Solution

The applied voltage forward biases each diode so that they conduct current in the same direction. Fig. 9.15 (*ii*) shows the circuit using simplified model. Referring to Fig. 9.15 (*ii*),

$$I_1 = \frac{\text{Voltage across } R}{R} = \frac{15 - 0.7}{0.5\ k\Omega} = 28.6 \text{ mA}$$

Since the diodes are similar, $I_{D1} = I_{D2} = \frac{I_1}{2} = \frac{28.6}{2} = \mathbf{14.3\ mA}$

Comments. Note the use of placing the diodes in parallel. If the current rating of each diode is 20 mA and a single diode is used in this circuit, a current of 28.6 mA would flow through the diode, thus damaging the device. By placing them in parallel, the current is limited to a safe value of 14.3 mA for the same terminal voltage.

9.6 Important Terms

While discussing the diode circuits, the reader will generally come across the following terms :

(*i*) **Forward current.** It is the current flowing through a forward biased diode. Every diode has a maximum value of forward current which it can safely carry. If this value is exceeded, the diode may be destroyed due to excessive heat. For this reason, the manufacturers' data sheet specifies the maximum forward current that a diode can handle safely.

(*ii*) **Peak inverse voltage.** *It is maximum reverse voltage that a diode can withstand without destroying the junction.*

If the reverse voltage across a diode exceeds this value, the reverse current increases sharply and breaks down the junction due to excessive heat. Peak inverse voltage is extremely important when diode is used as a rectifier. In rectifier service, it has to be ensured that reverse voltage across the diode does not exceed its PIV during the negative half-cycle of input a.c. voltage. As a matter of fact, PIV consideration is generally the deciding factor in diode rectifier circuits. The peak inverse voltage may be between 10V and 10 kV depending upon the type of diode.

(*iii*) **Reverse current or leakage current.** It is the current that flows through a reverse biased diode. This current is due to the minority carriers. Under normal operating voltages, the reverse current is quite small. Its value is extremely small (< 1μA) for silicon diodes but it is appreciable (≃ 100μA) for germanium diodes.

It may be noted that the reverse current is usually very small as compared with forward current. For example, the forward current for a typical diode might range upto 100mA while the reverse current might be only a few μA—a ratio of many thousands between forward and reverse currents.

9.7 Crystal Diode Rectifiers

For reasons associated with economics of generation and transmission, the electric power available is usually an a.c. supply. The supply voltage varies sinusoidally and has a frequency of 50 Hz. It is used for lighting, heating and electric motors. But there are many applications (*e.g.* electronic circuits) where d.c. supply is needed. When such a d.c. supply is required, the mains a.c. supply is rectified by using crystal diodes. The following two rectifier circuits can be used:-

(*i*) Half-wave rectifier (*ii*) Full-wave rectifier

9.8 Half-Wave Rectifier

In half-wave rectification, the rectifier conducts current only during the positive half-cycles of input a.c. supply. The negative half-cycles of a.c. supply are suppressed *i.e.* during negative half-cycles, no current is conducted and hence no voltage appears across the load. Therefore, current always flows in one direction (*i.e.* d.c.) through the load though after every half-cycle.

Circuit details. Fig. 9.16 shows the circuit where a single crystal diode acts as a half-wave rectifier. The a.c. supply to be rectified is applied in series with the diode and load resistance R_L. Generally, a.c. supply is given through a transformer. The use of transformer permits two advantages. Firstly, it allows us to step up or step down the a.c. input voltage as the situation demands. Secondly, the transformer isolates the rectifier circuit from power line and thus reduces the risk of electric shock.

Operation. The a.c. voltage across the secondary winding *AB* changes polarities after every half-cycle. During the positive half-cycle of input a.c. voltage, end *A* becomes positive *w.r.t.* end *B*. This makes the diode forward biased and hence it conducts current. During the negative half-cycle, end *A* is negative *w.r.t.* end *B*. Under this condition, the diode is reverse biased and it conducts no current,. Therefore, current flows through the diode during positive half-cycles of input a.c. voltage only ; it is blocked during the negative half-cycles [see Fig. 9.16 (*ii*)]. In this way, current flows through load R_L always in the same direction. Hence d.c. output is obtained across R_L. It may be noted that output across the load is pulsating d.c. These pulsations in the output are further smoothened with the help of *filter circuits* discussed later.

