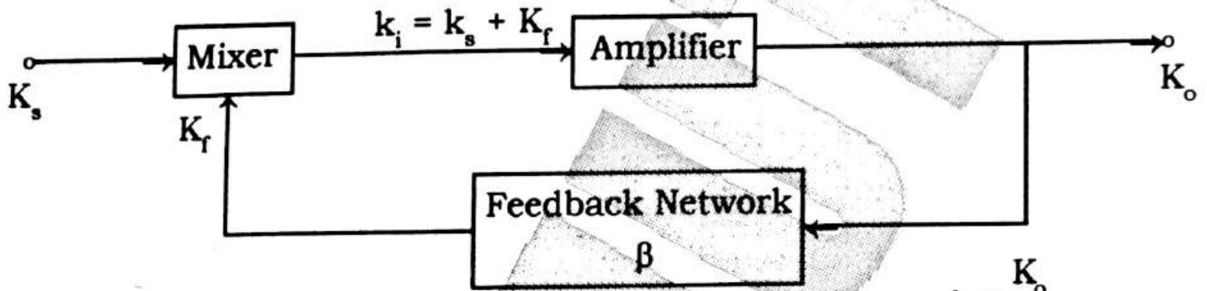
Chapter - 7
FEEDBACK AMPLIFIERS

7 - FEEDBACK IN AMPLIFIERS

<u>Basic Concepts</u> : The block diagram for a general purpose feedback system is shown in the figure. K_s is the source quantity, may be the current or voltage K_i is the input to the amplifier, K_o its output, K_f is the output of the feedback network (usually consisting of passive components) let 'A' be the gain of the amplifier $(=k_o/k_i)$ and 'β' be the gain of the feedback network $(=K_f/k_o)$, let 'A_f' be the gain of the amplifier with feedback $(=K_o/K_s)$, then



$$A = \frac{K_o}{K_i}$$

$$\beta = \frac{K_f}{K_o}$$

$$A_f = \frac{K_o}{K_s} = \frac{K_o}{K_i} \cdot \frac{K_i}{K_s}$$

$$A_f = \frac{K_o}{K_i} \cdot \frac{K_i}{K_i - K_f} = \frac{K_o}{K_i} \cdot \frac{1}{1 - \frac{K_f}{K_i}}$$

$$A_f = \frac{K_o}{K_i} \cdot \frac{1}{1 - \frac{K_o}{K_i} \cdot \frac{K_f}{K_o}}$$

$$A_f = \frac{A}{(1 - A\beta)} = \frac{A}{D}$$

There are two distinct possibilities. In case $D(=1-A\beta) > 1$, we have $|A_f| < |A|$ and the feedback is called negative or degenerative feedback. On the other hand if $D(=1-A\beta) < 1$, $|A_f| > |A|$ and the feedback is called positive or regenerative feedback. The latter case also includes the extreme condition $D(=1-A\beta) = 0$. Which is employed in oscillators.

Feedback not only changes the overall gain but also input impedence, output impedance, bandwidth, etc. We shall analyse these changes separately. The analysis pertains to negative feedback due to its advantages, which would become obvious later on.

NEGATIVE FEEDBACK:- The important property of negative feedback is the reduction in gain which is more than offset by its advantages. Further, the reduction in gain can always be made up by cascading stages.

STABILITY :- We assume that due to changes in the circuit components, supply voltage, etc., the amplifier gain *'A'* changes by an amount ΔA. We desire to know the change in the gain with feedback A_f, due to the same change in the circuit parameters..

For negative feedback. $|1-A\beta|$ being greater than 1. $\Delta A_f/A_f$ will be less than $\Delta A/A$. i.e. the percentage change in A_f would be less than that in A.

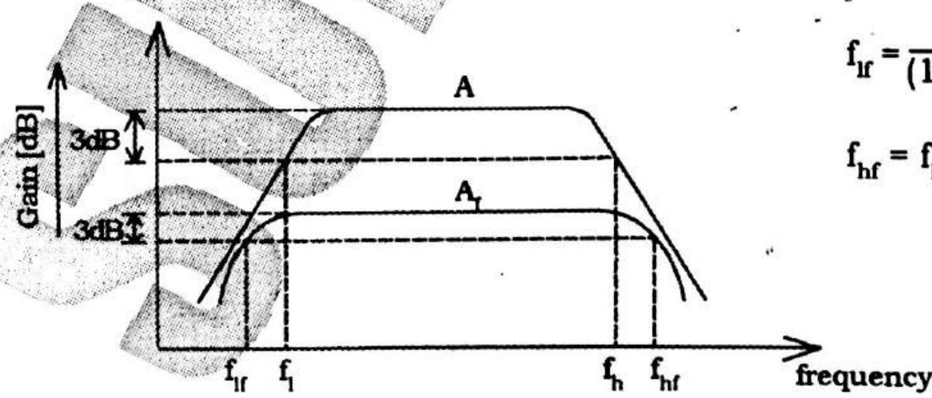
DISTORTION :- The distortion factor D_2 in case of no feedback & D_{2f} in case of feedback. leads to :

$$D_{2f} = \frac{D_2}{1-A\beta}$$

$|1-A\beta|$ being greater than unity in the case of negative feedback, this would reduce distortion. Negative feedback cannot reduce the distortion present in the input itself.

NOISE & PICKUP SIGNALS:- The application of negative feedback would bring about a reduction in noise. A signal at mains frequency (50 Hz) is invariably introduced in the amplifier through the d.c. supply of capacitive coupling. This is called a pickup or hum. Negative feedback would bring about a reduction in hum or pickup voltage.

INCREASE IN BANDWIDTH :- The application of negative feedback would bring about an increase in bandwidth. The upper cutoff frequency after feedback would be $f_h(1-A\beta)$ and in case of negative feedback, it would be higher than f_h. Similarly we find that the lower cutoff frequency after feedback would be $f_l/(1-A\beta)$ and in case of negative feedback it would be lower than f_l. In general the negative feedback would increase the bandwidth.



$$f_{lf} = \frac{f_l}{(1 + A\beta)} \text{ for NFB}$$

$$f_{hf} = f_h\,(1 + A\beta) \text{ for NFB}$$

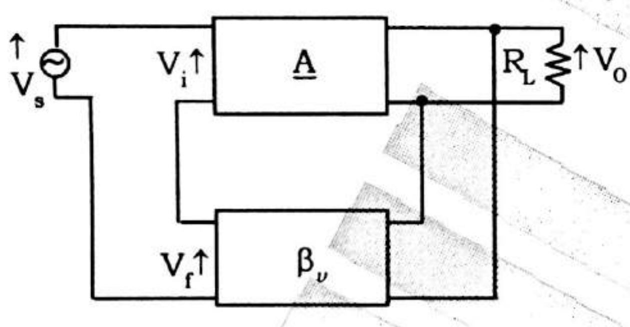
f_l = Lower cutoff frequency.
f_h = Upper cutoff frequency.
f_{lf} = Lower cutoff frequency, with negative feedback.
f_{hf} = Upper cutoff frequency, with negative feedback.
$f_h - f_l$ = Bandwidth without feedback.
$f_{hf} - f_{lf}$ = Bandwidth with feedback.

<u>TYPE OF NEGATIVE FEEDBACK</u>:- We presume that the quantities at the input and the output could be current or voltage. Depending upon what we consider for input and output. we can have distinct cases :.

1. Voltage - Series Feedback
2. Voltage - Shunt Feedback
3. Current - Series Feedback
4. Current - Shunt Feedback

1. <u>Voltage - Series Feedback</u> :- In a voltage - series feedback amplifier shown in figure1 the feedback signal V_f is proportional to the output signal V_o. The shunt connection at the output reduces R_o. The series connection at the input terminals increases R_i. The resultant amplifier is a true voltage amplifier and the voltage feedback factor is

$$\beta_v = \frac{V_f}{V_o}$$



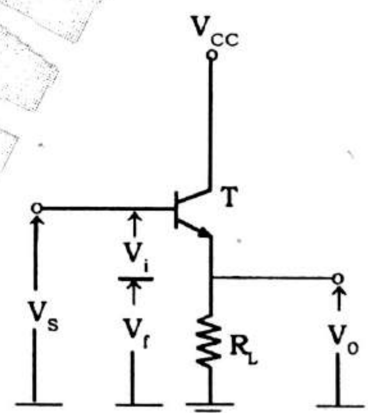
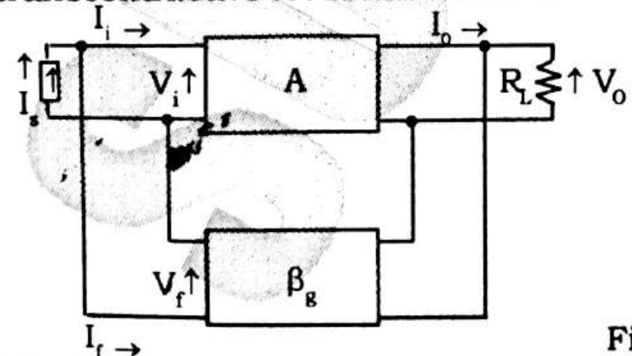


Fig (1)

2. <u>Voltage - Shunt Feedback</u> :- In a voltage - shunt feedback amplifier shown in figure 2 the feedback signal I_f is proportional to the output signal V_o. The shunt connection at the output and at input terminals reduces both R_o & R_i. The resulting amplifier is a transresistance type voltage amplifier and the transconductive feedback factor is

$$\beta_g = \frac{I_f}{V_o}$$



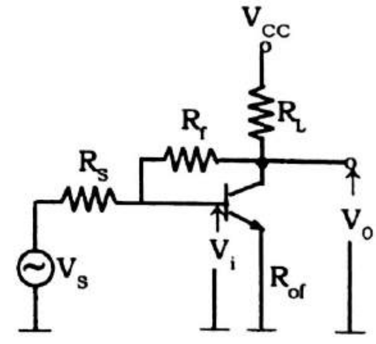


Fig (2)

3. <u>Current - Series Feedback</u> :- In a current-series feedback amplifier shown in fig.3 the series connection at the output and input terminals increase both R_o and R_i. The resulting amplifier is a transconductance type current amplifier and the transresistive feedback factor is

$$\beta_r = \frac{V_f}{I_o}$$

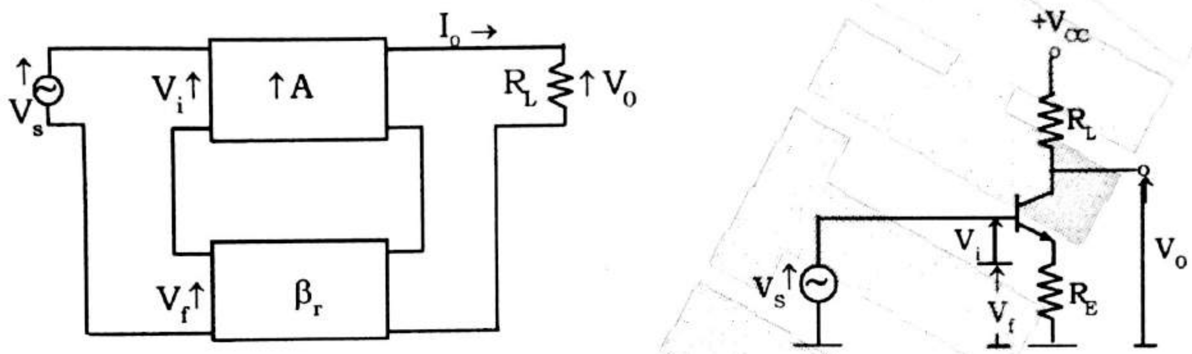


Fig (3)

4. <u>Current - Shunt Feedback</u> :- In a current–shunt feedback amplifier shown in fig.4 the series connection at the output increases R_o and the shunt connection at the input reduces R_i. The resulting amplifier is a true current amplifier and the current feedback factor is

$$\beta_i = \frac{I_f}{I_o}$$

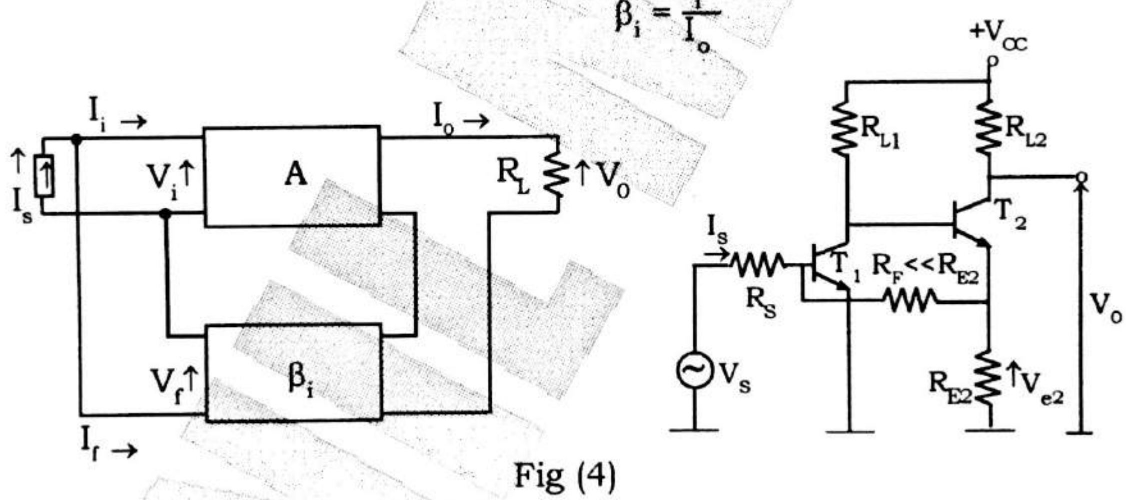
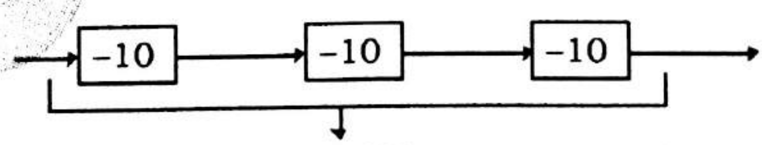


Fig (4)

Problem (1) The open-loop gain of an amplifier is –100. Feedback is introduced to achieve a closed-loop gain also of –100.Because of feedback,the open-loop gain must be increasd.To accomplish this, three cascaded stages each having a voltage gain of –10 are used. Determine the value of β.

Solution :



A = –1000

A_f = -100

A = -1000

$\beta = ?$

$$A_f = \frac{A}{1-A\beta}$$

$$-100 = \frac{-1000}{1+1000\,\beta}$$

$$\boxed{\begin{array}{l}\beta = 9\times10^{-3}\\ (1-A\beta) = 10\end{array}}$$

Problem (2) An amplifier without feedback has $f_l = 100$ Hz and $f_h = 10$ KHz is used such that $1 + A\beta = 10$ .Determine the bandwidth of the amplifier with and without feedback.

Solution: $1 + A\beta = 10$

$f_l = 100$ Hz

$f_h = 10$ KHz

$$f_{lf} = \frac{f_l}{(1 + A\beta)} = \frac{100}{10} = 10 \text{ Hz}$$

$$f_{hf}^{\bullet} = f_h\,(1 + A\beta) = 10 \times 10 = 100 \text{ KHz}$$

Bandwidth without NFB = $f_h - f_l$ = 9.9 KHz

Bandwidth with NFB = $f_{hf} - f_{lf}$ = 99.99 KHz

Problem (3) A single-stage RC-coupled amplifier with a midband voltage gain of 1000 is made into a feedback Amplifier by feeding 10% if its output voltage in series with the input opposing. If $f_l = 20$ Hz and $f_h = 50$ KHz for the amplifier without feedback, what are the corresponding values after feedback has been added.

Solution:

$A = 1000$

$\beta = 0.10$

$1 + A\beta = 101$

$f_l = 20$ Hz

$f_h = 50$ KHz

$$f_{lf} = \frac{f_l}{(1 + A\beta)} = \frac{20}{101} = 0.2 \text{ Hz}$$

$$f_{hf} = f_h\,(1 + A\beta) = 50 \times 101 = 5050 \text{ KHz}$$

Bandwidth without NFB = $f_h - f_l$ = 49.98 KHz

Bandwidth with NFB = $f_{hf} - f_{lf}$ = 5050 KHz

Problem(4) The overall gain of the two stage amplifier is 200 with negative feedback of 20% applied only to the second stage .Assuming that the first stage has negligible Distortion and that the second stage has a gain of 300 and 10% distortion without feedback, find

(1) The distortion of the second stage with feedback

(2) The gain of the first stage.

Solution :

$\beta = 0.20$

$A_2 = 300$

$D_2 = 10\ \%$

$$D_{2f} = \frac{D_2}{1+A_2\beta} = \frac{10}{1+300x0.20} = 0.164\%$$

$$A_{2f} = \frac{A_2}{1+A_2\beta} = \frac{300}{1+300x0.20} = 4.918$$

$A_o = A_1 \times A_{2f}$

$200 = A_1 \times 4.918$ $\boxed{A_1 = 40.66}$

Problem(5) An amplifier without feedback gives a fundamental output of 36V with 7% second-harmonic distortion when the input is 0.028V.

(i) If 1.2% of the output is feedback into the input in a negative voltage series-feedback circuit,what is the output voltage.

(ii) If the fundamental output is maintained at 36V, but the second harmonic distortion is reduced to 1 %, what is the input voltage?

