Chapter - 17

Electromagetic Waves, Communication and Contemporary Physics

Electromagnetic wave is present in our atmosphere in different forms, sometimes we are unable to detect their presence in the space. Light is also a form of electromagnetic wave. Infrared waves are also electromagnetic wave and keep the atmosphere heated-up. Microwaves are very useful in kitchen *i.e.*, in microwave oven and also in communication like radio, mobile telephony and RADAR.

In this chapter, we will study about the nature and properties of electromagnetic waves. Maxwell's equations are basis for electromagnetic waves. The most important prediction emerged from Maxwell's equations is the existence of electromagnetic waves, which are (coupled) time-varying electric and magnetic fields that propagate in space. This led to the remarkable conclusion that light is an electromagnetic wave. Maxwell's work thus unified the domain of electricity, magnetism and light. We will discuss about qualitative aspect of these. Communication is possible due to electromagnetic waves, technological use of electromagnetic waves by Marconi and others led in due course, the revolution in communication that we are witnessing today.

Later we will discuss about nanotechnology. This is new branch of science emerged in three decades. This basically depends on Quantum mechanics. Nanotechnology will bring a revolution in science. For example you consider that in summer you are wearing such clothes which make you feel cool and in winter you are wearing such clothes which make you feel warm after wearing.

17.1. Displacement current

We have discussed in Chapter-7 that an electric current produces a magnetic field around it. Maxwell showed that for logical consistency, a changing electric field must also produce a magnetic field.

To see how a changing electric field gives rise to a magnetic field, let us consider the process of charging of a capacitor and apply Ampere's circuital law given by

$$\oint \vec{B}.\vec{dl} = \mu_0 I \qquad ....(17.1)$$

Where line integral is along a closed path which encloses conduction current and I is given by $I = dq/dt$

To find magnetic field at a point outside the capacitor : Figure 17.1, shows a parallel plate capacitor C which is a part of circuit through which a time dependent current I flows. Let us find the magnetic field at a point p in a region outside the parallel plate capacitor. For this, we consider a plane circular loop of radius r whose plane is perpendicular to the direction of the current-carrying wire, and which is centred symmetrically with respect to the wire. (fig. 17.2 (a)). From symmetry, the magnetic field is directed along the circumference of the circular loop and is the same in magnitude at all points, the left side of equation (17.1) is B $(2\pi r)$.

So we have $B.(2\pi r)= \mu_0 I \qquad ...(17.1\ (a))$

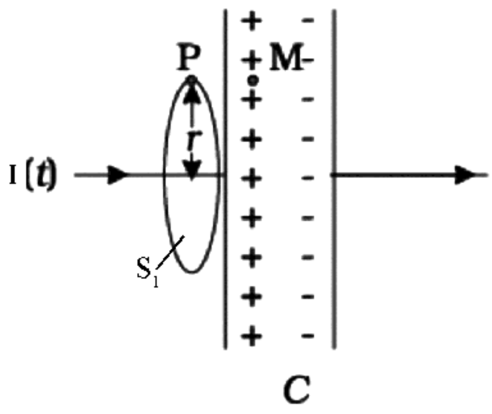
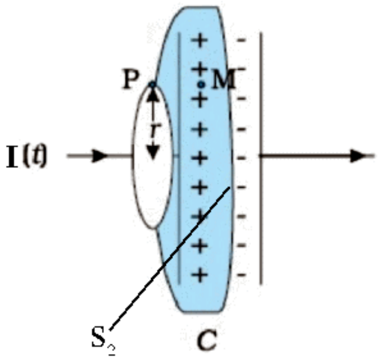
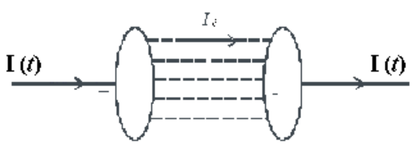


Fig. 17.1 : Time dependent current I (t) through capacitor & surfaces S_1 under considration

Now, consider a different surface, which has the same boundary. This is a pot like surface. (Figure 17.2 (a)) which nowhere touches the current, but has its bottom between the capacitor plates; its mouth is the circular loop mentioned above. Another such surface is shaped like a tiffin-box (without the lid) figure 17.3, On applying ampere's circuital law to such surfaces with the same perimeter, we find that the left hand side of equation (17.1) has not changed but the right hand side is zero and not $\mu_0 i$, since no current passes through the surface of figure 17.2(b). So we have a contradiction; calculated one way, there is a magnetic field at a point P; calculated another way, the magnetic field at P is zero.



(a)



(b)

Fig. 17.2 : (a) Electric field between charging plates (b) Displacement current between the plates

Since the contradiction arises from our use of Ampere's circuital law, this law must be missing something. The missing term must be such that one gets the same magnetic field at point P, no matter what surface is used.

We can actually guess the missing term by looking carefully in figure 17.3. Is there anything passing through the surface S between the plates of the capacitor? Yes, of course, the electric field. If the plates of the capacitor have an area A, and a total charge Q, the magnitude of the electric field E between the plates is $\frac{Q}{A\varepsilon_0}$. The field is perpendicular to the surface S of figure 17.2 (b). It has the same magnitude over the area A of the capacitor plates and vanishes outside it. So what is the electric flux ϕ_E through the surface S? Using Gauss's law, it is

$$\phi_E = |\vec{E}|A = \frac{1}{\varepsilon_0}\frac{Q}{A}A = \frac{Q}{\varepsilon_0} \qquad \text{......[17.1 (c)]}$$

Now if the charge Q on the capacitor plates changes with time, there is a current $I = (dQ/dt)$, so that using equation (17.1 (c)) we have

$$\frac{d\phi_E}{dt} = \frac{d}{dt}\left(\frac{Q}{\varepsilon_0}\right) = \frac{1}{\varepsilon_0}\frac{dQ}{dt}$$

This implies that for consistency,

$$\varepsilon_0\left(\frac{d\phi_E}{dt}\right) = I \qquad \text{......(17.2)}$$

This is the missing terms in Ampere's circuital law. If we generalise this law by adding to the total current carried by conductors through the surface, another term which is ε_0 times the rate of change of electric flux through the same surface, the total has the same value of current I for all surfaces. If this is done, there is no contradiction in the value of B obtained anywhere using the generalised ampere's law. B at the Point P is non-zero no matter which surface is used for calculating it. B at a point P outside the plates [figure 17.1(a)]is the same as at a point M just inside, as it should be. The current carried by conductors due to flow of charges is called conduction current. The current given by equation (17.2) is a new term, and is due to changing electric field (or electric displacement). It is therefore, called displacement current or Maxwell's displacement current. Figure. 17.3 shows the electric and magnetic fields inside the parallel plate capacitor discussed above.

