1 Diode

1.1 : P-N Junction

Q.1 What is p-n junction ?

Ans. : The two types of extrinsic materials are p type and n type.

- The p type and n type materials are chemically combined with a special fabrication technique to form p-n junction.
- On p-side there are large number of holes while on n-side there are large number of free electrons.

1.2 : Theory of P-N Junction

Q.2 Discuss the behaviour of p-n junction under no bias.

Ans. : • In a unbiased p-n junction diode, on p-side there are large number of holes while on n-side there are large number of electrons. Hence the overall there is nonuniform distribution of charge carriers.

- When such nonuniform distribution exists then the charge carriers start moving from high concentration area towards the low concentration area. This is called **diffusion.**
- In unbiased diode, the majority holes on p side start diffusing into n side while the majority free electrons on n side start diffusing into p side.
- In n region, the holes diffusing from n-side, recombine with free electrons. Thus due to additional positively charged holes, these atoms on n-side become **positive immobile ions,** just near the junction in n region.

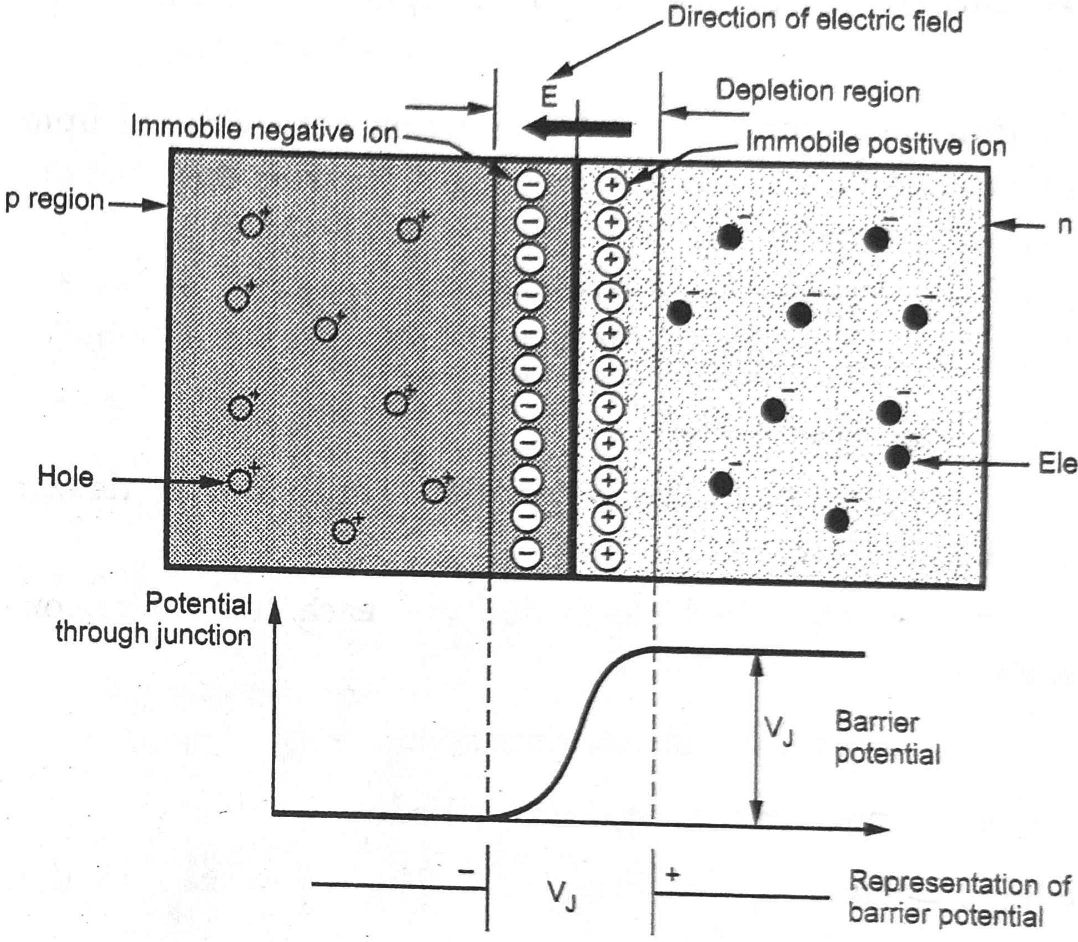


Fig. Q.2.1 The unbiased diode

- In p region, the free electrons diffusing from n-side, recombine with the holes of the atoms. Thus due to gain of additional negatively charged free electrons, these atoms become **negative immobile ions**, just near the junction in p-region.
- As more holes diffuse on n side, large immobile positive charge accumulates near the junction on n side. This positive charge repels the positively charged holes and the diffusion of holes stops.
- Similarly large negative charge accumulates near the junction on p side. This negative charge repels the negatively charged electrons and the diffusion of electrons stops.
- Thus there exists a wall near the junction with negative immobile charge on p side and positive immobile charge on n side. There are no charge carriers in this region. The region is depleted off the charge carriers hence called **depletion region, depletion layer**

or **space charge region**. The depletion region is shown in the Fig. Q.2.1.

- In equilibrium condition, the depletion region gets widened upto a point where no further electrons or holes can cross the junction. Thus it acts as a **barrier**.

1.3 : P-N Junction Diode

Q.3 Explain p-n junction diode.

Ans. : • The p-n junction forms a popular semiconductor device called **p-n junction diode**.

- Its two terminals are called electrodes, one each from p region and n region.
- It can conduct current only in one direction.
- The p region is anode and n region is cathode.
- Its symbol is shown in the Fig. Q.3.1. The arrowhead in the symbol indicates the direction of the conventional current which can flow when an external voltage is applied in a specific manner across the diode.

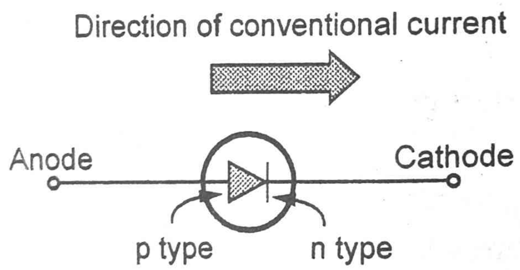


Fig. Q.3.1 Symbol of a diode

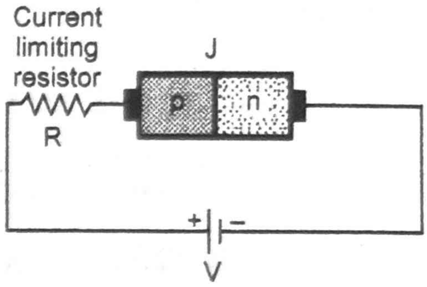
- Applying external voltage to p-n junction diode is called **biasing**.
- Depending upon the polarity of external d.c. voltage applied to diode, the biasing is classified as,

1. Forward biasing 2. Reverse biasing.

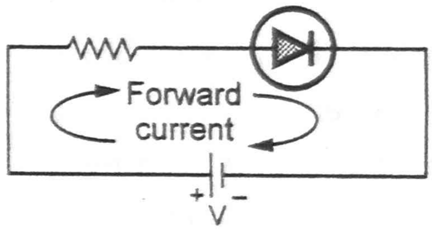
1.4 : Forward Biasing of Diode

Q.4 Explain the forward biasing of p-n junction diode.

Ans. : • When an external d.c. voltage is connected in such a way that p region is connected to positive and n region to negative of the d.c. voltage then the biasing is called **forward biasing**. It is shown in the Fig. Q.4.1.



(a) Forward biasing



(b) Symbolic representation

Fig. Q.4.1

- As long as applied voltage V is less than barrier potential there is no conduction.
- When applied voltage V is more than barrier potential, it overcomes the barrier potential and reduces the width of depletion region. This is because the negative of battery pushes the free electrons against the barrier from n to p region while positive of battery pushes holes against barrier from p to n region.
- As applied voltage is increased, at a particular value, the depletion region becomes very narrow and majority charge carriers can easily cross the junction.
- This large number of majority charge carriers constitute a current called **forward current**.
- The current in the p region is due to movement of holes so it is **hole current**. The current in the n region is due to movement of electrons so it is **electron current**. The holes in p region and electrons in n region are majority charge carriers. Hence the forward current is due to **majority charge carriers**.
- The forward current in a diode is shown in the Fig. Q.4.2.

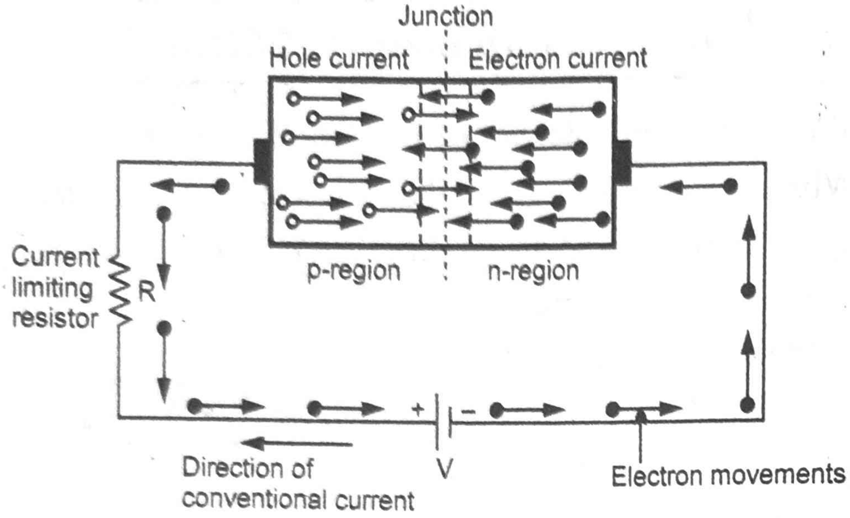
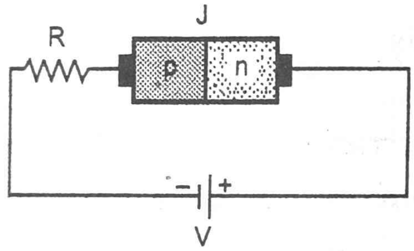


Fig. Q.4.2 Forward current in a diode

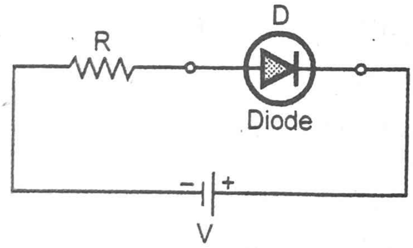
1.5 : Reverse Biasing of Diode

Q.5 Explain the reverse biasing of p-n junction diode.

Ans. : • When an external d.c. voltage is connected in such a way that p region is connected to negative and n region to positive terminal of the d.c. voltage then the biasing is called **reverse biasing**. It is shown in the Fig. Q.5.1.



(a) Reverse biasing

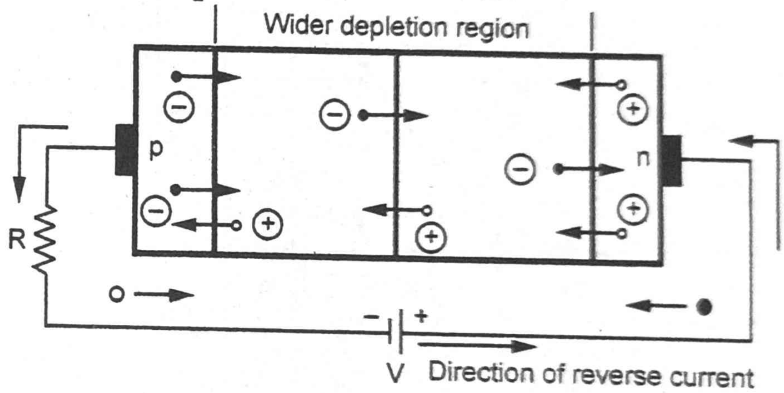


(b) Symbolic representation

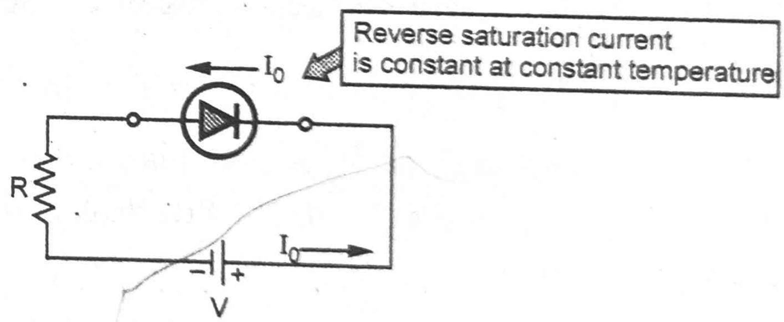
Fig. Q.5.1

- In reverse biasing, negative of battery attracts the holes in p region and positive of battery attracts the electrons in n region away from the junction.
- This widens the depletion region and barrier potential increases. No majority charge carrier can cross the junction.
- The resistance of the reverse biased diode is very high and the diode is said to be nonoperative in the reverse biased.

- However due to increased barrier potential, the free electrons on p side are dragged towards positive while holes on n side are dragged towards negative of the battery.
- This constitutes a current called **reverse current**. It flows due to **minority charge carriers** and hence its magnitude is very very small.
- For constant temperature, the reverse current is almost constant though applied reverse voltage is increased upto certain limit. Hence it is called **reverse saturation current** denoted as I_0. This is shown in the Fig. Q.5.2.
- The reverse current I_0 is of the order of few microamperes for Ge and few nanoamperes for Si diodes.



(a) Flow of minority charge carriers



(b) Direction of reverse current

Fig. Q.5.2 Reverse biased diode

1.6 : V-I Characteristics of Diode

Q.6 Draw and explain V-I characteristics of a p-n junction diode.

Ans. : • The graph of voltage applied across the p-n junction and the current flowing through the p-n junction is called **V-I characteristics** of p-n junction.

Forward Characteristics :

- In forward biasing V_f is the voltage across the p-n junction and I_f is the forward current hence graph of I_f against V_f is called forward characteristics of p-n junction.
- The forward characteristics of a diode is shown in the Fig. Q.6.1.

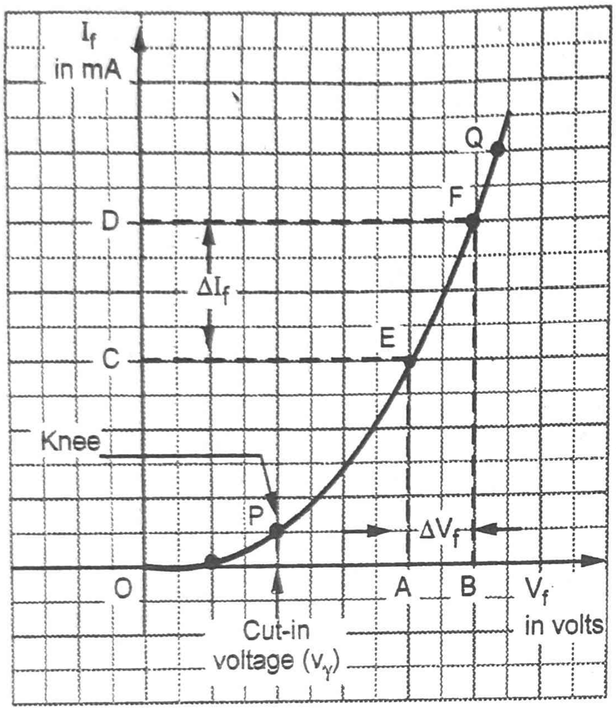


Fig. Q.6.1 Forward characteristics of a diode

- Basically forward characteristics can be divided into two regions :

1. **Region O to P** : As long as V_f is less than cut-in voltage (V_γ), the current flowing is very small. Practically this current is assumed to be zero.

2. **Region P to Q and onwards** : As V_f increases towards V_γ the width of depletion region goes on reducing. When V_f exceeds V_γ i.e. cut-in voltage, the depletion region becomes very thin and current I_f increases suddenly. This increase in the current is **exponential** as shown in the Fig. Q.6.1 by the region P to Q.

- The point P, after which the forward current starts increasing exponentially is called **knee** of the curve.

- The forward current is the conventional current, hence it is treated as positive and the forward voltage V_f is also treated positive. Hence the forward characteristics is plotted in the **first quadrant.**

Reverse Characteristics :

- The reverse voltage across the diode is V_R and reverse current through the diode is I_R hence graph of I_R against V_R is called reverse V-I characteristics of p-n junction.
- The polarity of V_R is opposite to V_f and direction of I_R is opposite to I_f hence both V_R and I_R are treated negative. Hence reverse characteristics are plotted in the **third quadrant.**
- As the reverse voltage is increased, reverse current increases initially but after a small voltage becomes constant equal to reverse saturation current I_0. This point is shown as P, in the Fig. Q.6.2.
- After this, though reverse voltage is increased, the reverse current remains constant till point A.
- At point A, reverse breakdown of the diode occurs and current increases sharply damaging the diode. This point is called **knee** of the reverse characteristics.
- The voltage corresponding to point A is called **reverse breakdown voltage** of the p-n junction denoted as V_{BR}.
- The reverse characteristics is shown in the Fig. Q.6.2.

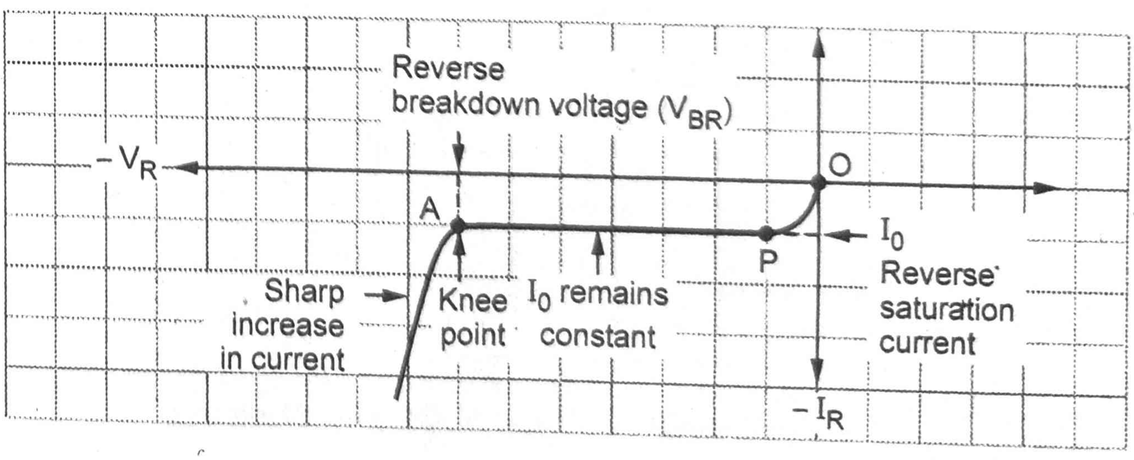


Fig. Q.6.2 Reverse characteristics of p-n junction diode

Q.7 Draw and comment on the V-I characteristics of typical Ge and Si diodes.

Ans. : • The cut-in voltage for germanium (Ge) diode is about 0.2 V while for Silicon (Si) diode is as about 0.6 V.

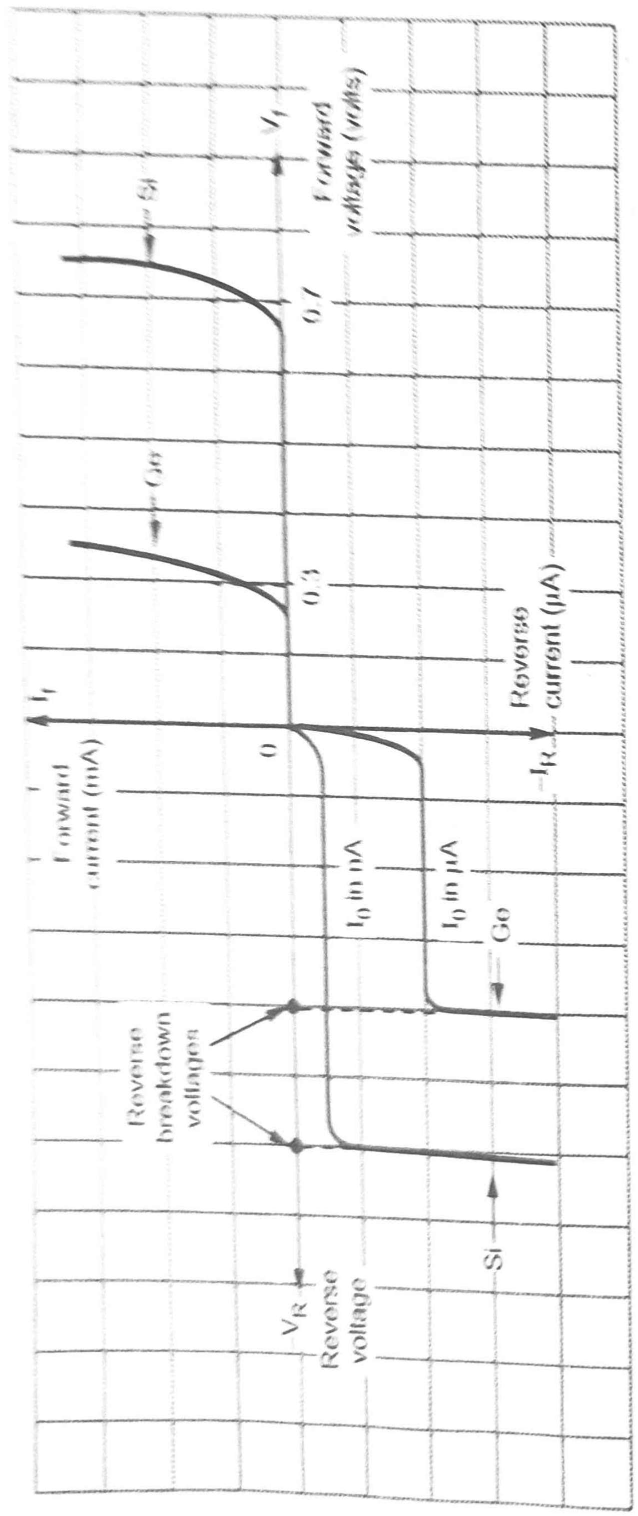


Fig. Q.7.1 V-I characteristics of typical Ge and Si diodes

- The potential at which current starts increasing exponentially is also called **offset potential, threshold potential** or **firing potential** of a diode.
- The Fig. Q.7.1 shows the V-I characteristics of typical Ge and Si diodes.
- The reverse saturation current I_0 is of the order of nA for silicon diode while it is of the order of μA for germanium diode.
- Reverse breakdown voltage for Si diode is higher than that of the Ge diode of a comparable rating.

