UNIT 5 LARGE SIGNAL AMPLIFIERS

Class A power amplifier with resistive and transformer coupled load- calculation of efficiency- Class B-Push pull-complementary symmetry - efficiency calculation- Class C Power Amplifier- Class AB operation and Class D type of operation- distortion in power amplifiers - Thermal stability of power amplifier.

5.1 Introduction to Large Signal Amplifiers

Consider a public address system (P.A.) or amplifying system as shown in the Fig. 5.1.

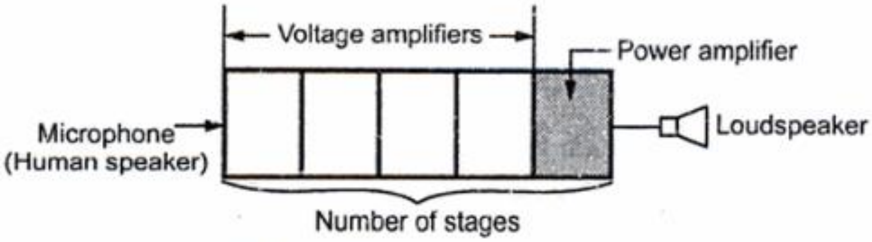


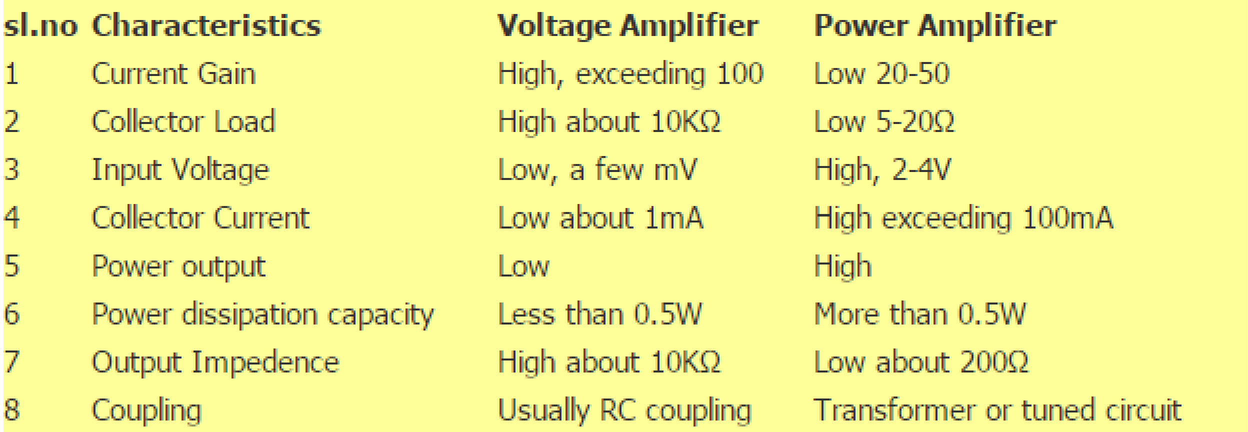
Fig. 5.1 Amplifying or P.A. system

The system consists of many stages connected in cascade. Hence basically it is a multistage amplifier. The input is sound signal of a human speaker and the output is given to the loudspeaker which is an amplified input signal. The input and the intermediate stages are small signal amplifiers. The sufficient voltage gain is obtained by all the intermediate stages. Hence these stages are called **voltage amplifiers**.

But the last stage gives an output to the load like a loud speaker. Hence the last stage must be capable of delivering an appreciable amount of a.c. power to the load. So it must be capable of handling large voltage or current swings or in other words large signals. The main aim is to develop sufficient power hence the voltage gain is not important, in the last stage. Such a stage, which develops and feeds sufficient power to the load like loudspeaker, servomotor, handling the large signals is called **Large Signal Amplifier** or **Power Amplifier.**

Power amplifiers find their applications in the public address systems, radio receivers, driving servomotor in industrial control systems, tape players, T.V. receivers, cathode ray tubes etc.

5.2 Comparison of Voltage Amplifiers and Power amplifiers



sl.no	Characteristics	Voltage Amplifier	Power Amplifier
1	Current Gain	High, exceeding 100	Low 20-50
2	Collector Load	High about 10KΩ	Low 5-20Ω
3	Input Voltage	Low, a few mV	High, 2-4V
4	Collector Current	Low about 1mA	High exceeding 100mA
5	Power output	Low	High
6	Power dissipation capacity	Less than 0.5W	More than 0.5W
7	Output Impedence	High about 10KΩ	Low about 200Ω
8	Coupling	Usually RC coupling	Transformer or tuned circuit

5.3 Features of Power Amplifiers

The various features of power amplifiers are,

1. A power amplifier is the last stage of multistage amplifier. The previous stages develop sufficient gain and the **input signal level or amplitude of a power amplifier is large** of the order of few volts.
2. The **output of power amplifier has large current and voltage swings**. As it handles large signals called power amplifiers.
3. **The h-parameter analysis** is applicable to the small signal amplifiers and hence **cannot be used for the analysis of power amplifiers**. The analysis of power amplifiers is carried out graphically by drawing a load line on the output characteristics of the transistors used in it.
4. The power amplifiers i.e large signal amplifiers are used to feed the loads like loudspeakers having low impedance. So for maximum power transfer the impedance matching is important. Hence **the power amplifiers must have low output impedance**. Hence common collecter or emitter follower circuit is very common in power amplifiers. The common emitter circuit with a step down transformer for impedance matching is also commonly used in power amplifiers.
5. The power amplifiers develop an a.c. power of the order of few watts. Similarly large power gets dissipated in the form of heat, at the junctions of the transistors used in the power amplifiers. **Hence the transistors used in the power amplifiers are of large size, having large power dissipation rating, called power transistors**. Such transistors have heat sinks. A heat sink is a metal cap having bigger surface area, press fit on the body of a transistor, to get more surface area, in order to dissipate the heat to the surroundings. In general, the power amplifiers have bulky components.
6. A faithful reproduction of the signal, after the conversion, is important. Due to nonlinear nature of the transistor characteristics, there exists a harmonic distortion in the signal. Ideally signal should not be distorted. **Hence the analysis of signal distortion in case of the power amplifiers is important.**
7. Many a times, the power amplifiers are used in public address systems and many audio circuits to supply large power to the loudspeakers. **Hence power amplifiers are also called audio amplifiers or audio frequency (A.F.) power amplifiers.**

5.4 Classification of Large Signal Amplifiers

For an amplifier, a quiescent operating point (Q point) is fixed by selecting the proper d.c. biasing to the transistors used. The quiescent operating point is shown on the load line, which is plotted on the output characteristics of the transistor. The position of the quiescent point on the load line decides the class of operation of the power amplifier. The various classes of the power amplifiers are :

i) Class A ii) Class B iii) Class C and iv) Class AB

These variations in I_C and V_{CE}, due to the change in I_B, can be shown graphically with the help of a load line as shown in the Fig. 5.2.

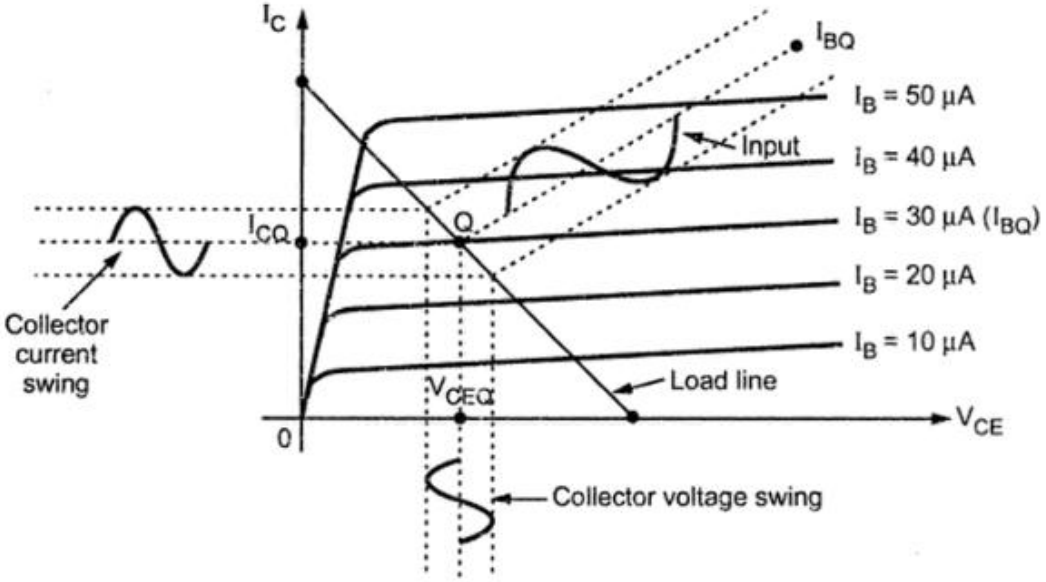


Fig. 5.2 Graphical representation of I_B, I_C and V_{CE} swings

The collector current varies above and below its quiescent value, in phase with the base current. The collector-to-emitter voltage varies above and below its quiescent value, 180° out of phase with the base current, as shown in the Fig. 5.2.

5.4.1 Class A Amplifier

The power amplifier is said to be class A amplifier if the Q point and the input signal are selected such that the output signal is obtained for a full input cycle.

Key Point: *For this class, position of the Q point is approximately at the midpoint of the load line.*

For all values of input signal, the transistor remains in the active region and never enters into cut-off or saturation region. When an a.c. input signal is applied, the collector voltage varies sinusoidally hence the collector current also varies sinusoidally. The collector current flows for 360° (full cycle) of the input signal. In other words, the angle of the collector current flow is 360° i.e. one full cycle.

The current and voltage waveforms for a class A operation are shown with the help of output characteristics and the load line, in the Fig. 5.3.

As shown in the Fig. 5.3, for full input cycle, a full output cycle is obtained. Here signal is faithfully reproduced, at the output, without any distortion. This is an important feature of a class A operation. The efficiency of class A operation is very small.

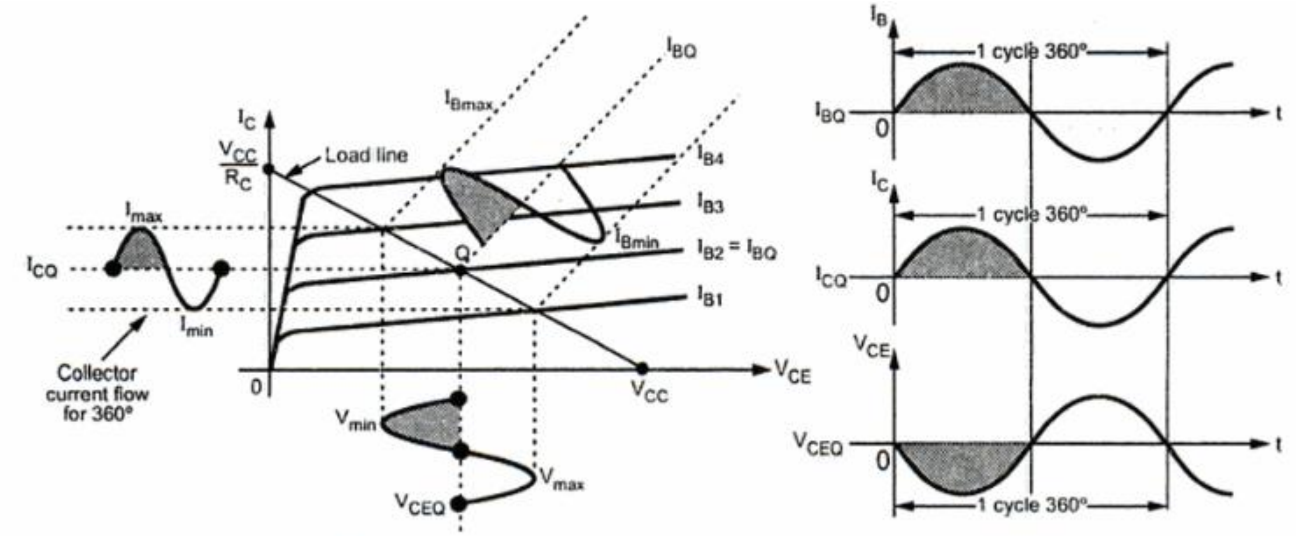


Fig. 5.3 **Waveforms representing class A operation**

5.4.2 Class B Amplifier

The power amplifier is said to be class B amplifier if the Q point and the input signal are selected, such that the output signal is obtained only for one half cycle for a full input cycle.

Key Point: *For this operation, the Q point is shifted on X-axis i.e. transistor is biased to cut-off.*

Due to the selection of Q point on the X-axis, the transistor remains, in the active region, only for positive half cycle of the input signal. Hence this half cycle is reproduced at the output. But in a negative half cycle of the input signal, the transistor enters into a cut-off region and no signal is produced at the output. The collector current flows only for 180° (half cycle) of the input signal. In other words, the angle of the collector current flow is 180° i.e. one half cycle.

The current and voltage waveforms for a class B operation are shown in the Fig. 5.4.

As only a half cycle is obtained at the output, for full input cycle, the output signal is distorted in this mode of operation. To eliminate this distortion, practically two transistors are used in the alternate half cycles of the input signal. Thus overall a full cycle of output signal is obtained across the load. Each transistor conducts only for a half cycle of the input signal.

The efficiency of class B operation is much higher than the class A operation.