Solution :

$V_o = 36$ Volt

$V_i = 0.028$ Volt

$A = \dfrac{V_o}{V_i} = 1285.7$

$D_2 = 7\%$

(i) $A = 1285.7$

$\beta = 0.012$

$V_i = 0.028$ volt

$A_f = \dfrac{A}{1+A\beta} = 78.26$

$A_f = \dfrac{V_o}{V_i}$

$78.26 = \dfrac{V_o}{0.028}$

$\boxed{V_o = 2.19 \text{ volt}}$

(ii) $V_o = 36$ volt

$D_2 = 7\ \%$

$D_{2f} = 1\ \%$

$A = 1285.7$

$D_{2f} = \dfrac{D_2}{1 + A\beta}$

$1 = \dfrac{7}{1 + A\beta}$

$(1 + A\beta) = 7$

$A_f = \dfrac{A}{1+A\beta} = \dfrac{1285.7}{7}$

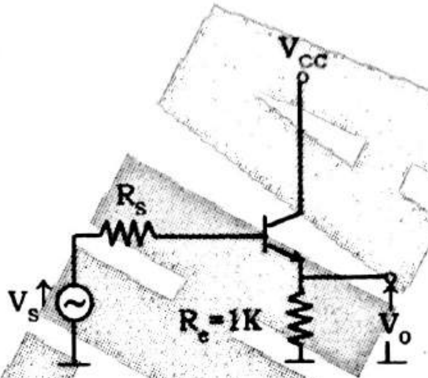
$A_f = 183.67$

$A_f = \dfrac{V_o}{V_i}$, $183.67 = \dfrac{36}{V_i}$

$\boxed{V_i = 0.196 \text{ volts}}$

Problem(6) Figure shown below illustrated the circuit of series voltage feedback amplifier. Determine A_{vf}, R_{if} and R_{of}

Data given $h_{ie} = 2$ k, $h_{fe} = 100$, $h_{re} = h_{oe} = R_s = 0$.



Solution :

$$A = A_v = \frac{V_o}{V_i} = \frac{h_{fe} I_b R_L}{h_{ie}\, I_b} = \frac{100 x 1}{2} = 50$$

$$\beta = \frac{V_f}{V_o} = 1$$

$R_i = h_{ie} = 2\ K\Omega$

$R_o = R_L = 1000\Omega$

1) $$A_{vf} = \frac{A_v}{1 + A_v \beta} = \frac{50}{1+50} = 0.98$$

2) $A_{if} = R_i\,(1 + A\beta) = 2\,(1+50) = 102\ K\Omega$

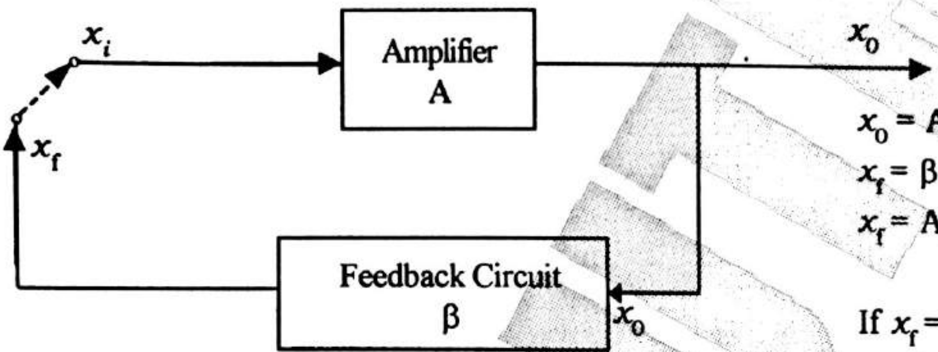
3) $$R_{of} = \frac{R_o}{1 + A\beta} = \frac{1000}{1+50} = 19.61\ \Omega$$

Chapter - 8

OSCILATORS

8 -OSCILLATORS

BARKHAUSEN CRITERIA



$x_0 = A\, x_i$
$x_f = \beta\, x_0$
$x_f = A\beta\, x_i$

If $x_f = x_i$
$A\beta\, x_i = x_i$
$A\beta = 1$

The oscillations in any amplifier would occur if a positive feedback with infinite gain can exist .The gain of the feedback amplifier would become infinite if the condition

$$1 - A\beta = 0$$

or

$$A\beta = 1$$

is satisfied. This condition is called Barkhausen criterion. In practice the amplifier gain A as well as β could be complex quantities and would be frequency dependent .Hence ,the product Aβ would be a complex quantity and Aβ = 1 would provide two distinct conditions,

$$(A\beta)Re = 1$$

and

$$(A\beta)Im = 0$$

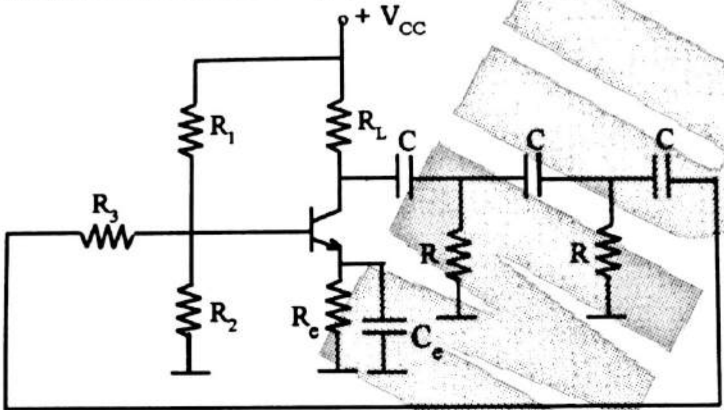
where (Aβ)Re represents the real part and (Aβ)Im the imaginary part *of* Aβ.

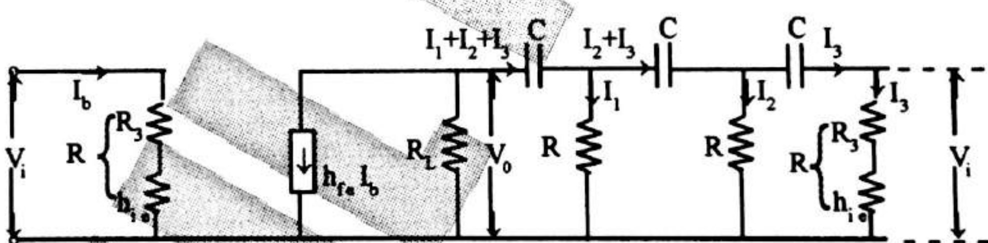
RC - OSCILLATOR :-

In CE configuration there is a 180° phase shift between the output voltage and the input voltage. For generation of oscillations ie. to satisfy the Barkhausen criteria, the feedback voltage has to be in phase with the input voltage. The feedback voltage is obtained from the output voltage. Hence, the feedback network should be designed to introduce a phase shift of 180°. This network is designed such that it provides 180° phase shift at one frequency, i.e. it automatically decides the ftequency of oscillation. The phase shift network could be a RC network. Such oscillator are called RC phase shift oscillators.

In case we employ two stage (or an even nunber of stages) of CE amplifier, the output would be in phase with the input. In this case the feedback network should not introduce any phase shift to satisfy Barkhausen Criteria. The netwolk could be again designed such that only at the frequency of oscillation the phase shift introduced by it is zero. One commonly employed method for this selection is a RC bridge such oscillator is a Wien Bridge oscillator.
(2X^{sis} with 180° phase shift therefore total 360° phase shift = 0 phase shift)

PHASE SHIFT OSCILLATOR:- A typical RC phase shift oscillator is shown in fig below. R_1 , R_2, R_e provide the necessary operating point. C_e is the by pass capacitor so that at the frequency of oscillation, R_e is completely bypassed. C and R constitute the necessary phase shifting networks.





1) $I_3R = V_i$ $\qquad I_3 = \dfrac{V_i}{R}$

2) $I_2R = \dfrac{I_3}{j\omega C} + I_3R = I_3\left[\dfrac{1+j\omega CR}{j\omega C}\right]$ $\qquad I_2 = \dfrac{V_i}{R}\left[\dfrac{1+j\omega CR}{j\omega CR}\right]$

3) $I_1R = \dfrac{I_2+I_3}{j\omega C} + I_2R = I_2\left[\dfrac{1+j\omega CR}{j\omega C}\right] + \dfrac{I_3}{j\omega C}$

$$I_1 = \frac{V_i}{R}\left[\frac{1+j\omega CR}{j\omega CR}\right]^2 + \frac{V_i}{j\omega CR^2}$$

4) $V_o = \dfrac{I_1 + 2I_2 + 3I_3}{j\omega C} + V_i$

5) $$V_o = \frac{\frac{V_i}{R}\left[\frac{1+j\omega CR}{j\omega CR}\right]^2 + \frac{V_i}{j\omega CR^2} + \frac{2V_i}{R}\left[\frac{1+j\omega CR}{j\omega CR}\right] + \frac{3V_i}{R}}{j\omega C} + V_i$$

$$6)\ \frac{V_o}{V_i} = \left[1 - \frac{5}{\omega^2 C^2 R^2}\right] + j\left[\frac{1}{\omega^3 C^3 R^3} - \frac{6}{\omega C R}\right]$$

But the imaginary part must be zero for zero phase shift.

$$\left[\frac{1}{\omega^3 C^3 R^3} - \frac{6}{\omega C R}\right] = 0$$

$$\boxed{\omega = \frac{1}{\sqrt{6}\,RC}}$$

$$\boxed{f = \frac{1}{2\pi\sqrt{6}\,RC}}$$

WIEN BRIDGE OSCILLATOR

The figure shows a two stage amplifier. The biasing components and the coupling capacitances can easily be identified. The oscillation frequency is assumed to be in the mid frequency range of the amplifier i.e. the influence of coupling and bypass capacitors is neglected and so also the shunt capacitances in the transistors equivalent circuit. The amplifier gain would be the products of the gains of the two stages, the output voltage V_o and the input voltage V_i would be in phase. Note that the emitter resistance of the first stage is not bypassed. Thus R_3 and R_e provides negative feedback. The positive feedback is achieved through R_1 C_1 and R_2 C_2 and is frequency selective.

Amplitude control, in the case of the Wien bridge oscillator, is achieved by employing non-linear R_e. Thus, the amplifier would operate in the linear region, but as the amplitude of oscillation changes, R_e would vary and provide amplitude control. As the amplitude of oscillation increase (decrease) so would R_e, bringing about an increase (decrease) in negative feedback and decrease (increase) in V_i. This would restore V_o such resistance are called voltage dependent resistances (VDR).

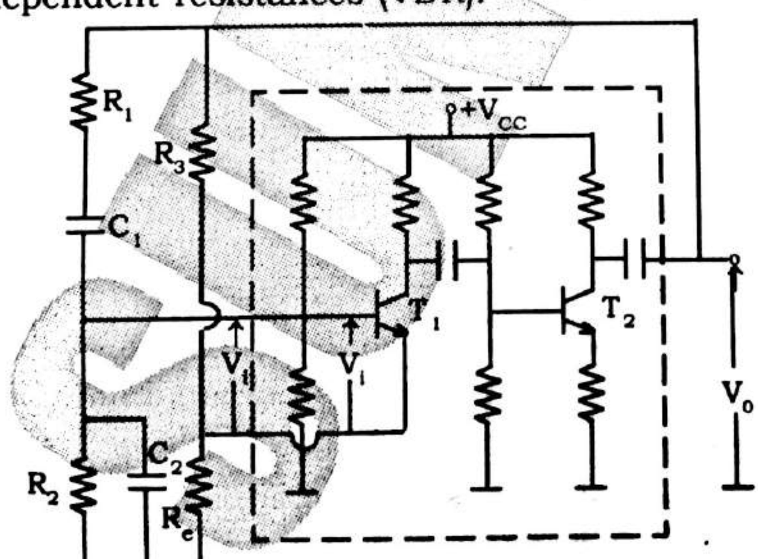


Figure (a)

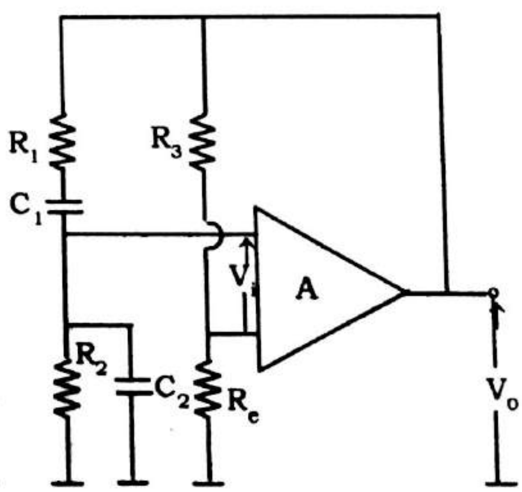
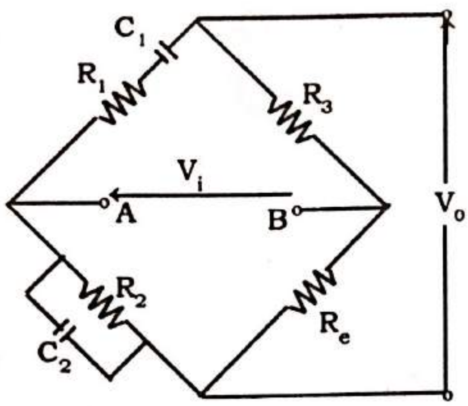
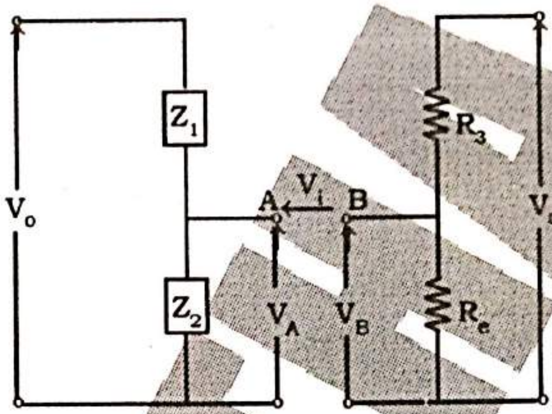


Figure (b)



Figure(c)



Figure(d)

$$V_i = V_A - V_B$$

$$V_i = \left(\frac{Z_2}{Z_1 + Z_2}\right) V_o - \left(\frac{R_e}{R_3 + R_e}\right) V_o$$

Let :- $R_1 = R_2 = R$
$C_1 = C_2 = C$

$$Z_1 = \frac{1 + j\omega CR}{j\omega C}$$

$$Z_2 = \frac{R}{1 + j\omega CR}$$

$$\frac{V_i}{V_o} = \frac{\left(\frac{R}{1 + j\omega CR}\right)}{\left(\frac{1 + j\omega CR}{j\omega C}\right) + \left(\frac{R}{1 + j\omega CR}\right)} - \frac{R_e}{R_3 + R_e}$$

$$\frac{V_i}{V_o} = \frac{j\omega CR}{(1 - \omega^2 C^2 R^2) + j(3\omega CR)} - \frac{R_e}{R_3 + R_e}$$

$$\frac{V_i}{V_o} = \frac{j\omega CR\left[(1 - \omega^2 C^2 R^2) - j(3\omega CR)\right]}{(1 - \omega^2 C^2 R^2)^2 + (3\omega CR)^2} - \frac{R_e}{R_3 + R_e}$$

$$\frac{V_i}{V_o} = \frac{3\omega^2 C^2 R^2 + j\omega CR(1 - \omega^2 C^2 R^2)}{(1 - \omega^2 C^2 R^2)^2 + (3\omega CR)^2} - \frac{R_e}{R_3 + R_e}$$

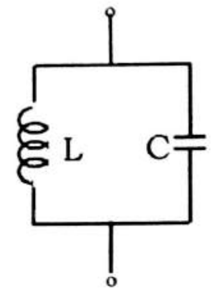
But the imaginary part must be zero for zero phase shift

