Chapter 6. POWER AMPLIFIERS

An amplifying system usually has several cascaded stages. The input and intermediate stages are small signal amplifiers. Their function is only to amplify the input signal to a suitable value. The last stage usually drives a transducer such as a loud speaker, CRT, Servomotor etc. Hence this last stage amplifier must be capable of handling and deliver appreciable power to the load. These large signal amplifiers are called as power amplifiers.

Power amplifiers are classified according to the class operation, which is decided by the location of the quiescent point on the device characteristics. The different classes of operation are:

(i) Class A

(ii) Class B

(iii) Class AB

((iv) Class C

CLASS A OPERATION:

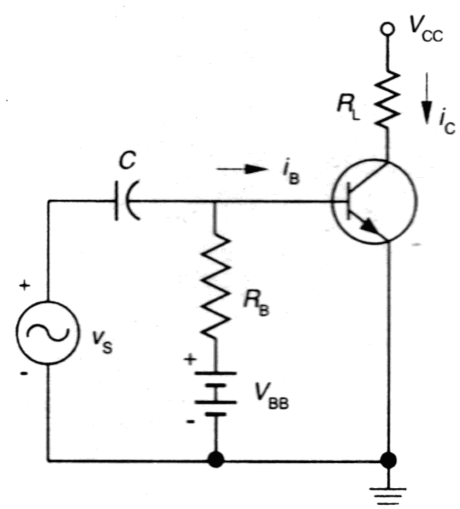

Fig.1 Series-fed transistor amplifier

A simple transistor amplifier that supplies power to a pure resistive load R_L is shown above. Let i_C represent the total instantaneous collector current, i_c designate the instantaneous variation from the quiescent value of I_C. Similarly, i_B ,i_b and I_B represent corresponding base currents. The total instantaneous collector to emitter voltage is given by v_c and instantaneous variation from the quiescent value V_C is represented by v_c.

Let us assume that the static output characteristics are equidistant for equal increments of input base current i_b as shown in fig. below.

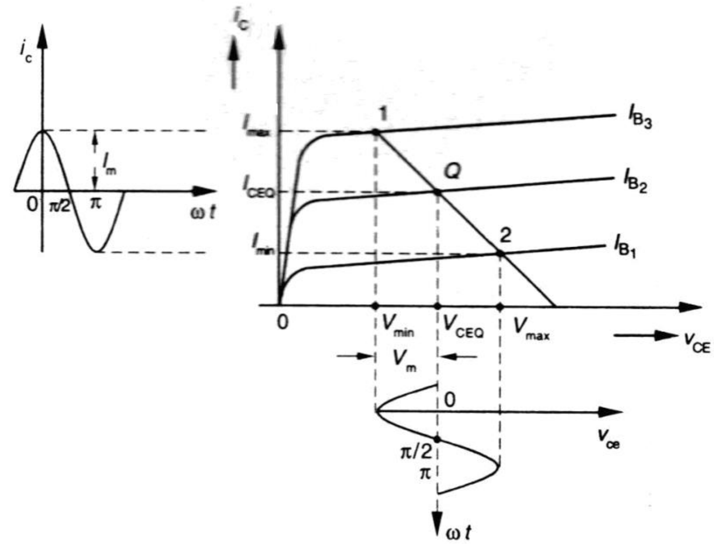

Fig. 2 The output characteristics and the current and voltage waveforms

If the input signal i_b is a sinusoid , the output current and voltage are also sinusoidal.Under these conditions, the non-linear distortion is neglible and the power output may be found graphically as follows.

$P = V_c I_c = I_c^2 R_L$ ------------------------------ (1)

Where V_c & I_c are the rms values of the output voltage and current respectively.The numerical values of V_c and I_c can be determined graphically in terms of the maximum and minimum voltage and current swings.It is seen that

$$I_c = \frac{I_m}{\sqrt{2}} = \frac{I_{max} - I_{min}}{2\sqrt{2}} \text{ ---------------------------- (2)}$$

and

$$V_c = \frac{V_m}{\sqrt{2}} = \frac{V_{max} - V_{min}}{2\sqrt{2}} \text{ ------------------------- (3)}$$

Power, $P_{ac} = \frac{V_m I_m}{2} = \frac{I_m^{\,2} R_L}{2} = \frac{V_m^{\,2}}{2R_L}$ ----------------- (4)

This can also be written as,

$$P_{ac} = \frac{(V_{max} - V_{min})(I_{max} - I_{min})}{8} \quad \text{--------------(5)}$$

DC power $P_{dc} = V_{CC} I_{CQ}$

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

MAXIMUM EFFICIENCY:

For a maximum swing, refer the figure below.

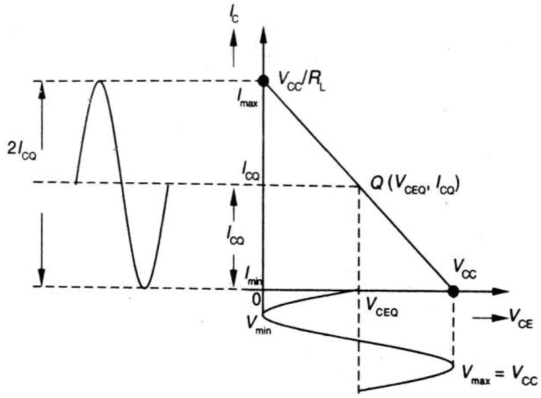

Fig. 3 **Maximum voltage and current swings**

$$V_{max} = V_{CC} \ \& V_{min} = 0$$

$$I_{max} = 2I_{CQ} \ \& I_{min} = 0$$

$$\eta_{max} = \frac{V_{CC}\, 2I_{CQ}}{8V_{CC} I_{CQ}} = 25\%$$

SECOND HARMONIC DISTORTION:

In the previous section, the active device (BJT) is treated as a perfectly linear device. But in general, the dynamic transfer characteristics are not a straight line. This non-linearity arises because of the static output characteristics are not equidistant straight lines for constant increments of input excitation. If the dynamic curve is non-linear over the operating range, the waveform of the output differs from that of the input signal. Distortion of this type is called non-linear or amplitude distortion.

To investigate the magnitude of this distortion, we assume that the dynamic curve with respect to the quiescent point 'Q' can be represented by a parabola rather than a straight line as shown below.

