Wave Guides:

wave guides consists of metallic tube with rectangular or circular cross-section. The waves (Em waves) are guided through these structure and hence called guided waves (* the propagation is by means of guided waves" ie the waves are guided along the conducting or over the dielectric surfaces).

- wave guides are usually applied in M-wave frequency range (4GHz to 18 GHz). Large guides are required to transmit RF Power at longer wavelengths.

- In wave guides, the electric and magnetic fields are confined to the space within the guide. There is no loss due to radiation. Dielectric losses are negligible since these wave guides are air filled. There will be power loss as heat in the walls which is very small.

- It is possible to propagate several modes of an energy (modes are nothing but sol^n to maxwell's field equations). A given waveguide has a definite cutoff frequency, for a given mode, if operating frequency is greater than cut off frequency (f_c) then that particular mode is passed through the waveguides without any attenuation. If $f<f_c$, then the particular mode will be attenuated even at shorter distance.

⇒ The Principle of wave guides in which guiding of waves is accomplished by bouncing of waves alternately within the guides.

⇒ wave guides field is in general a combination of both

(TE & TM).

TE (Transverse electric) → $E_{zs} = 0, H_{zs} \neq 0$

TM (Transverse magnetic field) → $E_{zs} \neq 0, H_{zs} = 0$

* Transmission line may operate from dc (f=0) to a very high frequency. waveguide can operate only above a certain frequency called the cut off frequency and therefore acts as a high pass filter. Transmission lines becomes inefficient due to skin effect and dielectric losses; waveguides are used at that range of frequencies to obtain longer bandwidth and lower signal attenuation.

- Transmission line can support only a transverse electromagnetic (TEM) wave, whereas a waveguide can support many possible field configuration.

TEM (Transverse electromagnetic) → $E_{zs} = 0 = H_{zs}$

TE mode – $E_{zs} = 0, H_{zs} \neq 0$

TM " → $E_{zs} \neq 0, H_{zs} = 0$,

$E = E_x a_x + E_y a_y + E_z a_z$

$E_s = (E_{xs}, E_{ys}, E_{zs})$

$H_s = (H_{xs}, H_{ys}, H_{zs})$

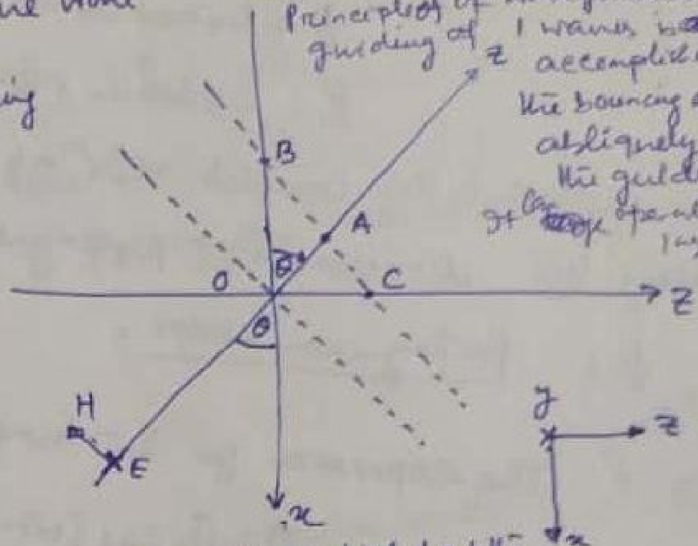
Uniform plane wave propagation in an arbitrary Direction:

(wave guide)

* In transmission lines are made up of two or more parallel conductors. Similarly the principle of wave guides in which guiding of waves were accomplished by the bouncing of waves obliquely within the guides. It can operate at large freq.

Let us consider a uniform plane wave propagating in the z' dir^n making an angle θ with the negative x axis.

Let the electric field of the wave be entirely in the y dir^n.