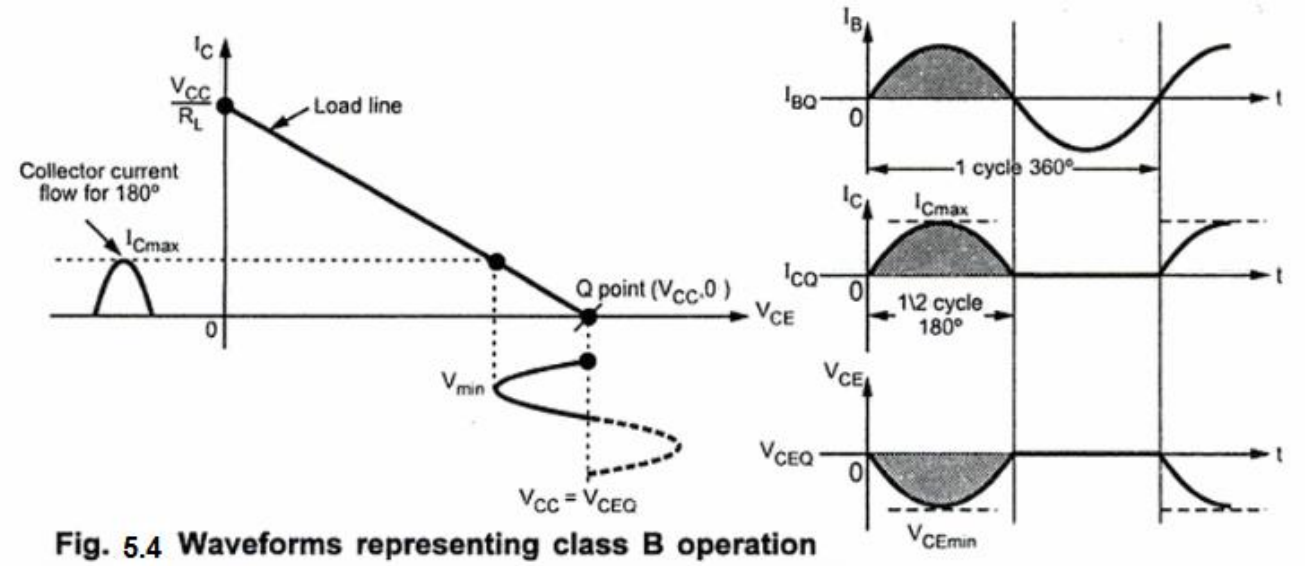


Fig. 5.4 Waveforms representing class B operation

5.4.3 Class C Amplifier

The power amplifiers is said to be class C amplifier, if the Q point and the input signal are selected such that the output signal is obtained for less than a half cycle, for a full input cycle.

Key Point : *For this operation, the Q point is to be shifted below X-axis.*

Due to such a selection of the Q point, transistor remains active, for less than a half cycle. Hence only that much part is reproduced at the output. For remaining cycle of the input cycle, the transistor remains cut-off and no signal is produced at the output. The angle of the collector current flow is less than 180°.

The current and voltage waveforms for a class C amplifier operation are shown in the Fig. 5.5

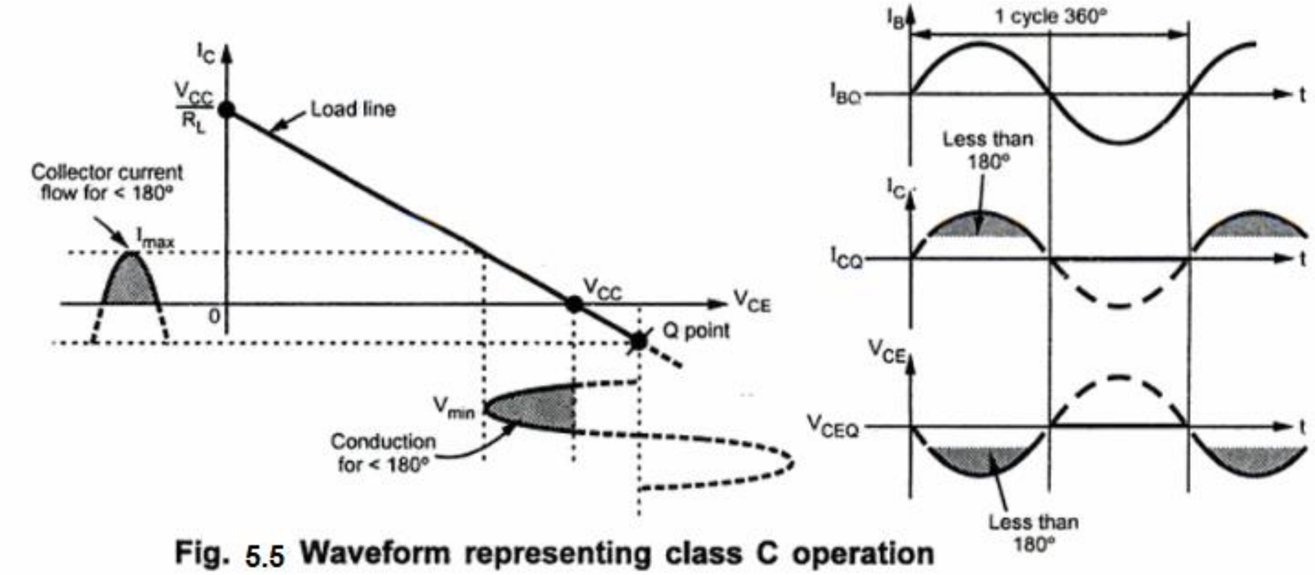


Fig. 5.5 Waveform representing class C operation

Key Point : *In class C operation, the transistor is biased well beyond cut-off. As the collector current flows for less than 180°, the output is much more distorted and hence the class C mode is never used for A.F. power amplifiers.*

But the efficiency of this class of operation is much higher and can reach very close to 100 %.

Applications : The class C operation is not suitable for audio frequency power amplifiers. The class C amplifiers are used in tuned circuits used in communication areas and in radio frequency (RF) circuits with tuned RLC loads. As used in tuned circuits, class C amplifiers are called **tuned amplifiers**. These are also used in mixer or converter circuits used in radio receivers and wireless communication systems.

The Fig. 5.6 shows the calss C tuned amplifier.

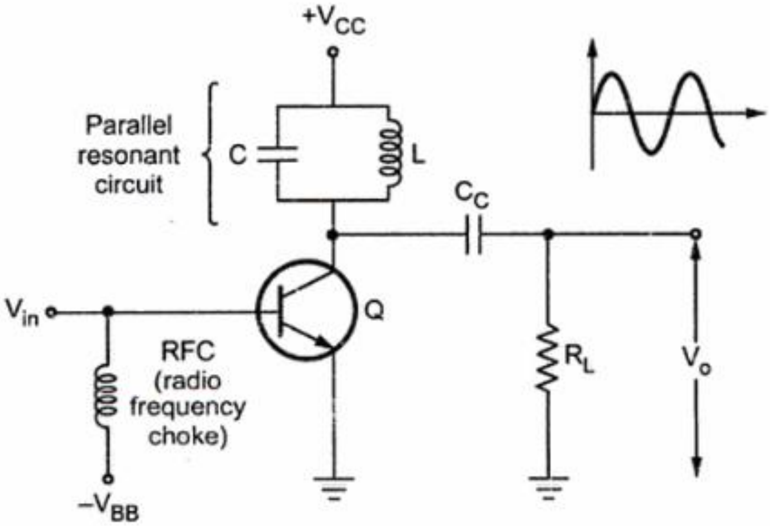


Fig. 5.6 Class C tuned amplifier

The LC parallel circuit is a parallel resonant circuit. This circuit acts as a load impedance. Due to class C operation, the collector current consists of a series of pulses containing harmonics i.e. many other frequency components along with the fundamental frequency component of input. The parallel tuned circuit is designed to be tuned to the fundamental input frequency. Hence it eliminates the harmonics and produce a sine wave of fundamental component of input signal. As the transistor and coil losses are small, the most of the d.c. input power is converted to a.c. load power. Hence efficiency of class C is very high.

5.4.4 Class AB Amplifier

The power amplifier is said to be class AB amplifier, if the Q point and the input signal are selected such that the output signal is obtained for more than 180° but less than 360°, for a full input cycle.

Key Point : *The Q point position is above X-axis but below the midpoint of a load line.*

The current and voltage waveforms for a class AB operation, are shown in the Fig. 5.7.

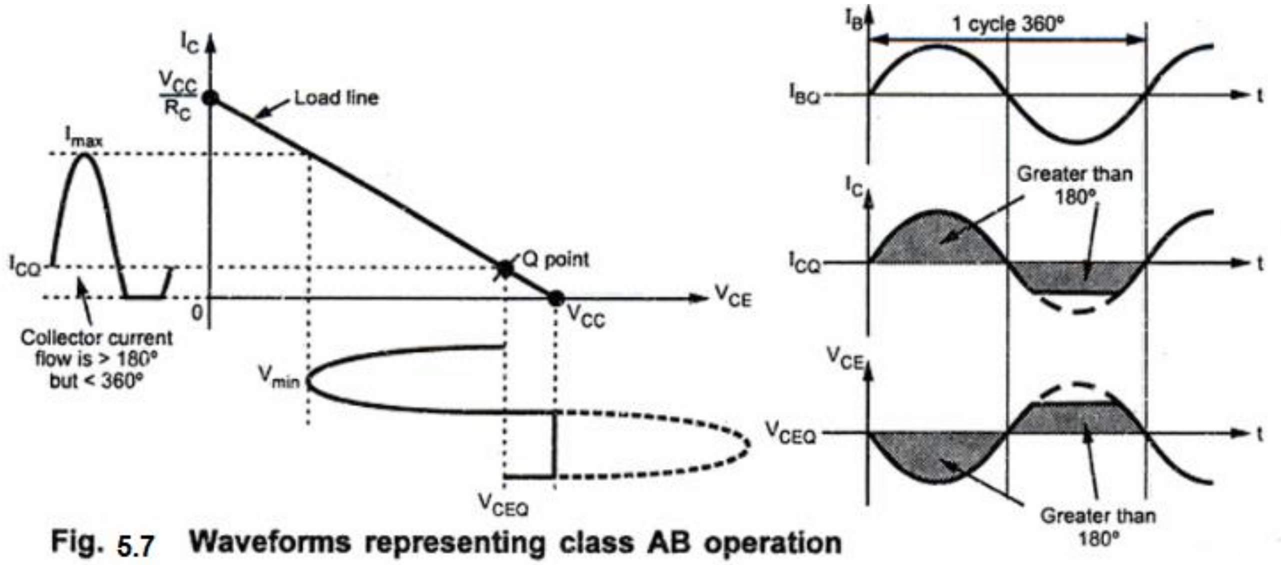


Fig. 5.7 Waveforms representing class AB operation

The output signal is distorted in class AB operation. The efficiency is more than class A but less than class B operation. The class AB operation is important to eliminate cross-over distortion.

In general as the Q point moves away from the centre of the load line below towards the X-axis, the efficiency of class of operation increases.

5.4.5 Comparison of amplifier classes

Class	A	B	C	AB
Operating cycle	360°	180°	Less than 180°	180° to 360°
Position of Q point	Centre of load line	On X-axis	Below X-axis	Above X-axis but below the centre of load line
Efficiency	Poor, 25 % to 50 %	Better, 78.5 %	High	Higher than A but less than B 50 % to 78.5 %
Distortion	Absent No distortion	Present More than class A	Highest	Present

5.5 Analysis of Class A Amplifiers

The class A amplifiers are further classified as **directly coupled** and **transformer coupled** amplifiers. In directly coupled type, the load is directly connected in the collector circuit. While in the transformer coupled type, the load is coupled to the collector using a transformer called an output transformer. Let us study in detail the various aspects of the two types of class A amplifiers.

5.6 Series Fed, Direct Coupled Class A Amplifier

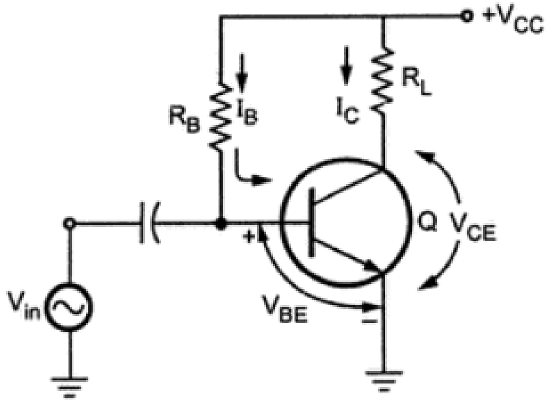


Fig. 5.8 **Large signal class A amplifier**

A simple fixed-bias circuit can be used as a large signal class A amplifier as shown in the Fig. 5.8.

The difference between small signal version of this circuit is that the signals handled by this large signal circuit are of the order of few volts. Similarly the transistor used, is a power transistor. The value of R_B is selected in such a way that the Q point lies at the centre of the d.c. load line.

The circuit represents the directly coupled class A amplifier as the load resistance is directly connected in the collector circuit. Most of the times the load is a loudspeaker, the impedance of which varies from 3 to 4 ohms to 16 ohms. The beta of the transistor used is less than 100.

Key Point : *This is called **directly coupled**, as the load R_L is directly connected in the collector circuit of power transistor.*

The overall circuit handles large power, in the range of a few to tens of watts without providing much voltage gain.

