ch 7

UNIT

Large Signal Amplifier

A practical amplifier always consists of a no. of stages that amplify a weak signal until sufficient power is available to operate a loud-speaker or other o/p devices. The first few stages in this multistage amplifier have the function of only voltage amplification. However, the last stage is designed to provide maximum power. This final stage is known as power stage.

The i/p signal to a multistage amplifier is generally small (a few mV or uV). So, first few stages of multistage amplifier handle small signals & have the function of only voltage amplification. The last stage handles a large signal & its job is to produce a large amount of power in order to operate the o/p device.

1) Small Signal Amplifier

The amplifier ckts which handle small i/p ac signal are called small signal amplifier. Voltage amplifiers are example of small signal amplifier.

2) Large Signal Amplifier

The amplifier ckts which handle large i/p ac signal (i.e. a few Volts) are known as large signal amplifier. The large signal amplifiers are designed to provide a large amount of ac power output so that they can operate the o/p devices like as Speaker. The large signal amplifier are also known as power amplifier.

Power amplifiers are used to deliver sufficient power to drive high power load such as motor, antenna, loud speaker.

The efficiency of power amplifier is given by,

$$\eta = \frac{\text{Desired ac o/p power}}{\text{Dc i/p power}} \times 100\%$$

$$= \frac{P_o(ac)}{P_i(dc)} \times 100\%$$

Physical quantity (speech) → Transducer (microphone) $\xrightarrow{\text{(weak low voltage ac signal (mV))}}$ Voltage Amplifier $\xrightarrow{\text{(high voltage ac signal (few Volts))}}$ Power Amplifier $\xrightarrow{\text{(High power ac signal)}}$ High Power Load (Speaker)

Fig: Block diagram of an audio amplifier system

* physical quantity ⇒ eg speech
* Transducer → microphone, that converts audio signal into electrical signal.
* Voltage amplifier → the primary function of voltage amplifier is to raise the voltage level of the signal.
* Power amplifier → raise the power level of the i/p signal & deliver large power ~~at~~ the o/p.

→ Power amplifier is normally used as the final stage of commⁿ system.

Classification of Power Amplifier

On the basis of position of operating point, or by the biasing techniques, power amplifier are classified as class A, B, AB & C amplifier.

1) Class A Amplifier:

The transistor is biased in such a way that the operating point (Q-point) lies at the center of active region. There is no distortion in o/p signal. However, amplitude distortion may occur if i/p signal is very large.

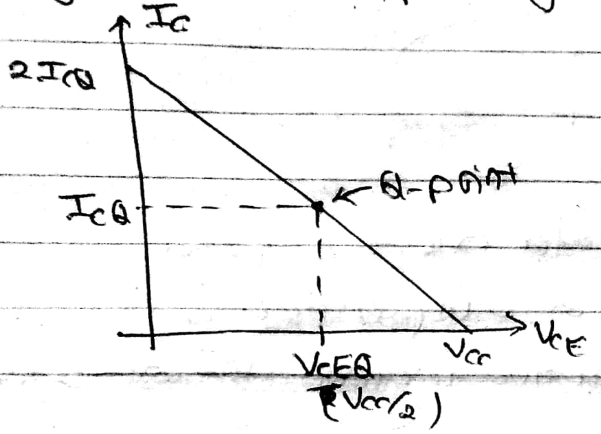


Fig: Q-point & DC load line

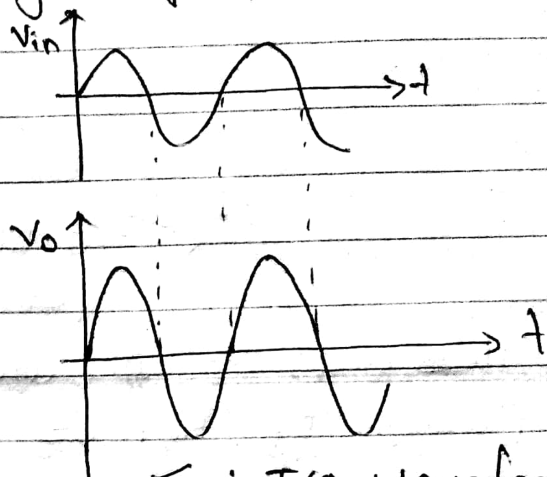


Fig: I/O waveform

There are 3 types of class A power amplifier.

i) Direct-coupled
ii) Transformer-coupled
iii) Capacitor-coupled.

Direct Coupled Class A Amplifier.

The direct coupled class A amplifier is also called series fed power amplifier because the load is connected in series with transistor as shown in fig.

The transistor is biased in such a way that it's operating point lies in active region during a complete cycle.