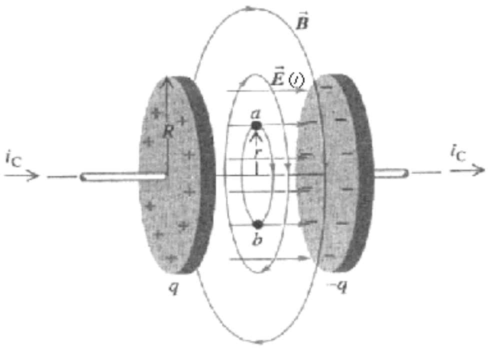


Fig. 17.3 : Magnetic field between the plates due to displacement current

The generalisation made by Maxwell then is the following. The source of a magnetic field is not just the conduction current due to flowing charges but also the time rate of change of electric field. More precisely, the total current I is the sum of the conduction current denoted by I_C, and the displacement current denoted by $(I_d = \varepsilon_0 d\phi_E / dt)$, so, we have

$$I = I_c + I_d$$

$$= I_C + \varepsilon_0 \frac{d\phi_E}{dt}$$

In explicit terms, this means that outside the capacitor plates, we have only conduction current $I_C = I$, and no displacement current *i.e.*, $I_d = 0$. On the other hand, inside the capacitor, there is no conduction current *i.e.*, $I_C = 0$, and there is only displacement current, so that $I_d = I$.

The generalized and correct law : Ampere's circuital law has the same form as equation (17.1), with one difference, the total current passing through any surface of which the closed loop is the perimeter' is the sum of the conduction current and the displacement current. The generalized law is

$$\oint \vec{B}.\vec{dl} = \mu_0 I_C + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$$

and is known as Ampere-Maxwell law.

In all respects, the displacement current has the same physical effects as the conduction current. In some cases, for example, steady electic fields in a conducting wire, the displacement current may be zero since the electric field E does not change with time. In other cases, for example, the charging capacitor above, both conduction and displacement currents may be present in different regions of space. In most of the cases they both may be present in the same region of space, as there exist no perfectly conducting or perfectly insulating medium. Most interestingly, there may be large regions of space where there is no conduction current, but there is only a displacement current due to time varying electric fields. In such a region, we expect a magnetic field, though there is no (conduction) current sources nearby! The prediction of such a displacement current can be verified experimentally. For example, a magnetic field (say at point M) between the plates of the capacitor in figure 17.1 (a) can be measured and is seen to be the same as that just outside (at P),

We can understand it by as follows

$$\oint \vec{B}.\vec{dl} = \mu_0 I_C + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$$

Using the relation for the surface inside the capacitor plates Fig. 17.2(b). We have

$B(2\pi r) = \mu_0 \varepsilon_0 A \frac{dE}{dt}$ $(\phi_E = EA$ and $I_C = 0$ inside the plates)

or $$B = \left(\frac{\mu_0 \varepsilon_0 \pi R^2}{2\pi r}\right)\frac{dE}{dt}$$

$$B = \left(\frac{\mu_0 \varepsilon_0 R^2}{2r}\right)\frac{dE}{dt}$$

This shown that B is produced due to dE/dt.

Example 17.1 : In charging a parallel plate capacitor of capacity 10µF, it takes 0.5 second to reach potential difference of 50 V. If plate area of the capacitor is 10×10^{-12}m², then find :

(i) Average conduction current at that time.

(ii) Average displacement current at that time.

(iii) Rate of change of electric field at that time.

Solution : (i) Average value of conduction current.

$$I = \frac{\Delta q}{\Delta t} = \frac{q_2 - q_1}{t_2 - t_1} = \frac{CV - 0}{0.5}$$

$$= \frac{10 \times 10^{-6} \times 50}{0.5} = 10^{-3} A$$

(ii) Average displacement current in capacitor = Conduction current

$$I_d = I = 10^{-3} A$$

(iii) $\therefore I_d = \varepsilon_0 A \frac{dE}{dt}$

$$\therefore \frac{dE}{dt} = \frac{Id}{\varepsilon_0 A} = \frac{10^{-3}}{8.85 \times 10^{-12} (10 \times 10^{-12})}$$

$$= 1.1 \times 10^9 V / ms$$

17.2. Maxwell's Equation, Qualitative Discussion:

Maxwell's equations represent the four basic laws of electricity and magnetism. These four laws are : Gauss's law in electrostatics, Gauss's law in magnetism, Faraday's law of electromagnetic induction and Maxwell-Ampere's circuital law. These equations are.

(i) $\oint \vec{E}.\vec{dA} = \frac{q}{\varepsilon_0}$ .... (17.3)

(ii) $\oint \vec{B}.\vec{dA} = 0$ .... (17.4)

(iii) $\oint \vec{E}.\vec{dl} = \frac{-d\phi_B}{dt}$ .... (17.5)

(iv) $\oint \vec{B}.\vec{dl} = \mu_0 I + \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$ .... (17.6)

Equation (17.3) represents Gauss's law in electrostatics. It states that the total electric flux through any closed surface S is always equal to $\frac{1}{\varepsilon_0}$ times the net charge inside the surface. This equation is called Maxwell's first equation. It is time independent steady state equation. It is true for both stationary and moving charges. We can infer from this equation that the electric lines of force do not constitute continuous closed path.

Equation (17.4) represents Gauss's law in magnetism. It state that the total magnetic flux through a closed surface is zero. This equation is called Maxwell's second equation. It is time independent equation. It expresses the fact that isolated magnetic poles do not exist in nature. We can infer from this equation that the magnetic field lines constitute continuous closed path.

Equation (17.5) represents Faraday's law of electromagnetic induction. this states that the line integral of electic field along a closed path is equal to the time-rate of change of magnetic flux through the surface bounded by that closed path. This equation is called Maxwell's third equation. It is time-dependent equation. We can infer from this equation that the time variation of magnetic field generates an electric field. This equatin is a relation between space integration of $\vec{E}$ and the time variation of $\vec{B}$. In this case electric field lines are closed loops.

Equation (17.6) represents Maxwell's Ampere's circuital law. It states that the line intergral of magnetic field along a closed path is equal to μ_0 times the sum of conduction and displacement currents. This equation is called Maxwell's fourth equation. It is a time dependent equation. This equation tells us that the time variation of electric field generates magnetic field.

If the electric field and magnetic field are present at any place, then the force on a charged particle is $\vec{F} = q[\vec{E} + (\vec{v} \times \vec{B})]$ and with the help of Maxwell equation all the events related to electro magnetism are explained easily.

17.3 Electromagnetic Wave and Their Characteristics

How are electromagnetic waves produced? Neither stationary charges nor charges in uniform motion (steady currents) can be sources of electromegnetic waves? The former produces only electrostatic fields, while the later produces magnetic fields that, however, do not vary with time. It is an important result of Maxwell's theory that accelerated charges radiate electromagnetic waves. Consider a charge oscillating with some frequency. (An oscillating charge is an example of accelerating charge). This produces an oscillating electric field in space, which produces an oscillating magnetic field, which in turn, is a source of oscillating electric field, and so on. the oscillating electric and magnetic fields thus regenerate each other, so to speak, as the waves propagates through the space. The frequency of the electomagnetic wave naturally equals the frequency of oscillation of the charge. The energy associated with the propagating wave comes at the expense of the energy of the source which accelerate the charge.

