$$\eta = \frac{P_{out\,(ac)}}{P_{in\,(dc)}} \times 100 = \frac{0.434}{1.4} \times 100 = 31\% \textbf{ Ans.}$$

16.8. CLASS B POWER AMPLIFIERS

In class B operation the transistor is so biased that zero-signal collector current is zero. Hence class B operation does not need any biasing system. The operating point is set at cutoff, as illustrated in Fig. 16.17. It remains forward biased for only half-cycle of the input signal *i.e.* its conduction angle is 180°.

As illustrated in Fig. 16.17, during the positive half cycle of the input ac signal, the circuit is forward biased and, therefore, collector current flows. On the other hand, during negative half cycle of the input ac signal, the circuit is reverse biased and no collector current flows.

16.8.1. Power and Efficiency Calculations. Input dc power, $P_{in\ (dc)} = V_{CC}\ I_{dc}$ where I_{dc} is the average or direct current taken from the collector supply.

$\frac{2.5 I_{CQ} \times 2V_{CC}}{8\, V_{CC}\, I_{CQ}} = \frac{1}{2} = 50\%$

$I_{CEQ\,max} = 2 I_{CQ}$

$min = 0$

$V_{CE\,min} = 0$

$V_{CEQ\,max} = 2V_{CC}$

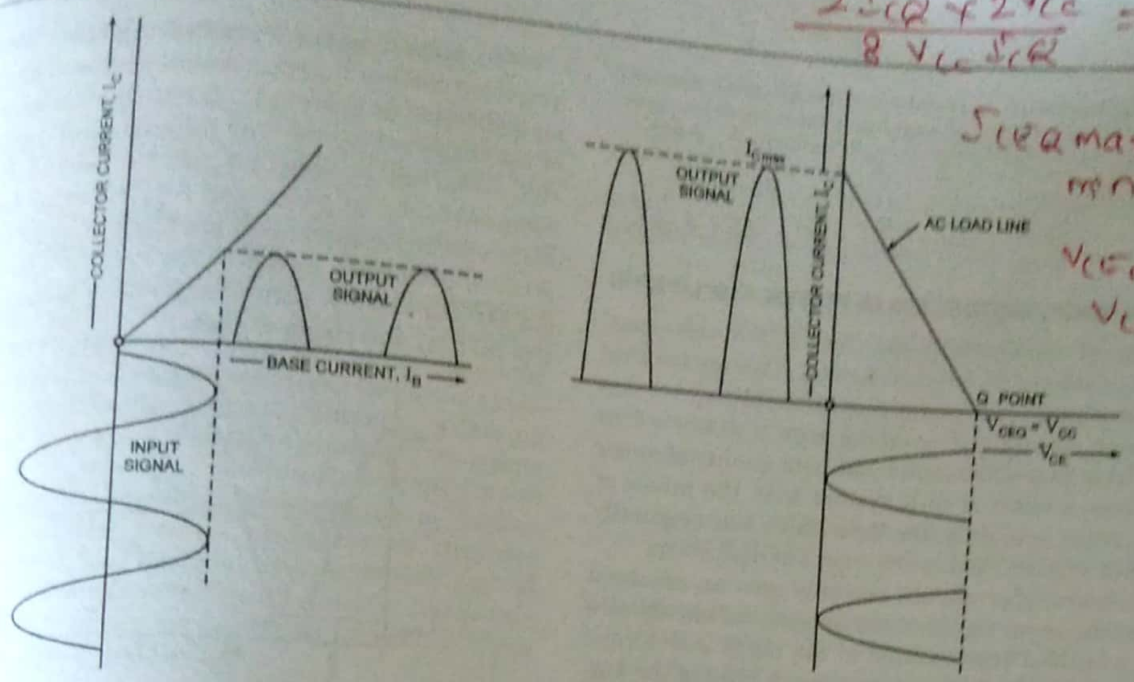

Fig. 16.17. *Class B Operation*

If $I_{C\,max}$ is the maximum or peak value of collector output current, then

$$I_{dc} = \frac{1}{2\pi}\int_0^{\pi} I_{C\,max} \sin\theta\, d\theta = \frac{I_{C\,max}}{2\pi}\left[-\cos\theta\right]_0^{\pi} = \frac{I_{C\,max}}{\pi}$$

$$\because i_C = I_{C\,max} \sin\theta \text{ for } 0 < \theta < \pi$$

$$P_{in\,(dc)} = \frac{V_{CC}\, I_{C\,max}}{\pi} \quad ...(16.20)$$

RMS value of collector current, $I_{C\,rms} = \frac{I_{C\,max}}{\sqrt{2}}$

RMS value of output voltage, $V_{rms} = \frac{V_{CC}}{\sqrt{2}}$

Hence output power during half cycle,

$$P_{out\,(ac)} = \frac{1}{2}\,\frac{I_{C\,max}}{\sqrt{2}} \times \frac{V_{CC}}{\sqrt{2}} = \frac{I_{C\,max}\, V_{CC}}{4} \quad ...(16.21)$$

In above equation factor $\frac{1}{2}$ is used because power is developed during one half cycle only.

DC power loss in load,

$$P_{R_C\,(dc)} = I_{dc}^2\, R_C = \left(\frac{I_{C\,max}}{\pi}\right)^2 R_C \quad ...(16.22)$$

DC power loss in collector region or transistor

$$= P_{in\,(dc)} - P_{R_C\,(dc)} - P_{out\,(ac)} \quad ...(16.23)$$

Overall efficiency,

$$\eta_{overall} = \frac{P_{out\,(ac)}}{P_{in\,(dc)}} = \frac{I_{C\,max}\, V_{CC}/4}{I_{C\,max}\, V_{CC}/\pi}$$

$$= \frac{\pi}{4} = 0.785 \text{ or } 78.5\% \quad ...(16.24)$$

Conclusions. 1. Severe distortion occurs because of absence of negative half cycle from the output.