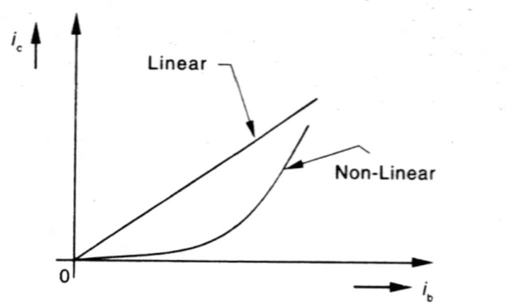

Fig. 4 Nonlinear dynamic characteristics

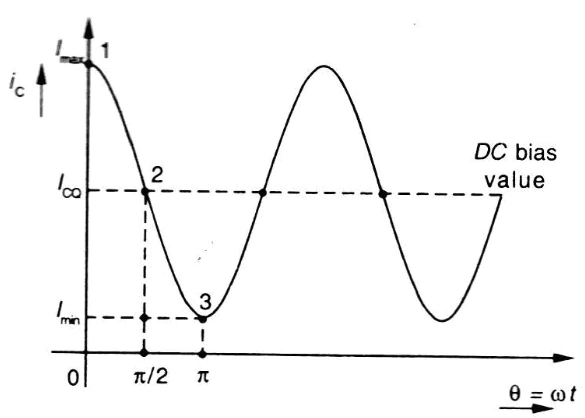

Fig. 1 Output current waveform

Thus instead of relating the alternating output current i_c with the input excitation i_b by the equation $i_c = Gi_b$ resulting from a linear circuit. We assume that the relationship between i_c and i_b is given more accurately by the expression

$$i_c = G_1 i_b + G_2 i_b^2 \quad \text{---(1)}$$

where the G' s are constants.

Actually these two terms are the beginning of a power series expansion of i_c as a function of i_b.

If the input waveform is sinusoidal and of the form

$$i_b = I_{bm} \operatorname{Cos} \omega t \text{ --(2)}$$

Substituting equation (3), into equation (2)'

$$i_c = G_1 I_{bm} \operatorname{Cos} \omega t + G_2 I_{bm}^2 \operatorname{Cos}^2 \omega t$$

Since $Cos^2 \omega t = \frac{1}{2} + \frac{1}{2} Cos 2\omega t$, the expression for the instantaneous total current reduces the form,

$$i_C = I_C + i_c = I_C + B_0 + B_1 \operatorname{Cos} \omega t + B_2 \operatorname{Cos} 2\omega t \quad \text{------------------------ (3)}$$

Where B's are constants which may be evaluated in terms of the G's.

The physical meaning of this equation is evident. It shows that the application of a sinusoidal signal on a parabolic dynamic characteristic results in an output current which contains, in addition to a term of the same frequency as the input, a second harmonic term and also a constant current. This constant term B_0 adds to the original dc value I_C to yield a total dc component of current $I_C + B_0$.Thus the parabolic non-linear distortion introduces into the output a component whose frequency is twice that of the sinusoidal input excitation.

The amplitudes B_0, B_1 & B_2 for a given load resistor are readily determined from either the static or the dynamic characteristics. From fig. 7.2 above, we observe that

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

$\omega t = \pi/2$, $i_c = I_C$ ---(4)

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

By substituting thase values in equation (4)'

$$I_{max} = I_C + B_0 + B_1 + B_2$$

$$I_C = I_C + B_0 - B_2 \quad \text{-- (5)}$$

$$I_{min} = I_C + B_0 - B_1 + B_2$$

This set of three equations determines the three unknowns B_0, B_1 & B_2.

It follows from the second group that

$$B_0 = B_2 \quad \text{--(6)}$$

By subtracting the third equation from the first,

$$B_1 = \frac{I_{\max} - I_{\min}}{2} \quad \text{--(7)}$$

Then from the first or last of equation (6),

$$B_2 = B_0 = \frac{I_{\max} + I_{\min} - 2Ic}{4} \quad \text{-- (8)}$$

The second harmonic distortion D_2 is defined as,

$$D_2 = \frac{|B_2|}{|B_1|} \quad \text{-- (9)}$$

If the dynamic characteristics is given by the parabolic form & if the input contains two frequencies ω_1 & ω_2, then the output will consist of a dc term & sinusoidal components of frequencies ω_1, ω_2, $2\omega_1$,$2\omega_2$, $\omega_1+\omega_2$ and $\omega_1-\omega_2$.The sum & difference frequencies are called intermodulation or combination frequencies.

HIGHER ORDER HARMONIC GENERATION

The analysis of the previous section assumed a parabolic dynamic characteristic. But this approximation is usually valid for amplifier where the swing is small. For a power amplifier with

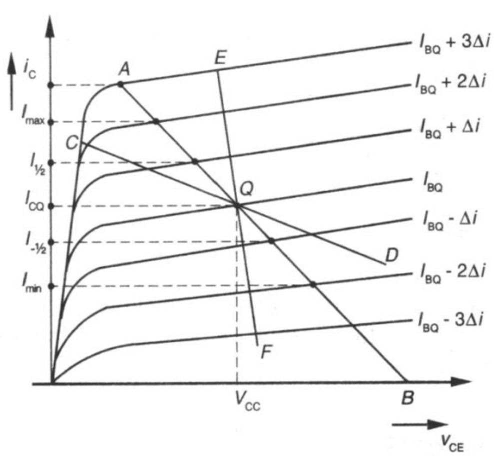

Fig. 2 **Graphical evaluation of harmonic distortion**

a large input swing, it is necessary to express the dynamic transfer curve with respect to the Q point by a power series of the form,

$$i_c = G_1 i_b + G_2 i^2{}_b + G_3 i^3{}_b + \text{---------------------------------- (1)}$$

If the input wave is a simple cosine function of time, then

$$i_b = I_{bm} Cos\omega t \quad \text{-- (2)}$$

Then, $i_c = B_0 + B_1 Cos\omega t + B_2 Cos2\omega t + B_3 Cos3\omega t + --- \ (3)$

Where B_0, B_2, B_3 – are the coefficients in the Fourier series for the current.

i.e. the total output current is given by

$$i_C = I_{CQ} + i_c = I_{CQ} + B_0 + B_1 Cos\omega t + B_2 Cos2\omega t + ------ (4)$$

Where ($\left(I_{CQ} + B_0\right)$ is the dc component. Since i_C is an even function of time, the Fourier series in equation (4) representing a periodic function possessing the symmetry, contains only Cosine terms.