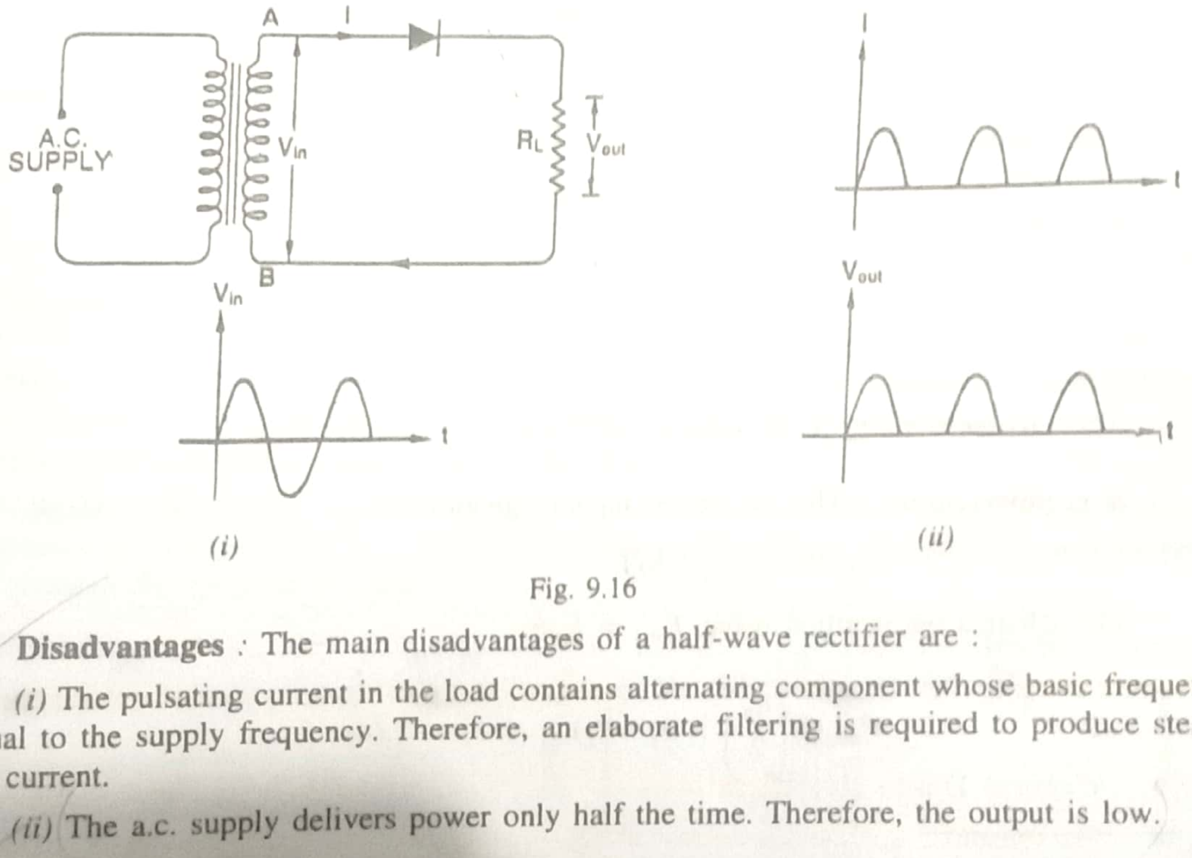


Fig. 9.16

Disadvantages : The main disadvantages of a half-wave rectifier are :

(*i*) The pulsating current in the load contains alternating component whose basic frequency is equal to the supply frequency. Therefore, an elaborate filtering is required to produce steady direct current.

(*ii*) The a.c. supply delivers power only half the time. Therefore, the output is low.