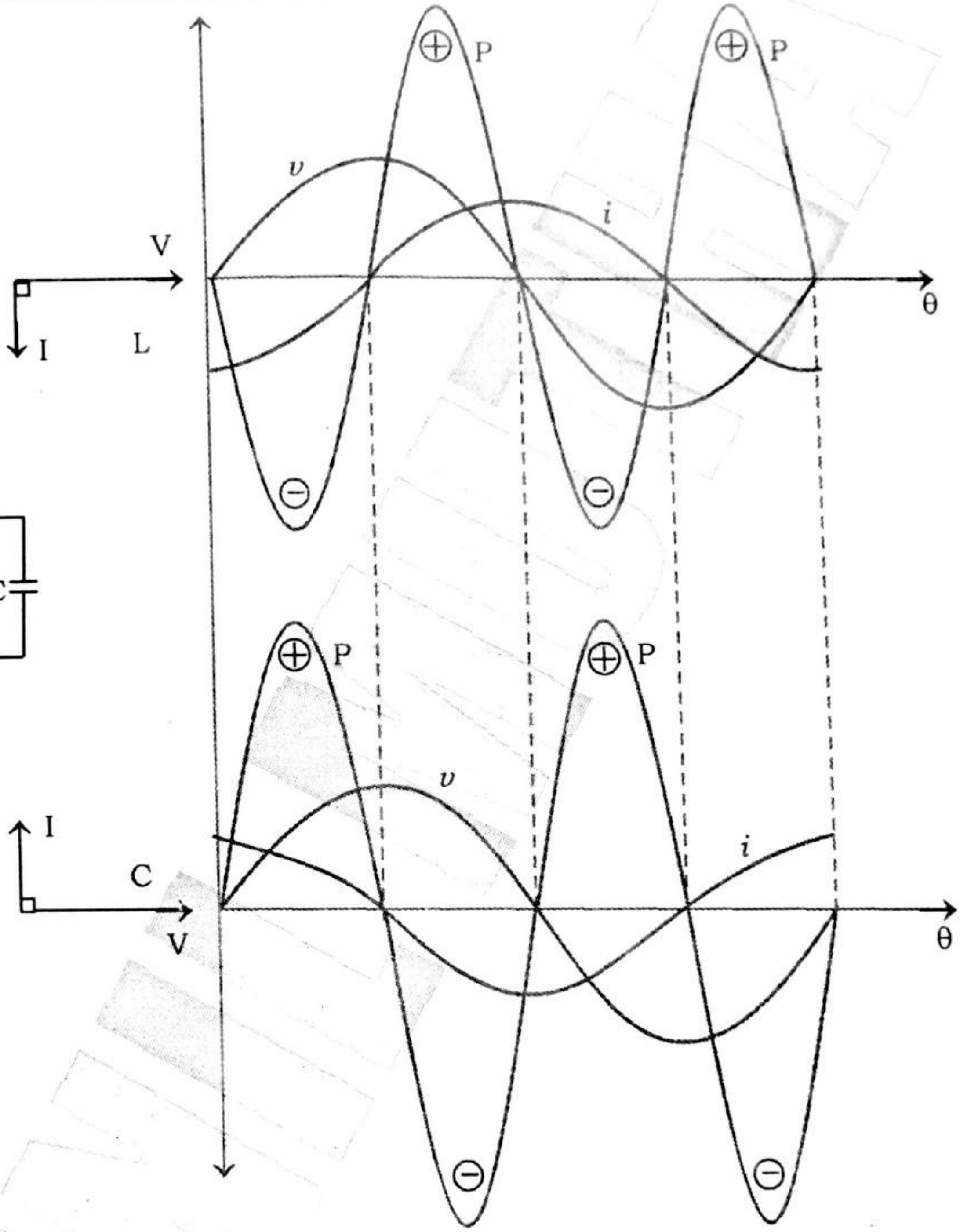
$$\omega CR(1 - \omega^2 C^2 R^2) = 0$$

$$1 - \omega^2 C^2 R^2 = 0$$

$$\boxed{\omega = \frac{1}{RC} \qquad f = \frac{1}{2\pi RC}}$$

WHENEVER AN INDUCTOR AND A CAPACITOR ARE CONNECTED IN PARALLEL, IT GIVES RISE TO AN OSCILLATORY CIRCUIT





$V_L = V_C$

$IX_L = IX_C$

$\omega L = \frac{1}{\omega C}$

$\omega = \frac{1}{\sqrt{LC}}$

$f = \frac{1}{2\pi} \frac{1}{\sqrt{LC}}$

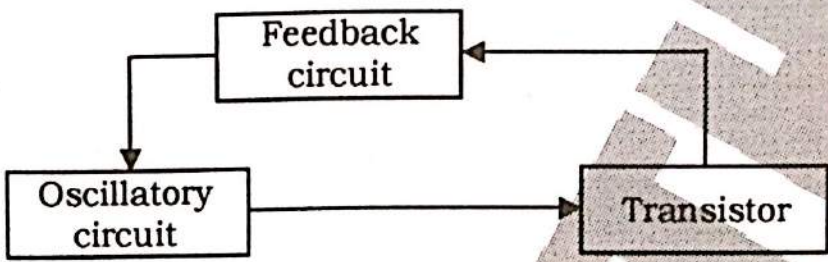
<u>TRANSISTOR OSCILATOR</u> :- A transistor with associated circuitry can work as an oscillator. Transistor oscillator require the same general circuit conditions as the vaccum tube oscillator, namely: .

1) An oscilatory circuit containing L and C which produces electronic oscillations.

2) An amplifier i.e. transistor to supply the losses that occur in the oscillatory circuit.

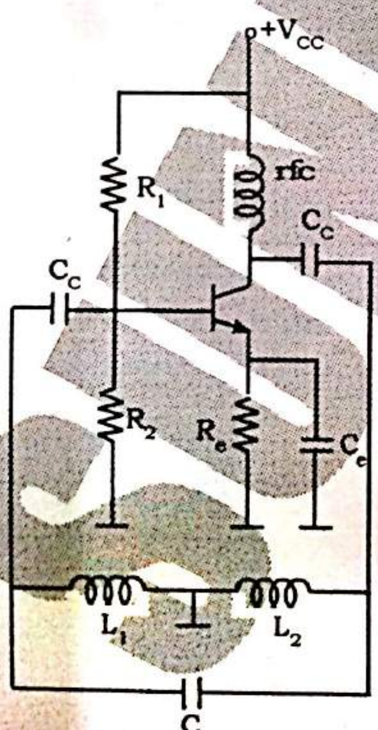
3) A feedback circuit to supply the energy to the oscillatory circuit in correct phase and magnitude.

Figure shows the block diagram of a transistor oscillator. The oscillations produced by the oscillatory circuit are amplified by the transistor. A portion of the transistor output is feedback to the oscillatory circuit in correct magnitude and phase by the feedback circuit. Thus, losses occuring in the LC circuit are continuously supplied and hence undamped oscillations are obtained.



DIFFERENT TYPES OF TRANSISTOR OSCILLATORS :- A transistor can work, as an oscillator to produce continuous undamped oscilations of any desired frequency, if oscillatory and feedback circuit are properly connected to it. All oscillators under different names have similar function but differ only in the way of feedback to supply losses to the oscillatory circuit.

HARTLEY OSCILLATOR:- This is popular oscillator and is very commonly used in radio receivers. Figure below shows the circuit of a hartley oscillator. It consists of two coils L_1 and L_2 wound over the same core. A capacitor C is connected across the combination of L_1, L_2 to form L-C circuit. The frequency of oscillations is determined by L_1, L_2 and C.



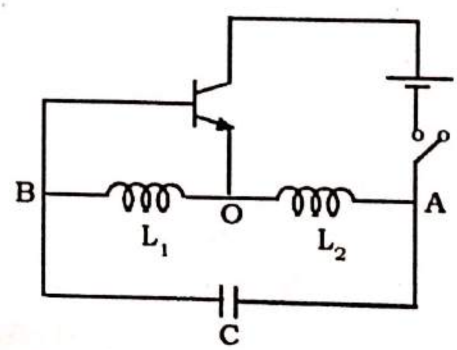
$$\omega = \frac{1}{\sqrt{LC}}$$

But, $L = L_1 + L_2$

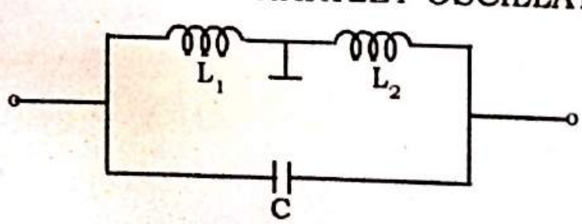
$$\omega = \frac{1}{\sqrt{(L_1+L_2)C}}$$

$$f = \frac{1}{2\pi\sqrt{(L_1+L_2)C}}$$

SIMPLIFIED CIRCUIT



TANK CIRCUIT OF HARTLEY OSCILLATOR



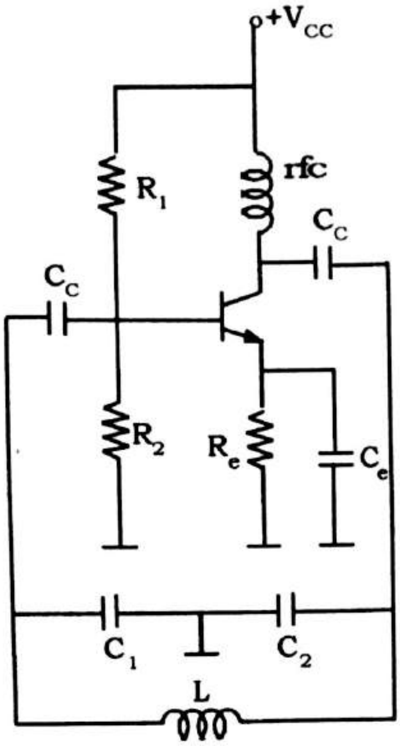
When the circuit is started by closing key K. the capacitor C is Charged. This capacitor discharges through L_1 and L_2 setting up oscillations of frequency.

The oscillations between O and B are applied in the base circuits and appear in the amplified form in the collector circuits. This amplified output has the same frequency as that of oscillatory circuit and supplied the losses which are occurring in the oscillatory circuits. Thus. energy is being continuously supplied to make up the losses occurring in the oscillatory circuits and hence undamped oscillations are possible.

The energy supplied to the oscillatory circuit is of correct phase as can be easily explained. The coils L_1 and L_2 are magnetically linked with each other so that points B and A are 180° out of phase. A further phase shift of 180° is produced by the transistor due to its properties. Thus, energy from the collector circuit supplied to oscillatory circuits is of correct phase and ensure proper feedback.

COLPITT'S OSCIILATOR :- Colpitt's oscillator is similar to Hartley oscillator in operation. The only difference is that in Colpitt's oscillator the coupling is capacitive instead of inductive. The figure below shows the circuit consists of an inductive coil in parallel with two series connected capacitors C_1 and C_2.
When the circuit is started, capacitors C_1 and C_2 are charged with polarities shown in the figure. These capacitors discharged through the coil, setting up oscillations of frequency.

The oscillations across C_1 are applied to the base circuit and appear in the amplified form in the collector circuit. Of course, the amplified output in the collector circuit has the same frequency as that of oscillatory circuit. This amplified output in the collector circuit is fed to the oscillator circuit in order to supply the losses. In this way, oscillatory circuit is continuously getting energy from the collector circuit to make up for the losses occurring in it and hence, ensure undamped oscillations. The energy supplied to the oscillatory circuit is of correct phase and can be easily seen. It is clear that 180° phase difference is created between points A and B i.e.. input is 180° out of phase with output. A further phase shift of 180° is produced by the transistor.



$$\omega = \sqrt{\frac{1}{LC}}$$

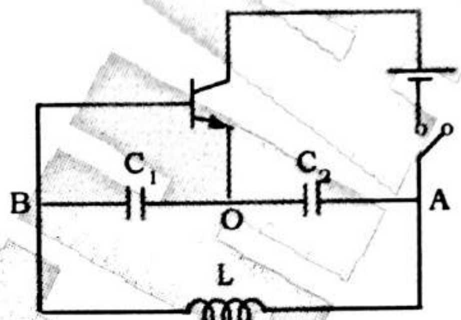
But, $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$

Therefore,

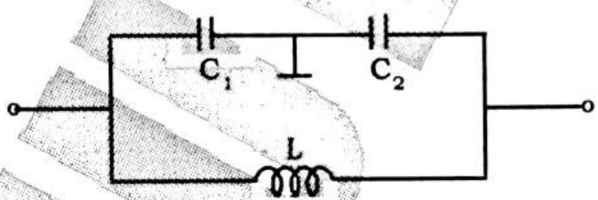
$$\omega = \sqrt{\frac{1}{L}\left(\frac{1}{C_1} + \frac{1}{C_2}\right)}$$

$$f = \frac{1}{2\pi}\sqrt{\frac{1}{L}\left(\frac{1}{C_1} + \frac{1}{C_2}\right)}$$

SIMPLIFIED CIRCUIT



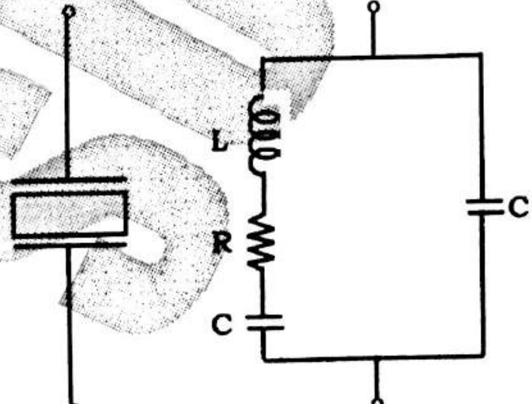
TANK CIRCUIT OF COLPITT OSCILLATOR

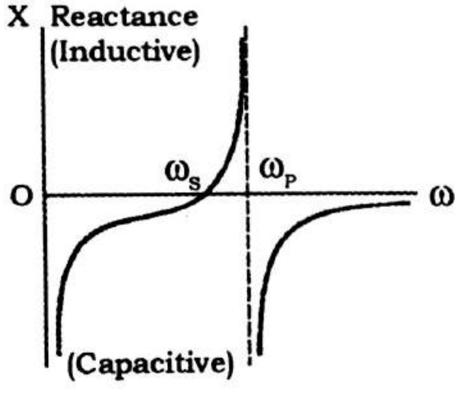


CRYSTAL OSCILLATORS

If a piezoelectric crystal, usually quartz, has electrodes plated on opposite faces and if a potential is applied between these electrodes, forces will be exerted on the bound chages within the crystal. If this device is properly mounted, deformations take place within the crystal , and an electromechanical system is formed which will vibrate when property excited.

The electrical equivalent circuit of a crystal is indicated in figure. The inductor L , capacitance C, and resistor R are the analogs of the mass, the compliance (the reciprocal of the spring constant), and the viscous-damping factor of the mechanical system. Typical values for a 90-kHz crystal are L=137H ,C=O.0235pF, and R=15K ,corresponding to Q=5,500. The dimensions of such a crystal are 30 by 4 by 1.5mm. Since C' represents the Electrostatic capacitance between electrodes with the crystal as a dielectric, its magnitude(~3.5pF) is very much larger than C.





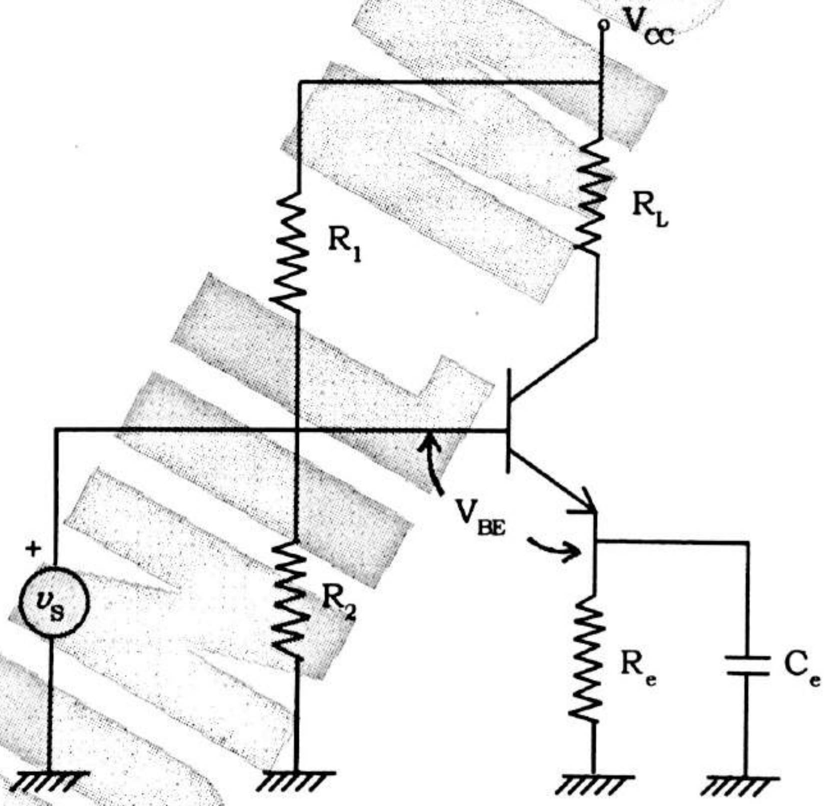
Chapter - 9
POWER AMPLIFIERS

9 - POWER AMPLIFIER

In power amplifier we are interested in developing large power at the load. For power amplification we use common emitter transistor amplifier because it is only common emitter configuration which can give both voltage gain as well as current gain. The common base configuration gives voltage amplification but not the current amplification. Similarly the common collector (the emitter follower) gives only current amplification and not voltage gain.

In power amplifiers the transistors that are used have high power rating and are provided with heat sink arrangement.

A typical amplifier can be analysed as follows :-

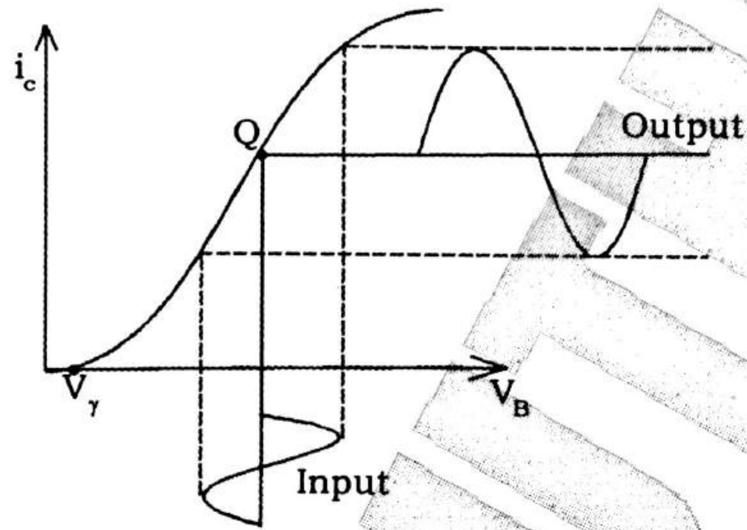


Classification of Power Amplifier :- The Power Amplifier can be classified as follows :

1. Class A amplifier.
2. Class B amplifier.
3. Class AB amplifier.
4. Class C amplifier.

1. Class A amplifier :-

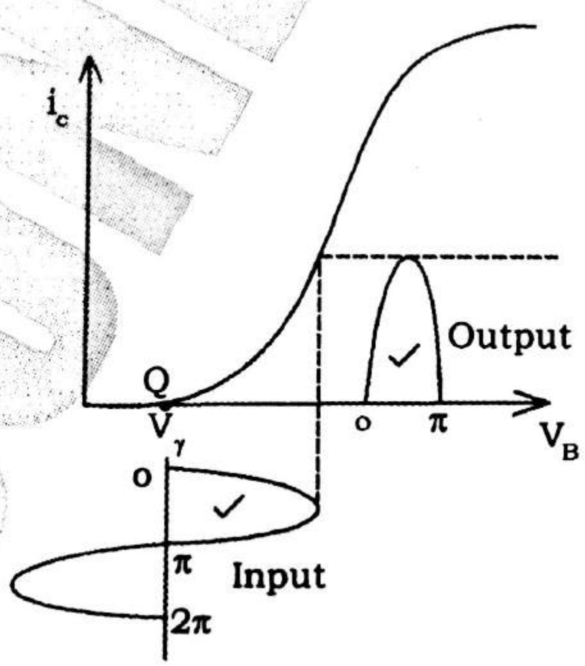
In class 'A' amplifier the quiescent point is selected at the centre of the load line so that the output is obtained for entire 360° of the input cycle, as shown -



In class 'A' amplifier, the distortion is less. The maximum efficiency available in class A amplifier is 50 %.

