# Analog Electronics

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## Unit - 4

## Power Amplifiers

### Power dissipations in Transistors

#### Small signal amplifier

A small signal amplifier is generally reffered to as a voltage amplifier because they usually convert a small input voltage to much larger output voltage. They have the ability to amplify a relatively small input signal. Since the signal voltage and current are small in small-signal amplifier, the amount of power handling capacity and power efficiency are of little concern.

#### Large signal amplifier / Power amplifier

Power amplifier primarily provide sufficient power to an output load to drive a speaker or other power device, typically a few watts to tens of watts.

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The main features of a large signal amplifier are the circuit's power efficiency, the maximum amount of power that the circuit is capable of handling, and the impedence matching to the output device. Power amplifiers are needed to withstand large voltage and current.

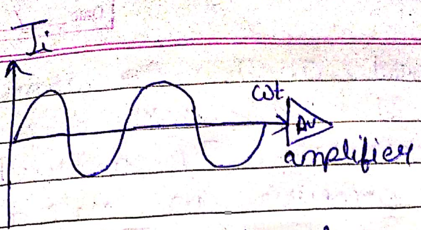
Classification Based on Biasing Condition

Based on the amount of transistor bias and amplitude of input signal, amplifiers can be classified into class A, class B, class AB and class C.

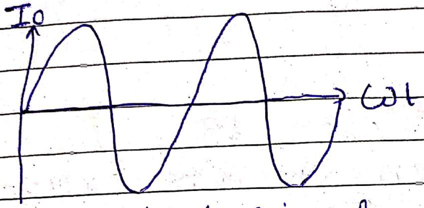
Basically, amplifier classes represent the amount of output signal varies over one cycle of operation for a full cycle of input signal.

1. Class A

In class A amplifier, the transistor is biased such that the output current flows, transistor is ON for the full cycle (360°) of the input ac signal



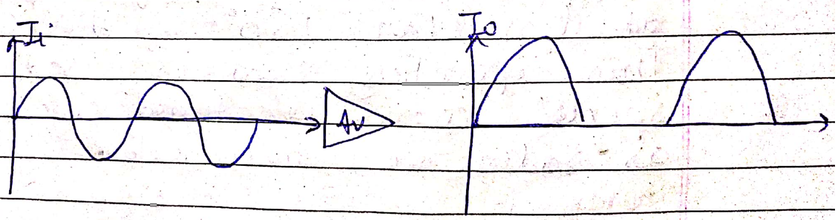

Input signal




output signal

(2) Class B

A class B circuit provides an output signal varying over one half the input cycle, or for 180° of signal




The output is not faithful from input if only one half cycle is present.
Two class B operations - one to provide output on the positive output

half cycle and another to provide operation on the negative output half cycle are necessary. The combined half cycles then provide an output for a full 360° of operation. This type of connection is reffered to as a push pull operation.

3. Class AB

In class AB, the transistor operates between the two extremes defined for class A and class B amplifier. Hence the output signal exists for more than 180° but less than 360° of the input ac signal.

4. Class C

The output of a class C amplifier is biased for operation at less than 180° of the cycle. This operating class is used in special areas of tuned circuits, such as radio or communications.

Amplifier Efficiency

The power efficiency of the amplifier, defined as the ratio of power output to the power input.

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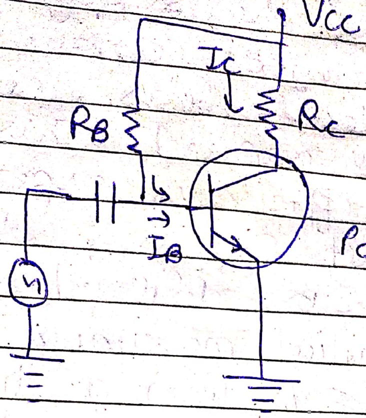
In class A amplifier, with dc bias at one half of the supply voltage level, uses a good amount of power to maintain bias, even with no input signal applied. This results in very poor efficiency, especially with small input signals, when very little ac power is delivered to the load. Its theoritical maximum conversion efficiency is 25% with a direct or series fed load connection and 50% with a transformer connection to the load.

