24
ELECTROMAGNETIC WAVES

24.1 INTRODUCTION

In the previous lesson you have studied about the various properties of longitudinal and transverse waves. The light is assumed to propagate in the from of transverse waves, which is different from the nature of sound waves that one assumed to be longitudinal As you know sound can not travel in vacuum but the light waves can travel in vacuum also. The question arises what is there in the structure of light waves which enables them to travel in vacuum and that too with very high speed or rather highest known speed? It is the electromagnetic nature (constitution) of light waves.

Now a days, you can hear the commentary of a hockey match or cricket match or the speech of president in your radios and transistors at the same time when they are being delivered. You can also watch the direct live telecast of these events in your T.V. sets at the same time even though they might be occurring in other countries at very far distances from your place. How this instantaneous transfer of information has been made possible? This all has been possible due to electromagnetic waves. You shall be studying regarding the nature of these waves in the present lessor and their important uses in various fields of science and technology.

24.2 OBJECTIVES

After studying this lesson, you should be able to :

- *trace the history of discovery of electromagnetic waves ;*
- *know the Hertz's method of production of e.m. waves;*
- *explain qualitatively the Maxwell's theory of e.m.waves;*
- *state the various properties of e.m. waves;*
- *make a chart of electro-magnetic waves spectrum;*
- *describe the uses of e.m. waves; and*
- *explain the use of e.m. waves in long distance communication instantaneous transmission of information like speech, picture with the use of transmitters and receivers.*

24.3. HISTORY OF E.M. WAVES

In the early nineteenth century two different units of electric charges were used one for electrostatics called e.s.u.(electro static unit) and the other for magnetic phenomena involving currents called e.m.u. (electro magnetic unit). These two units of charge had different physical dimensions. Their ratio (1e.m.u.: 1e.s.u.) turned out to have the units of velocity. Experimental measurement revealed that the ratio had a numerical value precisely equal to 3×10^8 ms^{-1} which is the speed of light in free space. It was the search for an explanation of this extra ordinary coincidence that led Maxwell, in 1864 to prove by theoretical reasoning that *an electrical disturbance should propagate in free space with a speed equal to that of light and hence to postulate* ***that light waves were electromagnetic waves.*** The series of events and discoveries which led to the introduction of the concept of e.m. waves by Maxwell can be summarized as follows:

In 1820, H.C. Oersted, showed that the magnetic compass needle was deflected by the wire carrying electric current. André Ampere attended Oersted's demonstration lecture. He was inspired to continue experiments in the same direction. Soon André Ampere discovered that the direct current in one wire exerts a force on another parallele wire carrying direct current. These discoveries of Oersted and Ampere established that a changing electric field gives rise to a magnetic field and a *changing magnetic field gives rise to an electric field.* Later Michael Faraday discovered laws of electromagnetic induction for such changes.

Thus, when either field (electric field or magnetic field) is changing with time a field of other kind is induced in adjacent regions of space. These induced fields are not confined but ordinarily extend outward into space. James Clark Maxwell (1864) in his famous treatise 'Electricity and Magnetism' (published in the Proceedings of Edinburg Royal society') introduced the concept of 'displacement-current'. This was used as the link between the concept of electromagnetic waves and propounded the famous ***'Maxwell's Theory of Electromagnetic Waves'.*** The theory was purely empirical and invited many criticisms and doubts. It had to wait for about twenty three years until Henry Hertz of Germany in 1887 conclusively demonstrated the generation of electromagnetic waves by oscillating electric dipole in the laboratory and succeeded in transmitting and receiving electromagnetic waves. He also produced stationary e.m waves and determined the wavelength (λ) by measuring the distance between two alternate nodes. Knowing the frequency ν of oscillating dipoles, he calculated the speed (υ) of these e.m. waves using the relation $\upsilon = \nu$ which came out to be the same as that proposed by Maxwell i.e. equal to speed of light. This was a great triumph for Maxwell's theory of e.m. waves.

24.3.1 Hertz Experiment to Produce e.m. Waves

Figure 24.1 shows the schematic representation of Hertz's set up. A and B are two metal sheets connected to a source of high voltage, which can ionise the air in the small gap between them to provide a path for discharge. The charge builds up on the two plates, reaches a maximum sufficient value to cause a spark (electrical discharge) in the air gap. The metal plates get discharged. The change again builds up and again there is a spark. The process is repeated again and again at a very high frequency (ν) which depends upon the capacitance (C) of the capacitor so formed by the two metal plates and the inductance (L) of the assembly by the relation,

$$\nu = \frac{1}{2\pi\sqrt{LC}}$$

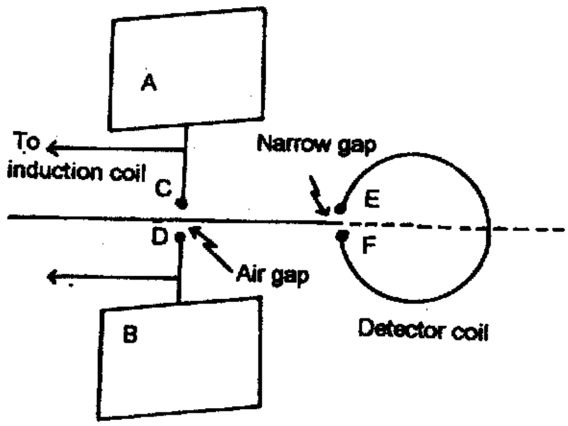

Fig.24.1: *Experimental set up of Hertz experiment.*

Because of very low value of inductance L, ν is very high and Hertz was able to produce e.m. waves (the energy radiations emitted due to the spark between the air gap) of wavelength around 6m. The detector is a coil with its plane perpendicular to the magnetic field produced by the oscillating current discharge between the air gap. The resultant electric field induced by the oscillating magnetic field causes sparks to appear at the narrow gap of the detector coil. This showed the production of e.m. waves at the air gap which travelled to the detector coil and got recorded in the form of spark at the narrow gap. Hertz's experiment, thus, established the formation of e.m. waves by oscillating electric dipoles.