1.7 : Ideal Diode

Q.8 Compare ideal and practical diode.

Ans. :

Sr. No.	Ideal diode	Practical diode
1.	The cut-in voltage is zero.	It has finite but small cut-in voltage.
2.	The internal forward resistance is zero.	It has small finite internal forward resistance.
3.	The voltage drop across forward biased ideal diode is zero.	There is finite voltage drop across forward biased practical diode.
4.	It acts as a short circuit (closed switch) in forward biased condition.	It does not act as a short circuit in forward biased condition.
5.	The internal resistance is infinite in reverse biased condition.	The internal resistance is very high but finite in reverse biased condition.
6.	It acts as on open circuit (open switch) in reverse biased condition.	It does not act as an open circuit in reverse biased condition. It carries very small reverse current.
7.	It does not exist in practice.	All the diodes are practical diodes.

Important Points To Remember

- Characteristics of ideal diode are shown in the Fig. 1.1.

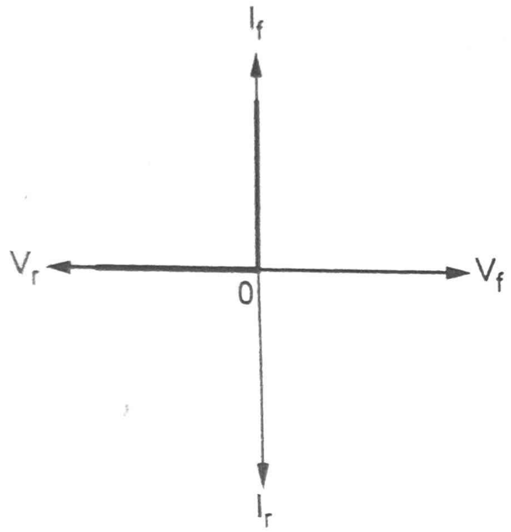


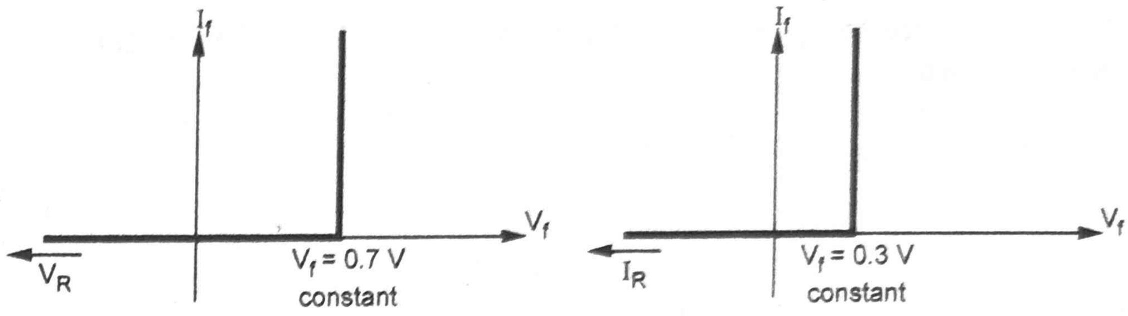
Fig. 1.1

- It can be seen that cut-in voltage is zero and diode conducts immediately when forward biased.
- In reverse biased, the reverse current is zero so it acts as an open switch.

1.8 : Second and Third Approximation

Q.9 Explain the second and third approximations of diode.

Ans. : Second approximation of diode : Practically the dynamic resistance of a diode is very small and is neglected. Due to this, the diode forward voltage drop is assumed constant equal to cut-in voltage of the diode. Thus the forward voltage drop of silicon diode is assumed constant equal to its cut-in voltage of 0.7 V while that of germanium diode is of 0.3 V. The reverse current is very small and neglected hence the diode is assumed to be open circuit in reverse biased condition. The second approximation characteristics is shown in the Fig. Q.9.1.



(a) Silicon diode (b) Germanium diode

Fig. Q.9.1 Second approximation of diode

Third approximation of diode : The approximation of characteristics with the help of pieces of straight lines is called third approximation or **linear piecewise approximation.**

- To obtain this approximation, $V_f = V_T = V_\gamma$ (cut in voltage) is marked on the voltage axis and then a straight line is drawn with a slope equal to the reciprocal of the dynamic resistance (r_d) of the diode.

- Thus the approximation consists of two straight lines, one horizontal and other with slope ($1/r_d$) as shown in the Fig. Q.9.2.

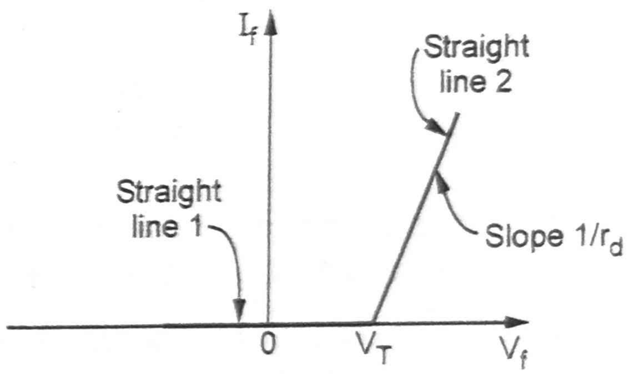


Fig. Q.9.2 Linear piecewise approximation

Q.10 Give the equivalent circuits of diode based on various approximations.

Ans. : For the analysis of various circuits, it is necessary to replace the diode by a battery and resistance depending on the approximation. This circuit is called equivalent circuit or circuit model of diode. In all such circuit models the reverse biased diode is assumed to be open circuited.

The Table Q.10.1 gives the equivalent circuits of a diode based on various approximations.

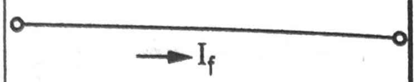
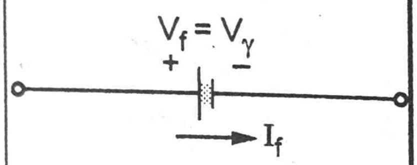
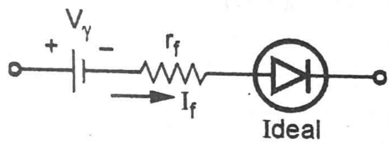
Sr. No.	Diode approximation	Behaviour	D.C. Equivalent circuit
1.	Ideal diode	$R_f = 0\ \Omega$ $R_r = \infty\ \Omega$ Short in forward bias.	
2.	Diode with constant forward voltage drop	The forward voltage drop is constant and it behaves as d.c. battery of voltage $V_f = V_\gamma$	
3.	Complete d.c. equivalent circuit	This assumes finite forward resistance which is its dynamic forward resistance r_f in series with battery of voltage V_γ.	 Total diode drop is, $V_f = V_\gamma + I_f r_f$

Table Q.10.1 D.C. Equivalent circuits of diode

Q.11 For the circuit shown, find the load voltage, load current and diode power using third approximation. Assume silicon diode with resistance of 0.2 Ω.

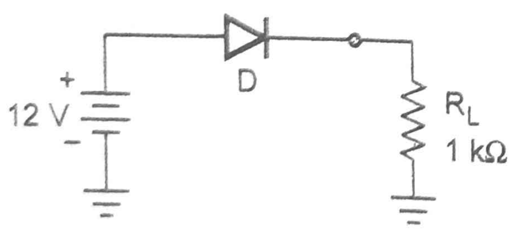


Fig. Q.11.1

Ans. : Replace diode by its equivalent circuit according to third approximation as shown in the Fig. Q.11.1(a).

Applying KVL,

$-0.7 - 0.2\,I_f - 1000\,I_f + 12 = 0$ i.e.

$I_f = \mathbf{11.297\ mA}$

$V_f = 0.7 + I_f\, r_f$

$= 0.7 + 11.297 \times 10^{-3} \times 02$

$= 0.70225\ V$

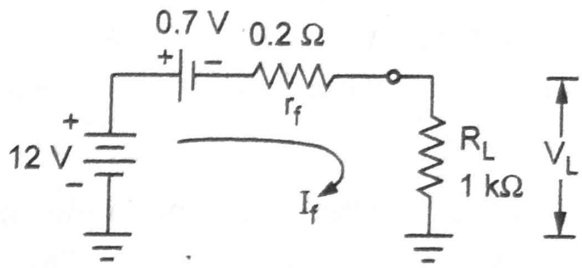


Fig. Q.11.1 (a)

$V_L = 11.297 \times 10^{-3} \times 1 \times 10^3$

$= \mathbf{11.297\ V}$

$P_D = V_f\, I_f = 0.70225 \times 11297 \times 10^{-3} = \mathbf{7.933\ mW}$

1.9 : Surface Mount Diodes

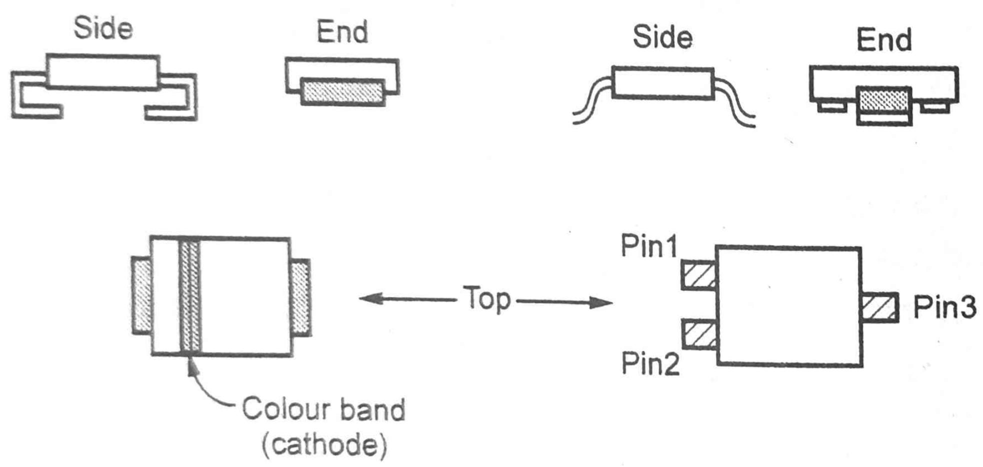
Q.12 Write a note on surface mount diodes.

Ans. : The diodes which can be mounted on the surface of a circuit board are called surface mounting diodes. These diodes are easy to test and can be easily removed and replaced on the circuit board. These diodes are relatively small and efficient in operation.

- The surface mount (SM) is one of the package styles used in the industry.
- The surface mount package uses two L bend leads and a coloured band on one end of the body which indicates the cathode lead.
- The Fig. Q.12.1(a) shows the two terminal surface mount style package used for the surface mount diodes.
- The total dimensions of such a surface mount style package depends on the current rating of the diode. The surface area is larger for high current rating diodes.
- In the high current rating diodes the heat produced at the junction is more which is to be dissipated as quickly as possible.

Increased surface area helps to increase the ability of the diode to dissipate the heat generated to keep the temperature within the specified limits.

- Increasing the width of the mounting terminals produces the effect of virtual heat sink, increasing the thermal conductance of the diode.
- Another surface mount style package is called small outline transistor (SOT) package. This package includes two diodes having common anode or common cathode connection as one of the terminals. These packages are small and used for the diodes with current rating less than 1 ampere. Due to small size it is difficult to provide the identification codes for such diodes.
- The Fig. Q.12.1(b) shows SOT style package.



(a) SM style packge (b) SOT style package

Fig. Q.12.1

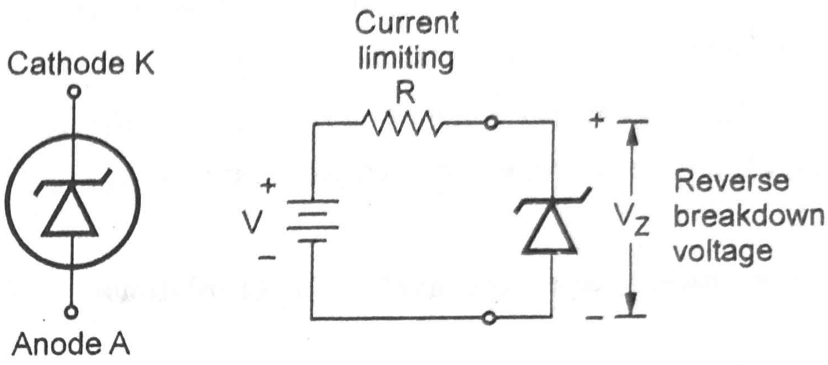
1.10 : Zener Diode

Q.13 What is zener diode ? Explain its V-I characteristics.

Ans. : • A zener diode is a silicon p-n junction semiconductor device which is operated in its **reverse breakdown** region.

- The zener diodes are fabricated with precise breakdown voltages by controlling the doping level during manufacturing.

- The Fig. Q.13.1 (a) shows the symbol of zener diode while the Fig. Q.13.1 (b) shows the the operation of zener diode in reverse breakdown region.



(a) Symbol **(b) Reverse biasing**

Fig. Q.13.1 Zener diode

- When the reverse voltage is applied to zener diode, at a certain reverse voltage, the reverse breakdown occurs and current in the zener diode increases rapidly. The sharp change in the zener current is called **knee** or **zener knee** of the reverse characteristics.
- The reverse bias voltage at which the breakdown occurs is called **zener breakdown voltage,** denoted as V_Z. This value is carefully designed by controlling the doping level during manufacturing.

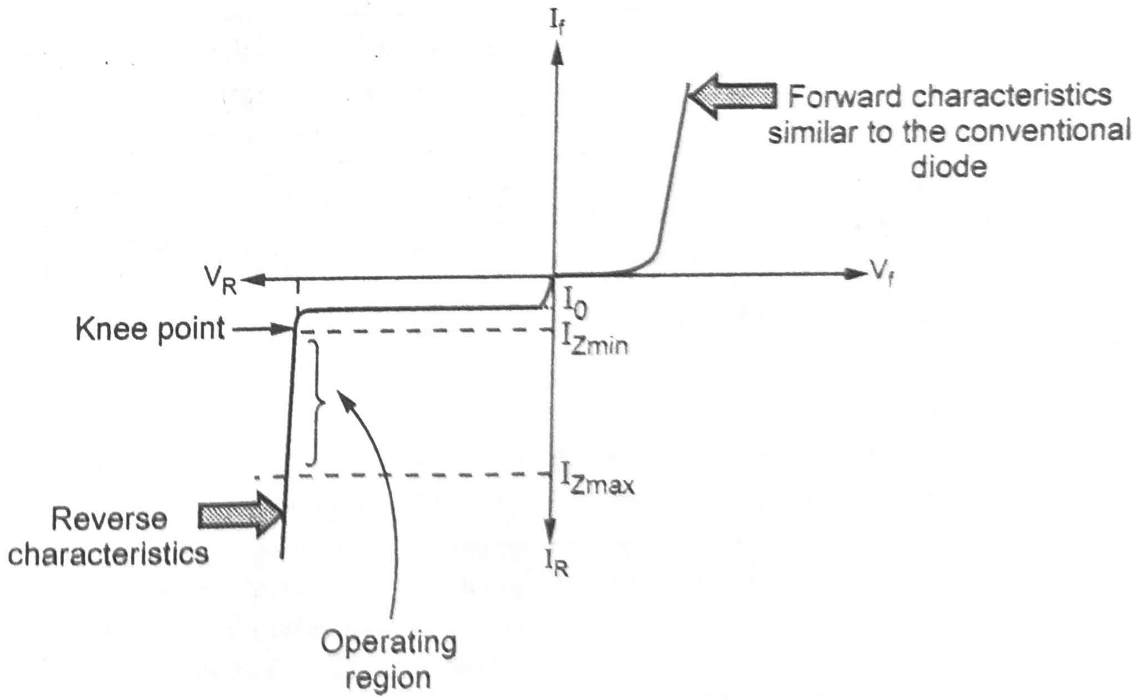


Fig. Q.13.2 V-I Characteristics of zener diode

- The V-I characteristics of zener diode is shown in the Fig. Q.13.2.
- For zener diodes, practically two currents are specified. The I_{Zmin} is minimum current through the zener diode to maintain its reverse breakdown operation.
- The I_{Zmax} is the maximum current which zener diode can take safely maintaining its reverse breakdown operation, i.e. constant V_Z across it.

Q.14 Compare between zener and avalanche breakdown.

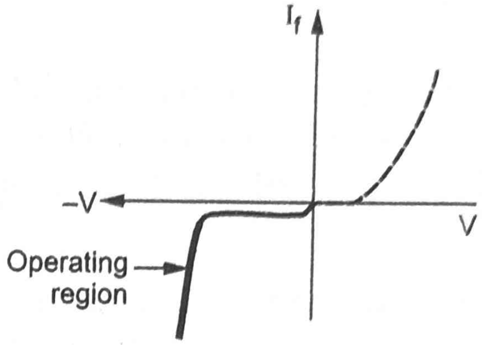
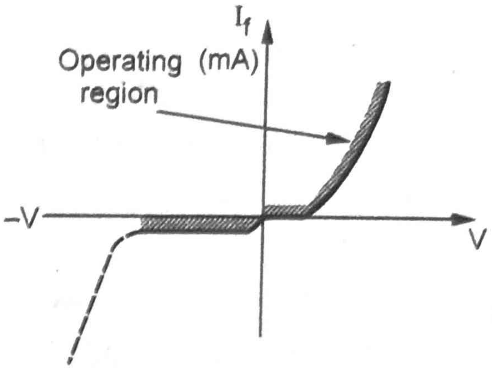
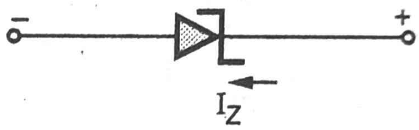
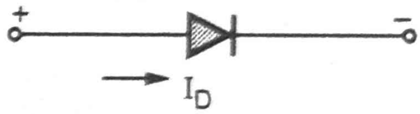
Ans. :

Sr. No.	Zener breakdown	Avalanche breakdown
1.	Breakdown is due to intense electric field across the junction.	Breakdown is due to the collision of accelerated charge carriers with the adjacent atoms and due to carrier multiplication.
2.	Occurs for zeners with zener voltage less than 6 V.	Occurs for zeners with zener voltage greater than 6 V.
3.	The temperature coefficient is negative.	The temperature coefficient is positive.
4.	The breakdown voltage decreases as junction temperature increases.	The breakdown voltage increases as junction temperature increases.
5.	The V-I characteristics is very sharp in breakdown region.	The V-I characteristics is not as sharp as zener breakdown.

Q.15 Compare zener diode and the conventional p-n junction diode.

Ans. :

No.	Zener diode	P-N junction diode
1.	Operated in reverse breakdown condition.	Operated in forward biased condition and never operated in reverse breakdown condition.

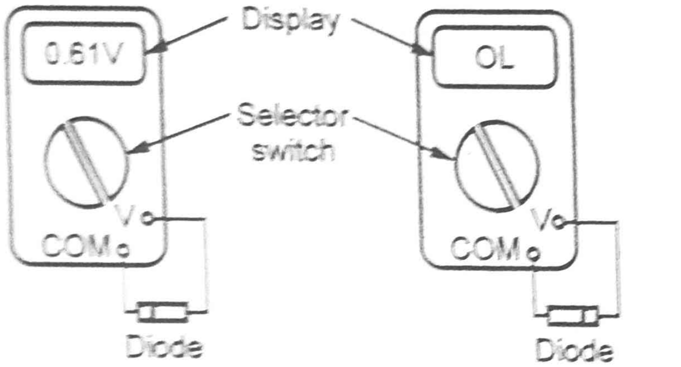
2.	The important region of operation lies in third quadrant.  	The important region of operation lies in first quadrant. 
3.	Dynamic zener resistance is very small in reverse breakdown condition.	The diode resistance in reverse biased condition is very high.
4.	Zener diode symbol is,  	The p-n junction diode symbol is, 
5.	The conduction in zener is opposite to that of arrow in the symbol, as operated in breakdown region.	The conduction when forward biased is in same direction as that of arrow in the symbol, when forward biased.
6.	The power dissipation capability is very high.	The power dissipation capability is very low compared to zener diodes.
7.	Applications of zener diode are voltage regulator, protection circuits, voltage limiters etc.	Applications of p-n junction diode are rectifiers, voltage multipliers, clippers, clampers and many electronic devices.

1.11 : Testing of Diode with Multimeter

Q.16 Explain the testing of diode with multimeter.

Ans. : • Digital multimeter has the diode testing ternimals or special diode test range.

- When the multimeter is used on this test range then it supplies a constant current of about 1 mA to a diode connected to its terminals.
- When the terminals are connected so as to forward bias the diode then for perfect diode, the meter shows forward voltage drop of the diode. It shows 0.55 to 0.7 V for the silicon diode as shown in the Fig. Q.16.1 (a).
- When the diode is reverse biased then for the perfect diode, meter gives overload indication by showing 'OL' or '1' on the display as shown in the Fig. Q.16.1 (b).



(a) Forward biased (b) Reverse biased

Fig. Q.16.1 Testing of diode with multimeter

- If 'OL' display occurs for both forward and reverse bias connections then diode is open circuited.
- While if the display shows '000' in both forward and reverse biased cases then the diode is short circuited.

1.12 : Rectifier

Q.17 What is rectifier ? What are its types ?

Ans. : • A rectifier is a device which converts a.c. voltage to pulsating d.c. voltage, using one or more p-n junction diodes.

- The three types of rectifiers using diodes are,
  - i) Half wave rectifier
  - ii) Full wave rectifier with center tap
  - iii) Bridge rectifier.

1.13 : Half Wave Rectifier

Q.18 Draw the half wave rectifier and explain its operation along with the waveforms.

Ans. : • The circuit diagram is shown in the Fig. Q.18.1.

- A sinusoidal a.c. voltage, having frequency of 50 Hz is applied to rectifier circuit using suitable step-down transformer, with necessary turns ratio.

