12

Transistor Audio Power Amplifiers

INTRODUCTION

A practical amplifier always consists of a number of stages that amplify a weak signal until sufficient power is available to operate a loudspeaker or other output device. The first few stages in this 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*.

The term audio means the range of frequencies which our ears can hear. The range of human hearing extends from 20 Hz to 20 kHz. Therefore, audio amplifiers amplify electrical signals that have a frequency range corresponding to the range of human hearing *i.e.* 20 Hz to 20 kHz. Fig. 12.1 shows the block diagram of an audio amplifier. The early stages build up the voltage level of the signal while the last stage builds up power to a level sufficient to operate the loudspeaker. In this chapter, we shall talk about the final stage in a multistage amplifier—the power amplifier.

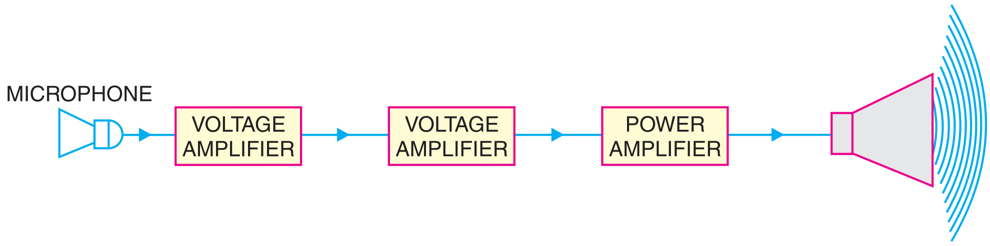


Fig. 12.1

12.1 Transistor Audio Power Amplifier

A transistor amplifier which raises the power level of the signals that have audio frequency range is known as **transistor audio power amplifier.**

Transistor Audio Power Amplifiers

In general, the last stage of a multistage amplifier is the *power stage.* 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. Typical load values range from 300Ω (for transmission antennas) to 8Ω (for loudspeakers). Although these load values do not cover every possibility, they do illustrate the fact that audio power amplifiers usually drive low-resistance loads. The typical power output rating of a power amplifier is 1W or more.

12.2 Small-Signal and Large-Signal Amplifiers

The input signal to a multistage amplifier is generally small (a few mV from a cassette or CD or a few μV from an antenna). Therefore, the first few stages of a multistage amplifier handle small signals 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).

(*i*) Small-signal amplifiers. Those amplifiers which handle small input a.c. signals (a few μV or a few mV) are called *small-signal amplifiers.* Voltage amplifiers generally fall in this class. 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.

(*ii*) Large-signal amplifiers. Those amplifiers which handle large input a.c. signals (a few volts) are called *large-signal amplifiers.* Power amplifiers fall in this class. The 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. It may be noted that all large-signal amplifiers are not necessarily power amplifiers but it is safe to say that most are. In general, where amount of power involved is 1W or more, the amplifier is termed as *power amplifier.*

12.3 Output Power of Amplifier

An amplifier converts d.c. power drawn from d.c. supply V_{CC} into a.c. output power. The output power is always less than the input power because losses occur in the various resistors present in the circuit. For example, consider the R-C coupled amplifier circuit shown in Fig. 12.2. The currents are flowing through various resistors causing I^2R loss. Thus power loss in R_1 is $I_1^2 R_1$, power loss in R_C is $I_C^2 R_C$, power loss in R_E is $I_E^2 R_E$ and so on. All these losses appear as heat. Therefore, losses occuring in an amplifier not only decrease the efficiency but they also increase the temperature of the circuit.

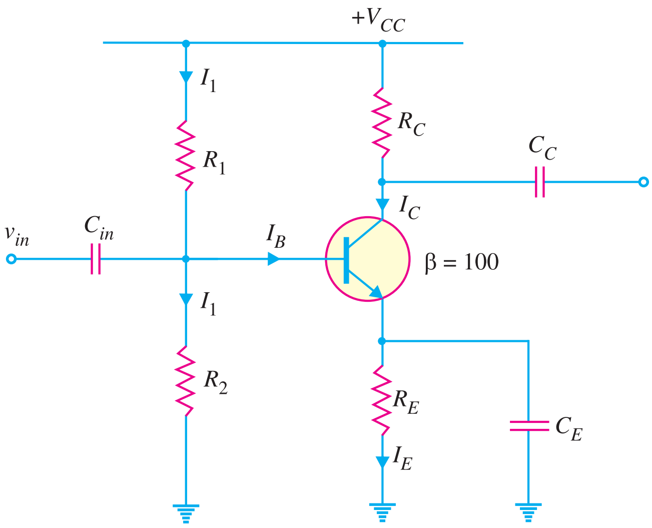


Fig. 12.2

When load R_L is connected to the amplifier, A.C. output power, $P_O = \dfrac{V_L^2}{R_L}$

where V_L = r.m.s. value of load voltage

Example 12.1. *If in Fig. 12.2; R_1 = 10 kΩ ; R_2 = 2.2 kΩ ; R_C = 3.6 kΩ ; R_E = 1.1. kΩ and V_{CC} = + 10 V, find the d.c. power drawn from the supply by the amplifier.*

Solution. The current I_1 flowing through R_1 also flows through R_2 (a reasonable assumption because I_B is small).

$$I_1 = \frac{V_{CC}}{R_1 + R_2} = \frac{10\text{V}}{10 \text{ k}\Omega + 2.2 \text{ k}\Omega} = \frac{10\text{V}}{12.2 \text{ k}\Omega} = 0.82 \text{ mA}$$

D.C. voltage across R_2, $V_2 = I_1 R_2 = 0.82 \text{ mA} \times 2.2 \text{ k}\Omega = 1.8\text{V}$

D.C. voltage across R_E, $V_E = V_2 - V_{BE} = 1.8\text{V} - 0.7\text{V} = 1.1\text{V}$

D.C. emitter current, $I_E = V_E/R_E = 1.1\text{V}/1.1 \text{ k}\Omega = 1 \text{ mA}$

$$\therefore \quad I_C \simeq I_E = 1 \text{ mA}$$

Total d.c current I_T drawn from the supply is

$$I_T = I_C + I_1 = 1 \text{ mA} + 0.82 \text{ mA} = 1.82 \text{ mA}$$

∴ D.C. power drawn from the supply is

$$P_{dc} = V_{CC} I_T = 10\text{V} \times 1.82 \text{ mA} = \textbf{18.2 mW}$$

Example 12.2. *Determine the a.c. load power for the circuit shown in Fig. 12.3.*

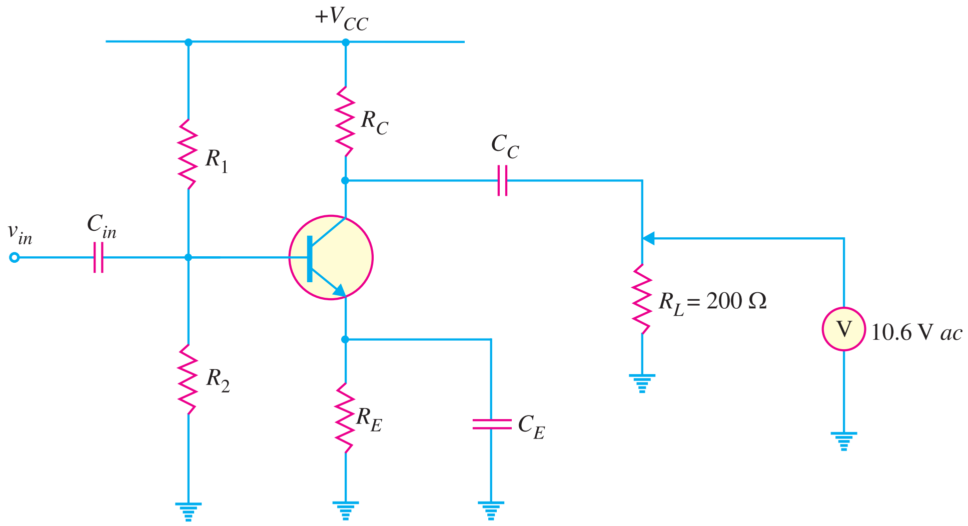


Fig. 12.3

Solution. The reading of a.c. voltmeter is 10.6V. Since a.c. voltmeters read r.m.s. voltage, we have,

$$\text{A.C. output power, } P_O = \frac{V_L^2}{R_L} = \frac{(10.6)^2}{200\ \Omega} = \mathbf{561.8\ mW}$$

Example 12.3. *In an RC coupled power amplifier, the a.c. voltage across load R_L (= 100 Ω) has a peak- to-peak value of 18V. Find the maximum possible a.c. load power.*

Solution. The peak-to-peak voltage, V_{PP} = 18V. Therefore, peak voltage (or maximum voltage) = $V_{PP}/2$ and the r.m.s value, $V_L = V_{PP}/2\sqrt{2}$.

$$\therefore \quad P_{O\,(max)} = \frac{V_L^2}{R_L} = \frac{(V_{PP}/2\sqrt{2})^2}{R_L} = \frac{V_{PP}^2}{8\ R_L}$$

Here V_{PP} = 18V and $R_L = 100\Omega$

$$\therefore \quad P_{O\,(max)} = \frac{(18V)^2}{(8 \times 100)\ \Omega} = 405 \times 10^{-3}\ \text{W} = \mathbf{405\ mW}$$

12.4 Difference Between Voltage and Power Amplifiers

The distinction between voltage and power amplifiers is somewhat artificial since useful power (*i.e.* product of voltage and current) is always developed in the load resistance through which current flows. The difference between the two types is really one of degree; it is a question of how much voltage and how much power. 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. 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 β (>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 (≃ 1 mA). If the collector current is small, we can use large R_C in the collector circuit.

