Chapter - 16

ELECTROMAGNETIC WAVES AND ELECTRONICS

Electromagnetic waves :

Faraday discovered the law of magnetic induction that a magnetic field,which is changing with time,causes an induced electric field.Maxwell showed that the opposite is also true:A changing electric field causes an induced magnetic field.This symmetrical relationship between changing electric and magnetic fields shows that if a change of electric and magnetic fields is taking place through any region,the electric and magnetic fields will propagate out of this region in the surrounding space.Such moving electric and magnetic fields are known as electromagnetic waves.When an electromagnetic wave is passing through some point in space,both the electric and magnetic fields at that point are changing with time.Maxwell showed that the electric field E and the magnetic induction B fluctuate. E and B are zero at the same time and they reverse direction together with each cycle.Another prediction of the Maxwell theory is that E and B are mutually perpendicular to each other and that both are perpendicular to the direction of propagation of the wave: Fig:16.1.

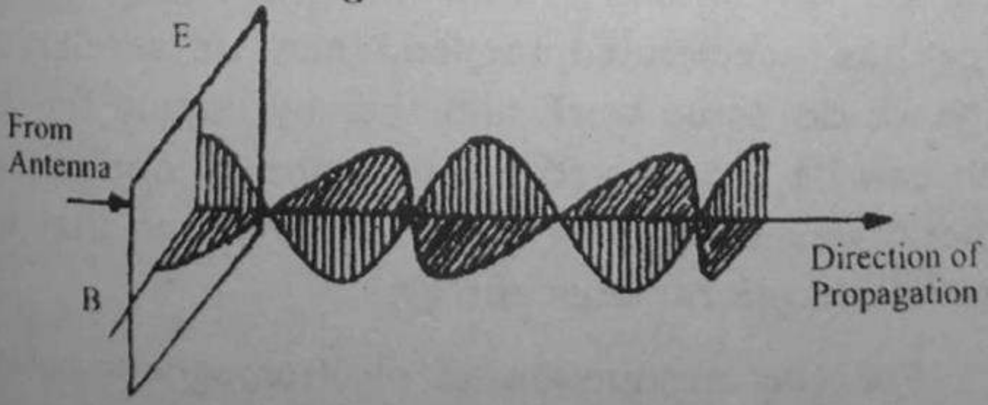


Fig: 16.1 (The E and B vectors in a plane electromagnetic waves travelling along the positive X-axis. The field vector are mutually perpendicular and are in phase.)

It can be shown that the speed (c) of the e.m waves depends upon the permeability and the permittivity of the medium through which it propagates

$$C = \sqrt{\frac{1}{\mu_0 \epsilon_0}}$$

$$= \frac{1}{\sqrt{4\pi \times 10^{-7} \text{Tm/A} \times 8.854 \times 10^{-12}\ \text{C}^2/\text{Nm}^2}}$$

$$\cong 2.998 \times 10^8 \text{ms}^{-1}$$

Thus the speed of electromagnetic wave is the same as the speed of a light wave in free space.Maxwell therefore proposed that the light is an electromagnetic radiation.

16.1 Production of electromagnetic waves (Radio waves)

All electric and magnetic fields arise due to moving charges.Our problem is to know the conditions where these fields would radiate away from the source from which they originate.

Now electric charge at rest gives rise to coulomb field around the charge which is stationary in space;a charge moving with constant speed is equivalent to a steady electric current which generates a magnetic field in the surrounding space.These fields also do not radiate.Hence we should expect radiation only when the charge has accelerated motion.When we accelerate the charge,we do some work and thereby supply the energy which can be propagated out in space in form of electromagnetic waves.Thus we know the condition that an accelerated charge radiates energy.

For the production of electromagnetic waves,we have a simple generator of electromagnetic waves as shown in Fig.16.2 where an antenna is formed by two metal rods connected to an alternating source of potential of frequency υ.This source is known as oscillator having wave shape of the potential as shown in Fig 16.2

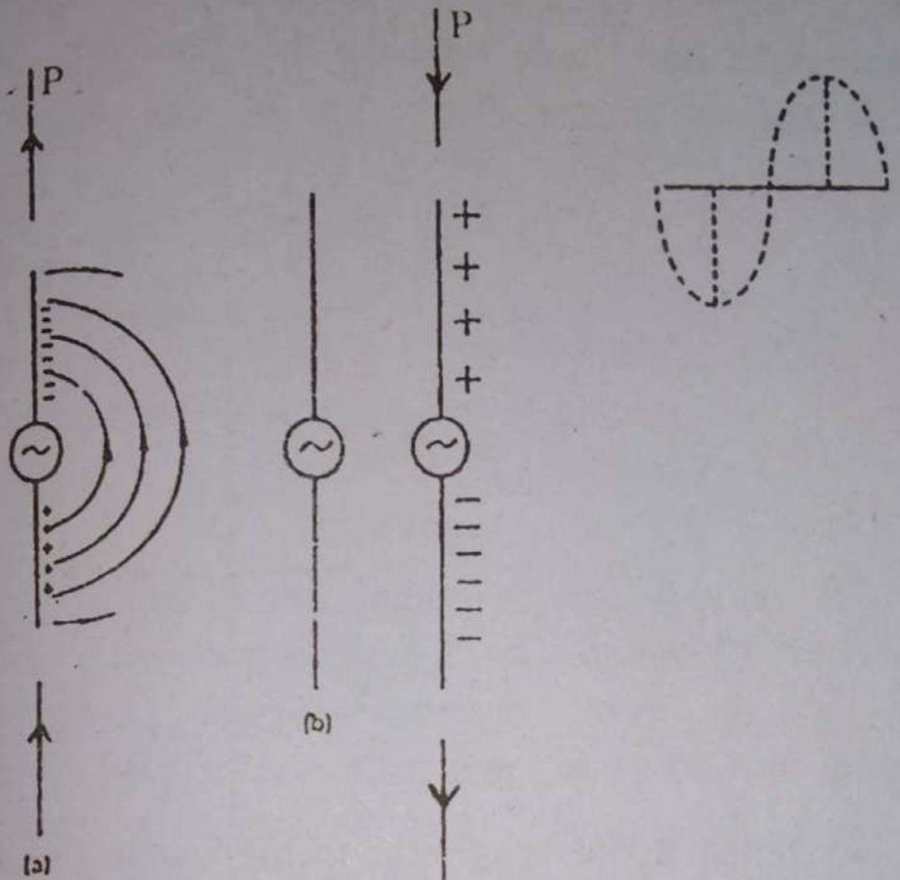


Fig: 16.2

The oscillator causes to flow back along the antenna.The system is shown at several times. In (a) $\frac{1}{4}$ cycle after start,negative charges,have been pushed to the end of the upper rod and an excess of positive charges remains on the bottom rod.At a time that is $\frac{1}{4}$ of a cycle later (b) the charges have come back together again and the rods are momentarily uncharged.Since later,at(c),the oscillator has reversed polarity and the charges are reversed,with the top rod positively charged.At any one instant,say (a),we see that the electric field surrounding the antenna is similar to that due to a pair of equal and opposite charges.At point P in (a), for instance,the electric field is upwards,but half a cycle later,at (c) it is downward.during the time between (a) and (c), positive charge is flowing up the antenna from bottom end to the top end.This upward current produces a magnetic field and the right hand rule tells us that the lines of induction of the magnetic field are of the form of circles.Fig:16.3

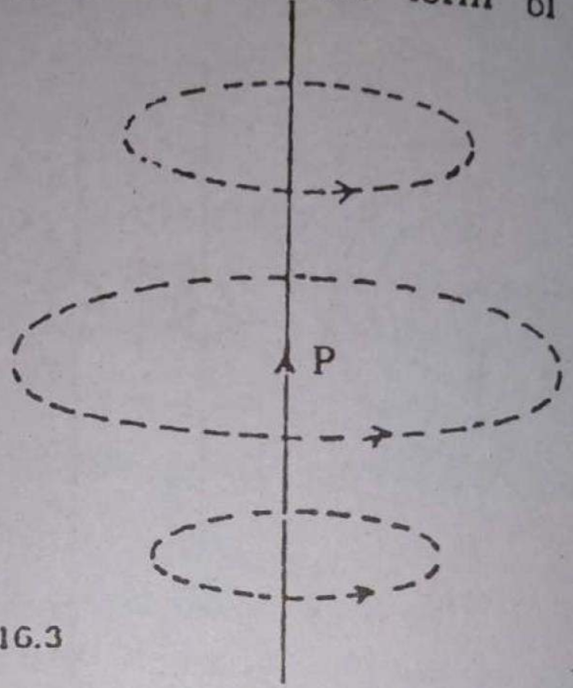


Fig.16.3

At point P,the magnetic induction is perpendicular to the plane of the paper. directed horizontally away from us.Later while charges are flowing back down the antenna,the magnetic induction B reverses direction but is still horizontal.

Thus we see that at P two fields coexist and that the E-field and the B-field are perpendicular to each other.At P,the wave is propagated horizontally,broad sides on to rods,at a point such as Q,the magnetic induction is zero (head on view of the current) and hence no wave is propagated along a direction parallel to the length of the antenna.

At any instant,the energy is stored in the space surrounding the antenna.Fig:16.4 shows the electric field (the accompanying magnetic field is not shown for simplicity) for a given instant.

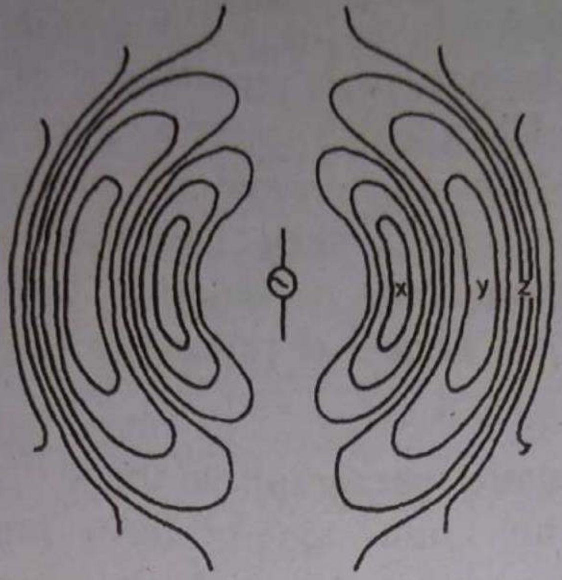


Fig. 16.4

The field in the region X is upwards. at Y it is zero and in the region Z. it is downward.Electric potential energy is stored wherever there is an electric field;the diagram shows that the energy at this instant is localized in the region X and Z separated by region Y where no energy is stored.As the wave spreads out,the regions of the energy concentration spreads out.

This is how the wave model explains the propagation of energy by radiation.As electric and magnetic fields can exists in vacuum and hence no medium is needed to transmit energy by an electromagnetic wave.

16.2 Information Carried by Electromagnetic waves and their Reception.

It is a common experience that sound waves(20 Hz to 20,000 H_Z) in air can be heard only over short distances. When long distance communication is needed and the free space is the communication channel, antennas radiate and they receive the signal. From the theory of the antenna,it turns out that antennas operate effectively only when their dimensions are of the order of magnitude of the wavelength of the signal being transmitted. For example,an audio tone of $4kH_z$ when converted into its electrical analog (i.e when passed through a transducer) corresponds to a wavelength of $(3 \times 10^8 (ms^{-1})/3 \times 10^3 H_z)$. 10^5m which is certainly an impracticable length of an antenna required for the transmission and reception of a tone of $3kH_z$. The required practical lenght of the antenna may be obtained by translating/shifting the electrical analog of the audio tone to a higher frequency.