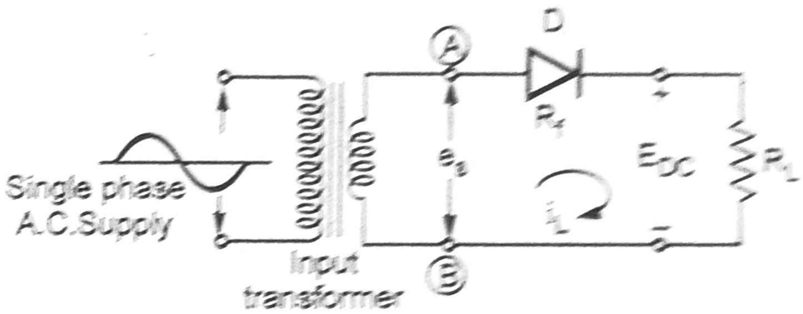


Fig. Q.18.1 Halfwave rectifier

- The transformer secondary voltage e_s is mathematically given by,

$$\boxed{e_s = E_{sm} \sin \omega t}$$

with $\omega = 2\pi f$ and

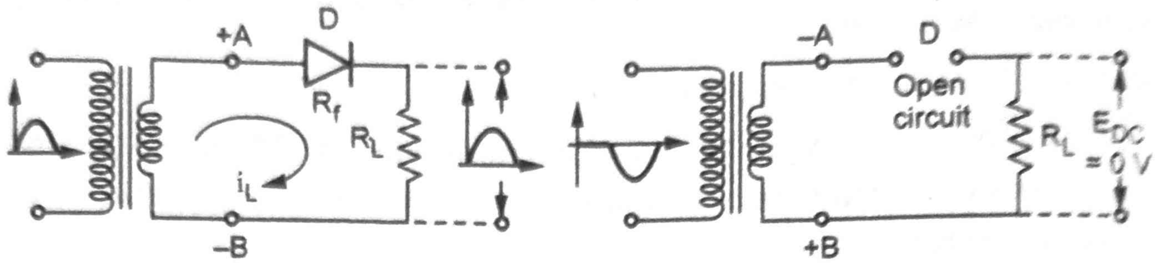
f = Supply frequency

- The turns ratio of transformer decides the secondary voltage e_s which is applied to rectifier.

Operation of the Circuit :

- During the positive half cycle of input a.c. voltage, terminal (A) becomes positive with respect to terminal (B). The diode is forward biased and the current flows in the circuit in the clockwise direction, as shown in the Fig. Q.18.2 (a). This current is also flowing through the load resistance R_L hence denoted as i_L (load current).
- During negative half cycle when terminal (A) is negative with respect to terminal (B), diode becomes reverse biased. Thus it acts

as an open circuit. Hence no current flows in the circuit as shown in the Fig. Q.18.2 (b).



(a) Diode forward biased (b) Diode reverse biased

Fig. Q.18.2

- Thus the circuit current, which is also the load current, is in the form of half sinusoidal pulses.
- The load voltage, being the product of load current and load resistance, will also be in the form of half sinusoidal pulses. The different waveforms are illustrated in Fig. Q.18.3.

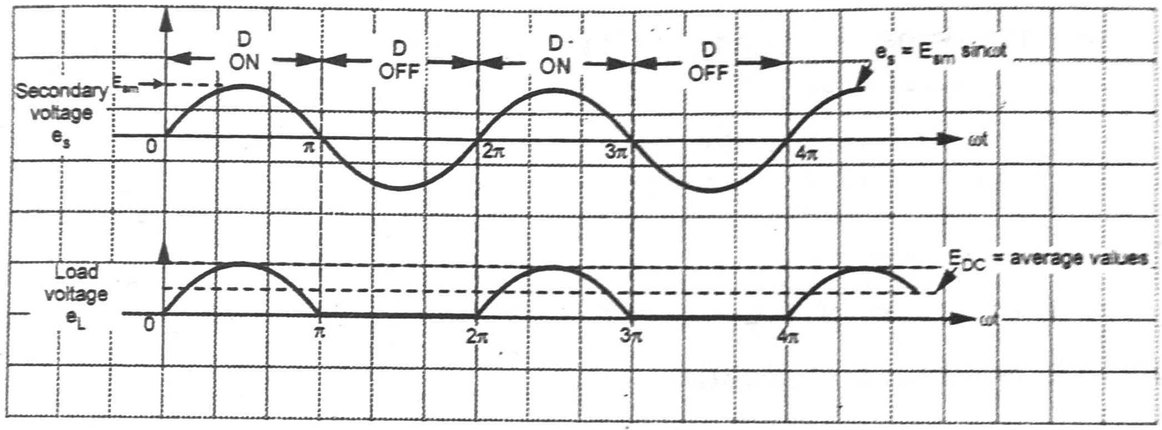


Fig. Q.18.3 Load current and load voltage waveforms for half wave rectifier

Important Points to Remember

- The peak value of the load current is given by,

$$\therefore \quad I_m = \frac{E_{sm}}{R_f + R_L + R_s}$$

where R_s = Resistance of secondary winding of transformer

R_f = Forward resistance of diode

- If R_s and R_f are not given they should be neglected while calculating I_m.

Q.19 Derive the expression for the d.c. load current, average d.c. load voltage and r.m.s. value of load current for the half wave rectifier.

Ans. : • The average or d.c. value of the load current (I_{DC}) : It is obtained by integration.

- Mathematically, current waveform can be described as,

$$i_L = I_m \sin \omega t \quad \text{for } 0 \le \omega t \le \pi$$

and

$$i_L = 0 \quad \text{for } \pi \le \omega t \le 2\pi$$

where

$$I_m = \text{Peak value of load current}$$

$$\therefore \quad I_{DC} = \frac{1}{2\pi}\int_0^{2\pi} i_L \, d(\omega t) = \frac{1}{2\pi}\int_0^{2\pi} I_m \sin(\omega t) d(\omega t)$$

- As no current flows during negative half cycle of a.c. input voltage, i.e. between $\omega t = \pi$ to $\omega t = 2\pi$, we change the limits of integration.

$$\therefore I_{DC} = \frac{1}{2\pi}\int_0^{\pi} I_m \sin(\omega t) d(\omega t) = \frac{I_m}{2\pi}[-\cos(\omega t)]_0^{\pi}$$

$$= -\frac{I_m}{2\pi}[\cos(\pi) - \cos(0)] = -\frac{I_m}{2\pi}[-1-1] = \frac{I_m}{\pi}$$

$$\therefore \quad \boxed{I_{DC} = \frac{I_m}{\pi} = \text{Average value}}$$

The average d.c. load voltage (E_{DC}) : It is the product of average D.C. load current and the load resistance R_L.

$$\therefore \quad \boxed{E_{DC} = I_{DC} R_L = \frac{I_m}{\pi} R_L = \frac{E_{sm}}{(R_f + R_L + R_s)\pi} R_L}$$

- The winding resistance R_s and forward diode resistance R_f are practically very small compared to R_L hence neglecting them,

$$\therefore \quad \boxed{E_{DC} \approx \frac{E_{sm}}{\pi}}$$

The RMS value of the load current (I_{RMS}) :

- The RMS means squaring, finding mean and then square root. Mathematically it is obtained as,

$$I_{RMS} = \sqrt{\frac{1}{2\pi}\int_0^{2\pi}(I_m \sin \omega t)^2 d(\omega t)} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2 \omega t \ d(\omega t)}$$

$$= I_m \sqrt{\frac{1}{2\pi}\int_0^{\pi}\frac{1-\cos 2\omega t}{2} d(\omega t)} = I_m \sqrt{\frac{1}{2\pi}\left\{\frac{\omega t}{2} - \frac{\sin 2\omega t}{4}\right\}_0^{\pi}}$$

$$= I_m \sqrt{\frac{1}{2\pi}\left(\frac{\pi}{2}\right)} = \frac{I_m}{2} \qquad \ldots \sin(2\pi) = \sin(0) = 0$$

$$\therefore \quad \boxed{I_{RMS} = \frac{I_m}{2} \text{ and } E_{L(RMS)} = I_{RMS}\, R_L = \frac{I_m}{2} R_L = \frac{E_{sm}}{2}}$$

Q.20 Derive the expression for the efficiency of half wave rectifier. And show that maximum theoretical efficiency of a half wave rectifier is 40.6 %.

Ans. : • The d.c. power output is,

$$\therefore \quad \boxed{P_{DC} = E_{DC}\, I_{DC} = I_{DC}^2 R_L = \left[\frac{I_m}{\pi}\right]^2 R_L = \frac{I_m^2}{\pi^2} R_L}$$

$$\therefore \quad \boxed{P_{DC} = \frac{E_{sm}^2 R_L}{\pi^2 [R_f + R_L + R_s]^2} \quad \text{using } I_m = \frac{E_{sm}}{R_f + R_L + R_s}}$$

- The **a.c. power input** taken from the secondary of transformer is the power supplied to three resistances namely load resistance R_L, the diode resistance R_f and winding resistance R_s.

The a.c. power is, $\boxed{P_{AC} = I_{RMS}^2 [R_L + R_f + R_s]}$ but $I_{RMS} = \frac{I_m}{2}$ for half wave,

$$\therefore \quad \boxed{P_{AC} = \frac{I_m^2}{4} [R_L + R_f + R_s]}$$

Rectifier efficiency : The **rectifier efficiency** is defined as the ratio of output d.c. power to input a.c. power.

$$\eta = \frac{\text{D.C. output power}}{\text{A.C. input power}} = \frac{P_{DC}}{P_{AC}} = \frac{\frac{I_m^2}{\pi^2} R_L}{\frac{I_m^2}{4} [R_f + R_L + R_s]} = \frac{(4/\pi^2) R_L}{(R_f + R_L + R_s)}$$

$\therefore$ Dividing by R_L to numerator and denominator,

$$\boxed{\eta = \frac{0.406}{1 + \left(\frac{R_f + R_s}{R_L}\right)}}$$

- Practically $(R_f + R_s) \ll R_L$, we get the maximum theoretical efficiency of half wave rectifier as,

$$\therefore \quad \boxed{\% \, \eta_{max} = 0.406 \times 100 = 40.6 \, \%}$$

- **More the rectifier efficiency, less are the ripple contents in the output.**

Q.21 Define the ripple factor. Derive its expression and hence find its value for the half wave rectifier.

Ans. : • The measure of ripples present in the output is with the help of a factor called **ripple factor** denoted by γ. It tells how smooth is the output.

- Mathematically **ripple factor** is defined as the ratio of R.M.S. value of the a.c. component in the output to the average or d.c. component present in the output.

$$\therefore \quad \boxed{\text{Ripple factor} \quad \gamma = \frac{\text{R.M.S. value of a.c. component of output}}{\text{Average or d.c. component of output}}}$$

- The output current is composed of a.c. component as well as d.c. component.

Let I_{ac} = R.M.S. value of a.c. component present in output

I_{DC} = D.C. component present in output

- I_{RMS} = R.M.S. value of total output current = $\sqrt{I_{ac}^2 + I_{DC}^2}$

i.e. $I_{ac} = \sqrt{I_{RMS}^2 - I_{DC}^2}$

$$\boxed{\text{Ripple factor} = \frac{I_{ac}}{I_{DC}} = \frac{\sqrt{I_{RMS}^2 - I_{DC}^2}}{I_{DC}} = \sqrt{\left(\frac{I_{RMS}}{I_{DC}}\right)^2 - 1}}$$ ... As per definition

- For a half wave circuit, $I_{RMS} = \frac{I_m}{2}$ while $I_{DC} = \frac{I_m}{\pi}$
- Using in the above expression for the ripple factor,

$$\boxed{\gamma = \sqrt{\left[\frac{\left(\frac{I_m}{2}\right)}{\left(\frac{I_m}{\pi}\right)}\right]^2 - 1} = \sqrt{\frac{\pi^2}{4} - 1} = \sqrt{1.4674} = \mathbf{1.21}}$$ ... Halfwave

This indicates that the ripple contents in the output are 1.21 times the d.c. component i.e. 121.1 % of d.c. component.

Important Points To Remember

- The voltage regulation is the factor which tells us about the change in the d.c. output voltage as load changes from no load to full load condition.
- If $(V_{dc})_{NL}$ = D.C. voltage on no load and $(V_{dc})_{FL}$ = D.C. voltage on full load then voltage regulation is defined as,

$$\therefore \quad \% \text{ Voltage regulation} = \frac{(V_{dc})_{NL} - (V_{dc})_{FL}}{(V_{dc})_{FL}} \times 100$$

- **Less the value of voltage regulation, better is the performance of rectifier circuit.**

Transformer Utilization Factor (TUF)

- The T.U.F. is defined as the ratio of d.c. power delivered to the load to the a.c. power rating of the transformer.

$$\therefore \text{ T.U.F.} = \frac{\text{D.C. power delivered to the load}}{\text{A.C. power rating of the transformer}} = \mathbf{0.287} \text{ for half wave.}$$

Q.22 A half wave rectifier from supply 230 V 50 Hz with step down transformer ratio 3 : 1 to a resistive load of 10 k Ω. The diode forward resistance is 75 Ω and transformer secondary is 10 Ω. Calculate the DC current, DC voltage, efficiency and ripple factor.

Ans. :

$$R_L = 10\text{ k}\Omega,\ R_f = 75\ \Omega,\ R_s = 10\ \Omega$$

$$E_{P(RMS)} = 230\text{ V},\ N_2/N_1 = 1 : 3$$

$$\frac{N_2}{N_1} = \frac{E_{s\,(RMS)}}{E_{p\,(RMS)}} \quad \text{i.e.} \quad \frac{1}{3} = \frac{E_{s\,(RMS)}}{230}$$

$$E_{s\,(RMS)} = 76.667\text{ V}$$

$$E_{sm} = \sqrt{2} \times E_{s\,(RMS)} = 108.423\text{ V}$$

$$I_m = \frac{E_{sm}}{R_L + R_f + R_s} = 10.751\text{ mA}$$

$$I_{DC} = \frac{I_m}{\pi} = \mathbf{3.422\ mA}$$

$$E_{DC} = I_{DC} R_L = 3.422 \times 10^{-3} \times 10 \times 10^3$$

$$= \mathbf{34.22\ V}$$

$$I_{RMS} = \frac{I_m}{2} = 5.3755\text{ mA}$$

$$P_{DC} = E_{DC} I_{DC} = 0.1171\text{ W}$$

$$P_{AC} = I_{RMS}^2 (R_L + R_s + R_f) = 0.2914\text{ W}$$

$$\therefore \quad \% \eta = \frac{P_{DC}}{P_{AC}} \times 100 = 40.18 \%$$

$$\text{Ripple factor} = \sqrt{\left(\frac{I_{RMS}}{I_{DC}}\right)^2 - 1} = 1.21$$

1.14 : Full Wave Rectifier

Q.23 With the help of circuit diagram and waveforms, explain the working of centre-tap full wave rectifier.

Ans. : • The full wave rectifier circuit is shown in the Fig. Q.23.1.

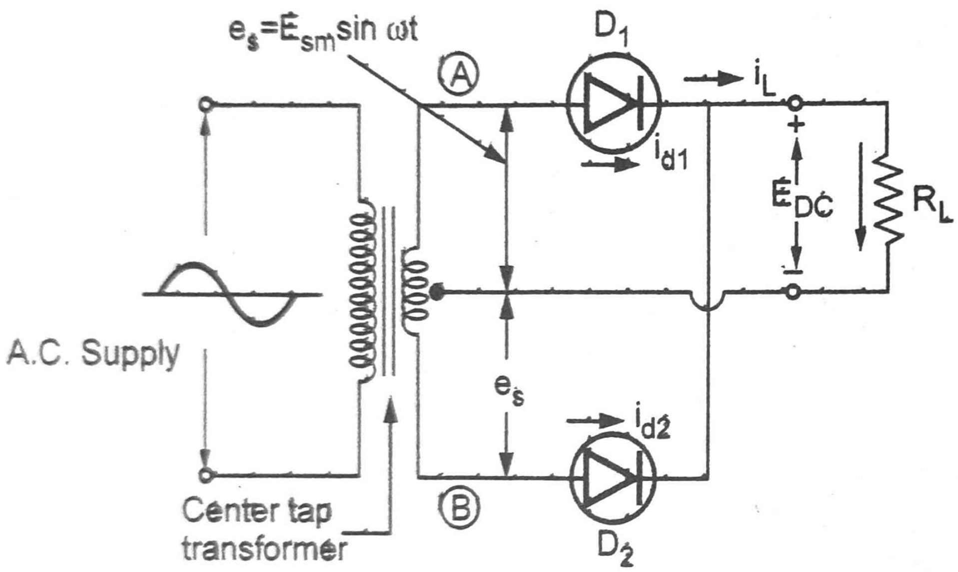


Fig. Q.23.1 Full wave rectifier

- It uses a center tap transformer.
- It uses two diodes which feed a common load resistance R_L.
- The a.c. voltage is applied through a suitable power transformer with proper turns ratio.

Operation of the Circuit :

- Consider the positive half cycle of ac input voltage in which terminal (A) is positive and terminal (B) is negative due to center tap transformer.

- The diode D_1 will be forward biased and hence will conduct; while diode D_2 will be reverse biased and will act as an open circuit and will not conduct. The diode D_1 supplies the load current, i.e. $i_L = i_{d1}$.
- In the next half cycle of ac voltage, polarity reverses and terminal (A) becomes negative and (B) positive. The diode D_2 conducts, being forward biased, while D_1 does not, being reverse biased. The diode D_2 supplies the load current, i.e. $i_L = i_{d2}$.
- The **load current flows in both the half cycles of ac voltage and in the same direction through the load resistance.** Hence we get rectified output across the load.
- The load current is sum of individual diode currents flowing in corresponding half cycles.
- The waveforms of secondary voltage (one half), load current and load voltage are shown in the Fig. Q.23.2.

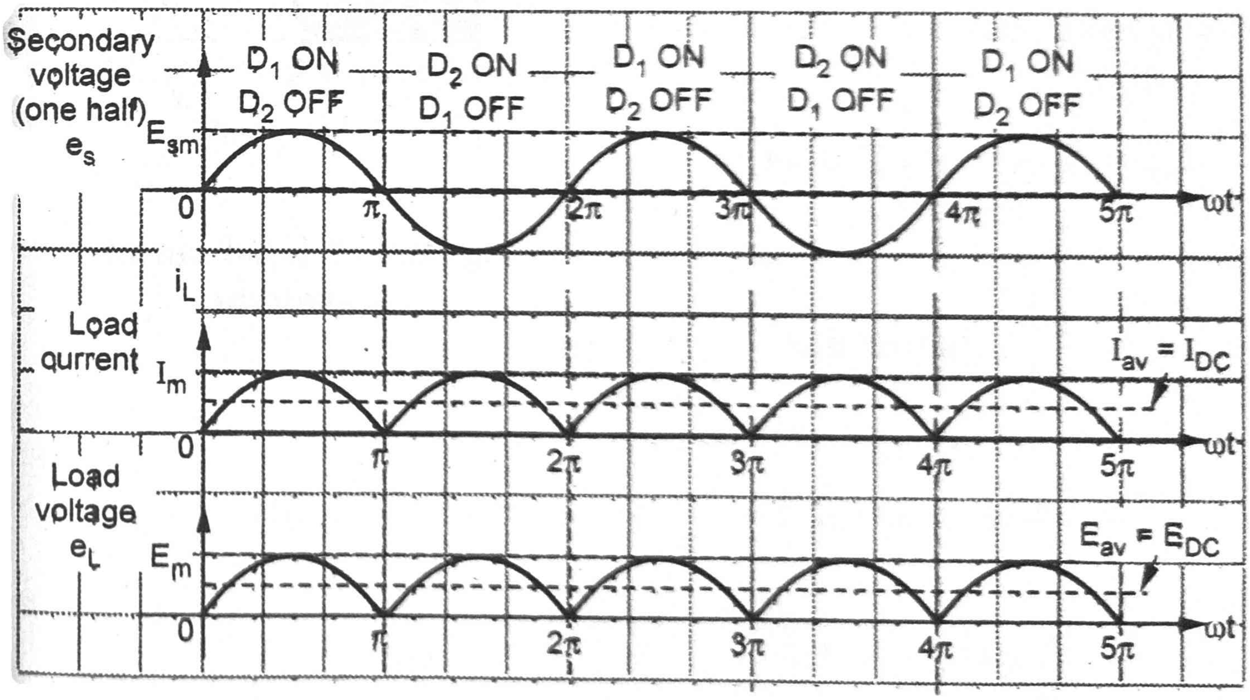


Fig. Q.23.2 Load current and voltage waveforms for full wave rectifier

Important Points to Remember

- R_f = Forward resistance of diodes and
  R_L = Load resistance
- R_s = Winding resistance of each half of secondary
- E_{sm} = Maximum value of a.c. input voltage across each half of secondary winding
- The maximum value of the load current
  $I_m = \frac{E_{sm}}{R_s + R_f + R_L}$.

Q.24 Derive the expressions for the average d.c. current, d.c. load voltage and RMS value of the load current for the full wave rectifier circuit with two diodes.

Ans. : The average or d.c. value of the load current (I_{DC}) :

- Consider one cycle of the load current i_L from 0 to π to obtain the average value which is d.c. value of load current.