Suppose we assume as an approximation that harmonics higher than the fourth are negligible in the above Fourier series, then we have five unknown terms $B_{0,} B_1, B_2, B_{3,}$ & B_4 .To evaluate those we need output currents at five different value of $I_{B.}$

Let us assume that $i_C = 2\Delta i Cos\omega t$ ----------------------------- (5)

Hence, $I_B = I_{BQ} + 2\Delta i Cos\omega t$ ----------------------------------- - (6)

At $\omega t = 0,\quad I_B = I_{BQ} + 2\Delta i,\quad i_C = I_{\max}$ ------------------- (7)

At $\omega t = \dfrac{\pi}{3},\ I_B = I_{BQ} + \Delta i,\quad i_C = I_{\frac{1}{2}}$ ------------------- ---(8)

At $\omega t = \dfrac{\pi}{2},\ I_B = I_{BQ},\quad i_C = I_{CQ}$ -------------------- (9)

At $\omega t = \dfrac{2\pi}{3},\ I_B = I_{BQ} - \Delta i,\quad i_C = I_{-\frac{1}{2}}$ ---------------------(10)

At $\omega t = \pi,\ I_B = I_{BQ} - 2\Delta i,\quad i_C = I_{\min}$ ----------------------(11)

By combining equations (4) & (7) to (11), we get five equations & solving them, we get the following relations,

$$B_0 = \frac{1}{6}\left[I_{\max} + 2I_{\frac{1}{2}} + 2I_{-\frac{1}{2}} + I_{\min}\right] - I_{CQ} \quad \text{------------------------- (12)}$$

$$B_1 = \frac{1}{3}\left[I_{\max} + I_{\frac{1}{2}} - I_{-\frac{1}{2}} - I_{\min} \right] \quad \text{-----------------------------------} \ (13)$$

$$B_2 = \frac{1}{4}\left[I_{\max} - 2I_{CQ} + I_{\min} \right] \quad \text{---------------------------------------} \ (14)$$

$$B_3 = \frac{1}{6}\left[I_{\max} - 2I_{\frac{1}{2}} + 2I_{-\frac{1}{2}} - I_{\min} \right] \quad \text{------------------------------} \ (15)$$

$$B_4 = \frac{1}{12}\left[I_{\max} - 4I_{\frac{1}{2}} + 6I_{CQ} - 4I_{-\frac{1}{2}} + I_{\min} \right] \quad \text{--------------------} \ (16)$$

The harmonic distortion is defined as,

$$D_2 = \frac{|B_2|}{|B_1|}, \ D_3 = \frac{|B_3|}{|B_1|}, \ D_4 = \frac{|B_4|}{|B_1|} \quad \text{-----------------------------} (17)$$

Where D_n represents the distortion of the n^{th} harmonic. Since this method uses five points on the output waveform to obtain the amplitudes of harmonics, the method is known as the five point method of determining the higher order harmonic distortion.

POWER OUTPUT DUE TO DISTORTION

If the distortion is not negligible, the power delivered to the load at the fundamental frequency is given by

$$P_1 = \frac{B_1^{\ 2} R_L}{2} \quad \text{---------------------------------} \ (1)$$

The ac power output is,

$$P_{ac} = \left(B_1^{\ 2} + B_2^{\ 2} + B_3^{\ 2} + --- \right) \frac{R_L}{2} \quad \text{--------} \ (2)$$

$$= \left(1 + D_2^{\ 2} + D_3^{\ 2} + ---- \right) P_1 \quad \text{---------} \ (3)$$

Where D_2, D_3 etc are the second, third harmonic distortions.

Hence, $P_{ac} = \left(1 + D^2\right) P_1$ -------------------------------- (4)

Where D is the total distortion factor & is given by

$$D = \sqrt{D_2^{\ 2} + D_3^{\ 2} + D_4^{\ 2} + -----} \quad \text{---------} \ (5)$$

For e.g. if $D = 10\%$ of the fundamental, then

$$P_{ac} = \frac{1 + (0.1)^2}{P_1}$$

$$\therefore P_{ac} = 1.01 P_1 \quad \text{-------------------------------------- (6)}$$

When the total distortion is 10%, the power output is only 1%.higher than the fundamental power. Thus, only a small error is made in using only the fundamental term P_1 for calculating the output power.

THE TRANSFORMER COUPLED AUDIO POWER AMPLIER

The main reason for the poor efficiency of a direct-coupled classA amplifier is the large amount of dc power that the resistive load in collector dissipates. This problem can be solved by using a transformer for coupling the load.

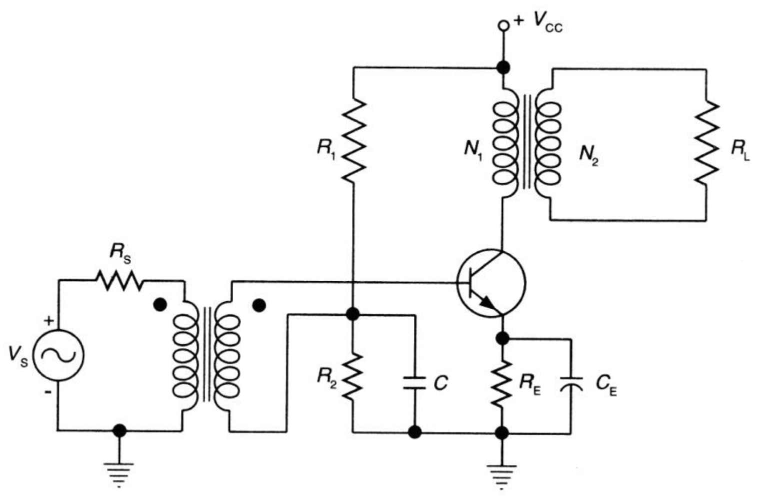

Fig. 3 Transformer-coupled transistor amplifier

TRANDFORMER IMPEDANCE MATCHING

Assume that the transformer is ideal and there are no losses in the transformer. The resistance seen looking into the primary of the transformer is related to the resistance connected across the secondary .The impedance matching properties follow the basic transformer relation.

$$V_1 = \frac{N_1}{N_2} V_2 \quad \text{and} \quad I_1 = \frac{N_2}{N_1} I_2 \quad \text{---------------------------------- (1)}$$

Where

$V_1 =$ Primary voltage, $V_2 =$ Secondary voltage.

$I_1 =$ Primary current, $V_2 =$ Secondary current.

$N_1 =$ No. of turns in the primary.

$N_2 =$ No. of turns in the secondary.

From Eq. (1)

$$\frac{V_1}{I_1} = \frac{\left(\frac{N_1}{N_2}\right)V_2}{\left(\frac{N_2}{N_1}\right)I_2} = \left(\frac{N_1}{N_2}\right)^2 \frac{V_2}{I_2}$$

$$\frac{V_1}{I_1} = \left(\frac{1}{n^2}\right)\frac{V_2}{I_2} \quad \text{--} \ (2)$$

As both $\frac{V_1}{I_1}$ & $\frac{V_2}{I_2}$ are resistive terms, we can write

$$R'_L = \frac{1}{n^2} R_L = \left(\frac{N_1}{N_2}\right)^2 R_L \quad \text{---------------------} \ (3)$$

In an ideal transformer, there is no primary drop.Thus the supply voltage V_{CC} appears as the collector-emitter voltage of the transistor.

i.e. $V_{CC} = V_{CE}$ ------------------------------------ (4)

When the values of the resistance R_B(= R_1I I R_2) and V_{CC} are known, the base current at the operating point may be calculated by the equation.