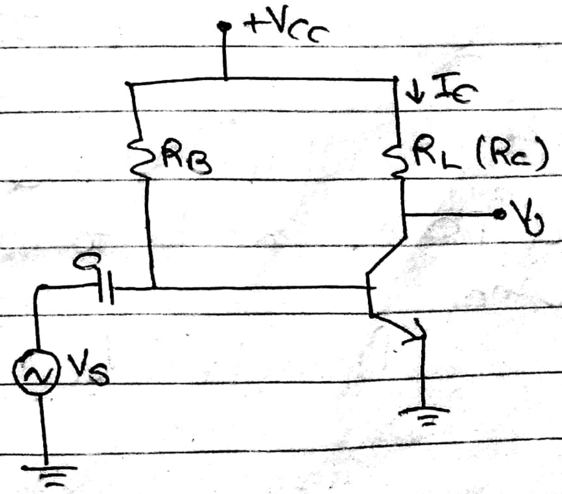


Fig: Direct-coupled class A Amplifier

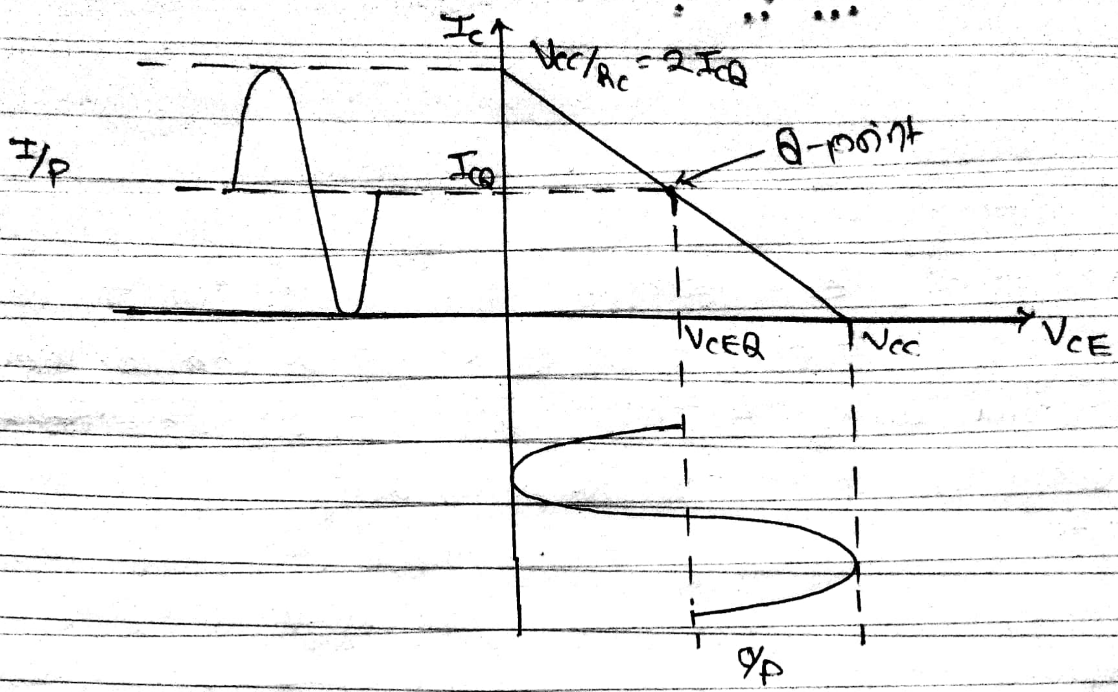


fig: I/O waveform for direct coupled class A amplifier.

In this case, Q-point lies at active region. The efficiency of power amplifier is given by,

$$\eta = \frac{\text{Average (ac) power delivered to the load}}{\text{Average (dc) power drawn from dc source}} \times 100\%$$

$$\text{or, } \eta = \frac{P_{o(ac)}}{P_{in(dc)}} \times 100\% \qquad \left(I_{rms} = \frac{I_m}{\sqrt{2}}\right)$$

where, $P_{o(ac)} = I_{C,rms} \times V_{CE,rms}$

$$= \frac{I_{CP}}{\sqrt{2}} \times \frac{V_{CEP}}{\sqrt{2}} = \frac{I_{CP} \times V_{CEP}}{2}$$

where, I_{CP} & V_{CEP} are peak collector current & peak collector to emitter voltage.

And,

$$P_{in(dc)} = V_{cc} \times I_{CQ}$$

Now,

$$\eta = \frac{I_{CP} \times V_{CEP}}{2 \times V_{cc} \times I_{CQ}} \times 100\%$$

For the max^m possible case,

$$V_{CEP} = V_{CEQ} = V_{CC}/2$$

$$\& \quad I_{CQ} = \frac{V_{CC}}{2R_C} = I_{CP}$$

Then,

$$\eta_{max} = \frac{I_{CQ} \times V_{CC}/2}{2 \times V_{CC} \times I_{CQ}} \times 100\% = \frac{1}{4} \times 100\%$$

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

The max^m possible efficiency of a direct coupled class A power amplifier is 25%, which is low & is due to large power dissipation in a power transistor.

The direct coupled class A amplifier used a good amount of power to maintain the DC-bias (i.e. to maintain Q-point in the middle of load line) to the transistor even with no signal applied. Thus it have very poor efficiency.