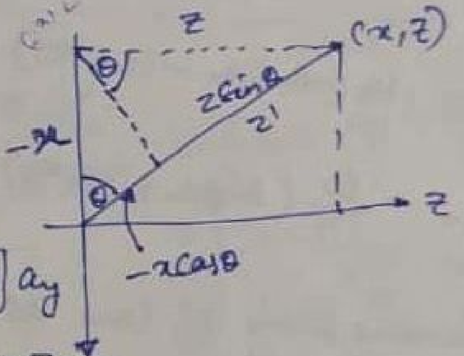


Here we can write the expression for the electric field of the wave as.

$$\vec{E} = E_0 \cos(\omega t - \beta z')\, a_y \quad \text{where } \beta = \omega\sqrt{\mu\epsilon} \text{ is the phase const.}$$

we have

$$z' = -x\cos\theta + z\sin\theta$$



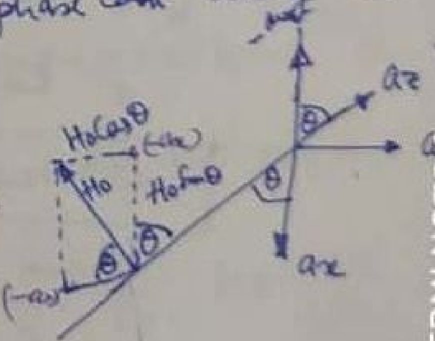
$$\vec{E} = E_0 \cos[\omega t - \beta(-x\cos\theta + z\sin\theta)]\, a_y$$

$$\vec{E} = E_0 \cos[\omega t - (-\beta\cos\theta)x - (\beta\sin\theta)z]\, a_y$$

$$\vec{E} = E_0 \cos[\omega t - \beta_x x - \beta_z z]\, a_y$$

where $\beta_x = -\beta\cos\theta$ and $\beta_z = \beta\sin\theta$ are the phase constants in the positive x and positive z-dir^n respectively.

Here $|\beta_x|$ and $|\beta_z|$ are less than β., the phase const along the dir^n of propagation of the wave



Here $\beta_x^2 + \beta_z^2 = (-\beta\cos\theta)^2 + (\beta\sin\theta)^2 = \beta^2$

and $a_{z'} = (-a_x)\cos\theta + a_z\sin\theta$

$a_{z'} = -a_x\cos\theta + a_z\sin\theta$

$a_{z'}$ is the unit vector directed along z' dir^n.

Thus the vector.

$$\vec{\beta} = \beta_x a_x + \beta_z a_z$$

$$\vec{\beta} = -\beta\cos\theta\, a_x + \beta\sin\theta\, a_z$$

which is the complete dirⁿ of propagation and the phase constant along the direction of propagation. Hence vector $\vec{\beta}$ is known as the Propagation vector.

The expression for the magnetic field of the wave

$$\vec{H} = \vec{H_0}\cos(\omega t - \beta z') \quad \text{where } |H_0| = \frac{E_0}{\eta}.$$

From the fig, $\vec{H_0} = +H_0\sin\theta(-a_x) + H_0\cos\theta(-a_z)$ $\quad * \ \vec{H} = H_{0x}(-a_x) + H_{0y}(-a_z)$

$$\vec{H_0} = H_0(-\sin\theta\, a_x - \cos\theta\, a_z)$$

$$H = H_0(-\sin\theta\, a_x - \cos\theta\, a_z)\cos[\omega t - \beta(-x\cos\theta + z\sin\theta)]$$

$$= -\frac{E_0}{\eta}(\sin\theta\, a_x + \cos\theta\, a_z)\cos[\omega t - \beta_x x - \beta_z z]$$

Now Generalizing the case of a uniform plane wave propagating in a completely arbitrary dirⁿ in three dimensions. and characterized by phase constants β_x, β_y and β_z in the x, y and z dirⁿ. respectively.

So the expression for the electric field as

$$E = E_0\cos(\omega t - \beta_x x - \beta_y y - \beta_z z + \phi_0)$$

$$= E_0\cos[\omega t - (\beta_x a_x + \beta_y a_y + \beta_z a_z)\cdot(x a_x + y a_y + z a_z) + \phi_0]$$

$$\boxed{E = E_0\cos[\omega t - \beta\cdot r + \phi_0]}$$

where $\beta = \beta_x a_x + \beta_y a_y + \beta_z a_z$

and propagating vector $r = x a_x + y a_y + z a_z$ is the position vector, ϕ_0 is the phase at the origin at $t=0$

The expression for the magnetic field of the wave is then given by

$$\boxed{H = H_0 \cos(\omega t - \beta \cdot r + \phi_0)}$$

where $|H_0| = \frac{|E_0|}{\eta}$.

Since E, H, and the dirⁿ of propagation are mutually perpendicular to each other. So

$$\vec{E_0} \cdot \beta = 0$$
$$\vec{H_0} \cdot \beta = 0$$
$$E_0 \cdot \vec{H_0} = 0$$

E×H should be directed along the propagation vector β.

so that β×E_0 is directed along H_0.