Class B amplifier with no dc bias for no input signal, can be shown to provide maximum efficiency that reaches 78.5%.

Class AB falls b/w class A and class B, it also falls b/w their efficiency ratings b/w 25% and 78.5%.

# Series fed Class A amplifier




fixed bias

The transistor used is a power transistor that is capable of operating in the range of few to tens of watts. The $\beta$ of a power transistor is generally less than 100.

Input power

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

output power

$$P_o(ac) = V_c \times I_c$$

$$\boxed{P_{o(ac)} = I_c^2 R_L}$$

$V_c$ and $I_c$ are rms values of output voltage and current. ($V_{cc}$, $I_{cQ}$

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$$V_c = \frac{V_{cc}}{\sqrt{2}} = \frac{V_{max} - V_{min}}{2\sqrt{2}}$$

$$I_c = \frac{I_{cc}}{\sqrt{2}} = \frac{I_{cmax} - I_{cmin}}{2\sqrt{2}}$$

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

$$= \frac{V_{cc}\, I_{cc}}{8}$$

$$\boxed{P_{o}(ac) = \frac{V_{cc}^2}{8 R_c}}$$

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

$$= V_{cc} \left( \frac{V_{cc}/R_c}{2} \right)$$

$$\boxed{P_{in}(dc) = \frac{V_{cc}^2}{2 R_c}}$$

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

$$= \frac{\frac{V_{cc}^2}{8 R_c}}{\frac{V_{cc}^2}{2 R_c}} \times 100$$

$$\boxed{\eta = 25\%}$$

## Formulas

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

$$P_{out}(ac) = \frac{V_{ce}(P) \times I_c(P)}{2}$$

$$= V_{ce}(rms)\ I_c(rms)$$

$$= I_c^2(rms)\ R_c$$

$$= \frac{I_c^2(P)}{2R_c}$$

$$= \frac{V_{ce}^2(P)}{2R_c}$$

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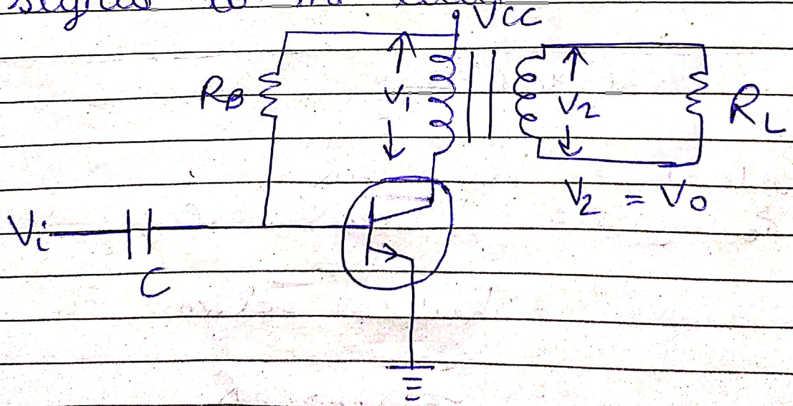
$$P_{out(ac)} = \frac{V_{ce(P-P)}\, I_{c(P-P)}}{8}$$

$$= \frac{V_{ce}^2{}_{(P-P)}}{8R_c}$$

maximum $\boxed{P_{o(ac)} = \frac{V_{cc}^2}{8R_c}}$

## Transformer Coupled Class A Amplifier

A form of class A amplifier having maximum efficiency of 50% uses a transformer to couple the output signal to the load.




$R_B = R_L'$

The transformer can step up or step down a voltage applied to one side directly as the ratio of the turns on each side.

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

The current in the secondary winding is inversely proportional to the no. of turns in the windings.