In the foregoing paragraph we have discussed the transmission of an audio tone,problem regarding the practicability of the antenna and the possible solution.We now discuss another problem whose solution once again needs frequency translation/shifting.

During conversation we generate an audio signal which has a range. Suppose the audio range extends from $20H_z$ to $10kH_z$. The ratio of the highest audio frequency to the lowest$(10kH_z)$ is 500.and therefore the antenna designed for one end of the range would be entirely too short or too long for the other end. Once again we can overcome this problem by translating/shifting the audio signal to a higher frequency. For example,the audio signal is translated to a frequency of 10^6H_z,then the range occupied is from $(20H_z +10^6H_z)$ to $(10^4H_z + 10^6H_z)$,yeilding a ratio of 1.00. Therefore translation of an audio signal allows the use of same antenna for both the lowest frequency and the highest frequency of the radio signal. Thus transmission of intelligence (i.e voice,music,code) is accomplished by translating the electrical analog corresponding to the intelligence signal with a high frequency (radio wave) having constant amplitude and fixed frequency generated locally by the transmitting equipments. The process of combining audio frequency (a–f) and radio frequency (r–f) waves to accomplish translation is called modulation.

The higher frequency wave having constant amplitude and a fixed frequency is called carrier wave, whereas the audio signal is referred to as a modulating signal. Therefore modulation is a technique by which some characteristic of the carrier wave is varied with time in accordance with the modulating signal (intelligence) Mathametically, a carrier wave is represented by a sinusoidal waveform

$$V_c(t) = A \sin(2\pi f_c t + \phi) \quad \text{------------}(16.1)$$

where

A - represents the amplitude of the carrier wave

f_c - represents the frequency of the carrier wave

ϕ - represents the phase angle.

The waveform represented by Eq. 16.1 is sketched in Fig: 16.5 (a).

A single tone (i.e a tone having one frequency) modulating signal can be represented by

$$V_m(t) = B \sin 2\pi f_m t$$

where B and f_m represent the amplitude and frequency of the modulating signal respectively. The wave form is sketched in Fig 16.5 (b).

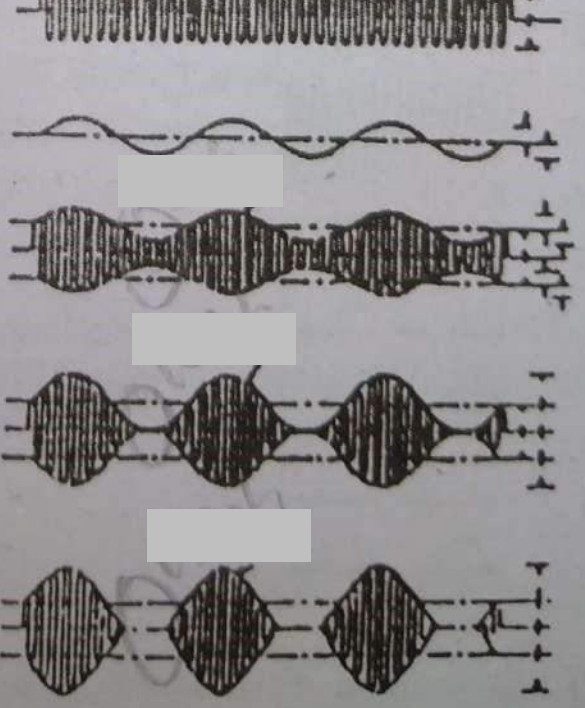


Fig. 16.5 a.b.c.

The sinusoidal wave form expressed in Eq:16.1 can be varried by using one of the three parameter namely. (i) the amplitude of the carrier wave A. (ii) the frequency of the carrier wave f_c and (iii) The phase angle 0. therefore three types of modulations can be devised namely (i) Amplitude Modulation (ii) Frequency Modulation (iii) Phase Modulation.

(a) AMPLITUDE MODULATION

In amplitude modulation (abbreviated A-M) the carrier wave amplitude, A, is varied in accordance with the modulating signal voltage.

Mathematically an amplitude modulated carrier for zero phase angle($\phi = 0$) from which the orignal signal is easily recoverable is generated by adding to the product of the modulation signal and carrier wave, the carrier signal itself.

$$V_{AM}(t) = A \cos 2\pi f_c t + A \cos 2\pi f_c t \times B \cos 2\pi f_m t \ldots (16.2)$$

The modulated wave form is sketched in Fig 16.5(c) shows that the out line of the modulated carrier wave is similar in form to the modulating signal, accordingly this outline is commonly called the modulation envelope. A schematic diagram of an amplitude modulator is shown in Fig. 16.6

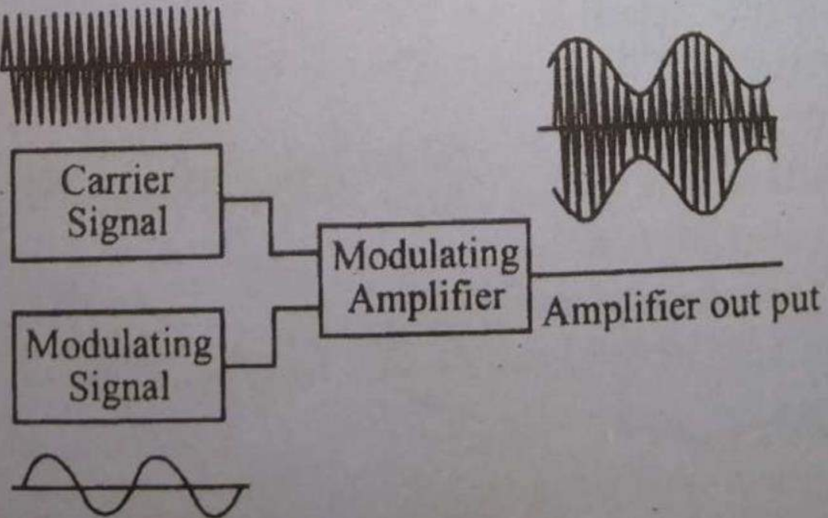


Fig 16.6 Amplitude modulation performed in an amplifier circuit

(b) PERCENTAGE OF MODULATION

In amplitude modulation it is common practice to refer to the percentage of modulation, and designated as M. The percentage of modulation shows the extent to which the modulating signal modulates the carrier wave (i.e. the extent to which a carrier has been amplitude modulated). Then if the modulation is symmetrical, the percentage of modulation is defined as

$$M = \frac{\text{Amplitude of modulating signal(volts)}}{\text{Amplitude of the carrier wave(volts)}} \times 100\% \quad ..(16.3)$$

$$M = \frac{B}{A} \times 100\,\% \quad \text{------------------(16.4)}$$

Let $M = \frac{B}{A} \times m_a$ -------------------(16.4)

Where m_a is termed as modulation index and both m_a and the modulation function, V_m (t), are constrained such that

$$V_m(t)_{max} < 1.0 < m_a < 1$$

then $M = m_a \times 100\%$

The Fig: 16.5(c), Fig: 16.5(d), Fig: 16.5(e) shows the effect of different amount of modulations (i) the Fig 16.5(c) shows 50% modulation(m_a= 0.5) the carrier wave is under modulated and the power output is reduced.(ii) Fig 16.5(d) shows100% modulation (m_a = 1), the carrier wave is fully modulated with maximum undistorted power output. (iii) Fig 16.5(e) shows the modulation exceeds 100% (m_a > 1), the carrier wave is over modulated and the output of the transmitter will be distorted version of the original modulating signal.

(c) SIDEBANDS

The second part of Eq.16.2 contains product of the carrier wave and the modulating signal. By virtue of this multiplication two new frequencies are generated and are equal to the sum and the difference of the carrier wave frequency and the modulating signal frequency, namely. (i) $(f_c + f_m)$. (ii) $(f_c - f_m)$.

In broadcasting a radio program, the modulating signal frequency(which corresponds to a single tone) varies continually over the frequency range $(f_{min}$ to $f_{max})$ of the modulating signal being transmitted. Accordingly, the single value of $(f_c + f_m)$ is replaced by a band of frequencies extending from $(f_c + f_{min})$ to $(f_c + f_{max})$ called upper sideband as show in Fig:16.7. Similarly, the single value of $(f_c - f_m)$ is replaced by a band of frequencies extending from $(f_c - f_{max})$ to $(f_c - f_{min})$ called lower sideband as shown in Fig 16.7. The width of each band is $(f_{max} - f_{min})$ and the system needs a channel bandwidth of twice the maximum frequency of modulating system.

$$\text{i.e} \quad (f_c + f_{max}) - (f_c - f_{max}) = 2f_{max}$$

It is important to note that the information (i.e, the intelligence signal) is being carried by the sidebands which are symmetrically located around the carrier wave frequency.

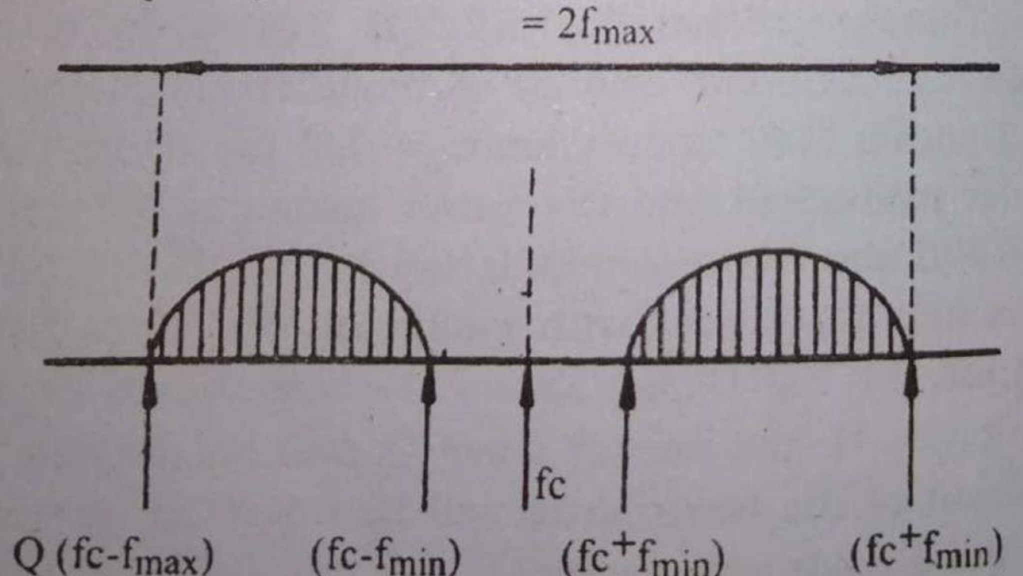


Fig. 16.7 Sidebands and Channel Bandwidth

(d) FREQUENCY MODULATION

In frequency modulation, the amplitude of the modulated carrier wave is maintained at its original strength. The frequency of the modulated carrier wave varies in proportion to the amplitude of the modulating signal, and at a rate determined by the frequency of the modulating signal. Fig:16.8 (a) shows unmodulated carrier. Fig:16.8 (a and b) shows that the frequency of the modulated carrier wave increases as the signal voltage incraeses and that it decreases as the signal voltage decreases. Comparison of Fig:16.8 (b) and Fig:16.8(c) shows that the variation in frequency is determined only by the amplitude of the signal, and the rate of variation in frequency of the carrier wave is determined by the frequency of the modulating signal.

