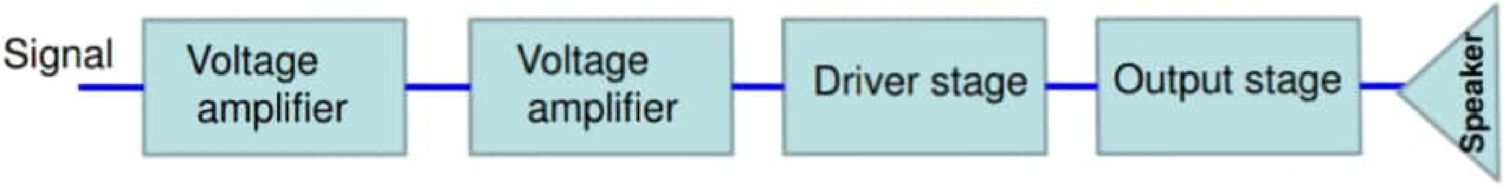
Power Amplifiers

➢ A Power amplifier is large signal amplifier and this is generally a last stage of a multistage amplifier.

➢ The function of a practical power amplifier is to amplify a weak signal until sufficient power is achieved to operate a loudspeaker or output device.

➢ Typical output power rating of a power amplifier will be 1W or higher. The schematic diagram of a practical power amplifier is shown below –



➢ The driver stage operates as a class A power amplifier and supplies the drive for the output stage.

➢ The last output stage is essentially a power amplifier and its purpose is to transfer maximum power to the output device (speaker). The output stage generally employ class B amplifiers in push-pull arrangement.

Power Amplifiers

- A large signal amplifier means much larger portion of load line is used during signal operation compared to small signal amplifier.

- A small signal amplifier (handle ac signal <10mV) operate over a linear portion of load line.

- In case of power amplifier, we can not use small signal approximation directly to calculate voltage gain, current gain and input/output impedance.

- Ideal power amplifier will deliver 100% of the power it draws from the supply to load. In practice, this can never occur.

- The reason for this is the fact that the components in the amplifier will all dissipate some of the power that is being drawn form the supply.

Performance parameters of power amplifier

Amplifier Efficiency : A **figure of merit** for the power amplifier is its efficiency

- **It is defined as a ratio of output ac power to the input dc power.**

$$\eta = \frac{ac\ \ output\ \ power}{dc\ \ input\ \ power} \times 100\% = \frac{P_o(ac)}{P_i(dc)} \times 100\%$$

Distortion

- **The change in output wave shape from the input wave shape of an amplifier is known as distortion.**

The distortion can be reduced using negative feedback in amplifier.

Power dissipation capability

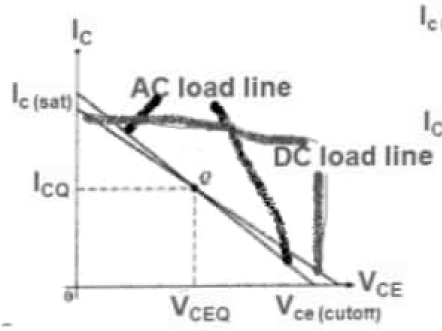
- **The ability of a power amplifier to dissipate heat is known as power dissipation capability.**

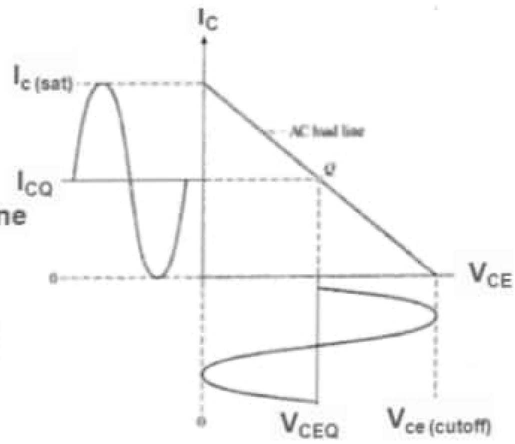
- To achieve better heat dissipation heat sink (metal case) is attached with power transistor. The increase surface area allows heat to escape easily.

AC Load line

The ac load line of a given amplifier will not follow the plot of the dc load line.

This is due to the dc load of an amplifier is different from the ac load.



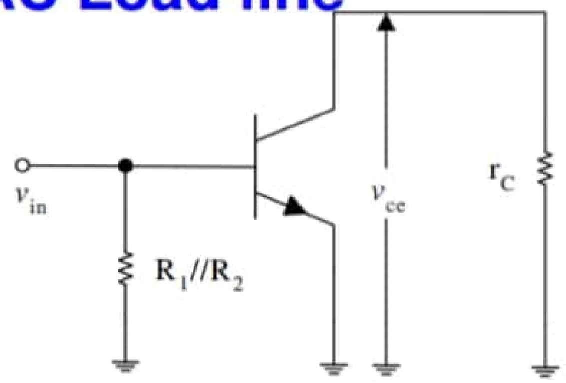


the ac load line will tell you the maximum possible peak-to-peak output voltage (V_{pp}) from a given amplifier.

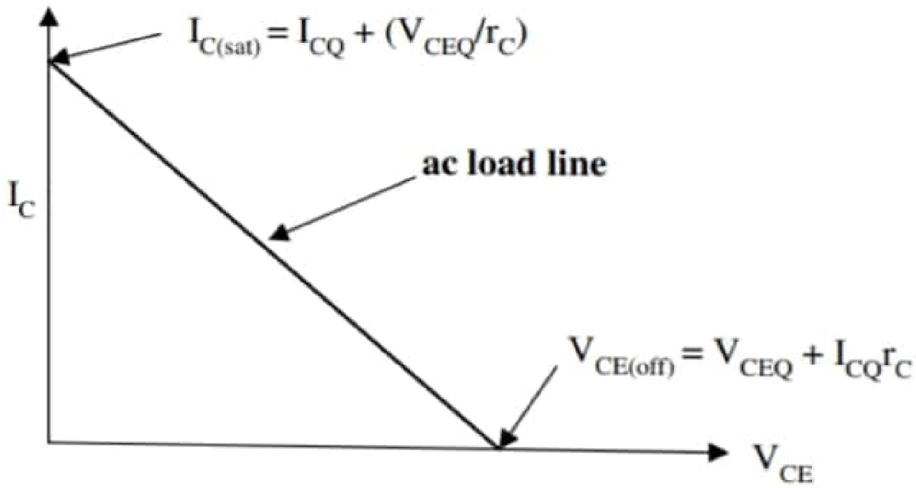
- When an ac signal is applied to the base of the transistor, I_C and V_{CE} will both vary around their *Q*-point values.