INTEXT QUESTIONS 24.1

1) *Which is a bigger unit for the measurement of electric charge e.s.u or e.m.u?*

....

2) *How did Hertz's experiment contributed to the Maxwell's theory of e.m. waves?*

....

3) *How Maxwell was able to correlate the laws of electricity and magnetism? Mention the physical quantity, he assumed to exist*

....

4) *Does the frequency of e.m. waves depend upon the potential difference applied at the air gap in the Hertz experiment?*

....

24.4 MAXWELL'S THEORY OF E.M. WAVES

Maxwell's great contribution was to point out that Ampere's circuital law needed an important modification. Faraday's law tells that a changing magnetic field can produce an electric field and there by an induced e.m.f. Maxwell suggested that a changing electric field should be able to produce a magnetic field. It was this addition that brought the whole package together into a unified theory of electricity and magnetism.

24.4.1 Displacement Current

Consider a parallel plate capacitor connected to an a.c. source, Fig (24.2). A capacitor consists of two parallel metal plates separated apart by some distance having insulating medium like air or any other dielectric medium. The a.c. ammeter shows a current flowing through the circuit seems to be broken in between the plates of the capacitor. The question arises, how can any current flow through a broken circuit? To understand this, Maxwell introduced the concept of displacement current I_d, to flow between the two plates through the air. Such a current is produced due to changing electric field in between the plates of the capacitor due to the applied a.c. source. He suggested that

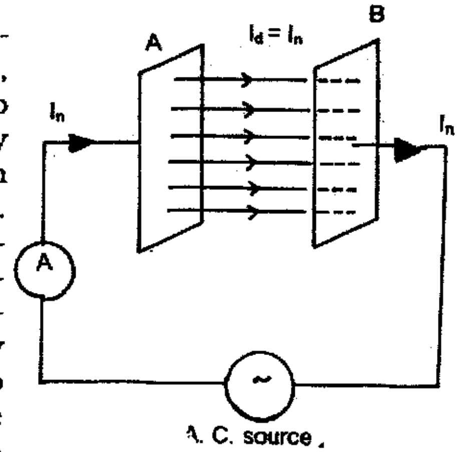

Fig.24.2: *Dispacement current I_d between the plates of the capacitor*

$$I_d = \varepsilon_0 \frac{d\phi_E}{dt} \tag{24.1}$$

where ϕ_E is electric flux $\frac{d\phi_E}{dt}$ is the rate of change of electric flux. Outside the plates, *conduction current* I_c is finite but the *displacement current* I_d is zero But between the plates displacement current is finite and the conduction current is zero. Thus though individually I_n and I_d are discontinuous, a constant current flows through the whole circuit. Here

$$I_d = I_c$$

That is conduction current gets converted into displacement current in between the plates.

Thus, displacement current is actually the real effective current in between the plates of the capacitor in an a.c. circuit and sets up due to changing electric field between the plates. This concept of displacement current introduced by Maxwell provided the necessary basis for understanding the e.m. waves.

24.4.2 Maxwell's Equations

During the course of analysis, Maxwell discovered that all the basic principles of electromagnetism can be formulated in terms of four fundamental equations, now called **Maxwell's Equations.** You must have studied till now all these four principles, they are:

i) **Gauss's law in electrostatics :** It states that the total normal electrical flux linked with a closed surface is equal to the net charge enclosed by that surface divided by ε_o (where ε_o is the permittivity of the free space).

Mathematically, it is stated as

$$\oint E.ds = \frac{q}{\varepsilon_0} \qquad (24.2)$$

ii) **Gauss's law in magnetostatics:** Since a magnetic N-pole always occurs together with a S-pole, the total normal magnetic flux linked with any closed surface is always zero, because as many lines come out of any surface enclosing any magnet, will enter into it. Mathematically, it is stated as

$$\oint \boldsymbol{B} .d\boldsymbol{s} = 0 \qquad (24.3)$$

This means that isolated monopoles do not exist. Therefore, it is known as law of absence of isolated magnetic poles also.

iii) **Ampere-Maxwell's law:** Ampere's law is a useful relation that is closely analogous to Gauss's law. While Gaus's law is a relation between the normal component of electric field at points on a closed surface and the net charge enclosed by the surface; Ampere's law is a relation between the tangential component of magnetic field at points on a *closed curve* and the *net current* through the area bounded by the curve

It states that line integral of magnetic field ***B*** around any closed circuit (loop) is equal to μ_o times the total current threading or passing through the enclosed area. Mathematically, it is stated as

$$\oint \boldsymbol{B} \cdot d\boldsymbol{l} = \mu_o (I + I_d) \qquad (24.4)$$

where, $$I_d = \varepsilon_o \frac{d\phi_\varepsilon}{dt}$$

iv) **Faraday's law:** ***Whenever, the magnetic flux linked with any closed circuit changes, an emf is induced in the circuit. The induced emf is equal to the rate of decrease of flux with time.*** Mathematically, it is stated as,

$$e = \oint \boldsymbol{E} \cdot dl = -\frac{d\phi_B}{dt} \qquad (24.5)$$

In the above forms, Maxwell's Equations apply to electric and magnetic fields (**E** and **B**) in vacuum. However, by changing μ_o to $\mu (= \mu_o \mu_r)$ and ε_o to $\varepsilon (= \varepsilon_o \cdot \varepsilon_r)$, where μ_r and ε_r are the relative permeability and the relative permittivity of the medium, the above equations become generalised to include fields in all medium (material mediums).

An important consequence of Maxwell's equations is the fact that they can be used to derive the law of conservation of charge. Any electromagnetic field must satisfy all the Maxwell's equations.