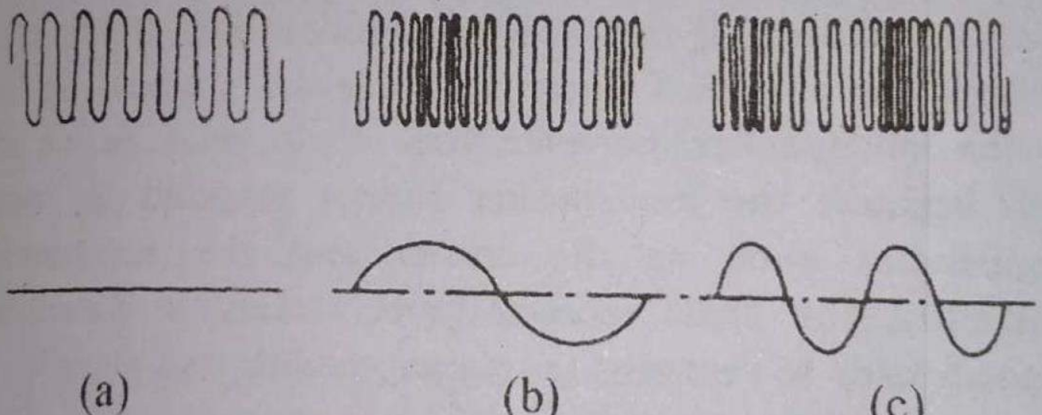


Fig: 16.8

The frequency of FM transmitter without any modulating signal input is called the centre frequency (or resting frequency) and corresponds to the original frequency of the FM transmitter. FM broadcast transmitters operate at frequencies of 88MHz to $108MH_Z$. When modulating signal is applied,the variation in frequency either above or below the resting frequency is known as frequency deviation, and the total deviation is called the carrier swing.

(e) RECEPTION OF ELECTROMAGNETIC WAVES

The process by which the original modulating signal,or intelligence,is recovered in the radio receiver is referred to as detection or demodulation.It was previously explained that an amplitude modulated carrier which has been modulated by intelligence (i.e voice,music) consists of the carrier wave,upper sideband and lower sideband frequencies and certainly does not contain the modulating frequencies.Therefore,the modulating signal,or frequencies must be reproduced in the receiver to complete the transmission and reception of intelligence.

The carrier with its upper and lower sidebands are radiated from the transmitting antenna in the form of electromagnetic waves.These electromagnetic waves,in turn,induce small voltages into the receiving antenna. These voltages are fed to a tuned radio frequency amplifier with sufficient bandwidth to include the upper and lower sidebands. If the receiver included only linear amplifiers, the amplified carrier and sidebands would be fed to the loudspeaker, however, this would produce no result because the loudspeaker cannot respond to radio frequencies such as the carrier and the sidebands. Therefore, the radio receiver must include a detector/demodulator to recover the original modulating signal.

Since each modulating frequency is the difference between a sideband frequency and the carrier frequency, it seems that a non linear device is needed to recover the modulating frequencies from the modulated carrier wave.

The most common technique of AM modulation,known as envelop detection is illustrated in Fig.16.9. The received AM wave is passed through a diode which acts a nonlinear device and eliminates the negative portions of the waves,converting it into a positive function with a nonzero average value. Since the message is contained in the low frequency variations(i.e the envelop) of this average about some nominal value, the resistor R and the capacitor C combination as shown in Fig16.9 recovers the modulation by separating out the envelope from the high frequency components as shown in Fig16.9.

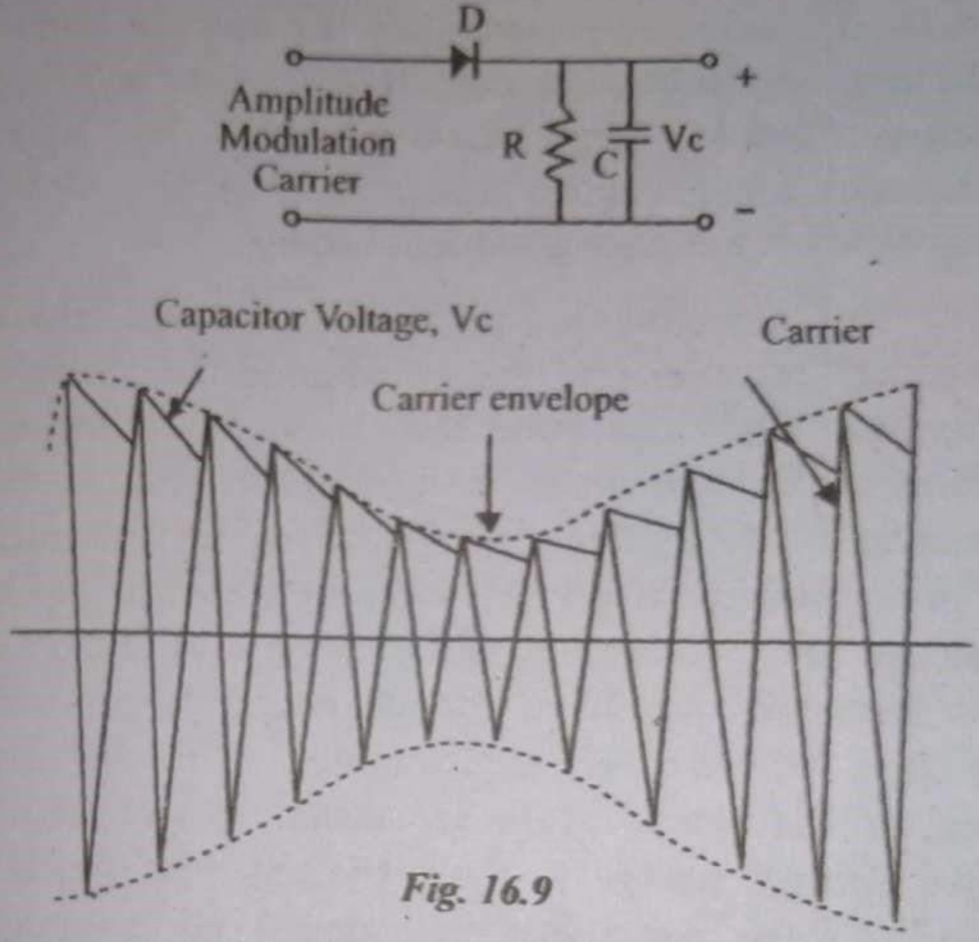
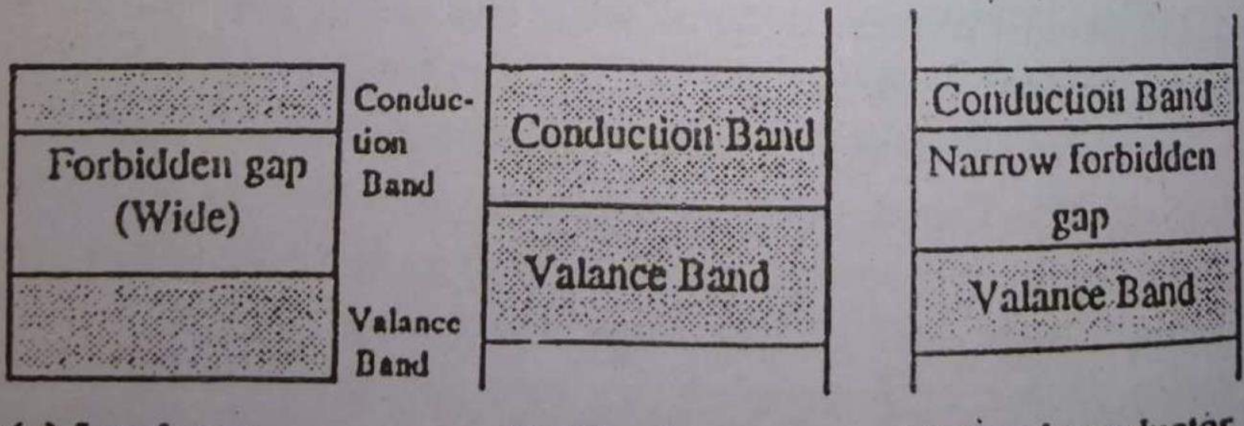


Fig. 16.9

16.3 The Band Theory of Solids.

One of the active fields of research today is called Solid State Physics. It deals with the structure and electrical properties of solids. According to Bohr atomic model electrons in a single atom can occupy only certain energy-levels. The detailed discussion of which is given in chapter 18. The lowest possible energy level is called the ground state and higher ones are called excited states. When atoms or molecules are in solid state, their outer electrons overlap. Hence their energy levels are changed some what and because of their interaction, the energy-levels are spread out into energy bands. The outer electrons can be considered to be in either of two bands. The lower valence band, which corresponds to the ground state;or the upper conduction band. No electron can have an energy in the "forbidden" energy gap between the two bands. Normally the electrons reside in the valence band where they are held more tightly to individual atom. In an insulator, the valence band is full, the conduction band is essentially empty, and the forbidden gap is fairly large as whown in Fig.16.10 (a). Hence normally there are no free states for the electrons to move into the higher conduction band.

In a conductor, on the other hand, there is no gap (fig. 16.10(b) and the two bands usually overlap or there is simply one band that is not filled and the electrons are free to move easily to other states. They can thus move about freely and carry on electric current. In a pure semiconductor the forbidden energy gap between valence and conduction bands is narrow Fig. 16.10(c). A few electrons may have enough energy to jump the gap, so there will be a very slight amount of electrical conduction. If the temperature is raised, more electrons will have enough energy to jump the gap and which further decreases the resistivity. In a doped semiconductor, the impurity provides additional energy states between the bands thus increasing the electrical conduction.



(a) Insulator (b) Conductor (c) Semi conductor

Fig. 16.10 (a) (b) (c)

16.4 Semi Conductors

The elements in the group IV i.e. silicon and germanium are semiconductors. They have narrow forbidden gap. When electrons are transferred from the valence band to the conduction band through some excitation, the valence band no longer remains filled and there are then energy levels whithin the valence band available for valence electrons in it, which can move successively just like cars in a traffic jam. When an opening appears in front of the first car, it moves froward to fill it, leaving an opening behind for the following car. This creation of openings and fillings by the car is repeated so that the net effect is that physical motion of the car is forward while opening behind then moves backward.In the electrical case, the vacancy created by the removal of an electron is a small positively charged region (absence of negative charge) is called a hole which is supposed to behave like a positively charged electron. When a nearby electron moves into a positive hole, it leaves behind another positive hole and so on the process continues till the end. Thus there is a net transport of positive charge which is called hole migration. Collectively electrons and holes are called carriers. Group IV elements Ge,Si are intrinsic semiconductors which form covalent bonds in which two atoms share one or more pairs of electrons. The following diagram fig. 16.11 of covalent bond for Ge shows the hole migration. Suppose that the electrons at A acquire some energy due to some excitation (say thermal) and become free so that covalent bond at A is broken. The electrons move through the crystal thus leaving behind a hole at A in the bond. Finding this vacancy, the electron at B may jump in there to occupy the vacant hole. This creates a hole at B, which may be filled by the electron at C and the process continues through successive electron movements till ultimately a hole appears at G. This may be said that a negative charge has moved from G to A or it will be convenient to regard a postive charge has moved from A to G.