9.9 Efficiency of Half-Wave Rectifier

The ratio of d.c. power output to the applied input a.c. power is known as **rectifier efficiency**

i.e.

$$\text{Rectifier efficiency, } \eta = \frac{\text{d.c. power output}}{\text{Input a.c. power}}$$

Consider a half-wave rectifier shown in Fig. 9.17. Let $V = V_m \sin\theta$ be the alternating voltage that appears across the secondary winding. Let r_f and R_L be the diode resistance and load resistance

$$= \frac{I_m}{\pi} \times R_L = \frac{V_m}{\pi (r_f + R_L)} \times R_L \qquad \left[\because I_m = \frac{V_m}{r_f + R_L}\right]$$

or
$$50 = \frac{V_m}{\pi (25 + 800)} \times 800$$

$$\therefore \quad V_m = \frac{\pi \times 825 \times 50}{800} = \mathbf{162\ V}$$

Hence a.c. voltage of maximum value 162 V is required.

9.9 Full-Wave Rectifier

In full-wave rectification, current flows through the load in the same direction for both half–cycles of input a.c. voltage. This can be achieved with two diodes working alternately. For the positive half-cycle of input voltage, one diode supplies current to the load and for the negative half-cycle, the other diode does so ; current being always in the same direction through the load. Therefore, a full-wave rectifier utilises both half-cycles of input a.c. voltage to produce the d.c. output. The following two circuits are commonly used for full-wave rectification :

(i) Centre-tap full-wave rectifier *(ii)* Full-wave bridge rectifier

9.10 Centre-Tap Full-Wave Rectifier

The circuit employs two diodes D_1 and D_2 as shown in Fig. 9.19. A centre tapped secondary winding *AB* is used with two diodes connected so that each uses one half-cycle of input a.c. voltage. In other words, diode D_1 utilises the a.c. voltage appearing across the upper half (*OA*) of secondary winding for rectification while diode D_2 uses the lower half winding *OB*.

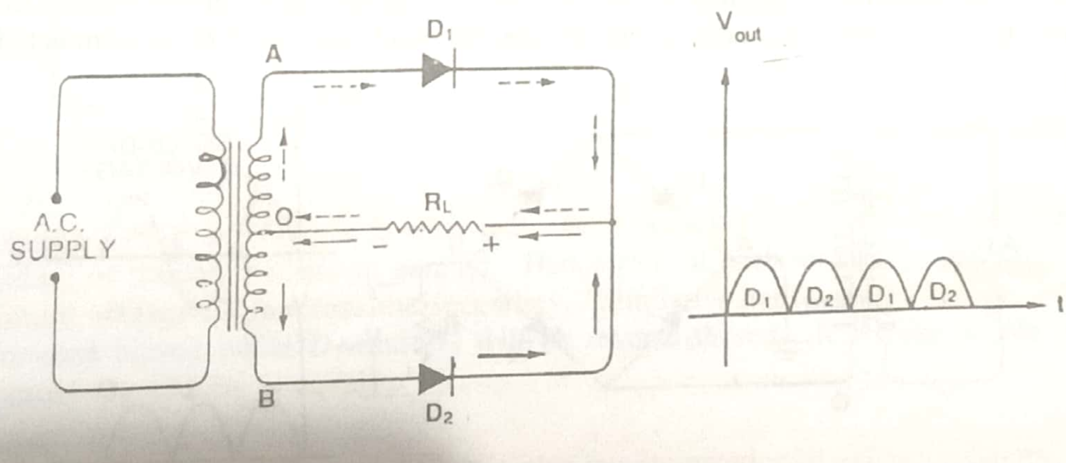


Fig. 9.19

Operation. During the positive half-cycle of secondary voltage, the end *A* of the secondary winding becomes positive and end *B* negative. This makes the diode D_1 forward biased and diode D_2 reverse biased. Therefore diode D_1 conducts while diode D_2 does not. The conventional current flow is through diode D_1, load resistor R_L and the upper half of secondary winding as shown by the dotted arrows. During the negative half-cycle, end *A* of the secondary winding becomes negative and end *B* positive. Therefore, diode D_2 conducts while diode D_1 does not. The conventional current flow is through diode D_2, load R_L and lower half winding as shown by solid arrows. Referring to Fig. 9.19, it may be seen that current in the load R_L is *in the same direction* for both half-cycles of input a.c. voltage. Therefore, d.c. is obtained across the load R_L. Also, the polarities of the d.c. output across the load should be noted.