2. As average current in class B operation $\frac{(I_{C\,max})}{\pi}$ is less than that in class A operation, so power dissipation is less and consequently overall efficiency is high [78.5% when peak input signal makes $V_{CE\,min} = 0$]. In general, overall efficiency is given as

$$\eta_{overall} = 78.5\left[1 - \frac{V_{CE\,min}}{V_{CC}}\right]\% \quad ...(16.25)$$

3. Zero signal input represents the best condition for class B operation as collector current is zero. This is quite contrary to class A operation. In class B operation the transistor dissipation increases with increased input signals.

4. Half sine-wave type of collector current contains very pronounced even harmonics (particularly the second one). Such impulses can be made useful either by using push-pull arrangement or by employing tuned amplifiers.

Example 16.9. Determine the overall efficiency of class B power amplifier when $V_{CC} = 20$ V and $V_{CE\,min} = 2.5$ V.

Solution : From Eq. (16.25)

$$\text{Overall efficiency, } \eta_{overall} = 78.5\left[1 - \frac{V_{CE\,min}}{V_{CC}}\right]\%$$

$$= 78.5\left(1 - \frac{2.5}{20}\right) = 68.69\% \textbf{ Ans.}$$

Example 16.10. For a class B amplifier providing a 20 V peak signal to 16 Ω load (speaker) and a power supply of $V_{CC} = 30$ V, determine the input power, output power and circuit efficiency. [*A.M.I.E. Sec B. Electronic Circuits Summer 2005*]

Solution : Maximum value of output signal, $V_{CE\,max} = 20$ V

Maximum (or peak) value of collector or output current,

$$I_{C\,max} = \frac{V_{CE\,max}}{R_L} = \frac{20}{16} = 1.25 \text{ A}$$

Input power,

$$P_{in(dc)} = \frac{V_{CC}\, I_{C\,max}}{\pi} = \frac{30 \times 1.25}{\pi} = 11.94 \text{ W} \quad \textbf{Ans.}$$

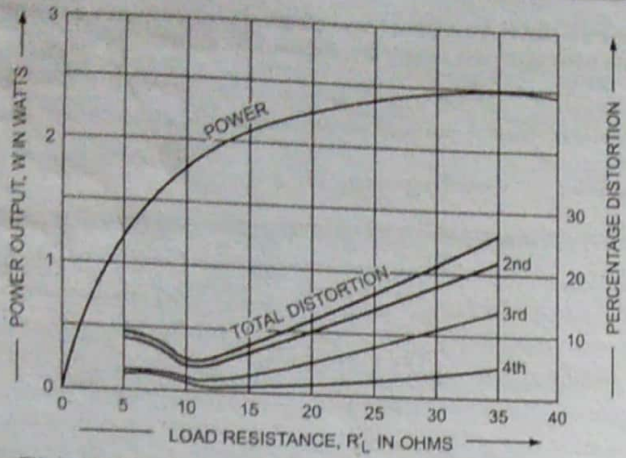

Fig. 16.19. ***Power Output and Distortion For a Typical Transistor Amplifier As a Function of Load Resistance, R'_L***

16.11. CLASS AB POWER AMPLIFIERS

In class AB power amplifiers, the biasing circuit is so adjusted that the operating point Q lies near the cutoff voltage. During a small portion of negative half cycle and for complete positive half cycle of the signal, the

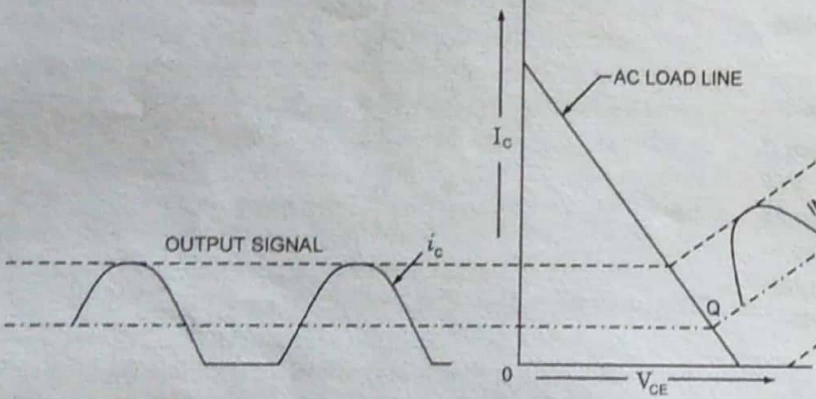

Fig. 16.20. ***Class AB Operation***

input circuit remains forward biased and hence collector current flows. But during a small portion (less than half cycle) of the negative cycle, the input circuit is reverse biased and, therefore, no collector current flows during this period. Class AB operation needs a push-pull connection to achieve a full output cycle.

16.12. CLASS C POWER AMPLIFIERS

A class C power amplifier is biased to operate for less than 180° of the input signal cycle, as shown in Fig. 16.21. The tuned circuit in the output, however, will provide a full cycle of output signal for the fundamental or resonant frequency of the tuned circuit (L and C tank circuit) of the output. The use of such amplifiers is, therefore, limited for a fixed frequency, as occurs in communication circuits. Operation of a class C circuit is not intended primarily for large signal or power amplifiers.

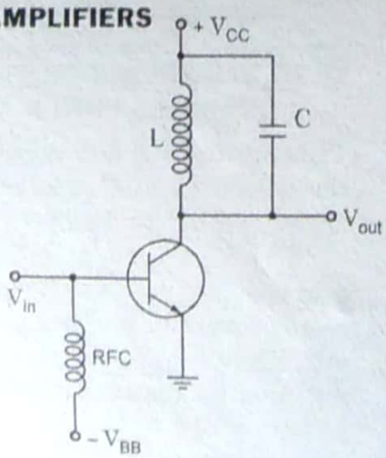

Fig. 16.21. ***Class C Amplifier Circuit***

16.13. CLASS D POWER AMPLIFIERS

Historically, audio-amplifiers have been configured as class A, class B or class AB and the art of design is well known. Also well-known is the poor efficiency of these amplifiers compared to that of class D amplifiers. Whereas the theoretical best efficiency for class B amplifiers is 78.5%, the practical upper limit is more nearly 70% when driving a purely resistive load. But when driving real speaker loads which can have power factor angles of 60° or more, efficiency can come down to 55% or less. Class D amplifiers, however, can attain efficiencies of 90%, and with careful component choices can exceed 95% even. Moreover, the power factor of the load does not affect the on-state power losses in the MOSFET switches normally used in such amplifiers. Using class D techniques, amplifiers capable of delivering several hundred watts to the load can be designed using small, inexpensive, stamped heat sinks. Efficiency of class D amplifiers opens the possibility for powerful, small, light amplifiers with good sound quality to be designed today.