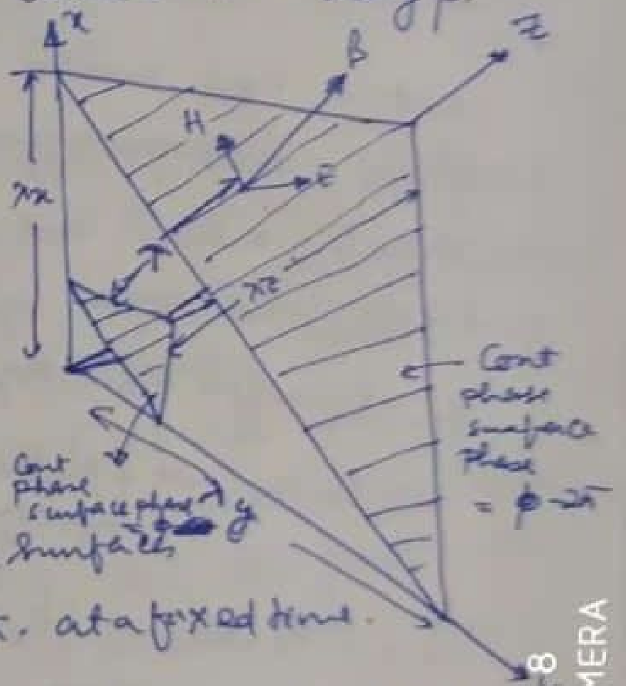
$$\text{So} \quad \vec{H_0} = \frac{\vec{a_\beta} \times \vec{E_0}}{\eta} = \frac{a_\beta \times E_0}{\sqrt{\mu/\epsilon}} = \frac{\omega\sqrt{\mu\epsilon}\, a_\beta \times E_0}{\omega\mu}$$

$$= \frac{\sqrt{\epsilon}\, a_\beta \times E_0}{\sqrt{\mu}} = \frac{\sqrt{\epsilon}\,\omega\, a_\beta \times E_0}{\omega\sqrt{\mu}} = \frac{\omega\sqrt{\mu\epsilon}\, a_\beta \times E_0}{\omega\mu}$$

$$= \frac{\beta\, a_\beta \times E_0}{\omega\mu} = \frac{\vec{\beta} \times \vec{E_0}}{\omega\mu}$$

where a_β is the unit vector along β.

$$\text{Thus} \quad \boxed{\vec{H} = \frac{1}{\omega\mu} \beta \times \vec{E}}$$



Let the apparent wavelengths λ_x, λ_y and λ_z along the co-ordinate axes x, y and z respectively, are the distances measured along those respective axes betⁿ two consecutive constant phase surfaces betⁿ which the phase difference is 2π, at a fixed time. and β_x, β_y, & β_z as being the phase constants along the x, y and z axes respectively.

$$\lambda_x = \frac{2\pi}{\beta_x}, \quad \lambda_y = \frac{2\pi}{\beta_y}, \quad \lambda_z = \frac{2\pi}{\beta_z}$$

$$\frac{1}{\lambda^2} = \frac{1}{(2\pi/\beta)^2} = \frac{\beta^2}{4\pi^2} = \frac{\beta_x^2 + \beta_y^2 + \beta_z^2}{4\pi^2} = \frac{1}{\lambda_x^2} + \frac{1}{\lambda_y^2} + \frac{1}{\lambda_z^2}$$

$$\boxed{\frac{1}{\lambda^2} = \frac{1}{\lambda_x^2} + \frac{1}{\lambda_y^2} + \frac{1}{\lambda_z^2}}$$

The apparent phase velocities V_{px}, V_{py} and V_{pz} along the x, y and z axes respectively, are the velocities with which the phase of the wave progresses with time along the respective axes, Thus

