CHAPTER THREE

PN JUNCTION DIODES

3.1 Introduction

When a p-type semiconductor material is suitably joined to n-type semiconductor, the contact surface is called a p-n junction. The p-n junction is also called as semiconductor diode. Figure 3.1 shows the schematic diagram (a) and block diagram (b) of the PN-junction. A PN-junction is formed by growing a single crystal of Si (or Ge), which is half p-type and half n-type.

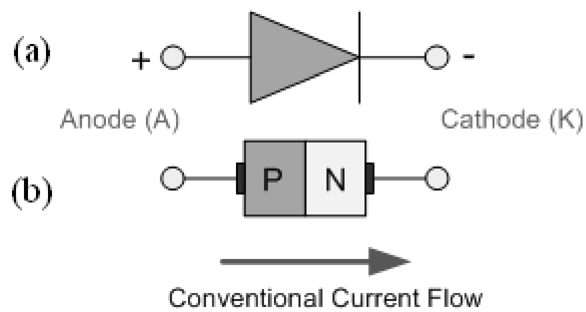


Figure 3.1: Schematic and block diagram of PN junction.

Owing to their random movement, some of the holes/electrons will move across the boundary/junction into the n-type/p-type semiconductors respectively. This movement of carriers (holes and electrons) across the junction is known as *diffusion*. It will be noted that diffusion takes place when there is a difference in the concentration of carriers in adjacent regions of a crystal; but drift of carriers takes place only when there is a difference of potential between two regions.

When free electrons diffuse into the p-type semiconductor, the region closest to the junction in the p-type semiconductor, acquires an excess negative charge which repels any more electrons trying to migrate from the n-type into the p-type semiconductor. Similarly, the diffusion of free holes into the n-type semiconductor causes the region closest to the junction in the n-type semiconductor to acquire a surplus of positive charge which prevents any further migration of holes across the boundary. These positive and negative charges are concentrated near the junction and thus form a potential barrier between the two regions. Free charge carriers can no more rest in a position around the potential barrier and therefore “become depleted of any free mobile carriers, forming the *depletion layer* (figure 3.2).

The external voltage required to overcome this barrier potential to allow electrons to move freely across the junction is dependent on the type of semiconductor material and temperature. For Silicon, this is about 0.7 volts and for Germanium, it is about 0.3 volts. This potential barrier will always exist even if the device is not connected to any external power source.

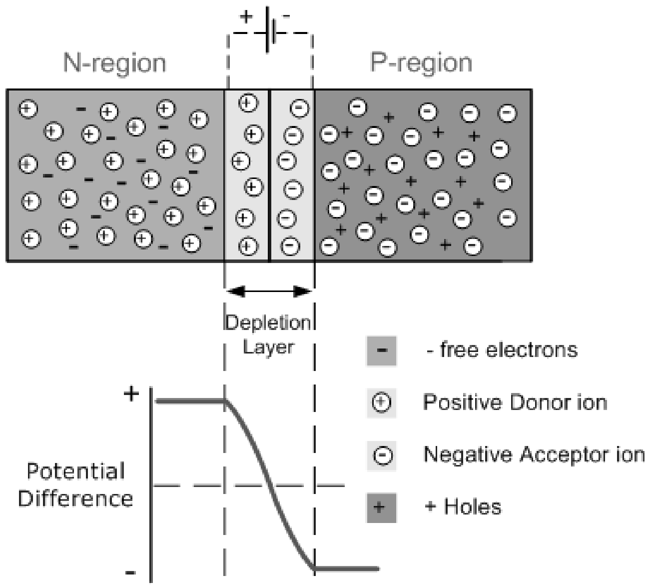


Figure 3.2: The pn-junction

3.2 Biasing

For semiconductors to conduct, a voltage potential is connected across it in a process called *biasing.* The external voltage, based on the how the biasing is done, can increase or decrease the potential barrier. There are three possible biasing conditions for the standard junction diode namely: zero biasing, reverse biasing and forward biasing.

3.2.1 Zero Bias

In zero bias condition, no external voltage is applied to the PN-junction (figure 3.3). If the diode's terminals are shorted together, a few holes (majority carriers) in the P-type material with enough energy to overcome the potential barrier will move across the junction against this barrier potential. This is known as the forward current (I_f). Holes generated in the N-type material (minority carriers), find this situation favourable and move across the junction in the opposite direction. This is known as the reverse current and is denoted by I_r. The two currents are equal and moving in opposite directions, given a resultant current of zero.

When this occurs, the junction is said to be in a state of dynamic equilibrium. This state of equilibrium can be broken by raising the temperature of the PN-junction causing an increase in the generation of minority carriers, thereby resulting in an increase in *leakage current*.

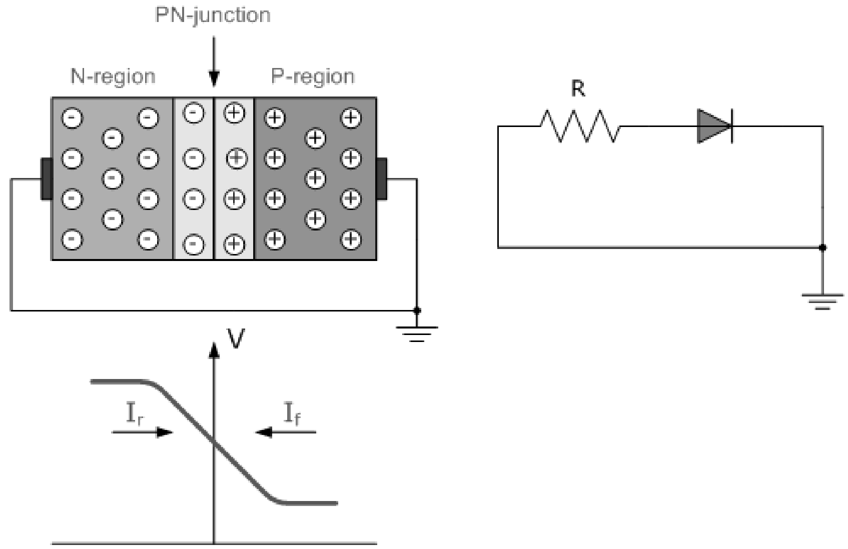


Figure 3.3: Zero biased diode

3.2.2 Reverse Bias

To reverse bias a diode, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material (figure 3.4). The positive voltage applied to the N-type material attracts electrons towards the positive electrode and away from the junction, while the holes in the P-type end are also attracted away from the junction towards the negative electrode. The net result is that, the depletion layer grows wider due to a lack of electrons and holes and presents a high impedance path. Consequently, a high potential barrier is created thus preventing current from flowing through the semiconductor material.

However, a very small leakage current does flow through the junction that can be measured in microamperes, (μA). If the reverse bias voltage, Vr applied to the junction is increased to a sufficiently high enough value, it will cause the PN-junction to overheat and fail due to the avalanche effect around the junction. This may cause the diode to become shorted and will result in maximum circuit current to flow and this is shown in the reverse characteristics curve below (figure 3.5).

