UNIT-VII Large Signal Amplifiers

→ Consider a public address (P.A) System or amplifying system shown in figure.

→ 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.

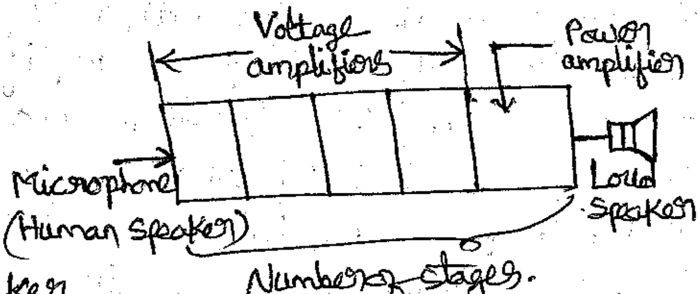


Fig: Power Amplifier system

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 systems, radio receivers, tape players, T.V receivers, driving servomotor in industrial control systems, Cathode ray tubes etc.

Features of power Amplifiers:

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 collector 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 non linear 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 loud speakers. Hence power amplifiers are also called audio amplifiers or audio frequency (A.F) power amplifier

Comparision of small signal and large signal Amplifiers:

Small Signal Amplifier	Large Signal Amplifier
① Voltage is amplified.	① power or current is amplified.
② The h-parameter analysis is applicable.	② The graphical analysis is required as h-parameters can not be used.
③ Harmonics are not present for sinusoidal signals.	③ Harmonics are present and must be considered while designing the amplifier
④ The normal transistors are sufficient.	④ The power transistors are required.
⑤ The heat sinks are not required as heat dissipation is not the problem.	⑤ The heat sinks are essential so as to dissipate large ~~heat~~ heat produced.
⑥ The size is small.	⑥ Due to large size transistors and transformers the overall size is large and bulky.
⑦ Distortion is not present	⑦ Due to the harmonics, signal is likely to be distorted.
⑧ The power handling capacity is small.	⑧ The power handling capacity is large.
⑨ The output current and voltage swings are small.	⑨ There are large output current and voltage swings.
⑩ The operating point is always on the linear portion of transfer characteristics.	⑩ The operating point can be anywhere on the transfer characteristics includin nonlinear region.
⑪ used as a voltage amplifier.	⑪ used as a last stage in public addres system and other audio circuits.

Classification of large signal Amplifiers:

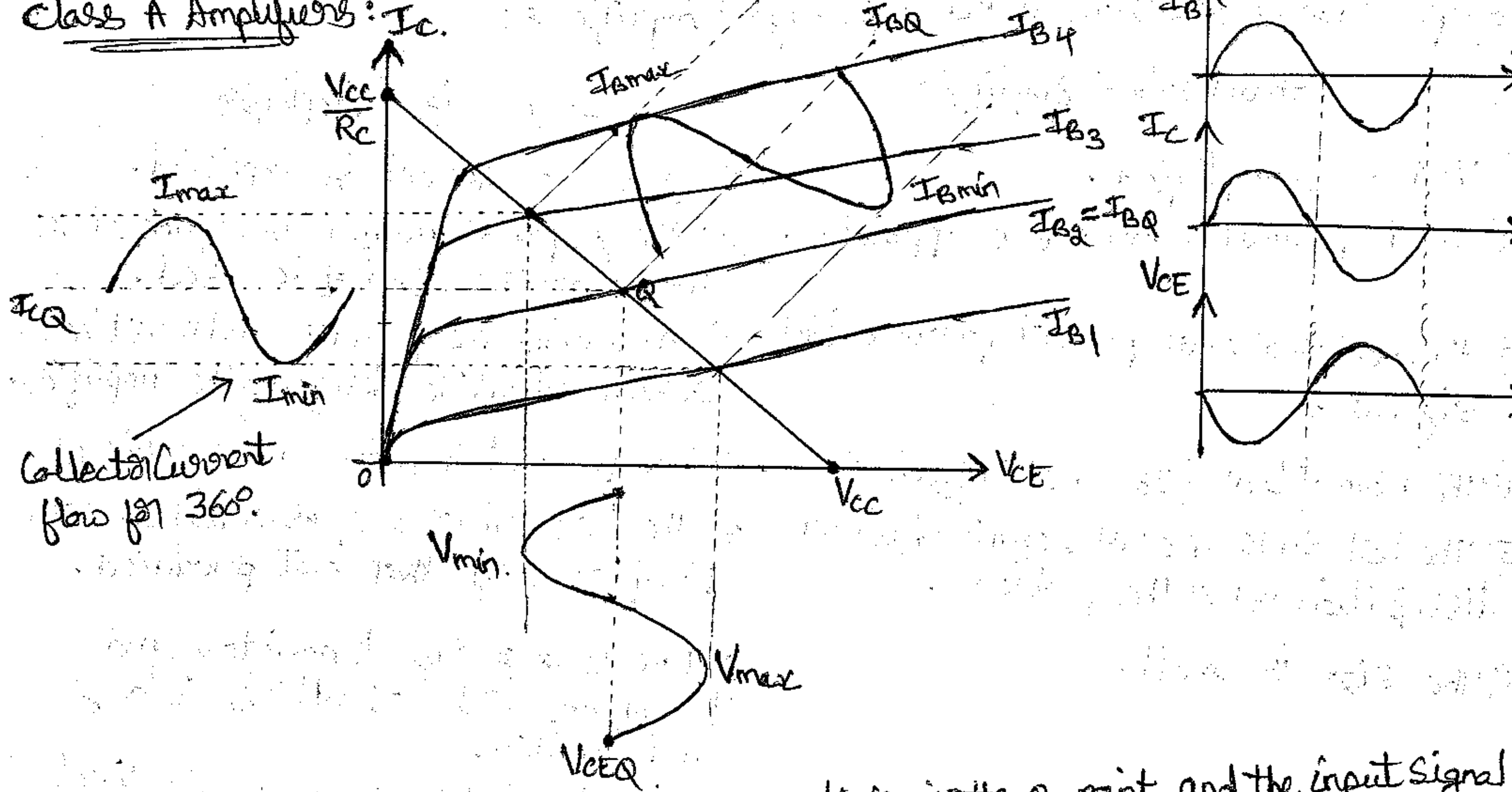
→ For an amplifier, a Q-point is fixed by selecting the proper d.c biasing to the transistors used. The Q-point is shown on the load line which is plotted on the output characteristics of the transistor.

→ 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,

① class A ② class B ③ class C and ④ class AB

Class A Amplifiers:



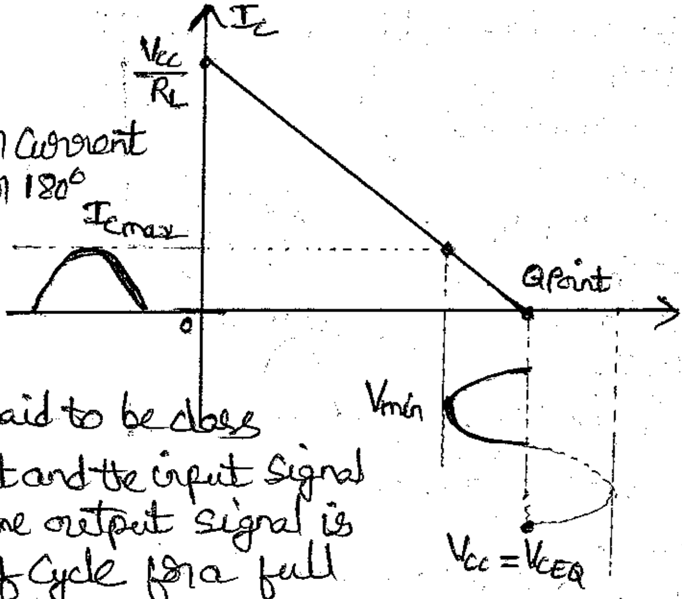
→ The power amplifier is said to be class A amplifier if the Q-point and the input signal are selected such that the output signal is obtained for a full input cycle.

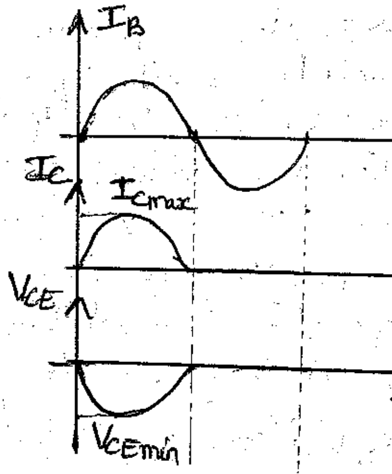
→ For this class, position of the Q-point is approximately at the midpoint of the load line.

→ 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.

→ As shown in figure 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.

Class B Amplifiers :





→ 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.

→ For this operation the Q-point is shifted on X-axis i.e transistor is biased to cut-off.

→ Due to 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.

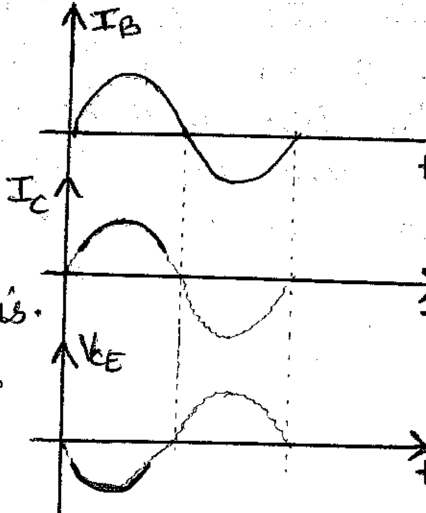
→ The collector current flows only for 180° (half cycle) of the input signal. In other words, the angle of the collector current flow is 180° i.e one half cycle.

→ 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.

Class C Amplifiers :



→ 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.

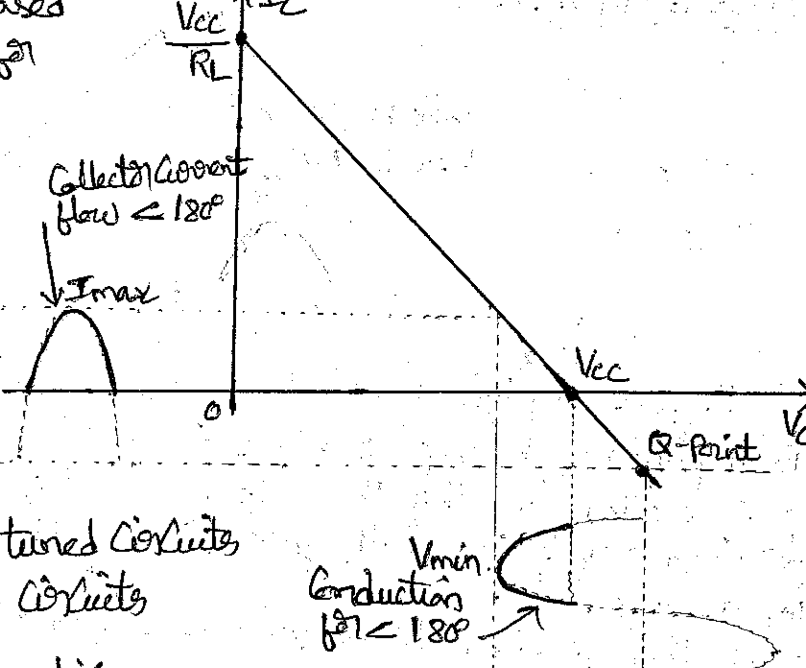
→ For this operation, the Q-point is to be shifted below X-axis.

→ Due to such a selection of 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, transistor remains cut-off and no signal is produced at the output. The angle of I_C flow is less than 180°.

→ In class C operation, the transistor is biased well beyond cut-off. As the I_C 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 of class C Amplifiers:

→ The class C operation is not suitable for A.F power amplifiers.

→ The class C amplifiers are used in tuned circuits used in communication areas and in 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.