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

$$\boxed{R_L' = a^2 R_L}$$

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

Since the voltage and current can ~~transfor~~ changed by transformer, an impedance from either side can also be changed.

$$\frac{R_L}{R_L'} = \frac{R_2}{R_1} = \frac{V_2/I_2}{V_1/I_1} = \frac{V_2 I_1}{V_1 I_2}$$

$$= \frac{N_2}{N_1}\frac{N_2}{N_1}$$

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

$$\frac{R_L'}{R_L} = \frac{R_1}{R_2} = \left(\frac{N_1}{N_2}\right)^2 = a^2$$

$$\boxed{R_L' = a^2 R_L}$$

## Class B Amplifier

The advantages of class B over Class A are

(i) possible to obtain greater power output

(ii) efficiency is higher

(iii) negligible power loss at no input signal.

### Efficiency

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

$$I_{dc} = \frac{2}{\pi} I_{(p)}$$

$$P_i(dc) = \frac{2 V_{cc} I_{(p)}}{\pi}$$

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$$P_{o(ac)} = \frac{V_L^2(rms)}{R_L}$$

$$= \frac{V_L^2(p-p)}{8 R_L}$$

$$= \frac{V_L^2(p)}{2 R_L}$$

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

$$= \frac{V_L^2(p)/2R_L}{V_{cc}\ (2/\pi)\ I(p)} \times 100\ \%$$

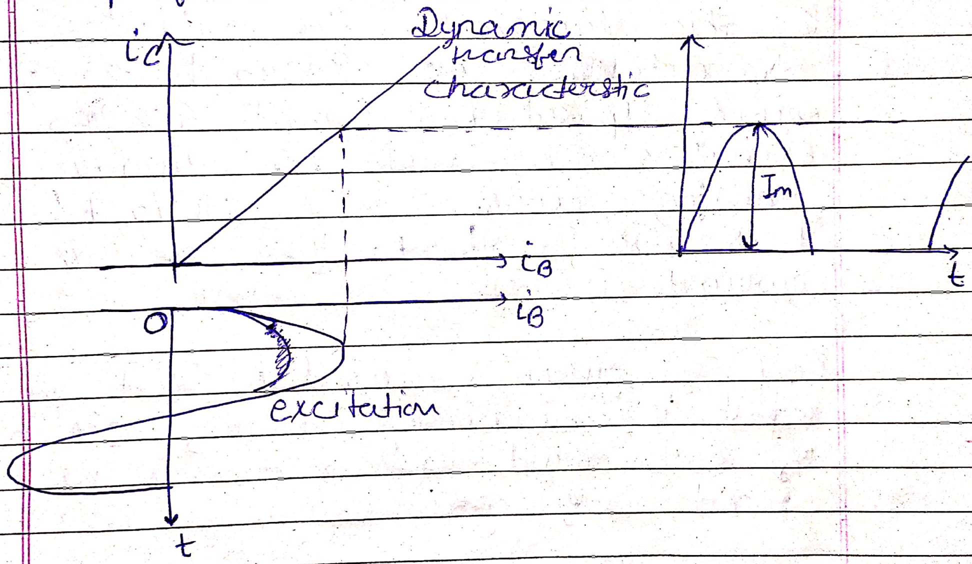
$$= \frac{\pi}{4} \frac{V_L(p)}{V_{cc}} \times 100\ \%$$

