Power Amplifiers :-

- A multistage ampl^r may be required to deliver a large amount of power to a passive load.
- This power may be in the form of :-
  - large current deliverd to small load resistance → Audio Speaker
  - large voltage -"- large load Resi → switching Power Supp.
- Imp function of o/p stage are -
  1. to provide a low o/p resistance → to deliver power to the load without loss of gain → Emitter follower / source F.
  2. to maintain linearity in the o/p signal.
- A measure of linearity of the o/p signal is the Total harmonic distortion (THD)
- Power dissipated in transistors of o/p stage should be as small as possible.

* voltage Amplifiers (VA) can't be used as Power Ampl^r (PA) :-

→ DC power taken by Ampl^r = $V_{cc} I_{cq}$ —— ①

DC power given to transistor = $V_{CEQ} \times I_{cq}$

But $V_{CEQ} = [V_{cc} - I_{cq}(R_c + R_E)]$

∴ DC power given to transistor = $V_{cc} \cdot I_{cq} - I_{cq}^2 (R_c + R_E)$ — ②

If we compare eqn ① & ②, Power lost = $I_{cq}^2 (R_c + R_E)$

means Power lost in RC & RE is large (heat)

so if power loss in VA can be controlled, we can use that as PA.

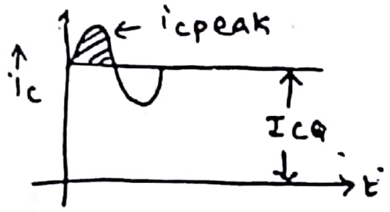
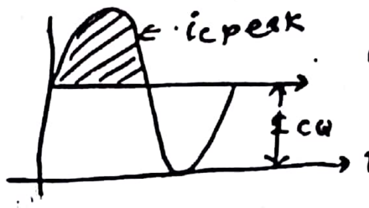
Possible methods to convert VA to PA :-

(i) Make $R_c = 0$
- we can't get o/p so it is Impossible

(ii) Make $R_E = 0$
- Stability suffer & can get distorted (clipped) o/p bcoz of drift of Q pt.

(iii) use L in place of Rc
- dc resist in collector ckt = 0 ∴ power lost $I_{cq}^2 R_c = 0$
  ac → X_L ↑↑ will get o/p vtg
- we can't match o/p resist. of BJT with imp of load so we can use Transformer in collector, R_L to secondary.

* comparision Betⁿ vtg Ampl^r & Power Ampl^r

VA (small signal Ampl^r)	PA (Large signal Ampl^r)
① It is used as initial stages of Audio system for vtg amplificatⁿ	It can be used as o/p stage of Audio stystem for power amplification
② when peak variation of the signal is very small compared to dc level → Small signal A.	when peak variation of the signal is appr. equal to dc level → large signal A
 icpeak << ICQ	 icpeak ≈ ICQ
③ useful ac power is less. Max dc power is wasted as power loss in transistors & Resi.	ac power loss can be increased by changing Q pt (dc power loss can be reduced). PA can be operated in class A, B or C Mode.
④ It is direct or RC coupled.	- transformer coupled to deliver max Power
⑤ DC stability is very IMP so proper biasing N/w is required to avoid thermal runaway.	Body of PA acts as Collect^r. so more heat is given to surroundings due to large surface area. Hence thermal runaway can be avoided.
⑥ used to amplify vtg & current levels of small signals.	used to convert dc i/p power to max ac o/p Power.
⑦ conversion efficiency $\%\eta_{max} = \frac{P_{o(ac)max}}{P_{i(dc)}} \times 100$ $= 25\%$	conversion Efficiency $\%\eta_{max} = \frac{P_{o(ac)max}}{P_{i(dc)}} \times 100$ is high class A $\eta_{max} = 50\%$ B $= 78.54\%$ C $= 85$ to 90%

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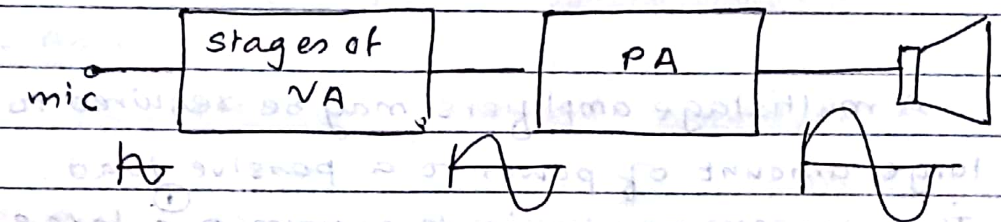
* as power dissipation in terms of heat is large, heat sink is required.

