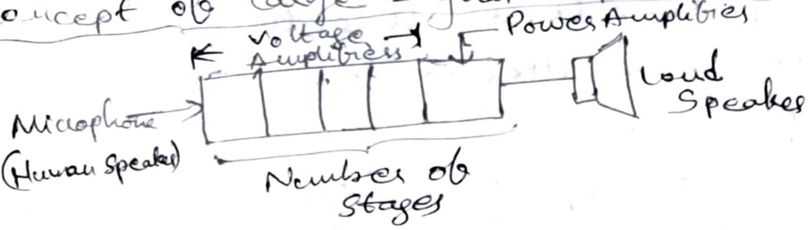
Unit - IV

Large Signal Amplifiers

Concept of large signal Amplification



← Amplifying or Public Address (PA) system

→ This system consists of many stages connected in cascade so it is a multistage amplifier.

→ The i/p is sound signal of a human speaker & the o/p is given to the loudspeaker.

→ The i/p & the intermediate stages are small signal amplifiers and they provide sufficient voltage gain. Hence these stages are called voltage amplifiers.

→ But the last stage gives an o/p to the load like loud speaker which 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.

→ Such a stage, which develops & 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 servomotors in industrial control systems, tape players, T.V. receivers, CRTs etc.

Features of Power Amplifiers

→ A power amplifier is the last stage of multistage amplifier. The previous stages develop sufficient gain & the i/p signal level or amplitude of a power amplifier is large of the order of few volts.

→ The o/p of power amplifier has large current & voltage swings. As it handles large signals, it is called power amplifier.

→ The h-parameter analysis is applicable to small signal amplifiers & hence cannot be used for analysis of power amplifiers.

↳ The analysis of power amplifiers is carried out graphically.

by drawing a load line on the o/p characteristics of the transistors used in it

→ The power amplifiers must have low o/p impedance to feed the low impedance loads like loudspeakers. Hence common collector or emitter follower ckt is very common in power amplifiers.

↳ The CE ckt with a step down transformer for impedance matching is also commonly used in power amplifiers.

→ The power amplifiers develop an a.c. power of order of few watts & large power gets dissipated in the form of heat, at the junctions of the transistors used in power amplifiers. Hence the transistors used in the power amplifiers are large in size, having large power dissipation rating, called power transistors.

↳ Such transistors have heat sinks. A heat sink is a metal cap having ~~bigger~~ 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.

→ Due to non linear nature of the transistor, there exists a harmonic distortion in the signal. Hence the analysis of signal distortion in case of power amplifiers is important.

→ The power amplifiers are used in public address systems & many audio ckts to supply large power to the loud speakers. Hence the power amplifiers are also called audio amplifiers or audio frequency (A.F.) power amplifiers.

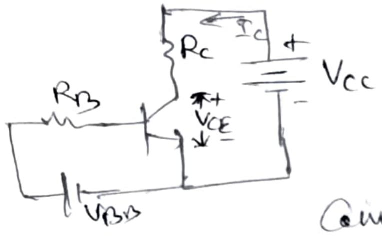
Classification of Large Signal Amplifiers

→ For an amplifier, a quiescent operating point (Q point) is fixed by selecting the proper d.c. biasing to the transistors used.

→ The position of the Q point on the load line decides the class of operation of the power amplifier.

→ Various classes of the power amplifiers are:

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



$-V_{CC} + I_C R_C + V_{CE} = 0 \Rightarrow V_{CC} = I_C R_C + V_{CE}$

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

Comparing with $y = mx + c$ (Straight line equation)

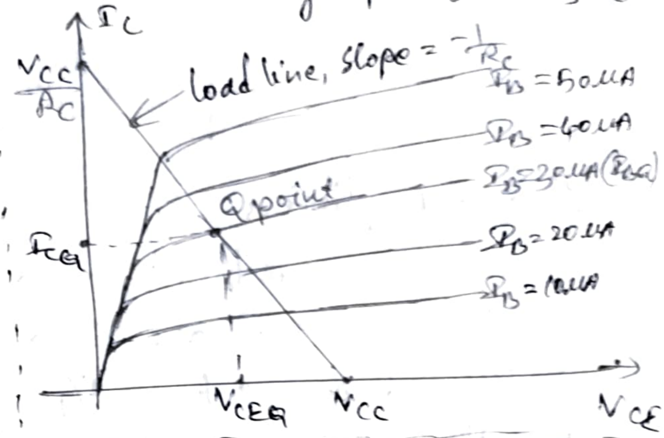
→ The slope of this straight line is $-\frac{1}{R_C}$ & its y-intercept is $\frac{V_{CC}}{R_C}$

→ So we can draw a straight line on the graph of I_C vs V_{CE} i.e. o/p characteristics

→ When $V_{CE} = V_{CC}$, $I_C = 0$

→ When $V_{CE} = 0$, $I_C = \frac{V_{CC}}{R_C}$

→ These 2 points can be located to draw a straight line on the o/p characteristics.



→ Such a line having slope as the reciprocal of the load resistance drawn on the o/p characteristics is called a d.c. load line.

→ The intersection of the o/p characteristic curve & a load line is the operating point. This point is fixed for a transistor called quiescent point or Q point. The corresponding value of base current is denoted as I_{BQ}

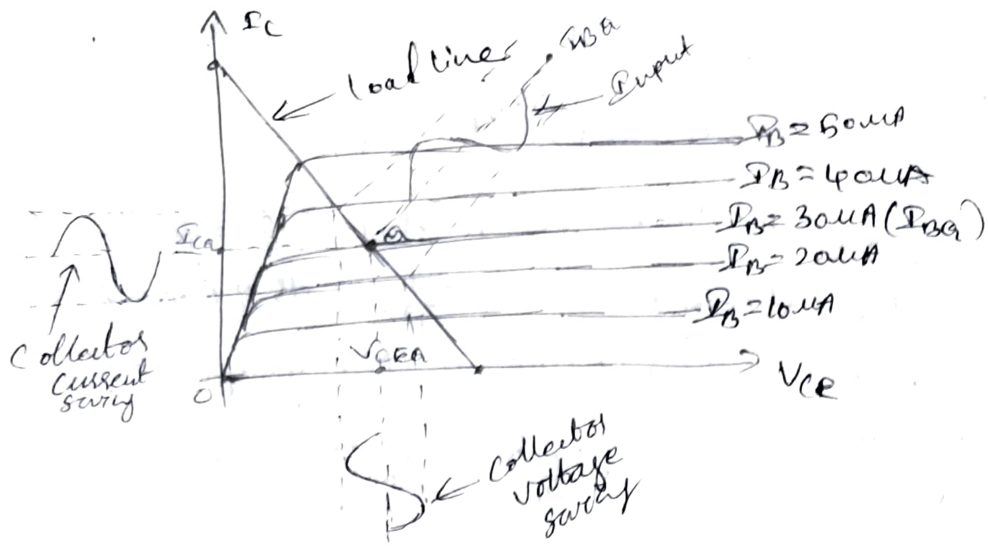
→ The values of collector current & the collector to emitter voltage, corresponding to the Q point are I_{CQ} & V_{CEQ} respectively

→ On this d.c. operating point, if an a.c. signal is superimposed by the application of a.c. sinusoidal voltage at the i/p, the base current varies sinusoidally about its quiescent value I_{BQ}

→ Since the transistor is biased to operate in active region the o/p is linearly proportional to the i/p.

→ The o/p i.e. collector current is β times larger than the i/p base current in the common emitter configuration. Hence ~~Hence~~ the collector current also varies sinusoidally about its quiescent value I_{CQ}.

→ The o/p voltage also varies sinusoidally about its quiescent value V_{CEQ}



Class A Amplifiers

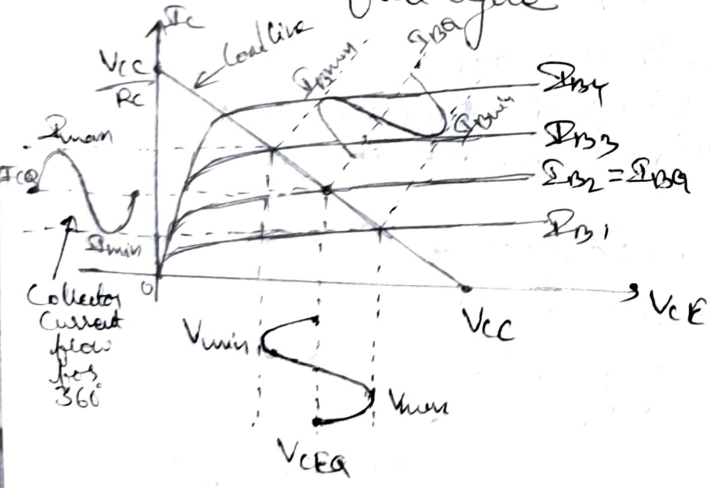
→ The power amplifier is said to be class A amplifier if the Q-point & the i/p signal are selected such that the o/p signal is obtained for a full i/p cycle.