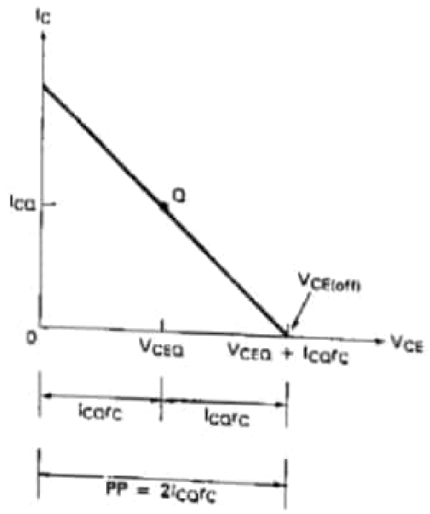
- When the *Q*-point is centered, I_C and V_{CE} can both make the maximum possible transitions above and below their initial dc values.

AC Load line

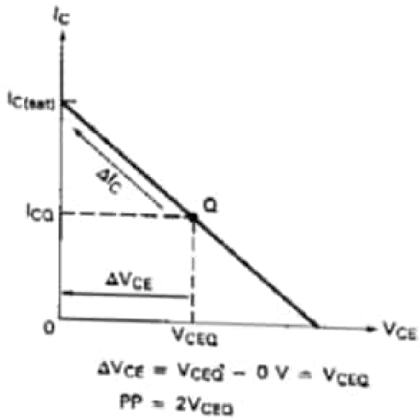


$r_C = R_C // R_L$



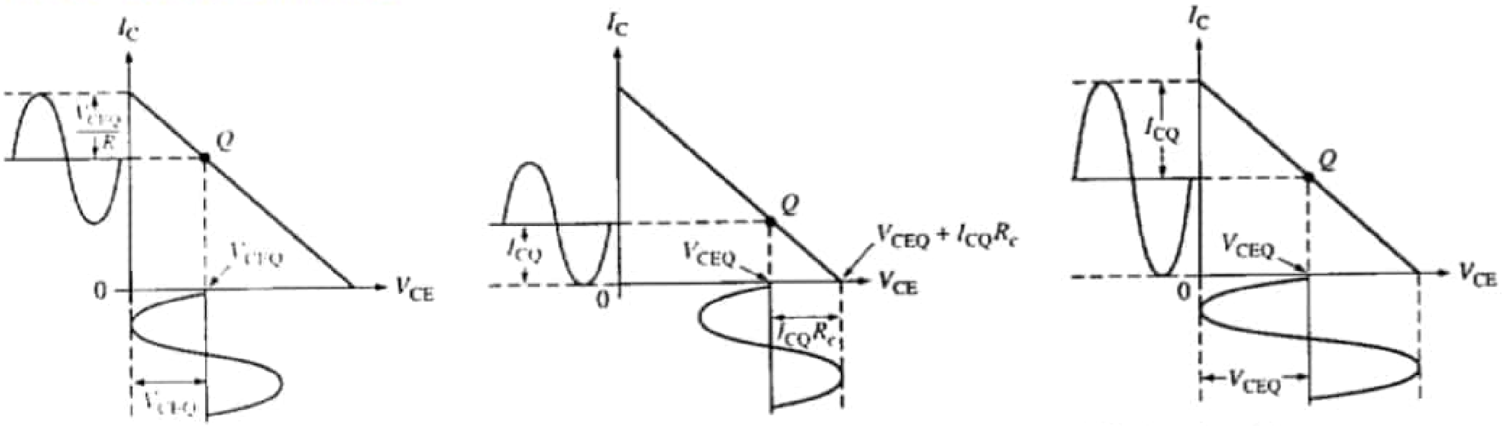


(a)



(b)

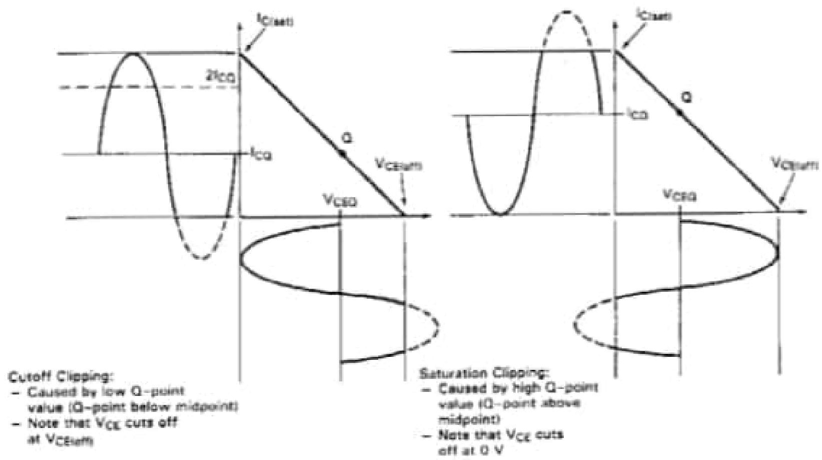
AC Load line



(a) Limited by saturation (b) Limited by cutoff (c) Centered Q-point

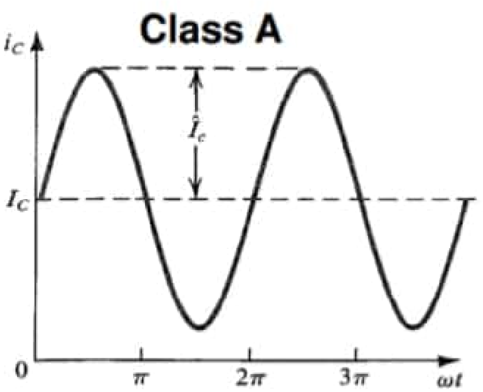
When the *Q*-point is below midpoint on the load line, the input signal may cause the transistor to cutoff. This can also cause a portion of the output signal to be clipped.

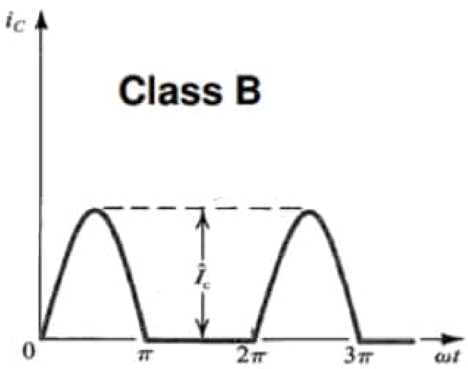
When the *Q*-point is above the center on the load line, the input signal may cause the transistor to saturate. When this happens, a part of the output signal will be *clipped* off.