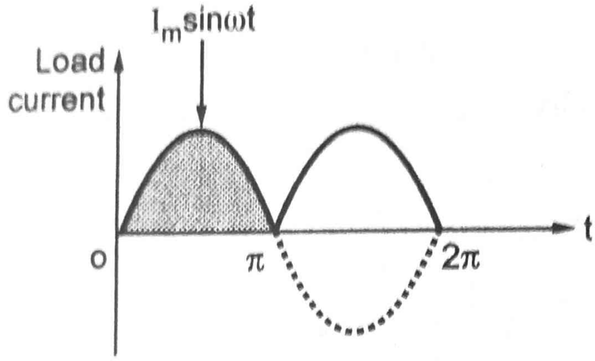


Fig. Q.24.1 Load current waveform

$$i_L = I_m \sin \omega t \qquad 0 \le \omega t \le \pi$$

$$I_{av} = I_{DC} = \frac{1}{\pi}\int_0^{\pi} i_L \, d(\omega t)$$

$$= \frac{1}{\pi}\int_0^{\pi} I_m \sin \omega t \, d\omega t$$

$$= \frac{I_m}{\pi}\left[(-\cos \omega t)_0^{\pi}\right] = \frac{I_m}{\pi}[-\cos\pi - (-\cos 0)]$$

$$= \frac{I_m}{\pi}[+1 - (-1)] \qquad \ldots \cos\pi = -1$$

$$\therefore \boxed{I_{DC} = \frac{2I_m}{\pi}}$$

Average DC Load Voltage (E_{DC}) :

- The d.c. load voltage is, $E_{DC} = I_{DC} R_L = \frac{2 I_m R_L}{\pi}$

  Substituting value of I_m,

$$E_{DC} = \frac{2 E_{sm} R_L}{\pi [R_f + R_s + R_L]} = \frac{2 E_{sm}}{\pi \left[1 + \frac{R_f + R_s}{R_L}\right]}$$

- But as R_f and $R_s << R_L$ hence $\frac{R_f + R_s}{R_L} << 1$,

$$\therefore \qquad \boxed{E_{DC} = \frac{2 E_{sm}}{\pi}}$$

RMS Load Current (I_{RMS}) : Mathematically it can be obtained as,

$$I_{RMS} = \sqrt{\frac{1}{2\pi} \int_0^{2\pi} i_L^2 \, d(\omega t)} = \sqrt{2 \times \frac{1}{2\pi} \int_0^{\pi} [I_m \sin(\omega t)]^2 \, d(\omega t)}$$

- The circuit has two half wave rectifiers similar in operation operating in two half cycles hence integration term is splitted as above.

$$I_{RMS} = I_m \sqrt{\frac{1}{\pi} \int_0^{\pi} \sin^2(\omega t) d(\omega t)}$$

$$= I_m \sqrt{\frac{1}{\pi} \int_0^{\pi} \frac{1 - \cos 2\omega t}{2} \, d(\omega t)}$$

$$= I_m \sqrt{\frac{1}{\pi} \left[\frac{\omega t}{2} - \frac{\sin(2\omega t)}{4}\right]_0^{\pi}} = I_m \sqrt{\frac{1}{\pi} \left[\frac{\pi}{2}\right]}$$

$$\boxed{I_{RMS} = \frac{I_m}{\sqrt{2}} \quad \text{and} \quad E_{L(RMS)} = I_{RMS} R_L = \frac{I_m}{\sqrt{2}} R_L}$$

Q.25 For a full wave rectifier with two diodes, prove that its ripple factor is 0.48 and its maximum efficiency is 81.2 %.

Ans. : Maximum theoratical efficiency :

- D.C. Power output = $E_{DC}I_{DC} = I_{DC}^2 R_L$

$$\therefore \quad \boxed{P_{DC} = \left(\frac{2I_m}{\pi}\right)^2 R_L = \frac{4}{\pi^2}\frac{E_{sm}^2}{(R_s+R_f+R_L)^2} \times R_L = \frac{4}{\pi^2} I_m^2 R_L}$$

$$\therefore \quad \text{AC power input } P_{AC} = I_{RMS}^2(R_f+R_s+R_L) = \left(\frac{I_m}{\sqrt{2}}\right)^2 (R_f+R_s+R_L) = \frac{I_m^2(R_f+R_s+R_L)}{2}$$

- Substituting value of I_m we get,

$$\therefore \quad \boxed{P_{AC} = \frac{E_{sm}^2}{(R_f+R_s+R_L)^2} \times \frac{1}{2} \times (R_f+R_s+R_L) = \frac{E_{sm}^2}{2(R_f+R_s+R_L)}}$$

$$\therefore \quad \text{Rectifier efficiency } \eta = \frac{P_{DC} \text{ output}}{P_{AC} \text{ input}} = \frac{\frac{4}{\pi^2} I_m^2 R_L}{\frac{I_m^2(R_f+R_s+R_L)}{2}} = \frac{8 R_L}{\pi^2(R_f+R_s+R_L)}$$

- But if $R_f + R_s << R_L$, neglecting it from denominator,

$$\eta_{max} = \frac{8 R_L}{\pi^2 (R_L)} = \frac{8}{\pi^2}$$

$$\therefore \quad \boxed{\% \eta_{max} = \frac{8}{\pi^2} \times 100 = 81.2 \%}$$

Ripple factor :

- The ripple factor is given by a general expression,

$$\text{Ripple factor} = \sqrt{\left[\frac{I_{RMS}}{I_{DC}}\right]^2 - 1}$$

- For full wave $I_{RMS} = I_m / \sqrt{2}$ and $I_{DC} = 2I_m / \pi$ so substituting above,

$$\therefore \quad \boxed{\text{Ripple factor} = \gamma = \sqrt{\left[\frac{I_m / \sqrt{2}}{2I_m / \pi}\right]^2 - 1} = \sqrt{\frac{\pi^2}{8} - 1} = 0.48}$$

- This indicates that the ripple contents in the output are 48 % of the d.c. component which is much less than that for the half wave circuit.

Important Points to Remember

- **PIV rating of diode in two diode full wave rectifier :**

$$\text{PIV of diode} = 2\ E_{sm}$$

- Note that E_{sm} = Maximum value of a.c. voltage across half the secondary of transformer.
- **The ripple frequency in full wave rectifier is '2f" Hz.**
- The average **TUF** for full wave rectifier is **0.693.**

Q.26 A single phase full-wave rectifier supplies power to a 1 kΩ load. The AC voltage applied to the diode is 300-0-300 V. If diode resistance is 25 Ω and that of the transformer secondary negligible. Determine average load current, average load voltage and rectification efficiency.

Ans. : Transformer voltage is 300 - 0 - 300 V

$$\therefore \quad E_{s\,(RMS)} = 300 \text{ V}, \; E_{sm} = \sqrt{2} \times 300 = 424.264 \text{ V}$$

$$I_m = \frac{E_{sm}}{R_f + R_L} = \frac{424264}{25 + 1 \times 10^3} = 0.4139 \text{ A}$$

$$I_{DC} = \frac{2 I_m}{\pi} = \frac{2\times 0.4139}{\pi} = \mathbf{0.2635\ A}$$

$$E_{DC} = I_{DC}\ R_L = 0.2635\times 1\times 10^3$$

$$= \mathbf{263.5\ V}$$

$$P_{DC} = I_{DC}^2 R_L = 69.4322\ W,$$

$$P_{AC} = I_{RMS}^2 (R_f + R_L)$$

$$\therefore \quad P_{AC} = \left(\frac{I_m}{\sqrt{2}}\right)^2 (R_f + R_L) = 87.798\ W$$

$$\therefore \quad \%\ \eta = \frac{P_{DC}}{P_{AC}}\times 100 = \frac{69.4322}{87.798}\times 100$$

$$= \mathbf{79.081\ \%.}$$

1.15 : Bridge Rectifier

Q.27 Draw the circuit of bridge rectifier and explain its operation. Give the input and output waveforms.

Ans. : • The basic bridge rectifier circuit is shown in Fig. Q.27.1.

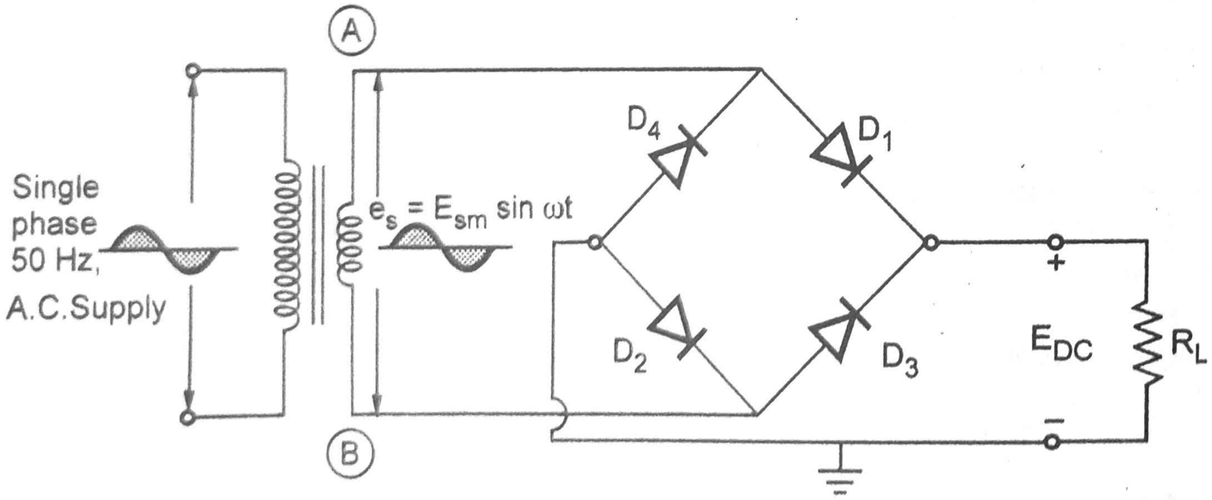


Fig. Q.27.1 Bridge rectifier circuit

• The bridge rectifier circuit is essentially a **full-wave rectifier circuit, using four diodes,** forming the four arms of an electrical bridge.

- To one diagonal of the bridge, the ac voltage is applied through a transformer if necessary and the rectified dc voltage is taken from the other diagonal of the bridge.

Operation of the circuit :

- Consider the positive half of ac input voltage. The point A of secondary becomes positive. The diodes D_1 and D_2 will be forward biased, while D_3 and D_4 reverse biased. The two diodes D_1 and D_2 conduct in series with the load and the current flows as shown in Fig. Q.27.2.

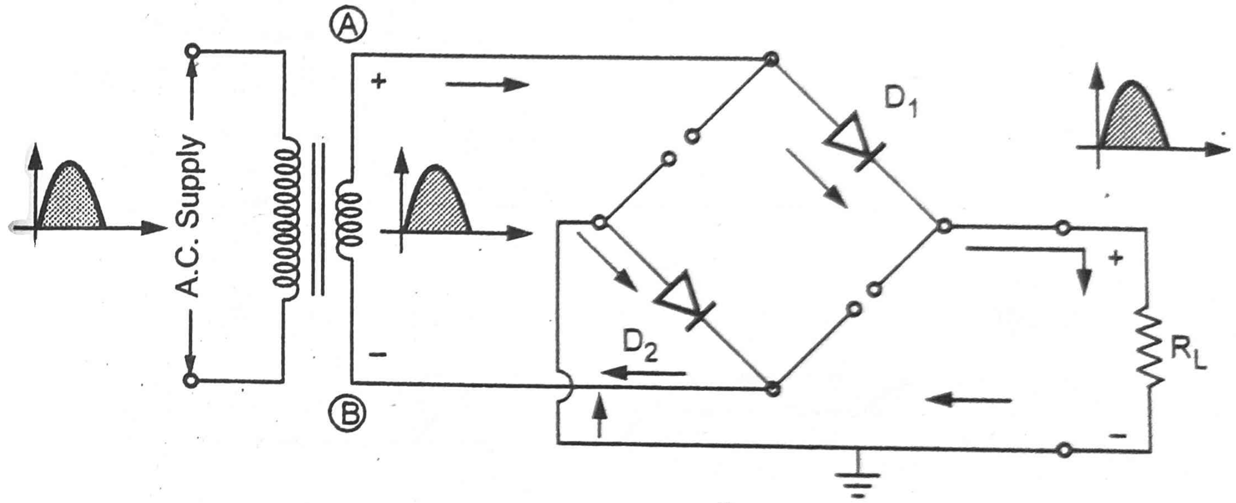


Fig. Q.27.2 Current flow during positive half cycle

- In the next half cycle, when the polarity of ac voltage reverses hence point B becomes positive diodes D_3 and D_4 are forward biased, while D_1 and D_2 reverse biased. Now the diodes D_3 and D_4 conduct is series with the load and the current flows as shown in Fig. Q.27.3.

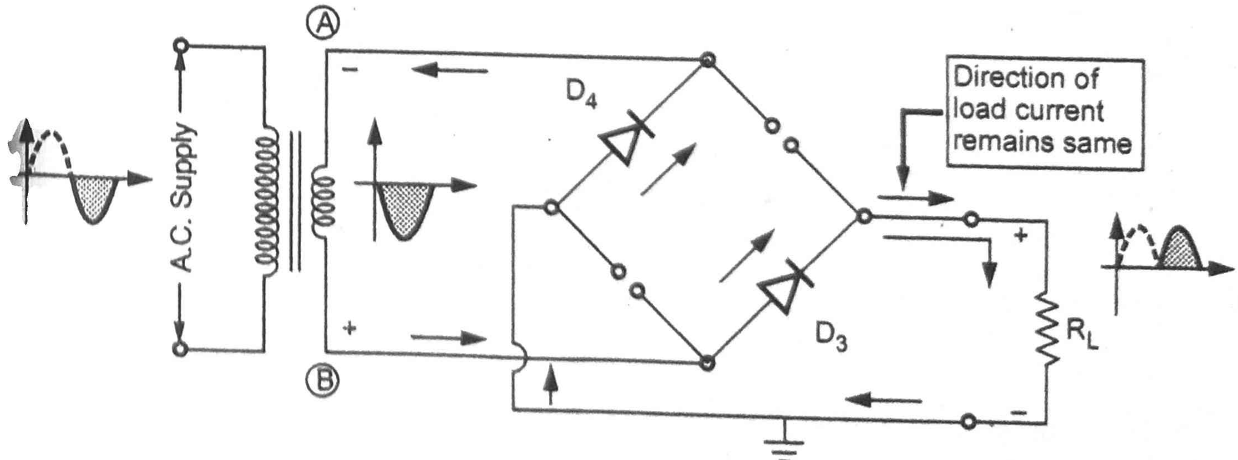


Fig. Q.27.3 Current flow during negative half cycle

- It is seen that in both cycles of ac, the load current is flowing in the same direction hence, we get a full-wave rectified output.
- The waveforms of load current and voltage are shown in the Fig. Q.27.4.

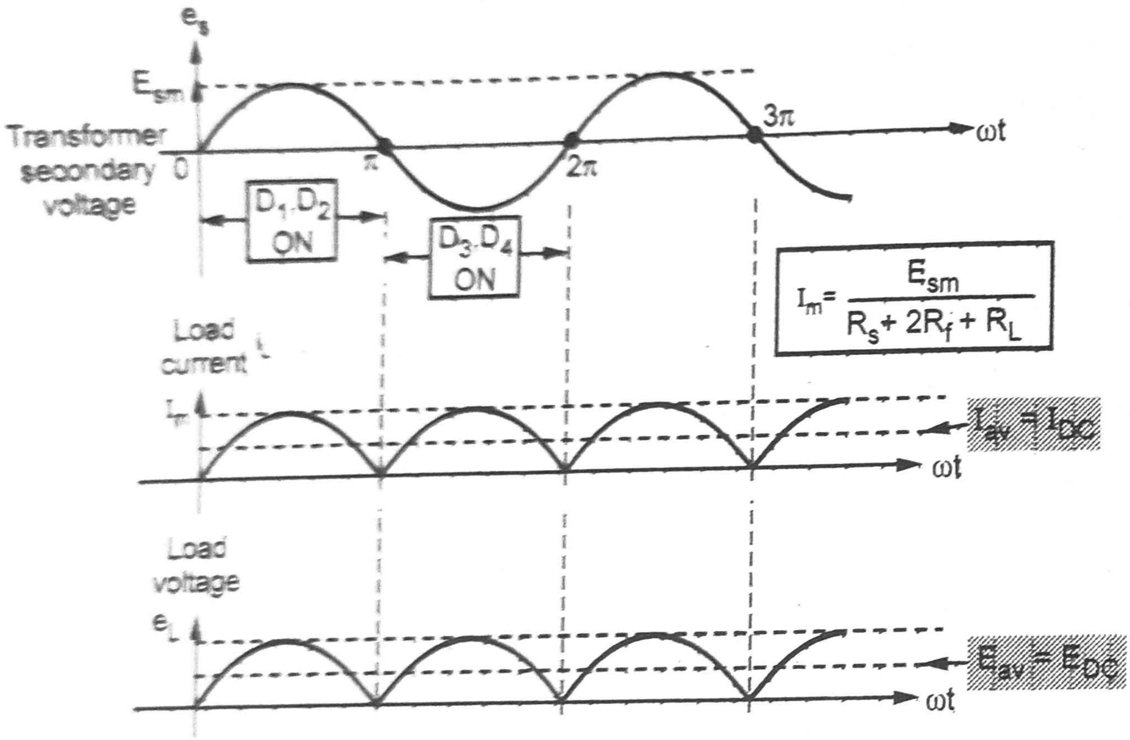


Fig. Q.27.4 Waveforms of bridge rectifier

Important Points to Remember

- **For bridge rectifier,** in each half cycle two diodes conduct hence in the various expressions R_f must be replaced by $2R_f$.
- $I_m = \frac{E_{sm}}{R_s + 2R_f + R_L}$
- $E_{DC} = I_{DC} R_L = \frac{2E_{sm}}{\pi}$,

$$E_{RMS} = \frac{I_m}{\sqrt{2}} R_L = \frac{E_{sm}}{\sqrt{2}(R_s + 2R_f + R_L)} R_L$$

- $P_{DC} = I_{DC}^2 R_L = \frac{4}{\pi^2} I_m^2 R_L$ and

$$P_{AC} = I_{RMS}^2 (R_s + 2R_f + R_L)$$

$$= \frac{I_m^2 (2R_f + R_s + R_L)}{2}$$

- $\eta = \frac{8R_L}{\pi^2 (R_s + 2R_f + R_L)}$, $\% \eta_{max} = 81.2 \%$,

ripple factor $\gamma = 0.48$, T.U.F. $= 0.812$

- The E_{sm} is the maximum value of a.c. voltage across full secondary winding of the transformer used.
- PIV rating for the diodes used in bridge rectifier is E_{sm}.

Q.28 A bridge rectifier is driving a load resistance of 100 Ω. It is driven by a source voltage of 230 V, 50 Hz. Neglecting diode resistances, calculate : i) Average d.c. voltage ii) Average direct current iii) Frequency of output waveform.

Ans. : Given, $R_L = 100\ \Omega$, $E_{s\,(RMS)} = 230$ V, $R_f = 0$, $f = 50$ Hz

$$E_{sm} = \sqrt{2} \times E_{s(RMS)} = \sqrt{2} \times 230 = 325 \text{ V}$$

i) Average d.c. voltage

$$E_{DC} = \frac{2E_{sm}}{\pi} = \frac{2 \times 325}{\pi} = 206.9 \text{ V} \qquad \ldots \text{ As } R_f = 0$$

ii) Average direct current

$$I_{DC} = \frac{2I_m}{\pi} \quad \text{where } I_m = \frac{E_{sm}}{R_L + 2R_f + R_s}$$

$$I_m = \frac{3.25}{100 + 0 + 0} = 3.25 \text{ A}$$

$$I_{DC} = \frac{2 \times 3.25}{\pi} = 2.06 \text{ A}$$

iii) Frequency of output waveform

$$= 2f = 2 \times 50 = 100 \text{ Hz}$$

1.16 : Filter

Q.29 Explain the need of the filter.

Ans. : • The output of a rectifier circuit is not pure d.c.; but it contains fluctuations or ripples, which are undesired.

- To minimize the ripple content in the output, filter circuits are used.

- **The filter is an electronic circuit composed of capacitor, inductor or combination of both and connected between the rectifier and the load so as to convert pulsating d.c. to pure d.c.**

- The filter circuits are connected between the rectifier and load, as shown in the Fig. Q.29.1.

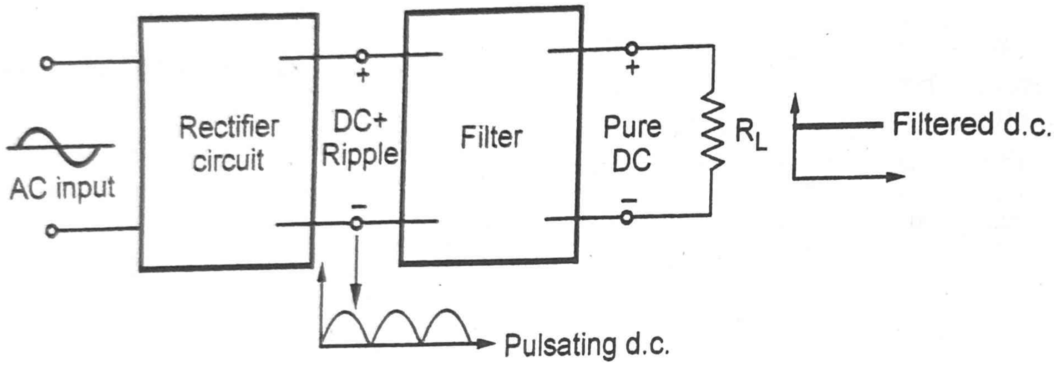


Fig. Q.29.1 Rectifier and filter

1.17 : Capacitor Filter Circuit

Important Points to Remember

- In capacitor filter circuit, a capacitor is connected in shunt with the load resistance. Looking from the rectifier side, the first element in the filter is capacitor hence it is also called capacitor input filter.

Q.30 Explain the operation of capacitor filter circuit with half wave rectifier.

Ans. : • The circuit diagram of half wave rectifier with shunt capacitor filter is shown in the Fig. Q.30.1.

- During the positive quarter cycle of the input, the capacitor C charges to peak value of the input i.e. E_{sm}. This is point A as shown in the Fig. Q.30.2.

- When input decreases, the C remains charged at E_{sm} and diode gets reverse biased.