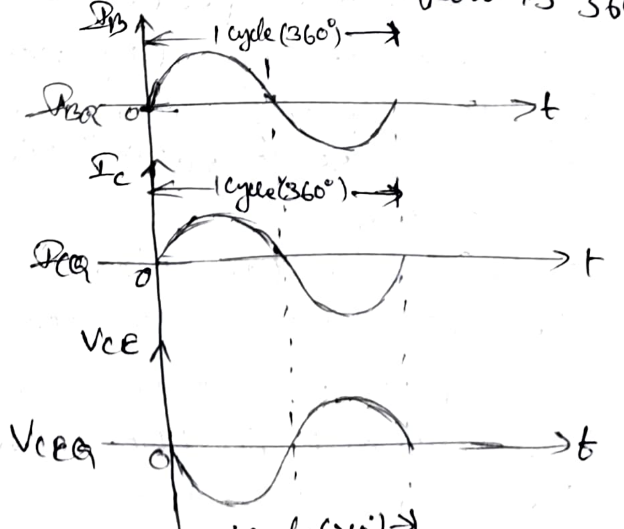
→ For this class, position of the Q point is approx.ly at the midpoint of the load line.

→ For all values of i/p signal, the transistor remains in the active region & never enters into cut-off or saturation region.

→ The collector current flows for 360°, (full cycle) of the i/p signal.

→ In other words, the angle of collector current flow is 360° i.e. one full cycle



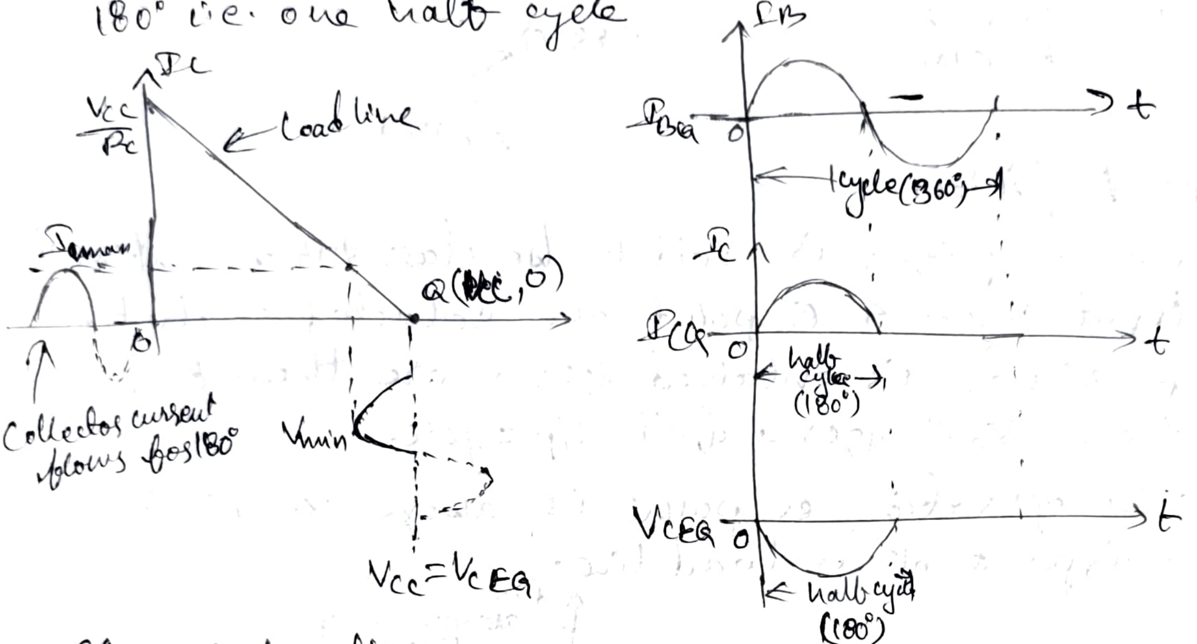


Class B Amplifiers

→ The power amplifier is said to be class B if the Q point & the i/p signal are selected, such that the o/p signal is obtained only for one half cycle for a full i/p cycle.

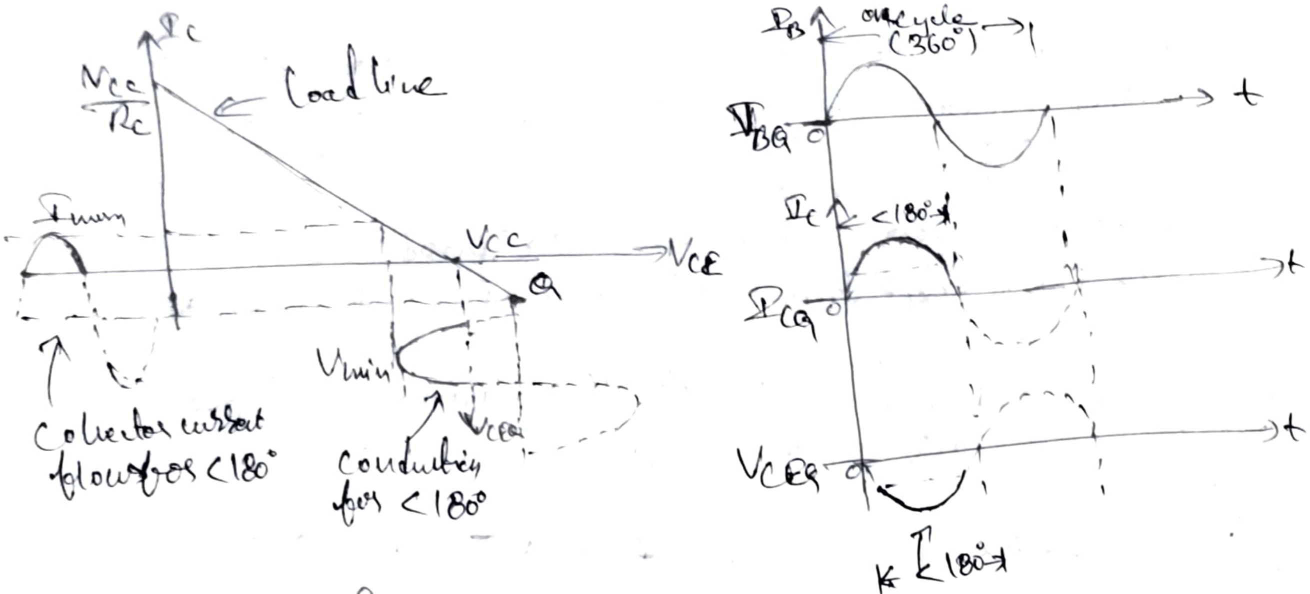
→ For this operation, the Q-point is shifted on x-axis i.e. transistor is biased in cut-off.

→ Due to the selection of Q-point on the X-axis, transistor remains in the active region only for +ve half cycle of the i/p signal.
→ Hence this half cycle is reproduced at the o/p.
But in -ve half cycle of the i/p signal, transistor enters into cut-off region & no signal is produced at the o/p.
→ The collector current flows only for 180° (half cycle) of the o/p signal.
→ In other words, the angle of the collector current flow is 180° i.e. one half cycle



Class C Amplifiers

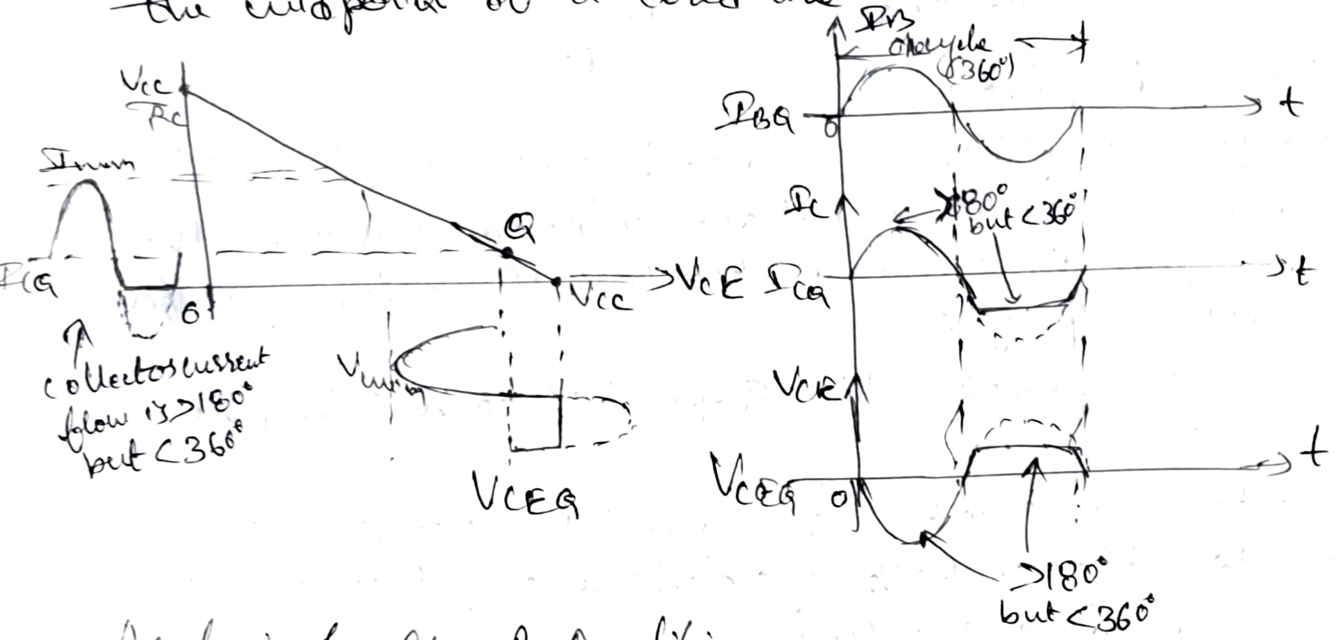
→ The power amplifier is said to be class C amplifier, if the Q point & the i/p signal are selected such that the o/p signal is obtained for less than a half cycle, for a full i/p cycle
→ For this operation, the Q-point is to be shifted below X-axis
→ Due to such selection of Q point, transistor remains active for less than a half cycle. Hence only that part is reproduced at the o/p.
→ For remaining cycle of the i/p cycle, transistor remains in cut-off & no signal is produced at the o/p.
→ The angle of collector current flow is less than 180°.



