$$v = \frac{\omega}{\beta}$$

$$v = \frac{\omega}{\sqrt{\omega^2 \mu \varepsilon - h_{nm}^2}}$$

- For TE wave The first few roots are,

$(ha^1)_{01} = 3.832$
$(ha^1)_{11} = 1.841$
$(ha^1)_{02} = 7.02$
$(ha^1)_{12} = 5.331$

- Properties of TEM waves

The TEM wave is a special case of guided wave propagation. Some of the important properties are,

The fields are entirely transverse

In the direction perpendicular to the direction of propagation, the amplitude of the field components are constant.

The velocity of propagation of TEM wave is impendent of frequency.

The cut-off frequency of the wave is Zero which indicate all the frequencies below fc can propagate along the guide.

- Rectangular wave guides
- *Wavelength* $\lambda = \frac{\lambda_c}{\sqrt{1-(\frac{m\lambda_c}{2a})^2}}$
- *The phase velocity*

$$\vartheta\rho = \frac{c}{\sqrt{1-(\frac{m\lambda}{2a})^2}}$$

- *The group velocity*

$$\vartheta_g = C\sqrt{1-(\frac{m\lambda}{2a})^2}$$

- *Phase shift* β,

$$\beta = \sqrt{\omega^2 \mu \varepsilon - (\frac{m\bar{\pi}}{a})^2}$$

- Relation between phase velocity and group velocity

$$\vartheta_g \, . \, \vartheta_p = \vartheta^2$$

- If $f < f_c$ - The propagation constant is real ie, $\propto \neq 0$, $\beta = 0$
- If $f > f_c$ - The propagation constant is imaginary ie, $\propto = 0, \beta = 0$

TWO MARKS

1. What are the three properties of EM Waves?

(i) EM Waves travel at very high velocity

ii) While traveling, they assume the properties of waves

iii) The EM energy radiates outwards

2. Explain unguided wave propagation

i) Waves propagate in unbounded media with infinite extent

ii) Signal transmitted is meant for everyone

iii) The EM energy associated with the wave radiates over a wide area

iv) Examples are TV or radio broadcasting.

3. Explain guided wave propagation

i)Wave energy is confined and guided by the guided structures

ii) Examples of guided structures are rectangular wave guides, circular wave guides etc.

iii) Transmitting power or fields are confined by the boundaries of a guided structures.

iv) The waves directed or guided by the guided structures are called guided waves.

v) Example is telephone signal transmission

4. Define wave:

A wave can be defined as a means of transporting energy or information from source to destination. In general, the wave is a function of space as well as time. The typical examples are radio waves, TV signals, Radar signals and light rays.

5. Explain TE waves:

The transverse electric (TE) waves have the magnetic field component in the direction of propagation but no component of electric field in the same direction. Hence the TE waves are also known as M-waves or H-waves. The lowest order mode possible with TE waves is 1. If the direction of propagation is in the Z direction, Then $E_z = 0$.

6. Define mode:

Mode is also called as field configuration. Mode is specified as 'm'. For different values of m, we get different field configurations. The wave associated with m is called TE_{mo} wave of TE_{mo} mode, TM_{mo} wave or TM_{mo} wave. The smallest possible value of m for TE waves is 1 whereas the smallest possible value of m for TM wave is 0.

7. Explain TM Waves:

The transeverse magnetic ™ waves have the electric field component in the direction of propagation but no component of magnetic field in the same direction. Hence the TM waves are also known as E-waves. The lowest order mode possible with TM wave is 0. If the direction of propagation is in the Z direction, then $H_z = 0$.

8. Explain the characteristics of TE and TM waves:

i) The Properties of TE & TM waves between parallel conducting planes are different than those of the uniform plane waves in free space.

ii) There is either sinusoidal or co sinusoidal variations of field components of E or H in the x- direction.

iii) There is no variation in magnitude or phase of field components in the y – direction.

iv) x-y plane is an equipage plane for each of the field component.

v) The lower frequencies are attenuated completely with no propagation, while the higher frequencies are allowed to propagate with no attenuation. Hence the system acts as high pass filter (HPF)

9. Explain TEM Waves:

If both the components of electric and magnetic fields are transverse to the direction of propagation, the wave is called TEM wave. It is also called as principal wave. If the direction of propagation is in the Z direction, then $E_z = 0$ & $H_z = 0$.

