UNIT - IV

LARGE SIGNAL AMPLIFIERS
(OR)
POWER AMPLIFIERS

Topics to be Covered:

1. Large Signal Amplifier Concept
2. Differences between Voltage (Small-Signal) amplifiers and Power (Large-Signal) amplifiers.
3. Classification of Power amplifiers
4. Non-linearity of transistors and Harmonics distortion, Total harmonic distortion and Power output. Total harmonic distortion and harmonic amplitudes
5. Determination of harmonic amplitudes
   (a) 3-point schedule
   (b) 5-point schedule
6. Transformer coupled class A power amplifier.
7. Efficiency of class A power amplifier (direct coupled and transformer coupled)
8. class-A push-pull amplifier and advantages.
9. class-B power amplifier and its efficiency
10. class-B push-pull amplifier and zero-crossover distortion.
11. Complementary-Symmetry class-B pushpull amplifier.
12. Thermal stability.
13. Heat sinks.
14. Problems.

① Power Amplifier (or) Large Signal Amplifier :

It is an electronic circuit which delivers large amount of power to the load. Power amplifiers are the last stage amplifiers of a multi-stage amplifying systems.

Note: ① In Power amplifiers the collector (o/p) current swing is very large, normally more than 100 mA.

② Power amplifier doesnot amplify the power of a given signal, but it converts the DC input power into ac output power.

② Differences between Voltage (Small Signal) amplifiers and Power (Large Signal) amplifiers :

	Parameter	Voltage Amp.	Power Amp.
		Small signal amplifiers	Large signal amplifier.
①	Signal Level		
②	Function	It raises the voltage level of the i/p signal.	It raises the power level of the i/p signal.
③	Input voltage level	very low (mV)	High (2-4 V)
④	β (Current gain)	High (~100)	Low (20~50)
⑤	Collector Resistance (R_c)	High (4-10 KΩ)	Low (5-20 Ω)
⑥	Collector current	Low (~1 mA)	High (>100 mA)
⑦	Output impedance	High (~12 KΩ)	Low (~200 Ω)
⑧	Output power	Low	High
⑨	Type of Coupling used	RC Coupling	Transformer Coupling
⑩	Heat generation	Low heat generated	More heat is generated.
⑪	Cooling Arrangement	Not Required	Required.
⑫	Application	Pre amplifier	Final stage amplifier (or) Driver amplifier.

③ Classification of Power Amplifiers:

Based on the selection of operating point or Q-point amplifiers are classified ~~into~~ as:

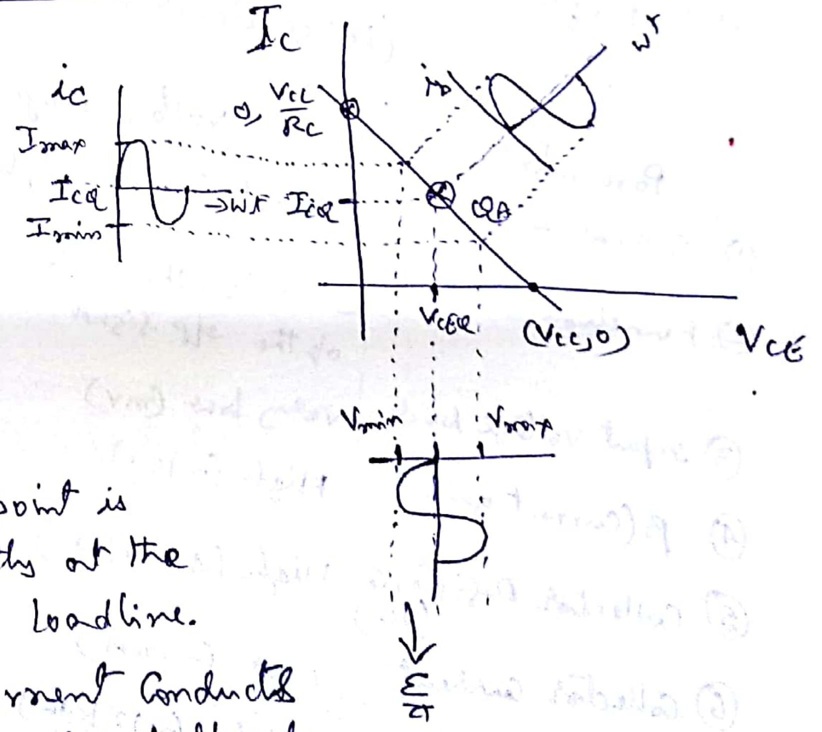
① class - A
② class - B
③ class - C
④ class - AB

→ The transistor produces o/p when it is in active region. (or) [The transistor is operated in active region.]

⑤ class - D
⑥ class - S

→ The transistor is operated in switching mode.

① class-A Amplifier:



Points:

① The operating point is selected exactly at the center of the loadline.

② Collector current conducts for 360° i.e. for full cycle.

③ For all values of input signal transistor remains in active region hence no distortion occurs.

④ The maximum (theoretical) conversion efficiency is 25% for RC coupling and 50% for transformer coupling.

(5) (i) $I_{dc} = I_{CQ}$; $V_{DC} = V_{CEQ}$ (or V_{CQ})

(ii) $I_m = \frac{(I_{max} - I_{min})}{2}$; $V_m = \frac{V_{max} - V_{min}}{2}$

(iii) $I_{rms} = \frac{I_m}{\sqrt{2}}$; $V_{rms} = \frac{V_m}{\sqrt{2}}$

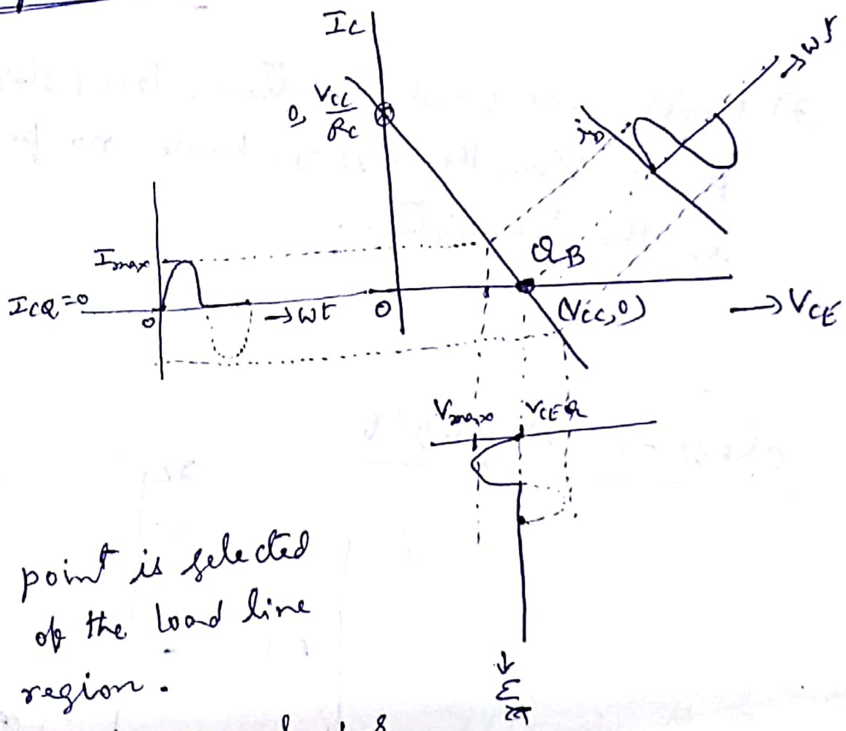
(6) The ac power delivered to load P_{ac} is given by

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

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

(7) Refer Note below

(2) class-B Amplifier :



Points :

(1) The operating point is selected at one end of the load line in cut-off region.

(2) Collector current conducts only for 180° i.e. during positive half-cycle.

(3) Only one half-cycle is amplified, other half-cycle is not amplified hence distortion occurs. Zero cross-over distortion occurs in this mode of operation.

(P.T.O.)

Note : (7) when input signal is present the dc input power is converted into ac and delivered to load. So the dc power dissipated in transistor is very less, hence transistor cool (not much heated). If ~~no~~ input is not present all the dc input power ($P_{dc} = V_{CC} \times I_{CQ}$) is dissipated in the transistor and ~~the~~ transistor is much heated.

④ The maximum conversion efficiency is 78.6%.

⑤ $I_{dc} = \frac{I_{max}}{\pi}$ (HWR) $\left[= \frac{I_m}{\pi}\right]$; $V_{DC} = \frac{V_{max}}{\pi}$ (HWR) $\left[= \frac{V_m}{\pi}\right]$

$I_m = I_{max}$; $V_m = I_{max}$

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

⑥ The ac power delivered to the load Pac is given by

$$P_{ac} = V_{rms} \times I_{rms}$$

$$\boxed{\therefore P_{ac} = \frac{V_m I_m}{4}}$$

⑦ Under zero-signal conditions, transistor doesn't draw any power from the supply, hence no power is dissipated in the transistor.