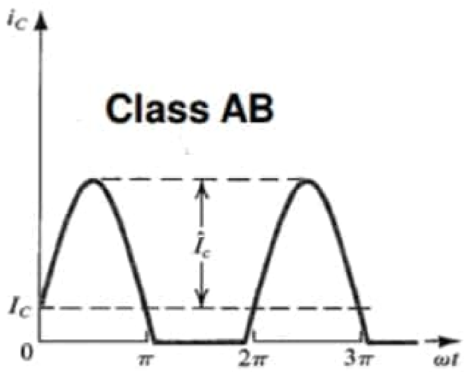


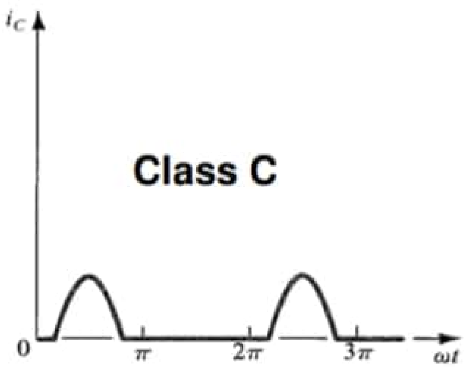
Output Stages: Power amplifier

➢ **Output stages are classified according to the collector current waveform that results when an input signal is applied.**





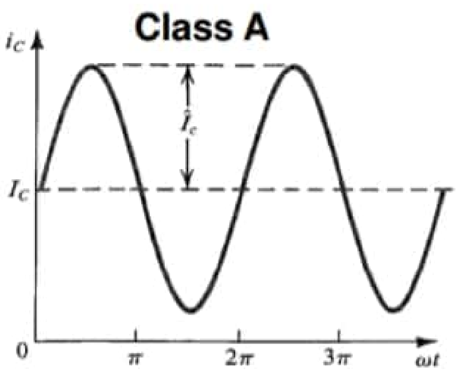


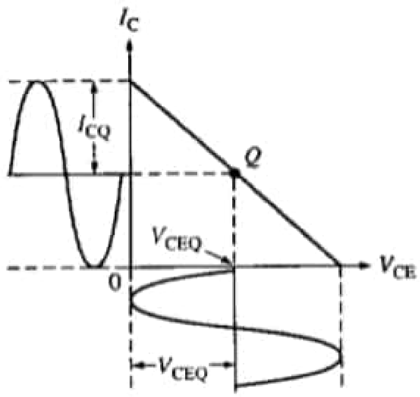


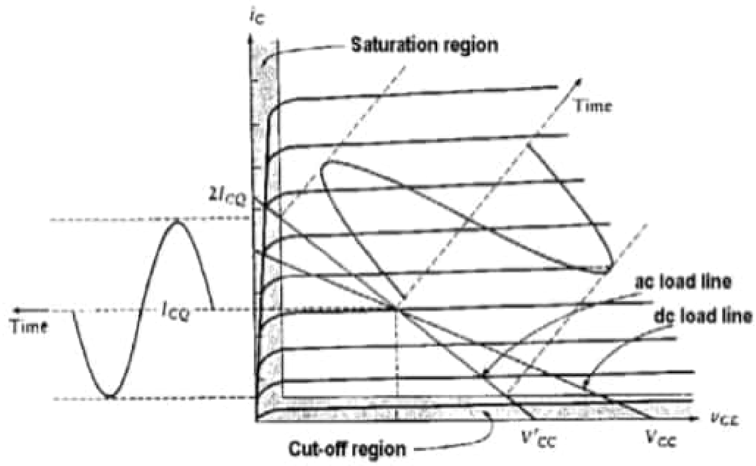
Amplifier	Maximum Efficiency, η_{max}
Class A	25%
Class B	78.5%
Class C	99%

Class A Power amplifier

➢ If the collector current flows at all times during the full cycle of the signal, the power amplifier is known as class A amplifier.







➢ With class A amplifier Q point lies middle of the load line so that signal can swing over the maximum possible range without saturating or cut off the transistor.

Efficiency: RC coupled Class A Power amplifier

The total dc power, $P_i(dc)$, that an amplifier draws from the power supply :

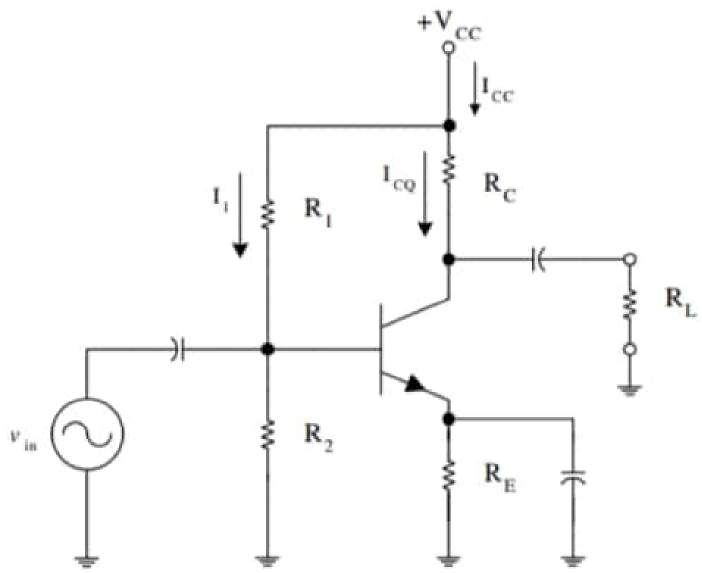
$$P_i(dc) = V_{CC} I_{CC} \qquad I_{CC} = I_{CQ} + I_1$$

$$I_{CC} \approx I_{CQ} \quad (I_{CQ} >> I_1)$$

$$P_i(dc) = V_{CC} I_{CQ}$$

$$P_o(ac) = V_{ce} \times I_{ce}$$

V_{ce} and I_{ce} represents rms value of the signal.



$$V_{ce} = \frac{V_{ce(p-p)}}{2\sqrt{2}} = \frac{V_{CC}}{2\sqrt{2}} \qquad I_{ce} = \frac{I_{ce(p-p)}}{2\sqrt{2}} = \frac{I_{CQ}}{2\sqrt{2}}$$

$$\eta = \frac{ac \;\; output \;\; power}{dc \;\; input \;\; power} \times 100\% = \frac{P_o(ac)}{P_i(dc)} \times 100\%$$

This circuit is rarely used due to poor efficiency.

$$\eta = \frac{V_{ce} \times I_{ce}}{V_{CC} \times I_{CQ}} \times 100\% = 25\%$$

That is 75% of the power supplied by the sources is dissipated in the transistors. This is a waste of power, and it leads to a potentially serious heating problems with the transistors.

