μA in the base current. Find the input resistance of the transistor.*

Solution. Change in base-emitter voltage is

---

* $R_C \parallel R_O = R_C$ as already explained.

$$\Delta V_{BE} = 200 \text{ mV}$$

Change in base current, $\Delta I_B = 100 \ \mu\text{A}$

$$\therefore \quad \text{Input resistance, } R_i = \frac{\Delta V_{BE}}{\Delta I_B} = \frac{200 \text{ mV}}{100 \ \mu \text{ A}} = \mathbf{2 \ k\Omega}$$

Example 8.29. *If the collector current changes from 2 mA to 3mA in a transistor when collector-emitter voltage is increased from 2V to 10V, what is the output resistance ?*

Solution. Change in collector-emitter voltage is

$$\Delta V_{CE} = 10 - 2 = 8 \text{ V}$$

Change in collector current is $\Delta I_C = 3 - 2 = 1 \text{ mA}$

$$\therefore \quad \text{Output resistance, } R_O = \frac{\Delta V_{CE}}{\Delta I_C} = \frac{8 \text{ V}}{1 \text{ mA}} = \mathbf{8 \ k\Omega}$$

Example 8.30. *For a single stage transistor amplifier, the collector load is $R_C = 2k\Omega$ and the input resistance $R_i = 1k\Omega$. If the current gain is 50, calculate the voltage gain of the amplifier.*

Solution. Collector load, $R_C = 2 \text{ k}\Omega$

Input resistance, $R_i = 1 \text{ k}\Omega$

Current gain, $\beta = 50$

$$\therefore \quad \text{Voltage gain, } A_v = \beta \times \frac{R_{AC}}{R_i} = \beta \times \frac{R_C}{R_i} \qquad [\because \text{ For single stage, } R_{AC} = R_C]$$

$$= 50 \times (2/1) = \mathbf{100}$$

8.22 Cut off and Saturation Points

Fig. 8.49 (*i*) shows *CE* transistor circuit while Fig. 8.49 (*ii*) shows the output characteristcs along with the d.c. load line.

(*i*) Cut off. The point where the load line intersects the $I_B = 0$ curve is known as *cut off*. At this point, $I_B = 0$ and only small collector current (*i.e.* collector leakage current I_{CEO}) exists. At cut off, the base-emitter junction no longer remains forward biased and normal transistor action is lost. The collector-emitter voltage is nearly equal to V_{CC} *i.e.*

$$V_{CE\,(cut\,off)} = V_{CC}$$

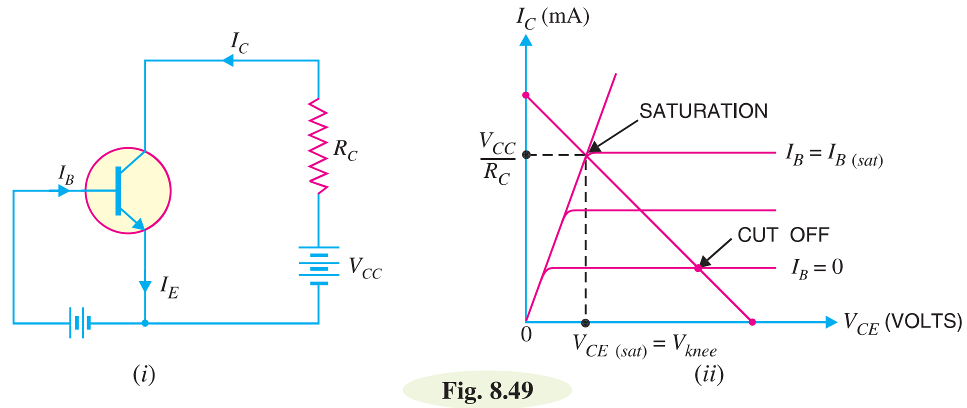


Fig. 8.49

(*ii*) Saturation. The point where the load line intersects the $I_B = I_{B(sat)}$ curve is called *saturation*. At this point, the base current is maximum and so is the collector current. At saturation, collector-base junction no longer remains reverse biased and normal transistor action is lost.

$$I_{C\,(sat)} \simeq \frac{V_{CC}}{R_C}\;;\quad V_{CE} = V_{CE(sat)} = V_{knee}$$

If base current is greater than $I_{B(sat)}$, then collector current cannot increase because collector-base junction is no longer reverse-biased.

(*iii*) Active region. The region between cut off and saturation is known as *active region*. In the active region, collector-base junction remains reverse biased while base-emitter junction remains forward biased. Consequently, the transistor will function normally in this region.

Note. We provide biasing to the transistor to ensure that it operates in the active region. The reader may find the detailed discussion on transistor biasing in the next chapter.

Summary. A transistor has two *pn* junctions *i.e.*, it is like two diodes. The junction between base and emitter may be called *emitter diode*. The junction between base and collector may be called *collector diode*. We have seen above that transistor can act in one of the three states : **cut-off, saturated** and **active**. The state of a transistor is entirely determined by the states of the emitter diode and collector diode [See Fig. 8.50]. The relations between the diode states and the transistor states are :

CUT-OFF : Emitter diode and collector diode are **OFF.**

ACTIVE : Emitter diode is **ON** and collector diode is **OFF.**

SATURATED : Emitter diode and collector diode are **ON.**

In the **active state**, collector current [See Fig 8.51 (*i*)] is β times the base current (*i.e.* $I_C = \beta I_B$). If the transistor is **cut-off,** there is no base current, so there is no collector or emitter current. That is collector emitter pathway is open [See Fig. 8.51 (*ii*)]. In **saturation,** the collector and emitter are, in effect, shorted together. That is the transistor behaves as though a switch has been closed between the collector and emitter [See Fig. 8.51 (*iii*)].