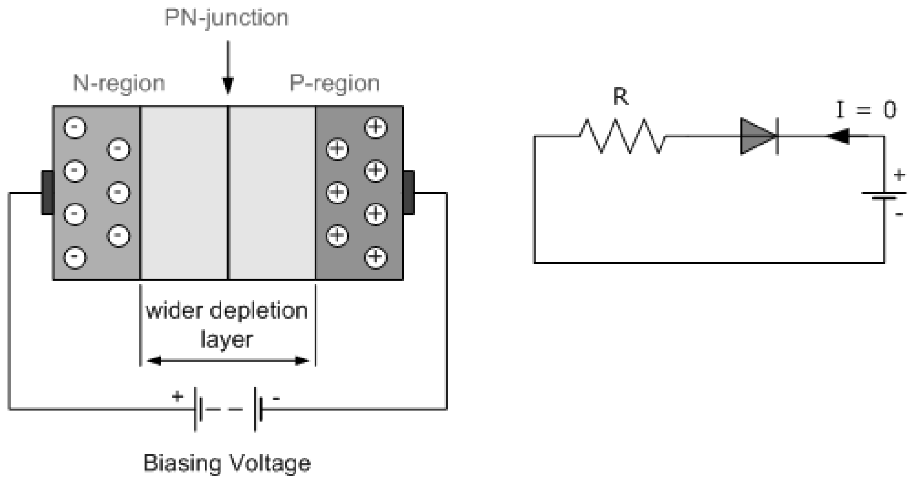


Figure 3.4: Reverse Biased Junction showing the Increase in the Depletion Layer.

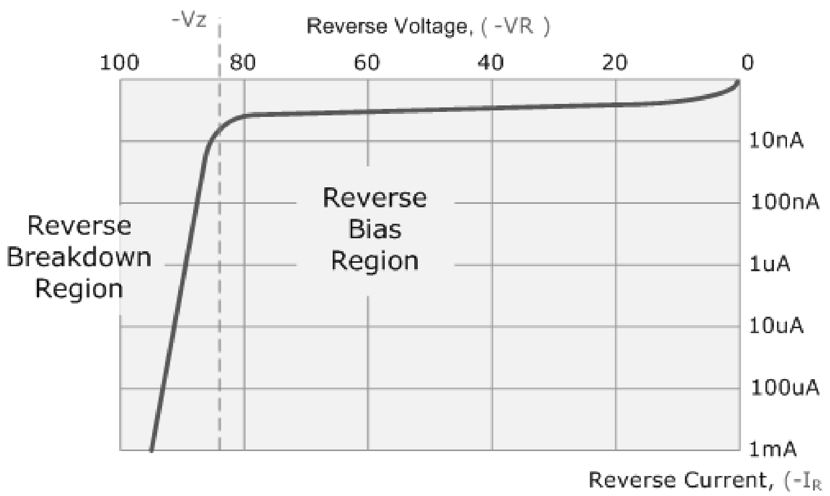


Figure 3.5: Reverse Characteristics Curve for a Diode.

3.2.3 Forward Bias.

When a diode is connected in a forward bias condition, a negative voltage is applied to the n-type material and a positive voltage is applied to the p-type material (figure 3.6). If this external voltage becomes greater than the value of the potential barrier, 0.7 volts for Silicon and 0.3 volts for Germanium, the potential barrier's opposition will be "subdued" and current will start to flow. The negative voltage repels electrons towards the junction giving them the energy to cross over and the holes are repelled in the opposite direction towards the junction by the positive voltage. These results in the depletion layer becoming very thin and narrow representing a low impedance path. In that event, a very small potential barrier is produced, allowing high currents to flow.

The point at which this takes place is represented on the static I–V characteristics curve below as the *knee point* (figure 3.7)

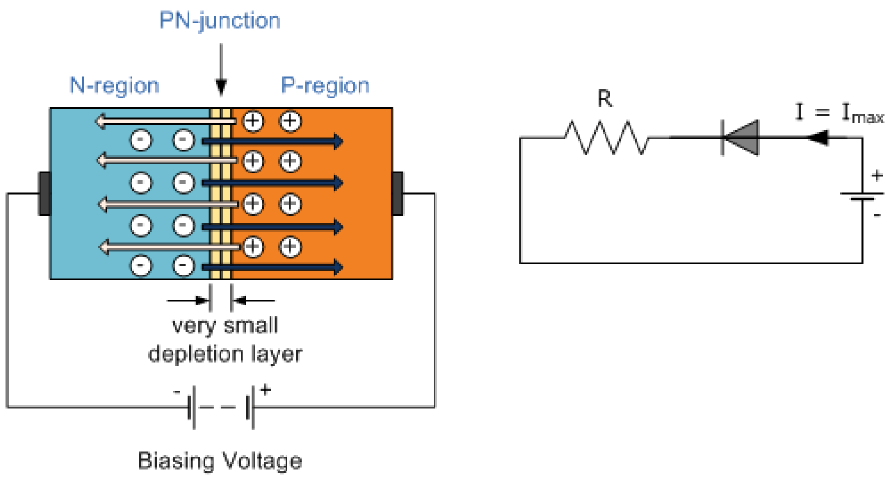


Figure 3.6: Forward Biased Junction Diode showing a Reduction in the Depletion Layer.

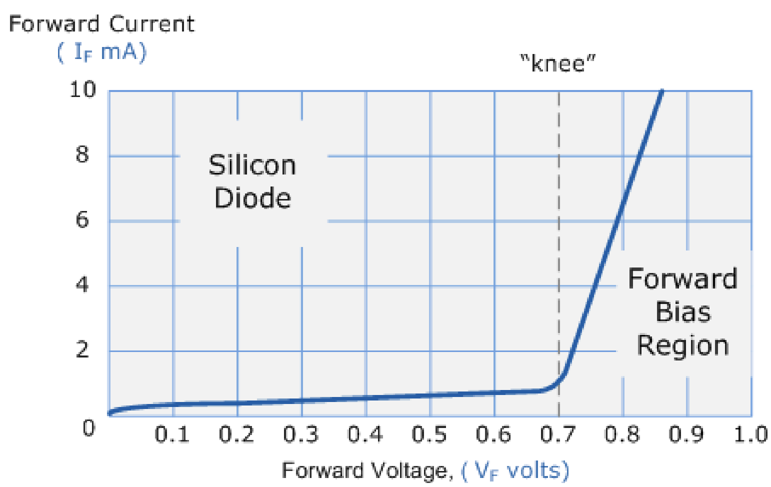


Figure 3.7: Forward Characteristics Curve for a Diode.

3.2.4 Basic Definitions

1. Knee voltage or Cut-in Voltage: It is the forward voltage at which the diode starts conducting.

2. Breakdown voltage: It is the reverse voltage at which the diode (p-n junction) breaks down with sudden rise in reverse current.

3. Peak-inverse voltage (PIV): It is the maximum reverse voltage that can be applied to a p-n junction without causing damage to the junction. If the reverse voltage across the junction exceeds its peak-inverse voltage, then the junction gets destroyed because of excessive heat. In rectification, one thing to be kept in mind is that, care should be taken that reverse voltage across the diode during negative half cycle of A.C. does not exceed the peak-inverse voltage of the diode. It is usually safer to select a diode that has reverse breakdown voltage at least 50% greater than the expected PIV.

