IV. POWER AMPLIFIERS

Introduction: Let us consider multistage public address system as shown in the figure.

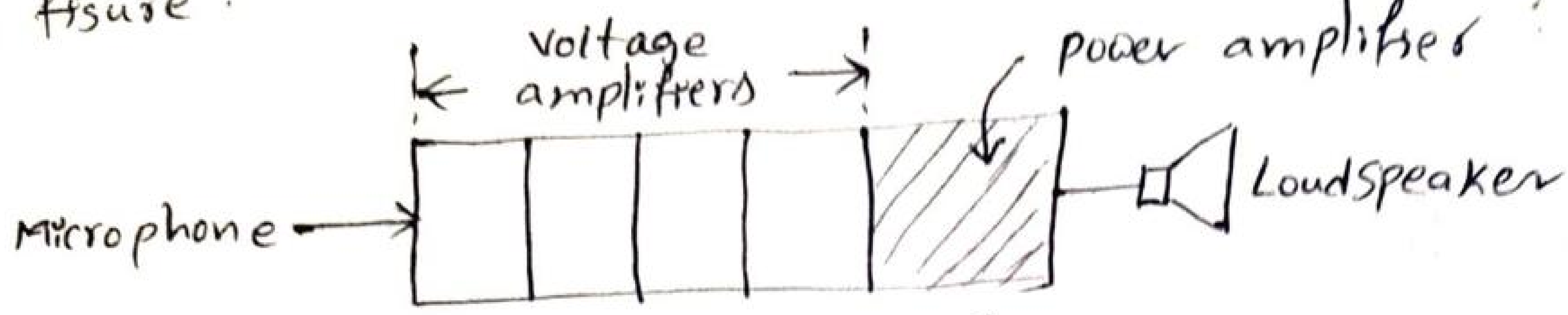


Fig: Public Address System.

The input and the intermediate stages are small signal amplifiers which are voltage amplifiers and the output stage is the power amplifier. It is capable of delivering a.c power to the load. power amplifiers are useful in public address systems, radio receivers, tape players, T.V receivers etc.

Features of power amplifiers:

1. Large input signal is applied in the order of few volts.
2. output has large voltage and current swings.
3. h-parameter analysis is not applicable
4. Impedance matching with the load is required.
5. power transistors with heat sink is used for large power dissipation.
6. When handling large power size becomes bulky.
7. Harmonic distortion is present.
8. Mainly used in audio circuits hence called audio frequency power amplifiers.

Impedance matching:

power amplifiers delivers the signal to the loud speaker having low impedance. Maximum power has to be delivered to the load. Hence, the load impedance and output impedance of power amplifier must be matched, means impedance matching is required in power amplifiers. Common collector circuit is used in power amplifiers because of low output impedance. Step down transformers are also used at the output side for impedance matching.

Classification of large signal or power amplifiers:

Based on the operating point on the load line the power amplifiers are classified as
i) Class A (ii) Class B (iii) Class C (iv) Class AB (v) Class D

Class A large signal amplifier:

Class A large signal amplifiers are classified as
i) Series fed, directly coupled (ii) Transformer coupled.

i) Series fed Directly Coupled Class A amplifier:

A large signal class A amplifier with fixed bias circuit is shown in the following figure.

In the circuit, transistor used is power transistor. The load R_L is directly connected to the collector terminal (output). The value of R_B is chosen in such a way that Q point is exactly in the middle of the d.c load line. This circuit handles large power in the range of few watts to tens of watts.

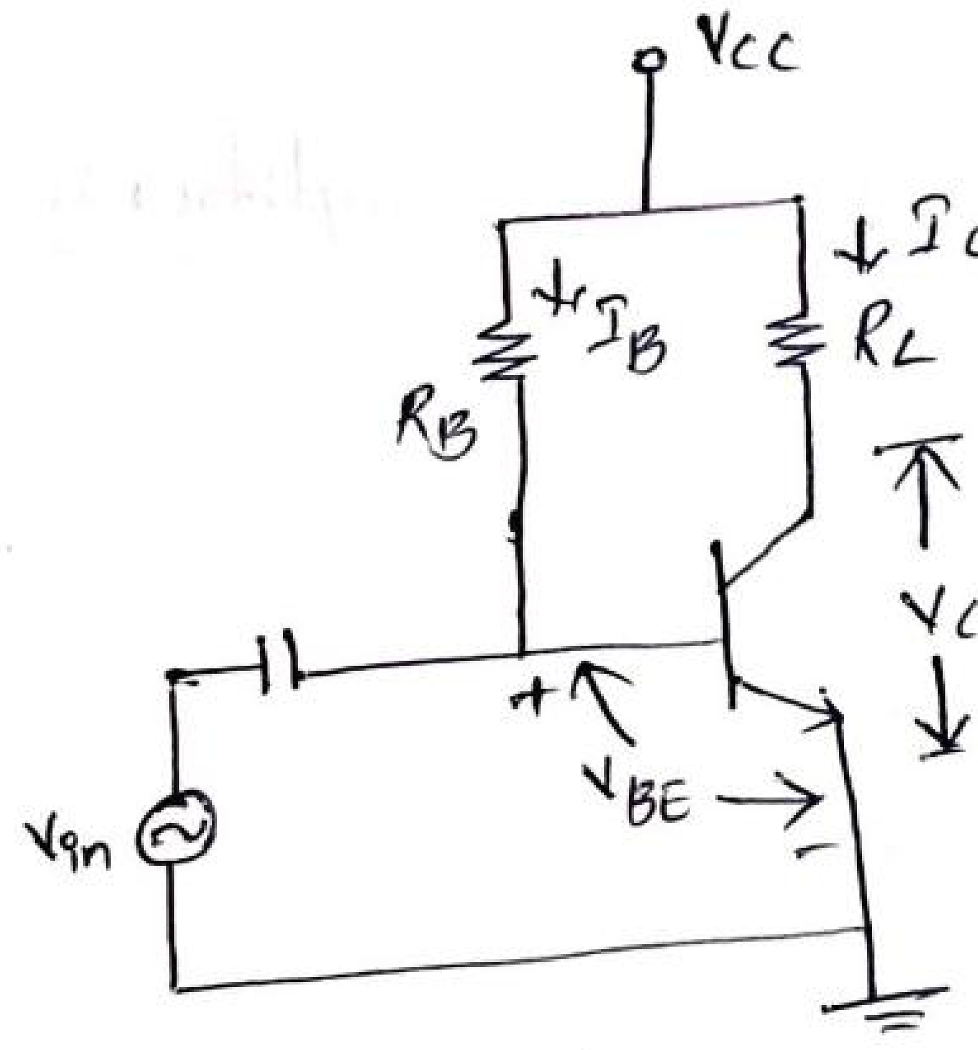


Fig: large signal class A amplifier

The graphical representation of class A amplifier is shown in the figure.

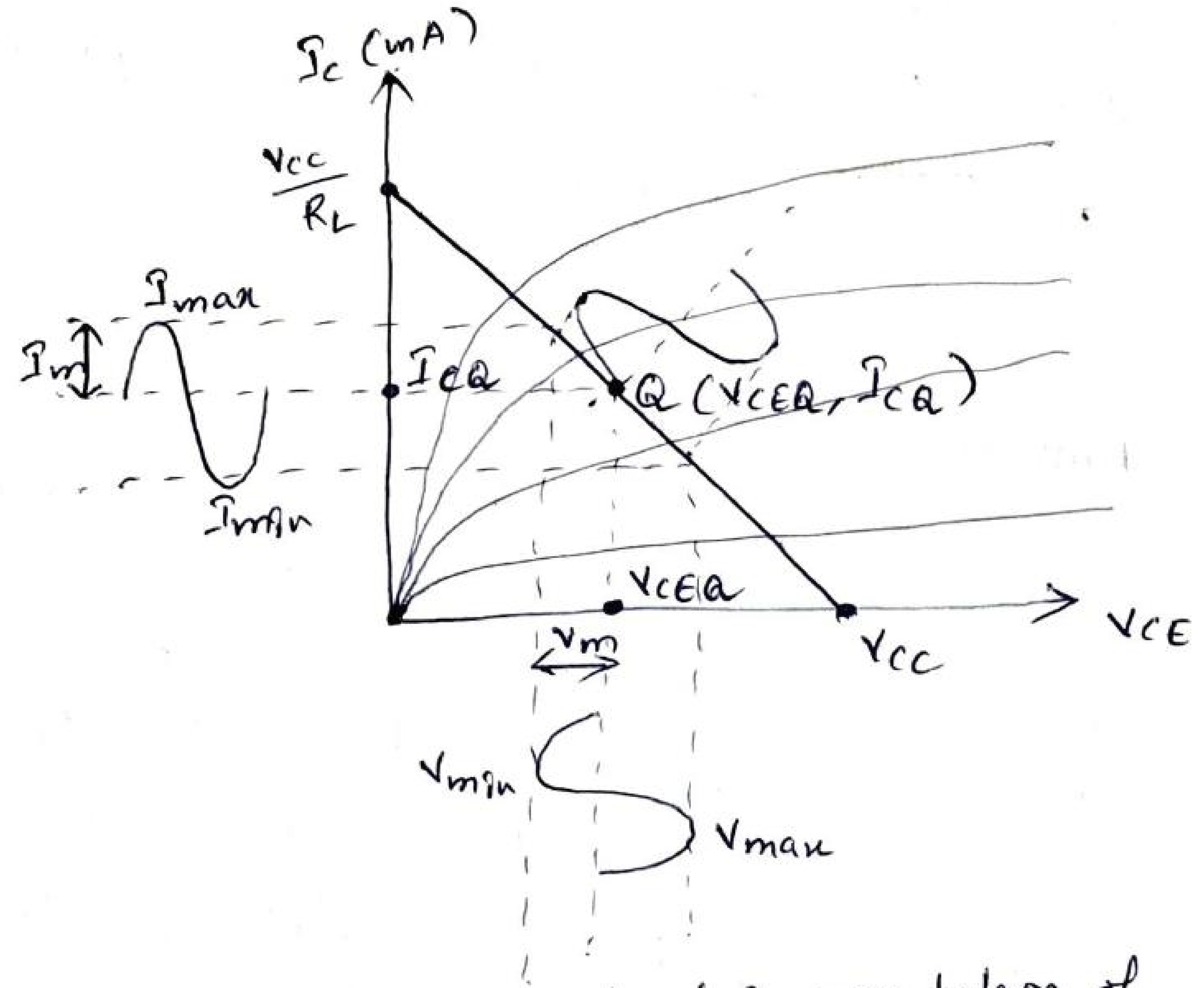


Fig: Graphical representation of class A amplifier

Applying KVL to the above circuit

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

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

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

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

From the above equation, the slope of the load line is $-\frac{1}{R_L}$.

D.C operation: If V_{cc} is applied to the circuit, R_B decides the d.c ~~base~~ base bias current I_{BQ}. This is achieved by writing KVL to the base - Emitter loop.

$$V_{CC} = I_B R_B + V_{BE}$$

$$I_B = I_{BQ} = \frac{V_{CC} - V_{BE}}{R_B} = \frac{V_{CC} - 0.7}{R_B} \quad (\because V_{BE} = 0.7)$$

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

$$\therefore \boxed{I_{CQ} = \beta I_{BQ}}$$

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

Hence Q point is defined as (V_{CEQ}, I_{CQ})

D.C power input: The d.c power is provided by the supply without any a.c signal.

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

A.C operation: When a.c signal is applied to the input base, then the base current also varies sinusoidally. As a result, the collector current and collector to emitter voltage also varies sinusoidally as shown in the graphical representation of class A amplifier.

The varying output current and voltage delivers an a.c power to the load.

A.C power output: The varying output voltage and current can be written as,

$$\underbrace{V_{PP}}_{\text{peak to peak ac output voltage}} = \underbrace{V_{max}}_{\text{max. value of collector voltage}} - \underbrace{V_{min}}_{\text{min. value of collector voltage}}$$

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

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

The rms value of a.c output voltage and current can be expressed as

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

$$V_m = I_m R_L$$

$$V_{rms} \cdot \sqrt{2} = I_{rms} \sqrt{2} R_L$$

$$\therefore \boxed{V_{rms} = I_{rms} R_L}$$

The rms values, peak values and peak to peak values is given by

rms values
$$\boxed{P_{ac} = V_{rms} \cdot I_{rms} \text{ (or) } I_{rms}^2 R_L \text{ (or) } \frac{V_{rms}^2}{R_L}}$$

peak values

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

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

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

peak to peak values

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

$$P_{ac} = \frac{V_{pp} I_{pp}}{8}$$

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

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

we know that $V_{pp} = V_{max} - V_{min}$; $I_{pp} = I_{max} - I_{min}$

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

Efficiency: The Efficiency of an amplifier is the amount of a.c power delivered to the load from the d.c Source.

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

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

Maximum Efficiency:

From the figure,

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

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

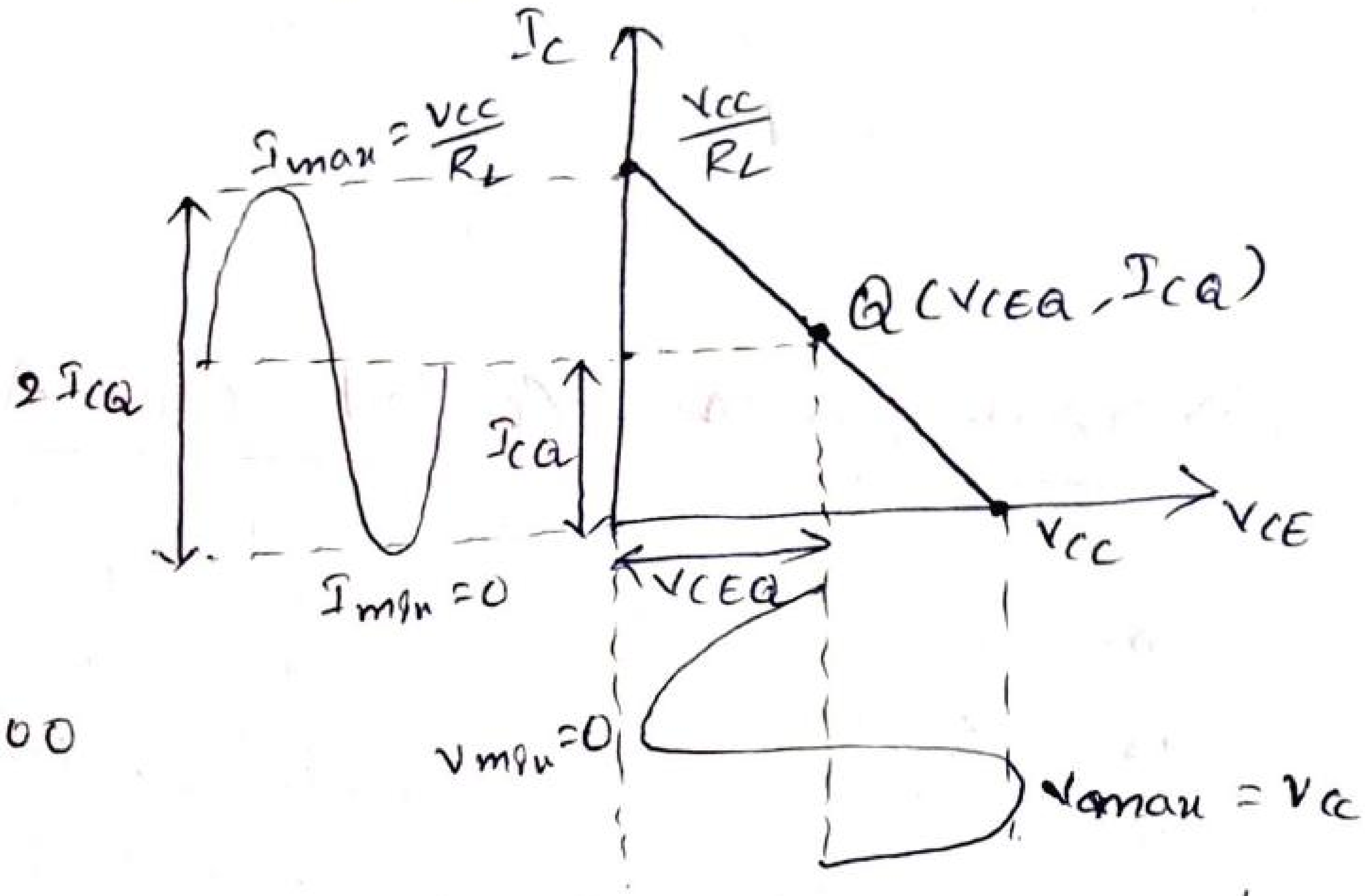


Fig: Maximum Voltage and Current Swings

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

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

$$\therefore \boxed{\% \eta_{max} = 25\%}$$

The maximum Efficiency of class A amplifier is 25%. ~~This~~ In practical we will get the Efficiency between 0 to 15%.

Power dissipation:

The amount of power dissipated by the transistor is the difference between the d.c power input P_{dc} and the a.c power delivered to the load P_{ac}.

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

Maximum power dissipation takes place when a.c input Signal is zero. This Entire power is dissipated in the form of heat.

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

Advantages :

1. circuit is simple
2. cheaper because load is directly connected to collector.
3. Less no. of components in the circuit.

Disadvantages :

1. Because of direct load is connected to collector, power is wasted.
2. power dissipation is more. Hence it requires heat sink.
3. output impedance is high hence circuit cannot be used for low impedance loads such as loudspeakers.
4. Efficiency is poor.

(ii) Transformer Coupled Class A amplifier :

For maximum power transfer to the load, the impedance matching is necessary. When low impedance loads like loud speakers are used, it is very difficult to set impedance matching by using direct coupled amplifier. When direct coupled is used it provides high impedance. This problem can be eliminated by using transfor coupled amplifier.

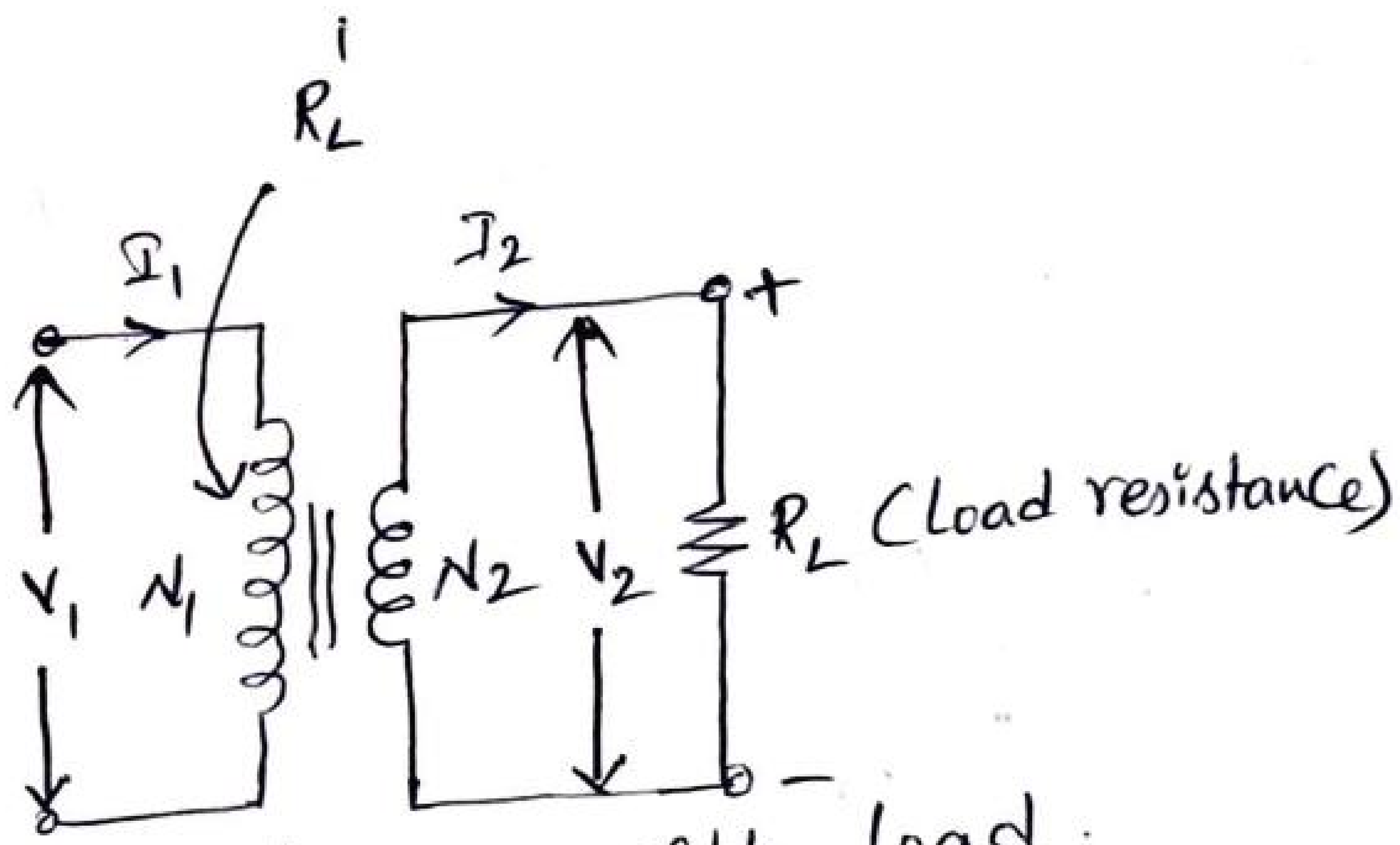


Fig: Transformer with load.