A class D amplifier is designed to operate with digital or pulse-type signals. It is necessary, however, to convert any input signal into a pulse-type waveform before using it to drive a large power load and to convert the signal back to a sinusoidal-type signal to recover the original signal. Figure 16.22 illustrates how a sinusoidal signal may be converted into a pulse-type signal using some form of sawtooth or chopping waveform to be applied with the input into a comparator type op-amp

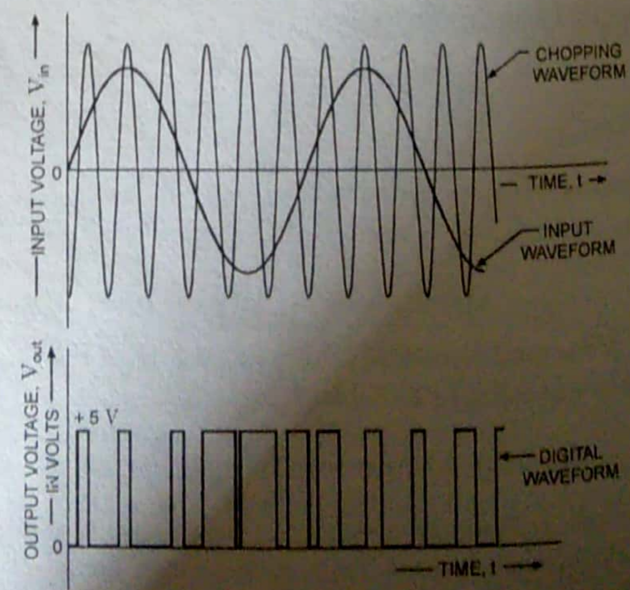

Fig. 16.22. ***Chopping of Sinusoidal Waveform For Generating Digital Waveform***

circuit* so that a representative pulse type signal is generated. While the letter D is used to describe the next type of bias operation after class C, the D could also be considered to stand for "Digital" since that is the nature of signals provided to the class D amplifier. Figure 16.23 shows a block diagram of the unit required to amplify the digital signal and then convert

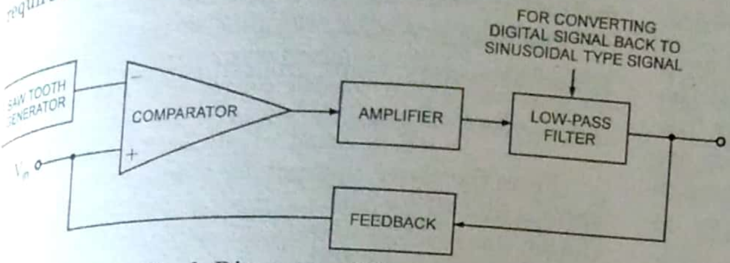

Fig. 16.23. *Block Diagram of Class D Power Amplifier*

...ck to the sinusoidal type signal employing a low-pass ...ter. Since the amplifier's transistor devices used to ...vide the output are basically either off or on, they ...vide current only when they are turned on, with little ...wer loss due to their low on-voltage. Since most of ...e power supplied to the amplifier is transferred to ...load, the efficiency of the circuit is typically very ... Power MOSFET devices have been quite popular ...the driver devices for the class D power amplifier.

Class D power amplifier efficiency is largely ...rmined by the ratio of the load resistance to the ...al dc loop resistance which is the sum of the $r_{DS\,(ON)}$ ...e MOSFETs, wire resistances (including the output ...r and current sense resistor if used, and the load ...stance. For highest efficiency, the MOSFET $r_{DS\,(ON)}$ ...stances, shunt and filter resistances should be small ...pared to the load resistance. In audio class D ...cations, MOSFETs are employed instead of IGBTs ...BJTs because the switching frequencies required to ...distortion low at 20 kHz signal frequencies can exceed ...kHz and neither the bipolar power transistors or ...Ts switch efficiently at such high frequencies.

...lthough class A, class AB, and class B, amplifiers ...mostly employed as power amplifiers, class D ...ifiers are popular because of their very high ...ency. Class C amplifiers do find use in tuned ...ts as employed in communications.

... PUSH-PULL AMPLIFIERS

...ady mentioned in Art. 16.4, *double-ended or push-...* ...plifier makes use of two identical transistors in ...e stage. It consists of two loops in which the tran-... ...ollector currents flow in opposite directions but ...the load. Push-pull amplifiers eliminate all of ...e drawbacks listed in Art. 16.7.5.

...push-pull amplifier is a power amplifier and is ...tly used in the output stages of electronic ... It is employed whenever high output at high ...y is required. The audio power amplifiers used in transistor receivers, tape-recorders, record-players, public address systems etc. make use of such circuits. These systems are usually operated by batteries or cells and, therefore, amplifier efficiency is of prime importance.

16.14.1. Basic Principle of Working of Push-Pull Amplifier. The basic principle on which a push-pull amplifier operates is that the input signal is converted before amplification, into two separate signals, which are identical except for a 180° phase difference. Each of these signals is applied as the input to one of the transistors of the push-pull amplifier. Since the inputs to the two transistors are 180° out of phase, so the output of the transistors. The output transformer is connected in the collector circuits of the transistors in such a way that the collector currents of the two transistors combine to provide an overall signal having the same waveform as the original input signal. The magnitude of this combined output signal is larger than the input signal. Push-pull amplifiers can be operated in class A, class AB or class B mode.