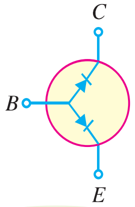
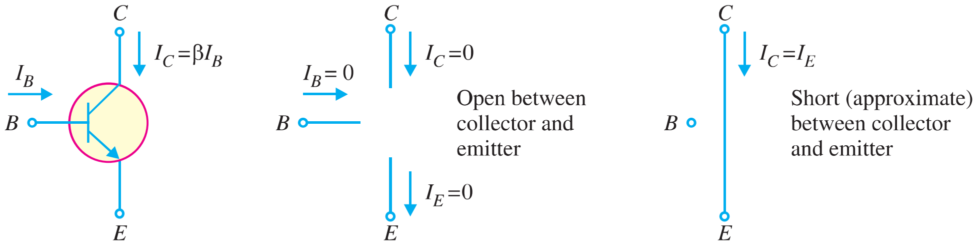


Fig. 8.50



(*i*) ACTIVE (*ii*) CUT-OFF (*iii*) SATURATED

Fig. 8.51

Note. When the transistor is in the active state, $I_C = \beta I_B$. Therefore, a transistor acts as an amplifier when operating in the active state. Amplification means *linear amplification*. In fact, small signal amplifiers are the most common *linear devices*.

Example 8.31. *Find $I_{C(sat)}$ and $V_{CE(cut\ off)}$ for the circuit shown in Fig. 8.52 (i).*

Solution. As we decrease R_B, base current and hence collector current increases. The increased collector current causes a greater voltage drop across R_C; this decreases the collector-emitter voltage. Eventually at some value of R_B, V_{CE} decreases to V_{knee}. At this point, collector-base junction is no longer reverse biased and transistor action is lost. Consequently, further increase in collector current is not possible. The transistor conducts maximum collector current ; we say the transistor is saturated.

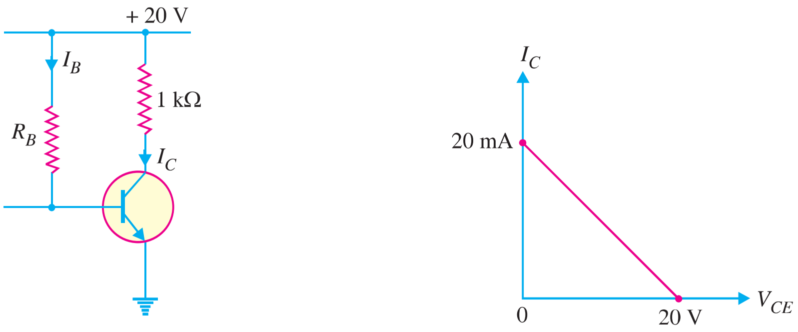
$$I_{C(sat)} = \frac{V_{CC} - {}^{*}V_{knee}}{R_C} = \frac{V_{CC}}{R_C} = \frac{20\text{ V}}{1\text{ k}\Omega} = \mathbf{20mA}$$

---

* V_{knee} is about 0.5 V for Ge transistor and about 1V for Si transistor. Consequently, V_{knee} can be neglected as compared to V_{CC} (= 20 V in this case).

As we increase R_B, base current and hence collector current decreases. This decreases the voltage drop across R_C. This increases the collector-emitter voltage. Eventually, when $I_B = 0$, the emitter-base junction is no longer forward biased and transistor action is lost. Consequently, further increase in V_{CE} is not possible. In fact, V_{CE} now equals to V_{CC}.

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



(*i*) (*ii*)

Fig. 8.52

Figure 8.52 (*ii*) shows the saturation and cut off points. Incidentally, they are end points of the d.c. load line.

Note. The exact value of $V_{CE(cut\text{-}off)} = V_{CC} - I_{CEO} R_C$. Since the collector leakage current I_{CEO} is very small, we can neglect $I_{CEO} R_C$ as compared to V_{CC}.

Example 8.32. *Determine the values of* $V_{CE\,(off)}$ *and* $I_{C\,(sat)}$ *for the circuit shown in Fig. 8.53.*

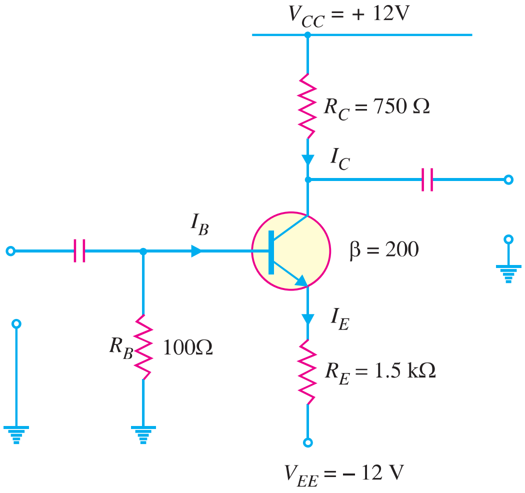


Fig. 8.53

Solution. Applying Kirchhoff's voltage law to the collector side of the circuit in Fig. 8.53, we have,

$$V_{CC} - I_C R_C - V_{CE} - {}^{*}I_C R_E + V_{EE} = 0$$

or $$V_{CE} = V_{CC} + V_{EE} - I_C (R_C + R_E) \quad \text{... }(i)$$

---

* Voltage across $R_E = I_E R_E$. Since $I_E \simeq I_C$, voltage across $R_E = I_C R_E$.