From the preceding discussion, it might appear easy to test the prediction that light is an electromagnetic wave. We might think that all we needed to do was to set up an ac circuit in which the current oscillate at the frequency of visible light, say yellow light. But, also, that is not possible. The frequency of yellow light is about 6×10^{14} Hz, while the frequency that we get even with modern electronic circuits is hardly about 10^{11} Hz. This is why the experimental demonstration of electromagnetic wave had to came in the low frequency region (the radiowave region), as in the Hertz's experiment (1887).

Hertz's successful experiment test the Maxwell's theory created a sensation and sparked off other important works in this field, two important achievements in this connection deserve mention. Seven years after Hertz, Jagdish Chandra Bose, working at Calcutta (now Kolkata) succeeded in producing and observing electromagnetic waves of much shorter wavelength (25 mm to 5 mm). His experiment, like that of Hertz's was confined to the laboratery. At around the same time, Guglielmo Marconi in Italy followed Hertz's work and succeeded in transmitting electromagnetic waves over distances of many kilometers. Marconi's experiment marks the begining of the field of communication using electromagnetic waves.

(i) Nature of electromagnetic waves and Propagation :

It can be shown from Maxwell's equations that electric and magnetic fields in an electromagnetic wave are prependicular to each other *and* to the direction of propagation. It appears reasonable, say from our discussion of the displacement current B and E are perpendicular to each other. In figure 17.4, we show a typical example of a plane electromagnetic wave propagating along the X-direction. The fields are shown as a function of x co-ordinate at given time t. The electric field E_y to along y - axis law varies simusoidally with x at given time t. The electric and magnetic fields E_x and B_z are perpendicular to each other, and to the direction x of propagation. We can write E_y and B_z as follows :

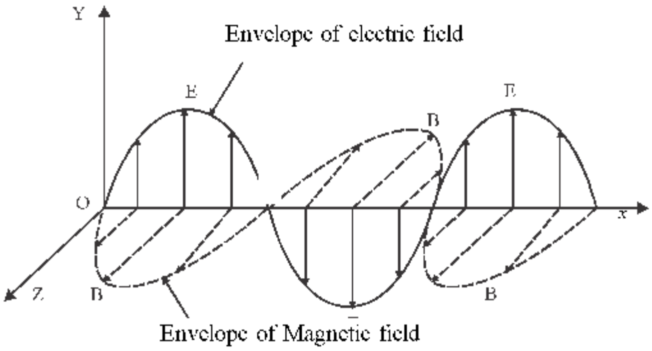


Fig. 17.4 : A linearly polarised EM wave propagating in the x-direction with the oscillating electric and magnetic field along Y and Z axis

The magnetic field B_z is along the Z axis and again varies sinusoidaly with x.

$$E_y = E_{oy}\sin(kx - \omega t) \qquad ....(17.7)$$

$$B_z = B_{oz}\sin(kx - \omega t) \qquad ....(17.8)$$

Here k is related to the wavelength λ of the wave by the usual equation $k = 2\pi/\lambda$ and ω is is the angular frequency, k is the magnitude of the wave vector (or propagation vector) $\vec{k}$ and its direction describes the direction of propagation of the wave. The speed of propagation of the wave is (ω/k) using equation (17.7) and (17.8) for E_y and B_z and Maxwell's equation, one finds that

$$c = \frac{\omega}{k} \text{ where, } c = \frac{1}{\sqrt{\mu_0\varepsilon_0}} \qquad ....(17.9)$$

The relation ω = ck is the standard one for waves. This relation is often written in terms of frequency ($v = \omega/2\pi$) and wavelength ($\lambda = 2\pi/k$) as

$$2\pi v = c\left(\frac{2\pi}{\lambda}\right)$$

Or $\quad v\lambda = c$

It is also seen from Maxwell's equation that the magnitude of the electric and magnetic fields in an electromagnetic wave are related as

$$B_0 = E_0 / c \qquad ....(17.10, a)$$

and $\quad E_o = cB_o \qquad ....(17.10, b)$

If electromagnetic wave propagate in any medium other than vaccum, then speed of light is given by :

$$v = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{c}{\sqrt{\mu_r \varepsilon_r}} \qquad \text{..........(17.11)}$$

Where ε is electric permittivity of the medium and μ is the magnetic permeability of the medium. ε_r is relative permittivity and μ_r is the relative permeability of the medium. This equation can be written as

$$\upsilon = \frac{c}{n} \qquad \text{..........(17.12)}$$

where, $n = \sqrt{\mu_r \varepsilon_r}$ is refractive index of the medium.

(ii) Energy Transmission by Electromagnetic Waves :

Electromagnetic waves carry energy as they travel through space and this energy is shared equally by the electric and magnetic fields. Energy density of an e.m. wave is the energy in unit volume of the space through which the wave travels.

We know that energy is stored in space wherever electric and magnetic fields are present.

In free space, the energy denisty of a static field E is

$$u_E = \frac{1}{2}\varepsilon_0 E^2$$

Again, in free space, the energy density of a static magnetic field is

$$u_B = \frac{B^2}{2\mu_0}$$

$\therefore B = E/c$ and $c = 1/\sqrt{\mu_0 \varepsilon_0}$, then

$$u_B = \frac{B^2}{2\mu_0} = \frac{E^2}{2c^2\mu_0} = \frac{E^2}{2\mu_0}(\mu_0\varepsilon_0)$$

$$= \frac{1}{2}\varepsilon_0 E^2 = u_E$$

∴ Total instantaneously energy density

$$u = u_B \quad u_E = 2u_E = 2u_B$$

$$= \varepsilon_0 E^2 = \frac{B^2}{\mu_0} \qquad \text{......(17.13)}$$

If $E = E_y = E_m \sin(kx - \omega t)$, then for full cycle, average value of

$$\sin^2(kx - \omega t), \langle \sin^2\theta \rangle = \langle \cos^2\theta \rangle = \frac{1}{2}$$

∴ Total mean energy density

$$u_{av} = \varepsilon_0 \langle E^2 \rangle_{av} = \frac{1}{2}\varepsilon_0 E_0^2 = \frac{B_0^2}{2\mu_0} \qquad \text{......(17.14)}$$

Rate of flow of energy through unit area is called Poynting vector, $\vec{S}$.

$$\vec{S} = \frac{1}{\mu_0}(\vec{E} \times \vec{B}) \qquad \text{......(17.15)}$$

and its magnitude, $S = \frac{EB}{\mu_0}$ ......(17.16)

For sinusoidal waves, Intensity I of plane electromagnetic wave is average of the poynting vector.

$$\therefore\ I = S_{av} = \frac{E_m B_m}{2\mu_0} = \frac{E_m^2}{2\mu_0 c} = cU_{av} \qquad \text{......(17.17)}$$

(iii) Momentum and pressure Associated with Electromagnetic Waves :

An electromagnetic wave transports linear momentum as it travels through space. If an elecromagnetic wave transfers a total energy U to a surface in time t, then total linear momentum delivered to the surface is

$$p = \frac{U}{c} \qquad \text{......(17.18)}$$

[Only for complete absorption of energy U]. If the wave is totally reflected, the momentum delivered to the surface will be $2U/c$.

$$p = \frac{2U}{c} \qquad \text{......(17.19)}$$

If surface is totally absorbing then the radiation pressure is

$$p = \frac{I}{c} \qquad ......(17.20)$$

and for complete reflecting surface,

$$p = \frac{2I}{c} \qquad ......(17.21)$$

Where I is intensity of the wave.