$N_1 \rightarrow$ No. of turns in primary
$N_2 \rightarrow$ No. of turns in secondary
$V_1 \rightarrow$ primary voltage
$V_2 \rightarrow$ secondary voltage
$I_1 \rightarrow$ primary current
$I_2 \rightarrow$ secondary current

Transformer:

Let us consider there are no losses in the transformer and winding resistances are assumed to be zero.

(a) turns ratio $\boxed{n = \frac{N_2}{N_1} \text{ or } \frac{N_2}{N_1} : 1}$

(b) voltage transformation

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

(c) Current transformation

$$\boxed{\frac{I_2}{I_1} = \frac{N_1}{N_2} = \frac{1}{n} = \frac{V_1}{V_2}}$$

(d) Impedance transformation — As the voltage and current get transformed from primary to secondary an impedance seen from either side.

we know that $\frac{V_2}{V_1} = \frac{N_2}{N_1} = n$ and $\frac{I_2}{I_1} = \frac{N_1}{N_2} = \frac{1}{n} = \frac{V_1}{V_2}$

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

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

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

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

R_L' is the reflected impedance in the step down transformer.

$$R_L' \gg R_L$$

Circuit diagram:

The circuit diagram for transformer coupled class A amplifier is shown in the figure. The loudspeaker connected to the secondary of the transformer acts a load.

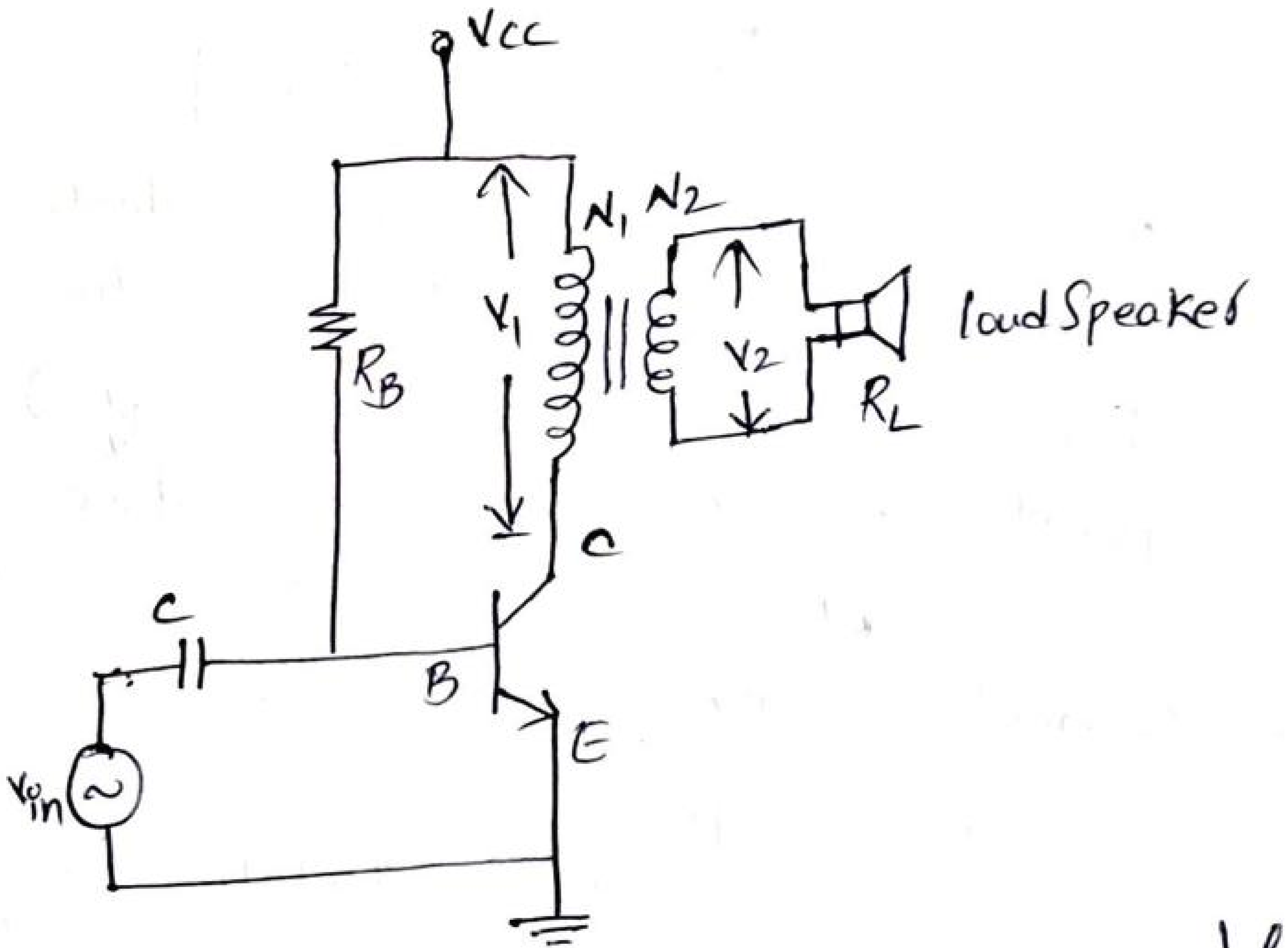


Fig: Transformer Coupled class A amplifier

DC operation:

For the transformer, the winding resistances are assumed as zero. Based on this, applying KVL to collector circuit, we get

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

This is the d.c bias voltage $\boxed{V_{CEQ} = V_{CC}}$

For the above condition of biasing, the d.c load line slope is ideally infinite and it is vertical. The intersection of the d.c load line and the base current set by the circuit is the operating point of the circuit. The load lines is shown in the following figure.

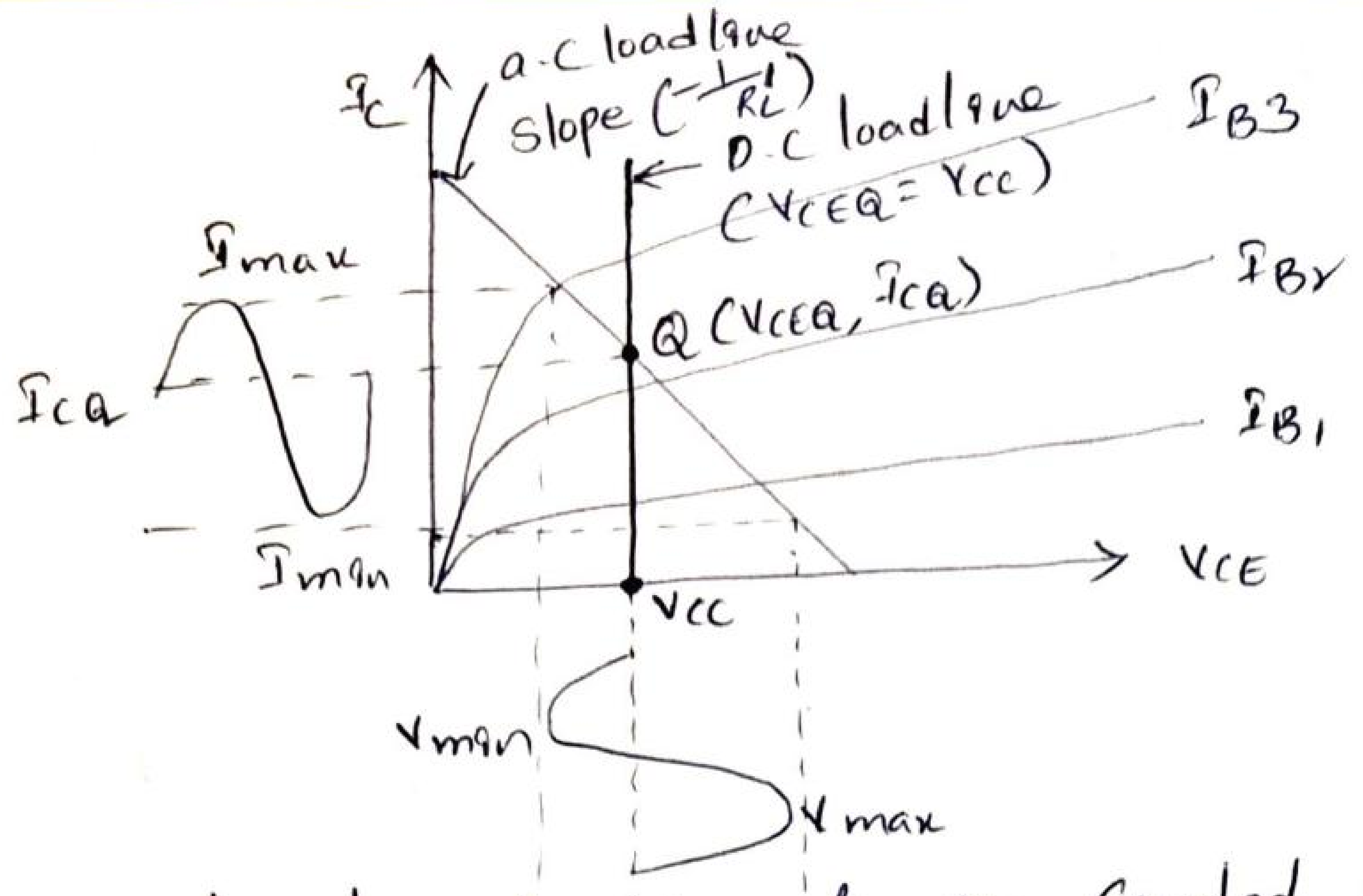


Fig: load lines for transformer Coupled Class A amplifier

D.C power input :

The d.c power input provided by the supply voltage when no ac signal input is given by

$$\boxed{P_{DC} = V_{CC}\, I_{CQ}}$$

A.c operation : The load impedance on the secondary winding is R_L and the reflected load on the primary is R_L'. The load line drawn with a slope of $(-\frac{1}{R_L'})$ and passing through the operating point is called a.c load line.

When input ac signal is applied, the output voltage and current swings sinusoidally.

A.C power output :

While calculating the power primary values of voltage, current and reflected load R_L' and on secondary side voltage, current and load R_L must be considered.

V_{1m} = 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

V_{2m} = peak value of secondary voltage

V_{2rms} = RMS value of secondary voltage

I_{2m} = peak value of secondary current

I_{2rms} = RMS value of secondary current.

The a.c power developed on the primary is given by

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

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

The a.c power delivered to the load on the secondary is given by

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

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

The slope of the a.c loadline can be expressed in terms of the primary current and primary voltage.

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

The general expression for Pac is given by

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

Maximum Efficiency:

From the following figure,

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

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

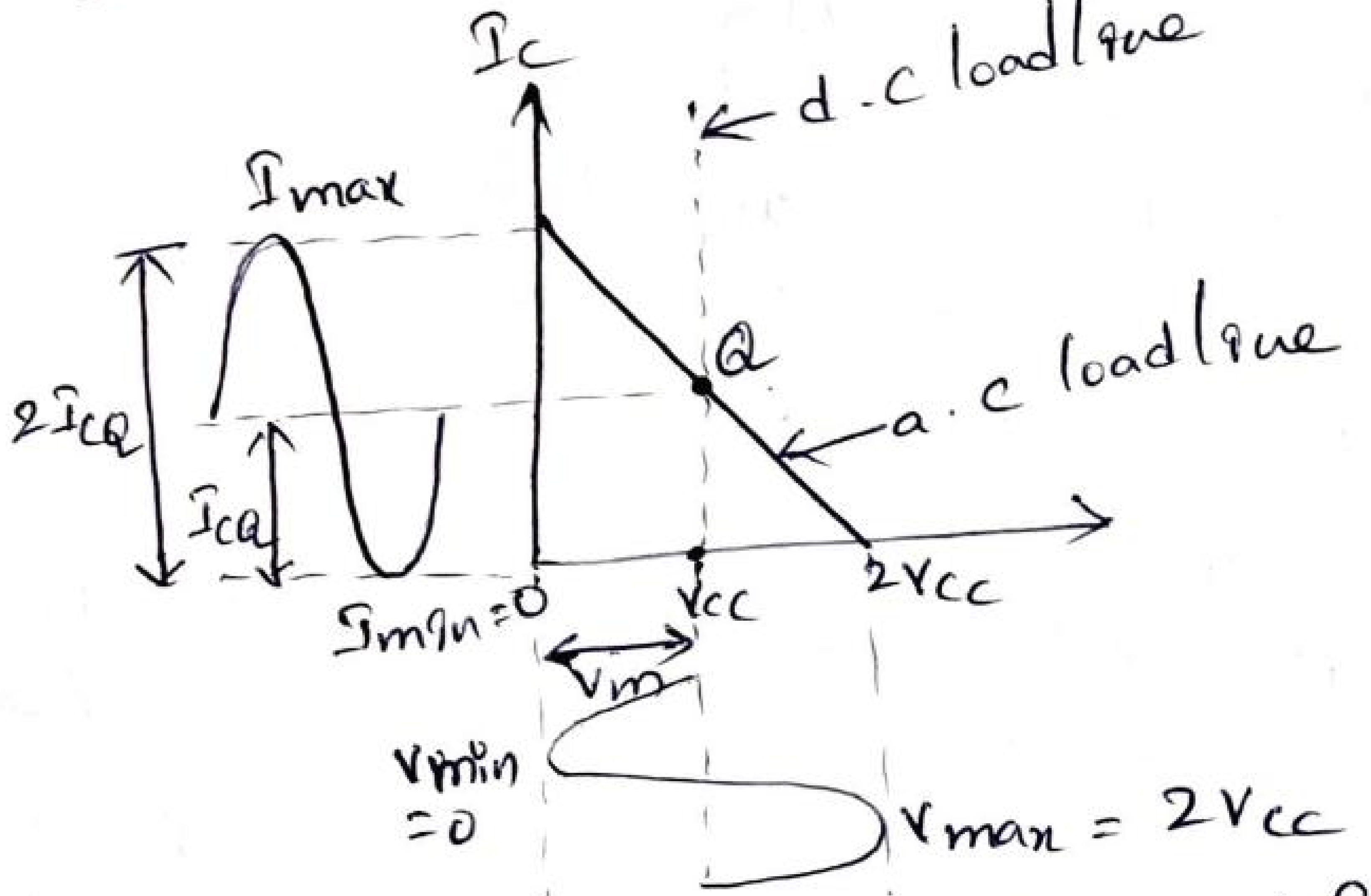


Fig: Maximum voltage and current swing

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

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

$$= \frac{2V_{cc} \cdot 2I_{CQ}}{8 V_{cc} I_{CQ}} = \frac{1}{2} \times 100 = 50\%$$

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

But for practical the efficiency is about 30 to 35%.

power dissipation:

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

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

$$\boxed{(P_d)_{max} = V_{cc} I_{CQ}} \quad (\text{when } P_{ac} = 0)$$

Advantages:

1. Efficiency is higher than direct coupled.
2. Because of transformer coupling d.c is blocked.
3. It provides impedance matching.

Disadvantages:

1. Because of transformer, the circuit becomes bulkier and costlier.
2. Design complexity is more
3. Frequency response is poor.

Distortion in amplifiers:

When an input a.c signal is applied to an amplifier, the output signal should not be changed or distorted with respect to amplitude, frequency and phase. Hence the possible distortions are amplitude distortion, frequency distortion and phase distortion. But the change in gain of the amplifier with respect to the frequency is called frequency distortion. It is not significant in AF power amplifiers. The dynamic characteristics of transistor is always linear. If there is a non linearity (output voltage differs from input signal) then the distortion is called non linear distortion or amplitude distortion or harmonic distortion. It plays a very important role in the analysis of A.F power amplifiers.

Harmonic distortion:

The undesired frequency components in the output waveform which are not present in the input signal. The frequency component of input signal and output signal are same then it is called as fundamental frequency component.

The harmonic components are the integer multiples of fundamental frequency components.

Let us consider the fundamental frequency is 'f' Hz then the additional frequency components are $2f, 3f, \ldots$. $2f$ is called as second harmonic frequency, $3f$ is called third harmonic frequency and so on. As the order of the harmonic increases, its amplitude decreases.

The distorted waveform is obtained by adding the fundamental and all other harmonic components.

The percentage of harmonic distortion can be calculated by comparing the amplitude of each order of harmonic with the amplitude of the fundamental frequency component.

The amplitude of the fundamental frequency component is B_1 and the amplitude of n^{th} harmonic component is B_n then the percentage of harmonic distortion due to n^{th} harmonic component is expressed as

$$\boxed{\% \, D_n = \frac{|B_n|}{|B_1|} \times 100}$$

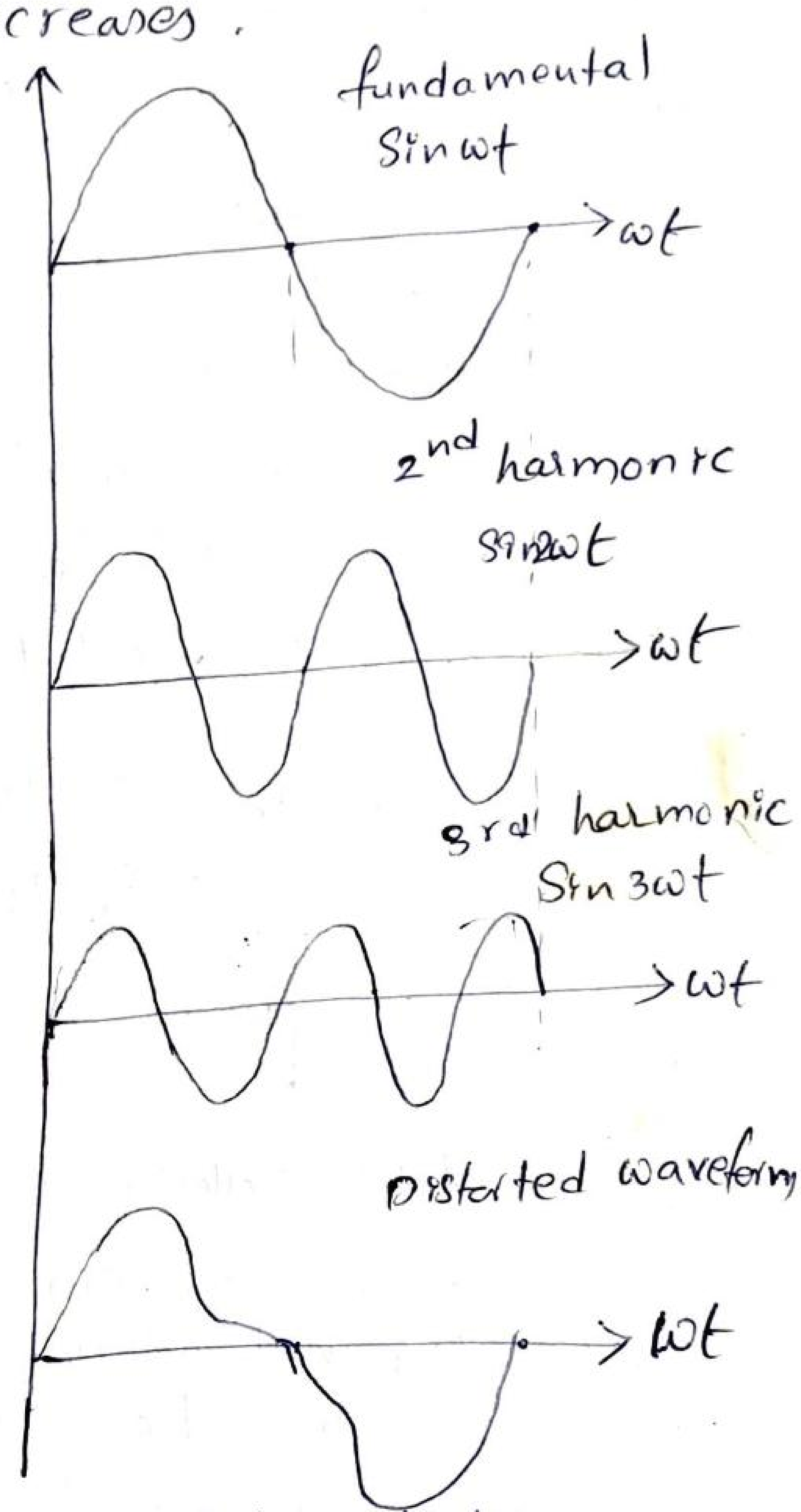


Fig: Distortion due to harmonic components.

Total harmonic distortion:

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

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

$D \rightarrow$ Total harmonic distortion

Second Harmonic distortion :

Because of Second harmonic distortion, the dynamic characteristics of a transistor is parabolic instead of straight line as shown in the figure.

