# 1. Large Signal Amplifiers

## 1.1 Introduction

The first few stages in a multistage amplifier have the function of only *voltage amplification*. However, the last stage is designed to provide maximum power. This final stage is known as *power stage*.

## 1.2 Transistor Audio Power Amplifier

*A transistor amplifier which raises the power level of the signals that have audio frequency range (20 Hz to 20 kHz) is known as* **transistor audio power amplifier.**

The power amplifier differs from all the previous stages in that here a concentrated effort is made to obtain maximum output power. A transistor that is suitable for power amplification is generally 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. Audio power amplifiers are used to deliver a large amount of power to a low resistance load.

## 1.3 Small Signal and Large Signal Amplifiers

The first few stages of a multistage amplifier handle small signals (a few $\mu$V from an antenna) and have the function of only voltage amplification. However, the last stage handles a large signal and its job is to produce a large amount of power in order to operate the output device (*e.g.* speaker).

### 1.3.1 Small-signal amplifiers.

Those amplifiers which handle small input a.c. signals (a few mV or a few $\mu$V) are called *small-signal amplifiers.* E.g voltage amplifiers. The small-signal amplifiers are designed to operate over the linear portion of the output characteristics. Therefore, the transistor parameters such as current gain, input impedance, output impedance etc. do not change as the amplitude of the signal changes. Such amplifiers amplify the signal with little or no distortion.

### 1.3.2 Large-signal amplifiers.

Those amplifiers which handle large input a.c. signals (a few volts) are called *large-signal amplifiers.* Eg Power amplifiers. Large-signal amplifiers are designed to provide a large amount of a.c. power output so that they can operate the output device *e.g.*a speaker. The main features of a large-signal amplifier or power amplifier are the circuit's power efficiency, the maximum amount of power that the circuit is capable of handling and the impedance matching to the output device.

## 1.4 Difference between Voltage and Power Amplifiers

A voltage amplifier is designed to achieve maximum voltage amplification. It is, however, not important to raise the power level. On the other hand, a power amplifier is designed to obtain maximum output power.

### 1.4.1 Voltage amplifier.

The voltage gain of an amplifier is given by:

$$A_v = \beta \times \frac{R_C}{R_{in}}$$

In order to achieve high voltage amplification, the following features are incorporated in such amplifiers:

i. The transistor with high $\beta$ (>100) is used in the circuit. In other words, those transistors are employed which have thin base.
ii. The input resistance $R_{in}$ of the transistor is sought to be quite low as compared to the collector load $R_C$.
iii. A relatively high load $R_C$ is used in the collector. To permit this condition, voltage amplifiers are always operated at low collector currents ($\cong$ 1 mA).

### 1.4.2 Power amplifier.

A power amplifier is required to deliver a large amount of power and as such it has to handle large current. In order to achieve high power amplification, the following features are incorporated in such amplifiers:

*i.* The size of power transistor is made considerably larger in order to dissipate the heat produced in the transistor during operation.

*ii.* Transformer coupling is used for impedance matching.

*iii.* The base is made thicker to handle large currents. In other words, transistors with comparatively smaller $\beta$ are used.

## 1.5 Performance Quantities of Power Amplifiers

### 1.5.1 Collector Efficiency

The main criterion for a power amplifier is not the power gain rather it is the maximum a.c. power output. Now, an amplifier converts d.c. power from supply into a.c. power output. Therefore, the ability of a power amplifier to convert d.c. power from supply into a.c. output power is a measure of its effectiveness. This is known as *collector efficiency* and may be defined as under:

*The ratio of a.c. output power to the zero signal power (i.e. d.c. power) supplied by the battery of a power amplifier is known as* **collector efficiency.**

Collector efficiency means as to how well an amplifier converts d.c. power from the battery into a.c. output power. For instance, if the d.c. power supplied by the battery is 10W and a.c. output power is 2W, then collector efficiency is 20%.

