1. PN JUNCTION DIODE

A diode is a two layer, two-terminal Semiconductor device. One terminal is attached to P material and the other to N material. The common connecting point where these materials are joined is called a junction. The terminal which is connected to P side is anode and the terminal which is connected to N side is called cathode.

A junction diode permits current carriers to flow readily in one direction and blocks the flow of current in the opposite direction.

Crystal structure of a PN junction diode

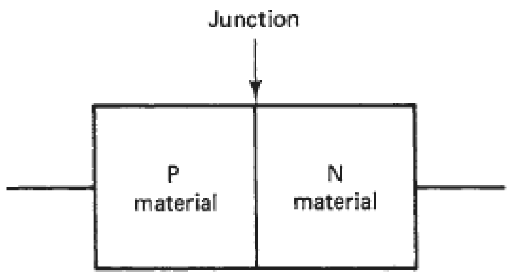
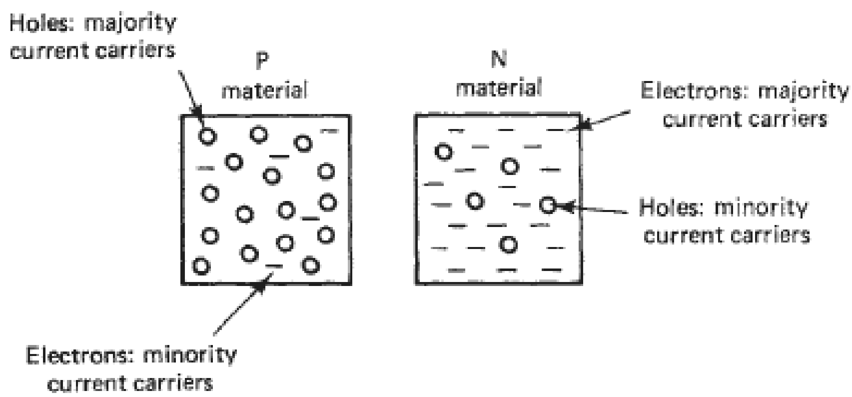


Figure 1.1

P and N type pieces of semiconductor material before they are formed into a P-N junction



Semiconductor

Figure 1.2

Formation of Depletion region

P region	Majority Holes	Minority Electrons
N region	Majority Electrons	Minority holes

When a junction diode is first formed, there is a unique interaction between current carriers.

Concentration of holes in the P region is more compared to the holes in the N region. Similarly the concentration of electrons in the N region is more compared to the electrons in the P region. This makes a density gradient across the junction.

Because the charge carriers are either all electrons or all holes they have the same polarity, and thus there is a force of repulsion between them. This produces a tendency for the electrons to move gradually or diffuse, away from the locality of high concentration toward one of low concentration unlit they are evenly distributed through out the material.

The movement of charge carriers constitutes an electric current, and so this type of current is known as diffusion current. Only those current carriers near the junction take part in the diffusion process.

When an electron migrates across the junction from N region to P region, it leaves behind an atom that is one electron short of its normal quota. This atom is now ionized and has a positive charge. These impurity ions so produced are fixed in their position in the crystal lattice in the N region. Upon entering the P material to fill holes, these same electrons create negative ions in the P region. These ions are also fixed and immobile.

The area of each side of the junction then contains a large number of positive and negative ions. The number of holes and electrons in this area becomes depleted. The term *depletion region is* used to describe this area. It represents an area that is void of majority current carriers. All P-N junctions develop a depletion zone when they are formed.

Barrier Potential

Before N and P materials are joined together at a common junction they are considered to be electrically neutral. After being joined, however, diffusion takes place immediately. The end result of diffusion is a charge buildup or *barrier potential* appearing across the junction.

Figure 1.3 shows the resulting barrier potential as a small battery connected across the P-N junction. This voltage will exist even when the crystal is not connected to an outside source of energy. For germanium the barrier potential is approximately 0.3 V, and 0.7 V for silicon. These voltage values cannot, however, be measured directly. They appear only across the space charge region of the junction. The barrier potential of a P-N junction must be overcome by an outside voltage source in order to produce current conduction.

FORWARD BIAS

An external voltage applied to a PN junction is called BIAS. The positive terminal of the bias battery is connected to the P-type material and the negative terminal of the battery is connected to the N-type material.

Forward and Reverse Characteristics of PN junction diode

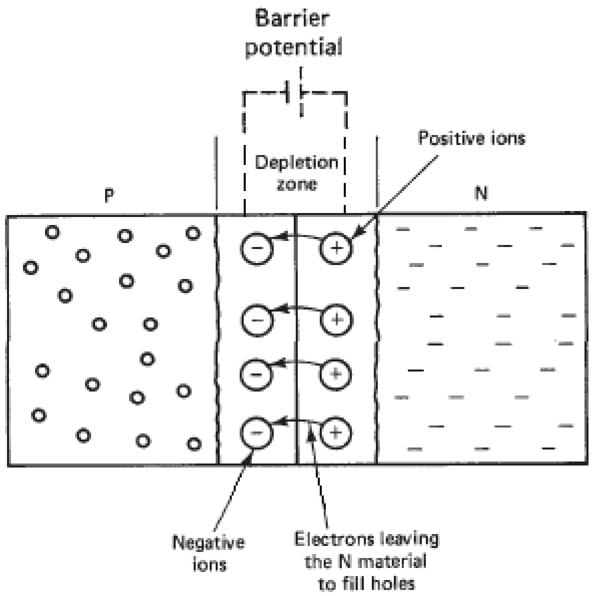


Figure 1.3

The positive potential repels holes toward the junction where they neutralize some of the negative ions. At the same time the negative potential repels electrons toward the junction where they neutralize some of the positive ions. Since ions on both sides of the barrier are being neutralized, the width of the barrier decreases. Thus, the effect of the battery voltage in the forward-bias direction is to reduce the barrier potential across the junction and to allow majority carriers to cross the junction.

It is important to remember that in the forward biased condition, conduction is by MAJORITY current carriers (holes in the P-type material and electrons in the N-type material). Increasing the battery voltage will increase the number of majority carriers arriving at the junction and will therefore increase the current flow.

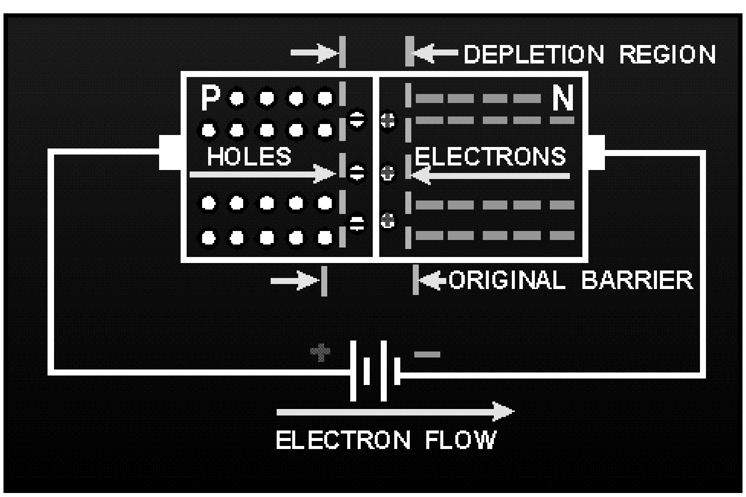


Figure 1.4

REVERSE BIAS

To reverse bias a junction diode, the negative battery terminal is connected to the P-type material and the positive battery terminal to the N-type material.

The negative potential attracts the holes away from the junction on the P side, while the positive potential attracts the electrons away from the edge of the barrier on the N side. This action increases the barrier width because there are more negative ions on the P side of the junction, and more positive ions on the N side of the junction. This increase in barrier width prevents current flow across the junction by majority carriers.

However, the current flow across the barrier is not quite zero because of the minority carriers crossing the junction. For the minority carriers the applied bias is a forward bias.

Since the minority carrier production is all because of external temperature or light it is independent of the reverse bias. This current is called reverse saturation current or reverse leakage current (I_o).

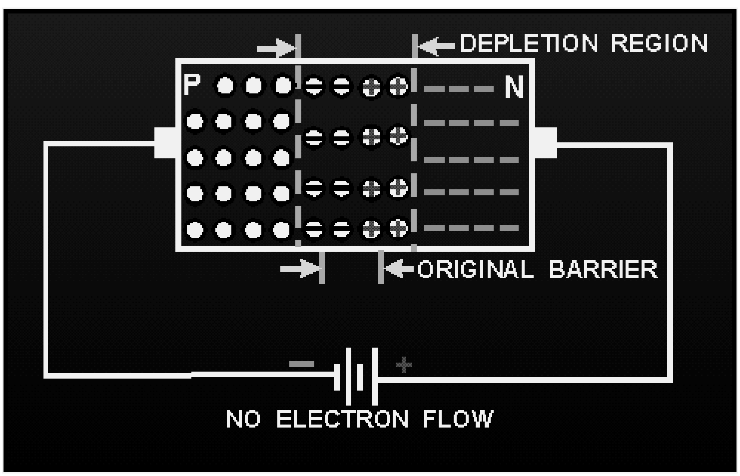


Figure 1.5

VI characteristics

Forward Characteristic

The relationship of forward voltage and forward current is called the volt- ampere, or *VI* characteristic of a diode.

When a diode is connected in the forward bias direction it conducts forward current I_F. The value of I_F is directly dependant on the amount of forward voltage V_F.

When the forward voltage of the diode equals 0V, the I_F equals 0 mA. This value starts at the origin point (0) of the graph. If V_F is gradually increased in 0.1-V steps, I_F begins to increase. When the value of V_F is great enough to overcome the barrier potential of the P-N junction, a substantial increase in I_F occurs. The point at which this occurs is often called the knee voltage V_K*(Cut-in voltage or threshold voltage).* For germanium diodes V_K is approximately 0.3 V and 0.7 V for silicon. If the value of I_F increases much beyond V_K, the forward current becomes quite large. This, in effect, causes heat to develop across the junction. Excessive junction heat can destroy a diode. To prevent this a protective resistor is connected in series with the diode.

Reverse Characteristic

When a diode is connected in the reverse bias direction it has an V_R— I_R characteristic. This characteristic has different values of I_R and V_R. Reverse current is usually quite small. The vertical I_R line in this graph has current values graduated in microamperes. Starting in zero when the reverse voltage of a diode is increased there is a very slight change in I_R. At the breakdown voltage V_{BR} point, current increases very rapidly. The voltage across the diode remains fairly constant at this time. Break down occurs in PN junction diode because of Avalanche effect.

Avalanche breakdown occurs in lightly doped diodes. Here the applied reverse voltage is not enough to break covalent bonds but can accelerate the minority carriers. Accelerated minority carriers collide with semiconductor atoms and produces new electron hole pairs. Newly created carriers also participation in current conduction and produce more electron hole pairs. This process is cumulative. The process continues to build up until an avalanche of current carriers takes place. When this occurs the process is irreversible and it may damage the junction.

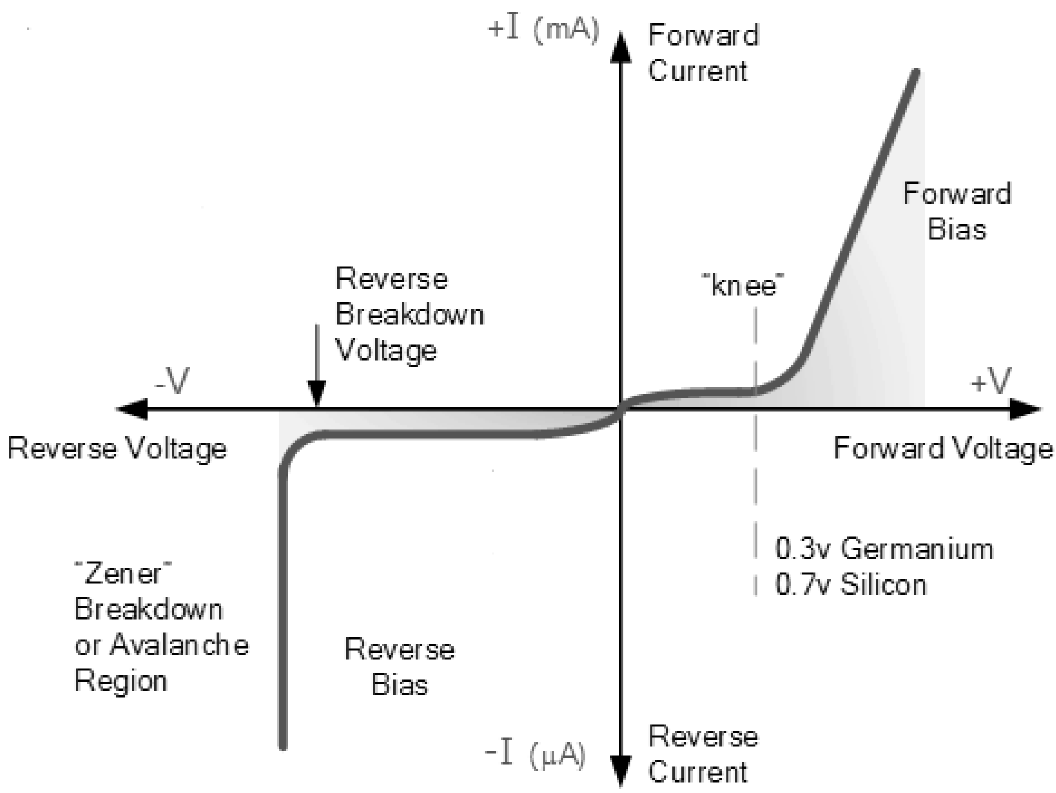


Figure 1.6

2. Static and Dynamic resistance of a PN junction diode

A diode is defined to have two kinds of resistances – *Static resistance* (r_{dc}) and AC *dynamic resistance*. (r_{ac})

The **static resistance** is given by the ratio of *dc voltage* across a diode to the dc current. This can be determined from the dc characteristic curve and is not constant and varies with forward bias. Depending upon the operating point its value could vary from 0.05 Ω to 250 Ω . For Reverse bias, rdc is 5M Ω.

The **Dynamic resistance** is the resistance offered by a diode to an ac signal. Since the slope of the curve at a particular voltage is given by ΔI_F / ΔV_F hence r_{ac} at that voltage is the reciprocal of the slope.

$$\mathbf{r_{ac} = \Delta V_F / \Delta I_F \ \ \Omega}$$

Its range is generally in 1 to 25 ohms and its value is determined by the shape of the curve at that point.

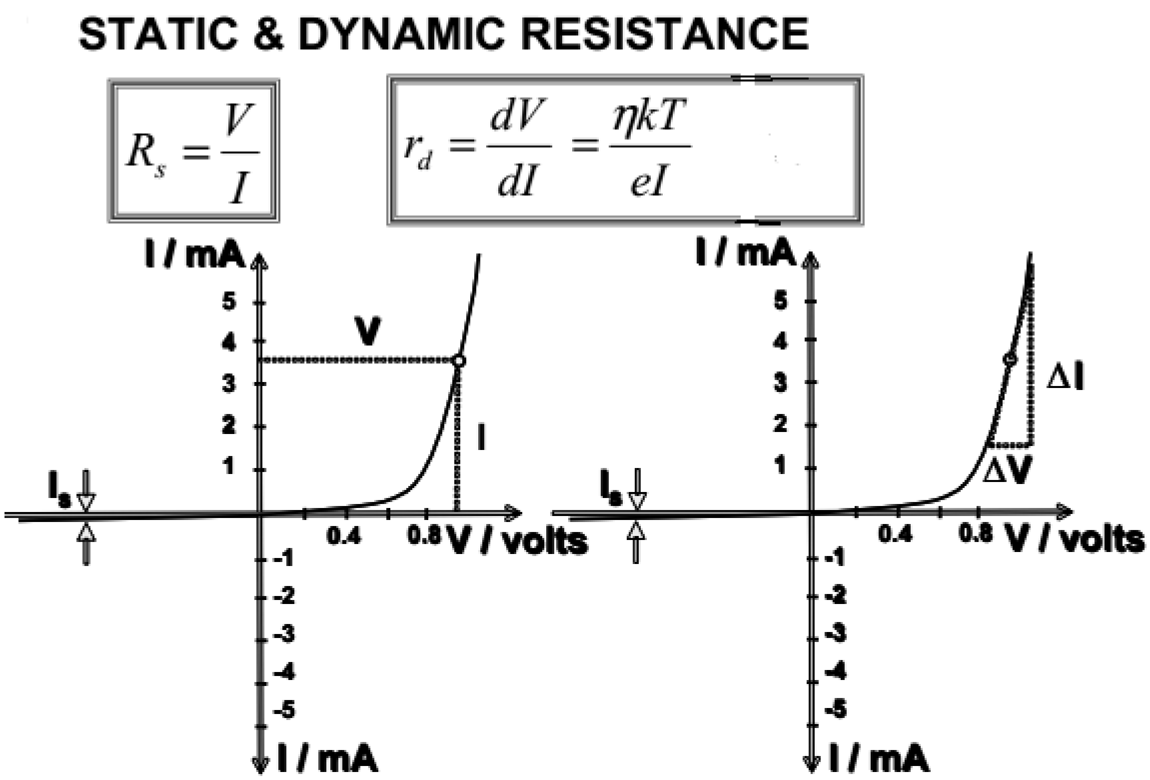


Figure 2.1

3. Temperature effects

Effects of temperature on forward characteristics

The voltage drop across a forward-biased pn-junction changes with temperature by approximately -1.8 mV/°C for a silicon device and by -2.02 mV/°C for germanium.