24.4.3 Physical Significance of Maxwell's Equations

i) The equations (24.2) and (24.4) show the presence of sources (i.e q and I) In source free regions, these reduce to

$$\oint \mathbf{E} \cdot d\mathbf{s} = 0 \text{ and } \oint \mathbf{B} \cdot d\mathbf{l} = \mu_o \varepsilon_o \frac{d\phi_E}{dt} \text{ respecively.}$$

ii) The equation (24.3) tells that magnetic field lines can not start from a point nor end at a point in space i.e. they form closed loops starting from N-pole and ending at S-pole. Only, within the magnet they travel from S-pole to N-pole.

iii) The equation (24.5) tells that electrostatic field lines do not form a closed loop.

iv) Maxwell's equations being the basic laws of classical electromagnetism, are true in all media and for any value of **E**, **B** or q or I. etc. within the domain of validity of classical electromagnetism.

v) Maxwell's equations provide the equation of motion of electromagnetic waves and establish that light waves are electromagnetic in nature.

24.4.4 Properties of e.m. waves

Rigorous mathematics with Maxwell's four equations have revealed following properties of e.m. waves:

i) e.m. waves are transverse in nature

ii) They consist of oscillating electric field (**E**) and magnetic fields (**B**) at right angles to each other and perpendicular to the direction of propagation (k). Also **E** = c**B**. [see figures 24.4 and 24.5]

iii) They propagate through free space in vacuum with a uniform velocity $= \frac{1}{\sqrt{\mu_o \varepsilon_o}} = 3\times10^8 \text{ ms}^{-1} = c$ (velocity of light) for a medium of permeability $\mu (= \mu_o \cdot \mu_r)$ and permittivity $\varepsilon (= \varepsilon_o \cdot \varepsilon_r)$ the velocity becomes

$$v = \frac{1}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\mu_o \varepsilon_o}\sqrt{\mu_r\, \varepsilon_r}} = \frac{c}{\sqrt{\mu_r \varepsilon_r}} < c$$

iv) The nature and action of these waves depends upon their frequency (or wavelength). Maxwell's theory placed no restriction on possible wavelengths for e.m. waves and hence e.m waves of wavelengths ranging from 6×10^6m to 6×10^{-13}m have been successfully produced. There is no limit to very long wavelengths which correspond to radio broadcast waves. The whole range of e.m. waves from very long to very short wavelengths is called the *electromagnetic spectrum.*

INTEXT QUESTION 24.2

1) *Give the name of the law associated with the following equations:*

   i) $\oint \mathbf{B}.\,d\mathbf{s} = 0$

   ii) $\oint \mathbf{B}.\,d\mathbf{l} = \mu_0 (I + I_d)$

2) *Which law tells the non-existence of isolated magnetic poles?*

   ....

3) *Which law tells that electric field lines do not form a closed curve?*

   ....

4) *What happens to the speed of the e.m. waves when they pass through a material medium?*

   ....

5) *What is the nature of e.m. waves?*

   ....

24.6 ELECTROMAGNETIC SPECTRUM

Maxwell gave the idea of e.m. waves. while Hertz. J.C.Bose. Marconi and others successfully produced such waves of different wavelengths experimentally. However, in all the methods. *the source of e.m. waves is the accelerated charge.*

Electromagnetic waves are classified according to the method of their generation and are named accordingly. Overlapping in certain parts of the spectrum by different classes of e.m. waves is also observed. This tells that the e.m. waves of wavelengths in the overlapping region can be produced by two different methods. It is ***important to remember that the physical properties of e.m. waves are determined by the frequencies or wavelengths and not by the method of their generation.*** A suitable classification of e.m waves is called the electromagnetic spectrum.

There is no sharp dividing point between one class of e.m. waves and the next. The different parts are as follows:

i) **The low frequency radiations** $\left\{\begin{matrix} \nu = 60\,\text{Hz to } 50\text{Hz} \\ \lambda = 5\times10^6\,\text{m to } 6\times10^6\,\text{m} \end{matrix}\right\}$: generated from a.c. circuits are classified as power frequencies or power waves or electric power utility e.m. waves. These *are the e.m. weaves of lowest* frequencies

ii) **Radio Waves** $\left\{\begin{matrix} \lambda = 0.3\text{m to } 10^6\,\text{m} \\ \nu = 10^9\,H_z \text{ to } 300\,H_z \end{matrix}\right\}$: Radio waves are the result of charges accelerating through conducting wires. They are generated in such electronic devices as L.C. oscillators and are *used exten-*

sively radio and television communications.

iii) **Microwaves** $\left\{\begin{matrix} \lambda = 10^{-3}\text{ m to } 0.3\text{m} \\ \nu = 10^{11}\text{ Hz } to\ 10^{9}\text{ Hz} \end{matrix}\right\}$: These are generated by oscillating currents in special vacuum tubes. Because of their short wavelengths, they are well suited for the radar system used in aircraft navigation, T.V. communication and for studying the atomic and molecular properties of matter. Microwave ovens use these radiations as heat waves. It is suggested that solar energy could be harnessed by beaming microwaves down to Earth from a solar collector in space.

iv) **Infra red waves** $\left\{\begin{matrix} \lambda = 7\times 10^{-7}\text{m to } 10^{-3}\text{m} \\ \nu = 4.3\times10^{14}\text{ Hz to } 3\times10^{11}\text{ Hz} \end{matrix}\right\}$: Infra red waves sometimes called as heat waves, are produced by hot bodies and molecules. These are readily absorbed by most materials. The temperature of the body, which absorbs these radiations, rises. Infra red radiations have many practical and scientific applications including physical therapy infrared photography etc. These are detected by a thermopile.

v) **Visible light** $\left\{\begin{matrix} \lambda = 4\times10^{-7}\text{ m } to\ 7\times10^{-7}\text{m} \\ \nu = 7.5\times10^{14}\text{ Hz to } 4.3\times10^{14}\text{ Hz} \end{matrix}\right\}$: These are the e.m. waves that human eye can detect or to which the human retina is sensitive. It forms a very small portion of the whole electromagnetic spectrum. These waves are produced by the rearrangment of electrons in atoms and molecules. When an electron jumps from outer orbit to inner orbit of lower energy, the balance of energy is radiated in the form of visible radiation. The various wavelengths of visible lights are classified with colours, ranging from violet $(\lambda \approx 4\times10^{-7}\text{ m})$ to red $(\lambda \approx 7\times10^{-7})$. Human eye is maximum sensitive to yellow-green light $(\lambda \approx 5\times10^{-7}\text{m})$. Light is the basis of optics and optical instruments.