### 1.5.2 Distortion

*The change of output wave shape from the input wave shape of an amplifier is known as* **distortion.**

A transistor like other electronic devices, is essentially a non-linear device. Therefore, whenever a signal is applied to the input of the transistor, the output signal is not exactly like the input signal *i.e.*distortion occurs. Distortion is not a problem for small signals (*i.e.*voltage amplifiers) since transistor is a linear device for small variations about the operating point. However, a power amplifier handles large signals and, therefore, the problem of distortion immediately arises. For the comparison of two power amplifiers, the one which has the less distortion is the better.

### 1.5.3 Power Dissipation Capability

*The ability of a power transistor to dissipate heat is known as* **power dissipation capability.**

A power transistor handles large currents and heats up during operation. As any temperature change influences the operation of transistor, therefore, the transistor must dissipate this heat to its surroundings. To achieve this, generally a *heat sink* (a metal case) is attached to a power transistor case. The increased surface area allows heat to escape easily and keeps the case temperature of the transistor within permissible limits.

## 1.6 Classification of Power Amplifiers

Transistor power amplifiers handle large signals. Many of them are driven so hard by the input large signal that collector current is either cut-off or is in the saturation region during a large portion of the input cycle. Therefore, such amplifiers are generally classified according to their mode of operation *i.e.* the portion of the input cycle during which the collector current is expected to flow. On this basis, they are classified as:

***(i)*** class *A* power amplifier ***(ii)*** class *B* power amplifier ***(iii)*** class *C* power amplifier

### 1.6.1 Class A Power Amplifier

*If the collector current flows at all times during the full cycle of the signal, the power amplifier is known as* **class A power amplifier.**

Obviously, for this to happen, the power amplifier must be biased in such a way that no part of the signal is cut off. Fig. 1.1(*i*) shows circuit of class *A* power amplifier. Note that collector has a transformer as the load which is most common for all classes of power amplifiers. The use of transformer permits impedance matching, resulting in the transference of maximum power to the load *e.g.* loudspeaker.

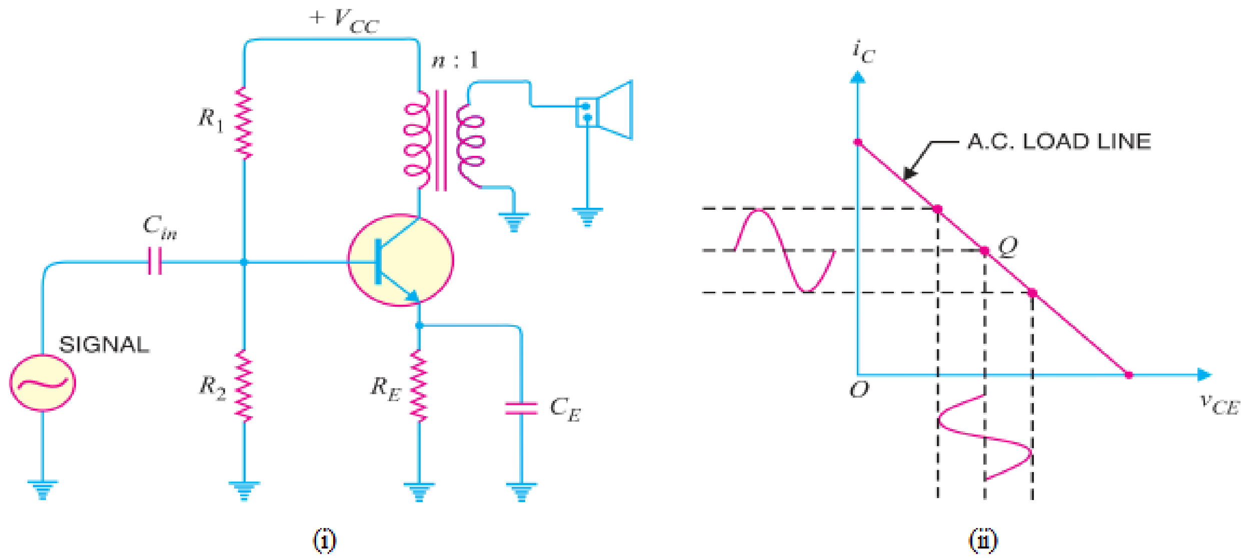



Fig. 1.1

Fig. 1.1 (*ii*) shows the class *A* operation in terms of *a.c.* load line. The operating point *Q* is so selected that collector current flows at all times throughout the full cycle of the applied signal. As the output wave shape is exactly similar to the input wave shape, therefore, such amplifiers have least distortion. However, they have the *disadvantage* of *low power output* and *low collector efficiency* (about 35%).