Large signal Amplifiers

* **Introduction :-**

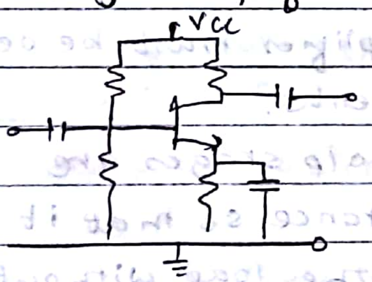
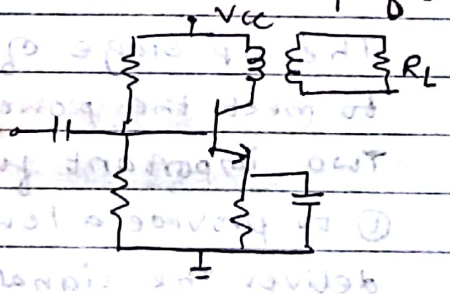
In loudspeakers or public address system, a very small o/p of microphone is to be amplified so many amplifiers are cascaded together.

First few amplifiers are always VA & last amplifier is always PA as it has to deliver more power to load (speaker.)



as the requirement of voltage swing at the i/p of P.A is large, Power amplifiers are called as Large Signal Amplifiers.

* Comparision betn VA & PA

Voltage Amplifiers	Power Amplifiers
	
i) It raise vtg level of applied i/p. signal.	It raises power level of applied i/p signal.
ii) requirement of i/p vtg swing is less	It requires ~~ment~~ of large vtg swing at its i/p.
iii) Power lost in components is more.	Design of ampl^r is such that power lost in components is minimum. (Here Power transistors are used ∴ power dissipation in transistor is large)
iv) power dissipation is low	* costly
iv) cheaper than PA	
v) Distortion is less	Distortion is more.

* Why the linear small signal models like re, pi, hybrid pi cannot be used for analysis of PA.?

⇒ Since power amplifier is a large signal amplr i.e i/p vtg swing to this amplifier is large, its operation enters in non linear region as well,

and re, hybrid pi these models are Linear models so cannot be used for anylisis of PA.

* A multistage amplifiers may be required to deliver a large amount of power to a passive load.

This power may be in the form of ① a large current delivered to a relatively small load resistance such as an audio speaker

or ② may be in the form of a large voltage delivered to a relatively large load resistance such as in a switching power supply.

The o/p stage of power amplifier must be designed to meet the power requirements.

Two important functions of o/p stages are

① to provide a low o/p resistance so that it can deliver the signal power to the load without loss of gain

② & to maintain linearity in the o/p signal.

THD * A measure of linearity of the o/p signal is the total harmonic distortion (THD)

It is the rms value of harmonic components of the o/p signal, excluding the fundamental expressed as a percentage of the fundamental.

- *A power amplifier is an amplifier which is capable of providing a large amount of power to the load such as loudspeaker*, a motor etc. It raises the power level of the electrical signals that have audio frequency range. It is more commonly known as **audio amplifier**. It is also known as **large signals amplifier** because it uses a large part of the a.c. load line for operation. In other words, *a power amplifier is a d.c. to a.c. power converter, whose action is controlled by the input signal.*
- For example, a public address system consists of a microphone, a multistage (voltage) amplifier, a power amplifier and a loudspeaker. When a person speaks into a microphone, it converts a sound waves into the electrical signal. This electrical signal is of very low voltage, usually a few mV. This signal, if fed directly, cannot drive the loudspeakers to give sound (audio) output. The voltage level of this signal is first raised to sufficiently high values (usually a few V_s) by passing it through a multistage voltage (or small signal) amplifier. This signal is then used to drive (or exite) the power amplifier, which is capable of delivering a large amount of power to the loudspeakers. The loudspeaker finally converts the electrical signal into the sound waves. Thus, large audience can hear the speech (or music) from the orchestra, tape recorder, record player, radio receiver, television receiver or any other such gadgets.

3.14.2 Block Diagram of a Power Transmitter

- A block diagram of a practical public address system is shown in Fig. 3.14.