vi) **Ultraviolet** $\left\{\begin{matrix} \lambda = 3\times10^{-9}\text{ m to } 4\times10^{-7}\text{ m} \\ \nu = 10^{-17}\text{ Hz } to\ 7.5\times10^{14}\text{ Hz} \end{matrix}\right\}$: Sun is the important source of ultraviolet radiations, which is the main cause of suntans. Most of the ultraviolet light from Sun is absorbed by atoms in the upper atmosphere i.e. stratosphere, which contains ozone gas. This ozone layer then radiates out the absorbed energy as heat radiations,. Thus, the lethal (harmful to living beings) radiations get converted into useful heat radiations by the ozone gas, which warms the stratosphere. These ultraviolet rays are used in killing the bacteria in drinking water, in sterilisation of operation theatres and also in checking the forgery of documents.

vii) **X-rays** $\left\{\begin{matrix} \lambda = 4\times10^{-13}\text{m to } 4\times10^{-8} \\ \nu = 7.5\times10^{20}\text{ Hz to } 7.5\times10^{15}\text{ Hz} \end{matrix}\right\}$: These are proluced by acceleration of high energy electrons bombarding a metal target (with high melting point) such as tungsten. X-rays find their important applications as a diagnostic X-rays in medical and as a treatment for certain forms of cancer. tool destroy living tissues and care must be taken to avoid over-exposure of body parts. X-rays are also used in study of crystal-structure. They are detected by photographic plates.

viii) **Gamma rays** $\left\{\begin{array}{l}\lambda = 6 \times 10^{-17} m \text{ to } 10^{-10} m \\ \nu = 5 \times 10^{24} Hz \text{ to } 3 \times 10^{18} Hz\end{array}\right\}$: These are emitted by radioactive nuclei such as cobalt (60) and ceasium (137) and also during certain nuclear reactions in nuclear reactors. These are highly penetrating and cause serious damage when absorbed by living tissues. Thick sheets of lead are used to shield the objects from the lethal effects of gamma rays.

The energy (E) of e.m. waves is directly proportional to their frequency ν $\left(E = h\nu = \frac{hc}{\lambda}\right)$ and inversely proportional to their wavelength (λ). Thus gamma rays are the most energetic and penetrating e.m. waves, while the power frequencies, and the A.M. radio waves are the weakest radiations. Gamma rays are used to detect metal flaws in metal castings. They are detected by Geiger tube or scintillation counter.

Depending upon the medium, various types of radiations in the spectrum will show different characteristic behaviours. For example, while whole of the human body is opaque to visible light, human tissues are transparent to X-rays but the bones are relatively opaque. Similarly Earth's atmosphere behaves differently for different types of radiations.

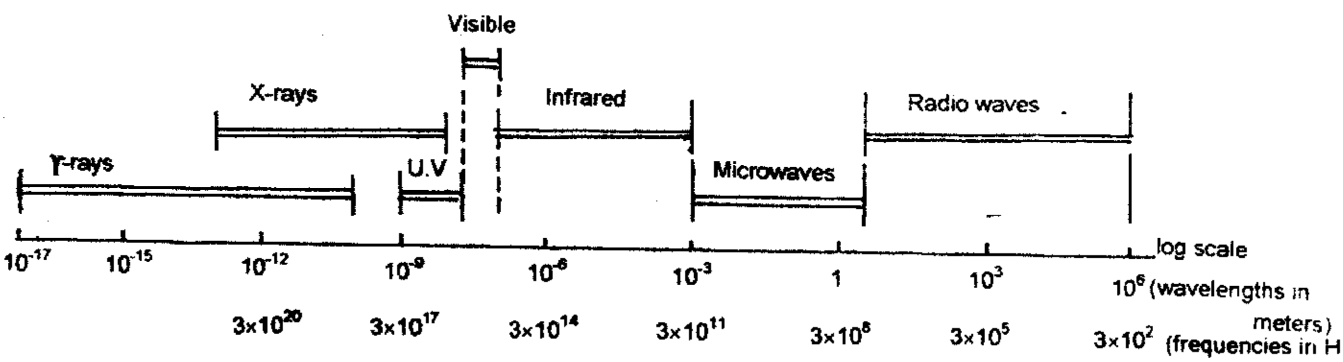

Fig. 24.3: *Elecromagnetic spectrum*

24.6.1 W.M. Wave Propagation

Figure (24.4) shows the relation between **E** and **B** of a linearly plane polarised electromagnetic waves propagating along Z-axis. Figure (24.5) represents the relative orientations of electric field **E** and magnetic field **B** with time in space in an e.m. wave whose frequency $\nu = 1/T$ and wavelength λ.