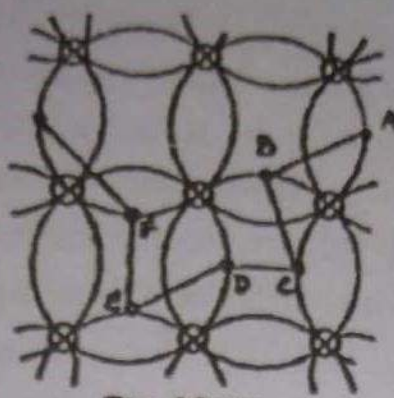
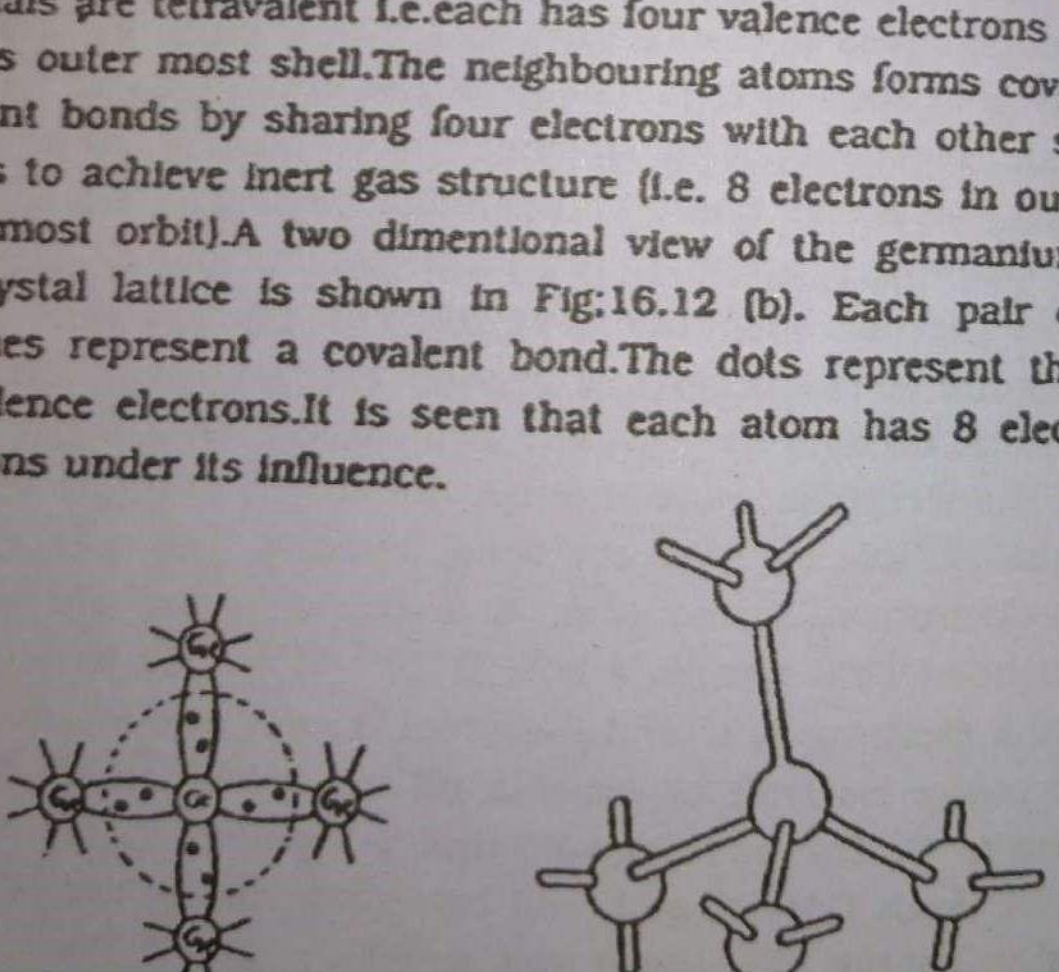


Fig. 16.11

In intrinsic semiconductors of group IV elements, the number of conduction electrons is equal to the number of holes.

16. 5 Atomic binding in semiconductors :

Semiconductors like germanium and silicon,have crystalline structure.Their atoms are arranged in an ordered array known as crystal structure.Both these materials are tetravalent i.e.each has four valence electrons in its outer most shell.The neighbouring atoms forms covalent bonds by sharing four electrons with each other so as to achieve inert gas structure (i.e. 8 electrons in outermost orbit).A two dimentional view of the germanium crystal lattice is shown in Fig;16.12 (b). Each pair of lines represent a covalent bond.The dots represent the valence electrons.It is seen that each atom has 8 electrons under its influence.



(b) (a)

Fig:16.12

A three dimentional view of germanium crystal lattice is shown in Fig;16.12 (a),where each atom is surrounded symmetrically by four other atoms forming a tetrahedral crystal.Each atom shares a valence electron with each of its four neighbours,thereby forming a stable structure.In case of pure (intrinsic) germanium, the covalent bonds have to be broken to provides electrons for conduction.There are many ways of breaking the covalent bond and hence setting the electrons free.

16.6 Preparation of semiconductors :

Intrinsic semiconductors Ge and Si of group IV have quite low values of conductivity due to small number of electrons and holes produced by thermal excitation.

To improve the conductivity and hence to change the electrical properties of semiconductors, elements from group III and V are added as an impurity in Ge and Si, and the semiconductor materials are said to be doped.

Thus doping is the addition of an impurity in a pure semiconducting material. Doped semiconductor materials are termed as extrinsic semiconductor, in which the concentration of impurity atoms is about one part per million.

There are two processes of doping.

(i) Donor doping

(ii) Acceptor doping.

(i) Donor doping:

Consider the intrinsic semiconductor Ge, doped with material of group V elements (arsenic, antimony or phosphorus) which have five electrons in their outermost orbit. Each Ge atom has four valence electrons, therefore each atom has four neighbourring atoms bound to it.

Four of the five electrons of antimony, the doping material, will form bonds with four electrons of Ge, while the fifth electron will remain as free charge carrier. When an electric field is applied, this free electron of antimony will be easily excited to jump to the conduction band from the valence band. Thus every antimony atom introduced into Ge contributes a conduction electron without creating a hole. Hence in addition to the electrons and holes available in Ge, the addition of antimony greatly increases the conductivity of the material. In this case, antimony is called a donor impurity and it makes Ge, an n-type (n for negative) semiconductor.

(ii) Acceptor doping:

If group III elements (boron, aluminium or gallium), which have three electrons in their outermost orbit, are added as an impurity in the intrinsic semiconductor Ge or Si, a deficiency of electrons in the crystal structure is introduced since three electrons of gallium are involved in the covalent bonding with the three atoms of Ge and the covalent bond with the fourth atom remains incomplete, thus creating a hole. Since after doping with group III elements the crystal structure becomes capable of accepting extra electrons, it is called acceptor doping and the material is called p-type (p for positive) semiconductor, due to the fact that there is a vacancy for negative charge or there is an existence of a hole. After application of an electric field their holes migrate to add to the conductivity. Thus we can prepare n-type or p-type extrinsic semiconductors by the addition of impurity in the intrinsic semiconductors from group V or III elements. In n-type semiconductor, current carried is mainly through electrons while in p-type semiconductor, the current is carried through holes.

16.7 Crystallography:

A crystal is a collection of atoms or molecules in which each atom is placed precisely in a definite pattern with respect to its neighbour in the solid. This pattern is repeated over and over again throughout the crystal. The study of the geometric form of crystalline solids by using X-rays, electron or neutron beams constitute the science of crystallography. Crystalline solids are those in which the atoms or molecules are arranged in a very regular and orderly fashion in a three dimentional pattern. Each atom or molecule is fixed at a definite point in space at a definite distance from and in a definite angular orientation to all others surrounding it. This internal spatial symmetry of atomic or molecular orientation is an essential feature of crystalline state. The angular arrangement of the space positions of the atoms in a crystal is called space lattice or lattice array.

16.8 Crystal Lattice and Unit Cell:

The entire lattice structure of a crystal consists of identical blocks of unit cells. The unit cell is the smallest block or geometrical figure from which the crystal is built up by repetition in three dimensions. The unit cell is a parallelopiped, which by moving in the direction of each of the coordinate axes X, Y and Z, arranged parallel to edges of the figure, the crystal lattice can be constructed. The length of the side of a unit cell is the distance between atoms of the same kind nd is known as lattice constant, as shown in fig. 16.13.

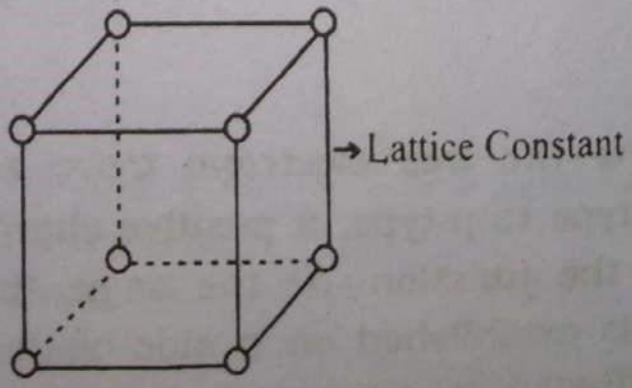


Fig. (16.13)

16.9 The p.n. Junction or Semi Conductor Diode

When a block of p-type material is put adjacent to a block of n-type material, the common plane is termed as p-n junction and the device is called semiconductor diode. Fig. 16.14(a) show a p-type and a n-type semiconductor. In a p-n junction, we know that n-type material has high concentration of free electrons while p-type material has those of holes. Therefore at the junction there is a tendency for the free electrons to diffuse over to the p-side and holes to the n-side. This process is called diffusion.

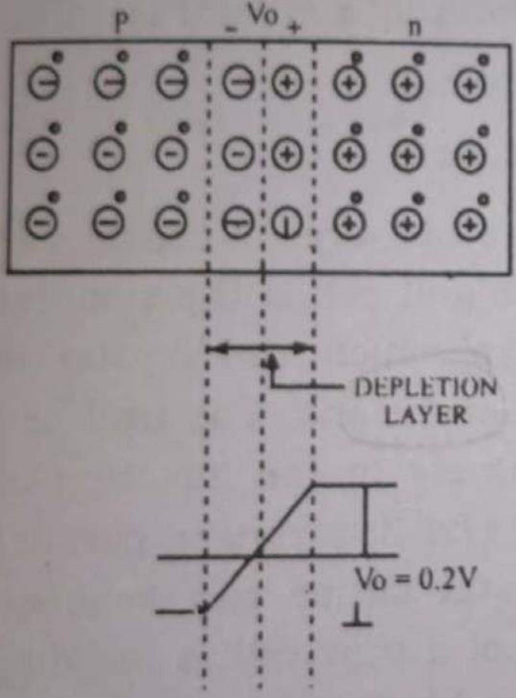


Fig. 16.14 (b)

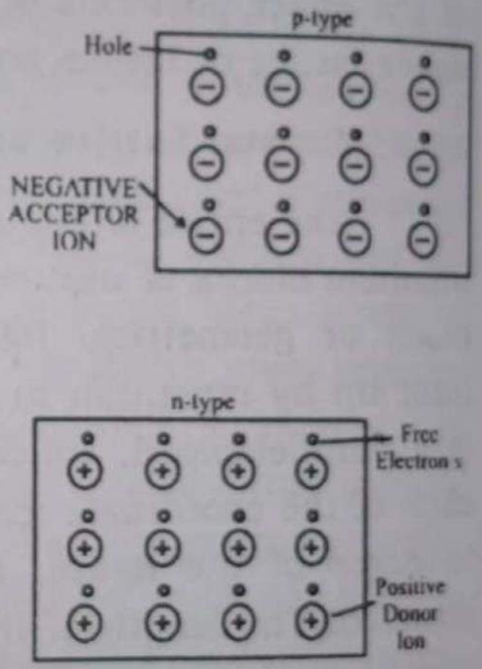


Fig. 16.14 (a)

As the free electrons move across the junction from n-type to p-type, a positive charge is built on the n side of the junction. At the same time, a net negative charge is established on p side of the junction and further diffusion is prevented. It is because now positive charge on n side repels holes to cross from the p side to n-type and negative charge on p side repels free electrons to enter from n-type to p-type. Thus, a barrier is set up against further movement of electrons and holes. This is called Potential barrier or Junction barrier, V_o, which is of the order of 0.1 to 0.7 volts. The potential distribution diagram is shown in fig. 16.14(b). This potential barrier gives rise to electric field which prevents the respective majority carriers from crossing the barrier region. It is to be noted that only inside the barrier, there is a positive charge on n side and a negative charge on the p side. This region is called depletion region. Outside the barrier on each side of the junction, the material is still neutral. When a p-n junction diode is connected across a battery, it permits the flow of current in one direction, similar to that of vacuum tube diode. It is a two terminal device and is symbolically represented in the following figure 16.14 (c).