16.15. CLASS A PUSH-PULL AMPLIFIER

A class A push-pull amplifier circuit is shown in Fig. 16.24. By class A push-pull amplifier means that current flows in the output of the active device (each transistor) for the whole of the input cycle.

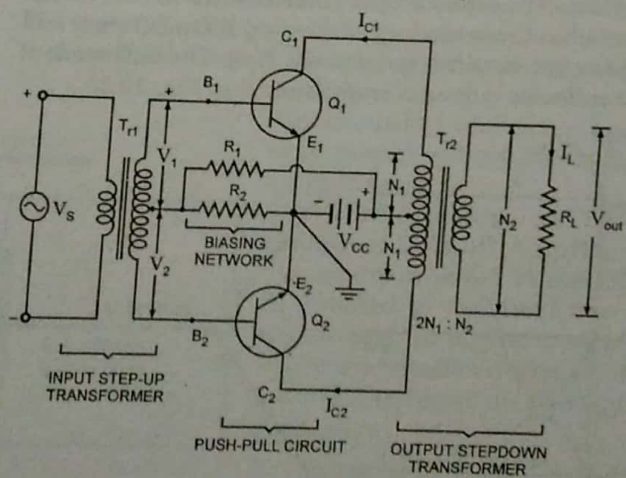

Fig. 16.24. *Push-Pull Amplifier Circuit*

16.15.1. Circuit Arrangement. The circuitry of a typical push-pull amplifier is shown in Fig. 16.24. As already mentioned, push-pull amplifier uses two identical transistors, say Q_1 and Q_2. The emitter terminals of the two transistors Q_1 and Q_2 connected together. The input signal is applied to the inputs of two transistors through centre-tapped step-up transformer T_{r1} which provides opposite polarity signals to the two transistors. The collector terminals of both

*...type op-amp circuit will be discussed in Art. 29.5.

the transistors are connected to end terminals of centre-tapped primary of output transformer T_{r_2}. The power supply V_{CC} is connected between the emitter terminals and the centre-tap of primary of output transformer. Resistors R_1 and R_2 are used to provide the proper bias for the circuit. The load R_L is connected across the secondary of the output transformer T_{r_2}. The turn-ratio ($2N_1 : N_2$) of the output transformer is chosen so as to match the load with the output impedance of the amplifier and therefore, transfer maximum power. The quiescent currents of the two transistors, which are equal in magnitude, flow in opposite directions through each half of primary of the output transformer T_{r_2}, so no saturation of the magnetic core occurs.

16.15.2. Circuit Operation. When the base current of one transistor is being driven positive with respect to the quiescent point Q, the collector current increases, thus causing a decrease in collector potential relative to ground. At the same time, however, a reverse action takes place in the base circuit of the second transistor, *i.e.* base current decreases causing a drop in the collector current with a consequent rise in collector potential w.r.t. ground. This means that the ac current flowing through the transformer primary winding is in the same direction. As I_{C_1} increases (*i.e.* pulls), the current I_{C_2} decreases (*i.e.* pushes). Hence the name *push-pull amplier*. The overall operation results in ac voltage induced in the secondary of the output transformer and thus ac power is delivered to the load. The difference of two collector currents is illustrated in Fig. 16.25.

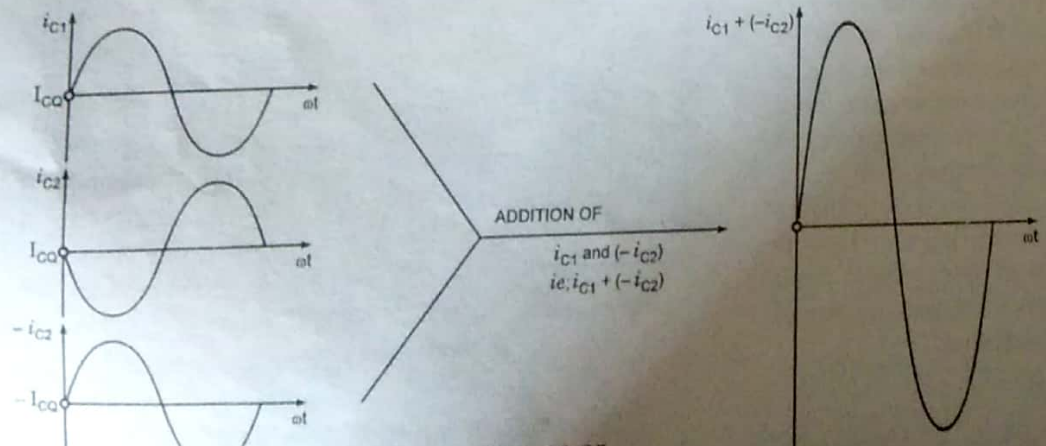

Fig. 16.25

16.15.3. **Distortion.** In view of the fact that the load current in the secondary of the output transformer is proportional to the difference of collector currents, it follows that the harmonic content will be less than it is in either of the collector currents because of cancellation effects. Thus the push-pull arrangement yields much less distortion in the output. This is illustrated below.

The base currents i_{b_1} and i_{b_2} of transistors Q_1 and Q_2 respectively are expressed as

$$i_{b_1} = I_b \sin(\omega t) \text{ and } i_{b_2} = I_b \sin(\omega t + \pi)$$

Their collector currents are expressed as

$$i_{C_1} = I_C + I_1 \sin \omega t + I_2 \sin 2\omega t + I_3 \sin 3\omega t + \ldots$$

$$i_{C_2} = I_C + I_1 \sin(\omega t + \pi) + I_2 \sin(2\omega t + 2\pi) + I_3 \sin(3\omega t + 3\pi)$$

$$= I_C - I_1 \sin \omega t + I_2 \sin 2\omega t - I_3 \sin 3\omega t + \ldots$$

and $$i_{C_1} - i_{C_2} = 2 I_1 \sin \omega t + 2 I_3 \sin 3\omega t + \ldots$$

The output voltage induced in the output transformer secondary, being proportional to $(i_{C_1} - i_{C_2})$,

$$v_{out} = K(i_{C_1} - i_{C_2})$$

$$= 2K[I_1 \sin \omega t + I_3 \sin 3\omega t + I_5 \sin 5\omega t + \ldots]$$

From the above equation for output voltage v_{out} it is obvious that all even harmonics are eliminated. This conclusion was reached on the assumption that the two transistors are identical. If their characteristics differ appreciably, the appearance of even harmonics is not ruled out.