A forward voltage drop at any temperature can be calculated from knowledge of V_F at the starting temperature (V_{F1} at T_1), the temperature change (ΔT), and the voltage/temperature coefficient (ΔV_F/°C). Figure 3.1 shows the temperate changes in the forward characteristics.

$$V_{F2} = (V_{F1} at T_1) + \left[\Delta T(\Delta V_F / °C)\right]$$

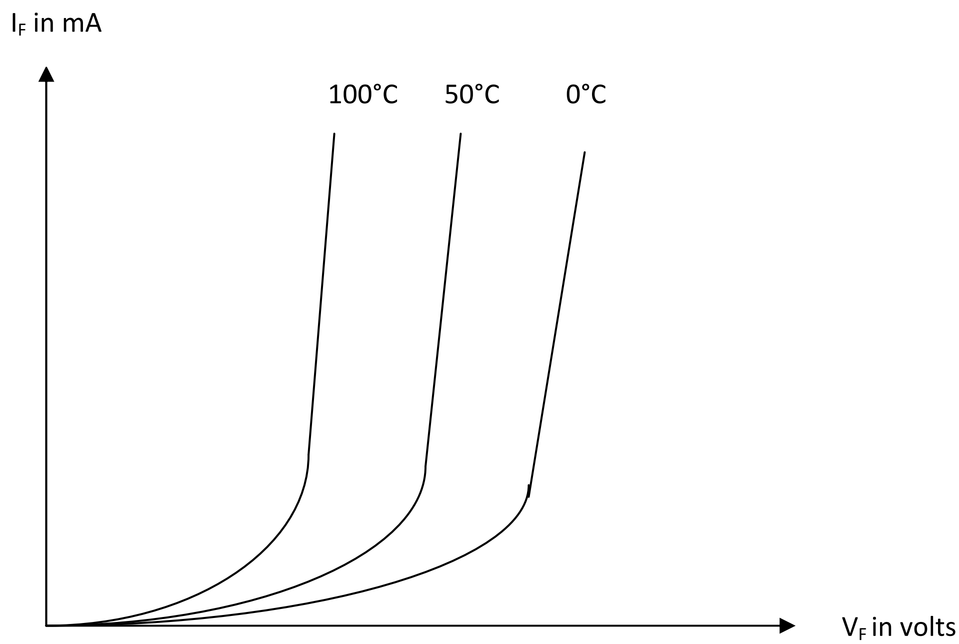


Figure 3.1

Effect of Temperature on Reverse biased pn-junction

The reverse saturation current (I_O) at a pn-junction consists of minority charge carriers. When the temperature of the semiconductor material is raised, increasing numbers of electrons break away from their atoms. This generates additional minority charge carriers, causing I_o to increase as the junction temperature rises. When I_o is known for a given temperature (T_1), it can be calculated for another temperature level (T_2) from the following equation:

$$I_{o(T2)} \approx I_{o(T2)}(2^{(T2-T1)/10})$$

For a silicon pn junction, the ideal reverse-saturation current density will increase by approximately a factor of 4 for every 10° C increase in temperature. Figure 3.2 reflects the effect of variations of reverse saturation with respect to temperature.

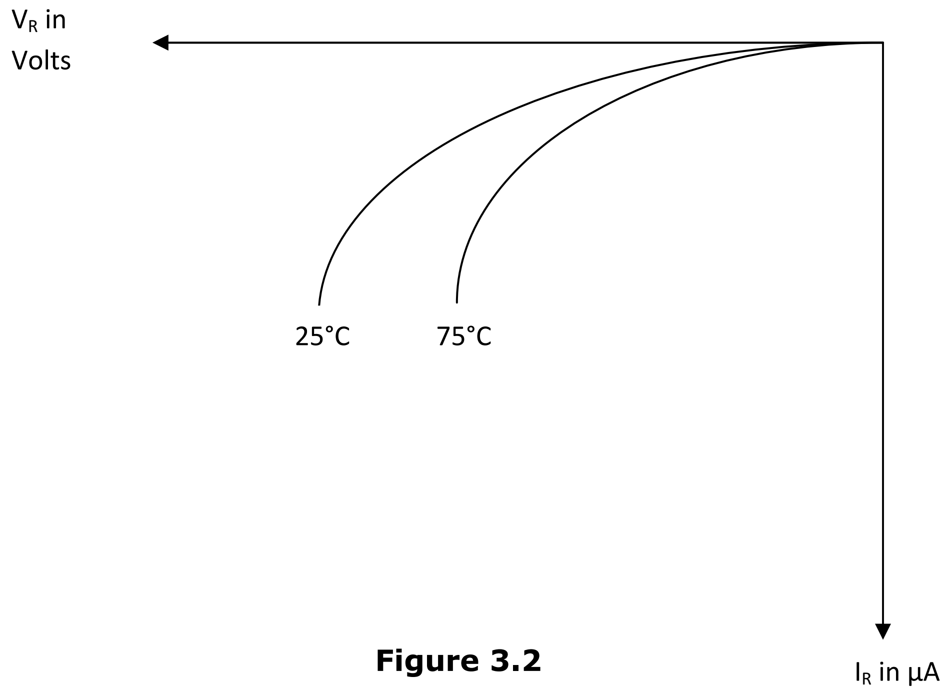


Figure 3.2

4. Diode Switching Characteristics

Diodes are often used in a switching mode. When applied bias voltage to the pn-junction is suddenly reversed in the opposite direction, the diode response reaches a steady state after an interval of time, called the recovery time. The forward recovery time, t_{fr} is defined as the time required for forward voltage or current to reach a specified value (time interval between the instant of 10 % diode voltage to the instant is voltage reaches with in 10% of its final value) after switching diode from its reverse to forward biased state. Fortunately, the forward recovery time posses no serious problem. Therefore only the reverse recovery time, t_{rr} has to be considered in practical applications.

When the pn-junction diode is forward biased, the minority electron concentration in the p-region is approximately linear. If the junction is suddenly reverse biased, at t_1, then because of this stored electronic charge, the reverse current (I_R) is initially of the same magnitude as the forward current (I_F). The diode will continue to conduct until the injected or excess minority carrier density ($p-p_o$) or ($n-n_o$) has dropped to zero. However, as the stored electrons are removed into the N-region and contact, the available charge quickly drops to an equilibrium level and a steady current eventually flows corresponding to the reverse bias voltage as shown in figure (c).

As shown in figure (b), the applied voltage $V_i = V_F$ for the time up to t_1 is in the direction to forward-bias the diode. The resistance R_L is large so that the drop across R_L is large when compared to the drop across the diode. Then current is

$I = V_F / R_L = I_F$. Then, at time $t = t_1$, the input voltage is suddenly reversed to the value of $-V_R$. Due to the reasons explained above, the current does not become zero and has the value $I= V_R/R_L = -I_R$ until the time $t = t_2$. At
$t = t_2$, when the excess minority carriers have reached the equilibrium state, the magnitude of the diode current starts to decrease, as shown in figure (d).

During the time interval from t_1 to t_2, the injected minority carriers have remained stored and hence this time interval is called the storage time (t_s).

After the instant $t = t_2$, the diode gradually recovers and ultimately reaches the steady-state. The time interval between t_2 and the instant t_3 when the diode has recovered nominally is called the transition time, t_t. The recovery is said to have completed

(i) when even the minority carriers remote from the junction have diffused to the junction and crossed it, and
(ii) When the junction transition capacitance C_T, across the reverse-biased junction has got charged through the external resistor R_L to the voltage $-V_R$.

The reverse recovery time (or turn-off- time) of the diode, t_{rr}, is the interval from the current reversal at $t = t_1$ until the diode has recovered to a specific extent in terms either of the diode current or of the diode resistance, i.e.

$t_{rr} = t_s + t_t$.

t_s---- Storage time
t_t-----Transition time
t_{rr}-----Reverse recovery time

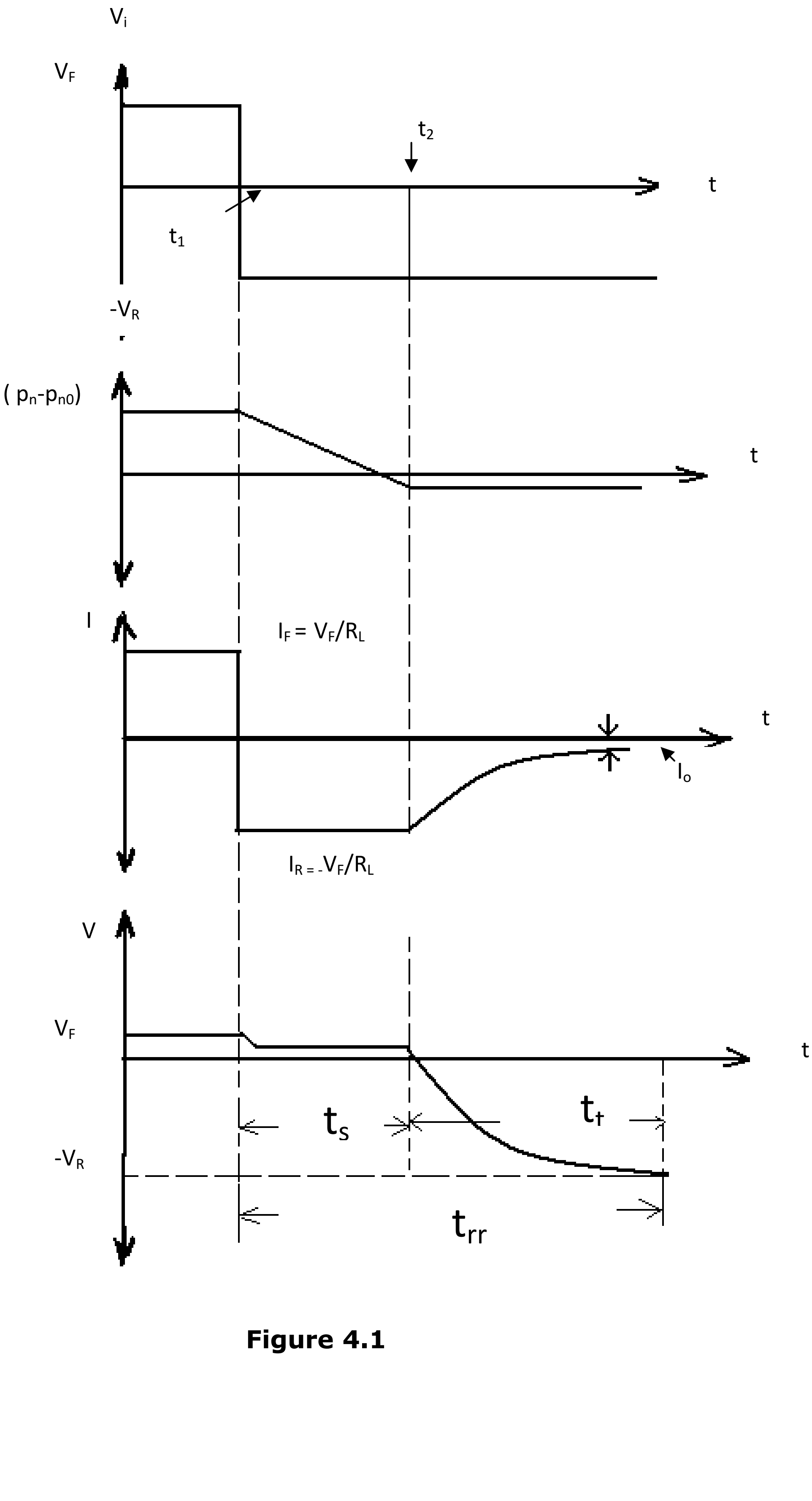


Figure 4.1

5. Drift and diffusion current

Current Flow

- Drift current: charged particle motion in response to an electric field.
- Diffusion current: Particles tend to spread out or re-distribute from areas of high concentration to areas of lower concentration.

Drift current

When an electric field is applied across the semiconductor material, the charge carriers attain a certain drift velocity V_d, which is equal to the product of the mobility of the charge carriers and the applied Electric Field intensity E.

Drift velocity V_d = mobility of the charge carriers multiplied by the Applied Electric field intensity.

Holes move towards the negative terminal of the battery and electrons move towards the positive terminal of the battery. This combined effect of movement of the charge carriers constitutes a current known as ***the drift current***.

Thus the drift current is defined as the flow of electric current due to the motion of the charge carriers under the influence of an external electric field.

Drift current due to the charge carriers such as free electrons and holes are the current passing through a square centimeter perpendicular to the direction of flow.

1. Drift current density J_n , due to free electrons is given by

$$J_n = q\, n\, \mu_n\, E \quad A / cm^2$$

2. Drift current density J_P, due to holes is given by

$$J_P = q\, p\, \mu_p\, E \quad A / cm^2$$

Where, n - Number of free electrons per cubic centimeter.
P - Number of holes per cubic centimeter
μ_n – Mobility of electrons in cm^2 / Vs
μ_p – Mobility of holes in cm^2 / Vs
E – Applied Electric filed Intensity in V /cm
q – Charge of an electron = 1.6×10^{-19} coulomb.

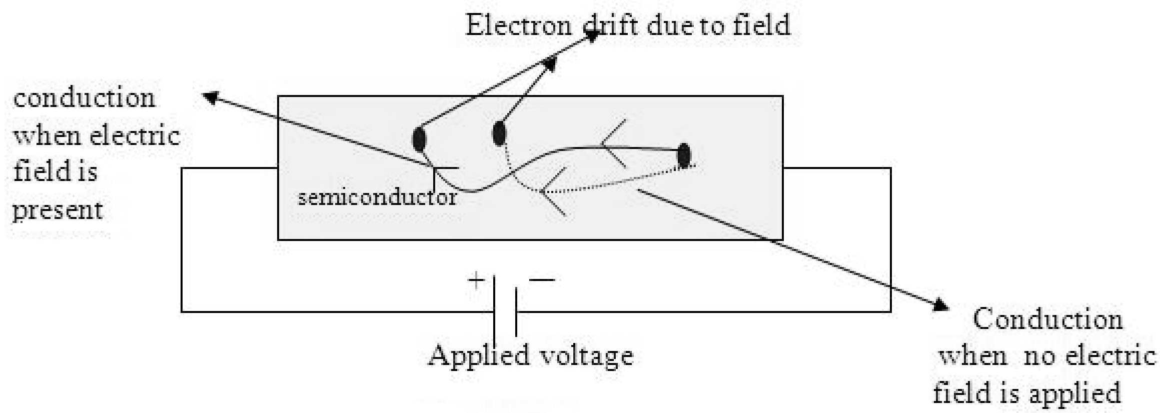


Figure 5.1

Diffusion Current

It is possible for an electric current to flow in a semiconductor even in the absence of the applied voltage provided a concentration gradient exists in the material. In a freshly formed pn-junction, P-region has more no. of holes; on the other hand N-region has more electrons.