Class AB Amplifiers

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

→ For this operation, Q point is above x-axis but below the midpoint of a load line.



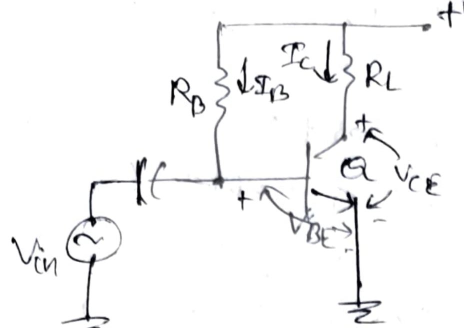
Analysis of Class A Amplifiers

→ Class A amplifiers are further classified as directly coupled & transformer coupled amplifiers.

→ In directly coupled type, the load is directly connected in the collector ckt.

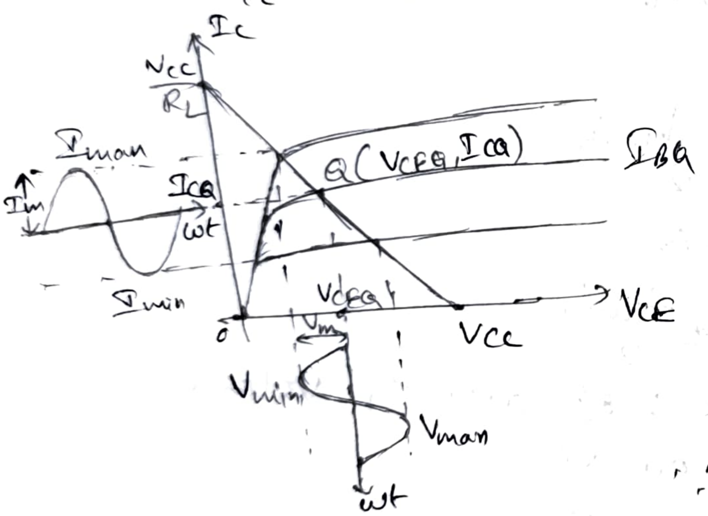
→ In transformer coupled type, the load is coupled to the collector using a transformer called an o/p transformer

Series Fed, Directly Coupled Class A Amplifier



- → A simple fixed bias ckt can be used as Class A amplifier
- → The difference b/w small signal version of this ckt is that the signals handled by this large signal ckt are of order of few volts
- → And the transistor used is power transistor
- → The value of R_B is selected in such a way that Q point lies at the centre of the d.c. load line.
- → This ckt represents the directly coupled class A power amplifier as the load resistance R_L is directly connected in collector ckt of power transistor.
- → Most of the times the load is a loud speaker, the impedance of which varies from 4Ω to 16Ω
- → The beta of the transistor used is less than 100.

$$-V_{CC} + I_C R_L + V_{CE} = 0 \Rightarrow I_C = \left(\frac{-1}{R_L}\right) V_{CE} + \frac{V_{CC}}{R_L}$$



D.C. Operation

- → The collector supply voltage V_{CC} & resistance R_B decides the d.c. base-bias current I_{BQ}.

$$I_{BQ} = \frac{V_{CC} - V_{BE}}{R_B}$$

$$\because V_{BE} = 0.7V, \quad I_{BQ} = \frac{V_{CC} - 0.7}{R_B}$$

- → The corresponding collector current is $I_{CQ} = \beta I_{BQ}$
- → The corresponding collector to emitter voltage is

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

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

D.C. Power Input

- → The d.c. power i/p is provided by supply.
- → With no a.c. i/p signal, the d.c. current drawn is the collector bias current I_{CQ}
- → Hence the d.c. power i/p is $\boxed{P_{dc} = V_{CC} \, I_{CQ}}$

A.C. Operation

→ When an i/p a.c. signal is applied, the base current varies sinusoidally.

→ Assuming that the non-linear distortion is absent, the ~~nature of the~~ collector current & collector to emitter voltage also varies sinusoidally.

→ The varying o/p voltage & o/p current delivers an a.c. power to the load.

A.C. Power Output

V_m = Amplitude (peak) of a.c. o/p voltage

V_{max} = Maxi. instantaneous value of the collector (o/p) voltage

V_{min} = Mini. instantaneous value of the collector (o/p) voltage

V_{pp} = Peak to peak value of a.c. o/p voltage across the load

I_{max} = Maxi. instantaneous value of the collector (o/p) current

I_{min} = Mini. instantaneous value of the collector (o/p) current

I_{pp} = Peak to peak value of a.c. o/p (load) current

I_m = Amplitude (peak) of a.c. o/p (load) current

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

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

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

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

→ Hence the r.m.s values of a.c. o/p voltage & current can be obtained as

$$V_{rms} = \frac{V_m}{\sqrt{2}} \; ; \quad I_{rms} = \frac{I_m}{\sqrt{2}}$$

$$V_{rms} = I_{rms} R_L$$

$$\Rightarrow V_m = I_m R_L$$

→ The a.c. power delivered by the amplifier to the load can be expressed by using r.m.s values, peak values & peak-to-peak values of o/p voltage & current

$$\therefore P_{ac} = V_{rms} I_{rms} = I_{rms}^2 R_L = V_{rms}^2 / R_L \quad \text{using r.m.s values}$$

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

$$\Rightarrow P_{ac} = \frac{V_m I_m}{2} = \frac{I_m^2 R_L}{2} = \frac{V_m^2}{2R_L}$$ using peak values

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

$$\Rightarrow P_{ac} = \frac{V_{pp} I_{pp}}{8} = \frac{I_{pp}^2 R_L}{8} = \frac{V_{pp}^2}{8R_L}$$ using peak to peak values

→ But $V_{pp} = V_{max} - V_{min}$ & $I_{pp} = I_{max} - I_{min}$, the a.c. power can be expressed as

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

Efficiency

→ The efficiency of an amplifier represents the amount of a.c. power delivered or transferred to the load, from the d.c. source.

→ The generalized expression for efficiency of an amplifier is

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

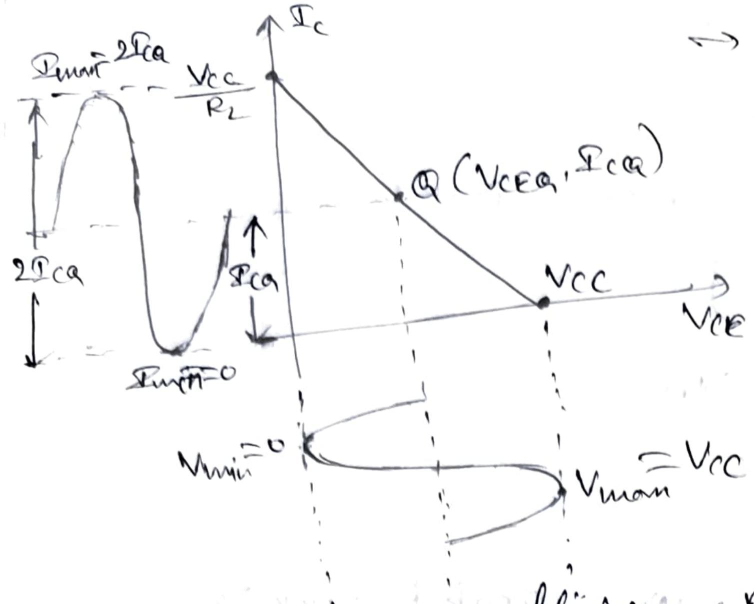
→ For class A operation

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

→ Efficiency is also called conversion efficiency of an amplifier.

