**UNIT – V**

**ELECTRO MAGNETIC WAVES**

**PART – A**

**1. Find the velocity of a plane wave in a lossless medium having a relative permittivity 2 and relative permeability of unity. (May 2017)**

For a given medium, the velocity of propagation is given by



v

**2. Define Skin depth or depth of penetration. (or) What is skin depth? (May 2017) (May 2016) (Dec 2015)**

It is defined a the depth in which the magnitude of the wave is attenuation to 37% (e-1) of its original value. It is denoted by





**3. Define standing wave ratio. (Dec 2016)**

The standing wave ratio (S) is defined as the ratio of maximum to minimum amplitudes of voltage.



**4. State the properties of uniform plane wave. (Dec 2016)**

It is a function of time and space. It shows an electric field and magnetic field vector both in same plane. It travels with high velocity. It radiates outwards from source in all direction. In space, at every point electric field and magnetic field are perpendicular to each other.

**5. Write Poynting vector (Dec 2016)**

If and **** are the time varying electric and magnetic field respectively, then the cross product of  and **** is called Poynting vector . Mathematically the Poynting vector is defined as,



**6. A plane wave travelling in air is normally incident on a block of paraffin’s with εr = 2.3. Find the reflection coefficient. (Dec 2015)**

Medium, 1 : Air η1 = η0 = 377 

Medium 2 : paraffin ∴ 

= 248.59 Ω

The reflection coefficient is given by



**7. What is the wavelength and frequency of a wave propagation in free space when β = 2? (May 2015)**

β = 2, Medium free space

Wavelength 

Frequency 

**8. The capacitance and inductance of an overhead transmission line are 0.0075 μF/km and 0.8 mH/km respectively. Determine the characteristic impedance of the line. (Dec 2014)**

Characteristic impedance 

∴ Z0 = 326.59 Ω

**9. If a plane wave is incident normally from medium 1 to medium 2, write the reflection and transmission coefficients. (Dec 2014)**

The transmission coefficient is denoted by  and it is given by



The reflection coefficient is denoted by  and it is given by



The terms η1 and η2 indicates the intrinsic impedances of dielectric 1 and dielectric 2 is medium 1 and medium 2 respectively.

**10. Calculate the depth of penetration of copper at 2MHz given the conductivity of copper σ=5.8×107 S/M and its permeability 1.26 μH/m. (May 14)**

The depth of penetration of copper is given by



**11. Define wave.**

If a physical phenomenon that occur at one place a given time is reproduced at other places at later times. The time delay being proportional to the space separation from the first location, then the group of phenomena constitutes a wave. A wave is a function of both space and time.

**12. Define plane wave?**

A wave is said to be plane wave if

a) The electric field and magnetic field lie in a plane perpendicular to the direction of wave propagation.

b) The field and are perpendicular to each other.

**13. Defined uniform plane waves?**

A wave is said to be plane wave if

a) The electric field and magnetic field lie in a plane perpendicular to the direction of wave propagation.

b) The field and are perpendicular to each other.

c) and are uniform in the plane perpendicular to the direction of propagation.(i.e., vary only in the direction of propagation).

**14. Define phase velocity?**

The phase velocity of a wave is the rate at which the phase of the wave propagates is space. This is the speed at which the phase of any one frequency components of the waves travels.

In general, let a wave gives by f(t, x) =

The solution is 





which is velocity i.e phase velocity 

**15. Define group velocity**?

The velocity with which the overall shape of a wave amplitude, known as the modulation or enveloped of the wave, propagates through a medium is known as the group velocity, given by 

x

Phase velocity

x

Group velocity

**6. Obtained the relationship between phase velocity and group velocity**

W.K.T 

Where c is the speed of light, ηr is the refractive index of the medium.

Also 

w.k.t 





**17. Define and derive the expression for intrinsic impedance**

The intrinsic impedance of a wave is defined as the ratio of the electric field to magnetic phasors (complex amplitudes)

i.e for a given electric field by Maxwell’ equation





 



is the intrinsic impedance.

**18. Define skin effect**

Skin effect is the tendency of an alternating electric current (AC) distribute itself within a conductor in such a way that the current density in the largest near the surface of the conductor while decreasing at greater depths

**19. Define surface impedance (Zs)**

The surface impedance is defined as the ratio of the tangential components of the electric field to the tangential component of magnetic field. Given by 

**20. Define loss tangent (tan 𝛉) (May 2015)**

Loss tangent is the ratio of the magnitude of conduction current density to displacement current density of the medium.