$$V_{px} = \frac{\omega}{\beta_x}$$

$$V_{py} = \frac{\omega}{\beta_y}$$

$$V_{pz} = \frac{\omega}{\beta_z}$$

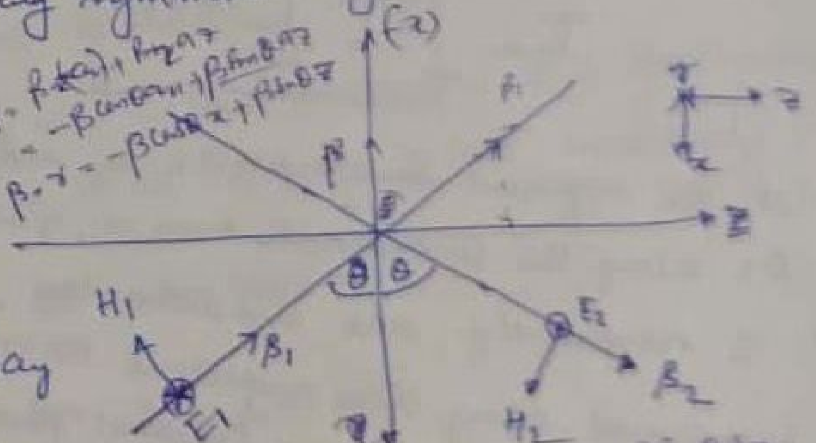
$$\frac{1}{V_p^2} = \frac{1}{(\omega/\beta)^2} = \frac{\beta^2}{\omega^2} = \frac{\beta_x^2 + \beta_y^2 + \beta_z^2}{\omega^2}$$

$$\boxed{\frac{1}{V_p^2} = \frac{1}{V_{px}^2} + \frac{1}{V^2_{py}} + \frac{1}{V^2_{pz}}}$$

Transverse Electric Waves in a Parallel-plate Waveguides

Let us now consider the superposition of two uniform plane wave propagating symmetrically with respect to the z-axis, as shown the electric fields are

$\beta_1 = \beta_x a_x + \beta_z a_z$
$= -\beta \cos\theta a_x + \beta \sin\theta a_z$
$\beta_1 \cdot r = -\beta x \cos\theta + \beta z \sin\theta$



$$E_1 = E_0 \cos(\omega t - \beta_1 \cdot r) a_y$$
$$= E_0 \cos(\omega t + \beta x \cos\theta - \beta z \sin\theta) a_y$$

$$E_2 = -E_0 \cos(\omega t - \beta_2 \cdot r) a_y \quad \beta_2 = \beta_x a_x + \beta_z a_z = \beta \cos\theta a_x + \beta \sin\theta a_z$$
$$= -E_0 \cos[\omega t - \beta x \cos\theta - \beta z \sin\theta] a_y$$

where $\beta = \omega\sqrt{\mu\epsilon}$ with ϵ and μ being permittivity and the permeability respectively of the medium.

The corresponding magnetic fields are given as

$$H_1 = \frac{E_0}{\eta}(-\sin\theta a_x - \cos\theta a_z) \cos(\omega t + \beta x \cos\theta - \beta z \sin\theta)$$

$$H_2 = \frac{E_0}{\eta}(\sin\theta a_x - \cos\theta a_z) \cos(\omega t - \beta x \cos\theta - \beta z \sin\theta)$$

where $\eta = \sqrt{\mu/\epsilon}$.

$H = H_1 + H_2$

$$= -\frac{E_0}{\eta}(\sin\theta\, a_x + \cos\theta\, a_z)\cos(\omega t + \beta x\cos\theta - \beta z\sin\theta)$$

$$+ \frac{E_0}{\eta}(\sin\theta\, a_x - \cos\theta\, a_z)\cos(\omega t - \beta x\cos\theta - \beta z\sin\theta)$$

$$H = -\frac{E_0}{\eta}\sin\theta\, a_x \cos(\omega t + \beta x\cos\theta - \beta z\sin\theta)$$

$$+ \frac{E_0}{\eta}\sin\theta\, a_x \cos(\omega t - \beta x\cos\theta - \beta z\sin\theta)$$

$$- \frac{E_0}{\eta}\cos\theta\, a_z \cos(\omega t + \beta x\cos\theta - \beta z\sin\theta)$$

$$- \frac{E_0}{\eta}\cos\theta\, a_z (\cos \omega t - \beta x\cos\theta - \beta z\sin\theta)$$

$$H = -\frac{E_0}{\eta}\sin\theta\Big[\cos(\omega t + \beta x\cos\theta - \beta z\sin\theta) - \cos(\omega t - \beta x\cos\theta - \beta z\sin\theta$$

$$- \frac{E_0}{\eta}\cos\theta\Big[\cos(\omega t + \beta x\cos\theta - \beta z\sin\theta$$
$$+ \cos(\omega t - \beta x\cos\theta - \beta z\sin\theta)\Big] a_z$$