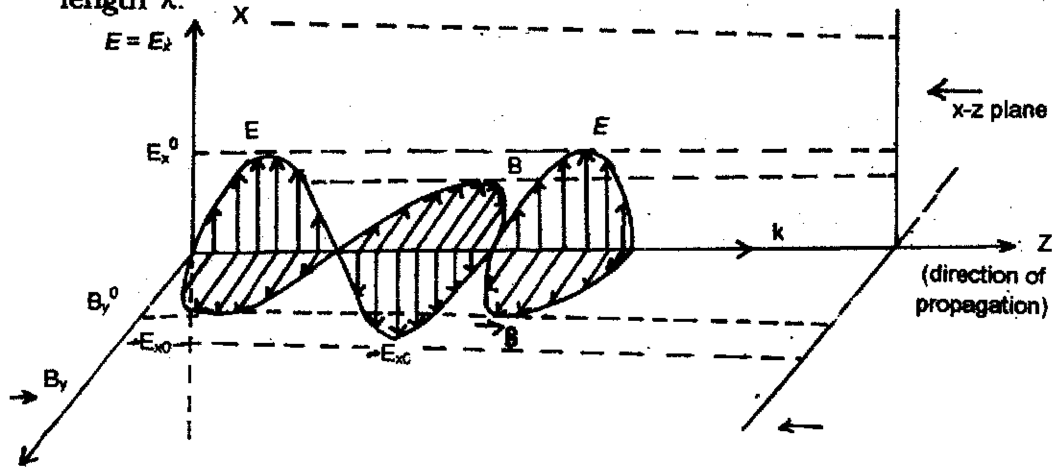

Fig 24.4: *Linearly plane polarised e.m. wave propagating along Z-axis.*

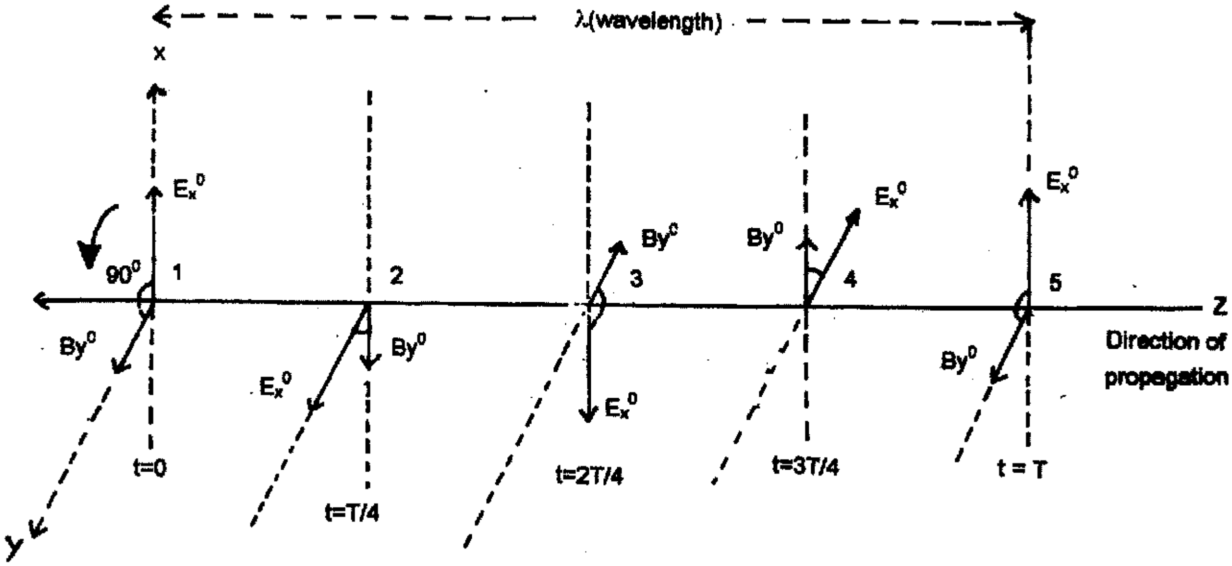

Fig 24.5: *Relative orientations of E°_x and E°_y over one wavelength distance at 5 different times in an e.m. waves.*

According to Maxwell's concept of the propagation of e.m. waves in space, the mutually perpendicular electric field (**E**) and magnetic field (**B**) vectors rotate about the direction of propagation (**k**) as axis, as the e.m. wave advances in space with constant angular velocity (as shown in figure 24.5).The phenomenon is similar to the rotational motion of a nut on a bolt (Figure 24.5(a)).

The frequency of rotation of E and B around axis of propagation gives the frequency of the e.m. wave.

The distance moved ahead in one rotation (i.e. the pitch of the screw) is a measure of the wavelength of the e.m. wave.The distance travelled in one second is equal to the velocity of the e.m. wave.

The velocity of the e.m. wave changes as it passes from one medium to another. This is due to the change caused in the wavelength of the e.m. wave. ***The frequency of the e.m. wave does not change with the change in the medium of the path of the e.m. wave.***

The most important characteristic of e.m. wave is that it can transport energy and linear momentum from one point to another point in space with the velocity of light.

INTEXT QUESTIONS 24.3

1) *Fill in the blanks:*

   i) *......................are generated by oscillating concerts in special vacuum tubes.*

   ii) Human eye is most sensitive to ....color light.

   iii) *...................... is the important source of ultraviolet radiation*

   iv) *...................... are used as the diagnostic tool in medical.*

   v) *Infrared radiations can be detected by a ....*

2) *Which of the e.m. waves are more energetic?*

   i) *Ultraviolet or infrared*

   ii) *x-rays or γ-rays*

3) *Which of the e.m. waves are used in aircraft navigation by radar?*

   ....

4) *Which gas in the atmosphere absorbs ultraviolet radiations from the Sun before reaching the earth's surface?*

   ....

5) *How are the electric field and magnetic field oriented with respect to each other in an e.m. wave?*

   ....

24.7 USES OF E.M. WAVES

The high frequency e.m. waves are used as carrier waves to transport sound waves and light waves to long distances without dissipation of energy. As carrier waves, e.m. waves, have been used for various purposes.

24.7.1 Wireless Radio Communication

The wireless-radio communication has been made possible only because of e.m. waves. The simplest scheme would be to convert the speech or music to be transmitted, to electric signals using a microphone, boost up the power of the signal using amplifiers and radiate the signal in space with the aid of an antenna. This constitutes the transmitter. At the receiving end, one could have a signal-pick-up- antenna feeding the speech or music signal to an amplifier and then a loudspeaker reproduces the speaker music.

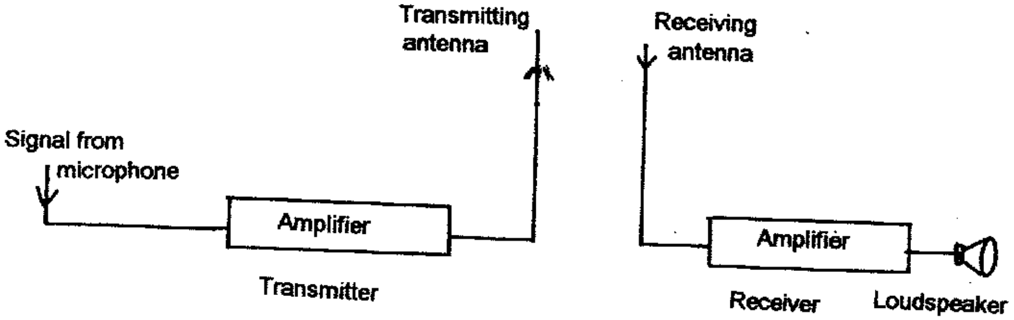

Fig 24.6: *Block diagram of wireless communication*

However, following difficulties arise:

i) Waves in the audio frequency range i.e. audible to human ears, (20 Hz to 20 kHz) can not be efficiently radiated and do not propagate well in space.

ii) Simultaneous transmission of different signals by different transmitters would lead to confusion at the receiver, due to overlapping.