Collector Efficiency (η_c)

Collector efficiency is defined by,

$$\eta_c = \frac{\text{Average (ac) power delivered to load}}{\text{Average (dc) power dissipated at collector}} \times 100\%$$

$$= \frac{P_o(ac)}{P_{tr}(dc)} \times 100\%$$

where, $P_o(ac) = \frac{I_{CP}}{\sqrt{2}} \times \frac{V_{CEP}}{\sqrt{2}} = \frac{I_{CP} \times V_{CEP}}{2}$

$\& \quad P_{tr}(dc) = V_{CC} \times I_{CQ} - I_{CQ}^2 \times R_C$ [source dc power − power at R_C

$$= (V_{CC} - I_{CQ} \times R_C)\, I_{CQ}$$

For max^m possible case,

$$I_{CP} = I_{CQ} = \frac{V_{CC}}{2R_C} \quad \& \quad V_{CEP} = \frac{V_{CC}}{2} = V_{CEQ}$$

$$\& \quad P_{tr}(dc) = \left(V_{CC} - \frac{V_{CC}}{2R_C} \times R_C\right) I_{CQ} = \frac{V_{CC}}{2} \times I_{CQ} = V_{CEQ} \times I_{CQ}$$

Then $\eta_{c,max} = \dfrac{I_{CQ} \times V_{CEQ}}{2 \times (V_{CEQ} \times I_{CQ})} \times 100\% = \frac{1}{2} \times 100\%$

$\therefore \eta_{c,max} = 50\%$

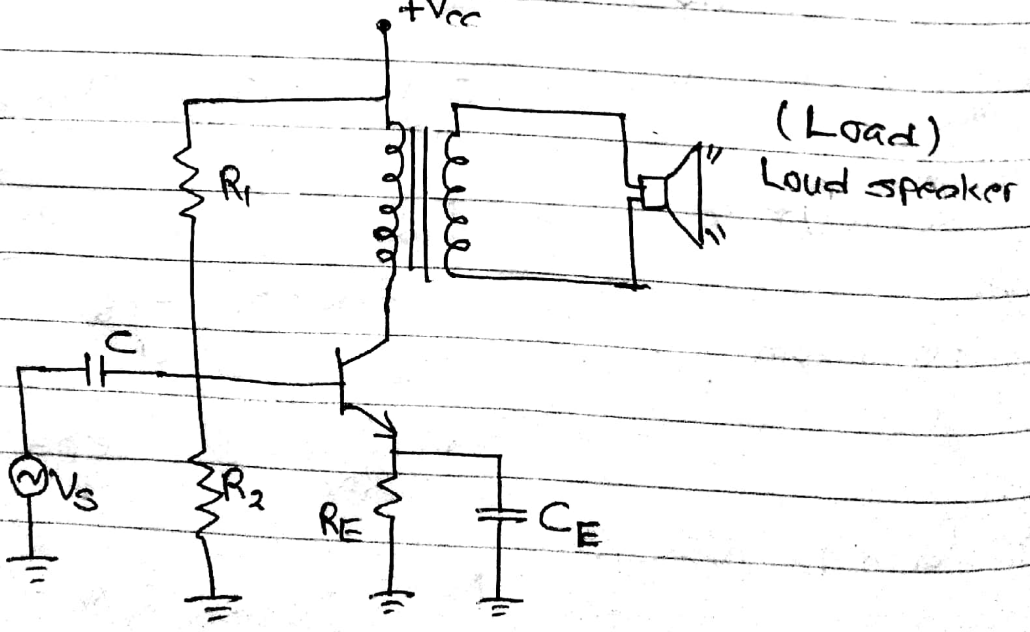
Thus, maxm possible collector efficiency of a direct-coupled class A amplifier is 50%.

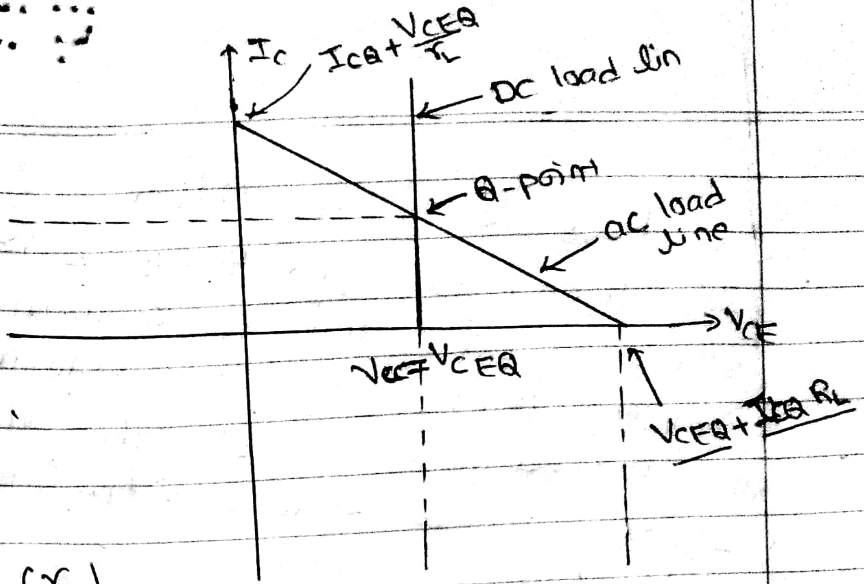
Transformer Coupled class A amplifier

In a direct coupled class A amplifier, a dc current flows through a resistance R_C (or R_L, load connected to collector) & large dc power is wasted across it. This wasted dc power doesn't contribute to the useful ac o/p power.

In a transformer coupled class A amplifier, transformer are used to couple power amplifier to their loads. There is no dc power loss in primary side of a transformer. However, ac power is coupled magnetically across the transformer into the load (i.e. speaker). Transformer coupling also provides an opportunity to achieve impedance matching for maxm power transfer.