The graphical representation of a class A amplifier is shown in the Fig. 5.9.

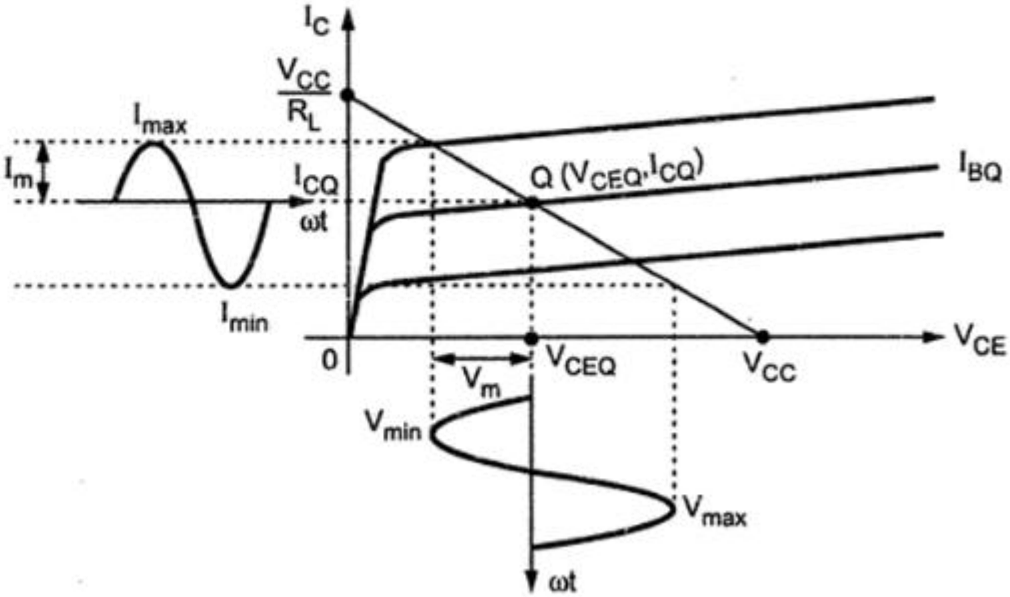


Fig. 5.9 **Graphical representation of class A amplifier**

Applying Kirchhoff's voltage law to the circuit shown in the Fig. 5.8, we get

$$V_{CC} = I_C R_L + V_{CE}$$

$$\therefore \quad I_C R_L = -V_{CE} + V_{CC}$$

$$\therefore \quad I_C = \left[-\frac{1}{R_L}\right] V_{CE} + \frac{V_{CC}}{R_L} \qquad \ldots (1)$$

The equation is similar to equation (1) of section and thus the slope of the load line is $-\frac{1}{R_L}$ while the Y-intercept is $\frac{V_{CC}}{R_L}$.

The change is because the collector resistance R_C is named as load resistance R_L in this circuit. The Q point is adjusted approximately at the centre of the load line.

5.6.1 DC Operation

The collector supply voltage V_{CC} and resistance R_B decides the d.c. base-bias current I_{BQ}. The expression is obtained applying KVL to the B-E loop and with V_{BE} = 0.7 V.

$$\therefore \quad \boxed{I_{BQ} = \frac{V_{CC} - 0.7}{R_B}} \qquad \ldots (2)$$

The corresponding collector current is then,

$$\boxed{I_{CQ} = \beta\, I_{BQ}} \qquad \ldots (3)$$

From the equation (1), the corresponding collector to emitter voltage is,

$$\boxed{V_{CEQ} = V_{CC} - I_{CQ} R_L} \qquad \ldots (4)$$

Hence the Q point can be defined as Q (V_{CEQ}, I_{CQ}).

5.6.2 DC Power Input

The d.c. power input is provided by the supply. With no a.c input signal, the d.c. current drawn is the collector bias current I_{CQ} . Hence d.c. power input is,

$$\boxed{P_{DC} = V_{CC}\, I_{CQ}} \qquad \ldots (5)$$

It is important to note that even if a.c. input signal is applied, the average current drawn from the d.c. supply remains same. Hence equation (5) represents d.c. power input to the class A series fed amplifier.

5.6.3 AC Operation

When an input a.c. signal is applied, the base current varies sinusoidally.

Assuming that the nonlinear distortion is absent, the nature of the collector current and collector to emitter voltage also vary sinusoidally as shown graphically in the Fig. 5.9.

The output current i.e. collector current varies around its quiescent value while the output voltage i.e collector to emitter voltage varies around its quiescent value. The varying output voltage and output current deliver an a.c. power to the load. Let us find the expressions for the a.c. power delivered to the load.

5.6.4 AC Power Output

For an alternating output voltage and output current swings, shown in the Fig. 5.9, we can write,

V_{min} = Minimum instantaneous value of the collector (output) voltage

V_{max} = Maximum instantaneous value of the collector (output) voltage

and V_{pp} = Peak to peak value of a.c. output voltage across the load.

$$\therefore \quad V_{pp} = V_{max} - V_{min} \qquad \dots (6)$$

Now V_m = Amplitude (peak) of a.c. output voltage as shown in the Fig. 5.9.

$$\therefore \quad \boxed{V_m = \frac{V_{pp}}{2} = \frac{V_{max} - V_{min}}{2}} \qquad \dots (7)$$

Similarly we can write for the output current as,

I_{min} = Minimum instantaneous value of the collector (output) current

I_{max} = Maximum instantaneous value of the collector (output) current

and I_{pp} = Peak to peak value of a.c. output (load) current

$$\therefore \quad I_{pp} = I_{max} - I_{min} \qquad \dots (8)$$

Now I_m = Amplitude (peak) of a.c. output (load) current as shown in the Fig. 5.9

$$\therefore \quad \boxed{I_m = \frac{I_{pp}}{2} = \frac{I_{max} - I_{min}}{2}} \qquad \dots (9)$$

Hence the r.m.s. values of alternating output voltage and current can be obtained as,

$$V_{rms} = \frac{V_m}{\sqrt{2}} \qquad \dots (10)$$

$$I_{rms} = \frac{I_m}{\sqrt{2}} \qquad \dots (11)$$

Hence we can write,

$$V_{rms} = I_{rms} R_L \qquad \dots (12)$$

i.e.

$$V_m = I_m R_L \qquad \dots (13)$$

The a.c. power delivered by the amplifier to the load can be expressed by using r.m.s values, maximum i.e. peak values and peak to peak values of output voltage and current.

i) Using r.m.s values

$$\therefore \quad \boxed{P_{ac} = V_{rms} I_{rms}} \quad \text{... (14)}$$

$$\text{or} \quad \boxed{P_{ac} = I_{rms}^2 R_L} \quad \text{... (15)}$$

$$\text{or} \quad \boxed{P_{ac} = \frac{V_{rms}^2}{R_L}} \quad \text{... (16)}$$

ii) Using peak values

$$P_{ac} = V_{rms} I_{rms} = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}}$$

$$\therefore \quad \boxed{P_{ac} = \frac{V_m I_m}{2}} \quad \text{... (17)}$$

$$\text{or} \quad \boxed{P_{ac} = \frac{I_m^2 R_L}{2}} \quad \text{... (18)}$$

$$\text{or} \quad \boxed{P_{ac} = \frac{V_m^2}{2 R_L}} \quad \text{... (19)}$$

iii) Using peak to peak values

$$P_{ac} = \frac{V_m I_m}{2} = \frac{\left(\frac{V_{PP}}{2}\right)\left(\frac{I_{PP}}{2}\right)}{2}$$

$$\boxed{P_{ac} = \frac{V_{pp} I_{pp}}{8}} \quad \text{... (20)}$$

$$\text{or} \quad \boxed{P_{ac} = \frac{I_{pp}^2 R_L}{8}} \quad \text{... (21)}$$

$$\text{or} \quad \boxed{P_{ac} = \frac{V_{PP}^2}{8 R_L}} \quad \text{... (22)}$$

But as $V_{pp} = V_{max} - V_{min}$ and $I_{pp} = I_{max} - I_{min}$; from equation (20), the a.c. power can be expressed as below, for graphical calculations.

$$\boxed{P_{ac} = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8}} \quad \text{... (23)}$$

5.6.5 Efficiency

The efficiency of an amplifier represents the amount of a.c. power delivered or transferred to the load, from the d.c. source i.e. accepting the d.c. power input. The generalised expression for an efficiency of an amplifier is,

$$\% \eta = \frac{P_{ac}}{P_{dc}} \times 100 \quad \ldots (24)$$

Now for class A operation, we have derived the expressions for P_{ac} and P_{dc}, hence using equations (5) and (23), we can write

$$\boxed{\% \eta = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8 V_{CC} I_{CQ}} \times 100} \quad \ldots (25)$$

The efficiency is also called **conversion efficiency** of an amplifier.

5.6.6 Maximum Efficiency

For maximum efficiency calculation, assume maximum swings of both the output voltage and the output current. The maximum swings are shown in the Fig. 5.10.

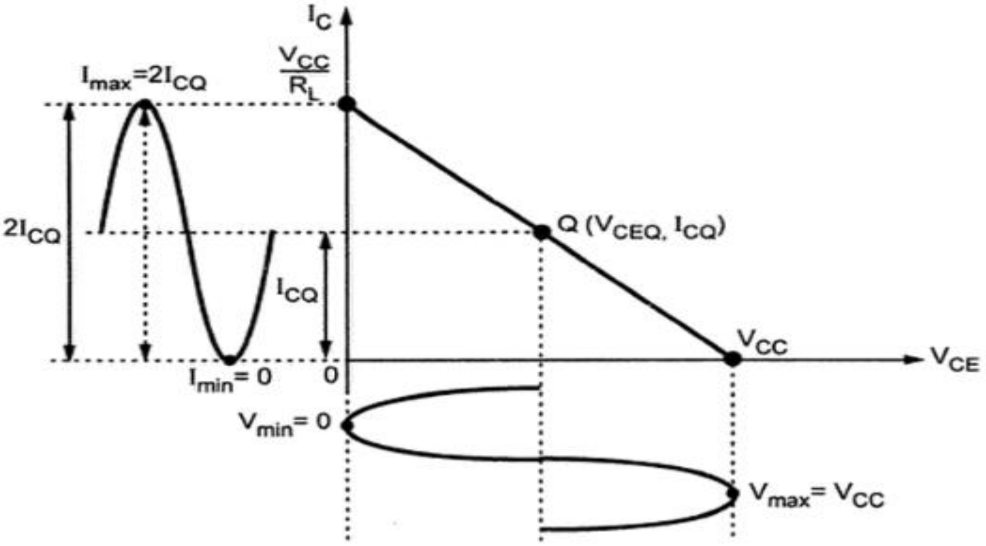


Fig. 5.10 Maximum voltage and current swings

From the Fig. 5.10, we can see that the minimum voltage possible is zero and maximum voltage possible is V_{CC}, for a maximum swing. Similarly the minimum current is zero and the maximum current possible is 2 I_{CQ}, for a maximum swing.

$$\boxed{\left.\begin{array}{l} V_{max} = V_{CC} \text{ and } V_{min} = 0 \\ I_{max} = 2 I_{CQ} \text{ and } I_{min} = 0 \end{array}\right\} \text{for maximum swing}}$$

Using equation (25) we can write,

$$\% \eta_{max} = \frac{(V_{CC} - 0)(2I_{CQ} - 0)}{8 V_{CC} I_{CQ}} \times 100 = \frac{2 V_{CC} I_{CQ}}{8 V_{CC} I_{CQ}} \times 100$$

$$= 25 \%$$

Key Point : ***Thus the maximum efficiency possible in case of directly coupled series fed class A amplifier is just 25 %.***

This maximum efficiency is an ideal value. For a practical circuit, it is much less than 25 %, of the order of 10 to 15 %.

Key Point : ***Very low efficiency is the biggest disadvantage of class A amplifier.***

5.6.7 Power Dissipation

As stated earlier, power dissipation in large signal amplifier is also large. The amount of power that must be dissipated by the transistor is the difference between the d.c. power input P_{dc} and the a.c. power delivered to the load P_{ac}.

$$P_d = \text{Power dissipation}$$

$$\text{i.e.} \quad \boxed{P_d = P_{DC} - P_{ac}} \qquad \dots (26)$$

The maximum power dissipation occurs when there is zero a.c. input signal. When a.c. input is zero, the a.c. power output is also zero. But transistor operates at quiescent condition, drawing d.c. input power from the supply equal to $V_{CC}\ I_{CQ}$. This entire power gets dissipated in the form of heat. Thus d.c. power input without a.c. input signal is the maximum power dissipation.

$$\boxed{(P_d)\text{max} = V_{CC}\ I_{CQ}} \qquad \dots (27)$$

5.6.8 Advantages and Disadvantages of Class A amplifier

The **advantages** of directly coupled class A amplifier can be stated as,

1. The circuit is simple to design and to implement.
2. The load is connected directly in the collector circuit hence the output transformer is not necessary. This makes the circuit cheaper.
3. Less number of components required as load is directly coupled.

The disadvantages are,

1. The load resistance is directly connected in collector and carries the quiescent collector current. This causes considerable wastage of power.
2. Power dissipation is more. Hence power dissipation arrangements like heat sink are essential.
3. The output impedance is high hence circuit cannot be used for low impedance loads, such as loudspeakers.
4. The efficiency is very poor, due to large power dissipation.