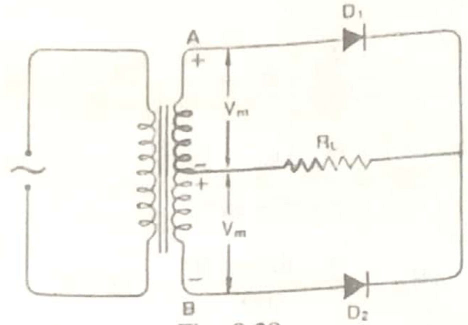


Fig. 9.20

Peak inverse voltage. Suppose V_m is the maximum voltage across the half secondary winding. Fig. 9.20 shows the circuit at the instant secondary voltage reaches its maximum value in the positive direction. At this instant, diode D_1 is conducting while diode D_2 is non-conducting. Therefore, whole of the secondary voltage appears across the non-conducting diode. Consequently, the peak inverse voltage is twice the maximum voltage across the half-secondary winding *i.e.*

$$PIV = 2\ V_m$$

Disadvantages

(*i*) It is difficult to locate the centre tap on the secondary winding.

(*ii*) The d.c. output is small as each diode utilises only one-half of the transformer secondary voltage.

(*iii*) The diodes used must have high peak inverse voltage.

9.11 Full-Wave Bridge Rectifier

The need for a centre tapped power transformer is eliminated in the bridge rectifier. It contains four diodes D_1, D_2, D_3 and D_4 connected to form bridge as shown in Fig. 9.21. The *a.c.* supply to be rectified is applied to the diagonally opposite ends of the bridge through the transformer. Between other two ends of the bridge, the load resistance R_L is connected.

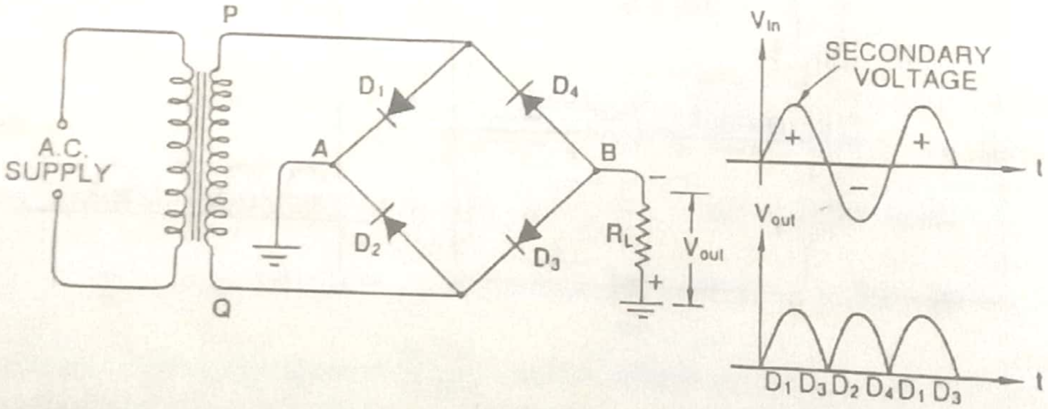


Fig. 9.21

Operation. During the positive half-cycle of secondary voltage, the end *P* of the secondary winding becomes positive and end *Q* negative. This makes diodes D_1 and D_3 forward biased while diodes D_2 and D_4 are reverse biased. Therefore, only diodes D_1 and D_3 conduct. These two diodes will be in series through the load R_L as shown in Fig. 9.22 (*i*). The conventional current flow is shown by dotted arrows. It may be seen that current flows from *A* to *B* through the load R_L.