Maximum Efficiency

→ For maximum efficiency calculation, assume the maximum swings of both the o/p voltage & the o/p current.



→ $V_{max} = V_{CC}$ & $V_{min} = 0$
$I_{max} = 2I_{CQ}$ & $I_{min} = 0$ } for maxi swing

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

$$= \frac{2 V_{CC} I_{CQ}}{8 V_{CC} I_{CQ}} \times 100$$

$$= 25\%.$$

→ Thus, the maxi efficiency possible in case of directly coupled series fed class A amplifier is just 25%.

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

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 b/w the d.c power i/p, P_{dc} & the a.c power delivered to the load, P_{ac}

P_d = Power dissipation

$$\boxed{P_d = P_{dc} - P_{ac}}$$

→ When a.c. i/p is zero, the a.c. power o/p must be zero. But transistor operates at quiescent condition, drawing d.c. i/p power from the supply equal to $V_{CC} I_{CQ}$

→ This entire power gets dissipated in the form of heat. Thus d.c. power i/p without a.c. i/p signal is the maxi. power dissipation.

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

→ The value of maxi power dissipation decides the maxi. power dissipation rating of the transistor to be selected for the amplifier.

Advantages

→ The ckt is simple to design & implement

→ The load is connected directly in the collector ckt, hence ~~the o/p transformer~~ is not necessary. This makes the ckt cheaper.

→ Less no. of components required as load is directly coupled

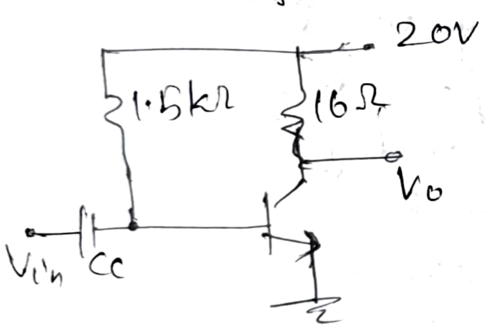
Disadvantages

→ The load resistance is directly connected in collector ckt & carries the quiescent collector current which causes considerable wastage of power.

→ Power dissipation is more. Hence power dissipation arrangements like heat sink are essential.

→ The ~~o/p impedance is high hence~~ efficiency is very poor due to large power dissipation.

Q. A series fed class A amplifier operates from d.c. source & applied sinusoidal i/p signal generates peak base current 9 mA. Calculate: i) Quiescent current I_{CQ}



ii) Quiescent voltage V_{CEQ}
iii) D.C. i/p power P_{dc}
iv) A.C. o/p power P_{ac}
v) Efficiency

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

$$I_{BQ} = \frac{V_{CC} - V_{BE}}{R_B} = 12.87 mA$$

i) $I_{CQ} = \beta I_{BQ} = 643.50 mA$

ii) $V_{CEQ} = V_{CC} - I_{CQ} R_L = 9.70 V$

iii) $P_{dc} = V_{CC} * I_{CQ} = 12.87 W$

iv) $I_c = \beta I_b = 450 mA$ (peak)

$$I_{C(rms)} = \frac{I_{C(peak)}}{\sqrt{2}} = 318.19 mA = I_{rms}$$

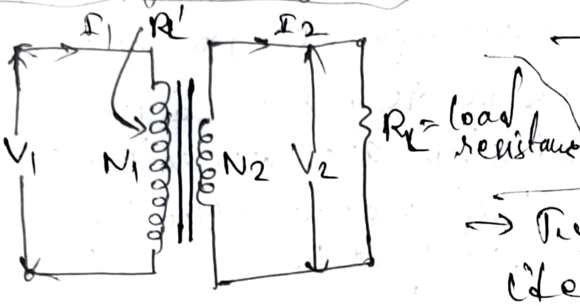
$$P_{ac} = I_{rms}^2 R_L = 1.619 W$$

v) $$\% \eta = \frac{P_{ac}}{P_{dc}} \times 100 = 12.58\%$$

Transformer Coupled Class A Amplifier

→ The o/p 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 o/p transformer & the amplifier is called transformer coupled class A amplifier.

Properties of Transformer



→ Consider a transformer which is connected to a load of resistance R_L
→ Transformer is assumed to be ideal for analysis purpose & there are no losses in the transformer.
→ The winding resistances are assumed to be zero

N_1 = No: of turns in primary winding
N_2 = No: of turns in secondary winding
V_1 = Voltage applied to primary winding
V_2 = Voltage on secondary winding
I_1 = primary winding current
I_2 = secondary winding current

Turns ratio: The ratio of no: of turns on secondary winding to the no: of turns on primary winding is called turns ratio of the transformer denoted by n.

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

→ Sometimes it is specified as $\frac{N_2}{N_1} : 1$ or $1 : \frac{N_1}{N_2}$

Voltage transformation:- The transformer transforms the voltage applied on one side to the other side proportional to the turns ratio.

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

→ In the amplifier analysis, the load impedance should be small. So no: of turns on primary winding must be more than the turns on secondary winding & turns ratio is less than unity. (step down transformer)

<u>Current transformation</u>:- The current in the secondary winding to the current in the primary winding is inversely proportional to the no: of turns of the windings. $\frac{I_2}{I_1} = \frac{N_1}{N_2} = \frac{1}{n}$

<u>Impedance transformation</u>:- As current & voltage get transformed from primary to secondary, an impedance seen from either side (primary or secondary) also changes.

→ The impedance of the load on secondary is R_L

→ The primary & secondary winding resistances are assumed to be zero. So the load impedance R_L, gets reflected on the primary side & behaves as if connected in the primary side

→ Such impedance transferred from secondary to primary is denoted by R_L' called reflected impedance

$$R_L = \frac{V_2}{I_2} \quad \& \quad R_L' = \frac{V_1}{I_1}$$

$$V_1 = \frac{N_1}{N_2} V_2 \quad \& \quad I_1 = \frac{N_2}{N_1} I_2$$

$$R_L' = \frac{\frac{N_1}{N_2} V_2}{\frac{N_2}{N_1} I_2} = \left(\frac{N_1}{N_2}\right)^2 \cdot \frac{V_2}{I_2}$$

$$\Rightarrow R_L' = \left(\frac{N_1}{N_2}\right)^2 R_L \qquad \Rightarrow R_L' = \frac{R_L}{n^2}$$

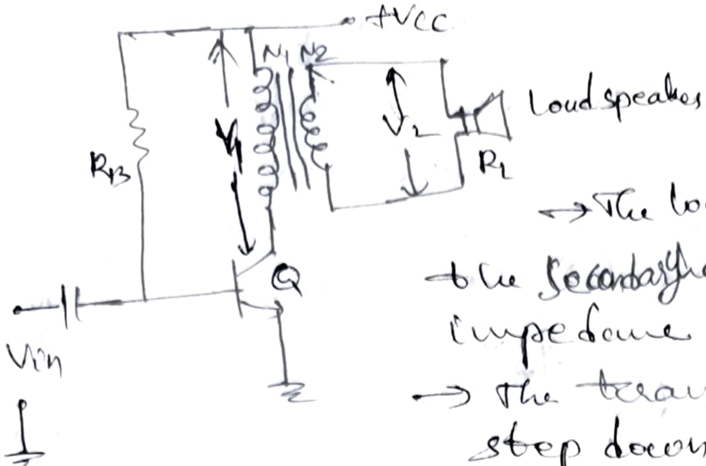
→ R_L' is always higher than R_L for a step down transformer

Q The load of 4Ω is connected to the secondary of a transformer having primary turns of 200 & the secondary turns of 20. Calculate the reflected load impedance on primary.

$$R_L = 4\Omega, \quad N_1 = 200, \quad N_2 = 20$$

$$n = \frac{N_2}{N_1} = \frac{20}{200} = 0.1$$

$$\therefore R_L' = \frac{4}{(0.1)^2} = \frac{R_L}{n^2} = 400\Omega$$



→ The loud speaker connected to the secondary acts a load having impedance of R_L Ω

→ The transformer used is a step down transformer with the turns ratio as $n = \frac{N_2}{N_1}$

D.C. Operation

~~For d.c., the winding resistance of windi~~

→ It is assumed that the winding resistances are 0 Ωs

→ Hence for d.c., the resistance is 0 Ω & there is no ~~dc~~ voltage drop across the primary winding of ~~the transformer~~.

