Module 6 : Wave Guides

Lecture 41 : Transverse Electric and Magnetic Mode

Objectives

In this course you will learn the following

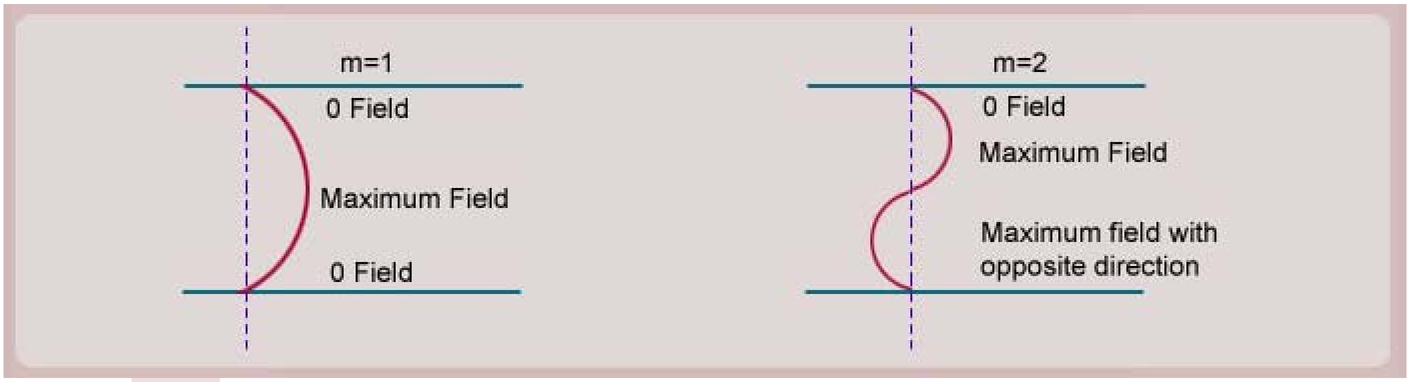
- Important features of Transverse Electric Waves.
- Fields for Transverse Magnetic (TM) Mode.
- Important features for Transverse Magnetic (TM) Mode.
- Important features of Transverse ElectroMagnetic Mode.

Important features of Transverse Electric Waves

- For a given value of 'm' the variation of the fields in the x - direction is fixed irrespective of the frequency.

- For example, for $m = 1$, the fields have one half cycle variation in the x - direction, for $m = 2$ the fields have one full cycle variation, i.e, two half cycle variation in the x - direction and so on.

  The field variation for $m = 1$ and $m = 2$ is shown in the following figure



- For $m = 1$, the electric field is maximum half way between the two planes and zero at the two planes.

  The field pattern is therefore unique for a given value of 'm'

- Since 'm' is an integer there is no gradual change between two field patterns. The field pattern exist as their individual identities.

- These unique field patterns are called '**MODAL FIELD PATTERNS**' and the propagation of electro magnetic energy in these patterns is refered to as the '**MODAL PROPAGATION**'

- The modal propagation is the interinsic characteristic of any bound structure like wave guide's .
  The electro magnetic fields inside the wave guide exist only in the form of the Modal Field patterns.

$$\beta = \beta_1 \sqrt{1 - \left(\frac{m\lambda_1}{2d}\right)^2} = \beta \sin\theta \text{ ------------- (6.5)}$$

$$\Rightarrow \sin\theta = \frac{\beta}{\beta_1} \text{ ------------- (6.6)}$$

- It can be seen from field expressions 6.5 and 6.6 that for $m = 0$ the electric field vanishes and consequently the time varying magnetic field also cannot exist. It therefore suggest that the field pattern corresponding to $m = 0$ cannot exist inside a parallel plane wave guide.

- It is clear from the field expressions that the wave travels in the $+z$ direction and the electric field which is y - oriented is always transverse to the direction of wave propagation. This mode is therefore called the '**TRANSVERSE ELECTRIC** or **TE MODE**' . The 'm' is put as the suffix to indicate the order of the mode.

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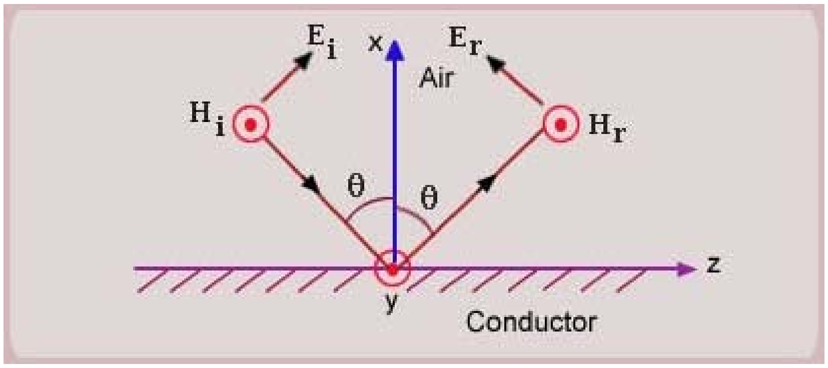
The TE_m mode is therefore a mode with fields having 'm' half cycle variations in the transverse plane.

- Since $m = 0$ is not possible we only have modes TE_1 , TE_2 , TE_3 ,.......