During the negative half-cycle of secondary voltage, end *P* becomes negative and end *Q* positive. This makes diodes D_2 and D_4 forward biased whereas diodes D_1 and D_3 are reverse biased. Therefore, only diodes D_2 and D_4 conduct. These two diodes will be in series through the load R_L as shown in Fig 9.22 (*ii*). The current flow is shown by the solid arrows. It may be seen that again current flows from A to B through the load *i.e.* in the same direction as for the positive half-cycle. Therefore, d.c. output is obtained across load R_L.

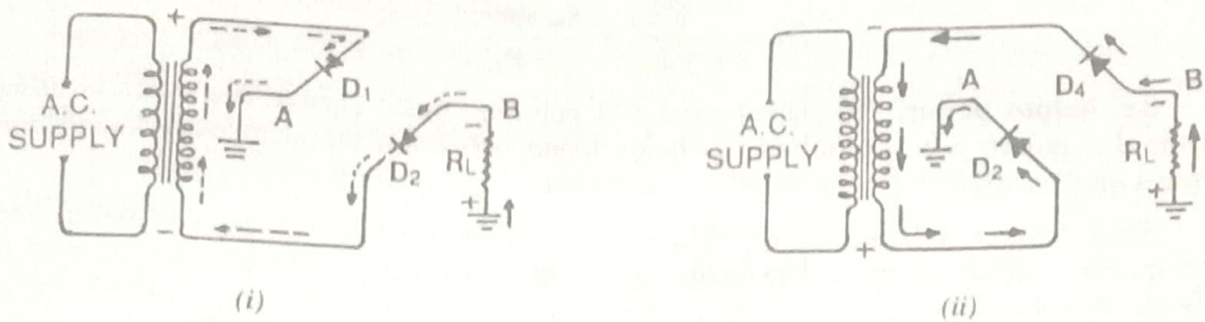


Fig. 9.22

Peak inverse voltage. The peak inverse voltage (PIV) of each diode is equal to the maximum secondary voltage of transformer. Suppose during half cycle of input a.c., end P of secondary is positive and end Q negative. Under such conditions, diodes D_1 and D_3 are forward biased while diodes D_2 and D_4 are reverse biased. Since the diodes are considered ideal, diodes D_1 and D_3 can be replaced by wires as shown in Fig. 9.23 (*i*). This circuit is the same as shown in Fig. 9.23 (*ii*).

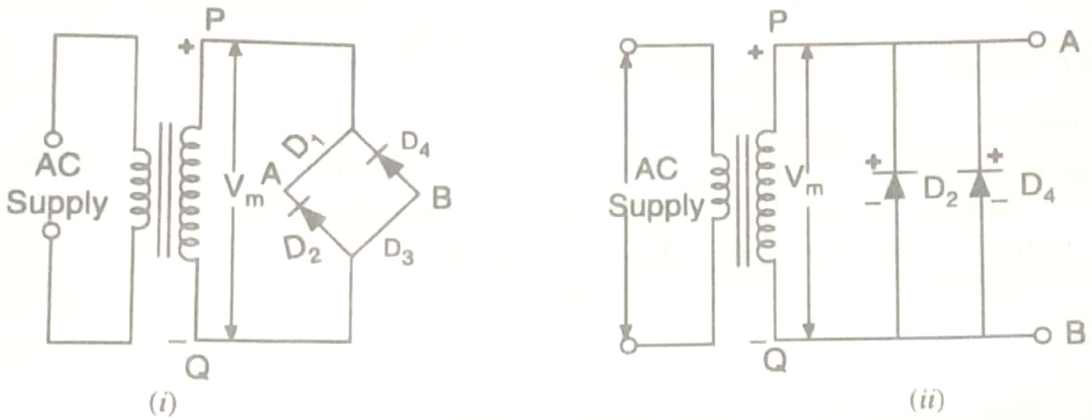


Fig. 9.23

Refering to Fig. 9.23 (*ii*), it is clear that two reverse biased diodes (*i.e.*, D_2 and D_4) and the secondary of transformer are in parallel. Hence PIV of each diode (D_2 and D_4) is equal to the maximum voltage (V_m) across the secondary. Similarly, during the next half cycle, D_2 and D_4 are forward biased while D_1 and D_3 will be reverse biased. It is easy to see that reverse voltage across D_1 and D_3 is equal to V_m.