The transformer coupled class A power amplifier is as shown below.





Here, we assume dc resistance of primary winding is negligibly small. The Dc load line is almost vertical.

&

$V_{CC} = V_{CEQ}$

The ac resistance (r_L) reflected to primary side is,

$$r_L = \left(\frac{N_P}{N_S}\right)^2 \times R_L$$

Where, N_P & N_S are no. of turns in primary & secondary windings respectively.

The slope of ac load line is $-1/r_L$.

Now, efficiency is given by,

$$\eta = \frac{P_o(ac)}{P_{in}(dc)} \times 100\%$$

where, $P_o(ac) = I_{C\,rms} \times V_{CE\,rms} = \frac{I_{CP}}{\sqrt{2}} \times \frac{V_{CEP}}{\sqrt{2}} = \frac{I_{CP} \times V_{CEP}}{2}$

and $P_{in}(dc) = V_{CC} \times I_{CQ} = V_{CEQ} \times I_{CQ}$

So,

$$\eta = \frac{I_{CP} \times V_{CEP}}{2 \times (V_{CEQ} \times I_{CQ})}$$

For max^m possible case,

$$I_{CP} = I_{CQ} \;\&\; V_{CEP} = V_{CEQ}$$

$$\therefore \eta_{max} = \frac{1}{2} \times 100\% = 50\%$$

i.e. max^m possible efficiency of transformer coupled class A amplifier is 50%, which is twice of direct coupled class A amplifier.

Class B Amplifier

The transistor operation is said to be of class B amplifier when the o/p current varies (only) during only one half-cycle of a sine-wave i/p. The transistor is biased in such a way that the zero-signal collector current becomes zero i.e. the operating point is set to the cut-off region.

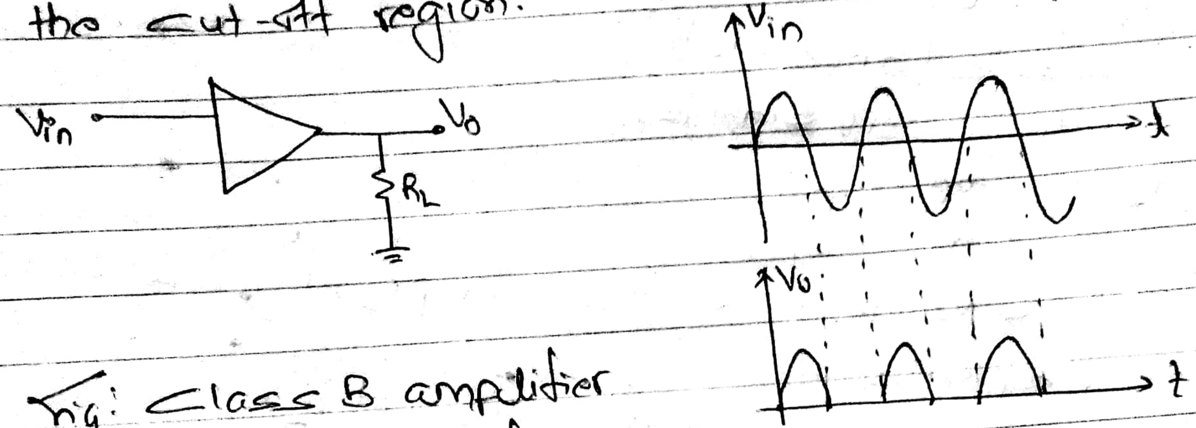


fig: Class B amplifier and its the I/o waveform.

The collector current flows for a half-cycle only. So the o/p waveform is highly distorted. This waveform is not suitable for audio application.

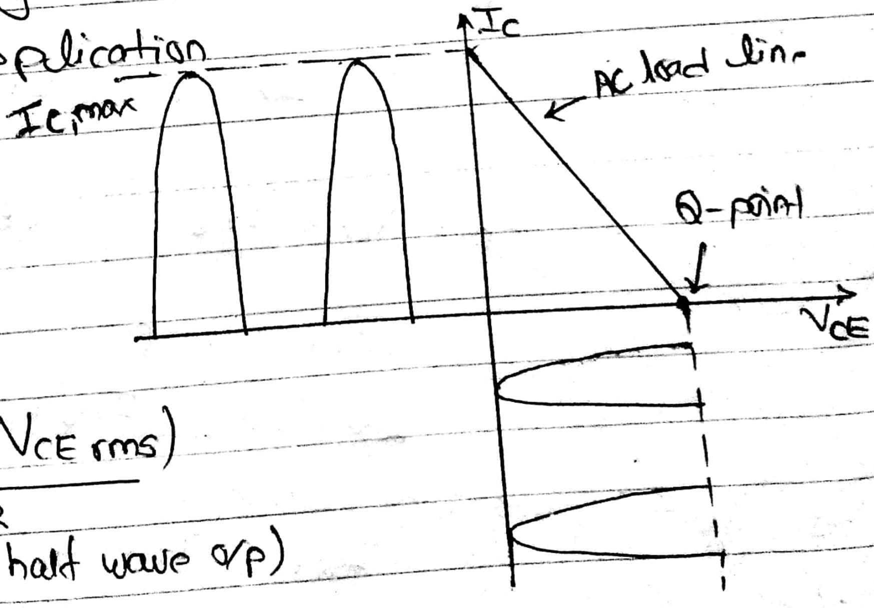


fig: AC load line & Q-point

Here, efficiency (η) is,

$$\eta = \frac{P_o(ac)}{P_{in}(dc)} \times 100\%$$

where, $P_o(ac) = \frac{(I_{C\,rms} \times V_{CE\,rms})}{2}$

(∵ only half wave o/p)

