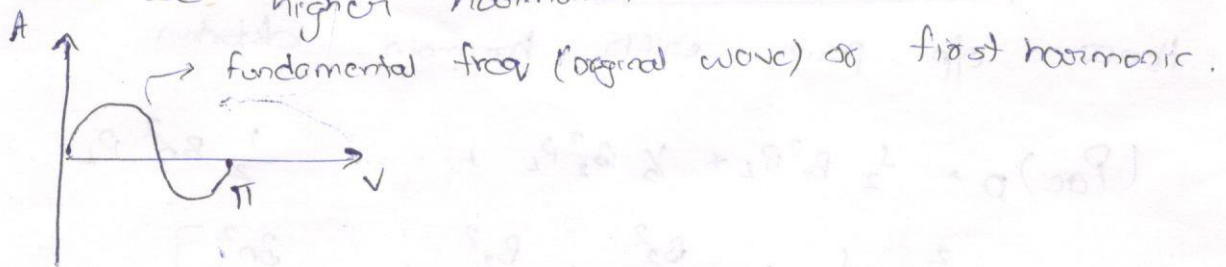


Harmonic :- It deals with waves with particular periodic waves. It is generally employed in music or acoustics, electronic power transmission, radio technology.

distortion :- This refers to disturbance in waves

As we know it is applied to repeating waves or signals, such as sin, cosine waves. A harmonic of such a wave is a wave with the freq. that is the integral multiple of frequency of the original wave, known as fundamental frequency. * The original wave is the first harmonic, the following harmonics are higher harmonics.



How this harmonics Related to (Electrical power)

Harmonic voltages & current in an electrical power system are a result of non-linear electrical loads. Harmonic frequency in the power grid are a frequent cause of power quality problems. Harmonics in power system result in increased heating in the equipment and conductors, misfiring in variable speed drives, and torque pulsation in motors. Reduction of harmonic is considered desirable.

∴ Power of due to distortion

$$P_{ac} = V \cdot I$$

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

$$V = i R$$

$$V_m = I_m R_L$$

$$P_{ac} = \frac{I_m^2 R_L}{2}$$

I_m = Peak value of the a/p current

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

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

$$I_m = B_1$$

$$\boxed{P_{ac} = \frac{1}{2} B_1^2 R_L}$$

Hence a/p power with harmonic distortion

$$(P_{ac})_D = \frac{1}{2} B_1^2 R_L + \frac{1}{2} B_2^2 R_L + \dots + \frac{1}{2} B_n^2 R_L$$

$$= \frac{1}{2} B_1^2 R_L \left[1 + \frac{B_2^2}{B_1^2} + \frac{B_3^2}{B_1^2} + \dots + \frac{B_n^2}{B_1^2} \right]$$

$$(P_{ac})_D = P_{ac} [1 + D_2^2 + D_3^2 + \dots + D_n^2]$$

$$D^2 = D_2^2 + D_3^2 + \dots + D_n^2$$

$$(P_{ac})_D = P_{ac} [1 + D^2]$$

if the total harmonic distortion $D = 0.15$

$$\begin{aligned} (P_{ac})_D &= P_{ac} [1 + (0.15)^2] \\ &= 1.0225 P_{ac} \end{aligned}$$

So there is 2.25 % increase in the power given to the load.

B_1, B_2, B_3 and B_4 are the Amp of the fundamental, 3rd, 5th & 7th harmonic components.

At 5 instants

At point 1 $\omega t = 0$ $i_c = I_{max}$

$$I_{max} = I_{CQ} + B_0 + B_1 + B_2 + B_3 + B_4 \rightarrow (6)$$

At point 2 $\omega t = \pi/3$ $i_c = I_{1/2}$

$$i_c = I_{CQ} + B_0 + B_1 \cos \pi/3 + B_2 \cos 2\pi/3 + B_3 \cos 3\pi/3 + B_4 \cos 4\pi/3$$

$$I_{1/2} = I_{CQ} + B_0 + 0.5 B_1 - 0.5 B_2 - B_3 - 0.5 B_4 \rightarrow (7)$$

At point 3 $\omega t = \pi/2$ $i_c = i_{CQ}$

$$i_c = I_{CQ} + B_0 + B_1 \cos \pi/2 + B_2 \cos 2\pi/2 + B_3 \cos 3\pi/2 + B_4 \cos 4\pi/2$$

$$I_{CQ} = I_{CQ} + B_0 - B_2 + B_4 \rightarrow (8)$$

At point 4 $\omega t = 2\pi/3$ $i_c = I_{-1/2}$

$$I_{-1/2} = I_{CQ} + B_0 - 0.5 B_1 - 0.5 B_2 + B_3 - 0.5 B_4 \rightarrow (9)$$

At point 4 $\omega t = \pi$ $i_c = I_{min}$

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

$$I_{min} = I_{CQ} + B_0 - B_1 + B_2 - B_3 + B_4 \rightarrow (10)$$

Solving (5) eq we get B_0, B_1, B_2, B_3, B_4 we get.