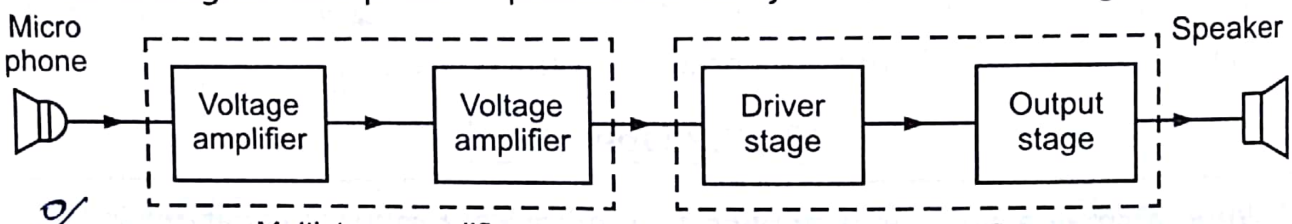


Fig. 3.14 : Public address system

- A practical power amplifier has the following stages of amplification :
  1. Multistage (voltage) amplifier,
  2. Driver stage,
  3. Output stage.

1. Multistage Amplifier :

- The multistage amplifier is basically a voltage amplifier, generally, it consists of two or more stages of voltage amplifiers. RC coupling is employed for this purpose.
- The electrical signals found, in practice, have extremely low voltage level (less than 10 mV). The voltage level of this weak signal is raised to a few volts in multistage voltage amplifier.

2. Driver Stage :

- The output from the last voltage amplifier stage of a multistage amplifier is fed to the driver stage of a power amplifier. It generally employs a Class A transformer coupled power amplifier. This is, in fact, a power stage which increases the current level of the electrical signal. It supplies the driving power necessary for operating the output stage. This stage makes the concentrated efforts to obtain *maximum power gain.*

- The stage of amplification which provides the necessary base current and voltage to the output stage is called the **driver stage**. It works as a power amplifier and drives the output stage. It also provides the impedance matching.

3. **Output Stage :**
   - The output power from the driver stage is fed to the output stage of a power amplifier. It is a final stage and feeds power directly to the loudspeaker. The output stage is normally a transformer coupled and employs Class B amplifiers in push-pull arrangement. This stage makes the concentrated efforts to obtain **maximum power output** .

3.14.3 Performance CE Parameters of Power Amplifiers

- The main objective for a power amplifier is to obtain maximum output a.c. power. Since, a transistor like any other electronic device has voltage, current and power dissipation limits, there are three parameters namely collector efficiency, distortion and power dissipation capability of a transistor which determines the performance of power amplifiers.

Specifications of Power Amplifier :

1. **Collector Efficiency :**
   - The major criterion for a power amplifier is not the power gain but the maximum a.c. power output. We have already discussed that an amplifier is basically an energy conversion device. Hence, the amplifier converts the d.c. power supply into the a.c. power output. Therefore, *ability of a power amplifier to convert d.c. power supply into a.c. power is a measure of its effectiveness and is called its* **circuit efficiency**. It is also called the **collector efficiency** or the **overall efficiency**.
   - *The circuit efficiency* may be defined as *the ratio of the maximum a.c. output power to the zero signal power*', i.e. d.c. input power supplied by the battery or d.c. power supply, of a power amplifier.

$$\text{Circuit efficiency, } \eta = \frac{\text{Maximum a.c. output power}}{\text{d.c. input power}}$$

   - The maximum theoretical values for circuit efficiency depend upon the way in which the load is coupled to the transistor and the class of operation of the amplifier. It ranges from 25% to 90%.

2. **Distortion :**
   - A good amplifier should produce the enlarged output but faithful reproduction of the input. However, in actual practice, it is not possible to construct such an ideal amplifier, whose output is exact reproduction of the input.

- The output is always found to be different from the input either in its waveform or frequency content. *This difference between the output and input of an amplifier is called* ***distortion***.
- The distortion may be defined as *'the change of output waveshape from the input waveshape of an amplifier'*.
- A transistor is essentially a non-linear device. Therefore, whenever a signal is applied to the transistor, the output signal is not exactly like the input signal. Thus, distortion occurs in the transistor amplifiers. It is not a problem for small signal (i.e. voltage) amplifiers, since transistor acts a linear device for small signal variations about the operating point.
- However, a power amplifier handles large signals, the distortion becomes a problem in such power amplifiers. They may be *amplitude (or harmonic) and crossover distortion*.