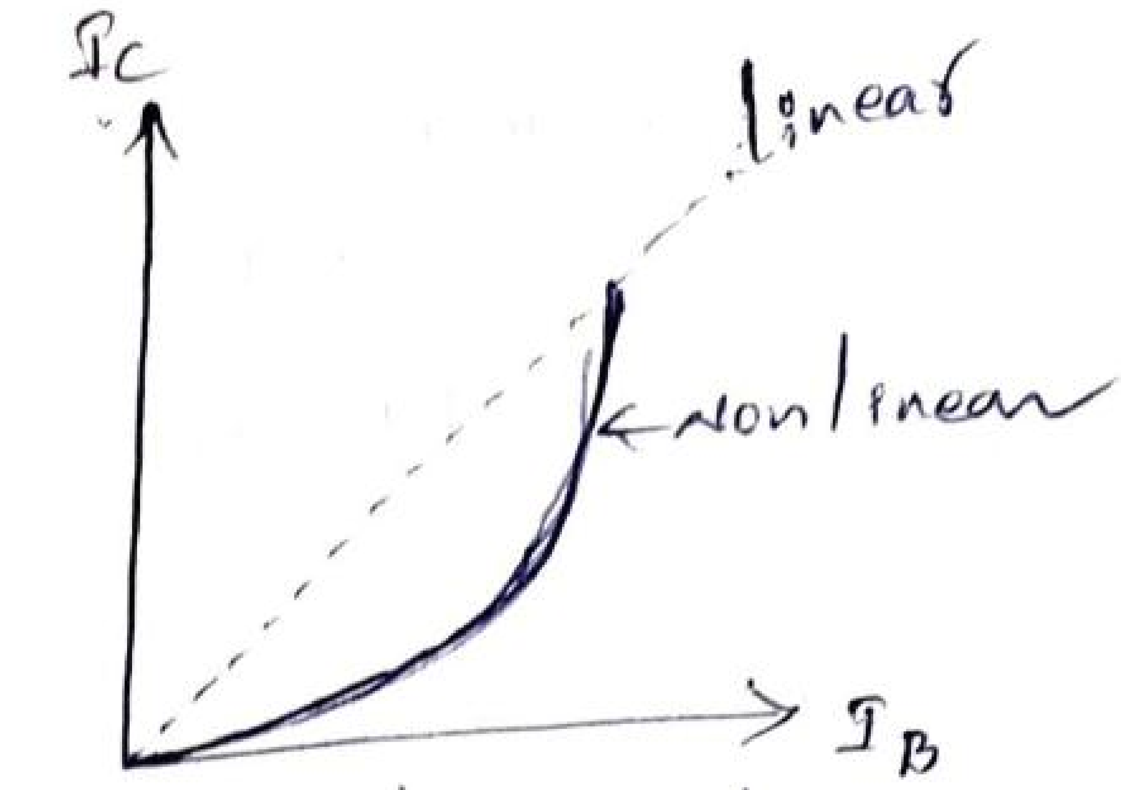


Fig: Non linear dynamic characteristics

Let an a.c input signal, causes the base current swing which is cosine.

$$i_b = I_{Bm} \cos\omega t$$

Due to non linearity, the relationship between i_b and i_c can expressed as

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

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

But $\cos^2\omega t = \frac{1+\cos 2\omega t}{2}$

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

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

$$\boxed{i_c = B_0 + B_1 \cos\omega t + \underbrace{B_2 \cos 2\omega t}_{\text{Second harmonic}}}$$

The total Collector current waveform is shown below.

The total collector current can be expressed in terms of its d.c bias value, d.c signal component and fundamental frequency and second harmonic component as,

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

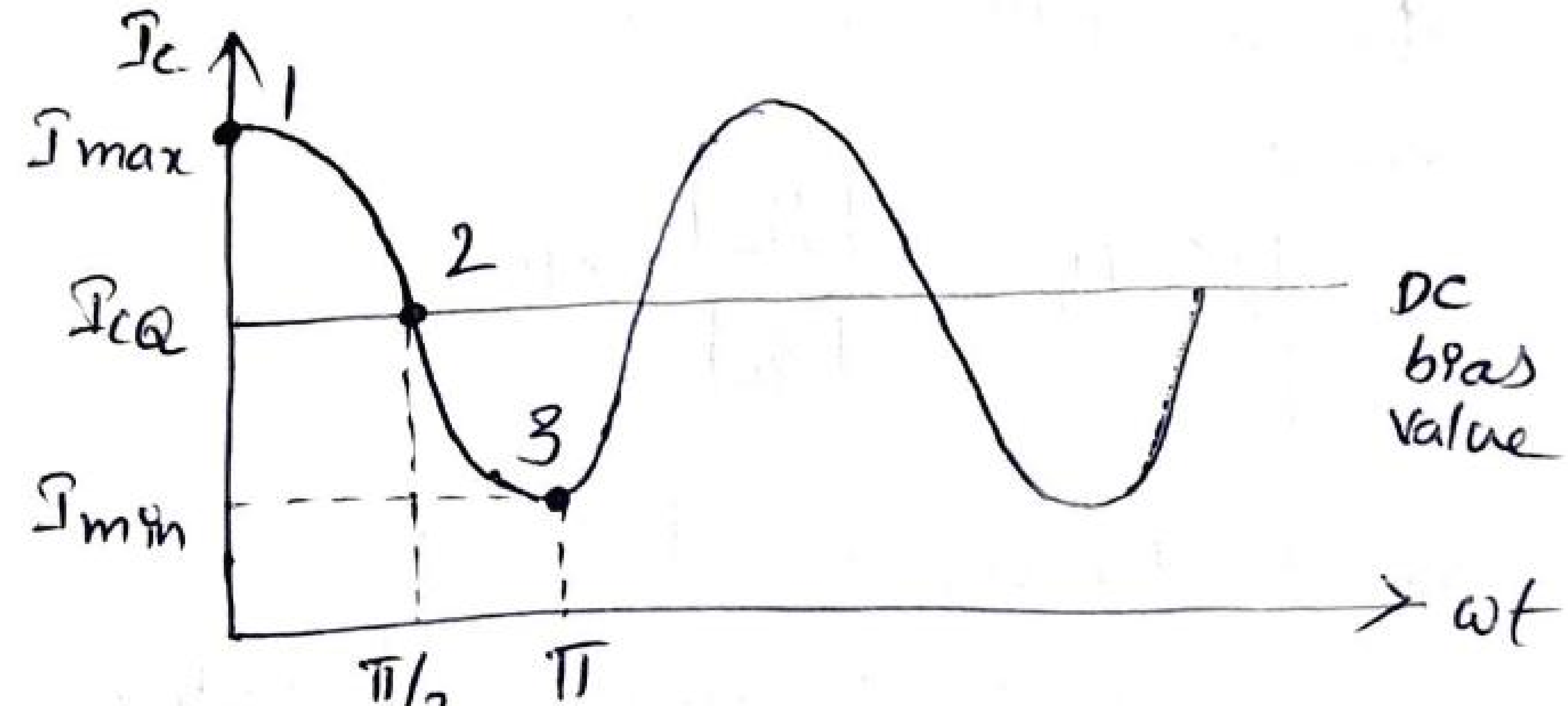


Fig: output current waveform

$I_{CQ} + B_0 \rightarrow$ d.c component

$B_1 \rightarrow$ Amplitude of fundamental frequency

$B_2 \rightarrow$ Amplitude of the second harmonic component.

Let us calculate the total current at various points 1, 2 and 3. (7)

i) At point 1, $\omega t = 0$ Substituting in $i_c = I_{CQ} + B_0 + B_1 \cos\omega t + B_2 \cos 2\omega t$, we get $i_c = I_{CQ} + B_0 + B_1 + B_2$

(ii) At point 2, $\omega t = \pi/2$

$$i_c = I_{CQ} + B_0 - B_2$$

(iii) At point 3, $\omega t = \pi$

$$i_c = I_{CQ} + B_0 - B_1 + B_2$$

But at $\omega t = 0$, $i_c = I_{max}$

at $\omega t = \pi/2$, $i_c = I_{CQ}$

at $\omega t = \pi$, $i_c = I_{min}$

$$\therefore I_{max} = I_{CQ} + B_0 + B_1 + B_2 \quad \text{--- (1)}$$

$$I_{CQ} = I_{CQ} + B_0 - B_2 \quad \text{--- (2)}$$

$$I_{min} = I_{CQ} + B_0 - B_1 + B_2 \quad \text{--- (3)}$$

from Eq (2), $B_0 = B_2$

$$I_{max} - I_{min} = I_{CQ} + B_1 + 2B_2 - I_{CQ} + B_1 - 2B_2$$
$$= 2B_1$$

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

$$I_{max} + I_{min} = I_{CQ} + B_1 + 2B_2 + I_{CQ} - B_1 + 2B_2$$
$$= 2I_{CQ} + 4B_2$$

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

$\therefore$ The second harmonic distortion can be calculated by

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

The above uses 3 points on the collector waveform for the calculation of B_0, B_1 & B_2 and hence it is called "Three point method".

power output due to distortion:

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

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

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

$B_1 = \frac{I_{max} - I_{min}}{2}$ [$\because I_m = B_1$ = fundamental freq component]

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

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

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

$= \frac{1}{2} B_1^2 R_L + \frac{1}{2} B_2^2 R_L + \frac{1}{2} B_3^2 R_L + \cdots$

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

$= \frac{1}{2} B_1^2 R_L \left[1 + D_2^2 + D_3^2 + \cdots\right]$

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

Analysis of class B amplifiers:

In Class B, the Q-point is selected on the x-axis. ~~in the active region and hence~~ Here only positive half cycle exists in the output. For negative half cycle, half cycle is produced at the output. there is no output signal.

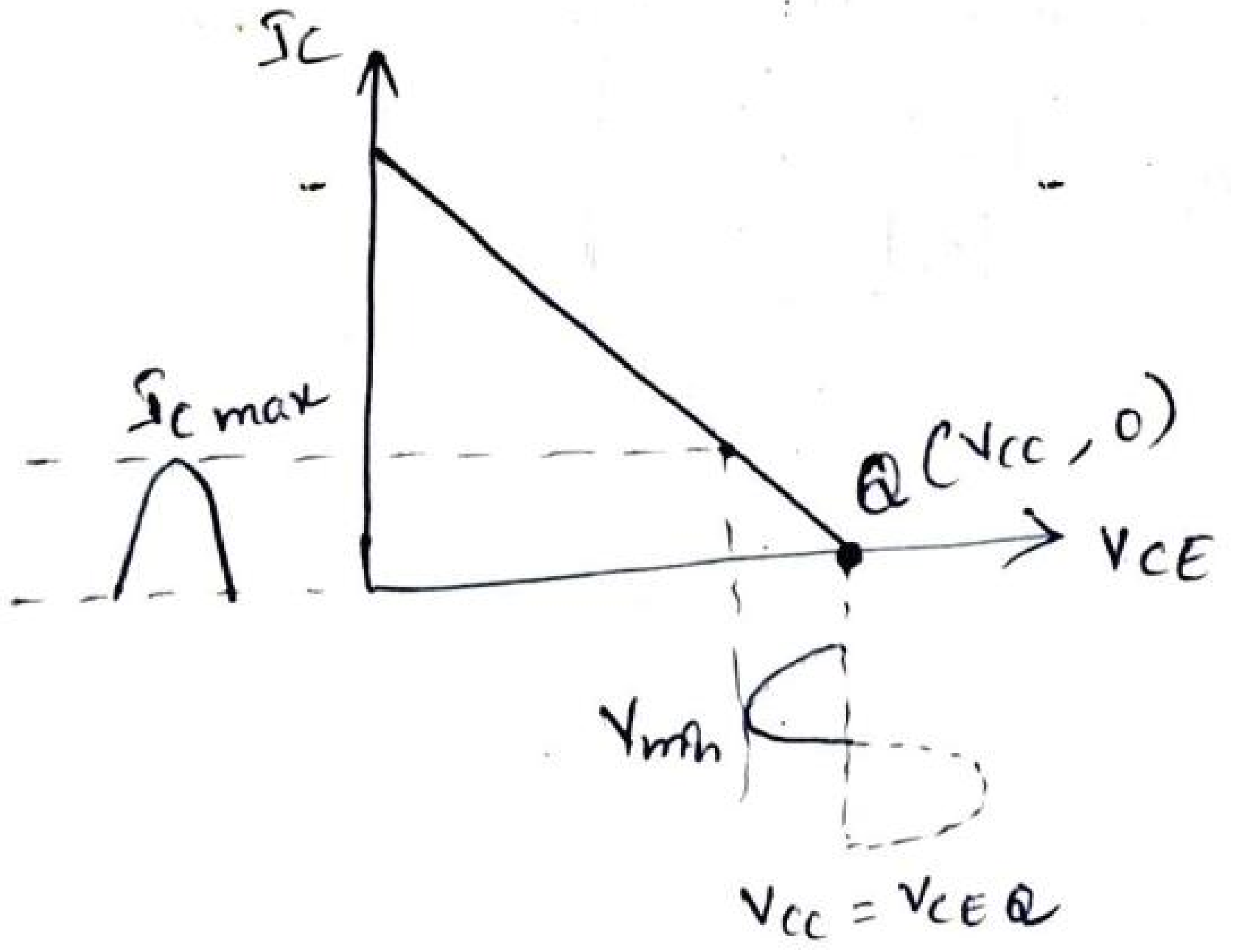


Fig: Class B of operation.

To avoid the Effect of negative half cycle, two transistors are used to produce a fullcycle of output signal across the load. It means each transistor conducts for a half cycle of the input. ~~It~~ Efficiency of Class B is much higher than class A.

Based on the type of transistors (pnp & npn) we have two circuits in Class B amplifier. They are.

1. when both the transistors are either pnp or npn, then the circuit is called pushpull class B AF power amplifier
2. when one transistor is pnp and second transistor is npn, then the circuit is called Complementary Symmetry class B AF power amplifier.

① pushpull class B amplifier:

This amplifier circuit requires two transformers, one at the input side called driver transformer and the other at the load called output transformer. Here in the circuit both transistors of type npn. The circuit diagram taking ~~the~~ for pushpull class B amplifier is shown below.

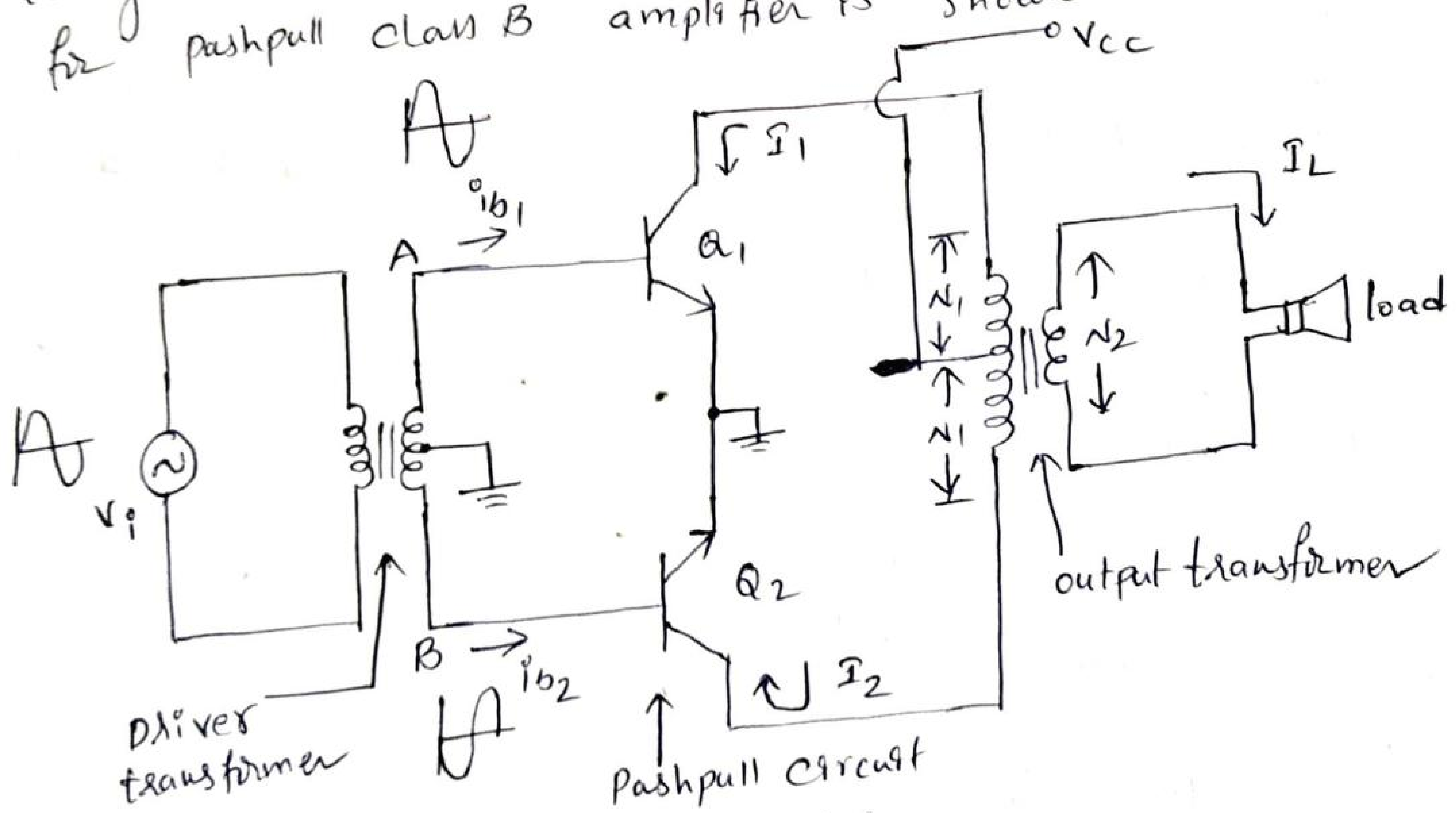


Fig: pushpull class B amplifier

Input signal is applied to the primary of driver transformer. Secondary consists of a center tap. With this center tap, for a positive halfcycle at point 'A' will be positive and at point B will be negative. These two signals at point A & B are equal but polarity is opposite.

output transformer ~~cons~~ primary has a Center tap, where the Center tap is Connected to Supply V_{cc}.

. working:

For +ve half cycle of the input signal, point 'A' is positive and point B is negative. Due to this transistor Q_1 Conducts and Q_2 is in off State.

$\therefore$ i_{b_1} flows and $i_{b_2}=0$

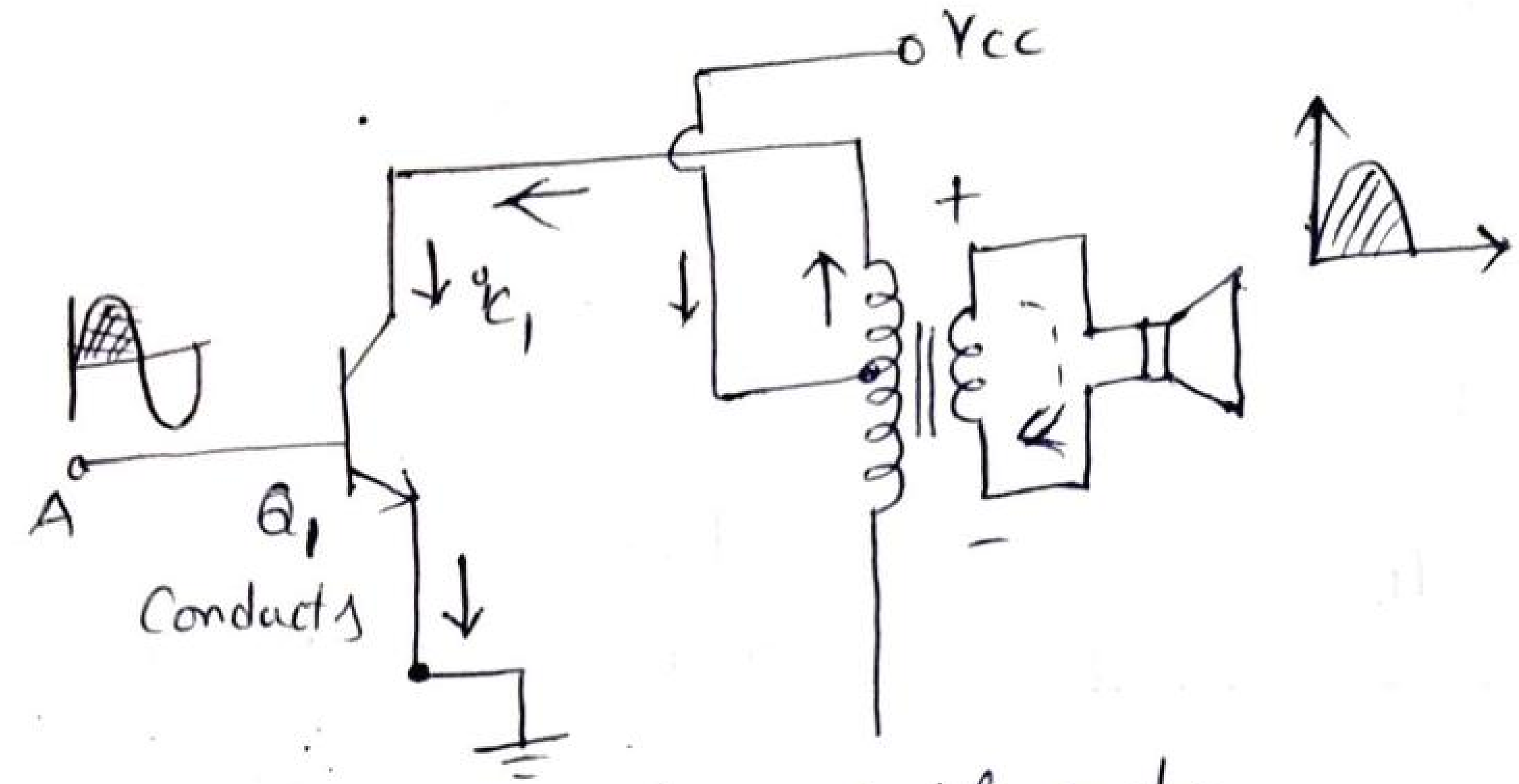


Fig: For positive half cycle

Hence Current i_{c_1} flows through the upper half of ~~the~~ primary of the output transformer.