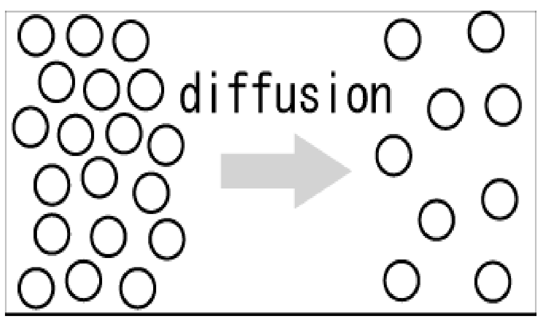


Figure 5.2

A concentration gradient exists across the material. Because the charge carriers are either all electrons or all holes they have the same polarity, and thus there is force of repulsion between them. This produces a tendency for the charge carriers, in a semiconductor material to move gradually from the region of higher concentration to that of lower concentration until they are eventually distributed throughout the material.

The current caused by the diffusion of carriers across the junction is called diffusion current.

Once a majority carrier crosses the junction, it becomes a minority carrier. It will continue to diffuse away from the junction and can travel a distance on average equal to the diffusion length before it recombines.

RECTIFIERS

Introduction:

For the operation of most of the electronics devices and circuits, a d.c. source is required. So it is advantageous to convert domestic a.c. supply into d.c. voltages. The process of converting a.c. voltage into d.c. voltage is called as rectification.This is achieved with i) Step-down Transformer, ii) Rectifier, iii) Filter and iv) Voltage regulator circuits.

These elements constitute d.c. regulated power supply shown in the figure below.

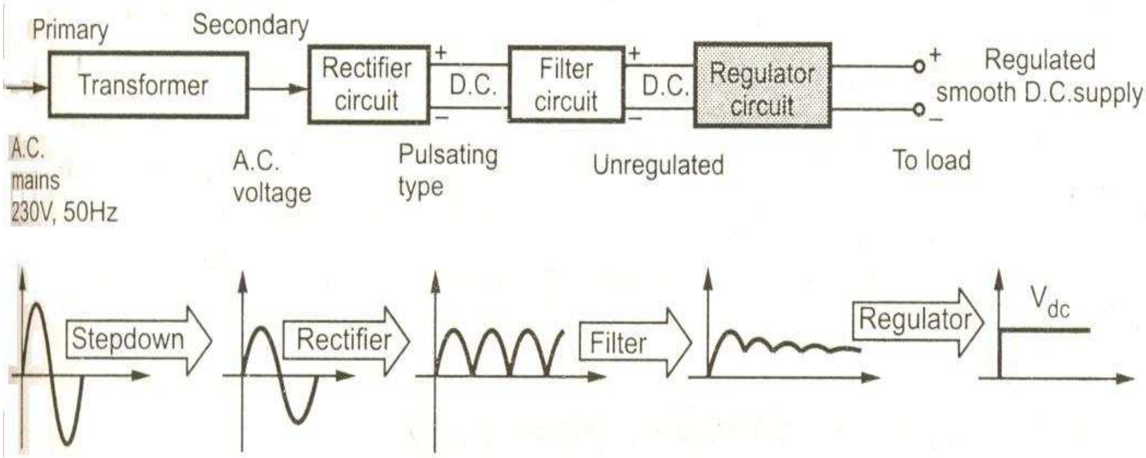


Fig. Block diagram of Regulated D.C. Power Supply

The block diagram of a regulated D.C. power supply consists of step-down transformer, rectifier, filter, voltage regulator and load.

An ideal regulated power supply is an electronics circuit designed to provide a predetermined d.c. voltage Vo which is independent of the load current and variations in the input voltage ad temperature.

If the output of a regulator circuit is a AC voltage then it is termed as voltage stabilizer, whereas if the output is a DC voltage then it is termed as voltage regulator.

The elements of the regulated DC power supply are discussed as follows:

TRANSFORMER:

A transformer is a static device which transfers the energy from primary winding to secondary winding through the mutual induction principle, without changing the frequency. The transformer winding to which the supply source is connected is called the primary, while the winding connected to the load is called secondary.

If N_1,N_2 are the number of turns of the primary and secondary of the transformer then $\alpha = \frac{N_2}{N_1}$ is called the turns ratio of the transformer.

The different types of the transformers are

1) Step-Up Transformer
2) Step-Down Transformer
3) Centre-tapped Transformer

The voltage, current and impedance transformation ratios are related to the turns ratio of the transformer by the following expressions.

Voltage transformation ratio : $\frac{V_2}{V_1} = \frac{N_2}{N_1}$

Current transformation ratio : $\frac{I_2}{I_1} = \frac{N_1}{N_2}$

Impedance transformation ratio : $\frac{Z_L}{Z_{in}} = \left(\frac{N_2}{N_1}\right)^2$

RECTIFIER:

Any electrical device which offers a low resistance to the current in one direction but a high resistance to the current in the opposite direction is called rectifier. Such a device is capable of converting a sinusoidal input waveform, whose average value is zero, into a unidirectional waveform, with a non-zero average component.

A rectifier is a device which converts a.c. voltage (bi-directional) to pulsating d.c. voltage (Uni-directional).

Important characteristics of a Rectifier Circuit:

1. **Load currents:** They are two types of output current. They are average or d.c. current and RMS currents.

   i) **Average or DC current:** The average current of a periodic function is defined as the area of one cycle of the curve divided by the base.

   It is expressed mathematically as $I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i d(\omega t)$; where $i = \mathrm{I_m} \sin \omega t$

   ii) **Effective (or) R.M.S. current:** The effective (or) R.M.S. current squared of a periodic function of time is given by the area of one cycle of the curve which represents the square of the function divided by the base.

   It is expressed mathematically as $I_{rms} = \left(\frac{1}{2\pi}\int_0^{2\pi} i^2 d(\omega t)\right)^{\frac{1}{2}}$

2. **Load Voltages:** There are two types of output voltages. They are average or D.C. voltage and R.M.S. voltage.

   i) **Average or DC Voltage:** The average voltage of a periodic function is defined as the areas of one cycle of the curve divided by the base.
   It is expressed mathematically as

   $$V_{dc} = \frac{1}{2\pi}\int_0^{2\pi} V d(\omega t) \text{ ; Where } V = V_{\mathrm{m}} \sin \omega t$$

   (or) $V_{dc} = I_{dc} \times R_L$

   ii) **Effective (or) R.M.S Voltage:** The effective (or) R.M.S voltage squared of a periodic function of time is given by the area of one cycle of the curve which represents the square of the function divided by the base.

$$V_{rms} = \left(\frac{1}{2\pi} \int_0^{2\pi} V^2 d(\omega t) \right)^{\frac{1}{2}} \qquad V_{rms} = I_{rms} \times R_L$$

3. **Ripple Factor (γ):** It is defined as ration of R.M.S. value of a.c. component to the d.c. component in the output is known as "Ripple Factor".

$$\gamma = \frac{V'_{rms}}{V_{dc}}$$

$$V'_{rms} = \sqrt{V_{rms}^2 - V_{dc}^2}$$

$$\therefore \gamma = \sqrt{\left(\frac{V_{rms}}{V_{dc}} \right)^2 - 1}$$

4. **Efficiency (η):** It is the ratio of d.c output power to the a.c. input power. It signifies, how efficiently the rectifier circuit converts a.c. power into d.c. power.

It is given by $$\eta = \frac{P_{dc}}{P_{ac}}$$

5. **Peak Inverse Voltage (PIV):** It is defined as the maximum reverse voltage that a diode can withstand without destroying the junction.

6. **Regulation:** The variation of the d.c. output voltage as a function of d.c. load current is called regulation. The percentage regulation is defined as

$$\% \text{ Regulation} = \frac{V_{no-load} - V_{full-load}}{V_{full-load}} \times 100\%$$

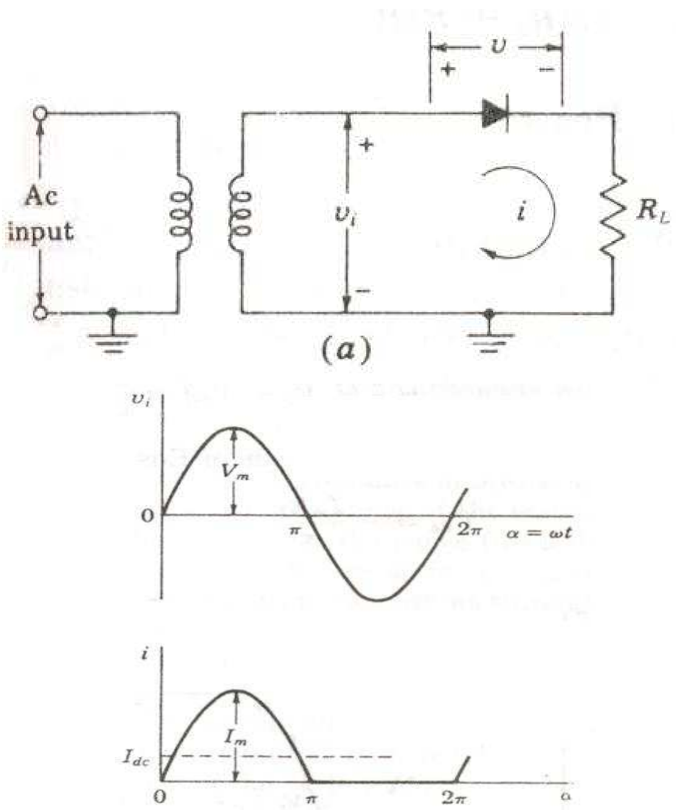
For an ideal power supply, % Regulation is zero.

Using one or more diodes in the circuit, following rectifier circuits can be designed.

1. Half - Wave Rectifier
2. Full – Wave Rectifier
3. Bridge Rectifier

HALF-WAVE RECTIFIER:

A Half – wave rectifier is one which converts a.c. voltage into a pulsating voltage using only one half cycle of the applied a.c. voltage. The basic half-wave diode rectifier circuit along with its input and output waveforms is shown in figure below.



The half-wave rectifier circuit shown in above figure consists of a resistive load; a rectifying element i.e., p-n junction diode and the source of a.c. voltage, all connected is series. The a.c. voltage is applied to the rectifier circuit using step-down transformer.

The input to the rectifier circuit, $V = V_m \sin \omega t$ Where Vm is the peak value of secondary a.c. voltage

Operation:

For the positive half-cycle of input a.c. voltage, the diode D is forward biased and hence it conducts. Now a current flows in the circuit and there is a voltage drop across R_L. The waveform of the diode current (or) load current is shown in figure.

For the negative half-cycle of input, the diode D is reverse biased and hence it does not conduct. Now no current flows in the circuit i.e., i=0 and Vo=0. Thus for the negative half-cycle no power is delivered to the load.

Analysis:

In the analysis of a HWR, the following parameters are to be analyzed.

i)	DC output current	ii)	DC Output voltage
iii)	R.M.S. Current	iv)	R.M.S. voltage
v)	Rectifier Efficiency (η)	vi)	Ripple factor (γ)
vii)	Regulation	viii)	Transformer Utilization Factor (TUF)
ix)	Peak Factor (P)		

Let a sinusoidal voltage V_i be applied to the input of the rectifier.

Then $V = V_m \sin \omega t$ Where Vm is the maximum value of the secondary voltage.

Let the diode be idealized to piece-wise linear approximation with resistance R_f in the forward direction i.e., in the ON state and R_r (=∞) in the reverse direction i.e., in the OFF state.

Now the current 'i' in the diode (or) in the load resistance R_L is given by

$$i = I_m \sin \omega t \qquad \text{for} \qquad 0 \le \omega t \le \pi$$

$$i=0 \qquad \text{for} \qquad \pi \le \omega t \le 2\pi$$

where $I_m = \dfrac{V_m}{R_f + R_L}$

i) Average (or) DC Output Current (I_{av} or I_{dc}):

The average dc current I_{dc} is given by

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i\,d(\omega t)$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} I_m \sin \omega t\, d(\omega t) + \int_{\pi}^{2\pi} 0 \times d(\omega t)\right]$$

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

$$= \frac{1}{2\pi}\left[I_m(+1-(-1))\right]$$

$$= \frac{I_m}{\pi} = 0.318\ I_m$$

Substituting the value of I_m, we get $I_{dc} = \dfrac{V_m}{\pi\left(R_f + R_L\right)}$

If $R_L >> R_f$ then $I_{dc} = \dfrac{V_m}{\pi R_L} = 0.318\ \dfrac{V_m}{R_L}$

ii) Average (or) DC Output Voltage (V_{av} or V_{dc}):

The average dc voltage is given by

$$V_{dc} = I_{dc} \times R_L = \frac{I_m}{\pi} \times R_L = \frac{V_m R_L}{\pi\left(R_f + R_L\right)}$$

$$\Rightarrow V_{dc} = \frac{V_m R_L}{\pi\left(R_f + R_L\right)}$$

If $R_L >> R_f$ then $V_{dc} = \dfrac{V_m}{\pi} = 0.318\ I_m \qquad \therefore V_{dc} = \dfrac{V_m}{\pi}$

iii) R.M.S. Output Current (I_{rms}):

The value of the R.M.S. current is given by

$$I_{rms} = \left[\frac{1}{2\pi}\int_0^{2\pi} i^2 d(\omega t)\right]^{\frac{1}{2}}$$

$$= \left[\frac{1}{2\pi}\int_0^{\pi} \mathrm{I}_m^2 \sin^2 \omega t . d(\omega t) + \frac{1}{2\pi}\int_{\pi}^{2\pi} .0 . d(\omega t)\right]^{\frac{1}{2}}$$

$$= \left[\frac{\mathrm{I}_m^2}{2\pi}\int_0^{\pi}\left(\frac{1-\cos\omega t}{2}\right) d(\omega t)\right]^{\frac{1}{2}}$$

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

$$= \left[\frac{\mathrm{I}_m^2}{4\pi}\left\{\pi - 0 - \frac{\sin 2\pi}{2} + \sin 0\right\}\right]^{\frac{1}{2}}$$

$$= \left(\frac{\mathrm{I}_m^2}{4}\right)^{\frac{1}{2}} \qquad = \frac{\mathrm{I_m}}{2}$$

$$\therefore I_{rms} = \frac{\mathrm{I_m}}{2} \quad I_{rms} = \frac{V_m}{2\left(R_f + R_L\right)}$$

iv) R.M.S. Output Voltage (V_{rms}):

R.M.S. voltage across the load is given by

$$V_{rms} = I_{rms} \times R_L = \frac{V_m R_L}{2\left(R_f + R_L\right)} = \frac{V_m}{2\left(1 + \frac{R_f}{R_L}\right)}$$

If $R_L >> R_f$ then $V_{rms} = \frac{V_m}{2}$

v) Rectifier efficiency (η) :

The rectifier efficiency is defined as the ration of d.c. output power to the a.c. input power i.e.,

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

$$P_{dc} = I_{dc}^2 R_L = \frac{I_m^2 R_L}{\pi^2}$$

$$P_{ac} = I_{rms}^2 \left(R_L + R_f\right) = \frac{I_m^2}{4}\left(R_L + R_f\right)$$

$$\therefore \eta = \frac{P_{dc}}{P_{ac}} = \frac{I_m^2 R_L}{\pi^2} \times \frac{4}{I_m^2 \left(R_L + R_f\right)} = \frac{4}{\pi^2}\left(\frac{R_L}{R_L + R_f}\right)$$

$$\Rightarrow \eta = \frac{4}{\pi^2} \times \frac{1}{\left(1 + \frac{R_f}{R_L}\right)} = \frac{0.406}{1 + \frac{R_f}{R_L}}$$

$$\Rightarrow \% \eta = \frac{40.6}{1 + \frac{R_f}{R_L}}$$

Theoretically the maximum value of rectifier efficiency of a half-wave rectifier is 40.6% when $\frac{R_f}{R_L} = 0$.

vi) Ripple Factor (γ):

The ripple factor γ is given by

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1} \quad \textbf{(or)} \quad \gamma = \sqrt{\left(\frac{V_{rms}}{V_{dc}}\right)^2 - 1}$$

$$\therefore \gamma = \sqrt{\left(\frac{I_m/2}{I_m/\pi}\right)^2 - 1} = \sqrt{\left(\frac{\pi}{2}\right)^2 - 1} = 1.21$$

$$\Rightarrow \gamma = 1.21$$

vii) Regulation:

The variation of d.c. output voltage as a function of d.c. load current is called *regulation.*

The variation of V_{dc} with I_{dc} for a half-wave rectifier is obtained as follows:

$$I_{dc} = \frac{I_m}{\pi} = \frac{V_m/\pi}{R_f + R_L}$$

But $V_{dc} = I_{dc} \times R_L$

$$V_{dc} = \frac{V_m}{\pi}\left[\frac{R_L}{R_f + R_L}\right] \qquad = \frac{V_m}{\pi}\left[1 - \frac{R_f}{R_f + R_L}\right]$$

$$= \frac{V_m}{\pi} - I_{dc} R_f$$

$$\therefore V_{dc} = \frac{V_m}{\pi} - I_{dc} R_f$$

This result shows that V_{dc} equals $\frac{V_m}{\pi}$ at no load and that the dc voltage decreases linearly with an increase in dc output current. The larger the magnitude of the diode forward resistance, the greater is this decrease for a given current change.

viii) Transformer Utilization Factor (UTF):

The d.c. power to be delivered to the load in a rectifier circuit decides the rating of the transformer used in the circuit. So, transformer utilization factor is defined as

$$\therefore TUF = \frac{P_{dc}}{P_{ac(rated)}}$$

The factor which indicates how much is the utilization of the transformer in the circuit is called Transformer Utilization Factor (TUF).