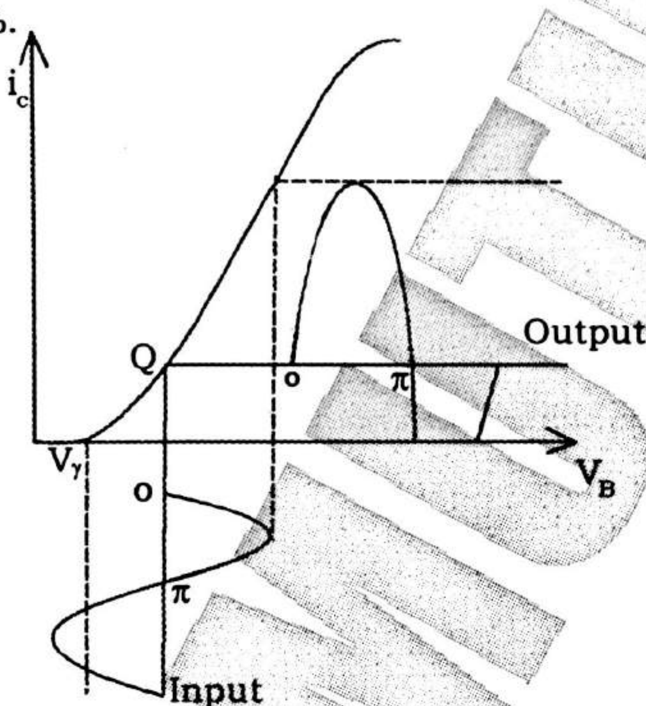
2. Class B amplifier :-

In class 'B' amplifier, the operating point is selected at $I_C = 0$, $V_B = V_{cutin}$ (V_γ) so that only in positive half cycle of the input signal, the output can be obtained; whereas during the negative half cycle of the input signal, the output cannot be obtained since the voltage across the base-emitter junction becomes less than the cutin voltage. Therefore output is obtained only for 180° of the input cycle. The maximum efficiency available in class 'B' amplifier is 78.5 % however it suffers from the drawback of crossover distortion.



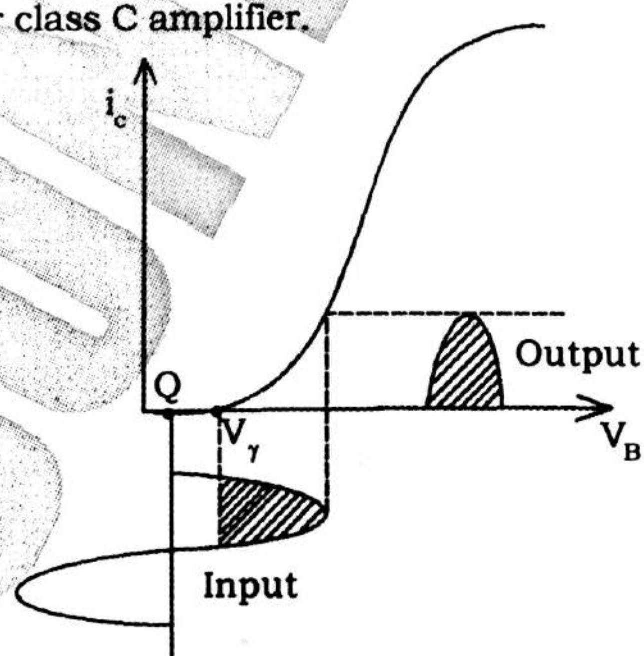
3. Class AB amplifier :-

In class 'AB' amplifier, the operating point is chosen such that the d.c. base voltage is more than the cutin value and less than that corresponding to class A so that the output is obtained for more than 180° but less than 360° of the input cycle. When the base voltage goes below cutin value the output becomes zero. The maximum efficiency available in class AB amplifier is between 50 to 78.5 %.



4. Class C Amplifier :-

In class C amplifier the quiescent point is selected at V_B = less than cutin voltage, so that when the input voltage becomes more than cutin value then the output is obtained and when the input voltage is less than cutin voltage, no output is obtained. The output is therefore available during only less than 180° of the input cycle. The maximum efficiency of class C amplifier is as high as 85%. In class C amplifier the distortions are maximum and therefore only tuned loads are used for class C amplifier.



Efficiency Calculation for Class 'A' amplifier :-

$$i_c = i_{c\,max} \sin wt$$

The rms value of collector current would be $i_c = \frac{i_{c\,max}}{\sqrt{2}}$ and the power output to the load is equal to $i_c^2 R_L$.

$$\therefore \quad P_0 = i_c^2 R_L = \frac{(i_{c\,max})^2 R_L}{2}$$

i.e. $$\boxed{P_0 = \frac{i_{c\,max}^2 R_L}{2}}$$

The power input is supplied by the battery whose voltage is V_{CC} and the constant current drawn from it is I_{CQ}

$$\therefore \quad P_{in} = V_{CC} I_{CQ}$$

$$\therefore \quad \boxed{\eta = \frac{P_0}{P_{in}}}$$

For maximum efficiency :-

In order to obtain maximum efficiency, the power output must be maximum and therefore $i_{c\,max}$ must be maximum. The maximum possible value of $i_{c\,max}$ is $\frac{(I_{c\,sat} - I_{CO})}{2}$ and the quiescent point collector current should be exactly in between $I_{c\,sat}$ and I_{co}.

$$I_{CQ} = \frac{I_{c\,sat} + I_{co}}{2}$$

Neglecting I_{co}, we get

$$I_{CQ} = \frac{I_{c\,sat}}{2}$$

$$\therefore \; i_{c\,max} = \frac{I_{c\,sat}}{2} = I_{CQ}$$

Therefore for maximum efficiency (η)

$$P_{0\,(max)} = \frac{(i_{c\,max})^2}{2} R_L$$

$$\therefore \quad P_{0\,(max)} = \frac{I^2_{CQ}}{2} R_L$$

i.e. $$\boxed{P_{0\,(max)} = \frac{I^2_{CQ} R_L}{2}}$$

Similarly for maximum swing in the collector voltage, we find -

$$V_{CQ} = \frac{V_{CC} + V_{CE\,sat}}{2}$$

But $V_{CE\,sat}$ is negligible (i.e. 0.1 to 0.2 V) compared to V_{CC}. $\therefore V_{CQ} = \frac{V_{CC}}{2}$

$\therefore \quad V_{CC} = 2\,V_{CQ}.$

Now,

$$P_{in} = V_{CC}\, I_{CQ}$$
$$P_{in} = 2\,V_{CQ}\, I_{CQ} \qquad \because V_{CC} = 2\,V_{CQ}$$

$P_{in} = 2\,(I_{CQ}\, R_L)\, I_{CQ}$ according to load line $V_{CQ} = I_{CQ}\, R_L$

$$\therefore \quad P_{in} = 2\,I^2_{CQ}\, R_L$$

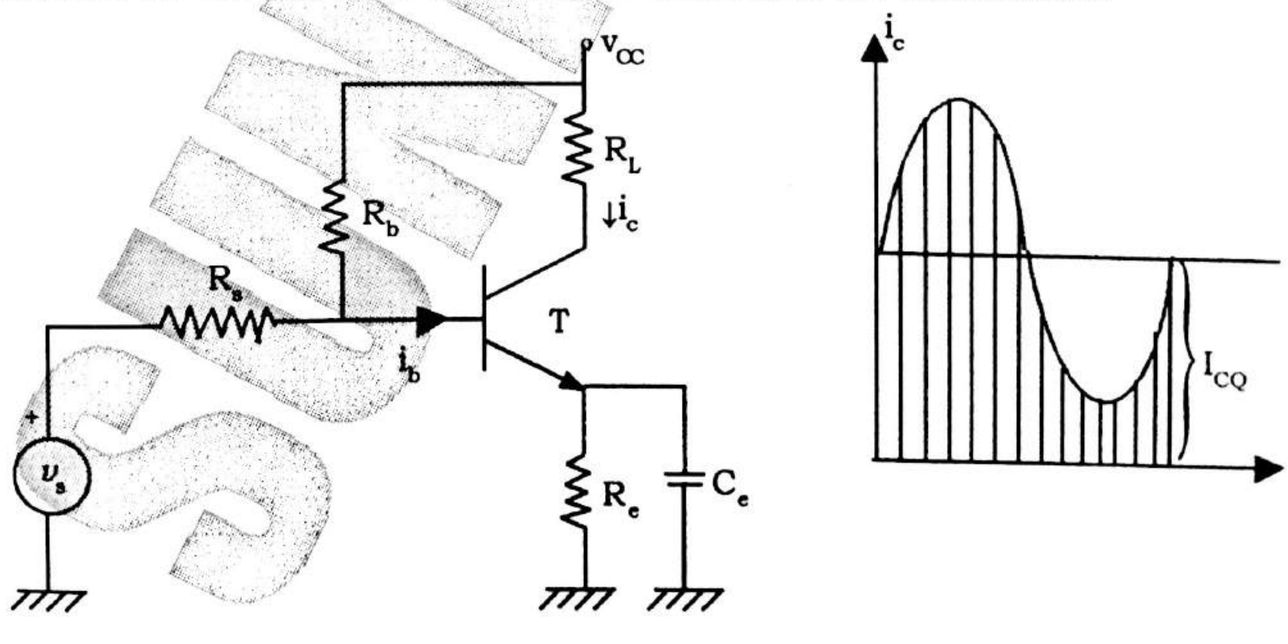
$\therefore$ Maximum efficiency $(\eta_{max}) = \frac{P_{0\,max}}{P_{in}}$

$$\therefore \quad \eta_{max} = \frac{\frac{I^2_{CQ}\, R_L}{2}}{2\,I^2_{CQ}\, R_L}$$

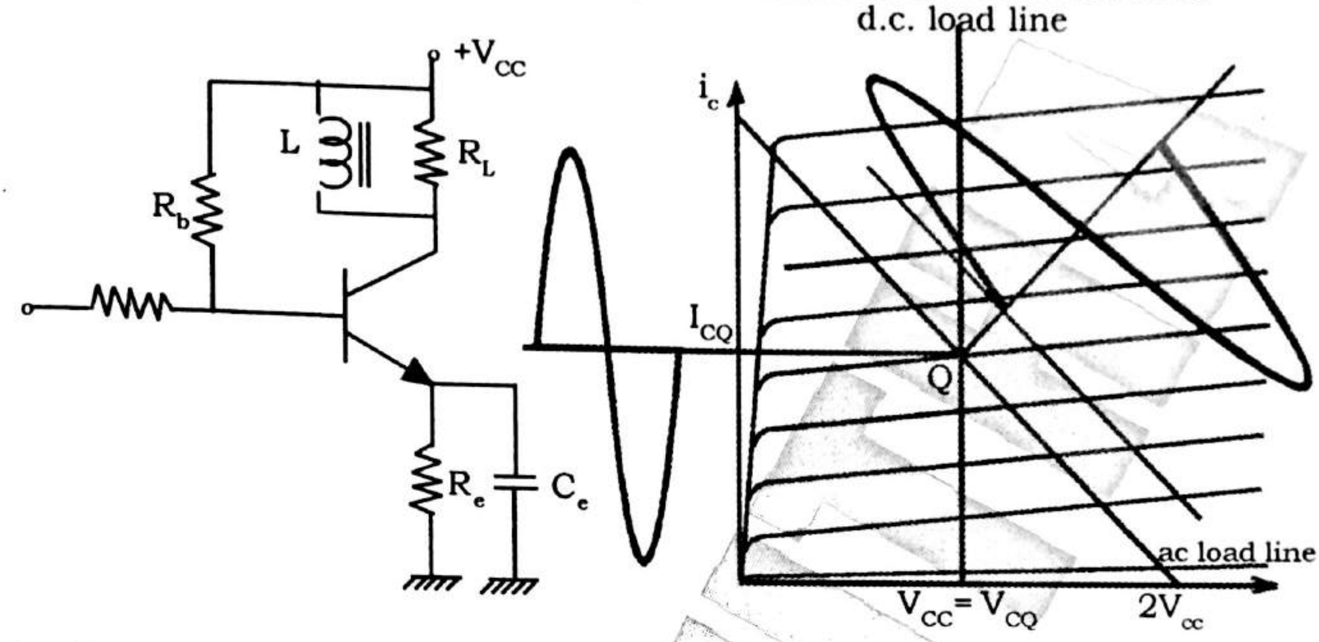
$$\eta_{max} = \frac{1}{4}$$

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

Therefore under most ideal condition the maximum efficiency under class 'A' operation is found to be 25 % which is extremely poor. Therefore in order to increase the efficiency we provide separate path for DC collector current so as to eliminate the losses due to d.c. collector current, in the load resistor.



Power amplifier with separate path for dc collector current :-



For d.c., frequency (f) = 0

$$X_L = 2\pi f L = 0$$

$\therefore$ for d.c., $V_{CQ} = V_{CC} - I_{CQ} \times X_L$

$$V_{CQ} = V_{CC} - I_{CQ} \times 0$$

$$\boxed{\therefore V_{CQ} = V_{CC}}$$

For fixing up the quiescent point, d.c. is to be applied to the transistor. The inductor 'L' offers a path of zero resistance to the d.c.

$$\therefore \quad V_{CQ} = V_{CC} - I_{CQ} X_L$$

$$\text{but } X_L = 0$$

$$\therefore \quad V_{CQ} = V_{CC}$$

$$P_{0\,max} = \frac{1}{2} I^2_{CQ} R_L$$

$$P_{in} = V_{CC} I_{CQ}$$

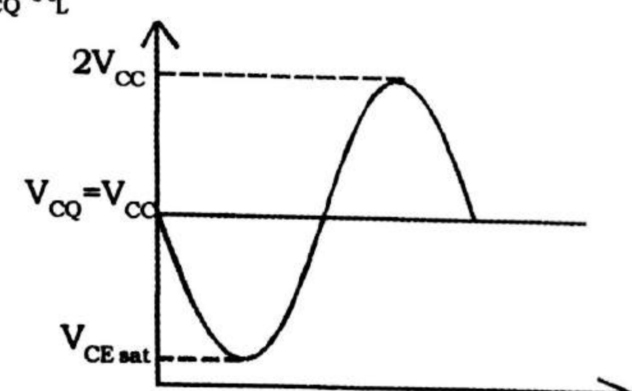
$$= V_{CQ} I_{CQ}$$

$$\therefore P_{in} = I^2_{CQ} R_L \qquad \because V_{CQ} = I_{CQ} R_L$$

$$\eta_{max} = \frac{P_{0\,max}}{P_{in}}$$

$$\eta_{max} = \frac{\frac{1}{2} I^2_{CQ} R_L}{I^2_{CQ} R_L}$$

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



By connecting an inductor in parallel with the load resistor, we have provided a separate path for the d.c. collector current. Previously the d.c. collector current was passing through R_L and creating power loss. By providing separate path for d.c., we have eliminated this power loss and we have increased the maximum efficiency to 50 %. Therefore the maximum efficiency under class 'A' condition is 50 %.