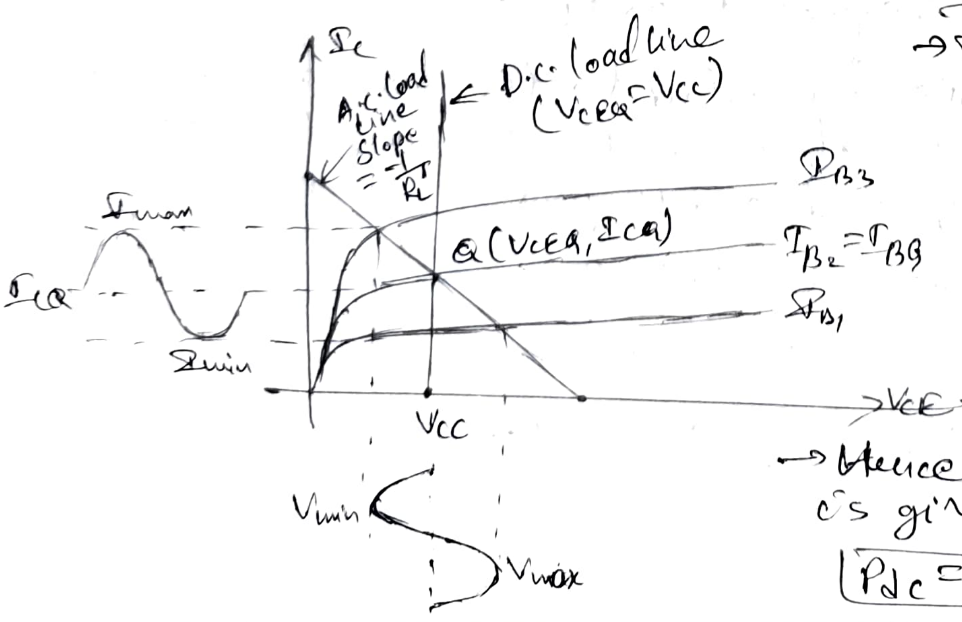
$$-V_{CC} + V_{CE} = 0 \Rightarrow V_{CC} = V_{CE}$$

→ The slope of the d.c. load line is reciprocal of the d.c. resistance in the collector ckt, which is zero in this case. Hence slope of the d.c. load line is ideally infinite.

→ So the d.c. load line in the ideal connection is a vertically straight line.

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

$$V_{CEQ} = V_{CC}$$



D.C. Power Input

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

→ Hence the d.c. power i/p is given by

$$P_{dc} = V_{CC} I_{CQ}$$

A.C. Operation

→ For the a.c. analysis, it is necessary to draw an a.c. load line on the o/p characteristics.

→ If the load on the secondary is the load impedance R_L Ω then the reflected load on the primary is R_L'

→ The load line drawn with a slope of $\left(\frac{-1}{R_L'}\right)$ & passing through the operating point (Q point) is called a.c. load line.

→ The o/p current i.e. collector current varies around its quiescent value I_{CQ}, when a.c. i/p signal is applied to the amplifier.

→ The corresponding o/p voltage also varies sinusoidally around its quiescent value V_{CEQ} which is V_{CC} in this case

A.C. Output Power

→ 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

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

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

$$= \frac{V_{1rms}^2}{R_L'}$$

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

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

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

→ Let V_{2m} = Peak value of secondary or load voltage

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

I_{2m} = Peak value of secondary or load current

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

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

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

→ The slope of the a.c. load line can be expressed in terms of primary current & primary voltage.

→ The slope of the a.c. load line is $= \frac{1}{R_L'} = \frac{I_{1m}}{V_{1m}}$

→ The generalized expression for a.c. power output is

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

→ The a.c. power calculated is the power developed across the primary winding of the o/p transformer.

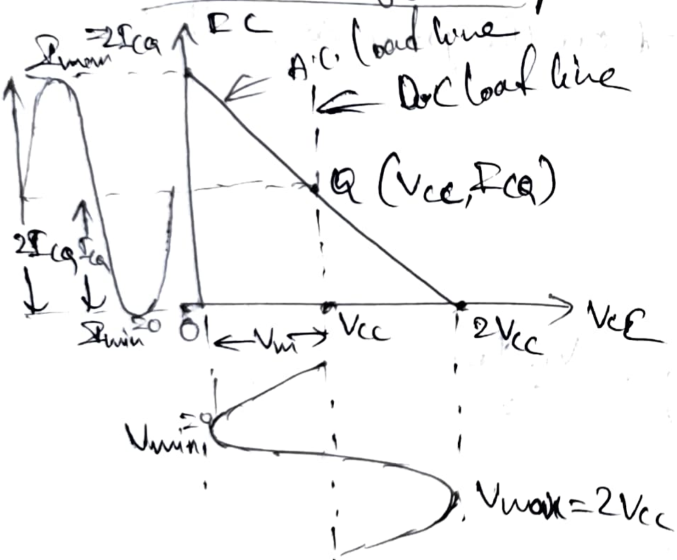
→ Assuming ideal transformer, the power delivered to the load on secondary, is same as that developed across the primary.

Efficiency

→ The general expression for efficiency is

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

Maximum Efficiency



→ Assume max. swings of both the o/p voltage & o/p current, to calculate max. efficiency.

→ Assuming that the Q point is exactly at the centre of the load line, for max. swing

$V_{min} = 0$ & $V_{max} = 2V_{CC}$ } for max. swing
$I_{min} = 0$ & $I_{max} = 2I_{CQ}$ }

$$\%\eta_{max} = \frac{(2V_{CC} - 0)(2I_{CQ} - 0)}{8 V_{CC} I_{CQ}} \times 100 = \frac{4 V_{CC} I_{CQ}}{8 V_{CC} I_{CQ}} \times 100$$

$$= 50\%$$

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

→ For practical ckt it is about 30 to 35%, which is much more than the directly coupled amplifier.

→ For max. efficiency, the power o/p is also max. For such max. o/p power, condition is $V_{min} = 0$ & $V_{max} = 2V_{CC}$

V_{1m} = Peak value of primary voltage

$$= \frac{V_{max} - V_{min}}{2} = V_{CC}$$

$\therefore V_{1m} = V_{CC}$ for max. o/p power

→ Similarly peak value of o/p current is equal to biasing collector current for max. o/p current swing.

$\therefore I_{1m} = I_{CQ}$ for max. o/p power

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

$$\therefore (P_{ac})_{max} = \frac{2V_{CC} \times 2I_{CQ}}{8} = \frac{4V_{CC}I_{CQ}}{8}$$

$$= \frac{1}{2} V_{CC} \cdot \frac{V_{CC}}{R_L'} = \frac{1}{2}\frac{V_{CC}^2}{R_L'} \quad \left(\because I_{CQ} = \frac{V_{CC}}{R_L'}\right)$$

Power Dissipation

→ The power dissipation by the transistor is the difference between the a.c. power o/p & the d.c. power i/p

$$\therefore P_d = P_{dc} - P_{ac}$$

→ The power dissipated by the transformer is very small due to negligible (d.c.) winding resistances & can be neglected.

→ When there is no i/p signal, the entire d.c. i/p power gets dissipated in the form of heat, which is the max. power dissipation

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

→ Class A amplifier dissipates less power when delivers max. power to the load. While it dissipates max. power while delivering zero power to the load.

→ Max. power dissipation decides the max. power dissipation rating for the power transistor to be selected for an amplifier.

Advantages

→ The efficiency of the operation is higher than directly coupled amplifier.

→ The d.c. bias current that flows through the load in case of directly coupled amplifier is stopped in case of transformer coupled

→ The impedance matching required for a max. power transfer is possible.

Disadvantages

→ Due to the transformer, the ckt becomes bulkier, heavier & costlier compared to directly coupled ckt.

→ The ckt is complicated to design & implement compared to directly coupled ckt.

→ The freq. response of the ckt is poor.

Q) The load speaker of 8Ω is connected to the secondary of the o/p ~~transformer~~ of a class A amplifier ckt. The quiscent collector current is 140mA. The turns ratio of the transformer is 3:1. The collector supply voltage is 10V. If a.c. power delivered to the loudspeaker is 0.48W, 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) DC power i/p
7) Efficiency
8) Power Dissipation.

$R_L = 8\Omega$, $I_{CQ} = 140\,mA$, $V_{CC} = 10V$, $P_{ac} = 0.48W$

$N_1 : N_2 = 3:1 \Rightarrow \frac{N_1}{N_2} = 3$ 2) $n = \frac{N_2}{N_1} = \frac{1}{3} = 0.333$

$R_L' = \frac{R_L}{n^2} = \frac{8}{(0.33)^2} = 72\Omega$

→ As the transformer is ideal, the power delivered to the load is same as the power developed across primary

1) P_{ac} (across primary) $= 0.48W$

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

$0.48 = \frac{V_{1rms}^2}{R_L'} \Rightarrow V_{1rms}^2 = 34.56$

$\Rightarrow V_{1rms} = 5.8787$ on primary

$\frac{V_{2rms}}{V_{1rms}} = \frac{N_2}{N_1} = n = 0.333$

$\Rightarrow V_{2rms} = V_{1rms} \times 0.333 = 1.9595\,V$

3) $V_{1rms} = 5.8787\,V$

4) $P_{ac} = 0.48 = I_{2rms}^2 R_L$

$\Rightarrow I_{2rms}^2 = \frac{0.48}{R_L} = 0.06$

$\Rightarrow I_{2rms} = 0.2449\,A$

5) $\frac{I_{2rms}}{I_{1rms}} = \frac{N_1}{N_2} = \frac{1}{n} = 3 \Rightarrow I_{1rms} = I_{2rms} \times n = 81.64mA$

6) $P_{dc} = V_{CC} I_{CQ} = 1.4W$

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

8) $P_d = P_{dc} - P_{ac} = 0.92W$

Distortion in Amplifiers (amplitude, freq., phase)

→ The i/p signal applied to the amplifiers is alternating in nature

→ The amplifier o/p should be reproduced faithfully, i.e., there should not be the change or distortion in amplitude, freq. & phase of the signal.