16.15.4. Advantages

1. Because of absence of even harmonics in the output of the push-pull amplifier, such a circuit gives more output per active device for a given amount of distortion or less distortion for a given power output per transistor.
2. As already mentioned earlier, the dc components of the collector current oppose each other magnetically in the transformer core. This eliminates any tendency toward core saturation and consequent non-linear distortion that may arise from the curvature of the transformer magnetization curve.
3. Another advantage of this system is that the effects of ripple voltage that may be contained in the power supply because of inadequate filtering will be balanced out. This cancellation results because the currents produced by the ripple voltage are in opposite directions in the transformer winding, and so will not appear in the load. Of curse, the power supply hum will also act on the voltage-amplifier stages, and so will be part of the input to the power stage. This hum will not be eliminated by the push-pull circuit.

16.15.5. Disadvantages. The drawbacks of push-pull amplifiers are (*i*) requirement of two identical* or matched pair transistors (*ii*) need of use of driver stage to furnish two equal and opposite voltages at the input and (*iii*) need of bulky and expensive transformer.

16.16. CLASS B PUSH-PULL AMPLIFIER

The circuitry for the class B push-pull operation is the same as that for the class A operation except that the devices are biased at cutoff. The transistor circuit of

* If the parameters of the two transistors used in the circuit are not identical, there will be unequal amplification of the two halves of input signal.

Fig. 16.24 operates as class B if $R_2 = 0$ because a transistor ...entially at cutoff if the base is shorted to the emitter.

The advantages of class B operation over class A operation are given below :

1. It is possible to obtain greater power output— class B push-pull amplifier provides practically 4-times the power supplied by a single-ended amplifier provided load resistance remains the same.
2. It gives higher operating efficiency (theoretical 78.5%). It is primarily due to the fact that no power is drawn by the circuit under zero-signal condition.

Because of above advantages, a push-pull class B ...istor circuit is preferred in systems where the ...r supply is limited, such as those operating from ...cells or a battery. The automatic cancellation of ...en-order harmonics from the output makes class ...sh-pull amplifiers highly desirable for communi... ...sound equipment.

The drawbacks of class B push-pull amplifiers are that ...armonic distortion is higher, self-bias cannot be used, ...the supply voltages must have good regulation.

Class B push-pull amplifiers are widely employed ...dio-work in portable record-players, as stereo-am...ers and in high-fidelity radio receivers.

...16.1. **Circuit Arrangement.** Circuitry for a class ...push-pull amplifier is shown in Fig. 16.26. As illus...ted in the figure, the bases of the two CE-connected ...ntical transistors Q_1 and Q_2 have been connected to ...e opposite ends of the secondary of the input trans...mer T_{r1}. Load resistance R_L is coupled to the collec...

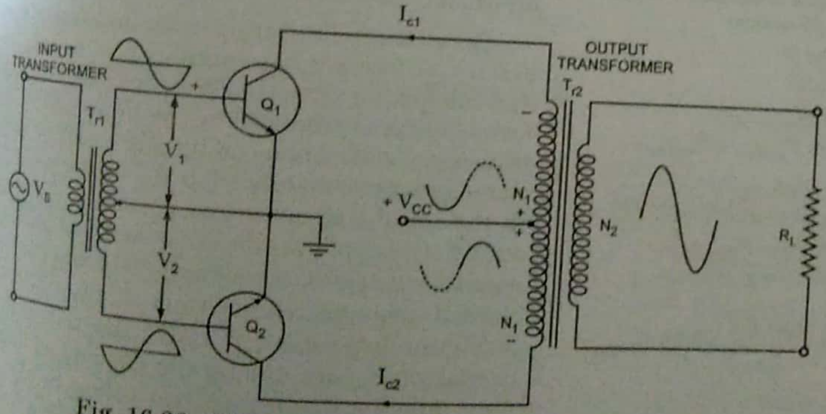

Fig. 16.26. ***Class B Push-Pull Amplifier***

...terminals of the two transistors through output ...former T_{r2}. The emitter terminals of the transis... ...connected to the centre tap of the secondary of ...put transformer T_{r1} while the supply V_{CC} is con... ...to the centre tap on the primary of output trans... ...This is done in order to have balanced circuits. ...ero-bias is required for cutoff, the two bases of ...transistors have been grounded.

...2. **Circuit Operation.** When the input signal is ...the centre-tapped secondary of the input transformer develops two signals which are identical but in phase opposition. The transistors, Q_1 and Q_2 are driven by these two signals. Thus when V_1 is going positive, V_2 is going negative, so that transistor Q_2 is being biased further off when transistor Q_1 is being biased on. As the collector current in Q_1 increases from zero, it produces a half sine wave of voltage across the upper half of the primary of the output transformer, as shown. When the positive half cycle of the input signal to Q_1 begins to go negative, the signal at Q_2 base is commencing to go positive. Thus, as Q_1 becomes biased off again, Q_2 is biased on and a half cycle of voltage waveform is generated across the lower primary winding of output transformer.

The effect of the two-half cycles in separate halves of the primary of output transformer is to produce a magnetic flux in the transformer core, which flows first in one direction and then in the opposite direction. This flux links with the secondary of the output transformer and generates a complete sine-wave output, which is passed on to the load. In the class B circuit, the two output transistors are said to be operating in push-pull.