4. Maximum Forward current/Current handling Capacity: It is the maximum instantaneous forward current that a p-n junction can conduct without damaging the junction. If the forward current is more than the specified rating, then the junction gets destroyed due to overheating.

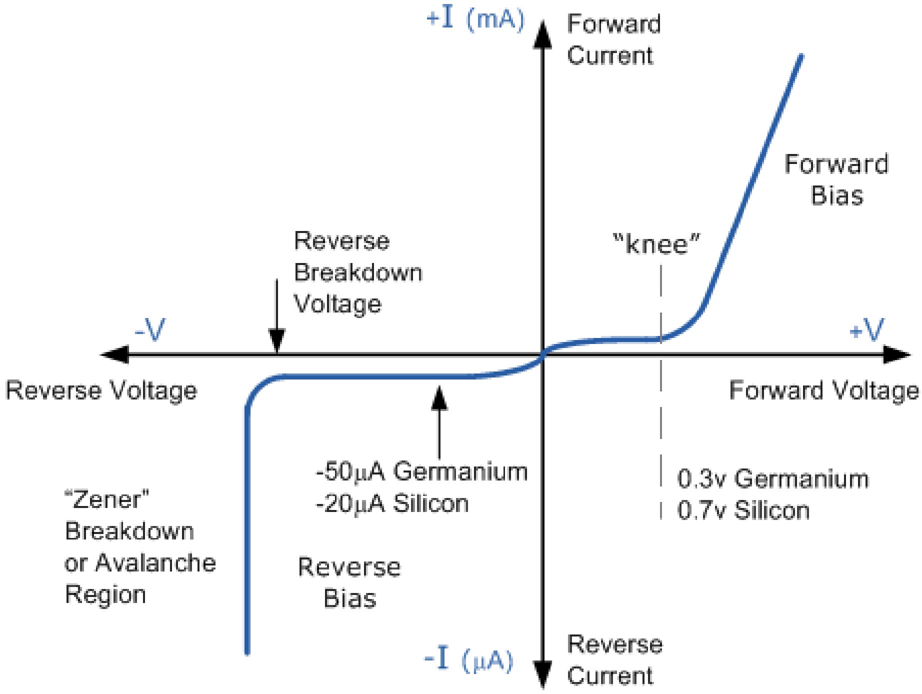


Figure 3.8: Volt-Ampere characteristics curve

3.3 Rectification

Rectification is the process of converting alternating voltages to direct voltages. A rectifier is a circuit which converts alternating current (ac) into a direct current (dc). Rectifiers are grouped into two categories depending on the period of conduction:

1. Half-wave rectifier
2. Full- wave rectifier.

3.3.1 Half-wave Rectification

A transformer is usually employed in order to step-down the supply voltage and also to prevent shocks. A diode is used to rectify the ac signal while, the pulsating dc is taken across the load resistor, R (figure 3.9)

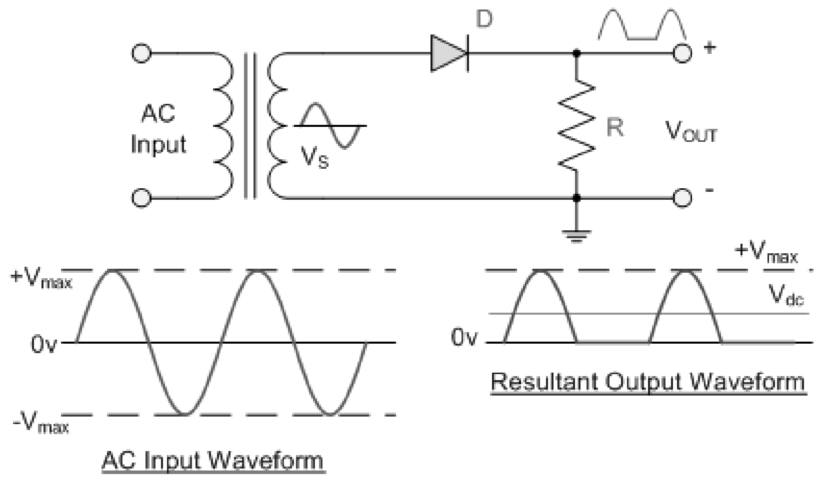


Figure 3.9: Half-wave Rectifier Circuit

When the sinusoidal input voltage goes positive, the diode is forward-biased and conducts current through the load resistor. The current produces an output voltage across the load, which has the same shape as the positive half-cycle of the input voltage.

When the input voltage goes negative during the second half of its cycle, the diode is reversed-biased. There is no current, so the voltage across the load is zero. The net result is that only the positive half- cycle of the ac input voltage appears across the load. Since the output does not change polarity, it is a pulsating dc voltage.

Note:

- The relation between turns ratio and voltages of primary and secondary of the transformer is given by $\frac{N_p}{N_s} = \frac{V_p}{V_s}$.
- RMS value of the voltage and maximum voltage value of voltage is related by the equation $V_{rms} = \frac{V_m}{\sqrt{2}}$ (for full-cycle of ac).

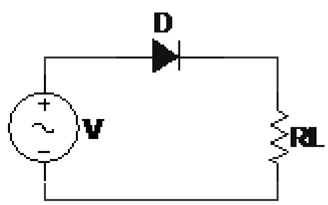
- If the type of diode is not specified then assume the diode to be of silicon type.
- For an ideal diode, forward resistance $r_f = 0$.

3.3.1.1 Average Value of the Half-Wave output Voltage

The average value of a half-wave output is the value of the output dc voltage. It can be calculated with the following equation,

$V_{dc} = \frac{V_m}{\pi}$, where V_m is the peak value of the half-wave output voltage

Consider the circuit below:



$V = V_d + V_R$

V_d has a very small value during the positive half-cycle when the diode conducts. Assuming ideal diode characteristics, then V_d =0 since the effective resistance of the diode, r_d is zero.

If the supply voltage is $V = V_m \sin \omega t$, then

$$i = \frac{V}{R} = \frac{V_m \sin \omega t}{R} = I_m \sin \omega t$$

The mean value of the current (neglecting the reverse current), I_{dc} is

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

$$I_{dc} = \frac{I_m}{2\pi}\left[-\cos \omega t\right]_0^{\pi}$$

$$I_{dc} = \frac{I_m}{2\pi}\left[-\cos \pi + \cos 0\right]$$

$$I_{dc} = \frac{I_m}{2\pi}\left[1+1\right]$$

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

The rms value of the current, I_{rms} can be derived as:

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

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

$$I_{rms}=\sqrt{\frac{I_m{}^2}{2\pi}\times\frac{1}{2}\left[\omega t+\frac{1}{2}\sin 2\omega t\right]_0^\pi}$$

$$I_{rms}=\sqrt{\frac{I_m{}^2}{4\pi}\times[\pi]}$$

$$I_{rms}=\frac{I_m}{2}=0.5I_m$$

The voltage across the load is given by:

$$V_R=Ri=R\,\mathrm{I_m}\sin\omega t=V_m\sin\omega t$$

Similarly, the mean value of the load voltage and the rms value of the effective input voltage are respectively given by:

$$V_{dc}=\frac{V_m}{\pi}=0.318V_m$$

$$V_{rms}=\frac{V_m}{2}=0.5V_m$$

3.3.1.2 Effect of Diode Barrier Potential on Half Rectifier output voltage

In our derivations, the diode was considered ideal. In a practical diode, the barrier potential is taken into account and hence, the output voltage will have a peak value that is 0.7v less than the peak value of the input voltage. The resistance of the diode may contribute a voltage according to Ohm's Law ($V=IR$).