Transformer coupled Class A amplifier

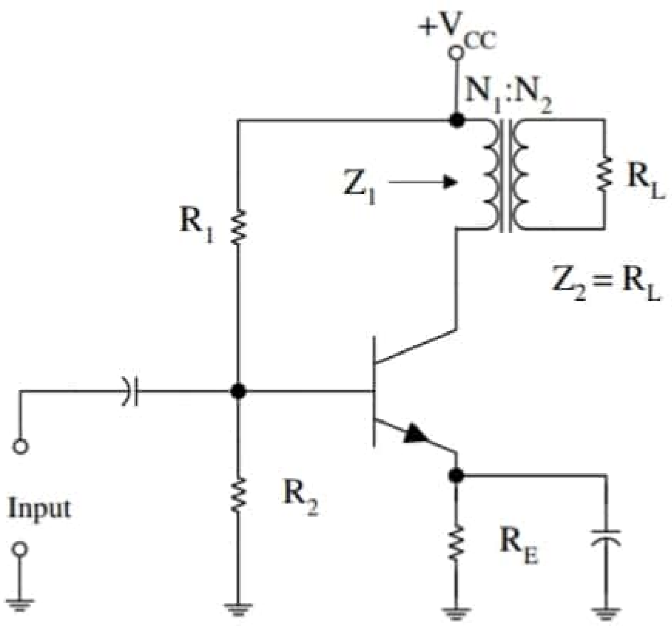
➢ **Lower dc power loss due to very small resistance of transformer primary coil**

➢ **Impedance matching**

The relationship between the primary and secondary values of voltage, current and impedance are summarized as:

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

$$\left(\frac{N_1}{N_2}\right)^2 = \frac{Z_1}{Z_2} = \frac{Z_1}{R_L}$$



N_1, N_2 = the number of turns in the primary and secondary
V_1, V_2 = the primary and secondary voltages
I_1, I_2 = the primary and secondary currents
Z_1, Z_2 = the primary and seconadary impedance ($Z_2 = R_L$)

Efficiency: Transformer coupled Class A amplifier

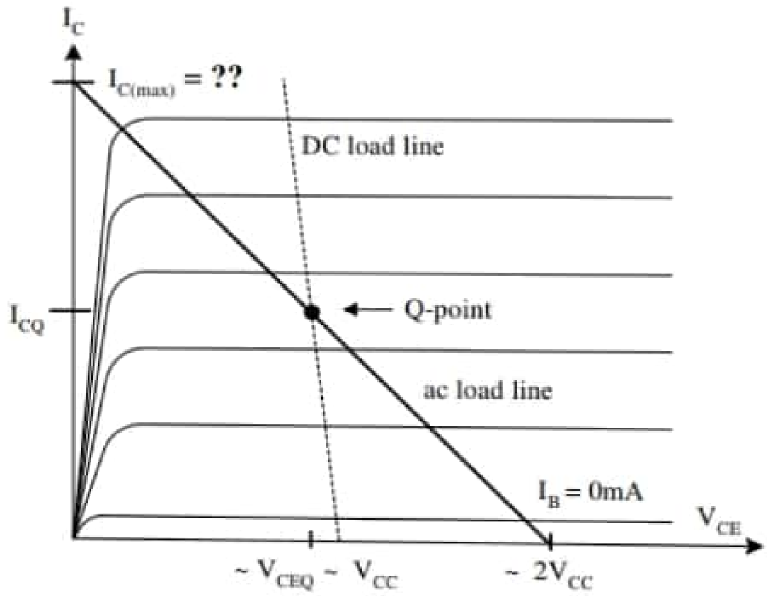
$$P_i(dc) = V_{CC} I_{CC}$$

$$P_o(ac) = V_{ce} \times I_{ce}$$

$$V_{ce} = \frac{V_{ce(p-p)}}{2\sqrt{2}} = \frac{V_{CC}}{\sqrt{2}}$$

$$I_{ce} = \frac{I_{ce(p-p)}}{2\sqrt{2}} = \frac{I_{CC}}{\sqrt{2}}$$

$$\eta = \frac{V_{ce} \times I_{ce}}{V_{CC} \times I_{CQ}} \times 100\% = 50\%$$



Principal advantage – lower distortion than Class C, B & AB.

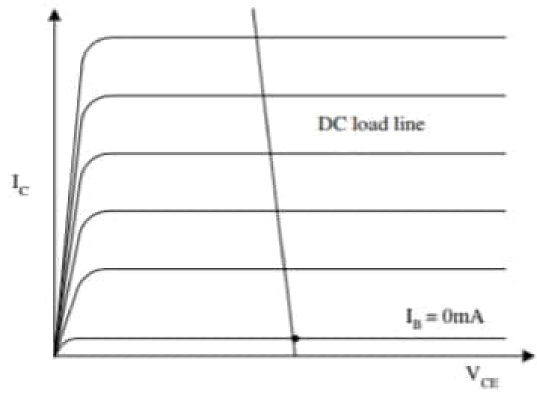
Principal disadvantage – lower power efficiency than Class C, B & AB.

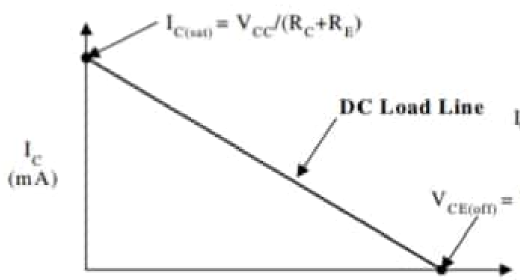
The transformer is subject to various power losses. Among these losses are couple loss and hysteresis loss. These transformer power losses are not considered in the derivation of the $\eta = 50\%$ value.