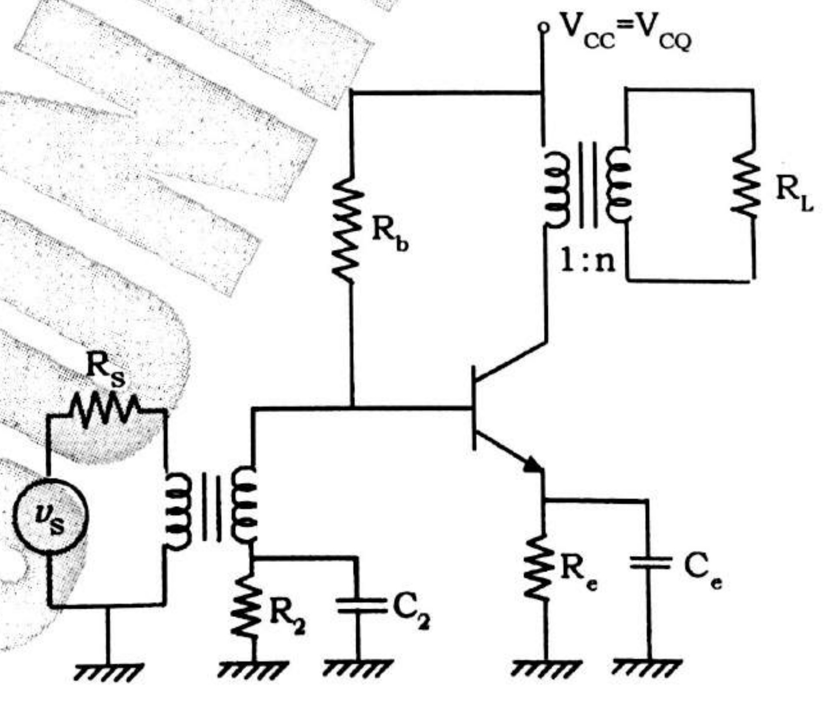
Method of increasing power output :-

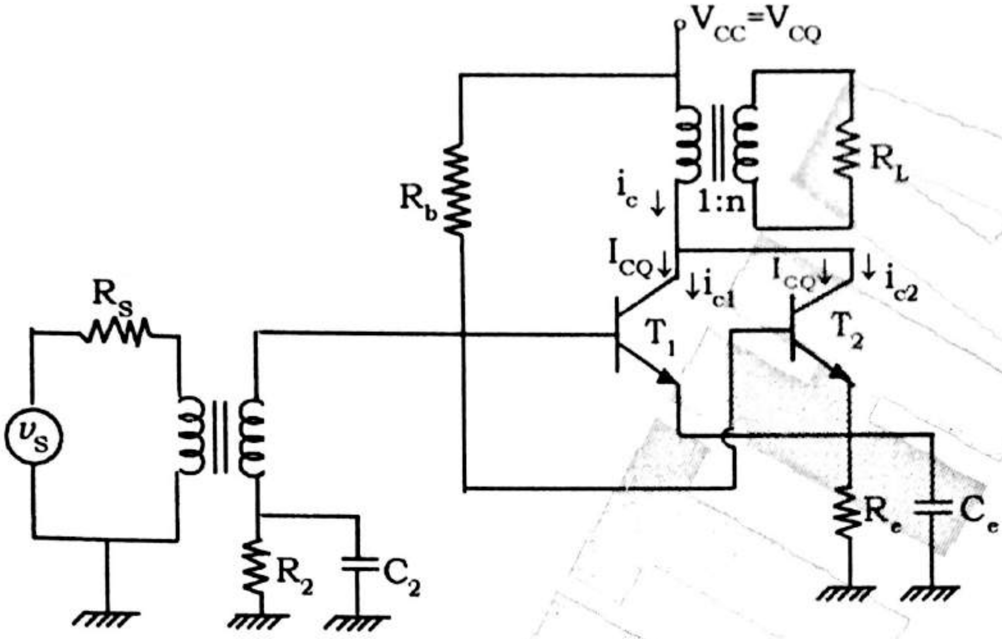
We have seen that an inductor must be connected in the collector circuit in order to provide the path of zero resistance to the d.c. collector current. This inductor coil may be the primary of a transformer, with the help of which we can increase the voltage to the load (load matching) as shown in the figure below. The transformer is also shown in the input circuit so as to provide d.c. isolation and increase the voltage level of the input signal.

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

$$\therefore \quad V_1 I_1 = V_2 I_2$$

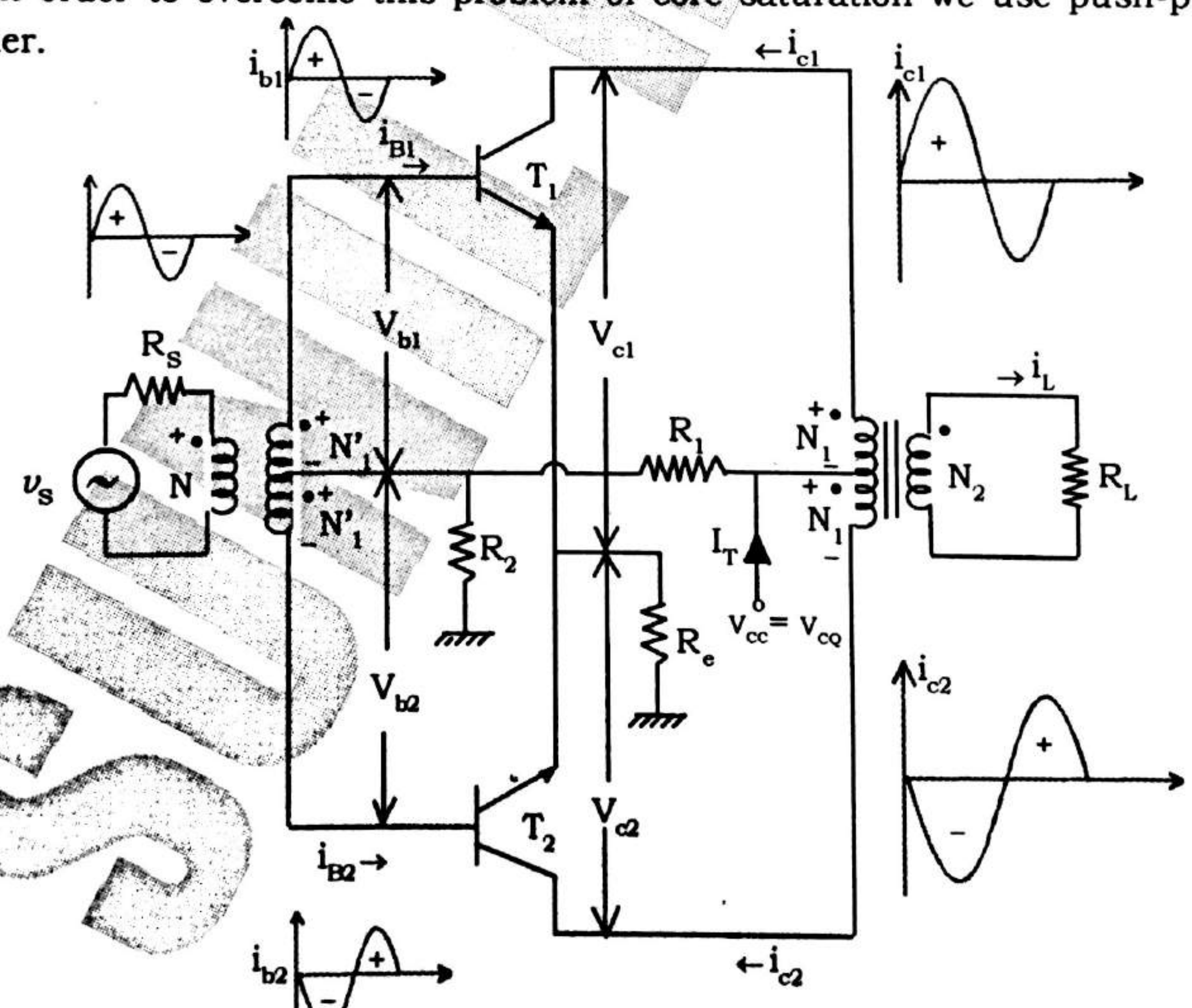
By providing the transformer at the output we have made the arrangement to increase the load voltage. But according to transformer fundamentals we know that if the secondary voltage is increased, the secondary current would decrease. But we want to provide more power to the load and hence we are interested in increasing the current also. This can be done by connecting number of transistors in parallel so that the primary current of the output transformer is sum total of collector currents of each transistor.





By providing number of transistors in parallel we are interested in increasing the current output to the load. But when number of transistors are connected in parallel each transistor will demand I_{CQ} (d.c.) and therefore the total d.c. through the primary of the transformer will be so large that it will saturate the transformer core providing no further scope for rate of change of flux to be produced by a.c. Therefore there would be very very less output available to the load.

In order to overcome this problem of core saturation we use push-pull amplifier.



Push-pull operation

$$i_{B1} = I_{BQ} + i_{Bm} \sin \omega t$$
$$i_{B2} = I_{BQ} + i_{Bm} \sin (\omega t - \pi)$$

$$i_{b1} = i_{bm} \sin \omega t$$
$$i_{b2} = i_{bm} \sin (\omega t + \pi) = - i_{bm} \sin \omega t$$

$$i_{c1} = i_{cm} \sin \omega t$$
$$i_{c2} = i_{cm} \sin (\omega t + \pi) = - i_{cm} \sin \omega t$$

$$i_{e1} = i_{b1} + i_{c1}$$
$$i_{e2} = i_{b2} + i_{c2}$$

$$i_L = 2 \frac{N_1}{N_2} i_{cm} \sin \omega t$$

Note :-
d.c. $\rightarrow I_B$
a.c. $\rightarrow i_b$
total $\rightarrow i_B$

The problem of core-saturation due to d.c. collector current is overcome in push-pull amplifier, the d.c. collector current flows through the primary of the output transformer produce their fluxes such that they cancel each other and net flux in the core due to the d.c. becomes zero because these fluxes cancel each other.

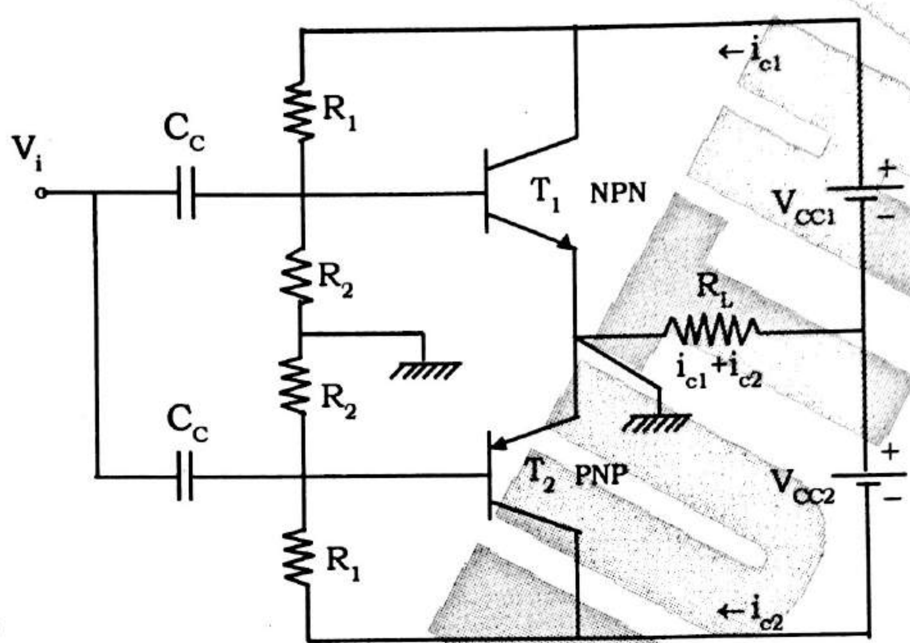
During the positive half of cycle of the input signal, i_{b1} is positive whereas i_{b2} is negative. Therefore i_{c1} would be positive and i_{c2} would be negative. During negative half cycle of the input signal, i_{b1} is negative, and i_{b2} is positive. Therefore i_{c1} is negative and i_{c2} is positive.

Both during positive half cycle and negative half cycle, one transistor pushes its collector current whereas the other transistor pulls the collector current through the load and therefore it is called as push pull amplifier and due to this feature the effects due to the a.c. collector current of the two transistors add up.

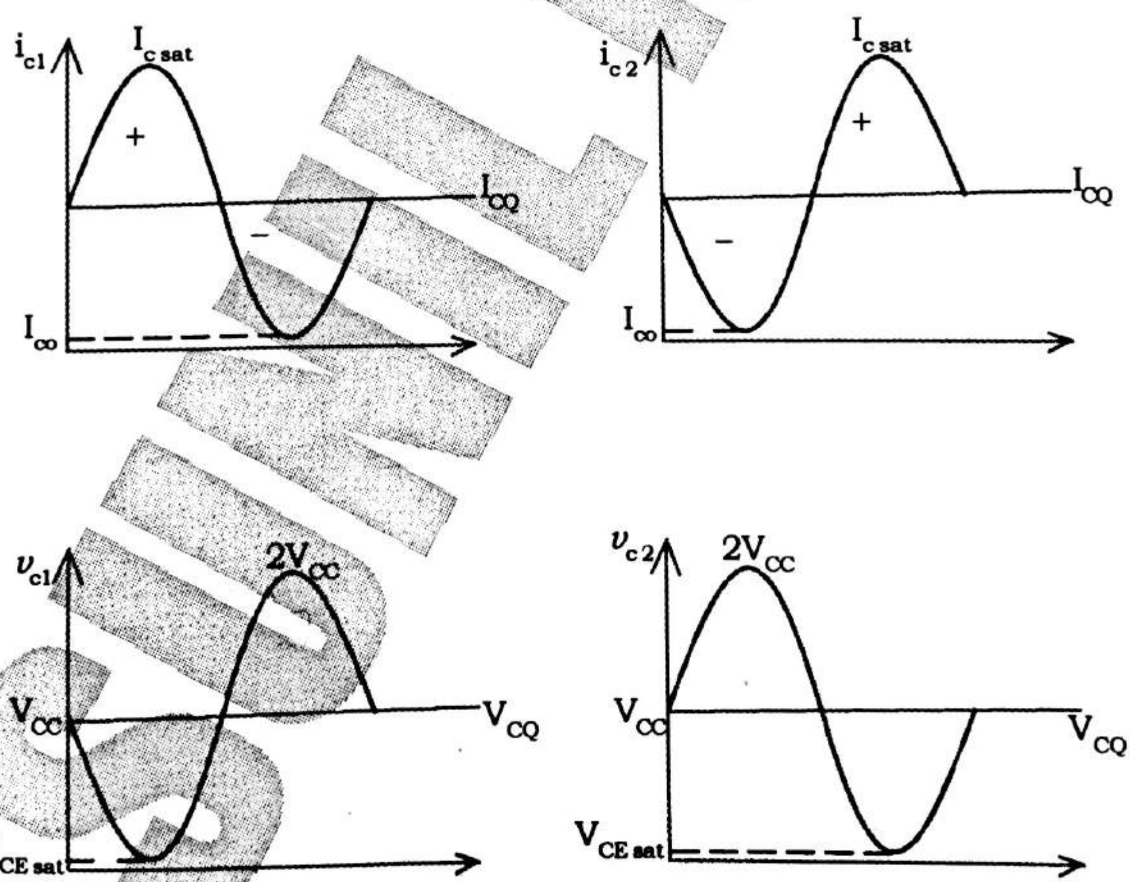
Due to the dot markings we find that the effect due to T_1 and T_2 add together to give the total load current -

$$i_L = 2 \frac{N_1}{N_2} i_{cm} \sin \omega t$$

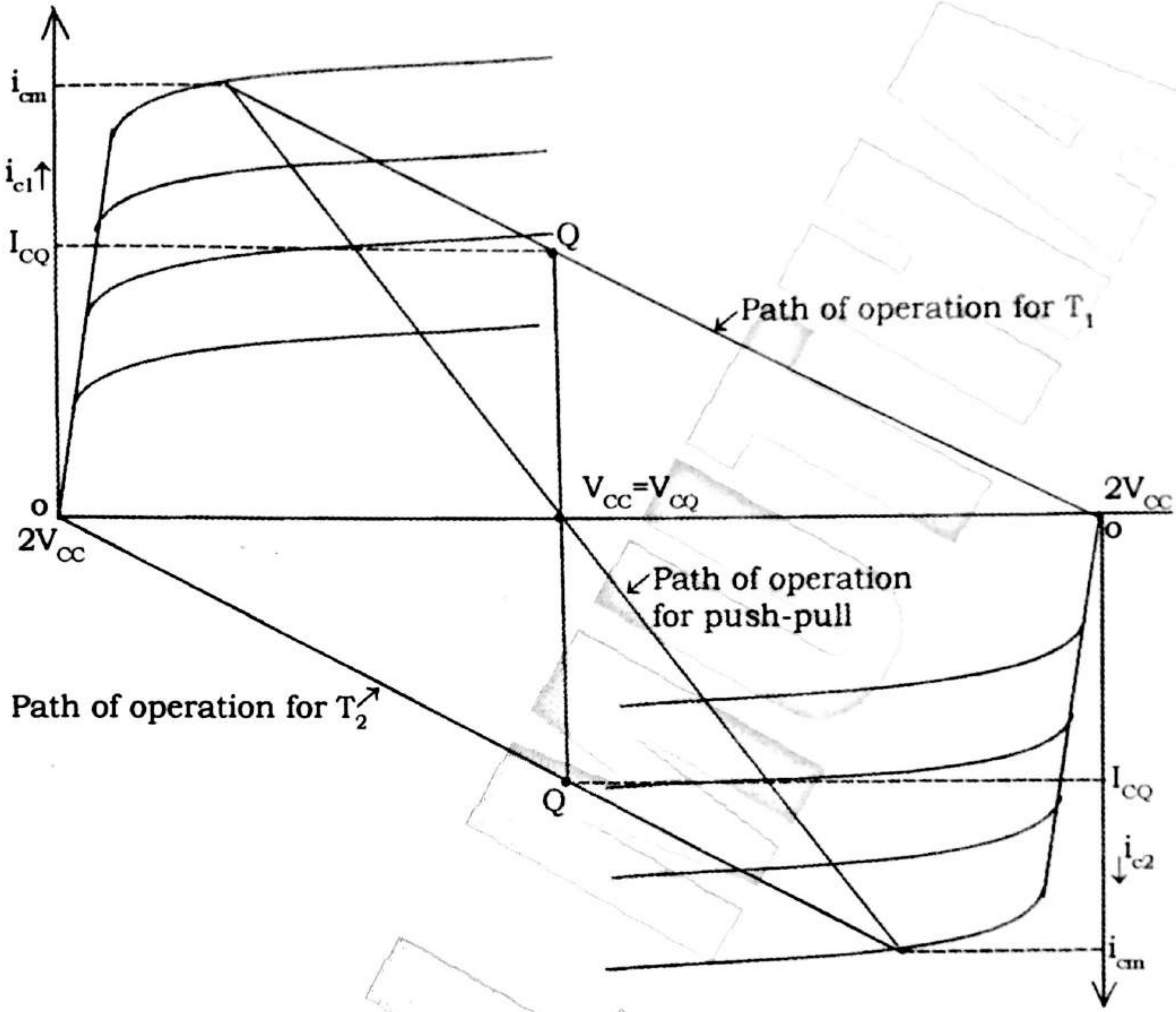
i_{b1} and i_{b2} are 180° out of phase and i_{c1} and i_{c2} are 180° out of phase. Therefore i_{e1} and i_{e2} are 180° out of phase. Therefore the a.c. components of emitter current of both the transistors cancel each other. Therefore there is no requirement of any emitter bypass capacitor whereas R_e is required to provide stability. The quiescent point in case of push pull amplifier is adjusted with the help of resistance R_1 and R_2. Therefore selecting suitable values of R_1 and R_2 we can make the same circuit to operate as class 'A' amplifier or class 'B' amplifier or class 'AB' amplifier etc. A push pull amplifier can also be designed without the help of a transformer by using a PNP transistor and a NPN transistor so that there is built-in phase shift of 180° in the currents of a PNP transistor and NPN transistor.