3.3.1.3 Efficiency of a half-wave rectifier

The ratio of dc power to the applied input ac power is known as rectifier efficiency.

Rectifier efficiency, $\eta = \dfrac{\text{output dc power}}{\text{input ac power}}$

$$\eta = \frac{I_{dc}{}^2 R}{I_{rms}{}^2 (r_f + R)}$$, where r_f is the forward resistance of the diode and R, the resistance of the load.

$$\eta = \frac{\left[\frac{I_m}{\pi}\right]^2 R}{\left[\frac{I_m}{2}\right]^2 (r_f + R)}$$

$$\eta = \frac{4}{\pi^2}\left[\frac{R}{(r_f + R)}\right]$$

$$\eta = \frac{0.405}{1 + \frac{r_f}{R}}$$

For maximum efficiency, the value of r_f should be negligible compared to R. Therefore, the maximum efficiency of the half-wave rectifier is 40.5%.

3.4 The Full-wave Rectifier

Full-wave rectifier is of two types

1. Centre tapped full-wave rectifier.
2. Bridge rectifier.

3.4.1 Centre tapped full-wave rectifier

The circuit consists of two *half-wave* rectifiers connected to a single load resistance with each diode taking its turn to supply current to the load (figure 3.10).

When point A is positive with respect to point B, diode D_1 conducts in the forward direction as indicated by the arrows. When point B is positive (in the negative half of the cycle) with respect to point A, diode D_2 conducts in the forward direction and the current flowing through resistor R is in the same direction for both circuits.

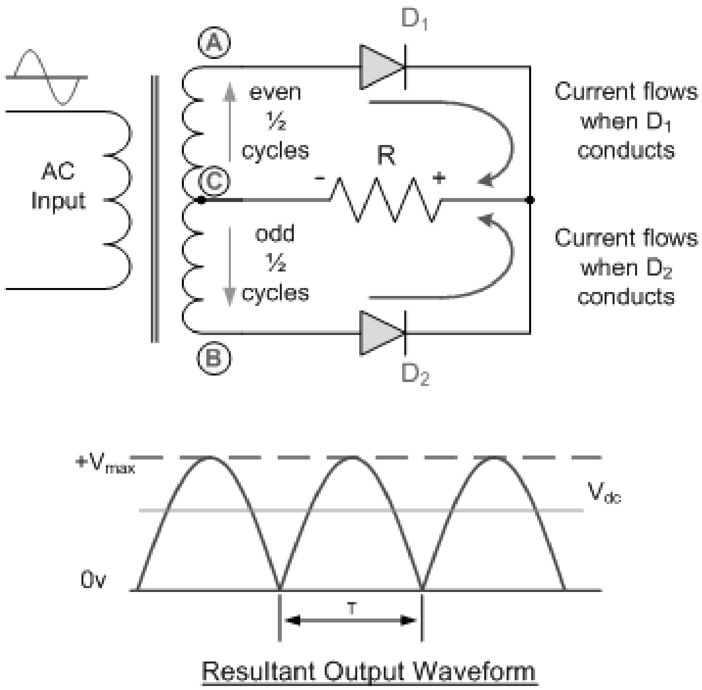


Figure 3.10: The Centre tapped full-wave rectifier

The dc voltage is calculated as:

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

3.4.1.1 Effect of turns ratio on full wave output voltage.

The maximum voltage, which occurs across the diode in the reverse direction, known as the peak inverse voltage (PIV), must be less than the breakdown voltage of the diode if it is not to conduct appreciably in the reverse direction. The diode is reverse-biased during the negative half-cycle and the maximum voltage applied to it equals the maximum secondary voltage, $V_{p(sec)}$(the case of a half-wave rectifier).

For a centre- tapped rectifier, the maximum voltage across each diode during the negative cycle is equal to half of the maximum secondary voltage. Since, the turns ratio directly imparts the maximum secondary voltage, it influences the output voltage. If the turns ratio is 1, the peak value of the rectified output voltage equals half of the peak of the primary input voltage.

Since $V_m = \frac{V_{p(sec)}}{2}$

$\Rightarrow V_{p(sec)} = 2V_m$

But $PIV = V_{p(sec)} = 2V_m$

3.4.1.2 Disadvantages

1. Since, each diode uses only one-half of the transformers secondary voltage, the d.c. output is comparatively small.
2. It is difficult to locate the centre-tap on secondary winding of the transformer.
3. The diodes used must have high peak-inverse voltage.

3.4.2 The Bridge Rectifier

The full wave rectification uses four individual rectifying diodes connected in a bridged configuration to produce the desired output but do not require a special centre- tapped transformer (figure 3.11). The four diodes labelled D_1 to D_4 are arranged in series pairs with only two diodes conducting current during each half cycle.

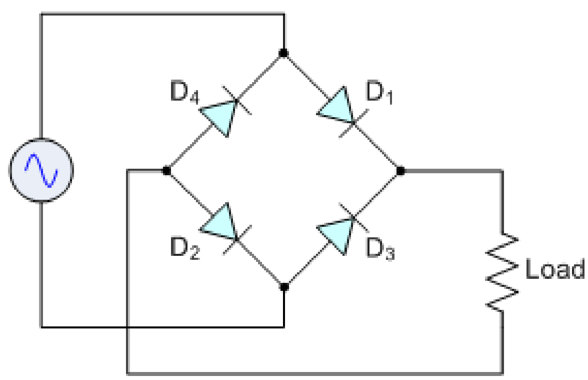
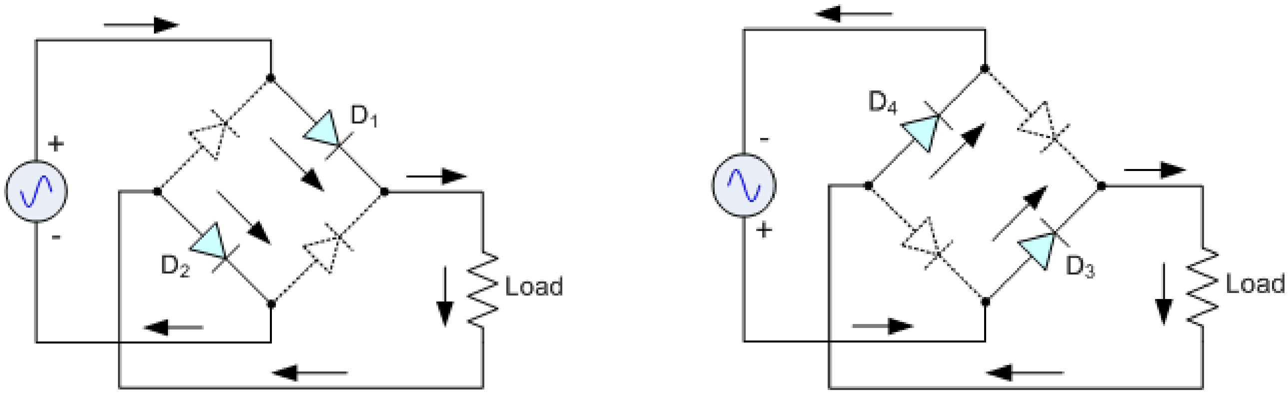


Figure 3.11: The full wave bridged rectifier

During the positive half cycle of the supply, diodes D_1 and D_2 conduct in series while diodes D_3 and D_4 are reverse biased and the current flows through the load as shown below (figure 3.12).