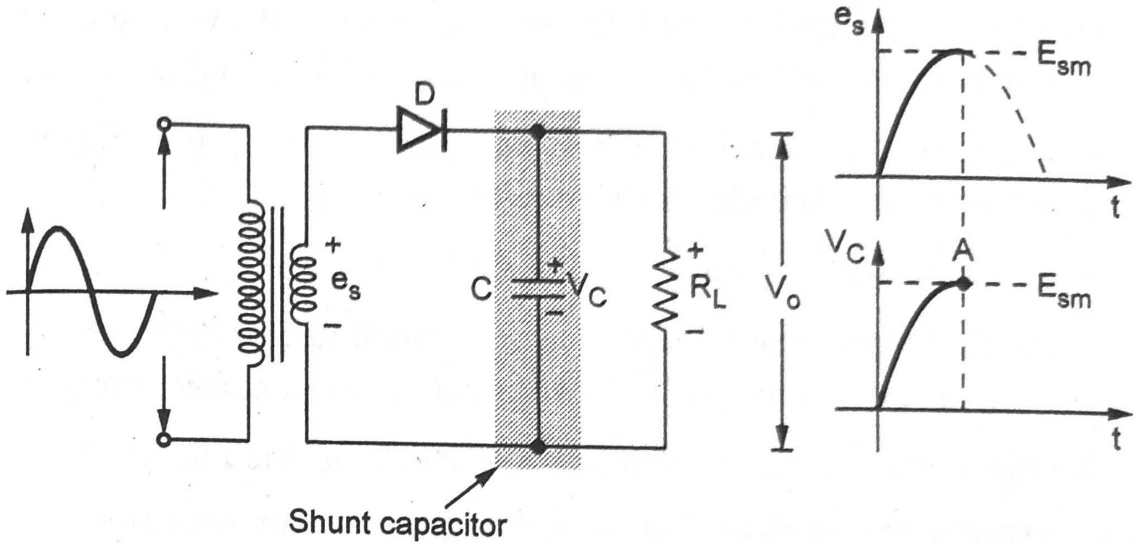


Fig. Q.30.1 Shunt capacitor filter with HWR

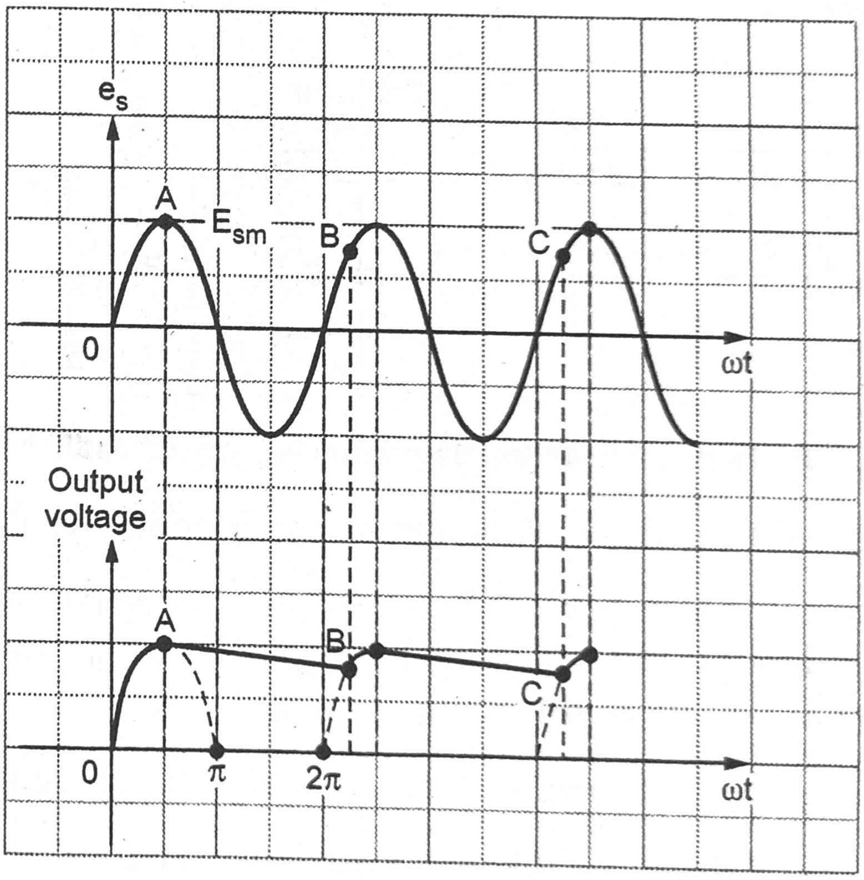


Fig. Q.30.2 Waveforms of shunt capacitor filter with HWR

- The capacitor C supplies the load R_L and starts discharging.
- Due to large time constant, capacitor discharges very little from E_{sm}.

- The capacitor supplies load for full negative half cycle and next part of positive half cycle till input is less than capacitor voltage.
- At point B, the capacitor starts charging as diode gets forward biased as input exceeds capacitor voltage.
- The point B is shown in the Fig. Q.30.3.
- As the discharging of capacitor is very small and charging time is very small, the ripples in the output get reduced considerably.
- The input and output waveforms are shown in the Fig. Q.30.3.

Q.31 Explain the operation of capacitor filter circuit with full wave rectifier.

Ans. : • The Fig. Q.31.1 show the capacitor input filter with full wave rectifier.

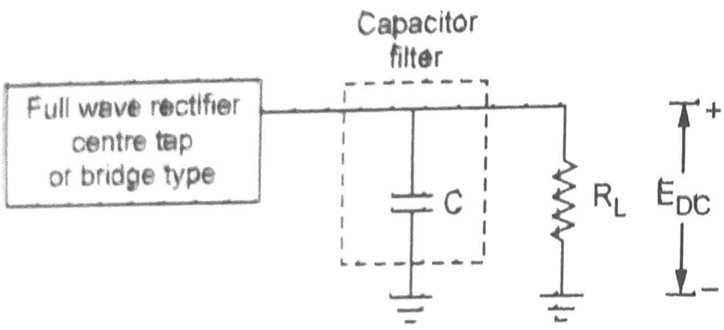


Fig. Q.31.1 Capacitor filter with full wave rectifier

- The full wave rectifier may be center tap or bridge rectifier.
- Immediately when power is turned on, the capacitor C gets charged through forward biased diode D_1 to E_{sm}, during first quarter cycle of the rectified output voltage.
- In the next quarter cycle from $\frac{\pi}{2}$ to π, the capacitor starts discharging through R_L. Once capacitor gets charged to E_{sm}, the diode D_1 becomes reverse biased and stops conducting.
- So during the period from $\frac{\pi}{2}$ to π, the capacitor C supplies the load current. It discharges to point B shown in the Fig. Q.31.2.

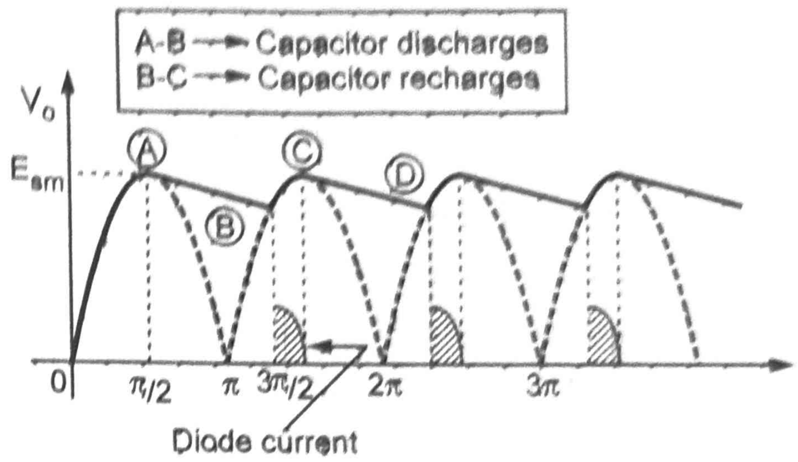


Fig. Q.31.2 FWR output with capacitor filter

- At point B, lying in the quarter π to $\frac{3\pi}{2}$ of the rectified output voltage, the input voltage exceeds capacitor voltage, making D_2 forward biased. This charges capacitor back to E_{sm} at point C.
- The time required by capacitor C to charge to E_{sm} is quite small and only for this period, diode D_2 is conducting.
- Again at point C, diode D_2 stops conducting and capacitor supplies load and starts discharging upto point D in the next quarter cycle of the rectified output voltage as shown in the Fig. Q.31.2. At this point, the diode D_1 conducts to charge capacitor back to E_{sm}. The diode currents are shown shaded in the Fig. Q.31.2.
- When the capacitor is discharging through the load resistance R_L, both the diodes are non-conducting. The capacitor supplies the load current.

The operation remains same if full wave rectifier with two diodes is replaced with bridge rectifier. In a bridge rectifier, C charges through D_1 and D_2 in one half cycle and it recharges through D_3 and D_4 in next half cycle.

Q.32 Derive the expression for the ripple factor of rectifier using a capacitor filter.

Ans. :

- Let T = Time period of the a.c. input voltage

$$\frac{T}{2} = \text{Half of the time period}$$

$$T_1 = \text{Time for which diode is conducting}$$

$$T_2 = \text{Time for which diode is non-conducting}$$

- During time T_1, capacitor gets charged and this process is quick. During time T_2, capacitor gets discharged through R_L. As time constant R_LC is very large, discharging process is very slow and hence $T_2 >> T_1$.
- Let V_r be the peak to peak value of ripple voltage, which is assumed to be triangular as shown in the Fig. Q.32.1.

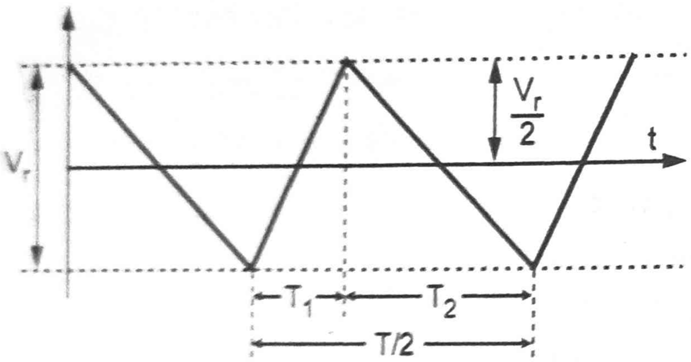


Fig. Q.32.1 Triangular approximation of ripple voltage

- For triangular assumption the r.m.s. value of the ripple voltage is given by,

$$\boxed{V_{r(rms)} = \frac{V_r}{2\sqrt{3}}} \quad \text{... As triangular} \quad \text{... (1)}$$

- During the time interval T_2, the capacitor C is discharging through the load resistance R_L. The charge lost is, $Q = CV_r$.
- But $i = \frac{dQ}{dt}$ hence $Q = \int_0^{T_2} i\,dt = I_{DC}\,T_2$ as **integration gives average or d.c. value**

- Hence $\quad I_{DC}\, T_2 = CV_r \quad$ i.e $\quad V_r = \dfrac{I_{DC}\, T_2}{C}$
- Now, $\quad T_1 + T_2 = \dfrac{T}{2}$ and $T_2 >> T_1$ hence $T_1 + T_2 \approx T_2 = \dfrac{T}{2}$

where $T = \dfrac{1}{f}$

$$\therefore \quad V_r = \frac{I_{DC}}{C}\left[\frac{T}{2}\right] = \frac{I_{DC} \times T}{2C} = \frac{I_{DC}}{2\, fC}$$

- But $\quad I_{DC} = \dfrac{E_{DC}}{R_L}$

$$\boxed{V_r = \frac{E_{DC}}{2\, f\, C\, R_L} = \textbf{Peak to peak ripple voltage}} \quad \text{... For full wave}$$

- The ripple factor is defined as the ratio of r.m.s. value of the a.c. component to the d.c. component. Hence the ripple factor of the capacitor filter with full wave rectifier is,

$$\boxed{\text{Ripple factor} = \frac{V_{r\,(rms)}}{E_{DC}} = \frac{1}{4\sqrt{3}\, f\, C\, R_L}} \quad \text{... For full wave}$$

- For **half wave rectifier** with capacitor input filter the ripple factor is,

$$\therefore \quad \boxed{\text{Ripple factor} = \frac{1}{2\sqrt{3}\, f\, C\, R_L}} \quad \text{... For half wave}$$

Important Points to Remember

- The ripple factor for capacitor input filter is,

$$\text{Ripple factor } (\gamma) = \frac{1}{4\sqrt{3}\, f\, C\, R_L} \text{ for full wave}$$

and $$\gamma = \frac{1}{2\sqrt{3}\, f\, C\, R_L} \text{ for half wave}$$

- The d.c. output voltage from a **capacitor filter** is,

$$E_{DC} = E_{sm} - I_{DC}\left[\frac{1}{4\,fC}\right] \text{ for full wave}$$

$$\text{and} \quad E_{DC} = E_{sm} - I_{DC}\left[\frac{1}{2\,fC}\right] \text{ for half wave}$$

- The **ripple voltage** present in the output with capacitor filter is,

$$V_{r(RMS)} = \frac{I_{DC}}{4\sqrt{3}fC} \text{ volts for full wave}$$

$$\text{and} \quad V_{r(RMS)} = \frac{I_{DC}}{2\sqrt{3}\,fC} \text{ volts for half wave}$$

- The r.m.s. ripple voltage is given by,

$$V_{r(RMS)} = E_{DC} \times \text{Ripple factor}$$

Q.33 State the advantages and disadvantages of capacitor filter.

Ans. : • The **advantages** of capacitor input filter are,

1. Less number of components.
2. Low ripple factor hence low ripple voltage.
3. Suitable for high voltage at small load currents.

- The **disadvantages** of capacitor input filter are,

1. Ripple factor depends on load resistance.
2. Not suitable for variable loads as ripple content increases as R_L decreases.
3. Regulation is poor.
4. Diodes are subjected to high surge currents hence must be selected accordingly.

1.18 : LC Filter or Choke Input Filter

Q.34 Explain the operation of choke input filter. State the expression for its ripple factor.

Ans. : A filter which uses one inductor and one capacitor is called LC filter. The filter element looking from the rectifier side is an inductor hence it is also called choke input filter or L-section filter.

- The Fig. Q.34.1 shows the choke input filter.

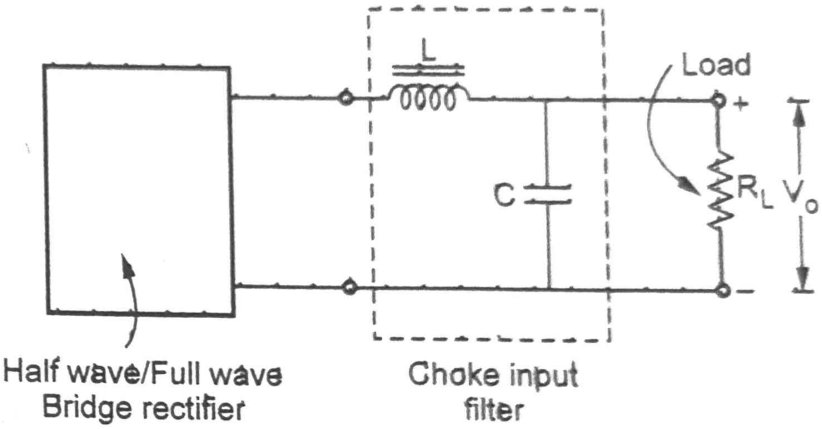


Fig. Q.34.1

- The rectifier output which is pulsating d.c. is applied to the choke L. The inductor offers very small resistance to d.c. and hence it allows d.c. component to pass to the load and it blocks a.c. component.
- Most of the ripples are blocked by an inductor but the remaining ripples are blocked by capacitor C. It offers small reactance to a.c. ripples and as connected in shunt with the load, it bypasses the remaining ripples.
- The capacitor C offers high reactance to d.c. hence it blocks d.c. component.
- Thus due to X_L and X_C reactances of L and C, almost pure d.c. component is available to the load. Due to the double filtering effect, the output of this filter is very smooth.
- Its ripple factor is given by,

$$\boxed{\gamma = \frac{1}{6\sqrt{2}\,\omega^2 LC}} \quad \ldots \omega = 2\pi f$$

- It can be seen that the ripple factor is not dependent on the load resistance, which is its important advantage. It remains constant at all the loads.

- The Fig. Q.34.2 shows the waveforms of LC filter.

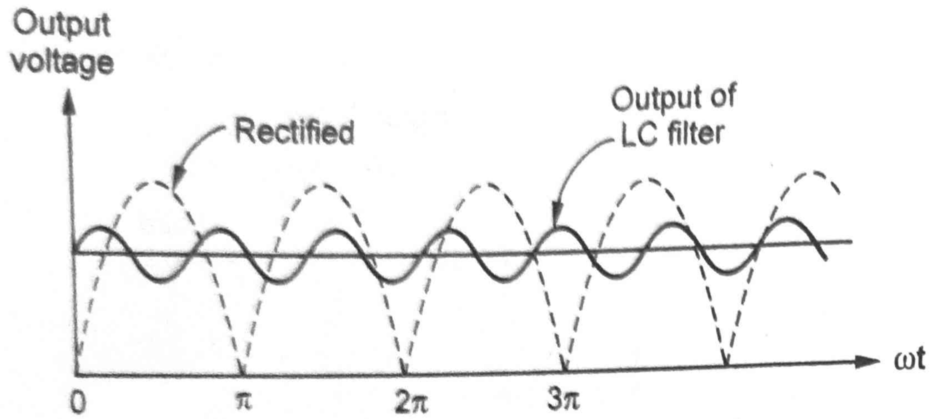


Fig. Q.34.2 Waveforms ac LC filter

This filter has good regulation and is suitable for all the loads, heavy as well as light loads.

Q.35 What is the necessity of bleeder resistance in LC filter ?

Ans. : Necessity of bleeder resistance : The basic requirement of an inductor is that the current through it must be continuous and not interrupted.

- If current through L is interrupted, it develops large back e.m.f. which may exceed PIV rating of the diodes and voltage rating of capacitor C. This may damage diodes and capacitor.

  To avoid this, inductor L must carry minimum current all the time continuously without any interruption. For this purpose a resistance R_B is connected across the output terminals, which is called **bleeder resistance.**

- The bleeder resistance is shown in the Fig. Q.35.1.

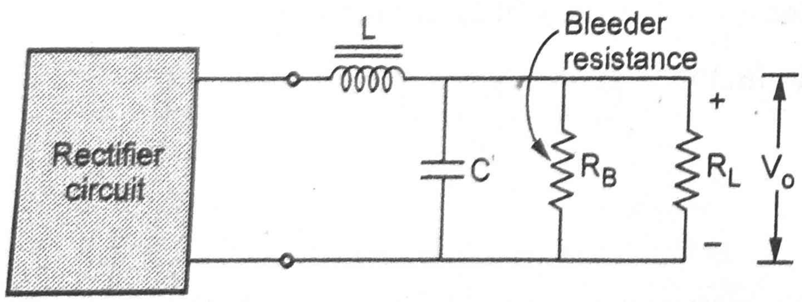


Fig. Q.35.1 LC filter with bleeder resistance

1.19 : π Filter or CLC Filter

Q.36 Explain the operation of π filter. State the expression for its ripple factor.

Ans. : • A filter which uses two capacitors and one inductor, is called CLC filter. The arrangement looks like a greek letter π (pi) hence is it is also called π filter.

- The capacitors are connected in shunt while an inductor is connected in series between the two shunt capacitors as shown in the Fig. Q.36.1.

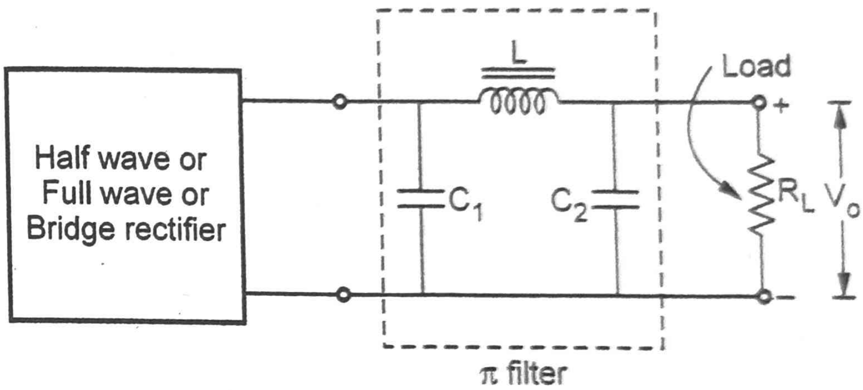


Fig. Q.36.1

- The rectifier output is given to the capacitor C_1 which is connected in parallel with the output of the rectifier. This capacitor offers very low reactance to the a.c. component but blocks d.c. component. Hence capacitor C_1 bypasses most of the a.c. component.
- The d.c. component then reaches to the choke L. The choke L offers very high reactance to a.c. component and very low reactance (almost zero) to d.c. So it blocks a.c. component and does not allow it to reach to load while it allows d.c. component to pass through it.
- The capacitor C_2 now allows to pass remaining a.c. component by offering very low reactance to a.c. ripples. Thus almost pure d.c. component reaches to the load.

- The ripple factor for this filter is,

$$\boxed{\gamma = \frac{\sqrt{2}}{8\omega^3 \, LC_1 \, C_2 \, R_L}} \quad \ldots \; \omega = 2\pi f$$

- It can be seen that the ripple factor increases as R_L decreases i.e. load current increases. Thus this filter is not suitable for high load currents hence it is preferred for light loads.
- The Fig. Q.36.2 shows the waveforms of π (Pi) filter.

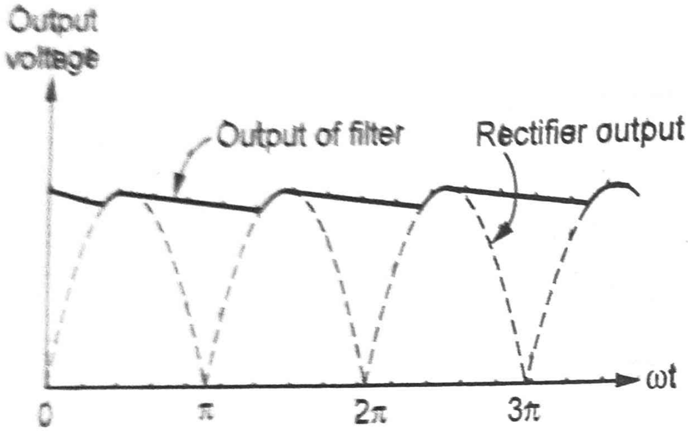


Fig. Q.36.2 Waveforms of π filter

- The output of this filter is very smooth but it is suitable only for light loads.

Q.37 State the advantages and limitations of π filter.

Ans. : • The various advantages of π filter are,

1) The ripple factor is much smaller than LC filter.
2) Higher d.c. output voltage at high load currents can be obtained.
3) The output is very smooth.
4) Easy from design point of view.
5) Useful for light loads.

- The disadvantages of π filter are,

1) It is bulky due to more number of filter components.

2) Higher PIV rating for the diodes is required.

3) Regulation is poor.

4) The large value of input capacitor C_1 in necessary.

5) The inductor of high current rating is required hence costly.

1.20 : Design of Capacitor in Capacitor Filter

Important Points To Remember

- Consider the path of the output voltage with ripple of a rectifier with capacitor filter as shown in the Fig. 1.2.