The a.c. power rating of transformer **= $V_{rms}\ I_{rms}$**

The secondary voltage is purely sinusoidal hence its rms value is $\frac{1}{\sqrt{2}}$ times maximum while the current is half sinusoidal hence its rms value is $\frac{1}{2}$ of the maximum.

$$\therefore P_{ac(rated)} = \frac{V_m}{\sqrt{2}} \times \frac{I_m}{2} = \frac{V_m I_m}{2\sqrt{2}}$$

The d.c. power delivered to the load $= I_{dc}^2 R_L = \left(\frac{I_m}{\pi}\right)^2 R_L$

$$\therefore TUF = \frac{P_{dc}}{P_{ac(rated)}}$$

$$= \left(\frac{I_m}{\pi}\right)^2 R_L = \frac{2\sqrt{2}}{V_m I_m}$$

$$= \frac{I_m^2 \cdot R_L \cdot 2\sqrt{2}}{\pi^2 \cdot I_m^2 \cdot R_L} \qquad (\because V_m \approx I_m R_L)$$

= 0.287

$$\therefore TUF = 0.287$$

The value of TUF is low which shows that in half-wave circuit, the transformer is not fully utilized.

If the transformer rating is 1 KVA (1000VA) then the half-wave rectifier can deliver 1000 X 0.287 = 287 watts to resistance load.

ix) Peak Inverse Voltage (PIV):

It is defined as the maximum reverse voltage that a diode can withstand without destroying the junction. The peak inverse voltage across a diode is the peak of the negative half-cycle. For half-wave rectifier, PIV is $\mathbf{V_m}$.

x) Form factor (F):

The Form Factor F is defined as

F = rms value / average value

$$F = \frac{\text{Im}/2}{\text{Im}/\pi}$$

$$F = \frac{0.5\,\text{Im}}{0.318\,\text{Im}} = 1.57$$

xi) Peak Factor (P):

The peak factor P is defined as

P= Peak Value / rms value $= \frac{V_m}{V_m/2}$ = 2 **P = 2**

Disadvantages of Half-Wave Rectifier:

1. The ripple factor is high.
2. The efficiency is low.
3. The Transformer Utilization factor is low.

Because of all these disadvantages, the half-wave rectifier circuit is normally not used as a power rectifier circuit.

Problems from previous external question paper:

1. A diode whose internal resistance is 20Ω is to supply power to a 100Ω load from 110V(rms) source pf supply. Calculate (a) peak load current (b) the dc load current (c) the ac load current (d) the percentage regulation from no load to full load.

Solution:

Given a half-wave rectifier circuit R_f=20Ω, R_L=100Ω

Given an ac source with rms voltage of 110V, therefore the maximum amplitude of sinusoidal input is given by

$\mathbf{V_m}$ = $\sqrt{2} \times V_{rms}$ = $\sqrt{2}$ x 110 = **155.56V**.

(a) Peak load current : $I_m = \frac{V_m}{R_f + R_L} \Rightarrow I_m = \frac{155.56}{120}$ = **1.29A**

(b) The dc load current : $I_{dc} = \frac{I_m}{\pi}$ = **0.41A**

(c) The ac load current : $I_{rms} = \frac{I_m}{2}$ = **0.645A**

(d) $V_{no\text{-}load}$: $\frac{V_m}{\pi} = \frac{155.56}{\pi}$ = **49.51 V**

$V_{full\text{-}load}$: $\frac{V_m}{\pi} - I_{dc}R_f$ = **41.26 V**

% Regulation **=** $\frac{V_{no-load} - V_{full-load}}{V_{full-load}} \times 100$ = **19.97%**

2. A diode has an internal resistance of 20Ω and 1000Ω load from 110V(rms) source pf supply. Calculate (a) the efficiency of rectification (b) the percentage regulation from no load to full load.

Solution:

Given a half-wave rectifier circuit R_f=20Ω, R_L=1000Ω

Given an ac source with rms voltage of 110V, therefore the maximum amplitude of sinusoidal input is given by

$$V_m = \sqrt{2} \times V_{rms} = \sqrt{2} \times 110 = 155.56V.$$

(a) % Efficiency (η) = $\frac{40.6}{1+\frac{20}{100}} = \frac{40.6}{1.02}$ **= 39.8%.**

(b) Peak load current : $I_m = \frac{V_m}{R_f + R_L} = \frac{155.56}{1020}$ = 0.1525 A

= 152.5 mA

The dc load current : $I_{dc} = \frac{I_m}{\pi}$ = **48.54 mA**

$V_{no\text{-}load}$ **=** $\frac{V_m}{\pi} = \frac{155.56}{\pi}$ = **49.51 V**

$V_{full\text{-}load}$ = $\frac{V_m}{\pi} - I_{dc}R_f$ = **49.51 – (48.54 x10^{-3} x 20)**

= 49.51 – 0.97 = 48.54 V

% Regulation **=** $\frac{V_{no-load} - V_{full-load}}{V_{full-load}} \times 100$

= $\frac{49.51 - 48.54}{48.54} \times 100$ **= 1.94 %**

3. An a.c. supply of 230V is applied to a half-wave rectifier circuit through transformer of turns ration 5:1. Assume the diode is an ideal one. The load resistance is 300Ω.

Find (a) dc output voltage (b) PIV (c) maximum, and (d) average values of power delivered to the load.

Solution: (a) The transformer secondary voltage = 230/5 = 46V.

Maximum value of secondary voltage, $V_m = \sqrt{2} \times 46 = 65V$.

Therefore, dc output voltage, $V_{dc} = \frac{V_m}{\pi} = \frac{65}{\pi}$ **= 20.7 V**

(b) PIV of a diode : V_m = **65V**

(c) Maximum value of load current, $I_m = \frac{V_m}{R_L} = \frac{65}{300}$ **= 0.217 A**

Therefore, maximum value of power delivered to the load,

$$\mathbf{P_m} = I_m^2 \times R_L = (0.217)^2 \times 300 = \mathbf{14.1W}$$

(d) The average value of load current, $I_{dc} = \frac{V_{dc}}{R_L} = \frac{20.7}{300}$ **= 0.069A**

Therefore, average value of power delivered to the load,

$$\mathbf{P_{dc}} = I_{dc}^2 \times R_L = (0.069)^2 \times 300 = \mathbf{1.43W}$$

FULL – WAVE RECTIFIER

A full-wave rectifier converts an ac voltage into a pulsating dc voltage using both half cycles of the applied ac voltage. In order to rectify both the half cycles of ac input, two diodes are used in this circuit. The diodes feed a common load R_L with the help of a center-tap transformer.

A center-tap transformer is the one which produces two sinusoidal waveforms of same magnitude and frequency but out of phase with respect to the ground in the secondary winding of the transformer. The full wave rectifier is shown in the figure below.

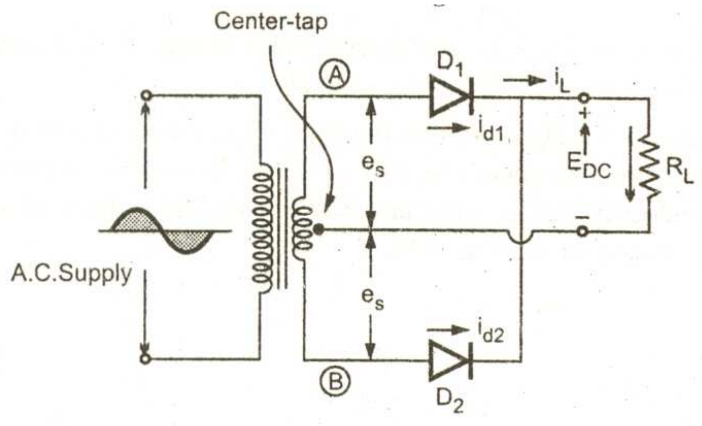


Fig. Full-Wave Rectifier.

The individual diode currents and the load current waveforms are shown in figure below:

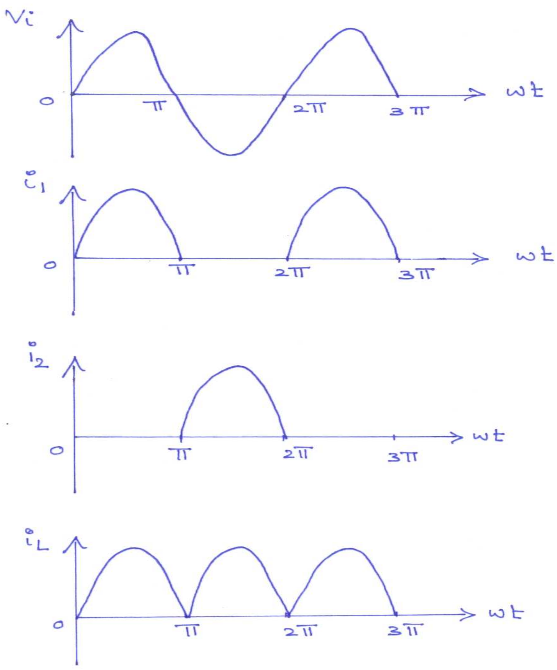


Fig. The input voltage, the individual diode currents and the load current waveforms.

Operation:

During positive half of the input signal, anode of diode D_1 becomes positive and at the same time the anode of diode D_2 becomes negative. Hence D_1 conducts and D_2 does not conduct. The load current flows through D_1 and the voltage drop across R_L will be equal to the input voltage.

During the negative half cycle of the input, the anode of D_1 becomes negative and the anode of D_2 becomes positive. Hence, D_1 does not conduct and D_2 conducts. The load current flows through D_2 and the voltage drop across R_L will be equal to the input voltage.

It is noted that the load current flows in the both the half cycles of ac voltage and in the same direction through the load resistance.

Analysis:

Let a sinusoidal voltage V_i be applied to the input of a rectifier. It is given by $V_i = V_m \sin\omega t$
The current i_1 though D_1 and load resistor R_L is given by

$$i_1 = I_m \sin\omega t \qquad \text{for} \qquad 0 \le \omega t \le \pi$$

$$i_1 = 0 \qquad \text{for} \qquad \pi \le \omega t \le 2\pi \qquad \text{Where } I_m = \frac{V_m}{R_f + R_L}$$

Similarly, the current i_2 through diode D_2 and load resistor R_L is given by

$$i_2 = 0 \qquad \text{for} \qquad 0 \le \omega t \le \pi$$

$$i_2 = I_m \sin\omega t \qquad \text{for} \qquad \pi \le \omega t \le 2\pi$$

Therefore, the total current flowing through R_L is the sum of the two currents i_1 and i_2.

i.e., $i_L = i_1 + i_2$.

i) Average (or) DC Output Current (I_{av} or I_{dc}):

The average dc current I_{dc} is given by

$$I_{dc} = \frac{1}{2\pi}\int_0^{2\pi} i_1 d(\omega t)\ \frac{1}{2\pi}\int_0^{2\pi} i_2 d(\omega t)$$

$$= \frac{1}{2\pi}\left[\int_0^{\pi} \mathrm{I_m} \sin\omega t d(\omega t) + 0 + 0 + \int_{\pi}^{2\pi} \mathrm{I_m} \sin\omega t d(\omega t)\right]$$

$$= \frac{\mathrm{I_m}}{\pi} + \frac{\mathrm{I_m}}{\pi}$$

$$= \frac{2\mathrm{I_m}}{\pi} = 0.318\ \mathrm{I_m}$$

$$\therefore I_{dc} = \frac{2\mathrm{I_m}}{\pi}$$

Substituting the value of $\mathrm{I_m}$, we get $\mathrm{I}_{dc} = \frac{2}{\pi}\frac{V_m}{\left(R_f + R_L\right)}$

This is double that of a Half-Wave Rectifier.

ii) Average (or) DC Output Voltage (V_{av} or V_{dc}):

The dc output voltage is given by

$$V_{dc} = I_{dc} \times R_L = \frac{2\mathrm{I_m} R_L}{\pi}$$

$$\Rightarrow V_{dc} = \frac{2}{\pi}\frac{V_m R_L}{R_f + R_L}$$

If $R_L >> R_f$ then $V_{dc} = \frac{2V_m}{\pi}$

iii) R.M.S. Output Current (I_{rms}):

The value of the R.M.S. current is given by

$$I_{rms} = \left[\frac{1}{2\pi}\int_0^{2\pi} i_L^2 d(\omega t)\right]^{\frac{1}{2}}$$

$$= \left[\frac{1}{2\pi}\int_0^{\pi} i_1^2 d(\omega t) + \frac{1}{2\pi}\int_{\pi}^{2\pi} i_2^2 d(\omega t)\right]^{\frac{1}{2}}$$

$$= \left[\frac{1}{2\pi}\int_0^{\pi} I_m^2 \sin^2 \omega t.d(\omega t) + \frac{1}{2\pi}\int_{\pi}^{2\pi} I_m^2 \sin^2 \omega t.d(\omega t)\right]^{\frac{1}{2}}$$

$$=\left[\frac{I_m^2}{2\pi}\int_0^{\pi}\left(\frac{1-\cos 2\omega t}{2}\right)d(\omega t)+\frac{I_m^2}{2\pi}\int_{\pi}^{2\pi}\left(\frac{1-\cos 2\omega t}{2}\right)d(\omega t)\right]^{\frac{1}{2}}$$

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

$$=\left\{\frac{I_m^2}{4\pi}[(\pi-0)-(0)]+\frac{I_m^2}{4\pi}[(2\pi-0)-(\pi-0)]\right\}^{\frac{1}{2}}$$

$$=\left[\frac{I_m^2}{4\pi}\times\pi+\frac{I_m^2}{4\pi}\times\pi\right]^{\frac{1}{2}} \qquad =\left(2\times\frac{I_m^2}{4}\right)^{\frac{1}{2}}=\frac{I_m}{\sqrt{2}}$$

$$\therefore I_{rms}=\frac{I_m}{\sqrt{2}} \quad \textbf{(or)} \quad I_{rms}=\frac{V_m}{\sqrt{2}\left(R_f+R_L\right)}$$

iv) R.M.S. Output Voltage (V_{rms}):

R.M.S. voltage across the load is given by

$$V_{rms}=I_{rms}\times R_L = \frac{V_m}{\sqrt{2}\left(R_f+R_L\right)}\times R_L$$

$$\Rightarrow V_{rms}=\frac{V_m}{\sqrt{2}\left(1+\frac{R_f}{R_L}\right)}$$

If $R_L >> R_f$ then $V_{rms}=\frac{V_m}{\sqrt{2}}$

v) Rectifier efficiency (η) :

The rectifier efficiency is defined as the ration of d.c. output power to the a.c. input power i.e., $\therefore \eta=\frac{P_{dc}}{P_{ac}}$

$$P_{dc} = I_{dc}^2 R_L = \frac{4I_m^2 R_L}{\pi^2}$$

$$P_{ac} = I_{rms}^2 \left(R_L + R_f \right) = \frac{I_m^2}{2} \left(R_L + R_f \right)$$

$$\therefore \eta = \frac{P_{dc}}{P_{ac}} = \frac{4I_m^2 R_L}{\pi^2} \times \frac{2}{I_m^2 \left(R_L + R_f \right)}$$

$$= \frac{8}{\pi^2} \left(\frac{R_L}{R_L + R_f} \right) \qquad = \frac{8}{\pi^2 \left(1 + \frac{R_f}{R_L} \right)} \qquad = \frac{0.812}{1 + \frac{R_f}{R_L}}$$

$$\Rightarrow \quad \% \eta = \frac{81.2}{1 + \frac{R_f}{R_L}}$$

Theoretically the maximum value of rectifier efficiency of a full-wave rectifier is 81.2% when $\frac{R_f}{R_L}$ = 0. Thus full-wave rectifier has efficiency twice that of half-wave rectifier.

