IES/GATE

Electronics & Telecommunication Engineering

VOLUME-VII

Microwaves Engineering
Advance Communication
Electro Megnetics

Contents

-: MICROWAVE ENGG (EMT + EDC) :-

→ Microwave components (Power Handling Devices)

- Rectangular Waveguides
- Cylindrical Waveguides
- Cavity Resonators
- Tees
- Directional coupler
- Isolators & circulators

→ Microwave Solid-State Devices (Low power)

- TED's – (oscillators)
  - → Transferred Electron Devices
  - Ga-As – (Gunn Diode)
- ATTs – (switches)
  - → Avalanche Transit-Time devices
- HBJTs – (Amplifier)
  - HEMFETs – MESFETs –

→ Microwave Vacuum-Tube (High Power)

M/W Tubes

- M-Type — Cross Field Structures
  - Magnetron (oscillator)
- O-Type — Linear Tubes
  - Cavity — Klystron (Amp), Reflex Klystron (oscillator)
  - Travelling Wave — TWT (Amp)

→ Miscellaneous

- Parametric Amplifier
- Microstrip Lines
- Measurements
- MASERs

Lecture-1

Microwave Frequencies : and Applications :-

↓

very small λ (less than m) compared to RF

Freq. Range : GHz to 10^{12} Hz (Tera Hz.)

→ λ - Range : few cm to few mm

Microwave Spectrum - (Sub bands) :-

L — (1-2) GHz → GSM

S — (2-4) GHz → Bluetooth (2.4), Wi-Fi

C — (4-8) GHz → Satellite Communication

X — (8-12) GHz

Ku — (12-18) GHz

K — (18-27) GHz

Ka — (27-45) GHz

> 45 GHz → mm bands

Microwave Applications :-

→ The available BW is higher than the existing RF due to higher carrier frequencies

eg:- RF - device

Operating freq. = 2.4 MHz

Use → 2.41 MHz

→ 2.39 MHz

BW → 0.02 MHz = 20 voice channels

= 20 KHz

eg:- M/W - Device

Operating freq. = 2.4 GHz

Use → 2.41 GHz

→ 2.39 GHz

BW → 0.02 GHz

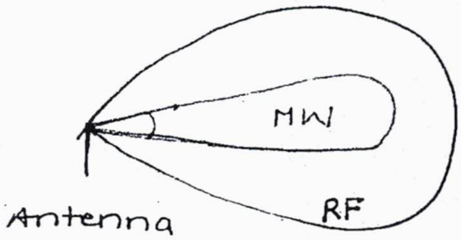
= 20 MHz → 100 video Channels

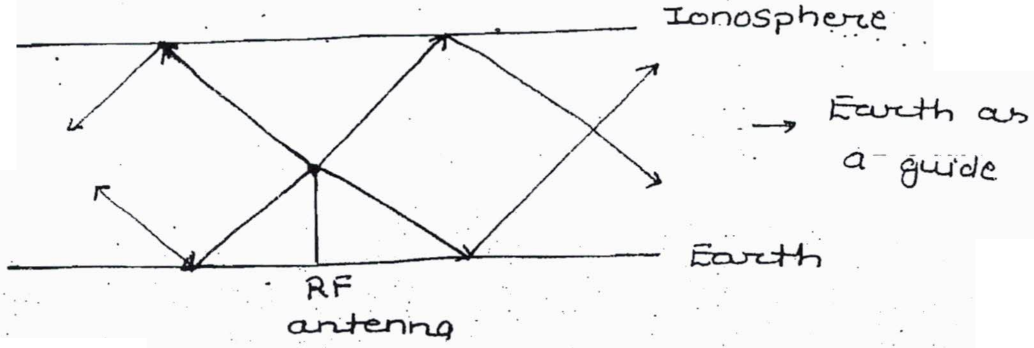
10,000 telephone lines

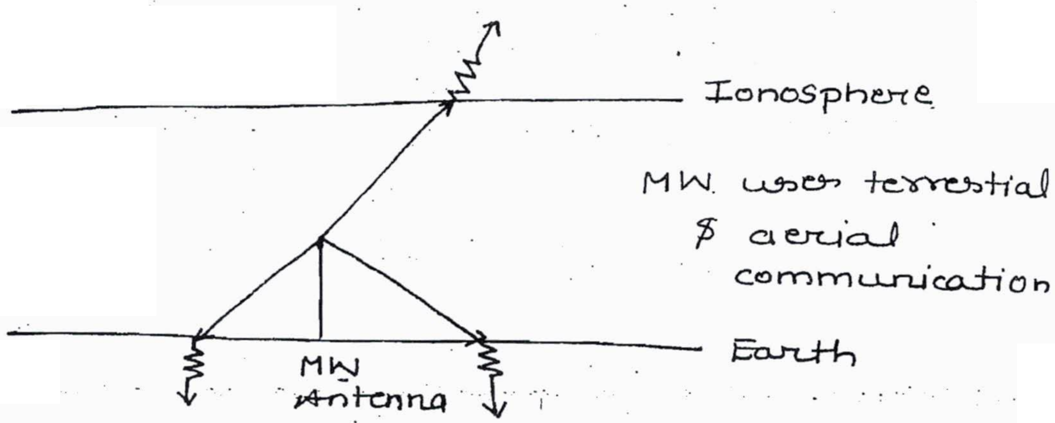
→ Penetration levels are high into clouds and ionosphere at reduced dispersing losses