(iv) Electromagnetic waves obey the principle of superposition. They show the properties of reflection, refraction, interference, diffraction and polorisation. Doppler effect is also observed for them.

Example 17.2 : An electric bulb is emitting uniform spherical wave in all directions. Assuming electromagnetic emission to be 50 W, then calculate (a) intensity (b) radiation pressure (c) magnitude of electric and magnetic fields at a point 3m away from the bulb.

Solution : At r distance from bulb, the energy will uniformly spread on area $4\pi r^2$.

(a) $$\text{Intensity} = \frac{\text{Power}}{\text{Area}} = \frac{50}{4\pi r^2}$$

$$= \frac{50}{4 \times 3.14 \times (3)^2} = 0.44 \text{ W/m}^2$$

(b) Radiation pressure,

$$p = \frac{I}{c} = \frac{0.44}{3 \times 10^8} = 1.47 \times 10^{-9} \text{ N/m}^2$$

(c) $$I = \frac{E_0^2}{2 m_0 c}$$

$$E_0 = \sqrt{2\mu_0 I c}$$

$$= \sqrt{2(2\pi \times 10^{-7} m/A) \times 0.44(W/m^2) \times 3 \times 10^8 m/s}$$

$$= 18.2 \text{ V/m}$$

and, $$B_0 = \frac{E_0}{c} = \frac{18.2}{3 \times 10^8} = 6.08 \times 10^{\ 8}\ T$$

17.4. Electromagnetic Spectrum

We have seen that all EM waves propagate with the speed of light c in vacuum. These waves transport momantum and energy. At the time of maxwell we knew only about visible light (some what about infrared). In 1888 Hertz generated radio waves. At present we are familier with all EM waves from radiowaves to γ - rays. In all the waves there is role of accelarated / decelarated charges. All these waves differ only in wavelength / frequency energy and related effects. Set of these waves expressed in a certain order of wavelength is called EM spectrum. This classification does not have well difined sharp boundries, their boundries overlap each other. For example wave of wavelength 0.1 Å may be called x-ray or γ-ray. They differ only in their origin (γ-ray are produced from within the nucleus where as x-rays are produced by bombarding high energy electrons on a heavy matel, and are of atomic origin).

Now we will discuss these different waves in the order of their decreasing wavelength.

Radiowaves : These waves are produced by oscillating electrons in a dipole antenna or conducting wires. LC circuits and electronic devices are used for their generation. They are used in Radio, Television and other communication systems. Their range is from 500 kH_z to 1000 MH_z. For AM modulated band the range is from 530 kH_z to 1710 kH_z. For FM band the range is between 88 MH_z to 108 MH_z, and approximately same for TV broadcast ie 54MH_z to 890 MH_z. UHF frequency ranging from 840 MH_z to 935 MH_z is used in cellural phone.

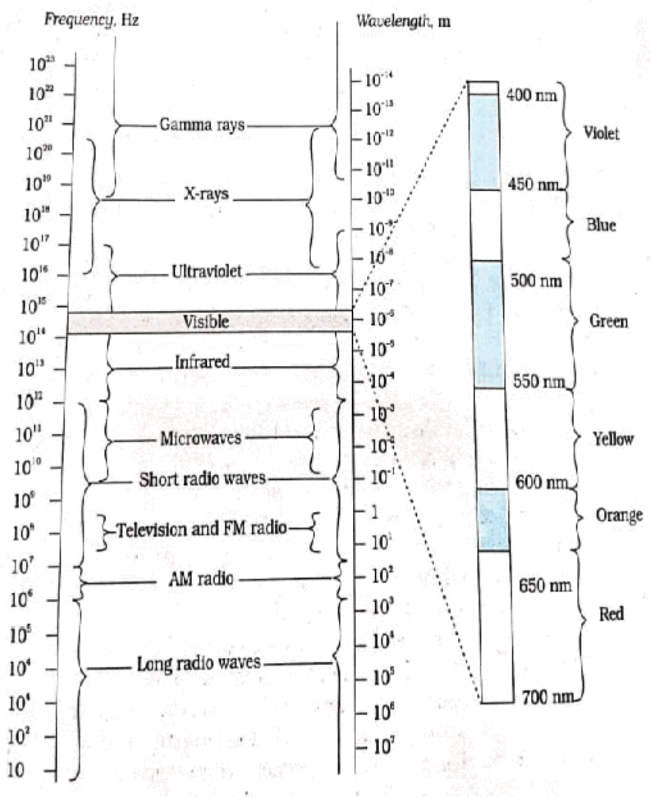


Fig. 17.5 : The electro magnetic spectrum with common names or various part of it.

Detection of radiowave is done by dipole antenna or magnetic a loop antenna. For first type electric field of the wave generate electric current while in loop antenna emf is induced and detected.

Microwaves : Range of these types of waves are from $\lambda = 0.001$ m to 0.1 m. They are also called mm waves. Their frequency is of the order of GHz. They are produced by electronic devices like magnetron, klystron and Gun diodes etc. They are used in RADAR system and navigation and speed guns. They are also used to investigate the properties of atoms and molecules. An interesting domestic use is in microwave oven. Water containing food can be cooked in microwave oven. The natural frequency of water molecule is 3GHz. When food is exposed to microwave radiation the water in it absorbs the microwave of this frequency by resonance and heated up and cooks the food. Utencils of porcelene or glass which has larger molucules and very low natural frequency are used. Hence food is cooked without heating the utencils thus saving energy. Metalic utencils are not used to avoid shock due to induced charges.

Infra red rayes : These rays are produced by oscillations of atoms and molecules in a hot body. Their wave length is from 1m to 700nm. These rays are used in physiotherapy, infrared photography and in remote control devices of electronic gadgets. The warmth that we feel in sun light is due to these rays.

Visible light : Human eyes are sensitive for these rays, of wavelength ranging from 380 nm to 788 nm corresponding to violet to red light. Sensitivity of our eyes differs for different wavelengths and is maximum for yellow green wavelength of 550 nm. These waves provide energy for photosynthesis in plants. These wave are produced by heating effect (bulb), transition of electrons from higher energy level to low energy level in excited atoms (flourosecent lamp) and direct conversion of bond energy to light energy in LED.