Advantages

(*i*) The need for centre-tapped transformer is eliminated.

(*ii*) The output is twice that of the centre-tap circuit for the same secondary voltage.

(*iii*) The *PIV* is one-half that of the centre-tap circuit.

Disadvantages

(*i*) It requires four diodes.

(*ii*) As during each half-cycle of a.c. input two diodes that conduct are in series, therefore, voltage drop in the internal resistance of the rectifying unit will be twice as great as in the centre tap circuit. This is objectionable when secondary voltage is small.

9.12 Efficiency of Full-Wave Rectifier

Fig. 9.24 shows the process of full wave rectification. Let $v = V_m \sin\theta$ be the a.c. voltage to be rectified. Let r_f and R_L be the diode resistance and load resistance respectively. Obviously,

Example 9.18. *A power supply A delivers 10V dc with a ripple of 0.5V r.m.s. while the power supply B delivers 25V dc with a ripple of 1mV, which is better power supply ?*

Solution

The lower the ripple factor of a power supply, the better it is.

For power supply A

$$\text{Ripple factor} = \frac{V_{ac\,(r.m.s.)}}{V_{dc}} = \frac{0.5}{10} \times 100 = 5\%$$

For power supply B

$$\text{Ripple factor} = \frac{V_{ac\,(r.m.s.)}}{V_{dc}} = \frac{0.001}{25} \times 100 = 0.004\%$$

Clearly, power supply *B* is better.

9.15 Comparison of Rectifiers

S. No.	Particulars	Half-wave	Centre-tap	Bridge type
1	No. of diodes	1	2	4
2	Transformer necessary	no	yes	no
3	Max. efficiency	40.6%	81.2%	81.2%
4	Ripple factor	1.21	0.48	0.48
5	Output frequency	f_{in}	$2\,f_{in}$	$2\,f_{in}$
6	Peak inverse voltage	V_m	$2\,V_m$	V_m

9.16 Filter Circuits

Generally, a rectifier is required to produce pure d.c. supply for using at various places in the electronic circuits. However, the output of a rectifier has pulsating *character *i.e.* it contains a.c. and d.c. components. The a.c. component is undesirable and must be kept away from the load. To do so, a *filter circuit* is used which removes (or *filters out*) the a.c. component and allows only the d.c. component to reach the load.

A filter circuit *is a device which removes the a.c. component of rectifier output but allows the d.c. component to reach the load.*

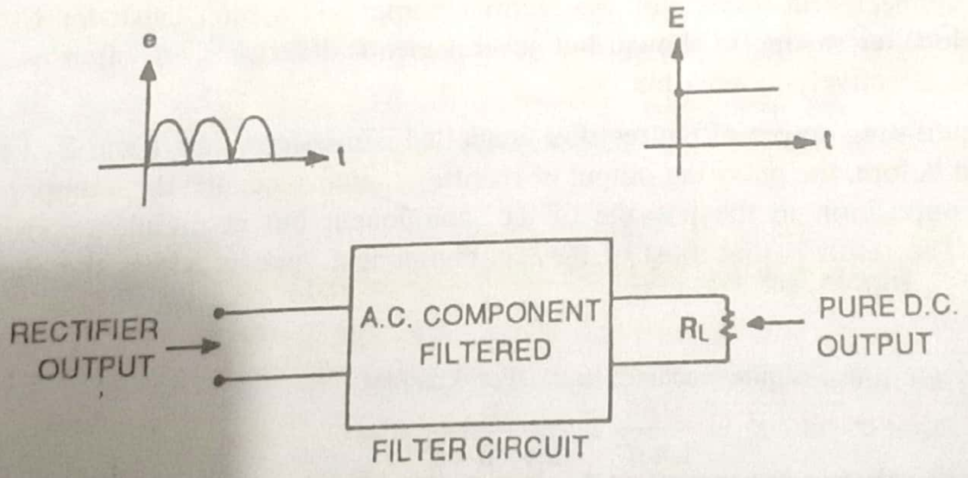


Fig. 9.32

* If such a d.c. is applied in an electronic circuit, it will produce a *hum*.