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) The base is made thicker to handle large currents. In other words, transistors with comparatively smaller β are used.

(iii) Transformer coupling is used for impedance matching.

The comparison between voltage and power amplifiers is given below in the tabular form :

S. No.	Particular	Voltage amplifier	Power amplifier
1.	β	High (> 100)	low (5 to 20)
2.	R_C	High (4 – 10 kΩ)	low (5 to 20 Ω)
3.	*Coupling*	usually $R – C$ coupling	Invariably transformer coupling
4.	*Input voltage*	low (a few mV)	High (2 – 4 V)
5.	*Collector current*	low (≃ 1 mA)	High (> 100 mA)
6.	*Power output*	low	high
7.	*Output impedance*	High (≃ 12 kΩ)	low (200 Ω)

Example 12.4. *A power amplifier operated from 12V battery gives an output of 2W. Find the maximum collector current in the circuit.*

Solution.

Let I_C be the maximum collector current.

$$\text{Power} = \text{battery voltage} \times \text{collector current}$$

or $$2 = 12 \times I_C$$

∴ $$I_C = \frac{2}{12} = \frac{1}{6}\text{ A} = \mathbf{166.7\ mA}$$

This example shows that a power amplifier handles large power as well as large current.

Example 12.5. *A voltage amplifier operated from a 12 V battery has a collector load of 4 kΩ. Find the maximum collector current in the circuit.*

Solution.

The maximum collector current will flow when the whole battery voltage is dropped across R_C.

∴ $$\text{Max. collector current} = \frac{\text{battery voltage}}{\text{collector load}} = \frac{12\text{ V}}{4\text{ k}\Omega} = \mathbf{3\ mA}$$

This example shows that a voltage amplifier handles small current.

Example 12.6. *A power amplifier supplies 50 W to an 8-ohm speaker. Find (i) a.c. output voltage (ii) a.c. output current.*

Solution.

(*i*) $P = V^2/R$

$\therefore$ a.c. output voltage, $V = \sqrt{PR} = \sqrt{50 \times 8} =$ **20 V**

(*ii*) a.c. output current, $I = V/R = 20/8 =$ **2.5 A**

12.5 Performance Quantities of Power Amplifiers

As mentioned previously, the prime objective for a power amplifier is to obtain maximum output power. Since a transistor, like any other electronic device has voltage, current and power dissipation limits, therefore, the criteria for a power amplifier are : ***collector efficiency, distortion*** and ***power dissipation capability***.

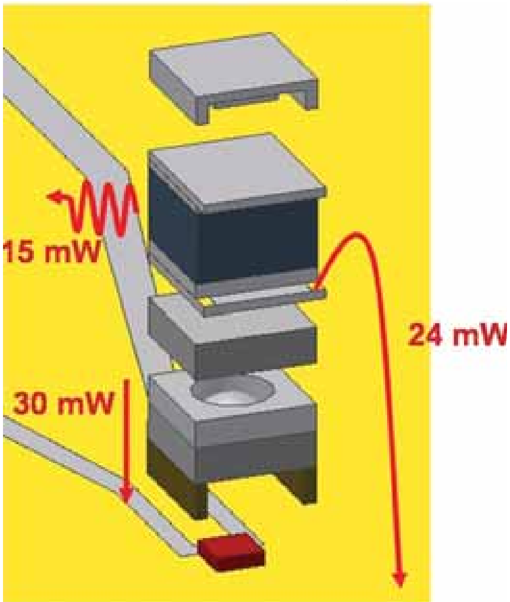
(*i*) **Collector efficiency.** The main criterion for a power amplifier is not the power gain rather it is the maximum a.c. power output. Now, an amplifier converts d.c. power from supply into a.c. power output. Therefore, the ability of a power amplifier to convert d.c. power from supply into a.c. 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%. The greater the collector efficiency, the larger is the a.c. power output. It is obvious that for power amplifiers, maximum collector efficiency is the desired goal.

(*ii*) **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. We shall discuss the method of reducing distortion in amplifiers in the chapter of negative feedback in amplifiers.



Power Dissipation Channels in a Microfabricated Atomic Clock

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

As stated before, 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.

12.6 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

(*i*) 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.**

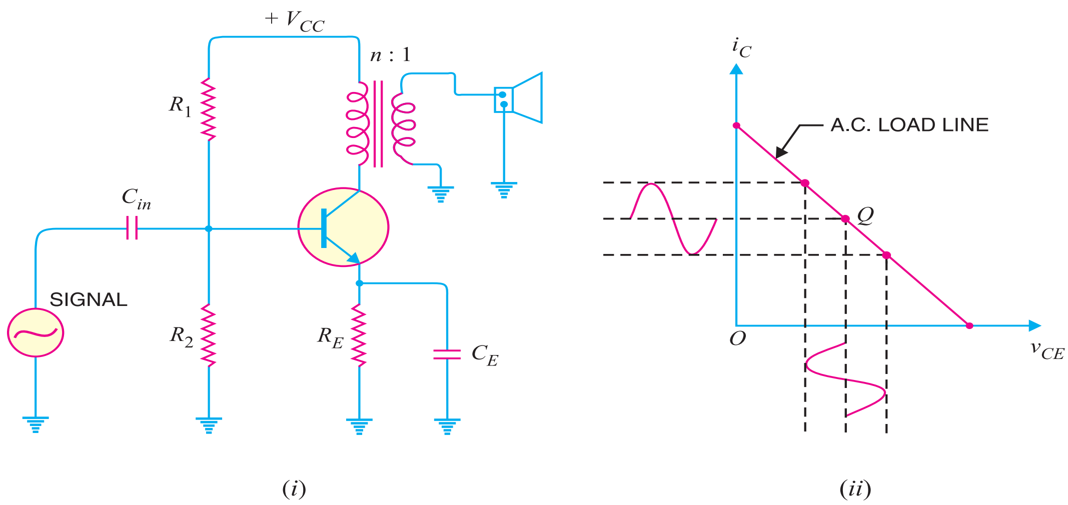


Fig. 12.4

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. 12.4 (*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. 12.4 (*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%).

(*ii*) 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. 12.5 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 half-cycle of the signal while the other amplifies the negative half-cycle.

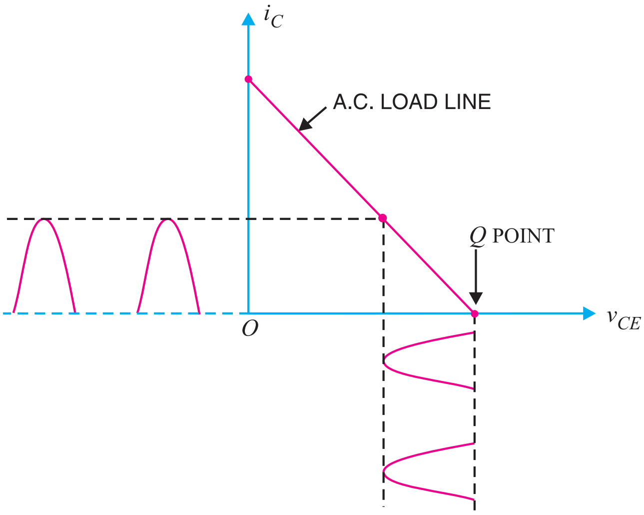


Fig. 12.5

(iii) **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.

12.7 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 :

* Note that d.c. input power to the collector circuit of power amplifier is the product of collector supply V_{CC} (and not the collector-emitter voltage) and the average (i.e. d.c.) collector current I_C.

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

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

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

12.8. Maximum Collector Efficiency of Series-Fed Class A Amplifier

Fig. 12.6 (*i*) shows a **series – fed class *A* amplifier. This circuit is seldom used for power amplification due to its poor collector efficiency. Nevertheless, it will help the reader to understand the class *A* operation. The d.c. load line of the circuit is shown in Fig. 12.6 (*ii*). When an *ac* signal is applied to the amplifier, the output current and voltage will vary about the operating point *Q*. In order to achieve the maximum symmetrical swing of current and voltage (to achieve maximum output power), the *Q* point should be located at the centre of the *dc* load line. In that case, operating point is $I_C = V_{CC}/2R_C$ and $V_{CE} = V_{CC}/2$.