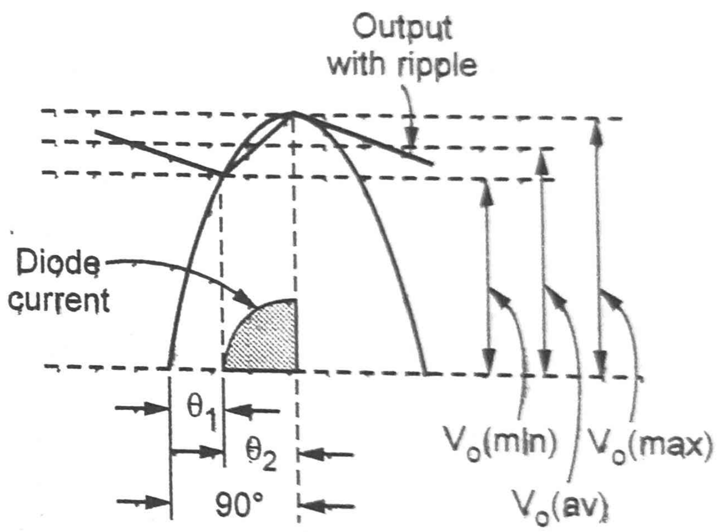


Fig. 1.2

V_T = Peak to peak ripple voltage

f = Input frequency

t_1 = Capacitor discharge time

t_2 = Capacitor charging time

From Fig. 1.2,

$$\theta_1 = \sin^{-1}\left[\frac{V_o\,(\min)}{V_o\,(\max)}\right]$$

$$\theta_2 = 90° - \theta_1$$

$$T = \frac{1}{f} \text{ and } t_1 + t_2 = T$$

$$t_2 = \frac{\theta_2 T}{360°}$$

For half wave, $t_1 = T - t_2$

For full wave, $t_1 = \frac{T}{2} - t_2$

$$\therefore \quad \boxed{C = \frac{I_L + 1}{V_r}}$$

For approximate calculations,

For half wave, $t_1 \approx T$

For full wave, $t_1 \approx \frac{T}{2}$

Q.38 The half wave rectifier d.c power supply is to supply 32 V to a 1 kΩ load. The peak to peak ripple voltage is not to exceed 10 % of average output voltage. If input frequency is 50 Hz, design the filter capacitor value.

Ans. :

$$V_o\,(av) = E_{DC} = 32 \text{ V}$$

$$\therefore \quad V_r = 10\ \%\ \text{of}\ V_o\,(av) = 3.2 \text{ V}$$

$$V_o\,(min) = V_o\,(av) - \frac{V_r}{2} = 30.4 \text{ V}$$

$$V_o\,(max) = V_o\,(av) + \frac{V_r}{2} = 33.6 \text{ V}$$

$$\therefore \quad \theta_1 = \sin^{-1}\left[\frac{V_o\,(min)}{V_o\,(max)}\right] = 64.79°$$

$$\therefore \quad \theta_2 = 90° - \theta_1 = 25.21°,\ T = \frac{1}{f} = 0.02 \text{ sec}$$

$$\therefore \quad t_2 = \frac{\theta_2 T}{360^\circ} = \frac{25.21^\circ}{360^\circ} \times 0.02 = 1.4 \text{ msec}$$

$$\therefore \quad t_1 = T - t_2 = 0.02 - 1.4 \times 10^{-3} = 18.6 \text{ msec}$$

$$I_L = \frac{V_o\,(av)}{R_L} = \frac{32}{1 \times 10^3} = 32 \text{ mA}$$

$$\therefore \quad C = \frac{I_L t_1}{V_r} = \frac{32 \times 10^{-3} \times 18.6 \times 10^{-3}}{3.2} = 186\ \mu\text{F}$$

Q.39 If in the Q.38, half wave rectifier is replaced by full wave rectifier, find the new capacitor value.

Ans. : All calculation till t_2 remain same.

$$t_1 = \frac{T}{2} - t_2 = \frac{0.02}{2} - 1.4 \times 10^{-3} = 8.6 \text{ msec}$$

$$I_L = \frac{32}{1 \times 10^3} = 32 \text{ mA}$$

$$\therefore \quad C = \frac{I_L t_1}{V_r} = 86\ \mu\text{F}$$

1.21 : Clipping Circuits

Q.40 Define clipper circuit. State its types.

Ans. : • The circuits which are used to clip off (remove) unwanted portion of the waveform, without distorting the remaining part of the waveform are called **clipper circuits** or **clippers.**

- The two types of clipper circuits are, i) Sries cippers and ii) Shunt clippers
- In series clipper the diode is connected in series with the load while in shunt clipper the diode is connected in parallel with the load.

Q.41 Draw the circuit of series positive clipper and explain its operation alongwith the waveforms.

Ans. : • The Fig. Q.41.1 shows positive series clipper circuit in which diode direction is opposite to that in negative series clipper circuit.

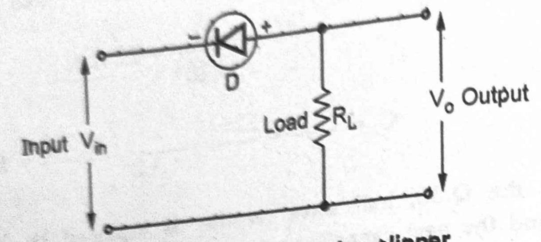


Fig. Q.41.1 Positive series clipper

- For positive half cycle of input, $V_{in} > 0V$ and diode is reverse biased. Hence it acts as open circuit and $V_o = 0V$.
- For negative half cycle, when $V_{in} < 0$, the diode conducts.
- Assuming ideal diode, the output voltage V_o available is same as the input voltage.
- Thus entire negative half cycle of input is available at the output.
- Thus positive series clipper clips off the positive part of the input waveform.
- The output waveforms for sinusoidal input are shown in the Fig. Q.41.2.

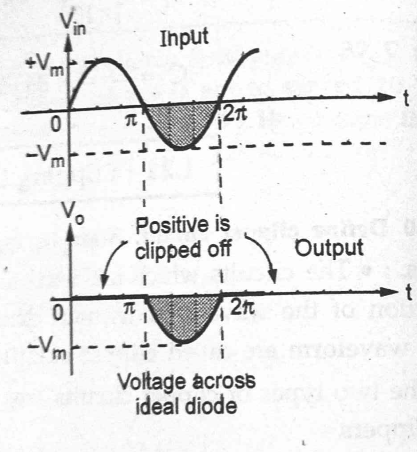


Fig. Q.41.2 Waveforms of series positive clipper

Q.42 Draw the circuit of series negative clipper and explain its operation alongwith the waveforms. Draw its transfer characteristics.

Ans. : • The circuit which clipps off the negative portion of the input is called negative clipper.

- Consider a series negative clipper shown in the Fig. Q.42.1, where diode is connected in series with the load.

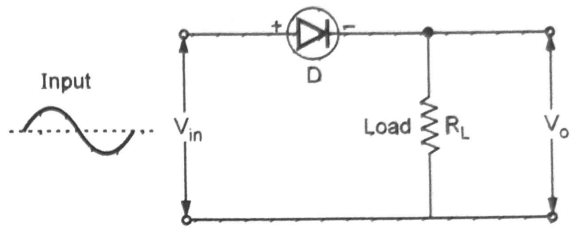


Fig. Q.42.1 Negative series clipper

- For a positive half cycle, the diode D is forward biased. Hence the entire positive half cycle is available across the load resistance R_L.
- While for a negative half cycle, diode D is reverse biased and hence will not conduct at all. Hence there will not be any voltage available across resistance R_L. Hence the negative half cycle of input voltage gets clipped off.
- The input waveform and the corresponding output voltage waveform is shown in the Fig. Q.42.2.

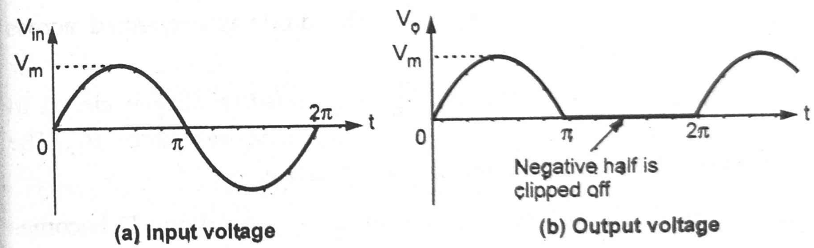


Fig. Q.42.2 Waveforms of series negative clipper

- The graph of output variable against input variable of the circuit is called transfer characteristics of the circuit.
- For the negative series clipper, the graph of V_o against V_{in} is its transfer characteristics.

- The mathematical equation for such a graph for negaive series clipper, **assuming ideal diode** is given by,

$$\boxed{\begin{array}{ll} V_o = V_{in} & \text{... For } V_{in} \geq 0 \\ V_o = 0, & \text{... For } V_{in} < 0 \end{array}}$$

- The graph showing the transfer characteristics is shown in the Fig. Q.42.3.

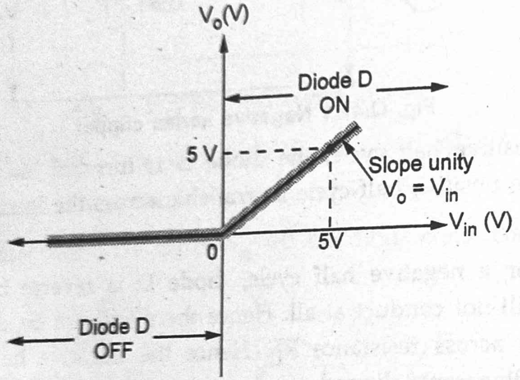


Fig. Q.42.3 Transfer characteristics

Q.43 Draw the parallel positive clipper and explain its operation alongwith the waveforms.

Ans. : • In a parallel clipper circuit, the diode is connected across the load terminals.

- The Fig. Q.43.1 shows the basic parallel positive clipper circuit in which diode D is connected across the load resistance R_L. The resistance R_1 is current controlling resistance.
- During **positive half cycle** of the input V_{in}, the diode D becomes **forward biased** and remains forward biased for the entire positive half cycle of the input.
- As ideal diode acts as short circuit when forward biased hence the current I flows entirely through diode D. The drop across short circuit diode is zero. Hence output voltage $V_o = 0\,V$ for entire positive half cycle.

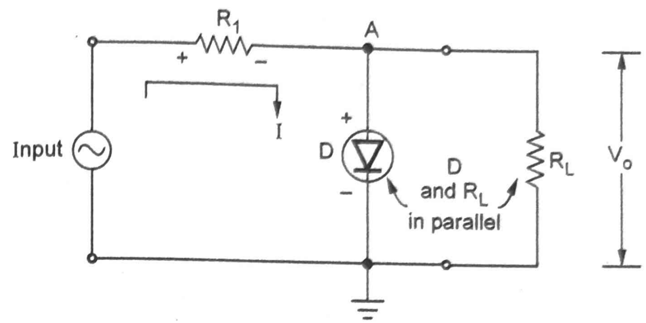


Fig. Q.43.1 Parallel positive clipper

- Thus positive half cycle gets clipped off.
- During **negative half cycle** of input, the diode is **reverse biased** and acts as open circuit. The entire current flows through R_L as shown in the Fig. Q.43.2.

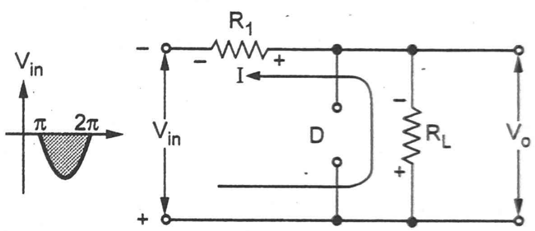


Fig. Q.43.2 Operation during negative half cycle

- Hence $V_o = \dfrac{V_{in} R_L}{R_L + R_1}$ using potential divider rule.
- Thus the output voltage V_o is same as V_{in}, for $R_1 \ll R_L$.
- Thus the entire negative half cycle of V_{in} gets reproduced at the output.
- The waveforms are shown in the Fig. Q.43.3.

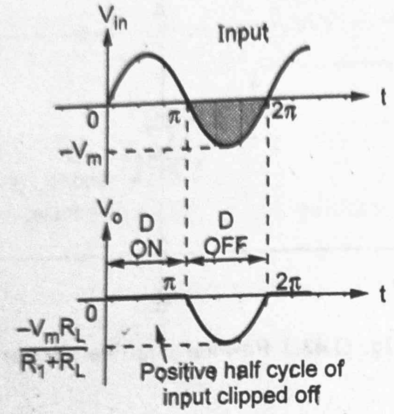


Fig. Q.43.3 Waveforms for parallel positive clipper

Q.44 Draw the parallel negative clipper and explain its operation alongwith the waveforms.

Ans. : • The Fig. Q.44.1 shows the basic parallel negative clipper circuit in which diode D is connected across the load resistance R_L. The resistance R_1 is current controlling resistance.

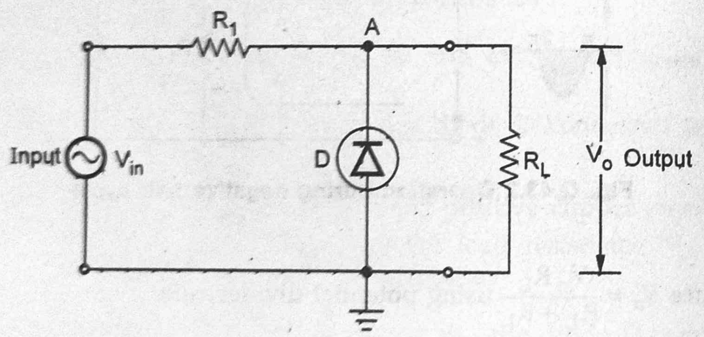


Fig. Q.44.1 Parallel negative clipper

- When V_{in} is positive then the diode is reversed biased and acts as an open circuit. The circuit is shown in the Fig. Q.44.2.

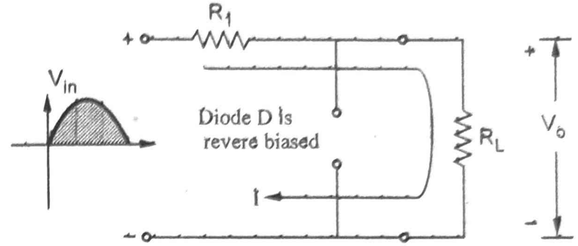


Fig. Q.44.2 Operation during positive half cycle

- Applying potential divider rule the output voltage is given by,
- $V_o = V_{in}\left[\frac{R_L}{R_1+R_L}\right] \approx V_{in}$ ... $R_1 << R_L$
- Thus the output voltage V_o is same as V_{in}, for $R_1 << R_L$.
- Hence the positive half cycle of V_{in} gets reproduced at the output.
- Consider the negative half cycle of V_{in}.

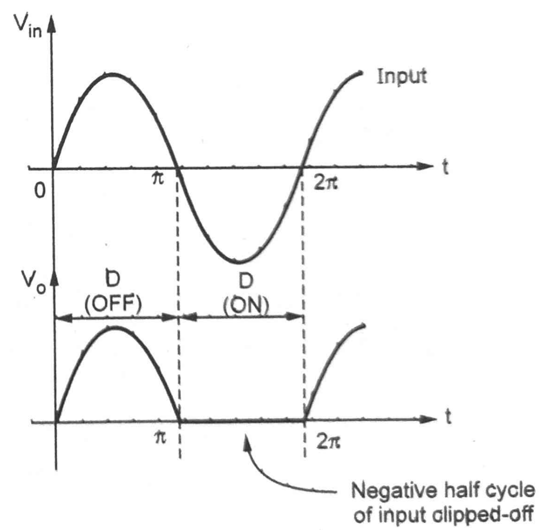


Fig. Q.44.3 Waveforms for parallel negative clipper

- As the diode is forward biased in this half cycle, the entire current passes through the diode as it acts as a closed switch.
- The forward biased diode produces short circuit across the load.
- The voltage across short circuit is zero hence the output voltage is zero for the entire negative half cycle of the input.
- Thus the negative half cycle gets clipped off and circuit acts as a negative clipper.
- The overall input and output waveforms are as shown in the Fig. Q.44.3.

Q.45 Explain the working of biased shunt clipper along with its waveforms.

Ans. : • When a battery is introduced in series with the diode to achieve the clipping above or below the certain reference voltage in a shunt clipper then it is called **biased shunt clipper.**

- The Fig. Q.45.1 shows the basic parallel positive clipper circuit with reference voltage.

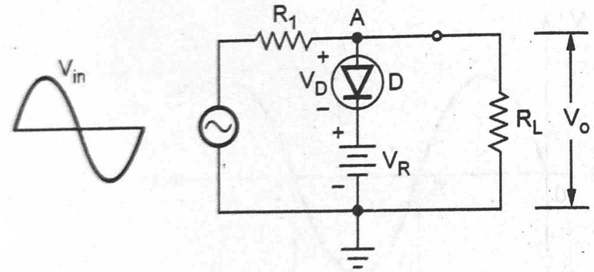


Fig. Q.45.1 Positive clipper with reference voltage

- The operation for **positive half cycle** of the input can be divided into two cases.

Case 1 : When V_{in} is positive but less than V_R, the diode D is **reverse biased** and acts as open circuit. The equivalent circuit is as shown in the Fig. Q.45.2.

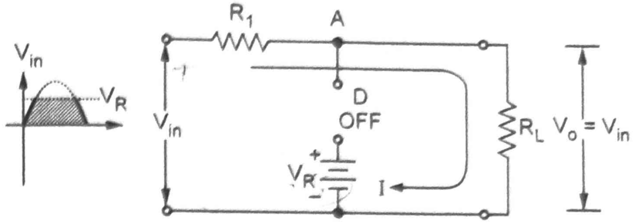


Fig. Q.45.2 0V < V_{in} < V_R

- Hence the output voltage is given by,

$$V_o = V_{in} \frac{R_L}{R_1 + R_L} = V_{in} \quad \dots \text{ for } R_1 << R_L$$

Case 2 : when V_{in} becomes greater than V_R, the diode D becomes **forward biased** and acts as short circuit. This is shown in the Fig. Q.45.3.

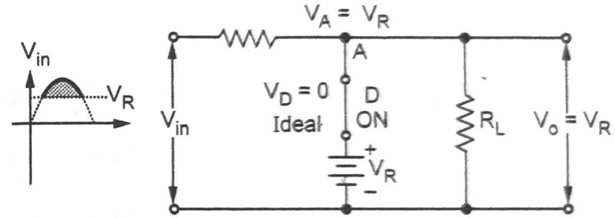


Fig. Q.45.3 V_{in} > V_R

- The output voltage now is same as voltage of node A which is V_R, as the drop across ideal ON diode is zero.

$\therefore \quad V_o = V_R \quad \dots \text{ for } V_{in} > V_R$

- When V_o again becomes less than V_R, the diode D becomes OFF and $V_o \approx V_{in}$.
- For the entire **negative half cycle** of the input, $V_{in} < V_R$ hence diode D remains reverse biased. It acts as open circuit.
- Thus $V_o = V_{in}$ and the entire negative half cycle is reproduced at the output.
- The input and output waveforms are shown in the Fig. Q.45.4.

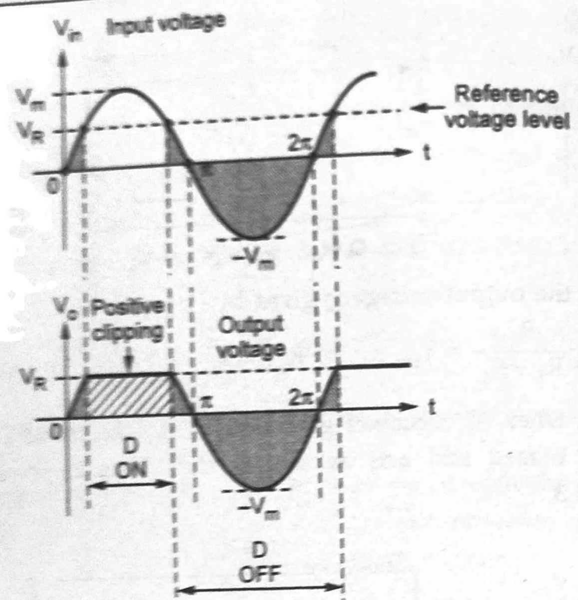


Fig. Q.45.4 Waveforms for positive biased shunt clipper

Q.46 Draw the circuit of two way clipper and explain its working with waveforms.

Ans. : • The circuit diagram of two way parallel clipper is shown in the Fig. Q.46.1.

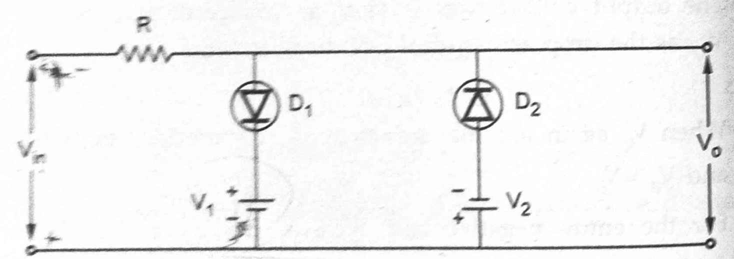


Fig. Q.46.1 Combinational clipper

- Assume that the input is purely sinusoidal in nature and diode D_1 and D_2 are ideal diodes.

Positive half cycle of the input :

- When V_{in} goes positive till it becomes more than V_1, D_1 and D_2, both the diodes are reverse biased. And $V_o = V_{in}$.
- When $V_{in} > V_1$, then D_1 becomes forward biased and conducts. While D_2 remains reverse biased for the entire positive half cycle of the input. Hence $V_o = V_1$.
- Thus when $V_{in} < V_1$, D_1 and D_2 are OFF and $V_o = V_{in}$.
- While when $V_{in} > V_1$, D_1 is ON and D_2 is OFF and $V_o = V_1$.