Then the output will be delivered to the load.

Similarly for negative half cycle point 'A becomes negative and point B becomes positive, As a Result Q_2 is in on State and Q_1 is in off State.

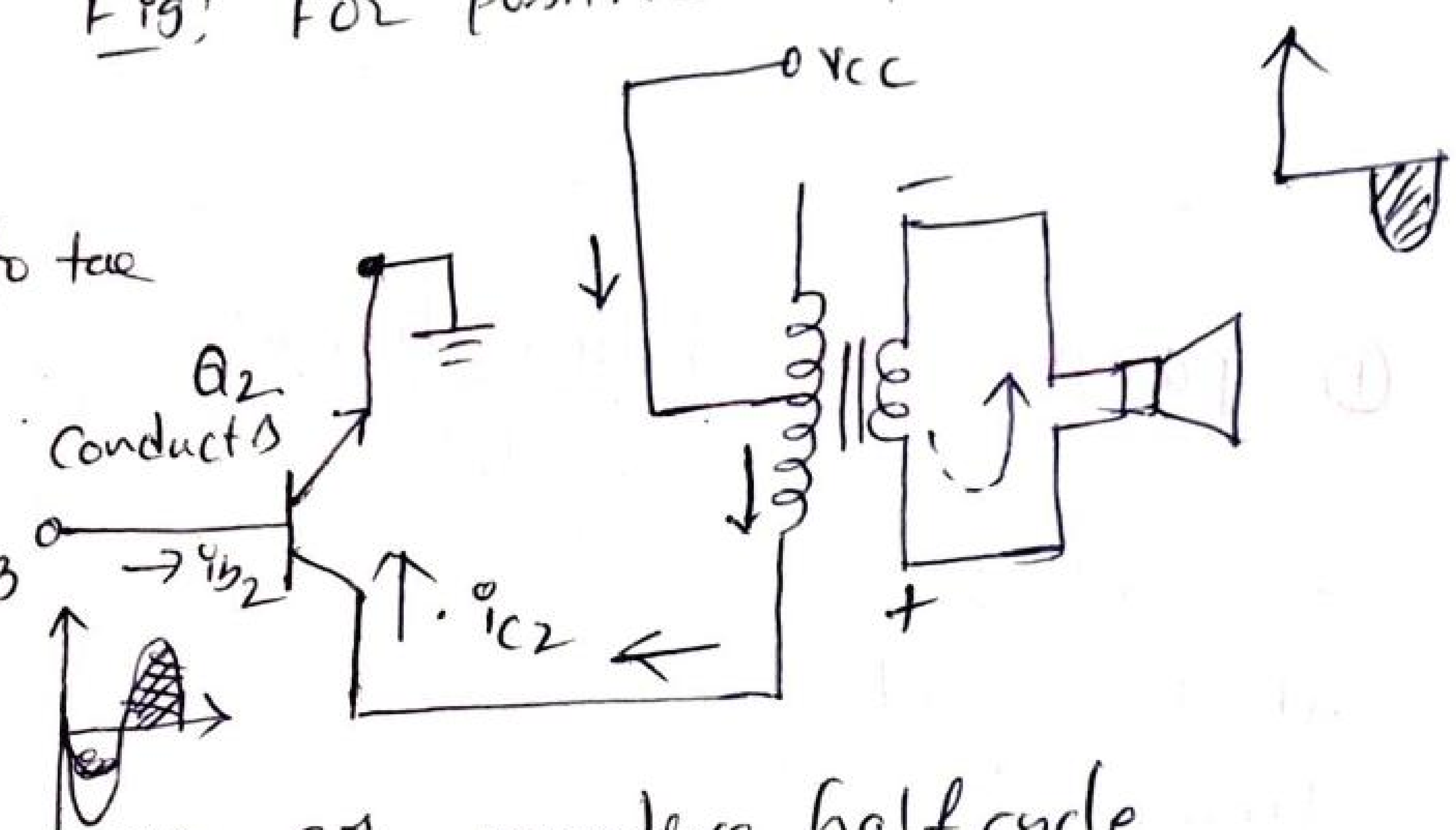
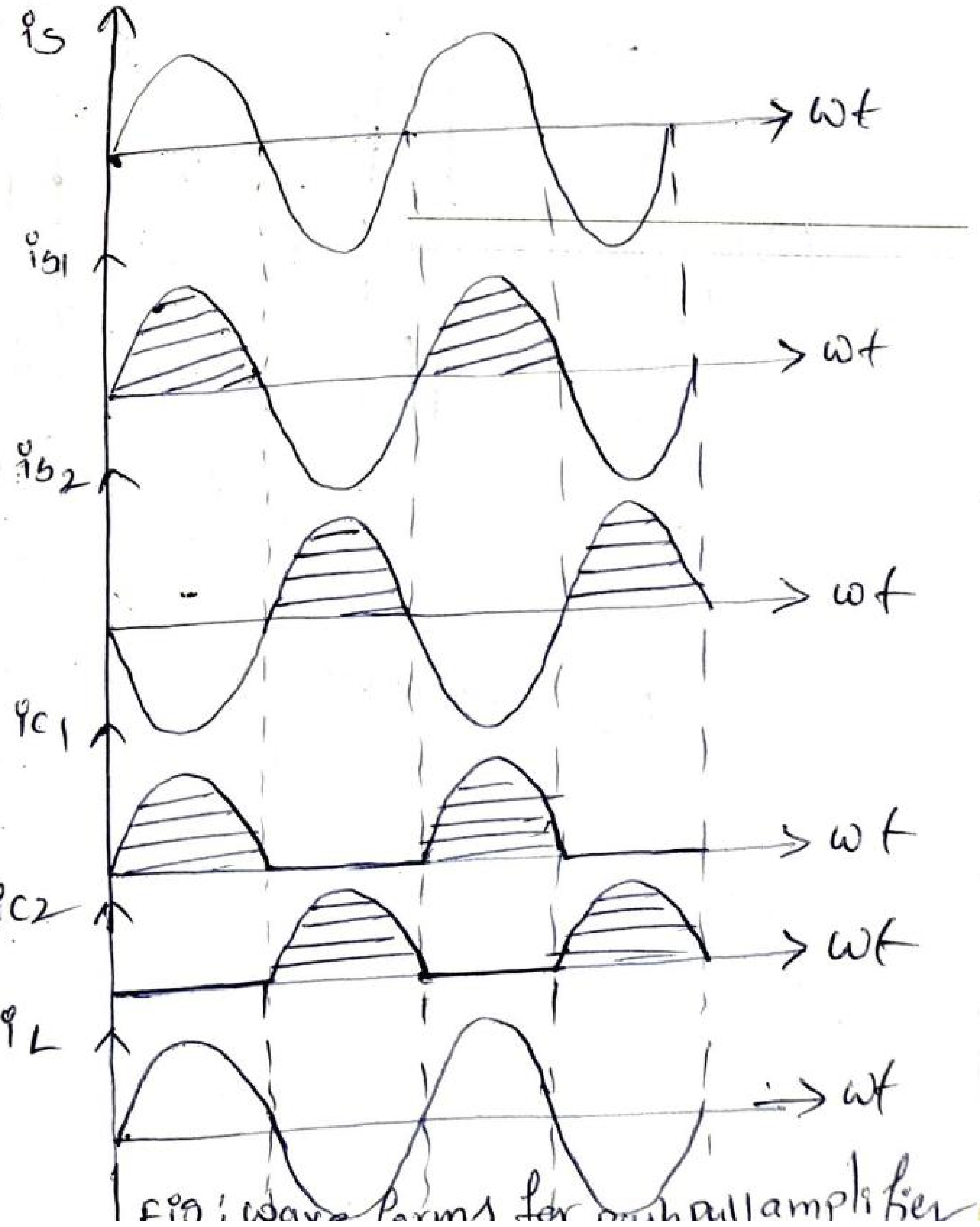


Fig: For negative half cycle

$\therefore$ $i_{b_1}=0$ and i_{b_2} flows. Hence Current i_{c_2} flows through the lower half of primary of the output transformer and output will be delivered to the load.

The wave forms for pushpull amplifier is shown in the figure.



D.C operation:

operating point is adjusted on the x-axis Such that $V_{CEQ}=V_{cc}$ and I_{CQ} is zero.

The Q point is V_{cc}, 0 , means there is no d-c base bias voltage.

Fig: wave forms for pushpullamplifier

DC power input:

Each transistor output is in the form of half wave rectifier o/p.

$\therefore$ I_m is the peak value of the output current of each transistor

$$\therefore \quad I_{dc} = I_{avg} = \frac{I_m}{\pi}$$

For both the transistors, total I_{dc} is

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

Total d.c power input is given by

$$P_{dc} = V_{CC} \cdot I_{dc} = \left(\frac{2I_m}{\pi}\right) V_{CC}$$

A.C operation:

For +ve half cycle applied to driver transformer Q_1 conducts and for -ve half cycle Q_2 conducts. When Q_1 conducts lower half of the primary of the output transformer doesnot carry any current. Hence only N_1 turns carry the current. Similarly for Q_2 conducts.

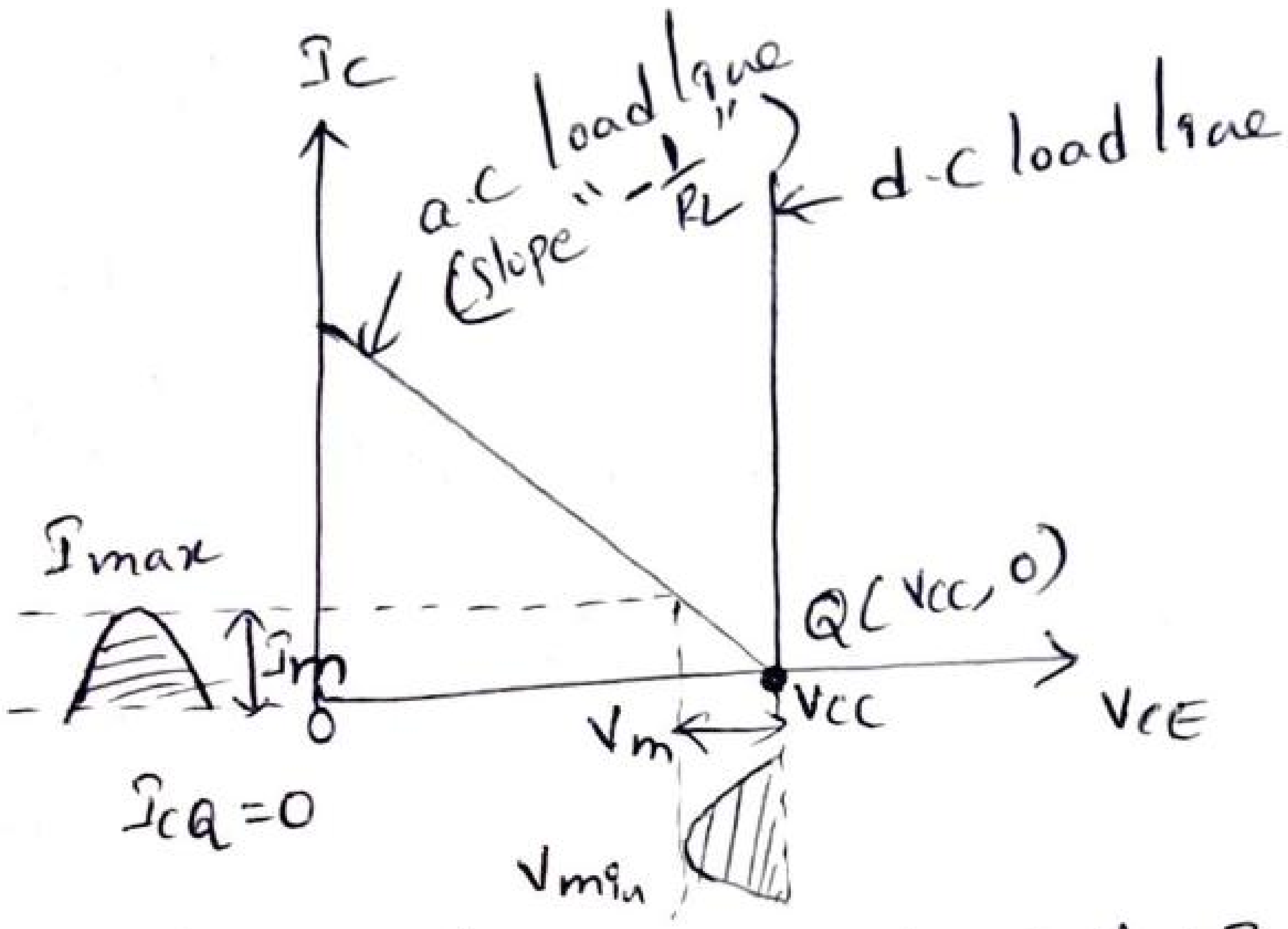


fig: loadlines for push pull class B amplifier

Hence the reflected load on the primary can be written as

$$\boxed{R_L' = \frac{R_L}{n^2}} \quad \text{where} \quad n = \frac{N_2}{N_1}$$

Transformer with turns ratio $2N_1 : N_2$ (output transformer)

$\therefore$ The slope of the a.c load line is $-\frac{1}{R_L'}$ and d.c load line is a vertical line passing through the operating point Q on the x-axis. The slope of ac load line can be expressed in terms of V_m and I_m as

$$\boxed{\frac{1}{R_L'} = \frac{I_m}{V_m}} \qquad \left(\text{i.e, } R_L' = \frac{V_m}{I_m}\right)$$

$I_m \rightarrow$ peak value of the collector current

A.C power output:

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

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

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

Efficiency :

The Efficiency of the class B amplifier can be calculated using the basic Equation

$$\% \eta = \frac{P_{ac}}{P_{dc}} \times 100 = \frac{\frac{V_m I_m}{2}}{\frac{2}{\pi} V_{cc} I_m} \times 100$$

$$\% \eta = \frac{\pi}{4} \cdot \frac{V_m}{V_{cc}} \times 100$$

Maximum value of V_m is V_{cc}

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

$$\boxed{\% \eta_{max} = 78.5\%}$$

In practical we set max Efficiency in the order of 65 to 70%.

power dissipation :

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

$$P_d = P_{dc} - P_{ac} = \frac{2}{\pi} V_{cc} I_m - \frac{V_m I_m}{2}$$

$$= \frac{2}{\pi} V_{cc} \frac{V_m}{R_L'} - \frac{V_m^2}{2 R_L'}$$

when there is no input signal, $V_m = 0$, power dissipation is zero and not the maximum. maximum power dissipation will be obtained by differentiating the above Equation w.r.t V_m and Equating it to zero.

$$\frac{dP_d}{dV_m} = \frac{2 V_{cc}}{\pi R_L'} - \frac{2 V_m}{2 R_L'} = 0$$

$$\Rightarrow \boxed{V_m = \frac{2}{\pi} V_{cc}}$$

$$\therefore (P_d)_{max} = \frac{2}{\pi} V_{cc} \left(\frac{2}{\pi} V_{cc}\right) \frac{1}{R_L'} - \left(\frac{2}{\pi} V_{cc}\right)^2 \frac{1}{2 R_L'}$$

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

Harmonic Distortion:

The base currents are in sinusoidal in nature and given by

$$i_{b_1} = I_{Bm} \cos\omega t \quad , \quad i_{b_2} = -I_{Bm} \cos\omega t$$

$\uparrow$ 180° out of phase

The collector currents of both the transistors can be expressed as

$$i_{c_1} = I_{CQ} + B_0 + B_1 \cos\omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + \cdots$$

$$i_{b_2} = -I_{Bm} \cos\omega t = I_{Bm} \cos(\omega t + \pi)$$

$$i_{C_2} = I_{CQ} + B_0 + B_1 \cos(\omega t + \pi) + B_2 \cos 2(\omega t + \pi) + \cdots$$

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

$I_L = i_{c_1} - i_{c_2}$ (Both the currents are in opposite direction)

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

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

$$I_L = 2 B_1 \cos 2\omega t + B_3 \cos 3\omega t + \cdots$$

from the above load current equation, it is evident that only even harmonics are eliminated and also d.c components ~~are~~ eliminated.

Hence the total distortion is less and d.c component flowing is zero.

The percentage of harmonic distortion is only due to odd harmonics and is given by

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

Total harmonic distortion

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

Advantages:

1. Efficiency is much higher than class A.
2. No power dissipation when there is no input signal
3. Even harmonics are eliminated there by decrease in harmonic distortion.
4. Due to transformer, impedance matching is possible
5. The current components flows in opposite direction and hence d.c saturation becomes zero.

Disadvantages:

1. Two Center tapped transformers are required.
2. Because of transformers circuit is bulky and costlier
3. Frequency response is poor.

Higher order Harmonic Distortion (Five point method): Continuation of Second harmonic distortion

As the non linearity in the dynamic characteristics increases, the order of the harmonic distortion also increases. The Collector current Expression due to higher order harmonics is given by

$$i_C = G_1 i_b + G_2 i_b^2 + G_3 i_b^3 + G_4 i_b^4$$

where, $i_b = I_{Bm} \cos \omega t$

$$\therefore i_C = G_1 I_{Bm} \cos \omega t + G_2 I_{Bm}^2 \cos^2 \omega t + G_3 I_{Bm}^3 \cos^3 \omega t + G_4 I_{Bm}^4 \cos^4 \omega t$$

Substituting $\cos^2 \omega t$, $\cos^3 \omega t$ and $\cos^4 \omega t$ and doing trignometric operations, we get

$$i_C = B_0 + B_1 \cos \omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + B_4 \cos 4\omega t$$

The above Equation Consists of 4^{th} older harmonics.

The total Collector Current including d.c bias Can be Expressed as

$$i_C = \underbrace{I_{CQ} + B_0}_{\text{D.C component}} + B_1 \cos \omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + B_4 \cos 4\omega t$$

$B_1, B_2, B_3, B_4 \rightarrow$ Amplitudes of fundamental, Second, third & fourth harmonic Components respectively.

Consider five instants as shown in the figure.

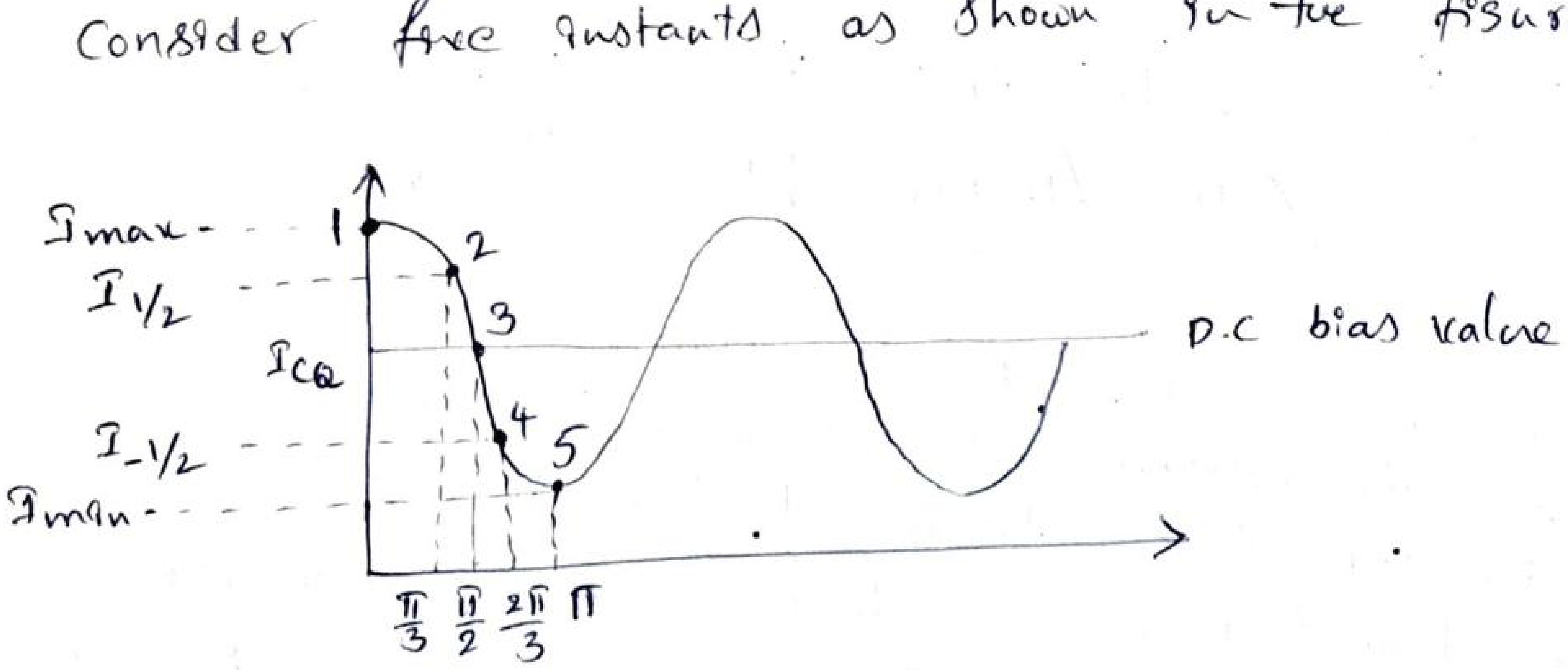


Fig: output current waveform

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

$$I_{max} = I_{CQ} + B_0 + B_1 + B_2 + B_3 + B_4$$

At point 2, $\omega t = \pi/3$, $i_c = I_{1/2}$

$$I_{1/2} = I_{CQ} + B_0 + 0.5 B_1 - 0.5 B_2 - B_3 - 0.5 B_4$$

At point 3, $\omega t = \pi/2$, $i_c = I_{CQ}$

$$I_{CQ} = I_{CQ} + B_0 - B_2 + B_4$$

At point 4, $\omega t = \frac{2\pi}{3}$, $i_c = I_{-1/2}$

$$I_{-1/2} = I_{CQ} + B_0 - 0.5 B_1 - 0.5 B_2 + B_3 - 0.5 B_4$$

At point 5, $\omega t = \pi$, $i_c = I_{min}$

$$I_{min} = I_{CQ} + B_0 - B_1 + B_2 - B_3 + B_4$$

Solving the above 5 Equations, we get the values of B_0, B_1, B_2, B_3 and B_4 as

$$B_0 = \frac{1}{6}\left[I_{max} + 2 I_{1/2} + 2 I_{-1/2} + I_{min} \right]$$

$$B_1 = \frac{1}{3}\left[I_{max} + I_{1/2} - I_{-1/2} - I_{min} \right]$$

$$B_2 = \frac{1}{4}\left[I_{max} - 2 I_{CQ} + I_{min} \right]$$

$$B_3 = \frac{1}{6}\left[I_{max} - 2 I_{1/2} + 2 I_{-1/2} - I_{min} \right]$$

$$B_4 = \frac{1}{12}\left[I_{max} - 4 I_{1/2} + 6 I_{CQ} - 4 I_{-1/2} + I_{min} \right]$$

The harmonic distortion coefficients can be obtained as

$$D_n = \frac{|B_n|}{|B_1|}$$

The above method uses 5 points on the o/p waveform to obtain the amplitudes of the various orders of harmonics, the method is called "five point method".

power output due to distortion:

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

The output power with harmonic distortion is

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

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

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

let $D^2 = D_2^2 + D_3^2 + \cdots + D_r^2$

where D is the total harmonic distortion

$$\therefore \boxed{(P_{ac})_D = P_{ac}\left[1 + D^2\right]}$$

Complementary Symmetry ClassB amplifier:

In this amplifier, the two transistors used are npn and pnp. This circuit doesnot consist any transformer. But with CE configuration, it becomes very difficult to match the output impedance for maximum power transfer without output transformer. Hence, matched pair of complementary transistors are used in common collector configuration in this circuit. The basic circuit diagram for complementary symmetry class B amplifier is shown below.