Class AB Amplifiers:

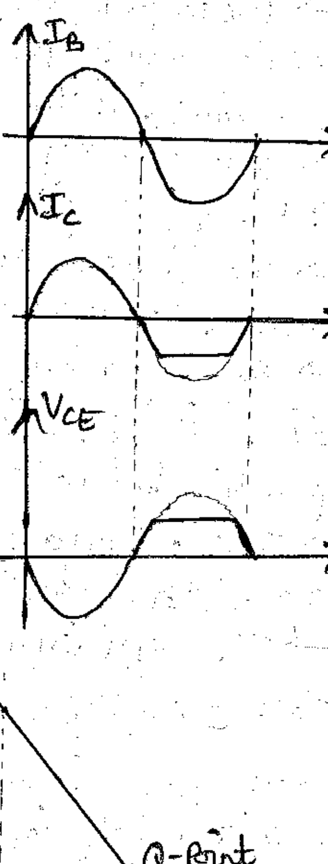
→ The power amplifier is said to be class AB amplifier, if Q-point and the input signal are selected such that the output signal is obtained for more than 180° but less than 360° for a full input cycle.

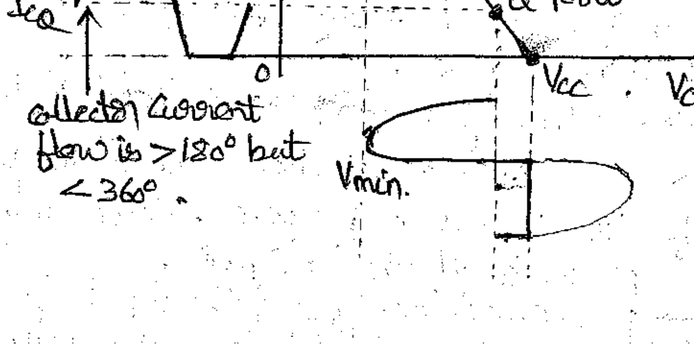
→ The Q-point position is above X-axis but below the midpoint of a load line.

→ 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 center of the load line below towards the x-axis, the efficiency of class of operation increases.





Comparision of amplifier classes :

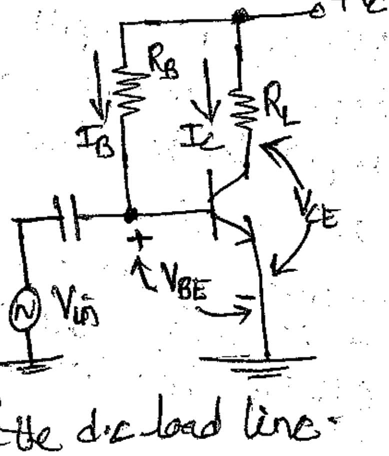
parameter	class A	class B	class C	class AB
① operating cycle	360°	180°	less than 180°	180° to 360°
② position of Q-point	Center of load line	on X-axis	Below X-axis	Above X-axis but below the Center of load line
③ Efficiency	Poor 25% to 50%	Better 78.5%	High	Higher than A but less than B. 50% to 78.5%
④ Distortion	Absent No distortion	present more than class A	Highest	present
⑤ Power dissipation in transistors	Very high	Low	Very Low	Moderate

Analysis of class A Amplifiers :

→ 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.

Series Fed, Directly Coupled Class A Amplifier:



→ A simple fixed bias circuit can be used as a large signal class A amplifier as shown in figure.

→ 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.

→ The overall Circuit handles large power, in the range of a few to tens of Watts without providing much Voltage gain.

Applying KVL we get,

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

$$\Rightarrow I_C R_L = V_{CC} - V_{CE}$$

$$\Rightarrow I_C = \left(\frac{-1}{R_L}\right) V_{CE} + \frac{V_{CC}}{R_L}$$

The above equation represents equation of a line with slope $\left(\frac{-1}{R_L}\right)$ and y-intercept is $\frac{V_{CC}}{R_L}$.

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 $V_{BE} = 0.7V$

$$\therefore \quad I_{BQ} = \frac{V_{CC} - 0.7}{R_B}$$

The Corresponding Collector Current is then, $I_{CQ} = \beta I_{BQ}$.

The Corresponding Collector to emitter Voltage is, $V_{CEQ} = V_{CC} - I_{CQ} R_L$

DC power Input

→ The d.c power input is provided by the Supply. With no a.c input signal, the dc Current drawn is Collector bias Current I_{CQ}.

Hence dc power input is, $P_{DC} = V_{CC} \cdot I_{CQ}$

Even if a.c input signal is applied, the average Current drawn from the d.c Supply remains Same. Hence above equation represents dc power input to the class A series fed amplifier.

AC operation:

→ when an ac input 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.

→ 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.

AC power output:

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

V_{max} = Maximum " " " "

V_{pp} = peak to peak value of ac output voltage across the load.

V_m = Amplitude (peak) of ac output voltage

$$V_{pp} = V_{max} - V_{min}.$$

$$V_m = \frac{V_{pp}}{2} = \frac{V_{max}-V_{min}}{2}$$

Similarly for output current,

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

I_{max} = Maximum " " " "

I_{pp} = peak to peak value of ac output (load) current.

I_m = Amplitude (peak) of ac output (load) current.

$$I_{pp} = I_{max} - I_{min}$$

$$I_m = \frac{I_{pp}}{2} = \frac{I_{max}-I_{min}}{2}$$

Hence the r.m.s values of alternating output voltage and current can be obtained as, $V_{rms} = \frac{V_m}{\sqrt{2}}$ and $I_{rms} = \frac{I_m}{\sqrt{2}}$

Hence, $V_{rms} = I_{rms} \cdot R_L$ i.e $V_m = I_m \cdot R_L$

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

using rms values,

$$P_{ac} = V_{rms} \cdot I_{rms}$$

$$P_{ac} = I_{rms}^2 \cdot R_L$$

$$P_{ac} = V_{rms}^2 / R_L$$

using peak values,

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

$$P_{ac} = \frac{I_m^2 R_L}{2}$$

$$P_{ac} = \frac{V_m^2}{2R_L}$$

Using peak to peak values,

$$P_{ac} = \frac{V_m I_m}{2} = \frac{\frac{V_{pp}}{2}\cdot\frac{I_{pp}}{2}}{2} = \frac{V_{pp}\cdot I_{pp}}{8}$$

$$P_{ac} = \frac{I_{pp}^2 \cdot R_L}{8}$$

$$P_{ac} = \frac{V_{pp}^2}{8R_L}$$

But as $V_{pp} = V_{max} - V_{min}$ and $I_{pp} = I_{max} - I_{min}$

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

<u>Efficiency</u>

→ The efficiency of an amplifier represents the amount of ac power delivered or transferred to the load, from the dc source i.e accepting the dc power input

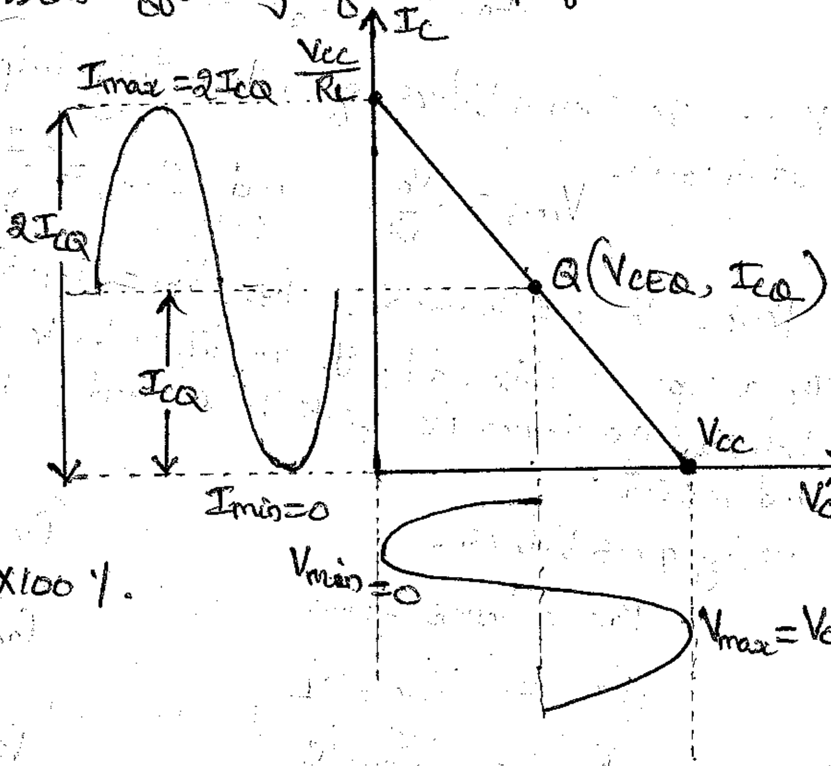
The generalised expression for an efficiency of an amplifier is;

$$\%\eta = \frac{P_{ac}}{P_{dc}} \times 100\%.$$

But $P_{dc} = V_{cc}\cdot I_{CQ}$ and $P_{ac} = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8}$

$$\therefore \quad \eta\% = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8V_{cc}\, I_{CQ}} \times 100\%.$$

The efficiency is also called Conversion efficiency of an amplifier.



<u>Maximum Efficiency:</u>

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

For maximum swing,

$V_{max} = V_{cc}$ and $V_{min} = 0$

$I_{max} = 2I_{CQ}$ and $I_{min} = 0$

$$\therefore \quad \eta\%_{max} = \frac{(V_{cc} - 0)(2I_{CQ} - 0)}{8V_{cc}\cdot I_{CQ}} \times 100\%.$$

$$= 25\%.$$

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%.

→ Very low efficiency is the biggest disadvantage of class A amplifier.

Power dissipation:

→ 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 dc power input Pdc and the ac power delivered to the load Pac.

i.e $P_d = P_{dc} - P_{ac}$

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

$P_{d(max)} = V_{cc} I_{CQ}$.

→ Thus value of maximum power dissipation decides the maximum power dissipation rating of the transistor to be selected for the amplifier.

Advantages:

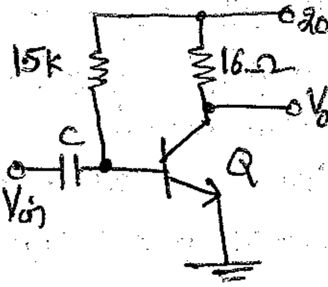
1) The circuit is simple to design and to implement.
2) The load is connected directly in the collector circuit hence the output transforme is not necessary. This makes the circuit cheaper.
3) Less no. of components required as load is directly coupled.

Disadvantages:

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 impedan loads, such as loudspeakers.
4) The efficiency is very poor, due to large power dissipation.

prob①: A series fed class A amplifier shown in figure operates from dc source and applied sinusoidal input signal generates peak base current 9mA. Calculate I_{CQ}, V_{CEQ}, P_{dc}, P_{ac} & $\eta\%$.

$\beta = 50$ & $V_{BE} = 0.7$



Sol^n: $I_{BQ} = \dfrac{V_{CC} - V_{BE}}{R_B} = \dfrac{20 - 0.7}{1.5 \times 10^3} = 12.87\,mA$

$I_{CQ} = \beta I_{BQ} = 50 \times 12.87 \times 10^{-3} = 643.5\,mA$

$V_{CC} - I_{CQ} R_L - V_{CEQ} = 0$

$\rightarrow V_{CEQ} = V_{CC} - I_{CQ} R_L = 20 - 643.5 \times 10^{-3} \times 16 = 9.7\,V$

$P_{DC} = V_{CC} \cdot I_{CQ} = 20 \times 643.5 \times 10^{-3} = 12.87\,W$

Peak current $i_b = 9\,mA$

peak $i_c = \beta i_b = 50 \times 9 \times 10^{-3} = 450\,mA$

$\therefore I_{c\,rms} = \dfrac{i_{c(peak)}}{\sqrt{2}} = \dfrac{450 \times 10^{-3}}{\sqrt{2}} = 318.19\,mA = I_{rms}$

$P_{ac} = I_{rms}^2 \cdot R_L = (318.19 \times 10^{-3})^2 \times 16 = 1.619\,W$

$\eta\% = \dfrac{P_{ac}}{P_{dc}} \times 100\% = \dfrac{1.619}{12.87} \times 100\% = 12.58\,\%$

$P_{ac} = \dfrac{i_c^2 R_L}{2}$

$P_{ac} = 1.62\,W$

prob②: Find the value of R_B of class A series fed amplifier to deliver 75mW of output power to a load of 4Ω & $V_{CC} = 16V$. At the operating point $I_{BQ} = 200\mu A$

$P_{d(max)} = 200\,mW$. $V_{BE} = 0.7V$.