Ultraviolet rays : This part of EM spectrum ranges from 1 nm to 380 nm. Sun is the major source of these rays. They are harmful to our skin and may cause skin cancer. Fortunately our atmosphere provides a natural shield in the form of Ozone layer which absorbe these rays and protect us. But human activity using CFC in aerosole and refegerators are responsible for depletion of ozone layer. Arc lamp and welding arc produced UV rays in large amount. The weldor uses special protection mask to save his eyes from UV rays which may damage ratina. They are used to detect fake currency notes. The numbers on genuine currency notes gives fluorescence in UV rays.

X-rays : They are produced by bombarding high energy electron beam on a heavy metal like tungston. The wavelength range is in between 1 nm to 10^{-3} nm. They are used in medical science and is crystallography. Over and unnecessory exposure should be avoided as it may cause cancer and other damages to tissues.

γ-rays : These are the shortest wavelength and most energetic waves known. Thery are produced from within a radioactive nuclied. After emmission of α or β rays. The nucleus comes in exeited state, which stablizes after emitting γ-rays. They are used to destroy cancer cells. To sterlize the medical equipment their uncontrolled exposure on human body may cause cancer too. The sun is the a natural source of almost entire EM spectrum.

17.5 Propagation of EM waves

EM waves are transmitted by an antenna in a communication system. As they propagate their intensity go on decreasing due to various reasons. Noise is also introcued during propagation. There are three modes of transmission of EM waves from transmitter to receiver (a) ground wave or surface wave propagation, (b) Space wave propogation, (c) Sky wave propagation.

17.5.1 Ground or Surface wave propogation

In this mode, both the transmitter antenna and reciever antenna are very near to Earth surface. Hence the wave propagates just gliding to the surface. The electric field of the wave induces charge on the surface and the wave get short circuited and get vertically polarized. The intensity of the wave decreases with distance. More over this mode is suitable only for low frequency EM waves, frequency less then 1 MHz. Since high frequency waves are more absorbed by earth. This mode is used for a limited distance of (500 km.) propagation.

17.5.2 Space wave propagation

In this mode of propagation the modulated carrier waves propagates direct from transmitter antenna to the receive antenna through troposphere. Slight bending towards earth is helpfull due to different refractive index of layers of troposphere (actually ionosphere). Due to curvature of earth the long distance communication is not possible and it limited to line fo sight distance. The height of antenna is an important factor in the range of communication system.

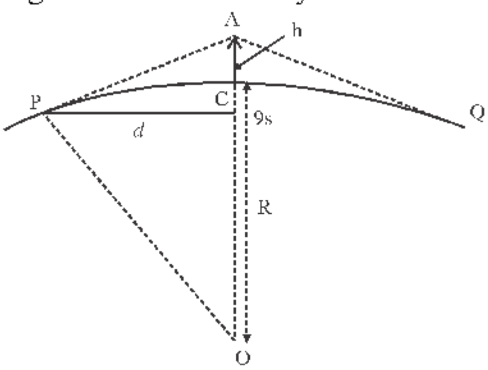


Fig. 17.6 : LOS in space wave propagation

In fig. 17.6, an antenna of height h is at a point C on earth surface. The EM waves from the top of antenna reach up to point P and Q on the surface. Hence the distance for the transmission is CP = CQ = d for the receiver of zero antenna height. If the radius of the earth is R and O is the center of the Earth from right angle tringle OPA,

$$OA^2 = OP^2 + PA^2 \quad (h << R,\ PA = PC)$$

or $$(R+h)^2 = R^2 + d^2\ (PA \simeq PC = d)$$

or $$R^2 + 2hR + h^2 = R^2 + d^2$$

or $$h(2R+h) = d^2$$

or $$h(2R) = d^2$$

($h << 2R$, so h^2 is negligible)

hence $$d = \sqrt{2Rh} \quad \ldots (17.22)$$

In this mode they waves between the frequency range 100 MHz to 200 MHz are used as carrier waves.

17.5.3 Sky waves propagation

Long range transmission is possible in this mode. The ionosphere plays a role of reflecting the waves back to the ground to receiver. The density of ions in the different layers is different and the reflective index of medium (ionosphere) decreases gradually with height. This reflection is not as reflection from a mirror but the wave gradualy bends back to the earth by the phenomenon of i.e. total internal reflection. This type of reflection is affected by atmospheric disturbances, frequency used and day night effect. During night the reflection is better due to merger of some layers of ionosphere. The maximum frequency that can be used is 30 MHz. Frequency greater than this is not reflected and so escapes.

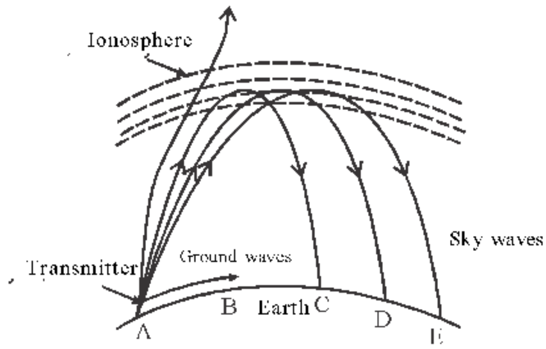


Fig. 17.7

Communication with Satellite

A communication satellite is at the height of ≈ 36000 km abvoe the earth and revolve round the earth with a time period of 24 hours. Hence it is stationery with respect to earth. The waves of frequency > 30 MHz which escape the ionosphere, reaches the satellite. The satellite retransmits the wave with another frequency called down link frequency. The frequency used in this mode is in UHF (Ultra high frequency) region. This mode is used in cellular telephony.

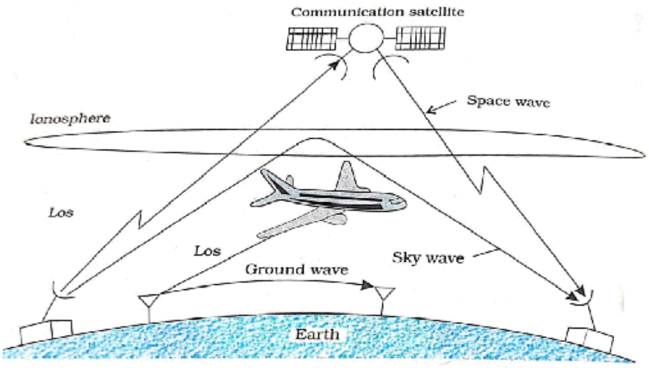


Fig. 17.7 : Various propagation modes for EM waves

17.6 Communication System

The exchange of information between two persons or system in the form of video, audio or data is called communication. Art of communication is as old as the human race. The art and the mechanism changed with time. In modern time there is revolation in this field. Mobile, cellular telephony and use of computer in fox, e-mail and other modes made the life easy. The basic components of a communication system are (i). Transmitter (ii). Communication channel (iii). Receiver Fig 17.8 gives the bolock diagram of the system. The information may be is any form such as video, audio, text and data which are non electrical in nature. First a device called a transducr is used to convert information in electrical signal which is suitable for transmission. This is message signal. This message signal is sent to receiver through chennel. This chennel could be a wire, coaxial cable, optical fiber or EM wave (Which carries the information after modulating HF carrier wave with information signal). In EM mode the channel is space, the wave travel from transmitter to receiver through space with speed of light. The antenna at receiver end defect the signal and change it into usable form. Unwanted signal is introduced as a noise during propagation. The information signal may be a analog or digital.