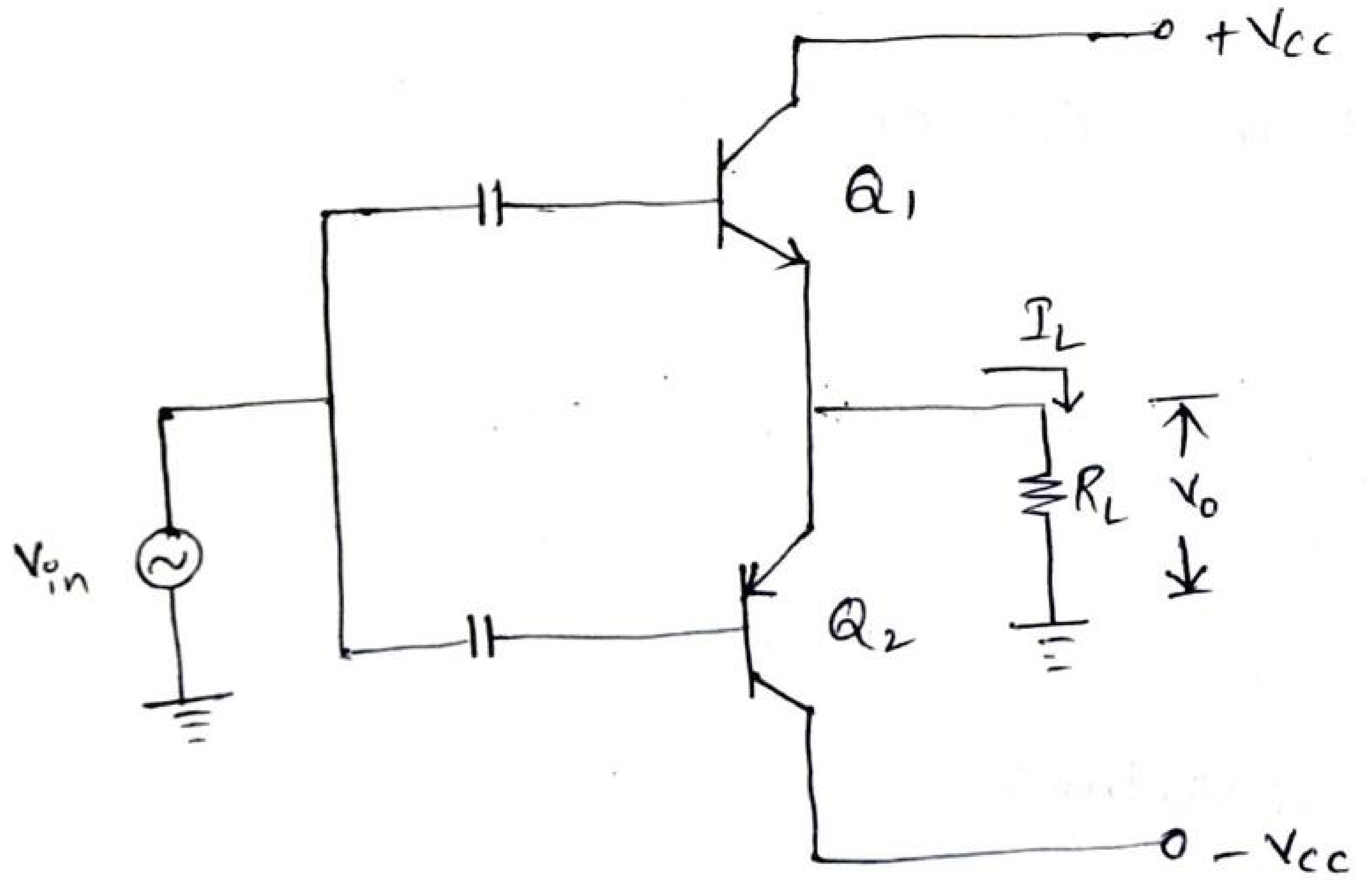


Fig: Complementary Symmetry ClassB amplifier.

when positive half cycle of the input signal is applied to Q_1 and Q_2 transistors, Q_1 will become on and Q_2 becomes off. This results a positive half cycle across the load R_L and it is shown below.

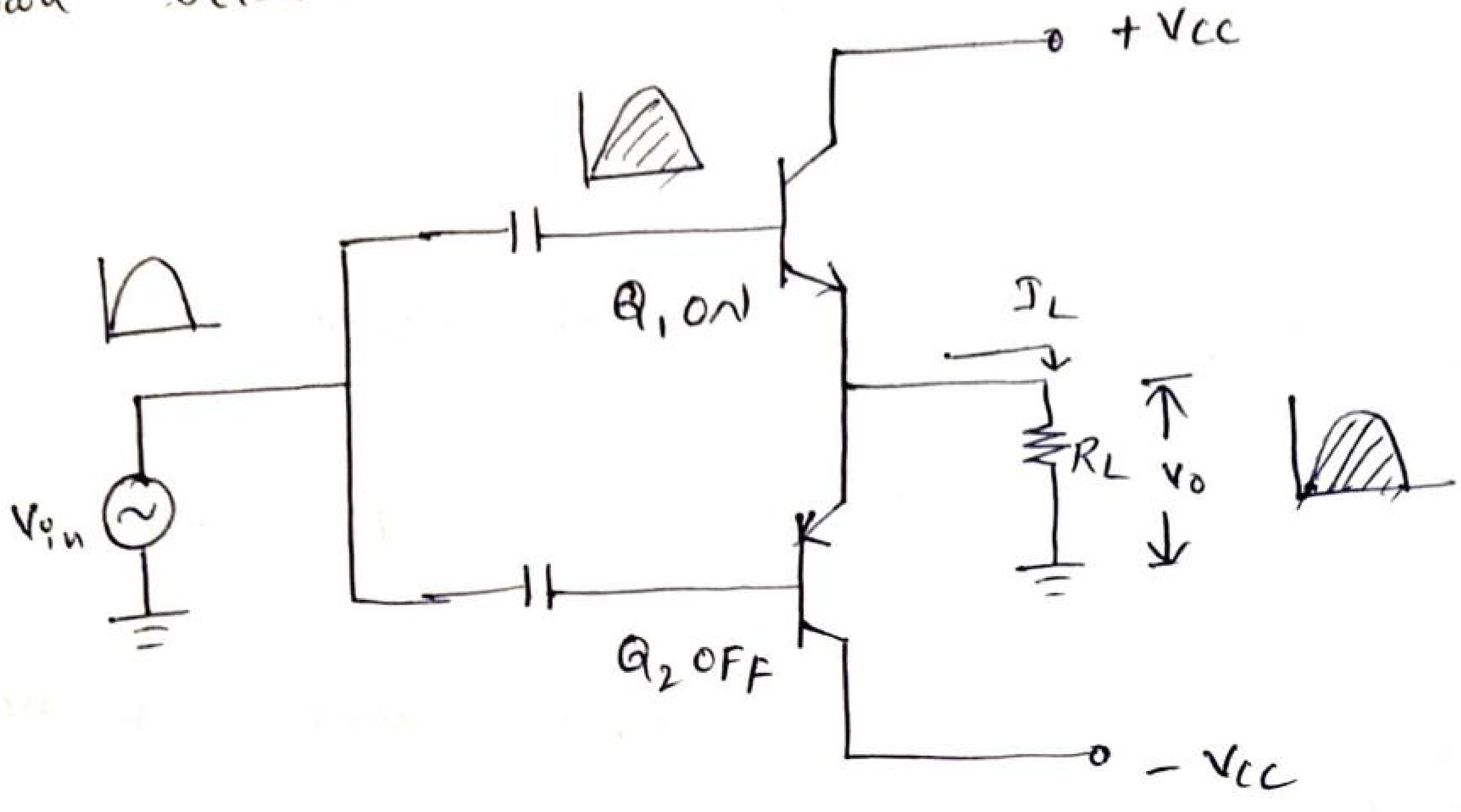


Fig: For positive half cycle

During negative half cycle of the input signal, Q_1 becomes off and Q_2 becomes on. The diagram for negative half cycle is shown below.

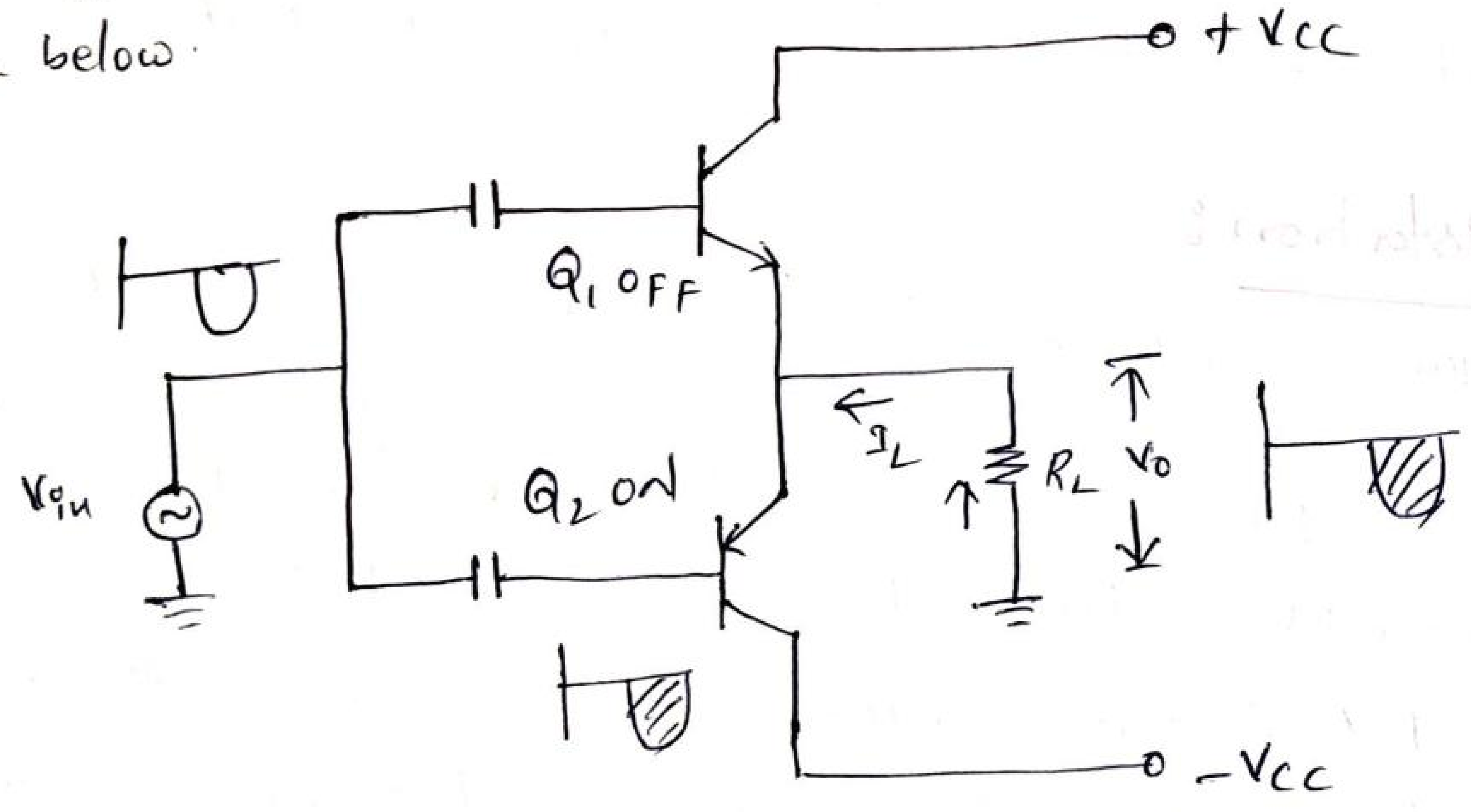


Fig: For negative half cycle

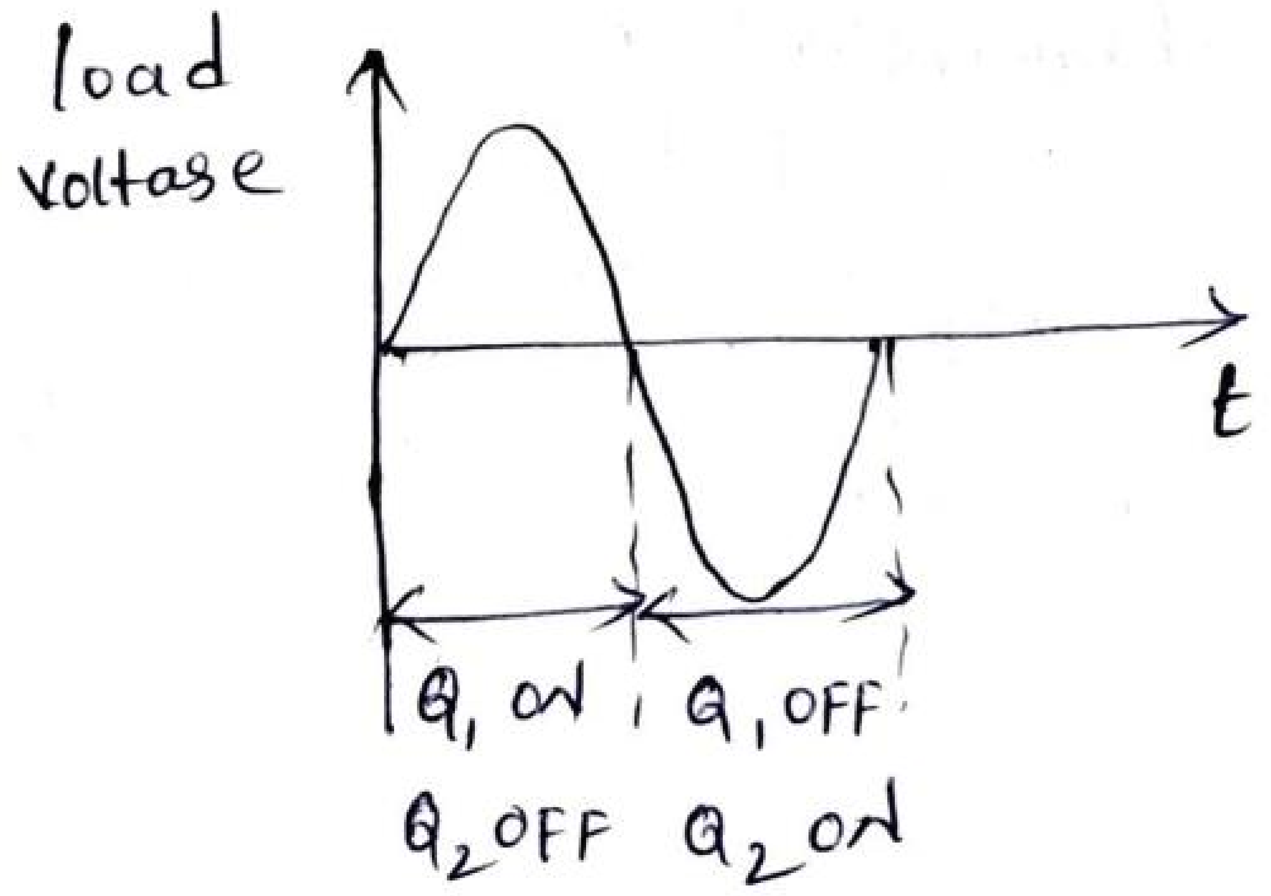


Fig: output voltage waveform

Mathematical Analysis :

The ~~basic~~ derivations of push pull transformer Coupled class B amplifier holds good for Complementary Symmetry class B amplifier. The only change is R_L must be used instead of R_L'.

Advantages :

1. It doesnot use transformer, as a result weight, size and cost is less
2. Due to common Collector Configuration, impedance matching is possible.
3. The frequency response improves due to transformer not used in this method.

Disadvantages :

1. It requires two power Supplies
2. The output is distorted due to cross over distortion.

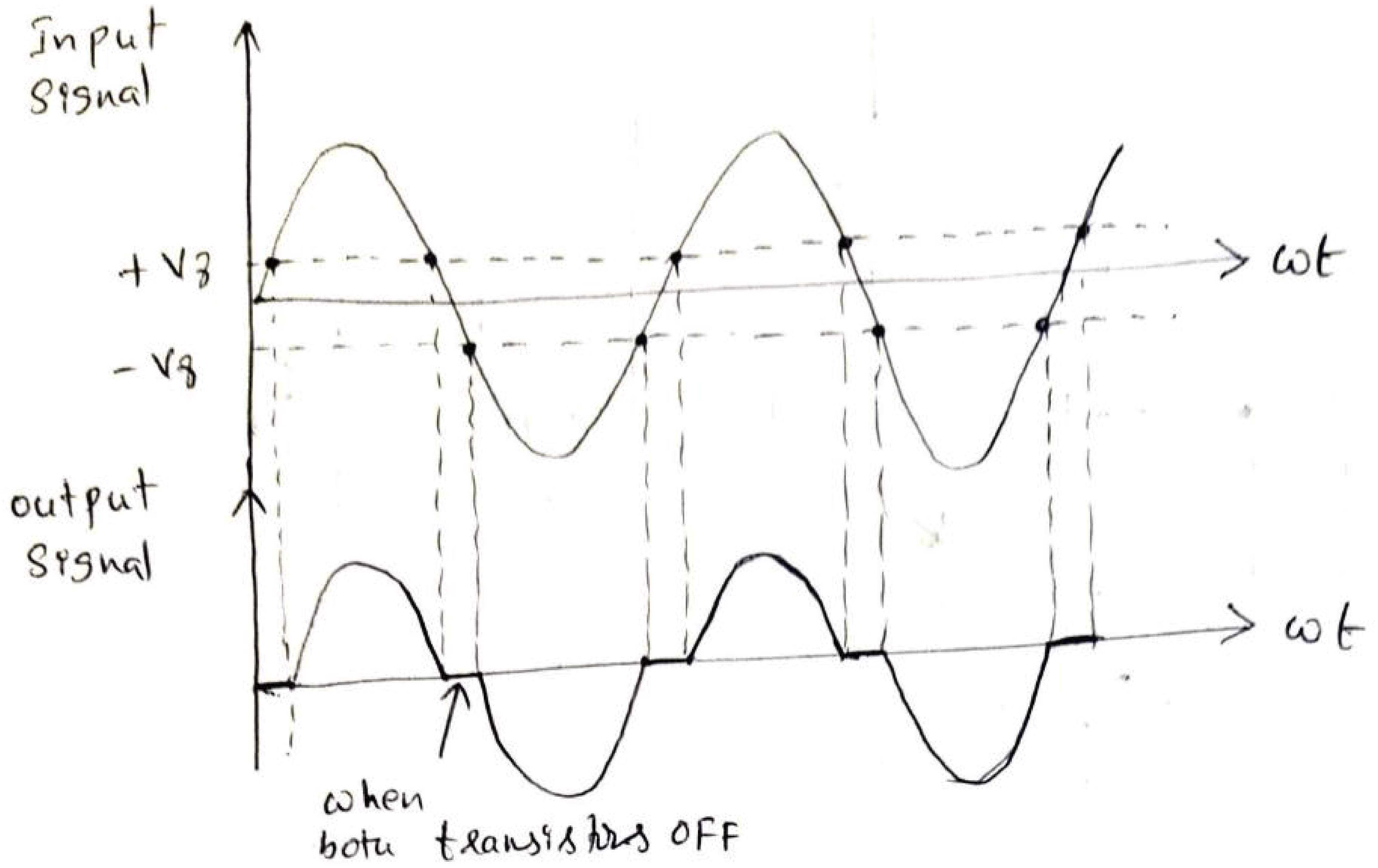
Crossover distortion :

The cross over distortion occurs in both the types of class B amplifiers. Because, for a transistor, it requires a voltage of 0.7 V to enter into ~~active~~ forward bias incase of a Si transistor. When the ~~i/p~~ applied input voltage is less than 0.7 V (cut in voltage of base Emitter junction), the collector Current remain zero and the transistor remains in Cutoff region.