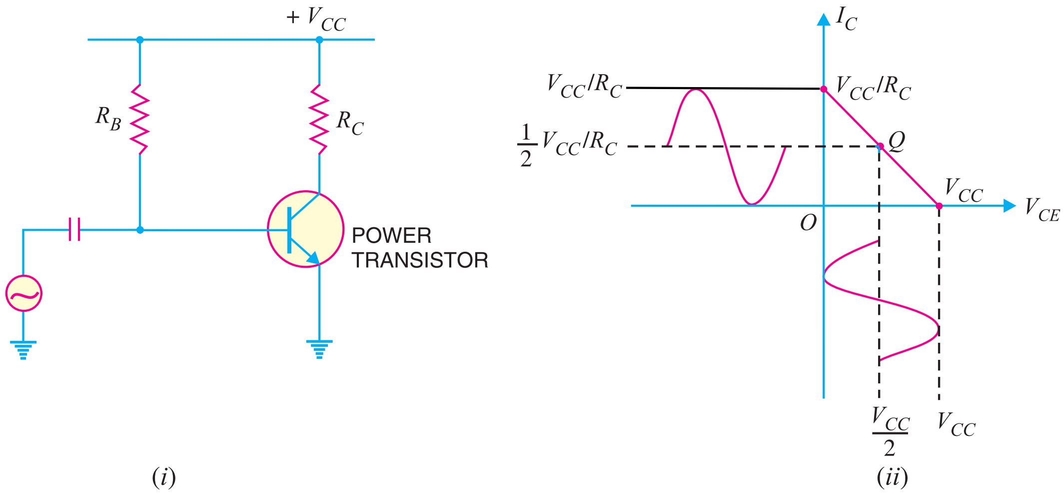


Fig. 12.6

$$\text{Maximum } v_{ce\,(p-p)} = V_{CC}$$

$$\text{Maximum } i_{c\,(p-p)} = V_{CC}/R_C$$

$$\text{Max. } ac \text{ output power,} \quad P_{o\,(max)} = \frac{v_{ce\,(p-p)} \times i_{c\,(p-p)}}{8} = \frac{V_{CC} \times V_{CC}/R_C}{8} = \frac{V_{CC}^2}{8\,R_C}$$

$$\text{D.C. power supplied, } P_{dc} = V_{CC}\, I_C = V_{CC}\left(\frac{V_{CC}}{2\,R_C}\right) = \frac{V_{CC}^2}{2\,R_C}$$

$$\therefore \quad \text{Maximum collector } \eta = \frac{P_{o(max)}}{P_{dc}} \times 100 = \frac{V_{CC}^2/8\,R_C}{V_{CC}^2/2\,R_C} \times 100 = 25\%$$

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

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

** Note that the input to this circuit is a large signal and that transistor used is a power transistor.

Thus the maximum collector efficiency of a class *A* series-fed amplifier is 25%. In actual practice, the collector efficiency is far less than this value.

Example 12.7. *Calculate the (i) output power (ii) input power and (iii) collector efficiency of the amplifier circuit shown in Fig. 12.7 (i). It is given that input voltage results in a base current of 10 mA peak.*

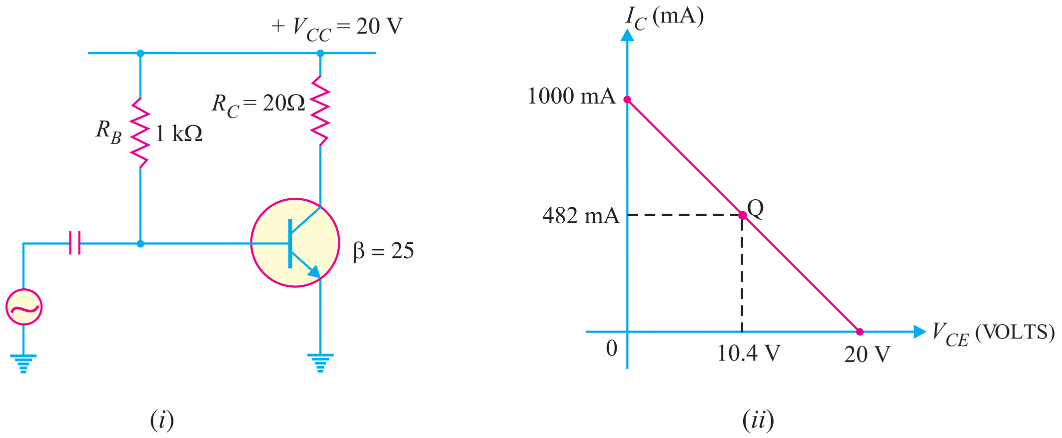


Fig. 12.7

Solution. First draw the *d.c.* load line by locating the two end points *viz.*, $I_{C\,(sat)} = V_{CC}/R_C = 20\text{ V}/20\ \Omega = 1\text{ A} = 1000\text{ mA}$ 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 :

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

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

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

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

(*i*) $i_c\text{-}(peak) = \beta\ i_b\ (peak) = 25 \times (10\text{ mA}) = 250\text{ mA}$

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

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

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

12.9. Maximum Collector Efficiency of Transformer Coupled Class A Power Amplifier

In class *A* power amplifier, the load can be either connected directly in the collector or it can be transformer coupled. The latter method is often preferred for two main reasons. First, transformer coupling permits impedance matching and secondly it keeps the d.c. power loss small because of the small resistance of the transformer primary winding.

Fig. 12.8 (*i*) shows the transformer coupled class *A* power amplifier. In order to determine maximum collector efficiency, refer to the output characteristics shown in Fig. 12.8 (*ii*). Under zero signal conditions, the effective resistance in the collector circuit is that of the primary winding of the transformer. The primary resistance has a very small value and is assumed zero. Therefore, d.c. load line is a vertical line rising from V_{CC} as shown in Fig. 12.8 (*ii*). When signal is applied, the collector current will vary about the operating point Q.

In order to get maximum a.c. power output (and hence maximum collector η), the peak value of collector current due to signal alone should be equal to the zero signal collector current I_C. In terms of a.c. load line, the operating point Q should be located at the centre of a.c. load line.

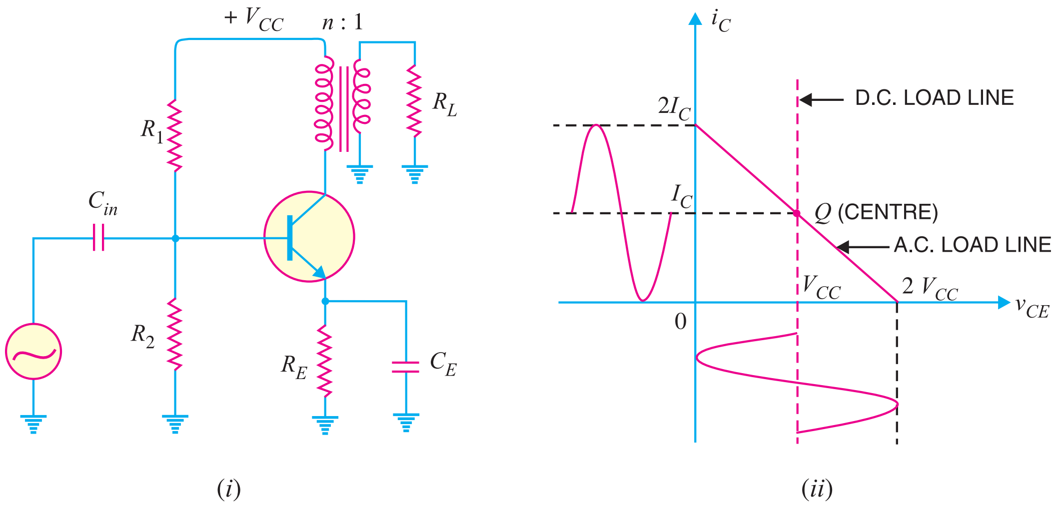


Fig. 12.8

During the peak of the positive half-cycle of the signal, the total collector current is $2\,I_C$ and $v_{ce} = 0$. During the negative peak of the signal, the collector current is zero and *$v_{ce} = 2V_{CC}$.

∴ Peak-to-peak collector-emitter voltage is

$$v_{ce\,(p-p)} = 2V_{CC}$$

Peak-to-peak collector current, $i_{c\,(p-p)} = 2\,I_C$

$$= \frac{v_{ce\,(p-p)}}{R'_L} = \frac{2V_{CC}}{R'_L}$$

where R'_L is the reflected value of load R_L and appears in the primary of the transformer. If $n\ (= N_p/N_s)$ is the turn ratio of the transformer, then, $R'_L = n^2\,R_L$.

$$\text{d.c. power input, } P_{dc} = V_{CC}\,I_C$$

$$= I_C^2\,R'_L \qquad (\because\ V_{CC} = I_C R'_L)$$

$$\text{Max.a.c. output power, } P_{o\,(max)} = \frac{v_{ce\,(p-p)} \times i_{c\,(p-p)}}{8}$$

$$= \frac{2V_{CC} \times 2\,I_C}{8}$$

$$= \frac{1}{2}\,V_{CC}\,I_C \qquad \text{...}(i)$$

$$= \frac{1}{2}\,I_C^2\,R'_L \qquad (\because\ V_{CC} = I_C R'_L)$$

* This occurs at the negative peak of the signal. Under such conditions, the voltage across transformer primary is V_{CC} but in such a direction so as to reinforce the supply.

∴ $v_{ce} = 2V_{CC}$

$$\therefore \qquad \text{Max. collector } \eta = \frac{P_{o\,(max)}}{P_{dc}} \times 100$$

$$= \frac{(1/2)\, I_C^2\, R'_L}{I_C^2\, R'_L} \times 100 = 50\%$$

12.10 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, $P_{ac} = 0$.

$$\therefore \qquad P_{dis} = P_{dc}$$

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 atleast 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 atleast 1W. 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 12.8. *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 W

a.c. power output, P_o = 4 W

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

(*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 = **10 W**

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

Example 12.9. *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 Ω

* However, resistance coupled class A power amplifier has a maximum collector efficiency of 25%.

Transformer turn ratio, $n = 10$

Zero signal collector current, $I_C = 100$ 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 12.10. *A class A transformer coupled power amplifier has zero signal collector current of 50 mA. If the collector supply voltage is 5 V, find (i) the maximum a.c. power output (ii) the power rating of transistor (iii) the maximum collector efficiency.*

Solution.