### 1.6.2 Class B Power Amplifier

*If the collector current flows only during the positive half-cycle of the input signal, it is called a* **class B power amplifier.**

In class *B* operation, the transistor bias is so adjusted that zero signal collector current is zero *i.e.* no biasing circuit is needed at all. During the positive half-cycle of the signal, the input circuit is forward biased and hence collector current flows. However, during the negative half-cycle of the signal, the input circuit is reverse biased and no collector current flows. Fig. 1.2 shows the class *B* operation in terms of a.c. load line. Obviously, the operating point *Q* shall be located at collector cut off voltage. It is easy to see that output from a class *B* amplifier is amplified half-wave rectification.

In a class *B* amplifier, the negative half-cycle of the signal is cut off and hence a severe distortion occurs. However, class *B* amplifiers provide *higher power output* and *collector efficiency* (50 60%). Such amplifiers are mostly used for power amplification in push-pull arrangement. In such an arrangement, 2 transistors are used in class *B* operation. One transistor amplifies the positive halfcycle of the signal while the other amplifies the negative half-cycle.

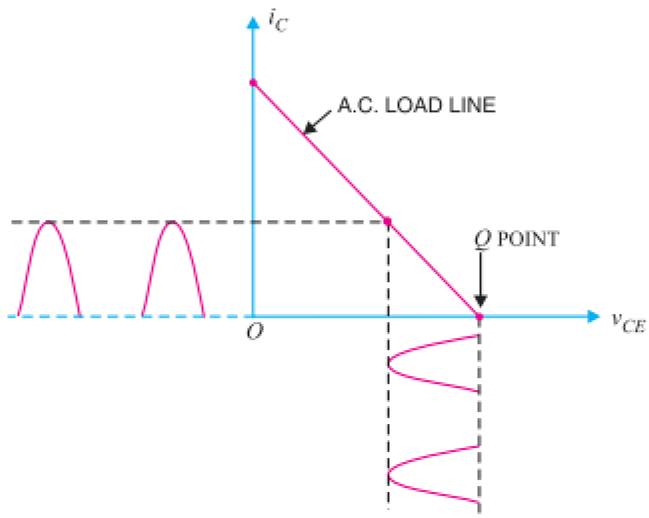



Fig. 1.2

### 1.6.3 Class C Power Amplifier

*If the collector current flows for less than half-cycle of the input signal, it is called* **class C power amplifier.**

In class *C* amplifier, the base is given some negative bias so that collector current does not flow just when the positive half-cycle of the signal starts. Such amplifiers are never used for power amplification. However, they are used as tuned amplifiers *i.e.* to amplify a narrow band of frequencies near the resonant frequency.

## 1.7 Expression for Collector Efficiency

For comparing power amplifiers, collector efficiency is the main criterion. The greater the collector efficiency, the better is the power amplifier.

Now, Collector efficiency, $\eta = \dfrac{\text{a.c. power output}}{\text{d.c. power input}}$

$$= \frac{P_o}{P_{dc}}$$

where $* \; P_{dc} = V_{CC} I_C$

$$P_o = V_{ce} I_c$$

where $V_{ce}$ is the *r.m.s.* value of signal output voltage and $I_c$ is the *r.m.s.* value of output signal current. In terms of peak-to-peak values (which are often convenient values in load-line work), the a.c. power output can be expressed as:

$$* \; P_o = [(0.5 \times 0.707)\, v_{ce\,(p-p)}]\,[(0.5 \times 0.707)\, i_{c\,(p-p)}]$$

$$= \frac{v_{ce(p-p)} \times i_{c(p-p)}}{8}$$

$\therefore$ Collector $\eta = \dfrac{v_{ce\,(p-p)} \times i_{c\,(p-p)}}{8\, V_{CC}\, I_C}$