We have $V_{CE\,(off)}$ when $I_C = 0$. Therefore, putting $I_C = 0$ in eq. (*i*), we have,

$$V_{CE\,(off)} = V_{CC} + V_{EE} = 12 + 12 = \mathbf{24V}$$

We have $I_{C\,(sat)}$ when $V_{CE} = 0$.

$$\therefore \quad I_{C\,(sat)} = \frac{V_{CC} + V_{EE}}{R_C + R_E} = \frac{(12+12)\,V}{(750+1500)\,\Omega} = \mathbf{10.67\ mA}$$

Example 8.33. *Determine whether or not the transistor in Fig. 8.54 is in stauration. Assume* $V_{knee} = 0.2V$.

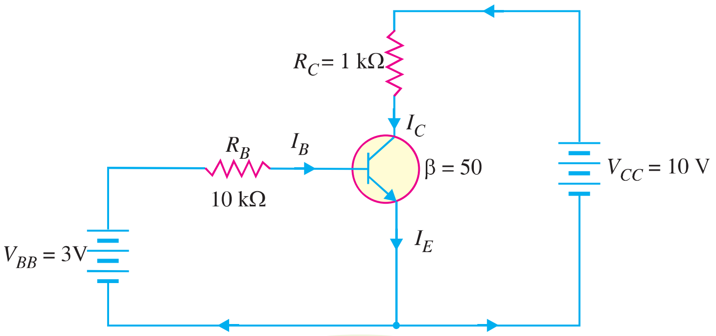


Fig. 8.54

Solution.

$$I_{C\,(sat)} = \frac{V_{CC} - V_{knee}}{R_C} = \frac{10\,V - 0.2\,V}{1\,k\Omega} = \frac{9.8\,V}{1\,k\Omega} = 9.8\text{ mA}$$

Now we shall see if I_B is large enough to produce $I_{C\,(sat)}$.

$$\text{Now} \quad I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{3V - 0.7V}{10\,k\Omega} = \frac{2.3\,V}{10\,k\Omega} = 0.23\text{ mA}$$

$$\therefore \quad I_C = \beta I_B = 50 \times 0.23 = 11.5\text{ mA}$$

This shows that with specified β, this base current (= 0.23 mA) is capable of producing I_C greater than $I_{C\,(sat)}$. Therefore, the transistor is **saturated.** In fact, the collector current value of 11. 5 mA is never reached. If the base current value corresponding to $I_{C\,(sat)}$ is increased, the collector current remains at the saturated value (= 9.8 mA).

Example 8.34. *Is the transistor in Fig. 8.55 operating in saturated state ?*

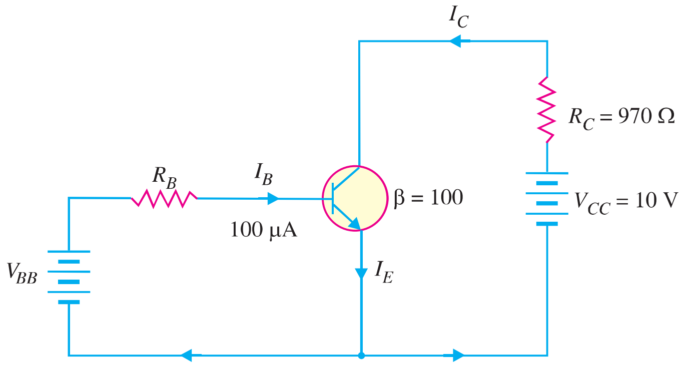


Fig. 8.55

Solution.

$$I_C = \beta I_B = (100)(100\ \mu\text{A}) = 10\ \text{mA}$$

$$V_{CE} = V_{CC} - I_C R_C = 10\text{V} - (10\ \text{mA})(970\Omega) = 0.3\text{V}$$

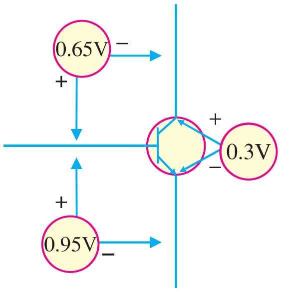


Fig. 8.56

Let us relate the values found to the transistor shown in Fig. 8.56. As you can see, the value of V_{BE} is 0.95V and the value of $V_{CE} = 0.3$V. This leaves V_{CB} of 0.65V (Note that $V_{CE} = V_{CB} + V_{BE}$). In this case, collector – base junction (*i.e.*, collector diode) is forward biased as is the emitter-base junction (*i.e.*, emitter diode). Therefore, the transistor is operating in the **saturation region.**

Note. When the transistor is in the saturated state, the base current and collector current are independent of each other. The base current is still (and always is) found only from the base circuit. The collector current is found apporximately by closing the imaginary switch between the collector and the emitter in the collector circuit.