$$H = -\frac{E_0}{\eta}\sin\theta\Big[-2 \sin(\beta x\cos\theta)\sin(\omega t - \beta z\sin\theta)\, a_x$$

$$- \frac{E_0}{\eta}\cos\theta\Big[2\cos(\beta x\cos\theta)\cos(\omega t - \beta z\sin\theta)\Big] a_z$$

$$\boxed{H = \frac{2E_0}{\eta}\sin\theta\,\sin(\beta x\cos\theta)\sin(\omega t - \beta z\sin\theta)\, a_x - \frac{2E_0}{\eta}\cos\theta\cdot\cos(\beta x\cos\theta)\cos(\omega t - \beta z\sin\theta)\, a_z} \quad (3)$$

Here the factor $\sin(\beta x\cos\theta)$ and $\cos(\beta x\cos\theta)$ for the x dependence and the factors $\sin(\omega t - \beta z\sin\theta)$ and $\cos(\omega t - \beta z\sin\theta)$ for the z-dependence, the component fields have standing wave character in the x dir^n and traveling wave character in the z-dir^n.
Thus we have standing waves in the x dir^n moving bodily

Perfectly

$$P = -E_y H_x a_z + E_y H_z a_x$$

$$P = +2E_0 \sin(\beta x \cos\theta) \sin(\omega t - \beta z \sin\theta) \times \frac{2E_0}{\eta} \sin\theta \sin(\beta x \cos\theta) \sin(\omega t - \beta z \sin\theta)$$

$$+ \{-2E_0 \sin(\beta x \cos\theta) \sin(\omega t - \beta z \sin\theta) \times -\frac{2E_0}{\eta} \cos\theta \cos(\beta x \cos\theta) \cos(\omega t - \beta z \sin\theta)$$

$$P = \frac{4E_0^2}{\eta} \sin\theta \sin^2(\beta x \cos\theta) \cdot \sin^2(\omega t - \beta z \sin\theta)\, a_z$$

$$+ \frac{4E_0^2}{\eta} \cos\theta \cdot \sin(\beta x \cos\theta) \cos(\beta x \cos\theta) \sin(\omega t - \beta z \sin\theta) \cos(\omega t - \beta z \sin\theta)$$

$$P = \frac{4E_0^2}{\eta} \sin\theta \sin^2(\beta x \cos\theta) \cdot \sin^2(\omega t - \beta z \sin\theta)\, a_z$$

$$+ \frac{E_0^2}{\eta} \cos\theta \cdot \sin 2\beta x \cos\theta) \cdot \sin 2(\omega t - \beta z \sin\theta) a_x$$

The time-average Poynting vector is given by

$$\langle P \rangle = \frac{1}{T}\int_0^T P\, dt$$

$$\langle P \rangle = \frac{4E_0^2}{\eta} \sin\theta \cdot \sin^2(\beta x \cos\theta) \langle \sin^2(\omega t - \beta z \sin\theta) \rangle a_z$$

$$+ \frac{E_0^2}{\eta} \cos\theta \sin(2\beta x \cos\theta) \cdot \langle \sin 2(\omega t - \beta z \sin\theta) \rangle a_x$$

$\sin^2(\omega t - \beta z \sin\theta)$

$\left[\frac{1 + \cos 2(\omega t - \beta z \sin\theta)}{2}\right]$

$$\boxed{\langle P \rangle = \frac{2E_0^2}{\eta} \sin\theta \cdot \sin^2(\beta x \cos\theta)\, a_z}$$

Then the time-average flow is entirely in the z-dirⁿ.

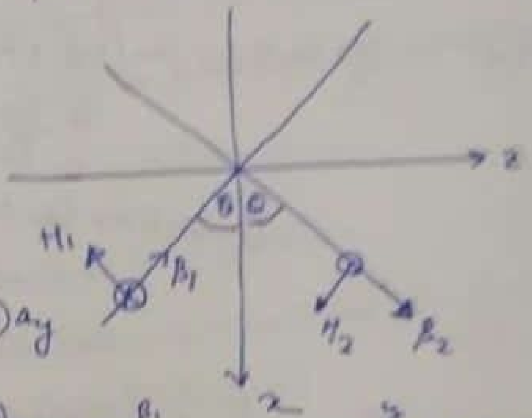
Since the composite electric field is directed entirely transverse to the x-dirⁿ i.e. the dirⁿ of time-average power flow whereas the composite magnetic field is not, the composite wave is known as Transverse electric TE wave.