$$A_e = \frac{\lambda^2}{4\pi} \cdot D$$

$$D \propto \frac{1}{\lambda^2}$$





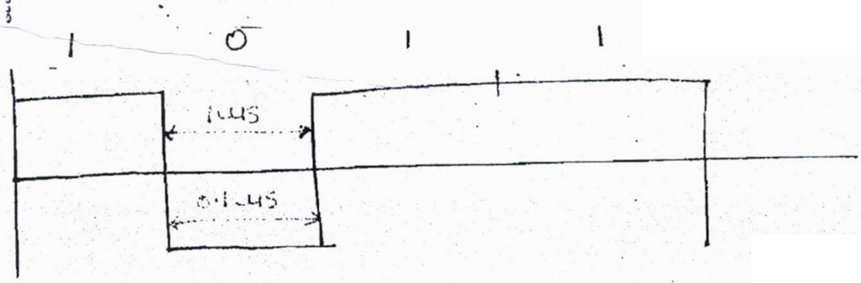


Application:–

→ satellite Communication, → Air Traffic control

→ M/W - links in LOS

→ High speed data transfer in solid state devices eg:-



$$\text{Bit Rate} = \frac{1}{10^{-6}} = 1 \text{ Mbps}$$

$$\text{Bit rate} = 10 \text{ Mbps}$$

Rectangular Waveguides :-

→ When the waves are $E(x, y, z, t)_{(x, y, z)}$

$H(x, y, z, t)_{(x, y, z)}$

→ The waves are confined in x & y directions Using four walls at

$x = 0$
$x = a$
$y = 0$
$y = b$

→ The confinement satisfies the boundary conditions that $E_{tang} = 0$ at guide walls

$E(x)_y$ or $E(x)_z = 0$ at $x = 0$ & $x = a$

$E(y)_x$ or $E(y)_z = 0$ at $y = 0$ & $y = b$

The $\nabla^2 E = \gamma^2 E$ results in

$$\gamma_x = \frac{m\pi}{a}, \quad \gamma_y = \frac{n\pi}{b}$$

$$\bar{\gamma} = \gamma_z = \sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 - \omega^2 \mu \epsilon}$$

For ω_c or cut-off frequency where $\bar{\gamma} = 0$.

$$\omega_c = \left(\sqrt{\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2}\right) c$$

1. $\sin\theta = \frac{f_c}{f}$

2. $\overline{V_p} = \frac{c}{\cos\theta}$

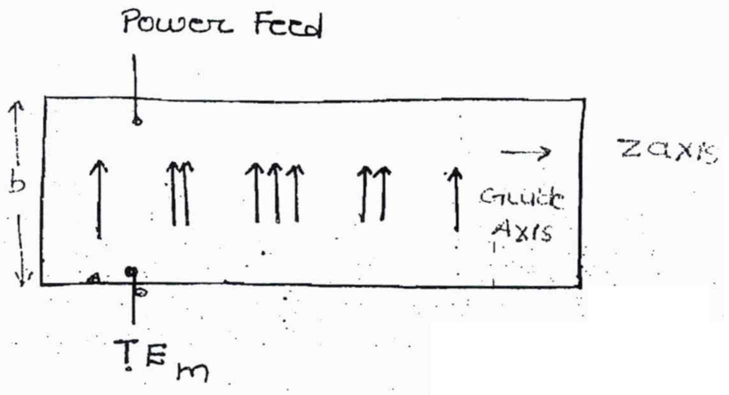
$\overline{V_g} = c \cdot \cos\theta$

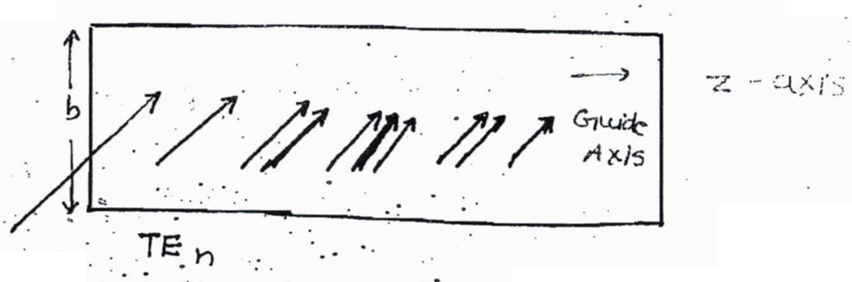
3. $\eta_{TE} = \frac{120\pi}{\cos\theta}$ $\eta_{TM} = 120\pi \cdot \cos\theta$

