CHAPTER

8 Electromagnetic Waves

Displacement Current

Displacement current is that current which appears in a region in which the electric field (and hence electric flux) is changing with time.

Note: We have

$$I_D = \varepsilon_0 \frac{d\phi_E}{dt} = \varepsilon_0 \frac{d}{dt}(EA) = \varepsilon_0 \frac{d}{dt}\left(\frac{qA}{\varepsilon_0 A}\right) = \frac{dq}{dt} = I$$

[Charging of plate of a capacitor]

Modified Ampere's Circuital Law

$$\oint \vec{B} \cdot \overrightarrow{dl} = \mu_0 \left(I + \varepsilon_0 \frac{d\phi_E}{dt} \right)$$

Electromagnetic Waves

$\oint \vec{E} \cdot \overrightarrow{dl} = -\frac{d\phi_B}{dt}$ and $\oint \vec{B} \cdot \overrightarrow{dl} = \mu_0 \varepsilon_0 \frac{d\phi_E}{dt}$ (Maxwell's equations)

These equations lead to the conclusion that, if either of the electric or magnetic field changes with time, the other field is induced in space. The net result of these interacting changing fields is the generation of electromagnetic disturbance, called electromagnetic waves which travel with the speed of light.

Mathematical Expression of EM Waves

$$E_y = E_0 \sin 2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right), B_Z = B_0 \sin 2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right)$$

Important Characteristics of EM Waves

(i) EM waves are produced by accelerated charged particles.

(ii) EM waves do not require any medium for their propagation. These waves can propagate in vacuum as well as in a medium.

Velocity of em waves in free space is given by

$$v = c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}} = 3 \times 10^8 \text{ m/s}$$

Velocity of em waves in a medium is given by

$$v = \frac{c}{\sqrt{\mu_r k}}$$

[μ_r = relative permeability of medium]

[k = dielectric constant of medium]

(iii) EM waves are transverse in nature i.e. E and B are perpendicular to each other as well as perpendicular to the direction of propagation of the wave. E and B are related as follow:

$$\frac{E_0}{B_0} = c \text{ or } \frac{E}{B} = c$$

(iv) EM waves carry energy, which is shared equally by electric and magnetic fields.

The average energy density of an EM wave is given by

$$u = u_E + u_B = 2u_E = 2u_B$$

where $u_E = \frac{1}{2}\varepsilon_0 E^2 = \frac{1}{2}\varepsilon_0 (Bc)^2$ $\quad\left[\because \frac{E}{B} = c\right]$

$$= \frac{1}{2}\varepsilon_0 B^2 \left(\frac{1}{\sqrt{\mu_0 \varepsilon_0}}\right)^2 = \frac{B^2}{2\mu_0} \quad \left[\because c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}\right]$$

(v) EM waves carry momentum and exert a radiation pressure

$P = \frac{F}{A} = \frac{1}{A}\frac{dp}{dt}$ and momentum $p = \frac{U}{c}$

(vi) EM waves transport energy. The rate of energy of EM wave transport per unit area is represented by a quantity called Poynting vector $(\vec{S})$ and is given by $\vec{S} = \frac{1}{\mu}(\vec{E} \times \vec{B})$

(vii) Electric vector of an em wave is responsible for optical effects, as $E_0 >> B_0$.

(viii) Intensity of an EM wave is given by

$$I = \frac{1}{2} c \varepsilon_0 E^2 = \frac{B^2 c}{2\mu_0}$$

CHAPTER

15 Communication Systems

1. Bandwidth of video signals is 4.2 MHz.
2. Coaxial cable is a widely used wire medium, which offers a bandwidth of approximately 750 MHz.
3. For transmission over long distances, signals are radiated into space using devices called antennas. The radiated signals propagate as electromagnetic waves and the mode of propagation is influenced by the presence of the earth and its atmosphere. Near the surface of the earth, electromagnetic waves propagate as surface waves. Surface wave propagation is useful up to a few MHz frequencies.
4. Communication through free space using radio waves takes place over a very wide range of frequencies from a few hundreds of KHz to a few GHz.
5. To radiate signals with high efficiency, the antennas should have a size comparable to the wavelength λ of the signal (at least ~ $\lambda/4$)
6. If an antenna radiates electromagnetic waves from a height h, then the range d is given by $\sqrt{2Rh}$ where R is the radius of earth.
7. The maximum line of sight distance d_M between the two antennas having heights h_T and h_R above the earth is given by $d_{\ddot{u}} = \sqrt{2Rh} + \sqrt{2Rh}$
8. Low frequencies cannot be transmitted to long distances. Therefore, they are superimposed on a high frequency carrier signal by a process known as modulation.
9. The method in which the amplitude of carrier wave is varied in accordance with the modulating signal keeping the frequency and phase of carrier wave constant is called amplitude modulation (AM).
10. Amplitude modulated signal contains frequencies $(\omega_c - \omega_m)$, ω_c and $(\omega_c + \omega_m)$.
11. Amplitude modulated waves can be produced by application of the message signal and the carrier wave to a non-linear device, followed by a band pass filter.
12. AM detection, which is the process of recovering the modulating signal from an AM waveform, is carried out using a rectifier and an envelope detector.