For harmonically varying fields



**21. State Snell’s law**

When a waves is travelling from one medium to another medium, the angle of incidence is related to angle of transmitted i.e, is termed as snell’s law.

**22. What is Brewster angle?**

Brewster angle is an angle at which there is no reflected waves when the incident wave is parallel polarized. Given by 

**23. State Slepian vector**

Slepian vector is a vector which is defined at every point such that is flux wiring out of any volume is zero (∇.S = 0) also  where v is the electric potential,is the magnetic field

**24. Define polarization**

Polarization of a uniform plane wave refers to the timing varying behaviour of electric field at some points in space i.e orientation ofat a given instant of time in space

**25. Define types of polarization.**

a) Linear polarization: Tip oftraces a straight line as times varies.

b) Circular polarization: Tip of  traces a circle as time varies.

c) Eliptical polarization: Tip of  traces an Elipes as time varies.

**26. Define propagation constant.**

Propagation constant represents the properties of the medium through which then wave is travelling. In general, the propagation constant can be expressed as

Propagation constant is a complex quantity made up of real and imaginary terms.

**27. What is called attenuation constant?**

When a wave propagates in the medium, it gets attenuated. The amplitude of the signal reduces. This is represented by attenuation constant. It is represented as the real part of propagation constant (). It is measured in neper per meter (NP/m). But practically it is expressed in decibel (dB).

**28. What is phase constant?**

When a wave propagates, phase change also takes place. Such a phase change is expressed by an imaginary part of the propagation constant (). It is called as phase shift constant or simply phase constant. It is measured in radian per meter (rad/m).

**29. State Poynting's Theorem**

Poynting's theorem states that the net power flowing out of a given volume is equal to the time rate of decrease in the energy stored within the volume minus the conduction losses.

**30. What will happen when the wave is incident obliquely over dielectric–dielectric boundary?**

When a plane wave is incident obliquely on the surface of a perfect dielectric part of the energy is transmitted and part of it is reflected. But in this case the transmitted wave will be refracted, that is the direction of propagation is altered.

**31. What is the fundamental difference between static electric and magnetic field lines?**

There is a fundamental difference between static electric and magnetic field lines. The tubes of electric flux originate and terminate on charges, whereas magnetic flux tubes are continuous.

**32. What are uniform plane waves?**

Electromagnetic waves which consist of electric and magnetic fields that are perpendicular to each other and to the direction of propagation and are uniform in plane perpendicular to the direction of propagation are known as uniform plane waves.

**33. What is the significant feature of wave propagation in an imperfect dielectric?**

The only significant feature of wave propagation in an imperfect dielectric compared to that in a perfect dielectric is the attenuation undergone by the wave.

**34. What is called wave velocity?**

The velocity of propagation is called as wave velocity. It is denoted as

Velocity of electromagnetic wave in free space is m/s

**35. Why dielectric medium is lossless dielectric.**

For perfect dielectric medium, both the fields of and are in phase. Hence there is no attenuation. Hence there is no loss.

**36. What is mean by lossy dielectric?**

The presence of attenuation indicates there is a loss in the medium. Hence such medium is called as lossy dielectric.

**37. What is Normal Incidence?**

When a uniform plane wave incidences normally to the boundary between the media, then it is known as normal incidence.

**38. What is the condition for practical dielectric?**

For practical dielectric, there is some conductivity, that is its value is not zero and hence there is some loss in practical dielectric but its value is very small.

**PART – B**

**1. Derive the generalized expression for wave equation. (Dec 2015, May 2016**

**Assumption:**

* We consider the medium to be linear, homogenous (i.e quantities are constant through t5he medium) and isotropic (i.eis a scalar constant so that and  have every where the same direction).
* We consider a sorce –free region of the medium.

By Maxwell equation 

also 

taking curl on both sides of b



Equation c is the three dimensional vector wave equation or Helmholtz equation in an absolutely or lossy dielectric medium.

Similarly 

Equation d is the Helmholtz equation in terms of magnetic field.

Case (a): Wave equation for perfect dielectric medium

In this case, the conductivity is zero (σ=0). Hence the wave equation and d are



Case (b): Wave equation for free space.