3. Power Dissipation Capability :

- As the transistor in a power amplifier handles large current, the heat is generated within the transistor due to excessive current passing through its junction during amplification. The transistor must dissipate this heat to its surroundings. Otherwise, excessive heat may damage the transistor.
- *The ability of a power transistor to dissipate heat is known as power dissipation capability.*
- If the heat generated within the transistor is greater than its power dissipation capability, then the transistor is likely to burn out. The maximum power dissipation in a transistor occurs under zero signal conditions. Therefore, the power dissipation capability of a power transistor must be at least equal to the zero signal rating. It may be increased by connecting a mass of metal (called *heat sink*) to the transistor case.

* Power Transistors :-

while studying power amplifiers, we must be considered the transistor limitations, like :-

1) Maximum Rated current (on order of Amp)
2) Maximum Rated voltage (on order of 100V)
3) Maximum Rated Power (on the order of W or tens of W)

we will consider these effects in BJT & in MOSFET

* Power BJTs :-

comparision of max ratings of a small signal & power BJT

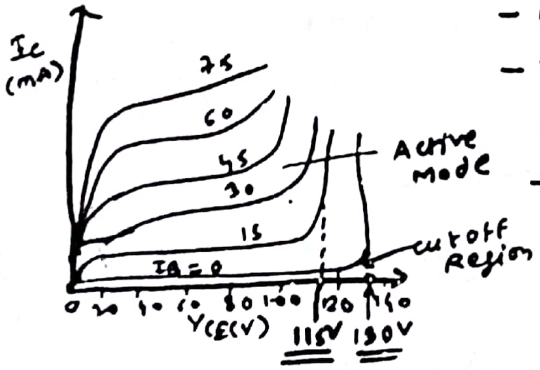
Parameter	small signal BJT (2N2222A)	Power BJT (2N3055)	Power BJT (2N6078)
$V_{CE(max)}$ (V)	40	60	250
$I_{C(max)}$ (A)	0.8	15	7
$P_{D(max)}$ (W) at $T=25^\circ C$	1.2	115	45
β	35-100	5-20	12-70
f_T (MHz)	300	0.8	1

(i) Maximum Rated Collector current ($I_{C,rated}$) -

- max. current that the wires can handle (connecting the semicond^r to Ext terminal)
- the collector current at which current gain falls below a min specified value
- the current that leads to the max power dissipation when transistor is in saturation.

(ii) Maximum voltage limitation :-

- associated with avalanche breakdown in RB, BC junct^n.



- Breakdown vtg when Base is open ie V_{CEO} at $I_B=0$ = 130V
- $V_{CE(sus)}$: max vtg necessary to sustain transistor in Breakdown ie $V_{CE(sus)}$ = 115V
- when BJT operating at High vtg & high current :- Second Breakdown
  → results +ve fb, further ↑current, ↑temp → semiconduct may melt producing perfailure.

(iii) Maximum Rated Power :-

inst. power in BJT is $P_Q = V_{CE} i_C + V_{BE} i_B$ But $i_B << i_C$

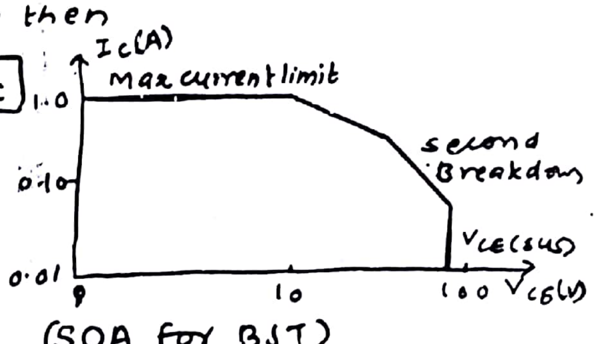
$\therefore$ $P_Q \cong V_{CE} i_C$ $\therefore$ avg power by integrating over 1 cycle,

$$\boxed{\bar{P}_Q = \frac{1}{T}\int_0^T V_{CE}\, i_C\, dt}$$

avg power dissipated must be kept below specified max value.
if we assume I_C & V_{CE} as dc quantities then

$$\boxed{\text{Max. Rated Power} = P_T = V_{CE} I_C}$$

- SOA : the region where transistor can be operated safely
- SOA is bounded by I_{cmax}, $V_{CE(sus)}$, P_T & BJT's IInd breakdown char. curve.