vi) **Ripple Factor** (γ) **:**

The ripple factor, γ is given by

$$\therefore \gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}} \right)^2 - 1} \quad \textbf{(or)} \quad \therefore \gamma = \sqrt{\left(\frac{V_{rms}}{V_{dc}} \right)^2 - 1}$$

$$\therefore \gamma = \sqrt{\left(\frac{I_m}{\sqrt{2}} \times \frac{\pi}{2 I_m} \right)^2 - 1} = \sqrt{\left(\frac{\pi}{2\sqrt{2}} \right)^2 - 1} = \mathbf{0.48}$$

$$\Rightarrow \gamma = 0.48$$

vii) **<u>Regulation:</u>**

The variation of V_{dc} with I_{dc} for a full-wave rectifier is obtained as follows:

$$V_{dc} = I_{dc} \times R_L$$

$$= \frac{2I_m}{\pi} R_L \qquad \left(\because I_{dc} = \frac{2I_m}{\pi} \right)$$

$$= \frac{2V_m R_L}{\pi\left(R_L + R_f\right)}$$

$$= \frac{2V_m}{\pi}\left[1 - \frac{R_f}{R_f + R_L}\right] \qquad = \frac{2V_m}{\pi} - I_{dc}R_f$$

$$\therefore V_{dc} = \frac{2V_m}{\pi} - I_{dc}R_f$$

The percentage regulation of the Full-wave rectifier is given by

$$\% \text{ Regulation} = \frac{V_{no-load} - V_{full-load}}{V_{full-load}} \times 100$$

$$= \frac{\frac{2V_m}{\pi} - \left(\frac{2V_m}{\pi} - I_{dc}R_f\right)}{\frac{2V_m}{\pi} - I_{dc}R_f} \times 100 \qquad = \frac{I_{dc}R_f}{I_{dc}R_L} \times 100$$

$$\Rightarrow \% \text{ Regulation} = \frac{R_f}{R_L} \times 100$$

viii) Transformer Utilization Factor (UTF):

The average TUF in full-wave rectifying circuit is determined by considering the primary and secondary winding separately. There are two secondaries here. Each secondary is associated with one diode. This is just similar to secondary of half-wave rectifier. Each secondary has TUF as 0.287.

TUF of primary = P_{dc} / Volt-Amp rating of primary

$$\therefore (TUF)_P = \frac{I_{dc}^2 . R_L}{\frac{I_m}{\sqrt{2}} . \frac{V_m}{\sqrt{2}}} = \frac{\left(2\frac{I_m}{\pi}\right)^2 . R_L}{\frac{V_m I_m}{2}}$$

$$= \frac{4I_m^2}{\pi^2} . \frac{2R_L}{I_m^2\left(R_f + R_L\right)} \qquad = \frac{8}{\pi^2}\left(\frac{1}{1 + \frac{R_f}{R_L}}\right)$$

If $R_L >> R_f$ then $(TUF)p = \frac{8}{\pi^2} = 0.812$.

$$\therefore (TUF)_{av} = P_{dc} / \text{V-A rating of transformer}$$

$$= \frac{(TUF)p + (TUF)s + (TUF)s}{3}$$

$$= \frac{0.812 + 0.287 + 0.287}{3} = 0.693$$

$$\therefore (TUF) = \mathbf{0.693}$$

ix) Peak Inverse Voltage (PIV):

Peak Inverse Voltage is the maximum possible voltage across a diode when it is reverse biased. Consider that diode D_1 is in the forward biased i.e., conducting and diode D_2 is reverse biased i.e., non-conducting. In this case a voltage V_m is developed across the load resistor R_L. Now the voltage across diode D_2 is the sum of the voltages across load resistor R_L and voltage across the lower half of transformer secondary V_m. Hence PIV of diode $D_2 = V_m + V_m = 2V_m$.

Similarly PIV of diode D_1 is $2V_m$.

x) Form factor (F):

The Form Factor F is defined as F = rms value / average value

$$F = \frac{Im/\sqrt{2}}{2\,Im/\pi} = \frac{0.707\,I_m}{0.63\,I_m} = 1.12 \qquad \mathbf{F=1.12}$$

xi) Peak Factor (P):

The peak factor P is defined as

$$P = \text{Peak Value / rms value} = \frac{I_m}{I_m/\sqrt{2}} = \sqrt{2} = 1.414 \qquad \mathbf{P = 1.414}$$

Problems from previous External Question Paper:

4) A Full-Wave rectifier circuit is fed from a transformer having a center-tapped secondary winding. The rms voltage from wither end of secondary to center tap is 30V. if the diode forward resistance is 5Ω and that of the secondary is 10Ω for a load of 900Ω, Calculate:

i) Power delivered to load,
ii) % regulation at full-load,
iii) Efficiency at full-load and
iv) TUF of secondary.

Solution: Given V_{rms} = 30V, R_f =5Ω, Rs=10Ω, R_L=900Ω

$$\text{But} \quad V_{rms} = \frac{V_m}{\sqrt{2}} \quad \Rightarrow V_m = 30 \times \sqrt{2} = 42.426 \text{ V.}$$

$$I_m = \frac{V_m}{R_f + R_S + R_L} = \frac{30\sqrt{2}}{5 + 10 + 900} = 46.36 \text{ mA.}$$

$$I_{dc} = \frac{2\,I_m}{\pi} = \frac{2 \times 46.36}{\pi} = 29.5\text{mA}$$

i) Power delivered to the load $= I_{dc}^2 R_L = \left(29.5 \times 10^{-3}\right)^2 \times 900$ = **0.783W**

ii) % Regulation at full-load = $\frac{V_{no-load} - V_{full-load}}{V_{full-load}} \times 100$

$$V_{no-load} = \frac{2V_m}{\pi} = \frac{2 \times 42.426}{\pi} = \mathbf{27.02\ V.}$$

$$V_{full-load} = I_{dc} R_L = 29.5 \times 10^{-3} \times 900 = 26.5\ V$$

% Regulation = $\frac{27.02 - 26.5}{26.5} \times 100$ = **1.96 %**

iii) Efficiency of Rectification = $\frac{81.2}{1 + \frac{R_f + R_S}{R_L}}$ = $\frac{81.2}{1 + \frac{15}{900}}$ = **79.8%**

iv) TUF of secondary = DC power output / secondary ac rating

Transformer secondary rating = $V_{rms} I_{rms}$ = $30 \times \frac{46.36}{\sqrt{2}} \times 10^{-3}$ W

$$P_{dc} = I_{dc}^2 R_L$$

$$\therefore TUF = \frac{0.783}{30 \times \frac{46.36}{\sqrt{2}} \times 10^{-3}} = \mathbf{0.796}$$

5) A Full-wave rectifier circuit uses two silicon diodes with a forward resistance of 20Ω each. A dc voltmeter connected across the load of 1kΩ reads 55.4volts. Calculate

i) I_{RMS},
ii) Average voltage across each diode,
iii) Ripple factor, and
iv) Transformer secondary voltage rating.

Solution:

Given R_f =20Ω, R_L=1kΩ, V_{dc} = 55.4V

For a FWR $V_{dc} = \frac{2V_m}{\pi}$ $\therefore V_m = \frac{55.4 \times \pi}{2}$ = **86.9 V**

$$I_m = \frac{V_m}{R_f + R_L}$$ **=0.08519A**

i) $I_{rms} = \frac{I_m}{\sqrt{2}}$ = 0.06024A

ii) V= 86.9/2 = 43.45V

iii) Ripple factor

$$\gamma=\sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2-1}$$, $I_{dc}=\frac{2I_m}{\pi}$ **=0.05423A** $I_{rms}=\frac{I_m}{\sqrt{2}}$ **=0.06024A**

$$\therefore \gamma=0.48$$

iv) Transformer secondary voltage rating: $V_{rms}=\frac{V_m}{\sqrt{2}}=\frac{86.9}{\sqrt{2}}$ **= 61.49 Volts.**

6) A 230V, 60Hz voltage is applied to the primary of a 5:1 step down, center tapped transformer used in the Full-wave rectifier having a load of 900Ω. If the diode resistance and the secondary coil resistance together has a resistance of 100Ω. Determine:

i) dc voltage across the load,
ii) dc current flowing through the load,
iii) dc power delivered to the load, and
iv) ripple voltage and its frequency.

Solution: Given $V_{p(rms)}$ = 230V

$$\frac{N_2}{N_1}=\frac{2V_{S(rms)}}{V_{P(rms)}} \qquad \Rightarrow \frac{1}{5}=\frac{2V_{S(rms)}}{230}$$

$\Rightarrow V_{S(rms)}$ = 23V

Given R_L =900Ω, R_f + Rs =100Ω

$$I_m=\frac{V_{sm}}{R_f+R_S+R_L}=\frac{\sqrt{2}V_{s(rms)}}{R_f+R_S+R_L}=\frac{\sqrt{2}\times 23}{900+100}$$ = **0.03252 Amp.**

$$\therefore I_{dc}=\frac{2I_m}{\pi}=\frac{2\times 0.03252}{\pi}$$ = **0.0207 Amp.**

i) V_{DC} = I_{DC} R_L = 0.0207 X 100 = **18.6365 Volts.**

ii) I_{DC} = **0.0207 Amp.**

iii) P_{dc} = $I_{dc}^2 R_L$ (or) V_{DC} I_{DC} = **0.3857 Watts.**

iv) PIV = $2V_{sm}$ = 2 X $\sqrt{2}$ X 23 = **65.0538 Volts**

v) Ripple factor = 0.482 = $\frac{V_{r(rms)}}{V_{DC}}$

Therefore, ripple voltage = $V_{r(rms)}$ = 0.482 x 18.6365
= 8.9827 Volts.

Frequency of ripple = 2f = 2x60 = **120 Hz**

Bridge Rectifier

The full-wave rectifier circuit requires a center tapped transformer where only one half of the total ac voltage of the transformer secondary winding is utilized to convert into dc output. The need of the center tapped transformer in a Full-wave rectifier is eliminated in the bridge rectifier.

The bridge rectifier circuit has four diodes connected to form a bridge. The ac input voltage us applied to diagonally opposite ends of the bridge. The load resistance is connected between the other two ends of the bridge. The bridge rectifier circuits and its waveforms are shown in figure.

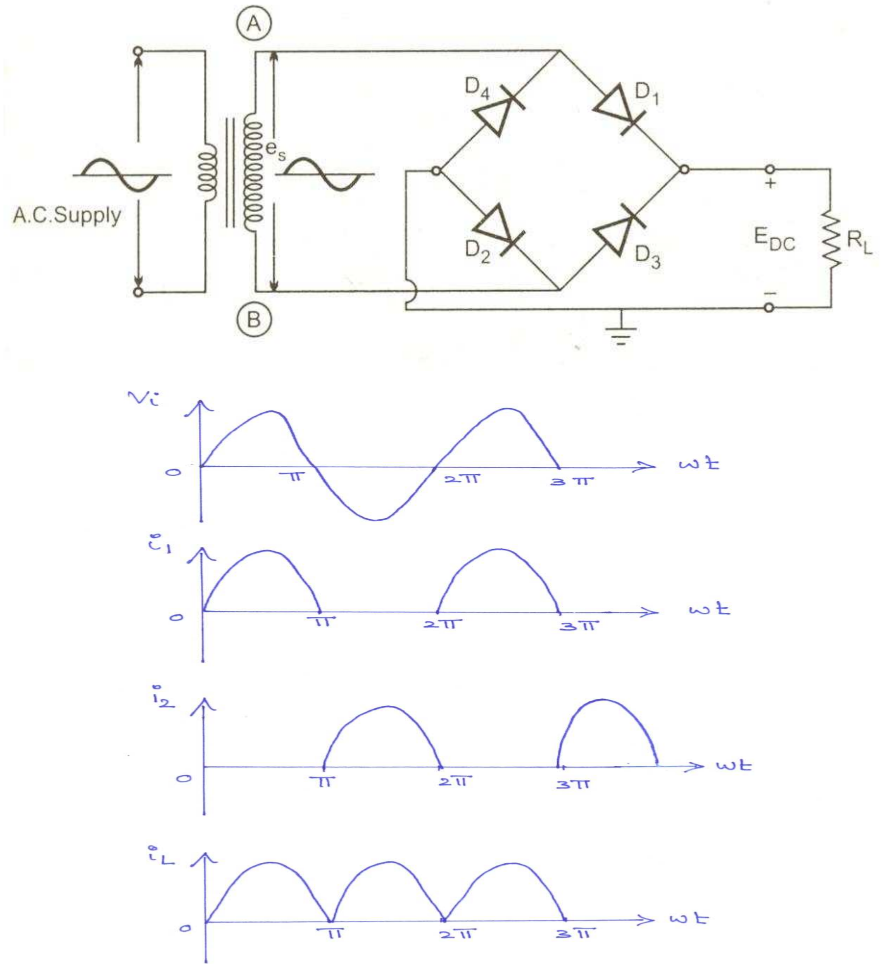


Fig. and waveforms

Operation:

For the positive half cycle of the input ac voltage diodes D_1 and D_3 conduct, whereas diodes D_2 and D_4 do not conduct. The conducting diodes will be in series through the load resistance R_L, so the load current flows through the R_L.

During the negative half cycle of the input ac voltage diodes D_2 and D_4 conduct, whereas diodes D_1 and D_3 do not conduct.

The conducting diodes D_2 and D_4 will be in series through the load resistance R_L and the current flows through the R_L, in the same direction as in the previous half cycle. Thus a bidirectional wave is converted into a unidirectional wave.

Analysis:

The average values of output voltage and load current, the rms values of voltage and current, the ripple factor and rectifier efficiency are the same as for as center tapped full-wave rectifier.

Hence,

$$V_{dc} = \frac{2V_m}{\pi}$$

$$I_{dc} = \frac{2I_m}{\pi} \qquad I_m = \frac{V_m}{R_f + R_L}$$

$$V_{rms} = \frac{V_m}{\sqrt{2}} \qquad I_{rms} = \frac{I_m}{\sqrt{2}}$$

Since the each half cycle two diodes conduct simultaneously

$$\gamma = 0.48$$

$$\eta = \frac{81.2}{1 + \frac{2R_f}{R_L}}$$

The transformer utilization factor (TUF) of primary and secondary will be the same as there is always through primary and secondary.

TUF of secondary = P_{dc} / V-A rating of secondary

$$= \frac{I_{dc}^2}{V_{rms} I_{rms}} = \frac{\left(\frac{2I_m}{\pi}\right)^2 R_L}{\left(\frac{V_m}{\sqrt{2}}\right)\left(\frac{I_m}{\sqrt{2}}\right)} = \mathbf{0.812}$$

TUF in case of secondary of primary of FWR is 0.812

$$\therefore (TUF)_{av} = \frac{(TUF)p + (TUF)s}{2}$$

$$= \frac{0.812 + 0.812}{2} = \mathbf{0.812}$$

$\therefore TUF$ **= 0.812**

The reverse voltage appearing across the reverse biased diodes is $2V_m$, but two diodes are sharing it, therefore the PIV rating of the diodes is V_m.

Advantages of Bridge rectifier circuit:

1) No center-tapped transformer is required.
2) The TUF is considerably high.
3) PIV is reduced across the diode.

Disadvantages of Bridge rectifier circuit:

The only disadvantage of bridge rectifier is the use of four diodes as compared to two diodes for center-tapped FWR. This reduces the output voltage.

Problems:

7. A bridge rectifier uses four identical diodes having forward resistance of 5Ω and the secondary voltage of $30V_{(rms)}$. Determine the dc output voltage for I_{DC}=200mA and the value of the ripple voltage.

Solution: $V_{s(rms)}$=30V, R_S=5Ω, R_f=5Ω, I_{DC}=200mA

Now $I_{DC} = 2\frac{I_m}{\pi}$

$$\therefore I_m = \frac{200\times10^{-3}\times\pi}{2}$$ **=** 0.3415 Amp.