Fields for Transverse Magnetic (TM) Mode

- Let us consider the co-ordinate system as shown in the below fig



- Let a plane wave with parallel polarization be incident at an angle θ .
- On the lines similar to that of Transverse Electric waves we can write the electric and magnetic fields above the conducting planes as

$$\mathbf{E_1} = 2E_{i0}e^{-j\beta_1 z\sin\theta}[\sin\theta\cos(\beta_1 x\cos\theta)\hat{\mathbf{x}} + j\cos\theta_i\sin(\beta_1 x\cos\theta)\hat{\mathbf{z}}] \quad \text{---------- (6.7)}$$

$$\mathbf{H_1} = 2\frac{E_{i0}}{\eta_1}\cos(\beta_1 x\cos\theta)e^{-j\beta_1 z\sin\theta}\hat{\mathbf{y}} \quad \text{---------- (6.8)}$$

- Applying boundary conditions that tangential components of electric field should be zero at the conducting plane i.e at $x = 0$ (only z component of the electric field is tangential to the conducting plane) we get,

$$\beta_1 x\cos\theta = m\pi \qquad m = 0, 1, 2, \ldots.. \quad \text{----------- (6.9)}$$

- This condition is identical to equation 6.3 and therefore all arguments presented for Transverse Electric case are applicable here also.
- For parallel plane wave guide with separation `d' between the two planes we get,

$$\cos\theta = \frac{m\pi}{\beta_1 d} = \frac{m\pi}{\frac{2\pi d}{\lambda_1}} = \frac{m\lambda_1}{2d} \quad \text{----------- (6.10)}$$

- The fields after substituting for θ become

$$\mathbf{E_1} = 2jE_{i0}\sin\left(\frac{m\pi x}{d}\right)e^{-j\beta z}\left(\frac{m\pi}{\beta_1 d}\right)\hat{\mathbf{z}} + 2E_{i0}\frac{\beta}{\beta_1}\cos\left(\frac{m\pi x}{d}\right)e^{-j\beta z}\hat{\mathbf{x}} \quad \text{------------ (6.11)}$$

$$\mathbf{H_1} = \frac{2E_{i0}}{\eta_1}\cos\left(\frac{m\pi x}{d}\right)e^{-j\beta z}\hat{\mathbf{y}} \quad \text{------------ (6.12)}$$

Important features for Transverse Magnetic (TM) Mode

- We can note that in this case also the fields travel in $+z$ direction however there is no component of magnetic field along the direction of the wave propagation. This mode is hence called '**TRANSVERSE MAGNETIC or TM MODE**'.

- Again, m is used as the suffix to TM to indicate the order of the mode.

Important Observation

- It is important to note that for $m = 0$, unlike the TE modes the fields for TM modes do not vanish and therefore the TM mode exist.

- The propagation constant β and the fields for TM_0 mode are as follows

$$\beta = \beta_1 \quad \text{--------- (6.13)}$$

$$\mathbf{E_1} = 2E_{i0}e^{-j\beta_1 z}\hat{\mathbf{x}} \quad \text{--------- (6.14)}$$

$$\mathbf{H_1} = \frac{2E_{i0}}{\eta_1}e^{-j\beta_1 z}\hat{\mathbf{y}} \quad \text{--------- (6.15)}$$

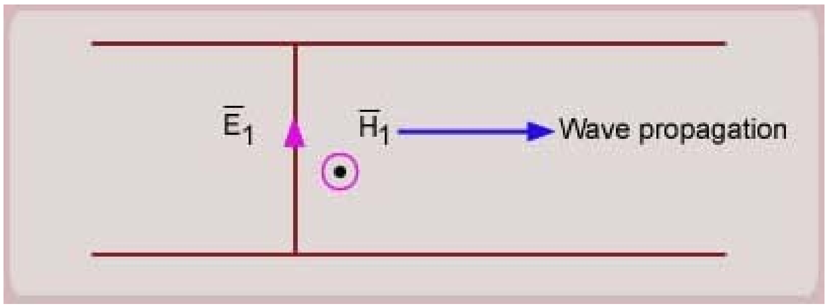
- It is interesting to note that for TM_0 mode not only the magnetic field is transverse to the wave propagation but even the electric field(which has only x component) also becomes transverse to the wave propagation. The electric and magnetic field both are transverse to the wave propagation and the mode becomes '**TRANSVERSE ELECTROMAGNETIC (TEM) MODE**'

Important features of Transverse ElectroMagnetic Mode

- For TEM mode the electric field, the magnetic field and the direction of modal propagation are perpendicular to each other.
- This mode is similar to the TEM wave in an unbound medium.
- The ratio of $|\mathbf{E}|$ to $|\mathbf{H}|$ is equal to the intrinsic impedence of the medium

$$\frac{|E|}{|H|} = \eta_1 = \text{Intrinsic impedance of the medium} \quad \text{-------- (6.16)}$$

- The field orientation of this mode will be as shown in the figure



- Since the modal field for TEM mode is identical to that in the unbound medium one would ask a question whether the wave guide boundaries play any role in propagation of the TEM mode?
- If we look at the fields of the TEM mode we note that electric field is perpendicular to the wave guide walls and magnetic field is parallel to the wave guide walls. Since neither normal components of electric field nor tangential component of electric field has boundary conditions the fields are not altered by the presence of the wave guide wall. The conducting waves are therefore transparent to the waves and the wave propagates as if it is propagating in an unbound media.
- The face constant of the mode is equal to the face constant of uniform plane wave in the medium.
- In most of the two conductor system(Transmission Lines) like the parallel wire line, co-axial cable etc., the propagation of electromagnetic energy takes place through this mode.

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Recap

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