Example : *A series fed class A amplifier shown in Fig. operates from d.c. source and applied sinusoidal input signal generates peak base current 9 mA. Calculate :*

i) Quiescent current I_{CQ}

ii) Quiescent voltage V_{CEQ}

iii) D.C. input power P_{DC}

iv) A.C. output power P_{ac}

v) Efficiency.

Assume $\beta = 50$ *and* $V_{BE} = 0.7\ V$.

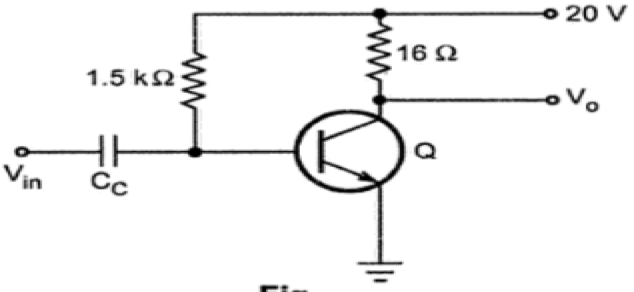


Fig.

Solution :

i) I_{CQ} $$I_{BQ} = \frac{V_{CC} - V_{BE}}{R_B} = \frac{20-0.7}{1.5\times10^3} = 12.87 \text{ mA}$$

$$I_{CQ} = \beta \times I_{BQ} = 50\times12.87 = \mathbf{643.50\ mA}$$

ii) V_{CEQ} $$V_{CC} = I_{CQ}R_L + V_{CEQ}$$

$$\therefore \quad V_{CEQ} = V_{CC} - I_{CQ}R_L = 20 - 643.50\times10^{-3}\times16 = \mathbf{9.70\ volts}$$

iii) P_{DC} $$P_{DC} = V_{CC}\times I_{CQ} = 20\times643.5\times10^{-3} = \mathbf{12.87\ watt}$$

iv) P_{ac} Peak current $i_b = 9$ mA

$$i_c = \beta\, i_b = 50\times9 = 450 \text{ mA (peak)}$$

$$\therefore \quad i_{c(rms)} = \frac{i_{c\,(peak)}}{\sqrt{2}} = \frac{450}{\sqrt{2}} = 318.19 \text{ mA} = I_{rms}$$

$$\therefore \quad P_{ac} = I_{rms}^2 R_L = (318.19\times10^{-3})^2\times16 = \mathbf{1.619\ \ watt}$$

v) Efficiency $$\eta = \frac{P_{ac}}{P_{DC}}\times100 = \frac{1.619}{12.87}\times100 = \mathbf{12.58\ \%}$$

5.7 Transformer Coupled Class A Amplifier

As stated earlier, for maximum power transfer to the load, the impedance matching is necessary. For loads like loudspeaker, having low impedance values, impedance matching is difficult using directly coupled amplifier circuit. This is because loudspeaker resistance is in the range of 3 to 4 ohms to 16 ohms while the output impedance of series fed directly coupled class A amplifier is very much high. This problem can be eliminated by using a transformer to deliver power to the load.

5.7.1 Properties of Transformer

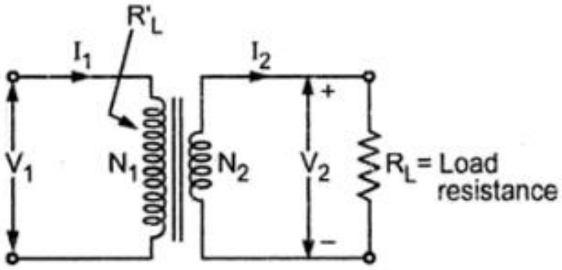


Fig. 5.11 Transformer with load

Consider a transformer as shown in the Fig. 5.11 which is connected to a load of resistance R_L.

While analysing the transformer, it is assumed that the transformer is ideal and there are no losses in the transformer. Similarly the winding resistances are assumed to be zero.

Let N_1 = Number of turns on primary

N_2 = Number of turns on secondary

V_1 = Voltage applied to primary

V_2 = Voltage on secondary

I_2 = Primary current

i) Turns Ratio : The ratio of number of turns on secondary to the number of turns on primary is called turns ratio of the transformer denoted by n.

$$\therefore \quad \boxed{n = \text{Turns ratio} = \frac{N_2}{N_1}} \quad \dots (1)$$

Some times it is specified as $\frac{N_2}{N_1} : 1$ or $\frac{N_1}{N_2} : 1$.

ii) Voltage Transformation : The transformer transforms the voltage applied on one side to other side proportional to the turns ratio. The transformer can be step up or step down transformer.

$$\therefore \quad \frac{V_2}{V_1} = \frac{N_2}{N_1} = n \quad \dots (2)$$

In the amplifier analysis, the load impedance is going to be small. And the transformer is to be used for impedance matching. Hence it has to be a step down transformer. Hence number of turns on primary are more than the secondary and turns ratio is less than unity, for such a step down transformer.

iii) Current Transformation : The current in the secondary winding is inversely proportional to the number of turns of the windings.

$$\therefore \qquad \frac{I_2}{I_1} = \frac{N_1}{N_2} = \frac{1}{n} \qquad \text{... (3)}$$

iv) Impedance Transformation : As current and voltage get transformed from primary to secondary, an impedance `seen' from either side (primary or secondary) also changes.

Now the impedance of the load on secondary is R_L as shown in the Fig. 5.11. The primary and secondary winding resistances are assumed to be zero. This load impedance R_L, gets reflected on the primary side and behaves as if connected in the primary side. Such impedance transferred from secondary to primary is denoted as R_L'.

Now using the equations (2) and (3) and the Fig. 5.11, we can write,

$$R_L = \frac{V_2}{I_2} \text{ and } R_L' = \frac{V_1}{I_1}$$

But $$V_1 = \frac{N_1}{N_2} V_2 \text{ and } I_1 = \frac{N_2}{N_1} I_2$$

$$\therefore \qquad R_L' = \frac{\frac{N_1}{N_2} V_2}{\frac{N_2}{N_1} I_2} = \left(\frac{N_1}{N_2}\right)^2 \times \frac{V_2}{I_2} = \frac{R_L}{\left(\frac{N_2}{N_1}\right)^2} = \frac{R_L}{n^2}$$

$$\therefore \qquad \boxed{R_L' = \frac{R_L}{n^2} = \left(\frac{N_1}{N_2}\right)^2 R_L} \qquad \text{... (4)}$$

The R_L' is the **reflected impedance** and is related to the square of the turns ratio of the transformer. Remember that for a step down transformer, the secondary voltage is less than the primary. And high voltage side is always high impedance side. **Hence R_L' is always higher than R_L, for a step down transformer.**

5.8 Analysis of Transformer Coupled Class A Amplifier

The basic circuit of a transformer coupled amplifier is shown in the Fig. 5.12. The loudspeaker connected to the secondary acts as a load having impedance of R_L ohms.

The transformer used is a step down transformer with the turns ratio as

$$\boxed{n = N_2/N_1}$$

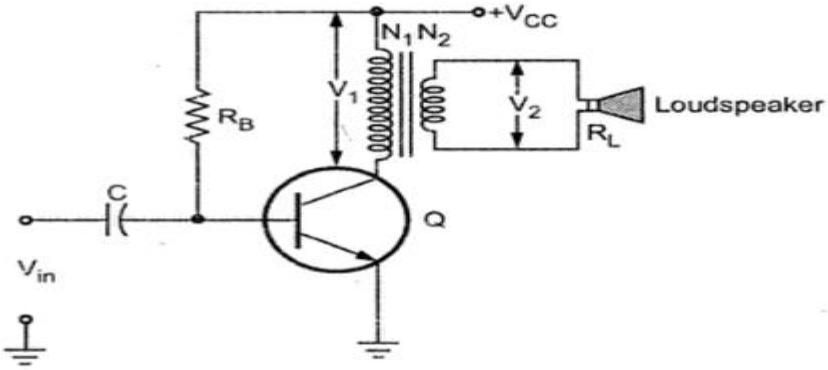


Fig. 5.12 Transformer coupled class A amplifier

5.8.1 DC Operation

It is assumed that the winding resistances are zero ohms. Hence for d.c. purposes, the resistance is 0 Ω. There is no d.c. voltage drop across the primary winding of the transformer. The slope of the d.c. load line is reciprocal of the d.c. resistance in the collector circuit, which is zero in this case. Hence slope of the d.c. load line is ideally infinite. This tells that the d.c. load line in the ideal condition is a vertically straight line.

Applying Kirchhoff's voltage law to the collector circuit we get,

$$V_{CC} - V_{CE} = 0$$

i.e. $V_{CC} = V_{CE}$ ... Drop across winding is zero

This is the d.c. bias voltage V_{CEQ} for the transistor.

So $$\boxed{V_{CEQ} = V_{CC}} \quad \text{... (5)}$$

Hence the d.c. load line is a vertical straight line passing through a voltage point on the X-axis which is $V_{CEQ} = V_{CC}$.

The intersection of d.c. load line and the base current set by the circuit is the quiescent operating point of the circuit. The corresponding collector current is I_{CQ}.

5.8.2 DC Power Input

The d.c. power input is provided by the supply voltage with no signal input, the d.c. current drawn is the collector bias current I_{CQ}.

Hence the d.c. power input is given by,

So $$\boxed{P_{DC} = V_{CC} I_{CQ}} \quad \text{... (6)}$$

The expression is same as derived earlier for series fed directly coupled class A amplifier.

5.8.3 AC Operation

For the a.c. analysis, it is necessary to draw an a.c. load line on the output characteristics.

For a.c. purposes, the load on the secondary is the load impedance R_L ohms. And the reflected load on the primary i.e. $R_L^{'}$ can be calculated using the equation (4). The load line drawn with a slope of $\left(\frac{-1}{R_L^{'}}\right)$ and passing through the operating point i.e. quiescent point Q is called **a.c. load line**. The d.c. and a.c. load lines are shown in the Fig. 5.13.

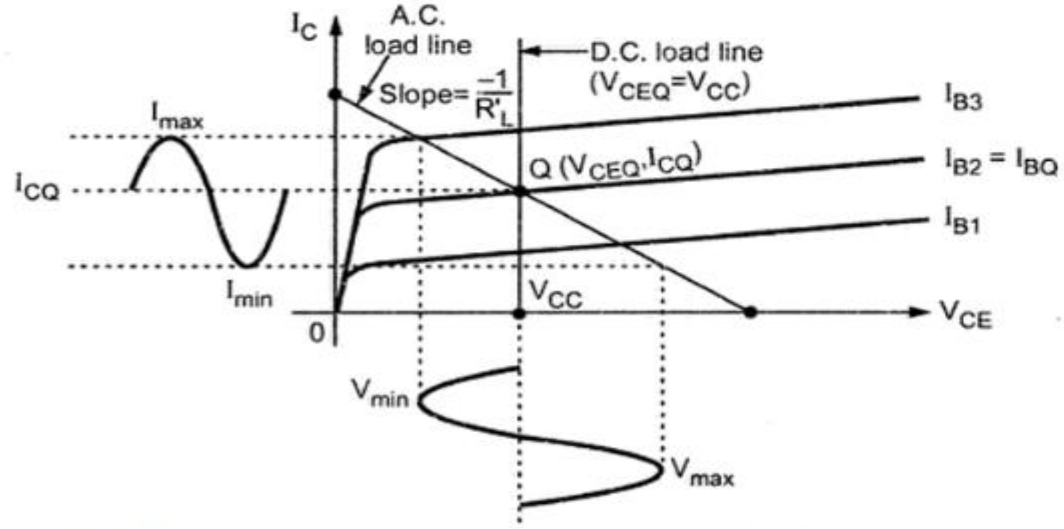


Fig. 5.13 Load lines for transformer coupled class A amplifier

The output current i.e. collector current varies around its quiescent value I_{CQ}, when a.c. input signal is applied to the amplifier. The corresponding output voltage also varies sinusoidally around its quiescent value V_{CEQ} which is V_{CC} in this case.

5.8.4 AC Output Power

The a.c. power developed is on the primary side of the transformer. While calculating this power, the primary values of voltage and current and reflected load $R_L^{'}$ must be considered. The a.c. power delivered to the load is on the secondary side of the transformer. While calculating load voltage, load current, load power the secondary voltage, current and the load R_L must be considered.

Let V_{1m} = Magnitude or peak value of primary voltage

V_{1rms} = R.M.S value of primary voltage

I_{1m} = Peak value of primary current

I_{1rms} = R.M.S value of primary current.

Hence the a.c. power developed on the primary is given by,

$$P_{ac} = V_{1rms} I_{1rms} \quad \text{... (7)}$$

$$P_{ac} = I^2_{1rms} R'_L \quad \text{... (8)}$$

$$P_{ac} = \frac{V^2_{1rms}}{R'_L} \quad \text{... (9)}$$

$$P_{ac} = \frac{V_{1m}}{\sqrt{2}} \cdot \frac{I_{1m}}{\sqrt{2}} = \frac{V_{1m} I_{1m}}{2} \quad \text{... (10)}$$

$$P_{ac} = \frac{I^2_{1m} R'_L}{2} \quad \text{... (11)}$$

$$P_{ac} = \frac{V^2_{1m}}{2 R'_L} \quad \text{... (12)}$$

Similarly the a.c. power delivered to the load on secondary, also can be calculated, using secondary quantities.