Sol^n: $P_{d(max)} = V_{CC} I_{CQ} \Rightarrow I_{CQ} = \dfrac{P_{d(max)}}{V_{CC}} = \dfrac{200 \times 10^{-3}}{16} = 12.5\,mA$

$\beta = \dfrac{I_{CQ}}{I_{BQ}} = \dfrac{12.5 \times 10^{-3}}{200 \times 10^{-6}} = 63$

$V_{CEQ} = V_{CC} - I_{CQ} \cdot R_L = 16 - 12.5 \times 10^{-3} \times 4 = 15.95\,V$

$I_{BQ} = \dfrac{V_{CC} - V_{BE}}{R_B} \Rightarrow R_B = \dfrac{16 - 0.7}{200 \times 10^{-6}} = 76.5\,K\Omega$

prob③: A power transistor working in class A operation has zero signal power dissipation of 5W. If AC power is 2W find collector efficiency and power rating of transistor

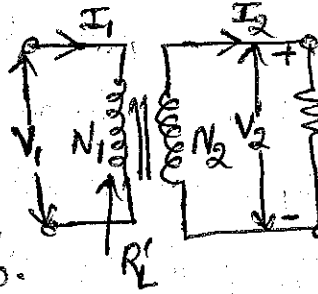
Sol^n: $P_{ac} = 2W$, P_{dc} = zero signal power dissipation = 5W

$\eta\% = \dfrac{P_{ac}}{P_{dc}} \times 100\% = \dfrac{2}{5} \times 100\% = 40\%$

$P_{d(max)}$ = zero signal power dissipation = 5W

Power rating of transistor = $P_{d(max)}$ = 5W

Properties of Transformer:



Consider a transformer as shown in figure 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 = No. of turns on primary
N_2 = No. of turns on Secondary
V_1 = Voltage applied to primary
V_2 = Voltage on secondary
I_2 =

Turns Ratio: The ratio of turns on secondary to the no. of turns on primar is called turns ratio of the transformer denoted by 'n'.

$$\therefore n = \text{Turns ratio} = \frac{N_2}{N_1}$$

Voltage transformation: The transformer transforms the Voltage applied o one side to other side proportional to the turns ratio. The transformer Can be step up or step down transformer.

$$\therefore \frac{V_2}{V_1} = \frac{N_2}{N_1} = n$$

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 no. of turns on primary are more than the secondary and turns ratio is less than unity for such a step down transforme

Current Transformation: The Current in the secondary winding is inversel proportional to the no. of turns of the windings.

$$\frac{I_2}{I_1} = \frac{N_1}{N_2} = \frac{1}{n}.$$

Impedance Transformation: As Current and Voltage get transformed from primary to secondary, an impedance seen from either side (primary to secondary) also changes.

Now the impedance of the load on secondary is R_L. 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'.

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

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

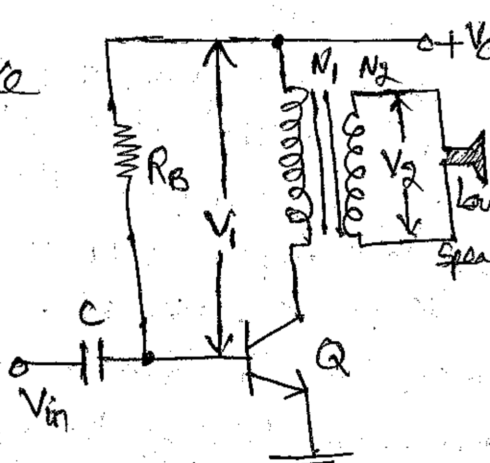
$$\therefore \; R_L' = \frac{(N_1/N_2)\,V_2}{(N_2/N_1)\,I_2} = \left(\frac{N_1}{N_2}\right)^2 * \frac{V_2}{I_2} = \frac{R_L}{(N_2/N_1)^2} = R_L/n^2$$

$$\boxed{\therefore \; R_L' = \frac{R_L}{n^2} = \left(\frac{N_1}{N_2}\right)^2 \cdot R_L}$$

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.

In the amplifier analysis, the load is on secondary while the active device, the transistor is on primary. Hence in all the calculations related to the transistor, the reflected load impedance R_L' must be considered rather than actual load impedance R_L.

Transformer Coupled class A Amplifier:



→ 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 3to4Ω to 16Ω 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.

→ The transformer is called an output transformer and the amplifier is called transformer coupled class A amplifier.

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

$$n = N_2 / N_1$$

DC operation:

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

Applying KVL to collector circuit,

$V_{CC} - V_{CE} = 0 \Rightarrow V_{CC} = V_{CE}$ i.e drop across winding is zero.

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

$$\text{so} \quad V_{CEQ} = V_{CC}$$

Hence the dc 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 dc 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}.

DC power Input:

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

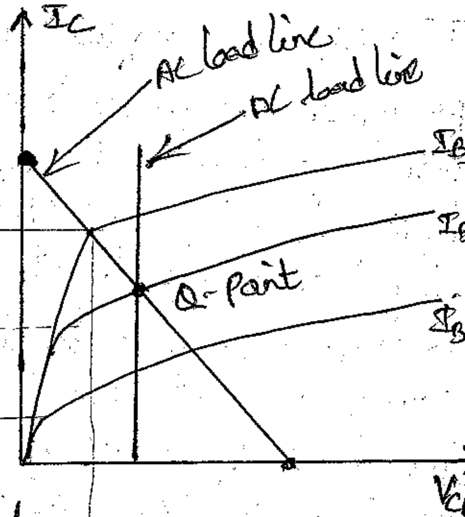
$$P_{DC} = V_{CC} \cdot I_{CQ}.$$

AC operation:

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

→ For ac purposes, the load on the secondary is the load impedance R_L ohms, and the reflected load on the primary is R_L'.

→ 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 ac load line.



→ The output current i.e collector current varies around its quiescent value I_{CQ}, when ac 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.

AC output power:

→ The ac 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 ac 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} = RMS value of primary voltage

I_{1m} = Peak value of primary current

I_{1rms} = RMS value of primary current

Hence ac power ~~[illegible]~~ developed on the primary is given by,

$$P_{ac} = V_{1rms} \cdot I_{1rms}$$

$$P_{ac} = I_{1rms}^2 R_L'$$

$$P_{ac} = V_{1rms}^2 / R_L'$$

$$P_{ac} = \frac{V_{1m}}{\sqrt{2}} \cdot \frac{I_{1m}}{\sqrt{2}} = \frac{V_{1m} \cdot I_{1m}}{2}$$

$$P_{ac} = \frac{I_{1m}^2 R_L'}{2}$$

$$P_{ac} = \frac{V_{1m}^2}{2R_L'}$$

similarly the ac power delivered to the load on secondary also can be calculated using secondary quantities.

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

V_{2rms} = RMS Value of secondary or load Voltage.

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

I_{2rms} = RMS Value of secondary or load current

$$P_{ac} = V_{2rms} \cdot I_{2rms} = I_{2rms}^2 \cdot R_L = V_{2rms}^2 / R_L$$

$$P_{ac} = \frac{V_{2m} \cdot I_{2m}}{2} = \frac{I_{2m}^2 R_L}{2} = \frac{V_{2m}^2}{2R_L}$$

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

→ In practical circuit, the transformer cannot be ideal. Hence the power delivered to the load on the secondary is slightly less than power developed on the primary. In such case, the transformer efficiency must be considered for calculating various parameters on the primary and secondary sides of the transformer.

→ The slope of the ac load line can be expressed in terms of the primary current and the primary voltage.

The slope of the ac load line is,

$$= \frac{1}{R_L'} = \frac{I_{1m}}{V_{1m}}.$$

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

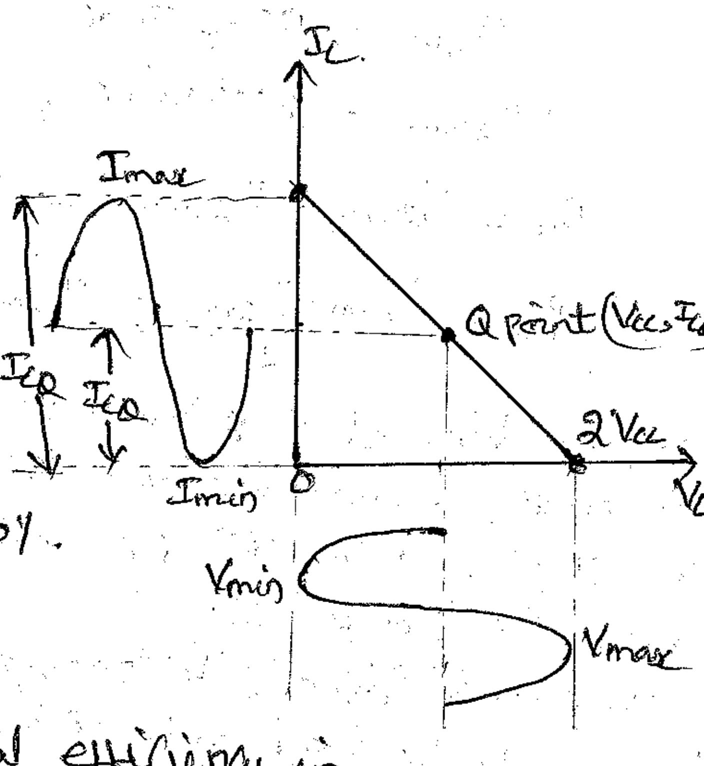
Note:

The ac power calculated is the power developed across the primary winding of the output transformer. Assuming ideal transformer, the power delivered to the load on secondary, is same as that developed across the primar If the transformer efficiency is known, the power delivered to the load must be calculated from the power developed on the primary considerin the efficiency of the transformer.

Efficiency:

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

Maximum Efficiency:



→ Assume maximum swings of both the output voltage and output current to calculate maximum efficiency.

$V_{min}=0$, $V_{max}=2V_{CC}$

$I_{min}=0$, $I_{max}=2I_{CQ}$.

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

$$\%\eta_{max} = 50\%$$

→ Here maximum possible theoretical efficiency in case of transformer coupled class A amplifier is 50%.

→ For practical circuit it is about 30 to 35% which is still much mor than the directly coupled amplifier. For maximum efficiency the powe output is also maximum. For such maximum output power conditio it is seen that, $V_{min}=0$ and $V_{max}=2V_{CC}$

i.e V_{1m} = peak value of primary voltage $= \frac{V_{max}-V_{min}}{2} = V_{CC}$

$\therefore V_{1m} = V_{CC}$ for maximum output power.

similarly from the maximum output current swing, the peak value of the output current is magnitude wise equal to the biasing collector current.

$$\therefore I_{1m} = I_{CQ}$$ magnitude wise for maximum output power.

$\therefore$ The magnitude of the slope of the ac load line is,

$$R_L' = \frac{V_{1m}}{I_{1m}} = \frac{V_{CC}}{I_{CQ}}$$

This expression is applicable only in case of maximum power output condition.

$$(P_{ac})_{max} = \frac{1}{2}\frac{V_{CC}^2}{R_L'} \qquad \{as\ V_{1m} = V_{CC}\}$$

Power dissipation:

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

$$P_d = P_{DC} - P_{ac}$$

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 dc input power gets dissipated in the form of heat, which is the maximum power dissipation.

$$\therefore (P_d)_{max} = V_{CC} I_{CQ}$$

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 ac input signal. The maximum power dissipation decides the maximum power dissipation rating for the power transistor to be selected for an amplifier.