(a) Positive cycle (b) Negative cycle

Figure 3.12: Full wave rectification

During the negative half cycle of the supply, diodes D3 and D4 conduct in series, but diodes D1 and D2 switch off as they are now reversed biased. The current flowing through the load is in the same direction as before. The output average voltage is calculated as:

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

3.4.2.2 Disadvantages

1. It requires four diodes.
2. The use of two extra diodes cause an additional voltage drop thereby reducing the output voltage.

3.4.2.3 Efficiency of a full-wave rectifier

Rectifier efficiency, $\eta = \dfrac{\text{output dc power}}{\text{input ac power}}$

For a bridge rectification circuit, the supply passes through two diodes ($2\,r_f$) at any particular time.

$\eta = \dfrac{I_{dc}{}^2 R}{I_{rms}{}^2 (2r_f + R)}$, where r_f is the forward resistance of the diode and R, the resistance of the load.

$$\eta = \frac{\left[\frac{2I_m}{\pi}\right]^2 R}{\left[\frac{I_m}{\sqrt{2}}\right]^2 (2r_f + R)}$$

$$\eta = \frac{8}{\pi^2}\left[\frac{R}{(r_f + R)}\right]$$

$$\eta = \frac{0.81}{1 + \frac{2r_f}{R}}$$

In the case of a centre-tap rectification circuit, only one diode conducts at any particular time. Thus, its efficiency will be

$$\eta = \frac{0.81}{1 + \frac{r_f}{R}}$$

For maximum efficiency, the value of r_f should be negligible compared to R. Therefore, the maximum efficiency of the full-wave rectifier is 81% and is twice as efficient as the half-wave rectifier.

3.5 Ripple factor

The pulsating output of a rectifier consists of dc and ac components (also known as ripples). The ac component is undesirable and account for the pulsations in the rectifier output. The effectiveness of a rectifier depends upon the magnitude of ac component in the output: the smaller this component, the more effective is the rectifier. The ratio of rms value of ac component to the dc component in the rectifier output is known as ripple factor (r).

$$r = \frac{I_{ac}}{I_{dc}} = \frac{V_{ac}}{V_{dc}}$$

3.5.1 Ripple factor for Half-wave rectification

By definition, the effective (rms) value of total load current is given by

$$I_{rms} = \sqrt{I_{ac}{}^2 + I_{dc}{}^2}$$

$$\Rightarrow I_{ac} = \sqrt{I_{rms}{}^2 - I_{dc}{}^2}$$

Dividing both sides of the equation by I_{dc}

$$\frac{I_{ac}}{I_{dc}} = \frac{1}{I_{dc}}\sqrt{I_{rms}{}^{2} - I_{dc}{}^{2}}$$

$$r = \frac{I_{ac}}{I_{dc}} = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^{2} - I_{dc}{}^{2}}$$

For a half-wave rectification, $I_{rms} = \frac{I_m}{2}$ and $I_{dc} = \frac{I_m}{\pi}$

Substituting these values into the ripple factor equation yields

Ripple factor, $r = 1.21$

It is clear that the ac component exceeds the dc component in the output of the half-wave rectifier.

3.5.2 Ripple factor for full-wave rectification

For a full-wave rectification, $I_{rms} = \frac{I_m}{\sqrt{2}}$ and $I_{dc} = \frac{2I_m}{\pi}$

Substituting the above values into ripple factor equation, we get

Ripple factor $r = 0.48$

This shows that in the output of full-wave rectifier, the dc component is more than the ac component.

3.6 Filters

The output obtained by the rectifier is not pure dc but it contains some ac components along with the dc output. These ac components are called as ripples, which are undesirable or unwanted. To minimize the ripples in the rectifier output, filter circuits are used. These circuits are normally connected between the rectifier and load as shown below in figure 3.13. A capacitor filter is used to illustrate the concept of filtering.

3.6.1 The Smoothing Capacitor

When the input signal rises, the diode is forward biased and for that reason it starts conducting since the capacitor acts as a short circuit for ac signals. The capacitor gets charged up to the peak of the input signal and the dc component flows through the load R_L .When the input signal falls, the diode gets reverse biased and the charged capacitor acts as a battery and it starts discharging through the load R_L .

The smoothing capacitor converts the full-wave rippled output of the rectifier into a smooth DC output voltage.

Two important parameters to consider when choosing a suitable a capacitor are its working voltage, which must be higher than the no-load output value of the rectifier and its capacitance value, which determines the amount of ripple that will appear superimposed on top of the DC voltage. Too low a value of capacitance, and the capacitor has little effect.

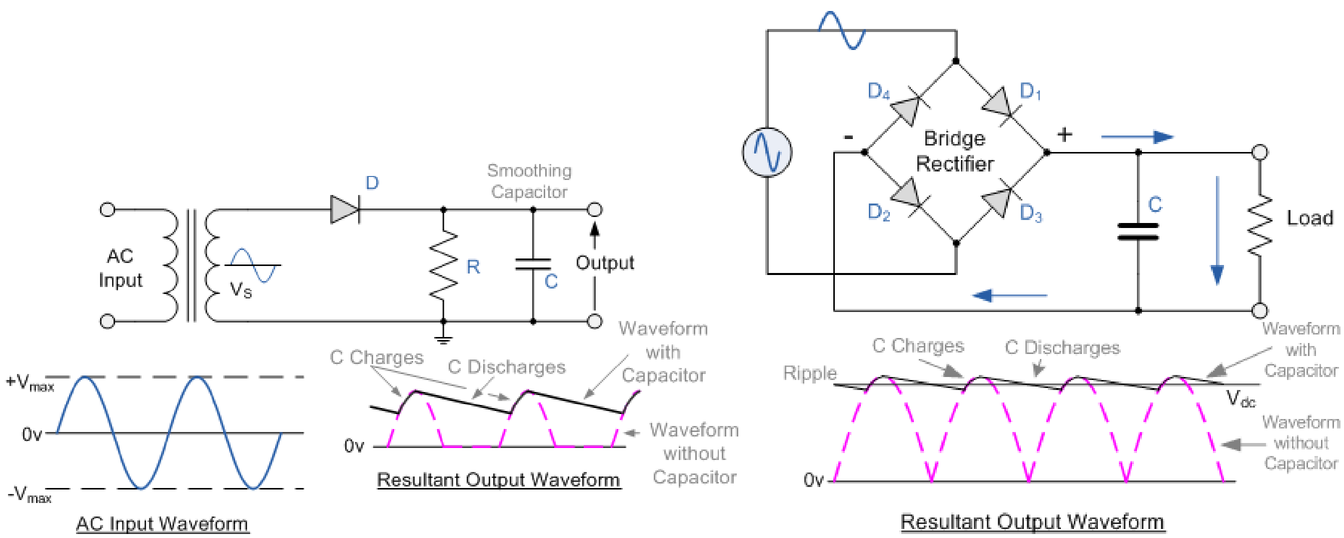


Figure 3.13: Filtering of rectified voltages

The ripple factor for a Half-wave rectifier with C-filer is given by $r = \frac{1}{2}\sqrt{3}f_c R_L$

The ripple factor of a full-wave rectifier with C-filter is given by $r = \frac{1}{4}\sqrt{3}f_c R_L$

3.7 The Zener Diode

A reverse biased diode passes very little current but will suffer breakdown or damage if the reverse voltage applied across it is made too high resulting in Zener diodes or breakdown diodes. Zener diodes are basically the same as the standard junction diode but are specially made to have a low pre-determined reverse breakdown voltage, called the Zener voltage (V_Z).