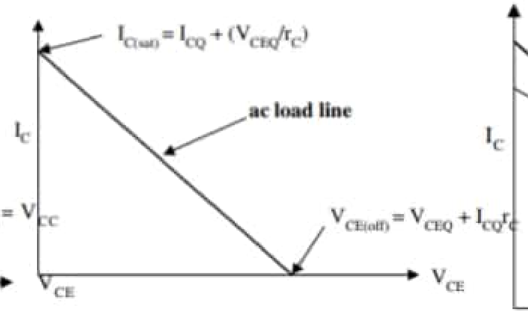
Supplement slide: How to draw AC and DC load line for Transformer coupled Class A amplifier

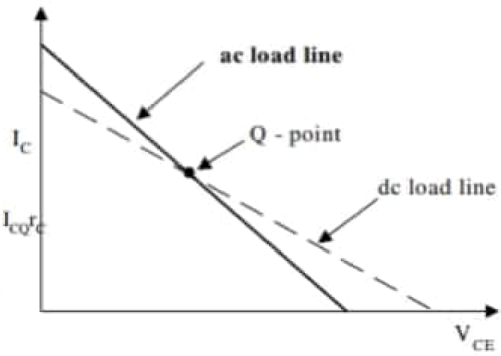
The nearly **vertical** load line of the transformer-coupled amplifier is caused by the **extremely low dc resistance** of the transformer primary.

$V_{CEQ} = V_{CC} - I_{CQ}(R_C + R_E)$ Where $R_C = Z_1$









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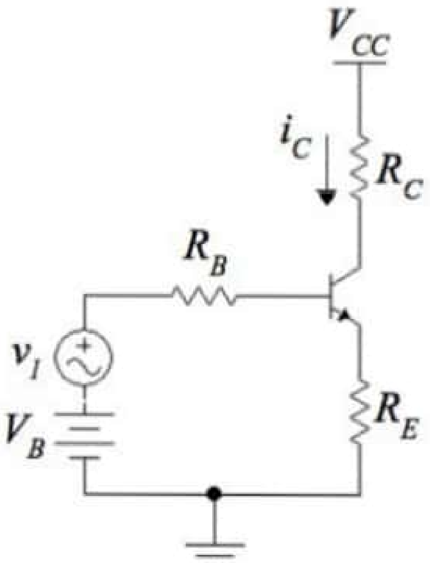
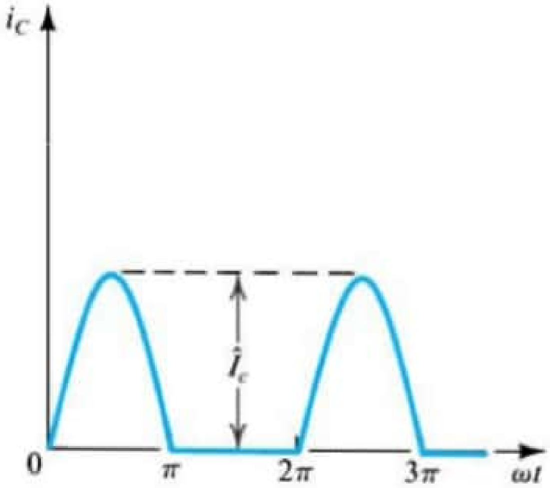
Class B Power amplifier

- **If the collector current flows during the half cycle of the signal only, the power amplifier is known as class B amplifier.**

- **To have this kind of operation, Q point must be located at cut-off.**





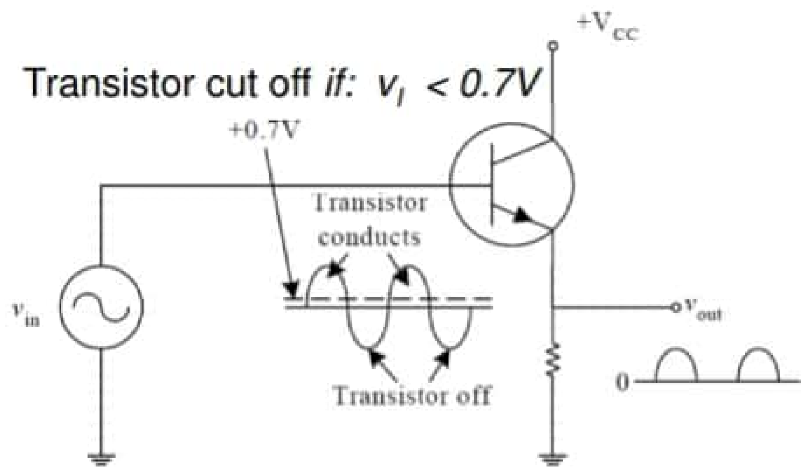
Transistor cut off ($i_C = 0$) if: $v_I + V_B < 0.7V$

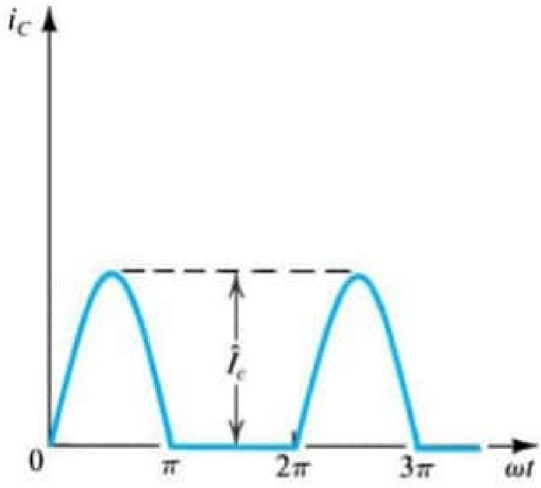
A 2nd class B BJT is needed to conduct for the negative v_I cycle.

Class B Power amplifier

➢ **If the collector current flows during the half cycle of the signal only, the power amplifier is known as class B amplifier.**

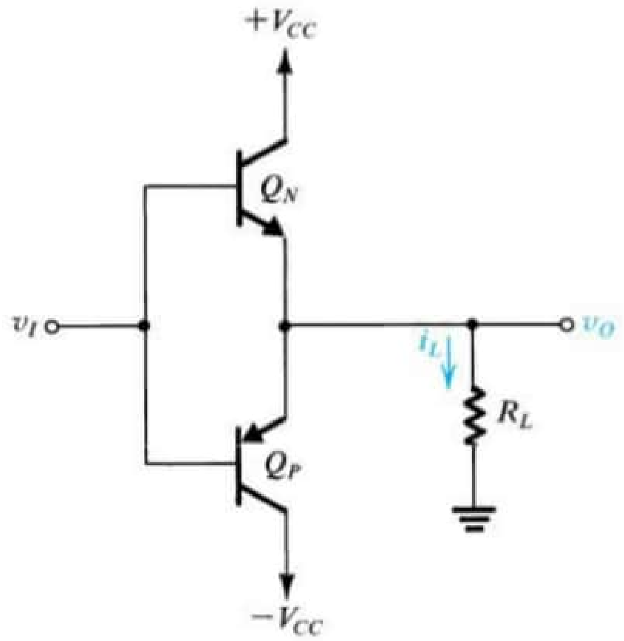
➢ **To have this kind of operation, Q point must be located at cut-off. At cut-off point $I_{CQ} = 0$ and $V_{CEQ} = V_{CE\text{-}off}$**