Both the difficulties could be overcome if the transmission is done at high frequencies. Hence methods are devised to translate the audio signals to the radio-frequency range before transmission and recover the audio frequency signals back at the receiver. The *process of frequency translation at the transmitter is called* **modulation**. The process of recovering the audio signal at the receiver end is called **demodulation**.

The modulation is done by mounting the audio-message on high frequency e.m. waves in the various wave bands, depending on the distance of destination. Then radio waves are thus used as *carrier waves*.

When the amplitude of the carrier waves gets modulated by mixing the audio message, we get **amplitude modulated** (A.M.) wave. If, however, the frequency of the carrier wave gets modulated, we have **frequency modulated** (F.M) waves.

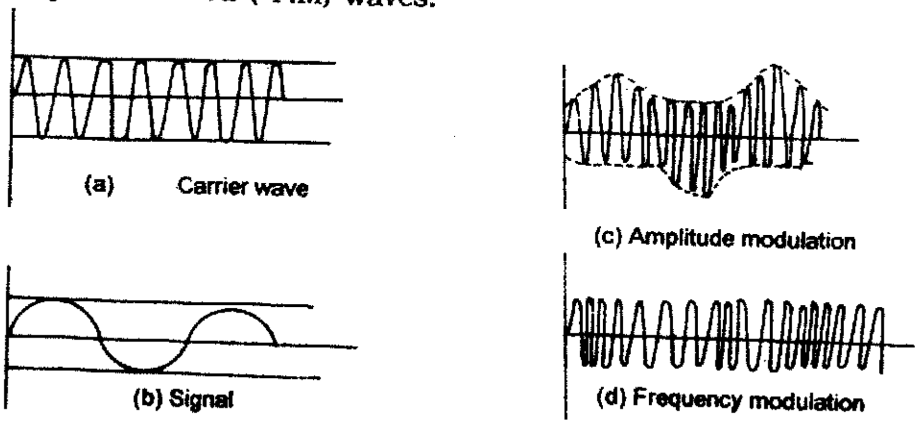

Fig.24.7: *(a) Carrier waves, (b) Signal waves (c) Amplitude modulation of carrier wave by signal, (d) Frequency modulation of carrier waves*

The radio waves i.e. the carrier e.m. waves vary in wavelength from a few mm to several kms.

If we consider the e.m. waves of wavelength in the range from 10 m to 600 m (frequency in the range 30 MHz to 0.5 MHz) we find that the lower atmosphere is more or less transparent to such waves, the upper atmosphere (ionosphere) reflects them back i.e. ionosphere is non-transparent to these range

(a) Amplitude Modulated Waves

When AM signal in the above range is transmitted by an antenna at a certain place on the Earth, it can reach at another distant place on the surface of the Earth in following two ways.

(i) By ground wave propagation:- The radio waves which travel directly from the transmitting antenna to the receiving antenna near the surface of the Earth are called **ground waves** and the propagation is termed as *ground wave propagation* or *surface wave propagation.*

The ground waves can not bend round the curvature of Earth. Also *ground wave transmission is found to become weaker for higher frequencies (i.e. lower wavelengths) of radio waves. Therefore, the ground wave transmission is useful with radio waves of wavelength 200 m or above. This* range *of the radio waves is called* ***Medium wave band.***

ii) By sky wave propagation:- the radio waves travel from the transmitting antenna to the ionosphere and then the reflected e.m. wave reaches the receiving antenna. Since the receiving antenna catches the waves coming from sky, this is called **sky waves propagation** and the e.m. waves reflected downwards towards Earth from the ionosphere are called **sky waves.** This mode of transmission is used for e.m. waves of wavelengths, 200 m or less. This region in radio waves is called short **wave band.** The sky waves can reach the points on Earth where ground waves can not reach due to curvature in Earth's surface. (Fig 24.8).

(b) Frequency Modulated Waves. (F.M band)

Beyond a certain frequency (above 40 MHz) i.e. below a certain wavelength (below 7.5m) of radio waves, the ionosphere bends any incident e.m wave but does not reflect it back towards the earth For example T.V signals usually have frequencies in the range 100 MHz to 200 MHz i.e. wavelengths in the range (3 m to 1.5 m). They are not reflected by the ionosphere and hence T.V transmission through sky waves is not possible. Hence reception is possible only if the receiving antenna directly intercepts the transmitted signal. ***The frequency band 30 MHz to 300 MHz is reserved for FM broadcasting.***

Have you seen high T.V towers fitted with dish type antenna receivers in your town somewhere? What is their function? For long distance transmissions of F.M band signals, receiving antenna stations are made in the form of such high towers, all along the route to the destination at various places within the reach of the direct ground waves. The more is the height of a T.V tower, the longer is the distance travelled by ground waves. These stations collect the signals and then retransmit in different directions to the nearby intermediate receiving antenna stations or T.V towers. By this technique, now T.V programs can be seen by the people living at far off places from the main T.V transmitting stations.

Do you know, when these high T.V towers were not there, the TV programs could be seen in T.Vs, within small radial distance of about 60 km only.