Example 8.35. *For the circuit in Fig. 8.57, find the base supply voltage (V_{BB}) that just puts the transistor into saturation. Assume β = 200.*

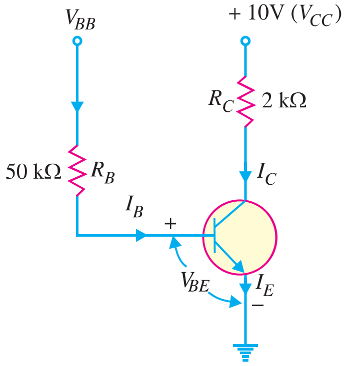


Fig. 8.57

Solution. When transistor first goes into saturation, we can assume that the collector shorts to the emitter (*i.e.* $V_{CE} = 0$) but the collector current is still β times the base current.

$$I_{C(sat)} = \frac{V_{CC} - V_{CE}}{R_C} = \frac{V_{CC} - 0}{R_C}$$

$$= \frac{10\ V - 0}{2\ k\Omega} = 5\ \text{mA}$$

The base current I_B corresponding to $I_{C\,(sat)}$ (=5 mA) is

$$I_B = \frac{I_{C\,(sat)}}{\beta} = \frac{5\ mA}{200} = 0.025\ \text{mA}$$

Applying Kirchhoff's voltage law to the base circuit, we have,

$$V_{BB} - I_B R_B - V_{BE} = 0$$

or

$$V_{BB} = V_{BE} + I_B R_B$$

$$= 0.7\text{V} + 0.025\ \text{mA} \times 50\ \text{k}\Omega = 0.7 + 1.25 = 1.95\text{V}$$

Therefore, for $V_{BB} \geq 1.95$, the transistor will be in *saturation.*

Example. 8.36. *Determine the state of the transistor in Fig. 8.58 for the following values of collector resistor :*

(i) $R_C = 2\ k\Omega$ (ii) $R_C = 4\ k\Omega$ (iii) $R_C = 8\ k\Omega$

Solution. Since I_E does not depend on the value of the collector resistor R_C, the emitter current (I_E) is the same for all three parts.

$$\text{Emitter voltage,} V_E = V_B - V_{BE} = V_{BB} - V_{BE}$$

$$= 2.7\text{V} - 0.7\ \text{V} = 2\text{V}$$

Also

$$I_E = \frac{V_E}{R_E} = \frac{2V}{1\ k\Omega} = 2\ \text{mA}$$

(*i*) When R_C = 2 kΩ. Suppose the transistor is active.

$$\therefore \quad I_C = I_E = 2\ \text{mA}$$

$$\therefore \quad I_B = I_C/\beta = 2\ \text{mA}/100 = 0.02\ \text{mA}$$

Collector voltage, $V_C = V_{CC} - I_C R_C$

$= 10\text{V} - 2\text{ mA} \times 2\text{ k}\Omega = 10\text{V} - 4\text{V} = 6\text{V}$

Since V_C (= 6V) is greater than V_E (= 2V), the transistor is **active.** Therefore, our assumption that transistor is active is correct.

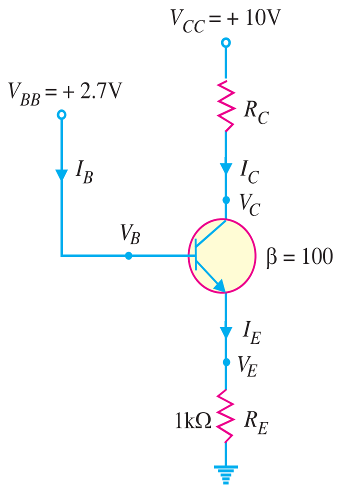


Fig. 8.58

***(ii)* When $R_C = 4\text{ k}\Omega$.** Suppose the transistor is active.

∴ $I_C = 2\text{mA}$ and $I_B = 0.02\text{ mA}$ ... as found above

Collector voltage, $V_C = V_{CC} - I_C R_C$

$= 10\text{V} - 2\text{ mA} \times 4\text{ k}\Omega = 10\text{V} - 8\text{V} = 2\text{V}$

Since $V_C = V_E$, the transistor is just at the edge of **saturation.** We know that at the edge of saturation, the relation between the transistor currents is the same as in the **active state.** Both answers are correct.

***(iii)* When $R_C = 8\text{ k}\Omega$.** Suppose the transistor is active.

∴ $I_C = 2\text{mA}$; $I_B = 0.02\text{ mA}$ ... as found earlier.

Collector voltage, $V_C = V_{CC} - I_C R_C$

$= 10\text{V} - 2\text{ mA} \times 8\text{ k}\Omega = 10\text{V} - 16\text{V} = -6\text{V}$

Since $V_C < V_E$, the transistor is **saturated** and our assumption is not correct.

Example 8.37. *In the circuit shown in Fig. 8.59, V_{BB} is set equal to the following values :*
(i) $V_{BB} = 0.5\text{V}$ (ii) $V_{BB} = 1.5\text{V}$ (iii) $V_{BB} = 3\text{V}$
Determine the state of the transistor for each value of the base supply voltage V_{BB}.

Solution. The state of the transistor also depends on the base supply voltage V_{BB}.

***(i)* For $V_{BB} = 0.5\text{V}$**

Because the base voltage V_B (= V_{BB} = 0.5V) is less than 0.7V, the transistor is **cut-off.**

***(ii)* For $V_{BB} = 1.5\text{V}$**

The base voltage V_B controls the emitter voltage V_E which controls the emitter current I_E.

Now $V_E = V_B - 0.7\text{V} = 1.5\text{V} - 0.7\text{V} = 0.8\text{V}$

$$\therefore \quad I_E = \frac{V_E}{R_E} = \frac{0.8\,V}{1\,k\Omega} = 0.8\text{ mA}$$

If the transistor is active, we have,

$I_C = I_E = 0.8\text{ mA}$ and $I_B = I_C/\beta = 0.8/100 = 0.008\text{ mA}$

∴ Collector voltage, $V_C = V_{CC} - I_C R_C$

$= 15\text{V} - 0.8\text{ mA} \times 10\text{ k}\Omega = 15\text{V} - 8\text{V} = 7\text{V}$

Since $V_C > V_E$, the transistor is **active** and our assumption is correct.