$$\text{or, } P_o(ac) = \frac{1}{2}\left(\frac{I_{CP}}{\sqrt{2}} \times \frac{V_{CEP}}{\sqrt{2}}\right)$$

$$= \frac{1}{4}\left(I_{CP} \times V_{CEP}\right)$$

Scanned by CamScanner

and, $P_{in}(dc) = V_{cc} \times I_{dc} = V_{cc} \times \frac{I_{cp}}{\pi}$

So, $\eta = \frac{\frac{1}{4}(I_{cp} \times V_{cEP})}{V_{cc} \times \frac{I_{cp}}{\pi}} = \frac{\pi}{4} \frac{(\cancel{I_{cp}} \times V_{cEP})}{V_{cc} \times \cancel{I_{cp}}} \times 100\%$

For max^m possible conditions,

$$V_{CEP} = V_{cc}$$

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

i.e. max^m possible efficiency of class B amplifier is 78.5% .

Class AB Amplifier

As crossover distortion occur in class B amplifier, to avoid crossover distortion, biasing ckt is required. In class AB amplifier, transistor are biased at a non-zero dc current, much smaller than peak current of sine wave. The max^m efficiency of class AB amplifier is slightly less than that of class B amplifier.

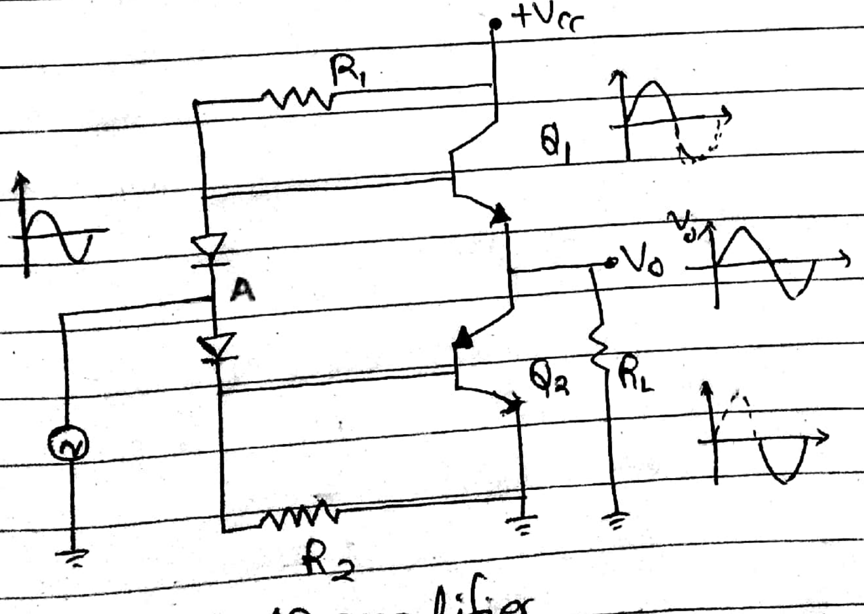
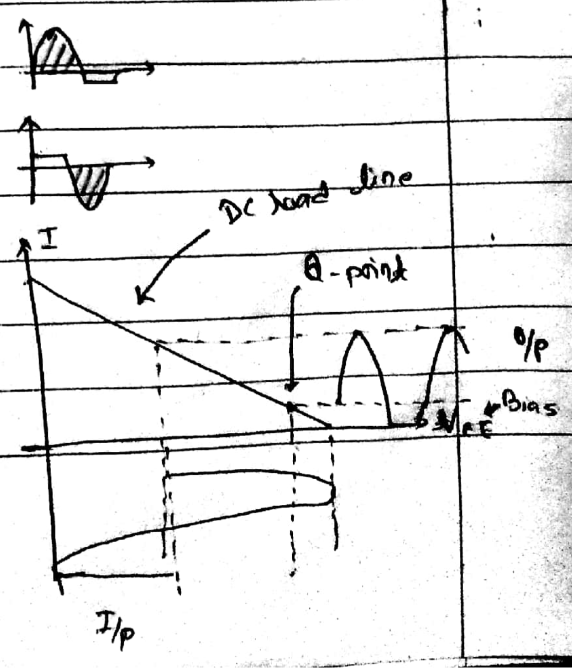


Fig: class AB amplifier



Here, bias voltage for ~~~~ transistor Q_1 & Q_2 are obtained from the voltage drop in diodes D_1 & D_2 respectively.

When $V_i = 0$, $V_1 = V_{O1}$ & $V_2 = -V_{O2}$

Thus crossover distortion is eliminated by providing the forward bias to each transistor.

If $R_1 = R_2$ & D_1 and D_2 are matched, voltage at point A will be zero (i.e. no dc voltage). This eliminates the need for i/p (coupling capacitor).