Negative half cycle of the input :

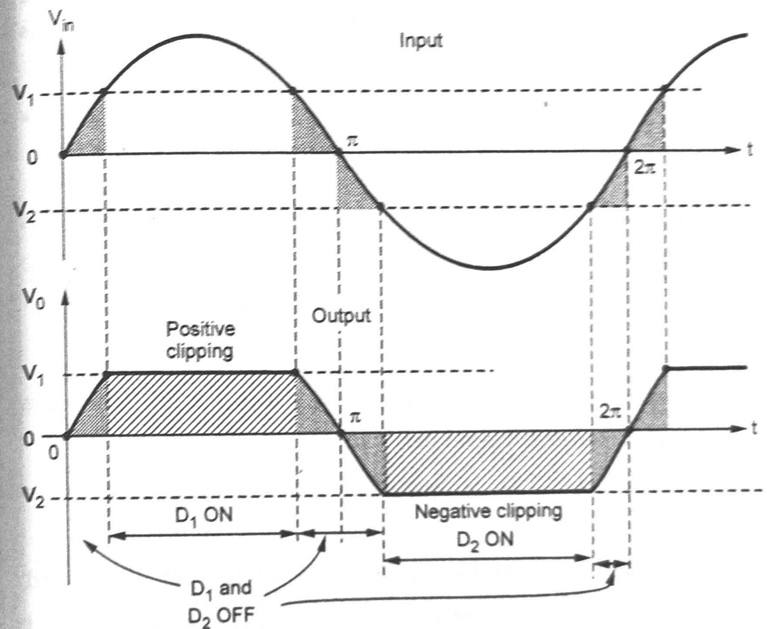


Fig. Q.46.2 Waveforms of two way clipper

- In the negative half cycle, as long as V_{in} is greater than V_2, the diode D_2 remains reverse biased. The D_1 remains OFF for the entire negative half cycle of the sinput.

- When V_{in} becomes less than V_2, the diode D_2 becomes forward biased and conducts. The diode D_1 is still OFF. Hence $V_o = V_2$. The output V_o is negative as the polarities of V_2 are opposite to that of V_1.
- Thus when $V_{in} > V_2$, D_1 and D_2 are OFF and $V_o = V_{in}$
- While when $V_{in} < V_2$, D_1 is OFF and D_2 is ON and $V_o = V_2$
- The input and output waveforms for the two way clipper are shown in the Fig. Q.46.2.

Q.47 Draw and explain the operation of zener diode shunt clipper.

Ans. : • The zener diode shunt clipper uses two back to back series connected zener diodes in shunt with the load resistance. This is shown in the Fig. Q.47.1

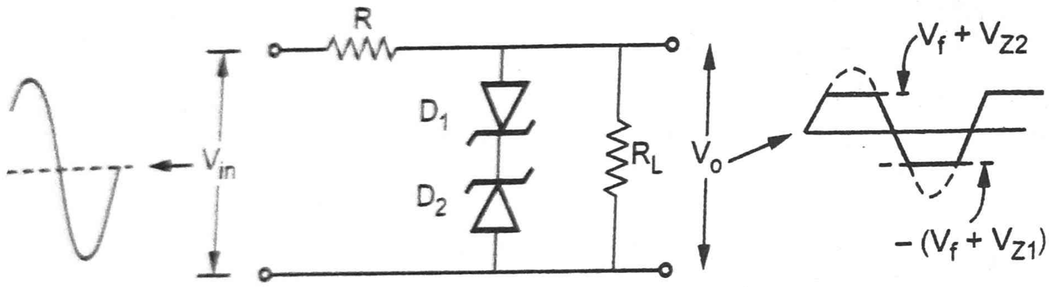


Fig. Q.47.1

- The voltage across forward biased zener diode is V_f while the voltage across reverse biased zener diode is V_Z.
- The zener voltage of D_1 is V_{Z1} white the zener voltage of D_2 is V_{Z2}.
- For positive half cycle, for sufficient input voltage, D_1 is forward biased while D_2 is in reverse breakdown. This limits the output voltage to $(V_f + V_{Z2})$.
- For negative half cycle, for sufficient negative voltage, D_2 is forward biased and D_1 is in reverse breakdown. This limits the output voltage to $-(V_f + V_{Z1})$.

- Using different zener voltage, different clipping levels in positive and negative half cycles can be obtained.
- This clipper eliminates the need of separate batteries which are required in shunt biased clippers.

1.22 : Clamping Circuits

Q.48 What is clamper ? Which are the two basic elements of clamper ? How clampers are classified ?

Ans. : • The circuits which are used to add a d.c. level as per the requirements to the a.c. output signal are called **clamper circuits.**

- The capacitor, diode and resistance are the three basic elements of a clamper circuit. The clamper circuits are also called **d.c. restorer** or **d.c. inserter circuits.**
- Depending upon whether the positive d.c. or negative d.c. shift is introduced in the output waveform, the clampers are classified as,

a) Negative clampers and b) Positive clampers.

Q.49 Draw a negative clamper circuit and explain its operation.

Ans. : • A negative clamper is shown in the Fig. Q.49.1.

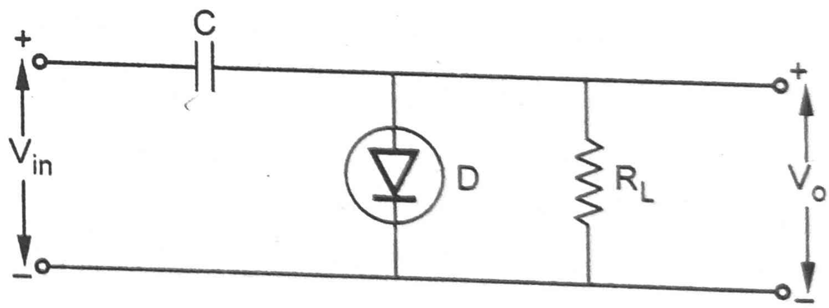


Fig. Q.49.1 Negative clamper

- During the first quarter of **positive cycle** of the input voltage V_{in}, the capacitor gets charged through **forward biased diode** D upto the maximum value V_m of the input signal V_{in}.
- The capacitor charging is almost instantaneous.

- The capacitor once charged to V_m, acts as a battery of voltage V_m because of its large time constant, as shown in the Fig. Q.49.2.

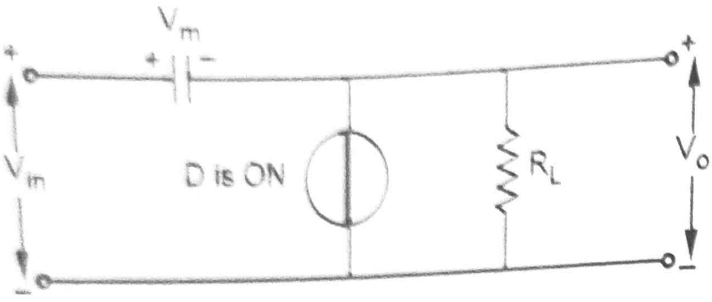


Fig. Q.49.2

- Thus when D is ON, the output voltage V_o is zero.
- As input voltage decreases after attaining its maximum value V_m, the capacitor remains charged to V_m and the diode D becomes reverse biased as shown in the Fig. Q.49.3.

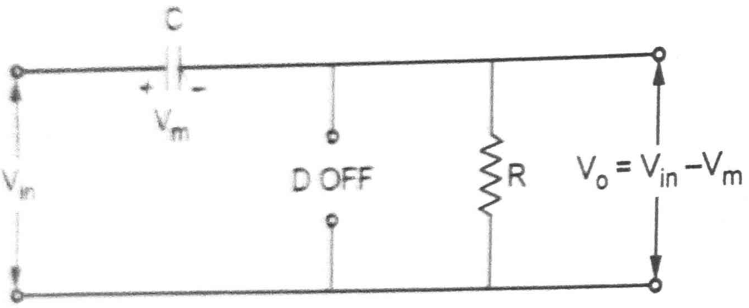


Fig. Q.49.3

- Due to large RC time constant the capacitor holds its entire charge and capacitor voltage remains as $V_C = V_m$.
- The output voltage V_o is now given by, $V_o = V_{in} - V_C = V_{in} - V_m$.
- *This is as good as adding a negative d.c. level equal to* $-V_m$ to the *output.*
- *Assuming ideal diode,* the input and output waveforms are *shown in the Fig. Q.49.4.*

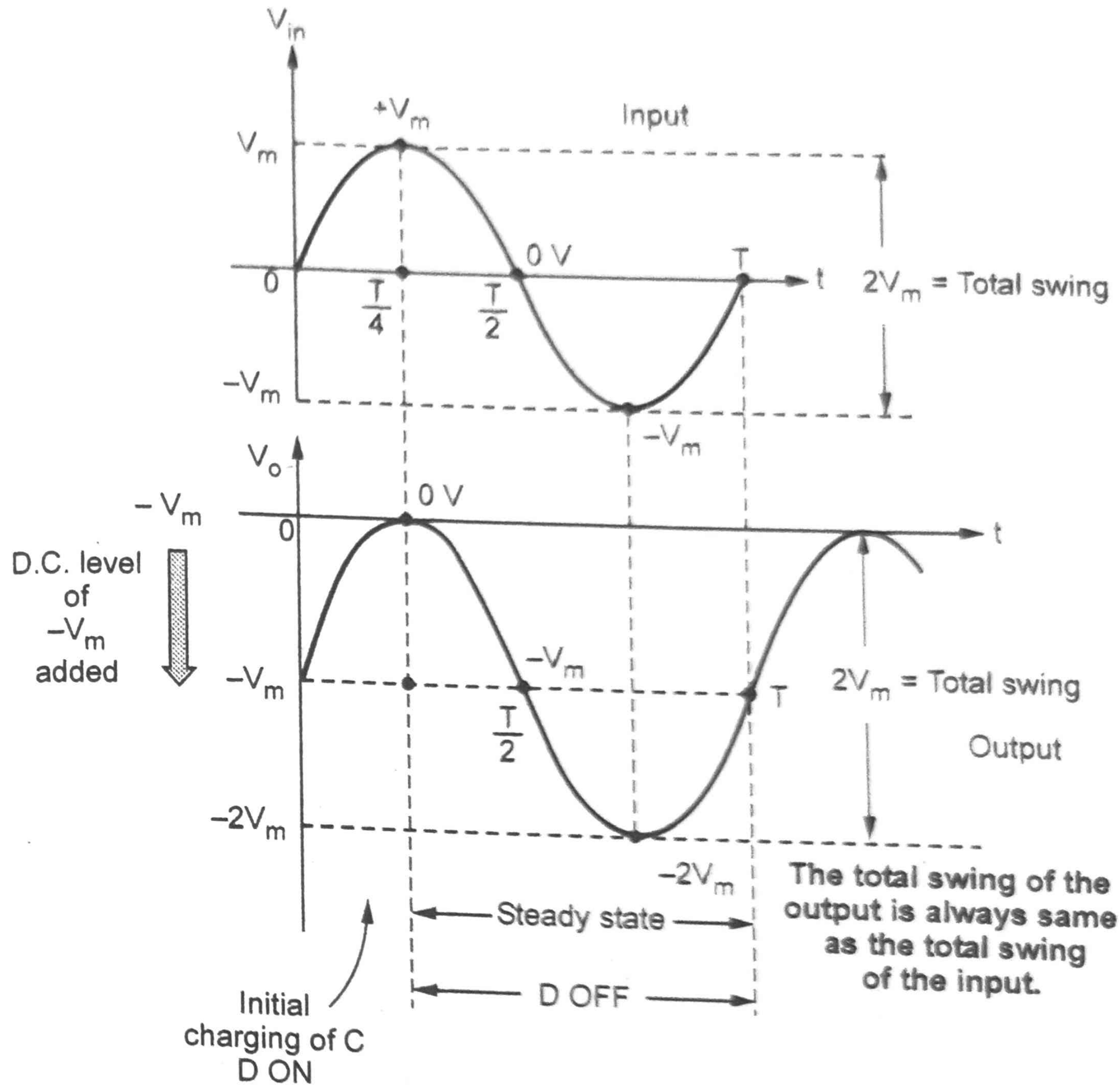


Fig. Q.49.4 Negative clamper waveforms

Q.50 Draw a positive clamper and explain its working alongwith the waveforms.

Ans. : • The positive clamper circuit is shown in the Fig. Q.50.1.

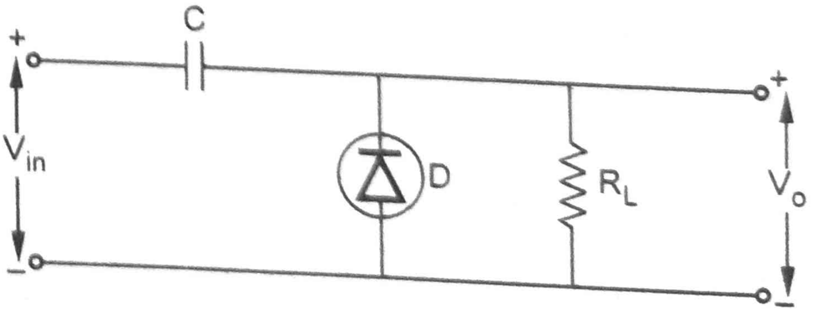


Fig. Q.50.1 Positive clamper

- During the first quarter of **negative half cycle** of the input voltage V_{in}, diode D gets forward biased and almost instantaneously capacitor gets charged equal to the maximum value V_m of the input signal V_{in}, with the polarities as shown in the Fig. Q.50.2.

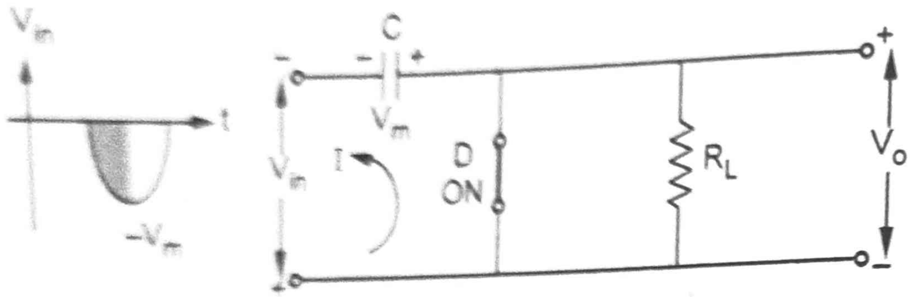


Fig. Q.50.2

- In the **positive half cycle**, the diode D is reverse biased. The capacitor starts discharging through R_L. But due to large time constant, it hardly gets discharged during positive half cycle of V_{in}. This is shown in the Fig. Q.50.3.

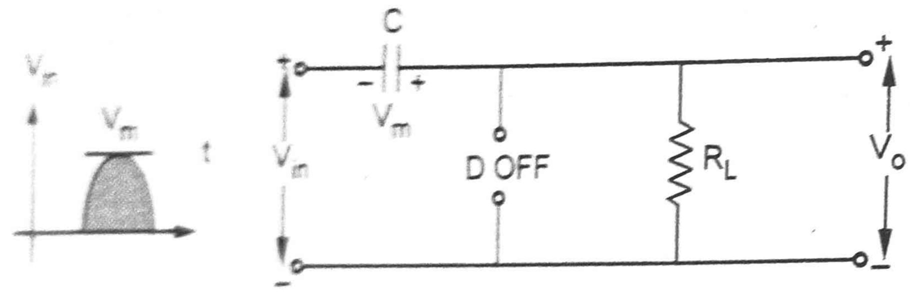


Fig. Q.50.3

- *The capacitor holds its entire charge, all the time.*
- *Hence applying KVL,* $V_o = V_{in} + V_m$.
- *Assuming ideal diode, the input and output waveforms are shown in the Fig. Q.50.4.*

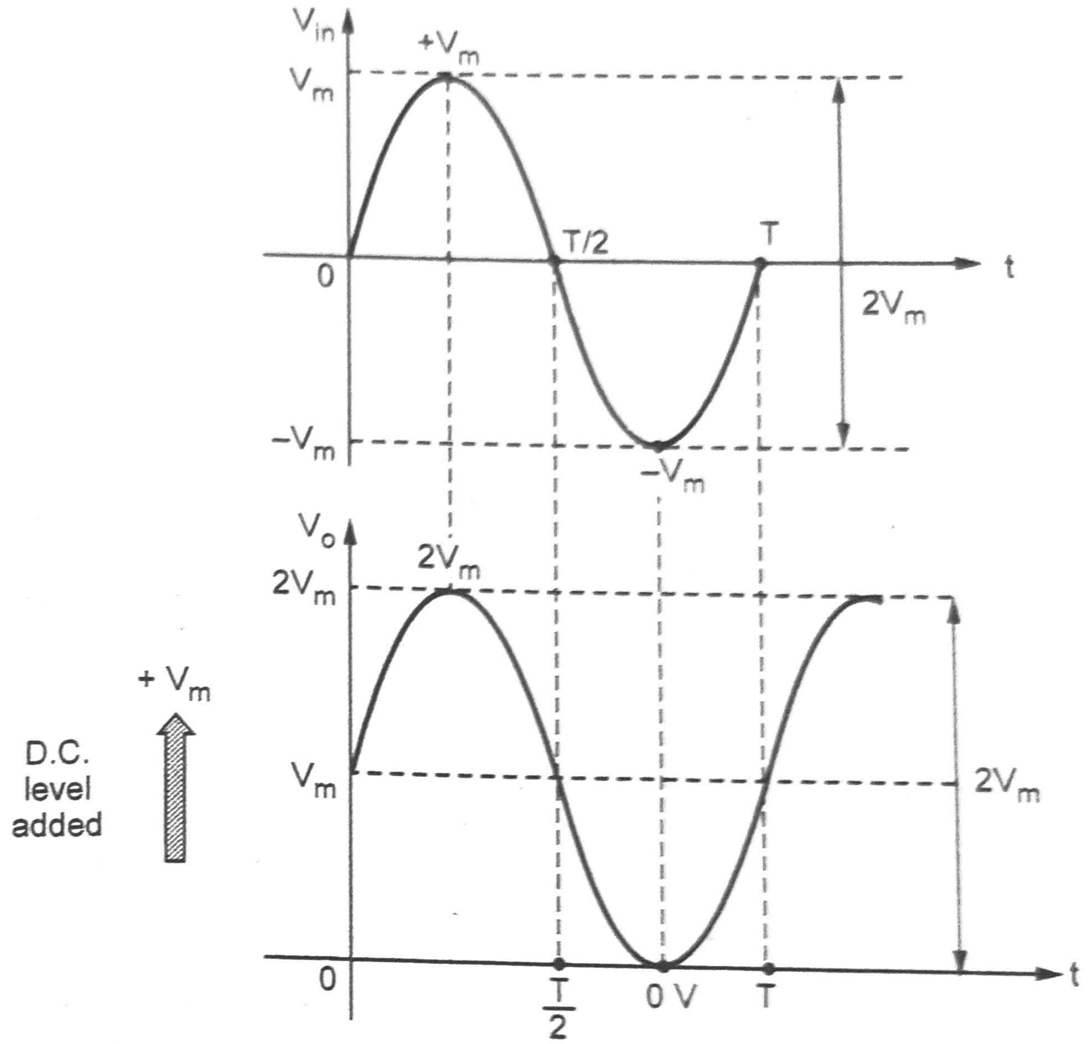


Fig. Q.50.4 Positive clamper waveforms

1.23 : Voltage Multiplier Circuits

Q.51 Draw the circuit of half wave voltage doubler and explain its working.

Ans. : • The Fig. Q.51.1 shows the circuit diagram of a **half wave voltage doubler.**

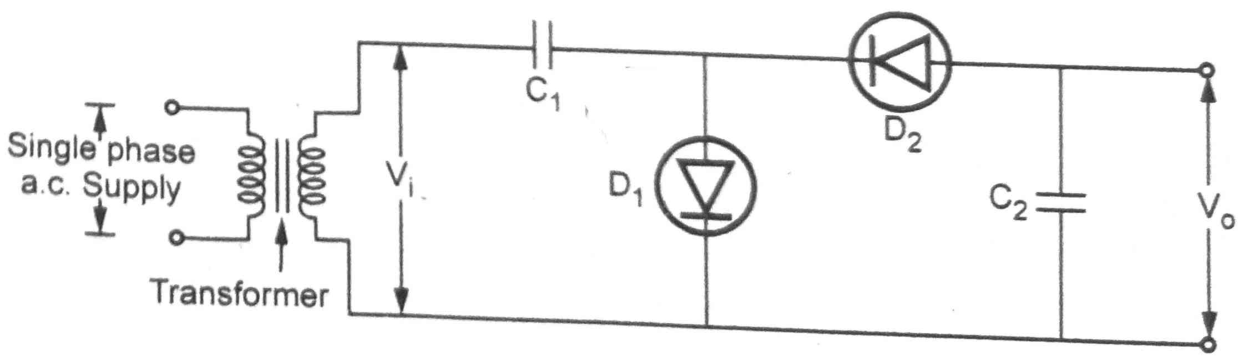


Fig. Q.51.1 Half wave voltage doubler

Positive half cycle of input :

- During positive half cycle of V_i, D_1 will be forward biased and the diode D_2 will be reverse biased.
- The capacitor C_1 will get charged equal to V_m as shown in the Fig. Q.51.2.

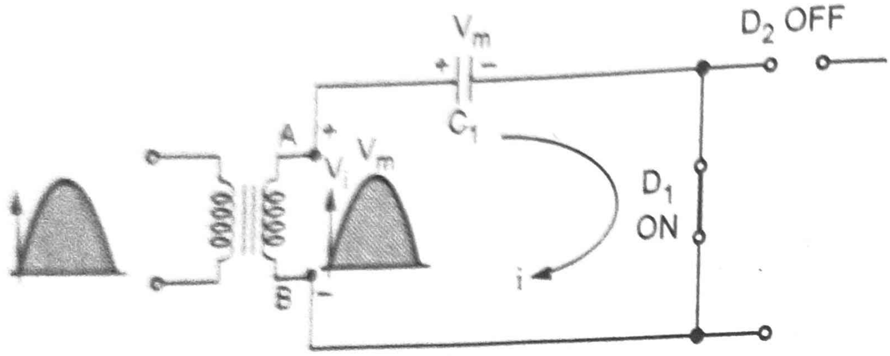


Fig. Q.51.2

- The charging of capacitor C_1 is very fast.

As D_2 is reverse biased, next part of the circuit remains isconnected from the circuit.

ive half cycle of input :

ng negative half cycle, the diode D_1 will be reverse biased d the diode D_2 will be forward biased.

- The capacitor C_1 remains charged at V_m. So the voltage V_m on C_1 adds to the input voltage.
- So capacitor C_2 will get charged equal to 2 V_m with the polarities as shown in Fig. Q.51.3.