(i) Max. a.c. power output, $P_{o\,(max)} = \dfrac{V_{CC}\,I_C}{2}$ ...See Art. 12.9

$$= \frac{(5\text{ V}) \times (50\text{ mA})}{2} = \mathbf{125\ mW}$$

(ii) D.C input power, $P_{dc} = V_{CC}\,I_C$

$$= (5\text{ V}) \times (50\text{ mA}) = 250\text{ mW}$$

Since the maximum power is dissipated in the zero signal conditions,

$\therefore$ Power rating of transistor = **250 mW**

The reader may note that in class *A* operation :

$$P_{o(max)} = \frac{P_{dis}}{2}$$

or

$$P_{dis} = 2\,P_{o\ (max)}$$

It means that power rating of the transistor is twice as great as the maximum a.c. output power. For example, if a transistor dissipates 3 W under no signal conditions, then maximum a.c. output power it can deliver is 1.5 W.

(iii) Max. collector $\eta = \dfrac{P_{o\,(max)}}{P_{dc}} \times 100 = \dfrac{125\text{ mW}}{250\text{ mW}} \times 100 = \mathbf{50\%}$

Example 12.11. *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 a.c. output power.*

Solution.

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

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

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

Example 12.12. *A power transistor working in class A operation is supplied from a 12-volt battery. If the maximum collector current change is 100 mA, find the power transferred to a 5 Ω loudspeaker if it is :*

(i) directly connected in the collector

(ii) transformer-coupled for maximum power transference

Find the turn ratio of the transformer in the second case.

Solution.

Max. collector current change, $\Delta I_C = 100\,\text{mA}$

Max. collector-emitter voltage change is

$$\Delta V_{CE} = 12\,\text{V}$$

Loudspeaker resistance, $R_L = 5\,\Omega$

(i) Loudspeaker directly connected. Fig. 12.9 (*i*) shows the circuit of class *A* power amplifier with loudspeaker directly connected in the collector.

$$\text{Max. voltage across loudspeaker} = \Delta I_C \times R_L = 100\text{ mA} \times 5\ \Omega = 0.5\text{ V}$$

$$\text{Power developed in the loudspeaker} = 0.5\text{ V} \times 100\text{ mA}$$

$$= 0.05\text{ W} = \mathbf{50\ mW}$$

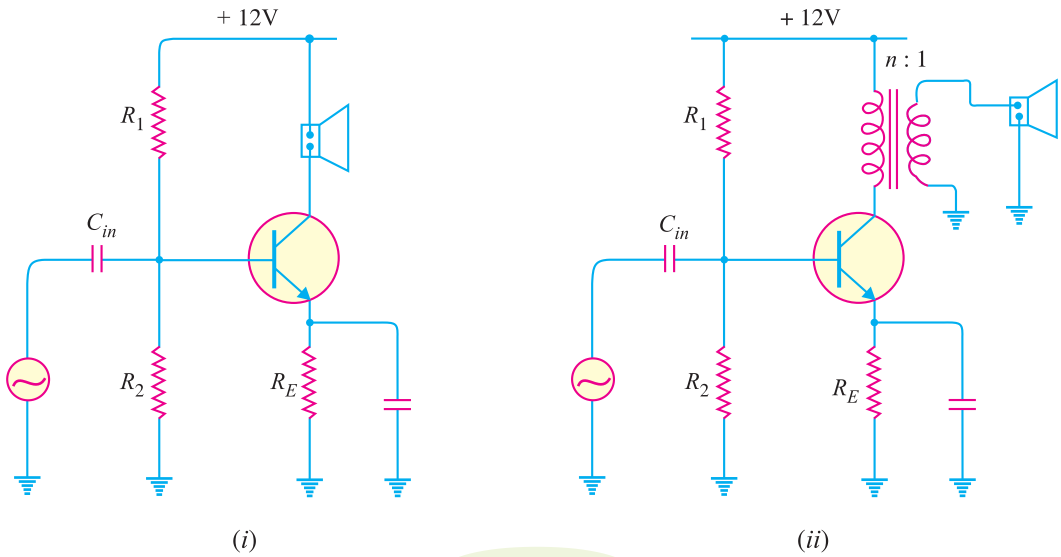


Fig. 12.9

Therefore, when loudspeaker is directly connected in the collector, only 50 mW of power is transferred to the loudspeaker.

(ii) Loudspeaker transformer coupled. Fig. 12.9 (*ii*) shows the class *A* power amplifier with speaker transformer coupled. As stated before, for impedance matching, step-down transformer is used.

$$\text{Output impedance of transistor} = \frac{\Delta V_{CE}}{\Delta I_C} = 12\text{ V}/100\text{ mA} = 120\ \Omega$$

In order to transfer maximum power, the primary resistance should be 120 Ω.

Now, load R'_L as seen by the primary is

$$R'_L = n^2 R_L$$

or $$120 = n^2 R_L$$

or $$n^2 = \frac{120}{5}$$

∴ $$\text{Turn ratio, } n = \sqrt{\frac{120}{5}} = \mathbf{4.9}$$

Transformer secondary voltage

$$= \frac{\text{Primary voltage}}{n} = 12/4.9 = 2.47 \text{ V}$$

$$\text{Load current, } I_L = \frac{2.47 \text{ V}}{5 \, \Omega} = 0.49 \text{ A}$$

Power transferred to the loudspeaker

$$= I_L^2 R_L$$

$$= (0.49)^2 \times 5 = 1.2 \text{ W} = \mathbf{1200 \ mW}$$

It is clear that by employing transformer coupling, we have been able to transfer a large amount of power (1200 mW) to the speaker. The main consideration in power amplifiers is the maximum power output and, therefore, transformer coupling is invariably used.

Example 12.13. *A common emitter class A transistor power amplifier uses a transistor with β = 100. The load has a resistance of 81.6 Ω, which is transformer coupled to the collector circuit. If the peak values of collector voltage and current are 30 V and 35 mA respectively and the corresponding minimum values are 5 V and 1 mA respectively, determine :*

(*i*) *the approximate value of zero signal collector current*

(*ii*) *the zero signal base current*

(*iii*) P_{dc} *and* P_{ac} (*iv*) *collector efficiency* (*v*) *turn ratio of the transformer.*

Solution.

In an ideal case, the minimum values of $v_{CE\,(min)}$ and $i_{C\,(min)}$ are zero. However, in actual practice, such ideal conditions cannot be realised. In the given problem, these minimum values are 5 V and 1mA respectively as shown in Fig. 12.10.

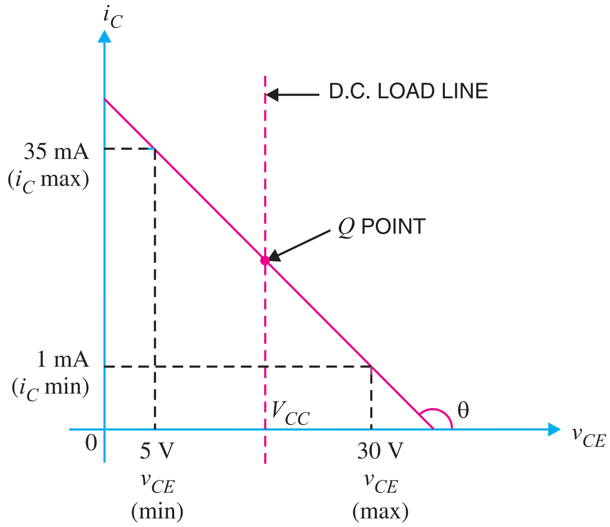


Fig. 12.10

(*i*) The zero signal collector current is approximately half-way between the maximum and minimum values of collector current *i.e.*

$$\text{Zero signal } I_C = \frac{35 - 1}{2} + 1 = \mathbf{18 \ mA}$$

(*ii*) $$\text{Zero signal } I_B = I_C / \beta = 18/100 = \mathbf{0.18 \ mA}$$

(iii) Zero signal $V_{CE} = \frac{30-5}{2} + 5 = 17.5\text{ V}$

Since the load is transformer coupled, $V_{CC} \simeq 17.5$ V.

d.c. input power, $P_{dc} = V_{CC} I_C = 17.5\text{ V} \times 18\text{ mA} = \mathbf{315\ mW}$

a.c. output voltage, $V_{ce} = \frac{30-5}{2\sqrt{2}} = 8.84\text{ V}$

a.c. output current, $I_c = \frac{35-1}{2\sqrt{2}} = 12\text{ mA}$

$\therefore$ a.c. output power, $P_{ac} = V_{ce} \times I_c$

$= 8.84\text{ V} \times 12\text{ mA} = \mathbf{106\ mW}$

(iv) Collector $\eta = \frac{P_{ac}}{P_{dc}} \times 100 = \frac{106}{315} \times 100 = \mathbf{33.7\%}$

(v) The a.c. resistance R'_L in the collector is determined from the slope of the line.

$$\text{Slope} = -\frac{1}{R'_L} = \frac{35-1}{5-30} = \frac{-34}{25}\text{ kilo mho}$$

$$\therefore \quad R'_L = \frac{25}{34}\text{ k}\Omega = \frac{25}{34} \times 1000 = 735\ \Omega$$

$$\therefore \quad \text{Turn ratio, } n = \sqrt{\frac{R'_L}{R_L}} = \sqrt{\frac{735}{81.6}} = \mathbf{3}$$

Example 12.14. *In a class A transformer coupled amplifier, the collector current alternates between 3mA and 110 mA and its quiscent value is 58 mA. The load resistance is 13Ω and when referred to primary winding, it is 325Ω. The supply voltage is 20V. Calculate (i) transformer turn ratio (ii) a.c. output power (iii) collector efficiency.*

Solution. The conditions of the problem are represented in Fig. 12.11. The zero signal $I_C = 58$ mA.