→ Hence the possible distortions in any amplifier are amplitude distortion, phase distortion & freq. distortion.

→ But the phase distortions are not detectable by human ears are insensitive to the phase changes. While the change in gain of the amplifier w.r.t. the freq. is called freq. distortion.

→ It is assumed that the transistor is perfectly linear device. That is the dynamic characteristic of a transistor is a straight line over the operating range [$i_c = K i_b$]

→ But in practical ckts, the dynamic characteristics are not perfectly linear. Due to such nonlinearity in the dynamic characteristic, the waveform of the o/p voltage differs from that of the i/p signal.

→ Such a distortion is called nonlinear distortion or amplitude distortion or harmonic distortion.

Harmonic Distortion

→ The harmonic distortion means the presence of the freq. components in the o/p waveform, which are not present in the i/p signal.

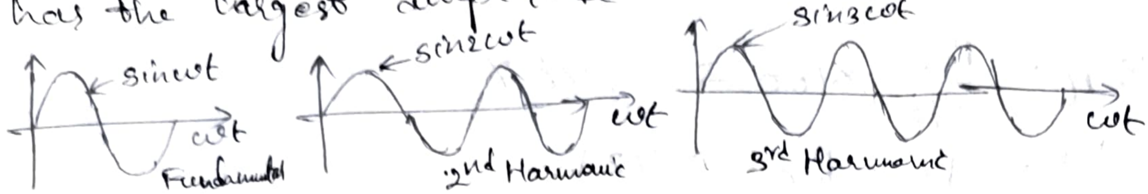
→ The component with freq. same as the i/p signal is called fundamental freq. component.

→ The additional freq. components present in the o/p signal are having freq. components which are integer multiples of fundamental freq. component. These components are called harmonic components or harmonics.

→ For example, if the component at f Hz & additional freq. components at 2f Hz, 3f Hz, 4f Hz & so on.

→ The 2f component is called second harmonic, the 3f component is called third harmonic & so on.

→ Out of all the harmonic components, the second harmonic has the largest amplitude.



Distorted waveform

→ The distorted waveform can be obtained by adding the fundamental & harmonic components

→ The percentage harmonic distortion due to each order (2^{nd}, 3^{rd} & so on) can be calculated by comparing amplitude of each harmonic with the amplitude of the fundamental freq. component

→ If the fundamental freq. component has an amplitude of B_1 & 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

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

→ So $\% D_2 = \frac{|B_2|}{|B_1|} \times 100$, $\% D_3 = \frac{|B_3|}{|B_1|} \times 100$

Total Harmonic Distortion

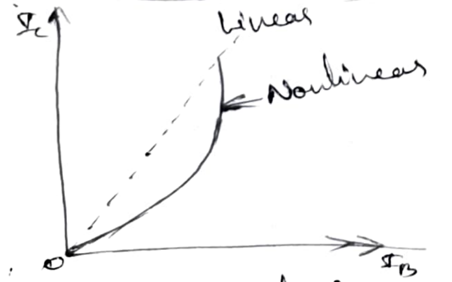
→ The o/p signal gets distorted due to various harmonic distortion components

→ The total harmonic distortion is the effective distortion due to all the individual components is given by

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

where D = total harmonic distortion.

Second Harmonic Distortion (Three Point Method)



→ To find the second harmonic distortion, assume that the dynamic transfer characteristics of the transistor is parabolic (nonlinear) in nature rather than a straight line (linear)

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

Power Output due to Distortion

$P_{ac} = \frac{1}{2} B_1^2 R_L$

→ Hence the power o/p with harmonic distortion is

$(P_{ac})_D = \frac{1}{2} B_1^2 R_L + \frac{1}{2} B_2^2 R_L + \frac{1}{2} B_3^2 R_L + \cdots \frac{1}{2} B_n^2 R_L$

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

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

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

D = total harmonic distortion

→ If the total harmonic distortion is 15% i.e. $D = 0.15$

then $(P_{ac})_D = P_{ac}\left[1 + (0.15)^2\right] = 1.0225\, P_{ac}$

→ So there is 2.25% increase in the power given to the load.

Q) A transistor supplies 0.85 W to a 4kΩ load. The zero signal D.C. collector current is 31 mA & the D.C. collector current with signal is 34 mA. Determine the second harmonic distortion.

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

The current without signal is $I_{CQ} = 31\,mA$

The current with signal is $I_{CQ} + B_0 = 34\,mA$

$\Rightarrow B_0 = 34 - 31 = 3\,mA$

But $B_2 = B_0 = 3\,mA$

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

$(P_{ac})_D = \frac{1}{2} B_1^2 R_L + \frac{1}{2} B_2^2 R_L$

$\Rightarrow 0.85 = \frac{1}{2} B_1^2 \times 4 \times 10^3 + \frac{1}{2}(3 \times 10^{-3})^2 \times 4 \times 10^3$

$\Rightarrow B_1 = 20.396\,mA$

$\therefore D_2 = \frac{|B_2|}{|B_1|} \times 100 = 14.708\%$

Analysis of Class B Amplifiers

- ~~Due to~~ The collector current flows only for a half cycle for a full cycle of the i/p signal. Hence the o/p signal is distorted.
→ To get a full cycle across the load, a pair of transistors is used in class B operation.
→ The 2 transistors conduct in alternate half cycles of the i/p signal & a full cycle across the load is obtained.

→ The 2 transistors are identical in characteristics & called matched transistors.

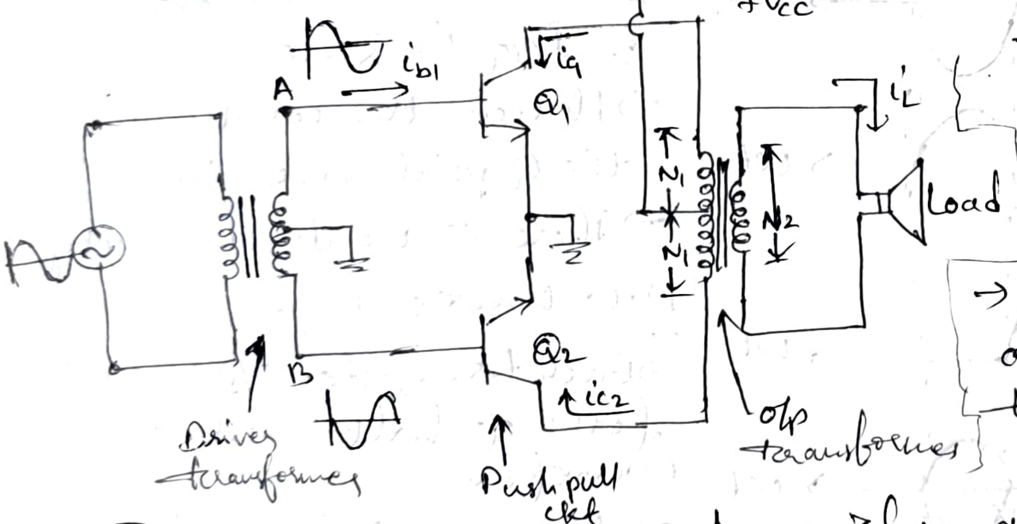
→ Depending upon the types of the 2 transistors whether p-n-p or n-p-n, the 2 ckt configurations of class B amplifier are possible. These are

↳ When both the transistors are of same type, i.e either n-p-n or p-n-p then the ckt is called push pull class B A.F power amplifier ckt

↳ When the 2 transistors form a complementary pair i.e one n-p-n & other p-n-p then the ckt is called complementary symmetry class B A.F. power amplifier ckt.

Push Pull Class B Amplifier

→ The push pull ckt requires 2 transformers, one as i/p transformer called driver transformer & the other to connect the load called o/p transformer



→ The i/p signal is applied to the primary of the driver transformer.

→ Both the transformers are centre tapped transformers.

→ In the ckt, both Q_1 & Q_2 transistors are of n-p-n type.

→ The ckt can use both Q_1 & Q_2 of p-n-p type. In such a case, the only change is that supply voltage must be $-V_{CC}$, the basic ckt remains same.