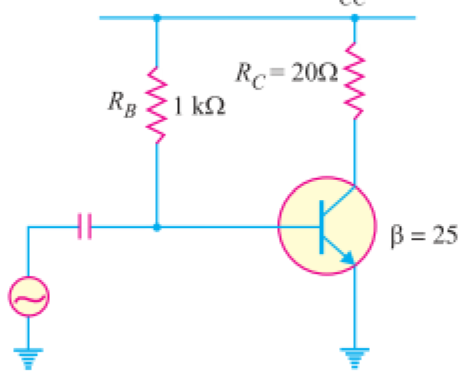
where;

$$\text{r.m.s. value} = \frac{1}{2}\left[\frac{\text{peak-to-peak value}}{\sqrt{2}}\right]$$

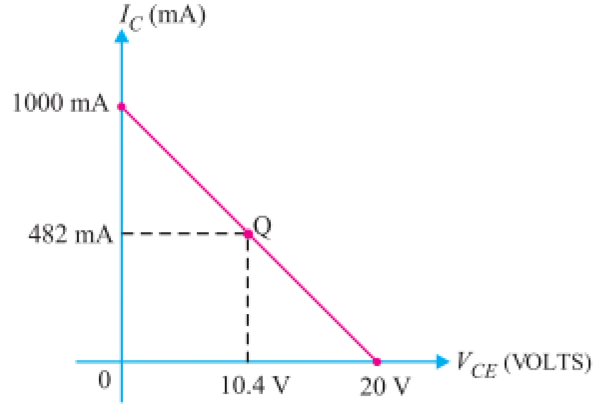
$$= 0.5 \times 0.707 \times \text{peak-to-peak value}$$

**Example 1.1:**

Calculate the (i) output power (ii) input power and (iii) collector efficiency of the amplifier circuit shown in Fig. 1.3 (i). It is given that input voltage results in a base current of 10 mA peak.




(i)




(ii)

Fig. 1.3

**Solution.** First draw the *d.c.* load line by locating the two end points *viz.*, $I_{C\,(sat)} = V_{CC}/R_C$ = 20 V/20 Ω = 1 A = 1000 mA and $V_{CE} = V_{CC} = 20$ V as shown in Fig. 12.7 (*ii*). The operating point $Q$ of the circuit can be located as under :

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{20 - 0.7}{1\text{ k}\Omega} = 19.3\text{ mA}$$

$$\therefore \quad I_C = \beta I_B = 25\,(19.3\text{ mA}) = 482\text{ mA}$$

Also $$V_{CE} = V_{CC} - I_C R_C = 20\text{ V} - (482\text{ mA})\,(20\ \Omega) = 10.4\text{ V}$$

The operating point $Q$ (10.4 V, 482 mA) is shown on the d.c. load line.

(*i*) $i_c$-(*peak*) = β $i_b$ (*peak*) = 25 × (10 mA) = 250 mA

$$\therefore \quad P_{o\,(ac)} = \frac{i_c^2(peak)}{2} R_C = \frac{(250 \times 10^{-3})^2}{2} \times 20 = \mathbf{0.625\ W}$$

(*ii*) $P_{dc} = V_{CC} I_C = (20\text{ V})\,(482 \times 10^{-3}) = \mathbf{9.6\ W}$

(*iii*) $$\text{Collector } \eta = \frac{P_o(ac)}{P_{dc}} \times 100 = \frac{0.625}{9.6} \times 100 = \mathbf{6.5\ \%}$$

## 1.8 Important Points About Class A Power Amplifier

i. A *transformer coupled class *A* power amplifier has a maximum collector efficiency of 50% *i.e.*, maximum of 50% d.c. supply power is converted into a.c. power output. In practice, the efficiency of such an amplifier is less than 50% (about 35%) due to power losses in the output transformer, power dissipation in the transistor etc.

ii. The power dissipated by a transistor is given by:

$$P_{dis} = P_{dc} - P_{ac}$$

where $P_{dc}$ = available d.c. power

$P_{ac}$ = available a.c. power

Clearly, in class *A* operation, the transistor must dissipate less heat when signal is applied and therefore runs cooler.