(i) Let n $(= N_p/N_s)$ be the turn ratio of the transformer.

$$\therefore \quad R'_L = n^2 R_L$$

$$\text{or} \quad n = \sqrt{\frac{R'_L}{R_L}} = \sqrt{\frac{325}{13}} = \mathbf{5}$$

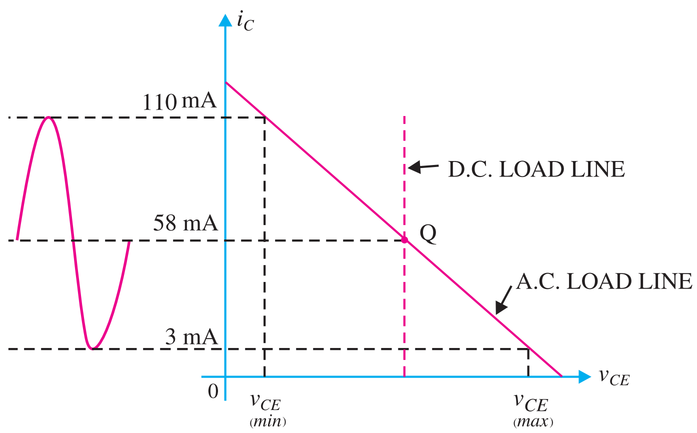


Fig. 12.11

(ii) A.C. output power, $P_{ac} = \frac{1}{2} I_C^2 R'_L$

$$= \frac{1}{2}(58\text{ mA})^2 \times 325\Omega = \mathbf{546\ mW}$$

(iii) D.C. input power, $P_{dc} = V_{CC} I_C = 20\text{ V} \times 58\text{ mA} = 1160\text{ mW}$

$$\therefore \quad \text{Collector } \eta = \frac{546}{1160} \times 100 = \mathbf{47\%}$$

12.11 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 and (*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.**

Thermal runaway must always be avoided. If it occurs, permanent damage is caused and the transistor must be replaced.

12.12 Heat Sink

As power transistors handle large currents, they always heat up during operation. Since transistor is a temperature dependent device, the heat generated must be dissipated to the surroundings in order to keep the temperature within permissible limits. Generally, the transistor is fixed on a metal sheet (usually aluminium) so that additional heat is transferred to the *Al* sheet.

The metal sheet that serves to dissipate the additional heat from the power transistor is known as **heat sink.**

Heat Sink

Most of the heat within the transistor is produced at the **collector junction. The heat sink increases the surface area and allows heat to escape from the collector junction easily. The result is that temperature of the transistor is sufficiently lowered. Thus heat sink is a direct practical means of combating the undesirable thermal effects *e.g.* thermal runaway.

* Almost the entire heat in a transistor is produced at the collector-base junction. If the temperature exceeds the permissible limit, this junction is destroyed and the transistor is rendered useless.

** Most of power is dissipated at the collector-base junction. This is because collector-base voltage is much greater than the base-emitter voltage, although currents through the two junctions are almost the same.

It may be noted that the ability of any heat sink to transfer heat to the surroundings depends upon its material, volume, area, shape, contact between case and sink and movement of air around the sink. Finned aluminium heat sinks yield the best heat transfer per unit cost.

It should be realised that the use of heat sink alone may not be sufficient to prevent thermal runaway under all conditions. In designing a transistor circuit, consideration should also be given to the choice of (*i*) operating point (*ii*) ambient temperatures which are likely to be encountered and (*iii*) the type of transistor *e.g.* metal case transistors are more readily cooled by conduction than plastic ones. Circuits may also be designed to compensate automatically for temperature changes and thus stabilise the operation of the transistor components.

12.13 Mathematical Analysis

The permissible power dissipation of the transistor is very important item for power transistors. The permissible power rating of a transistor is calculated from the following relation :

$$P_{total} = \frac{T_{J\,max} - T_{amb}}{\theta}$$

where P_{total} = total power dissipated within the transistor

$T_{J\,max}$ = maximum junction temperature. It is 90ºC for *germanium* transistors and 150ºC for *silicon* transistors.

T_{amb} = ambient temperature *i.e.* temperature of surrounding air

θ = *thermal resistance *i.e.* resistance to heat flow from the junction to the surrounding air

The unit of θ is ºC/ watt and its value is always given in the transistor manual. A low thermal resistance means that it is easy for heat to flow from the junction to the surrounding air. The larger the transistor case, the lower is the thermal resistance and *vice-versa*. It is then clear that by using heat sink, the value of θ can be decreased considerably, resulting in increased power dissipation.

Example 12.15. *A power transistor dissipates 4 W. If T_{Jmax} = 90ºC, find the maximum ambient temperature at which it can be operated. Given θ = 10ºC/W.*

Solution.

$$P_{total} = 4 \text{ W}$$
$$T_{J\,max} = 90\text{ºC}$$
$$\theta = 10\text{ºC/W}$$

Now $$P_{total} = \frac{T_{J\,max} - T_{amb}}{\theta}$$

or $$4 = \frac{90 - T_{amb}}{10}$$

∴ Ambient temperature, T_{amb} = 90 – 40 = **50ºC**

The above example shows the effect of ambient temperature on the permissible power dissipation in a transistor. The lower the ambient temperature, the greater is the permissible power dissipation. Thus, a transistor can pass a higher collector current in winter than in summer.

Example 12.16. (*i*) *A power transistor has thermal resistance θ = 300ºC/W. If the maximum junction temperature is 90ºC and the ambient temperature is 30ºC, find the maximum permissible power dissipation.*

* The path of heat flow generated at the collector-base junction is from junction to case, from case to sink and from sink to atmosphere.

(ii) If a heat sink is used with the above transistor, the value of θ is reduced to 60ºC/W. Find the maximum permissible power dissipation.

Solution.

(i) *Without heat sink*

$$T_{J\,max} = 90ºC$$
$$T_{amb} = 30ºC$$
$$\theta = 300ºC/W$$

$$\therefore \quad P_{total} = \frac{T_{J\,max} - T_{amb}}{\theta} = \frac{90-30}{300} = 0.2 \text{ W} = \mathbf{200\ mW}$$

(ii) *With heat sink*

$$T_{J\,max} = 90ºC$$
$$T_{amb} = 30ºC$$
$$\theta = 60ºC/W$$

$$\therefore \quad P_{total} = \frac{T_{J\,max} - T_{amb}}{\theta} = \frac{90-30}{60} = 1 \text{ W} = \mathbf{1000\ mW}$$

It is clear from the above example that permissible power dissipation with heat sink is 5 times as compared to the case when no heat sink is used.

Example 12.17. *The total thermal resistance of a power transistor and heat sink is 20°C/W. The ambient temperature is 25°C and $T_{J\,max}$ = 200°C. If V_{CE} = 4 V, find the maximum collector current that the transistor can carry without destruction. What will be the allowed value of collector current if ambient temperature rises to 75°C ?*

Solution.

$$P_{total} = \frac{T_{Jmax} - T_{amb}}{\theta} = \frac{200-25}{20} = 8.75 \text{ W}$$

This means that maximum permissible power dissipation of the transistor at ambient temperature of 25°C is 8.75 W *i.e.*

$$V_{CE}\, I_C = 8.75$$

$$\therefore \quad I_C = 8.75/4 = \mathbf{2.19\ A}$$

Again

$$P_{total} = \frac{T_{J\,max} - T_{amb}}{\theta} = \frac{200-75}{20} = 6.25 \text{ W}$$

$$\therefore \quad I_C = 6.25/4 = \mathbf{1.56\ A}$$

This example clearly shows the effect of ambient temperature.

12.14 Stages of A Practical Power Amplifier

The function of a practical power amplifier is to amplify a weak signal until sufficient power is available to operate a loudspeaker or other output device. To achieve this goal, a power amplifier has generally three stages *viz. voltage amplification stage*, *driver stage* and *output stage*. Fig. 12.12 shows the block diagram of a practical power amplifier.

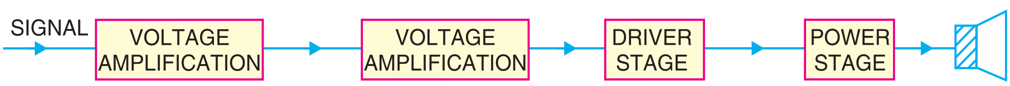


Fig. 12.12

(*i*) ***Voltage amplification stage.*** The signals found in practice have extremely low voltage level (< 10 mV). Therefore, the voltage level of the weak signal is raised by two or more voltage amplifiers. Generally, *RC* coupling is employed for this purpose.

(*ii*) ***Driver stage.*** The output from the last voltage amplification stage is fed to the driver stage. It supplies the necessary power to the output stage. The driver stage generally employs class *A* transformer coupled power amplifier. Here, concentrated effort is made to obtain *maximum power gain.*

(*iii*) ***Output stage.*** The output power from the driver stage is fed to the output stage. It is the final stage and feeds power directly to the speaker or other output device. The output stage is invariably transformer coupled and employs class *B* amplifiers in push-pull arrangement. Here, concentrated effort is made to obtain *maximum power output.*

12.15 Driver Stage

The stage that immediately precedes the output stage is called the *driver stage*. It operates as a class *A* power amplifier and supplies the drive for the output stage. Fig. 12.13 shows the driver stage. Note that transformer coupling is employed. The primary of this transformer is the collector load. The secondary is almost always centre-tapped so as to provide equal and opposite voltages to the input of push-pull amplifier (*i.e.* output stage). The driver transformer is usually a step-down transformer and facilitates impedance matching.