10. Mention some of the properties of TEM WAves:

i) The fields are entirely transverse.

ii) In the direction perpendicular to the direction of propagation, the amplitude of the field components are constant.

iii) The velocity of propagation of TEM wave is independent of the frequency.

iv) The cut-off frequency of TEM wave is zero, indicating all the frequencies below zero can propagate along the guide.

11. What is cut-off frequency and write the expression for cut-off frequency when the wave is propagated in between two parallel plates.

The frequency at which the wave motion stops is called the cut-off frequency of the wave guide. The cut-off frequency $f_c = m/2a\sqrt{\mu\varepsilon}$ where m is the mode, μ is permeability, ε is permittivity and a is distance of separation between the two parallel plates. It is also defined as the frequency at which the propagation constant changes from real to imaginary or it is the frequency below which signal suffers only attenuation and above which there is no attenuation.

12. Define intrinsic impedance:

It is defined as the ratio of amplitudes of electric to magnetic fields between the parallel planes. It is denoted as

$$\eta = \sqrt{\mu/\varepsilon}$$

13. Differentiate TE and TM waves:

TE	TM
Electric field strength E is entirely transverse $E_z = 0$	Magnetic field strength H is entirely transverse $H_z = 0$
It has Z component of magnetic field H_z in the direction of propagation	It has z component of electric field E_z in the direction of propagation
The dominant mode is TE_{10} mode	The dominant mode is TE_{11} mode

14. Define wave impedance:

Wave impedance is defined as the ratio of electric field component to that of magnetic field component. In the positive directions, the ratios of electric to magnetic field strengths are defined as

$$Z_{xy}^{+} = \frac{E_x}{Hy} \;;\; Z_{yz}^{+} = \frac{E_y}{Hz} \;;\; Z_{zx}^{+} = \frac{E_z}{Hx}$$

$$Z_{yx}^{+} = -\frac{E_y}{Hx} \;;\; Z_{zy}^{+} = -\frac{E_z}{Hy} \text{ and } Z_{zx}^{+} = -\frac{E_x}{Hz}$$

wave impedance in the –ive direction are

$$Z_{xy}^{-} = -\frac{E_x}{Hy} \;;\; Z_{yz}^{-} = -\frac{E_y}{Hz} \text{ and } Z_{zx}^{-} = -\frac{E_z}{Hx}$$

$$Z_{yx}^{-} = \frac{E_y}{Hx} \;;\; Z_{zy}^{-} = \frac{E_z}{Hy} \text{ and } Z_{zx}^{-} = +\frac{E_x}{Hz}$$

A cut-off frequency wave impedance for TE waves is infinity whereas for TM waves the value is zero.

The value is η= 377Ω

15. Define phase velocity:

It is defined as the velocity of propagation of equiphase surface along a guide, Vp = ω/β. Phase velocity is always greater than free space velocity c.

16. Write the field components for electromagnetic wave propagating between the parallel planes of perfect conductors.

$$E_x = \frac{-\gamma}{h^2}\frac{\partial Ez}{\partial x} \;;\quad E_y = \frac{j\omega\mu}{h^2}\frac{\partial Hz}{\partial x}$$

$$H_x = \frac{-\gamma}{h^2}\frac{\partial Hz}{\partial x} \;;\quad H_y = \frac{-j\omega\mu}{h^2}\frac{\partial Ez}{\partial x}$$

$$(h^2 = \gamma^2 + \omega^2\mu\varepsilon)$$

17. Write the field components for TE and TM wave between two parallel planes

TE	TM
$E_x = E_z = H_y = 0$	$E_y = E_x = H_z = 0$
$E_y = C\,\text{Sin}\left(\frac{m\pi}{a}x\right) e^{-\gamma\beta z}$	$E_x = \frac{\rho}{\omega\varepsilon} C\,\text{Cos}\left(\frac{m\pi}{a}x\right) e^{-j\beta z}$
$H_z = \frac{-m\pi c}{j\omega\mu a}\,\text{Cos}\left(\frac{m\pi}{a}x\right) e^{-\gamma\beta z}$	$E_z = \frac{-jm\pi}{j\omega\mu a} C \sin\left(\frac{m\pi}{a}x\right) e^{-j\beta z}$
$H_x = \frac{-\beta c}{\omega\mu}\,\text{Sin}\left(\frac{m\pi}{a}x\right) e^{-\gamma\beta z}$	$H_y = C\cos\left(\frac{m\pi}{a}x\right) e^{-j\beta z}$

18. Write the field components for TEM wave between two parallel planets.

$$Ey = Ez = Hx = hz = 0$$

$$Hy = C\,.e^{-j\beta z}$$

$$E_x = \frac{\beta}{\omega\varepsilon}\,Ce^{-j\beta z}$$

19. Write the relation between group velocity and phase velocity.

Le Vg be the group velocity and Vp be the phase velocity. Then Vp Vg = c^2 where is the velocity of light in free space. c = 3 x 10^8 m/sec.