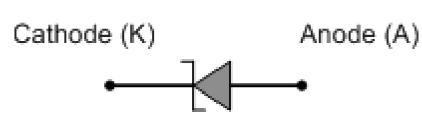


Figure 3.14: Symbol of zener diode

In the forward direction, it behaves just like a normal signal diode passing current, but when the reverse voltage applied to it exceeds the selected reverse breakdown voltage, a process called avalanche breakdown occurs in the depletion layer and the current through the diode increases to the maximum circuit value, which is usually limited by a series resistor. The point at which current flows can be very accurately controlled (to less than 1% tolerance) in the doping stage of the diode construction giving it a specific Zener Breakdown voltage (Vz) ranging from a few volts up to a few hundred volts.

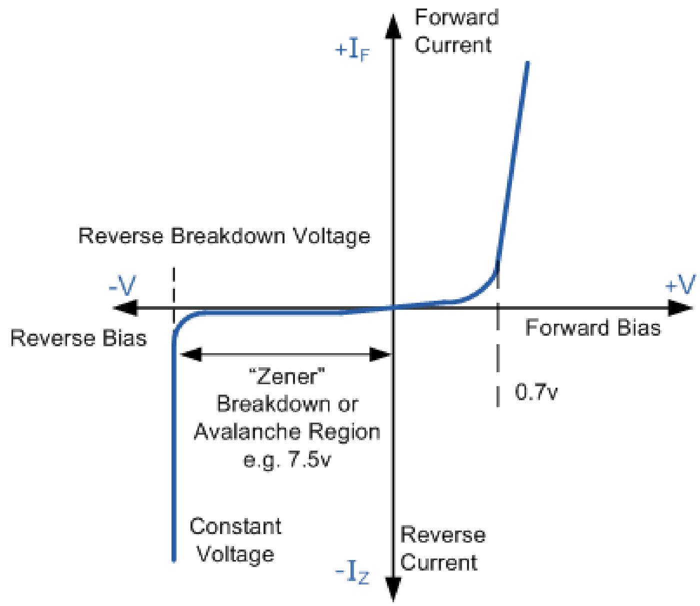


Figure3.15: Zener Diode I-V Characteristics

Zener Diodes are used in the reverse bias mode, i.e. the anode connects to the negative supply and from its I-V characteristics curve above, and we can see that the zener diode has a region in its reverse bias characteristics of almost a constant voltage regardless of the current flowing through the diode. This voltage across the diode (its zener voltage, V_Z) remains nearly constant even with large changes in current through the diode caused by variations in the supply voltage or load. This ability to control itself can be used to great effect to regulate or stabilize a voltage source against supply or load variations. The diode will continue to regulate until the diode current falls below the minimum I_Z value in the reverse breakdown region.

3.7.1 Voltage Regulation

3.7.1.1 Voltage Zener Regulaton

By connecting a simple Zener stabiliser circuit as shown below across the output of the rectifier, a more stable reference voltage can be produced.

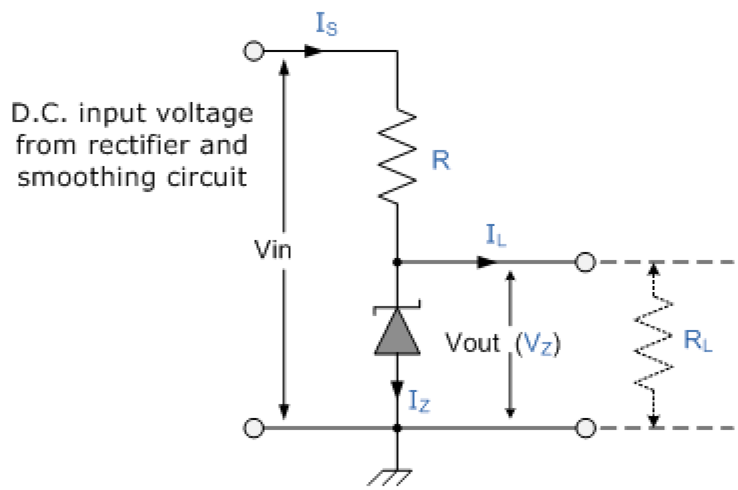


Figure3.16: Zener Diode Stabiliser

The resistor R is connected in series to limit the current flow to the diode. The input voltage source, V_{in} is connected across the combination while the stabilised output voltage V_{out} is taken from across the Zener diode. The Zener diode is connected with its cathode terminal connected to the positive rail of the DC supply so it is reverse biased and will be operating in its breakdown condition. When no load resistance, R_L is connected to the circuit, no load current ($I_L = 0$), is drawn and all the circuit current passes through the zener diode which dissipates its maximum power. Care must be taken when selecting the appropriate value of resistance such that the Zener maximum power rating is not exceeded under this "no-load" condition. There is a minimum Zener current for which the stabilization of the voltage is effective and the Zener current must stay above this value when operating within its breakdown region at all times. The upper limit of current is of course dependent upon the power rating of the device.

Worked example:

A 5.0V stabilized power supply is required from a 12V d.c input. The maximum power rating of the zener diode is 2W. Using the circuits above calculate:

(a) The maximum current flowing in the zener diode

$$I_{Z\max} = \frac{P_Z}{V_Z} = \frac{2}{5} = 400mA$$

(b) The value of the series resistor R.

$$R = \frac{V_{in} - V_Z}{I_Z} = \frac{12-5}{400\times10^{-3}} = 17.5\Omega$$

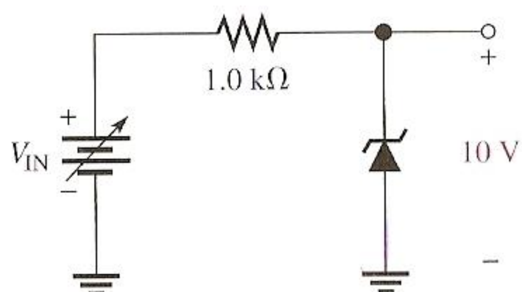
(c) The load current I_L if a load resistor of 1kΩ is connected across the zener diode.

$$I_L = \frac{V_Z}{R_L} = \frac{5}{1\times10^3} = 5mA$$

(d) The total supply current I_S

$$I_s = I_Z + I_L = 400mA + 5mA = 405mA$$

(a) In the circuit below the 10V zener diode can maintain regulation over a range of current values from $4mA$ to $40mA$. Calculate the range of input voltage for which the diode can maintain the regulated output.