As explained above, a full sine-wave is developed at the output of the transformer. When no signal is present, both transistors remain off, and thus no current is drawn from dc supply source V_{CC}. Hence there is no dissipation of power with zero-signal. Some power is dissipated in each transistor only while the transistor is conducting.

The load resistance (usually a loudspeaker) is connected across the secondary of the output transformer. The turn-ratio $2N_1 : N_2$ of the transformer is chosen so that load resistance R_L is matched with the output impedance of the transistor. Undermatched conditions, maximum power is delivered to the load by the amplifier.

16.16.3. Conversion Efficiency of Class B Amplifier. The power provided to the load R_L coupled to the amplifier is drawn from the dc power supply V_{CC} and is considered an input dc power. The input dc power is given as

$P_{in\,(dc)} = V_{CC}\, I_{dc}$ where I_{dc} is the average or direct current taken from the dc supply V_{CC}.

In class B operation the current drawn from a single power supply is a full-wave rectified signal, thus

$$I_{dc} = \frac{1}{\pi}\int_0^{\pi} I_{C\,max} \sin\theta\, d\theta = \frac{2\, I_{C\,max}}{\pi}$$

$$\text{Thus } P_{in\,(dc)} = \frac{2}{\pi} V_{CC}\, I_{C\,max} \quad \text{...(16.38)}$$

$$\text{AC power output, } P_{out\,(ac)} = V_{rms}\, I_{rms}$$

$$= \frac{V_{CC}}{\sqrt{2}} \cdot \frac{I_{C\,max}}{\sqrt{2}} = \frac{V_{CC}\, I_{C\,max}}{2} \quad \text{...(16.39)}$$

Total collector power dissipation for the two transistors,

$$= P_{in\,(dc)} - P_{out\,(ac)}$$

$$= \frac{2}{\pi} V_{CC} I_{C\,max} - \frac{V_{CC} I_{C\,max}}{2} = 2 I_{C\,max}\left(\frac{V_{CC}}{\pi} - \frac{V_{CC}}{4}\right)$$

Overall efficiency,

$$\eta_{overall} = \frac{P_{out\,(ac)}}{P_{in\,(dc)}} = \frac{V_{CC} I_{C\,max}/2}{2 V_{CC} I_{C\,max}/\pi}$$

$$= \frac{\pi}{4} = 0.785 \text{ or } 78.5\% \quad ...(16.40)$$

Example 16.13. A class B push-pull amplifier must deliver 10 W of audio-power to the output load. (*i*) If the output transformer is 80% efficient, what is the minimum power drain on the power supply under optimum conditions and (*ii*) what is the minimum average dissipation rating required for each transistor ?

Solution : Power delivered to load, $P_L = 10$ W

AC power output of amplifier,

$$P_{out\,(ac)} = \frac{P_L}{\text{Output transformer efficiency}} = \frac{10}{0.8} = 12.5 \text{ W}$$

Efficiency of a class B push-pull amplifier under optimum conditions, $\eta = 78.5\% = 0.785$

(*i*) Minimum power drain on the power supply

$$= P_{in\,(dc)} = \frac{P_{out\,(ac)}}{\eta} = \frac{12.5}{0.785} = 15.9 \text{ W} \quad \textbf{Ans.}$$

(*ii*) Minimum average power dissipation,

$$P_d = P_{in\,(dc)} - P_{out\,(ac)} = 15.9 - 12.5 = 3.4 \text{ W}$$

Minimum average dissipation rating required for each transistor

$$= \frac{P_d}{2} = \frac{3.4}{2} = 1.7 \text{ W} \quad \textbf{Ans.}$$

Example 16.14. A class B push-pull power amplifier is supplied with $V_{CC} = 50$ V. The signal swings the collector voltage down to $V_{min} = 5$ V. The total dissipation in both transistors is 40 W. Find the total power and conversion efficiency.

Solution : DC supply voltage, $V_{CC} = 50$ V

$V_{min} = 5$ V

Total power dissipation, $P_d = 40$ W

Also total power dissipation, $P_d = P_{in\,(dc)} - P_{out\,(ac)}$

$$\therefore 40 = \frac{2}{\pi} V_{CC} I_{C\,max} - \frac{I_{C\,max}}{2}(V_{CC} - V_{C\,min})$$

$$= I_{C\,max}\left[\frac{2 V_{CC}}{\pi} - \frac{V_{CC} - V_{C\,min}}{2}\right]$$

$$= I_{C\,max}\left[\frac{2 \times 50}{\pi} - \frac{50 - 5}{2}\right] = 9.33\, I_{C\,max}$$

$$\text{or } I_{C\,max} = \frac{40}{9.33} = 4.287 \text{ A}$$

Total power input,

$$P_{in\,(dc)} = \frac{2}{\pi} V_{CC} I_{C\,max} = \frac{2}{\pi} \times 50 \times 4.287$$

$$= 136.45 \text{ W} \quad \textbf{Ans.}$$

AC power output,

$$P_{out\,(ac)} = \frac{I_{C\,max}}{2}(V_{CC} - V_{min}) = \frac{4.4287}{2} \times (50 - 5)$$

$$= 99.65 \text{ W}$$

Conversion efficiency,

$$\eta = \frac{P_{out\,(ac)}}{P_{in\,(dc)}} \times 100 = \frac{99.65}{136.45} \times 100$$

$$= 73.03\% \quad \textbf{Ans.}$$

Example 16.15. Consider the idealised push-pull class B power amplifier shown in Fig. 16.24. Given that $R_2 = 0$, $V_{CC} = 20$ V, $N_2 = 2N_1$, $R_L = 20\ \Omega$ and the transistors have $h_{FE} = 20$. The input is sinusoid. For the maximum output signal at $V_{max} = V_{CC}$ determine (*i*) the output signal power, (*ii*) the collector dissipation in each transistor.