Let V_{2m} = Magnitude or peak value of secondary or load voltage

$V_{2\,rms}$ = R.M.S value of secondary or load voltage

I_{2m} = Magnitude or peak value of secondary or load current.

I_{2rms} = R.M.S. value of secondary or load current

$$\boxed{P_{ac} = V_{2rms} I_{2rms} = I^2_{2rms} R_L = \frac{V^2_{2rms}}{R_L}} \quad \text{... (13)}$$

or

$$\boxed{P_{ac} = \frac{V_{2m} I_{2m}}{2} = \frac{I^2_{2m} R_L}{2} = \frac{V^2_{2m}}{2R_L}} \quad \text{... (14)}$$

Power delivered on primary is same as power delivered to the load on secondary, assuming **ideal transformer**. Primary and Secondary values of voltages and currents are related to each other through the turns ratio of the transformer.

The generalised expression for a.c. power output represented by the equation (23) in section (6.7), can be used as it is for transformer coupled amplifier. The expression is mentioned again for the convenience of the reader.

$$\therefore \quad \boxed{P_{ac} = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8}}$$

5.8.5 Efficiency

The general expression for the efficiency remains same as that given by equations (24) and (25)

$$\% \eta = \frac{P_{ac}}{P_{dc}} \times 100 = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8 V_{CC} I_{CQ}} \times 100$$

5.8.6 Maximum Efficiency

Assume maximum swings of both the output voltage and output current, to calculate maximum efficiency, as shown in the Fig. 5.14.

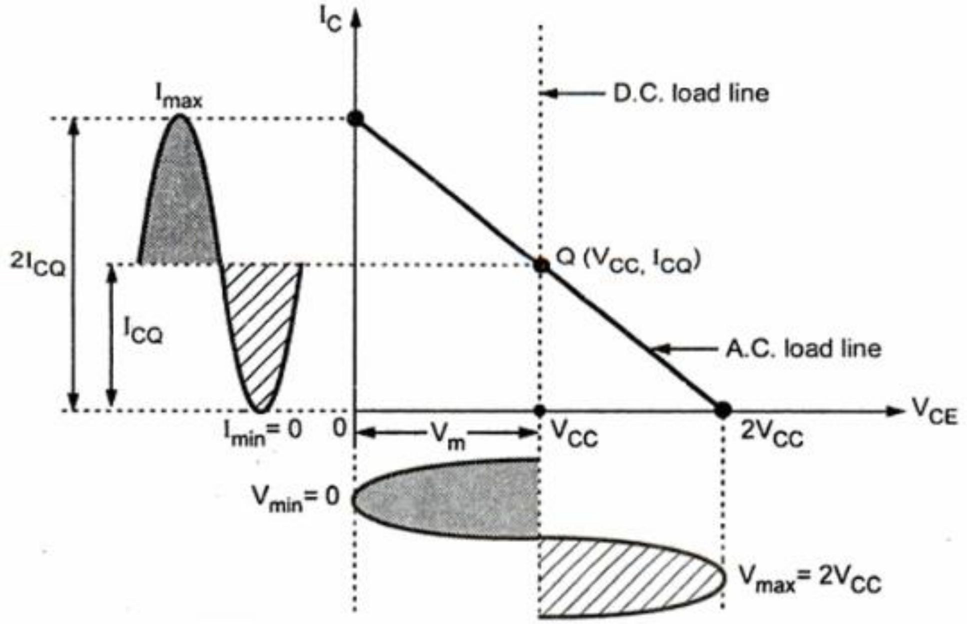


Fig. 5.14 Maximum voltage and current swings

From the Fig. 5.14, assuming that the Q point is exactly at the centre of the load line, for maximum swing we can write,

$$\left.\begin{aligned} V_{min} &= 0 \text{ and } V_{max} = 2 V_{CC} \\ I_{min} &= 0 \text{ and } I_{max} = 2 I_{CQ} \end{aligned}\right\} \text{ for maximum swing}$$

Using equation (25) of section 6.7,

$$\% \eta_{max} = \frac{(2V_{CC} - 0)(2I_{CQ} - 0)}{8 V_{CC} I_{CQ}} \times 100$$

$$= \frac{4 V_{CC} I_{CQ}}{8 V_{CC} I_{CQ}} \times 100 = 50 \%$$

Key Point : *Hence maximum possible theoretical efficiency in case of transformer coupled class A amplifier is 50 %.*

5.8.7 Power Dissipation

The power dissipation by the transistor is the difference between the a.c. power output and the d.c. power input. The power dissipated by the transformer is very small due to negligible (d.c.) winding resistances and can be neglected.

$$\therefore \quad P_d = P_{DC} - P_{ac} \quad \ldots (16)$$

When the input signal is larger, more power is delivered to the load and less is the power dissipation. But when there is no input signal, the entire d.c. input power gets dissipated in the form of heat, which is the maximum power dissipation.

$$\therefore \quad \boxed{(P_d)_{max} = V_{CC}\, I_{CQ}} \quad \ldots (17)$$

Thus the class A amplifier dissipates less power when delivers maximum power to the load. While it dissipates maximum power while delivering zero power to the load i.e. when load is removed and there is no a.c. input signal. The maximum power dissipation decides the maximum power dissipation rating for the power transistor to be selected for an amplifier.

5.8.8 Advantages and Disadvantages of Transformer Coupled Class A Amplifier

The **advantages** of transformer coupled class **A amplifier** circuit are,

1. The efficiency of the operation is higher than directly coupled amplifier.
2. The d.c. bias current that flows through the load in case of directly coupled amplifier is stopped in case of transformer coupled.
3. The impedance matching required for maximum power transfer is possible.

The **disadvantages** are,

1. Due to the transformer, the circuit becomes bulkier, heavier and costlier compared to directly coupled circuit.
2. The circuit is complicated to design and implement compared to directly coupled circuit.
3. The frequency response of the circuit is poor.

Example : *The loudspeaker of 8 Ω is connected to the secondary of the output transformer of a class A amplifier circuit. The quiescent collector current is 140 mA. The turns ratio of the transformer is 3:1. The collector supply voltage is 10 V. If a.c. power delivered to the loudspeaker is 0.48 W, assuming ideal transformer, calculate :*

1. *A.C. power developed across primary*
2. *R.M.S. value of load voltage*

3. *R.M.S. value of primary voltage*
4. *R.M.S. value of load current*
5. *R.M.S. value of primary current*
6. *The D.C. power input*
7. *The efficiency*
8. *The power dissipation*

Solution : $R_L = 8\ \Omega, I_{CQ} = 140\text{ mA}, V_{CC} = 10\text{ V}$

$$P_{ac} = 0.48\text{ W}$$

The turns ratio are specified as $\frac{N_1}{N_2} : 1$ i.e. 3:1

$$\therefore \quad \frac{N_1}{N_2} = 3$$

$$\therefore \quad n = \frac{N_2}{N_1} = \frac{1}{3} = 0.3333$$

$$\therefore \quad R'_L = \frac{R_L}{n^2} = \frac{8}{(0.333)^2} = 72\ \Omega$$

1. As the transformer is ideal, whatever is the power delivered to the load, same is the power developed across primary.

$$\therefore \quad P_{ac}\text{ (across primary)} = \mathbf{0.48\ W}$$

2. Using equation (9),

we get, $$P_{ac} = \frac{V_{1rms}^2}{R'_L}$$

$$\therefore \quad 0.48 = \frac{V_{1rms}^2}{72}$$

$$V_{1rms}^2 = 34.56$$

$$\therefore \quad V_{1rms} = 5.8787\text{ V on primary}$$

But r.m.s. value of the load voltage is V_{2rms}

So $$\frac{(V_1)_{rms}}{(V_2)_{rms}} = \frac{N_1}{N_2} = \frac{3}{1}$$

$$\therefore \quad (V_2)_{rms} = \frac{(V_1)_{rms}}{3} = \frac{5.8787}{3} = \mathbf{1.9595\ V}$$

This is the r.m.s. value of the load voltage.

3. The r.m.s value of the primary voltage is $(V_1)_{rms}$ as calculated above.

$$\therefore \quad (V_1)_{rms} = \mathbf{5.8787\ V}$$

4. The power delivered to the load $= I_{2rms}^2 \times R_L$ ... Refer equation 13.

$$\therefore \quad 0.48 = I_{2rms}^2 \times 8$$

$$\therefore \quad I_{2rms}^2 = 0.06$$

$$\therefore \quad I_{2rms} = \mathbf{0.2449\ A}$$

This is the r.m.s value of the load current as the resistance value used is R_L and not R_L'.

5. The r.m.s values of primary and secondary are related through the transformation ratio.

$$\therefore \quad \frac{(I_1)_{rms}}{(I_2)_{rms}} = \frac{N_2}{N_1} = n = 0.333$$

$$\therefore \quad (I_1)_{rms} = (I_2)_{rms} \times n = 0.2449 \times 0.333 = 0.0816A = 81.64\ mA.$$

6. The d.c. power input is,

$$P_{DC} = V_{CC}\ I_{CQ} = 10 \times 140 \times 10^{-3} = \mathbf{1.4\ W}$$

7. $$\% \eta = \frac{P_{ac}}{P_{dc}} \times 100 = \frac{0.48}{1.4} \times 100 = \mathbf{34.28\%}$$

8. $$P_d = P_{DC} - P_{ac} = 1.4 - 0.48 = \mathbf{0.92\ W}$$

This is the power dissipation.

5.9 Analysis of Class B Amplifiers

As stated earlier, for class B operation, the quiescent operating point is located on the X-axis itself. Due to this collector current flows only for a half cycle for a full cycle of the input signal. Hence the output signal is distorted. To get a full cycle across the load, a pair of transistors is used in class B operation. The two transistors conduct in alternate half cycles of the input signal and a full cycle across the load is obtained. The two transistors are identical in characteristics and called matched transistors.

Depending upon the types of the two transistors whether p-n-p or n-p-n, the two circuit configurations of class B amplifier are possible. These are,

1. When both the transistors are of same type i.e. either n-p-n or p-n-p then the circuit is called **push pull class B** A.F. power amplifier circuit.
2. When the two transistors form a complementary pair i.e. one n-p-n and other p-n-p then the circuit is called **complementary symmetry class B** A.F. power amplifier circuit. Let us analyse these two circuits of class **B** amplifiers in detail.

5.10 Push Pull Class B Amplifier

The push pull circuit requires two transformers, one as input transformer called **driver transformer** and the other to connect the load called **output transformer**. The input signal is applied to the primary of the driver transformer. Both the transformers are centre tapped transformers. The push pull class B amplifier circuit is shown in the Fig. 5.15.

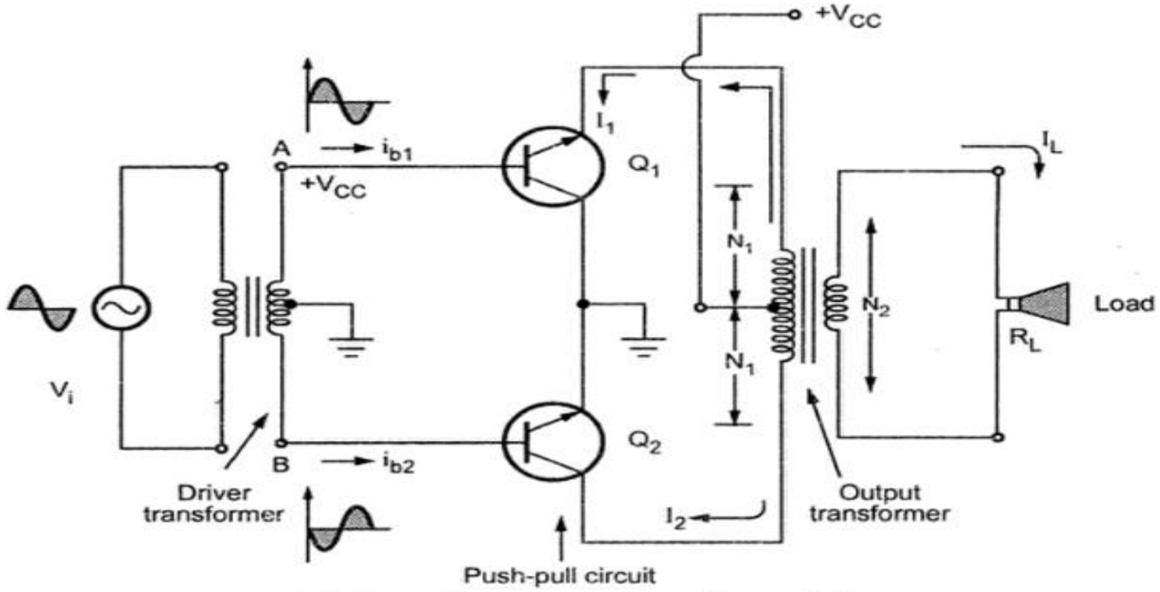


Fig. 5.15 Push pull class B amplifier

In the circuit, both Q_1 and Q_2 transistors are of n-p-n type. The circuit can use both Q_1 and Q_2 of p-n-p type. In such a case, the only change is that the supply voltage must be $-V_{CC}$, the basic circuit remains the same. Generally the circuit using n-p-n transistors is used. Both the transistors are in common emitter configuration.

The driver transformer drives the circuit. The input signal is applied to the primary of the driver transformer. The centre tap on the secondary of the driver transformer is grounded. The centre tap on the primary of the output transformer is connected to the supply voltage $+ V_{CC}$.

