UNIT V ELECTROMAGNETIC WAVES

PART – A

1. What is wave?

If a physical phenomenon that occurs at one place at a given time is reproduced atr other places at later times, the time delay being proportional to the space separation from the first location, then the group of phenomena constitute a wave.

2. Give the wave equation in terms of electric field and magnetic field.

The electromagnetic wave equation in terms of electric field is, $\nabla^2 E - \mu\varepsilon \frac{\partial E}{\partial t} - \mu\varepsilon \frac{\partial^2 E}{\partial t^2} = 0$

The electromagnetic wave equation in terms of magnetic field is, $\nabla^2 H - \mu\varepsilon \frac{\partial H}{\partial t} - \mu\varepsilon \frac{\partial^2 H}{\partial t^2} = 0$

3. Give the wave equation in free space.

The wave equation in free space in terms of electric field is, $\nabla^2 E - \mu\varepsilon \frac{\partial^2 E}{\partial t^2} = 0$

The wave equation in free space in terms of magnetic field is, $\nabla^2 H - \mu\varepsilon \frac{\partial^2 H}{\partial t^2} = 0$

4. List out the properties of a uniform plane wave.

If the plane of wave is the same for all points on a plane surface, it is called plane wave. If the amplitude is also constant in a plane wave, it is called uniform plane wave. The properties of uniform plane waves are:

a) At every point in space, E and H are perpendicular to each other and to the direction of travel.
b) The fields vary with time at the same frequency, everywhere in space.
c) Each field has the same direction, magnitudes and phase at every point in any plane perpendicular to the direction of wave travel.

5. Give the expression for the characteristic impedance of the wave.

The characteristic impedance or intrinsic impedance is the ratio of the electric field intensity to the magnetic field intensity.

$\frac{E}{H} = \sqrt{\frac{\mu}{\varepsilon}}$ where, μ is the permeability of the medium and ε is the permittivity of the medium.

6. What is Vector Helmholtz equation.

The wave equation in lossless medium in phasor form is called the vector Helmholtz equation.

$$\nabla^2 E + \omega^2 \mu\varepsilon E = 0$$

7. Give the wave equation for a conducting medium.

The wave equation for a conducting medium in phasor form is given as,

$$\nabla^2 E - j\omega\mu(\sigma + j\omega\varepsilon)E = 0$$

8. What is skin effect and skin depth?

In a good conductor the wave is attenuated as it progresses. At higher frequencies the rate of attenuation is very large, and the wave may penetrate only a very short distance before being reduced to a small value. This effect is called skin effect.

The skin depth (δ) is defined as that depth in which the wave has been attenuated to 1/e or approximately 37% of its original value. It is also known as depth of penetration.

$\delta = \frac{1}{\alpha}$ where , α is the attenuation constant, $\alpha = \omega\sqrt{\frac{\mu\varepsilon}{2}\left(\sqrt{1+\frac{\sigma^2}{\omega^2\varepsilon^2}}-1\right)}$

9. Give the expression for attenuation constant and phase shift constant for a wave propagating in a conducting medium.

The attenuation constant for a wave propagating in a conducting medium is,

$$\alpha = \omega\sqrt{\frac{\mu\varepsilon}{2}\left(\sqrt{1+\frac{\sigma^2}{\omega^2\varepsilon^2}}-1\right)}$$

The phase shift constant for a wave propagating in a conducting medium is,

$$\beta = \omega\sqrt{\frac{\mu\varepsilon}{2}\left(\sqrt{1+\frac{\sigma^2}{\omega^2\varepsilon^2}}+1\right)}$$

10. Give the expression for the velocity of propagation of a wave in any medium.

The velocity of propagation of a wave in any medium is

$v = \frac{\omega}{\beta} = \frac{1}{\sqrt{\mu\varepsilon}}$ where, ω is the angular velocity and β is the phase shift.

11. Define pointing theorem.

The vector product of electric field intensity and magnetic field intensity at any point is a measure of the rate of energy flow per unit area at that point.

$P = E \times H$

12. What is Brewster angle?

Brewster angle is an incident angle at which there is no reflected wave for parallel polarized wave.