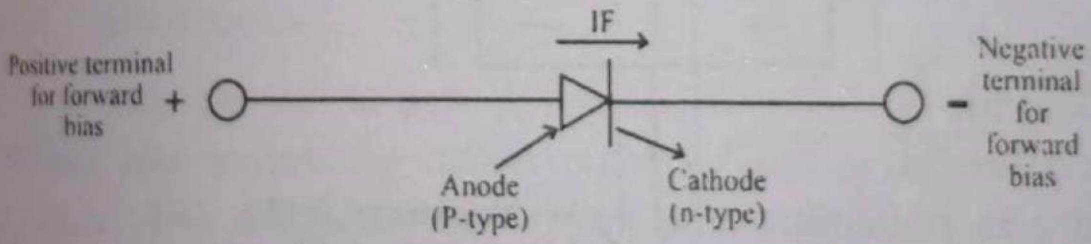


Fig. 16.14 (c)

The application of some electric potential across the diode is known as biasing.

16.10 Biasing

The potential difference across a p-n junction can be applied in two ways, namely

(i) forward biasing and

(ii) reverse biasing.

(i) Forward biasing:

When external voltage applied to the junction is in such a direction that it cancels the potential barrier, thus permitting current flow. It is called forward biasing. To apply forward bias, connect positive terminal of the battery to p-type and negative terminal to n-type as shown in fig.16.15 The applied forward potential establishes an electric field which acts against the field due to potential barrier. Therefore the resultant field is weekend and the barrier height is reduced at the junction as shown in fig. 16.15. As potential barrier voltage is very small (0.1 to 0.3 V), therefore, a small forward voltage is sufficient to completely eliminate the barrier. Once the potential barrier is eliminated by the forward voltage, junction resistance becomes almost zero and a low resistance path is established for the entire circuit. Therefore current flows in the circuit.

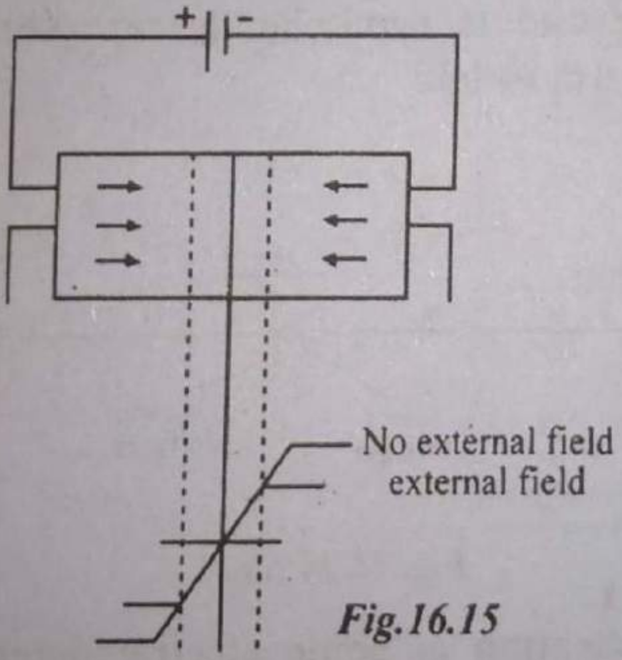


Fig.16.15

(ii) Reverse biasing :

When the external voltage applied to the junction is in such a direction that potential barrier is increased, it is called reverse biasing.To apply reverse bias, connect negative terminal of the battery to P-type and positive terminal to n-type as shown in fig.16.16. It is clear that applied reverse voltage establishes an electric field which acts in the same direction as the field due .to potential barrier.Therefore, the resultant field at the junction is strengthened and the barrier height is increased as shown in fig. This increased potential barrier prevents the flow of charge carriers across the junction.Thus, a high resistance path is established for the entire circuit and hence the current does not flow.

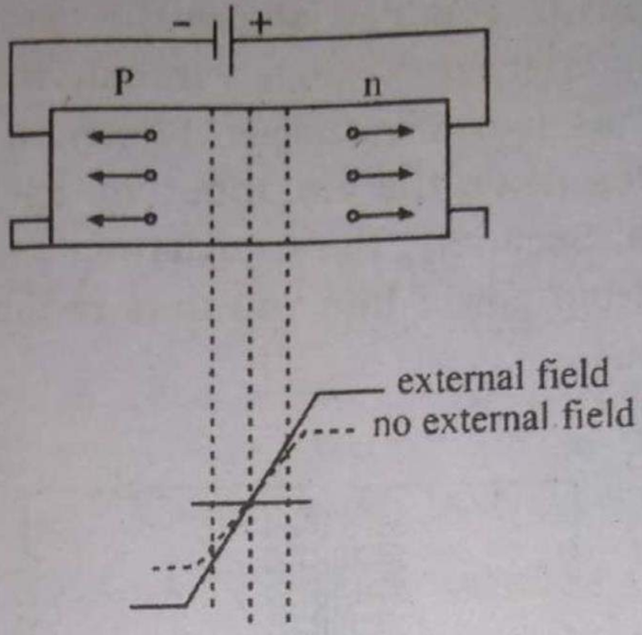


Fig. 16.16

16.11 Semi Conductor Diode (Crystal Diode) Rectifiers.

The device which converts alternating current/ voltage into pulsating direct current/voltage is called a rectifier. The following two types of rectification can be obtained using a diode (i) halfwave rectifier and (ii) full wave rectifier.

A semiconductor diodes, also known as crystal diodes, can be used for rectification purposes. The details of each is given as follows.

(i) Halfwave rectifier :

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

Circuit details :

Figure 16.17 shows the circuit where a single diode acts as a halfwave rectifier. The a.c. signal to be rectified is applied in series with the diode and load resistance R_L. The d.c. output is obtained across the load R_L. Generally, a.c. supply is given through a transformer. The use of transformer has two advantages. Firstly, it allows us to step up or step down the a.c. input voltage as the situation demands. Secondly, the transformer isolates the rectifier circuit from power line and thus reduces the risk of electric shock.

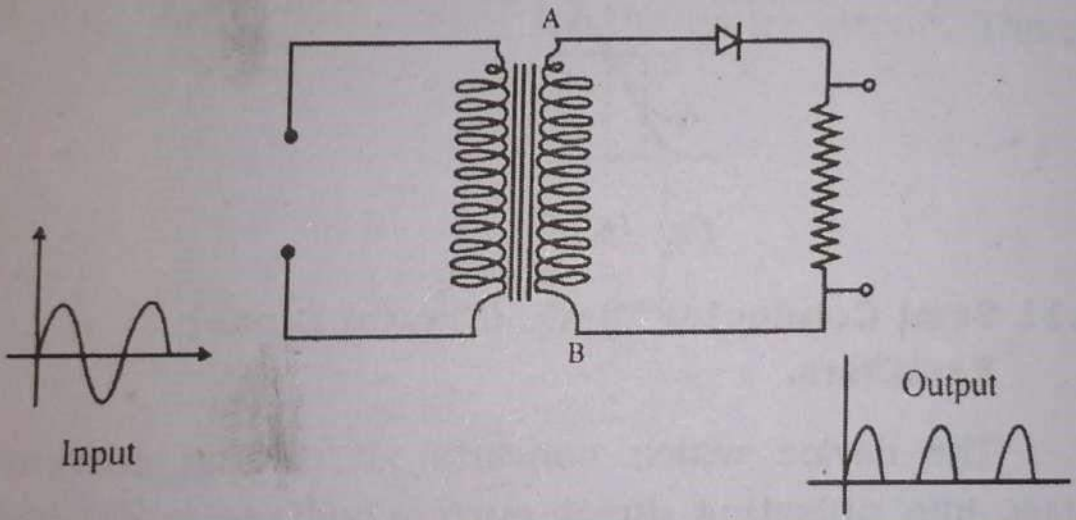


Fig. 16.17

Operation :

The a.c. voltage across the secondary winding AB changes polarities after every half cycle. During the positive half cycle of input a.c. voltage, end A becomes positive with respect to end B. This makes the diode forward biased and hence it conducts current. During the negative half cycle, end A is negative with respect to end B. Under this condition the diode is reverse biased and it conducts no current, therefore the current flows through the diode during positive half cycles of input a.c. voltage and it is blocked during the negative half cycles. In this way current flows through load R_L always in the same direction. Hence d.c. output is obtained across R_L. It may be noted that output across load is pulsating d.c. These pulsations in the output are further smoothened with the help of filter circuits.

(II) Fullwave rectifier :

In fullwave rectification, current flows through the load in the same direction for both half cycles of input a.c. voltage. This can be achieved with two diodes working alternately. For the positive half cycle of input voltage, one diode supplies current to the load and for the negative half cycle, the other diode does so; current being always in the same direction through the load.Therefore, a fullwave rectifier utilizes both half cycles of input a.c. voltage to produce the d.c. output.

(III) Construction of Fullwave rectifier :

The circuit employees two diodes D_1 and D_2 as shown in fig.16.18. A center tapped secondary winding AB is used with two diodes connected so that each uses one half cycle of input a.c. voltage. In other words D_1 utilizes the a.c. voltage appearing across the upper half OA of secondary winding for rectification while diode D_2 uses the lower half winding OB.