Advantages:

1) The efficiency of operation is higher than directly coupled amplifiers.
2) The dc bias current that flows through the load in case of directly coupled amplifiers is stopped in case of transformer coupled.
3) The impedance matching required for maximum power transfer is possibl

Disadvantages:

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

Comparision of Series Fed and Transformer Coupled Amplifiers:

Series fed class A	Transformer Coupled class A
1) Load is directly connected in collector so transformer not required.	1) output transformer is used to connect the load.
2) simple to design and implement	2) Complicated to design.
3) The output impedance is high hence can not be used for low impedances.	3) Low impedance matching is possible due to transformer.
4) load resistance carries the I_{CQ} hence considerable wastage of power.	4) The I_{CQ} flows through primary of transformer which has zero dc resistan Hence power wastage is small.
5) Less no. of components are required.	5) More no. of components required
6) The circuit is not heavier, bulkier and costlier.	6) The transformer makes the circuit heavier, bulkier and costlier.
7) Maximum efficiency is 25%.	7) Maximum efficiency is 50%.
8) The frequency response is better	8) The frequency response is poor.

Prob ①: Calculate the transformer turns ratio required to match a 8 ohms Speaker load to an amplifier so that the effective load resistance is 3.2kΩ

Soln: $R_L' = 3.2k\Omega$ and $R_L = 8\Omega$

$$n^2 = \frac{R_L}{R_L'} = \left(\frac{N_2}{N_1}\right)^2 \rightarrow \frac{8}{3.2\times10^3} = \left(\frac{N_2}{N_1}\right)^2 \Rightarrow \frac{N_1}{N_2} = 20$$

∴ Turns ratio is 20:1

Prob ②: Calculate the turns ratio required to connected four parallel 16Ω speakers so that they appear as an 8kΩ effective load.

Soln: $R_L' = 8k\Omega$, $R_L = 16 \| 16 \| 16 \| 16 = 4\Omega$

$$R_L' = \frac{R_L}{n^2} \Rightarrow n^2 = \frac{R_L}{R_L'} = \frac{4}{8\times10^3} = 5\times10^{-4}$$

$$\rightarrow n = 0.02236$$

$$n = \frac{N_2}{N_1} = 0.02236 \Rightarrow \frac{N_1}{N_2} = 44.7213$$

∴ Turns ratio is 44.7213 : 1

Prob ③: In case of a class A power amplifiers circuit $R_L = 5\Omega$. Transistor ratings are $P_{d(max)} = 10W$, $V_{CE(sat)} = 1V$, $V_{CE(max)} = 12V$. Transformer Coupling is used with $n = 2$. Determine the efficiency of the amplifier.

Soln: $R_L' = R_L \times n^2$ $\left\{ \because n > 1 \text{ so consider } N_1 : N_2 \;\; \therefore R_L' > R_L \right\}$

$R_L' = 5\times4 = 20\Omega$

$P_{dc} = P_{d(max)} = 10W$.

$$V_{CC} = \frac{V_{CE(max)} - V_{CE(sat)}}{2} = \frac{12-1}{2} = 5.5V$$

For maximum condition, $V_{CE(max)} = 2V_{CC}$

$$\therefore P_{ac} = \frac{1}{2}\frac{V_{CC}^2}{R_L'} = 0.7562W$$

$$\%\eta = \frac{P_{ac}}{P_{dc}} \times 100\% = 7.56\%.$$

prob ④: Design a class A transformer coupled amplifier using a BJT to deliver 100mW of audio power into 8Ω load. At the operating point $I_B = 250\mu A$ $V_{CC} = 16V$. The Collector dissipation should not exceed 200mW. $R_L' = 1K\Omega$.

Sol^n: $R_L' = 1K\Omega$, $R_L = 8\Omega$

$$n^2 = \frac{R_L}{R_L'} = \frac{8}{10^3} \Longrightarrow n = 0.089 = \frac{N_2}{N_1} \Rightarrow N_1 : N_2 \text{ is } 11.18 : 1$$

$$P_{DC} = P_{d(max)} = P_{ac} = 200m - 100m = 100mW$$

$$P_{DC} = V_{CC} \cdot I_{CQ} \Rightarrow I_{CQ} = \frac{P_{DC}}{V_{CC}} = \frac{100 \times 10^{-3}}{16} = 6.25mA$$

$$\beta = \frac{I_{CQ}}{I_{BQ}} = \frac{6.25m}{250\mu} = 25$$

$$\therefore R_B = \frac{V_{CC} - V_{BE}}{I_{BQ}} = \frac{16 - 0.7}{250 \times 10^{-6}} = 61.2 K\Omega$$

---

prob ⑤: The loudspeaker of 8Ω is Connected to the secondary of the output transformer of a class A amplifier Circuit. The quiescent Collector Current is 140mA. The turns ratio of the transformer is 3:1. The Collector supply Voltage is 10V. If ac power delivered to the loudspeaker is 0.48W developed assuming ideal transformer, Calculate,

a) power developed across primary
b b) RMS Value of load Voltage
a c) RMS Value of primary Voltage
c d) RMS Value of load Current
d e) RMS Value of primary Current
e f) DC power input
b g) power dissipation
h) % η

Sol^n: $R_L = 8\Omega$, $I_{CQ} = 140mA$, $V_{CC} = 10V$, $P_{ac} = 0.48W$, $\frac{N_1}{N_2} = \frac{3}{1}$

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

$$R_L' = R_L / n^2 = 8/(0.3333)^2 = 72\Omega$$

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

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

7 ⑫

a ✓ b) $P_{ac} = V_{1rms}^2 / R_L'$

$\therefore 0.48 = V_{1rms}^2 / 72 \Rightarrow V_{1rms} = 5.8787$ on primary

But rms value of load Voltage is V_{2rms}

$$\therefore \frac{V_{1rms}}{V_{2rms}} = \frac{N_1}{N_2} = \frac{3}{1}$$

$$\therefore V_{2rms} = \frac{V_{1rms}}{3} = \frac{5.8787}{3} = 1.9595\,V$$

b ✓ c) RMS value of primary Voltage is $V_{1rms} = 5.8787V$

c × d) power delivered to the load is $= I_{2rms}^2 \times R_L$

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

$$\longrightarrow I_{2rms} = 0.2449A$$

This is the rms value of the load current as the resistance value used is R_L and not R_L'.

d × e) $\frac{I_{1rms}}{I_{2rms}} = \frac{N_2}{N_1} = n = 0.3333 \Rightarrow I_{1rms} = 81.64mA$

e ✓ f) $P_{DC} = V_{CC} \cdot I_{CQ} = 10 \times 140 \times 10^{-3} = 1.4W$

f × g) $P_d = P_{DC} - P_{ac} = 1.4 - 0.48 = 0.92W$

g h) $\%\eta = \frac{P_{ac}}{P_{dc}} \times 100\% = \frac{0.48}{1.4} \times 100\% = 34.28\%$

c) $P_{ac} = \frac{V_{2rms}^2}{R_L} = 0.24$

$P_{ac} = I_{2rms}^2 R_L$

$0.24 = I_{2rms}^2 \times 8 \Rightarrow I_{2rms} = 0.17A$

d) $\frac{I_{1rms}}{I_{2rms}} = \frac{N_2}{N_1} = n$

$\frac{I_{1rms}}{0.17} = 0.33 \Rightarrow I_{1rms} = 56.6mA$

f) $P_d = P_{dc} - P_{ac}$

$= 1.4 - 0.2$

$= 1.16W$

g) $\eta\% = \frac{P_{ac}}{P_{dc}} \times 100$

$= \frac{0.24}{1.4} \times 10$

$= 17\%$

Distortion in 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 distortion and frequency distortion.

→ But the phase distortions are not detectable by human ears as human ears are insensitive to the phase changes.

→ The change in gain of the amplifier w.r.t frequency is called frequency distortion.

→ The frequency distortion is not significant in A.F power amplifiers.

→ It is assumed that the transistor is perfectly Linear device i.e the dynami characteristics of a transistor is a straight line over the operating range. [$I_c = K I_b$],

→ But in practical circuits, the dynamic characteristics is not perfectly linear. Due to such non-linearity in the dynamic characteristics, the waveform of the output Voltage differs from that of the input signal. Such a distortion is called non-linear distortion or amplitude distortion or harmonic distortion,

Harmonic Distortion :

→ Harmonic distortion means the presence of frequency components in the output waveform 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 havin 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 frequen 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.

→ The Second harmonic has the largest amplitude out of all the harmonic Components.

→ As the order of the harmonic increases, its amplitude decreases.

→ 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.

→ If the fundamental frequency Component has an amplitude of B_1 and the nth harmonic Component has an amplitude of B_n, then the percentage harmonic distortion due to nth harmonic Component is given as,

$$\%\ n^{th} \text{ harmonic distortion} = \% D_n = \frac{|B_n|}{|B_1|} \times 100\%$$

$$\text{i.e } \% D_2 = \frac{|B_2|}{|B_1|} \times 100\% \quad , \quad \% D_3 = \frac{|B_3|}{|B_1|} \times 100\%$$

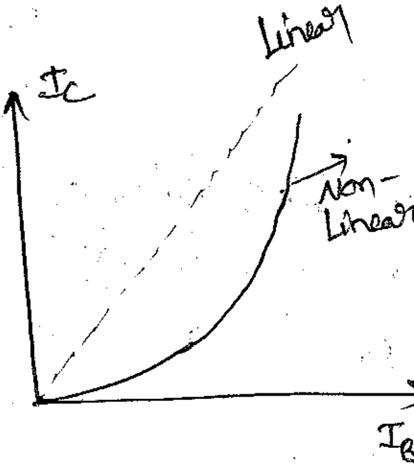
Total Harmonic Distortion :

→ 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 as,

$$\% D = \sqrt{D_2^2 + D_3^2 + D_4^2 + \cdots} \times 100\%$$

where 'D' is total harmonic distortion.

Second Harmonic Distortion (Three point method) :



→ To investigate the Second harmonic distortion, assume that the dynamic transfer characteristics of the transistor is parabolic (nonlinear) in nature rather than a straight line (linear) as shown.

→ Such type of nonlinearity introduces harmonic distortion, in which Second harmonic is the most dominant.

→ Let an ac input signal, causes the base current swing which is Cosine in nature.

$$\therefore \ i_b = I_{bm} \cos\omega t$$

→ Due to this collector current swings around its quiescent value but the relation between i_b and i_c is non-linear.

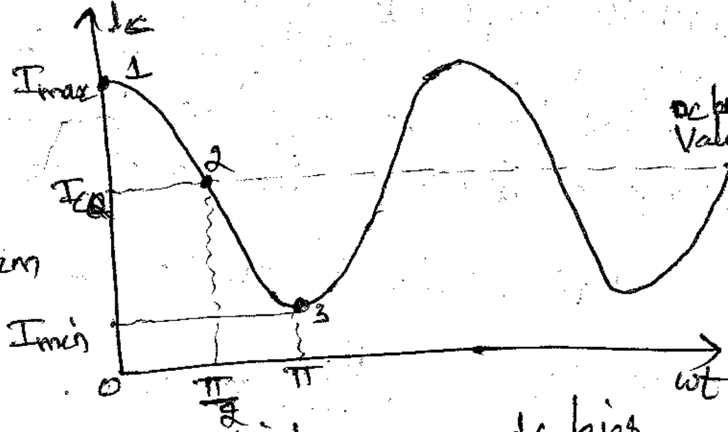
$$i_c = G_1 i_b + G_2 i_b^2.$$

$$= G_1 I_{Bm} \cos\omega t + G_2 I_{Bm}^2 \cos^2\omega t$$

$$= G_1 I_{Bm} \cos\omega t + G_2 I_{Bm}^2 \frac{1+\cos 2\omega t}{2}$$

$$i_c = G_1 I_{Bm} \cos\omega t + \frac{1}{2} G_2 I_{Bm}^2 + \frac{G_2}{2} I_{Bm}^2 \cos 2\omega t$$

$$i_c = B_0 + B_1 \cos\omega t + B_2 \cos 2\omega t.$$



The last term represents the second harmonic component. Thus the equation shows that there is second harmonic component present.