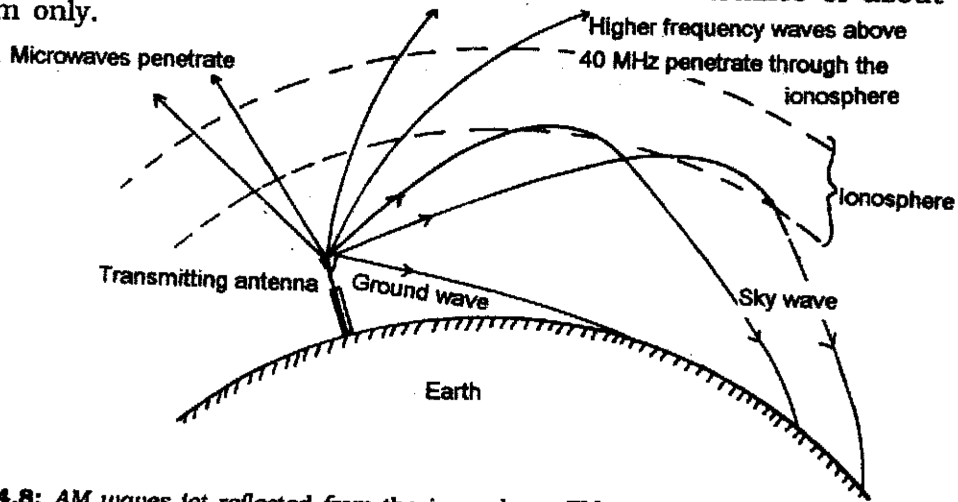

Fig 24.8: *AM waves jet reflected from the ionosphere; FM waves bend but penetrate through the atmosphere. Microwaves penetrate the atmosphere without bending.*

24.7.2 Use of Microwaves in Radar and Satellite Communication

Radio waves of wavelengths smaller than T.V signals are the microwaves. They have the property of being transmitted in atmosphere without much spread (or attenuation) or deflection. These are used in radar to locate the instantaneous position of the aeroplanes in space and also to know their distance from the radio station. The microwaves pulses are beamed in different directions at small intervals of time. They get reflected back from any solid obstacle which comes in their path. The time lapse between the instant of transmission and the instant of re-reception of the reflected microwave pulse gives the distance of the obstacle

If d = distance of an obstacle say an aeroplane

$2d$ = distance for the forward and backward journey of the pulse

t = time interval recorded

and, c = velocity of microwaves = velocity of light

Then,

$$2d = ct. \quad \Rightarrow \quad d = \frac{1}{2}ct.$$

In more recent times microwaves have revolutionised tele-communication. Using artificial satellites, it has become possible to transmit signals from one point on the Earth to practically any other point on the Earth Fig (24.9).

The signals from the broadcasting stations are beamed towards an artificial Earth satellite. which in turn broadcasts it back (by reflection) to different points on the earth. Since the satellite is high above it can send back the signals to a large part of the Earth's surface. To continuously use an artificial satellite to transmit messages over a particular portion of Earth's surface, the orbiting satellite should appear stationary with respect to the transmitting station on the spinning Earth. This is achieved by setting the height and velocity of the satellite so that its time period of revolution around the Earth becomes exactly equal to the spinning period (24 hrs) of Earth about its axis. This enables the satellite to appear stationary with respect to Earth it always appears in the same direction above the transmitting antenna. Such an artificial satellite is called a *geo-stationary satellite* and is used for long distance transmission of micro waves.

Do you know, that you are able to see the direct live telecast of cricket matches being played in other countries via such satellite communication technique only. Now-a-days, such satellites have been launched in space by some developing and developed countries. Some times one country has to hire these satellites for telecasting of some important events occuring in other countries or different parts of the same country. Fig. (24.9)

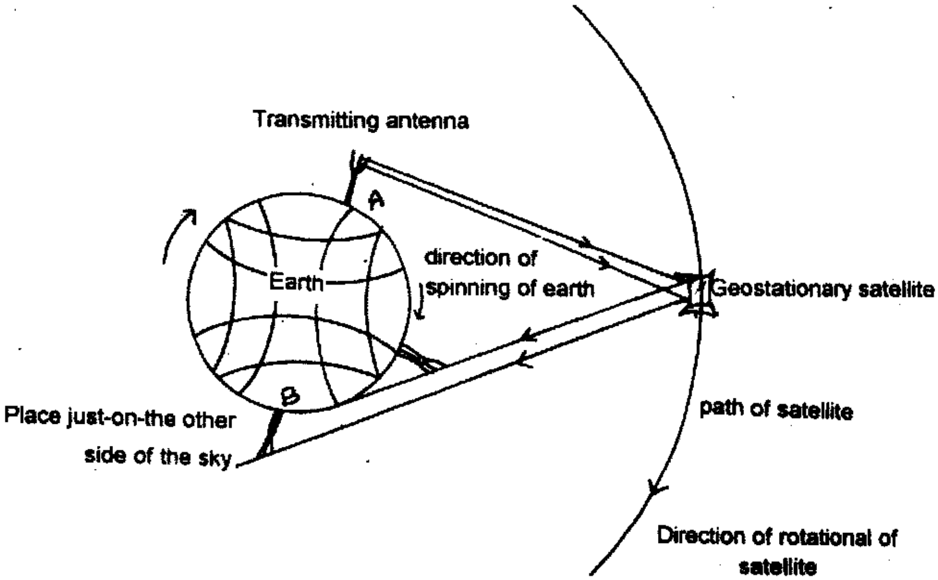

Fig. 24.9: *Signal transmission via satellite*

Because the *geo-stationary* satellites are at a particular height above the Earth, three such satellites are required to cover the whole globe, each being able to cover only one third surface of the spherical globe.

For long distance transmission of video signals, you have known about the use of repeaters installed in the form of high towers fitted with collector and transmitter antennas (disk antenna).

A communication satellite is essentially a microwave link repeater. It receives beamed up microwaves at it from Earth station, amplifies them and returns it to Earth at a frequency of about 2 gigahertz. This prevents interference between the uplink and the downlink.

The device which converts frequency of the received signals to giga-hertz is called *frequency converter* or *transponder.*

The Earth stations are fitted with dish antennas which are very large size paraboloidal antennas.