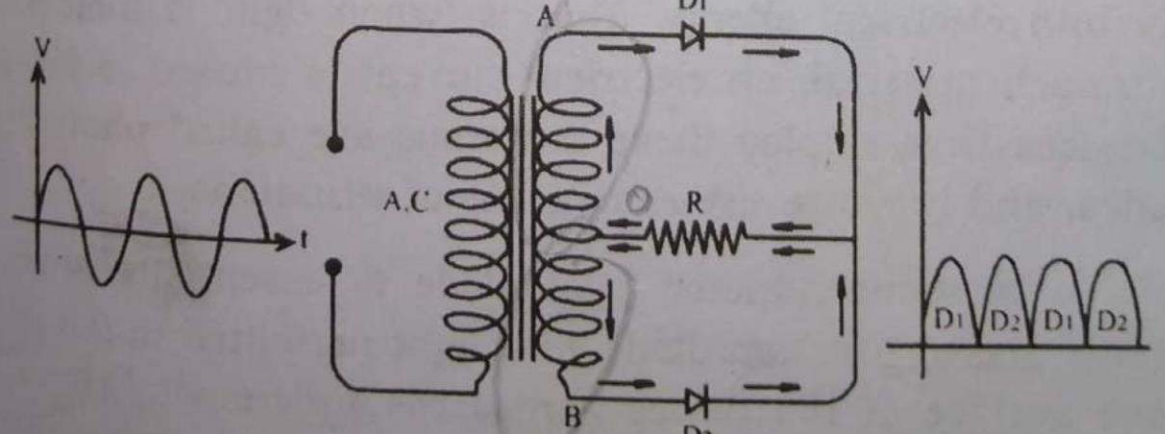


Fig. 16.18

Operation :

During the positive half cycle of secondary voltage, the end A of secondary winding becomes positive and end B negative. This makes the diode D_1 forward biased and diode D_2 reverse biased. Therefore, diode D_1 conducts while diode D_2 does not. The conventional current flow is through diode D_1, load resistor R_L and the upper half of the secondary winding, as shown by the dotted arrow. During the negative half cycle, end A of the secondary winding becomes negative and end B positive. Therefore, diode D_2 conducts while diode D_1 does not. The conventional current flows is through diode D_2, load R_L and lower half winding as shown by solid arrow. Referring to fig. 16.11 it may be seen that current in the load R_L is in the same direction for both half cycles of input voltage. Therefore, d.c. output is obtained across the load R_L for both cycles of the input a.c.

The full wave rectifier output is more efficient source f power and is easier to filter than a half wave rectifier output. Also, its average value of d.c. voltage is much higher than fo the half wave rectifier.

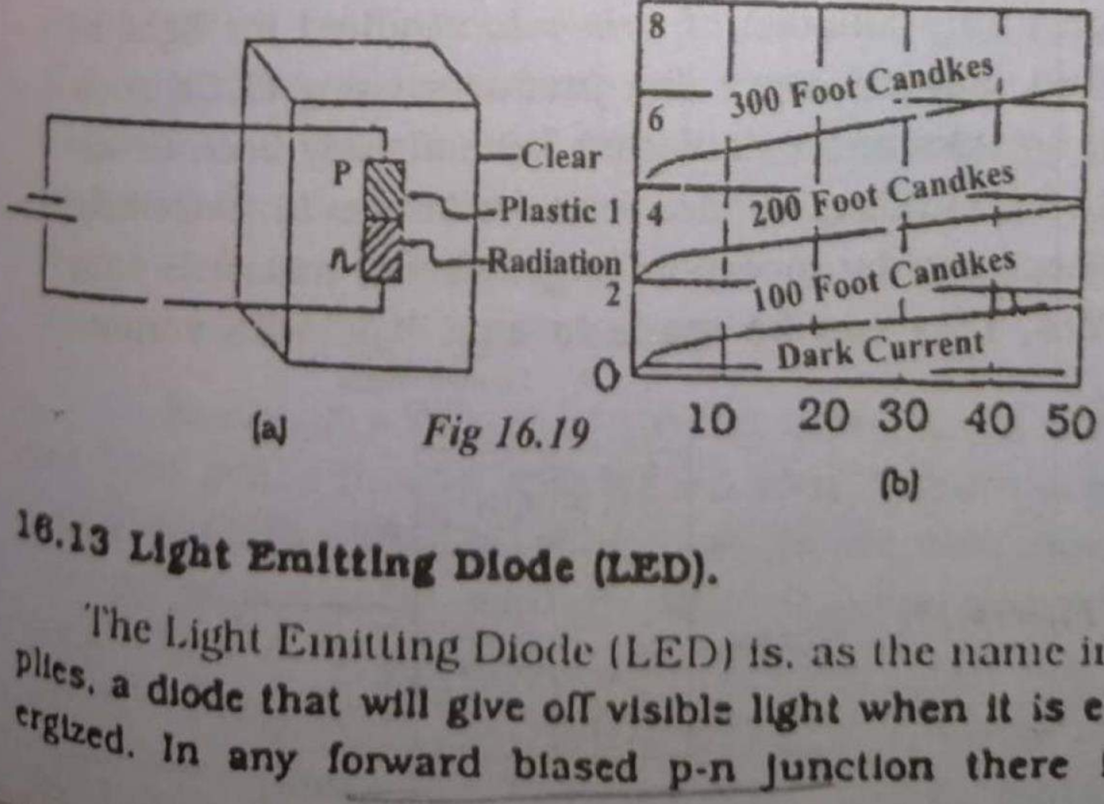
16.12 Photodiodes:

Certain type of semiconductor materials have the interesting property that they convert light energy directly into electrical energy. That is, when light is incident on such material, an electrical current is caused to flow. Devices that employ these materials are called photodiodes, and they.are used in variety of situations.

A semiconductor photodiode is essentially a reverse biased junction diode with light permitted to fall on cne surface of the device across the junction fig.16.19. The remaining sides are kept unilluminated. Then the diode current varies almost linearly with the light flux. Fig. 16.19 shows the structure. The p-n junction is embedded in a clear plastic capsule. All the sides of the plastic capsule except the illuminated one are painted black or enclosed in a metallic case. Fig. 16.19 shows the voltage ampere characteristic curves for a typical germanium photodiode. With no illumination, there exists only the small reverse saturation current (I_o). On illuminating the reverse biased p-n junction, new electron-hole pairs are formed, the concentration of which is proportional to the incident light flux. Under large reverse bias condition, the total reverse current I is given by :

$$I = I_s + I_o$$

where I_s is the short circuit current and is proportional to the light intensity. Curves for three different values of illumination are shown in fig. 16.19(b). As with the barrier layer photoelectric cell, the spectrum sensitivity of photodiode is determined by photoelectric properties of semionductor material. Photodiode compare favourably with photoelectric cells in that they have smaller size and weight, higher integral sensitivity and a lower working voltage. Photodiodes are used in high speed reading of computer punched cards and tapes, light detection system, light operated switches, production line counting of objects etc.



(a) Fig 16.19 (b)

16.13 Light Emitting Diode (LED).

The Light Emitting Diode (LED) is, as the name implies, a diode that will give off visible light when it is energized. In any forward biased p-n junction there is, within the structure and primarily close to the junction, a recombination of holes and electrons. The recombination requires that the energy possessed by the unbound free electron be transferred to another state. In all semiconductor p-n junctions some of this energy will be given off as heat and some in the form of photons. In silicon and germanium the greater percentage is given up in the form of heat and the emitted light is in significant. In other materials, such as gallium arsenide phosphide (Ga As P) or gallium phosphide (Ga P), the number of photons of light energy emitted is sufficient to create a very visible light source. The process of giving off light by applying an electrical source of energy is called electroluminescence. As shown in fig.16.20, the conducting surface, connected to the p-material, is much smaller to permit the emergence of the maximum number of photons of light energy. Note in the figure that the recombination of the injected carriers due to the forward biased junction is resulting in emitted light at the site of recombination. There may, of course, be some absorption of photon energy in the structure itself but a very large percentage are able to leave, as shown in the figure.

LEDs can be used in battery operated devices because only tiny amount of power is required for light to be emitted. Several every day products using LEDs such as digital clocks and calculators have already been developed. Light emitting diodes can be made in extremely small sizes, and by incorporating different materials into the diodes, they can be made to emit light with various colours.

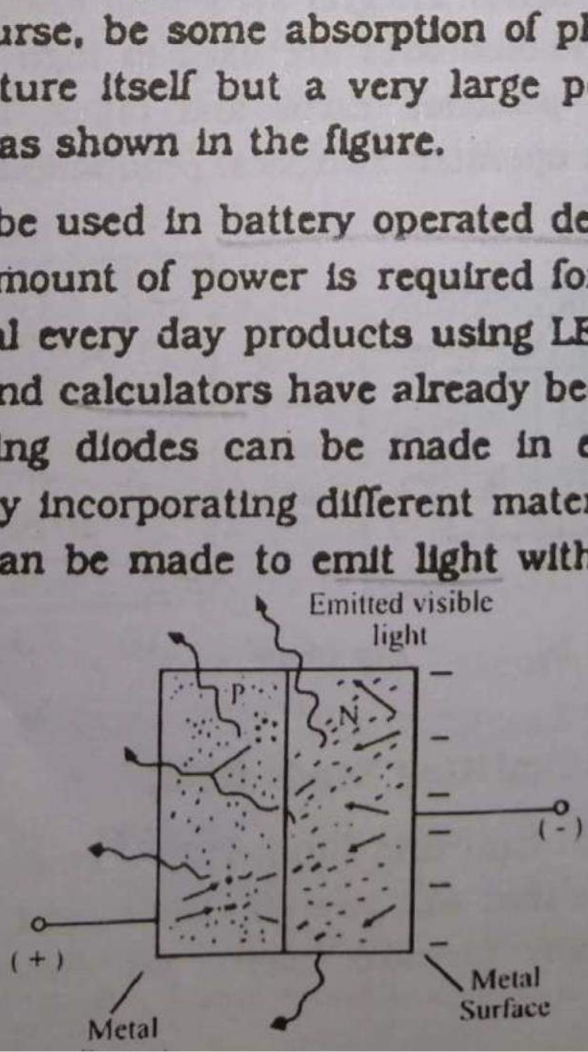


Fig (16.20)

16.14 Solar cell

A solar cell is a photodiode that is used to extract energy from sun light. The basic construction of a silicon p-n junction is shown in Fig. 16.21. As shown in the top view, every effect is made to ensure that the surface area perpendicular to the sun is a maximum. Also note that the metallic conductor connected to the p-type material are such that they ensure that a maximum number of photons of light energy will reach the junction.

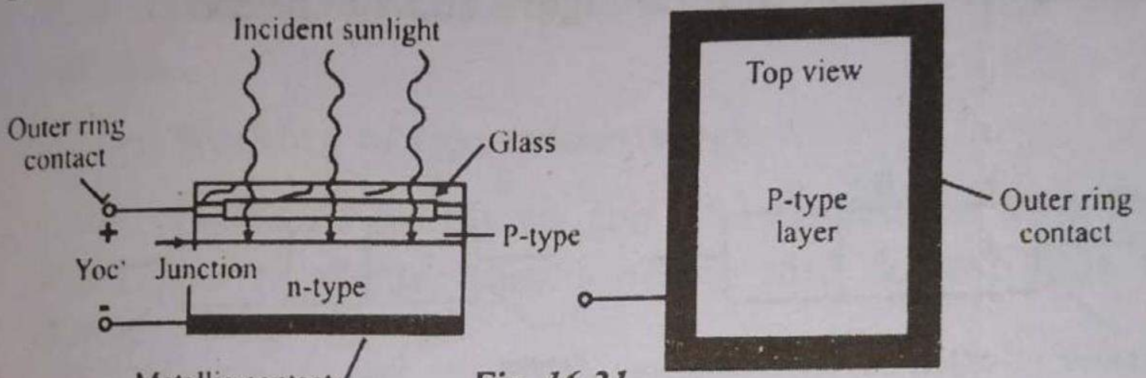


Fig. 16.21

A photon of light energy in this region may collide with a valence electron and impart to it sufficient energy to leave the parent atom. The result is a generation of free electron, and holes. This phenomena will occur on each side of the junction. In the p-type material the newly generated electrons are minority carriers and will move rather freely across the junction as explained for the basic p-n junction with no applied bias. A similar discussion is true for the holes generated in the n-type material. The result is an increase in the minority carrier flow which is opposite in direction to the conventional forward current of a p-n junction.