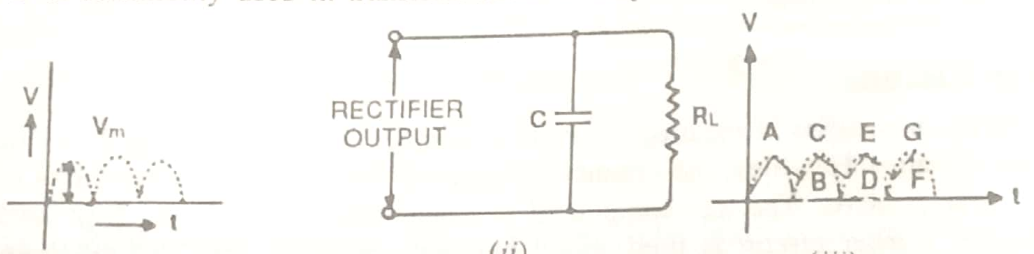
Obviously, a filter circuit should be installed between the rectifier and the load as shown in Fig. 9.32. A filter circuit is generally a combination of inductors (L) and capacitors (C). The filtering action of L and C depends upon the basic electrical principles. A capacitor passes a.c. readily but does not *pass d.c. at all. On the other hand, an inductor **opposes a.c. but allows d.c. to pass through it. It then becomes clear that suitable network of L and C can effectively remove the a.c. component, allowing the d.c. component to reach the load.

9.17 Types of Filter Circuits

The most commonly used filter circuits are *capacitor filter, choke input filter* and *capacitor input filter or π–filter*. We shall discuss these filters in turn.

(i) **Capacitor filter.** Fig. 9.33 *(ii)* shows a typical capacitor filter circuit. It consists of a capacitor C placed across the rectifier output in parallel with load R_L. The pulsating direct voltage of the rectifier is applied across the capacitor. As the rectifier voltage increases, it charges the capacitor and also supplies current to the load. At the end of quarter cycle [Point A in Fig. 9.33 *(iii)*], the capacitor is charged to the peak value V_m of the rectifier voltage. Now, the rectifier voltage starts to decrease. As this occurs, the capacitor discharges through the load and voltage across it (*i.e.* across parallel combination of *R-C*) decreases as shown by the line *AB* in Fig. 9.33 *(iii)*. The voltage across load will decrease only slightly because immediately the next voltage peak comes and recharges the capacitor. This process is repeated again and again and the output voltage wave form becomes *ABCDEFG*. It may be seen that very little ripple is left in the output. Moreover, output voltage is higher as it remains substantially near the peak value of rectifier output voltage.

The capacitor filter circuit is extremely popular because of its low cost, small size, little weight and good characteristics. For small load currents (say upto 50 *mA*), this type of filter is preferred. It is commonly used in transistor radio battery eliminators.



(i) *(ii)* *(iii)*

Fig. 9.33

(ii) **Choke input filter.** Fig. 9.34 shows a typical choke input filter circuit. It consists of a †choke L connected in series with the rectifier output and a filter capacitor C across the load. Only a single filter section is shown, but several identical sections are often used to reduce the pulsations as effectively as possible.

The pulsating output of the rectifier is applied across terminals 1 and 2 of the filter circuit. As discussed before, the pulsating output of rectifier contains a.c. and d.c. components. The choke offers high opposition to the passage of a.c. component but negligible opposition to the d.c. component. The result is that most of the a.c. component appears across the choke while whole

* A capacitor offers infinite reactance to d.c. For d.c., $f = 0$

$$\therefore \quad X_c = \frac{1}{2\pi fC} = \frac{1}{2\pi \times 0 \times C} = \infty$$

Hence, a capacitor does not allow d.c. to pass through it.