The action of push pull amplifier can be understood very clearly from the following graph -



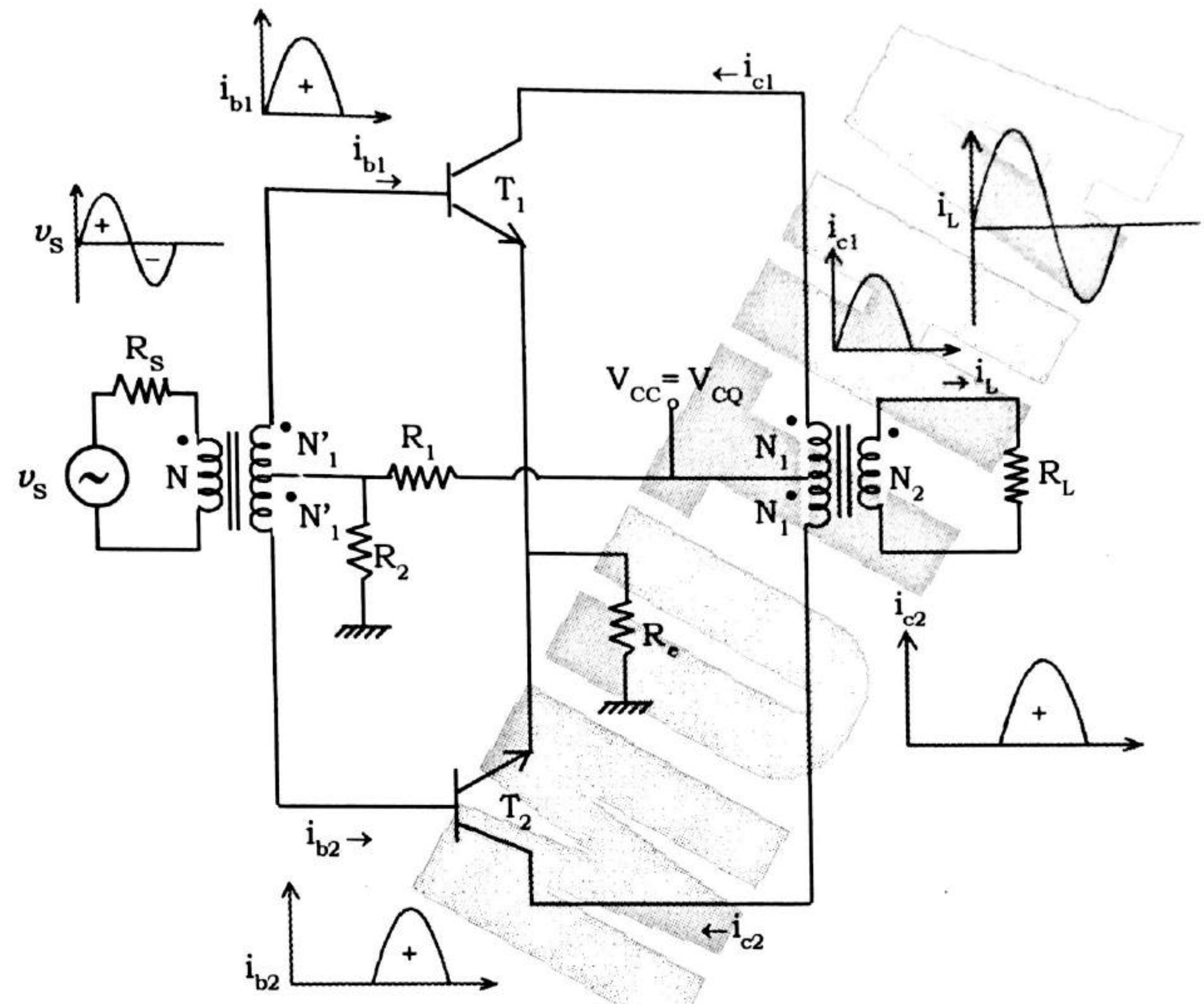
The graphical representation of class 'A' amplifier is as shown -

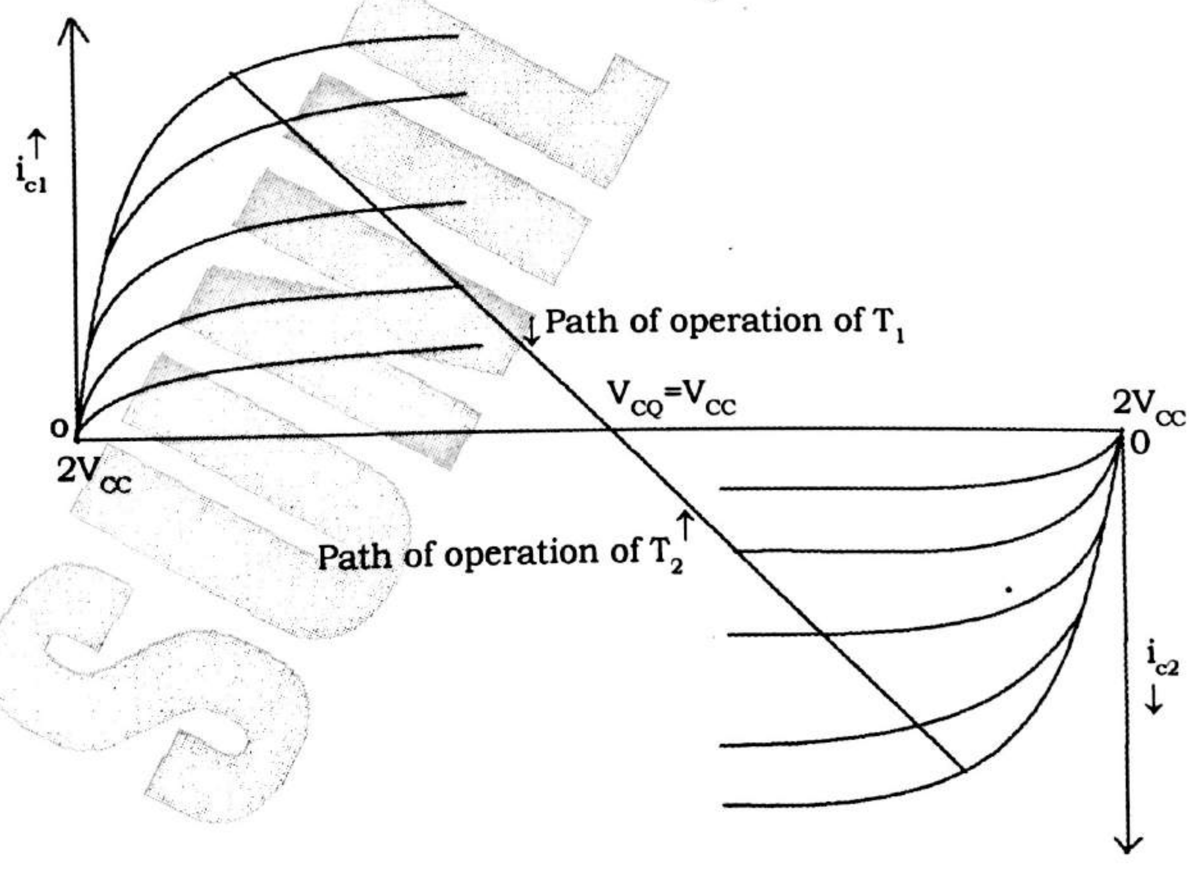


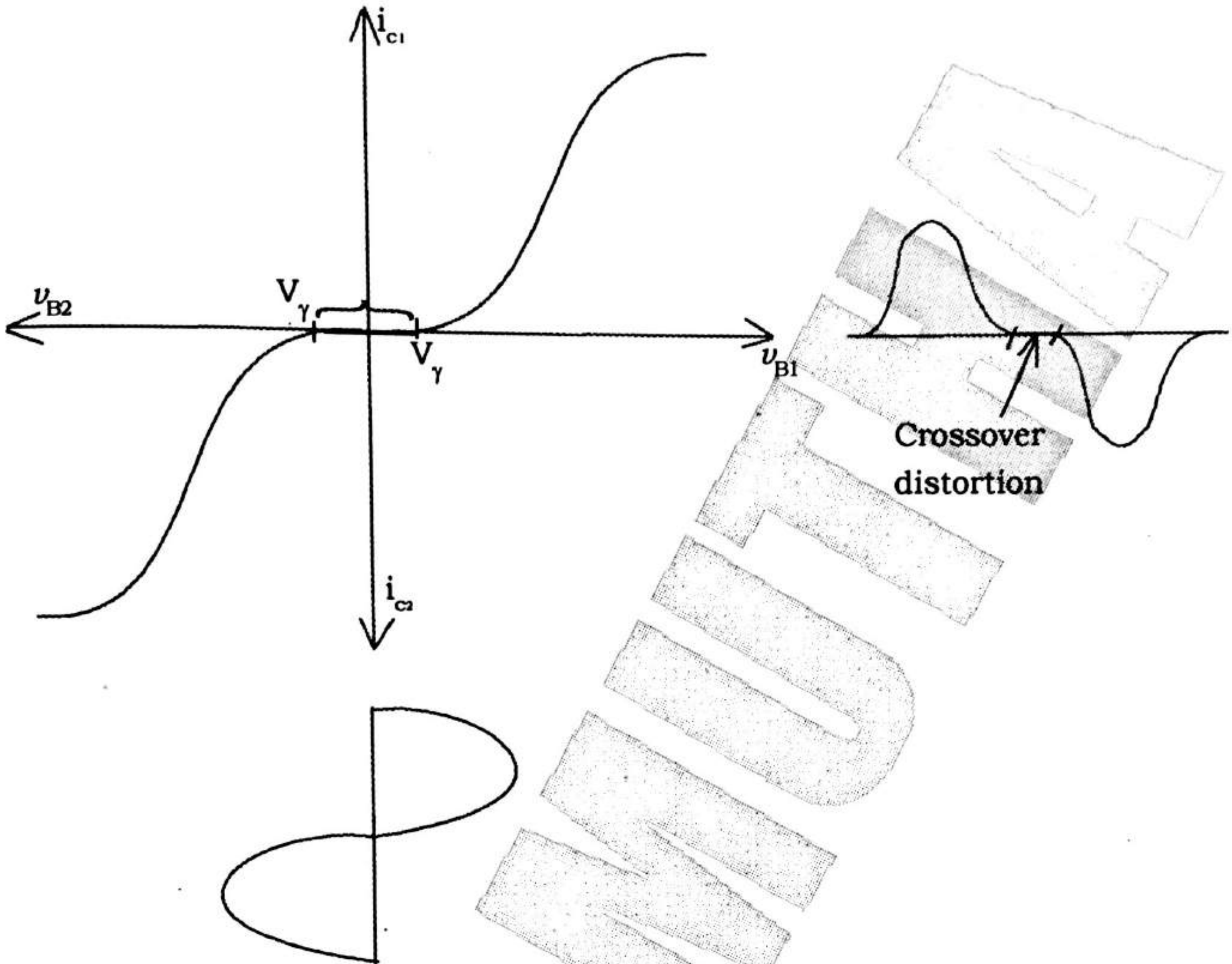
The graphical representation of class 'A' amplifier is shown in the figure. The upper part is CE output, characteristics of T_1. Similarly the lower half of the characteristics represents the CE output characteristics of T_2. These two characteristics are plotted on the same V_{CE} axis so that for T_1, V_{CE} goes from 0 to 2 V_{CC} from left to right and for T_2 it goes from 0 to 2 V_{CC} from right to left. As the collector potential of T_1 goes to $V_{CE\,sat}$ (nearly equal to zero), the V_{CE} for T_2 goes to 2 V_{CC} and similarly when V_{CE} for T_2 goes to $V_{CE\,sat}$ ($\cong$0), V_{CE} for T_1 goes to 2 V_{CC} i.e. in short when the collector potential and collector current of one transistor is rising that of other transistor is falling and vice versa. For 'Q' point, collector current I_{CQ} flowing through the two transistors, the output current is zero. This is very clear from the path of operation of push-pull.

Though we find that in class 'A' amplifier the output is obtained for entire 360° of the input cycle and the distortion is minimum. Still the major drawback of such amplifier is the extremely poor efficiency. The maximum efficiency is 50 % that too under idealised condition. $V_{CE\,sat}$ = 0, I_{CO} = 0 and no transformer losses.

Class 'B' Amplifier :-







Draw back of class 'B' = crossover distortion

In class 'B' operation, the quiescent point is adjusted by adjusting the values of R_1 and R_2 so that the d.c. base emitter voltage is equal to the cutin voltage and the d.c. collector current is zero.

During positive half cycle of the input signal, the base voltage of T_1 becomes more than cutin and therefore T_1 conducts giving half cycle of collector current output. During this period T_2 remains off, since its base voltage is less than cutin voltage.

During negative half cycle of the input signal, T_1 remains off and T_2 conducts, since the base voltage of T_2 becomes more than the cutin value. Therefore during positive half cycle T_1 conducts and gives output to the load. Similarly during negative half cycle, T_2 conducts and gives negative half cycle output to the load. Therefore though each transistor conducts for only half cycle, the load gets full cycle output.

In the graphical representation for the class 'B' push pull amplifier shown as the common emitter output characteristics of T_1 and T_2 plotted together, we find that path of operation of T_1 is such that it conducts only during positive half cycle whereas for T_2 it is such that T_2 conducts during negative half cycle.

However the operation of push pull indicates that the load gets full cycle output. If we construct the dynamic mutual characteristics (V_b versus i_c), we find that though i_{c1} flows during positive half cycle and i_{c2} flows during negative half cycle, there is a dead zone during which neither T_1 nor T_2 conducts and this give rise to crossover distortion.

The class 'B' amplifier has maximum efficiency as high as 78.5 % but it suffers from the drawback of crossover distortion.

Efficiency Calculation for Class 'B' amplifier :-

During positive half cycle T_1 draws collector current from V_{CC}. During negative half cycle T_2 draws collector current from V_{CC}. Therefore average power input is -

$$P_{in} = V_{CC}\left(\frac{2\,i_{cm}}{\pi}\right)$$

$$\boxed{P_{in} = \frac{2\,V_{CC}\,i_{cm}}{\pi}} \quad \text{——— ①} \qquad \text{Average value} = \frac{2\text{ max. value}}{\pi}$$

The load resistance can be transferred to the primary side such that

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

$$P_o = \left(\frac{i_{cm}}{\sqrt{2}}\right)^2 R'_L$$

$$\therefore \quad \boxed{P_o = \frac{i^2_{cm}\,R'_L}{2}} \quad \text{——— ②}$$

For maximum efficiency, power output should be maximum.

$$i_{cm}\,R'_L = V_{CC} - V_{CE\,sat} \qquad \text{if } V_{CE\,sat} \text{ neglected}$$

$$\therefore \quad V_{CC} = i_{cm}\,R'_L$$

$$P_{o\,max} = \frac{i_{cm}\,V_{CC}}{2}$$

$$\therefore \quad \eta_{max} = \frac{P_{o\,max}}{P_{in}}$$

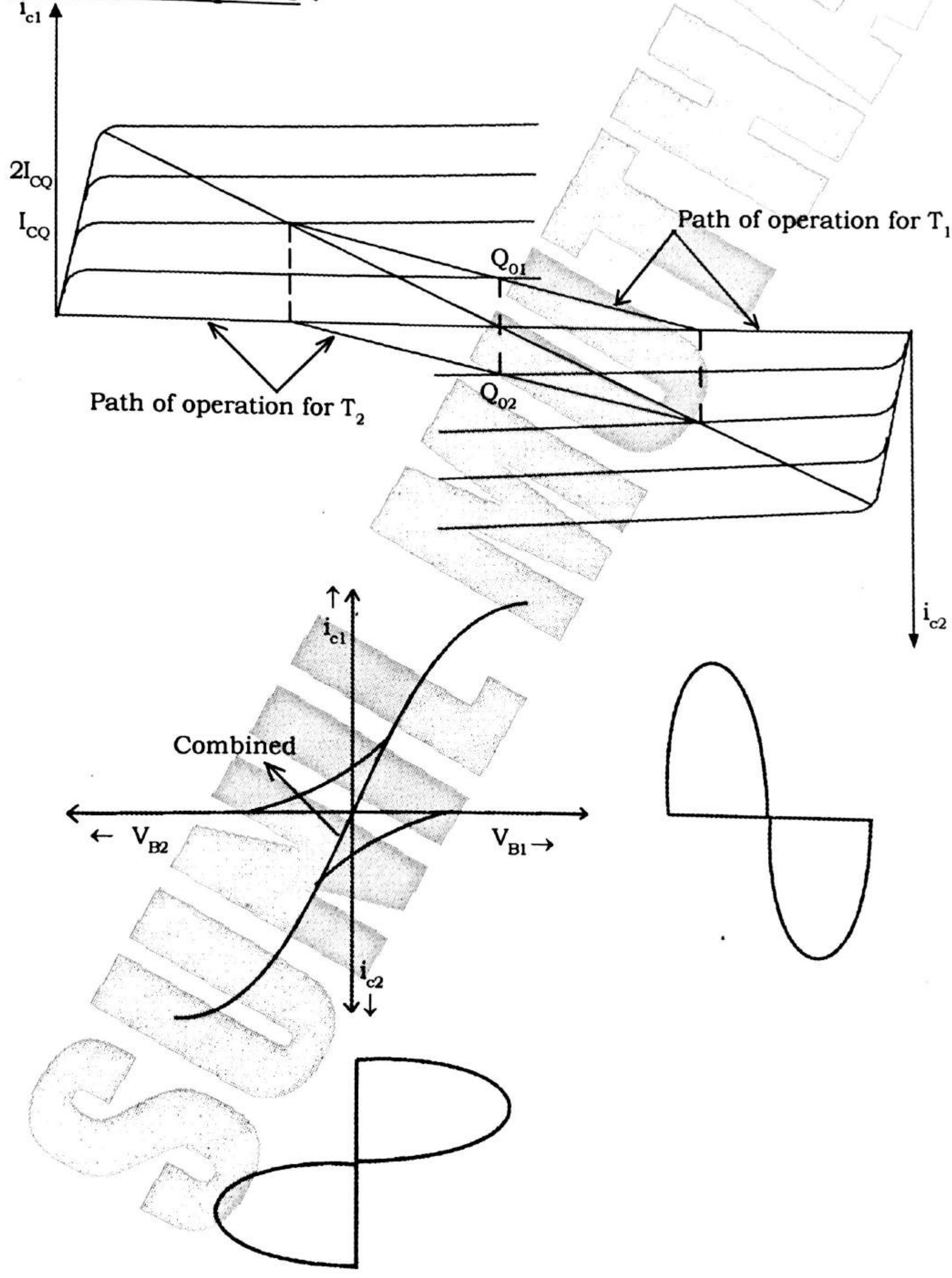
$$= \frac{i_{cm}\,V_{CC}/2}{2\,V_{CC}\,i_{cm}/\pi}$$

$$= \frac{\pi}{4}$$

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

Though the maximum efficiency of class 'B' amplifier is 78.5 %, it suffers from a drawback of deadzone which gives rise to crossover distortion. This drawback is eliminated in class 'AB' amplifier.