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} \approx \frac{V_{CC}}{R_B} \quad \text{----------------------} \ (5)$$

OPERATING POINT:

Operating point is obtained graphically at the point of intersection of the dc load line and the transistor base current curve.

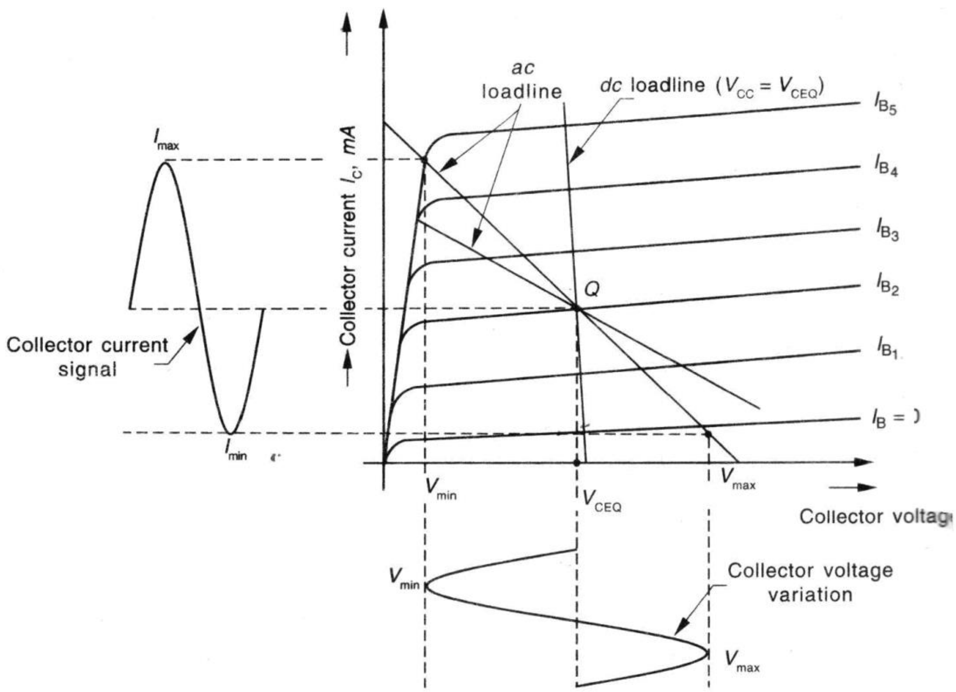

Fig. 4 Collector characteristics of a power transistor showing the *dc* and the

After the operating point is determined; the next step is to construct the ac load line passing through this point.

AC LOAD LINE:

In order to draw the ac load line, first calculate the load resistance looking into the primary side of the transformer. The effective load resistance is calculated using Eq.(3) from the values of the secondary load resistance and transformer ratio. Having obtained the value of R'_L, the ac loads line must be drawn so that it passes through the operating point Q and has a slope equal to $-\frac{1}{R'_L}$. The dc and the ac load lines along the operating point Q are shown. In the above figure, two ac load lines are drawn through Q for different values of R'_L.

For R'_L very small, the voltage swing and hence the output power 'P', approaches zero.For R'_L very large, the current swing is small and again 'P' approaches zero.The variation of power & distortion wrto load resistance is shown in the plot below.

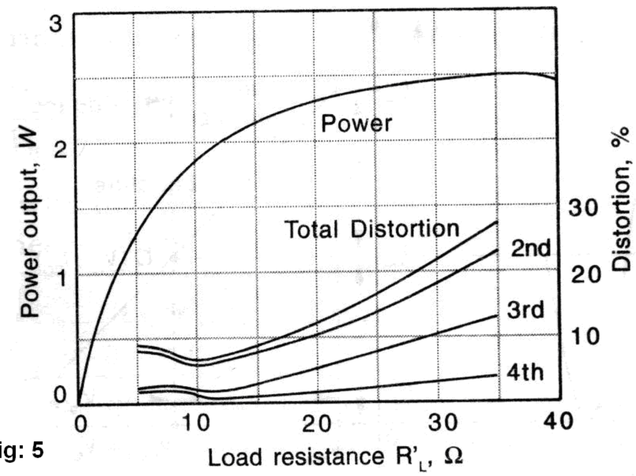

Fig: 5

Output power and distortion as a function of load resistance

EFFICIENCY:

Assume that the amplifier as supplying power to a pure resistance load. Then the average power input from the dc supply ic $V_{CC}I_C$. The power absorbed by the output circuit is, $I_C{}^2R_1 + I_CV_{ce}$, where I_C &V_{ce} are the rms output current & voltage respectively & R_1 is the static load resistance. If P_D is the average power dissipated by the active device, then by the principle of conservation.of energy,

$$V_{CC}I_C = I_C{}^2R_1 + I_CV_{ce} + P_D \text{ ------------ (1)}$$

Since $V_{CC} = V_{CEQ}I_C - V_{ce}I_c$, P_D may be written in the form,

$$P_D = V_{CEQ}I_C - V_{ce}I_c \text{---------------------- (2)}$$

If the load is not pure resistance, then $V_{ce}I_e$ must be replaced by $V_{ce}I_c$ must be replaced by $V_{ce}I_cCos\phi$, where $Cos\phi$ is the power factor of the load.