$$\begin{aligned} I_{max} + I_{min} &= I_{CQ} + B_0 + B_1 + B_2 + B_3 + B_4 \\ &= I_{CQ} + B_0 - B_1 + B_2 - B_3 + B_4 \end{aligned}$$

$$I_{max} + I_{min} = 2I_{CQ} + 2B_0 + 2B_2 + 2B_4 \rightarrow //$$

$$2I_{1/2} = 2I_{CQ} + 2B_0 + B_1 - B_2 - 2B_3 - B_4$$

$$2I_{-1/2} = 2I_{CQ} + 2B_0 - B_1 - B_2 + 2B_3 - B_4$$

Adding Eq (1) & (2) to find B_0

$$\begin{aligned} I_{\max} + I_{\min} + 2I_{\frac{1}{2}} + 2I_{-\frac{1}{2}} &= 6I_{CQ} + 6B_0 \\ &= 6[I_{CQ} + B_0] \\ &= 6B_0 \end{aligned}$$

$$\therefore B_0 = \frac{1}{6} [I_{\max} + I_{\min} + 2I_{\frac{1}{2}} + 2I_{-\frac{1}{2}}]$$

$$I_{\max} - I_{\min} = 2B_1 + 2B_3$$

$$2I_{-\frac{1}{2}} - 2I_{\frac{1}{2}} = -2B_1 + 4B_3$$

$$I_{\max} - I_{\min} + 2I_{-\frac{1}{2}} - 2I_{\frac{1}{2}} = \cancel{2B_1} + 2B_3 - \cancel{2B_1} + 4B_3 = 6B_3$$

$$\therefore B_3 = \frac{1}{6} [I_{\max} - I_{\min} + 2I_{-\frac{1}{2}} - 2I_{\frac{1}{2}}]$$

Similarly

$$B_0 = \frac{1}{6} [I_{\max} + 2I_{\frac{1}{2}} + 2I_{-\frac{1}{2}} + I_{\min}]$$

$$B_1 = \frac{1}{3} [I_{\max} + I_{\frac{1}{2}} - I_{-\frac{1}{2}} - I_{\min}]$$

$$B_2 = \frac{1}{4} [I_{\max} - 2I_{CQ} + I_{\min}]$$

$$B_3 = \frac{1}{6} [I_{\max} - 2I_{\frac{1}{2}} + 2I_{-\frac{1}{2}} - I_{\min}]$$

$$B_4 = \frac{1}{12} [I_{\max} - 4I_{\frac{1}{2}} + 6I_{CQ} - 4I_{-\frac{1}{2}} + I_{\min}]$$

Here the harmonic distortion co-efficient can be obtained by

$$D_n = \frac{|B_n|}{|B_1|}$$

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

As the Amp of the fundamental & 2nd harmonic are known, the 2nd harmonic distortion can be cal as

$$\% D_2 = \frac{|B_2|}{|B_1|} \times 100$$

As the method uses three point on the collector current wave form to obtain the amplitude of the harmonics this is called 3-point method of determining 2nd harmonic distortion. Similarly, five point method for higher order harmonic distortion (five point method).

As the non-linearity present in dynamic characteristic increases, the order of the harmonic distortion also increases.