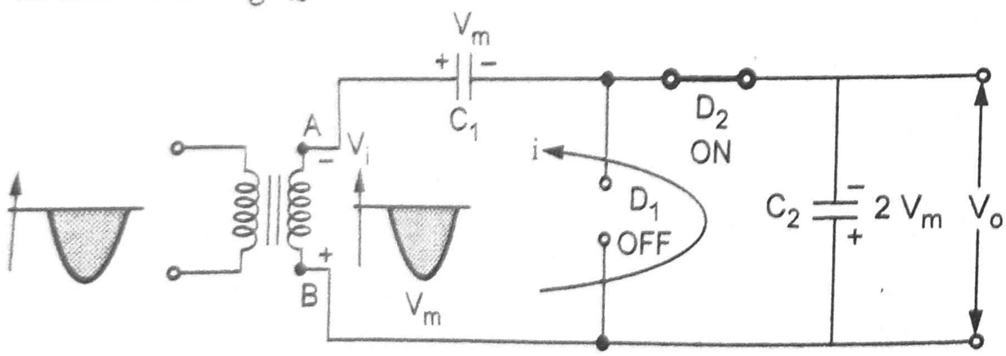


Fig. Q.51.3

- It retains this voltage as long as load is connected to the circuit.
- Thus the ouput is double of the input hence the circuit is called **voltage doubler.**

Q.52 Draw the circuit of full wave voltage doubler and explain its working.

Ans. : • The Fig. Q.52.1 shows a full wave voltage doubler.

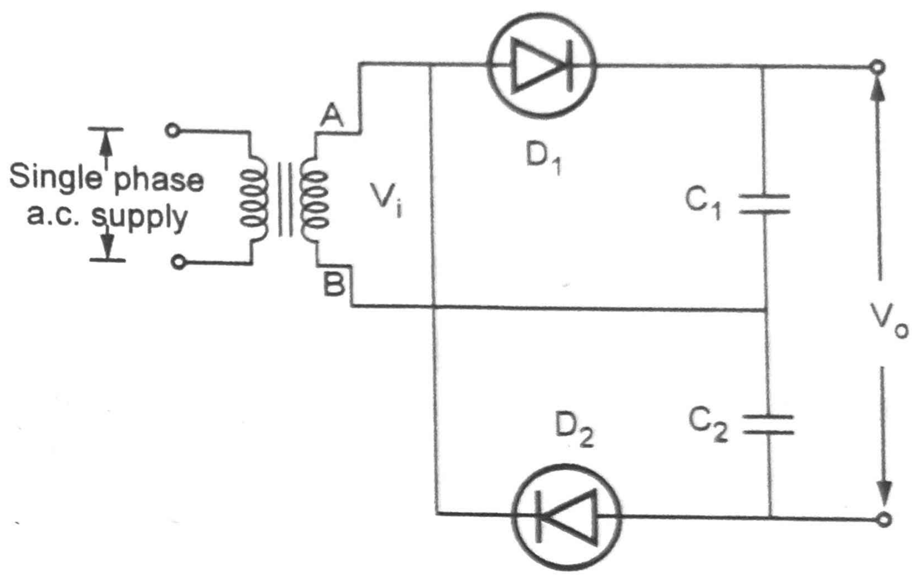


Fig. Q.52.1 Full wave voltage doubler

Positive half cycle of input :

- In the positive half cycle of the secondary voltage of transformer, the diode D_1 is forward biased.
- Thus the capacitor C_1 charges through the forward biased diode D_1, equal to V_m which is the peak of secondary transformer voltage, assuming ideal diodes.
- This is shown in the Fig. Q.52.2.

Negative half cycle of input :

- In the negative half cycle of the secondary voltage of transformer, the diode D_2 is forward biased while the diode D_1 is reverse biased.

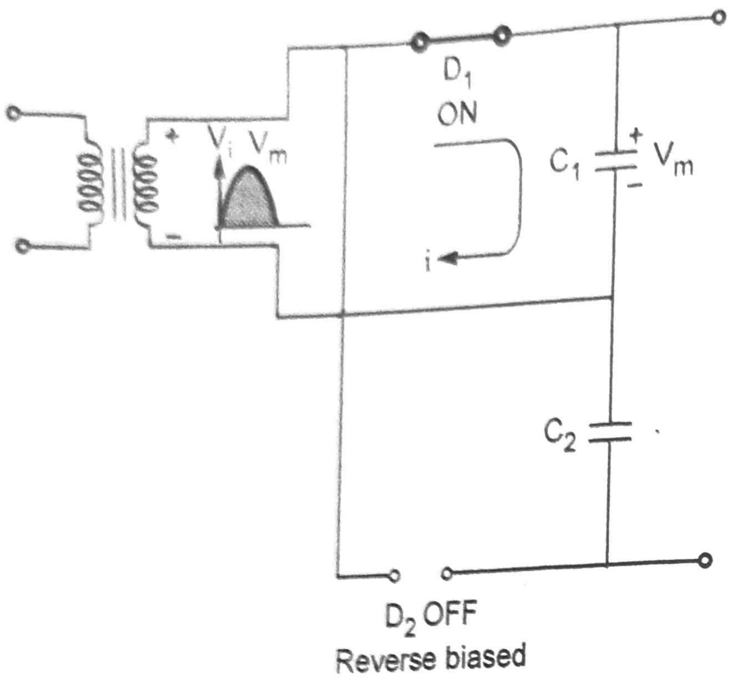


Fig. Q.52.2 Positive half cycle of input

- The capacitor C_2 gets charged equal to V_m with the polarity as shown in the Fig. Q.52.3.

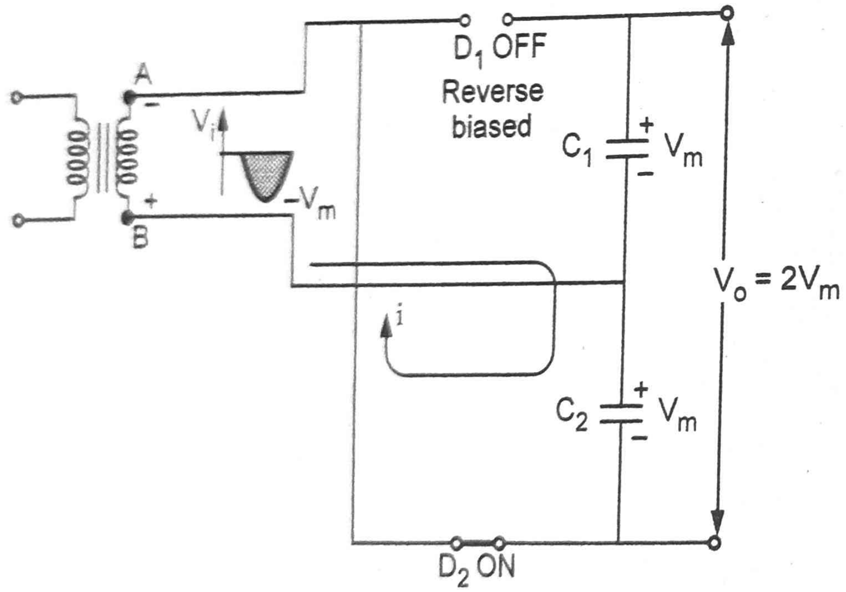


Fig. Q.52.3 Negative half cycle of input

- The output is taken across 2 capacitors in series.
- $\therefore\ V_o = V_{C1} + V_{C2} = V_m + V_m = 2V_m$
- Thus the ouput is double of the input hence the circuit is called **voltage doubler.**

Q.53 Explain voltage tripler and voltage quadrupler.

Ans. : Voltage tripler circuit : The Fig. Q.53.1 shows a voltage tripler circuit.

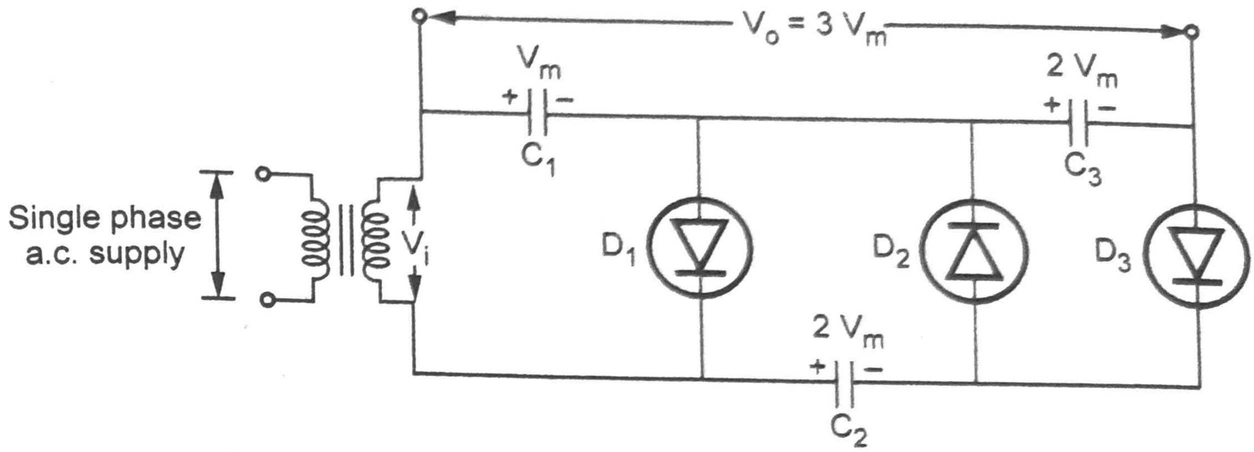


Fig. Q.53.1 Voltage tripler

- During **first positive half cycle** of the input, the diode D_1 becomes forward biased while D_2 and D_3 are reverse biased.
- The capacitor C_1 charges to V_m through the forward biased diode D_1 with the polarities as shown in the Fig. Q.53.2.

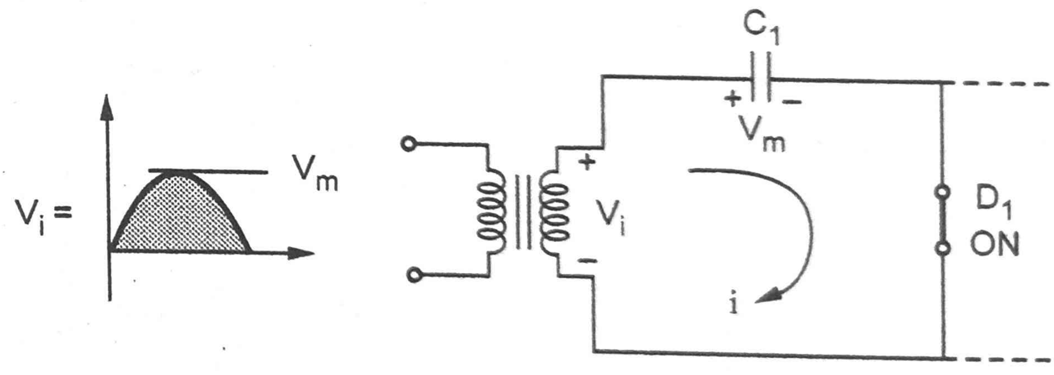


Fig. Q.53.2 C_1 charges to V_m through diode D_1

- During **next negative half cycle** of the input, the diode D_2 is forward biased.
- The capacitor C_1 holds its entire charge and its voltge remains at V_m.

- Hence the capacitor C_2 charges to $2V_m$ with the polarities as shown in the Fig. Q.53.3.

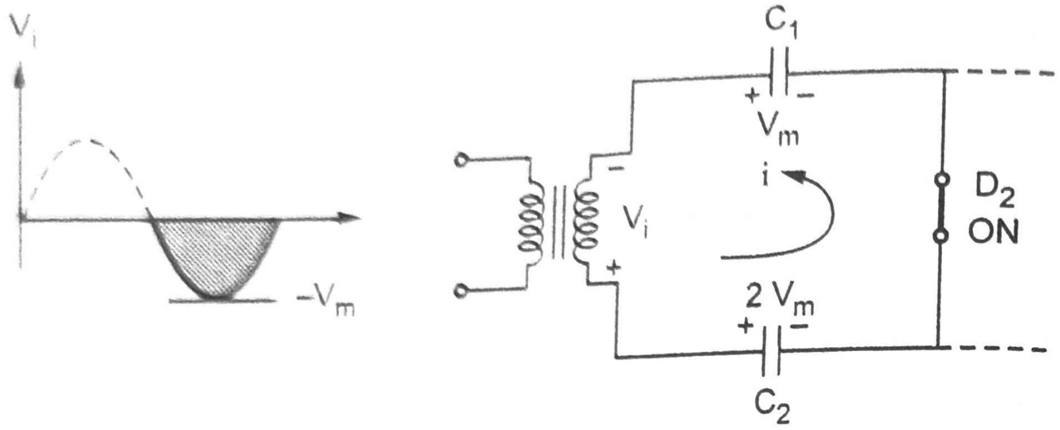


Fig. Q.53.3

- The diodes D_1 and D_3 are reverse biased.
- Applying KVL, $+V_m - V_{C2} + V_{C1} = 0$ i.e. $V_{C2} = V_m + V_{C1} = 2V_m$
- In the **next positive half cycle** of the input, the diode D_3 is forward biased because C_2 retains its charge and voltage across it to $2V_m$ while C_1 retains voltage across it to V_m.
- The diodes D_1 and D_2 are reverse biased.
- Thus the capacitor C_3 charges to $2V_m$ through forward biased D_3 with the polarities as shown in the Fig. Q.53.4.

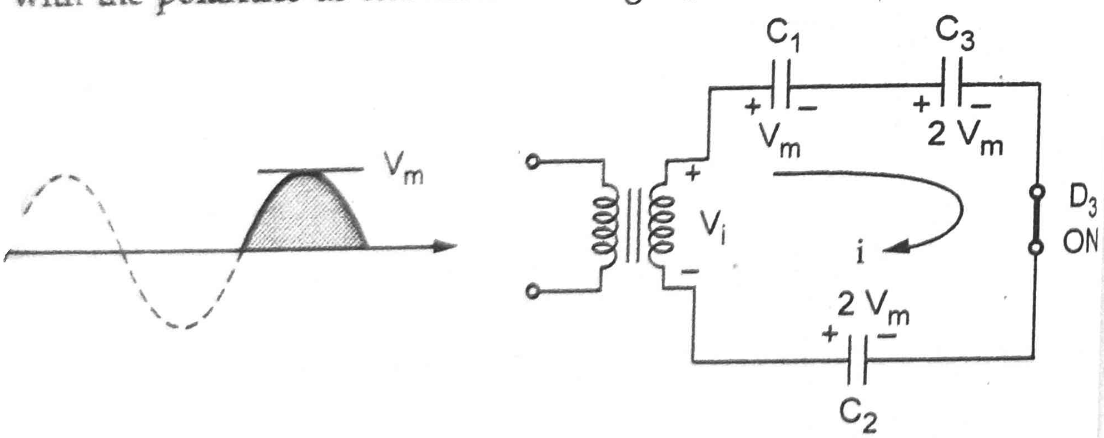


Fig. Q.53.4

- Applying KVL, $+V_m - V_m - V_{C3} + V_{C2} = 0$ i.e. $V_{C3} = V_{C2} = 2V_m$

- The output V_o is taken across the capacitors C_1 and C_3 i.e.
  $V_o = V_{C1} + V_{C3} = 3V_m$.
- Thus the output is three times the peak of the input voltage and circuit works as **voltage tripler.**

Voltage quadrupler circuit : The Fig. Q.53.5 shows a voltage quadrupler circuit.

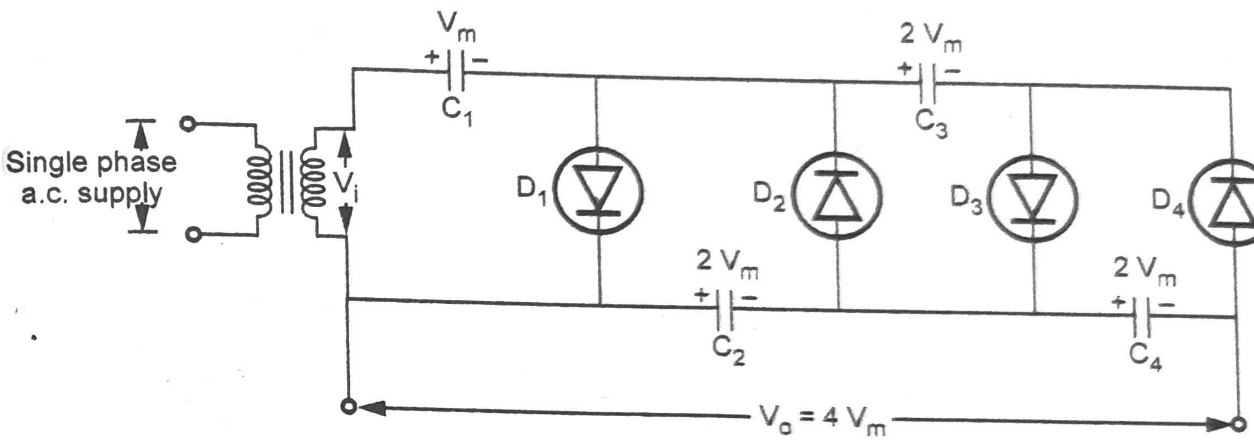


Fig. Q.53.5 Voltage quadrupler

- Analyse the circuit exactly similar to the voltage tripler for first three half cycles and in the next half cycle the diode D_4 will be forward biased with all other capacitors holding their charges and hence the same voltages across them.
- Thus the capacitor C_4 charges to $2V_m$, with the polarity shown in the Fig. Q.53.5 in a negative half cycle, through D_4.
- The output V_o is taken across the capacitors C_2 and C_4.

$$\therefore \qquad V_o = V_{C2} + V_{C4} = 2V_m + 2V_m = 4V_m$$

Thus the output is four times the peak of the input voltage and circuit works as **voltage quadrupler.**

1.24 : Reading Datasheet of Semiconductor Diode

Important Points To Remember

- The manufacturer of diode provides the detail information about the diode, in the form of datasheet. The various diode parameters are specified in the datasheet which help us to select the diode for an application circuit.

Q.54 Explain the various diode parameters specified in its datasheet.

Ans. : The various diode parameters specified in the datasheet are,

i) Reverse saturation current : The constant reverse current flowing through the diode, when it is reverse biased is called **reverse saturation current** of diode denoted as I_0.

- It is constant at constant temperature, though reverse voltage is increased till breakdown of diode occurs.

ii) Reverse breakdown voltage : When the reverse voltage is increased, at a certain value the breakdown of diode occurs and reverse current increases very sharply. This voltage is called reverse down voltage and denoted as V_{BR}. The diode gets damaged breakdown.

e voltage : A small forward voltage applied to a forward iased diode at which current starts increasing exponentially i.e. rapidly is called knee voltage of a diode.

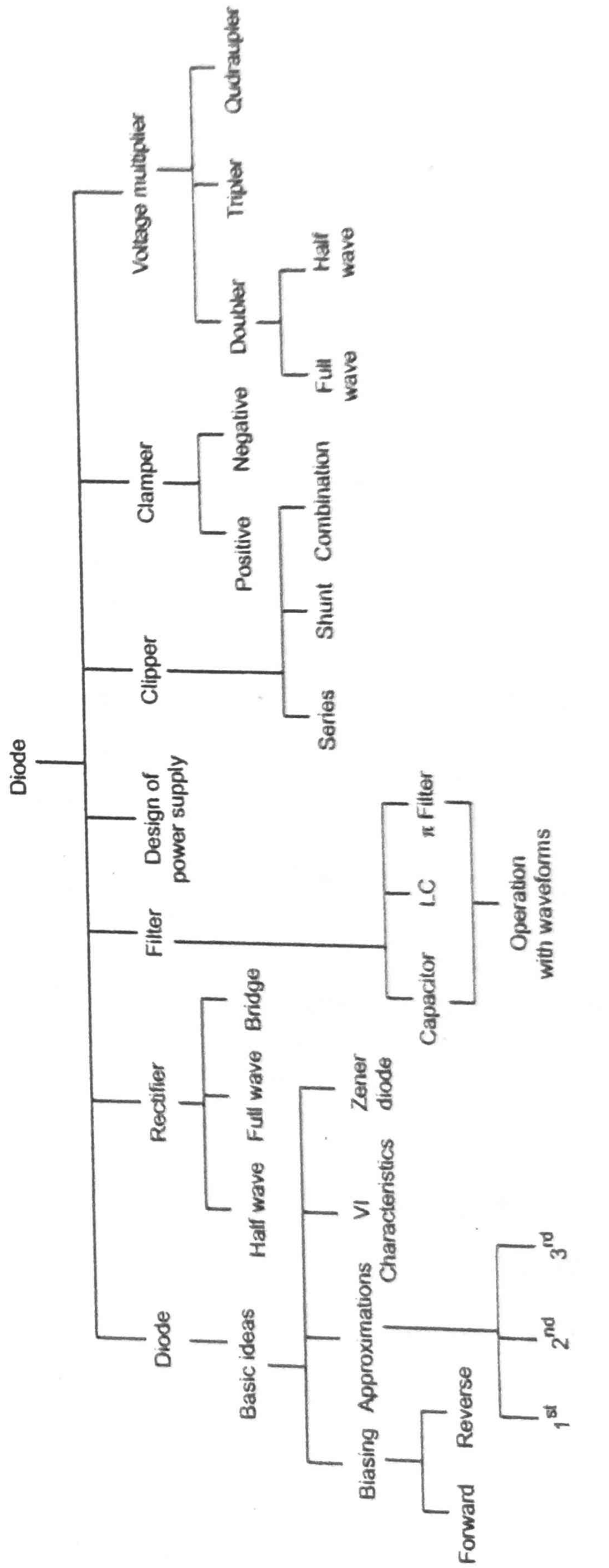
iv) Maximum forward current : The maximum current that a forward biased diode can withstand before burning out or being seriously degraded, due to high junction temperature is called maximum forward current. It is denoted as I_F (max).

v) Peak inverse voltage : The maximum voltage applied to the diode in the reverse direction without breakdown of the diode is called peak inverse voltage of a diode. It is also called PIV rating of a diode.

vi) Maximum power rating : The maximum power that the diode can dissipate safely, without increasing the junction temperature above its limiting value is called maximum power rating (MPR) of a diode. It is measured in watts.

vii) Forward voltage drop : It is the maximum forward voltage drop specified at certain forward current and temperature. It is denoted as V_F.

Memory Map



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