Selenium and silicon are the widely used material for solar cell, although gallium arsenide, indium arsenide and cadmium sulphide, among others are also used. Commercial silicon solar cell have high stability and conversion efficiency approximately 14%. Solar cells are used for converting solar light energy in to electrical energy in space vehicles.

16.15 Transistor:

The word transistor is the combination of two words, first transfer and second resistor. It is an active semiconductor device that has three electrodes. The first device that was invented was the "bipolar junction transistor" (BJT).

The transistor may consist of an p-type material sandwiched between two n-type materials called npn transistor, as shown in the figure 16.22(a) below:

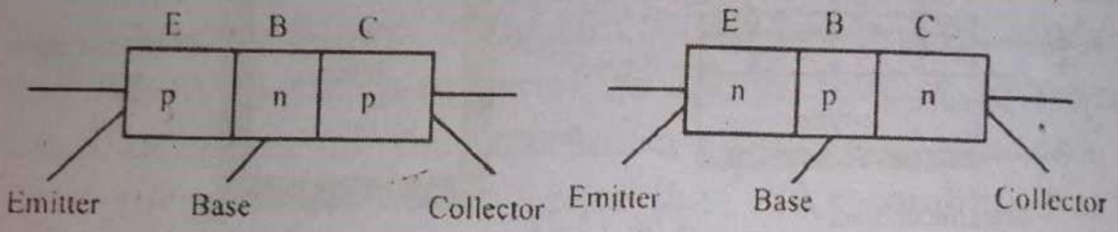


Fig. 16.22 (a)

The central layer between the two is called the base. Among the remaining two, one is called emitter and the other collector, according to the function they perform during operation. These three electrodes are provided with terminals for connection in the circuit. Symbols used for npn and pnp transistors are shown below in Fig. 16.22 (b).

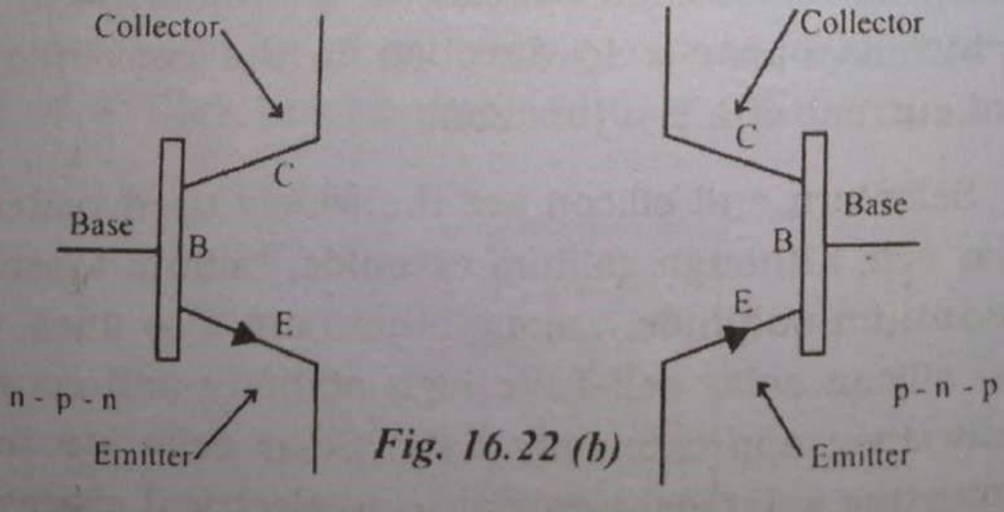


Fig. 16.22 (b)

The arrows of the transistor show the direction of the conventional current from p to n.

16.16 Transistor Operation:

The emitter-base junction of a transistor is forward biased whereas the collector-base junction is reverse biased. If we ignore the presence of emitter-base junction, no current would flow in the collector circuit because of reverse biasing. However, if emitter-base junction is also present, then forward bias on it causes the emitter current to flow. Thus the current in the collector circuit depends upon the emitter current. We shall now discuss the transistor action for npn and pnp transistors.

i) Working of npn transsistor:

Fig.16.23 (a) Shows the npn transistor with forward bias to emitter-base junction and reverse bias to collector-base junction.

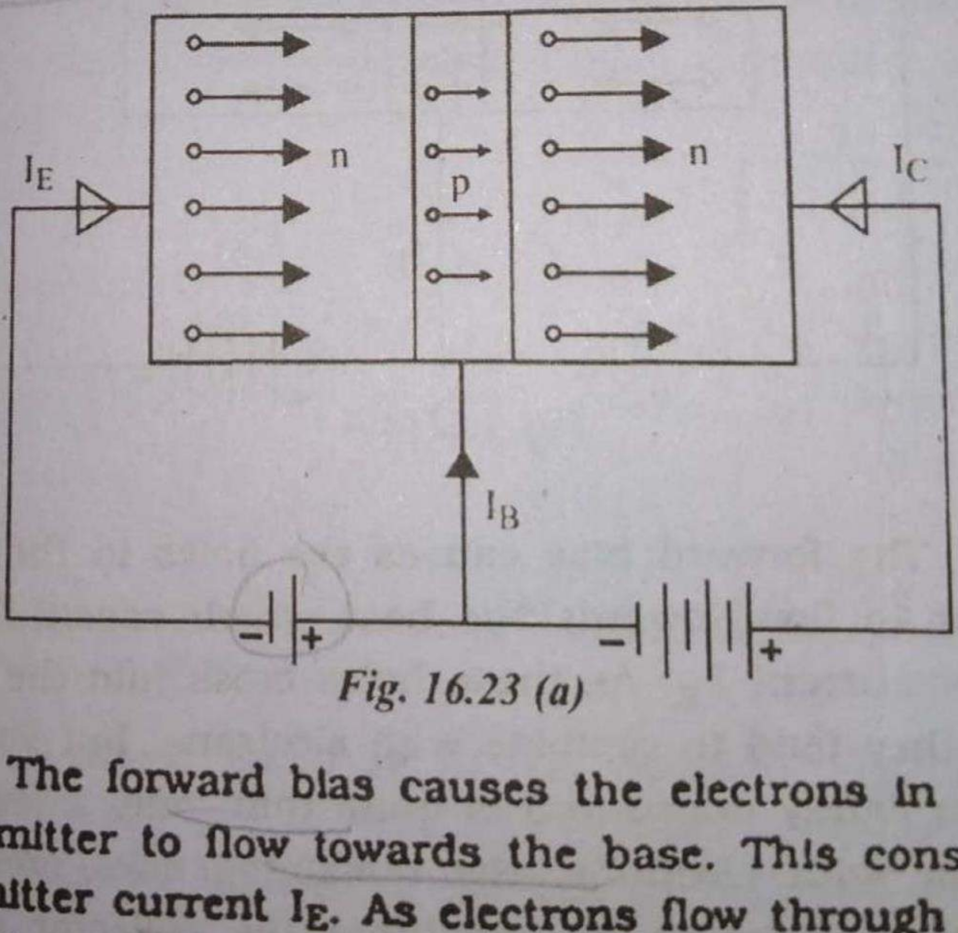


Fig. 16.23 (a)

The forward bias causes the electrons in the n-type emitter to flow towards the base. This constitutes the emitter current I_E. As electrons flow through p-type base, they tend to combine with holes. Since the base is lightly doped and is very thin, therefore, only a few electrons (less than 5%) combine with holes to constitute base current I_B. The remainder (more than 95%) cross over into the collector region to constitute collector current I_C. In this way, almost the entire emitter current flows in the collector circuit. It is clear that

$$I_E = I_B + I_C$$

We define α as the ratio of I_C and I_E i.e.

$$\text{Current gain } \alpha = \frac{I_C}{I_E}$$

ii) Working of pnp transistor:

Fig. 16.23 (b) Shows the basic connections of a pnp transistor.

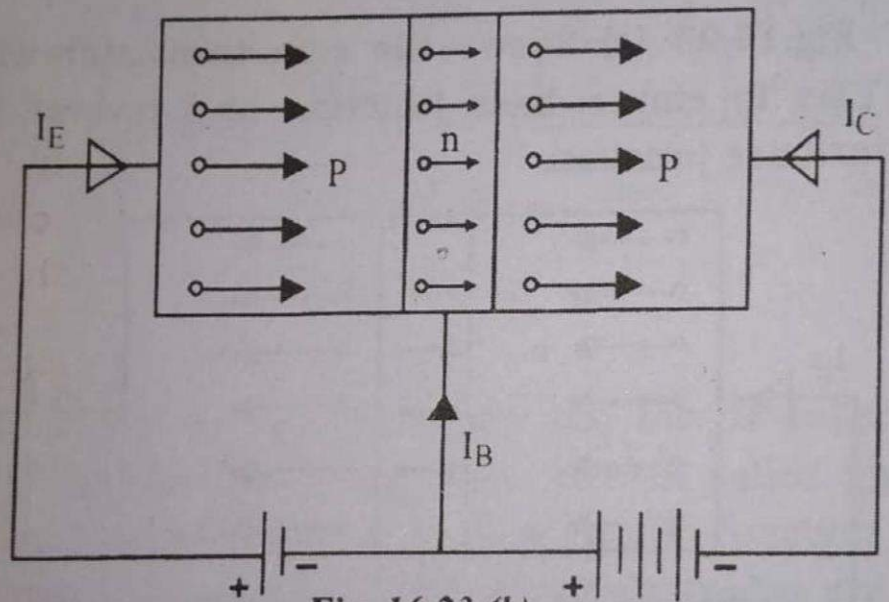
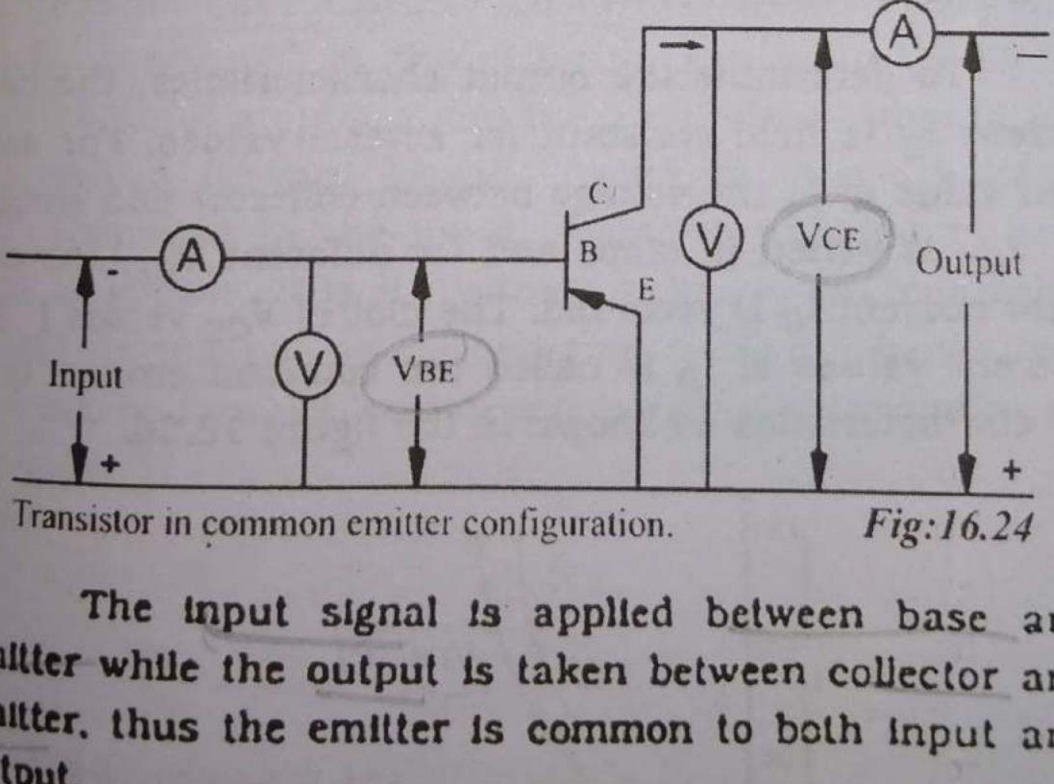


Fig. 16.23 (b)

The forward bias causes the holes in the p-type emitter to flow towards the base which constitutes the emitter current I_E. As these holes cross into the n-type base, they tend to combine with electrons, but since the base is lightly doped and is quite thin, only a few holes combine with electrons, the remaining ones cross into the collector region, to constitute the collector current I_C. In this way almost the entire emitter current flows in the collector circuit. Here the current conduction is by holes, but in the external connecting wires, the current is still by electrons.