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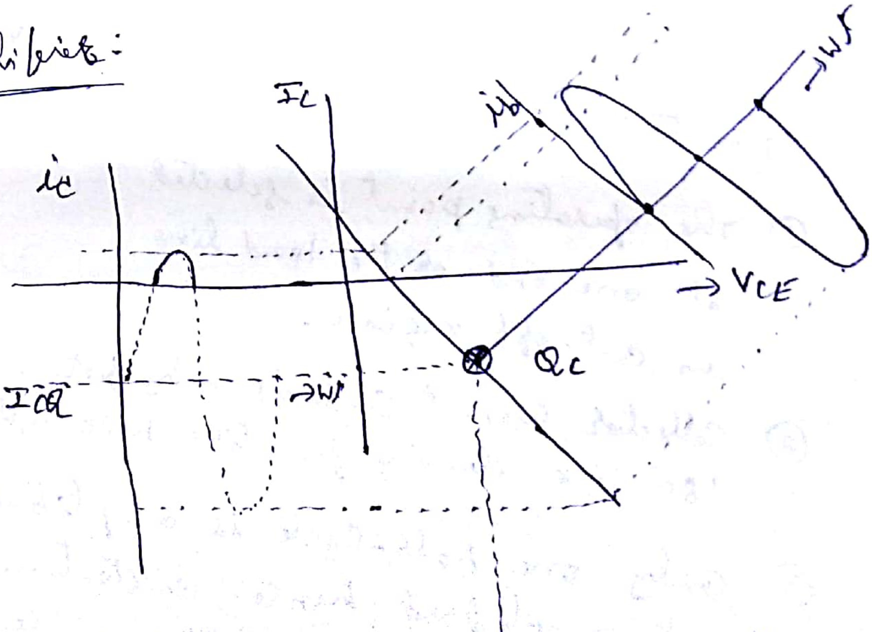
③ **Class-C Amplifier:**



Points:

① The operating point is selected well below cut-off region.

② Collector current conducts only for less than 180°, i.e. for small portion of positive peaks, and only peaks are amplified.

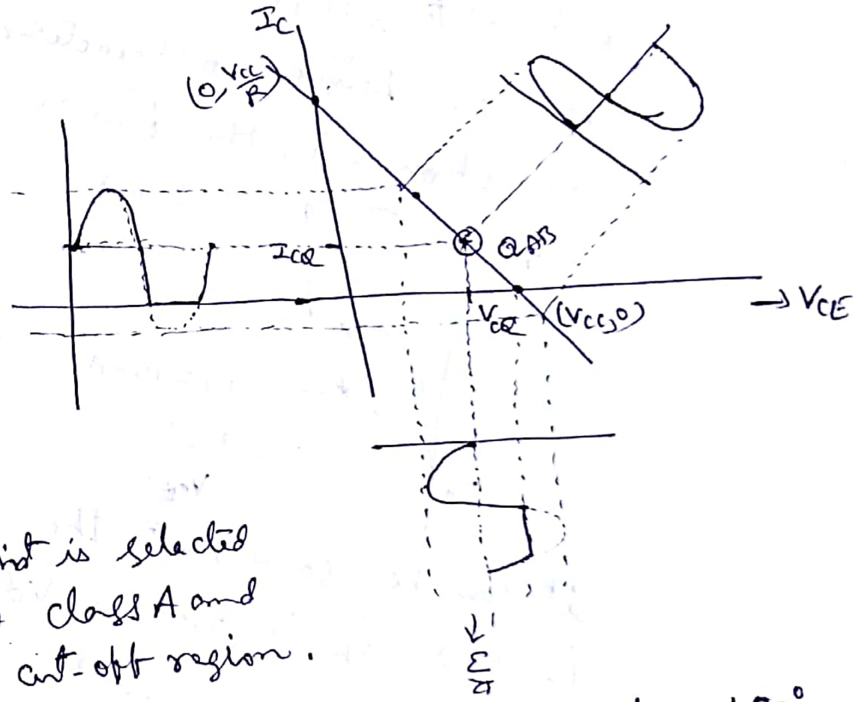
(Co...)

3. Severe distortion occurs.

4. The maximum conversion efficiency is more than 90%, above 95% efficiency can be achieved practically.

5. The power calculations are to be done by using graphical methods only.

4. Class-AB Amplifier:



Points:

1. The operating point is selected between that of class A and class B, above cut-off region.

2. Collector current conducts for little more than 180°.

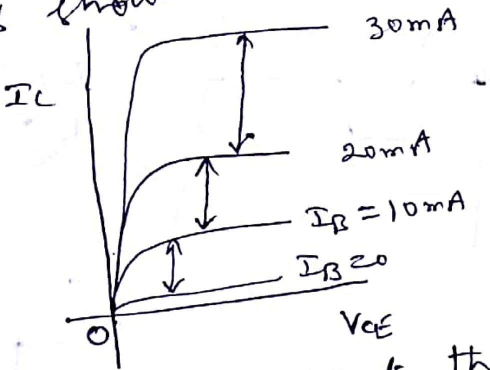
3. In class AB mode zero-crossover distortion is eliminated.

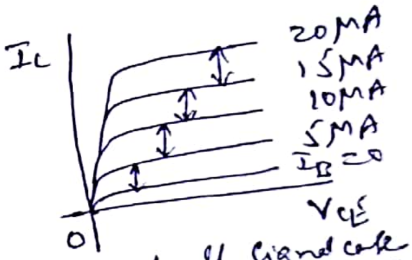
4. The maximum conversion efficiency is between that of class A and class B and varies with the location of the Q-point.

(P.T.O.)

(4) Non-linearity in Transistors and Harmonic distortion:

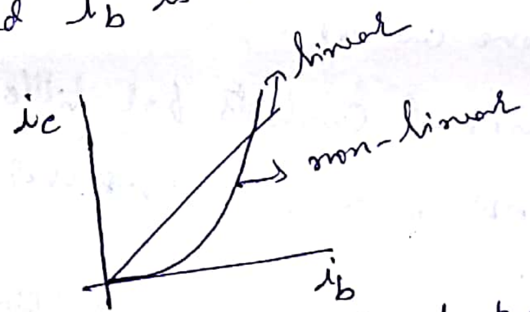
In small signal amplifiers the collector current swing is very small ($\sim 1\,mA$), hence all part of the input signal waveform will be amplified with same gain. This can be observed from the static o/p characteristics of a BJT, that the spacing between ~~co~~ characteristics curves is uniform for equal increments of base current. But as the collector current swing is large then the spacing between characteristic curves is not uniform, under such a situation as shown in the figure.





For small signal case

it can be said that the linear relation between i_c and i_b is not valid, as shown in diagram.



Now i_c is to be made proportional to not only i_b and also to i_b^2, i_b^3, i_b^4, ... etc., to include the non-linear behaviour of the transistor.

$$\therefore\ i_c \propto i_b$$
$$\propto i_b^2$$
$$\cdots$$

$$\therefore\ i_c = G_1 i_b + G_2 i_b^2 + G_3 i_b^3 + \cdots\cdots$$

Note: $i_c \rightarrow$ ac Collector Current
$i_b \rightarrow$ ac Base Current
} it is assumed the transistor is properly biased for its active region.

(P.T.O.)..⑤

Let $i_b = A \cos \omega t$

then the ac collector current i_c is given by

$$i_c = G_1 A \cos \omega t + G_2 A^2 \cos^2 \omega t + G_3 A^3 \cos^3 \omega t + \cdots$$

$$= G_1 A \cos \omega t + G_2 A^2 \left(\frac{1+\cos 2\omega t}{2}\right) + G_3 A^3 \left(\frac{\cos 3\omega t + 3\cos \omega t}{4}\right) + \cdots$$

Important

$$\boxed{\therefore i_c = B_0 + B_1 \cos \omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + \cdots}$$

From this expression it is known that due to non-linearity of the transistor, the output consists of a dc component B_0 and higher frequency components $2\omega t$, $3\omega t$, ... etc, which are not present in the input signal. All the higher frequency components are integer multiples of fundamental frequency (ωt). These are called as Harmonics. These components are called the fundamental ~~harmonic~~ harmonics will deshape the fundamental frequency component and hences introduces distortion in the amplitude of the fundamental frequency signal. So, this distortion is called as Amplitude distortion. (or) Harmonic distortion or Non-linear distortion.

quantitatively the harmonic distortion is expressed as

$D_2 = \left|\frac{B_2}{B_1}\right| \rightarrow 2^{nd}$ Harmonic distortion

$D_3 = \left|\frac{B_3}{B_1}\right| \rightarrow 3^{rd}$ Harmonic distortion

- - - - - - - - -

$D_n = \left|\frac{B_n}{B_1}\right| \rightarrow n^{th}$ Harmonic distortion.

Note: 2^{nd} Harmonic distortion is more severe as $B_2 > B_3 > B_4 > \cdots$

(P.T.O.)