The TE wave for electric field in eqⁿ (1) is zero when $\sin(\beta x \cos\theta) = 0$ i.e. $\beta x \cos\theta = \pm m\pi$, $m = 0, 1, 2, \dots$

$$x = \frac{\pm m\pi}{\ldots} = \pm \frac{m\lambda}{2\cos\theta} \quad \boxed{x = \pm \frac{m\lambda}{2\cos\theta}}$$

Transverse Electric Waves in a Parallel plate wave guides

Let us consider that the superposition of two uniform plane wave propagating symmetrically with respect to the z-axis as shown.

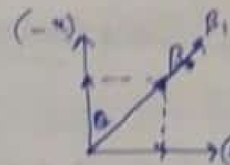


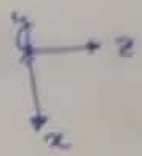
The electric fields are

$$E_1 = E_0 \cos(\omega t - \beta_1 \cdot r)\, a_y$$

+y dir

$$E_1 = E_0 \cos(\omega t + \beta x \cos\theta - \beta z \sin\theta)\, a_y$$





-y dir

~~$E_2 = E_0 \cos$~~

$$E_2 = -E_0 \cos(\omega t - \beta_2 \cdot r)\, a_y$$

$$E_2 = -E_0 \cos[\omega t - \beta x \cos\theta - \beta z \sin\theta]\, a_y$$

where $\beta = \omega\sqrt{\mu\epsilon}$

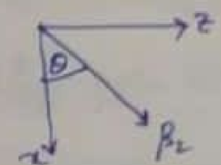
ϵ, μ are permittivity and permeability of the medium.

$\beta_1 = -\beta \cos\theta (a_x) + \beta \sin\theta\, a_z$

$\beta_1 = -\beta \cos\theta\, a_x + \beta \sin\theta\, a_z$

$r = x a_x + y a_y + z a_z$

$\beta_1 \cdot r = -\beta \cos\theta\, x + \beta \sin\theta\, z$



$\beta_2 = \beta \cos\theta\, a_x + \beta \sin\theta\, a_z$

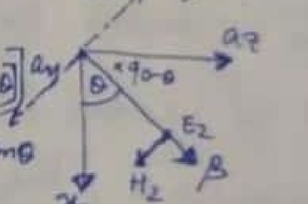
$\beta_2 \cdot r = \beta \cos\theta\, x + \beta \sin\theta\, z$

The corresponding magnetic field given as

$$H_1 = \frac{E_0}{\eta}(-\sin\theta\, a_x - \cos\theta\, a_z) \cos[\omega t + \beta x \cos\theta - \beta z \sin\theta]$$

$a_z \sin(90-\theta) = a_z \cos\theta$

$$H_2 = \frac{E_0}{\eta}[(\sin\theta\, a_x - \cos\theta\, a_z) \cos[\omega t - \beta x \cos\theta - \beta z \sin\theta]]$$



where $\eta = \sqrt{\frac{\mu}{\epsilon}}$.

$(a_x \sin\theta - a_z \cos\theta)$

The electric and magnetic field of superposition of the two waves are given by $E = E_1 + E_2$

$\cos(A-B) - \cos(A+B) = 2\sin A \sin B$

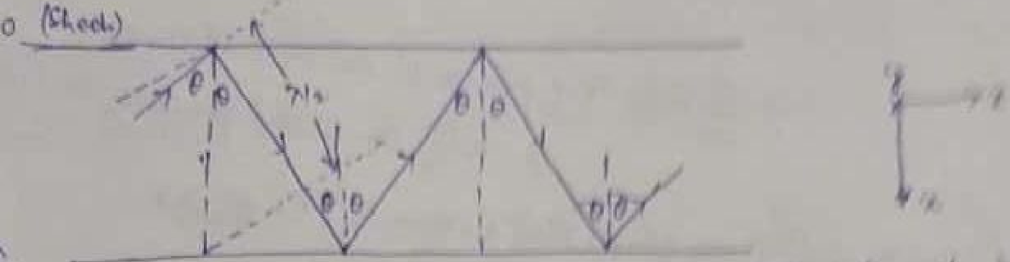
$$E = E_0 \cos(\omega t + \beta x \cos\theta - \beta z \sin\theta)\, a_y - E_0 \cos[\omega t - \beta x \cos\theta - \beta z \sin\theta]$$

$$\boxed{E = -2E_0 \sin(\beta x \cos\theta) \sin(\omega t - \beta z \sin\theta)\, a_y}$$

— for case-β≠ ...) let us consider that the super position of

Thus if we place perfectly conducting sheets in these planes the wave will propagate undisturbed.