Hence the total collector current waveform shown in figure which is swinging about its quiescent value I_{CQ}.

Hence the total collector current can be expressed in terms of dc bias value, dc signal component, fundamental frequency and second harmonic component as,

$$i_c = I_{CQ} + B_0 + B_1 \cos\omega t + B_2 \cos 2\omega t$$

where, $I_{CQ} + B_0$ = dc component, independent of time
B_1 = Amplitude of the fundamental frequency
B_2 = Amplitude of the second harmonic component

To find the value of total collector current at various instants 1, 2 and 3 as shown in figure consider,

At point 1, $\omega t = 0$ & $i_c = I_{max}$

$$\therefore i_c = I_{max} = I_{CQ} + B_0 + B_1 + B_2$$

At point 2, $\omega t = \pi/2$ & $i_c = I_{CQ}$

$$\therefore I_{CQ} = I_{CQ} + B_0 - B_2 \Rightarrow \boxed{B_0 = B_2.}$$

At point 3, $\omega t = \pi$ & $i_c = I_{min}$

$$\therefore I_{min} = I_{CQ} + B_0 - B_1 + B_2.$$

$$I_{max} - I_{min} = 2B_1 \Rightarrow \boxed{B_1 = \frac{I_{max} - I_{min}}{2}}$$

$$I_{max} + I_{min} = 2I_{CQ} + 2B_0 + 2B_2 \qquad \{\because B_0 = B_2\}$$

$$= 2I_{CQ} + 2B_2 + 2B_2$$

$$= 2I_{CQ} + 4B_2$$

$$\therefore B_2 = \frac{I_{max} + I_{min} - 2I_{CQ}}{4}.$$

As the amplitudes of the fundamental and the second harmonic are known, the second harmonic distortion can be calculated as,

$$\% D_2 = \frac{|B_2|}{|B_1|} \times 100\%$$

As the method uses three points on the collector current waveform to obtain the amplitudes of the harmonics, the method is called "Three point method" of determining the second harmonic distortion.

Power output due to distortion:

when distortion is negligible, the power delivered to the load is given by,

$$P_{ac} = \frac{I_m^2 R_L}{2}$$

where $I_m = \frac{I_{PP}}{2} = \frac{I_{max} - I_{min}}{2}$

But $B_1 = \frac{I_{max} - I_{min}}{2} \Rightarrow I_m = B_1$

$$\therefore P_{ac} = \frac{B_1^2 R_L}{2}$$

with distortion, the power delivered to the load increases proportional to the amplitude of the harmonic component.

$(P_{ac})_D$ = A.C power output with harmonic distortion

$$= \frac{B_1^2 R_L}{2} + \frac{B_2^2 R_L}{2} + \frac{B_3^2 R_L}{2} + \cdots$$

$$= \frac{B_1^2 R_L}{2}\left[1 + \frac{B_2^2}{B_1^2} + \frac{B_3^2}{B_1^2} + \cdots\right]$$

$$(P_{ac})_D = P_{ac}\left[1 + D_2^2 + D_3^2 + \cdots\right] = P_{ac}(1 + D^2)$$

prob ①: prove that in class A amplifier if distortion is 10% power given to the load is increased by 1%.

Solⁿ: $(P_{ac})_D = P_{ac}(1+D^2)$

$D = 10\% = 0.1$

$\therefore (P_{ac})_D = P_{ac}[1+(0.1)^2] = 1.01 P_{ac}$ i.e

This shows that power given to the load is increased from 1 to 1.01 i.e increased by 1%.

prob ②: A transistor supplies 0.85W to a 4K Ω load. The zero signal DC collector current is 31mA and DC collector current with signal is 34mA. Determine the second harmonic distortion.

Solⁿ: $R_L = 4K\Omega$, $(P_{ac})_D = 0.85W$

Collector current without signal is $I_{CQ} = 31mA$

collector current with signal is $I_{CQ} + B_0 = 34mA$

$B_0 = 34m - 31m = 3mA$

$B_2 = B_0 = 3mA$

$(P_{ac})_D = P_{ac}[1+D_2^2] = \frac{1}{2}B_1^2 R_L\left[1+\frac{B_2^2}{B_1^2}\right]$

$\Rightarrow 0.85 = \frac{1}{2}B_1^2 R_L + \frac{1}{2}B_2^2 R_L$

$0.85 = \frac{1}{2}B_1^2 \times 4\times10^3 + \frac{1}{2}\times(3\times10^{-3})^2\times4\times10^3$

$\Rightarrow B_1 = 20.396\,mA$

$\%\, D_2 = \frac{|B_2|}{|B_1|}\times100\% = \frac{3\times10^{-3}}{20.396\times10^{-3}}\times100 = 14.708\%$

prob ③: A single transistor amplifier with transformer coupled load produces harmonic amplitudes in the output as,

$B_0 = 1.5mA$, $B_3 = 4mA$ Find the % total harmonic distortion.

$B_1 = 120mA$, $B_4 = 2mA$

$B_2 = 10mA$, $B_5 = 1mA$

Soln: $D_2 = \frac{|B_2|}{|B_1|} = \frac{10}{120} = 0.0833$ $D_3 = \frac{|B_3|}{|B_1|} = \frac{4}{120} = 0.0333$

$D_4 = \frac{|B_4|}{|B_1|} = \frac{2}{120} = 0.01667$ $D_5 = \frac{|B_5|}{|B_1|} = \frac{1}{120} = 0.00833$

$$\% D = \sqrt{D_2^2 + D_3^2 + D_4^2 + D_5^2} \times 100$$

$$= \sqrt{(0.0833)^2 + (0.0333)^2 + (0.01667)^2 + (0.00833)^2} \times 100$$

$$= 9.1624\%$$

prob ④: A sinusoidal signal $V_s = 1.75 \sin(600t)$ is fed to a power amplifier. The resulting output current is

$I_o = 15 \sin 600t + 1.5 \sin 1200t + 1.2 \sin 1800t + 0.5 \sin 2400t$

Calculate the percentage increase in power due to distortion.

Soln: $I_o = B_1 \sin \omega t + B_2 \sin 2\omega t + B_3 \sin 3\omega t + B_4 \sin 4\omega t$

$\therefore B_1 = 15, B_2 = 1.5, B_3 = 1.2$ & $B_4 = 0.5$

$D_2 = \frac{|B_2|}{|B_1|} = \frac{1.5}{15} = 0.1$, $D_3 = \frac{|B_3|}{|B_1|} = \frac{1.2}{15} = 0.08$

$D_4 = \frac{|B_4|}{|B_1|} = \frac{0.5}{15} = 0.0333$

$$(P_{ac})_D = P_{ac}[1 + D^2] = P_{ac}[1 + D_2^2 + D_3^2 + D_4^2]$$

$$(P_{ac})_D = P_{ac}[1 + (0.1)^2 + (0.08)^2 + (0.0333)^2]$$

$$(P_{ac})_D = 1.0175 P_{ac}$$

% increase in power due to distortion $= \frac{(P_{ac})_D - P_{ac}}{P_{ac}} \times 100\%$

$$= \frac{1.0175 P_{ac} - P_{ac}}{P_{ac}} \times 100\%$$

$$= 1.75\%$$

prob(5): The dynamic transfer characteristics curve for a given transistor is, i_c (in mA) = $50 i_b + 1000 i_b^2$ where $i_b = 10 \cos 2\pi(100t)$ in mA. Calculate percentage harmonic distortion.

Soln: $i_c = G_1 i_b + G_2 i_b^2 \Rightarrow G_1 = 50 \;\&\; G_2 = 1000$

$i_b = I_{Bm}\cos\omega t$ hence $I_{Bm} = 10\text{ mA}$

$$i_c = G_1 I_{Bm}\cos\omega t + G_2 I_{Bm}^2 \cos^2\omega t$$

$$= G_1 I_{Bm}\cos\omega t + G_2 I_{Bm}^2\left[\frac{1+\cos 2\omega t}{2}\right]$$

$$= \frac{1}{2} G_2 I_{Bm}^2 + G_1 I_{Bm}\cos\omega t + \frac{1}{2} G_2 I_{Bm}^2 \cos 2\omega t$$

$$i_c = B_0 + B_1\cos\omega t + B_2\cos 2\omega t$$

$$\Rightarrow B_0 = B_2 = \frac{1}{2} G_2 I_{Bm}^2 = \frac{1}{2}\times 1000 \times (10\times10^{-3})^2$$

$$B_0 = B_2 = 0.05$$

$$B_1 = G_1 I_{Bm} = 50\times 10\times10^{-3} = 0.5$$

$$\therefore \% D_2 = \frac{|B_2|}{|B_1|}\times 100 = \frac{0.05}{0.5}\times 100 = 0.1\times 100 = 10\%.$$

prob(6): For harmonic distortions of $D_2 = 0.1$, $D_3 = 0.02$ and $D_4 = 0.01$ with fundamental component of output signal $I_1 = 4A$ and $R_L = 8\Omega$. Calculate the total harmonic distortion, fundamental power component and total power.

Soln: $D_2 = 0.1$, $D_3 = 0.02$, $D_4 = 0.01$ $\&$ $R_L = 8\Omega$

$B_1 = I_1 = 4A$, $B_2 = B_1\times D_2 = 4\times 0.1 = 0.4$

$B_3 = B_1\times D_3 = 4\times 0.02 = 0.08$, $B_4 = B_1\times D_4 = 4\times 0.01 = 0.04$.

$$\% D = \sqrt{D_2^2 + D_3^2 + D_4^2}\times 100\% = 10.2469\%.$$

$$P_{ac} = \frac{1}{2} B_1^2 R_L = \frac{1}{2}\times 4^2\times 8 = 64W$$

$$(P_{ac})_D = P_{ac}(1+D^2) = 64\times\left[1+(0.102469)^2\right] = 64.672W$$

①

3.9 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.

3.10 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. 3.21.

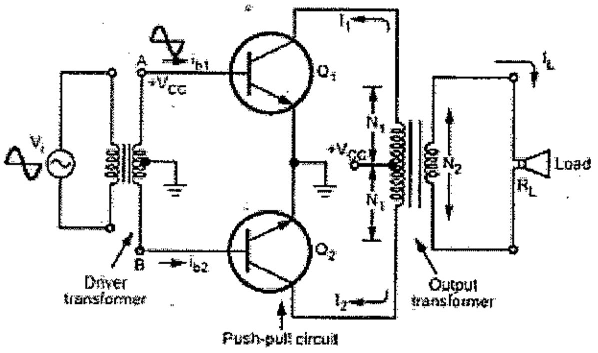


Fig. 3.21 Push pull class B amplifier

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 centre 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.

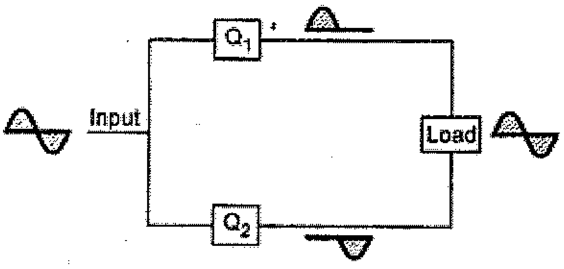


Fig. 3.22 Basic push pull operation

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. 3.22.

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. 3.23.