(SOA for BJT)

- Device must remain within safe operat^n area at all times.

* Power MOSFETs :-

- These transistor must also operate within SOA.

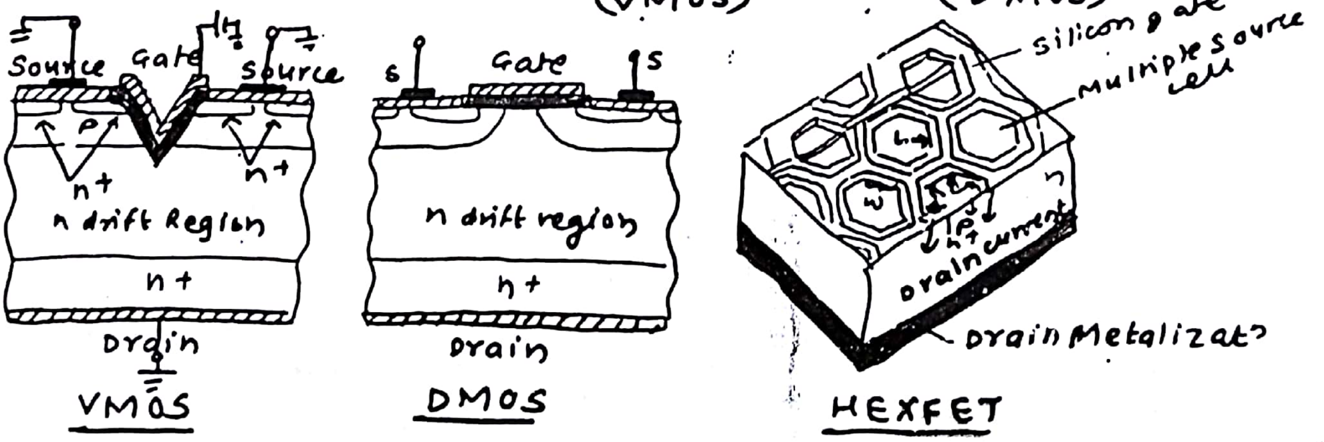
characteristics of Two power MOSFETs :-

Parameter	2N6757	2N6792
$V_{DS(max)}$ (V)	150	400
$I_{D(max)}$	8	2
P_D (W)	75	20

- faster switching time
- No IInd breakdown
- stable gain
- Resp. time over a wide temp range

construction :- surface area must be large so Gate & Source on Top & Drain at bottom.

- can be manufactured by vertical MOS (VMOS) or double diffused process (DMOS)



VMOS DMOS HEXFET

- DMOS can be used to produce a large no. of closely packed hexagonal cells on a single silicon chip.
- single power MOSFET chip may contain 25,000 paralleled cells.

ckt operation :-

- when gate is made +ve w.r.t S & D, electrons are attracted in p-material, towards Gate.
- Hence p-material near V groove becomes n type due to excessive electrons & channel is formed betⁿ S & D.
- The D-S resist is very low hence high I_D flows.
- There are two conduction paths betⁿ S & D, hence current level further increases.
- The storage charge in the device is less therefore switching time is very low. & switching freq is very high.

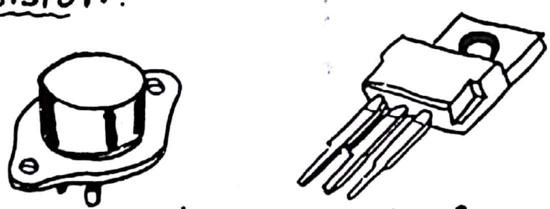
Applications :-

- As switching time is very low, it is used in High freq switching applications where power requirement is very high.

(i) AC Motor control
(ii) switching Power supplies.

* Heat Sinks :-

- Power dissipated in transistor increases its internal temp. above the ambient temp.
- If device or junctⁿ Temp T_j becomes too high, transistor may suffer permanent damage.
- So special precaution should be taken while packaging.
- We can use Heat Sinks so that heat can be conducted from transistor..