Let the mathematical expression for the collector current due to higher order harmonic be

$$i_c = K_1 i_b + K_2 i_b^2 + K_3 i_b^3 + K_4 i_b^4 \rightarrow (1)$$

sub input signal $i_b = I_{bm} \cos \omega t$ eqn (1)

$$i_c = K_1 I_{bm} \cos \omega t + K_2 I_{bm}^2 \cos^2 \omega t + K_3 I_{bm}^3 \cos^3 \omega t + K_4 I_{bm}^4 \cos^4 \omega t \rightarrow (2)$$

Sub $\cos^2 \omega t$, $\cos^3 \omega t$, & $\cos^4 \omega t$ & using trigonometric eqn, eqn (2)

$$i_c = B_0 + B_1 \cos \omega t + K_2 I_{bm} \frac{1 + \cos 2\omega t}{2} \rightarrow (3)$$

$$i_c = B_0 + B_1 \cos \omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + B_4 \cos 4\omega t \rightarrow (4)$$

The total current at collector including dc bias can be written as

$$i_c = I_{CQ} + B_0 + B_1 \cos \omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + B_4 \cos 4\omega t \rightarrow (5)$$

where $\frac{I_{CQ} + B_0}{2}$ is the dc component.

(2)

It can be seen that due to presence of harmonics, the dc current increases. Practically the presence of harmonic can be detected by connecting milliammeter in the collector circuit. The readings can be observed without an a.c input signal and with ac input signal. If the two readings are almost same there are no harmonics present. But if milliammeter shows an increase in current, when an input is applied, then the harmonics can be concluded to be present in the a.p signal.

Now to find the value of total collector current at the various instants 1, 2 & 3

At point 1, $\omega t = 0$, sub in 5

$$\therefore i_c = I_{CQ} + B_0 + B_1 + B_2 = I_{\max} \rightarrow 6$$

Here the eq

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

$$\therefore i_c = I_{CQ} + B_0 - B_2 = I_{CQ} \rightarrow 7$$

At point 3 $\omega t = \pi$

$$\therefore i_c = I_{CQ} + B_0 - B_1 + B_2 = I_{\min} \rightarrow 8$$

But at

$$\omega t = 0, i_c = I_{\max}$$

$$\omega t = \pi/2, i_c = I_{CQ}$$

$$\omega t = \pi, i_c = I_{\min}$$

Hence the Eq

from Eq (3)

$$B_0 = B_2$$

Now

$$I_{\max} - I_{\min} = I_{CQ} + \cancel{B_0} + B_1 + \cancel{B_2} - I_{CQ} - \cancel{B_0} + B_1 - \cancel{B_2}$$

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

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

$$I_{\max} + I_{\min} = I_{CQ} + \cancel{B_0} + \cancel{B_1} + \cancel{B_2} + I_{CQ} + \cancel{B_0} - \cancel{B_1} + \cancel{B_2}$$

$$= 2I_{CQ} + 2B_0 + 2B_2$$

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

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

As the Amp of the fundamental & 2nd harmonic are known, the 2nd harmonic distortion can be cal as

$$\% D_2 = \frac{|B_2|}{|B_1|} \times 100$$

As the method uses three point on the collector current wave form to obtain the amplitude of the harmonics. This is called 3-point method of determining 2nd harmonic distortion.

Higher order harmonic distortion (five point method)

As the non-linearity present in dynamic character increase, the order of the harmonic distortion also increases.

Let the mathematical expression for the collector current due to higher order harmonic be

$$i_c = K_1 i_b + K_2 i_b^2 + K_3 i_b^3 + K_4 i_b^4 \rightarrow (1)$$

sub in p signal $i_b = I_{bm} \cos \omega t$ we get.

$$i_c = K_1 I_{bm} \cos \omega t + K_2 I_{bm}^2 \cos^2 \omega t + K_3 I_{bm}^3 \cos^3 \omega t + K_4 I_{bm}^4 \cos^4 \omega t \rightarrow (2)$$

Sub $\cos^2 \omega t$, $\cos^3 \omega t$, & $\cos^4 \omega t$ & using trigonometric eqn, we get.

$$i_c = B_0 + B_1 \cos \omega t + K_2 I_{bm} \frac{1 + \cos 2\omega t}{2} \rightarrow (3)$$

$$i_c = B_0 + B_1 \cos \omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + B_4 \cos 4\omega t \rightarrow (4)$$

The total current at collector including dc bias can be written as

$$i_c = I_{CQ} + B_0 + B_1 \cos \omega t + B_2 \cos 2\omega t + B_3 \cos 3\omega t + B_4 \cos 4\omega t \rightarrow (5)$$

where $\underline{I_{CQ} + B_0}$ is the dc component.

(3)

B_1, B_2, B_3 and B_4 are the Amp of the fundamental, 3rd & 4th harmonic components.