With respect to the center tap, for a positive half cycle of input signal, the point A shown on the secondary of the driver transformer will be positive. While the point B will be negative. Thus the voltages in the two halves of the secondary of the driver transformer will be equal but with opposite polarity. Hence the input signals applied to the base of the transistors Q_1 and Q_2 will be 180° out of phase.

The transistor Q_1 conducts for the positive half cycle of the input producing positive half cycle across the load. While the transistor Q_2 conducts for the negative half cycle of the input producing negative half cycle across the load. Thus across the load, we get a full cycle for a full input cycle. The basic push pull operation is shown in the Fig. 5.16.

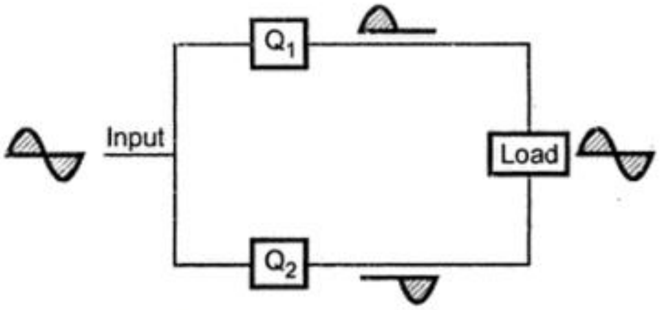


Fig. 5.16 Basic push pull operation

When point A is positive, the transistor Q_1 gets driven into an active region while the transistor Q_2 is in cut-off region. While when point A is negative, the point B is positive, hence the transistor Q_2 gets driven into an active region while the transistor Q_1 is in cut-off region.

The waveforms of the input current, base currents, collector currents and the load current are shown in the Fig. 5.17.

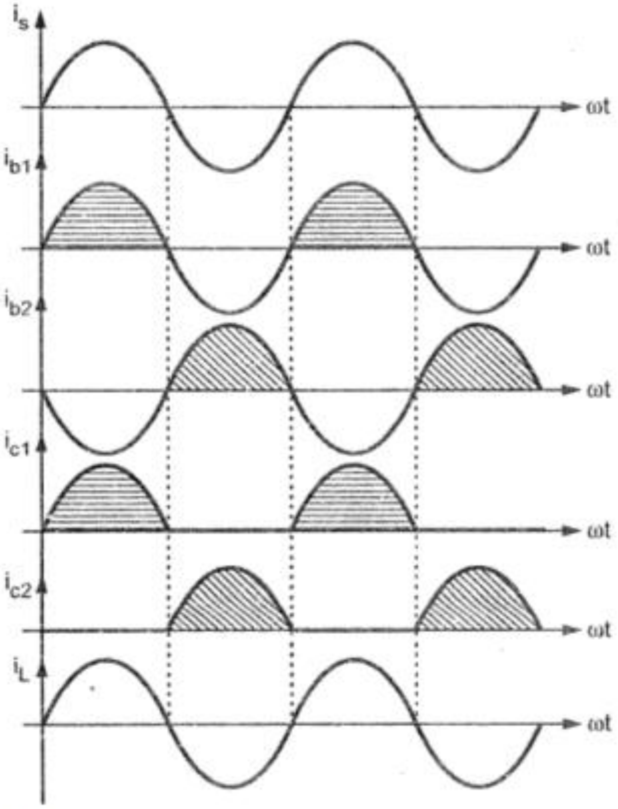


Fig. 5.17 Waveforms for push pull class B amplifier

5.10.1 DC Operation

The d.c. biasing point i.e. Q point is adjusted on the X-axis such that $V_{CEQ} = V_{CC}$ and I_{CEQ} is zero. Hence the co-ordinates of the Q point are (V_{CC}, 0). There is no d.c. base bias voltage.

5.10.2 DC Power Input

Each transistor output is in the form of half rectified waveform. Hence if I_m is the peak value of the output current of each transistor, the d.c. or average value is $\frac{I_m}{\pi}$, due to half rectified waveform. **The two currents, drawn by the two transistors, form the d.c. supply are in the same direction. Hence the total d.c. or average current drawn from the supply is the algebraic sum of the individual average current drawn by each transistor.**

$$\therefore \quad \boxed{I_{dc} = \frac{I_m}{\pi} + \frac{I_m}{\pi} = \frac{2\,I_m}{\pi}} \quad \dots (1)$$

The total d.c. power input is given by,

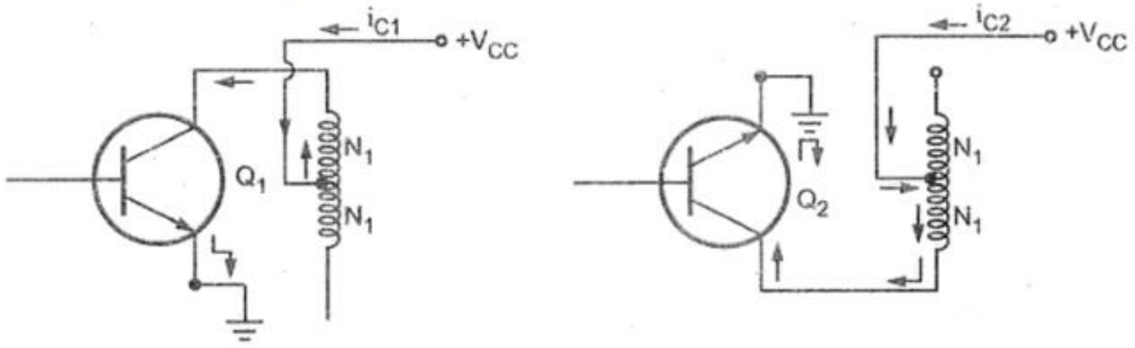
$$P_{DC} = V_{CC} \times I_{dc}$$

$$\therefore \quad \boxed{P_{DC} = \left(\frac{2I_m}{\pi}\right)V_{CC}} \quad \dots (2)$$

5.10.3 AC Operation

When the a.c. signal is applied to the driver transformer, for positive half cycle Q_1 conducts. The path of the current drawn by the Q_1 is shown in the Fig. 5.18 (a).

For the negative half cycle Q_2 conducts. The path of the current drawn by the Q_2 is shown in the Fig. 5.18 (b).



(a) Q_1 conduction

(b) Q_2 conduction

Fig. 5.18

It can be seen that when Q_1 conducts, lower half of the primary of the output transformer does not carry any current. Hence only N_1 number of turns carry the current. While when Q_2 conducts, upper half of the primary does not carry any current. Hence again only N_1 number of turns carry the current. Hence the reflected load on the primary can be written as,

$$\therefore \quad \boxed{R'_L = \frac{R_L}{n^2}} \quad \dots (3)$$

where $n = \frac{N_2}{N_1}$

The slope of the a.c. load line (magnitude of slope) can be represented interms of V_m and I_m as,

$$\frac{1}{R'_L} = \frac{I_m}{V_m}$$

$$\therefore \quad \boxed{R'_L = \frac{V_m}{I_m}} \qquad \dots (4)$$

where I_m = Peak value of the collector current

5.10.4 AC Power Output

As I_m and V_m are the peak values of the output current and the output voltage respectively, then

$$V_{rms} = \frac{V_m}{\sqrt{2}}$$

and $$I_{rms} = \frac{I_m}{\sqrt{2}}$$

Hence the a.c. power output is expressed as,

$$P_{ac} = V_{rms}\ I_{rms} = I^2_{rms}\ R'_L = \frac{V^2_{rms}}{R'_L} \qquad \dots (5)$$

While using peak values it can be expressed as,

$$\therefore \quad \boxed{P_{ac} = \frac{V_m I_m}{2} = \frac{I^2_m R'_L}{2} = \frac{V^2_m}{2R'_L}} \qquad \dots (6)$$

5.10.5 Efficiency

The efficiency of the class B amplifier can be calculated using the basic equation.

$$\% \eta = \frac{P_{ac}}{P_{DC}} \times 100 = \frac{\left(\frac{V_m I_m}{2}\right)}{\frac{2}{\pi} V_{CC} I_m} \times 100$$

$$\therefore \quad \boxed{\% \eta = \frac{\pi}{4} \frac{V_m}{V_{CC}} \times 100} \qquad \dots (7)$$

5.10.6 Maximum Efficiency

From the equation (7), it is clear that as the peak value of the collector voltage V_m increases, the efficiency increases. The maximum value of V_m possible is equal to V_{CC} as shown in the Fig. 5.19.

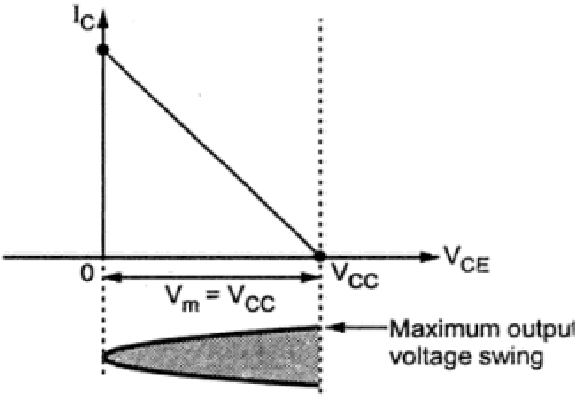


Fig. 5.19

$$\boxed{V_m = V_{CC} \text{ for maximum } \eta}$$

$$\therefore \ \% \eta_{max} = \frac{\pi}{4} \times \frac{V_{CC}}{V_{CC}} \times 100$$

$$= 78.5 \ \%$$

Key Point : *Thus the maximum possible theoretical efficiency in case of push pull class B amplifier is 78.5 % which is much higher than the transformer coupled class A amplifier.*

For practical circuits it is upto 65 to 70 %.

5.10.7 Power Dissipation

The power dissipation by both the transistors is the difference between a.c. power output and d.c. power input.

$$\therefore \quad P_d = P_{DC} - P_{ac} = \frac{2}{\pi} V_{CC} I_m - \frac{V_m I_m}{2}$$

$$\therefore \quad P_d = \frac{2}{\pi} V_{CC} \frac{V_m}{R_L'} - \frac{V_m^2}{2R_L'} \qquad \dots (8)$$

5.10.8 Advantages and Disadvantages of Push Pull Class B Amplifier

The advantages of push pull class B operation are :

1. The efficiency is much higher than the class A operation.
2. When there is no input signal, the power dissipation is zero.
3. The even harmonics get cancelled. This reduces the harmonic distortion.
4. As the d.c. current components flow in opposite direction through the primary winding, there is no possibility of d.c. saturation of the core.
5. Ripples present in supply voltage also get eliminated.
6. Due to the transformer, impedance matching is possible.

The disadvantages of the circuit are :

1. Two center tap transformers are necessary.
2. The transformers, make the circuit bulky and hence costlier.
3. Frequency response is poor.

Example : *A class B, push pull amplifier drives a load of 16 Ω , connected to the secondary of the ideal transformer. The supply voltage is 25 V. If the number of turns on the primary is 200 and the number of turns on the secondary is 50, calculate maximum power output, d.c. power input, efficiency and maximum power dissipation per transistor.*

Solution : $R_L = 16\ \Omega,\ V_{CC} = 25\ V$

Now $2N_1 = 200,\quad N_2 = 50$

$\therefore\quad N_1 = 100$

$\therefore\quad n = \frac{N_2}{N_1} = \frac{50}{100} = 0.5$

$\therefore\quad R'_L = \frac{R_L}{n^2} = \frac{16}{(0.5)^2} = 64\ \Omega$

For maximum power output, $V_m = V_{CC}$

i) $(P_{ac})_{max} = \frac{1}{2}\frac{V_{CC}^2}{R'_L} = \frac{1}{2}\times\frac{(25)^2}{64} = \mathbf{4.8828\ W}$

ii) $P_{dc} = \frac{2}{\pi} V_{CC}\, I_m$

Now $\frac{V_m}{I_m} = R'_L$

and $V_m = V_{CC}$ ... Refer equation (4)

$\therefore\quad I_m = \frac{V_{CC}}{R'_L} = \frac{25}{64} = 0.3906\ A$

$\therefore\quad P_{DC} = \frac{2}{\pi}\times 25\times 0.3906 = \mathbf{6.2169\ W}$

iii) $\%\,\eta = \frac{P_{ac}}{P_{DC}}\times 100 = \frac{4.8828}{6.2169}\times 100 = \mathbf{78.5\ \%}$

iv) $(P_d)_{max} = \frac{2}{\pi^2}\times (P_{ac})_{max}$ for each transistor $= \frac{2}{\pi^2}\times 4.8828$

$= 0.9894\ W = \mathbf{1\ W}$

5.11 Complementary Symmetry Class B Amplifier

As stated earlier, instead of using same type of transistors (n-p-n or p-n-p), one n-p-n and other p-n-p is used, the amplifier circuit is called as complementary symmetry class B amplifier. This circuit is transformer less circuit. But with common emitter configuration, it becomes difficult to match the output impedance for maximum power transfer without an output transformers. Hence the matched pair of complementary transistors are used in common collector (emitter follower) configuration, in this circuit. This is because common collector configuration has lowest output impedance and hence the impedance matching is possible. In addition, voltage feedback can be used to reduce the output impedance for matching.