The output from the last voltage amplification stage forms the input to the driver stage. The driver stage renders power amplification in the usual way. It may be added that main consideration here is the maximum power gain. The output of the driver stage is taken from the centre-tapped secondary and is fed to the output stage.

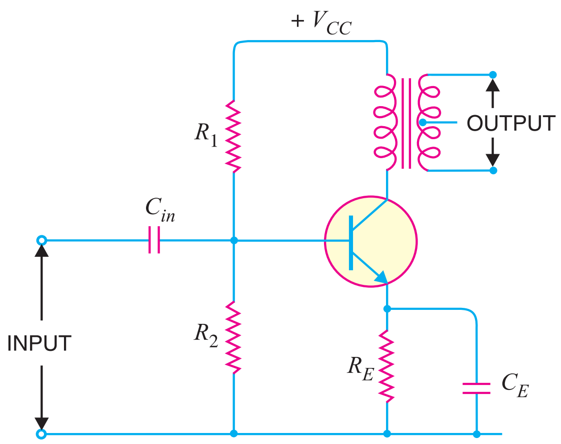


Fig. 12.13

12.16 Output Stage

The output stage essentially consists of a power amplifier and its purpose is to transfer maximum power to the output device. If a single transistor is used in the output stage, it can only be employed as class *A* amplifier for faithful amplification. Unfortunately, the power efficiency of a class *A* amplifier is very low (≃ 35%). As transistor amplifiers are operated from batteries, which is a costly source of power, therefore, such a low efficiency cannot be tolerated.

In order to obtain high output power at high efficiency, pushpull arrangement is used in the output stage. In this arrangement, we employ two transistors in class *B* operation. One transistor amplifies the positive half-cycle of the signal while the other transistor amplifies the negative half-cycle of the signal. In this way, output voltage is a complete sine wave. At the same time, the circuit delivers high output power to the load due to class *B* operation.

12.17 Push-Pull Amplifier

The push-pull amplifier is a power amplifier and is frequently employed in the output stages of electronic circuits. It is used whenever high output power at high efficiency is required. Fig. 12.14 shows the circuit of a push-pull amplifier. Two transistors T_{r1} and T_{r2} placed back to back are employed. Both transistors are operated in class *B* operation *i.e.* collector current is nearly zero in the absence of the signal. The centre-tapped secondary of driver transformer T_1 supplies equal and opposite voltages to the base circuits of two transistors.

Push-Pull Amplifier

The output transformer T_2 has the centre-tapped primary winding. The supply voltage V_{CC} is connected between the bases and this centre tap. The loudspeaker is connected across the secondary of this transformer.

Circuit operation. The input signal appears across the secondary *AB* of driver transformer. Suppose during the first half-cycle (marked 1) of the signal, end *A* becomes positive and end *B* negative. This will make the base-emitter junction of T_{r1} reverse biased and that of T_{r2} forward biased. The circuit will conduct current due to T_{r2} only and is shown by solid arrows. Therefore, this half-cycle of the signal is amplified by T_{r2} and appears in the lower half of the primary of output transformer. In the next half-cycle of the signal, T_{r1} is forward biased whereas T_{r2} is reverse biased. Therefore, T_{r1} conducts and is shown by dotted arrows. Consequently, this half-cycle of the signal is amplified by T_{r1} and appears in the upper half of the output transformer primary. The centre-tapped primary of the output transformer combines two collector currents to form a sine wave output in the secondary.

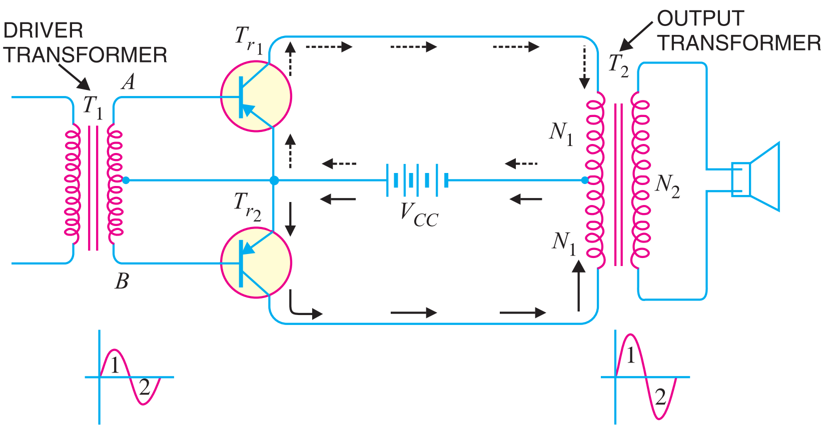


Fig. 12.14

It may be noted here that push-pull arrangement also permits a maximum transfer of power to the load through impedance matching. If R_L is the resistance appearing across secondary of output transformer, then resistance R'_L of primary shall become :

$$R'_L = \left(\frac{2N_1}{N_2}\right)^2 R_L$$

where N_1 = Number of turns between either end of primary winding and centre-tap

N_2 = Number of secondary turns

Advantages

(*i*) The efficiency of the circuit is quite high ($\simeq$ 75%) due to class *B* operation.

(*ii*) A high a.c. output power is obtained.

Disadvantages

(*i*) Two transistors have to be used.

(*ii*) It requires two equal and opposite voltages at the input. Therefore, push-pull circuit requires the use of driver stage to furnish these signals.

(*iii*) If the parameters of the two transistors are not the same, there will be unequal amplification of the two halves of the signal.

(*iv*) The circuit gives more distortion.

(*v*) Transformers used are bulky and expensive.

12.18 Maximum Efficiency for Class B Power Amplifier

We have already seen that a push-pull circuit uses two transistors working in class *B* operation. For class *B* operation, the Q-point is located at cut-off on both d.c. and a.c. load lines. For maximum signal operation, the two transistors in class B amplifier are alternately driven from cut-off to saturation. This is shown in Fig. 12.15 (*i*). It is clear that a.c. output voltage has a peak value of V_{CE} and a.c. output current has a peak value of $I_{C\,(sat)}$. The same information is also conveyed through the a.c. load line for the circuit [See Fig. 12.15 (*ii*)].

$\therefore$ Peak a.c. output voltage $= V_{CE}$

Peak a.c. output current $= I_{C\,(sat)} = {}^{*}\dfrac{V_{CE}}{R_L} = \dfrac{V_{CC}}{2\,R_L}$ $\left(\because\ V_{CE} = \dfrac{V_{CC}}{2}\right)$

Maximum average a.c. output power $P_{o\,(max)}$ is

$P_{o\,(max)}$ = Product of r.m.s. values of a.c. output voltage and a.c. output current

$$= \frac{V_{CE}}{\sqrt{2}} \times \frac{I_{C\,(sat)}}{\sqrt{2}} = \frac{V_{CE}\,I_{C\,(sat)}}{2}$$

$$= \frac{V_{CC}}{2} \times \frac{I_{C\,(sat)}}{2} = \frac{V_{CE}\,I_{C\,(sat)}}{4} \qquad \left(\because\ V_{CE} = \frac{V_{CC}}{2}\right)$$

$$\therefore \quad P_{o\,(max)} = 0.25\,V_{CC}\,I_{C\,(sat)}$$

The input d.c. power from the supply V_{CC} is

$$P_{dc} = V_{CC}\,I_{dc}$$

* Since the two transistors are identical, half the supply voltage is dropped across each transistor's collector-emitter terminals *i.e.* $V_{CE} = \dfrac{V_{CC}}{2}$

Also peak voltage across each transistor is V_{CE} and it appears across R_L.

$$\therefore I_{C\,(sat)} = \frac{V_{CE}}{R_L} = \frac{V_{CC}}{2} \times \frac{1}{R_L} = \frac{V_{CC}}{2\,R_L}$$

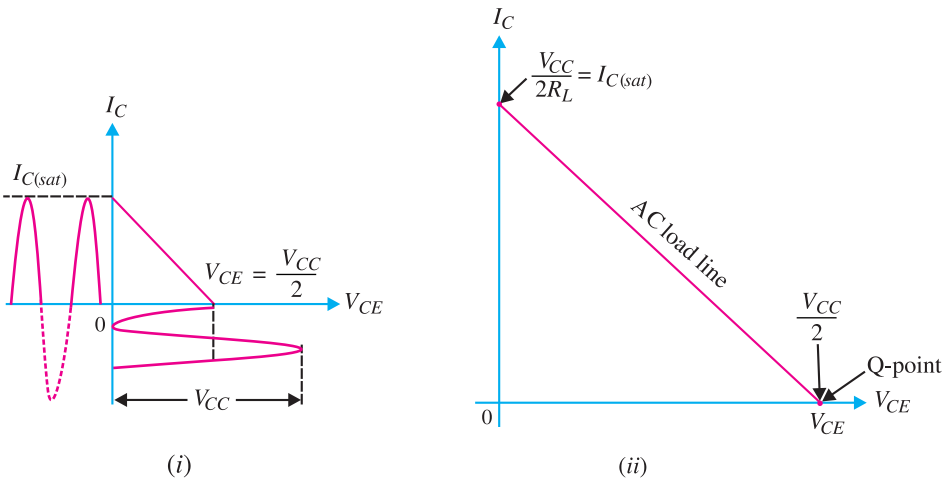


Fig. 12.15

where I_{dc} is the average current drawn from the supply V_{CC}. Since the transistor is on for alternating half-cycles, it effectively acts as a half-wave rectifier.

$$\therefore \quad I_{dc} = \frac{I_{C\,(sat)}}{\pi}$$

$$\therefore \quad P_{dc} = \frac{V_{CC}\ I_{C\,(sat)}}{\pi}$$

$$\therefore \quad \text{Max. collector } \eta = \frac{P_{o\,(max)}}{P_{dc}} = \frac{0.25\,V_{CC}\ \ I_{C\,(sat)}}{\left(V_{CC}\ I_{C\,(sat)}\right)/\pi} \times 100 = 0.25\pi \times 100 = 78.5\%$$

Thus the maximum collector efficiency of class *B* power amplifier is 78.5%. Recall that maximum collector efficiency for class A transformer coupled amplifier is 50%.