**We know $X_L = 2\pi fL$. For d.c., $f = 0$, and therefore $X_L = 0$. Hence inductor passes d.c. quite readily. For a.c., it offers opposition and drops a part of it.

† The shorthand name of inductor coil is choke

of d.c. component passes through the choke on its way to load. This results in the reduced pulsations at terminal 3.

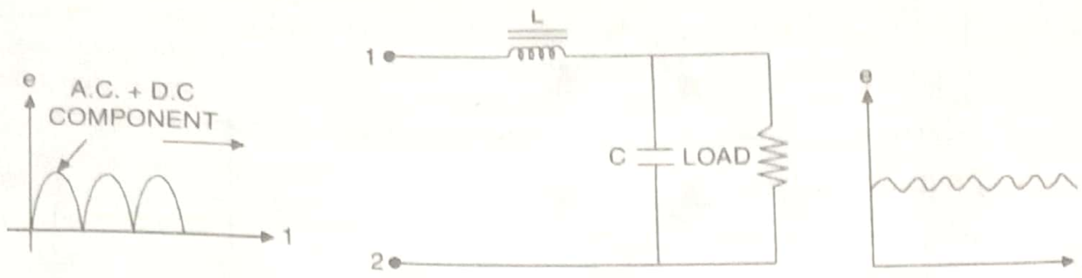


Fig. 9.34

At terminal 3, the rectifier output contains d.c. component and the remaining part of a.c. component which has managed to pass through the choke. Now, the low reactance of filter capacitor bypasses the a.c. component but prevents the d.c. component to flow through it. Therefore, only d.c. component reaches the load. In this way, the filter circuit has filtered out the a.c. component from the rectifier output, allowing d.c. component to reach the load.

(iii) **Capacitor input filter** *or* **π–filter.** Fig. 9.35 shows a typical capacitor input filter or *π–filter. It consists of a filter capacitor C_1 connected across the rectifier output, a choke L in series and another filter capacitor C_2 connected across the load. Only one filter section is shown but several identical sections are often used to improve the smoothing action.

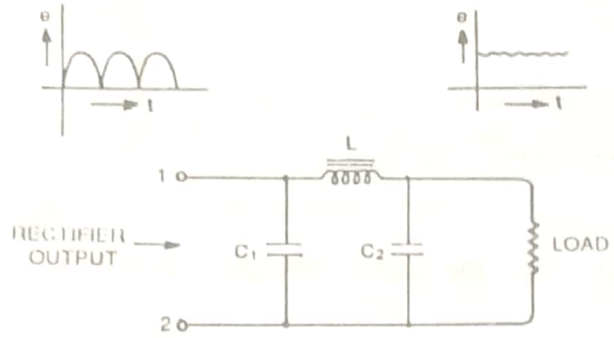


Fig. 9.35

The pulsating output from the rectifier is applied across the input terminals (*i.e.* terminals 1 and 2) of the filter. The filtering action of the three components *viz* C_1,L and C_2 of this filter is described below :

(a) The *filter capacitor* C_1 offers low reactance to a.c. component of rectifier output while it offers infinite reactance to the d.c. component. Therefore, capacitor C_1 bypasses an appreciable amount of a.c. component while the d.c. component continues its journey to the choke L.

(b) The *choke L* offers high reactance to the a.c. component but it offers almost zero reactance to the d.c. component. Therefore, it allows the d.c. component to flow through it, while the **unbypassed a.c. component is blocked.

(c) The *filter capacitor* C_2 bypasses the a.c. component which the choke has failed to block. Therefore, only d.c. component appears across the load and that is what we desire.

Example 9.19. *The choke of Fig. 9.36 has a d.c. resistance of 25 Ω. What is the d.c. voltage if the full-wave signal into the choke has a peak value of 25.7 V ?*

* The shape of the circuit diagram of this filter circuit appears like Greek letter π (pi) and hence the name π–filter.

** That part of a.c. component which could not be bypassed by capacitor C_1.