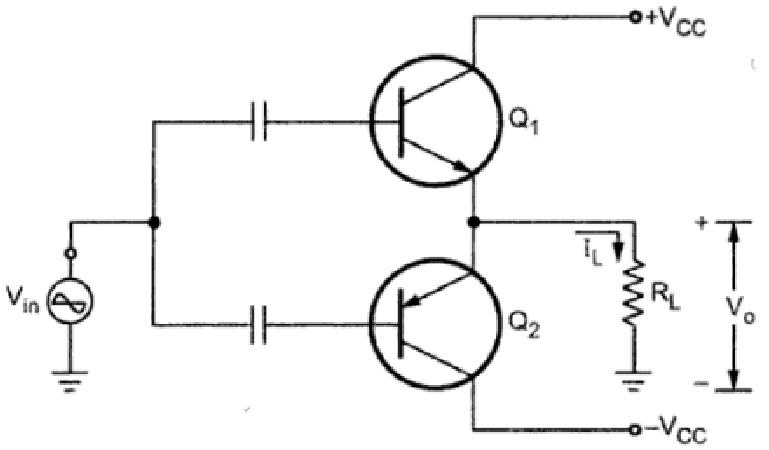


Fig. 5.20 Complementary symmetry class B amplifier

The basic circuit of complementary symmetry class-B amplifier is shown in the Fig. 5.20.

The circuit is driven from a dual supply of $\pm V_{CC}$. The transistor Q_1 is n-p-n while Q_2 is of p-n-p type.

In the positive half cycle of the input signal, the transistor Q_1 gets driven into active region and starts conducting. The same signal gets applied to the base of the Q_2 but as it is of complementary type, remains in off condition, during positive half cycle. This results into positive half cycle across the load R_L. This is shown in the Fig. 5.21.

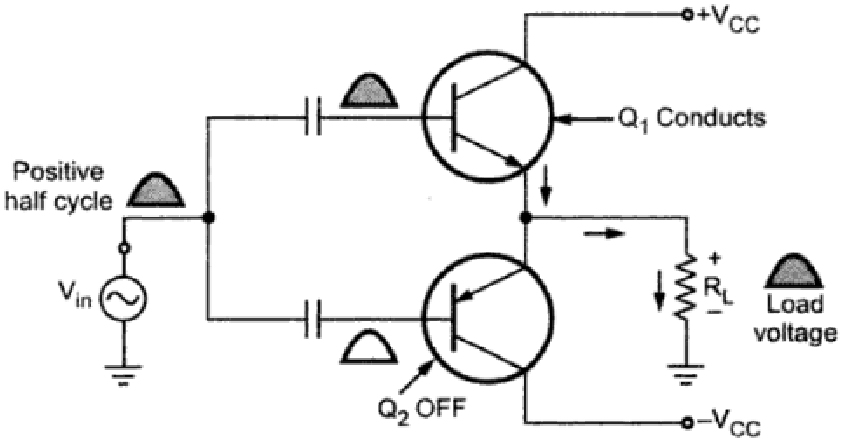
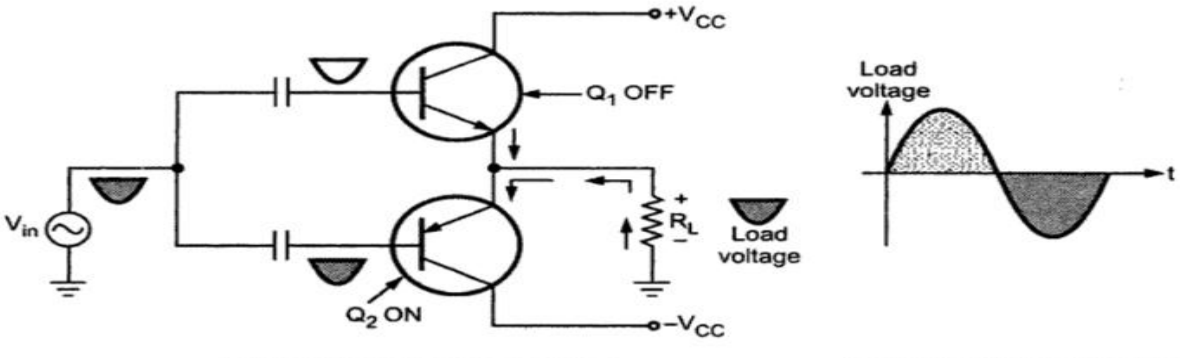


Fig. 5.21 Positive half cycle operation

During the negative half cycle of the signal, the transistor Q_2 being p-n-p gets biased into conduction. While the transistor Q_1 gets driven into cut off region. Hence only Q_2 conducts during negative half cycle of the input, producing negative half cycle across the load R_L, as shown in the Fig. 5.22 (a).

Thus for a complete cycle of input, a complete cycle of output signal is developed across the load as shown in the Fig. 5.22 (b)



(a) Negative half cycle operation (b) Load voltage waveform

Fig. 5.22

5.11.1 Mathematical Analysis

All the results derived for push pull transformer coupled class B amplifier are applicable to the complementary class B amplifier. The **only change is that as the output transformer is not present, hence in the expressions, R_L value must be used as it is, instead of R'_L.**

5.11.2 Advantages and Disadvantages of Complementary Symmetry Class B Amplifier

The advantages are :

1. As the circuit is transformerless, its weight, size and cost are less.
2. Due to common collector configuration, impedance matching is possible.
3. The frequency response improves due to transformerless class B amplifier circuit.

The disadvantages are :

1. The circuit needs two separate voltage supplies.
2. The output is distorted to cross-over distortion.

Example : *A complementary symmetry push-pull amplifier is operated using $V_{CC} = \pm 10\,V$ and delivers power to a load $R_L = 5\,\Omega$.*

Calculate :

(i) Maximum output power

(ii) Power rating of transistors

(iii) D.C. output power.

Solution : $V_{CC} = \pm 10$ V, $R_L = 5\Omega$

i) $$(P_{ac})_{max} = \frac{1}{2}\frac{V_{CC}^2}{R_L} = \frac{(10)^2}{2\times 5} = \mathbf{10\ W}$$

ii) To decide **Power rating of transistors** means to find $(\mathbf{P_d})_{\max}$

For $(P_d)_{\max}$, $V_m = \frac{2}{\pi}V_{CC} = 6.3662\ V$

And $R_L = \frac{V_m}{I_m}$, $\therefore I_m = \frac{V_m}{R_L} = \frac{6.3662}{5} = 1.2732\ A$

$$\therefore P_{DC} = V_{CC}\, I_{DC} = V_{CC} \times \frac{2I_m}{\pi} \qquad \ldots\ I_{DC} = \frac{2I_m}{\pi}$$

$$= \frac{10 \times 2 \times 1.2732}{\pi} = 8.1056\ W$$

and $P_{ac} = \frac{V_m I_m}{2} = \frac{6.3662 \times 1.2732}{2} = 4.0527\ W$

$$\therefore (P_d)_{\max} = P_{DC} - P_{ac} = 4.0528\ W$$

$\therefore$ P_D rating for each transister $= \frac{(P_D)_{\max}}{2} = \mathbf{2.026\ W}$

iii) For $(P_{ac})_{\max}$, $V_m = V_{CC} = 10\ V$

$$\therefore I_m = \frac{V_m}{R_L} = \frac{10}{5} = 2A$$

$$\therefore P_{DC} = V_{CC} \times \frac{2I_m}{\pi} = \frac{10 \times 2 \times 2}{\pi} = \mathbf{12.7323\ W}$$

This is P_{DC}, **when output power is maximum**

5.12 Comparison of Push Pull and Complementary symmetry circuits

	Push Pull Class B	**Complementary Symmetry Class B**
1.	Both the transistors are similar either pnp or npn.	Transistors are complementary type i.e. one npn other pnp.
2.	The transformer is used to connect the load as well as input.	The circuit is transformerless.
3.	The impedance matching is possible due to the output transformer.	The impedance matching is possible due to common collector circuit.
4.	Frequency response is poor.	Frequency response is improved.
5.	Due to transformers, the circuit is bulky, costly and heavier.	As transformerless, the circuit is not bulky and costly.
6.	Dual power supply is not required.	Dual power supply is required.
7.	Efficiency is higher than class A.	The efficiency is higher than the push pull.

5.13 Class D Amplifier

The Fig. 5.23 shows the basic concept of class D amplifier. The amplifier consists of two complementary symmetry transistors driving a load R_L. This means one transistor is p-n-p and other is n-p-n.

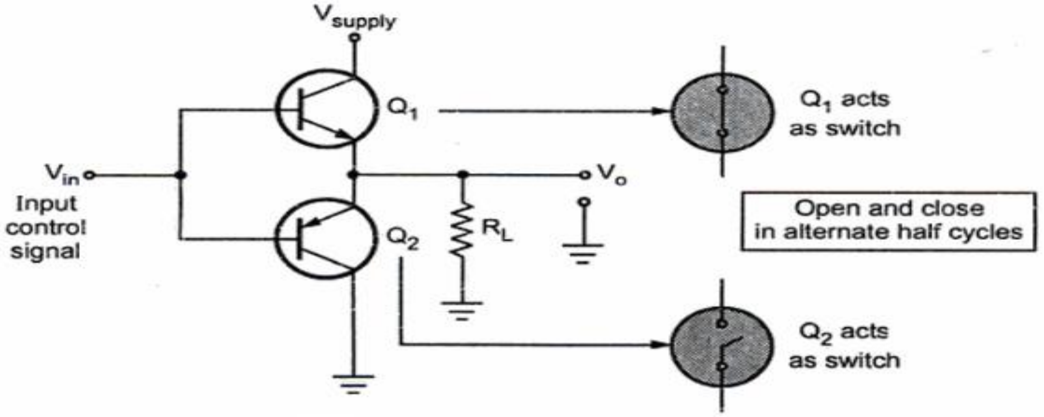


Fig. 5.23 Concept of class D amplifier

The transistors are biased in such a way that they behave as ideal switches. When transistor is ON, it is biased to saturation so that voltage across it is zero while current is high. When transistor is OFF, it is biased to cut-off so that current through it is zero while voltage is high. Thus when input goes positive Q_1 conducts heavily acting as closed switch while Q_2 is OFF. While when input goes negative, Q_2 conducts heavily acting as closed switch while Q_1 is OFF. Thus the load voltage V_o across R_L has one of two possible values which are V_{supply} or 0 V. This is a type of digital output having two levels high and low.

The transistors dissipate almost zero power as in any of the states, either voltage is zero or current is zero for the transistors. Thus entire power input is available to the load. **Hence efficiency of class D amplifiers is almost 100 %.** The figure of merit which is the ratio of the maximum power dissipated in transistor to that delivered to the load, is zero. These facts make the class D amplifier as an ideal amplifier.

Practically class D amplifiers are designed to operate with digital or pulse type of signals. The basic block diagram of unit used along with class D amplifier in the application circuits is shown in the Fig. 5.24.

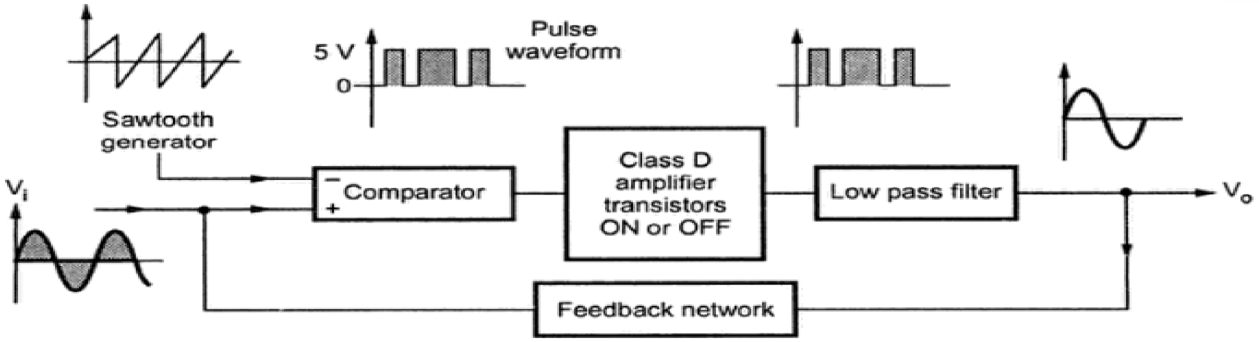


Fig. 5.24 Block diagram of class D amplifier

The op-amp comparator is used for which one input is sawtooth type while other is sinusoidal. The comparator converts sinusoidal signal to digital pulse type signal with the help of sawtooth waveform. This is called **chopping** of sinusoidal signal to produce digital signal. This signal drives the class D smplifier. When pulse signal is high the transistors are ON and when it is low, the transistors are OFF. Thus most of the power supplied is delivered to the load by producing high power output signal. The digital signal is converted back to the original sinusoidal signal using low pass filter. Using feedback network, it is fed back to the comparator. Practically instead of power BJT, power MOSFET devices are used as driver devices for class D amplifier.

The class D amplifiers are mainly used in the pulse and digital circuits.

5.14 Distortion in Power Amplifiers

The input signal applied to the amplifiers is alternating in nature. The basic features of any alternating signal are amplitude, frequency and phase. The amplifier output should be reproduced faithfully i.e. there should not be the change or distortion in the amplitude, frequency and phase of the signal. Hence the possible distortions in any amplifier are amplitude distortion, phase distortions and frequency distortion. But the phase distortions are not detectable by human ears as human ears are insensitive to the phase changes. While **the change in gain of the amplifier with respect to the frequency is called frequency distortion**.