In this case 



Note that the quality 1/thus the dimension of velocity. In free space is



In an homogenous medium of permittivity & and permeabilityμ, v = 

Case (c): Wave equation for time harmonic fields

For time harmonic field, the instantaneous (time domain) vector is related to the phasor (frequency domain) vector by



Where γ →propagation constant =

α →real part of γ- attenuation constant which define the rate at which the field waves propagate 

β → imaginary of γ – phase constant which define the rate at which the phase changes as the wave propagation 

Further, 



**2. Derive the solution of wave equation for uniform plane waves**

Let the uniform plane wave h only a z-component of electric field and x-component of magnitude field, which are both function of only y. For this uniform plane wave, the component wave equations for the only two field components (Ezs, Hxs) are



In equations (a) and (b) Ezs and Hxs are functions of y only. Therefore (a) and (b) can be written as





**3. Derive the expression for propagation of uniform plane waves through different media. (May 2015, Dec 2014, May 2016, Dec 2016, May 2017)**

We small consider the wave propagation along y- direction, so that the electric field has only x-complex Hx. The solution of wave equation gives here H0 =E0/η. We now consider the wave propagation through the following medium.

a) Wave propagation through imperfect loss y dielectric medium.

For a lossy dielectric medium, we have the condition,



Also phase constant is



Here is the phase shift for a perfect dielectric. The effect of a small amount of loss is to add the term as a small correction factor.

 velocity of propagation 



Here is the velocity of the wave propagation is perfect dielectric σ = 0. The effect of a small amount of loss is to reduce slightly the velocity of wave propagation.

Intrinsic impedance for me lossy dielectric is 





Here two, the effect of loss is to add a small reactive component to the intrinsic impedance. Hence if electric field is 

b) Wave propagation through perfect dielectric medium.

In this case , 

Phase constant , velocity of wave propagation 

Intrinsic impedance . Therefore if 

Thus , we that for perfect dielectric medium, the wave propagates without any attenuation and the electric and magnetic field are in phase with each other.

c) Wave propagation through free space:

In this case 

attenuation constant α =0, phase constant β = 

Velocity of wave propagation 

Intrinsic impedance 

If the 



d) Wave propagation through conducting medium.

It is well known that for conducting medium 

Propagation constant 



**4. Static and device the necessary equation for Poynting theorem and Poynting vector. (May 2015, Dec 2015, May 2017 )**

Pointing vector is defined as It represents the energy flux (W/m2) of an electromagnetic wave.

Poynting theorem states that the vector product  at any point is a measure of the rate of the energy flow per unit area at that point. The direction of power flow is in the direction of the unit vector along the product and in perpendicular to bothand .

Derivation: By modified amperes law 

i.e 

multiplying on both sides 

using the identify 

thus 



Also 



Integrating over a volume on both sides

`

This the mathematical form of Poynting theorem.

Average power calculation using Poynting vector

Let 

The instantaneous Poynting vector given as 



Using the trigonometric identify cos x cosy = ½[cos (x+y)+cos(x-y)]



The time average Poynting vector is





**5. Explain and derive the necessary equation for reflecting and reflecting of plane electromagnetic waves at the interface between two dielectrics.**

When a plane wave propagating in a homogenous medium encounters an interface with a different medium, a portion of the wave is reflected from the interface while the reminder of the waves is permitted. The portion of reflection and transmission depends on the parameters of the medium. We consider the reflection and refraction of a plane wave incident on a single boundary separating two different dielectric media. Two types of incidence may occur. a) Normal Incidence b) Oblique incidence

a) **Normal Incidence**:

When a plane Electromagnetic wave is incident normally at the interface between two dielectrics, part of the energy is transmitted and part of it is reflected.

Let, Ei, Electric field strength of the incident waves striking the interface

Er Electric field strength of the reflecting wave leaving the interface

Et Electric field strength of the transmitted wave propagated into the second dielectric

Hi, Hr, Ht corresponding magnetic field strengths

 are the permittivity and permeability of the first dielectric

are the permittivity and permeability of the second dielectric

intrinsic impedance of the first dielectric

 intrinsic impedance of the second dielectric

So, 

According to the continuity of the tangential components of E and H



The reflection co-efficient or reflectance is defined as the ratio of reflected waves to incident wave

i.e Reflectance, 

The transmission co-efficient or transmittance is defined as the ratio of transmitted wave to incident wave



For non magnetic dielectrics 



So the reflectance and transmittance for non-magnetic dielectrics are

Reflectance 

Transmittance 

b) **Oblique Incidence**:

Any plane waves which is obliquely incident on a planar media interface can be represent by a linear combination of two special cases

1. Perpendicular or horizontal polarization and

2. Parallel or vertical polarization.

Perpendicular or horizontal polarization is one which is perpendicular to the plane of incidence.