Power Considerations and Total Harmonic distortion:

When this ac collector current is allowed through a load of R_L, the total ac power (P_T) developed in the load is given by

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

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

$$\therefore P_T = P_1\left[1 + D_2^2 + D_3^2 + D_4^2 + \cdots\right]$$

$$\therefore P_T = P_1(1 + D^2)$$

where $\boxed{P_1 = \frac{B_1^2 R_L}{2}}$ → Power delivered by fundamental harmonic to the load.

$\boxed{D^2 = D_2^2 + D_3^2 + D_4^2 + \cdots}$ → Total harmonic distortion.

Instaneous Collector Current:

The instantaneous collector current i_C is given by sum of ac and dc (Quiescent) currents.

$$\therefore i_C = I_{CQ} + i_c$$

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

Note: Under zero-signal conditions the DC current through the transistor is I_{CQ} only, when an ac signal applied at input terminal an additional dc component B_0 also flows through the transistor. So, the total dc flowing through the transistor is $(I_{CQ} + B_0)$ when ac input signal is applied.

5 Determination of Harmonic Amplitudes:

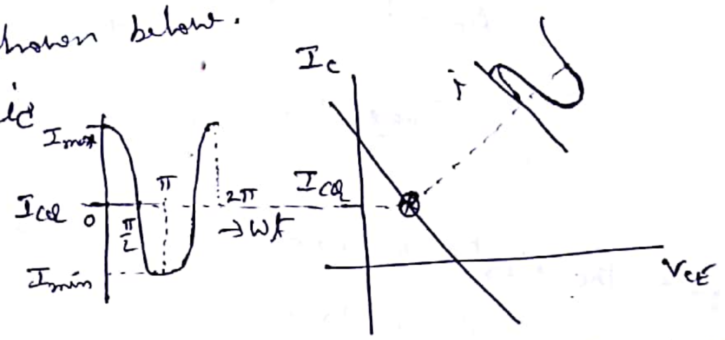
To determine the amplitude of harmonic components ~~for~~ static or dynamic characteristics are used, for a given load load resistance. Two methods are used to determine these amplitudes. They are

(a) 3-point schedule (This gives B_0, B_1 & B_2)

(b) 5-point schedule (This gives B_0, B_1, B_2, B_3 & B_4).

(a) 3-point schedule:

For a given input cosine wave, the o/p waveform is as shown below.



From this output signal, the instaneous collector current

when $wt = 0$ is $i_c = I_{max}$

when $wt = \frac{\pi}{2}$ is $i_c = I_{cQ}$ $\quad\Big\}$ — I

when $wt = \pi$ is $i_c = I_{min}$

but we know the instaneous current i_c is given by

$$i_c = I_{cQ} + B_0 + B_1 \cos wt + B_2 \cos 2wt$$

$\therefore$ when $wt = 0 \Rightarrow i_c = I_{cQ} + B_0 + B_1 + B_2$

when $wt = \frac{\pi}{2} \Rightarrow i_c = I_{cQ} + B_0 - B_2$ $\quad\Big\}$ — II

when $wt = \pi \Rightarrow i_c = I_{cQ} + B_0 - B_1 + B_2$

Note: using 3-point schedule we can get three harmonic values.

(P.T.O.)

From equations I and II we can write

$$I_{CQ} + B_0 + B_1 + B_2 = I_{max} \quad \text{--- III}$$

$$I_{CQ} + B_0 - B_2 = I_{CQ} \quad \text{--- IV}$$

$$I_{CQ} + B_0 - B_1 + B_2 = I_{min} \quad \text{--- V}$$

Solve the above equations for B_0, B_1 & B_2.

from IV $\boxed{B_0 = B_2}$

III + V $\Rightarrow$ $2I_{CQ} + 2B_0 + 2B_2 = I_{max} + I_{min}$

$$\boxed{\therefore\ B_0 = B_2 = \frac{I_{max} + I_{min} - 2I_{CQ}}{4}}$$

III − V $\Rightarrow$ $\boxed{B_1 = \frac{I_{max} - I_{min}}{2}}$

Therefore the first 3 harmonics are

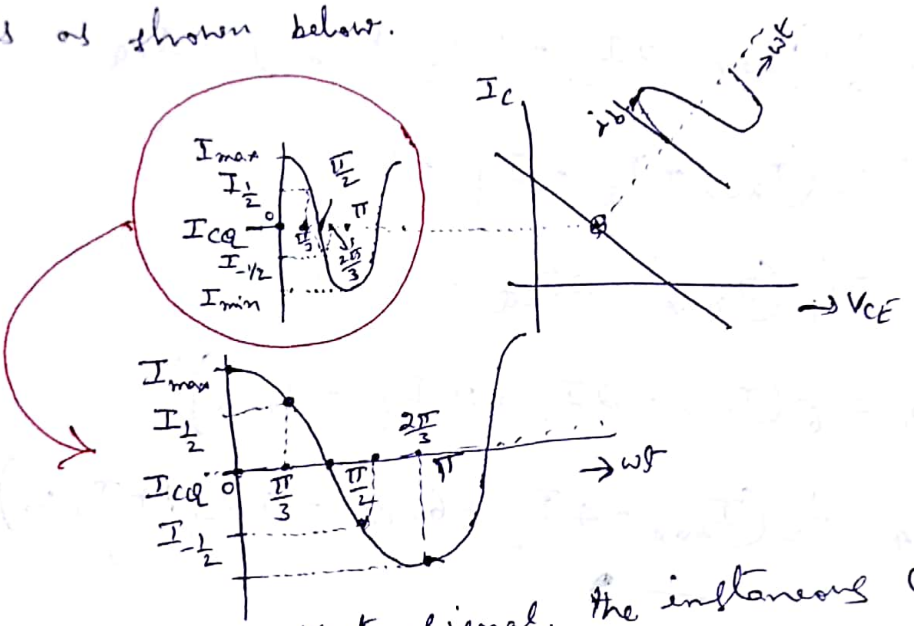
$$B_1 = \frac{I_{max} - I_{min}}{2}$$

$$B_0 = B_2 = \frac{I_{max} + I_{min} - 2I_{CQ}}{4}$$

Note: when three point schedule is considered the second harmonic B_2 is equal to B_0, the excess dc current through ~~the~~ transistor when input signal applied.

(b) 5 - Point Schedule:

For the given input Cosine signal the output waveform is as shown below.



From this output signal, the instaneous collector current at different instants of ωt can be as below.

$$\left.\begin{aligned}
\text{when}\quad \omega t &= 0 \Rightarrow i_c = I_{max}\\
\omega t &= \frac{\pi}{3} \Rightarrow i_c = I_{\frac{1}{2}}\\
\omega t &= \frac{\pi}{2} \Rightarrow i_c = I_{CQ}\\
\omega t &= \frac{2\pi}{3} \Rightarrow i_c = I_{-\frac{1}{2}}\\
\omega t &= \pi \Rightarrow i_c = I_{min}
\end{aligned}\right\} - \text{I}$$

But we know the instantaneous collector is given by

$$i_c = I_{CQ} + B_0 + B_1\cos\omega t + B_2\cos 2\omega t + B_3\cos 3\omega t + B_4\cos 4\omega t.$$

$$\left.\begin{aligned}
\text{when}\quad \omega t = 0 &\Rightarrow i_c = I_{CQ} + B_0 + B_1 + B_2 + B_3 + B_4\\
\omega t = \frac{\pi}{3} &\Rightarrow i_c = I_{CQ} + B_0 + \frac{B_1}{2} - \frac{B_2}{2} - B_3 - \frac{B_4}{2}\\
\omega t = \frac{\pi}{2} &\Rightarrow i_c = I_{CQ} + B_0 - B_2 + B_4\\
\omega t = \frac{2\pi}{3} &\Rightarrow i_c = I_{CQ} + B_0 - \frac{B_1}{2} - \frac{B_2}{2} + B_3 - \frac{B_4}{2}\\
\omega t = \pi &\Rightarrow i_c = I_{CQ} + B_0 - B_1 + B_2 - B_3 + B_4
\end{aligned}\right\} - \text{II}$$

(P.T.O.)

Solving the above equations for B_0, B_1, B_2, B_3 & B_4 the following expression can be obtained.

$$B_0 = \frac{1}{6}\left(I_{max} + 2I_{\frac{1}{2}} + 2I_{-\frac{1}{2}} + I_{min}\right) - I_{CQ}$$

$$B_1 = \frac{1}{3}\left(I_{max} + I_{\frac{1}{2}} - I_{-\frac{1}{2}} - I_{min}\right)$$

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

$$B_3 = \frac{1}{6}\left(I_{max} - 2I_{\frac{1}{2}} + 2I_{-\frac{1}{2}} - I_{min}\right)$$

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

Note: Using 5-point schedule we can obtain 5 harmonic values. It can be observed that $B_0 \neq B_2$ as in 3-point schedule. Even then in problems we can use the formula $B_0 = B_2$, while calculating harmonic distortion.