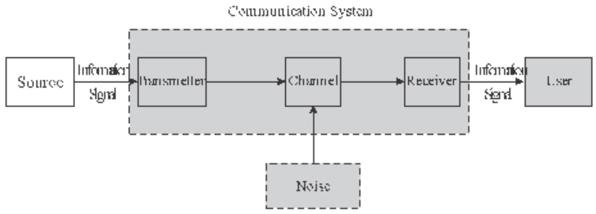


Fig. 17.8 : Communication system

17.7 Modulation

Normally the information signals are of low frequency, so even after converting into electrical form are not suitable for long distance transmission. A high frequency wave called carrier wave (Since it carries the signal) is used for transmission. The information signal is superimposed or loaded with carrier wave. The process of superimposing the signal with carrier wave is called moderation. The carrier wave may be mathematically represented by $c(t) = A_c \sin(\omega_c t + \phi)$

Here $c(t)$ is the instantanious value of voltage or current, the wave has three characters. Namely Amplitude A_c , frequency ω_c and ϕ (is initial phase angle). In the process of modulation any one character of the carrier wave is modified as per the information signal. Hence the modulation is of three types :

(i) Amplitude modulation, called AM.

(ii) Frequency modulation, called F.M

(iii) Phase modulation called, PM.

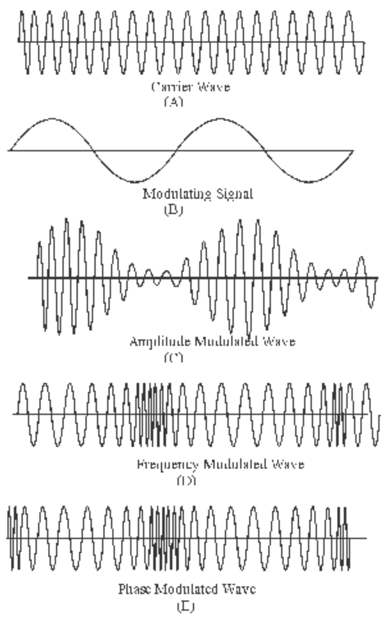


Fig. 17.9 : Analog modulation

(i) Amplitude modulation:-

The figure (A) Showes a carrier wave of deferent high frequency. Figure (B) shows modulating signal. The figure (c) shows an amplitude modulated wave modulated carrier wave. Note that the frequency and phase of the wave remain unchanged, but the amplitude changes with change in signal. The modulated wave carries the information as the change in amplitude which can be sensed (detected) at the receiver end.

(ii) Frequency Modulation :-

Frequency modulated wave is represented by fig (D). Shown is the diagram that amplitude and phase of the modulated wave remains unchanged, while the frequency of the carrier wave is changed as per the amplitude of the signal. ie when signal amplitude is high the frequency is high and vice-versa. Hence the information is carried by the wave in the form of change in frequency.

(iii) Phase modulation:-

In this mode, the phase of the carrier wave is changed as per the instantaneous values of signal voltage. It is to be noticed in the diagram (D) and (E) that both FM and PM are similar. In both, change of frequency is there, but is PM the phase of the wave either leads or lags as per signal voltage.

17.7.1 Need of Modulation :-

As it is clear that low frequency information signal is not suitable for long range transmission even if it is converted into electrical form. We need a carrier wave to carry the signal.

(i) Need of Antenna :

In electronic circuits the modulated wave is electrical in nature and it has to be converted into EM wave, which is done by a dipole antenn. It needs very high antenna (at least of the order of $\lambda/4$) so that it carries all the information of the signal (or the time variation of signal). For a wave of 20 kHz , λ is 15km. Clearly such long antenna is not possible. To reduce the high of antenna we should load the information on the high frequency carrier wave.

(ii) Effective Power Radiated by Antenna :-

The effective power radiated by an antenna is related to (i) antenna length l and (ii) the radiated frequency/ wave length λ by P α $(l/\lambda)^2$. It is clear from the given relation that for same antenna length, the wave length of the radiated wave should be very small for more power to be radiated. That is the reason for loading the signal on a high frequency/low wavelength carrier wave.

(iii) Mixing of the information:-

When so many persons are talking at a time, the listener is unable to make any sense of that. Similarly when so many transmitter are radiating information, the receiver can't make any sense. That`s why each transmitter is allotted one fixed carrier frequency (which carries the information) and the receiver is tuned to this frequency only, so others are eliminated.

17.7.2 Amplitude Modulation :

In amplitude modulation, the amplitude of the carrier wave is changed as per change in signal amplitude.Let $c(t) = A_c \sin\omega_c t$ and $m(t) = A_m \sin\omega_m t$ represent carrier wave and singal respectively, where $\omega_c = 2\pi f_c$ and $\omega_m = 2\pi f_m$ are freqeuncy of carrier wave and signal.

After modulation the carrier wave is -

$$c_m(t) = (A_c + A_m \sin\omega_m)\sin\omega_c t$$

$$= A_c\left(1 + \frac{A_m}{A_c}\sin\omega_m t\right)\sin\omega_c t$$

Here the singal is present in the amplitude of the above wave. We can write it as -

$$c_m(t) = A_c\sin\omega_c t + mA_c\sin\omega_m t\sin\omega_c t \qquad ...(1)$$

where $m = \dfrac{A_m}{A_c}$ is modulation index, and $m \le 1$.

Using - $\sin A\sin B = \frac{1}{2}\left[\cos(A-B) - \cos(A+B)\right]$

We can write eqn (1) for $c_m(t)$ as -

$$c_m(t) = A_c\sin\omega_c t + \frac{mA_c}{2}\cos(\omega_c - \omega_m)t$$

$$-\frac{mA_c}{2}\cos(\omega_c + \omega_m)t$$

here $\omega_c - \omega_m$ and $\omega_c + \omega_m$ are called lower and upper sideband frequencies these, hence the carrier wave also contains these upper and lower sideband frequencies along with ω_c.