16.17 Transistor Characteristics:

When we want to use the transistor as an amplifier, then we apply the input between two terminals of the transistor and obtain the amplified output at the other two terminals.The transistor is basically a three terminal device, so we declare one terminal as being common to both sides.the input and the output. The transistor can be operated in any one of the three useful configurations which is usually named by the common terminal i.e. Common Base (CB), Common Emitter (CE) and Common Collector(CC).**The static characteristics** for the transistor contain two sets of curves - first set, the input characteristics, gives the relationship between input voltage and input current, while the second set is the output characteristics which gives the voltage and current relationship at the output terminal. Let us only consider the common emitter configuration and it's characteristics. This is the configuration most commonly used in devices.



Transistor in common emitter configuration. *Fig:16.24*

The input signal is applied between base and emitter while the output is taken between collector and emitter, thus the emitter is common to both input and output.

(i) Input Characteristics:

To draw the input characteristics, the output voltage V_{CE} is held constant and for different values of input voltage V_{BE}, the base current I_B is recorded. The process is repeated for different values of V_{CE}. Now a plot of base emitter voltage V_{BE} versus base current I_B gives the input characteristics for different values of V_{CE} being constant, as shown in Fig. 16.25.

[redacted]

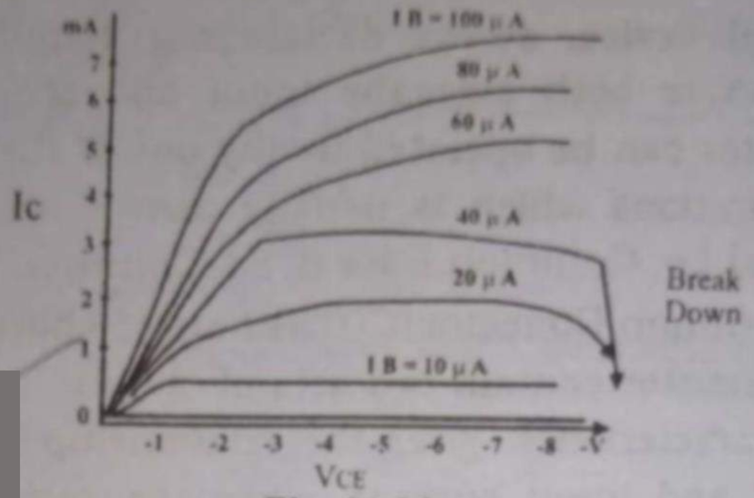


Fig. 16.25

[redacted]

[redacted]

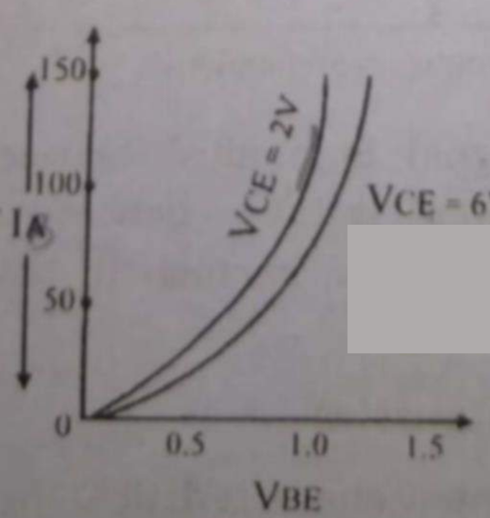
[redacted]

It should be noted that for a given V_{BE}, I_B decreases with the increase in V_{CE}. This is due to increase in junction potential across the collector base junction.

(ii) Output Characteristics:

To determine the output characteristics, the base current I_B is held constant for several values. For each fixed value of I_B the voltage between collector and emitter i.e. V_{CE} is varied in steps and for different V_{CE}, the collector current I_C is recorded. The plot of V_{CE} verses I_c for different values of I_B is called the common emitter output characteristics as shown in the figure 16.26.

[redacted]



[redacted]

Fig. 16.26

Here the collector base junction is reverse biased and the emitter base junction is forward biased so as we increase the voltage V_{CE}. the majority carriers are emitted from the emitter and also more are collected at the collector. Due to collection of more majority carriers at the collector, the current I_c is increased. It is clear from the figure that the collector current becomes zero when voltage between collector and emitter is zero. Similarly,we can draw the common collector characteristics also.

16.18 Transistor As An Amplifier :

An amplifier is a device that raises the strength of a weak signal.Fig. 16.27 (a). Transistors can be used for the purpose of amplification of weak signals and thus act as an amplifier.

To understand the function of transistor as an amplifier. Fig. 16.27 (b), the weak signal is applied between emitter base junction and output taken across the load R_C connected in the collector circuit. In order to achieve faithful amplification, the input circuit should always remain forward biased. To do so, a d.c voltage V_{EE} is applied in the input circuit in addition to the signal as shown. This d.c voltage is known as bias voltage and its magnitude is such that it always keeps the input circuit forward biased regardless of the polarity of the signal.

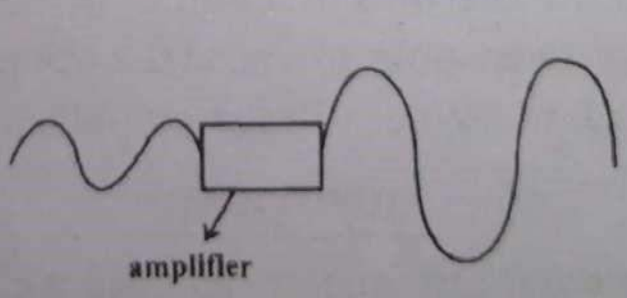


Fig. 16.27(a)

As the input circuit has low resistance, therefore, a small change in signal voltage causes an appreciable change in emitter current.This causes almost the same change in collector current due to transistor action. The collector current flowing through a high load resistance R_C produces a large voltage across it.Thus a weak signal applied in the input circuit appears in the amplified form in the collector circuit. It is in this way that a transistor acts as an amplifier.

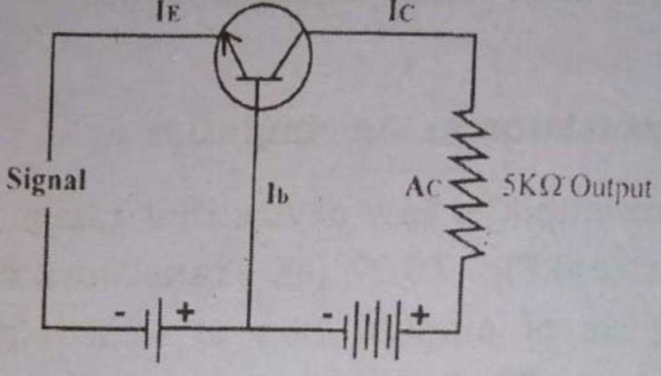


Fig. 16.27(b)

Illustration:

The action of a transistor as an amplifier can be made more illustrative if one considers typical circuit values. Suppose collector load resistance $R_C = 5K\ \Omega$.Let us further assume that a change of 0.1 V in signal voltage produces a change of 1mA in emitter current. Obviously, the change in collector current would also be approximately 1mA.This collector current flowing through collector load R_C would produce a voltage $= 5k\Omega \times 1mA = 5V$. Thus, a change of 0.1V in the signal has caused a change of 5V in the output circuit. In other words, the transistor has been able to raise the voltage level of the signal from 0.1 to 5V i.e. voltage amplification is 50.

QUESTIONS

16.1 Under what circumstances does a charge radiates electromagnetic waves ?

16.2 In an electromagnetic wave, what is the relationship, if any, between the variations in the electric and magnetic fields?

16.3 A radio transmitter has a vertical antenna. Does it matter whether the receiving antenna is vertical or horizontal ?

16.4 Explain, Why are light wave able to travel through a vacuum, whereas sound waves cannot ?

16.5 Explain the condition under which radiation of electromagnetic waves takes place from a certain source ?

16.6 Describe the electromagnetic wave spectrum ?

16.7 What are semiconductors? Describe the structure of germanium crystal ?

16.8 Can a diode be used for amplifying a weak signal?

16.9 What is the difference between n-type and p-type germanium?

16.10 Are radio waves a form of light ?

16.11 Can electromagnet wave be propagated through a piped vacuum?

16.12 What is the difference between amplitude modulation and frequency modulation ?

16.13 Give the energy band description of semiconductors ?

16.14 Discuss the effect of temperature on semiconductors ?

16.15 Give the mechanism of hole current in semiconductors ?

16.16 What is crystallography. Explain the space lattice?

16.17 Explains the lattice unit cell and lattice parameter of a unit cell?

16.18 What is pn - junction? Explain the formation of potential barrier in pn-junction?

16.19 Explain photodiodes and solar cells ?

16.20 Discuss in detail the light emitting diodes ?

16.21 What do you understand by valence band, conduction band and energy gap ?

16.22 What is transistor? Why it is so called.Show diagrammatically the battery connection to a (i) pnp transistor (ii) npn transistor, for it's normal working ?

16.23 Describe the operation of a transistor amplifier?

16.24 In what wave-length range do radar signals lie ?

PROBLEMS

16.1 Light is said to be a transverse wave phenomenon. What is that varies at right angles to the direction in which a light wave travel ?

16.2 A radar sends out 0.05μs pulses of microwaves whose wave length is 2.5 cm. What is the frequency of these microwaves? How many waves does each pulse contain ?

16.3 A nanosecond is 10^{-9}s (a) What is the frequency of electromagnetic wave whose period is 1ns? (b) What is it's wave length? (c) To what class of electromagnetic waves does it belong?

Ans: (10^9 Hz, 0.3m)

16.4 With a sketch explain the working of (i) Half wave rectifier (ii) Full wave rectifier ?

16.5 Explain the difference between the band structure of a semiconductor and that of a metal. Why does a semiconductor acts as an insulator at 0°K and why does it's conductivity increases with increasing temperature ?