Power dissipated by transistors. The power dissipated (as heat) by the transistors in class *B* amplifier is the difference between the input power delivered by V_{CC} and the output power delivered to the load *i.e.*

$$P_{2T} = P_{dc} - P_{ac}$$

where P_{2T} = power dissipated by the two transistors

∴ Power dissipated by each transistor is

$$P_T = \frac{P_{2T}}{2} = \frac{P_{dc} - P_{ac}}{2}$$

Note. For collector efficiency of class *C* amplifiers, the reader may refer to Chapter 15 (Transistor tuned amplifiers).

Example 12.18. *For a class B amplifier using a supply of V_{CC} = 12V and driving a load of 8Ω, determine (i) maximum load power (ii) d.c. input power (iii) collector efficiency.*

Solution. $V_{CC} = 12\text{ V}\ ;\ R_L = 8\Omega$

(i) Maximum load power, $P_{o\,(max)} = 0.25\ V_{CC}\,I_{C\,(sat)}$

$$= 0.25\ V_{CC} \times \frac{V_{CC}}{2\,R_L} \qquad \left(\because I_{C\,(sat)} = \frac{V_{CC}}{2\,R_L}\right)$$

$$= 0.25 \times 12 \times \frac{12}{2 \times 8} = \mathbf{2.25\ W}$$

(ii) D.C. input power, $P_{dc} = \dfrac{V_{CC}\, I_{C\,(sat)}}{\pi} = \dfrac{V_{CC}}{\pi} \times \dfrac{V_{CC}}{2\, R_L}$

$$= \frac{12}{\pi} \times \frac{12}{2 \times 8} = \mathbf{2.87\ W}$$

(iii) Collector $\eta = \dfrac{P_{o\,(max)}}{P_{dc}} \times 100 = \dfrac{2.25}{2.87} \times 100 = \mathbf{78.4\%}$

Example 12.19. *A class B push-pull amplifier with transformer coupled load uses two transistors rated 10 W each. What is the maximum power output one can obtain at the load from the circuit?*

Solution. The power dissipation by each transistor is $P_T = 10$W. Therefore, power dissipated by two transistors is $P_{2T} = 2 \times 10 = 20$W.

Now $\quad P_{dc} = P_{o\,(max)} + P_{2T}$; Max. $\eta = 0.785$

$$\therefore \quad \text{Max } \eta = \frac{P_{o\,(max)}}{P_{dc}} = \frac{P_{o\,(max)}}{P_{o\,(max)} + P_{2T}} = \frac{P_{o\,(max)}}{P_{o\,(max)} + 20}$$

or $$0.785 = \frac{P_{o\,(max)}}{P_{o\,(max)} + 20}$$

or $$0.785\, P_{o\,(max)} + 15.7 = P_{o\,(max)}$$

or $$P_{o\,(max)}\,(1 - 0.785) = 15.7$$

$$\therefore \quad P_{o\,(max)} = \frac{15.7}{1 - 0.785} = \frac{15.7}{0.215} = \mathbf{73.02\ W}$$

Example 12.20. *A class B amplifier has an efficiency of 60% and each transistor has a rating of 2.5W. Find the a.c. output power and d.c. input power*

Solution. The power dissipated by each transistor is $P_T = 2.5$W.

Therefore, power dissipated by the two transistors is $P_{2T} = 2 \times 2.5 = 5$W.

Now $\quad P_{dc} = P_{ac} + P_{2T}$; $\eta = 0.6$

$$\therefore \quad \eta = \frac{P_{ac}}{P_{dc}} = \frac{P_{ac}}{P_{ac} + P_{2T}}$$

or $$0.6 = \frac{P_{ac}}{P_{ac} + 5} \quad \text{or} \quad 0.6\ P_{ac} + 3 = P_{ac}$$

$$\therefore \quad P_{ac} = \frac{3}{1 - 0.6} = \frac{3}{0.4} = \mathbf{7.5\ W}$$

and $$P_{dc} = P_{ac} + P_{2T} = 7.5 + 5 = \mathbf{12.5\ W}$$

Example 12.21. *A class B amplifier uses V_{CC} = 10V and drives a load of 10Ω. Determine the end point values of the a.c. load line.*

Solution.

$$I_{C\,(sat)} = \frac{V_{CC}}{2\, R_L} = \frac{10\text{V}}{2\,(10\ \Omega)} = \mathbf{500\ mA}$$

This locates one end-point of the a.c. load line on the collector current axis.

$$V_{CE\,(off)} = \frac{V_{CC}}{2} = \frac{10\text{V}}{2} = \mathbf{5V}$$

This locates the second end-point of the a.c load line on the collector-emitter voltage axis. By joining these two points, the a.c. load line of the amplifier is constructed.

12.19 Complementary-Symmetry Amplifier

By complementary symmetry is meant a principle of assembling push-pull class *B* amplifier without requiring centre-tapped transformers at the input and output stages. Fig. 12.16 shows the transistor push-pull amplifier using complementary symmetry. It employs one *npn* and one *pnp* transistor and requires no centre-tapped transformers. The circuit action is as follows. During the positive-half of the input signal, transistor T_1 (the *npn* transistor) conducts current while T_2 (the *pnp* transistor) is cut off. During the negative half-cycle of the signal, T_2 conducts while T_1 is cut off. In this way, *npn* transistor amplifies the positive half-cycles of the signal while the *pnp* transistor amplifies the negative half-cycles of the signal. Note that we generally use an output transformer (not centre-tapped) for impedance matching.

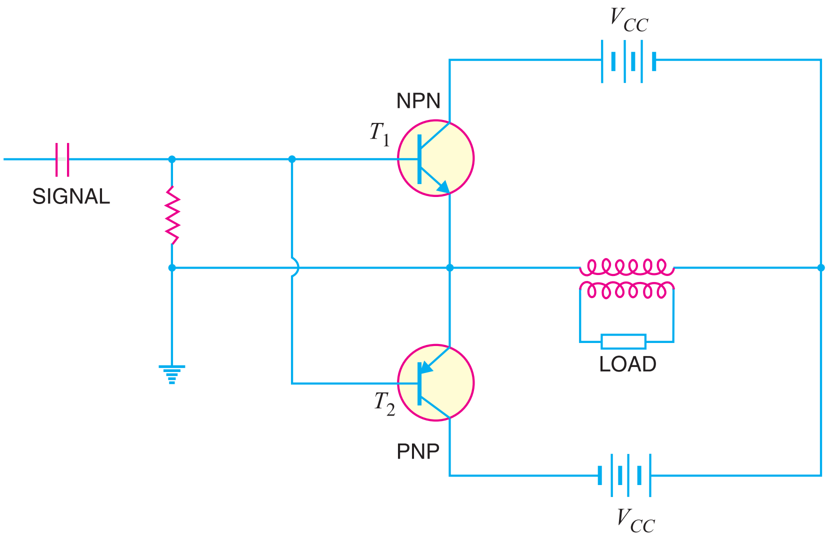


Fig.12.16

Advantages

(i) This circuit does not require transformer. This saves on weight and cost.

(ii) Equal and opposite input signal voltages are not required.

Disadvantages

(i) It is difficult to get a pair of transistors (*npn* and *pnp*) that have similar characteristics.

(ii) We require both positive and negative supply voltages.