iii. When no signal is applied to a class *A* power amplifier, $P_{ac} = 0$;

$$P_{dis} = P_{dc}$$

Thus in class $A$ operation, maximum power dissipation in the transistor occurs under zero signal conditions. Therefore, the power dissipation capability of a power transistor (for class $A$ operation) must be at least equal to the zero signal rating. For example, if the zero signal power dissipation of a transistor is 1 W, then transistor needs a rating of at least 1 W. If the power rating of the transistor is less than 1 W, it is likely to be damaged.

iv. When a class $A$ power amplifier is used in the final stage, it is called **single ended class A power amplifier.**

**Example 1.2:**

A power transistor working in class A operation has zero signal power dissipation of 10 watts. If the a.c. output power is 4 watts, find:

i. Collector efficiency
ii. Power rating of transistor

**Solution.**

Zero signal power dissipation, $P_{dc} = 10 \text{ W}$

a.c. power output, $P_o = 4 \text{ W}$

*(i)* Collector efficiency $= \dfrac{P_o}{P_{dc}} \times 100 = \dfrac{4}{10} \times 100 = \mathbf{40\%}$

*(ii)* The zero signal power represents the worst case *i.e.* maximum power dissipation in a transistor occurs under zero signal conditions.

$\therefore$ Power rating of transistor $= \mathbf{10\ W}$

It means to avoid damage, the transistor must have a power rating of atleast 10 W.

**Example 1.3:**

A class A power amplifier has a transformer as the load. If the transformer has a turn ratio of 10 and the secondary load is 100 Ω, find the maximum a.c. power output. Given that zero signal collector current is 100 mA.

**Solution:**

Secondary load, $R_L = 100\Omega$

Transformer turn ratio, $n = 10$

Zero signal collector current, $I_C = 100 \text{ mA}$

Load as seen by the primary of the transformer is

$$R'_L = n^2 R_L = (10)^2 \times 100 = 10{,}000\ \Omega$$

$$\therefore \quad \text{Max. a.c. power output} = \frac{1}{2} I_C^2 R'_L = \frac{1}{2}\left(\frac{100}{1000}\right)^2 \times 10{,}000$$

$$= \mathbf{50\ W}$$

**Example 1.4:**

In a certain transistor amplifier, $i_{c(max)} = 160$ mA, $i_{c(min)} = 10$ mA, $V_{ce(max)} = 12$ V and $V_{ce(min)} = 2$ V. Calculate the ac output power.

**Solution:**

$$\text{A.C. output power, } P_o = \frac{v_{ce\ (p-p)} \times i_{c\ (p-p)}}{8}$$

Here $v_{ce\ (p-p)} = 12\text{V} - 2\text{V} = 10\text{V}$ ; $i_{c\ (p-p)} = 160 \text{ mA} - 10 \text{ mA} = 150 \text{ mA}$

$$\therefore \quad P_o = \frac{10 \text{ V} \times 150 \text{ mA}}{8} = \mathbf{187.5\ mW}$$

## 1.9 Thermal Runaway

All semiconductor devices are very sensitive to temperature variations. If the temperature of a transistor exceeds the permissible limit, the transistor may be permanently damaged. Silicon transistors can withstand temperatures upto 250ºC while the germanium transistors can withstand temperatures upto 100ºC.

There are two factors which determine the operating temperature of a transistor *viz*.

i. Surrounding temperature
ii. Power dissipated by the transistor.

When the transistor is in operation, almost the entire heat is produced at the collector-base junction. This power dissipation causes the junction temperature to rise. This in turn increases the collector current since more electron-hole pairs are generated due to the rise in temperature. This produces an increased power dissipation in the transistor and consequently a further rise in temperature. Unless adequate cooling is provided or the transistor has built-in temperature compensation circuits to prevent excessive collector current rise, the junction temperature will continue to increase until the maximum permissible temperature is exceeded. If this situation occurs, the transistor will be permanently damaged.

*The unstable condition where, owing to rise in temperature, the collector current rises and continues to increase is known as* **thermal runaway.**