Class C Amplifier

=> ... Assignment

Push-pull Amplifier

Class B operation provides only half o/p. To obtain full cycle o/p two transistor conducting on opposite half cycle are used, one part of the ckt push the signal high during one half cycle & other part pulls the signal low during another half cycle of i/p. This arrangement is called push-pull amplifier. (One transistor conduct the current when i/p is +ve & the other conducts it when i/p is -ve).

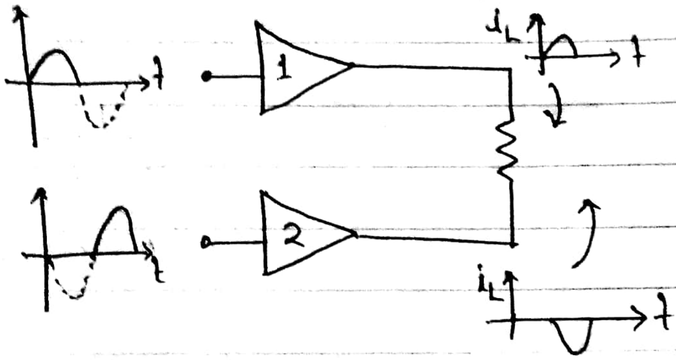


Fig: Push-pull operation

Here, amplifier 1 drives curren i_L through R_L in clockwise direction (push operation) & amplifier 2 drives current i_L through R_L in anticlockwise direction (pull operation). When any 1 of the amplifier conducts the current, the other amplifier turn off.

Transformer Coupled class B push-pull Amplifier

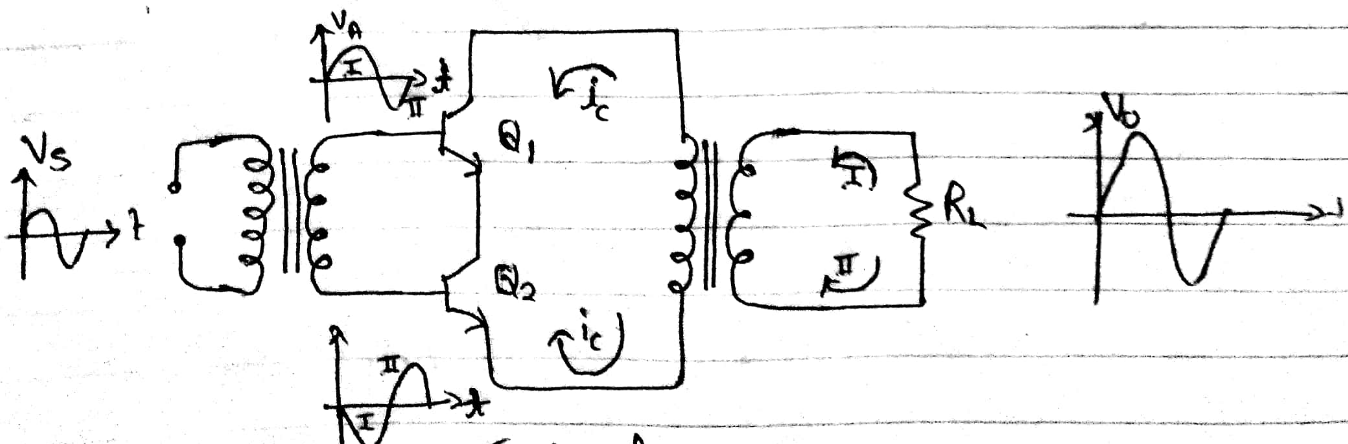


Fig: Transformer coupled class B push-pull amp.

Operation:

During the +ve half cycle (I), Q_1 is forward biased i.e. Q_1 is ON & Q_2 is reverse biased i.e. Q_2 is off.
During -ve half cycle (II), Q_1 is off & Q_2 is ON.
Thus at the load, complete cycle is obtained.

Its efficiency is, $\eta = \frac{P_o(ac)}{P_{in}(dc)} \times 100\%$

We assume
i) Two transistors are perfectly matched.
ii) Transformer windings has zero resistance.

Let I_p represents peak value of current in primary, then peak value of current in secondary winding is given by,

$$I_{PL} = (N_P/N_S) I_p$$

Similarly, peak value of voltage is,

$$V_{PL} = \left(\frac{N_S}{N_P}\right) V_P$$

So, $P_o(ac) = V_{PLrms} * I_{PLrms}$

$$= \frac{N_S}{N_P} * \frac{V_P}{\sqrt{2}} \times \left(\frac{N_P}{N_S} \times \frac{I_P}{\sqrt{2}}\right) = \frac{V_P I_P}{2}$$

& $P_{in}(dc) = V_{cc} \times$ average current through power supply.
Since, power supply current is full wave rectified wave form having peak value,

$$I_P = 2 \times \frac{I_{peak}}{\pi}$$

$$\text{So, } P_{in}(dc) = \frac{2 \times V_{cc} \times I_P}{\pi}$$

$$\text{Now, } \eta = \frac{V_P I_P}{2 \times \left(\frac{2 \times V_{cc} \times I_P}{\pi}\right)} \times 100\% = \frac{\pi}{4} \times \frac{V_P}{V_{cc}} \times 100\%$$

Under max^m cond^n, $V_P = V_{cc}$

$$\therefore \eta = \frac{\pi}{4} \times 100\% = 78.5\%$$

where, $P_{o(ac)} = I_{c\,rms} \times V_{CE\,rms}$

$$= \frac{I_{cp}}{\sqrt{2}} \times \frac{V_{CEP}}{\sqrt{2}} = \frac{I_{cp} \times V_{CEP}}{2}$$