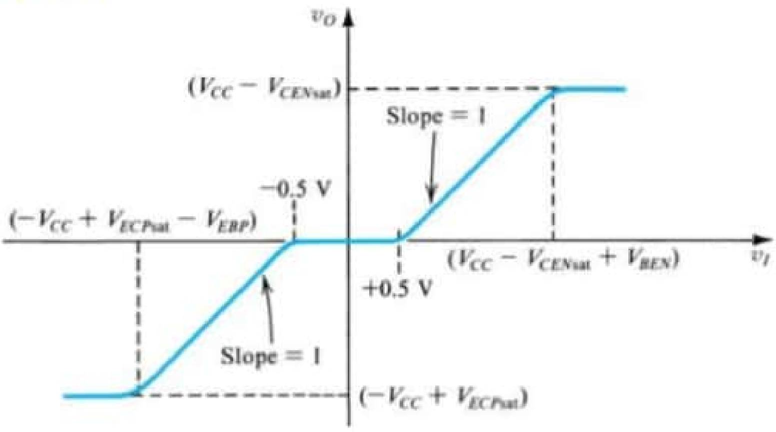




➢ The **advantage of a class-B amplifier is that the collector current is zero when the input signal to the amplifier is zero.**
Therefore the transistor dissipate no power in the quiescent condition.

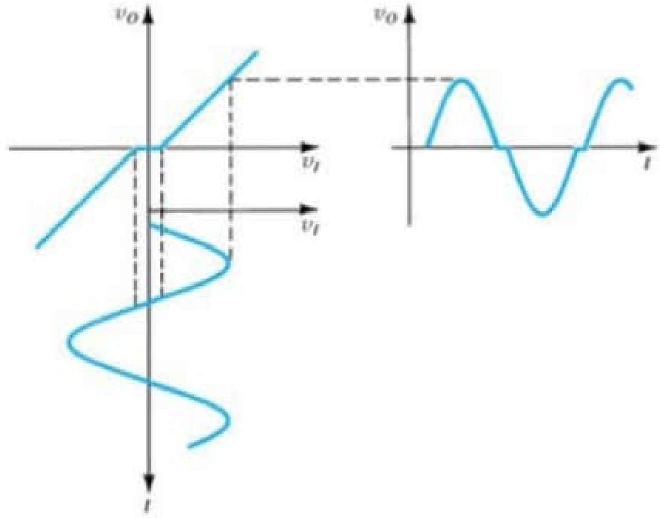
Class B Push-Pull amplifier





Class B Crossover Distortion

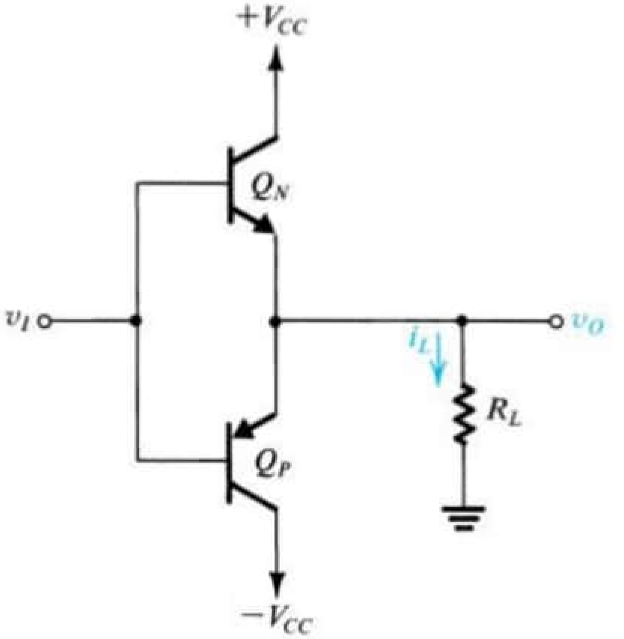
Crossover distortion in audio power amps produces unpleasant sounds.