(P.T.O.) (8)

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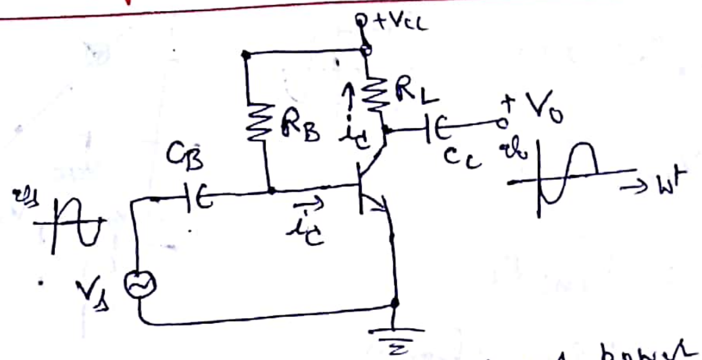
(6) CLASS-A POWER Amplifiers:

a) RC - Coupled (or) directly Coupled class A - amplifier:

b) Transformer Coupled class-A power amplifiers

c) class-A push-pull power amplifier.

(a) RC Coupled class-A power amplifier (or) series-fed amplifier



① A simple RC coupled class A power amplifier is as shown above.

② The fixed biasing resistor R_B is selected such that the operating point is exactly at the center of the load line.

③ The collector current flows for 360°.

④ Load R_L value is generally 4 to 16 Ω

⑤ The current gain β of the transistor is small.

⑥ The ~~Base~~ Collector current will be normally more than 10 mA.

⑦ DC operation of the ckt:

The operating point V_{CEQ}, I_{CQ} should be fixed from the static o/p characteristics of the power transistor provided by the manufacturer. The load resistance R_L value is known. It is required to calculate the value of R_B. V_{CC} value should be selected double to V_{CEQ}.

$$\therefore \quad R_B = \frac{V_{CC} - V_{BE}}{I_B} \; \Omega$$

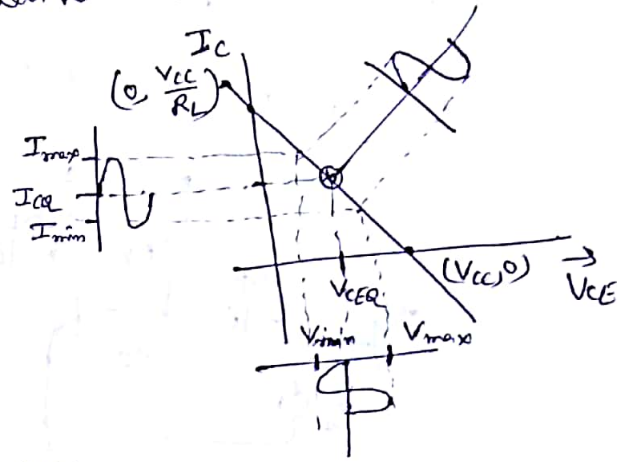
$$\text{where } I_B = I_{BQ} = \frac{I_{CQ}}{\beta}$$

in the above equations V_{CC}, V_{BE}, I_{CQ}, V_{CEQ} & β are known.

(P.T.O.)

(8) AC operation:

When an input ac signal is applied at base, ~~the~~ ac collector current flows through the load R_L. For a power amplifier, it is important to calculate how much ac power is delivered to the load.



The ac power delivered load can be obtained as

$$P_{ac} = P_{rms} = V_{rms} \times I_{rms}$$

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

From the waveform shown

$$V_{rms} = \frac{V_m}{\sqrt{2}} \quad \text{where} \quad V_m = \frac{V_{max} - V_{min}}{2} = V_{CEQ}$$

$$\text{and } I_{rms} = \frac{I_m}{\sqrt{2}} \quad \text{where} \quad I_m = \frac{I_{max} - I_{min}}{2} = I_{CQ}$$

$$\boxed{\therefore P_{ac} = \frac{V_m I_m}{2} = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8}}$$

Important

(9) Maximum Conversion efficiency:

The Conversion efficiency (η) of a power amplifier is defined as the ratio of ac power delivered to the load to the input dc power (the dc power drawn from V_{CC}).

We know

$$P_{dc} = V_{DC} \times I_{DC}$$

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

$$\text{and } P_{ac} = V_{rms} \times I_{rms}$$

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

(P.T.O.) (9)

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

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

under maximum conditions

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

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

$$\therefore \% \eta_{max} = \frac{\cancel{V_{CC}} \times \cancel{2I_{CQ}}}{\cancel{8}_{4} \times \cancel{V_{CC}} \times \cancel{I_{CQ}}} \times \cancel{100}^{25} \%$$

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

Therefore the power conversion efficiency of a RC coupled amplifier is only 25% . This means only 25% of the input dc power is converted into ac and delivered to the load and remaining 75% of the input power is dissipated in the form of heat, in the transistor circuit.

(b) **Transformer Coupled class-A power Amplifier :**

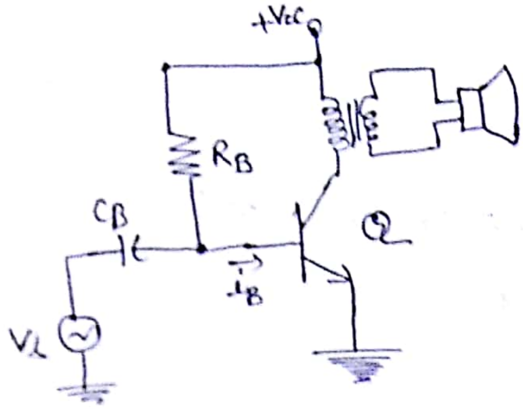
Transformer Coupled class-A power amplifier

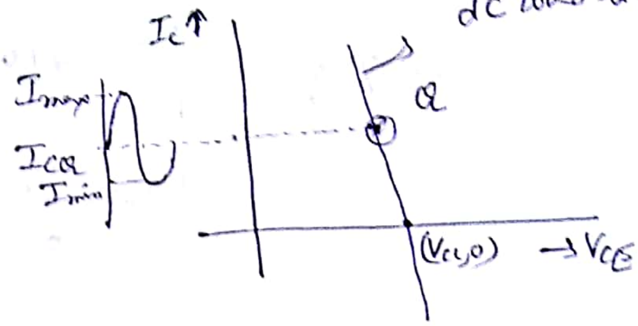
① The transformer Coupled class-A power amplifier is as shown in the Circuit.

② The Primary ~~win~~ of Transformer is Connected in Collector Circuit and the load R_L is Connected to Secondary.

③ As the primary dc resistance is very very small the DC load line will be almost perpendicular to V_{CC} axis

(P.T.O.)





④ Conversion Efficiency of X^{mer} Coupled class A Power Amplifier:-

The max. theorical efficiency or Collector Circuit efficiency is is defined as

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

where

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

and

$$P_{ac} = V_{rms} \times I_{rms}$$

where $V_{rms} = \frac{V_{cc}}{\sqrt{2}}$ and $I_{rms} = \frac{I_{CQ}}{\sqrt{2}}$

$$= \frac{V_{cc}\, I_{CQ}}{2}$$

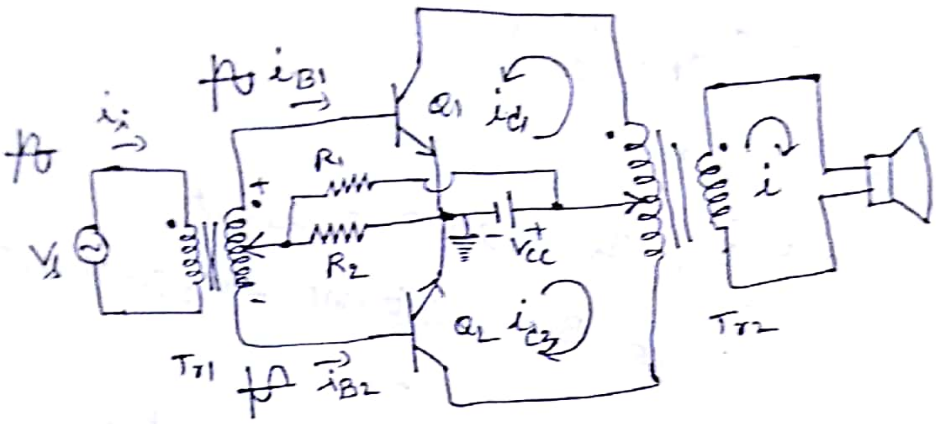
$$\therefore \% \eta_{max} = \frac{\cancel{V_{cc}}\,\cancel{I_{CQ}}}{2 \times \cancel{V_{cc}} \times \cancel{I_{CQ}}} \times 100\%$$

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

Hence the maximum conversion efficiency with X^{mer} Coupling is 50%. This means only 50% of the input dc power is Converted into ac and delivered to the load, here the efficiency of the Transformer is assumed as 100%. and it is ideal transformer. Therefore for a practical amplifier the efficiency will be much small than 50%.