An Earth station is related to a satellite in much the same way as a terminal is related to microwave repeater. However, there is one significant difference: where a link terminal may be connected to several links and a repeater works in just one chain, So here it is the earth station that works just as the satellite and the satellite repeate works with any number of Earth terminal stations. That is to say, any Earth station facing a particular satellite may communicate with every Earth station in the same satellite region. This multiple access ability is a distinct advantage of satellites over cables.

The Earth station receivers are low noise amplifiers (LNAs) located close to the wave-guide in the centre of the antenna and is a multistage travelling wave amplifier.

High reliability of satellite is marred sometimes by causes such as cyclones and maintenance or failure of terrestrial links.

INTEXT QUESTIONS 24.4

1) *Which type of waves reach longer distances on Earth when emitted from a transmitting antenna ground waves or sky waves.*

   ....

2) *What is the relation between the frequencies of sky waves and the ground waves? Are they same or different?*

   ....

3) *Which type of waves are used in satellite communication and why?*

4) *State True or False:*

   ....

i) *the medium wave band is used for long distance communication while short wave band is used for short distance communication.*

ii) *The e.m. waves of frequencies above 40 MHz are not reflected back to earth by the ionosphere.*

iii) *T.V transmission takes place through sky waves in the absence of satellite.*

iv) *Microwaves get easily reflected by the solid obstacle in their path but not by the ionospheric layer of the atmosphere.*

v) *T.V towers are installed to receive and retransmit the sky waves.*

vi) *Radar uses microwaves for navigation.*

vii) *Geostationary satellite is fitted with a transmitter antenna for long distance communication of audio and Video signals.*

24.8 WHAT YOU HAVE LEARNT

- Electromagnetic waves are electrical disturbances propagatings in free space with a speed equal to that of light.
- Hertz experimentally established the formation of e.m. waves by oscillating electric dipole.
- Displacement current is the real effective current in between the plates of a capacitor due to the changing electric field between them.
- Gauss's law in electrostatics, Gauss's law in magnetostatics, Ampere-Maxwell's law and faraday's law are four Maxvwell's equation.
- Electromagnetic waves are transverse in nature.
- Depending upon the medium, various type of e.m. radiations in e.m. spectrum show different characteristic behaviour.
- The frequency of e.m. waves does not change with the change in the medium of path of e.m. waves.
- e.m. waves are used for wireless radio communication, TV transmission, satellite communication etc.

24.9 TERMINAL QUESTIONS

1) Who and when, first of all, showed that a magnetic field is created in the neighbourhood of a direct current carrying wire?
2) Who discovered that the direct current in wire exerts a force on another nearby placed parallel wire carrying direct current?
3) When and who first of all thought of the existence of e.m. waves?
4) When and who first of all produced e.m. waves in the laboratory?
5) What is the displacement current? Give its mathematical expression.
6) A capacitor is connected to an a.c. source. The conduction current through the circuit is 2 ampere, what is the value of displacement current?
7) Write all the four Maxwell's equations. Write the names of the laws associated with each of them.
8) State Ampere's law. How was it modified by Maxwell?
9) Write the characteristic properties of e.m. waves which make them different from sound waves.
10) How does the velocity of e.m. waves depend upon the permeability μ and permittivity ε of the medium through which they pass?
11) Give the range of wavelengths of the following e.m: waves:

    i) Radio Waves, ii) Microwaves ; iii) Ultraviolet ; iv) x-rays.
12) How are x-rays produced?
13) Can e.m. waves of all frequencies propagate through vacuum?

14) What is the range of wavelengths of A.M. waves used as sky waves.

15) What is the difference between A.M e.m wave & F.M e.m wave?

16) What are geo-stationary satellites? What are their uses in telecommunication?

17) What is a transponder?

18) What is the principle of working of a dish antenna? Is it used as a transmitting antenna or as a receiving antenna or for both purposes?

19) Make a chart of the electromagnetic spectrum.

20) Fill in the blanks.

i) A charging electric field produces a ____________ in the adjacent region.

ii) ____________ are more harmful to our eyes than x-rays.

iii) ____________ are emitted from radio active nuclei of cobalt.

iv) Infra red rays are less energetic than ____________.

v) In an e.m. wave propagating along z-direction, if the ***E*** field oscillates in the X.Z place then the ***B*** field will oscillate in the ____________ plane.

vi) The ratio $\frac{E}{H}$ in free space of e.m. wave is called ____________ of the free space and is measured in ____________.

vii) The frequency range of F.M band is ____________.

viii) ____________ signal is frequency modulated in T.V broadcasting.

CHECK YOUR ANSWERS

Intext Questions 24.1

1) e.m.u., 1 e.m.u. = 3×10^8 . e.s.u.

2) It showed that e.m. waves do exist and can be produced by oscillating electric dipoles.

3) He introduced the concept of displaced current. (Just like a changing magnetic field produces an electric field, the changing electric field should also produce a magnetic field). He was thus able to correlate the laws of electricity and magnetism with the introduction of the concept of displacement current.

4) No.

Intext Questions 24.2

1) i) Gauss's law in electrostatics

ii) Ampere Maxwell's law

2) Gauss's law in magnetostatics.

3) Faraday's law

4) It decreases by a factor of $\frac{1}{\sqrt{\mu_r \epsilon_r}}$.

5) They are transverse waves consisting of rotating **E** and **B** fields in a plane perpendicular to the direction of propagation.

Intext Questions 24.3

1) i) *microwaves* (ii) *yellow-green* (iii) *Sun* (iv) *x-rays* (v) *thermopile*

2) Watt per metre square

3) i) Ultraviolet ii) γ rays

4) Microwaves

5) Ozone

6) ***E*** and ***B*** are at right angles to each other in a plane perpendicular to the direction of propagation of an e.m. wave.

Intext Questions 24.4

1) Sky waves

2) Sky waves propagation is used with higher frequency e.m. waves.

3) Microwaves; because they move without spreading or deviations directly to the satellite because of their high penetration power and hence can be easily aimed towards the satellite for being reflected to reach the other parts of the earth, not approachable by ground waves.

4) i) False (ii) True (iii) False (iv) True (v) True (vi) True (vii) True