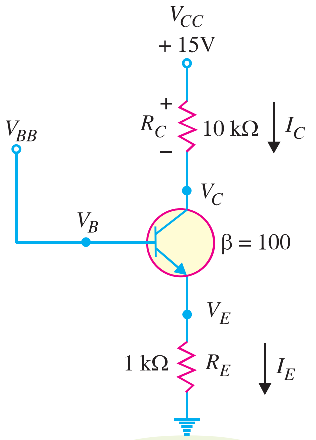


Fig. 8.59

***(iii)* For $V_{BB} = 3\text{V}$**

$V_E = V_B - 0.7\text{V} = 3\text{V} - 0.7\text{V} = 2.3\text{V}$

$$\therefore \quad I_E = \frac{V_E}{R_E} = \frac{2.3\,V}{1\,k\Omega} = 2.3\text{ mA}$$

Assuming the transistor is active, we have,

$$I_C = I_E = 2.3 \text{ mA} \quad ; \quad I_B = I_C/\beta = 2.3/100 = 0.023 \text{ mA}$$

Collector voltage, $V_C = V_{CC} - I_C R_C$

$$= 15\text{V} - 2.3 \text{ mA} \times 10 \text{ k}\Omega = 15\text{V} - 23\text{V} = -8\text{V}$$

Since $V_C < V_E$, the transistor is **saturated** and our assumption is not correct.

8.23 Power Rating of Transistor

The maximum power that a transistor can handle without destruction is known as **power rating** *of the transistor.*

When a transistor is in operation, almost all the power is dissipated at the reverse biased *collector-base junction. The power rating (or maximum power dissipation) is given by :

$$P_{D\,(max)} = \text{Collector current} \times \text{Collector-base voltage}$$

$$= I_C \times V_{CB}$$

$$\therefore \quad P_{D\,(max)} = I_C \times V_{CE}$$

$[\because V_{CE} = V_{CB} + V_{BE}$. Since V_{BE} is very small, $V_{CB} \simeq V_{CE}]$

While connecting transistor in a circuit, it should be ensured that its power rating is not exceeded otherwise the transistor may be destroyed due to excessive heat. For example, suppose the power rating (or maximum power dissipation) of a transistor is 300 mW. If the collector current is 30 mA, then maximum V_{CE} allowed is given by ;

$$P_{D\,(max)} = I_C \times V_{CE\,(max)}$$

or $$300 \text{ mW} = 30 \text{ mA} \times V_{CE\,(max)}$$

or $$V_{CE\,(max)} = \frac{300 \text{ mW}}{30 \text{ mA}} = 10\text{V}$$

This means that for $I_C = 30$ mA, the maximum V_{CE} allowed is 10V. If V_{CE} exceeds this value, the transistor will be destroyed due to excessive heat.

Maximum power dissipation curve. For **power transistors, it is sometimes necessary to draw maximum power dissipation curve on the output characteristics. To draw this curve, we should know the power rating (*i.e.* maximum power dissipation) of the transistor. Suppose the power rating of a transistor is 30 mW.

$$P_{D\,(max)} = V_{CE} \times I_C$$

or $$30 \text{ mW} = V_{CE} \times I_C$$

Using convenient V_{CE} values, the corresponding collector currents are calculated for the maximum power dissipation. For example, for $V_{CE} = 10$V,

$$I_C\,(max) = \frac{P_{D\,(max)}}{V_{CE}} = \frac{30 \text{ mW}}{10 \text{ V}} = 3\text{mA}$$

This locates the point *A* (10V, 3 mA) on the output characteristics. Similarly, many points such as *B, C, D etc.* can be located on the output characteristics. Now draw a curve through the above points to obtain the maximum power dissipation curve as shown in Fig. 8.60.

In order that transistor may not be destroyed, the transistor voltage and current (*i.e.* V_{CE} and I_C) conditions must at all times be maintained in the portion of the characteristics below the maximum power dissipation curve.

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* The base-emitter junction conducts about the same current as the collector-base junction (*i.e.* $I_E \simeq I_C$). However, V_{BE} is very small (0.3 V for *Ge* transistor and 0.7 V for *Si* transistor). For this reason, power dissipated at the base-emitter junction is negligible.

** A transistor that is suitable for large power amplification is called a *power transistor.* It differs from other transistors mostly in size ; it is considerably larger to provide for handling the great amount of power.

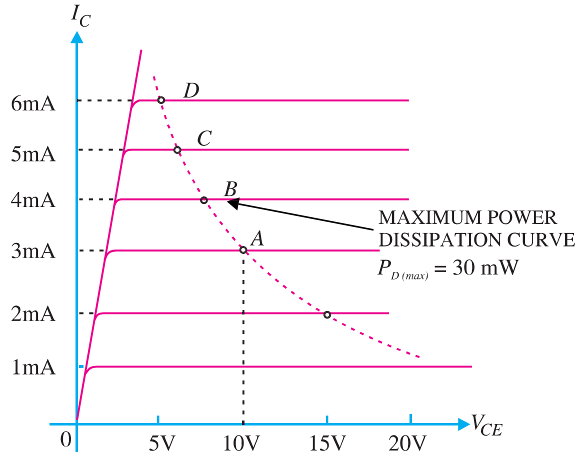


Fig. 8.60

Example 8.38. *The maximum power dissipation of a transistor is 100mW. If V_{CE} = 20V, what is the maximum collector current that can be allowed without destruction of the transistor?*

Solution.
$$P_{D\,(max)} = V_{CE} \times I_{C\,(max)}$$

or
$$100 \text{ mW} = 20 \text{ V} \times I_{C\,(max)}$$

$$\therefore \quad I_{C\,(max)} = \frac{100 \text{ mW}}{20 \text{ V}} = \mathbf{5\ mA}$$

Thus for V_{CE} = 20V, the maximum collector current allowed is 5 mA. If collector current exceeds this value, the transistor may be burnt due to excessive heat.