WhenEver two transistors are used in the circuit and only one transistor is Conducted for one half cycle of the input signal, the output gets distorted for Both positive half cycle and negative half cycle because of V_γ.

Scanned by TapScanner

The distorted output waveform is shown below.



Fig; Cross over distortion

The distortion that occurs in the output signal is known as cross over distortion.

Elimination of cross over distortion:

The crossover distortion is because of the cut in voltage of the transistor. To overcome this a small forward bias is applied to the transistors.

There are two types of amplifiers that uses forward bias voltage. They are

1. pushpull class AB amplifier
2. Complementary symmetry class AB amplifier.

1. push pull class AB amplifier:

The forward bias voltage to base Emitter junction of each transistor is provided by using a diode as shown in the following figure.

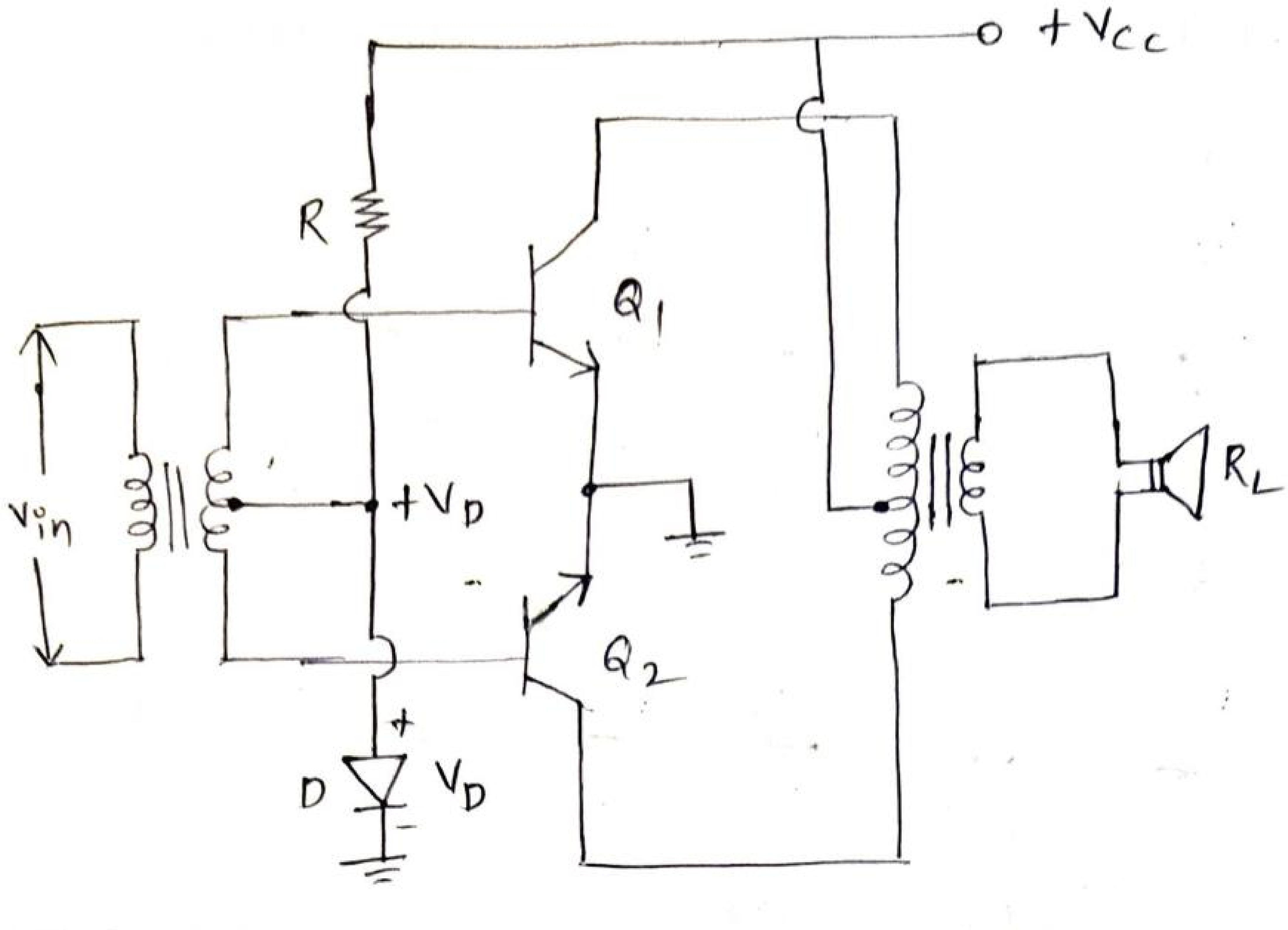


Fig: used diode.

Because of the diode 'D' used in the above circuit, the crossover distortion is eliminated. But the operating point 'Q' shifts upwards on the load line. Hence, the operation of the amplifier is no longer in class B, but it becomes class AB operation.

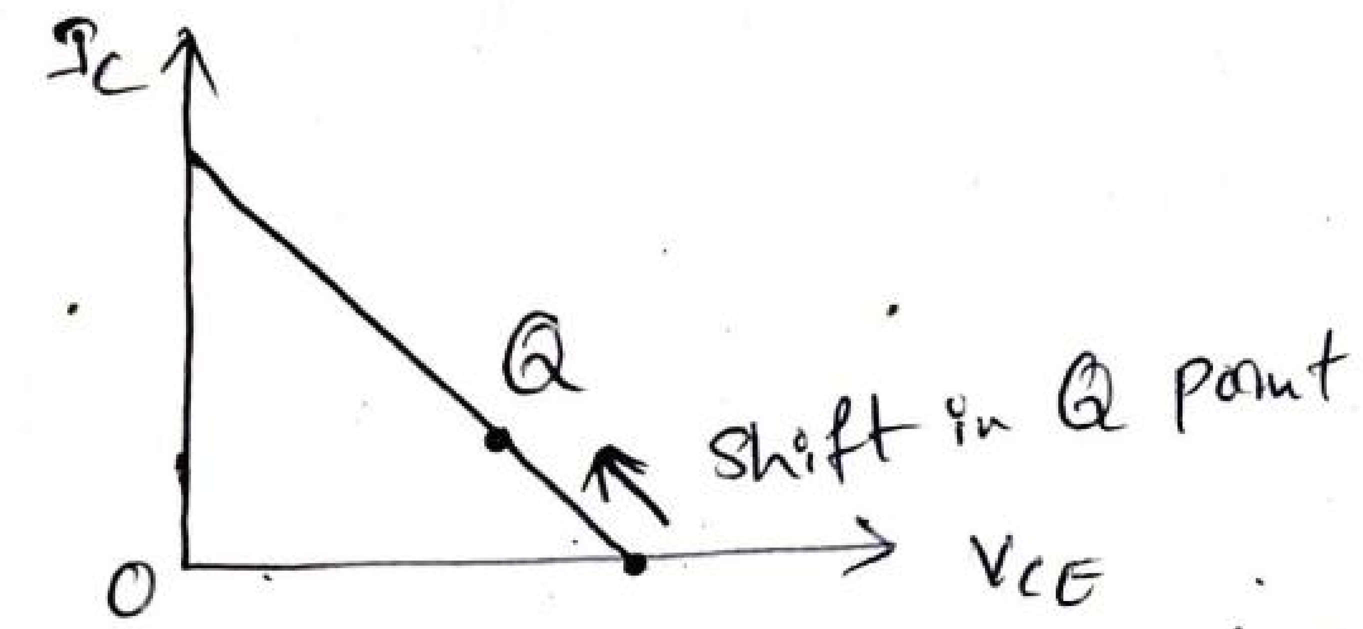


Fig: operating point in class AB.

2. Complementary Symmetry class AB amplifier :

In pushpull amplifier, only one diode is sufficient to provide the cut in voltage. Incase of Complementary Symmetry base Emitter junctions of Q_1 & Q_2 required to provide fixed bias. For both transistors (assume Silicon) a fixed bias of $0.7+0.7 = 1.4\,V$ is required. This is achieved by the use of potential divider as shown in the figure.

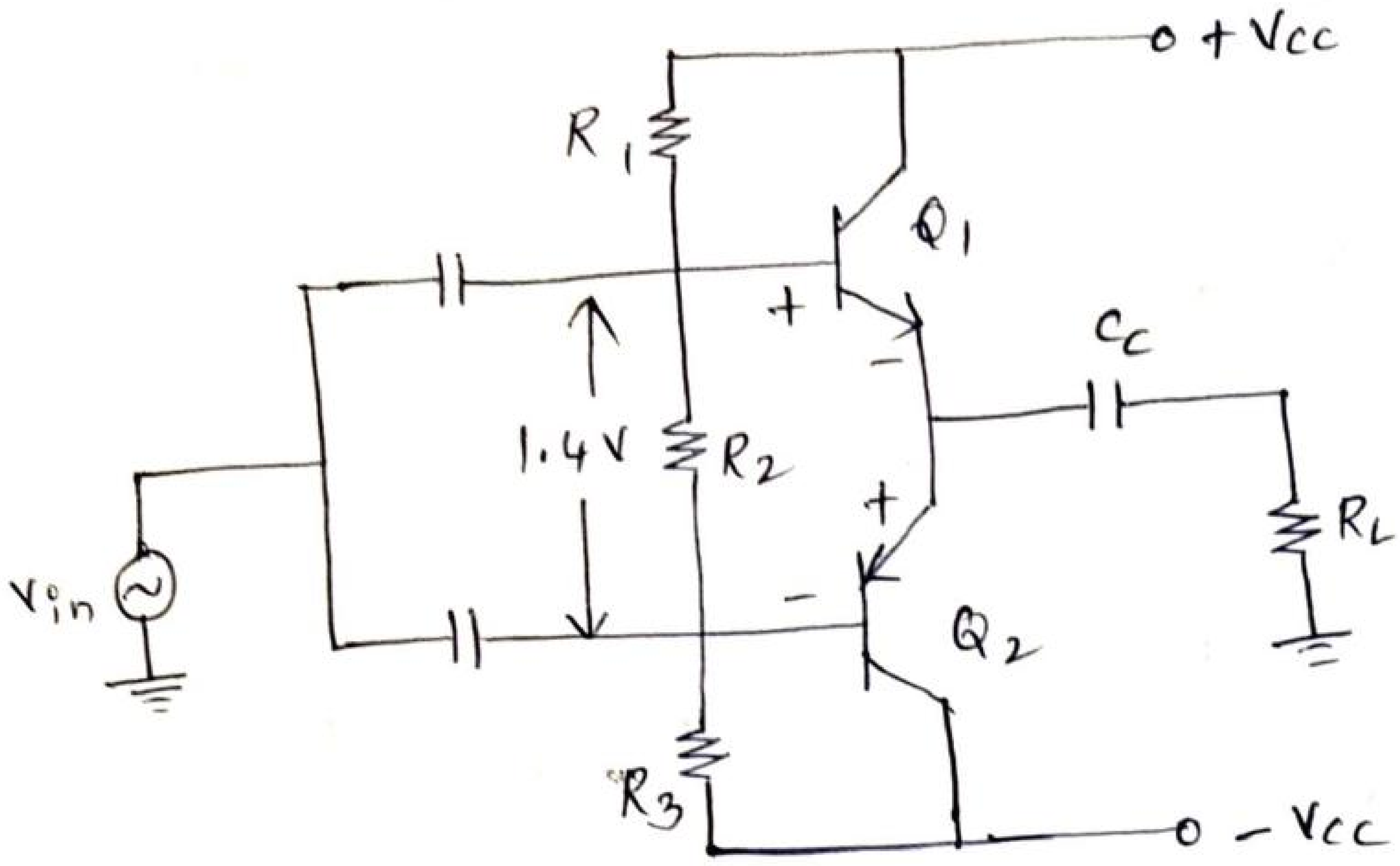


Fig: By using potential divider

Junction voltages changes w.r.t temperature. In the above figure, R_2 can be replaced by two diodes connected in series as shown in the figure.

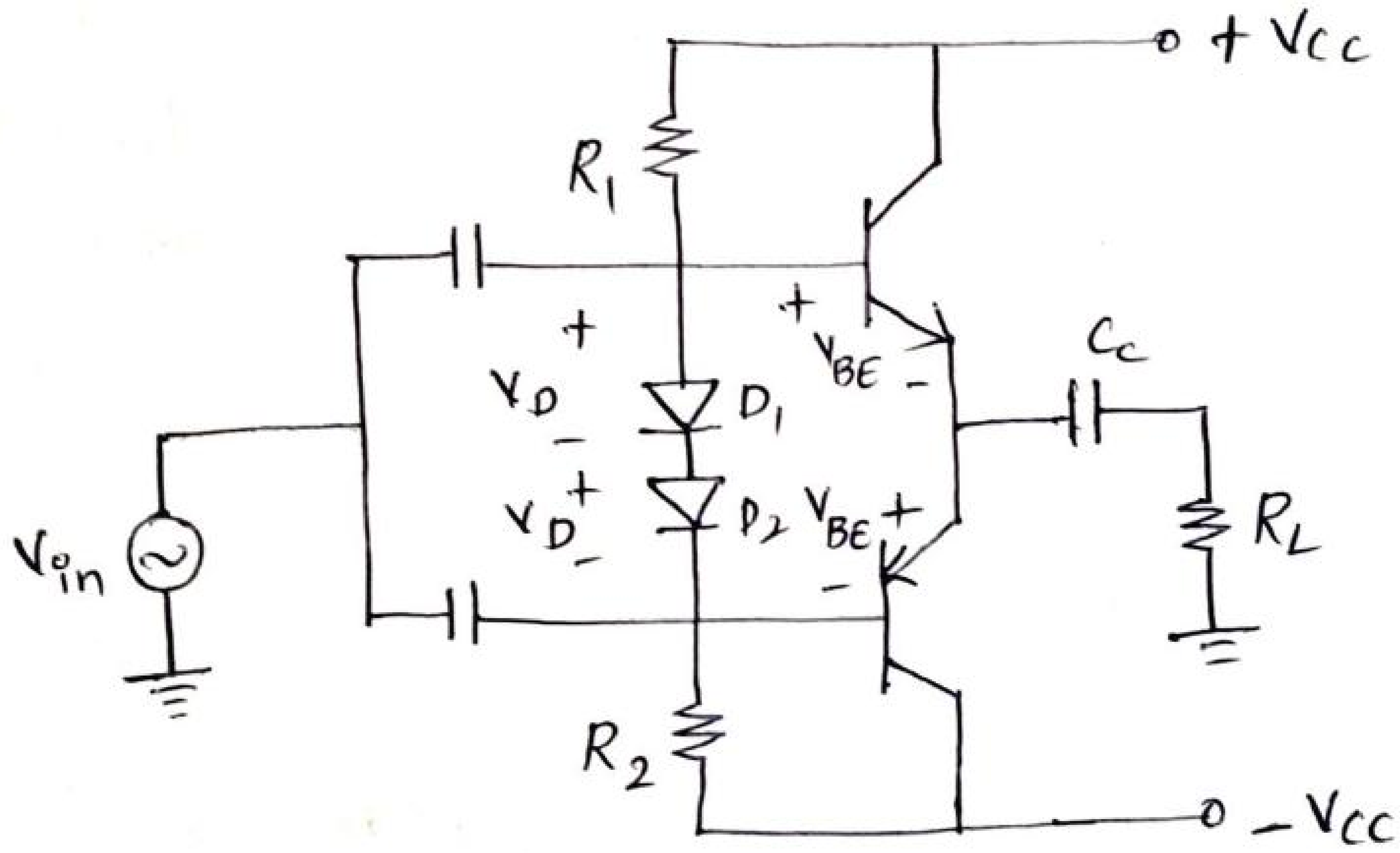


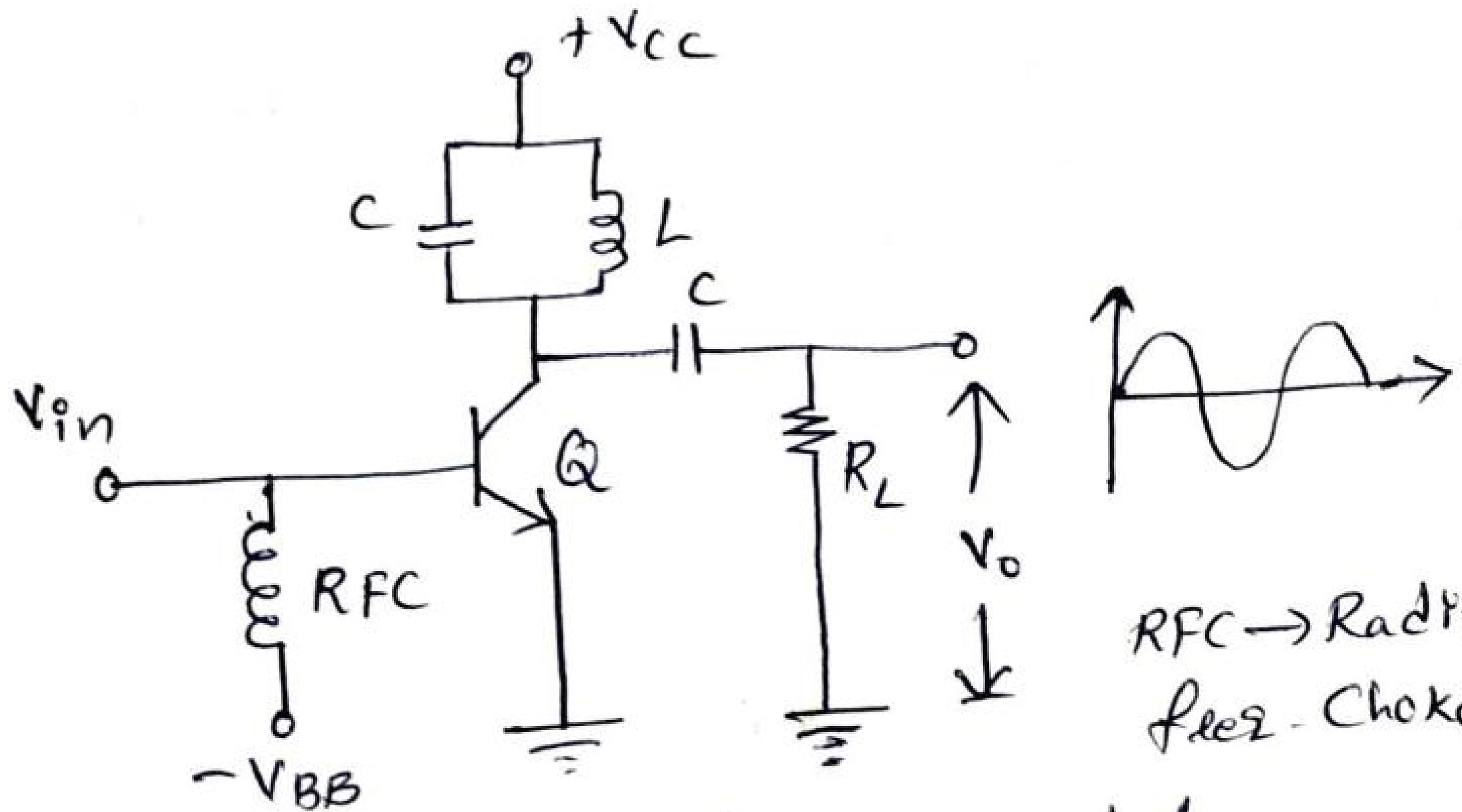
Fig: By using two diodes.

Class C Amplifier:

In class C amplifier, a resonant circuit is used as a load. Most of the class-C amplifiers are tuned amplifiers.

Resonant frequency:

The basic circuit for class C tuned amplifier is shown in the figure.



RFC → Radio freq. Choke

Fig: Class C tuned amplifier.