Class 'AB' Amplifier :-



The drawback of class 'B' amplifier was that its output consists of crossover distortion due to deadzone (due to cutin voltage). This drawback can be overcome by biasing the transistor in such a manner that its base voltage is more than cutin voltage. This operation is in between class 'A' and 'B' and therefore it is called class 'AB' amplifier. If the 'Q' point is adjusted to the centre of the loadline, it becomes class 'A' amplifier giving very low efficiency. If the 'Q' point is adjusted such that $V_B = V_\gamma$ then the efficiency is very high.

Therefore in class 'AB' operation we will select the 'Q' point such that V_B is slightly greater than cutin (V_γ) so that the cross over distortion is also removed and efficiency is also maintained high.

In class 'AB' amplifier, T_1 starts conducting before T_2 becomes 'off' and similarly T_2 starts conducting before T_1 becomes 'off', as clearly observed from thier dynamic mutual characteristics.

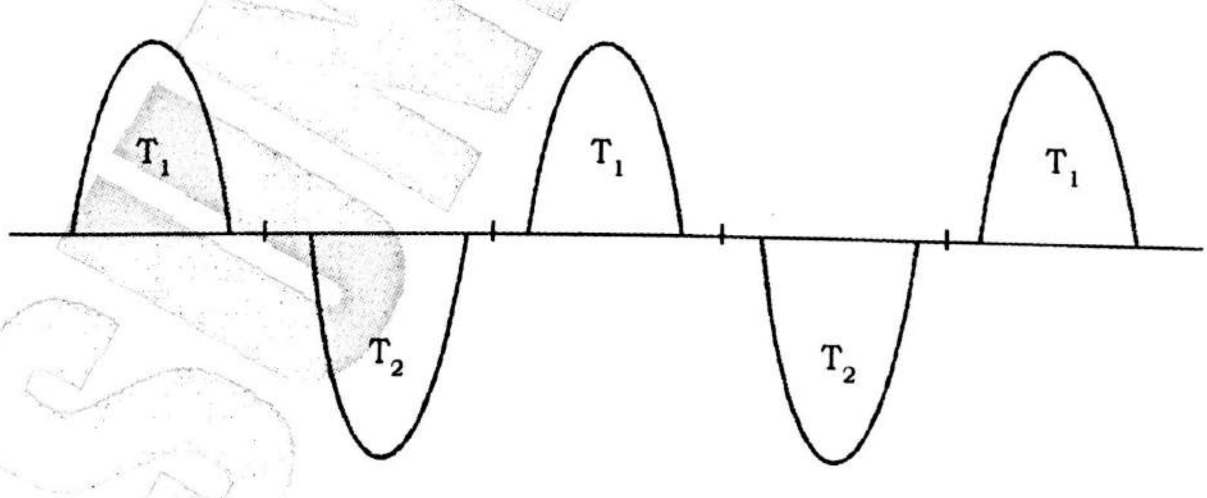
In class 'AB' operation the maximum efficiency is between 50% to 78.5%.

Class 'C' Amplifier :

In class 'C' amplifier, the collector current of each transistor flows for less than 180° of the input cycle. Even under push-pull operation the load current would not be sinusoidal and hence if resistive load is applied the output voltage would also be nonsinusoidal, indicating heavy distortion. Since we always desire to develop power at the input frequency, the collector current being in the form of pulses, therefore tuned load must be employed in case of class 'C' amplifiers in order to get good output.

In class 'C' amplifier we always employ resonant load. The maximum efficiency in class 'C' amplifier can be as high as 85%.

Collector current output under push-pull condition.



Q.1. Draw a circuit of transformer coupled class B push pull amplifier. How will you modify the same for class AB operation ? What is the advantage ?

See Page 12

The drawback of class 'B' amplifier was that its output consists of crossover distortion due to deadzone (due to cutin voltage). This drawback can be overcome by biasing the transistor in such a manner that its base voltage is more than cutin voltage. This operation is in between class 'A' and 'B' and therefore it is called class 'AB' amplifier. If the 'Q' point is adjusted to the centre of the loadline, it becomes class 'A' amplifier giving very low efficiency. If the 'Q' point is adjusted such that $V_B = V_\gamma$ then the efficiency is very high.

Therefore in class 'AB' operation we will select the 'Q' point such that V_B is slightly greater than cutin (V_γ) so that the cross over distortion is also removed and efficiency is also maintained high.

Q.2. A sinusoidal signal V_S = 175 sin 600 t is fed to an amplifier. The resulting output current is of the form.

$$I_0 = 15 \sin (600t) + 1.5 \sin (1200t) + 1.2 \sin (1800t) + 0.5 \sin (2400t) + ...$$

Calculate (a) Second, third and fourth harmonic distortions.

(b) % increase in power because of distortion.

Solution : $I_0 = I_1 + I_2 + ...$ (Comparing given equation with this)

The % hormonic distortion of each component is given by

$$D_2 = \frac{I_2}{I_1} \times 100 = \frac{1.5}{15} \times 100 = 10\%$$

$$D_3 = \frac{I_3}{I_1} \times 100 = \frac{1.2}{15} \times 100 = 8\%$$

$$D_4 = \frac{I_4}{I_1} \times 100 = \frac{0.5}{15} \times 100 = 3.33\%$$

This distortion factor is $D = \sqrt{D_2^2 + D_3^2 + D_4^2}$

$$= \sqrt{(10^2 + (8)^2 + (3.33)^2} = 13.23\%$$

The net power is $P_T = (1 + D^2)\, P$

$$= [\, 1 + (0.1323)^2 \,]\, P = 1.0175\ P$$

Thus the % increase in power $= \dfrac{1.0175P - P}{P} \times 100$

$$= 1.75\%$$

Q.3. A transistor having collector breakdown voltage 40 V, and maximum collector current of 0.8 A is to be used in a class A transformer coupled amplifier to drive a 4 Ω load. Assume ideal characteristics.

(i) What should be the turns ratio $N_1:N_2$?

(ii) What is the maximum power delivered to load ?

(iii) What should be the supply voltage V_{CC} ?

(iv) What is the power dissipation in the transistor ?

Solution : (i) Breakdown voltage means maximum voltage V_m.

$$V_m = 40 \text{ V}$$

maximum collector current $I_m = 0.8 \text{ A}$

$$R_L = 4\ \Omega$$

Reflected load impedance $R'_L = \frac{V_m}{I_m} = \frac{40}{0.8} = 50\ \Omega$

Now, we have $R'_L = \left[\frac{N_1}{N_2}\right]^2 \times R_L$

$$\therefore \quad \frac{N_1}{N_2} = \sqrt{\frac{R'_L}{R_L}} = \sqrt{\frac{50}{4}} = 3.53$$

$\therefore$ Thus ratio $N_1:N_2 = 3.53:1$

(ii) Maximum power delivered to load is

$$(P_{ac})_{max} = \frac{I^2_m R'_L}{2} = \frac{(0.8)^2 \times 50}{2} = 16 \text{ W}$$

(iii) For class A transformer coupled amplifier,

$$V_{CC} = V_m = 40 \text{ V}.$$

(iv) Power dissipation in the transistor is $= P_{DC} - P_{ac}$

Now, $P_{DC} = V_{CC} \times I_C = 40 \times 0.8 = 32 \text{ W}$

$$P_{ac} = 16 \text{ W}$$

$\therefore$ Power dissipation $= 32 - 16 = 16$ W.

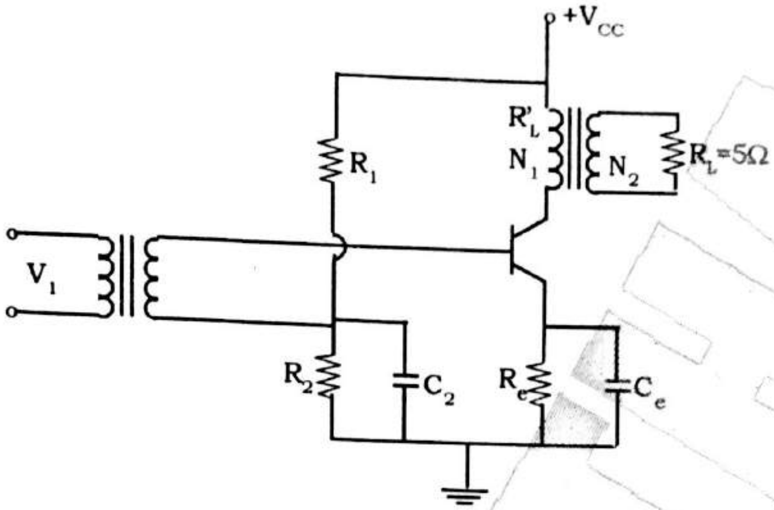
Q.4. A power transistor operating in class A in the circuit shown is to deliver a maximum of 5 W to a 5 Ω load. The quiescent point is adjusted for symmetrical clipping and collector supply $V_{CC} = 20$ V. Assume $V_{min} = 0$ and ideal condition.

(a) What is the transfomer turns ratio ?

(b) What is peak collector current ?

(c) What is the quiescent operating point ?

(d) What is collector efficiency ?



Solution :

$R_L = 5\ \Omega$ $\quad\quad P_{ac} = 5\ W$

for ideal condition $\quad V_m = V_{CC} = 20\ V$

Now, output power is given by, $\quad P_{ac} = \dfrac{V^2_m}{2\ R'_L} = \dfrac{I^2_m R'_L}{2}$

$\therefore \quad 5 = \dfrac{(20)^2}{2\ R'_L}$

$\therefore \quad R'_L = 40\ \Omega$

Reflected load impedance is given by, $R'_L = \left[\dfrac{N_1}{N_2}\right]^2 \times R_L$

Transformer turns ratio is given by, $\dfrac{N_2}{N_1}$

$$\frac{N_2}{N_1} = \left[\frac{R_L}{R'_L}\right]^{\frac{1}{2}} = \left[\frac{5}{40}\right]^{\frac{1}{2}} = 0.3535$$

(b) Peak collector current $\quad I_m = \dfrac{V_m}{R'_L} = \dfrac{V_{CC}}{R'_L} = \dfrac{20}{40} = 0.5\ A$

(c) Quiescent operating point I_{CQ}, V_{CE}

$$I_{CQ} = I_m = 0.5\ A$$
$$V_{CE} = V_{CC} = 20\ V$$

(d) Efficiency $\quad$ Input power $= P_{dc} = I_{CQ} \times V_{CC} = 0.5 \times 20 = 10\ W$

$$P_{ac} = 5\ W$$

$\therefore \quad$ Efficiency $\eta = \dfrac{P_{ac}}{P_{dc}} = \dfrac{5}{10} = 0.5 \quad\quad \%\eta = 50\%$

Q.5. A given transistor has a dissipation rating of 20 W. What is the maximum ideal power output to be expected when such devices are used with transformer coupling as

(a) Single ended class A, one transistor

(b) Push pull class A.

(c) Push pull class B ?

Solution :

a) Single ended class A, one transistor

$\eta = 50\ \%$ $\qquad P_d = 20\ W$

$P_{in} = P_o + P_d$

$$\eta = \frac{P_o}{P_o + P_d} \times 100$$

$$50 = \frac{P_o}{P_o + 20} \times 100$$

$$\boxed{P_o = 20\ \text{Watts}}$$

b) Push pull class A.

$\eta = 50\ \%$ $\qquad P_d = 2 \times 20 = 40\ W$

$P_{in} = P_o + P_d$

$$\eta = \frac{P_o}{P_o + P_d} \times 100$$

$$50 = \frac{P_o}{P_o + 40} \times 100$$

$$\boxed{P_o = 40\ \text{Watts}}$$

c) Push pull class B

$\eta = 78.5\ \%$ $\qquad P_d = 2 \times 20 = 40\ W$

$P_{in} = P_o + P_d$

$$\eta = \frac{P_o}{P_o + P_d} \times 100$$

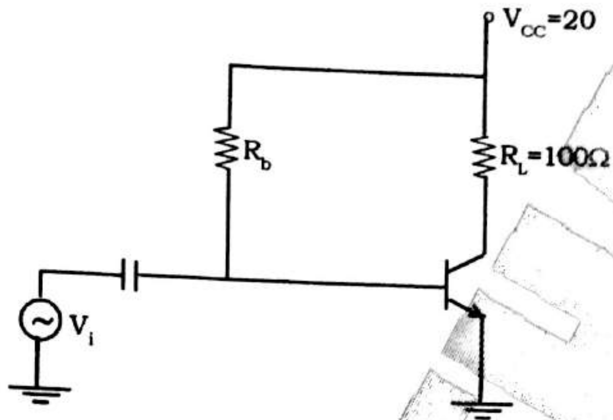
$$78.5 = \frac{P_o}{P_o + 40} \times 100$$

$$\boxed{P_o = 146\ \text{Watts}}$$

Q.6. In the power amplifier shown $\beta = 100$. Determine

(a) The value of R_b that locates quiescent point in the centre of the load line.

(b) Maximum output power.



Solution : Since Q-point is in the centre of the load line, transistor is in class A mode and in active region,

also $$V_{CE} = \frac{V_{CC}}{2} = \frac{20}{2} = 10\text{ V}$$

for $R_C = 100\ \Omega$, $$I_C = \frac{V_{CC} - V_{CE}}{R_C} = \frac{20 - 10}{100} = 100\text{ mA}$$

for $\beta = 100$, $$I_B = \frac{I_C}{\beta} = \frac{100}{100} = 1\text{ mA}$$ and

$$R_b = \frac{V_{CC} - V_{BE}}{I_B} = \frac{20 - 0.7}{1}$$

$$R_b = 19.3\text{ K}\Omega$$

(b) Here the amplifier is class A,

$\therefore$ Maximum signal a.c. power,

$$(P_{ac})_{max} = \frac{I_{CQ}^2 R_L}{2}$$

where $I_m = I_{CQ} = 100$ mA

$$\therefore (P_{ac})_{max} = \frac{(100)^2 \times 0.1}{2}$$

$$\therefore (P_{ac})_{max} = 500\text{ mW} = 0.5\text{ W}$$

Q.7. A single transistor is operating as an ideal class B amplifier with 1 k load. A d.c. meter in the collector circuit reads 10 mA. How much signal power is delivered in the load ?

Solution : Output of amplifier will contain only half cycles of input signal

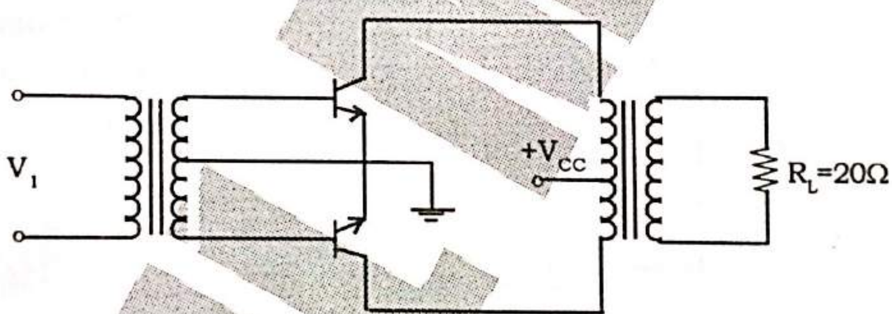
$\therefore$ average value of collector current $= I_{dc} = \dfrac{I_m}{\pi}$

$\therefore$
$$I_m = I_{dc} \times \pi = 10 \times 3.14 = 31.4 \text{ mA}$$
and RMS value of this current will be

$$I_{rms} = \frac{I_m}{2} = 15.7 \text{ mA}$$

$$P_{ac} = I^2_{rms} R_L$$
$$P_{ac} = (15.7 \times 10^{-3})^2 \times 1 \times 10^3$$
$$P_{ac} = 246.49 \text{ mW} = 0.246 \text{ W}$$

Q.8. The idealised push pull class B amplifier is shown with $V_{CC} = 20$ V, $N_2 = 2 N_1$, $R_L = 20\ \Omega$ and the transistors have $h_{fe} = 20$. The input is sinusoidal. For the maximum output signal at $V_m = V_{CC}$, determine (a) Output signal power (b) The collector dissipation in each transistor.