(P.T.O.)

(c) Class-A Push-pull power Amplifier:



(1) Push-Pull amplifier ~~are~~ operated in class-A mode is as shown above.

(2) In this circuit 2 transistors Q_1 & Q_2 are used in CE configuration and the biasing resistors R_1 & R_2 are selected such that the operating point is exactly at the center of the load line.

(3) The two transistors are exactly identical

(4) Two center tapped transformers are used, as shown.

(5) The two base currents are out of - phase by 180°.

(6) Let $i_i = A\cos\omega t$ then

$$i_{b1} = A\cos\omega t \quad \text{hence}$$

$$i_{c_1} = I_{CQ} + B_0 + B_1\cos\omega t + B_2\cos 2\omega t + \cdots \quad \text{—(I)}$$

and

$$i_{b2} = -A\cos\omega t$$

$$\therefore i_{b2} = A\cos(\pi + \omega t)$$

and

$$i_{c_2} = I_{CQ} + B_0 + B_1\cos(\pi + \omega t) + B_2\cos(2\omega t + 2\pi) \cdots \quad \text{—(II)}$$

(P.T.O.)

⑦ Therefore the current i flowing through load is directly proportional to the difference of i_{c_1} and i_{c_2}.

$$\therefore i \propto (i_{c_1} - i_{c_2})$$

$$\therefore i = K(i_{c_1} - i_{c_2})$$

$$= K[I_{CQ} + B_0 + B_1 \cos \omega t + B_2 \cos 2\omega t + \ldots \ldots - I_{CQ} - B_0 - B_1 \cos(\pi + \omega t) - B_2 \cos 2(\pi + \omega t) - \ldots \ldots]$$

$$= K[I_{CQ} + B_0 + B_1 \cos \omega t + B_2 \cos 2\omega t + \ldots \ldots - I_{CQ} - B_0 + B_1 \cos \omega t - B_2 \cos 2\omega t + B_3 \cos 3\omega t - B_4 \cos 4\omega t + - + \ldots \ldots]$$

$$\therefore i = K[2B_1 \cos \omega t + 2B_3 \cos 3\omega t + \ldots \ldots] \quad \text{--- (III)}$$

⑧ It is to be observed that the load current i does not contains any dc component and all even harmonics are eliminated.

⑨ Because of 2 transistors output current is doubled. K is the transfer gain factor. The main advantage of push-pull amplifier is decrement of second harmonic distortion.

⑩ If the two transistors are not identical then some residue of even harmonics may remain.

—

(P.T.O.).. ⑪

IMP →

Advantages of a Push-pull system:

① Push-pull configuration eliminates even harmonics.
② Produces less distortion for a given power output.
③ Eliminates the tendency towards core saturation of the output transformer as the dc components of collector currents of Q_1 and Q_2 oppose each other magnetically.
④ The effects of ripple in power supply, due to in-adequate filtering, will be balanced out.

Disadvantages:

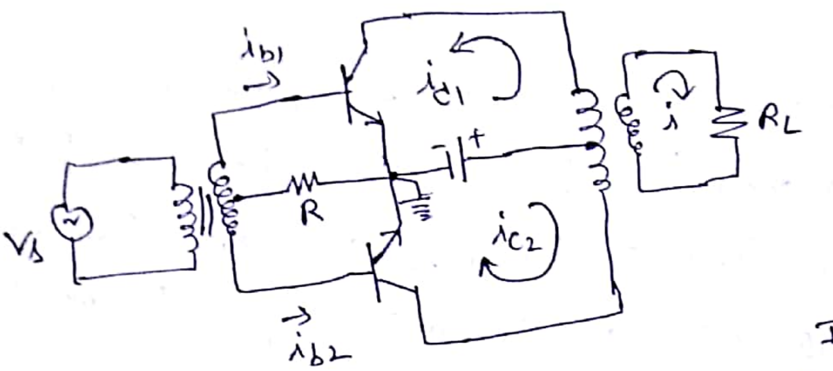
① If the transistors are not identical then residue of even harmonics will be present.
② Two center-tapped transformers are needed.
③ Circuit is bulky and costly.
④ Two center tapped transformers are needed.

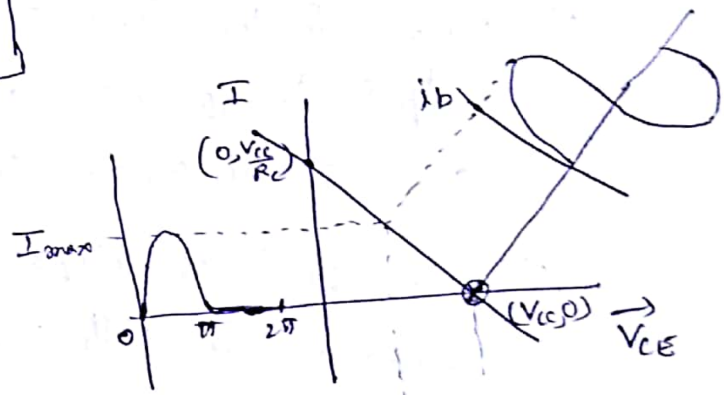
9) Class-B Power Amplifier & Efficiency:

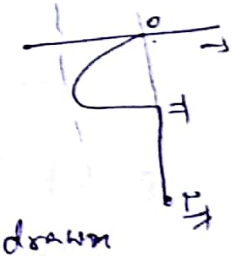
A class-B push-pull amplifier is as shown below.

① A class-B push-pull amplifier is as shown below.
② For class B, the operating point is selected in cut-off region hence no biasing circuit is required.
③ Due to absence of biasing, the circuit doesnot draw any power from supply under zero-signal conditions and hence the device is cool under zero-signal conditions.
④ Circuit draws power when input signal is applied, hence the conversion efficiency is high.
⑤ Collector current conducts in Q_1 for positive half-cycle and in Q_2 for negative half-cycle.

(P.T.O.)







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⑥ **Maximum Conversion Efficiency:**

The conversion efficiency η is defined as the ratio of ac power delivered to load to that of dc power drawn from power supply.

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

where, under maximum conditions

$$P_{ac} = V_{rms} \times I_{rms}$$ [$\because$ the final o/p is full sine wave].

$$= \frac{V_m \times I_m}{2}$$

$$\therefore P_{ac} = \frac{V_{cc} \times I_m}{2}$$

and

$$P_{dc} = V_{cc} \times 2 I_{CQ}$$ [$\because$ 2 transistors draw equal currents of I_{CQ}]

$$= \frac{2 V_{cc} I_m}{\pi} = \frac{2 V_{cc} I_m}{\pi}$$ and $I_{CQ} = \frac{I_m}{\pi}$

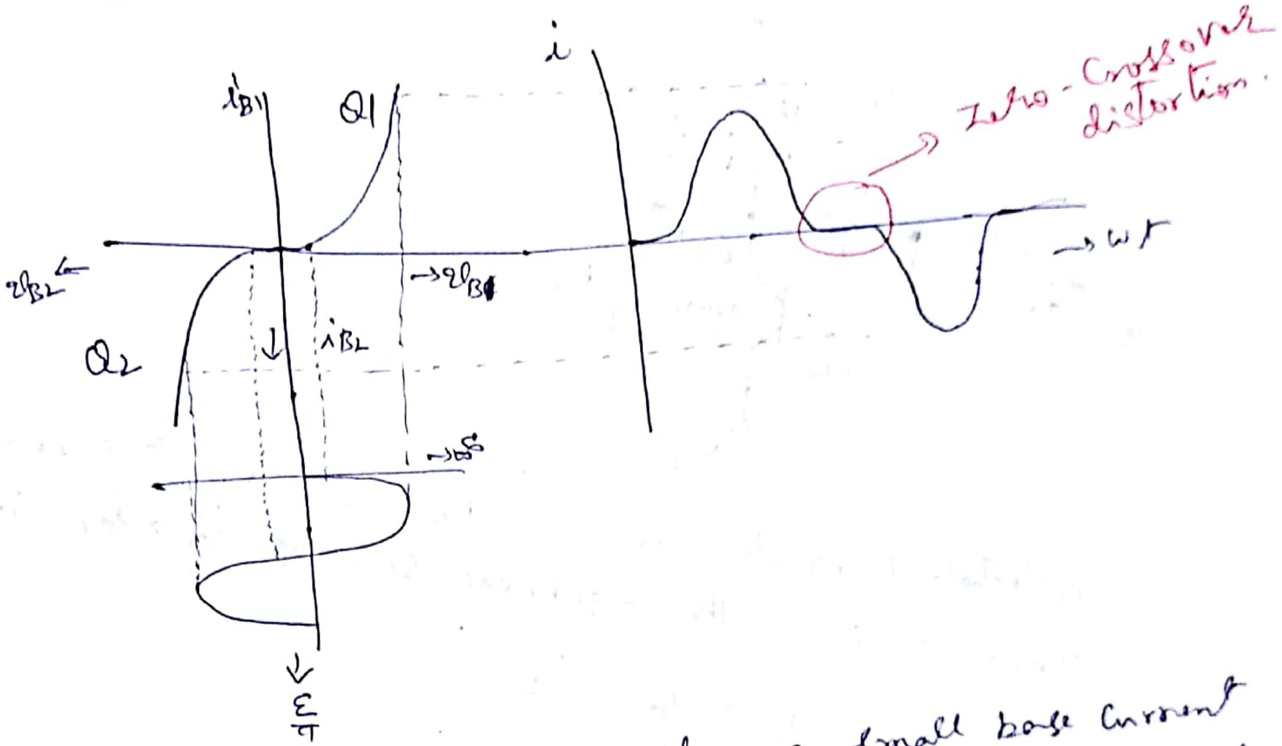
$$\therefore \% \eta_{max} = \frac{\pi}{4} \times 100$$

$$= 78.5\%$$

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

(10) Zero-Cross over distortion.

