14. Electromagnetic Waves

Electromagnetic waves

- These are the waves in which the electric and the magnetic field vary sinusoidally at right angle to each other as well as to the direction of propagation.
- The speed of electromagnetic waves in free space is given by

  c=1μ0ε0= 3×108 ms-1.

- For an electromagnetic wave travelling along positive Z-axis, electric field oscillates along X-axis and is given by $E_x = E_0 \sin(kz - \omega t)$ and magnetic field oscillates along Y-axis and is given by $B_y = B_0 \sin(kz - \omega t)$.
- The relation between the amplitudes of magnetic and electric fields is $B_0 = \frac{E_0}{c}$.

  The intensity of electromagnetic wave is given by 12ε02E02c.
- The velocity of light in a material medium is given by

  $v = \frac{1}{\sqrt{\mu \in}}$

  Here,
  ∈ = permittivity of material medium
  μ = permeability of material medium
- Electromagnetic waves carry energy and momentum and they also exert pressure, called radiation pressure.
- When the total energy (U) is transferred to a surface in time t, the magnitude of the total momentum delivered to the surface is given by

  $p = \frac{U}{c}$, where c = speed of light
- Hertz set up an experiment in order to produce and detect electromagnetic waves. In this experiment, a high voltage source causes spark to oscillate and, thus, electromagnetic waves are produced by the oscillating spark.
- Different electromagnetic waves:

•	Type	Wavelength range
(a)	Radio waves	>0.1 m
(b)	Microwave	0.1 m to 1 mm
(c)	Infra-red	1 mm to 700 nm
(d)	Visible light	700 nm to 400 nm
(e)	Ultra-violet	400 nm to 1 nm

(f)	X-rays	1 nm to 10^{-3} nm
(g)	Gamma rays	$<10^{-3}$ nm

- Uses of electromagnetic radiations:

Electromagnetic radiations	**Uses**
Visible Light	In photography, in photosynthesis in plants and in enabling us to see objects around us
Infrared	to identify molecular structure of compounds, ion long distance photography, diagnosing tumors, in TV remote and solar energy operated devices.
UV	Used as sterilizer, in fluorescent lamps, treatment of diseases skin and bone, in radiography, to study of crystal structure.
X-rays	in treatment of cancer and skin diseases, locate fractured bones, in radiography, to study of crystal structure.
γ-rays	in treatment of cancer, used as catalyst in manufacturing of some chemicals, to produce photoelectric effect, and in radiography.
Microwave	In RADAR, satellite communication and ovens.
Radio wave	In communication, TV and Radio broadcasting.

- Bandwidth − Bandwidth refers to the frequency range over which an equipment operates or the portion of the spectrum occupied by the signal.
- Bandwidth of an analogue signal − The range over which the frequencies in an analogue signal vary.

- Bandwidth of a digital signal - A digital signal is in the form of a rectangular wave. It is a superposition of sinusoidal waves of different frequencies. Bandwidth of a digital signal is infinite.

Bandwidth of Transmission Medium

- Wire, free space, and fibre optic cables are the commonly used transmission media.
- A coaxial cable offers a bandwidth of approximately 750 MHz.
- Free-space communication takes place over a wide frequency range of a few hundred kHz to a few GHz.
- An optical fibre offers a transmission bandwidth in excess of 100 GHz.

Propagation of Electromagnetic Waves

- An antenna at the transmitter radiates the electromagnetic waves, which travel through space and reach the receiving antenna at the other end.
- The transmitting antenna converts the electric signals to electromagnetic waves.
- The receiving antenna converts the electromagnetic waves into electric signals.
- Ground wave propagation − In this type of wave propagation, the radio waves from the transmitting antenna propagate along the surface of the earth to reach the receiving antenna. Its frequency range is less than a few MHz.
- Sky waves − In this type of wave propagation, the radio waves from the transmitting antenna reach the receiving antenna after reflection from the ionosphere. Its frequency ranges from 30 to 40 MHz.
    - $d_M = \sqrt{2Rh_T} + \sqrt{2Rh_R}$

$h_R \rightarrow$ Height of receiving antenna

$d_M \rightarrow$ Maximum line of sight distance

- **Layers of the atmosphere**

- The troposphere extends up to a height of 12 km from the earth's surface. It contains most of the water vapour of the atmosphere.
- The stratosphere is the layer above the troposphere and extends from 10 km to 50 km from the surface of the earth. This region contains the ozone layer.
- The mesosphere is the layer above the stratosphere. It extends from 50 km to 80 km from the surface of the earth.
- The ionosphere extends from 80 km to thousands of km. It is composed of positive and negative ions that play an important role in radio and telecommunications.