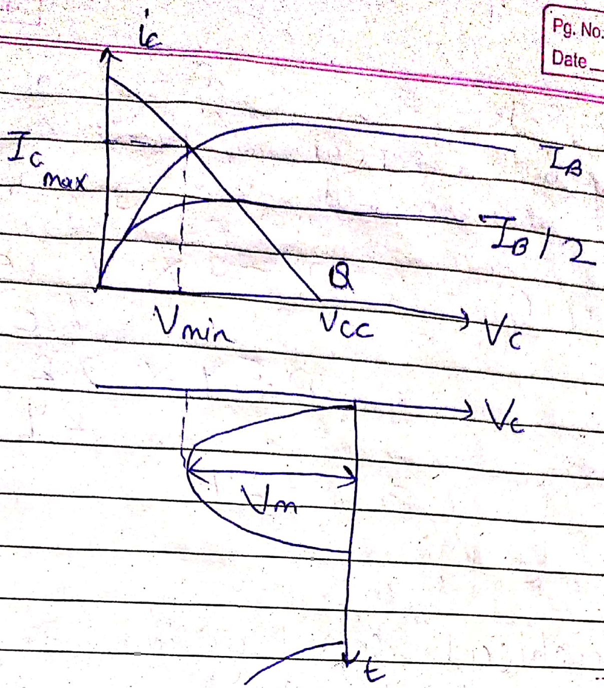
$$V_L(p) = V_{cc}$$

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

$$\boxed{\eta = 78.5\ \%}$$

Graphical construction to determine the output waveforms of class B amplifier






In this diagram, the output characteristics are assumed to be equally spaced for equal intervals of excitation so that the dynamic transfer curve is a straight line. It is also assumed that the minimum current is 0.

For a given sinusodial input, the output is sinusodial during one half of each period and 0 during the second half cycle.

Such a large value of efficiency in class B results from the fact when there is no excitation there is no current in a class B system. Whereas in class A system even where there is no excitation (at zero input signal) there is a drain current $I_{CQ}$ from the power supply.

Further, In class B amplifier the dissipation at the collector is zero in quiescent state and increases with excitation, whereas the heating of collectors of a class A system is maximum at zero input and decreases as the signal increases.

## Complementry Symmetry (Class B) Push Pull amplifier

In complementary symmetry class B amplifier, a pnp - npn transistor pair is used to obtain a full cycle output across a load using half cycles of operations from each transistor.

When common emitter is used in push pull amplifier, it becomes difficult to match the output impedance for maximum power transfer without an output transfer. Hence a matched pair of complementry transistors are used in common collector configuration which has the lowest output impedence and hence impedence matching is possible.