$\theta_B = \tan^{-1}\sqrt{\frac{\varepsilon_1}{\varepsilon_2}}$ Where ε_1 is dielectric constant of medium 1

ε_2 is dielectric constant of medium 2

13. State one dimensional wave equation.

$$\frac{\partial^2 E}{\partial x^2} = \mu\varepsilon\frac{\partial^2 E}{\partial t^2}$$

14. What is the velocity of electromagnetic wave in free space and in lossless dielectric.

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

15. Represent equation of electromagnetic wave in the phasor form.

Wave equation in phasor form is

$$\nabla^2 E - \omega^2 \mu \varepsilon E - j\omega\mu\sigma E = 0 \qquad \text{Or} \nabla^2 E - \gamma^2 E = 0$$

Where $\gamma^2 = j\omega\mu(\sigma + j\omega\varepsilon)$

16. For a lossy dielectric material having $\mu_r = 1$, $\varepsilon_r = 48$, $\sigma = 20 s/m$. Calculate the propagation constant at a frequency of 16GHZ.

Given data: $\mu_r = 1$ $\varepsilon_r = 48$ $\sigma = 20 s/m$. f = 16MHZ
Find: propagation constant (γ)

Formula: $\gamma = \sqrt{j\omega\mu(\sigma + j\omega\varepsilon)}$

Soluation:

$$\gamma = \sqrt{j\omega\mu\sigma(1 + \frac{j\omega\varepsilon}{\sigma})}$$

$$\frac{\omega\varepsilon}{\sigma} = 2.13$$

$$\gamma = \sqrt{j\omega\mu\sigma(1 + j\,2.13)} = \sqrt{-5381697 + j\,2526618} = \sqrt{5945288.9 \angle -64.8^\circ} = 2438 \angle -32.4^\circ$$

Result: $\gamma = 2438 \angle -32.4^\circ$

17. Brief about the intrinsic impedance for a perfect dielectric medium.

Intrinsic impedance for a perfect dielectric medium is given by

$$\eta = \sqrt{\frac{j\omega\mu}{j\omega E}} = \sqrt{\frac{\mu}{E}} \ \Omega$$

η is a real positive, Phase angle is zero, For a perfect dielectric, both the field E and H are in phase.

18. Brief about complex pointing vector.

The complex pointing vector is given by

P = ½ E x H

Product of E and H is a vector product. Mutually perpendicular components of E and H contribute to the power flow. This power flow is directed along the normal to the plane containing E and H.

19. What is mean by Linear polarization?

The electric field E is the resultant of E_X and E_Y, and the direction of it depends on the relative magnitude of E_X and E_Y.

The angle made by E with x axis is given by

$$\tau = \tan^{-1}\left(\frac{E_y}{E_x}\right)$$

If the resultant E is oriented in a direction which is constant with time, the wave is said to be linearly polarized.

20. State Snell's Law.

When a wave is travelling from one medium to another medium, the angle of incidence is related to angle of reflection as follows.

$$\frac{\sin\theta_i}{\sin\theta_t} = \sqrt{\frac{\mu_1}{\mu_2}} = \sqrt{\frac{\varepsilon_1}{\varepsilon_2}}$$

PART – B

1. a) A plane wave propagating through a medium with $\varepsilon_r = 8$, $\mu_r = 2$ has $\bar{E} = 0.5\, e^{-z/3} \sin(10^8 t - z)\, a_x .V/m.$ **Determine , Wave velocity, The loss tangent, intrinsic impedance and H field.**

b) derive the general electromagnetic wave equation.

2. a) For a parallel polarized wave, explain clearly about Snell's Law and critical angle.

b) Sea water plays a vital role in the study of submarine communications. Assuming that for seawater σ = 4 S/m, $\varepsilon_r = 80$, $\mu_r = 1$ and f= 100 MHz.Calculate

a) The phase velocity
b) The wavelength
c) The skin depth
d) The intrinsic impedance.

3. **a)An electric field in free space is given by** $E = 50\cos(10^8 t + x)\, a_y .V/m.$ **Find the direction of the wave propagation, calculate phase constant and the time taken to travel a distance of $a/2$.**
b) Prove pointing theorem

4. a)A **lossy material has $\mu_r = 5$, $\varepsilon_r = 2$. If at 5MHZ,the phase constant is 10 red/m. calculate the loss tangent, the permittivity, the attenuation constant and the intrinsic impedance.**

b) For a parallel polarized wave, explain clearly about Snell's Law and critical angle.

5. **a) Explain the wave propagation in lossy dielectrics.**
b) Define the terms: intrinsic impedence, propagation constant, relection and refraction coefficients.