In a class-B push-pull amplifier, an appreciable base current flows after the input signal exceeds the cut-in voltage (V_γ) of the transistor, until that no collector flows through the transistor. This creates a distortion called as ZERO-CROSS OVER distortion. This distortion is as shown in the graph.

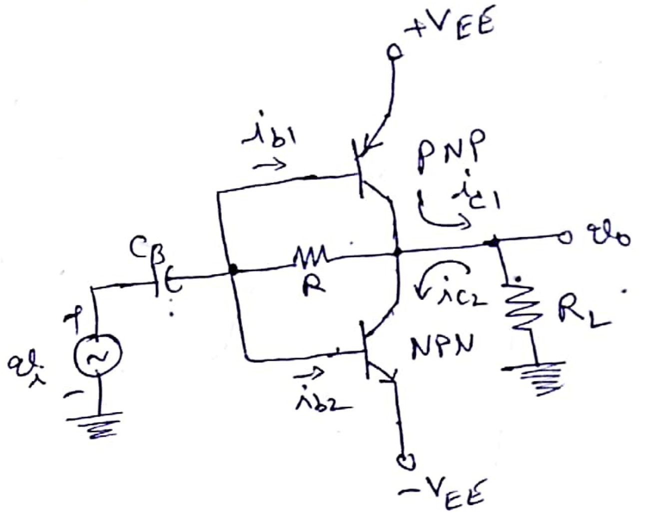


To over come this problem a small base current is to be allowed through the transistors. To obtain this a biasing circuit is to designed such that the operating point is just above cut-off region of the transistors. For this the R_1 and R_2 resistances shown be selected such that the voltage drop across R_2 is equal to the cut-in voltage (V_γ). This mode of operation is called as class-AB. The efficiency of class B and class AB amplifier is less than that of class-A more than that of class-A.

(P.T.O.)

(11) Complementary Symmetry class-B push-pull amplifiers:

The main draw back of class-B Push-pull amplifier is the need of 2 center-tapped transformers, which makes the circuit more costly and bulky. To avoid this difficulty one PNP and one NPN transistor are used as shown in the diagram. The direction of two



collector currents are as shown. The net current through R_L is the algebraic sum of i_{c_1} & i_{c_2} i.e.

$$\boxed{i_L = i_{c_1} - i_{c_2}}$$

Elimination of ~~odd~~ even harmonics:

Let the input current is i_i given by

$$i_i = A \cos \omega t$$

$\therefore i_{b2} = A \cos \omega t$, for this NPN is Forward biased and conducts

$$\therefore i_{c2} = I_{CQ} + B_0 + B_1 \cos \omega t + B_2 \cos 2\omega t + \ldots$$

and $i_{b1} = A \cos \omega t$, for this the PNP transistor does not conduct because i_b is +ve and base is -ve.

Therefore i_{b1} can be represented as

$$i_{b1} = A \cos \omega t$$
$$= -A \cos(\omega t + \pi)$$

(P.T.O.)

for this the base emitter junction of PNP is forward biased and hence i_{C_1} starts flowing and given by

$$i_{C_1} = I_{CQ} + B_0 + B_1 \cos(\omega t+\pi) + B_2 \cos 2(\omega t+\pi) + B_3 \cos 3(\omega t+\pi) + \cdots$$

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

Therefore the load current i_L can obtained as

$$i_L = i_{C_1} - i_{C_2}$$

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

From this expression it can be said that

a) All even harmonics are eliminated in Complementary Symmetry class-B push-pull circuit.

b) No dc component flows through load.

c) Power supply ripples will be balanced out.

d) The characteristics of PNP and NPN transistors should be matched together, otherwise even harmonic residues may be present.

(12) Thermal stability:

The average power dissipated in an active device can be obtained by using the principle of conservation of energy.

Assume an amplifier is supplying power to a pure resistive load (R_L). The average power input from dc power supply is $V_{CC} \times I_{CQ}$. According to conservation of energy we can write

(P.T.O.)

~~$V_{CE} \times I_{CQ}$~~

$$\boxed{V_{CC} \times I_{CQ} = (I^2_{CQ} R_L) + (V_{rms} \times I_{rms}) + P_D} \quad \text{— I}$$

where $I^2_{CQ} R_L$ = DC power dissipated across load.

$V_{rms} I_{rms}$ = AC power delivered to load.

P_D = The power dissipated in the active device and associated circuitry. [Generally reffered as the power dissipation in active device.]

But we know (KVL to o/p loop)

$$\boxed{V_{CC} = I_{CQ} R_L + V_{CEQ}} \quad \text{— II}$$

substituting II in I gives

$$I^2_{CQ} R_L + (V_{CEQ} \times I_{CQ}) = I^2_{CQ} R_L + V_{rms} I_{rms} + P_D$$

$$\boxed{\therefore\ P_D = V_{CEQ} I_{CQ} - V_{rms} I_{rms}} \quad \text{— III}$$

This equation gives the amount of power dissipated in the active device, in the form of heat. ~~when~~ under zero-signal conditions the ac power delivered to load is zero i.e. $V_{rms} I_{rms} = 0$, then maximum power will be dissipated in the active device and it may lead to ~~..~~ distruction of the active device. To safe gaurd the transistor, this excess heat should be sent out from the junction of the transistor.

(P.T.O.) - 14

(P.T.O.)

Let the ambient temperature of the air around the transistor is $T_A{}^\circ C$ and the temperature of the collector-base junction is $T_J{}^\circ C$. When transistor heating means T_J is more than T_A. So, it can be ~~and~~ concluded that more the value of $(T_J - T_A)$ ~~more~~ the more the power dissipation.

$$\therefore (T_J - T_A) \propto P_D$$

$$\therefore T_J - T_A = \Theta P_D$$

(H)

$$\boxed{\therefore \Theta = \frac{(T_J - T_A)}{P_D}}$$

where Θ is called the Thermal resistance, units °C/W. This represents total thermal resistance from transistor junction to the ambient temperature. Generally manufacturers and referred as Θ_{J-A}. from Junction to case as mention Thermal resistance, Θ_{J-C}.

$$\therefore P_D = \frac{T_J - T_A}{\Theta_{J-A}}$$

Θ_{J-A} can be represented as sum of Θ_{J-C} and Θ_{C-A}.

$$\boxed{\therefore \Theta_{J-A} = \Theta_{J-C} + \Theta_{C-A}}$$

In this expression Θ_{J-C}, is determined by the type of the manufacture of the transistor and how it is located in the case, but Θ_{C-A} is determined by the surface area of the case or flange and its contact with air. If the effective surface area of the case could be increased then Θ_{C-A} could be decreased.

(P.T.O.)

This ~~a~~ can be achieved by using a heat sink. The thermal resistance (θ) should be as small as possible for larger power dissipation. For high power transistors its value will be as small as 0.2°c/W and for low power transistors its value will be upto 1000°c/W with no cooling mechanism. Finally, for High thermal stability the thermal resistance should be as small as possible.

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(13) Heat sink:

The need of heat sinks is to take away the heat dissipated on the case of a power transistor. Normally heat sinks are made with material having very good thermal conductivity. The shape and size of the heat sink depends on the amount of power dissipation required in a transistor. Different type of transistor package ~~need~~ need different shaped heat sinks. ~~Case~~ & care should be taken that the case (collector) should not be shorted to ground.

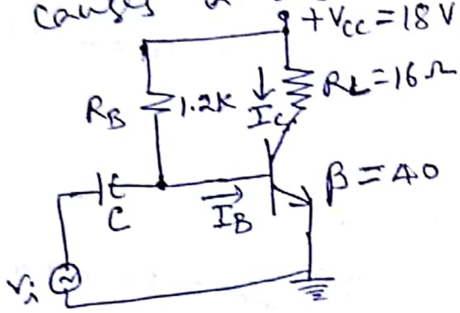
Beryllium oxide insulating washer along with Silicon Grease can be used to mount the transistor on heat sinks. These two materials provide good thermal conductivity. The thermal resistance of the heat sink is about 3°c/W, can be used with the transistors having power dissipation of about 100W.