## Advantages

1. Due to ~~collector~~ common collector configuration, impedence matching is possible.

2. The frequency response improves due to transformerless class B amplifier circuit.

## Disadvantages

1. The circuit needs two separate voltage supplies.

2. The output is distorted due to cross over distortion.

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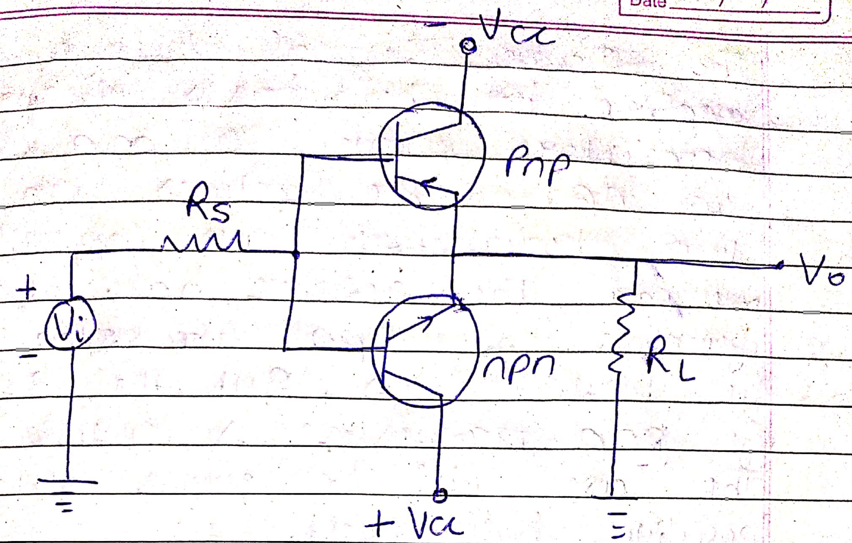
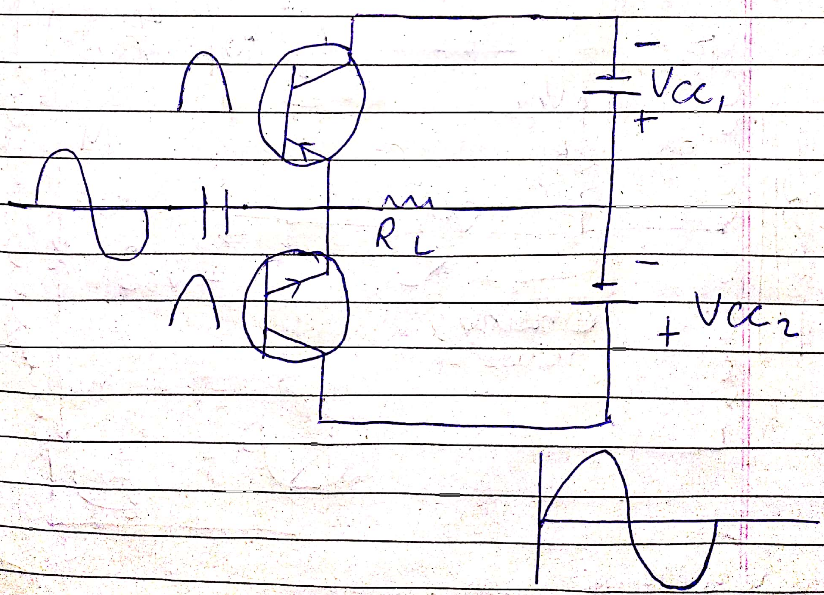
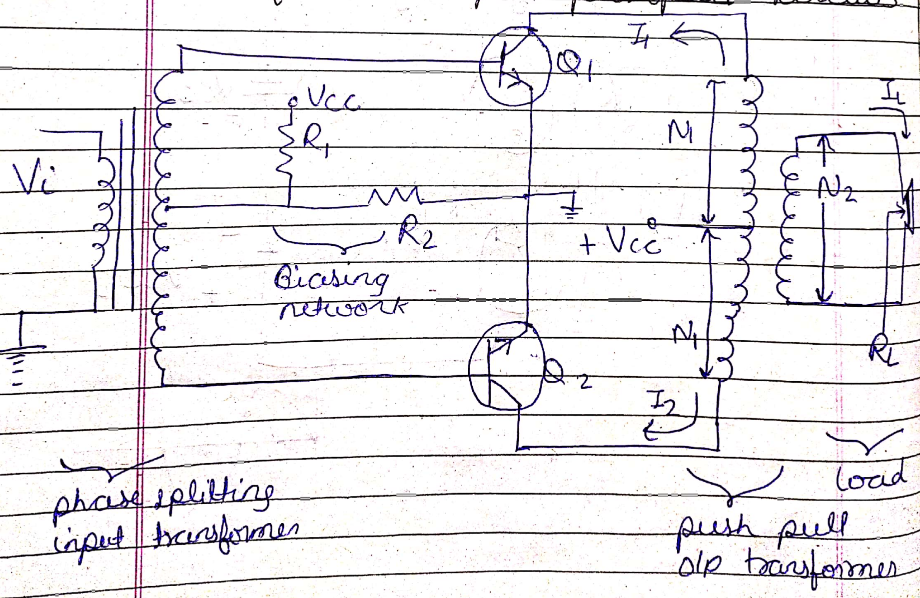



Class B push pull amplifier with Complementary Symmetry.



The same signal voltage is applied to the bases of two transistors, one a pnp and other an npn, the actions on the two transistors are opposite. During the positive half cycle, BE junction of npn transistor would be forward bias, But the BE junction of pnp transistor is reverse biased. The case will be reverse during the negative half cycle.

Transformer Coupled pushpull circuits



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The transformer coupled push pull amplifier has two disadvantages :-

1. It requires a bulky and expensive output transformer.

2. It requires two out of phase input signal which necessitates an input center tapped transformer or phase inverter.

During the first half cycle of operation, transistor $Q_1$ is driven into conduction whereas transistor $Q_2$ is driven off. The current $I_1$ through the transformer results in the first half cycle of signal to the load. During the second half cycle of input signal, $Q_2$ conducts whereas $Q_1$ stays off, the current $I_2$ through the transformer resulting in the second half cycle to the load.