Note. Suppose the collector current becomes 7mA. The power produced will be 20 V × 7 mA = 140 mW. The transistor can only dissipate 100 mW. The remaining 40 mW will raise the temperature of the transistor and eventually it will be burnt due to excessive heat.

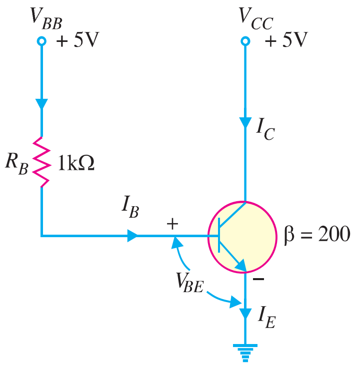


Fig. 8.61

Example 8.39. *For the circuit shown in Fig. 8.61, find the transistor power dissipation. Assume that β = 200.*

Solution.

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{(5 - 0.7)\,V}{1\,k\Omega} = 4.3 \text{ mA}$$

$$\therefore \quad I_C = \beta I_B = 200 \times 4.3 = 860 \text{ mA}$$

Now
$$V_{CE} = V_{CC} - I_C\,R_C = 5 - I_C \times 0 = 5\text{V}$$

$\therefore$ Power dissipation, $P_D = V_{CE} \times I_C$

$$= 5\text{V} \times 860 \text{ mA} = 4300 \text{ mW} = \mathbf{4.3W}$$

Example 8.40. *For the circuit shown in Fig. 8.62, find the power dissipated in the transistor. Assume β = 100.*

Solution. The transistor is usually used with a resistor R_C connected between the collector and its power supply V_{CC} as shown is Fig. 8.62. The collector resistor R_C serves two purposes. Firstly, it allows us to control the voltage V_C at the collector. Secondly, it protects the transistor from excessive collector current I_C and, therefore, from excessive power dissipation.

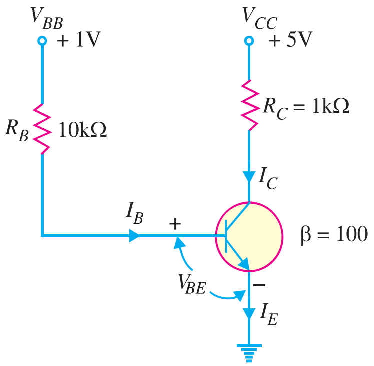


Fig. 8.62

Referring to Fig. 8.62 and applying Kirchhoff's voltage law to the base side, we have,

$$V_{BB} - I_B R_B - V_{BE} = 0$$

$$\therefore \quad I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{1\,V - 0.7\,V}{10\,k\Omega} = \frac{0.3\,V}{10\,k\Omega} = 0.03 \text{ mA}$$

Now $I_C = \beta I_B = 100 \times 0.03 = 3 \text{ mA}$

$$\therefore \quad V_{CE} = V_{CC} - I_C R_C = 5\text{V} - 3 \text{ mA} \times 1 \text{ k}\Omega = 5\text{V} - 3\text{V} = 2\text{V}$$

∴ Power dissipated in the transistor is

$$P_D = V_{CE} \times I_C = 2\text{V} \times 3 \text{ mA} = \mathbf{6\ mW}$$

Example 8.41. *The transistor in Fig. 8.63 has the following maximum ratings :*

$$P_{D\,(max)} = 800\ mW\ ;\ V_{CE\,(max)} = 15V\ ;\ I_{C\,(max)} = 100\ mA$$

Determine the maximum value to which V_{CC} can be adjusted without exceeding any rating. Which rating would be exceeded first ?

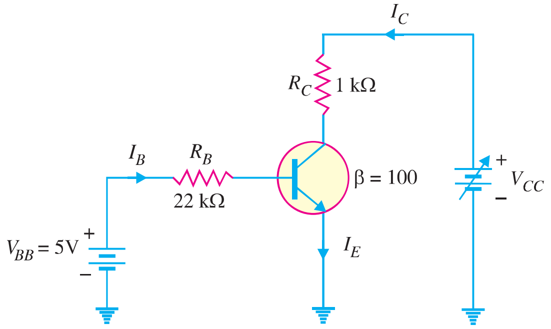


Fig. 8.63

Solution.

$$I_B = \frac{V_{BB} - V_{BE}}{R_B} = \frac{5V - 0.7V}{22\,k\Omega} = \frac{4.3\,V}{22\,k\Omega} = 195\ \mu\text{A}$$

$$\therefore \quad I_C = \beta I_B = 100 \times 195\ \mu\text{A} = 19.5 \text{ mA}$$

Note that I_C is much less than $I_{C(max)}$ and will not change with V_{CC}. It is determined only by I_B and β. Therefore, **current rating is not exceeded.**

Now $V_{CC} = V_{CE} + I_C R_C$

We can find the value of V_{CC} when $V_{CE\,(max)} = 15$V.

$$\therefore \quad V_{CC\,(max)} = V_{CE\,(max)} + I_C R_C$$

$$= 15\text{V} + 19.5 \text{ mA} \times 1 \text{ k}\Omega = 15\text{V} + 19.5 \text{ V} = 34.5\text{V}$$

Therefore, we can increase V_{CC} to **34.5V** before $V_{CE\,(max)}$ is reached.

$$P_D = V_{CE\,(max)} I_C = (15\text{V})\,(19.5 \text{ mA}) = 293 \text{ mW}$$

Since $P_{D\,(max)} = 800$ mW, **it is not exceeded** when $V_{CC} = 34.5$V.