END OF UNIT - IV.

Problems from UNIT – IV and V

UNIT – IV

1. Calculate the input power, output power and the efficiency of class-A amplifier shown below. The input voltage causes a base current of 5 mA rms.



Sol: It is assumed that $\beta_{ac} = \beta_{dc} = 40$ (as given)

$$\therefore I_B(dc) = \frac{V_{CC} - V_{BE}}{R_B} = \frac{18 - 0.7}{1.2K} = \frac{17.3}{1.2}\ mA = 14.42\ mA$$

$$\therefore I_C(dc) = \beta_{dc} \times I_B(dc) = 40 \times 14.62\ mA = 576.67\ mA$$

$$\therefore P_{DC} = V_{CC} \times I_C(dc)$$
$$= 18 \times 576.67\ mW$$
$$\boxed{\therefore P_{DC} = 10.38\ W}$$

$$I_{C(rms)} = \beta_{ac} \times I_{B(rms)}$$
$$= 40 \times 5\ mA$$
$$= 200\ mA$$

$$\therefore P_{ac} = I_{C(rms)}^2 \times R_L$$
$$= (200)^2 \times 10^{-6} \times 16$$
$$\boxed{\therefore P_{ac} = 640\ mW}$$

$$\therefore \%\eta = \frac{P_{ac}}{P_{dc}} = \frac{640 \times 10^{-3}}{10.38} \times 100 = 6.165\%$$

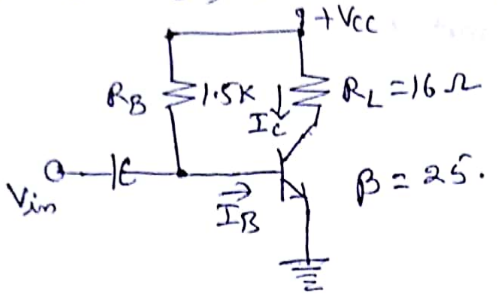
$$\boxed{\therefore \%\eta = 6.165\%}$$

(P.T.O.)

(2) A series fed class A amplifier shown, uses a supply voltage of 20V. The ac input voltage results in a base current of 9 mA peak. Calculate

a) Q-point , b) D.C. input power c) AC output power

d) Efficiency , e) Power dissipation f) Maximum Power dissipation.



$I_{BQ} \rightarrow$ Quiscent Base Current

$I_{CQ} \rightarrow$ " Collector Current

$V_{CEQ} =$ " Collector to Emitter voltage.

Sol: It is assumed $\beta_{ac} = \beta_{ac} = 25$ (as given).

a) $I_{BQ} = \frac{V_{CC} - V_{BE}}{R_B} = \frac{20 - 0.7}{1.5}\,mA = \frac{19.3}{1.5}\,mA = 12.87\,mA$

$\therefore I_{CQ} = \beta_{dc} \times I_{BQ} = 25 \times 12.87\,mA = 321.67\,mA$

$\therefore V_{CEQ} = V_{CC} - I_{CQ} R_L = 20 - 321.67 \times 10^{-3} \times 16 = 14.85\,V$

$\therefore$ Q-point Co-ordinates are $(14.85V, 321.67\,mA)$.

b) $P_{DC} = V_{CC} \times I_{CQ} = 20 \times 0.32167\,W = 6.4334\,W$

c) $P_{ac} = I_{c\,rms}^2 R_L$

$I_{c\,rms} = \frac{I_{cm}}{\sqrt{2}} = \frac{\beta_{ac} \times I_{Bm}}{\sqrt{2}} = \frac{25 \times 9 \times 10^{-3}}{\sqrt{2}} = 159\,mA$

$\boxed{\therefore P_{ac} = 405\,mW}$

d) $\%\,\eta = \frac{P_{ac}}{P_{dc}} = \frac{405 \times 10^{-3}}{6.4334} = 6.297\,\%$

e) We know $P_{DC} = P_{ac} + P_D$

$P_{ac} \rightarrow$ ac power delivered to load

$P_D \rightarrow$ Power dissipated in transistor.

$\therefore P_D = P_{DC} - P_{AC} = 6.4334 - 0.405 = 6.0284\,W$

f) P_{Dmax} is the power dissipated in active device when input signal is zero. $\therefore P_{Dmax} = 6.4334\,W$.

(P.T.O.).. (2)

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(3) A single Transistor amplifier produces harmonics as shown below.

$B_0 = 1.5\ mA$; $B_1 = 120\ mA$; $B_2 = 10\ mA$; $B_3 = 4\ mA$

$B_4 = 2\ mA$; $B_5 = 1\ mA$.

determine second harmonic distortion and total harmonic distortion

Sol: Second harmonic distortion $D_2 = \left|\frac{B_2}{B_1}\right| = \left|\frac{10}{120}\right| \times 100$

$= 0.0833$

$\therefore \boxed{D_2 = 8.33\ \%}$

$$D = \sqrt{D_2^2 + D_3^2 + D_4^2 + D_5^2}$$

$$D_3 = \frac{4}{120} = 0.0332$$

$$D_4 = \frac{2}{120} = 0.0166$$

$$D_5 = \frac{1}{120} = 0.0083$$

$\therefore D = 0.09157$

$\boxed{D = 9.157\%}$

---

(4) A Power amplifier supplies 3W to a load of 6KΩ. The zero signal dc collector current is 55 mA and the DC collector current with signal is 60 mA. What is the second harmonic distortion?

Sol: given $P_{ac} = 3W$ and $R_L = 6k\Omega$

We know $P_{ac} = \frac{B_1^2 R_L}{2} = 3$

$$\therefore B_1^2 = \frac{6}{R_L} = \frac{6}{6k} = 1 \times 10^{-3}$$

$\therefore B_1 = 0.0316\ A = 31.6\ mA$

given $I_{CQ} = 55mA$ (under zero signal conditions)

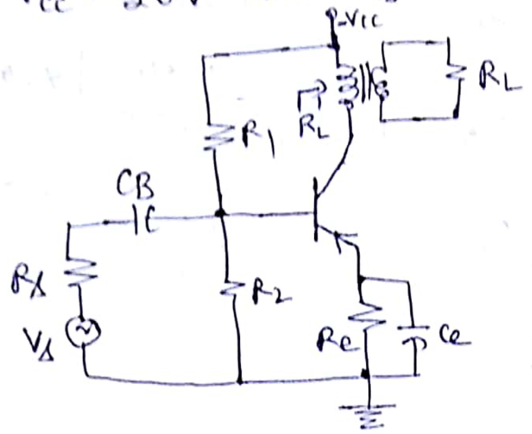
and $I_{CQ} + B_0 = 60\ mA$ (under signal conditions)

$\therefore B_0 = 5\ mA$. but we know $B_2 = B_0$

$\therefore D_2 = \frac{B_2}{B_1} = \frac{5}{31.6} = 0.1582$ $\boxed{\therefore D_2 = 15.82\%}$

(P.T.O.)

(5) A power transistor operating class A is as shown in figure, is to deliver a maximum of 5W to a 4-Ω load. The quiescent point is adjusted for symmetrical clipping and $V_{cc} = 20V$ and assume ideal characteristics with $V_{min} = 0$.



① what is the transformer turns ratio $\frac{N_2}{N_1}$

② what is peak collector current

③ what is the quiescent operating I_{CQ}, V_{CEQ}

④ what is the collector-circuit efficiency.

We know for an ideal transformer

$P_1 = P_2 \Rightarrow V_1 I_1 = V_2 I_2$

$\therefore \frac{V_1}{V_2} = \frac{I_2}{I_1}$ and

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

for step down transformer $N_2 < N_1$.

$$\boxed{\therefore \frac{I_2}{I_1} = \frac{N_1}{N_2}}$$

Sol: It is assumed that the transformer is ideal step down transformer. So to deliver 5W power to the 4-Ω load R_L, in the primary circuit the max. ac power should be equal to 5W.

$\therefore P_1 = P_2$

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

where I_{1rms} is the primary rms current and R_L' is the resistance seen into primary winding.

$$\therefore R_L' = \left(\frac{I_{2rms}}{I_{1rms}}\right)^2 R_L$$

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

$R_L' \rightarrow$ the reflected load on primary side.