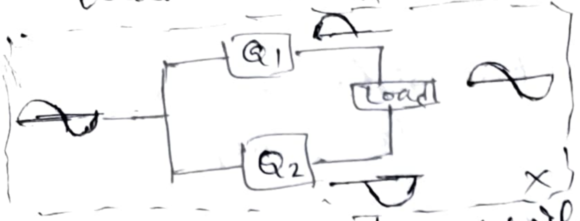
→ Both transistors are in common emitter configuration.

→ With respect to the centre tap, for a +ve half cycle of i/p signal, the point A on the secondary of driver transformer will be +ve.

→ While the point B will be -ve

→ Thus the voltages in the 2 halves of the secondary of the driver transformer will be equal but with opposite polarity.

→ Hence the i/p signals applied to the base of the transistors Q_1 & Q_2 will be 180° out of phase.

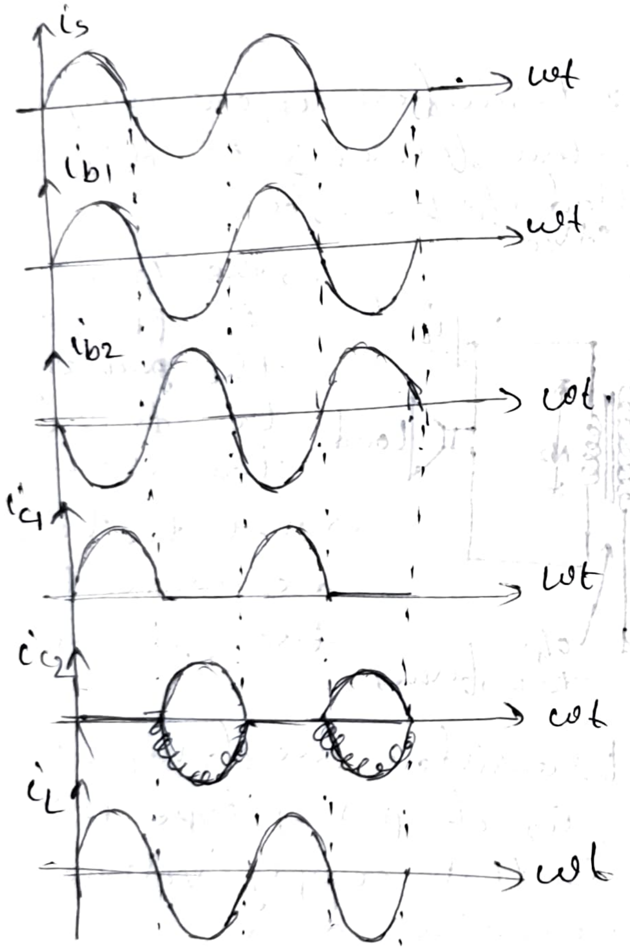


→ The transistor Q_1 conducts for the +ve half cycle of the i/p producing +ve half cycle across the load

→ While the transistor Q_2 conducts for the -ve half cycle of the i/p producing -ve half cycle across the load.

→ Thus across the load, we get a full cycle for a full i/p cycle.

→ The waveforms of the i/p current, base currents, collector currents & the load current are as follows



D.C. Operation

→ The d.c. biasing point i.e Q point is adjusted on the x-axis such that $V_{CEQ} = V_{CC}$ & I_{CQ} is zero.

→ Hence the coordinates of the Q point are $(V_{CC}, 0)$

→ There is no d.c. bias voltage

D.C. Power Input

→ Each transistor o/p is in the form of half rectified waveform

→ Hence if I_m is the peak value of o/p current of each transistor, the d.c. or average value is $\frac{I_m}{\pi}$, due to half rectified waveform

→ The 2 currents, drawn by the 2 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.

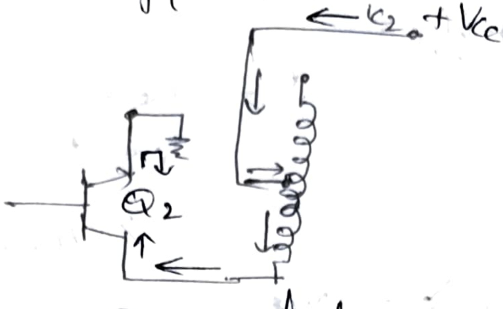
$$I_{dc} = \frac{I_m}{\pi} + \frac{I_m}{\pi} = \frac{2I_m}{\pi}$$

→ The total d.c. power i/p is given by $P_{dc} = V_{CC} \times I_{dc}$

$$\therefore \quad P_{dc} = \frac{2 I_m}{\pi} \times V_{CC}$$

A.C. Operation

Q_1 conduction

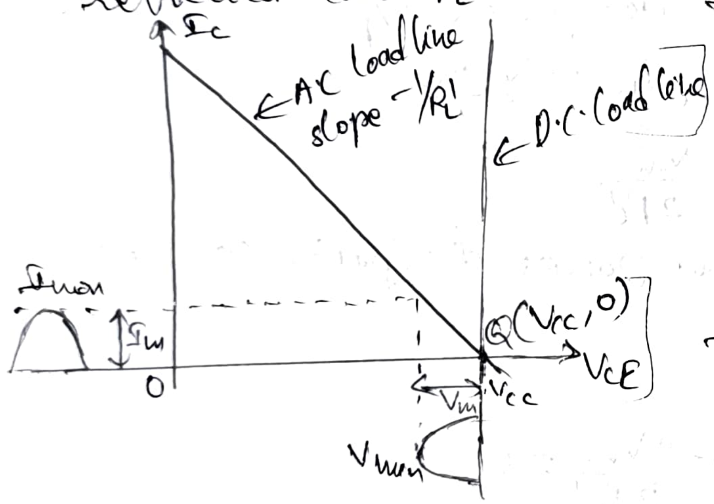


Q_2 conduction

→ The reflected load on the primary can be written as $R_L' = \frac{R_L}{n^2}$ 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'



→ 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 slope of the a.c. load line (magnitude of slope) can be represented in terms of V_m & I_m as

$$\frac{1}{R_L'} = \frac{I_m}{V_m} \Rightarrow R_L' = \frac{V_m}{I_m}$$

A.C. Power Output

→ The a.c. power o/p is

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

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

Efficiency

→ Efficiency of class B amplifier can be calculated using the basic equation.

$$(P_d)_{max} = \frac{2V_{cc}^2}{\pi^2 R_L'} = \frac{4}{\pi^2}\left(\frac{V_{cc}^2}{2R_L'}\right)$$

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

→ This maxi. power dissipation is due to both the transistors hence the maxi. power dissipation per transistor is $(P_d)_{max}/2$

$$\therefore (P_d)_{max} \text{ per transistor} = (P_d)_{max}/2$$

$$= \frac{2}{\pi^2}(P_{ac})_{max}$$

→ This is maxm. power dissipation rating of each transistor.

Harmonic Distortion

→ Let the base i/p currents are sinusoidal in nature & given by $i_{b1} = I_{Bm}\cos\omega t$ & $i_{b2} = -I_{Bm}\cos\omega t = I_{Bm}\cos(\omega t+\pi)$

→ The -ve sign indicates that both are 180° out of phase.

→ Due to nonlinear dynamic characteristics, the collector current of the 2 transistors can be expressed interms of harmonic components as,

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

$$i_{c2} = I_{CQ} + B_0 + B_1\cos(\omega t+\pi) + B_2\cos 2(\omega t+\pi) + B_3\cos 3(\omega t+\pi) + \ldots$$

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

→ The load current is the difference b/w the two. This is because in the primary of the transformer the 2 currents are in opposite direction

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

$$= 2B_1\cos\omega t + 2B_3\cos 3\omega t + \ldots$$

→ The even harmonic components 2nd, 4th, 6th & so on get eliminated & also the d.c. component gets eliminated.

→ Hence the percentage harmonic distortion is only due to odd harmonics is given by

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

→ Hence the total harmonic distortion is

$$\% D = \sqrt{D_3^2 + D_5^2 + D_7^2 + \ldots} \times 100$$

Advantages

- → Efficiency is much higher than class A operation
- → When there is no i/p signal, the power dissipation is zero
- → Even harmonics get cancelled which reduces harmonic distortion
- → Ripples present in supply voltage also get eliminated
- → Due to the transformer impedance matching is possible

Disadvantages

- → Two center tap transformers are necessary
- → Transformers make the ckt bulky & also costlier
- → Freq. response is poor.

Q) A class B push pull amplifier drives a load of 16Ω, connected to the secondary of the ideal transformer. The supply voltage is 25V. If the no. of turns on primary is 200 & the no. of turns on secondary is 50. Calculate max power o/p, d.c. power i/p, efficiency & max. power dissipation per transistor.