& $P_{in(dc)} = V_{cc} \times I_{dc}$

where, $I_{dc} = \frac{2 I_{cp}}{\pi}$ (for full wave rectifier)

Now,

$$\eta = \frac{I_{cp} \times V_{CEP}}{2 \times \left(\frac{V_{cc} \times 2 I_{cp}}{\pi}\right)} = \frac{\pi}{4} \frac{V_{CEP}}{V_{cc}} \times 100\%$$

For max^m possible case,

$$V_{cc} = V_{CEP}$$

$$\therefore \eta = \frac{\pi}{4} \times 100\% = 78.5\%$$

Thus max^m possible efficiency of the transformer coupled class B push-pull amplifier is 78.5%

The total power dissipated in the transistor is the difference betn the total power supplied by dc source & total power delivered to the load.

$$P_d = P_{in(dc)} - P_{o(ac)}$$

$$= V_{cc} \times I_{dc} - V_p I_p / 2$$

$$= V_{cc} \times \frac{2 I_{cp}}{\pi} - \frac{V_p \times I_{cp}}{2}$$

$$= \frac{2 I_{cp} V_{cc}}{\pi} - \frac{V_p I_{cp}}{2}$$

Power dissipation (P_d) is max^m when

$$V_p = \frac{2 V_{cc}}{\pi}$$

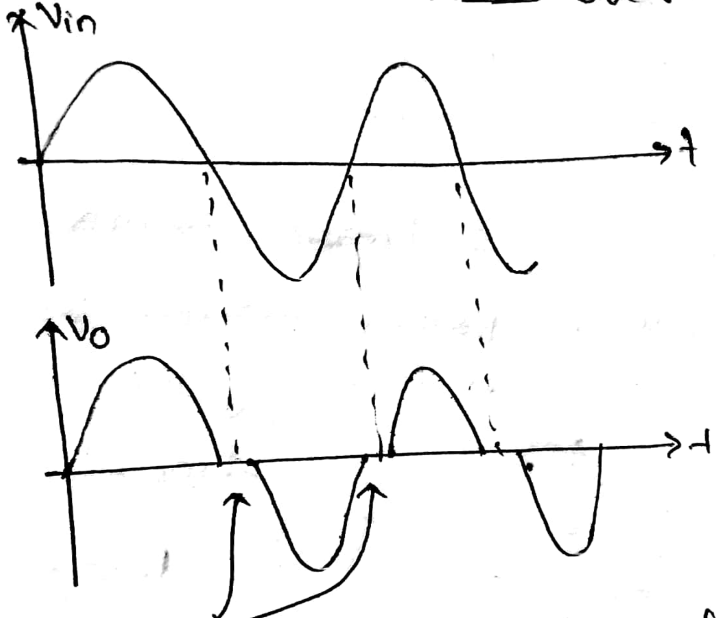
$$= 0.636 V_{cc}$$

$$\therefore P_d = \frac{2 I_{cp} V_{cc}}{\pi} - \frac{2 V_{cc}}{\pi} \times \frac{I_{cp}}{2}$$

$$= \frac{I_{cp} V_{cc}}{\pi}$$

Cross over Distortion

In class B push-pull amplifier, both transistors remains off untill the magnitude of voltage at their base is less than 0.7V. During that period, there will be no o/p. As a result o/p waveform will not be pure sine form, but is of distorted form. This type of distortion is called cross over distortion.



Cross over distortion (1.4V dead band)

Removal of Cross over Distortion

Cross over distortion occur due to non-conduction of both transistors when the signal is below 0.7V. To remove or minimize this, both transistors can be forward biased with small voltage. This type of operation is called class AB operation.

In class AB operation, cross over distortion is eliminated by biasing each transistor slightly into conduction. When a small forward biasing voltage is applied across each base emitter junction, then it is not necessary for i/p signal to overcome the 0.7V of BE junction before active operation can occur.