20. Define group velocity:

It is defined as the velocity with which the energy propagate along the guide. $V_g = d\omega/d\beta$ where ω is the angular frequency and β is the phase constant. Group velocity is always less than free space velocity c.

21. Why is circular or rectangular form used as waveguide?

Waveguides usually take the form of rectangular or circular cylinders because of its simpler forms in use and less expensive to manufacture.

22. What is an evanescent mode?

When the operating frequency is lower than the cut-off frequency, the propagation constant becomes real i.e., $\gamma = \alpha$. The wave cannot be propagated. This non- propagating mode is known as evanescent mode.

23. What is the dominant mode for the TE waves in the rectangular waveguide?

The lowest mode for TE wave is TE10 (m=1 , n=0)

24.What is the dominant mode for the TM waves in the rectangular waveguide?

The lowest mode for TM wave is TM11(m=1 , n=1)

25. What is the dominant mode for the rectangular waveguide?

The lowest mode for TE wave is TE10 (m=1 , n=0) whereas the lowest mode for TM wave is TM11(m=1 , n=1). The TE10 wave have the lowest cut off frequency compared to the TM11 mode. Hence the TE10 (m=1 , n=0) is the dominant mode of a rectangular waveguide. Because the TE10 mode has the lowest attenuation of all modes in a rectangular waveguide and its electric field is definitely polarized in one direction everywhere.

26.Which are the non-zero field components for the for the TE_{10} mode in a rectangular waveguide?

Hx, Hz and Ey.

27. Which are the non-zero field components for the for the TM_{11} mode in a rectangular waveguide?

Hx, Hy ,Ey. and Ez.

28. Define characteristic impedance in a waveguide

The characteristic impedance Zo can be defined in terms of the voltage-current ratio or in terms of power transmitted for a given voltage or a given current. Zo (V,I) = V/I

29.Why TEM mode is not possible in a rectangular waveguide?

Since TEM wave do not have axial component of either E or H ,it cannot propagate within a single conductor waveguide.

30.Explain why TM01 and TM10 modes in a rectangular waveguide do not exist.

For TM modes in rectangular waveguides, neither m or n can be zero because all the field equations vanish (i.e., Hx, Hy ,Ey. and Ez.=0). If m=0,n=1 or m=1,n=0 no fields are present. Hence TM01 and TM10 modes in a rectangular waveguide do not exist.

31. What are degenerate modes in a rectangular waveguide?

Some of the higher order modes, having the same cut off frequency , are called degenerate modes. In a rectangular waveguide , TEmn and TMmn modes (both $m \neq 0$ and $n \neq 0$) are always degenerate.

32.What is a circular waveguide?

A circular waveguide is a hollow metallic tube with circular cross section for propagating the electromagnetic waves by continuous reflections from the surfaces or walls of the guide

33.Why circular waveguides are not preferred over rectangular waveguides?

The circular waveguides are avoided because of the following reasons:

a) The frequency difference between the lowest frequency on the dominant mode and the next mode is smaller than in a rectangular waveguide, with b/a= 0.5

b) The circular symmetry of the waveguide may reflect on the possibility of the wave not maintaining its polarization throughout the length of the guide.

c) For the same operating frequency, circular waveguide is bigger in size than a rectangular waveguide.

34..Mention the applications of circular waveguide.

Circular waveguides are used as attenuators and phase-shifters

35.Which mode in a circular waveguide has attenuation effect decreasing with increase in frequency?

TE01

36.What are the possible modes for TM waves in a circular waveguide?

The possible TM modes in a circular waveguide are : TM01 , TM02 ,TM11, TM12

37.What are the root values for the TM modes?

The root values for the TM modes are:

(ha)01 = 2.405 for TM01

(ha)02 = 5.53 for TM02

(ha)11 = 3.85 for TM11

(ha)12 = 7.02 for TM12

38.What are the possible modes for TE waves in a circular waveguide?