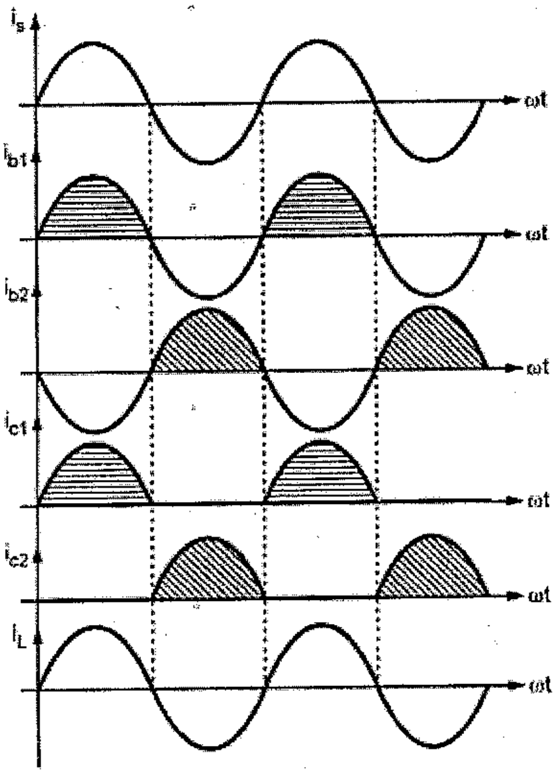


Fig. 3.23 Waveforms for push pull class B amplifier

> **Key Point:** *For the output transformer, the number of the turns of each half of the primary is N_1 while the number of the turns on the secondary is N_2. Hence the total number of primary turns is $2N_1$. So turns ratio of the output transformer is specified as $2N_1$. So turns ratio of the output transformer is specified as $2N_1 : N_2$.*

3.10.1 D.C.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.

3.10.2 D.C.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.**

$$\boxed{\therefore I_{DC} = \frac{I_m}{\pi} + \frac{I_m}{\pi} = \frac{2 I_m}{\pi}} \quad \text{... (1)}$$

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

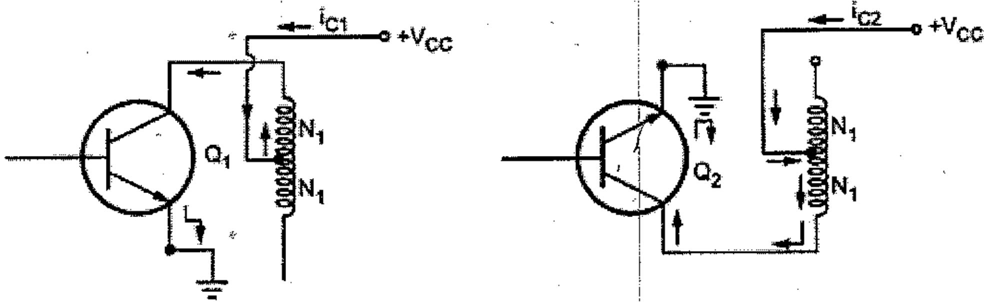
$$P_{DC} = V_{CC} \times I_{DC}$$

$$\boxed{\therefore P_{DC} = \frac{2}{\pi} V_{CC} \; I_m} \quad \text{... (2)}$$

3.10.3 A.C.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. 3.24.

For the negative half cycle Q_2 conducts. The path of the current drawn by the Q_2 is shown in the Fig. 3.24 (b).



(a) Q_1 conduction

(b) Q_2 conduction

Fig. 3.24

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,

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

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

It is important to note that the step down turns ratio is $2N_1 : N_2$ but while calculating the reflected load, the ratio n becomes N_2/N_1. So each transistor shares equal load which is the reflected load R'_L given by the equation (3).

The slope of the a.c. load line is $-1/R'_L$ while the d.c. load line is the vertical line passing through the operating point Q on the x-axis. The load lines are shown in the Fig. 3.25.

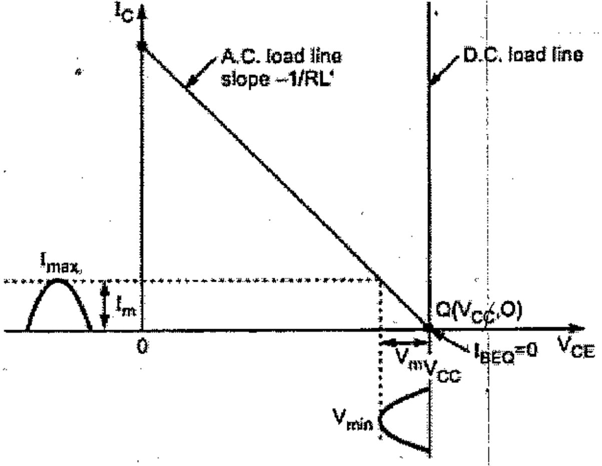


Fig. 3.25 Load lines for push pull class B amplifier

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

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

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

where $\quad I_m$ = Peak value of the collector current

3.10.4 A.C. 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 $\quad I_{rms} = \frac{I_m}{\sqrt{2}}$

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

$$P_{ac} = V_{rms}\ I_{rms} = I_{rms}^2\ R'_L = \frac{V_{rms}^2}{R'_L} \qquad \text{... (5)}$$

While using peak values it can be expressed as,

$$\boxed{P_{ac} = \frac{V_m I_m}{2} = \frac{I_m^2 R'_L}{2} = \frac{V_m^2}{2R'_L}} \qquad \text{... (6)}$$

3.10.5 Efficiency

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

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

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

3.10.6 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. 3.26.

$$\therefore\ \%\ \eta_{max} = \frac{\pi}{4} \times \frac{V_{CC}}{V_{CC}} \times 100 = 78.5\ \%$$

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.

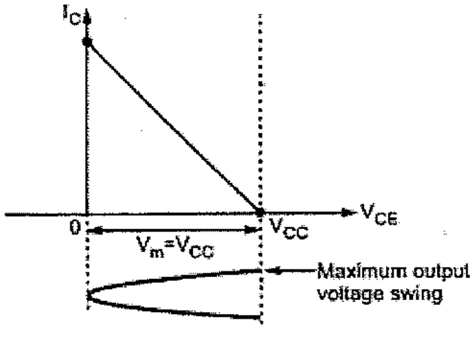


Fig. 3.26

③

3.10.7 Power Dissipation

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

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

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

Let us find out the condition for maximum power dissipation. In case of class A amplifier, it is maximum when no input signal is there. But in class B operation, when the input signal is zero, $V_m = 0$ hence the power dissipation is zero and not the maximum.

Maximum power dissipation : The condition for maximum power dissipation can be obtained by differentiating the equation (8) with respect to V_m and equating it to zero.

$$\therefore \frac{d\,P_d}{d\,V_m} = \frac{2}{\pi}\frac{V_{CC}}{R_L'} - \frac{2V_m}{2R_L'} = 0$$

$$\therefore \frac{2}{\pi}\frac{V_{CC}}{R_L'} = \frac{V_m}{R_L'}$$

$$\boxed{V_m = \frac{2}{\pi} V_{CC}} \qquad \dots (9)$$

This is the **condition for maximum power dissipation**. Hence the maximum power dissipation is,

$$(P_d)_{max} = \frac{2}{\pi} V_{CC} \times \frac{2}{\pi}\frac{V_{CC}}{R_L'} - \frac{4}{\pi^2}\frac{V_{CC}^2}{2R_L'}$$

$$= \frac{4}{\pi^2}\frac{V_{CC}^2}{R_L'} - \frac{2}{\pi^2}\frac{V_{CC}^2}{R_L'}$$

$$\boxed{\therefore (P_d)_{max} = \frac{2}{\pi^2}\frac{V_{CC}^2}{R_L'}} \qquad \dots (10)$$

Key Point: *For maximum efficiency,* $V_m = V_{CC}$ *hence the power dissipation is not maximum when the efficiency is maximum. And when power dissipation is maximum, efficiency is not maximum.* ***So maximum efficiency and maximum power dissipation do not occur simultaneously,*** *in case of class B amplifiers.*

Now $\qquad P_{ac} = \dfrac{V_m^2}{2R_L'}$

and $\qquad V_m = V_{CC}$ is the maximum condition.

Hence $\qquad (P_{ac})_{max} = \dfrac{V_{CC}^2}{2R_L'} \qquad \dots (11)$

Now $\qquad (P_d)_{max} = \dfrac{2V_{CC}^2}{\pi^2 R_L'} = \dfrac{4}{\pi^2}\left(\dfrac{V_{CC}^2}{2R_L'}\right)$

$\therefore \qquad (P_d)_{max} = \dfrac{4}{\pi^2}(P_{ac})_{max} \qquad \dots (12)$

This much power is dissipated by both the transistors hence the maximum power dissipation per transistor is $(P_d)_{max}/2$.

$$\therefore (P_d)_{max} \text{ per transistor} = \frac{\frac{4}{\pi^2}(P_{ac})_{max}}{2}$$

$$\boxed{\therefore (P_d)_{max} \text{ per transistor} = \frac{2}{\pi^2}(P_{ac})_{max}} \qquad \dots (13)$$

This is the **maximum power dissipation rating** of each transistor. For example, if 10 W maximum power is to be supplied to the load, then power dissipation rating of each transistor should be $\frac{2}{\pi^2} \times 10$ i.e. 2.02 W.

Ex. 3.6 : *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.*

Sol. : $R_L = 16\,\Omega \qquad V_{CC} = 25\text{ V}$

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

$\therefore \quad N_1 = 100$

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

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

$= 64\,\Omega$

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

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

$= 4.8828\text{ W}$

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

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

and $\quad V_m = V_{CC}$ ... refer equation (3.82)

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

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

$= 6.2169\text{ W}$

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

$= 78.5\%$

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

$= \frac{2}{\pi^2} \times 4.8828$

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

④

Example 3.7 : *Prove that in case of push pull class B amplifier, the efficiency at the time of maximum power dissipation is just 50%.*

Solution : The maximum power dissipation occurs when the value of V_m is

$$V_m = \frac{2}{\pi} V_{CC} \qquad \text{... refer equation (9)}$$

Now
$$P_{ac} = \frac{V_m I_m}{2}$$

So at the time of maximum power dissipation, it is

$$P_{ac} = \frac{2}{\pi} \frac{V_{CC} I_m}{2} = \frac{V_{CC} I_m}{\pi}$$

Now
$$P_{DC} = \frac{2}{\pi} V_{CC}\, I_m$$

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

$$= 50\ \%$$

Thus efficiency is just 50 % when the power dissipation is maximum. While the maximum efficiency of the class B operation, is 78.5 %.

3.10.8 Harmonic Distortion

Let the base input currents are sinusoidal in nature and given by,

$$i_{b1} = I_{Bm} \cos \omega t \text{ and } i_{b2} = -I_{Bm} \cos \omega t$$

The negative sign indicates that both are 180° out of phase.