The above equation expresses the amount of power that must be dissipated by the active device. If the ac output power is zero i.e. If no applied signal exists, then

$$P_D = V_{CE}I_C \text{ -------------------------------- (3)}$$

$$\%Efficiency, \eta = \frac{ac\,output\,power}{dc\,power\,input} X100 \quad \text{--------------} (4)$$

In general, $$\eta = \frac{\left(\frac{1}{2}\right) B_1^{\,2} R'_L}{V_{CC}\left(I_C + B_0\right)} X100\% \quad \text{---------------} (5)$$

In the distortion components are neglected, then

$$\%\eta = \frac{\left(\frac{1}{2}\right) V_m I_m}{V_{CC} I_C} X100 = 50 \frac{V_m I_m}{V_{CC} I_C} \quad \text{--------------------} (6)$$

MAXIMUM EFFICIENCY:

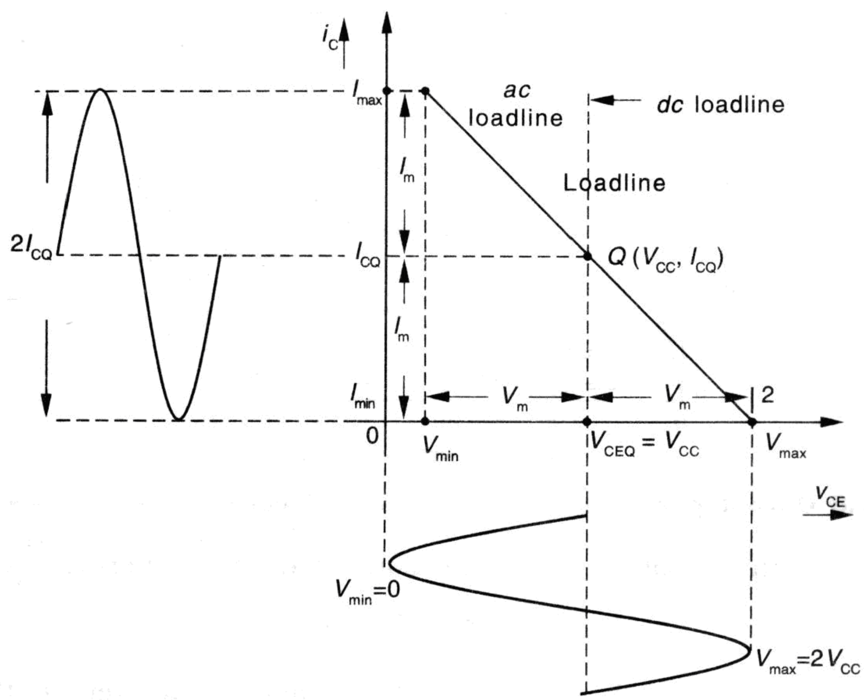

Fig. 6 Maximum voltage and current

An approximate expression for efficiency can be obtained by assuming ideal characteristic curves. Referring to above fig., maximum values of the sine wave output voltage is,

$$V_m = \frac{V_{max} - V_{min}}{2} \quad \text{--------------------------} (7)$$

And $$I_m = I_{CQ} \quad \text{----------------------------------} (8)$$

The rms value of collector voltage,

$$V_{rms} = \frac{V_m}{\sqrt{2}} = \frac{V_{\max} - V_{\min}}{2\sqrt{2}} \quad \text{-------------- (9)}$$

Similarly, $$I_{rms} = \frac{I_{\max} - I_{\min}}{2\sqrt{2}} \quad \text{--------------------- (10)}$$

The output power is,

$$P_{ac} = V_{rms}.I_{rms} = \frac{(V_{\max} - V_{\min})}{2\sqrt{2}} \cdot \frac{(I_{\max} - I_{\min})}{2\sqrt{2}}$$

$$= \frac{(V_{\max} - V_{\min}).(I_{\max} - I_{\min})}{8} \text{----------------(11)}$$

The input power is,

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

$$\eta = \frac{P_{ac}}{P_{dc}} = \frac{(V_{\max} - V_{\min})(I_{\max} - I_{\min})}{8V_{CC}I_{CQ}} \text{-------------(12)}$$

The efficiency of a transformer coupled class A amplifier can also be expressed as,

$$\eta = 50\left(\frac{V_{\max} - V_{\min}}{V_{\max} + V_{\min}}\right)\% \quad \text{-------------------------- (13)}$$

The efficiency will be maximum when $V_{\min} = 0$, $I_{\min} = 0, V_{\max} = 2V_{cc}$ & $I_{\max} = 2I_{CQ}$, substituting these values in eq.(12), we get

$$\eta_{\max} = \frac{2V_{CC}.2I_{CQ}}{8V_{CC}.I_{CQ}} X100 = 50\% \quad \text{----------------- (14)}$$

In practice, the efficiency of class A power amplifier is less than 50% due to losses in the transformer winding.

DRAWBACKS:

(1) Total harmonic distortion is very high.

(2) The output transformer is subject to saturation problem due to the dc current in the primary.

PUSH-PULL AMPLIFIER:

The distortion introduced by the non-linearity of the dynamic transfer characteristic may be eliminated by a circuit known as a known as push-pull configuration. It employs two active devices and requires input signals 180 degrees out of phase with each other.

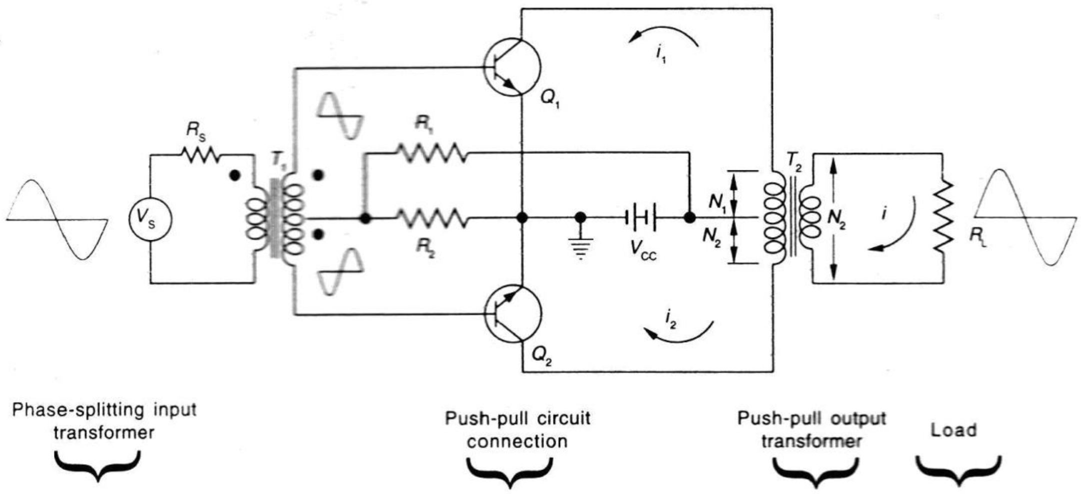

Fig. 1 Transformer-coupled class-B push-pull amplifier

The above figure shows a transformer coupled push-pull amplifier. The circuit consists of two centre tapped transformers T_1 & T_2 and two identical transistors Q_1 and Q_2.The input transformer T_1 does the phase splitting. It provides signals of opposite polarity to the transistor inputs. The output transformer T_2 is required to couple the ac output signal from the collector to the load.

On application of a sinusoidal signal, one transistor amplifies the positive half-cycle of the input, whereas the other transistor amplifies the negative half cycle of the same signal. When a transistor is operated as class-B amplifier, the bias point should be fixed at cut-off so that practically no base current flows without an applied signal.