[*U.P.S.C. I.E.S. Electrical Engineering II 2006*]

Solution : Load seen by the transformer primary,

$$R_L' = R_L \times \left(\frac{N_1}{N_2}\right)^2 = R_L\left(\frac{N_1}{2N_1}\right)^2 = \frac{20}{4}\ \Omega = 5\ \Omega$$

Peak value of ac output current, $I_{max} = \dfrac{V_{max}}{R_L'} = \dfrac{V_{CC}}{R_L'}$

(*i*) Thus ac power output,

$$P_{out(ac)} = I_{rms}^2 R_L' = \frac{I_{max}^2}{2} R_L' = \frac{1}{2}\frac{V^2{}_{CC}}{R_L'}$$

$$= \frac{V_{CC}^2}{2R_L'} = \frac{(20)^2}{2 \times 5} = 40 \text{ W} \quad \textbf{Ans.}$$

Power input,

$$P_{in\,(dc)} = \frac{2}{\pi} V_{CC} I_{C\,max} = \frac{2}{\pi} V_{CC} \times \frac{V_{CC}}{R_L'}$$

$$= \frac{2V_{CC}^2}{\pi R_L'} = \frac{2 \times 20^2}{\pi \times 5} = 50.93 \text{ W.}$$

Total collector power dissipation for the two transistors

$$= P_{in(dc)} - P_{out(ac)} = 50.93 - 40 = 10.93 \text{ W}$$

(*ii*) Collector dissipation in each resistor $= \dfrac{10.93}{2} = 5.465$ W. **Ans.**

16.17. CROSSOVER DISTORTION

In addition to the distortion introduced due to the nonlinearity of the collector characteristics and due to non-matching of the two transistors, there is one more source of distortion, that caused by nonlinearity of the input characteristic.

Recall that silicon transistors must have at least 0.5 V to 0.6 V of forward base-emitter bias before they will go into conduction. Since in class B push-pull amplifiers the forward bias is produced by the input signal, both of the transistors will be non-conducting (or off), when the input signal is approximately ± 0.5 V. This forms a "dead band" in the input and produces *crossover distortion* in the output. In simple words, crossover distortion occurs as a result of one transistor cutting-off before the other begins conducting, as illustrated in Fig. 16.27 (*a*). The distortion introduced is called the crossover distortion because it occurs during the time operation crossover from one transistor to the other in the push-pull amplifier. The same is shown in Fig. 16.27 (*b*) by using transfer characteristics of the two transistors.

To eliminate crossover distortion, it is necessary to add a small amount of forward bias to take the transistors to the average of conduction or slightly beyond. This does slightly lowers the efficiency of the circuit and there is a waste of standby power, but it alleviates the crossover distortion problem. Technically the operation of transistors lies between class B and class A mode. Therefore, the circuit operation is often referred to as being class AB operation (refer Art. 16.18).

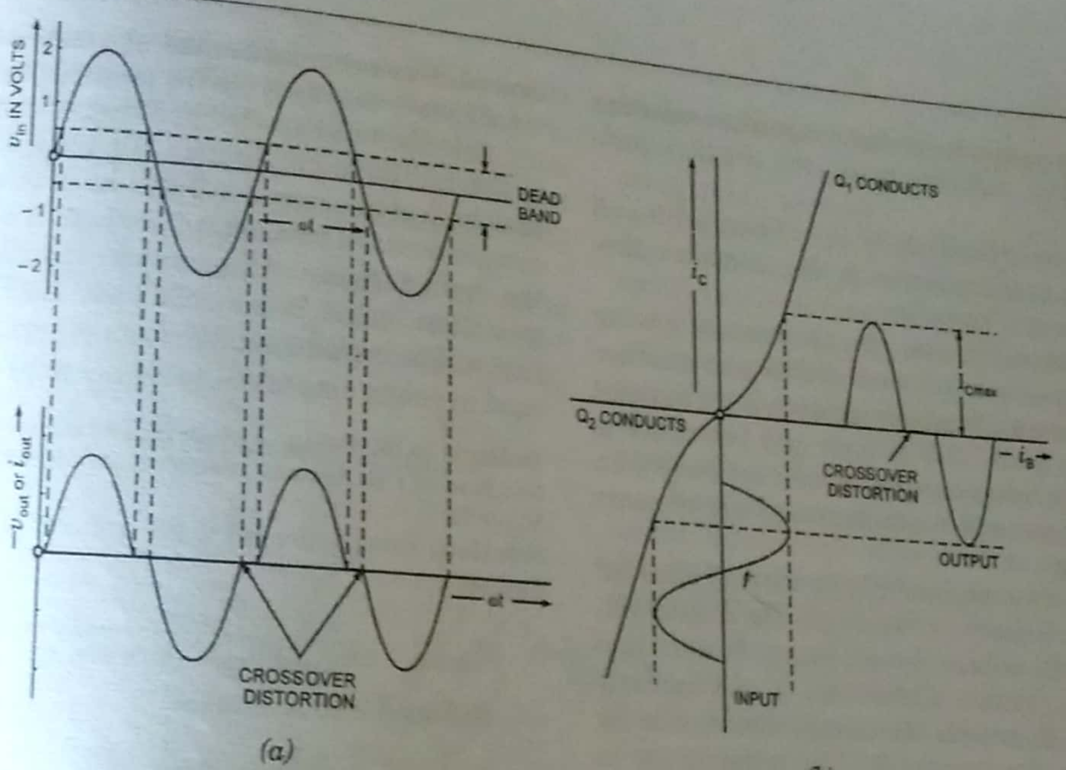

Fig. 16.27. *Crossover Distortion*

16.18. CLASS AB PUSH-PULL AMPLIFIERS

The basic circuit of class AB push-pull amplifier is the...

signals which necessitates an input tapped transformer or phase inverter, and thus makes the circuitry quite complicated.

The above two drawbacks of an ordinary push-pull amplifier have been overcome in the complementary symmetry push-pull amplifier.

This arrangement uses two transistors having complementary symmetry (one N-P-N and another P-N-P). The term complementary arises from the fact that one transistor is the N-P-N type and the other is P-N-P type. They have symmetry as they are made with the same material and technology and are of same maximum rating.