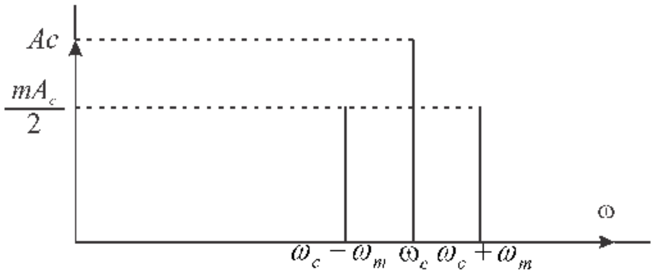


Fig. 17.10 Graph between amplitude and frequency in amplitude modulation

Note : In amplitude modulation, the amplitude of signal voltage is added with the amplitude of carrier wave changes between A_{max} and A_{min} this change represents up to what extent the carrier wave is modulated. Amplitude modulation index is -

$$i.e., \mu = \frac{A_m}{A_c} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$$

If m = 0; there is modulation

$m \geq 1$, over modulation

$0 < m < 1$, normal modulation

17.7 .3 Transmission and Reception of Amplitude modulated waves

The above mentioned modulated wave can not be transmitted as such. First its power is increased using a power amplifier, then it is transmitted by an appropriate antenna. The process is shown is block diagram -

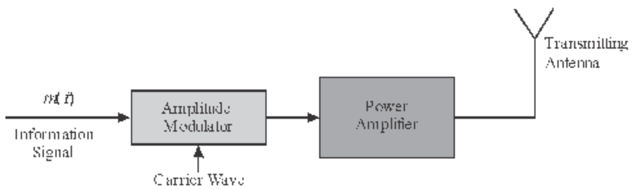


Fig. 17.11 Block diagram of a transmitter

The modulated transmitted wave get weakned (attenenated) in transmission channel, hence the signal that we recieve by the recieving antenna is very weak. It can not be used as such. We amplify this signal in two steps. (1) Radio freqeuncy amplification. (2) I F or intermediate frequency amplification. Now the information signal (which is mixed carrier wave) is obtained by separating it from carrier wave using a detector, this process is called demodulation. The information is signal is again amplified to get it in a usable form.

Example 17.4 : A carrier wave of peak value 12V is used for transmission. What will be the peak value of signal to obtain a modulation index of m = 0.75.

Solution : Amplitude of carrier wave $A_c = 12V$

Modulation index $m = 0.75$

$\because \quad A_m = mA_c = 0.75 \times 12 = 9\text{V}$

Example 17.5 : After modulation the amplifide of carrier wave varies between 5V and 2V. What is depth of modulation ?

Solution : Here $A_m = 5V$ and $A_{min} = 2V$

Modulation index $m = \frac{A_{max} - A_{min}}{A_{max} + A_{min}} = \frac{5-2}{5+2} = \frac{3}{7}$

or $\quad m = \frac{3}{7} \times 100\% = 42.8\%$

17.8 Nanotechnology :

Nano science is the branch of technology in which study of bodies of size less than 100 nm is taken

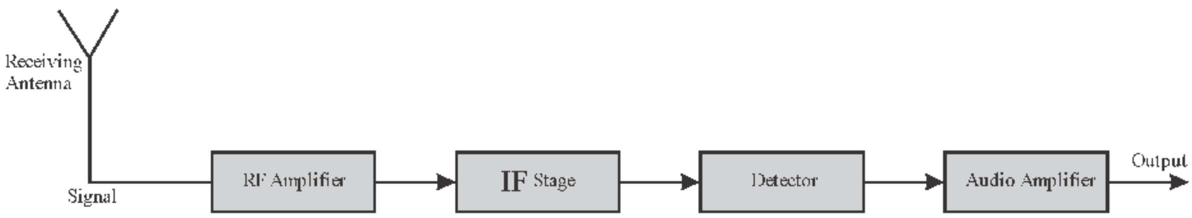


Fig. 17.12 : Block diagram of a receiver

up. Thickness of human hair is of the order 60000 to 80000 nm. From this we can experience the smallness of nanotechnology. Scienstists have discovered serveral nano particles and thin films whose properties are different than that of their ordinary size. There are enormous possibilities of fabricating better structures, devices and materials using nano particles and nano films. There are three specialities in nanotechnologies -

1. Size less then 100 nm.
2. Unique properties due to small size.
3. Control on structure and properties up to nano scale.

There are many examples of nano structures in nature. For example, some catalysts, filter particles and some minerals which have different properties at nanoscale. In previous decade the fabrication of functional enginnered materials and devices were made possible after understanding and controlling the nanostructures.

During last 40 years a techniques of nano and microlithography have been developed, which revolutionised the micro electronics. With the help of this technique new microprocessors were developed which have small size and many fold efficiency. In previous years micro mechanic and micro optical devices were developed.

Another branch of nanotechnology is moleculer and chemical technique by which new consumer products are being obtained by controlling the chemical properties of the molecules.

17.8.1 Nanostructures in Nature

Fine observation of plants and animals around us reveals many specific features at nano level. Few esamples are -

1. Insect eyes have many small bulges of hexagonal shape of size few hundres nanometre in size. These are smaller than the wave length of vissible light (380-780nm), hence they have less reflectivity and more absorption of light which make them able to see in a better way as compared to human beings in dim light conditions. On this basis scientists have fabricated such nano strutures which absorb more infrared light these nano structures are used to increase efficiency of thermo volt aic cell.
2. Wings of butterfly has multilayered nano patterns, which filters the white light and reflects a particular color. Thses nano structurs are of the size of wavelength of light, the interfreance of ligth at the wings are used in critical analysis of colours.
3. Edlewiess is an alpine plant, which is found in hight mountain ranges. whave level of UV rays is high. The flower of this plant is covered by hollow nanofibers which absorbs UV rays and refflects white light. So the flower appears white. These nano structures protact plant from hight energy radiations. On the basis scientist are working on device which can protect us from high energy radiations.

17.8 .2 Observations of nano strucutre

The ordinary microscopes are not suitable for observing nano structure. Some complex devices are used for this purpose.

Few are-

(i) Optical Microscope - It can be used to oberserve a nano structure of size 250 nm which is longer than the 1actual nano partides. This also the limit of such microscopes.

(ii) Electron Microscope - In this microscope electron beam is used in place of visible light due to which particles of few nano meter size can be studied. Due to its high resolution structure of a few non can be observed.

(iii) Scanning Probe Microscope - The nano particles of size 1nm can be observed by such microscope. Nano technology is the most active field of research in solid state physics, chemistry, electical enginnering bio-chemistry and approximately all branches of science, which is going to have a deep impact on our economy and life style.

Important Points

1. **Displacement Current :** it is that current which comes into existence (in addition of conduction current) whenever the electric field and hence the electric flux changes with time. It is given by

$$I_d = \varepsilon_0 \frac{d\phi_E}{dt} = \varepsilon_0 A \frac{dE}{dt}$$

2. **Maxwell's Equations :**

(i) $\oint \vec{E}.\vec{dA} = \frac{q}{\varepsilon_0}$

(ii) $\oint \vec{B}.\vec{dA} = 0$

(iii) $\oint \vec{E}.\vec{dl} = \frac{d\phi_B}{dt} = -\frac{d}{dt}[\oint \vec{B}.\vec{dA}]$

(iv) $\oint \vec{B}.\vec{dl} = \mu_0 \left[I_c + \varepsilon_0 \frac{d\phi_E}{dt} \right]$

3. Basic Properties of E.M. Waves :

(i) The oscillation of $\vec{E}$ and $\vec{B}$ fields are perpendicular to each other as well as to the direction of propagation of the wave.