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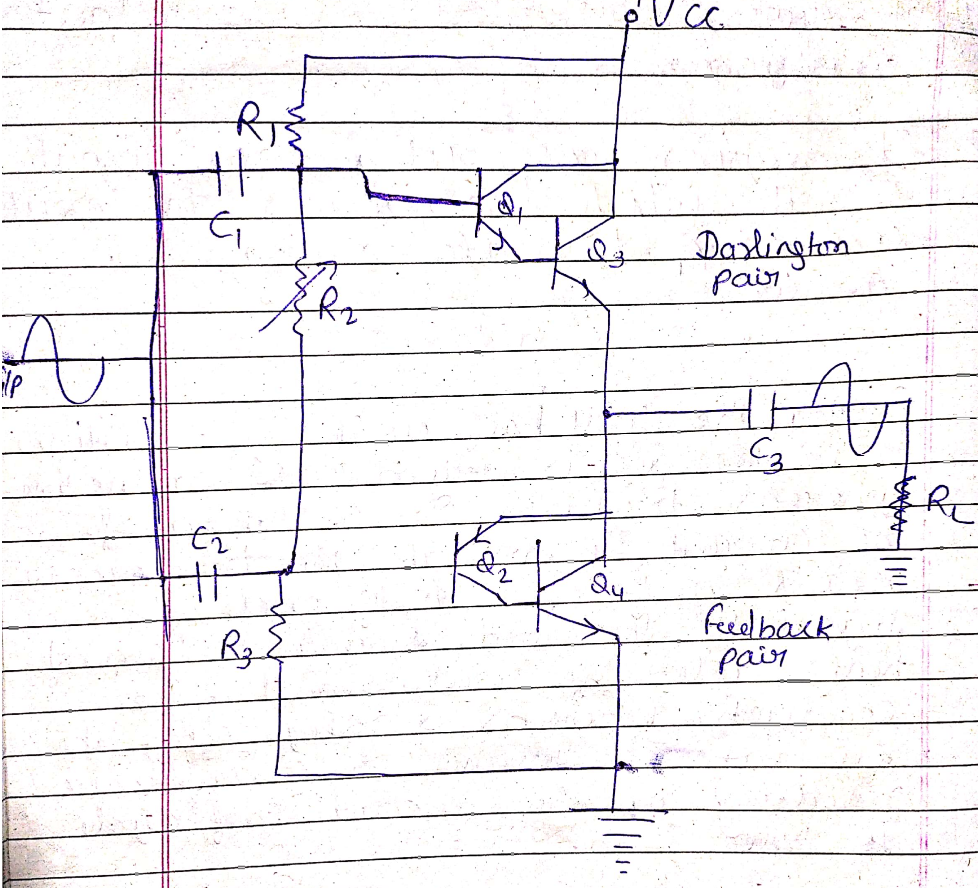
# Quasi Complementary Push Pull Amplifier

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## Power Calculation of class B push pull amplifier

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

$V_m = V_{cc}$, the o/p power is max.