E:\new\EMT\UNIT 5\Fig 1. 1.eps

Fig. (a)

Parallel or vertical polarization is one in which electric field is parallel to the plane of incidence.

E:\new\EMT\UNIT 5\Fig 1. 2.eps

Fig. (b)

For fig. (c) the plane of the paper is the plane of incidence. Figure shows two rays of the EM waves Ray 1; reflected along AE, transmitted along AD, Ray 2: reflecting along BG transmitted along BF.

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Fig. (c)

The direction AE and BG are parallel, AD and BF parallel. The line AC, which is perpendicular to the incident rays, represents the equation surface in medium 1. The line DB, which is perpendicular to the transmitted represented the equality phase surface in medium 2.

Ray 1 travels the distance AD,

Ray 2 travels the distance CB and reflected ray 1 travel the distance AE.



Also AE=CB 

**Perpendicular polarization**: For perpendicular polarization, from the both condition 

Also therefore 



Hence the reflection coefficient is

The transmission coefficient can be evaluated as follows,



**Parallel Polarization:**

For parallel polarization, from the boundary condition that the tangential component of a vector  is continuous across the boundary,

 







Reflection co-efficient 

Similarly transmission co-efficient 



**6. The electric field in free space is given by **

**(i) Find the direction of wave propagation**

**(ii) Calculate and the time it takes to travel a distance .**

**(iii) Sketch the wave at t = 0, T/4, T/2.**

Solution:

(i) From the positive sign in ()it is concluded that the waves is propagating in direction.

(ii) Here as the wave is travelling in speed of light ‘c’, 

But 

(iii) At t = 0 , Ey **=** 50cos βx

****

**E:\new\EMT\UNIT 5\Fig 1. 4.eps**

**7. Show that the total power flow along a coaxial cable will be given the surface integration of the Poynting vector over any closed surface. (Dec 2014)**

Consider a co axial cable in which the power is transferred to the load resistance R along cable. There are two conductors namely inner conductor and outer conductor concentric to each other. Let the radius of the inner conductors be ‘a’ units and the inner radius of the outer conductor is ‘b’ unit as shown in fig.

I

I

E

H

2a

2b

V

Fig. Voltage and current is coaxial cable.

In the cable, there exists a dc voltage V between the two conductors, while the steady current I flows in the inner and outer conductors as shown in fig. The magnetic field strength H will be directed in the circular path about the axis as shown in the fig. In the region between the two conductors, the current enclosed is equal to the magneto-motive force around any of the circles of H.



The magnetic field H is constant along any of the circular point. Let r be the radius of any circle considered then the magneto motive force is given by



Let q be the charge per unit length, then the p.d. between the inner and outer conductor of a coaxial cable is given by



Similarly the magnitude electric field intensity E for a coaxial cable is given by



From equation 1 and 2 we can write



According to the Poynting theorem, the Poynting vector is given by 

But the power flow in the direction parallel to the axis of the cable. As and are mutually perpendicular to each other everywhere the magnitude of the poynting vector is given by



The total power flow along the cable can be obtained by integrating the poynting vector over any cross-sectional surface with area 2rdr.



Above result is certainly an unusual result the power flow is the product of voltage and current.

**8. Find the velocity of a plane wave in a lossless having a relativity of 5 and relative permeability of 1. (Dec 2014)**

For lossless medium, the velocity of plane wave is given by



**9. A uniform plane wave propagation in a medium has if the medium is characterized by **

**Given,**

****

Thus En = 2, w = 108 rad/sec

The nature of the medium: as , the medium is not perfect dielectric



Hence at 

For a good conductor



Now the intrinsic impedance is given by



Now the wave propagation is +ve direction. But is in direction. So to achieve proper direction of wave propagation, must be in -direction such that 

Now, 

Hence the expression for is given by



**10. A 6580MHz uniform plane wave is propagation in material medium of . If the amplitude of electric field intensity is 500V/m/.Calculate the plane construct propagation constant, velocity, wavelength a intrinsic impedance. (Dec 2016)**

**Solution**

For a lossless medium then

i) Attenuation constant 

ii) Plane constant 



iii) Wavelength is medium is given by



iv) The velocity of propagation is given by



v) The intrinsic impedance is given by



vi) The propagation constant γ is given by