If base current is removed causing the transistor to turn off, $V_{CE\,(max)}$ **will be exceeded** because the entire supply voltage V_{CC} will be dropped across the transistor.

8.24. Determination of Transistor Configuration

In practical circuits, you must be able to tell whether a given transistor is connected as a common emitter, common base or common collector. There is an easy way to ascertain it. Just locate the terminals where the input a.c. singal is applied to the transistor and where the a.c output is taken from the transistor. The remaining third terminal is the common terminal. For instance, if the a.c input is applied to the base and the a.c output is taken from the collector, then common terminal is the emitter. Hence the transistor is connected in **common emitter configuration.** If the a.c. input is applied to the base and a.c output is taken from the emitter, then common terminal is the collector. Therefore, the transistor is connected in **common collector configuration.**

8.25 Semiconductor Devices Numbering System

From the time semiconductor engineering came to existence, several numbering systems were adopted by different countries. However, the accepted numbering system is that announced by Proelectron Standardisation Authority in Belgium. According to this system of numbering semiconductor devices :

(*i*) Every semiconductor device is numbered by five alpha-numeric symbols, comprising either two letters and three numbers (*e.g.* BF194) or three letters and two numbers (*e.g.* BFX63). When two numbers are included in the symbol (*e.g.* BFX63), the device is intended for industrial and professional equipment. When the symbol contains three numbers (*e.g.* BF194) , the device is intended for entertainment or consumer equipment.

(*ii*) The first letter indicates the nature of semiconductor material. For example :

A = germanium, B = silicon, C = gallium arsenide, R = compound material (e.g. cadmium sulphide)

Thus AC125 is a germanium transistor whereas BC149 is a silicon transistor.

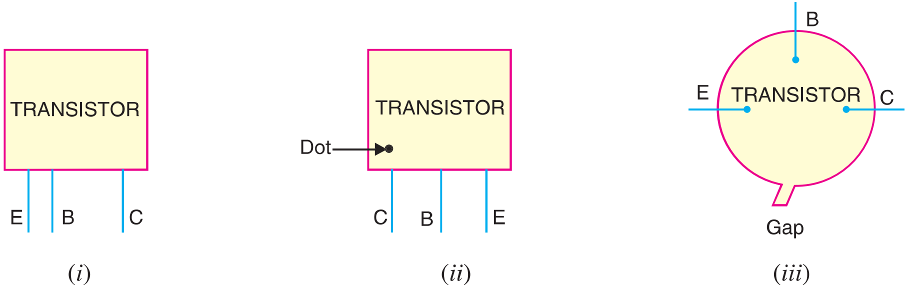
(*iii*) The second letter indicates the device and circuit function.

A = diode
B = Variable capacitance diode
C = A.F. low powered transistor
D = A.F. power transistor
E = Tunnel diode
F = H.F. low power transistor
G = Multiple device
H = Magnetic sensitive diode
K = Hall-effect device
L = H.F. power transistor
M = Hall-effect modulator
P = Radiation sensitive diode
Q = Radiation generating diode
R = Thyristor (SCR or triac)
S = Low power switching transistor
T = Thyristor (power)
U = Power switching transistor
X = diode, multiplier
Y = Power device
Z = Zener diode

8.26 Transistor Lead Identification

There are three leads in a transistor *viz.* collector, emitter and base. When a transistor is to be connected in a circuit, it is necessary to know which terminal is which. The identification of the leads of transistor varies with manufacturer. However, there are three systems in general use as shown in Fig. 8.64.

(*i*) When the leads of a transistor are in the same plane and unevenly spaced [See Fig. 8.64 (*i*)], they are identified by the positions and spacings of leads. The central lead is the base lead. The collector lead is identified by the larger spacing existing between it and the base lead. The remaining lead is the emitter.



(*i*) (*ii*) (*iii*)

Fig. 8.64

(*ii*) When the leads of a transistor are in the same plane but evenly spaced [See Fig. 8.64 (*ii*)], the central lead is the base, the lead identified by dot is the collector and the remaining lead is the emitter.

(*iii*) When the leads of a transistor are spaced around the circumference of a circle [See Fig. 8.64 (*iii*)], the three leads are generally in E-B-C order clockwise from a gap.

8.27 Transistor Testing

An ohmmeter can be used to check the state of a transistor *i.e.,* whether the transistor is good or not. We know that base-emitter junction of a transistor is forward biased while collector-base junction is reverse biased. Therefore, forward biased base-emitter junction should have low resistance and reverse biased collector-base junction should register a much higher resistance. Fig. 8.65 shows the process of testing an *npn* transistor with an ohmmeter.

(*i*) The forward biased base-emitter junction (biased by internal supply) should read a low resistance, typically 100 Ω to 1 kΩ as shown in Fig. 8.65 (*i*). If that is so, the transistor is good. However, if it fails this check, the transistor is faulty and it must be replaced.