Therefore, $R_L = \frac{V_m}{I_m}$

$$I_m = \frac{V_m}{R_L} = \frac{V_{cc}}{R_L}$$

$$P_{dc} = \frac{2}{\pi} V_{cc} I_m$$

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

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

$$= \frac{V_{cc}^2}{2R_L} \Big/ \frac{2}{\pi}\frac{V_{cc}^2}{R_L}$$

$$\boxed{\eta = 78.5\%}$$

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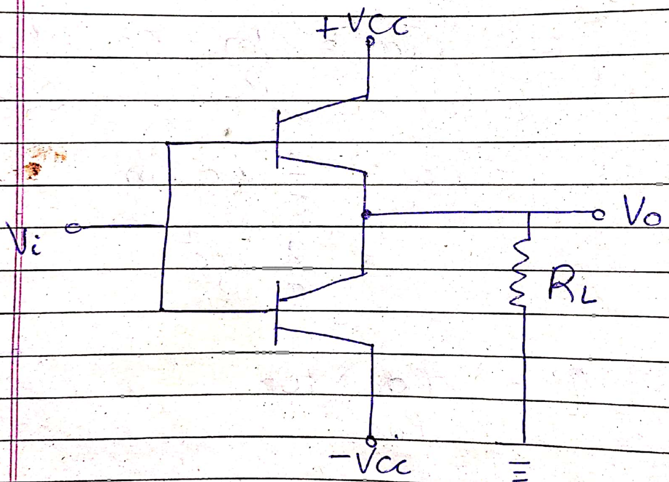
Q In the ideal class B amplifier with complementary symmetry, $V_{CC} = 15\,V$ and $R_L = 10\,\Omega$. Determine the

(a) maximum signal output power, the corresponding collector dissipation and conversion efficiency.

(b) maximum dissipation of each transistor and the corresponding conversion efficiency.




(a) $V_{CC} = 15\,V$, $R_L = 10\,\Omega$

$$P_{o(ac)} = \frac{V_{CC}^2}{2R_L}$$

$$= \frac{15 \times 15}{2 \times 10} = 11.25\,W$$

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$$P_{in}(dc) = \frac{2}{\pi}\frac{V_{cc}^2}{R_L}$$

$$= \frac{2}{\pi} \times \frac{(15)^2}{\cancel{10}\,5}$$

$$= \frac{225}{5\pi} = \frac{45}{\pi}$$

$$= 14.33\,W$$

$$\eta = \frac{11.25}{14.33} \times 100$$

$$\boxed{\eta = 78.5\,\%}$$

2) $$P_o(ac) = \left(\frac{I_m}{\sqrt{2}}\right)^2 R_L$$

$$I_m = \frac{V_{cc}}{\pi R_L}$$

$$P_o(ac) = \frac{V_{cc}^2}{2\pi^2 (R_L)^2} \times R_L$$

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

$$P_{in}(dc) = \frac{V_{cc} I_m}{\pi} = \frac{V_{cc}^2}{\pi^2 R_L}$$

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$$\eta = \frac{P_o(ac)}{P_i(dc)}$$

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

If ideal push pull amplifier operates at maximum dissipation show that its efficiency is 50%.

Maximum power dissipation

$$P_D = \frac{2V_{cc}I_m}{\pi} - \frac{I_m^2 R_L}{2}$$

$P_D$ is max. at

$$I_m = \frac{2V_{cc}}{\pi R_L}$$

$$= \frac{2 \times 15}{\pi \times 10} = 0.995\,A$$

$$P_D = \frac{2 \times 15 \times 0.995}{\pi} - \frac{(0.995)^2 \times 10}{2}$$

$$= 4.56\,W$$

## Amplifier Distortion

Any signal varying over less than the full 360' cycle is considered to have distortion. An ideal amplifier is capable of amplifying a pure sinusodial signal to provide a large version, the resulting waveform being a pure single frequency sinusodial signal. When distortion occurs the output will not be an exact duplicate of the input signal. The diff. b/w O/P waveform & I/P waveform is called distortion. Distortion can occur because the dynamic transfer curve is non leniar over the region of operation described by a paracbolic equation, hence this distortion is called non leniar or amplitude distortion.

## Harmonic distortion

Harmonic distortion is caused by the non lenicarity of the characterstic curve of an active device. The output waveforms now consist of fundamental and higher harmonics

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Harmonic distortion occurs when output waveforms consist harmonic frequency (not just the fundamental component).