Consider an input signal (base current of the form $i_{b1} = I_{bm} Cos\omega t$ applied to Q_1 .

The output current of this transistor is given as,

$$i_1 = I_C + B_0 + B_1 Cos\omega t + B_2 Cos2\omega t + B_3 Cos3\omega t + --- \quad \text{---------} (1)$$

The corresponding input signal to Q_2 is

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

The output current of this transistor is obtained by replacing ωt by $(\omega t + \pi)$ in expression for i_1. i.e.

$$i_2(\omega t) = i_1(\omega t + \pi) \text{ ------------------ (2)}$$

$$i_2 = I_C + B_0 + B_1 Cos(\omega t + \pi)$$

$$= I_C + B_0 - B_1 Cos\omega t + B_2 Cos2\omega t - B_3 Cos3\omega t + ------- \text{ (3)}$$

As illustrated in the above fig., the current i_1 & i_2 are in opposite directions through the output transformer windings. The total output current is the proportional to the difference between the collector currents in the two transistors. i.e.

$$i = k(i_1 - i_2) = 2k(B_1 Cos\omega t + B_3 Cos3\omega t + --------) \text{ -------- (4)}$$

This expression shows that a push-pull circuit cancels out all even harmonics in the output and will leave the third harmonic as the principal source of distortion. This is true only when the two transistors are identical. If their characteristics differ appreciably, the even harmonics may appear.

ADVANTAGES OF PUSH-PULL SYSTEM:

Because no even harmonics are present in the output of a push-pull amplifier ,such a circuit will give more output per active device for given amount of distortion. Also, a push-pull arrangement may be used to obtain less distortion for given power output per transistor.

It can be noticed that the dc component of the collector current oppose each other magnetically in the transformer core. This eliminates any tendency towards core saturation and consequent non-linear distortion that might arise from the curvature of the magnetization curve.

Another advantage of this system is that the effects of ripple voltages that may be contained in the power supply because of inadequate filtering will be balanced out. This cancellation results because the currents produced by this ripple voltage are in opposite directions in the transformer winding and so will not appear in the load.

CLASS-B AMPLIFIER

The circuit for the class-B push pull system is the same as that for the class A system except that the devices are biased approximately at cut-off. The above circuit (class A) operates in class B if R_2 =0 because a silicon transistor is essentially at cut –off if the base is shorted to the emitter.

ADVANTAGES OF CLASS B OPERATION

(1) It is possible to obtain greater power output

(2) Efficiency is higher

(3) Negligible power loss at no signal.

DRAWBACKS OF CLASS B AMPLIFIER

(1) Harmonic distortion is higher

(2) Self bias can't be used

(3) Supply voltage must have good regulation

POWER CONSIDERATION.

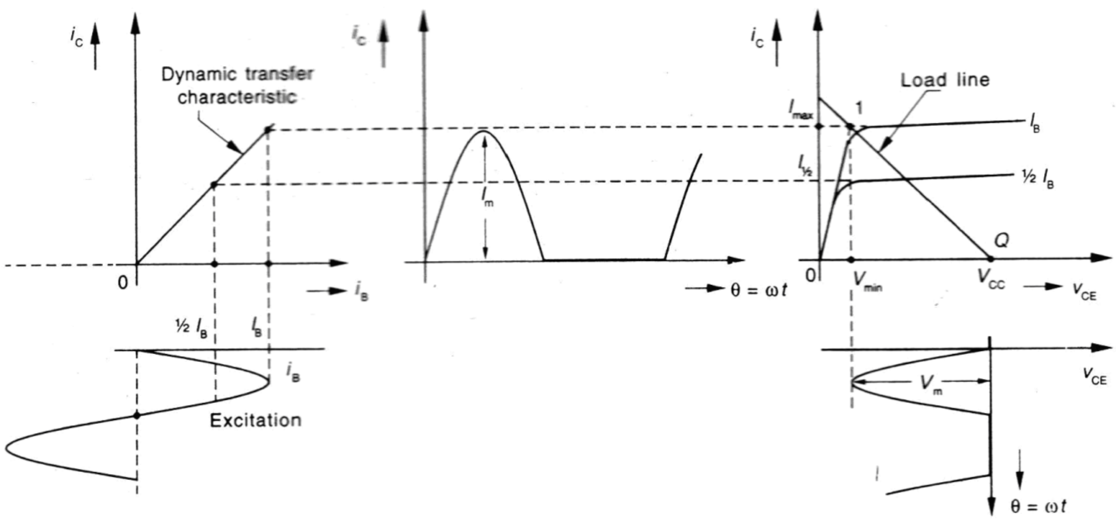

Fig. 2 Graphical construction for determining the output waveforms of a single class-B transistor stage

To investigate the power conversion efficiency of the system, it is assumed that the output characteristics are equally spaces for equal intervals of excitation, so that the dynamic transfer curve is a straight line. It also assumes that the minimum current is zero. The graphical construction from which to determine the output current & voltage wave3shapes for a single transistor operating as a class B stage is indicated in the above figure. Note that for sinusoidal excitation, the output is sinusoidal during one half of each period and is zero during the second half cycle. The effective load resistance is $R''_L = \left(\frac{N_1}{N_2}\right)^2 R_L$ where N_1 represents the number of primary turn to the center tap.

The waveform illustrated in the above figure represents one transistor Q_1 only. The output of Q_2 is, of course, a series of sine loop pulses that are 180 degrees out of phase with those of Q_1.The load current, which is proportional to the difference between the two collector currents, is therefore a perfect sine wave for the ideal conditions assumed. The power output is

$$P = \frac{I_m I_m}{2} = \frac{I_m (V_{CC} - V_{min})}{2} \quad \text{-------------------------- (1)}$$

The corresponding direct collector current ion each transistor under load is the average value of the half sine loop since $I_{dc} = \frac{I_m}{\pi}$ for this waveform, the dc input power from the supply is,

$$P_i = 2\frac{I_m V_{CC}}{\pi} \quad \text{----------------------- (2)}$$

The factor 2 in this expression arises because two transistors are used in the push-pull system. From equations (1) and (2) ,

$$\eta = \frac{P_0}{P_i} X100 = \frac{\pi}{4}\frac{V_m}{V_{CC}} = \frac{\pi}{4}\left(1 - \frac{V_{min}}{V_{CC}}\right) X100\%$$

Since $V_{min} \angle\angle V_{CC}$

$$\eta = \frac{\pi}{4} X100\% = 78.5\% \quad \text{---------------------- (3)}$$

The large value of η results from the fact that there is no current in a class B system if there is no excitation, where as there is a drain from the power supply in class A system even at zero signal.