At 5 instants

At point 1 $\omega t = 0$ $i_c = I_{max}$

$$I_{max} = I_{c0} + B_0 + B_1 + B_2 + B_3 + B_4 \rightarrow (6)$$

At point 2 $\omega t = \pi/3$ $i_c = I_{1/2}$

$$i_c = I_{c0} + B_0 + B_1 \cos \pi/3 + B_2 \cos 2\pi/3 + B_3 \cos 3\pi/3 + B_4 \cos 4\pi/3$$

$$I_{1/2} = I_{c0} + B_0 + 0.5 B_1 - 0.5 B_2 - B_3 - 0.5 B_4 \rightarrow (7)$$

At point 3 $\omega t = \pi/2$ $i_c = i_{c0}$

$$i_c = I_{c0} + B_0 + B_1 \cos \pi/2 + B_2 \cos 2\pi/2 + B_3 \cos 3\pi/2 + B_4 \cos 4\pi/2$$

$$I_{c0} = I_{c0} + B_0 - B_2 + B_4 \rightarrow (8)$$

At point 4 $\omega t = 2\pi/3$ $i_c = I_{-1/2}$

$$I_{-1/2} = I_{c0} + B_0 - 0.5 B_1 - 0.5 B_2 + B_3 - 0.5 B_4 \rightarrow 9$$

At point 4 $\omega t = \pi$ $i_c = I_{min}$

$$i_c = I_{c0} + B_0 + B_1 \cos \pi + B_2 \cos 2\pi + B_3 \cos 3\pi + B_4 \cos 4\pi$$

$$I_{min} = I_{c0} + B_0 - B_1 + B_2 - B_3 + B_4 \rightarrow (10)$$

Solving (5) eq we get B_0, B_1, B_2, B_3, B_4 we get.

$$\begin{aligned} I_{max} + I_{min} &= I_{c0} + B_0 + B_1 + B_2 + B_3 + B_4 \\ &= I_{c0} + B_0 - B_1 + B_2 - B_3 + B_4 \end{aligned}$$

$$I_{max} + I_{min} = 2I_{c0} + 2B_0 + 2B_2 + 2B_4 \rightarrow 11$$

$$2I_{1/2} = 2I_{c0} + 2B_0 + B_1 - B_2 - 2B_3 - B_4$$

$$2I_{-1/2} = 2I_{c0} + 2B_0 - B_1 - B_2 + 2B_3 - B_4$$

$$2I_{1/2} + 2I_{-1/2} = 4I_{c0} + 4B_0 - 2B_2 - 2B_4 \rightarrow 12$$

$\cos 0 = 1$	0
$\cos 30 = \sqrt{3}/2$	$\pi/6$
$\cos 45 = 1/\sqrt{2}$	$\pi/4$
$\cos 60 = 1/2$	$\pi/3$
$\cos 90 = 0$	$\pi/2$
$\cos 120 = -1/2$	$2\pi/3$
$\cos 135 = -1/\sqrt{2}$	
$\cos 150 = -\sqrt{3}/2$	
$\cos 180 = -1$	π
$\cos 270 = 0$	

Adding Eq (11) & (12) to find B_0

$$\begin{aligned} I_{\max} + I_{\min} + 2I_{\gamma_2} + 2I_{-\gamma_2} &= 6I_{CQ} + 6B_0 \\ &= 6[I_{CQ} + B_0] \\ &= 6B_0 \end{aligned}$$

$$\therefore B_0 = \frac{1}{6} [I_{\max} + I_{\min} + 2I_{\gamma_2} + 2I_{-\gamma_2}]$$

$$I_{\max} - I_{\min} = 2B_1 + 2B_3$$

$$2I_{-\gamma_2} - 2I_{\gamma_2} = -2B_1 + 4B_3$$

$$\begin{aligned} I_{\max} - I_{\min} + 2I_{-\gamma_2} - 2I_{\gamma_2} &= 2B_1 + 2B_3 - 2B_1 + 4B_3 \\ &= 6B_3 \end{aligned}$$

$$\therefore B_3 = \frac{1}{6} [I_{\max} - I_{\min} + 2I_{-\gamma_2} - 2I_{\gamma_2}]$$