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

Let us take

$P_{ac} = \frac{V_{rms}^2}{R_L'} = 5W$ (given) but $V_{rms} = \frac{V_m}{\sqrt{2}}$ (class A)

$\therefore \frac{V_m^2}{2R_L'} = 5W$ but for xmer coupled amplifier $V_m = V_{cc}$

$\therefore R_L' = \frac{V_{cc}^2}{10} = \frac{400}{10} = 40\Omega$ $\boxed{\therefore R_L' = 40\Omega}$

(P.T.O.)

$$\therefore \left(\frac{N_1}{N_2}\right)^2 = \frac{R_L'}{R_L} = \frac{40}{4} = 10$$

$$\therefore \frac{N_2}{N_1} = \frac{1}{\sqrt{10}} = 0.316 \qquad \boxed{\therefore \frac{N_2}{N_1} = 0.316}$$

(2) We know

$$P_{ac} = I_{rms}^2 R_L' \qquad \left[\because I_{rms} = \frac{I_m}{\sqrt{2}} \text{ for classA}\right]$$

$$\therefore \frac{I_m^2 R_L'}{2} = 5$$

$$\therefore I_m^2 = \frac{10}{40} = \frac{1}{4}$$

$$\therefore I_m = \frac{1}{2} = 0.5A$$

Therefore the peak collector current $I_m = 0.5A$

(3) The quiescent point is adjusted for symmetrical clipping and hence $I_{min} = 0$ and $V_{min} = 0$

Therefore $I_m = I_{CQ}$

$$\boxed{\therefore I_{CQ} = 0.5A}$$

Because the amplifier is transformer coupled amp hence $V_{CEQ} = V_{CC} = 20V$.

$\therefore$ The operating point (I_{CQ}, V_{CEQ}) is $(0.5A, 20V)$.

(4) $$\%\eta = \frac{P_{ac}}{P_{dc}} \quad ; \quad P_{ac} = 5W \text{ (given)}$$

$$P_{dc} = V_{CC} \times I_{CQ} = 20 \times 0.5 W = 10W$$

$$\therefore \%\eta = \frac{5}{10} \times 100 = 50\%$$

$$\boxed{\therefore \%\eta = 50\%}$$

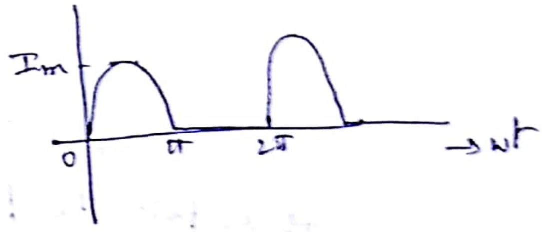
(P.T.O.)

⑥ A single Transistor is operating as an ideal class B amplifier with a 1K load. A dc meter in the collector circuit reads 10 mA. How much signal power is delivered to the load?

Sol: The given data is

$R_L = 1\,K\Omega$; $I_{dc} = 10\,mA$ and $P_{ac} = ?$

We know the o/p of a class B amplifier is Half wave Rectified output as shown.



We know that

$I_{dc} = \frac{I_m}{\pi}$ (for HWR)

$\therefore I_m = \pi \times I_{dc}$

$\therefore I_m = 10 \times \pi$

$\therefore I_{rms} = \frac{I_m}{2}$ (for HWR)

$\therefore I_{rms} = \frac{10 \times \pi}{2} = 5\pi\ mA = 15.7\ mA.$

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

$= (15.7 \times 10^{-3})^2 \times 1 \times 10^{3}$ W

$P_{ac} = 0.246$ W

$\boxed{\therefore P_{ac} = 246\ mW}$

END OF PROBLEMS FOR UNIT - IV.

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UNIT - IV LARGE SIGNAL AMPLIFIERS

*① Classify amplifiers based on the location of operating point.

*② Distinguish Voltage [small signal] amplifiers and Power (Large signal) amplifiers.

③ With neat diagram explain transformer coupled class A amplifier.

*④ Prove the ~~ ~~ maximum efficiency of RC coupled class A amplifier is 25% and for transformer coupled class A amplifier is 50%.

⑤ List the advantages and disadvantages of push-pull system.

⑥ Prove that all even harmonics are eliminated in push-pull class A amplifier.

*⑦ Perform 3-point (or 5-point) schedule to determine the harmonic amplitudes.

*⑧ Draw the circuit of ~~a~~ Complementary Symmetry class-B amplifier and prove all even harmonics are eliminated.

*⑨ Explain zero-crossover distortion.

⑩ Write short notes on the following:

(a) Thermal stability in power amplifiers

(b). Heat sinks.

⑪ Problems [Already given with solutions].

(P.T.O.)

UNIT-V. TUNED AMPLIFIERS

1. Define Q-factor and derive an expression for Q-factor of a) RL circuit and b) RC circuit.

*2. Draw the equivalent circuit of capacitive coupled single tuned amplifier and derive the equation for its ~~at~~ voltage gain.

3. Derive the Band width equation for a capacitive coupled single tuned amplifier.

*4. Discuss the effect of cascading single tuned amplifiers on Band width.

*5. what is the principle of stagger tuned amplifier? Derive the expression for its voltage gain and explain its frequency response and advantages.

6. Discuss the instability in tuned amplifiers.

*7. Write short notes on
   a) Neutralization
   b) Unilateralization.

8. Draw the circuit of a double tuned amplifier and derive the expression for voltage gain.

*9. A single tuned amplifier has a BW of 100 KHz. 3 such stages are cascaded. Calculate the BW when

*10. A tank circuit has a capacitor of 100 pF and inductor of 100 μH, the resistance of the inductor is 5 Ω. Determine (a) Resonant frequency (b) Q-factor (c) Band width.

END

Question Bank on POWER AMPLIFIERS

Questions for 2 Marks

1. Draw the block diagram practical power amplifier.
2. What is the function of power amplifier?
3. What is the need of power amplifier?
4. Explain voltage amplification stage in case of power amplifier.
5. Explain voltage driver stage in case of power amplifier.
6. Explain voltage output stage in case of power amplifier.
7. What is the difference between voltage amplifier and power amplifier?
8. Sketch ac load line in case of class A power amplifier.
9. Sketch ac load line in case of class B power amplifier.
10. What do you mean by class C power amplifier?
11. Write the principal of class C push-pull amplifier.
12. What are the advantages of class C push-pull amplifier?
13. What are the disadvantages of class C push-pull amplifier?
14. Sketch cross over distortion.
15. Why heat sink is necessary in case of power transistor?
16. Determine the power that 2N1707 can safely dissipate in free air when TA=500C. Given TJ=2000C and θJ-A=1000c/w.
17. Determine the power that 2N1707 can safely dissipate in free air when TA=600C. Given TJ=2100C and θJ-A=1100c/w.
18. Determine the power that 2N1707 can safely dissipate in free air when TA=550C. Given TJ=1900C and θJ-A=1000c/w.

Questions for 3 marks.

1. Determine power dissipation capability of 2N1701 transistor which has been heated with heat sink having θHS-A=θS-A=100c/w. Given TA=500C, TJ=2000C and θJ-c=70c/w θC-A=930c/w.
2. Determine power dissipation capability of 2N1701 transistor which has been heated with heat sink having θHS-A=θS-A=120c/w. Given TA=520C, TJ=2100C and θJ-c=80c/w θC-A=940c/w.
3. Explain in detail difference between voltage amplifier and power amplifier.
4. Write the advantages and disadvantages of power amplifiers.
5. Derive the relation between maximum power and load resistance.
6. A Si power transistor must dissipate 10 watt at a maximum ambient temperature of 450C. If Tjmax=2250C, θJ-C=120c/w and θC_A=200c/w. What is heat sink thermal resistance in QS-A?
7. A Si power transistor must dissipate 12 watt at a maximum ambient temperature of 460C. If Tjmax=2200C, θJ-C=110c/w and θC_A=220c/w. What is heat sink thermal resistance in QS-A?
8. Sketch and label the diagram of class B push-pull amplifier.

Questions for 4 marks.

1. Explain voltage amplification stage and driver stage in case of power amplifier.
2. Explain voltage amplification stage and output stage in case of power amplifier.
3. Explain driver stage and output stage in case of power amplifier.
4. Explain class A power amplifier and class B power amplifier.
5. Explain class A power amplifier and class C power amplifier.
6. Explain class B power amplifier and class C power amplifier
7. Describe the cross over efficiency of class B push-pull amplifier. How it can be minimized?
8. Draw the composite characteristics curves for two transistors.

Questions for 6 marks.

1. Explain in detail classification of power amplifier.
2. With the neat diagram explain the class B push-pull amplifier.
3. Explain in detail about heat sink.
4. Solve the following example
   a) Determine power dissipation capability of 2N1701 transistor which has been heated with heat sink having 0HS-A=0S-A=100c/w. Given TA=500C, TJ=2000C and 0J-c=70c/w 0C-A=930c/w.
   b) Determine power dissipation capability of 2N1701 transistor which has been heated with heat sink having 0HS-A=0S-A=120c/w. Given TA=520C, TJ=2100C and 0J-c=80c/w 0C-A=940c/w.
5. Solve the following example
   1. A power transistor has thermal resistance Q=3000c/w if maximum junction temperature is 900C. Find the maximum permissible power dissipation.
   2. If a heat sink is used with the above transistor, the value of Q is reduced to 600 c/w. Find maximum permissible power.