Key Point : *The frequency distortion is not significant in A.F. power amplifiers.*

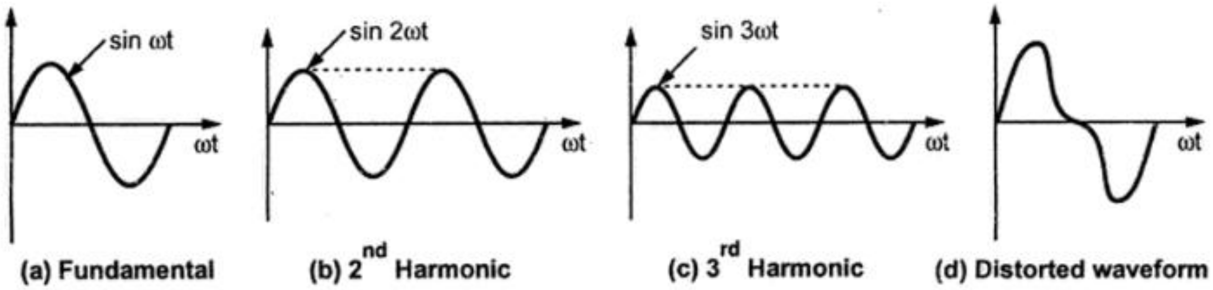
In the earlier discussion, it is assumed that the transistor is perfectly linear device. That is the dynamic characteristics of a transistor is a straight line over the operating range $[i_c = Ki_b]$. But in practical circuits, the dynamic characteristics is not perfectly linear. Due to such nonlinearity in the dynamic characteristics, the waveform of the output voltage differs from that of the input signal. Such a distortion is called **nonlinear distortion** or **amplitude distortion** or **harmonic distortion**.

5.14.1 Harmonic Distortion

The harmonic distortion means the presence of the frequency components in the output wave form, which are not present in the input signal. The component with frequency same as the input signal is called fundamental frequency component. The additional frequency components present in the output signal are having frequency components which are integer multiples of fundamental frequency component. These components are called harmonic components or harmonics. For example if the **fundamental frequency** is f Hz, then the output signal contains fundamental frequency component at f Hz and additional frequency components at 2f Hz, 3f Hz, 4f Hz and so on. The 2f component is called **second harmonic**, the 3f component is called **third harmonic** and so on. The fundamental frequency component is not considered as a harmonic. Out of all the harmonic components, the second harmonic has the largest amplitude.

As the second harmonic amplitude is largest, the second harmonic distortion is more important in the analysis of A.F. power amplifiers. The Fig. 5.24 shows the various harmonic components.

It can be seen from the Fig. 5.24 that the distorted waveform can be obtained by adding the fundamental and the harmonic components. The percentage harmonic distortion due to each order (2nd, 3rd and so on) can be calculated by comparing the amplitude of each order of harmonic with the amplitude of the fundamental frequency component.



(a) Fundamental (b) 2nd Harmonic (c) 3rd Harmonic (d) Distorted waveform

Fig. 5.24 Distortion due to harmonic components

If the fundamental frequency component has an amplitude of B_1 and the n th harmonic component has an amplitude of B_n then the percentage harmonic distortion due to n th harmonic component is expressed as,

$$\boxed{\%\ n^{th}\ \text{harmonic distortion} = \%\ D_n = \frac{|B_n|}{|B_1|} \times 100} \quad \ldots (1)$$

So $$\%\ D_2 = \frac{|B_2|}{|B_1|},\ \%\ D_3 = \frac{|B_3|}{|B_1|} \text{ and so on.}$$

5.14.1.1 Total harmonic Distortion

When the output signal gets distorted due to various harmonic distortion components, the total harmonic distortion, which is the effective distortion due to all the individual components is given by

$$\boxed{\%\ D = \sqrt{D_2^2 + D_3^2 + D_4^2 + \ldots} \times 100} \quad \ldots (2)$$

where D = Total harmonic distortion

As stated earlier, the most important component in the distortion is the second harmonic distortion. Let us discuss the graphical method of calculating second harmonic distortion.

5.14.2 Crossover Distortion

For a transistor to be in active region the base emitter junction must be forward biased. The junction cannot be made forward biased till the voltage applied becomes greater than cut-in voltage (V_γ) of the junction, which is generally 0.7 V for silicon and 0.2 V for germanium transistors. Hence as long as the magnitude of the input signal is less than the cut in voltage of the base emitter junction, the collector current remain zero and transistor remains in cut-off region,

Hence there is a period between the crossing of the half cycles of the input signal, for which none of the transistors is active and the output is zero. Hence the nature of the output signal gets distorted and no longer remains same as that of input. Such a distorted output wave form due to cut-in voltage is shown in the Fig. 5.25.

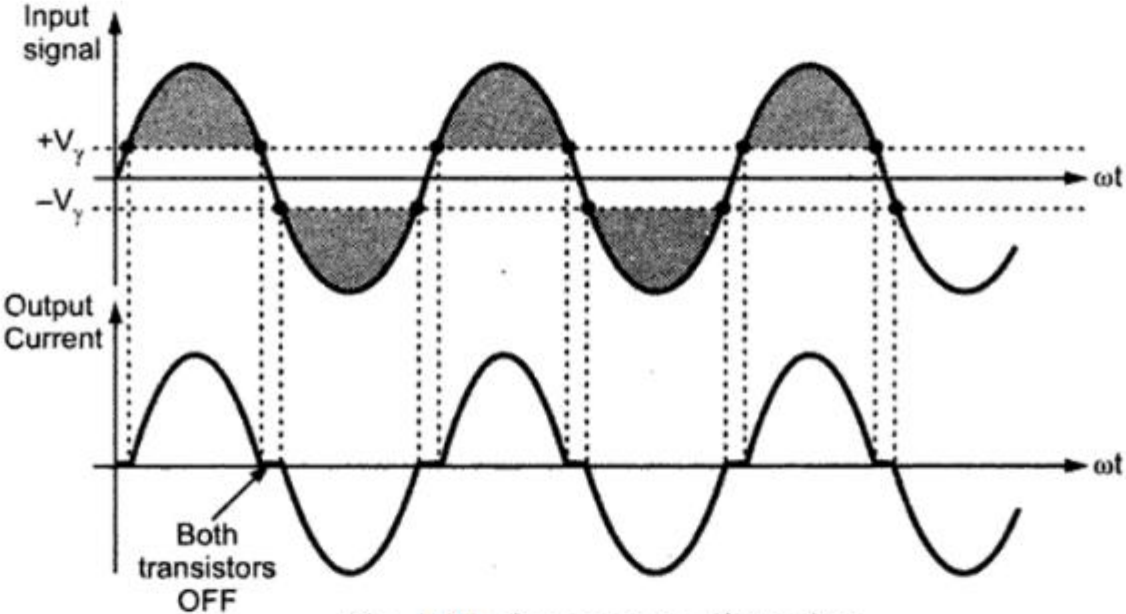


Fig. 5.25 Cross-over distortion

Such a distortion in the output signal is called a **cross-over distortion**. Due to cross-over distortion each transistor conducts for less than a half cycle rather than the complete half cycle. The part of the input cycles for which the two transistors conduct alternately is shown shaded in the Fig. 5.25. The cross-over distortion is common in both the types of class B amplifiers.

5.14.2.1 Elimination of Crossover Distortion

To eliminate the cross-over distortion some modifications are necessary, in the basic circuits of the class B amplifiers. The basic reason for the cross over distortion is the cut in voltage of the transistor junction. To overcome this cut-in voltage, a small forward biased is applied to the transistors. Let us see the practical circuits used to apply such forward biased, in the two types of class B amplifiers.

5.14.3 Intermediation Distortion

Another type of distortion present in the power amplifiers is intermodulation distortion. Due to the nonlinearity in the amplifier characteristics, sum and difference components of the input frequency appear at the output of the amplifier. These components distort the output of the power amplifier and such a distortion is called **intermodulation distortion**.

5.15 Thermal stability of power amplifier

The heat dissipation problem is very much analogous to a simple electric circuit and the Ohm's law. An electric current flows when there exists a potential difference while the heat flows when there exists a temperature difference $(T_2 - T_1)$. Then similar to a electric resistance a thermal resistance can be obtained as,

$$\boxed{\theta = \frac{T_2 - T_1}{P_d} \ ^\circ\text{C/W or } ^\circ\text{C/mW}} \qquad \dots (3)$$

Where P_d is the heat dissipated or heat flow, due to the power dissipation.

From the above relation we can write,

$$T_2 - T_1 = \theta P_d \ ^\circ\text{C} \qquad \dots (4)$$

and

$$P_d = \frac{T_2 - T_1}{\theta} \text{ W or mW} \qquad \dots (5)$$

Now to develop the thermal-electric analogy let us define some parameters as,

T_J = Junction Temperature

T_C = Case Temperature

T_A = Ambient Temperature

θ_{JA} = Total thermal resistance
(junction to ambient)

θ_{JC} = Transistor thermal resistance
(junction to case)

θ_{CS} = Insulator thermal resistance
(case to heat sink)

θ_{SA} = Heat sink thermal resistance
(heat sink to ambient)

The Fig. 5.26 shows a heat flow from a power transistor to ambient air via a heat sink.

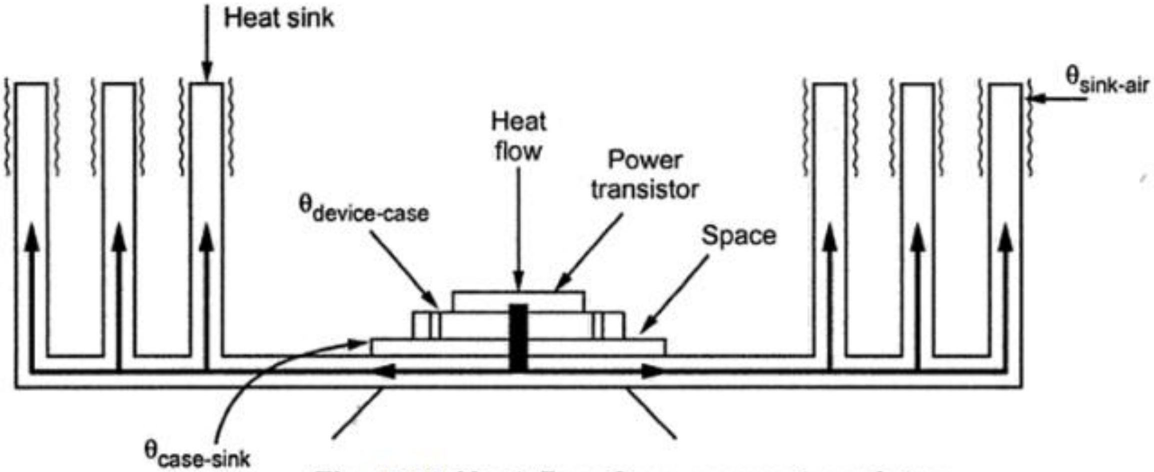


Fig. 5.26 Heat flow from power transistor

From this heat flow diagram, an electrical analogous circuit can be obtained as,

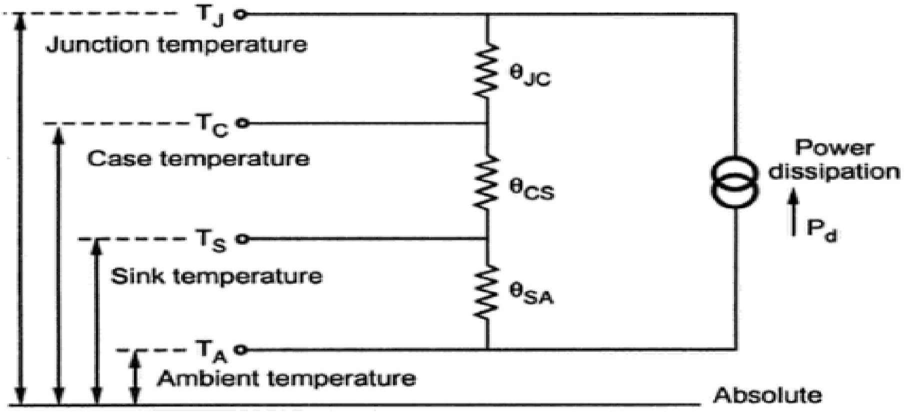


Fig. 5.27 Electrical analogous circuit

The electrical analogous circuit is a simple series circuit.

Thus from the property of series circuit, the total thermal resistance can be obtained as,

$$\boxed{\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA} \quad {}^\circ C/W} \quad \dots (6)$$

But $\theta_{JA} = \frac{T_J - T_A}{P_d}$ ... from definition of θ in equation (3)

$$\therefore \quad \boxed{T_J = P_d\, \theta_{JA} + T_A} \quad \dots (7)$$

Thus the total power handling capacity P_d of the device can be obtained as,

$$\boxed{P_d = \frac{T_J - T_A}{\theta_{JA}} = \frac{T_J - T_A}{\theta_{JC} + \theta_{CS} + \theta_{SA}}} \quad \dots (8)$$

Similarly the temperatures of case and sink can be obtained from,

$$\theta_{CS} = \frac{T_C - T_S}{P_d} \qquad \dots (9)$$

$$\theta_{SA} = \frac{T_S - T_A}{P_d} \qquad \dots (10)$$

or

$$\theta_{CS} + \theta_{SA} = \frac{T_C - T_A}{P_d} \qquad \dots (11)$$