Finally

$$B_0 = \frac{1}{6} [I_{\max} + 2I_{\gamma_2} + 2I_{-\gamma_2} + I_{\min}]$$

$$B_1 = \frac{1}{3} [I_{\max} + I_{\gamma_2} - I_{-\gamma_2} - I_{\min}]$$

$$B_2 = \frac{1}{4} [I_{\max} - 2I_{CQ} + I_{\min}]$$

$$B_3 = \frac{1}{6} [I_{\max} - 2I_{\gamma_2} + 2I_{-\gamma_2} - I_{\min}]$$

$$B_4 = \frac{1}{12} [I_{\max} - 4I_{\gamma_2} + 6I_{CQ} - 4I_{-\gamma_2} + I_{\min}]$$

Here the harmonic distortion Co-efficient can be obtained by

$$D_n = \frac{|B_n|}{|B_1|}$$

Power of due to distortion

$$P_{ac} = V \cdot I$$

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

$$V = i R$$

$$V_m = i_m R_L$$

$$P_{ac} = \frac{I_m^2 R_L}{2}$$

I_m = Peak value of the a/p current

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

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

$$I_m = B_1$$

$$P_{ac} = \frac{1}{2} B_1^2 R_L$$

Hence a/p power with harmonic distortion

$$(P_{ac})_D = \frac{1}{2} B_1^2 R_L + \frac{1}{2} B_2^2 R_L + \dots + \frac{1}{2} B_n^2 R_L$$

$$= \frac{1}{2} B_1^2 R_L \left[1 + \frac{B_2^2}{B_1^2} + \frac{B_3^2}{B_1^2} + \dots + \frac{B_n^2}{B_1^2} \right]$$

$$(P_{ac})_D = P_{ac} [1 + D_2^2 + D_3^2 + \dots + D_n^2]$$

$$D^2 = D_2^2 + D_3^2 + \dots + D_n^2$$

$$(P_{ac})_D = P_{ac} [1 + D^2]$$

If the total harmonic distortion $D = 0.15$

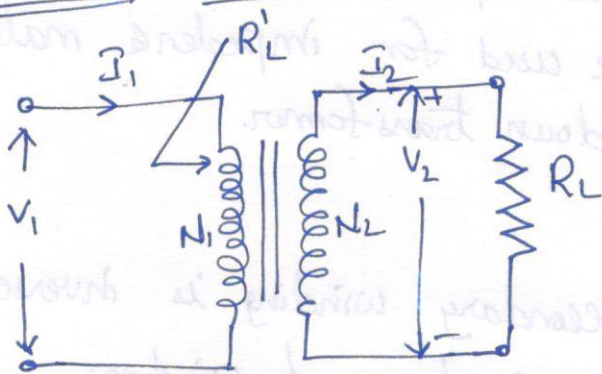
$$(P_{ac})_D = P_{ac} [1 + (0.15)^2]$$

$$= 1.0225 P_{ac}$$

So there is 2.25 % increase in the power given to the load.

Transformer Coupled class A Amplifier:-

- * For maximum power transfer to the load, the impedance matching is necessary.
- * For loads like loudspeaker, having low impedance values, impedance matching is difficult using directly coupled amplifier circuit.
- * This is because loudspeaker resistance is in the range of 3 to 4 ohms to 16 ohms while the output impedance of series fed directly coupled class A amplifier is very much high.
- * This problem can be eliminated by using transformer to deliver power to the load. The transformer is called an output transformer and amplifier is called transformed coupled class A amplifier.

Properties of transformer:-

* Consider a transformer as shown in the fig. which is connected to a load resistance R_L .

* While analysing transformer, it is assumed that the transformer is ideal and there are no losses in transformer. Similarly the winding

resistances are assumed to be zero.

N_1 = Number of turns on primary

N_2 = Number of turns on secondary

V_1 = Voltage applied to primary

V_2 = Voltage on secondary.

I_2 = primary current.

1) Turns ratio:-

The ratio of no. of turns on secondary to the no. of turns on primary is called turns ratio and is denoted by n .

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

* Sometimes it is specified as $\frac{N_2}{N_1} : 1$ (or $\frac{N_1}{N_2} : 1$)

2) Voltage transformation:-

The transformer transforms the voltage applied on one side to other side proportional to turns ratio. The transformer can be step up or step down transformer.

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

In amplifier analysis, load impedance is going to be small. And the transformer is to be used for impedance matching. Hence it has to be a step down transformer.