The possible TE modes in a circular waveguide are : TE01 , TE02 , TE11, TE12

39. What are the root values for the TE modes?

The root values for the TE modes are:

(ha)01 = 3.85 for TE01

(ha)02 = 7.02 for TE02

(ha)11 = 1.841 for TE11

(ha)12 = 5.53 for TE12

40. What is the dominant mode in a circular waveguide

The dominant mode for TM waves in a circular waveguide is the TM01 because it has the root value of 2.405. The dominant mode for TE waves in a circular waveguide is the TE11 because it has the root value of 1.841 .Since the root value of TE11 is lower than TM01 , TE11 is the dominant or the lowest order mode for a circular waveguide.

41. Mention the dominant modes in rectangular and circular waveguides

For a rectangular waveguide, the dominant mode is TE01

For a circular waveguide, the dominant mode is TE11

42.Why is TM01 mode preferred to the TE01 mode in a circular waveguide?

TM01 mode is preferred to the TE01 mode in a circular waveguide, since it requires a smaller diameter for the same cut off wavelength.

43.What are the performance parameters of microwave resonator?

The performance parameters of microwave resonator are:

(i) Resonant frequency
(ii) Quality factor
(iii) Input impedance

44.What is resonant frequency of microwave resonator?

Resonant frequency of microwave resonator is the frequency at which the energy in the resonator attains maximum value. i.e., twice the electric energy or magnetic energy.

45. Define quality factor of a resonator.

The quality factor Q is a measure of frequency selectivity of the resonator. It is defined as

$Q = 2\pi \times$ Maximum energy stored / Energy dissipated per cycle

$= \omega W / P$

Where W is the maximum stored energy

P is the average power loss

46.What is a resonator?

Resonator is a tuned circuit which resonates at a particular frequency at which the energy stored in the electric field is equal to the energy stored in the magnetic field.

47.How the resonator is constructed at low frequencies?

At low frequencies upto VHF (300 MHz) , the resonator is made up of the reactive elements or the lumped elements like the capacitance and the inductance.

48.What are the methods used for constructing a resonator?

The resonators are built by

a) using lumped elements like L and C
b) using distributed elements like sections of coaxial lines
c) using rectangular or circular waveguide

49. What are cavity resonators?

Cavity resonators are formed by placing the perfectly conducting sheets on the rectangular or circular waveguide on the two end sections and hence all the sides are surrounded by the conducting walls thus forming a cavity. The electromagnetic energy is confined within this metallic enclosure and they acts as resonant circuits .

50. What are the types of cavity resonators?

There are two types of cavity resonators. They are:

a) Rectangular cavity resonator
b) Circular cavity resonator

51. Why rectangular or circular cavities can be used as microwave resonators?

Rectangular or circular cavities can be used as microwave resonators because they have natural resonant frequency and behave like a LCR circuit.

52.How the cavity resonator can be represented by a LCR circuit?

The electromagnetic energy is stored in the entire volume of the cavity in the form of electric and magnetic fields. The presence of electric field gives rise to a capacitance value and the presence of magnetic field gives rise to a inductance value and the finite conductivity in the walls gives rise to loss along the walls giving rise to a resistance value. Thus the cavity resonator can be represented by a equivalent LCR circuit and have a natural resonant frequency

53. What is the dominant mode for rectangular resonator?

The dominant mode of a rectangular resonator depends on the dimensions of the cavity.

For b<a<d, the dominant mode is TE101

54. What is the dominant mode for circular resonator?

The dominant mode of a circular resonator depends on the dimensions of the cavity. For d< 2a, the dominant mode is TM010

55. When a medium is said to be free- space.

A free-space medium is one in which there are no conduction currents and no charges.

QUESTION BANK

1. Derive the expression for the Applications of Maxwell’s equations.
2. Discuss the characteristics of TE and TM waves and also derive the cut off frequency and phase velocity from the propagation constant?
3. Derive the expression for the field strength for TE and TM waves between parallel plates propagating in Z direction?
4. Derive the field configuration, cut off frequency and velocity of propagation for TM waves in rectangular wave guides?
5. Determine the solution of electric and magnetic fields of TE waves guided along rectangular wave guides?
6. Discuss the characteristics of TE and TM waves and also derive the cut off frequency and phase velocity from the propagation constant for rectangular waveguide?
7. Derive the TM wave components in circular wave guides using Bessel functions?
8. What is meant by cavity resonator? Derive the expression for the resonant frequency of the rectangular cavity resonator?
9. Derive the expression for cut off frequency, phase constant and phase velocity of wave in a circular wave guide?
10. Derive the TE wave components in circular wave guides using Bessel functions?
11. Determine the solution of electric and magnetic fields of TM waves guided along rectangular wave guides?
12. Derive the expression for Quality factors