But $$I_m = \frac{V_{sm}}{R_S + 2R_f + R_L} = \frac{\sqrt{2}V_{s(rms)}}{R_S + 2R_f + R_L}$$

$$\Rightarrow 0.3415 = \frac{\sqrt{2}\times30}{5+(2\times5)+R_L}$$

$\Rightarrow R_L$ = 120.051Ω ≈ 120Ω

$V_{DC} = I_{DC} R_L$ = 200 x10^{-3} x120 = 24Volts

Ripple factor = $\frac{V_{r(rms)}}{V_{dc}}$

For Bridge rectifier, ripple factor = 0.482

$\therefore V_{r(rms)}$ = rms value of ripple voltage

= Vdcx0.482

= 24x0.482

=11.568 Volts

8. In a bridge rectifier the transformer is connected to 220V, 60Hz mains and the turns ratio of the step down transformer is 11:1. Assuming the diode to be ideal, find:

i) I_{dc}

ii) voltage across the load

iii) PIV assume load resistance to be 1kΩ

Solution: $\frac{N_2}{N_1} = \frac{1}{11}$, $V_{p(rms)}$ = 220V, f=60Hz, R_L= 1kΩ

$$\frac{N_2}{N_1} = \frac{V_{S(rms)}}{V_{P(rms)}} \Rightarrow \frac{1}{11} = \frac{V_{S(rms)}}{220} \Rightarrow V_{S(rms)} = \frac{220}{11} = 20\text{V}$$

$$V_{sm} = \sqrt{2}Vs(rms)$$

i) $$I_m = \frac{V_{sm}}{R_L} = \frac{28.2842}{1\times10^{-3}}$$ = 28.2842 mA

$$\therefore I_{dc} = \frac{2I_m}{\pi}$$ **= 18 mA**

ii) $V_{dc} = I_{dc} R_L$ = 18x10^{-3}Xx10^{-3} = **18 Volts**

iv) PIV = V_{sm} = **28.2842 Volts**

Comparison of Rectifier circuits:

Sl. No.	Parameter	Half-Wave Rectifier	Full-Wave Rectifier	Bridge Rectifier
1.	Number of diodes	1	2	4
2.	Average dc current, I_{dc}	$\frac{I_m}{\pi}$	$\frac{2I_m}{\pi}$	$\frac{2I_m}{\pi}$
3.	Average dc voltage, V_{dc}	$\frac{V_{sm}}{\pi}$	$\frac{2V_{sm}}{\pi}$	$\frac{2V_{sm}}{\pi}$
4.	RMS current, I_{rms}	$\frac{I_m}{2}$	$\frac{I_m}{\sqrt{2}}$	$\frac{I_m}{\sqrt{2}}$
5.	DC Power output, P_{dc}	$\frac{I_m^2 R_L}{\pi^2}$	$\frac{4I_m^2 R_L}{\pi^2}$	$\frac{4I_m^2 R_L}{\pi^2}$
6.	AC Power input, P_{AC}	$\frac{I_m^2\left(R_L+R_f+R_S\right)}{4}$	$\frac{I_m^2\left(R_f+R_S++R_L\right)}{2}$	$\frac{I_m^2\left(2R_f+R_S++R_L\right)}{2}$
7.	Max. rectifier efficiency (η)	40.6%	81.2%	81.2%
8.	Ripple factor (γ)	1.21	0.482	0.482
9.	PIV	V_m	$2V_m$	$2V_m$
10.	TUF	0.287	0.693	0.812
11.	Max. load current (I_m)	$\frac{V_{sm}}{R_S+R_f+R_L}$	$\frac{V_{sm}}{R_S+R_f+R_L}$	$\frac{V_{sm}}{R_S+2R_f+R_L}$

The Harmonic components in Rectifier circuits:

An analytical representation of the output current wave in a rectifier is obtained by means of a Fourier series. The result of such an analysis for the half-wave rectifier circuit leads to the following expression for the current waveform.

$$i=\mathrm{I_m}\left[\frac{1}{\pi}+\frac{1}{2}\sin\omega t-\frac{2}{\pi}\sum_{K=2,4,6.....}\frac{\cos\omega t}{(K+1)(K-1)}\right]$$

The lowest angular frequency present in this expression is that of the primary source of the a.c. power. Except for this single term of angular frequency (ω), all other terms in the above expression are even harmonics of the power frequency.

We know that the full-wave circuit consists essentially of two half-wave circuits which are so arranged that one circuit conducts during one half cycle and the second operates during the second half cycle. That is, the currents are functionally related by the expression $i_1(\alpha)=i_2(\alpha+\pi)$.

Therefore the total load current is $i=i_1+i_2$.

The expression for the output current waveform of the full wave rectifier circuit is of the form

$$i = I_m\left[\frac{2}{\pi} - \frac{4}{\pi}\sum_{K=2,4,6.....}\frac{\cos K\omega t}{(K+1)(K-1)}\right]$$

In the above equation, we observe that the fundamental angular frequency (ω) has been eliminated from the equation. The lowest frequency in the output is being 2ω, which is a second harmonic term. This offers a definite advantage in the effectiveness of filtering of the output.

Filter Circuits

Introduction

A power supply must provide ripple free source of power from an A.C. line. But the output of a rectifier circuit contains ripple components in addition to a D.C. term. It is necessary to include a filter between the rectifier and the loads in order to eliminate these ripple components. Ripple components are high frequency A.C. Signals in the D.C output of the rectifier. These are not desirable, so they must be filtered. So filter circuits are used.

Many types of passive filters are in use such as.

- Shunt capacitor filter
- Series inductor filter
- Chock input (LC) filter
- Pi(π) section filter or CLC filter or capacitor input filter .

Shunt capacitor filter

This type of filter consists of large value of capacitor connected across the load resistor R_L as shown in figure 5.1. This capacitor offers a low reactance to the a.c. components and very high impedance to d.c. so that the a.c. components in the rectifier output find low reactance path through capacitor and only a small part flows through R_L, producing small ripple at the output as shown in figure.

Here Xc (=1/2πfC, the impedance of capacitor) should be smaller than R_L. Because, current should pass through C and C should get charged. If C value is very small, Xc will be large and hence current flows through R_L only and no filtering action takes place.

The capacitor C gets charged when the diode (in the rectifier) is conducting and gets discharged (when the diode is not conducting) through RL. When the input voltage $v = Vm\, sin\, \omega t$ is greater than the capacitor voltage, C gets charged. When the input voltage is less than that of the capacitor voltage, C will discharge through R_L. The stored energy in the capacitor maintains the load voltage at a high value for a long period. The diode conducts only for a short interval of high current. The waveforms are as shown in figure 5.2. Capacitor opposes sudden fluctuations in voltage across it. So the ripple voltage is minimized.

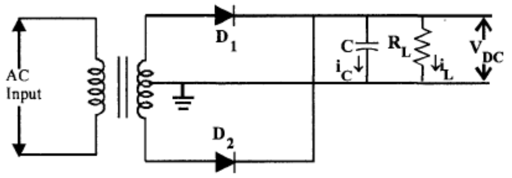


Fig 5.1 CT FWR with shunt Capacitor filter

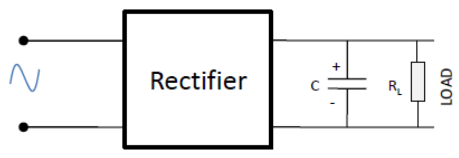


Fig 5.3 Rectifier with shunt Capacitor filter

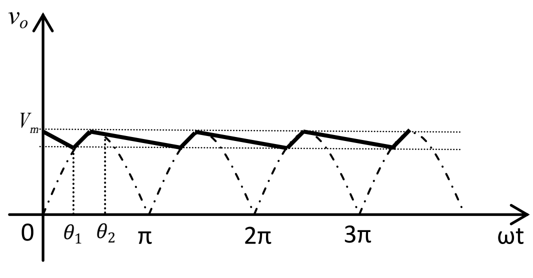


Fig 5.2 Filter output waveform

The discharging of the capacitor depends upon the time constant $C.R_L$. Hence the smoothness and the magnitude of output voltage depend upon the value of capacitor C and R_L. As the value of C increases the smoothness of the output also increases. But the maximum value of the capacitor is limited by the current rating of the diode. Also decrease in the value of R_L increases the load current and makes the time constant smaller. These types of filters are used in circuits with small load current like transistor radio receivers, calculators, etc. The ripple factor in capacitor filter is given b $\boldsymbol{\gamma = 1/4\sqrt{3}fCR_L}$y.

Advantages

- Low cost
- Small size and weight
- Good characteristics
- Can be connected for both HW and FW rectifiers
- Improved d.c. output

Disadvantages

- Capacitor draws more current

Series inductor filter

The working of series inductor filter depends on the inherent property of the inductor to oppose any variation in current intend to take place. Fig 5.4 shows a series inductor filter connected at the output of a FWR. Here the reactance of the inductor is more for ac components and it offers more opposition to them. At the same time it provides no impedance for d.c. component. Therefore the inductor blocks a.c. components in the output of the rectifier and allows only d.c. component to flow through R_L.

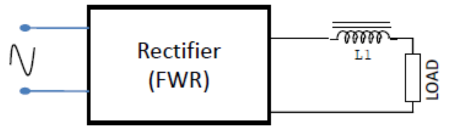


Fig 5.5 Rectifier with series inductor filter

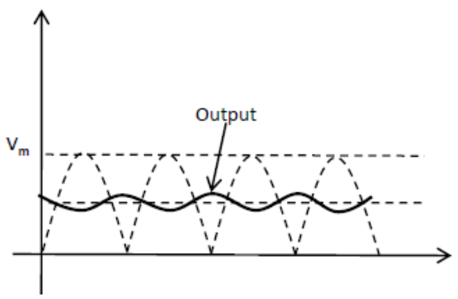


Fig 5.5 Filter output waveform

The action of an inductor depends upon the current through it and it requires current to flow at all time. Therefore filter circuits consisting inductors can only be used together with full wave rectifiers.

In inductor filter an increase in load current will improve the filtering action and results in reduced ripple. Series inductor filters are used in equipments of high load currents. The ripple factor in series inductor filter $\boldsymbol{\gamma = R_L/3\sqrt{2}\omega L}$

Advantages

- Sudden changes in current is smoothen out
- Improved filtering action at high load currents

Disadvantages

- Reduced output voltage due to the drop across the inductor.
- Bulky and large in size
- Note suite for HWR

LC filter

It is a combination of inductor and capacitor filter. Here an inductor is connected in series and a capacitor is connected in parallel to the load as shown in fig 5.6. As discussed earlier, a series inductor filter will reduce the ripple, when increasing the load current. But in case of a capacitor filter it is reverse that when increasing current the ripple also increases. So a combination of these two filters would make ripple independent of load current. The ripple factor of a chock input filter is given by $\boldsymbol{\gamma = 1.194/LC}$ **(by taking f=50Hz)**

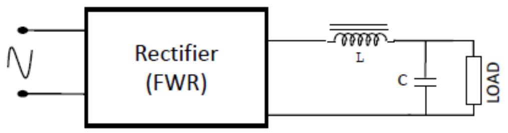


Fig 5.6 Rectifier with LC filter

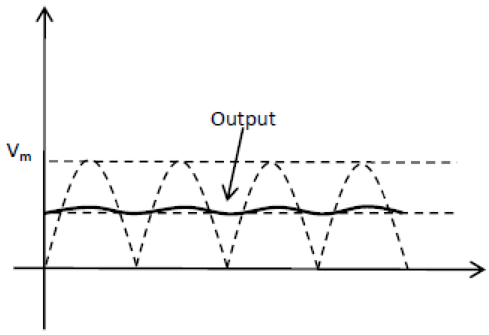


Fig 5.7 output waveform of Rectifier with LC filter

Since the d.c. resistance of the inductor is very low it allows d.c. current to flow easily through it. The capacitor appears open for d.c. and so all d.c. component passes through it. The capacitor appears open for d.c. and so all d.c components passes through the load resistor R_L.

5.4.1 Bleeder resistor

For optimum functioning, the inductor requires a minimum current to flow through, at all time. When the current falls below this rat, the output will increase sharply and hence the regulation become poor. To keep up the circuit current above this minimum value, a resistor is permanently connected across the filtering capacitor and is called **bleeder resistor**. This resistor always draws a minimum current even if the external load is removed. It also provides a path for the capacitor to discharge when power supply is turned off.

Advantages

- Reduced ripples at the output
- Action is independent of load current

Disadvantages

- Low output voltage
- Bulky and large in size
- Not suit to connect with HWR.

π – filter (Capacitor input filter) or CLC filter

This filter is basically a capacitor filter followed by an LC filter as shown in fig 5.8. Since its shape (C-L-C) is like the letter π it is called π – filter. It is also called capacitor input filter because the rectifier feeds directly into the capacitor C_1. Here the first capacitor C_1 offers a low reactance to a.c. component of rectifier output but provide more reactance to d.c components. Therefore most of the a.c. components will bypass through C_1 and the d.c. component flows through chock L. The chock offers very high reactance to the a.c. component. Thus it blocks a.c. components while pass the d.c. The capacitor C_2 bypasses any other a.c. component appears across the load and we get study d.c. output as shown below. The ripple factor in a π-section filter is given by $\gamma = \sqrt{2}\, X_{C1} X_{C2} / X_L R_L$

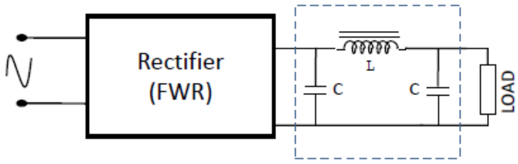


Fig 5.8 Rectifier with CLC filter

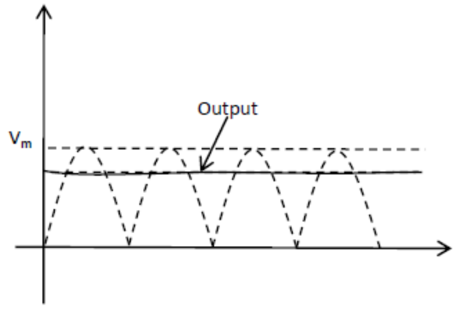


Fig 5.9 output waveform of Rectifier with CLC filter

Advantages

- More output voltage
- Ripple less output
- Suitable to be used with both HWR and FWR

Disadvantages

- Large in size and weight
- High cost

ZENER DIODE

The characteristics of a regular junction diode show that it is designed primarily for operation in the forward direction. Reverse biasing will generally not cause current conduction until higher values of reverse voltage are reached. If V_R is great enough, however, breakdown will occur and cause a reverse current flow. Junction diodes are usually damaged when operated in breakdown region.

Zener diodes are heavily doped p-n junction diodes, specially designed to operate in the reverse breakdown region without damage.

Mechanism of Zener Breakdown

Zener breakdown occurs at junctions which being heavily doped has narrow depletion layers. When operated in reverse bias and the, reverse voltage is increased beyond some value, breakdown occurs. The breakdown voltage sets a very strong electric field across a narrow depletion layer. This field is strong enough to rupture the covalent bonds thereby generating electron-hole pairs. This electron-hole pairs participate in conduction processes.

In this region even a small increase in reverse voltage is capable of producing large number of current carriers. That is why the junction has a very low resistance. This mechanism of chare carrier production is called Zener Breakdown.

Symbol

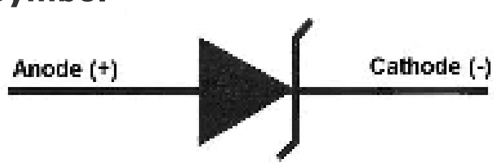


Figure A

Note: The symbol of zener diode id very similar to that of a regular diode but the cathode is, however, drawn with a bent line. This is supposedly done to represent the letter Z.

VI Characteristics of Zener Diode

Forward Characteristics

Figure B shows the volt-ampere characteristic of a typical Zener diode. In order to get the characteristics curve the zener must be operated in both forward and reverse operating mode.

In the forward bias direction this device behaves like an ordinary silicon diode. The positive terminal of the bias battery is connected to the P-type material and the negative terminal of the battery is connected to the N-type material.