3) Current transformation:-

The current in the secondary winding is inversely proportional to the number of turns of windings.

$$\frac{I_2}{I_1} = \frac{N_1}{N_2} = \frac{1}{n}$$

4) Impedance transformation:-

As current and voltage get transformed from primary to Secondary, an impedance seen from either side also changes. The impedance of the load on secondary is R_L .

$$R_L = \frac{V_2}{I_2} \quad \text{and} \quad R_L = \frac{V_1}{I_1}$$

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

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

$$R_L' = \frac{\frac{N_1}{N_2} V_2}{\frac{N_2}{N_1} I_2} = \left(\frac{N_1}{N_2} \right)^2 \times \frac{V_2}{I_2}$$

$$\boxed{R_L' = \frac{R_L}{n^2}}$$

The R_L is reflected impedance.

Problem

The load of 4Ω is connected to the Secondary of a transformer having primary turns of 200 and secondary turns of 20. Calculate the reflected load impedance on primary.

Solution Given that

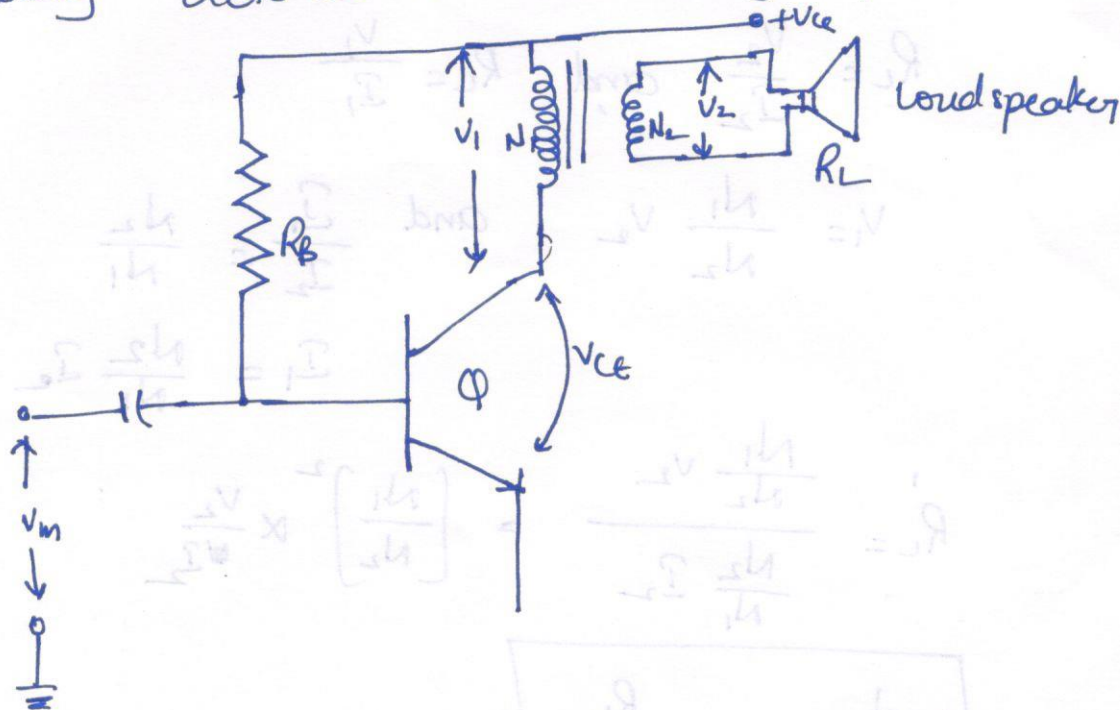
$$R_L = 4\Omega \quad N_1 = 200 \quad N_2 = 20$$

$$n = \frac{N_2}{N_1} = \frac{20}{200} = 0.1$$

$$R_L' = \frac{R_L}{n^2} = \frac{4}{(0.1)^2} = 400\Omega$$

Circuit diagram of transformer Coupled Amplifier:-

The basic circuit of a transformer coupled amplifier is shown in below fig. The loudspeaker connected to the secondary acts as a load having impedance of R_L .



The transformer used is a step down transformer with turns ratio as $n = \frac{N_2}{N_1}$.

DC operation:-

- (*) It is assumed that winding resistances are 0 Ω . Hence for dc. purposes the resistance is 0 Ω .
- (*) There is no voltage drop across the primary winding of the transformer.
- (*) The slope of the d-c load line is reciprocal of the d-c resistance in collector circuit, which is zero in this case.
- (*) Hence slope of d-c load line is ideally infinite. The d-c load line is vertically straight line.