The circuit of a complementary push-pull class AB power amplifier is shown in Fig. 16.29. The resistors R_1 and R_2 provide the voltage divider bias to forward bias the emitter-base junction of transistor Q_1 and similarly resistors R_3 and R_4 provide the voltage divider bias for emitter junction of transistor Q_2. The resistors are so selected that under zero-signal condition, the operating point is cutoff and so no collector current flows.

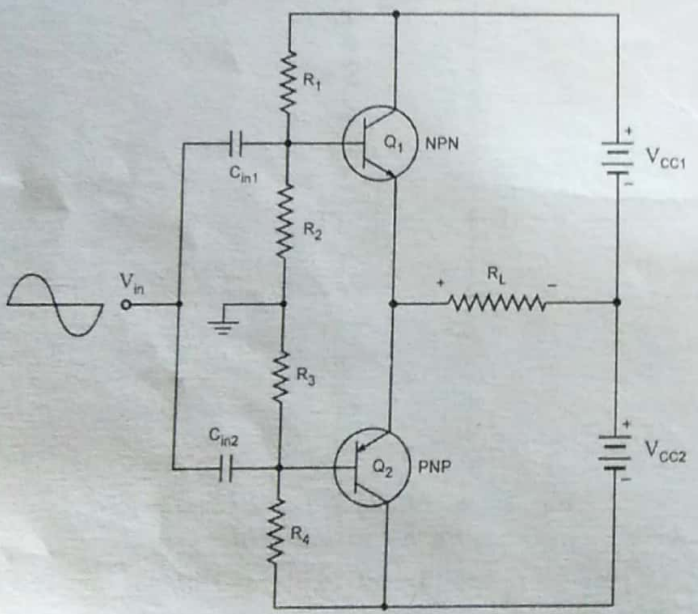

Fig. 16.29. ***Complementary Symmetry Push-Pull Class B Power Amplifier***

The signal applied at the input goes to the base of both the transistors. The two transistors conduct in opposite half cycles of the input. For example during the positive half cycle of the input signal, the NPN transistor Q_1 is forward biased and conducts while the PNP transistor Q_2 is reverse-biased and so does not conduct. This results in a half cycle of output voltage across the load, resistor R_L. Similarly during the negative half cycle only the PNP transistor Q_2 is forward biased and conducts and develops second-half cycle of the output voltage across the load resistor R_L. Transistor Q_1 being reverse-biased does not conduct during the negative half cycle of the input signal. Thus, during a complete cycle of input, a complete cycle of the output signal is developed.

Since collector current from each transistor flows through the load during alternate half cycles of the input signal, no centre-tapped output transformer is required. However, for impedance matching an output transformer (without centre tapping) can be used.

One obvious drawback of this circuit arrangement is the requirement for two supply voltages. Another drawback of this circuit is difficulty of obtaining matched complementary transistors. If there is an unbalance in the characteristics of the two transistors, even harmonics will no longer be cancelled and considerable distortion will be introduced. Very often negative feedback is used in power amplifiers to reduce nonlinear distortion.

Example 16.16. Design a push-pull amplifier to deliver 200 mW to a load of 6 Ω. Assume transformer efficiency to be 70% and V_{CC} = 12 V.

Solution : Load delivered to the primary of the output transformer,

$$P'_{out\,(ac)} = \frac{P_{out\,(ac)}}{\text{Transformer efficiency, } \eta} = \frac{200\text{ mW}}{0.70} = 285\text{ mW}$$

Reflected load resistance,

$$R'_L = \frac{V_{CC}^2}{2P'_{out\,(ac)}} = \frac{12^2}{2 \times 285 \times 10^{-3}} = 252\ \Omega$$

As primary is centred tapped, collector-to-collector resistance,

$$R_{C\text{-}C} = 4R'_L = 4 \times 252 = 1{,}008\ \Omega$$

Transformer turn-ratio,

$$\frac{N_1}{N_2} = \sqrt{\frac{R_{C\text{-}C}}{R_L}} = \sqrt{\frac{1{,}008}{6}} = 13$$

Secondary voltage of output transformer,

$$V_{rms} = \sqrt{200 \times 10^{-3} \times 6} = 1.1\text{ V}$$

Primary voltage of output transformer = Turn-ratio × output voltage = 13 × 1.1 = 14.3 V ≈ 14.5 V (say)

Thus output transformer will be of rating 1.1/14.5 V with a minimum power rating of 300 mW (> 285 mW)

Assuming the transistor is driven over the extreme of the ac load line, the maximum collector current in each transistor,

$$I_{C\,max} = \frac{V_{CC}}{R'_L} = \frac{12}{252} = 48\text{ mA}$$

The dc input power,

$$P_{in\,(dc)} = V_{CC} \times I_{dc} = V_{CC} \times \frac{2\,I_{C\,max}}{\pi}$$

$$= 12 \times \frac{2}{\pi} \times 48\text{ mA} = 367\text{ mW}$$

Power dissipation in both transistors,

$$2P_C = P_{in\,(dc)} - P_{out\,(ac)} = 367 - 200 = 167\text{ mW}$$

Power dissipation in single transistor $= \frac{167}{2} = 83.5$ mW

$$V_{CE\,max} = 2V_{CC} = 2 \times 12\text{ V} = 24\text{ V}$$

Thus specification of required transistors

$$P_{C\,max} > 83.5\text{ mW}$$

$$V_{CE\,max} = 24\text{ V}$$

$$I_{C\,max} = \frac{48\text{ mA}}{2} = 24\text{ mA}$$

Select a transistor 2N109, from data sheet, which has $V_{CE\,max}$ of 25 V and power dissipation capacity of 165 mW. **Ans.**

16.21. QUASI-COMPLEMENTARY PUSH-PULL AMPLIFIER

In practical power amplifier circuits, it is preferable to employ NPN transistors for both high-current output