$(D_n)$ % $n^{th}$ harmonic distortion $= \frac{|A_n|}{|A_1|} \times 100\%$

where, $A_1$ = amplitude of fundamental frequency

$A_n$ = amplitude of $n^{th}$ frequency

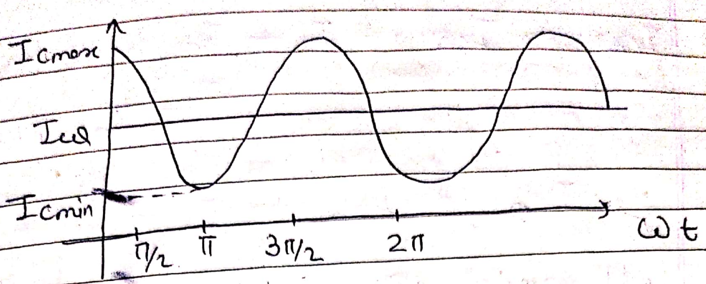
The fundamental component is typically larger than any harmonic component.

<u>Total Harmonic distortion</u>

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

For a signal occuring in class AB or class B, the distortion may be mainly even harmonics, of which the second harmonic component is largest.

# Second Harmonic Distortion




An eqⁿ that approximately describes the distorted signal waveform is

$$i_C \simeq I_{CQ} + I_0 + I_1 \cos \omega t + I_2 \cos \omega t$$

The current waveform consist the original quiescent current $I_{CQ}$ which occurs with zero input signal; an additional dc current $I_0$, due to non zero average of the distorted signal; the fundamental component of distorted ac signal, $I_1$ and a second harmonic component $I_2$, at twice the fundamental frequency.

At point 1 ($\omega t = 0$)

$$i_C = I_{Cmax} = I_{CQ} + I_0 + I_1 \cos 0 + I_2 \cos 0$$

$$I_{Cmax} = I_{CQ} + I_0 + I_1 + I_2 \quad \text{— (1)}$$

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

$$i_c = I_{CQ} = I_{CQ} + I_0 + I_1 + I_1 \cos\frac{\pi}{2} + I_2 \cos \pi/2$$

$$I_{CQ} = I_{CQ} + I_0 - I_1 + I_2 \quad \text{— (2)}$$

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

$$i_c = i_{c_{min}} = I_{CQ} + I_0 + I_1 \cos \pi + I_2 \cos \pi$$

$$I_{cmin} = I_{CQ} + I_0 - I_1 + I_2 \quad \text{— (3)}$$

~~$I_{CQ}$ = I~~ On solving (1), (2) & (3)

$$I_0 = I_2 = \frac{I_{cmax} + I_{cmin} - 2I_{CQ}}{4}$$

$$I_1 = \frac{I_{cmax} - I_{cmin}}{\cancel{4}\ 2}$$

Second harmonic distortion $(D_2)$

$$D_2 = \left|\frac{I_2}{I_1}\right| \times 100\,\%$$

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$$\boxed{D_2 = \left| \frac{\frac{1}{2}(I_{cmax} + I_{cmin}) - I_{CQ}}{I_{cmax} - I_{cmin}} \right| \times 100\%}$$

In a similar manner, the second harmonic distortion can be expressed in terms of measured C-E voltages:

$$\boxed{D_2 = \left| \frac{\frac{1}{2}(V_{CE\,max} + V_{CE\,min}) - V_{CEQ}}{V_{CE\,max} - V_{CE\,min}} \right| \times 100\%}$$

Power of Signal having distortion

If the distortion is present, the o/p power at the fundamental frequency is given by

$$\boxed{P_1 = \frac{I_1^2 R_C}{2}}$$

Total power due to all the harmonic components

$$\boxed{P = (I_1^2 + I_2^2 + I_3^2 + \dots)\frac{R_C}{2}}$$

$$\boxed{P = (1 + THD^2) P_1}$$

where THD = Total harmonic distortion

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## Cross over Distortion

This is caused by the non leniarity of the input characteristics of the transistor. Transistor do not turn ON at zero volt applied to the emitter junction but only when the emitter junction is forward biased. As a result, the sinusodial base voltage excitation will not result in sinusodial O/P current.

To minimise cross over distortion, the transistor must operate in a class AB mode where a small stand by current flows at zero excitation.