Typical Heat Sink

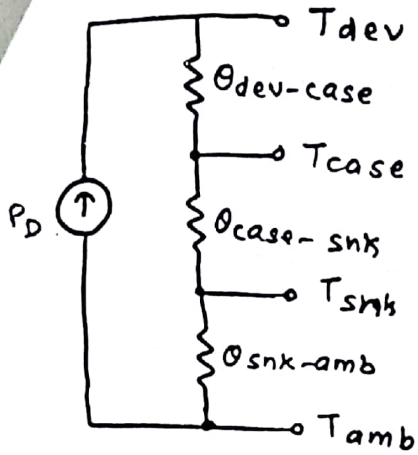
Packaging Schemes for Power transistor

Design :- θ = thermal Resist °C/W , P = thermal power through the element.

Temp. diff $\boxed{T_2 - T_1 = P\theta}$

Temp diff $\xrightarrow[\text{Analog of}]{\text{Electrical}}$ Vtg

Power/Heat Flow ⟶ current.



– Electrical equt. ckt for Heat flow from the device to the ambient –

(6)

Manufacture's data sheets for power devices give Max. operating junctⁿ or device temp T_{jmax} & Thermal Resist from junct to case ⇒ $\theta_{jc} = \theta_{dev-case}$

Betⁿ case & Heatsink ⇒ $\theta_{case-snk}$

Betⁿ Heatsink & ambient ⇒ $\theta_{snk-amb}$

∴ $T_{dev} - T_{amb}$ = Temp diff betⁿ device & Ambient

$$\boxed{T_{dev} - T_{amb} = P_D(\theta_{dev-case} + \theta_{case-snk} + \theta_{snk-amb})}$$

P_D = power dissipated in device.

∴ $T_{case} - T_{snk} = P_D(\theta_{case-snk})$

If Heat sink is not used, $\boxed{T_{dev} - T_{amb} = P_D(\theta_{dev-case} + \theta_{case-amb})}$

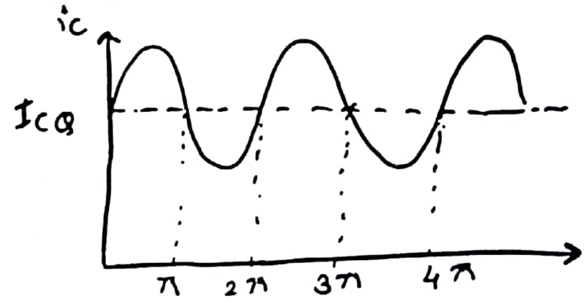
where $\theta_{case-amb}$ = Thermal Resist. betⁿ case & ambient.

* Classes of Amplifiers :-

– according to % of time & o/p transistors are conducting (ON)

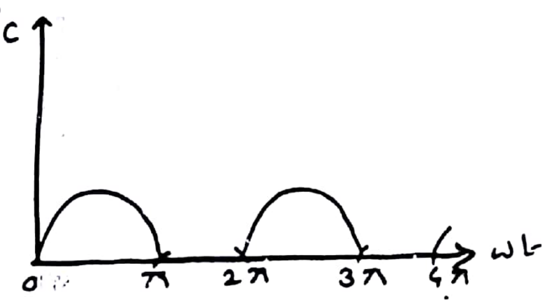
four principal classifications are :-

① class A



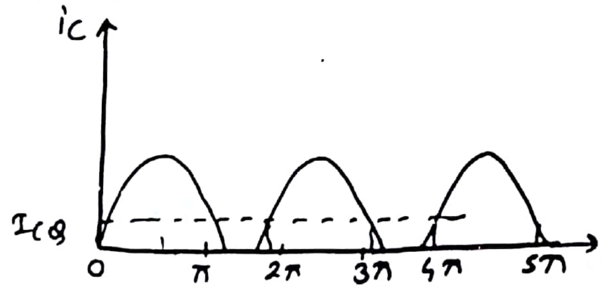
Biased at Icq, conduct for entire cycle

② class B



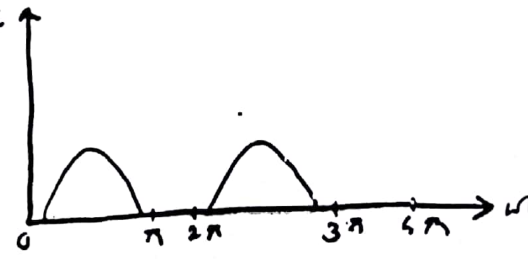
conducts for $\frac{1}{2}$ of each sine wave i/p

③ class AB



Biased at small Icq & conducts for slightly more than half cycle

④ class C



conducts for less than half cycle.