Solution : Output power $\quad P_{ac} = I_{rms} \cdot V_{rms} = \dfrac{I_m V_m}{2}$

$$V_m = V_{CC} = 20 \text{ V given}$$

$$I_m = \frac{V_m}{R'_L}$$

Reflected impedance $\quad R'_L = \left[\dfrac{N_1}{N_2}\right]^2 \times R_L$

$$R'_L = \left[\frac{1}{2}\right]^2 \times 20 = 5\Omega$$

$$I_m = \frac{20}{5} = 4 \text{ A}$$

Now, $$P_{ac} = \frac{I_m V_m}{2} = \frac{4 \times 20}{2} = 40 \text{ W}$$

Total d.c. power taken by two transistors = P_{dc}

$$P_{dc} = I_{dc} \times V_{CC} = \frac{2 I_m}{\pi} \times V_{CC}$$

$$P_{dc} = \frac{2 \times 4}{\pi} \times 20 = 50.93 \text{ W}$$

∴ Total power dissipated in two transistors,

$$P_{dissipated} = P_{dc} - P_{ac}$$
$$= 50.93 - 40 = 10.93 \text{ W}$$

∴ Power dissipated in each transistor $= \frac{10.93}{2} = 5.46$ W.

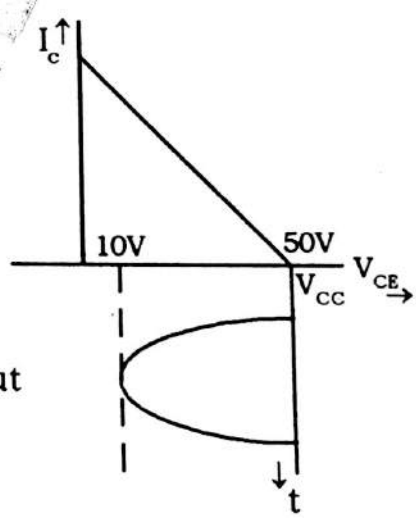
Q.9. A class B push pull amplifier is supplied with $V_{CC} = 50$ V, and the signal swing the collector voltage down to $V_{min} = 10$ V. The dissipation in both the transistor totals 40 W.

(a) Find the load presented by output transformer.

(b) Find the load power.

(c) Find the conversion efficiency.

Solution :



$$V_m = V_{CC} - V_{min}$$
$$V_m = 50 - 10 = 40 \text{ W}$$

Power dissipation = 40 W

$$P_{diss} = P_{dc} \text{ input} - P_{ac} \text{ output}$$

$$40 = V_{CC} \cdot I_{dc} - \frac{V_m I_m}{2}$$

$$40 = V_{CC} \times \frac{2 I_m}{\pi} - \frac{V_m \times V_m}{2 R'_L} \qquad \text{as } I_m = \frac{V_m}{R'_L}$$

$$40 = 2\frac{V_{CC} \times V_m}{\pi R'_L} - \frac{V^2_m}{2 R'_L}$$

$$R'_L = \frac{1}{40}[2 V_{CC} V_m - \frac{V^2_m}{2}]$$

$$R'_L = \frac{1}{40}[2 \times 50 \times 40 - \frac{(40)^2}{2}] = 11.83 \ \Omega$$

R'_L is the total load presented by output transformer.

(b) Load power $= P_{ac} = \frac{V^2_m}{2\,R'_L} = \frac{(40)^2}{2 \times 11.83} = 67.62$ W

(c) Conversion efficiency $\eta = \frac{P_{ac}}{P_{dc}}$

$$\eta = \frac{P_{ac}}{P_{diss} + P_{ac}}$$

$$\eta = \frac{67.62}{40+67.62} = 0.6283$$

$\therefore$ $\% \eta = 62.83\%$

Q.10. With the load of 4 Ω, a push pull amplifier takes 3.25 A from the dc supply with the sinusoidal signal (a) What is the ac power output (b) With V_{CC} = 24 V, what are the conversion efficiency and dissipation ? (c) what is the maximum possible dissipation ?

Solution :(a) $R'_L = 4\ \Omega,\ I_{dc} = 3.25$ A, $P_{ac} = ?$

$$P_{ac} = \frac{V_m I_m}{2} = \frac{I^2_m R'_L}{2} \quad \text{........(1)}$$

$$I_{dc} = \frac{2\,I_m}{\pi}$$

$$\therefore I_m = \frac{\pi}{2} I_{dc} \quad \text{........(2)}$$

$$\therefore P_{ac} = \frac{\pi^2}{4} \cdot \frac{I^2_{dc} R'_L}{2} \quad \text{from (1) and (2)}$$

$$\therefore P_{ac} = \frac{\pi^2}{4} \times \frac{(3.25)^2 \times 4}{2} = 52.124 \text{ W}$$

(b) $V_{CC} = 24$ V

$\therefore P_{dc} = I_{dc} \times V_{CC} = 3.25 \times 24 = 78$ W

$\therefore$ Conversion efficiency $\eta = \frac{P_{ac}}{P_{dc}}$

$$\eta = \frac{52.124}{78} = 0.6682$$

$\therefore \%\eta = 66.82\%$

and collector dissipation $= P_{dc} - P_{ac}$

$= 78 - 52.124$

$= 25.87$ W

(c) Maximum possible dissipation will be when $V_m = \frac{2\,V_{CC}}{\pi}$

$$P_{dissipation_{max}} = \frac{2\,V^2_{CC}}{\pi^2\,R'_L} = \frac{2 \times (24)^2}{\pi^2 \times 4} = 29.18\ W$$

Q.11. Two transistors are operated at V_{CC} = 15 V and each is mounted on a heat sink capable of dissipating 5 W. Calculate the peak current I_m at the maximum loss, the load per transistor and the maximum possible power output from the two transistor in class B.

Solution : Maximum power dissipation of each transistor = 5 W

$\therefore$ Total power dissipated = 10 W

Now, $$P_{dissipation(max)} = \frac{2\,V^2_{CC}}{\pi^2\,R'_L} \qquad \therefore R'_L = \frac{2 \times (15)^2}{\pi^2 \times 10} = 4.56\ \Omega$$

also $$I_m = \frac{V_m}{R'_L} = \frac{2\,V_{CC}}{\pi} \times \frac{1}{R'_L} = \frac{2 \times 15}{\pi \times 4.56} = 2.1\ A$$

Maximum a.c. power to the load will be obtained when $V_m = V_{CC}$

$$(P_{ac})_{max} = \frac{V^2_{CC}}{2\,R'_L} = \frac{(15)^2}{2 \times 4.56} = 24.67\ W$$

Q.12. The ideal class B push pull amplifier is shown with V_{CC} = 15 V, R_L = 4 Ω. The input signal is sinusoidal.

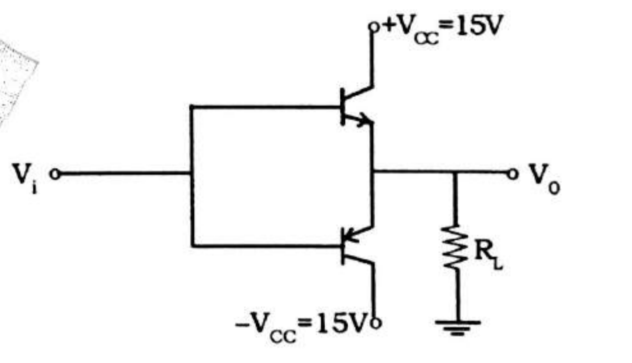
Determine :

(a) Maximum output signal power.

(b) Maximum d.c. power.

(c) The conversion efficiency.

(d) What is the maximum dissipation of each transistor and what is the efficiency under this condition ?



Solution : (a) Maximum output signal power

$$(P_{ac})_{max} = \frac{V^2_m}{2\,R_L}$$

and $V_m = V_{CC}$ = 15 V

$$\therefore (P_{ac})_{max} = \frac{(15)^2}{2 \times 4} = 28.125\ W$$

(b) Input d.c. power $P_{dc} = I_{dc} \times V_{CC}$

$$I_{dc} = \frac{2\,I_m}{\pi} = \frac{2 \times V_m}{\pi \times R_L} \qquad \text{but } V_m = V_{CC}$$

$$P_{dc} = \frac{2\,V_m}{\pi\,R_L} \times V_m$$

$$P_{dc} = \frac{2 \times (15)^2}{\pi \times 4} = 35.8\text{ W}$$

Collector dissipation $= P_{dc} - P_{ac} = 35.8 - 28.125 = 7.68\text{ W}$

$\therefore$ dissipation per transistor $= \frac{7.68}{2} = 3.84\text{ W}$

(c) Conversion efficiency $\eta = \frac{P_{ac}}{P_{dc}} = \frac{28.125}{35.8} = 0.7856$

$$\%\eta = 78.56\%$$

(d) Maximum dissipation occurs when $V_m = \frac{2\,V_{CC}}{\pi}$

$$P_{dissipation} = \frac{2V_{CC}^2}{\pi^2\,R_L} = \frac{2 \times (15)^2}{\pi^2 \times 4} = 11.398\text{ W}$$

$\therefore$ Maximum dissipation per transistor $= \frac{11.398}{2} = 5.699\text{ W}$

Maximum d.c. power input $= 2 \times P_{dissipation}$

$= 2 \times 11.398 = 22.79\text{ W}$

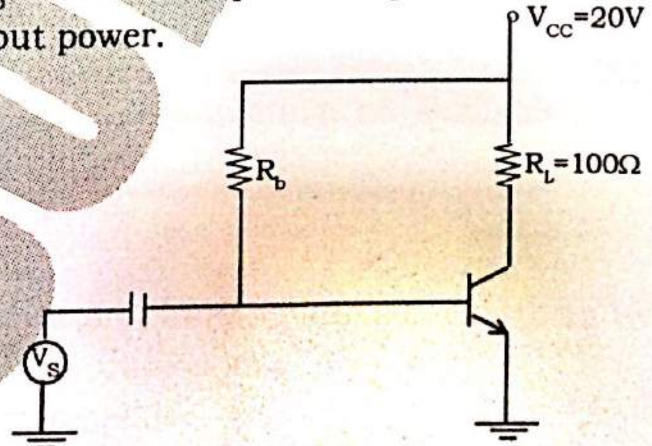
$$\therefore \eta = \frac{P_{ac}}{P_{dc}} = \frac{11.398}{22.79} = 0.5$$

$$\therefore \%\eta = 50\%$$

Q.13. In the power amplifier shown $\beta = 100$. Determine :

(a) The value of R_b that locates quiescent point in the centre of the load lines.

(b) Maximum output power.



Solution : Since Q point is in the centre of the load line, transistor is in class A mode, and in active region.

$\therefore \quad V_{CE} = \frac{V_{CC}}{2} = \frac{20}{2} = 10\text{ V} \qquad R_L = 100\ \Omega = 0.1\text{K}$

By KVL, $\quad I_c = \frac{V_{CC} - V_{CE}}{R_L} = \frac{20-10}{0.1} = 100\text{ mA}$

as $\beta = 100$, $\quad I_B = \frac{I_C}{\beta} = \frac{100}{100} = 1\text{ mA}$

also $\quad R_b = \frac{V_{CC} - V_{BE}}{I_B} = \frac{20-0.7}{1} = 19.3\text{ K}\Omega$

(b) Power output $\quad P_{ac} = \frac{V_m I_m}{2}$

$I_m = I_{CQ} = 100\text{ mA}$ and $V_m = \frac{V_{CC}}{2} = 10\text{ volt}$

$P_{ac} = \frac{10 \times 100}{2} = 500\text{ mW}$

$P_{ac} = 0.5\text{ W}$

Q.14. A transistor power amplifier delivers an output of 10 watts with an efficiency of 45%. Determine (a) d.c. power input (b) power that must be dissipated as heat ?

Solution : (a) $\quad P_{ac} = 10\text{ W}$

$\%\eta = 45\%$

$\therefore \eta = 0.45 \qquad \eta = \frac{P_{ac}}{P_{dc}}$

$\therefore P_{dc}\text{ input} = \frac{P_{ac}}{\eta} = \frac{10}{0.45} = 22.22\text{ watts.}$

(b) Power dissipated = Power Input – Power Output

= 22.22 – 10

= 12.2 watts.

Q.15. Transistors with following ratings are available

$V_{CEO} = 40\text{ V}$,

$I_{C\,max} = 5\text{ Amps.}$,

$P_{d\,max} = 40\text{ watts.}$

Find the maximum output power obtainable with these transistors are in

(i) Class A transformer coupled amplifier

(ii) Class B push-pull amplifier

Solution :

(i) For class A transformer coupled amplifier, efficiency is 50% approx.

$$\eta = \frac{P_0}{P_0 + P_d}$$

$$\therefore 0.5 = \frac{P_0}{P_0 + 40}$$

$$P_{0\,max} = P_0 = P_{ac\,max} = 40 \text{ watts}$$

(ii) For class B push-pull amplifier

$$\text{Output Power } P_{ac} = \frac{V_m I_m}{2}$$

$$V_m = V_{CC} = 40 \text{ V}$$

and

$$I_m = I_{C\,max} = 5 \text{ Amp}$$

$$\therefore P_{ac} = \frac{40 \times 5}{2} = 100 \text{ watts}$$

Q.16. In Ideal Class B push-pull power amplifier with $V_{CC} = 25$ V, $N_2 = 2N_1$, $R_L = 25\ \Omega$ and $h_{fe} = 25$.

(i) Find the maximum output power, input power and efficiency.

(ii) Maximum power dissipation in transistor corresponding output voltage level.

(iii) Power dissipation in transistor at maximum power output.

Solution : Power Output = $P_{ac} = \frac{I_m}{\sqrt{2}} \times \frac{V_m}{\sqrt{2}}$ where $V_m = V_{CC}$ and $I_m = \frac{V_m}{R'_L}$

$$R'_L = \left[\frac{N_1}{N_2}\right]^2 \times R_L$$

$$R'_L = \left[\frac{1}{2}\right]^2 \times 25 = 6.25\Omega$$

$$\therefore P_{ac} = \frac{V^2_{CC}}{2\,R'_L} = \frac{(25)^2}{2 \times 6.25} = 50 \text{ watts}$$

Total Power Input $= P_{dc}$

$$P_{dc} = I_{dc} V_{CC}$$

$$= 2\,\frac{I_m}{\pi} \times V_{CC} = \frac{2 \times V_m}{\pi\,R'_L} \times V_{CC}$$

$$= \frac{2 \times (25)^2}{\pi \times 6.25} = 63.66 \text{ watts}$$

$\therefore$ Total Power dissipated $= P_{dc} - P_{ac} = 63.66 - 50 = 13.66$ watts

$\therefore$ Maximum power dissipated in each transistor $= \frac{13.66}{2} = 6.83$ watts

Q.17. Calculate the thermal resistance for the transistor of which $P_{C\,(max)} = 125$ mW at 25°C free air temperature and maximum junction temperature $T_j = 150$ °C. What is the junction temperature if the collector dissipation is 75 m watts ?

Solution : (a) We have $T_j - T_A = \theta\, P_D$ where T_j is the junction temperature and T_A is free air temperature.

$$\therefore\ 150 - 25 = \theta \times 125$$

$$\therefore\ \theta = 1°C/mW$$

(b) Also, $\theta \,.\, d\,P_D = d\,T_j$ $\quad \therefore \int_{25°C}^{T_j} d\,T_j = \theta \times 75 = 75°C$

$$\therefore\ T_j - 25 = 75 \qquad \therefore\ T_j = 100°C$$

Q.18. Bipolar junction transistor with maximum rated collector current of 5 A, maximum rated collector voltage of 30 V and maximum rated collector dissipation of 20 W is available (i) Find the optimum value of R'_L for maximum power output and hence $P_{0\,(max)}$ if the above transistor is used in transformer coupled class A power amplifier. (ii) Find collector power dissipation when no signal is applied and when full signal is applied. (iii) What would be the $P_{0\,(max)}$ if above transistors is used class B - push pull amplifier ? Comment on the results.

Solution :

$$I_{C\,max} = 5\text{ A}$$

$$V_{CE\,max} = 30\text{ V}$$

$$P_{diss} = 20\text{ W}$$

For transformer coupled class A power amplifier

$$V_{CC} = V_m = V_{CE\,max} = 30\text{ V}$$

Assuming efficiency $\eta = 50\%$

$$P_{ac\,max} = P_d = 20\text{ W}$$

and

$$P_{ac} = \frac{V^2_{CC}}{2\,R'_L}$$

where R'_L is reflected resistance of transformer primary.

$$\therefore\ R'_L = \frac{V^2_{CC}}{2\,P_{ac}} = \frac{(30)^2}{2 \times 20} \qquad \therefore\ R'_L = 22.5\text{ W}$$

and

$$P_{0\,(max)} = P_{ac} = 20\text{ watts}$$

(ii) When no signal is applied, collector dissipation is equal to maximum collector dissipation = 20 W.

(iii) When transistors are used in class B - push-pull

$$P_{0\,(max)} = \frac{V_m I_m}{2} = \frac{30 \times 5}{2} = 75 \text{ watts}$$

Output a.c. power for class B push pull is greater than that of class A power amplifier.

NOTES