The direction of wave is in the direction of $(\vec{E} \times \vec{B})$

(ii) In free space they travels with speed $c = 3\times10^8$ m/s. their velocity in a medium of refractive indes n is $\upsilon - c/n$ where $n = \sqrt{(\mu_r \varepsilon_r)}$.

(iii) The electromagnetic waves carry energy as they travel through space and this energy is shared equally by the electric and magnetic fields. The average energy density of an electromagnetic wave is

$$u = u_E + u_B = \frac{1}{2}\left[\varepsilon_0 E_0^2 + \frac{B_0^2}{\mu_0}\right] \text{ in free space.}$$

(iv) Momentum of the electromagnetic wave $p - U/c$ (U = total transferred energy) and pressure on totally absorbing surface due to this momentum, pressure = I/C For Totally reflecting surface $p = 2I/C$

5. the main part of an electomagnetic spectrum in the order of increasing wavelength from 10^{-2}Å or 10^{-12} m to 10^6m are γ-rays, X-rays, UV rays, visible light, infrared rays, microwaves and radiowaves.

6. **Propagation of Electromagnetic Waves :**

These are propagated through three modes :

(i) Ground wave propagation

(ii) Space wave propagation

(iii) Sky wave propagation

7. **Communication Systems :** The setup used to transmit information from one point to another is called communication system. A communication system mainly consists of

(i) Transmitter

(ii) Communication channel

(iii) Receiver

8. **Modulation :** Modulation is the process of changing some characteristics (amplitude, frequency or phase) of high frequency carreir wave in accordance with the instantaneous value of the low frequency audio signal called the modulating signal. We have three types of modulation :

(i) Amplitude modulation

(ii) Frequency modulation

(iii) Phase modulation

9. **Need for Modulation :**

(i) Size of the antenna

(ii) Radiated power by the antenna

(iii) Mixing of different signals

10. Amplitude modulated wave consist of carrier frequency ω_c in addition to $\omega_c - \omega_m$ and $\omega_c + \omega_m$ called side bands

$$\text{Modulation index } \mu = \frac{A_m}{A_c}$$

11. Nanotechnology is the engineering of tailoring of functional systems at the molecular or atomic scale.

Questions for Practice

Multiple Choice type Questions :

1. Average energy density radiated in electromagnetic wave is related to :

(a) Only electric field

(b) Only magnetic Field

(c) Both electric and magnetic field

(d) Average energy density is zero

2. Waves related to telecommunication are

(a) Infrared (b) Visible light

(c) Microwaves (d) Ultraviolet ray

3. electromagnetic waves does not transport :

(a) Energy (b) Charge

(c) Momentum (d) Information

4. If $\vec{E}$ and $\vec{B}$ are electric and magnetic field vectors of electromagnetic waves, then the propagation of electromagnetic wave is along :

(a) $\vec{E}$ (b) $\vec{B}$

(c) $\vec{E} \times \vec{B}$ (d) $\vec{E}.\vec{B}$

5. Which radiation has least wavelength?

(a) X - ray (b) γ-ray

(c) β-ray (d) α-ray

6. Mark the wrong option related to characteristic of electromagnetic waves :

(a) Both electric field and magnetic field vector occupy maximum and minimum value at same time and position.

(b) In electromagnetic waves, the energy is equally distributed among electric and magnetic field vectors.

(c) Electric and magnetic field vectors are parallel to each and they are perpendicular to the direction of propogation of the wave.

(d) They do not require any medium for their propagation.

7. For whom the ground waves are possible ?

(a) Low radio frequency at low range

(b) High Radio frequency at low range

(c) Low radio frequency at high range

(d) Low radio frequency at low range

8. The height of TV tower is h meter. If radius of the Earth is R, then during TV transmission, the area coverage is (if h < R) :

(a) πR^2 (b) πh^2

(c) $2\pi Rh$ (d) πRh

9. For propagation of radiowaves the mode used is :

(a) Ground wave propagation

(b) Sky wave propagation

(c) Space wave propagation

(d) All of the above

10. In a amplitude modulated wave the maximum amplitude is 10 V and minimum amplitude is 2V. The modulation factor m is :

(a) 2/3 (b) 1/3

(c) 3/4 (d) 1/5

11. Modulation Factor of Over modulated wave is

(a) 1 (b) Zero

(c) < 1 (d) > 1

Answer (Multiple Choice Question)

1. (c) 2. (c) 3. (a) 4. (c)

5. (b) 6. (c) 7. (a) 8. (c)

9. (d) 10. (a) 11. (d)

Very Short Answer Type Questions :

1. What is the speed of the electromagnetic waves in vaccum?

2. For electromagnetic waves, what is the effect on refractive index of Ionosphere on increasing height from Earth's surface.

3. the vibration of $\vec{E}$ of an electromagnetic wave propagation in X-direction are parallel to Y-axis. Then in which axis vibration of $\vec{B}$ are parallel?

4. For long distance propagation, which method is used for propagation?

5. What are the frequency limits of sky waves in sending singnal to remote places?

6. Name the part of the communication system which converts signal to suitable form to send on communication channel to receiver.

7. Name the method used to superimpose signal on carrier wave?

8. Which types of matter are studied in Nanotechnology?

Short Answer Type Questions :

1. Name the components of electromagnetic spectrum in decreasing order of wavelength.

2. Write four main characteristics of electromagnetics waves.

3. Explain ground waves and sky waves.

4. What is communication system?

5. Name the part of the communication system.

6. Explain modulation.

7. Give the name of the instruments used to observe nanostructures.

Essay Type Questions :

1. What is the nature of electromagnetic wave? Explain the Hertz's experiment related to electromagnetic wave.

2. Describe various components of electromagnetic wave and explain their characteristics.

3. Explain the process of modulation and demodulation. How they are used in message signal propagation?

4. Explain with diagram amplitude modulation, frequency modulation and phase modulation.

5. Describe some examples of Nanotechnique observed in nature .

Numerical Questions :

1. A plane electromagnetic wave travels in free space along the X-direction. At a particular point in space the maximum value of $\vec{E}$ is 600 volt/meter. What is $\vec{B}$ at this point? ($c = 3 \times 10^8$ m/s)
[**Ans.** 2×10^{-6} wb/m^2]

2. A TV transmitting antenna is 75 m tall. How much maximum distance and area cover by it? radius of Earth = 6.4×10^6 m
[**Ans.** 31 km, 3014 km^2]