POWER DISSIPATION

The power dissipation P_C in both transistors is the difference between the ac power output and dc power input.

$$P_C = P_{dc} - P_{ac} = P_i - P_0$$

$$= \frac{2}{\pi} V_{CC} I_m - \frac{V_m I_m}{2}$$

$$= \frac{2}{\pi} V_{CC} \frac{V_m}{R'_L} - \frac{V_m{}^2}{2R_L'} \quad \text{---------------------------- (5)}$$

This equation shows that the collector dissipation is zero at no signal $(V_{m=} = 0)$,

Rises as V_m is increases and passes through a maximum at $V_m = \frac{2V_{CC}}{\pi}$.

MAXIMUM POWER DISSIPATION

The condition for maximum power dissipation can be found by differentiating eq.(5) wrt V_m and equating it to zero.

$$\frac{dP_C}{dV_m} = \frac{2}{\pi}\frac{V_{CC}}{R_L{}'} - \frac{2V_m}{2R_L{}'} = 0$$

$$\frac{V_m}{R_L{}'} = \frac{2}{\pi}\frac{V_{CC}}{R_L{}'}$$

$$\therefore V_m = \frac{2}{\pi}V_{CC} \quad \text{----------------------------------- (6)}$$

Substituting the value of V_m in eq.(5), we get

$$\text{P } P_{C,\max} = \frac{2}{\pi}\frac{V_{CC}}{R_L{}'}\left(\frac{2}{\pi}V_{CC}\right) - \left(\frac{2}{\pi}V_{CC}\right)^2 X \frac{1}{2R_L{}'}$$

$$= \frac{4V_{CC}{}^2}{\pi^2 R_L{}'} - \frac{2}{\pi^2}\frac{V_{CC}{}^2}{R_L{}'} = \frac{2}{\pi^2}\frac{V_{CC}{}^2}{R_L{}'} \quad \text{------------- (7)}$$

Output power, $P_0 = \dfrac{V_m{}^2}{2R_L{}'}$

When $V_m = V_{CC}$

$$P_{0,\max} = \frac{V_{CC}{}^2}{2R_L{}'} \quad \text{--- (8)}$$

Equation (7) can be written as

$$P_{C,\max} = \frac{4}{\pi^2}\left(\frac{V_{CC}{}^2}{2R_L{}'}\right) = \frac{4}{\pi^2}P_{0,\max}$$

$$P_{C,\max} = \frac{4}{\pi^2}P_{0,\max} = 0.4P_{0,\max} \quad \text{---------------------- (9)}$$

Equation (9) gives the maximum power dissipated by both the transistors and therefore the maximum power dissipation per transistor is, $\dfrac{P_{C,\max}}{2}$.

$$\therefore P_{C,\max} \text{ per transistor} = \frac{4}{\pi^2}\frac{P_{0,\max}}{2} = 0.2P_{0,\max} \quad \text{----- (10)}$$

If, for e.g. 10W maximum power is to be delivered from a class B push-pull amplifier to the load, then power dissipation ratio of each transistor should be 0.2 X 10W=2W.

HARMONIC DISTORTION

The output of a push-pull system always possesses mirror symmetry, so that $I_C = 0, I_{\max} = -I_{\min}$ & $I_{\frac{1}{2}} = -I_{-\frac{1}{2}}$

We know that $$B_0 = \frac{1}{6}\left[I_{\max} + 2I_{\frac{1}{2}} + 2I_{-\frac{1}{2}} + I_{\min} \right] - I_C$$

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

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

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

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

When $I_C = 0, I_{\max} = -I_{\min}$ & $I_{\frac{1}{2}} = -I_{-\frac{1}{2}}$, the above equations reduce to

$$B_0 = B_2 = B_4 = 0 \quad \text{------------------------ (11)}$$

$$B_1 = \frac{2}{3}\left(I_{\max} + I_{\frac{1}{2}} \right) \quad \text{------------------------ (12)}$$

$$B_3 = \frac{1}{3}\left(I_{\max} - 2I_{\frac{1}{2}} \right) \text{------------------------ (13)}$$

Note that there is no even harmonic distortion. The major contribution to distortion is the third harmonic and is given by ,

$$D_3 = \frac{|B_3|}{|B_1|} \times 100\% \quad \text{------------------------- (14)}$$

The output power taking distortion into account is given by

$$P_0 = (1 + D_3)^2 \frac{B_1^{\,2} R_L^{'}}{2} \text{ --------------------- (15)}$$

SPECIAL CIRCUITS

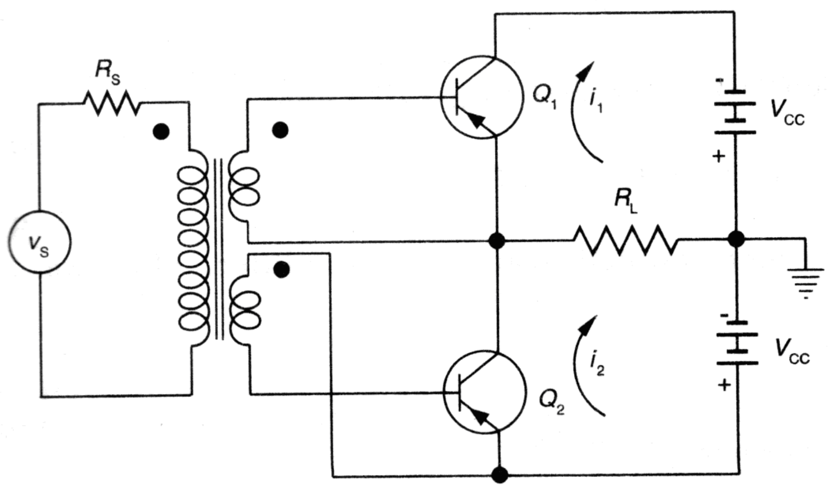

Fig 3

A circuit that avoids using the output transformer is shown above. This configuration requires a power supply whose centre tap is grounded. Here, high powered transistors are used. They have a collector to emitter output impedance in the order of 4Ω to 8Ω.This allows single ended push-pull operation. The voltage developed across the load is again due to the difference in collector currents $i_1 - i_2$, so this is a true push-pull application.

PROBLEMS

P1. Calculate the input power and efficiency of the amplifier shown below for an input Voltage resulting in a base current of 10mA peak. Also calculate the power dissipated by the transistor.