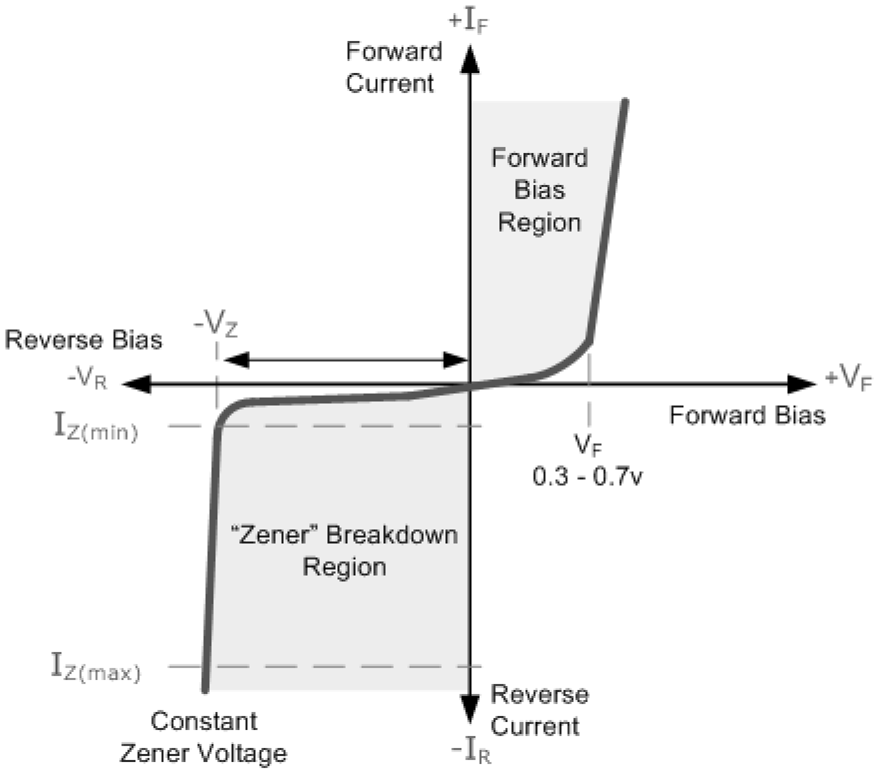


Figure B

When the forward voltage of the diode equals 0V, the I_F equals 0 mA. This value starts at the origin point (0) of the graph. If V_F is gradually increased in 0.1-V steps, I_F begins to increase. When the value of V_F is great enough to overcome the barrier potential of the zener diode, a substantial increase in I_F occurs. The point at which this occurs is often called the knee voltage V_K *(Cut-in voltage or threshold voltage).*

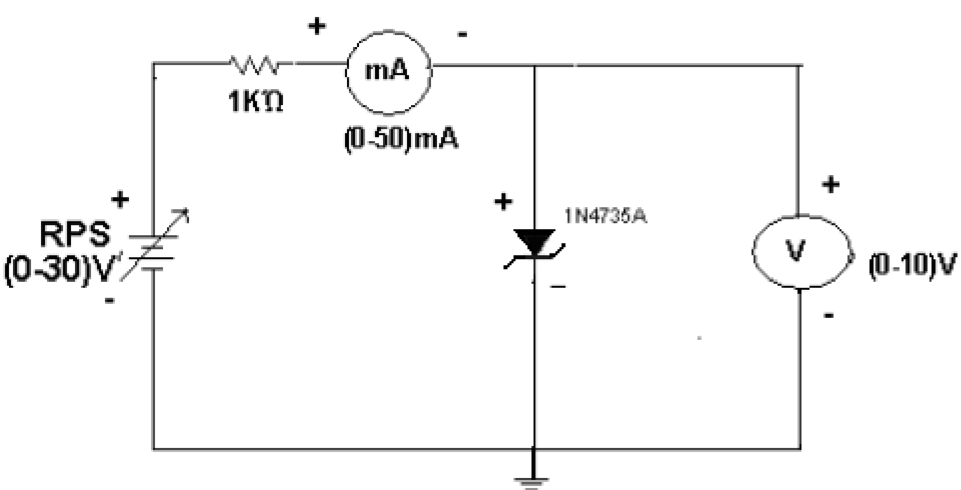


Figure C

Reverse Characteristics

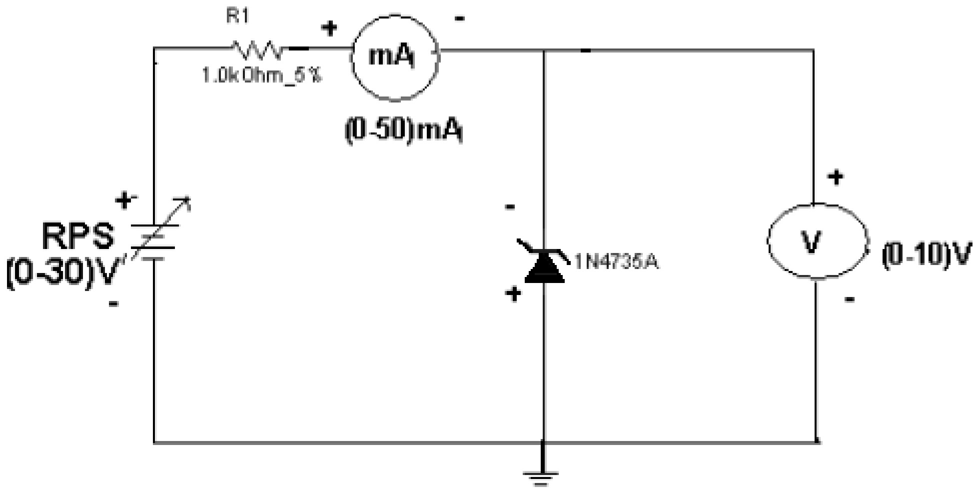


Figure D

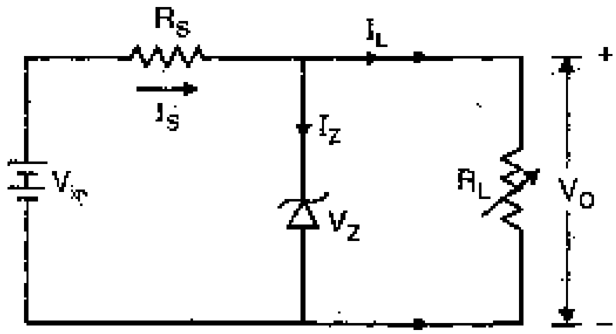
In the reverse bias direction, there is practically no reverse current flow until the breakdown voltage is reached. When this occurs there is a sharp increase in reverse current. Varying amounts of reverse current can pass through the diode without damaging it. The breakdown voltage or zener voltage (V_Z) across the diode remains relatively constant. The maximum reverse current is limited, however, by the wattage rating of the diode and a series resistor. Manufacturers rate zener diodes according to their V_Z value and the maximum power dissipation (*PD*) at 25°C.

Because of the constant V_Z characteristic of a zener diode, it is used primarily to regulate voltages. A large change in I_R will cause only a small change in V_Z. This means that a zener diode can be used as an alternate current path. The constant V_Z developed across the diode can then be applied to a load device. The load voltage thus remains at a constant value by altering the current flow through the zener diode.

Applications of Zener Diode ---Zener diode as Voltage Regulator

Shunt voltage regulator

One of the simple Linear Power Supply is the Zener Shunt regulator. This type of regulator is typically used for very low voltage regulation for less than 200mW of a load. A series resistance(R) is placed between a higher voltage (V_{in}) and it is used to limit the current to the load and zener diode. The zener diode compensates for the variation in load current.



Operation:

The Zener requires a current limiting resistor in series to it to restrict the current flow through the Zener. Also for proper operation of this circuit the voltage across the input of the regulator circuit must be greater than the voltage across the output. The equation of the circuit is given below.

- $V_{in} = (I_z + I_L)R_s + V_o$ (or)
- $V_{in} = (I_z + I_L)R_s + V_z$

Case (i) Fixed R_L and Variable V_{in}

Since V_Z is constant, i $V_{in}\uparrow$ $I_S\uparrow$ R_sI_s drop $\uparrow$

The increase in current is observed by zener diode, there by keeping the V_o constant.

Similarly when $V_{in}\downarrow$ $I_S\downarrow$ R_sI_s drop $\downarrow$

Current through the zener decreases to compensate for decrease in I_s.

Case (ii) Fixed V_{in} and variable R_L

When $R_L\uparrow$ $I_L\downarrow$ $I_Z\uparrow$ since V_{in} is fixed the excess current is observed by the zener.

If $R_L\downarrow$ $I_L\uparrow$ $I_Z\downarrow$ current in the zener branch decrease, there by compensating for increase in I_L.

The variation in the current is all observed by the zener diode.

Note:

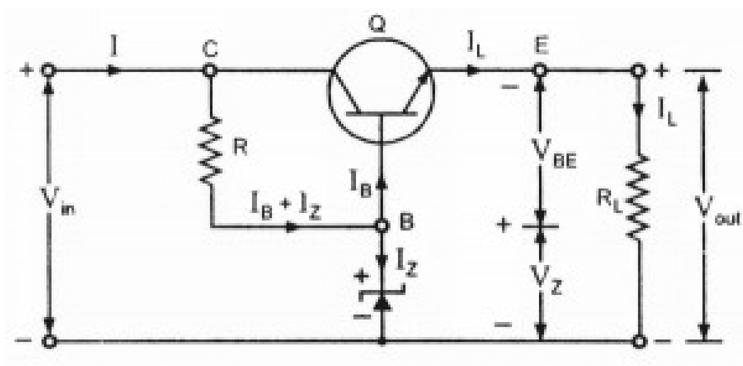
- With the supply voltage below V_Z, the zener will not conduct. The output voltage will be equal to supply voltage minus voltage drop of the resistor R_s.
- If the supply voltage is turned up to exceed V_z, the Zener will start to conduct.

Advantages and Disadvantages

- Very simple to Design.
- The zener voltage V_Z will drift with temperature. It is the disadvantage of this linear power supply. The drift characteristics are given in many zener diode data sheets.
- Very inefficient.
- Power is dissipated in series resistor as well as in Zener.
- The output voltage cannot be chosen at will but is a function of the available diode breakdown voltages.
- Efficiency is less.

Transistor Series Voltage Regulator or Emitter Follower Voltage Regulator

A zener diode voltage regulator is inefficient when the supply is used with equipment that draws high current. When a supply must deliver a lot of current, a power transistor is used along with the Ziner diode as shown below.



Transistor Series Voltage Regulator

This circuit is called a series regulator because collector and emitter terminals of the transistor are in series with the load, as illustrated in the figure. This circuit is also called an emitter follower voltage regulator because transistor Q is connected in emitter follower configuration. Here, the transistor Q is termed a series-pass transistor. The unregulated dc supply (or filtered output from the rectifier) is fed to the input terminals and regulated output voltage V_{out} is obtained across the load resistor R_L. Zener diode provides the reference voltage and the transistor acts as a variable resistor, whose resistance varies with the operating conditions (base current I_B). The principle of operation of such a regulator is based on the fact that a large proportion of the change in supply (or input) voltage appears across the transistor and, therefore output voltage tends to remain constant.

Keeping in mind the polarities of different voltages we have

$$\mathbf{V_{out} = V_z - V_{BE}}$$

The base voltage of the transistor remains almost constant being equal to that across the Zener diode, V_z.

Operation

(i) Let the supply (or input) voltage increase which will cause the output voltage V_{out} to increase. An increase in output voltage V_{out} will result in decrease of V_{BE} because V_z is fixed and decrease in V_{BE} will reduce the level of conduction. This will lead to increase in the collector-emitter resistance of the transistor causing an increase in collector to emitter voltage and as a result the output voltage will be reduced. Thus output voltage will remain constant. Similar explanation can be given for decrease in supply voltage.

(ii) Now let us consider the effect of change in load on the output voltage — say current is increased by decrease in R_L. Under such a situation the output voltage V_{out} tends to fall and, therefore, V_{BE} tends to increase. As a result the conduction level of the transistor will increase leading to decrease in the collector-emitter resistance. The decrease in the collector-emitter resistance of the transistor will cause the slight increase in input current to compensate for the decrease in R_L. Thus the output voltage being equal to $I_L R_L$ remains almost constant. Similar explanation will hold true for increase in R_L.

The advantage of such a circuit is that the changes in Zener current are reduced by a factor β and thus the effect of Zener effect is greatly reduced and much more stabilized output is obtained.

Output voltage from a series regulator, $\mathbf{V_{out} = (V_z - V_{BE})}$, and maximum load current $I_{L(max)}$ can be the maximum emitter current that the transistor Q is capable of passing. For a 2N 3055 transistor load current I_L could be 15 A. When load current I_L is zero, the current drawn from the supply is approximately (I_z + $I_{C(min)}$).

The Zener regulator (resistor R and Zener diode form a simple Zener regulator) has to supply only the base current of the transistor. The emitter follower voltage regulator is, therefore, much more efficient than a simple Zener regulator.

Limitations

- The output voltage cannot be maintained absolutely constant because both V_{BE} and V_z decrease with the increase in room temperature. Further, V_{BE} increases slightly with the increase in load.
- The output voltage cannot be changed as there is no provision for it in the circuit.
- It cannot provide good regulation at high currents because of small amplification provided by one transistor.
- It has poor regulation and ripple suppression with respect to input variations as compared to other regulators.
- The power dissipation of a pass transistor is large because it is equal to V_{cc} I_c and almost all variation appears at V_{CE} and the load current is approximately equal to collector current. Thus for heavy load currents pass transistor has to dissipate a lot of power and, therefore, becoming hot.

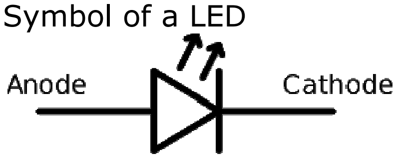
Because of above limitations application of this regulator is limited to low output voltages.

Light Emitting Diode (LED)

Introduction

A light emitting diode (LED) is known to be one of the best optoelectronic devices out of the lot. The device is capable of emitting a fairly narrow bandwidth of visible or invisible light when its internal diode junction attains a forward electric current or voltage. The visible lights that an LED emits are usually orange, red, yellow, or green. The invisible light includes the infrared light. The biggest advantage of this device is its high power to light conversion efficiency. That is, the efficiency is almost 50 times greater than a simple tungsten lamp. The response time of the LED is also known to be very fast in the range of 0.1 microseconds when compared with 100 milliseconds for a tungsten lamp. Due to these advantages, the device wide applications as visual indicators and as dancing light displays.

Symbol of a LED

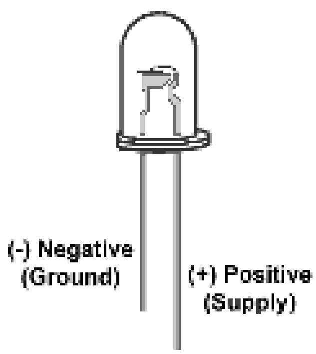


Construction

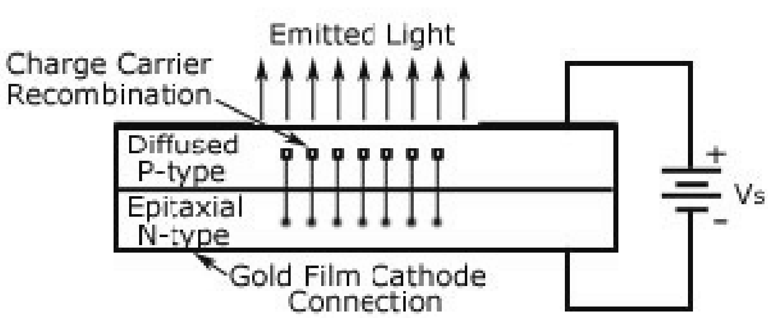
The constructional diagram of a LED is shown below. An N-type epitaxial layer is grown upon a substrate, and the P-region is produced by diffusion. The P-region that includes the recombination of charge carriers is shown is the top. Thus the P-region becomes the device surface. In order to allow more surface area for the light to be emitted the metal anode connections are made at the outer edges of the P-layer. For the light t0 be reflected as much as possible towards the surface of the device, a gold film s applied to the surface bottom. This setting also enables to provide a cathode connection. The reabsorption problem is fixed by including domed lenses for the device. All the wires in the electronic circuits of the device are protected by encasing the device. The light emitted by the device depends on the type of semiconductor material used. Infrared light is produced by using Gallium Arsenide (GaAs) as semiconductor. Red or yellow light is produced by using Gallium-Arsenide-Phosphorus (GaAsP) as semiconductor. Red or green light is produced by using Gallium-Phosphorus (GaP) as semiconductor.