The waveform for class C operation is shown below

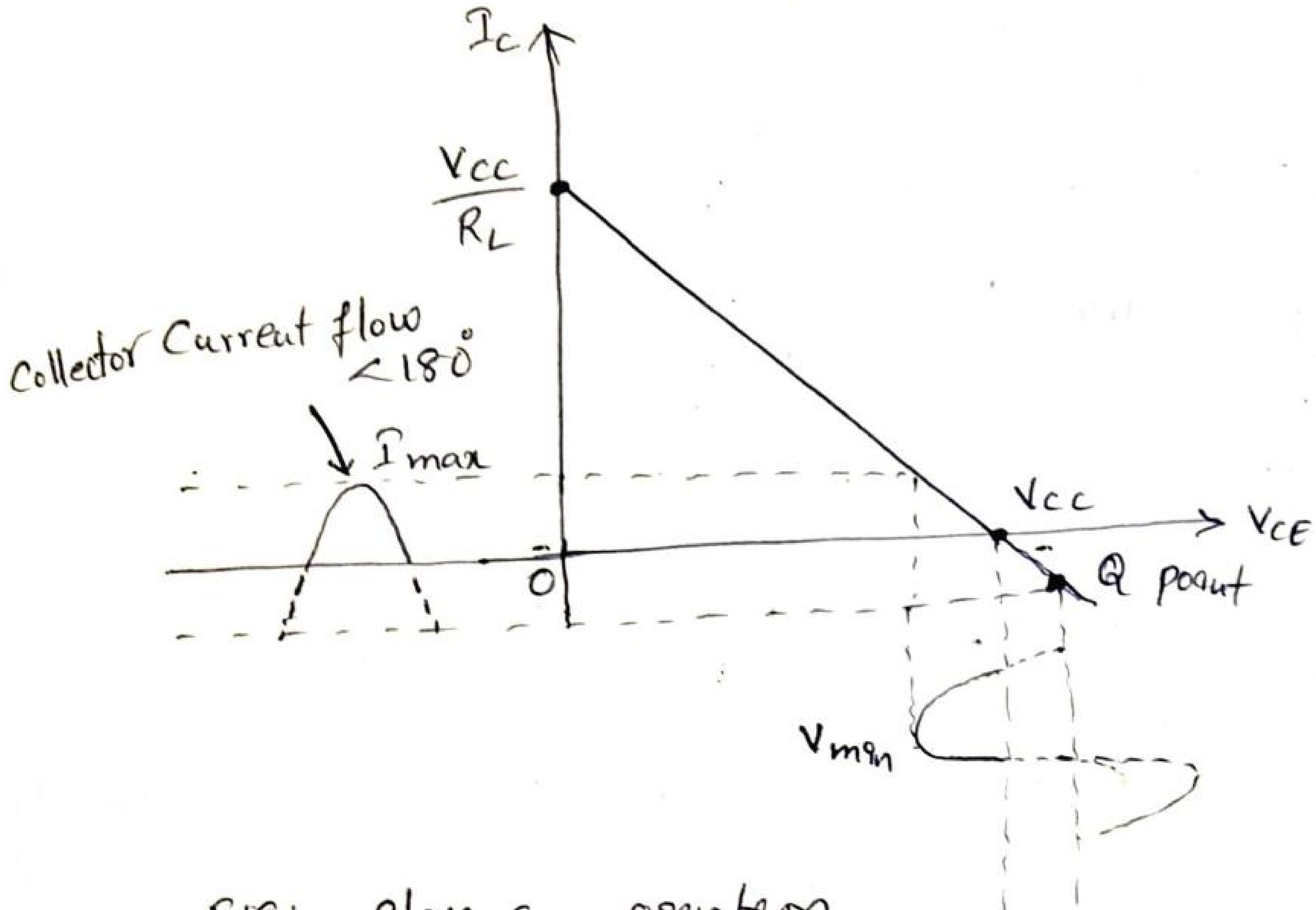


Fig: class C operation

In class C, the collector current flows less than half a cycle of the
hence it consists of a series of pulses with the harmonics of the
input signal. A parallel tuned circuit acting as a load is tuned
to the ~~harmonic freq~~ input frequency. It filters the harmonic
frequencies and produce a sine wave output containing fundamental
component of the input signal. Input a.c signal is applied at base
and output is collected at collector. This is output is a inverted
and is connected to load resistance R_L through coupling capacitor.
The output voltage is maximum at resonant frequency. The resonant
frequency is given by

$$\boxed{f_r = \frac{1}{2\pi\sqrt{LC}}}$$

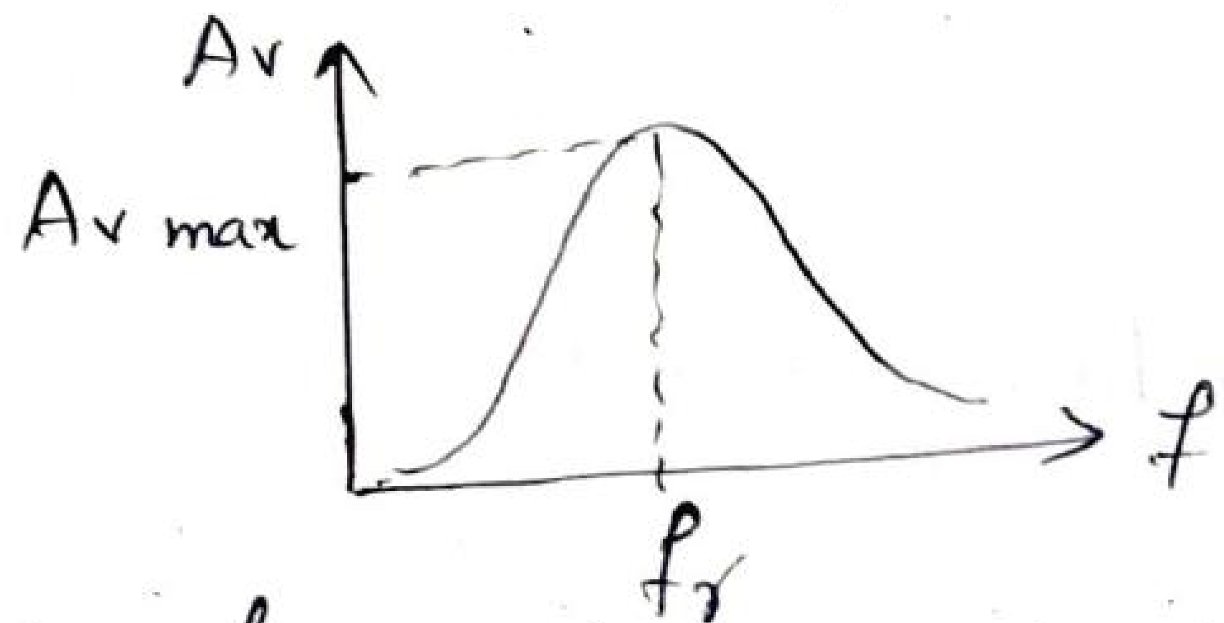


fig: Frequency response

From the frequency response waveform, the gain drops on both the sides of resonant frequency. These amplifiers are used to amplify only narrowband of frequencies.

Loadlines: The d-c Equivalent circuit for unbiased class C amplifier is shown in the figure.

R_S is the Series Resistance of the inductor L. R_S is normally a very low value. For d-c Capacitor 'C' acts as a open circuit and it does not affect the d-c operation.

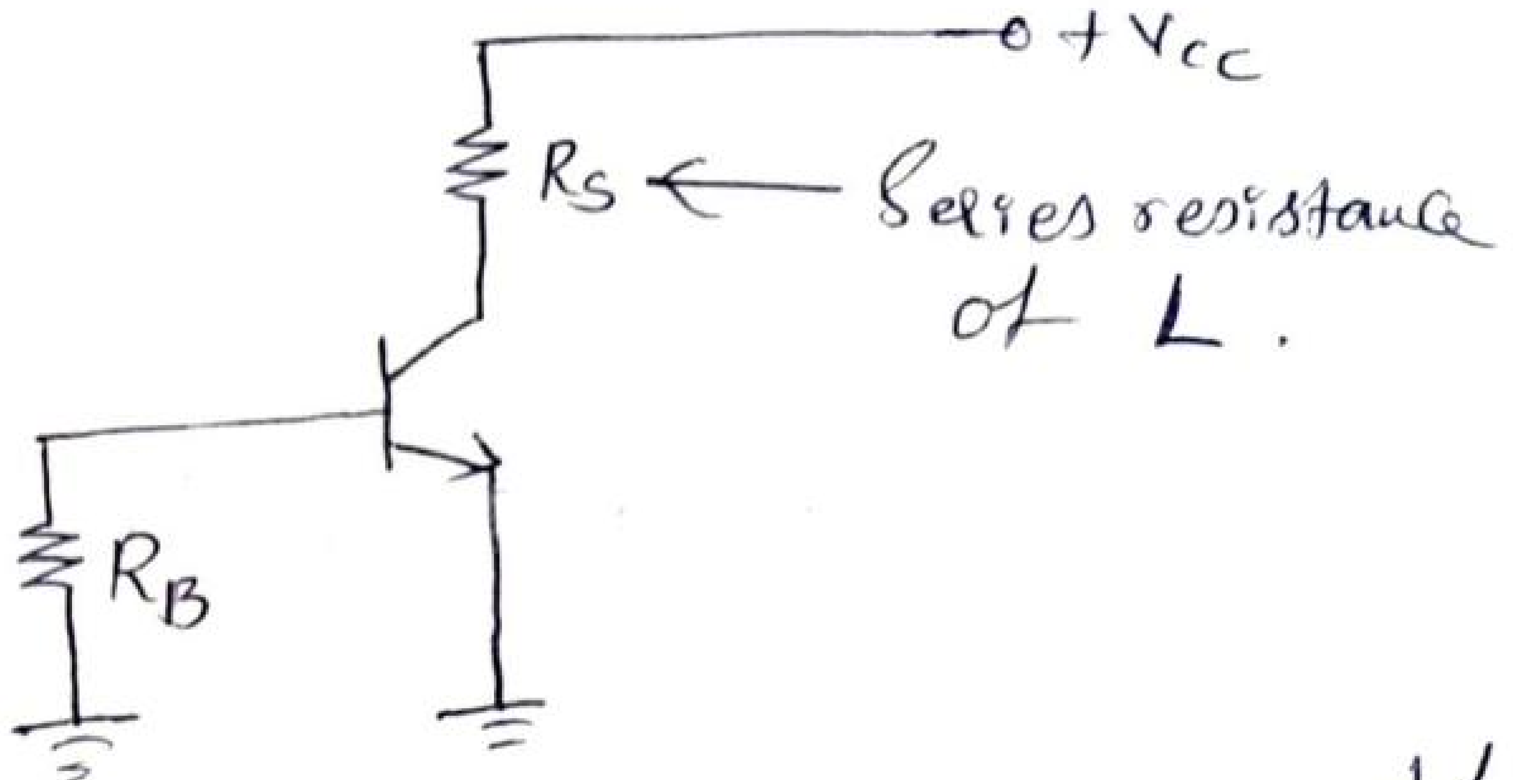


fig: DC Equivalent of class C amplifier

The slope of the d-c loadline is reciprocal of R_S and it is very high value (infinity) means the d-c loadline is vertical.

For a-c loadline 'Q' point is designated at the lower End of the a-c loadline. when a-c input Signal is applied, a-c operating point moves up towards Saturation point. The maximum value of Collector Current when $V_{CE}=0$ is V_{CC}/r_c. The load lines are shown in the above figure.

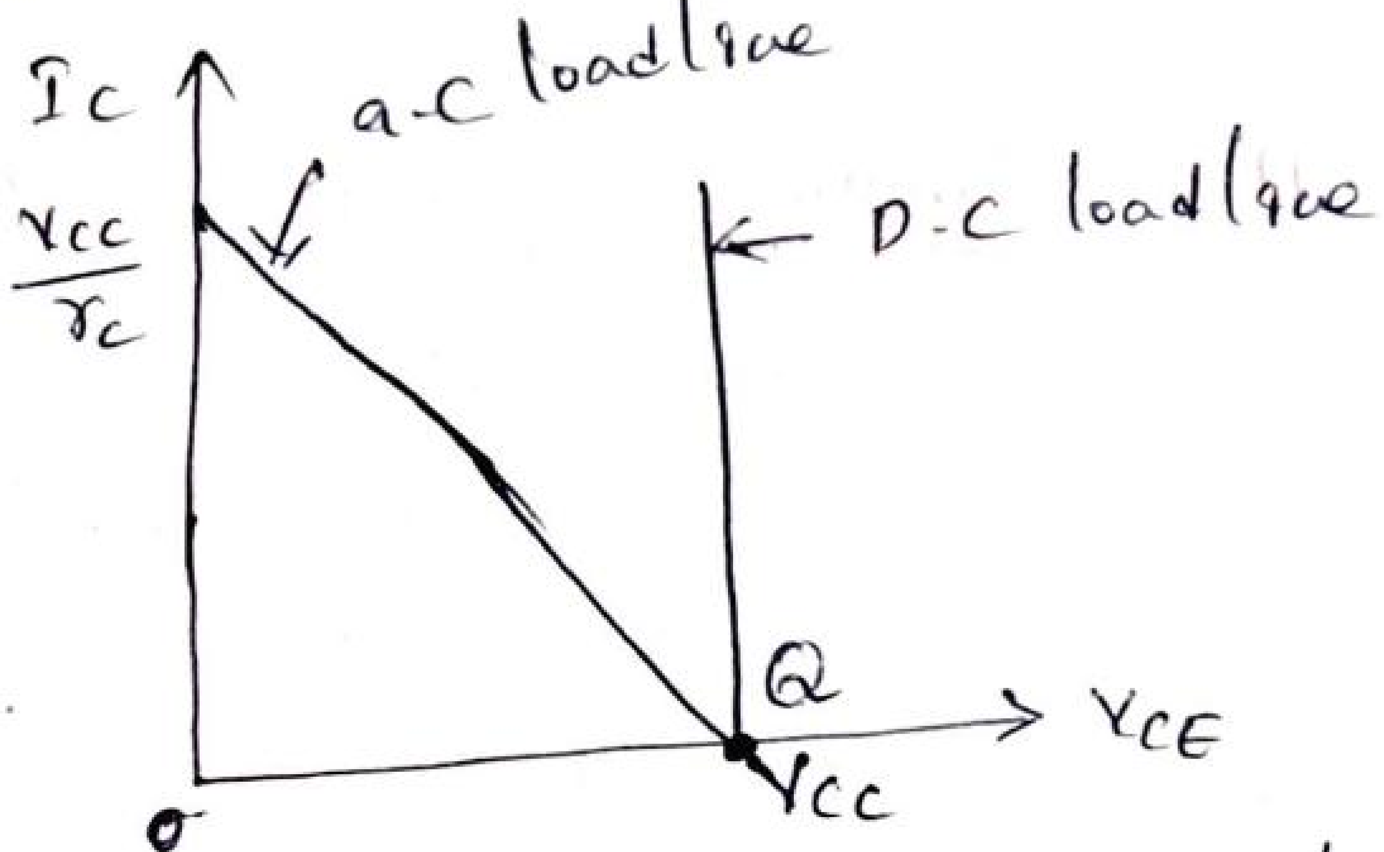


fig: loadlines for class C amplifier

A.C Equivalent circuit:

The a-c Equivalent circuit of class C amplifier is shown below

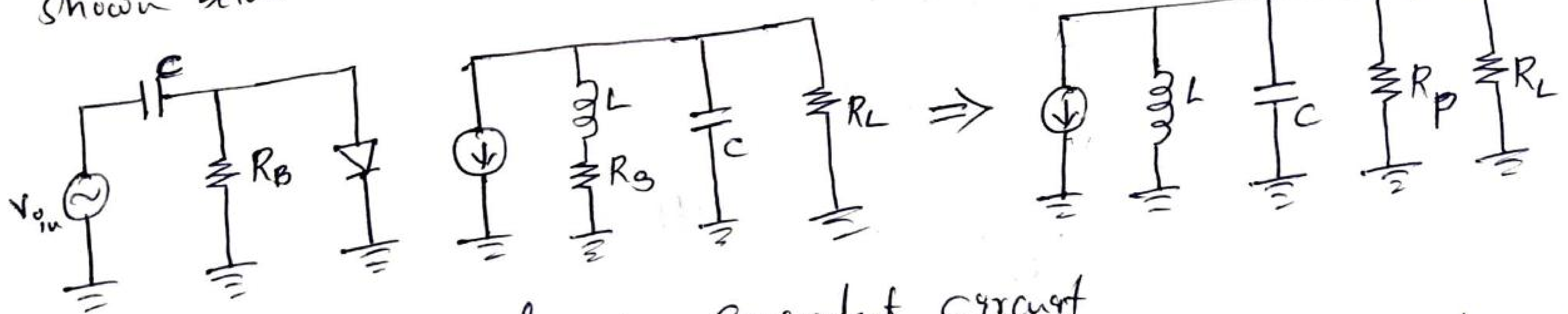


fig: A.C Equivalent circuit

Inductor has a Series Resistance R_S and the Quality factor 'Q' of the inductor is

$$\boxed{Q_L = \frac{X_L}{R_S} = \frac{\omega_r L}{R_S}}$$

$Q_L \rightarrow$ Quality factor of coil
$X_L \rightarrow$ Inductive reactance of coil
$R_S \rightarrow$ Series coil resistance

The Series resistance R_S Can be replaced by a parallel resistance R_P.

$$\boxed{R_P = Q_L \omega_r L = Q_L X_L}$$

At resonance, X_L Cancels X_C and hence only R_P remains in parallel with R_L. The total a.c resistance at collector is

$$r_c = R_P \parallel R_L$$

The overall circuit Q factor is given by

$$Q = \frac{r_c}{\omega_r L} = \frac{r_c}{X_L}$$

D.C clamping of input Signal :

The input capacitor with Emitter diode forms a Clamper Circuit and hence signal available across the Emitter diode is a negatively clamped. The waveform along with the circuit is shown below.

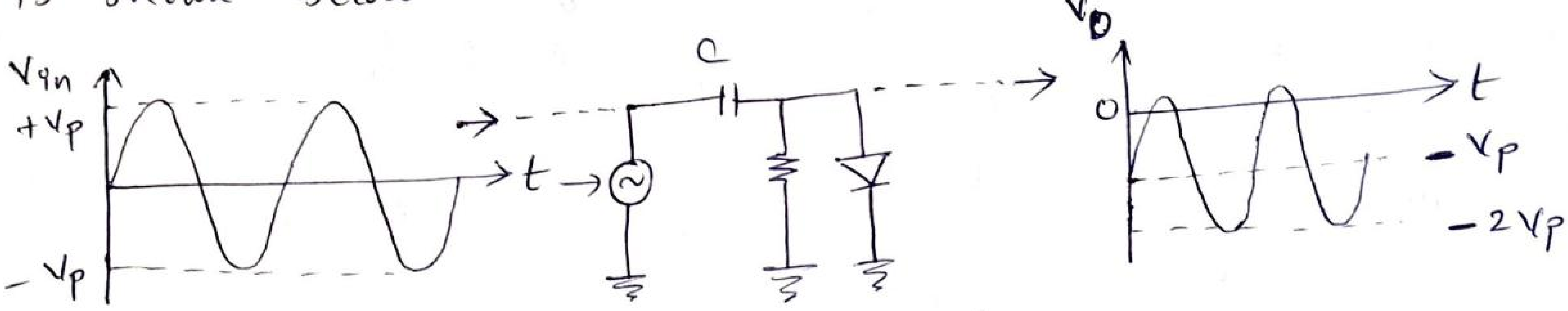
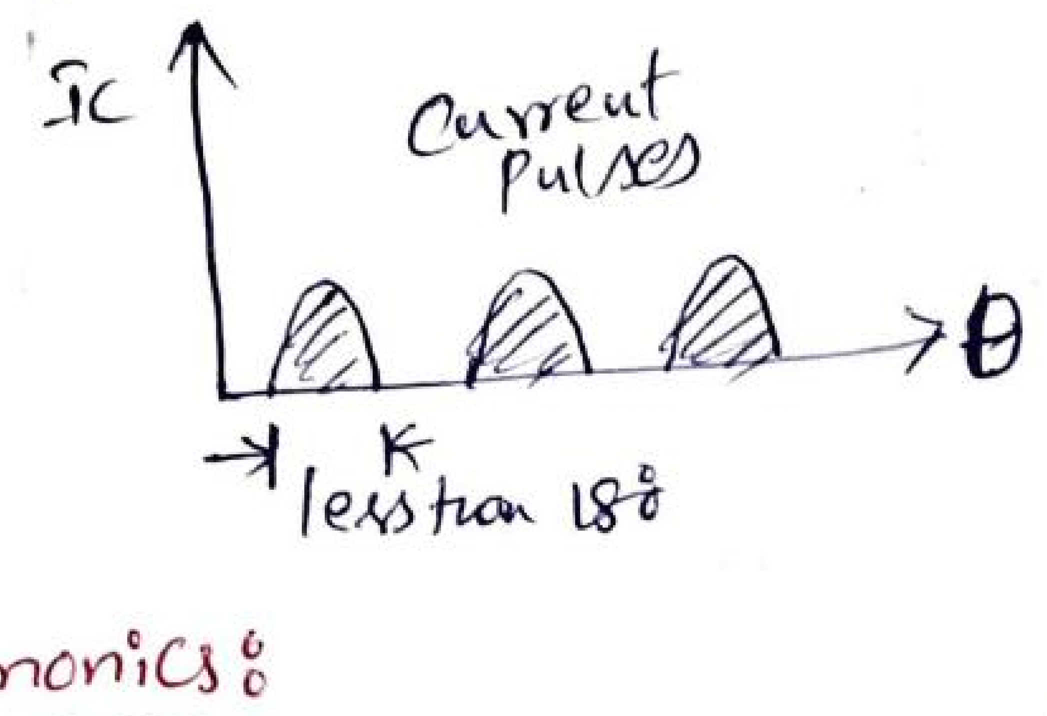


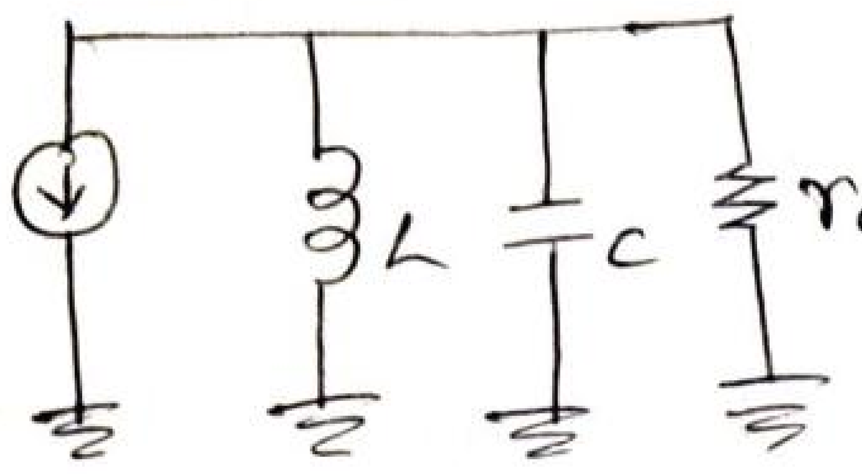
Fig: DC Clamping of input

The input is clamped by $-V_P$. only positive peaks of the input Can turn on the Emitter diode. Hence the Current flows in brief Pulses and it is Shown in the figure.