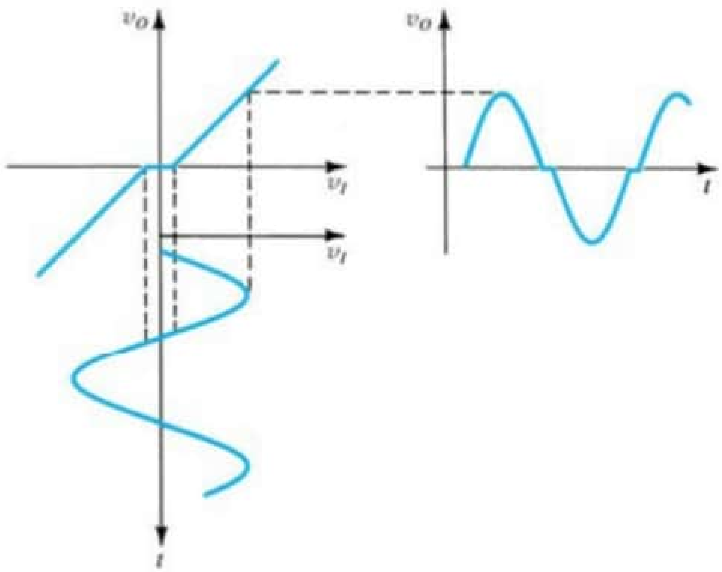


Class B Push-Pull amplifier

A 2nd class B BJT is needed to conduct for the negative v_I *cycle.*

complementary-symmetry amplifier



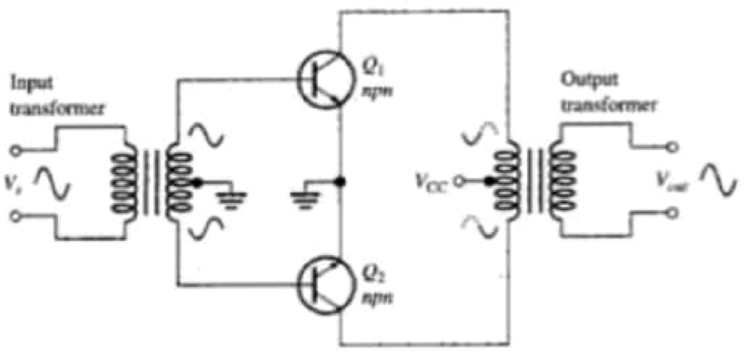


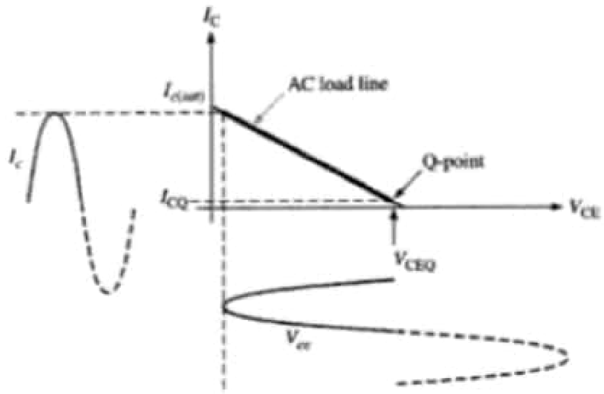
Class B Crossover Distortion

Complementary transistors means one of the transistors is a *npn and the other is pnp.* **Need dual-polarity power supplies.**

Crossover distortion in audio power amps produces unpleasant sounds.

Efficiency: Push Pull Class B Power amplifier



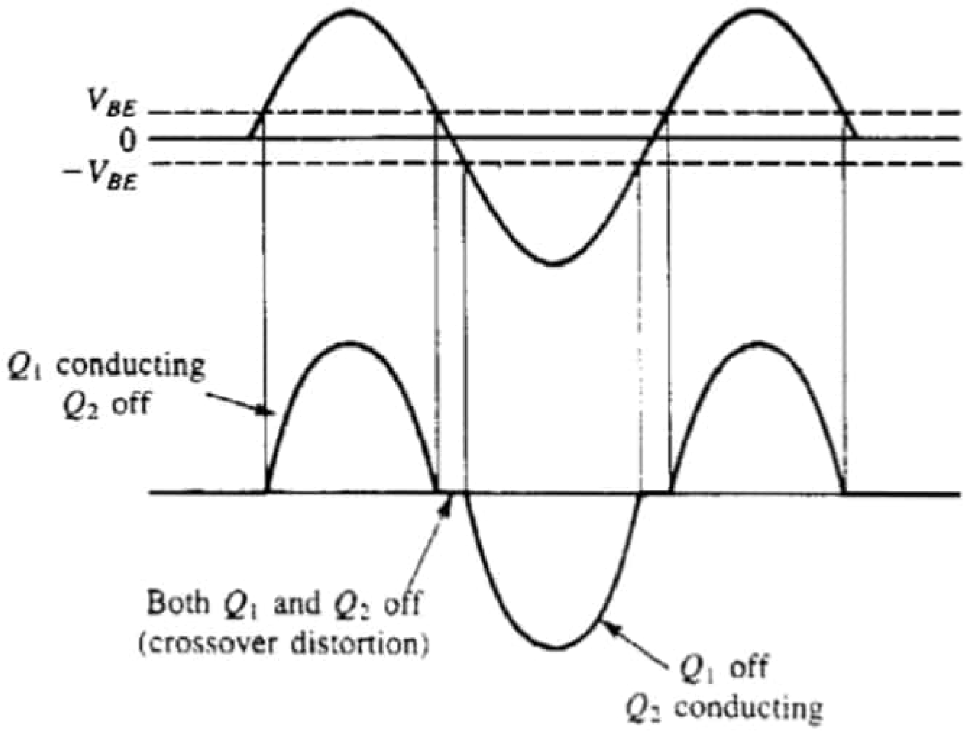


$$P_i(dc) = V_{CC} I_{DC} = \frac{V_{CC} I_C}{\pi} \qquad P_o(ac) = V_{ce} \times I_{ce}$$

$$V_{ce} = \frac{V_{ce-p}}{\sqrt{2}} = \frac{V_{CC}}{2\sqrt{2}} \qquad I_{ce} = \frac{I_{ce-p}}{\sqrt{2}} = \frac{I_C}{\sqrt{2}}$$

$$\eta = \frac{P_o(ac)}{P_i(dc)} \times 100\% \qquad \eta = \frac{V_{ce} \times I_{ce}}{V_{CC} \times I_{CQ}} \times 100\% = 0.25\pi\% = 78.5\%$$

Class B Crossover Distortion

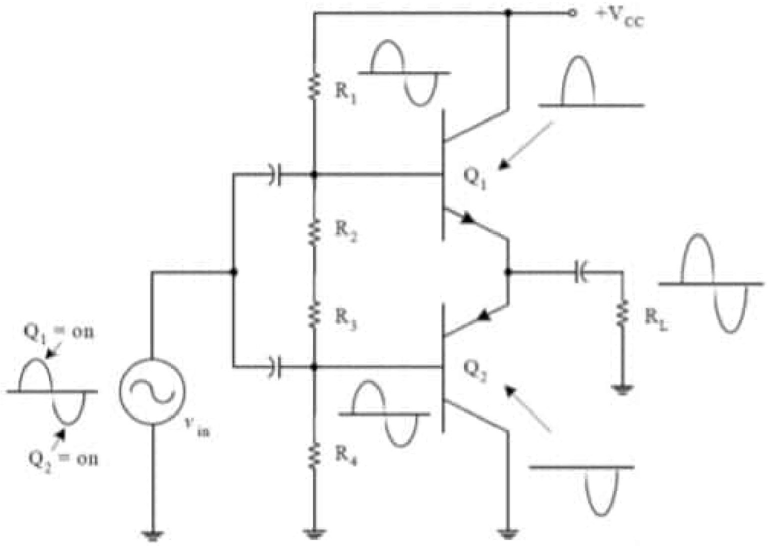


Crossover distortion in audio power amplifers produces unpleasant sounds.