Principle and working

In LEDs the P-N junction emits light when energy is applied on it. This phenomenon is generally called electroluminance, which can be defined as the emission of light from a semi-conductor under the influence of an electric field.



LED Construction



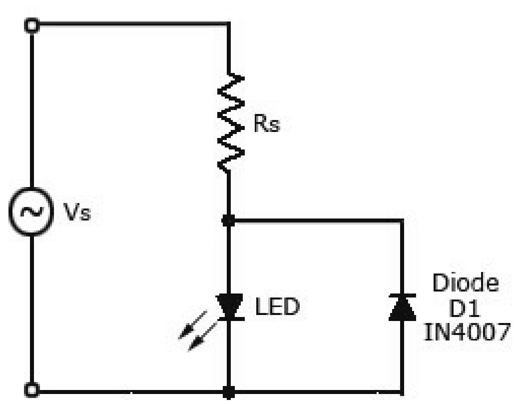
The electrons dissipate energy in the form of heat for silicon and germanium diodes. But in Galium- Arsenide-phosphorous (GaAsP) and Galium-phosphorous (GaP) semiconductors, the electrons dissipate energy by emitting photons. If the semiconductor is translucent, the junction becomes the source of light as it is emitted, thus becoming a light emitting diode (LED). But when the junction is reverse biased no light will be produced by the LED, and, on the contrary the device may also get damaged.

P type of semiconductor consists of large number of holes while N type of semiconductor consists of large number of electrons. At zero bias (no voltage across junction), depletion region exists and it separate out two regions. When LED is forward biased, barrier potential reduces and depletion region becomes narrow. Electron crosses the depletion region and recombines with holes. Similarly holes crosses depletion region and recombine with electrons. Each recombination of hole and electron produces photon (light). The intensity of light emitted depends on the number of minority carriers available for recombination. Wavelength (or frequency) of emitted light depends on band-gap energy. The light emitting diode works by the process of spontaneous emission.

Light source material must have direct band gap. In a direct band gap semiconductor material electron and hole recombine directly across band gap without need of third particle to conserve momentum.
Light source materials are made from compound of group-III (Al,Ga,In) and group-V (P,As,Sb) element. The wavelength generated by the LED depends on bandgap energy and band gap energy depends on doping level of above elements.

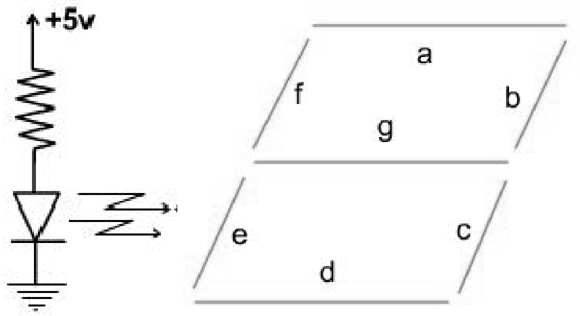
Application of LEDs
LED as indicator
The circuit shown below is one of the main applications of LED. The circuit is designed by wiring it in inverse parallel with a normal diode, to prevent the device from being reverse biased. The value of the series resistance should be half, relative to that o f a DC circuit.

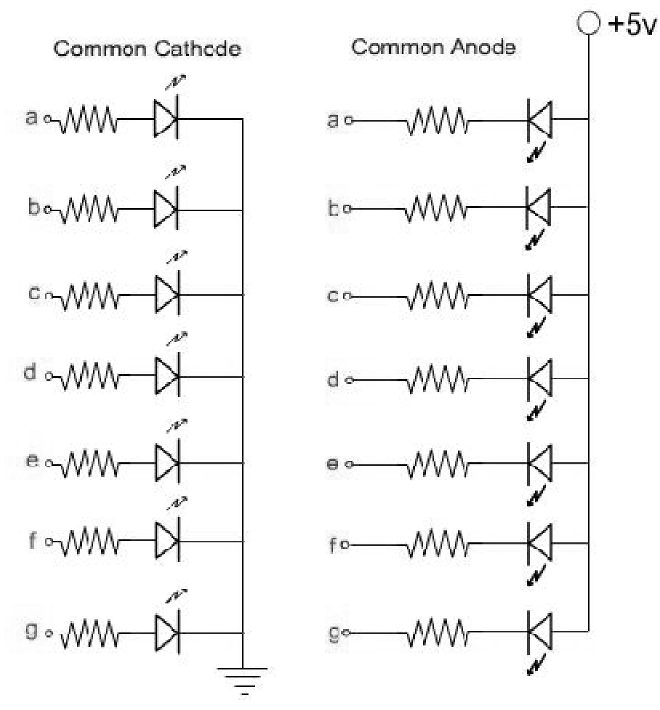
LED As An Indicator



Seven segment LED display

LEDS displays are made to display numbers from segments. One such design is the seven-segment display as shown below. Any desired numerals from 0-9 can be displayed by passing current through the correct segments. It contains seven rectangular LEDs. Each LED is called a Segment. External resistors are used to limit the currents to safe Values. It can display any letters a, b, c, d, e, f, g. The LEDs of seven-segment display are connected in either in common anode configuration or in common cathode configuration.





Advantages of LED's

- Very low voltage and current are enough to drive the LED.
- Voltage range – 1 to 2 volts.
- Current – 5 to 20 milli amperes.
- Total power output will be less than 150 milli watts.
- The response time is very less – only about 10 nanoseconds.

- The device does not need any heating and warm up time.
- Miniature in size and hence light weight.
- Have a rugged construction and hence can withstand shock and vibrations.
- An LED has a life span of more than 20 years.

Disadvantages

- A slight excess in voltage or current can damage the device.
- The device is known to have a much wider bandwidth compared to the laser.
- The temperature depends on the radiant output power and wavelength.

LCD (Liquid Crystal Display)

Introduction

The most common application of liquid crystal technology is in liquid crystal displays (LCDs). LCD display are used in wide range of applications ranging from small wrist watch and pocket calculator to an advanced VGA computer screen, this type of display has evolved into an important and versatile interface.

A liquid crystal display consists of an array of tiny segments (called pixels) that can be manipulated to present information. This basic idea is common to all displays, ranging from simple calculators to a full color LCD television. LCDs are light modifiers, not light producers. All the other devices are self-illuminating as they produce their own light. The LCD does not make its own light, but operates by modifying light from other sources. This distinction is very important and is responsible for the low power consumption of the LCD.

The external light modified by the LCD may be ambient light or a special light source installed within the device just to supply the LCD some light to modify.

Construction of LCD

Liquid crystals (LCs) are matter in a state that has properties between those of conventional liquid and those of solid crystal. It is a material (usually, an organic compound) which flows like a liquid at room temperature, but its molecules may be oriented in a crystal-like way. Examples of liquid crystals can be found both in the natural world and in technological applications. Most contemporary electronic displays use liquid crystals. Lyotropic liquid-crystalline phases are abundant in living systems. For example, many proteins and cell membranes are LCs.

Basic structure of an LCD

A liquid crystal cell consists of a thin layer (about 10μm) of a liquid crystal sandwiched between two glass sheets with transparent electrodes deposited on their inside faces. With both glass sheets transparent, the cell is known as *transmittive type cell.* When one glass is transparent and the other has a reflective coating, the cell is called *reflective type.*

Normally a thin layer of liquid crystal is transparent to incident light but when an electric field is applied across it, its molecular arrangement is disturbed causing changes in its optical properties.

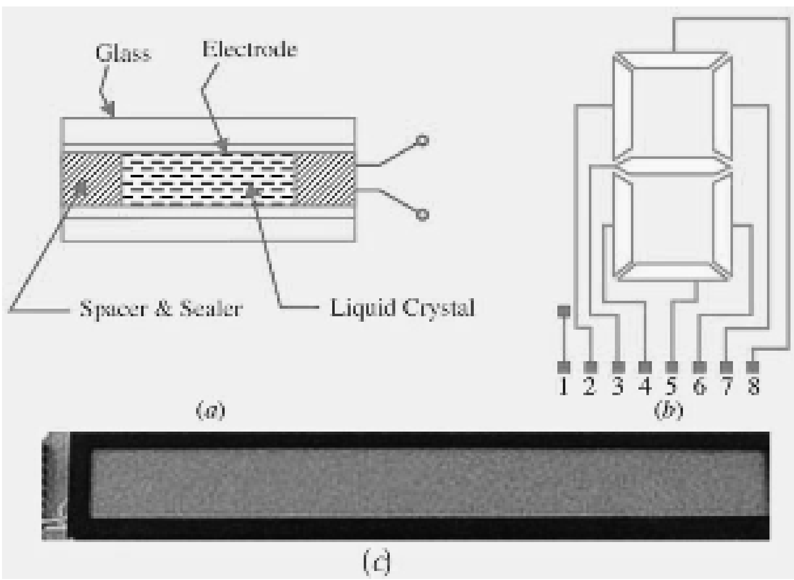
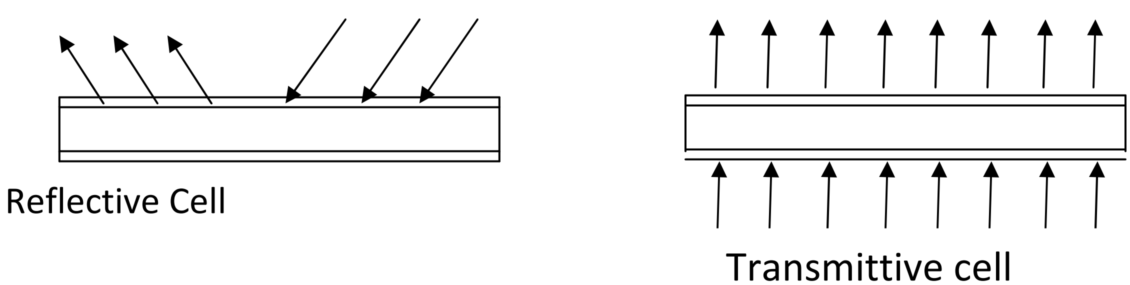


Figure (a) structure of LCD cell (b) Seven segment display and (c) an LCD Panel



Working

Based on the construction, LCDs are classified in to two types

(i) Dynamic scattering display

The display consists of two glass plates each coated with tin oxide (SnO_2) on the inside with transparent electrodes separated by a liquid crystal layer 5 to 50 micrometer thick. The oxide coating on the front sheet is etched to produce a single or multi segment pattern of characters with each segment properly insulated from each other. A weak electric field applied to a liquid crystal tends to align molecules in the direction of the field. The voltage exceeds a certain threshold value the domain structure collapses and the appearance is changed. As the voltage grows further the flow becomes turbulent and the substance turns optically in homogenous .liquid crystal scatters high. When the liquid is not activated, it is transparent. When the liquid is activated the molecular turbulence causes light to be scattered in all directions and the cell appears to be bright. This phenomenon is called Dynamic Scattering.

(ii) Field effect display.

Two thin polarising optical filters are placed at the inside of each glass sheet. The LCD material is of twisted nematic type which twists the light passing through the cell when the latter is not energized. This allows light to pass through the optical filters and the cell appears bright. When ***Field effect display*** is energized, the energized areas of LCD absorb the incident light and, hence give a localized black display.

Applications of LCD

LCD seven segment display

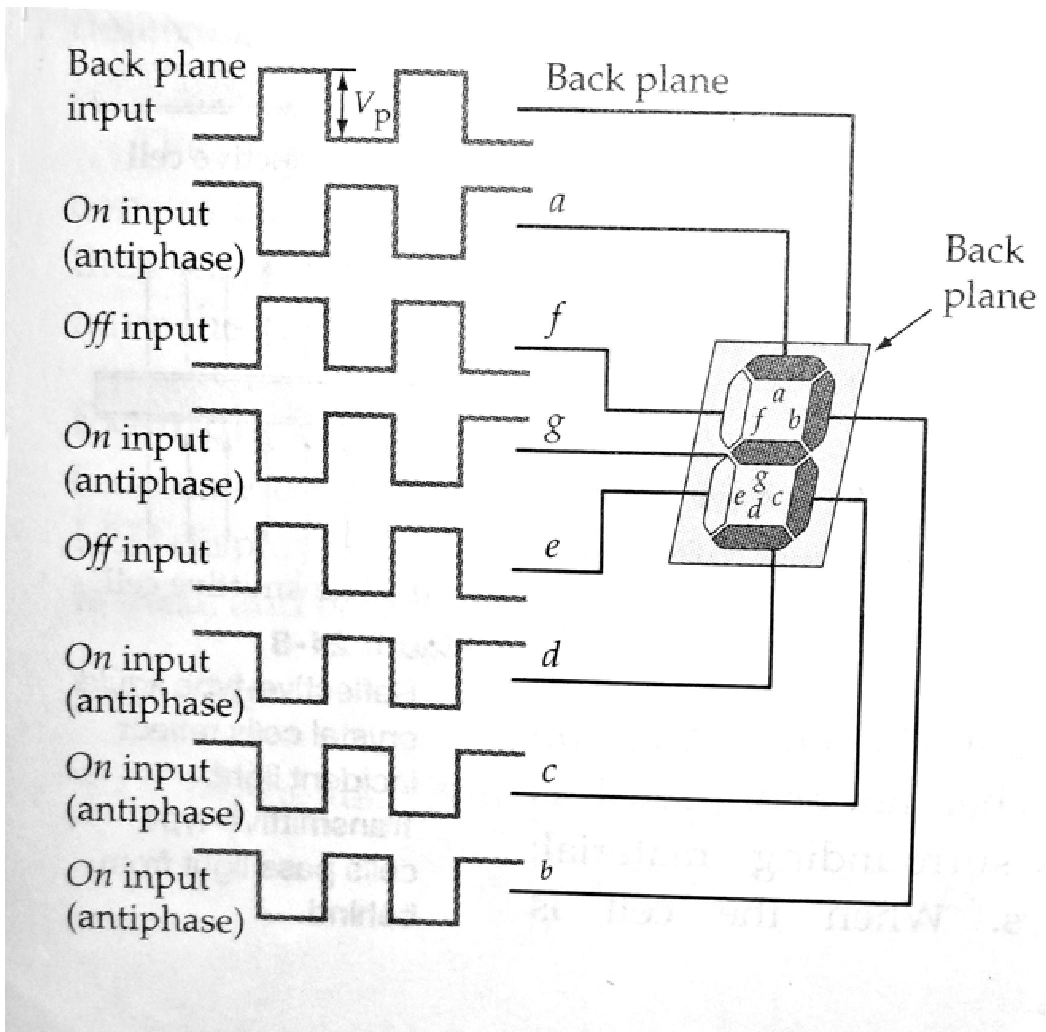
Because liquid crystal cell are light reflectors or transmitters rather than light generators, they consume very small quantities of energy. The only energy required by the cell is that needed to activate the liquid crystal. The total current flow through four small seven segment LCDs is usually about 20μ amps. However, LCD requires an AC voltage supply, in the form of either a sine wave or a square wave. This is because a continuous direct current produces a plating of the cell electrodes that could damage the device. Repeated reversal of the current prevents this problem.

A typical LCD supply is a 3V to 8V peak to peak square wave with a frequency of 60Hz. Figure illustrates the square wave drive method. The back plane, which is common to all of the cells, is supplied with a square wave (with peak voltage V_p). Similar square waves applied to each of the other terminals or either in phase or in anti phase with the back plane square wave. Those cells with waveforms in phase with the back plane waveform (cells e and f) have no voltage developed across them. Since both terminals of the segment are at the same potential, they are not energized. The cells with square waves in anti phase with the back plane input have a square wave with peak voltage to V_p developed across them, they are energized.

Advantages and Disadvantages

Unlike LED displays, which are usually quite small, LCD can be fabricated in almost any convenient size. The major advantage of LCDs is their low power consumption. Perhaps the major disadvantage of the LCD is it’s decay time of

150ms (or more). This is very slow compared to the rise and fall times of LEDs. In fact the human eye can sometimes observe the fading out of LCD segments switching off.



Comparison

LED	LCD
Consumes more Power In terms of milli watt	Consumes less power in terms of micro watts
Good brightness levels	Moderate brightness levels
Temp range -40 to 85˚C	-2 to 60˚C
Life time 1,00,000 hrs	50,000 hrs
Operating Voltage 1.5 to 5Vdc Response time 50 to 500 nano sec	Operating voltage range is 3 to 20V a.c. Response time 50 to 200msec