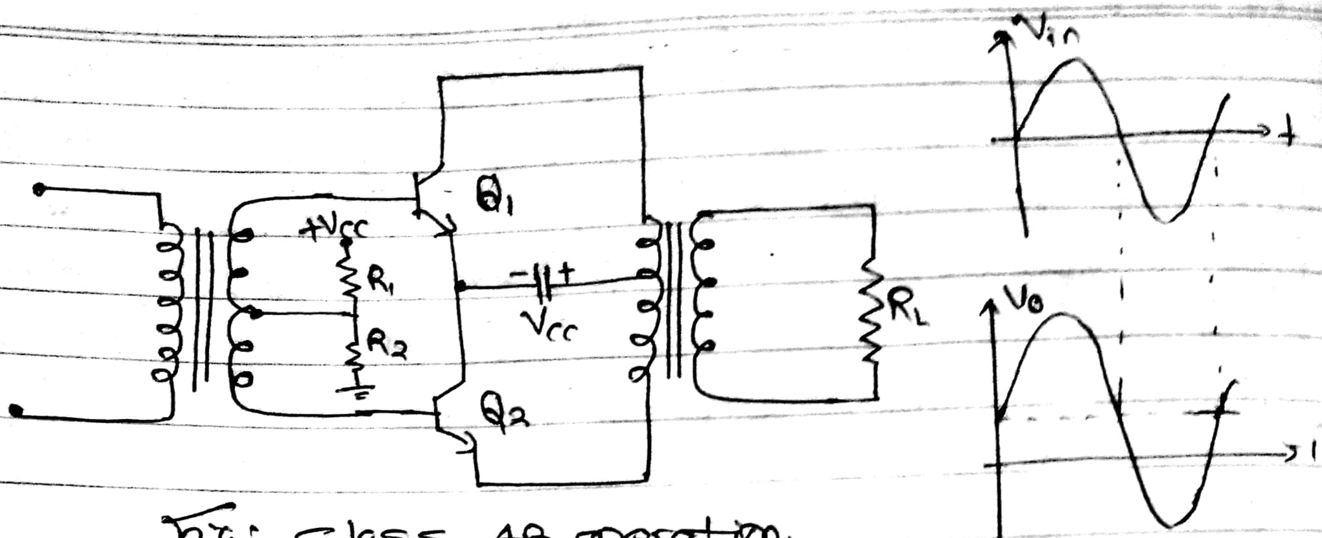


Fig: class AB operation.

Power Dissipation & Heat Sink

The common emitter amplifier, power dissipation curve & its dc load line are shown in figure.

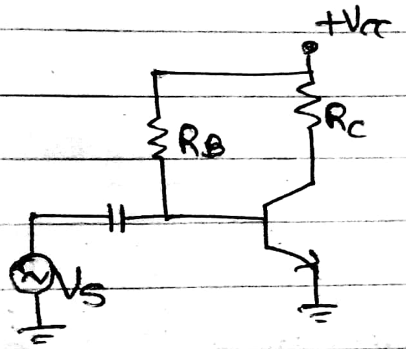


Fig: common emitter amplifier

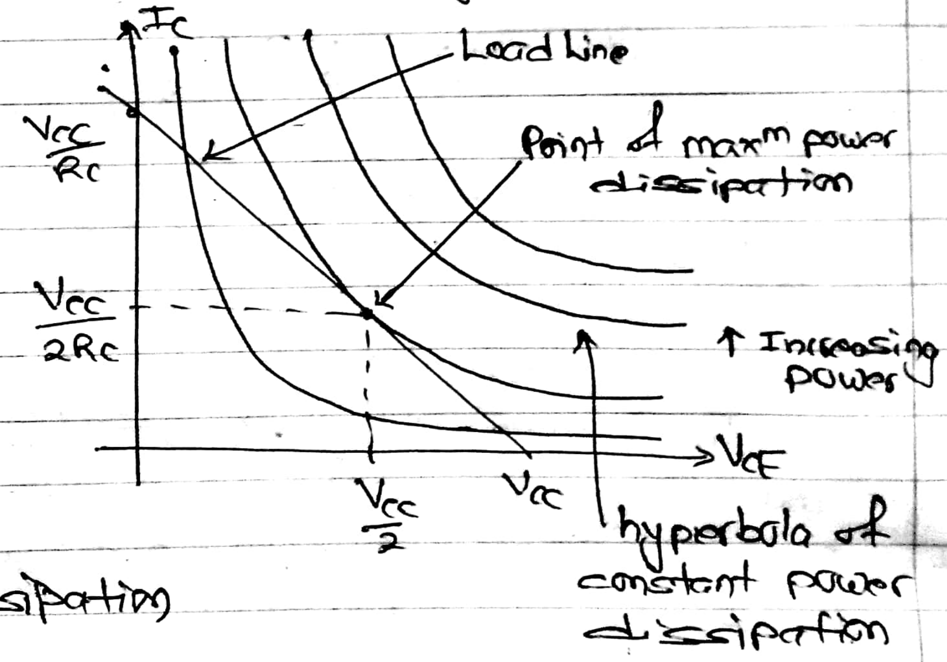


Fig: Power dissipation curve

The total power dissipation at the junction is,

$$P_d = V_{CB} I_C + V_{BE} I_E$$
$$\simeq V_{CE} I_C$$

For a fixed value of P_d, the power dissipation curve i.e. $P_d = V_{CE} I_C$ is a hyperbola. The power dissipation varies as amplifier o/p changes. For safe operation,

the load line must lie below & left of hyperbola corresponding to ~~max~~^{m} permissible power dissipation.
At the point of max^m power dissipation,

$$V_{CE} = V_{CC}/2$$
$$\& \; I_C = V_{CC}/2R_C$$

So, max^m power dissipation is,

$$P_{d,max} = V_{CE} \times I_C = \frac{V_{CC}}{2} \times \frac{V_{CC}}{2R_C} = \frac{V_{CC}^2}{4R_C}$$

To ensure that the load line lies below the hyperbola of max^m dissipation, it is required that,

$$\frac{V_{CC}^2}{4R_C} < P_{d,max}$$

where $P_{d,max}$ is the manufacturer specified max^m dissipation at a specified ambient temp^r.

Heat Sink

Semiconductor diodes are cooled by conduction, radiation & convection methods. Heat is conducted from a junction, through the s/c material, through the case & into the surrounding air. It is also radiated from the surface of the case. To improve the conduction & radiation of heat from the case to the surrounding air, power devices are often equipped with heat sinks.