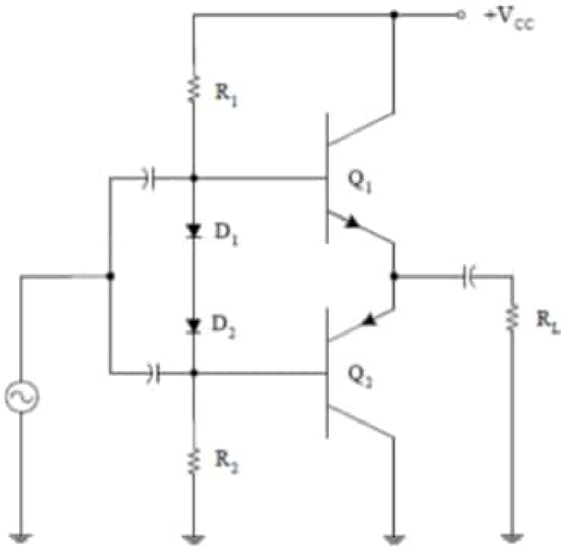
To prevent crossover distortion, both transistors will normally be biased at a level that is slightly ***above cutoff.***

Class AB power amplifier

To eliminate crossover distortion, both transistors in the push-pull arrangement must be biased slightly above cut-off when there is no signal.



Voltage Divider bias



Diode biasing circuit

In voltage divider bias circuit difficult to maintain a stable bias point due to changes in V_{BE} over **temperature changes. (i.e. Δtemp → Δ*Q-point*)**

When the diode characteristics of **D1 and D2 are closely matched to the transconductance characteristics of the transistors, a stable bias can be maintained over temperature.**

Power Transistor Heat Sinking

Power transistor can dissipate many watts.

All power devices are packaged in cases that permit contact between a metal surface and an external heat sink.

In most cases that metal surface of device is electrically connected to one terminal (e.g. for power transistors the case is always connected to the collector).

heat sink :- provides additional surface area to conduct heat away from the transistors more quickly to prevent overheating.

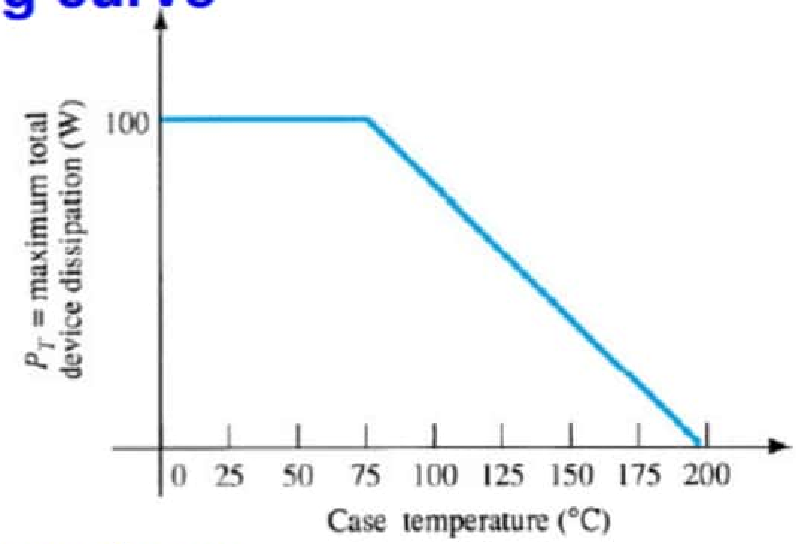
The whole point of heat sinking is to keep the transistor junction below some maximum specified operating temperature.

For Si transistors in metal packages the maximum junction temperature is usually 200^0C, whereas for transistors in plastic packages it is usually 150^0C.

Power Transistor derating curve

$$P_D(T_1) = P_D(T_0) - \kappa(T_1 - T_0)$$

Where
$P_D(T_0)$ = Max dissipated power at T_0
$P_D(T_1)$ = Max dissipated power at T_1
T_0 = temp at which derating starts
T_1 = Temp of interest
κ = derating factor (W /°C)



Power Transistor Thermal analogy

$$P_{total} = \frac{T_{j,\max} - T_{amb}}{\theta} \qquad \theta = \theta_{jc} + \theta_{cs} + \theta_{sa}$$

P_{total} = total dissipated power in the transistor ; $T_{j\text{-}max}$ = Max junction temperature ;

T_{amb} = ambient temp ; Θ = total thermal resistance

θ_{jc} = junction to case thermal resistance ; θ_{cs} = case to heat sink thermal resist

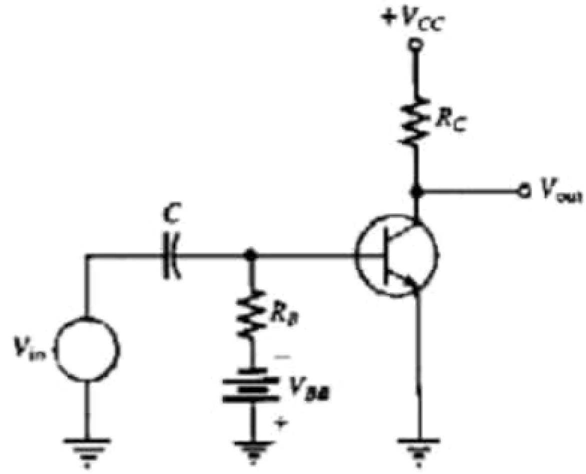
θ_{sa} = sink to ambient thermal resistance

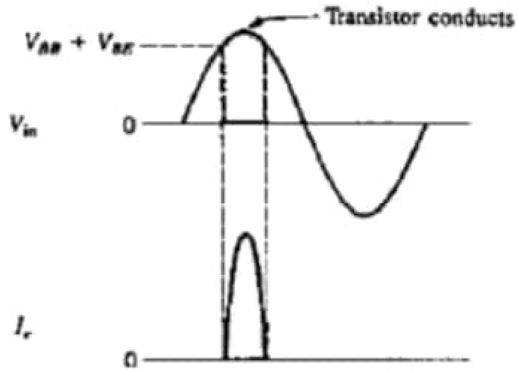
Class C power amplifier

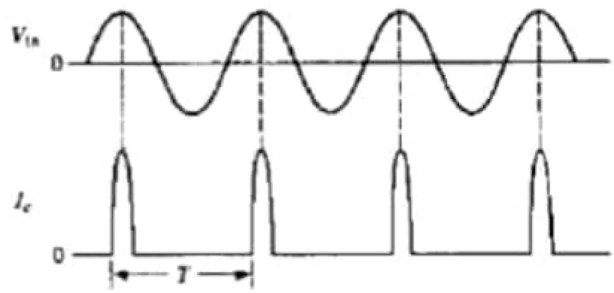
Class C amplifiers are used extensively in radio communications circuits.

A class C amplifier conducts for less than 180°.

The transistor is biased with a negative V_{BE} Thus it will conduct only when the input signal is above a specified positive value.
i.e. transistor 'ON' when $V_{in} > V_{BB} + V_{BE}$







The power dissipation of the transistor in a class-C amplifier is low because it is on for only a small percentage of the input cycle.