$R_L = 16\Omega$, $V_{cc} = 25V$ $2N_1 = 200$ $N_2 = 50$

$\Rightarrow N_1 = 100$

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

$$R_L' = \frac{R_L}{n^2} = 64\Omega$$

for max. power o/p $V_m = V_{cc}$

i) $$(P_{ac})_{max} = \frac{V_{cc}^2}{2R_L'} = 4.8828W$$

ii) $$P_{dc} = \frac{2}{\pi} V_{cc} I_m = \frac{2}{\pi} V_{cc} \cdot \frac{V_{cc}}{R_L'} \quad \left(\because \frac{V_m}{I_m} = R_L',\ V_m = V_{cc}\right)$$

$$= \frac{2}{\pi} \cdot \frac{V_{cc}^2}{R_L'} = 6.2169W$$

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

(iv) $$(P_d)_{max} \text{ per transistor} = \frac{2}{\pi^2}(P_{ac})_{max} = 0.9894W \approx 1W$$

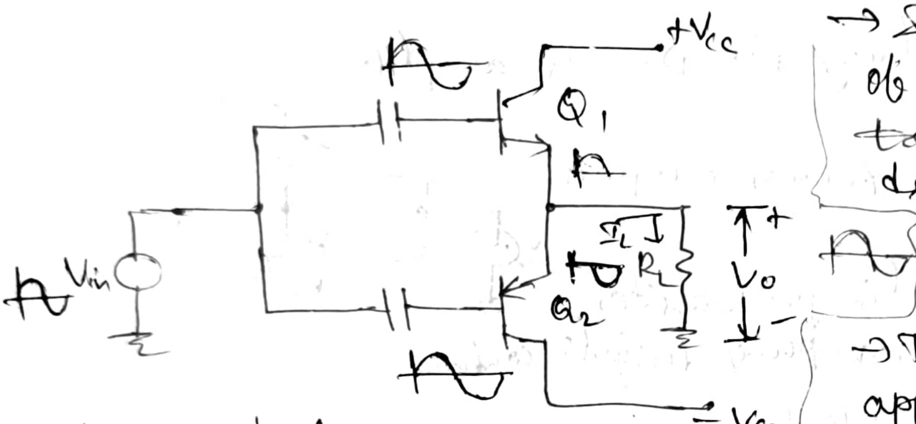
Complementary Symmetry Class B Amplifier

→ Instead of using same type of transistors, one p-n-p & the other n-p-n is used, then the amplifier ckt is called complementary symmetry class B amplifier.

→ This ckt is transformerless ckt

→ With common emitter configuration, it becomes difficult to match the o/p impedance for max. power transformer without an o/p transformer.

→ Hence the matched pair of complementary transistors are used in common collector (emitter follower) configuration in this ckt.



→ In the +ve half cycle of the i/p signal, the transistor Q_1 gets driven into active region & 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 +ve half cycle.

→ This results in +ve half cycle across the load R_L

→ During the -ve half cycle of the signal, the transistor Q_2 being p-n-p gets biased into condution

→ While the transistor Q_1 gets driven into cutoff region.

→ Hence only Q_2 conducts during -ve half cycle of the i/p, producing -ve half cycle across the load R_L

→ Thus for a complete cycle of i/p, a complete cycle of o/p signal is developed across the load.

Mathematical Analysis

→ All the results derived for push pull transformer coupled class B amplifier are applicable to complementary class B amplifier.

→ The only change is that ~~as~~ the o/p transformer is not present, hence in the expression, R_L value must be used instead of R_L'.

Advantages

→ As ckt is transformerless, its weight, size & cost are less

→ Due to CC configuration, impedance matching is possible.

→ Freq. response improves due to transformerless class B ckt.

Disadvantages

→ The ckt needs 2 seperate voltage supplies

→ The o/p is distorted due to cross-over distortion

Q) ~~For~~ Class B complementary A.F power amplifiers, calculate

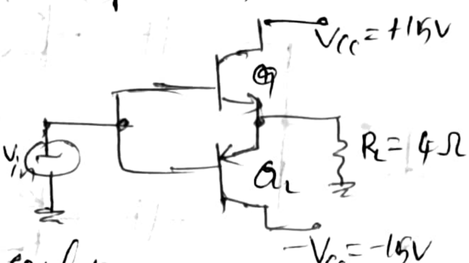
i) Max. a.c. power.

ii) Collector dissipation for max. a.c. power

iii) Efficiency

(iv) Max. power dissipation per transistor

v) Efficiency under max. power dissipation condition



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

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

ii) For max. ~~ac~~ power, $V_m = V_{CC}$

$P_{dc} = \frac{2}{\pi} V_{CC} I_m = \frac{2V_{CC}^2}{\pi R_L}$ $\left(\because I_m = \frac{V_m}{R_L}, V_m = V_{CC}\right)$

$= 35.809W$

$P_d = P_{dc} - P_{ac} = 7.684W$

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

(iv) For max. power ~~transistor~~ dissipation, $V_m = \frac{2}{\pi} V_{CC}$

$= 9.5492V$

$I_m = \frac{V_m}{R_L} = 2.3873A$

$P_{dc} = \frac{2}{\pi} V_{CC} I_m = 22.797W$

$P_{ac} = \frac{1}{2}\frac{V_m^2}{R_L} = 11.398W$

$(P_d)_{max} = P_{dc} - P_{ac} = 11.39W$

$\therefore (P_d)_{max} = 5.699W$ per transistor

v) Efficiency under $(P_d)_{max}$

$= \frac{P_{ac} \text{ under } (P_d)_{max}}{P_{dc} \text{ under } (P_d)_{max}} \times 100$

$= \frac{11.398}{22.797} \times 100 = 50\%$

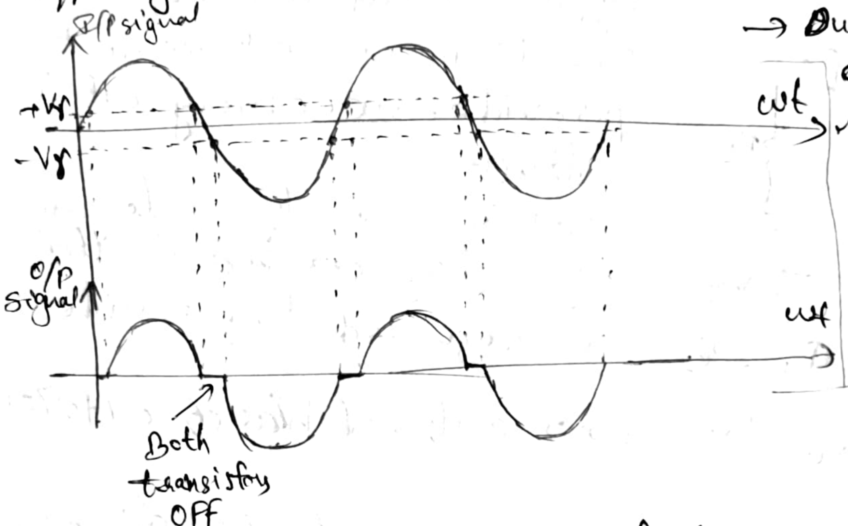
Cross-Over Distortion

→ For a transistor to be in active region the base emitter junction must be forward biased.

→ The junction cannot be forward biased till the voltage applied becomes greater that cut-in voltage (V_γ) of the junction, which is generally 0.7 V for silicon & 0.2 V for germanium transistor.

→ Hence there is a period b/w the crossing of the half cycles of i/p signal, for which none of the transistors is active & the o/p is zero

→ Hence the nature of o/p signal gets distorted & no longer remains same as that of i/p. Such a distortion in the o/p signal is called cross-over distortion



→ Due to cross-over distortion each transistor conducts for less than a half cycle rather than the complete half cycle.

→ The cross-over distortion is common in both types of class B amplifier

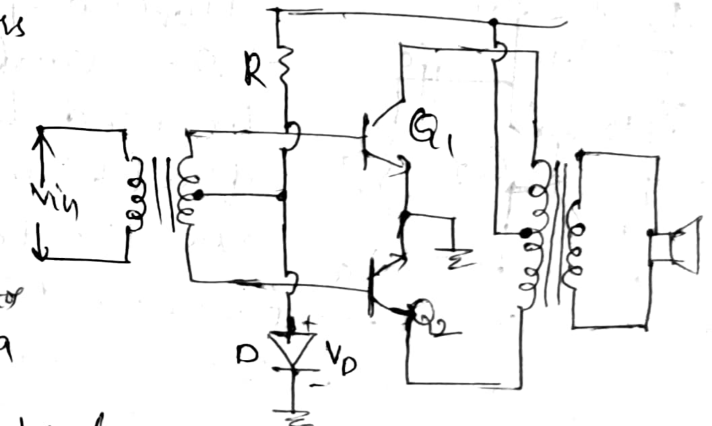
Elimination of Cross-Over Distortion

→ To eliminate the cross-over distortion some modification are necessary in the basic ckts of class B amplifier.

→ To overcome the cut-in voltage, (which is basic reason for cross-over distortion) a small forward biased is applied to the transistors

Push Pull Class AB Amplifier

→ Forward biased voltage across the base-emitter junction of each transistor is provided by using a diode



→ The drop across the diode D is equal to the cut-in voltage of the base-emitter junction of the transistor.