(b) The range of input voltage for which the diode can maintain the regulated output.

For the minimum input voltage, $I_s = 4mA$

$$V_R = I_s R = 4\times10^{-3}\times1\times10^3 = 4V$$

$$V_{in} = V_R + V_Z = 4V + 10V = 14V$$

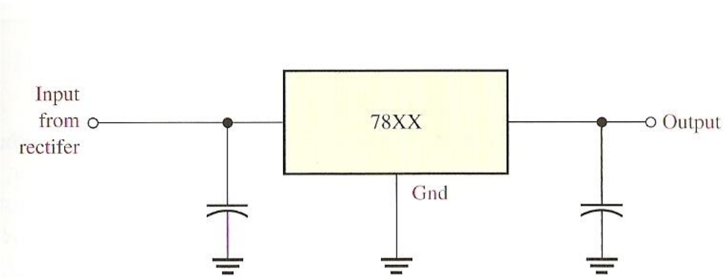
For the minimum input voltage, $I_s = 40mA$

$$V_R = I_s R = 40\times10^{-3}\times1\times10^3 = 40V$$

$$V_{in} = V_R + V_Z = 40V + 10V = 50V$$

3.8 IC voltage regulator

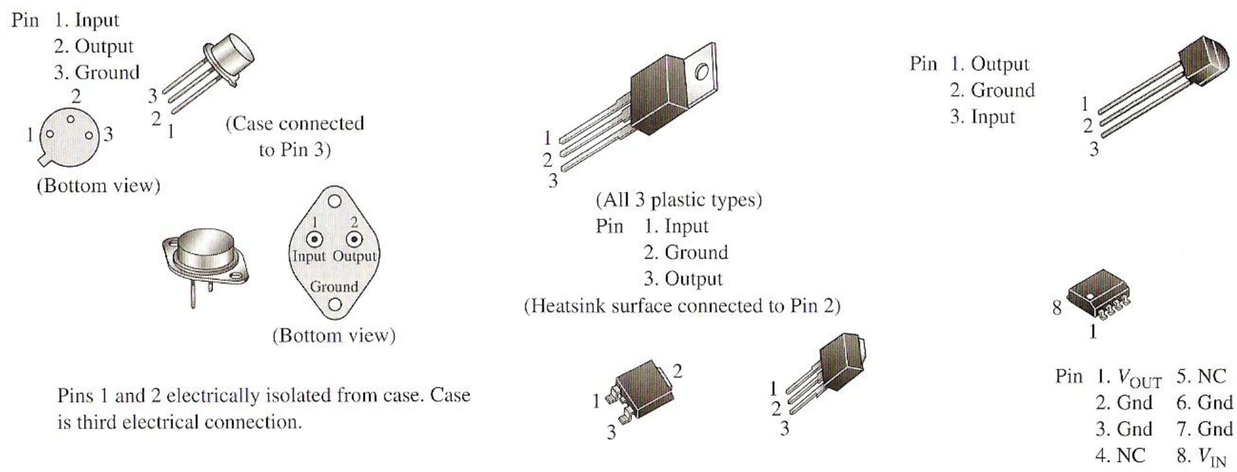
An integrated circuit regulator is a device that is connected to the output of a filtered rectifier and maintains a constant output voltage despite changes in the input. While filters can reduce the ripple from power supplies to a low value, the most effective filter is a combination of a capacitor input filter used with an IC voltage regulator. Popular IC regulators have three terminals: an input, an output and a reference terminal. Three terminal regulators designed for a fixed output voltage require only external capacitors to complete the regulation portion of the power supply as shown in the figure. Example an IC regulators are the 78xx series.



(a) Standard configuration

Type number	Output voltage
7805	+5.0 V
7806	+6.0 V
7808	+8.0 V
7809	+9.0 V
7812	+12.0 V
7815	+15.0 V
7818	+18.0 V
7824	+24.0 V

(b) The 7800 series



(c) Typical metal and plastic packages

Figure 3.18:

3.9 Percentage Regulation

The regulation is a merit used to specify the performance of a voltage regulator. It can be in terms of input (line) or load regulation.

Line regulation specifies how much change occurs in the output for a given change in the input voltage. It is typically defined as:

$$Line\ regulation = \frac{\Delta V_{out}}{\Delta V_{in}}$$

Load regulation specifies how much change occurs in the output over a certain range of load current values, usually from minimum current (no load) to maximum current (full load). It is normally calculated with the formula:

$$Load\ \ regulation = \frac{V_{no\ load} - V_{full\ load}}{V_{full\ load}} = \frac{V_{NL} - V_{FL}}{V_{FL}}$$

Worked example:

Assume a certain 7805 regulator has a measured no load output voltage of 5.18V and a full- load output of 5.15V. What is the load regulation expressed in percentage?

Solution:

$$Load\ \ regulation = \frac{V_{NL} - V_{FL}}{V_{FL}} = \left(\frac{5.18 - 5.15}{5.15}\right) \times 100\% = 0.58\%$$

3.9 Special Purpose Diodes:

3.9.1 Light Emitting Diodes (LEDs)

LEDs are the most visible type of diode that emits a fairly narrow bandwidth of either visible coloured light, invisible infra-red or laser type light when a forward current is passed through them. When the diode is forward biased, electrons from the semiconductor's conduction band combine with holes from the valence band, releasing sufficient energy to produce photons of light. Because of this thin layer, a reasonable number of these photons can leave the junction and radiate away producing a coloured light output.

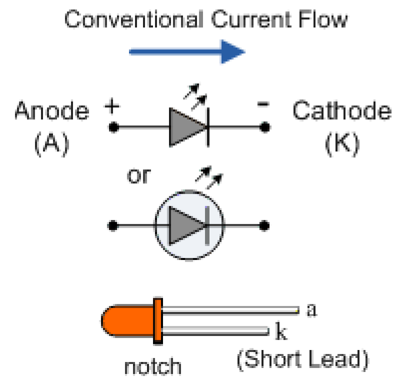


Figure 3.19: Light emitting diode

Unlike normal diodes which are made for signal detection and power rectification, and which are generally made from either Germanium or Silicon semiconductor material, LEDs are made from compound type semiconductor materials such as Gallium Arsenide (GaAs), Gallium Phosphide (GaP), Gallium Arsenide Phosphide (GaAsP), Silicon Carbide (SiC) or Gallium Indium Nitride (GaInN). The exact choice of the semiconductor material used will determine the overall wavelength of the photon light emissions and therefore the resulting colour of the light emitted.