Due to nonlinear dynamic characteristics, the collector current of the two transistors can be expressed in terms of harmonic components as,

$$i_{c1} = I_{CQ} + B_0 + B_1 \cos \omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + \ldots \qquad \ldots (14)$$

Now
$$i_{b2} = -I_{Bm} \cos \omega t = I_{Bm} \cos(\omega t + \pi)$$

Hence the collector current for the second transistor can be obtained by replacing ωt by $\omega t + \pi$ in the expression for i_{c1}.

$$\therefore i_{c2} = I_{CQ} + B_0 + B_1 \cos(\omega t + \pi) + B_2 \cos 2(\omega t + \pi) + \ldots$$

$$= I_{CQ} + B_0 - B_1 \cos \omega t + B_2 \cos 2\omega t - B_3 \cos 3\omega t + \ldots \qquad \ldots (15)$$

Now the load current is the difference between the two. This is because, in the primary of the transformer the two currents are in opposite direction.

$$\therefore i_L = i_{c1} - i_{c2}$$

$$= (I_{CQ} + B_0 + B_1 \cos \omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + \ldots)$$

$$- (I_{CQ} + B_0 - B_1 \cos \omega t + B_2 \cos 2\omega t - B_3 \cos 3\omega t + \ldots)$$

while
$$\boxed{\therefore i_L = 2 B_1 \cos \omega t + 2 B_3 \cos 3\omega t + \ldots} \qquad \ldots (16)$$

It can be seen that **the even harmonic components** 2nd, 4th, 6th **and so on, get eliminated. Similarly the d.c. component also gets eliminated.** Hence the total distortion is less and as d.c. component flowing is zero, there is no possibility of d.c. saturation of the core. Hence the percentage harmonic distortion is only due to odd harmonics given by,

$$\% D_3 = \frac{|B_3|}{|B_1|} \times 100, \; \% D_5 = \frac{|B_5|}{|B_1|} \times 100 \ldots$$

Hence the total harmonic distortion is,

$$\boxed{\% D = \sqrt{D_3^2 + D_5^2 + D_7^2 + \ldots} \times 100} \qquad \ldots (17)$$

This is based on the assumption that the two transistors are exactly matched. Otherwise even harmonics may be present in the output signal.

3.10.9 Advantages and Disadvantages

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.

3.9 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.

The basic circuit of complementary symmetry class-B amplifier is shown in the Fig. 3.28

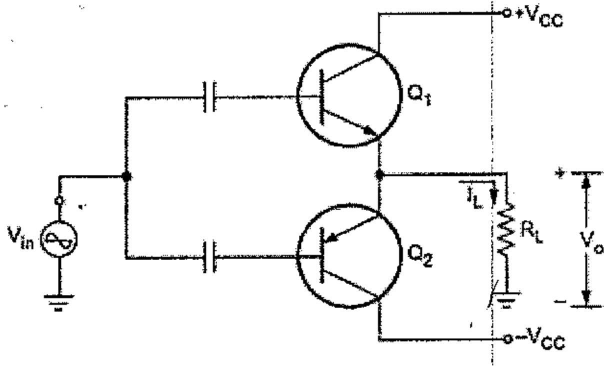


Fig. 3.28 Complementary symmetry class B amplifier

The circuit is driven from a dual supply of ± 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. 3.29.

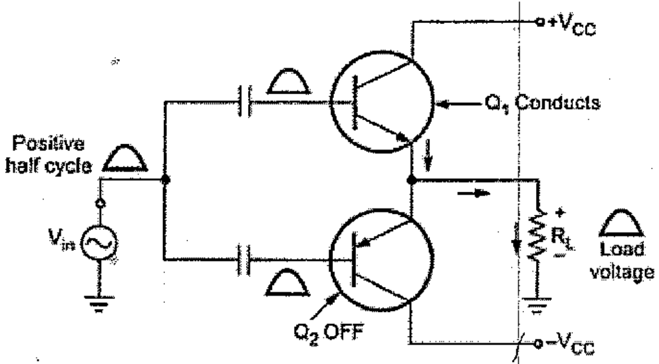
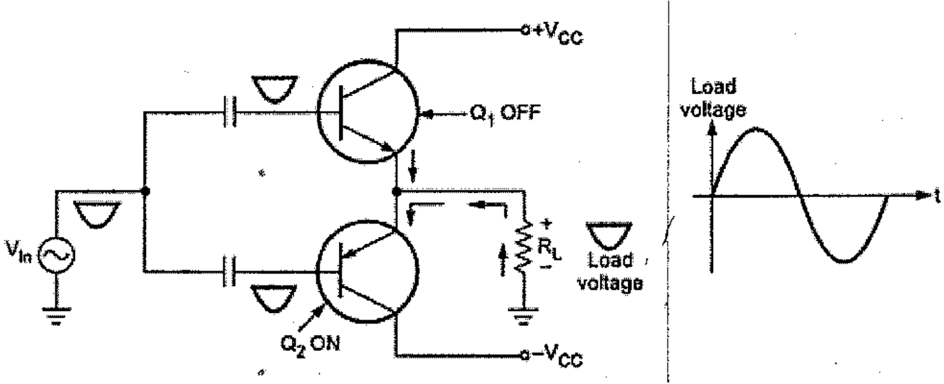


Fig. 3.29 Positive half cycle operation

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. 3.30 (a).

Thus for a complete cycle of input, a complete cycle of output signal is developed across the load as shown in the Fig. 3.30 (b)



(a) Negative half cycle operation (b) Load voltage wave form

Fig. 3.30

Note : 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'.

3.9.1 Advantages and Disadvantages

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.

Ex. 3.8 : *Class B complementary A.F. power amplifiers shown in the Fig.3.31. Calculate,*

i) Maximum a.c. power which can be developed.

ii) Collector dissipation while developing maximum a.c. power.

iii) Efficiency

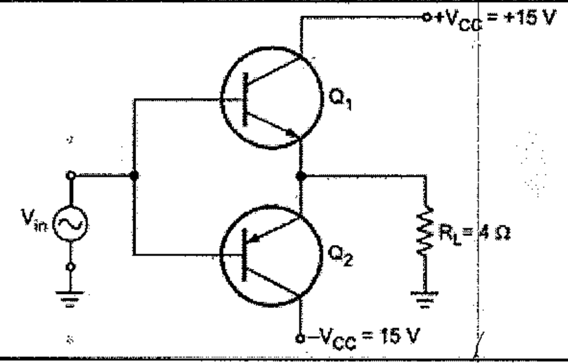


Fig. 3.31

Sol . : From the Fig. 3.31,

$$V_{CC} = 15\text{ V}, R_L = 4\ \Omega$$

Use the expressions derived for push pull class B replacing R_L' by R_L .

i)
$$(P_{ac})_{max} = \frac{1}{2}\frac{V_{CC}^2}{R_L} = \frac{1}{2}\frac{(15)^2}{4} = 28.125\text{ W}$$

ii) When power developed is maximum, $V_m = V_{CC}$

$$R_L = \frac{V_m}{I_m}$$

$$\therefore \quad I_m = \frac{V_m}{R_L} = \frac{V_{CC}}{R_L} = \frac{15}{4} = 3.75\text{ A}$$

$$\therefore \quad P_{dc} = \frac{2}{\pi}V_{CC}\,I_m = \frac{2}{\pi}\times 15\times 3.75 = 35.809\text{ W}$$

$$\therefore \quad P_d = P_{dc} - P_{ac} = 35.809 - 28.125 = 7.684\text{ W}$$

This is the total collector dissipation under maximum power condition.

iii)
$$\%\eta = \frac{P_{ac}}{P_{dc}}\times 100 = \frac{28.125}{35.809}\times 100 = 78.5\ \%$$

3.12 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.

Table 3.2

Note that the other features of class B such as 180° conduction for each transistor, zero power dissipation when a.c. singnal is absent, cross-over distortion etc. are common for both the circuits.

Key Point: *While solving the problems on class B large signal amplifiers, given power is to be assumed maximum unless and otherwise specified and use* $(P_{ac})_{max} = \frac{1}{2}\frac{V_{CC}^2}{R_L}$ *or* $\frac{1}{2}\frac{V_{CC}^2}{R_L'}$ *depending upon type of the circuit.*

If V_{in} *is given then as common collector circuit has unity gain,* $V_{out} = V_{in}$ *and then voltage across* R_L *is same as* V_{in}*. The peak value of* V_{in} *is and* $V_m \neq V_{cc}$ *in such a case.*

If supply given is dual such as $V_{CC} = \pm 12$ V, ± 20 V *etc. , it is dual supply version.*

But if supply given is $V_{CC} = 12$ V, 20 V *then it is single supply version and in such a case use* $V_{CC} = \frac{1}{2}$ *(given +* V_{CC} *) i.e* $\frac{12}{2} = 6$ V, $\frac{20}{2} = 10$ V *etc. The single supply version is discussed in the section 3.15.*

Example 3.11 : *A complementary push-pull amplifier has capacitive coupled load* $R_L = 8\Omega$*, supply voltage* ± 12 V*, calculate :*

1) P_{ac} *max*

2) P_d *of each transistor and*

3) *Efficiency.*

Solution : $R_L = 8\Omega$, $V_{CC} = \pm 12$ V hence dual supply version

1) $$(P_{ac})_{max} = \frac{1}{2}\frac{V_{CC}^2}{R_L} = \frac{1}{2} \times \frac{(12)^2}{8} = 9 \text{ W}$$

2) $$P_{DC} = V_{CC}\, I_{DC} \text{ but } I_{DC} = 2\frac{I_m}{\pi}$$

$$= V_{CC}\left(2\frac{I_m}{\pi}\right)$$

now $$R_L = \frac{V_m}{I_m} \text{ i.e } I_m = \frac{V_m}{R_L} \text{ and } V_m = V_{CC}$$

$$\therefore P_{DC} = V_{CC} \times 2 \times \frac{V_{CC}}{R_L} \times \frac{1}{\pi} = \frac{(12)^2 \times 2}{8 \times \pi} = 11.4591 \text{ W}$$

$$\therefore \text{Total } P_d = P_{DC} - P_{ac} = 11.4591 - 9 = 2.4591 \text{ W}$$

$$\therefore P_d \text{ per transistor} = \frac{2.4591}{2} = 1.2295 \text{ W}$$

3) $$\% \eta = \frac{P_{ac}}{P_{DC}} \times 100 = \frac{9}{11.4591} \times 100 = 78.5 \%$$

3.10 Cross-Over 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. 3.32.

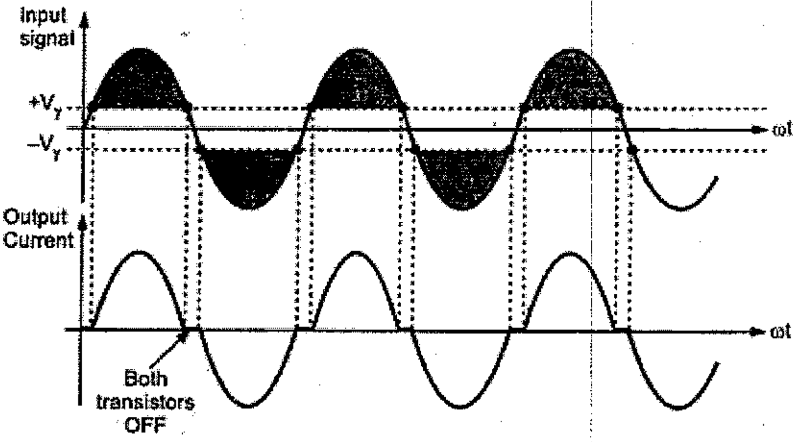


Fig. 3.32 Cross-over distortion

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. 3.32. The cross-over distortion is common in both the types of class B amplifiers.

3.11 Elimination of Cross-Over 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.

3.11.1 Push Pull Class B Amplifier

The forward biased across the base-emitter junction of each transistor is provided by using a diode as shown in the Fig. 3.33.

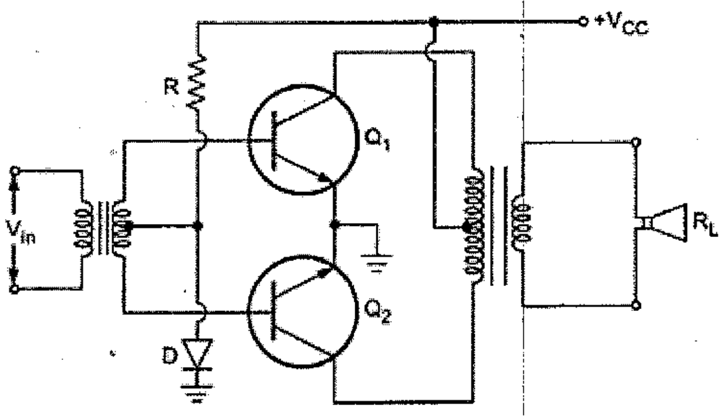


Fig. 3.33

The drop across the diode D is equal to the cut-in voltage of the base-emitter junction of the transistor. Hence both the transistors conduct for full half cycle, eliminating the cross-over distortion.