MULTIPLE-CHOICE QUESTIONS

1. The output stage of a multistage amplifier is also called ....
   (*i*) mixer stage (*ii*) power stage
   (*iii*) detector stage (*iv*) R.F. stage

2. .... coupling is generally employed in power amplifiers.
   (*i*) transformer (*ii*) *RC*
   (*iii*) direct (*iv*) impedance

3. A class *A* power amplifier uses ....
   (*i*) two transistors (*ii*) three transistors
   (*iii*) one transistor (*iv*) none of the above
4. The maximum efficiency of resistance loaded class *A* power amplifier is ....
   (*i*) 78.5% (*ii*) 50%
   (*iii*) 30% (*iv*) 25%
5. The maximum efficiency of transformer coupled class *A* power amplifier is ....
   (*i*) 30% (*ii*) 50%
   (*iii*) 80% (*iv*) 45%
6. Class .... power amplifier has the highest collector efficiency.
   (*i*) *C* (*ii*) *A*
   (*iii*) *B* (*iv*) *AB*
7. Power amplifiers handle .... signals compared to voltage amplifiers.
   (*i*) small (*ii*) very small
   (*iii*) large (*iv*) none of the above
8. In class *A* operation, the operating point is generally located .... of the d.c. load line.
   (*i*) at cut off point (*ii*) at the middle
   (*iii*) at saturation point
   (*iv*) none of the above
9. Class *C* amplifiers are used as ....
   (*i*) AF amplifiers (*ii*) detectors
   (*iii*) R.F. amplifiers (*iv*) none of the above
10. A power amplifier has comparatively ....β.
    (*i*) small (*ii*) large
    (*iii*) very large (*iv*) none of the above
11. The maximum collector efficiency of class *B* operation is ....
    (*i*) 50% (*ii*) 90%
    (*iii*) 60.5% (*iv*) 78.5%
12. A 2-transistor class *B* power amplifier is commonly called .... amplifier.
    (*i*) dual (*ii*) push-pull
    (*iii*) symmetrical (*iv*) differential
13. If a transistor is operated in such a way that output current flows for 60º of the input signal, then it is ...... operation.
    (*i*) class *A* (*ii*) class *B*
    (*iii*) class *C* (*iv*) none of the above
14. If the zero signal power dissipation of a transistor is 1 W, then power rating of the transistor should be atleast ....
    (*i*) 0.5 W (*ii*) 0.33 W
    (*iii*) 0.75 W (*iv*) 1 W
15. When a transistor is cut off, ...
    (*i*) maximum voltage appears across transistor
    (*ii*) maximum current flows
    (*iii*) maximum voltage appears across load
    (*iv*) none of the above
16. A class *A* power amplifier is sometimes called .... amplifier.
    (*i*) symmetrical (*ii*) single-ended
    (*iii*) reciprocating (*iv*) differential
17. Class .... operation gives the maximum distortion.
    (*i*) *A* (*ii*) *B*
    (*iii*) *C* (*iv*) *AB*
18. The output stage of a multistage amplifier usually employs ....
    (*i*) push-pull amplifier
    (*ii*) preamplifier
    (*iii*) class *A* power amplifier
    (*iv*) none of the above
19. The size of a power transistor is made considerably large to ....
    (*i*) provide easy handling
    (*ii*) dissipate heat
    (*iii*) facilitate connections
    (*iv*) none of the above
20. Low efficiency of a power amplifier results in ....
    (*i*) low forward bias
    (*ii*) less battery consumption
    (*iii*) more battery consumption
    (*iv*) none of the above
21. The driver stage usually employs ....
    (*i*) class *A* power amplifier
    (*ii*) push-pull amplifier
    (*iii*) class *C* amplifier
    (*iv*) none of the above
22. If the power rating of a transistor is 1 W and collector current is 100 mA, then maximum

allowable collector voltage is ....

(*i*) 1 V (*ii*) 100 V
(*iii*) 20 V (*iv*) 10 V

23. When no signal is applied, the approximate collector efficiency of class *A* power amplifier is ....

(*i*) 10% (*ii*) 0%
(*iii*) 25% (*iv*) 50%

24. What will be the collector efficiency of a power amplifier having zero signal power dissipation of 5 watts and a.c. power output of 2 watts ?

(*i*) 20% (*ii*) 80%
(*iii*) 40% (*iv*) 50%

25. The output signal voltage and current of a power amplifier are 5 V and 200 mA ; the values being r.m.s. What is the power output ?

(*i*) 1 W (*ii*) 2 W
(*iii*) 4 W (*iv*) none of the above

26. The maximum a.c. power output from a class *A* power amplifier is 10 W. What should be the minimum power rating of the transistor used ?

(*i*) 10 W (*ii*) 15 W
(*iii*) 5 W (*iv*) 20 W

27. For the same a.c. power output as above, what should be the minimum power rating of transistor for class *B* operation ?

(*i*) 10 W (*ii*) 4 W
(*iii*) 8 W (*iv*) none of the above

28. The push-pull circuit must use ..... operation.

(*i*) class *A* (*ii*) class *C*
(*iii*) class *B* (*iv*) class *AB*

29. The class B push-pull circuit can deliver 100 W of a.c. output power. What should be the minimum power rating of each transistor ?

(*i*) 20 W (*ii*) 40 W
(*iii*) 10 W (*iv*) 80 W

30. What turn ratio (N_p/N_s) of transformer is required to match 4 Ω speaker to a transistor having an output impedance of 8000 Ω ?

(*i*) 35.2 (*ii*) 44.7
(*iii*) 54.3 (*iv*) none of the above

31. A transformer coupled class *A* power amplifier has a load of 100 Ω on the secondary. If the turn ratio is 10 : 1, what is the value of load appearing on the primary ?

(*i*) 5 kΩ (*ii*) 20 kΩ
(*iii*) 100 kΩ (*iv*) 10 kΩ

32. Power amplifiers generally use transformer coupling because transformer permits ....

(*i*) cooling of the circuit
(*ii*) impedance matching
(*iii*) distortionless output
(*iv*) good frequency response

33. Transformer coupling can be used in .... amplifiers.

(*i*) either power or voltage
(*ii*) only power
(*iii*) only voltage (*iv*) none of the above

34. The output transformer used in a power amplifier is a ...... transformer.

(*i*) 1 : 1 ratio (*ii*) step-up
(*iii*) step-down (*iv*) none of the above

35. The most important consideration in power amplifiers is......

(*i*) biasing the circuit
(*ii*) collector efficiency
(*iii*) to keep the transformer cool
(*iv*) none of the above

36. An *AF* amplifier is shielded to ....

(*i*) keep the amplifier cool
(*ii*) protect from rusting
(*iii*) prevent induction due to stray magnetic fields
(*iv*) none of the above

37. The pulsating d.c. applied to power amplifier causes ....

(*i*) burning of transistor
(*ii*) hum in the circuit
(*iii*) excessive forward voltage
(*iv*) none of the above

38. The disadvantage of impedance matching is that it ....

(*i*) gives distorted output

(*ii*) gives low power output
(*iii*) requires a transformer
(*iv*) none of the above

39. If the gain versus frequency curve of a transistor amplifier is not flat, then there is .... distortion.

(*i*) amplitude (*ii*) intermodulation
(*iii*) frequency (*iv*) none of the above

40. The most costly coupling is .... coupling.

(*i*) *RC* (*ii*) direct
(*iii*) impedance (*iv*) transformer.

Answers to Multiple-Choice Questions

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

Chapter Review Topics

1. What is an audio power amplifier ? What is its need ?
2. Explain the difference between a voltage and a power amplifier.
3. What do you understand by class A, class B and class C power amplifiers ?
4. Define and explain the following terms as applied to power amplifiers :
   (*i*) collector efficiency (*ii*) distortion (*iii*) power dissipation capability
5. Show that maximum collector efficiency of class A transformer coupled power amplifier is 50%.
6. Draw the block diagram of a practical power amplifier.
7. Explain the push-pull circuit with a neat diagram.
8. Write short notes on the following :
   (*i*) Heat sink (*ii*) Driver stage
   (*iii*) Output stage (*iv*) Complementary-symmetry amplifier

Problems

1. The resistance of the secondary of an output transformer is 100 Ω. If the output impedance is 10 kΩ, find the turn ratio of the transformer for maximum power transference. **[n = 10]**
2. A power transistor working in class A operation has zero signal power dissipation of 5 watts. If a.c. output power is 2 watts, find (*i*) collector efficiency (*ii*) power rating of transistor. **[(*i*) 40% (*ii*) 5 watts]**
3. A class A power amplifier has a maximum a.c. power output of 30 W. Find the power rating of the transistor. **[60 W]**
4. The a.c. power output of a class A power amplifier is 2 W. If the collector efficiency is 40%, find the power rating of the transistor. **[5 W]**
5. In a class A transformer coupled amplifier, collector current alternates between 3 mA and 110 mA and its quiescent value is 58 mA. The load resistance is 15 Ω and when referred to primary winding is 325 Ω. The supply voltage is 20V. Find (*i*) transformer turn ratio (*ii*) a.c. power output (*iii*) power rating of transistor.

6. A transistor has thermal resistance θ = 80°C/W. If the maximum junction temperature is 90°C and the ambient temperature is 30°C, find the maximum permissible power dissipation.

[750 mW]

7. A power transistor dissipates 4 W. If $T_{J\,max}$ = 90°C, find the maximum ambient temperature at which it can be operated. Given thermal resistance θ = 8°C/W. **[58 °C]**

8. A class A transformer-coupled amplifier uses a 25 : 1 transformer to drive a 4Ω load. Calculate the effective a.c. load (seen by the transistor connected to the larger turns side of the transformer).

[2.5 kΩ]

9. Calculate the transformer turns ratio required to connect 4 parallel 16Ω speakers so that they appear as an 8 kΩ effective load. **[44.7]**

10. For a class B amplifier with V_{CC} = 25V driving an 8Ω load, determine :
    (*i*) maximum input power
    (*ii*) maximum output power
    (*iii*) maximum circuit efficiency

[(*i*) 49.7W (*ii*) 39.06W (*iii*) 78.5 %]

Discussion Questions

1. Why does collector efficiency play important part in power amplifiers ?
2. Why does the problem of distortion arise in power amplifiers ?
3. Why are power amplifiers classified on the basis of mode of operation ?
4. Why does the output stage employ push-pull arrangement ?
5. Why is driver stage necessary for push-pull circuit ?
6. Why do we use transformer in the output stage ?

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