$x = 0$ (Sheets)



$x = \frac{\lambda}{2\cos\theta}$ (Sheets)

uniform plane wave bouncing obliquely bet^n two parallel plane perfectly conducting sheets

Let us consider that for uniform plane wave bouncing obliquely bet^n two parallel plane perfectly conducting sheets. The above fig shows that the two sheets in the plane $x=0$ and $x = \frac{\lambda}{2\cos\theta}$. thereby guiding the wave and hence the energy in the z-dir^n, parallel to the plates. Then we have a parallel plate wave guide.

The above fig shows that constant phase surfaces of the obliquely bouncing wave that $\frac{\lambda}{2\cos\theta}$ is simply one half of the apparent wave length of that wave in the x-dir^n. ~~of~~ Thus field have one half apparent wave length in the x-dir^n,

If ~~the~~ ~~both sheets~~ we place the perfectly conducting sheets in the plane $x = 0$ and $x = \frac{m\lambda}{2\cos\theta}$, the fields will then have m number of one-half apparent wave length in the x-dir^n bet^n the plates. The field have no variation in the y-dir^n. Thus the fields are corresponds to $\boxed{\text{TE}_{m0} \text{ modes}}$. Here the subscript m ...

the x dirⁿ and m is denoted as the number of one half apparent wave lengths in that dirⁿ and the subscripts '0' refers to the 'y' dirⁿ and '0' denoted as zero number of one half apparent wavelengths in that dirⁿ.

Case 1: → Let us consider a parallel plate wave guide with perfectly conducting plates situated in the planes $x = 0$ and $x = a$, and it is TEmo waves guided by fixed space 'a' betⁿ them, then for the plate,

$x = 0$

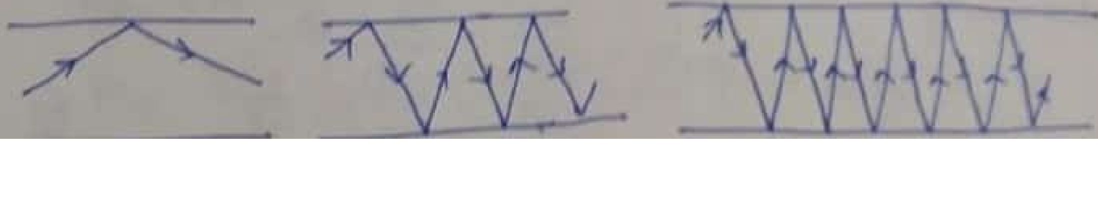
$$a = \frac{m\lambda}{2\cos\theta}$$

$$\cos\theta = \frac{m\lambda}{2a} = \frac{m}{2a} \cdot \frac{1}{f\sqrt{\mu\epsilon}}$$

$x = a$

Case 2: → Since the wave of different wavelength (or frequencies) bounces obliquely betⁿ the plates at different values of the angle θ, for very small wavelength (very high frequencies), $\frac{m\lambda}{2a}$ is small, $\cos\theta \approx 0$, $\theta = 90°$ and the wave simply slide betⁿ the plates as in the case of transmission line.

As λ increases (f decreases), $\frac{m\lambda}{2a}$ increases θ decreases and the wave bounce more and more obliquely.



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For $\lambda > 2a$, $\frac{m\lambda}{2a} > 1$, $\cos\theta > 1$, and θ has no real sol and its indicates that propagation does not occur for the wavelength in the waveguide modes, This condition is known as the cut off condition.