Typical LED Characteristics			
Semiconductor Material	Wavelength	Colour	V_F @ 20mA
GaAs	850-940nm	Infra-Red	1.2v
GaAsP	630-660nm	Red	1.8v
GaAsP	605-620nm	Amber	2.0v
GaAsP:N	585-595nm	Yellow	2.2v
GaP	550-570nm	Green	3.5v
SiC	430-505nm	Blue	3.6v
GaInN	450nm	White	4.0v

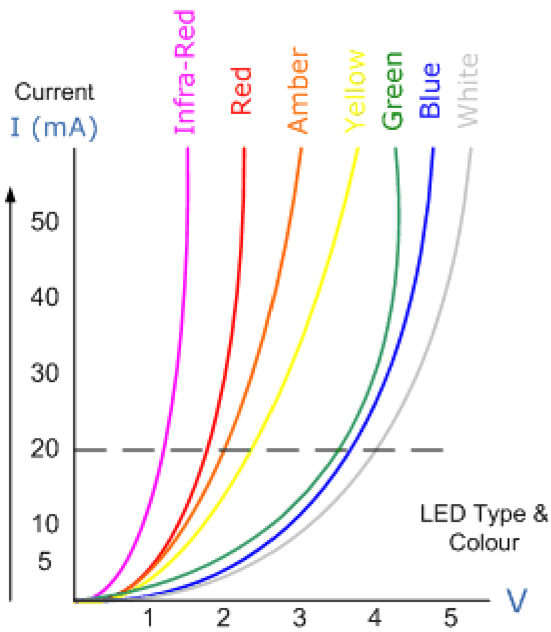


Figure3.20: Light Emitting Diodes $I-V$ Characteristics.

Before a light emitting diode can "emit" any form of light, it needs current to flow through it, as it is a current dependent device. As the LED is to be connected in a forward bias condition across a power supply, it should be current limited using a series resistor to protect it from excessive current flow. From the table above we can see that each LED has its own forward voltage drop across the PN-junction and this parameter which is determined by the semiconductor material used is the forward voltage drop for a given amount of forward conduction current, typically for a forward current of 20mA. In most cases LEDs are operated from a low voltage DC supply, with a series resistor to limit the forward current to a suitable value from say 5mA for a simple LED indicator to 30mA or more where a high brightness light output is needed.

3.9.1.1 Applications of LEDs

LEDs are commonly used for indicator lamps and readout displays on a wide variety of devices. A common type of display using LEDs is a 7-segment display. A 7-segment LED display provides a very convenient way of displaying information or digital data in the form of Numbers, Letters or even Alpha-numerical characters. As the name suggests, the means of display consists of 7 individual LEDs (the segments), within one single display package. In order to produce the required numbers or characters from 0 to 9 and A to F respectively, the correct combination of LED segments need to be illuminated on the display. A standard 7-segment LED display generally has 8 input connections, one for each LED segment and one that acts as a common terminal or connection for all the internal segments.

3.9.2 The Photodiode

The photodiode is a pn junction device that operates in reverse bias as shown in figure. The photodiode has a small transparent window that allows light to strike the pn junction. Typical photodiodes are show figure.

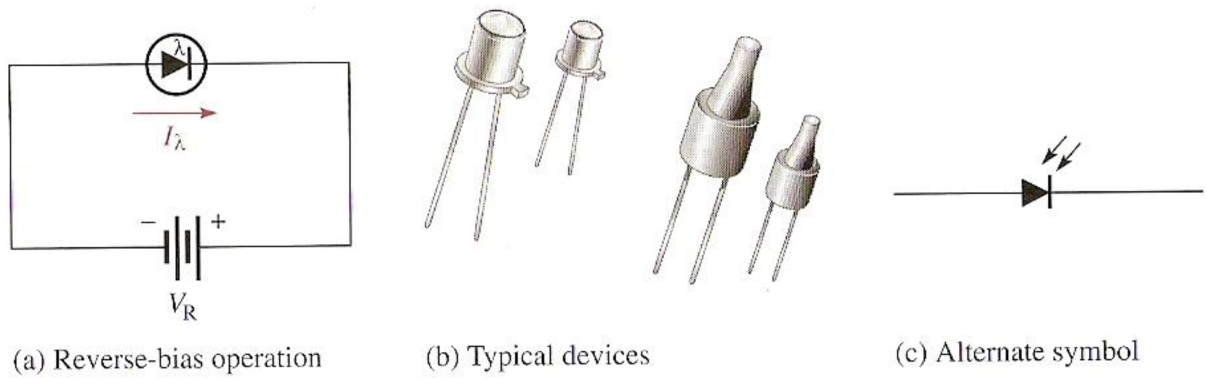


Figure 3.22: Photodiodes

In the photodiode, the reverse current increases with the light intensity at the exposed pn junction. When there is no incident light, the reverse current, $I\lambda$ is almost negligible and is called dark current. An increase in the amount of light intensity, expressed as irradiance (mW/cm^2), produces an increase in the reverse current as shown by the graph in figure.

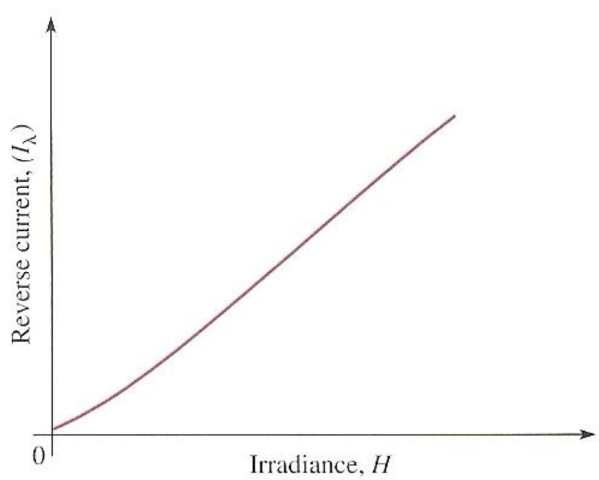


Figure3.22: Graph of reverse current versus irradiance for a photodiode.

An application of photodiode is depicted in figure. Here, a beam of light continuously passes across a conveyor belt and into a transparent window behind which is a photodiode circuit. When the light beam is interrupted by an object passing by on the conveyor belt, the sudden reduction in the diode current activates a control circuit that advances a counter by one. The total count of object that has passed that point is displayed by the counter. This basic concept can be extended and used for production control, shipping, and monitoring of activity on production lines.

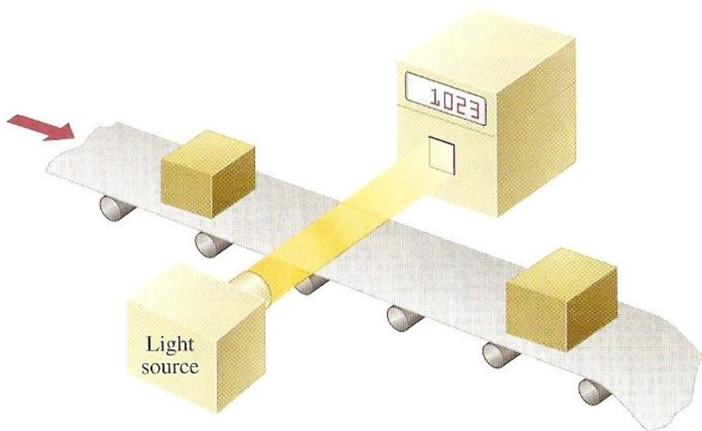


Figure3.23: A photodiode circuit used in systems that counts objects as they pass on a conveyor belt.