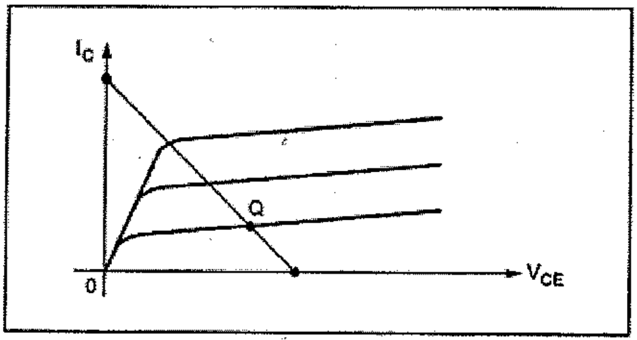


Fig. 3.34

Due to the forward biased provided to eliminate the cross over distortion, the Q point shifts upwards on the load line as shown in the Fig. 3.34. Hence the operation of the amplifier no longer remains class B but becomes class AB operation.

But as the amplifier handles the large signals in the range of volts, compared to these signals the shift in Q point is negligibly small. Hence for all the practical purposes, the operation is treated as class B operation and all the expression derived are applicable to these modified circuits.

3.11.2 Complementary Symmetry Class B Amplifier

In push pull, transformer coupled type, the drop across forward biased one diode is sufficient, to provide necessary cut in voltage. But in case of complementary symmetry circuit, base emitter junctions of both Q_1 and Q_2, are required to provide a fixed bias. Hence for silicon transistors a fixed bias of 0.7 + 0.7 = 1.4 V is required. This can be achieved by using a potential divider arrangement as shown in the Fig. 3.35.

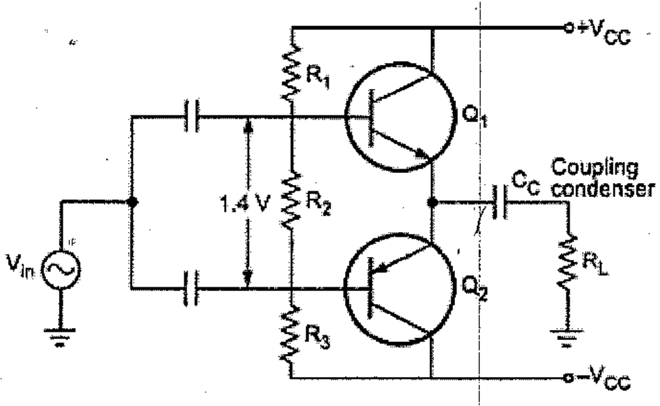


Fig. 3.35

But in this circuit, the fixed bias provided is fixed equal to say 1.4 V. While the junction cut-in voltage changes with respect to the temperature. Hence there is still possibility of a distortion. Hence instead of R_2, the two diodes can be used to provide the required fixed bias. As the temperature changes, along with the junction characteristics, the diode characteristics get changed and maintain the necessary biasing required to overcome the cross-over distortion. The arrangement of the circuit with the two diodes is shown in the Fig. 3.36.

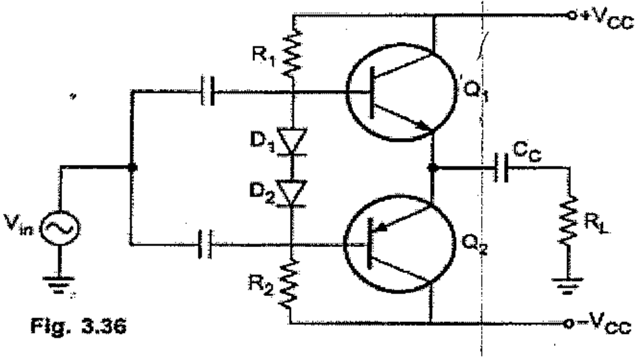


Fig. 3.36

3.12 Complementary Symmetry Single Supply Version

The main disadvantage as seen earlier of complementary amplifier is the use of dual supply. But in practice the circuit can be modified by grounding $- V_{CC}$ terminal. The resulting circuit is called single supply version of complementary symmetry class B amplifier as shown in the Fig. 3.37.

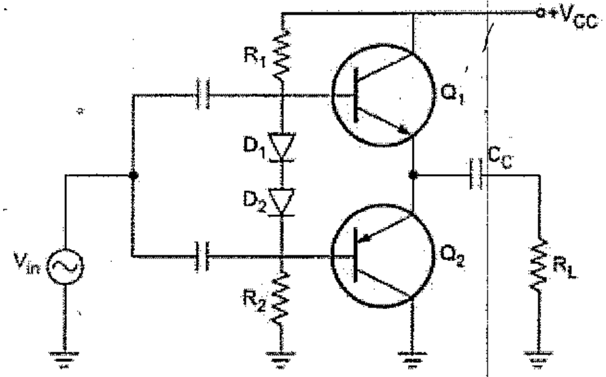


Fig. 3.37 Single supply version of complementary symmetry class B amplifier

All the expression derived for dual supply version are still applicable to single supply version. Only change required is that the value of V_{CC} must be taken as $V_{CC}/2$, while calculating the various parameters of the circuit.

3.13 Safe Operating Area (S.O.A.) for A Transistor

From the various ratings of a transistor such as $(I_c)_{max}$, $(V_{CE})_{max}$, $(P_d)_{max}$ the safe operating area (S.O.A.) for a transistor can be shown on its output characteristics. The power transistor must have safe operating limits which are supplied by the manufacturers.

$(I_C)_{max}$ = Maximum collector current rating
$(V_{CE})_{max}$ = Maximum collector to emitter voltage rating
$(P_d)_{max}$ = Maximum power dissipation rating

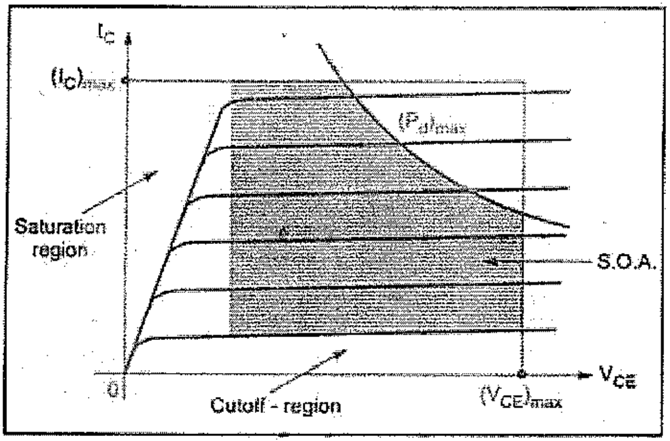


Fig. 3.38 Safe operating area

The power dissipation is given by V_{CE} I_c and the corresponding maximum dissipation curve of $(V_{CE})_{max}$, $(I_C)_{max}$, $(P_d)_{max}$ curve, cut off and saturation region together define the limits on safe operating area for a transistor. The safe operating area for a transistor is shown shaded, in the Fig. 3.38.

The actual values of $(V_{CE})_{max}$ and $(I_C)_{max}$ depends on the circuit values, Q point and the class of operation of an amplifier. Similarly the maximum power dissipation rating for various classes are also discussed earlier. All these values must be located in a safe operating area for a power transistor selected. In other words, a power transistor should be selected such that all these values will be located within the safe operating area for that transistor.

3.14 Heat Sinking for Power Transistors

The maximum power handled by a particular power transistor and the temperature of the transistor junctions are closely related. This is because of the fact that the junction temperature increases due to the power dissipation. The collector dissipation can be obtained as

$$P_d = V_{CE} I_C$$

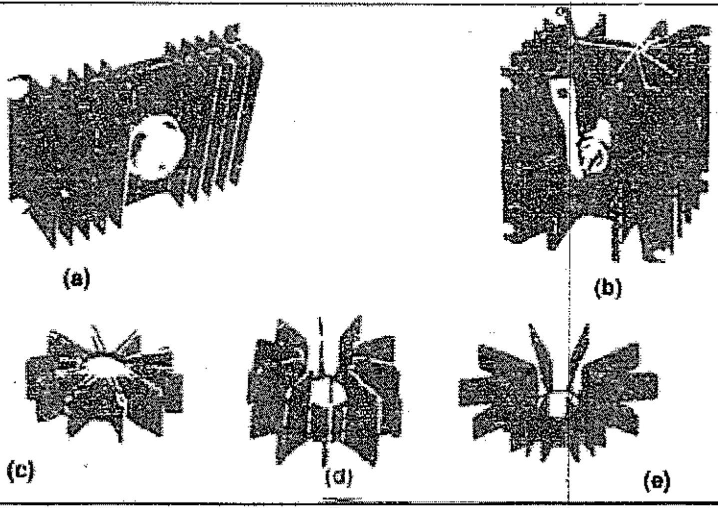
Let T_j be the junction temperature which due to power dissipation. Manufacture provides the maximum permissible value of T_j and corresponding maximum available value of the power dissipation P_d. If the temperature keeps on increasing, at a certain temperature, the crystalline structure is destroyed and there is no chance of recovery. The lower limit of a semiconductor is taken as,

$$-65^{\circ}C \le T_j \le (T_j)_{max} \qquad \text{... (3.97)}$$

Where $(T_j)_{max}$ is specified by the manufacturers.

3.14.1 Heat Sinks

A heat sink is a mechanical device which is connected or press fit to the case of the transistor that provides a large surface area, to dissipate the developed heat. The heat sink carries the heat to the surroundings. Due to the heat sinks, power handling capacity of the transistors can approach the rated maximum value. The heat sinks cause the temperature of the case to be lowered. If the heat developed is transferred to the surroundings instantaneously, the collector dissipation rating would be infinite. In practice this is not possible due to a thermal lag. The various standard shapes and sizes of the heat sink are shown in the Fig. 3.39. The heat sinks shown in (a) and (b) are called natural convection coolers while shown in (c), (d) and (e) are typical shape-on dissipators for various case sizes.



(a) (b)

(c) (d) (e)

Fig. 3.39 Typical heat sinks

3.14.2 Thermal Analogy of Power Transistors

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,

$$\theta = \frac{T_2 - T_1}{P_d} \ ^\circ C/W \text{ or } ^\circ C/mW \qquad \dots (3.98)$$

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

From the above relation we can write,

$$T_2 - T_1 = \theta P_d \ ^\circ C \qquad \dots (3.99)$$

and

$$P_d = \frac{T_2 - T_1}{\theta} \text{ W or mW} \qquad \dots (3.100)$$

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 entire circuit including transistor and heat sink is a series circuit, from thermal point of view as shown in the Fig. 3.40.

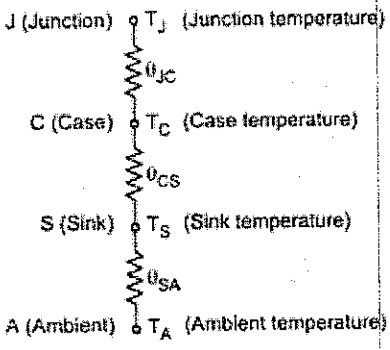


Fig. 3.40 Series thermal circuit

A special silicon grease is often used to establish good heat conducting path between the case and the heat sink. Hence the temperature of heat sink and case are considered different. From the property of series circuit we can write,

$$\theta_{JA} = \theta_{JC} + \theta_{CS} + \theta_{SA} \ ^\circ C/W \qquad \dots (3.101)$$

Applying the Kirchhoff's law we get,

$$T_J = T_A + \theta_{JA} P_d \ ^\circ C \qquad \dots (3.102)$$

The equation is similar to the equation (3.99). the P_d is the collector power dissipation i.e. the power dissipated at the collector junction. The equation shows that the junction temperature floats on the ambient temperature and higher the value of the ambient temperature lower is the value of allowable power dissipation.