The cut off wavelength (λ_c) is given by

$$\boxed{\lambda_c = \frac{2a}{m}}$$

is is simply the wavelength for which the spacing a is equa n number of one half wavelength,

Here the cut off frequency is given by

$$\lambda_c = \frac{2\pi}{\beta} = \frac{2\pi}{\omega\sqrt{\mu\epsilon}} = \frac{2\pi}{2\pi f_c\sqrt{\mu\epsilon}}$$

$$\frac{2a}{m} = \frac{1}{f_c\sqrt{\mu\epsilon}} \qquad \boxed{f_c = \frac{m}{2a\sqrt{\mu\epsilon}}}$$

propagation of a particular mode is possible only if f is greater than the values of f_c for that mode. Therefore the wave of a given frequency f can propagate in all mo for which the cut off wavelengths are greater than wavelength & the cut off frequencies are less than the frequency.

$$\text{again} \quad \cos\theta = \frac{m\lambda}{2a} = \frac{\beta}{\beta a} \qquad \lambda_c = \frac{2a}{m}$$

$$= \frac{\lambda}{2a/m} = \frac{\lambda}{\lambda_c} = \frac{f_c}{f} \qquad \frac{2a}{m} = \frac{1}{f_c\sqrt{\mu\epsilon}}$$

$$\sin\theta = \sqrt{1-\cos^2\theta} = \sqrt{1-\left(\frac{\lambda}{\lambda_c}\right)^2} = \sqrt{1-\left(\frac{f_c}{f}\right)^2} \qquad \frac{2a}{m} = \frac{1}{f_c\sqrt{\mu\epsilon}}$$

$$\beta\cos\theta = \frac{2\pi}{\lambda}\cdot\frac{\lambda}{\lambda_c} = \frac{2\pi}{\lambda_c} = \frac{2\pi}{\frac{2a}{m}} = \frac{m\pi}{a}$$

$$\beta\sin\theta = \frac{2\pi}{\lambda}\sqrt{1-(\lambda/\lambda_c)^2}$$

Since $\beta \sin\theta$ are the phase constant along the z-dir^n. so we can define the guide wavelength (λ_g), to be the wavelength in the z-dir along the guide.

$$\text{ie} \quad \lambda_g = \frac{2\pi}{\beta \sin\theta} = \frac{2\pi}{\frac{2\pi}{\lambda}\sqrt{1-(\lambda/\lambda_c)^2}} = \frac{\lambda}{\sqrt{1-(\lambda/\lambda_c)^2}}$$

$$\boxed{\lambda_g = \frac{\lambda}{\sqrt{1-(\lambda/\lambda_c)^2}}}$$

Similarly the apparent wavelength in the z-dir^n, of the obliquely bouncing uniform plane waves.

The phase velocity along the guide axis, is the apparent phase velocity in the z-dir^n, of the obliquely bouncing uniform plane wave

$$\text{ie} \quad V_{pz} = \frac{\omega}{\beta \sin\theta} = \frac{V_p}{\sin\theta} = \frac{V_p}{\sqrt{1-(\lambda/\lambda_c)^2}} = \frac{V_p}{\sqrt{1-(f_c/f)^2}}$$

$$\boxed{V_{pz} = \frac{V_p}{\sqrt{1-(f_c/f)^2}}}$$

we can obtain the expression for the electric field and magnetic ~~on the fields~~

are

$$\vec{E} = -2E_0 \sin\left(\frac{m\pi x}{a}\right) \sin\left(\omega t - \frac{2\pi}{\lambda_g} z\right) a_y$$

$$H = \frac{2E_0}{\eta}\frac{\lambda}{\lambda_g} \sin\left(\frac{m\pi x}{a}\right) \sin\left(\omega t - \frac{2\pi}{\lambda_g} z\right) a_x$$

$$- \frac{2E_0}{\eta}\frac{\lambda}{\lambda_c} \cos\left(\frac{m\pi x}{a}\right) \cos\left(\omega t - \frac{2\pi}{\lambda_g} z\right) a_z$$

are expression for the $TE_{m,0}$ mode fields in the parallel plate wave guides.

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Dispension:

As we know that for the propagating range of frequencies, the phase velocity and the wavelength along the ax of the Parallel-plate waveguides are given by

$$v_{pz} = \frac{v_p}{\sqrt{1-(f_c/f)^2}} \text{ and } \lambda_g = \frac{\lambda}{\sqrt{1-(f_c/f)^2}}$$

where $v_p = \frac{1}{\sqrt{\mu\epsilon}}$, $\lambda = \frac{v_p}{f\sqrt{\mu\epsilon}}$ and f_c is the cut off frequen

As for a particular mode, the phase velocity of propaga along the guide axis varies with the frequency. As consequence of this ees of the guided wave propaga the field patterns of the different frequency component signal comprising a band of frequencies do not mainta same phase relationships as they propagate down the

This phenomenon is known as dispension.