Filtering the harmonics:

The current pulses Consist of harmonics i.e. f, 2f, 3f, ... nf. At fundamental frequency, the impedance of the tank circuit is high and it produces large voltage gain. For all other harmonics, the tank Circuit impedance is low and the Corresponding Voltage gain is also low. Hence all other harmonics are filtered and a pure sine wave of fundamental frequency appears across the tank circuit as shown in the figure.



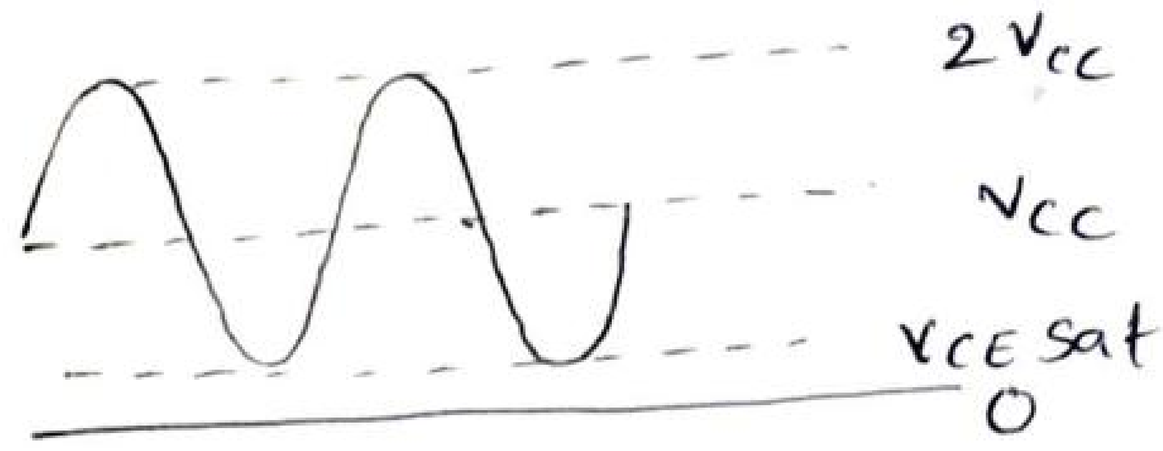
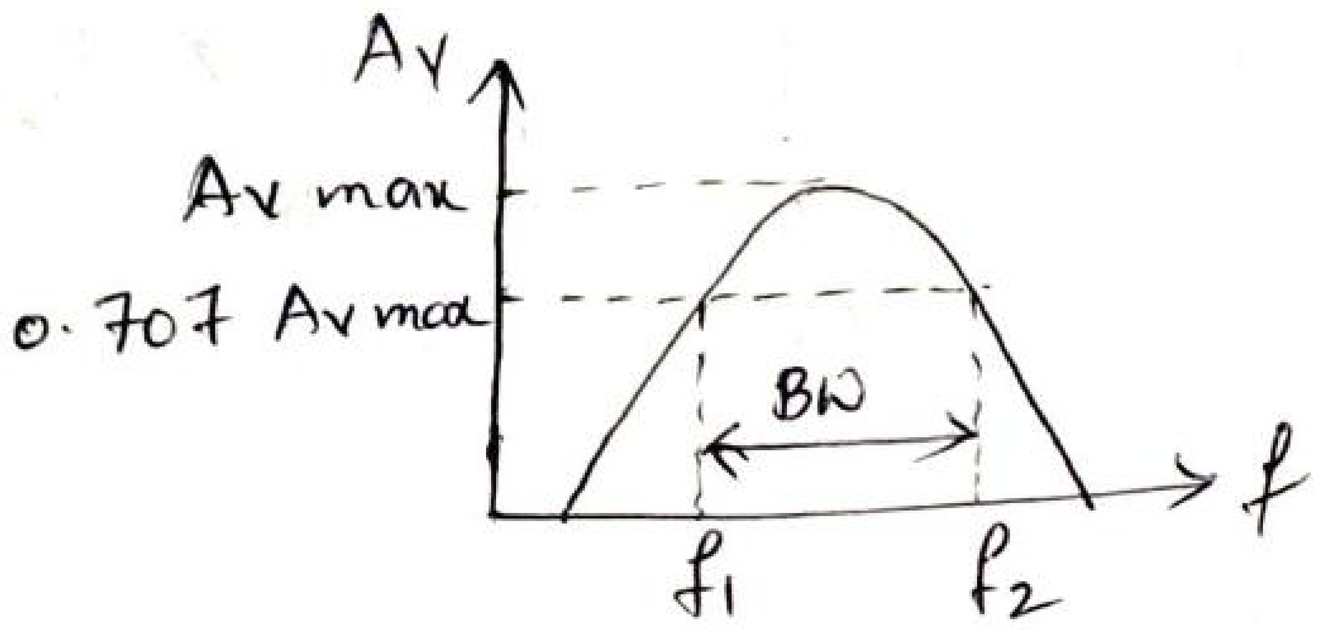


Fig: Collector voltage waveform

Bandwidth: The bandwidth of the resonant circuit is defined as

$BW = f_2 - f_1$

$f_2 \rightarrow$ upper half power frequency (3 dB)
$f_1 \rightarrow$ lower half power frequency (3 dB)

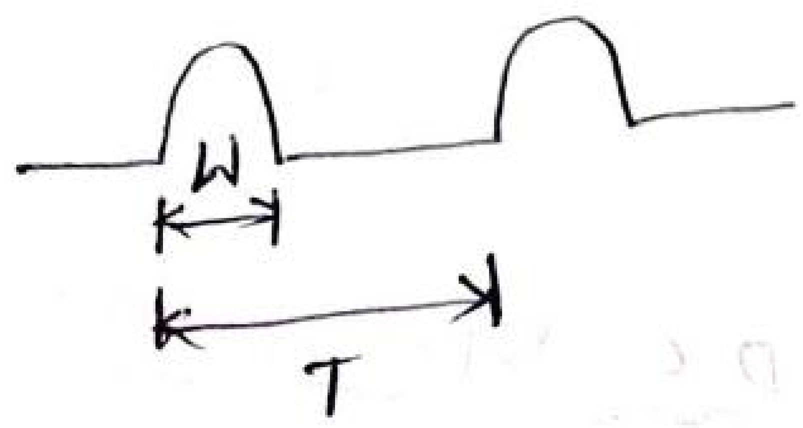


The bandwidth of class c tuned amplifier is $BW = \frac{f_r}{Q}$

Duty cycle: It is the ratio of ON period of the transistor to total period of the pulses.

Duty cycle $= D = \frac{W}{T}$

$W \rightarrow$ width of pulse
$T \rightarrow$ period of pulse



output power:

The rms value of output voltage across load resistance is measured then the output power is given by

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

we know that $V_{PP} = 2V_m$
$= 2\sqrt{2}\, V_{rms}$

$$\therefore P_{out} = \frac{(V_{PP}/2\sqrt{2})^2}{R_L} = \frac{V_{PP}^2}{8R_L}$$

Transistor dissipation:

The maximum output of a class c tuned amplifier is shown in the following figures.

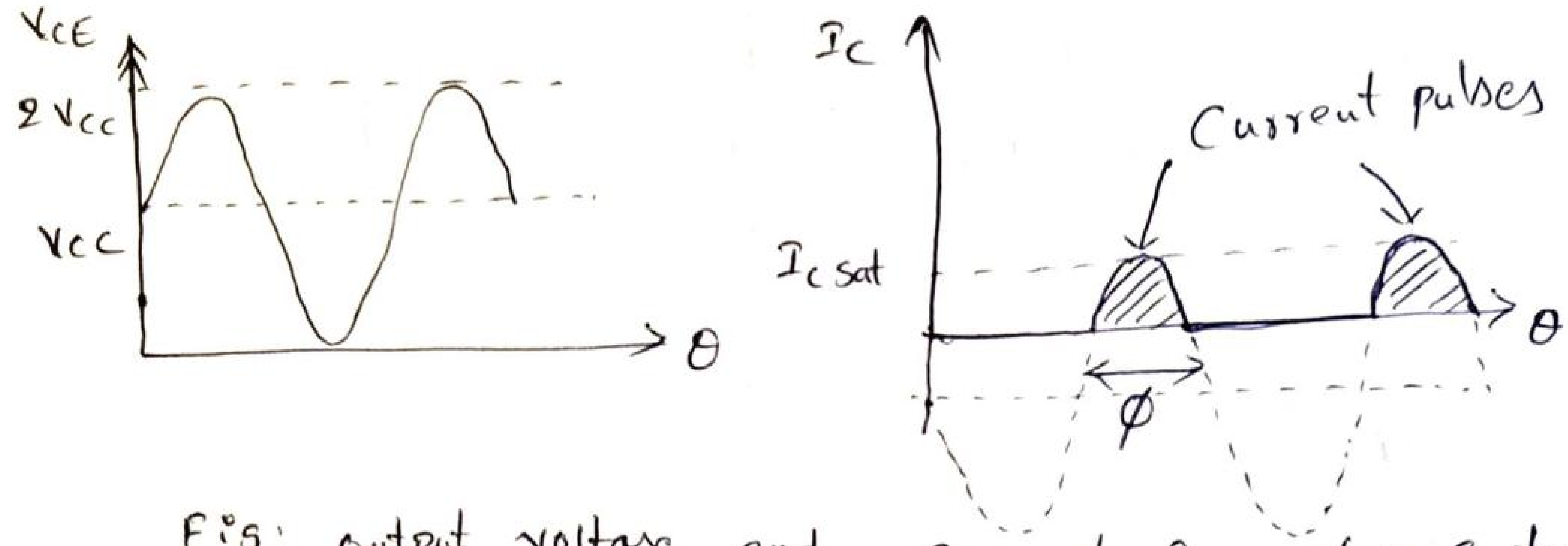


Fig: output voltage and current for class C tuned amplifier.

The power dissipation depends on the conduction angle ϕ. Lesser the conduction angle and less is the transistor dissipation. The variation of the transistor dissipation with ϕ is shown in the figure.

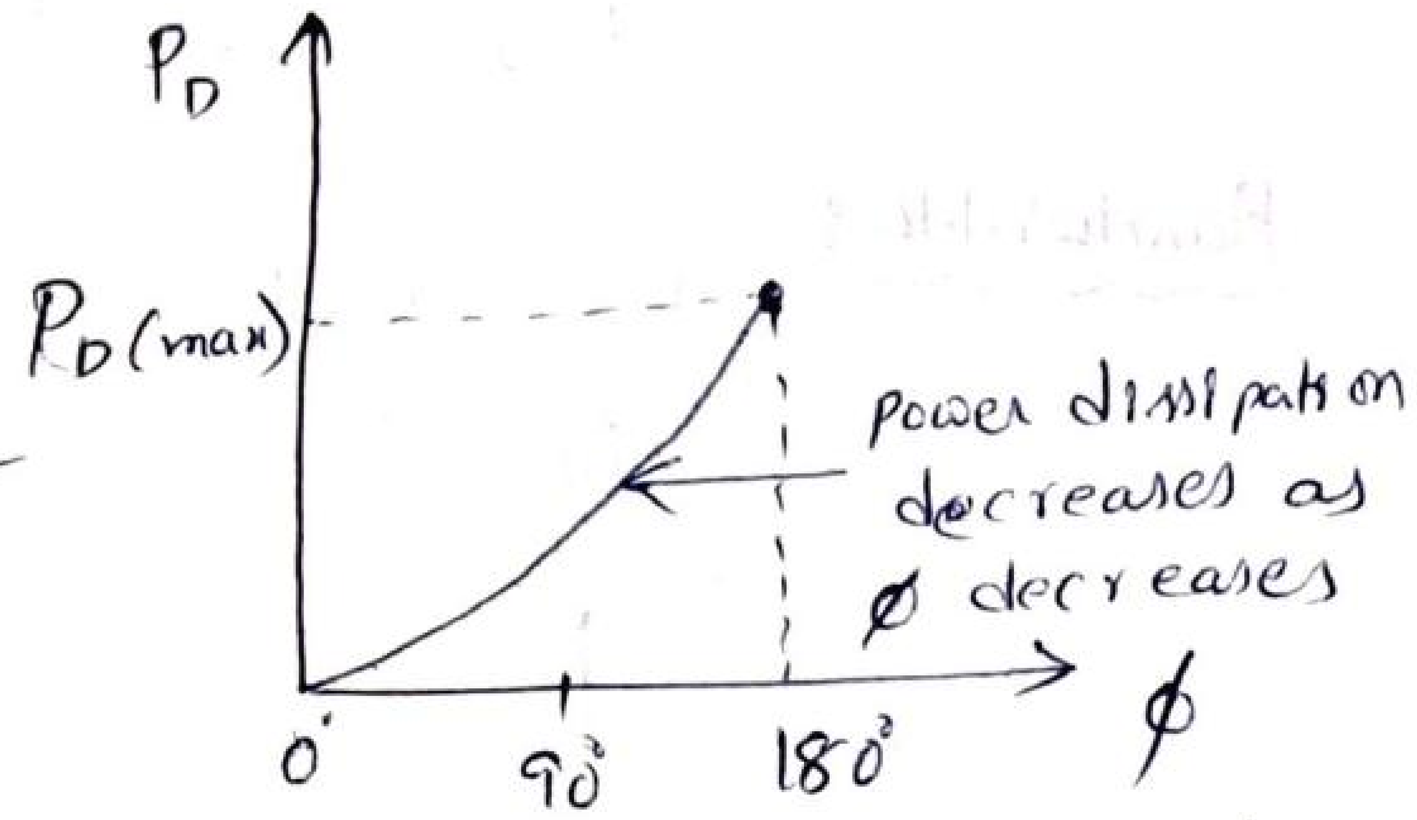


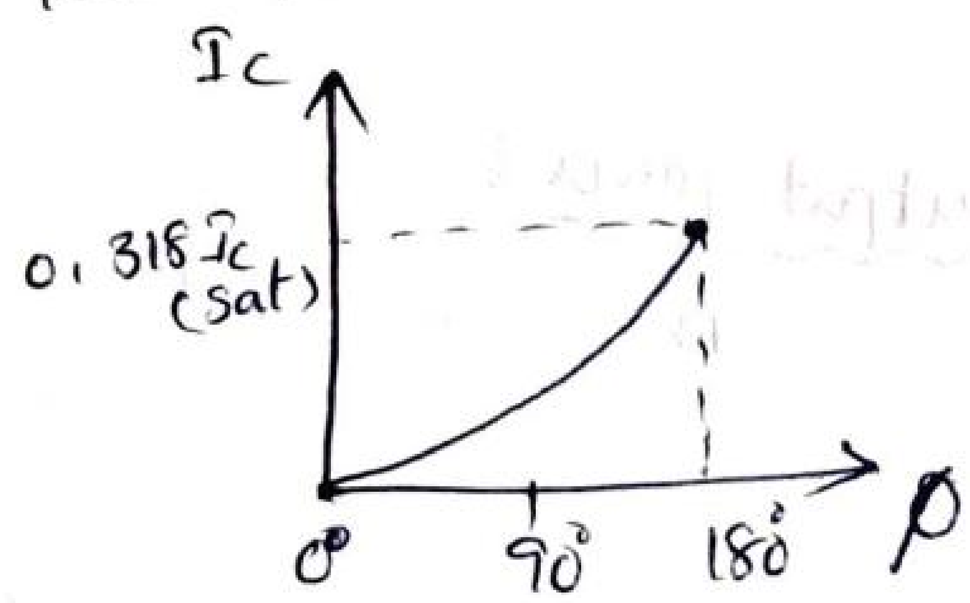
Fig: Transistor dissipation.

Maximum power dissipation at $\phi = 188$ is given by

$$\boxed{P_D(max) = \frac{V_{pp}^2(max)}{40\, r_c}} \qquad (V_{pp}(max) = 2V_{cc})$$

D.C input power:

If the conduction angle is made 180° then the current waveform becomes half wave rectified waveform.



$$\therefore I_{dc} = \frac{I_c(sat)}{\pi} = 0.318\, I_c(sat)$$

As the biasing resistors are absent then the d.c collector current is the only current drawn in class C amplifier

$$\boxed{P_{DC} = V_{cc}\, I_{dc}}$$

Efficiency:

The efficiency is given by

$$\% \eta = \frac{P_{out}}{P_{DC}} \times 100 = \frac{P_{out}}{V_{cc}\, I_{dc}} \times 100$$

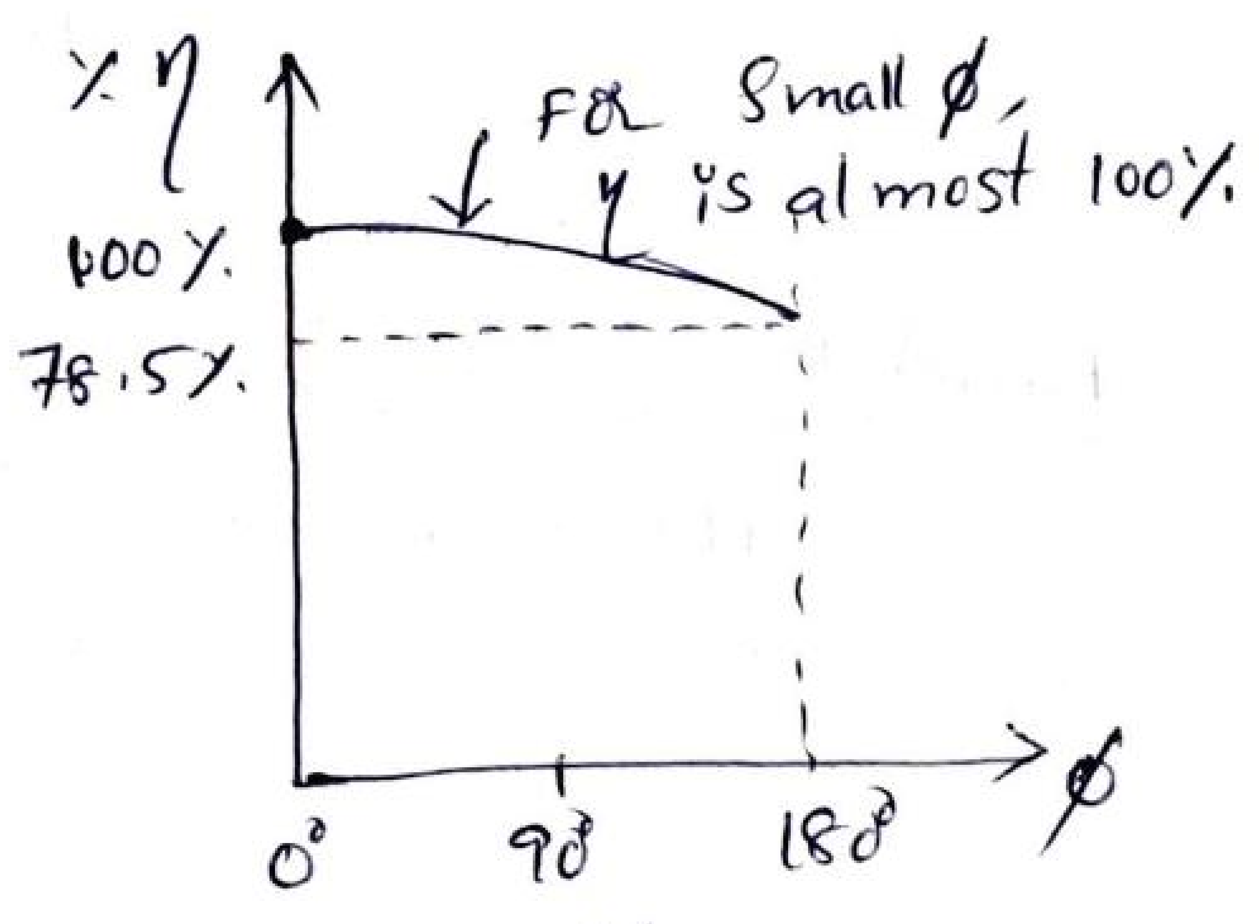


Fig: Efficiency

Efficiency depends on Conduction angle. In class C, most of the d.c input power is converted into a.c load power because the transistor and coil losses are small. when the conduction angle is 180 then the Efficiency is 78.5%. (17)

Class C tuned amplifier is the RF power amplifier and is used as final amplifier stage in communication circuits.