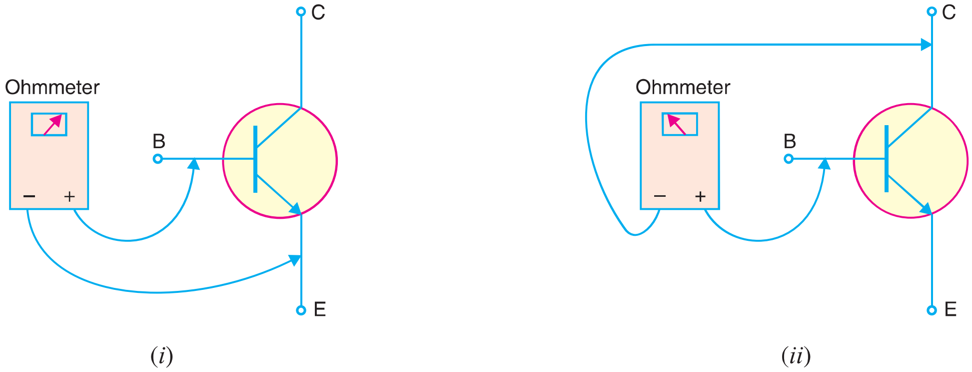


Fig. 8.65

(*ii*) The reverse biased collector-base junction (again reverse biased by internal supply) should be checked as shown in Fig. 8.65 (*ii*). If the reading of the ohmmeter is 100 kΩ or higher, the transistor is good. If the ohmmeter registers a small resistance, the transistor is faulty and requires replacement.

Note. When testing a *pnp* transistor, the ohmmeter leads must be reversed. The results of the tests, however, will be the same.

8.28 Applications of Common Base Amplifiers

Common base amplifiers are not used as frequently as the *CE* amplifiers. The two important applications of *CB* amplifiers are : (*i*) to provide voltage gain without current gain and (*ii*) for impedance matching in high frequency applications. Out of the two, the high frequency applications are far more common.

(*i*) To provide voltage gain without current gain. We know that a *CB* amplifier has a high voltage gain while the current gain is nearly 1 (*i.e.* $A_i \simeq 1$). Therefore, this circuit can be used to provide high voltage gain without increasing the value of circuit current. For instance, consider the case where the output current from an amplifier has sufficient value for the required application but the voltage gain needs to be increased. In that case, *CB* amplifier will serve the purpose because it would increase the voltage without increasing the current. This is illustrated in Fig. 8.66. The *CB* amplifier will provide voltage gain without any current gain.

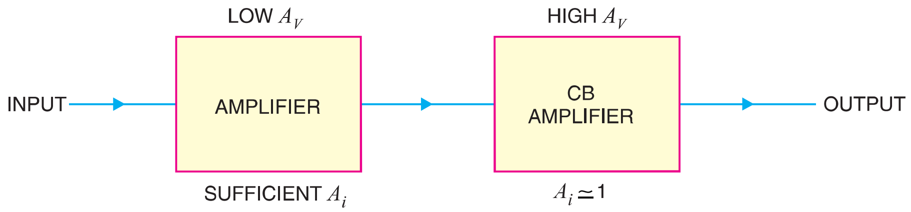


Fig. 8.66

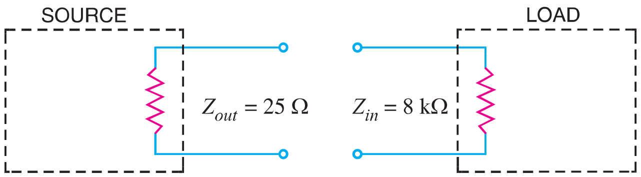


Fig. 8.67

(ii) **For impedance matching in high frequency applications.** Most high-frequency voltage sources have a very *low output impedance.* When such a low-impedance source is to be connected to a high-impedance load, you need a circuit to match the source impedance to the load impedance. Since a common-base amplifier has *low input impedance* and *high output impedance*, the common-base circuit will serve well in this situation. Let us illustrate this point with a numerical example. Suppose a high-frequency source with internal resistance 25 Ω is to be connected to a load of 8 kΩ as shown in Fig. 8.67. If the source is directly connected to the load, small source power will be transferred to the load due to mismatching. However, it is possible to design a *CB* amplifier that has an input impedance of nearly 25 Ω and output impedance of nearly 8 kΩ. If such a *CB* circuit is placed between the source and the load, the source will be matched to the load as shown in Fig. 8.68.

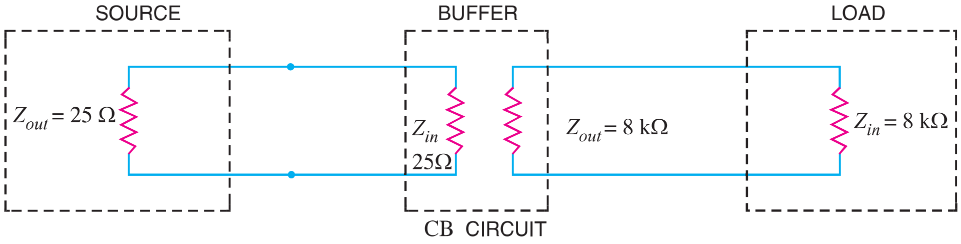


Fig. 8.68

Note that source impedance very closely matches the input impedance of *CB* amplifier. Therefore, there is a maximum power transfer from the source to input of *CB* amplifier. The high output impedance of the amplifier very nearly matches the load resistance. As a result, there is a maximum power transfer from the amplifier to the load. The net result is that maximum power has been transferred from the original source to the original load. A common-base amplifier that is used for this purpose is called a *buffer amplifier*.