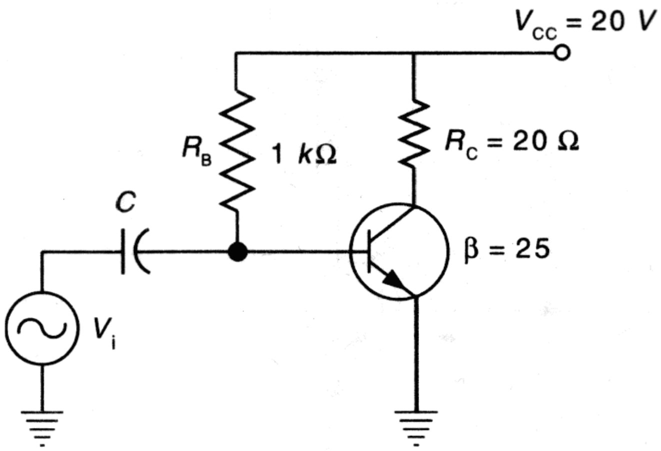

Fig. 4

SOLN: The Q point for the given circuit is determined as follows.

$$I_B = \frac{V_{CC} - V_{BE}}{R_B} = \frac{20 - 0.7}{1X10^3} = 19.3mA$$

$$I_C = \beta I_B = 25X19.3mA = 482.5mA$$

$$V_{CE} = V_{CC} - I_C R_C = 20 - 482.5X10^{-3} X20 = 10.35V$$

$$I_c(peak) = \beta I_B(peak) = 25X10mA = 250mA$$

$$P_{ac} = \left(\frac{I_{CPEAK}}{\sqrt{2}}\right) = 0.625W$$

Input power, $P_{dc} = V_{CC} I_C = 20X482.5X10^{-3} = 9.6W$

Efficiency, $\eta = \frac{P_{ac}}{P_{dc}} = \frac{0.625}{9.65} X100\% = 6.48\%$

Power dissipated by the transistor, $P_C = P_{dc} - P_{ac} = 9.65 - 0.625 = 9.025W$

P2: A class A power amplifier with a direct coupled load has a collector efficiency of 30% and delivers a power input of 10W.Find (a) the dc power input (b) the power dissipation `of full output and (C) the desirable power dissipation rating of the BJT.

SOLN: Given $P_{ac} = 10W, \eta = 30\% = 0.30$

(a) $\eta = \frac{P_{ac}}{P_{dc}}$

$$\therefore P_{dc} = \frac{P_{ac}}{\eta} = \frac{10}{0.3} = 33.33W$$

(b) Dissipation at full output, $P_C = 33.33 - 5 = 28.33W$

(c) Dissipation at no output, $P_C^{'} = P_{dc} = 33.33W$

$\therefore$ BJT rating = 33.33W

P3: A BJT supplies 0.85 W to a 4KΩ load. The zero signal dc collector current is 31 mA. Determine the percent second harmonic distortion.

SOLN: Given $P = 0.85W, I_{C,Zero} = 31mA$

$R_L = 4k\Omega, I_{C,signal} = 34mA$

Using the dynamic characteristics of the transistor,

$i_c = G_1 i_b + G_2 i^2{}_b$ We have

$B_0 = I_C signal - I_C nosignal$

=34-31=3mA

Power, $P = \frac{B_1{}^2 R_L}{2} or B_1{}^2 = \frac{2P}{R_L}$

$$B_1{}^2 = \frac{2X0.85}{4K} = 430X10^{-6}$$

Or $B_1 = 20.6mA$

The second harmonic distortions,

$$D_2 = \frac{|B_2|}{|B_1|} X100\% = \frac{3mA}{20.6mA} X100\% = 14.6\%$$

P4. Design a class B push pull circuit to deliver 200mW to a 4Ω load. Output transformer efficiency is 70%., V_{CE}=25V, average rating of the transistor to be used is 165Mw at $25^0 C$ .Determine V_{CC} , collector to collector resistance R_{CC},

SOLN: Given P_{ac}=200mW, R_L=4Ω, $\eta = 0.7$, $V_{CE(max)}$ =25V, P_{trans}=165mW, at 25^0C,R_E=10Ω.

Assume that the given power delivered to the load is maximum.

$P_{ac} = \frac{P_{ac\max}}{\eta} = \frac{200}{0.7} = 285.714mW$ on primary of transformer.

Maximum voltage rating per transistor is $2V_{CC}$.

V_{CC} =12.5V.

Let V_{CC}=12V

$$P_{acprimary} = \frac{1}{2}\frac{V_{CC}^{\ 2}}{R'_L}$$

$$R'_L = \frac{1}{2}\frac{V_{CC}^{\ 2}}{P_{acprimary}} X \frac{(12)^2}{285.714X10^{-3}} = 252\Omega$$

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

$$n^2 = \frac{R_L}{R'_L} = \frac{4}{252} = 0.125$$

$$\therefore \frac{N_1}{N_2} = 8$$

P5: A single stage, class A amplifier has V_{CC}=20V, V_{CEQ} = 10V, I_{CQ}= 600mA, and ac output current is varied by $\pm 300mA$ with the ac input signal. Determine the (a) power supplied by the dc source to the amplifier circuit (b) dc power consumed by the load resistor (c) ac power developed across the load resistor (d) dc power delivered to the transistor (e) dc power wasted in the transistor collector (f) overall efficiency (g) collector efficiency.

SOLN: Given V_{CC} = 20V, V_{CEQ}=10V, I_{CQ} = 600Ma, R_L = 16Ω, I_{max}= 300Ma

(a) Power supplied by the dc source to the amplifier circuit is given by

$P_{dc} = V_{CC} .I_{CQ}$=20X0.6=12W

(b) DC power consumed by the load resistor is given by

$P_{Ldc} = (I_{CQ})^2 R_L = (0.6)^2X16 = 5.76$ W

(c) AC power developed across the load resistor is P_{ac}.

$$I = \frac{\text{Im}}{\sqrt{2}} = \frac{0.3}{\sqrt{2}} = 0.212$$

$$P_{ac} = I^2 R_L = (0.212)^2 16 = 0.72W$$

(d) DC power delivered to the transistor’

$$P_{tr(dc)} = P_{dc} - P_{Ldc} = 12 - 5.76 = 6.24W$$

(e) DC Power wasted in the transistor collected is

$$P_{dc} = P_{tr(dc)} - P_{ac} = 6.24 - 0.72 = 5.52W$$

(f) Overall efficiency, $\eta = \frac{P_{ac}}{P_{dc}} = \frac{0.72}{12} = 0.06 = 6\%$

(g) Collector efficiency, $\eta_C = \frac{P_{ac}}{P_{tr(dc)}} = \frac{0.72}{6.24} = 11.5\%$