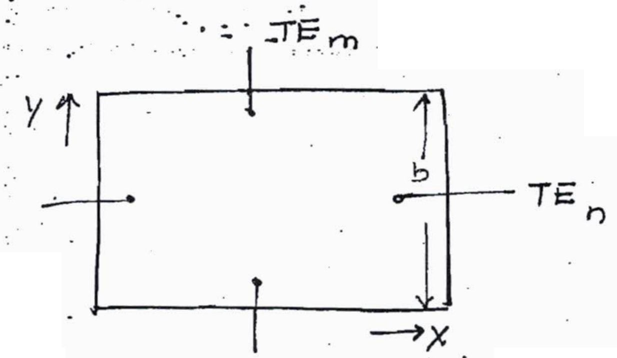
→ With $E_z = 0$, the wave is $E(x,y,z,t)_{(x,y)}$

$H(x,y,z,t)_{(x,y,z)}$

called as TE Wave







Toppersnotes
Unleash the topper in you

I → With $H_z = 0$, the wave is $E(x, y, z, t)_{(x, y, z)}$

$H(x, y, z, t)_{(x, y)}$

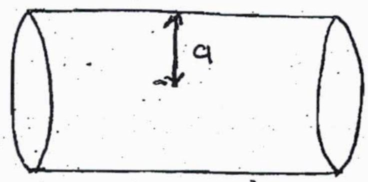
called as TM Wave

Cylindrical Wave Guides :—

→ With the blunt edges the power losses at waveguides twist and bends is considerably high.

→ The smooth or cylindrical structure the losses can be minimize

→ It is a single conductor hollow structuring used to confine EM waves in vertical directions with $\rho = a$



→ When the waves are

$$E(\rho, \phi, z, t)_{(\rho, \phi, z)}$$

$$H(\rho, \phi, z, t)_{(\rho, \phi, z)}$$

Applying $E_{tang} = 0$ for the wave at $\rho = a$

$$\boxed{\begin{aligned} E(\rho = a)_\phi &= 0 \\ E(\rho = a)_z &= 0 \end{aligned}}$$

Applying Helmholtz's Equations

$$\nabla^2 E = \gamma^2 E$$

with $\gamma = j\omega\sqrt{\mu_0 \epsilon_0}$ = free space prop. constant

$$\nabla^2 E = \frac{1}{\rho}\frac{\partial}{\partial \rho}\left(\rho \cdot \frac{\partial E}{\partial \rho}\right) + \frac{1}{\rho^2}\cdot\frac{\partial^2 E}{\partial \phi^2} + \frac{\partial^2 E}{\partial z^2} = -\omega^2 \mu \epsilon E$$

→ The final wave solution is a product (AND) solution of ρ, ϕ, z, t Harmonic

ⓐ $E(z)/H(z) \longrightarrow e^{-\bar{\gamma} z}$ i.e. Natural Harmonic at $\bar{\gamma}$ rate

$\bar{\gamma} = \gamma_z$ = Propogation constant along guide axis

ⓑ $H(\phi)/E(\phi)$ is also Harmonic as $\sin(n\phi)$ or $\cos(n\phi)$

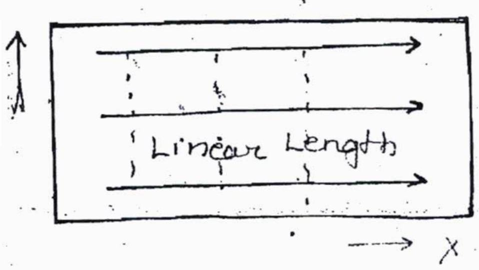
where n = any integer corresponding to no. of feed points in ϕ direction

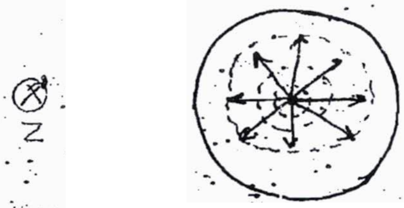
→ The $E(\rho)$ or $H(\rho)$ is a Bessel Harmonic or derivative of Bessel Harmonic

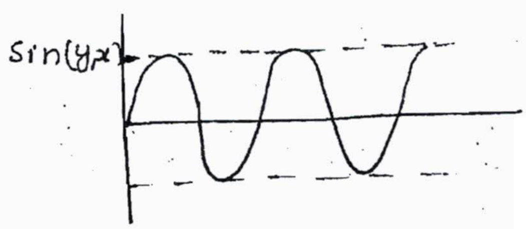
as $J_n(\beta_\rho \cdot \rho)$ or $J_n'(\beta_\rho \cdot \rho)$

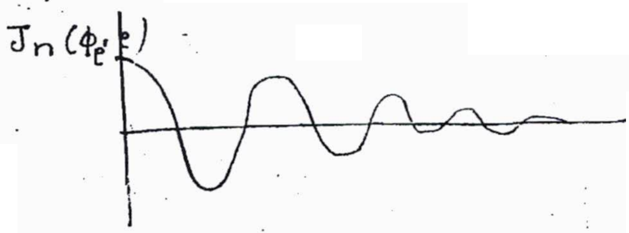
where β_ρ = Propogation constant in the ρ direction

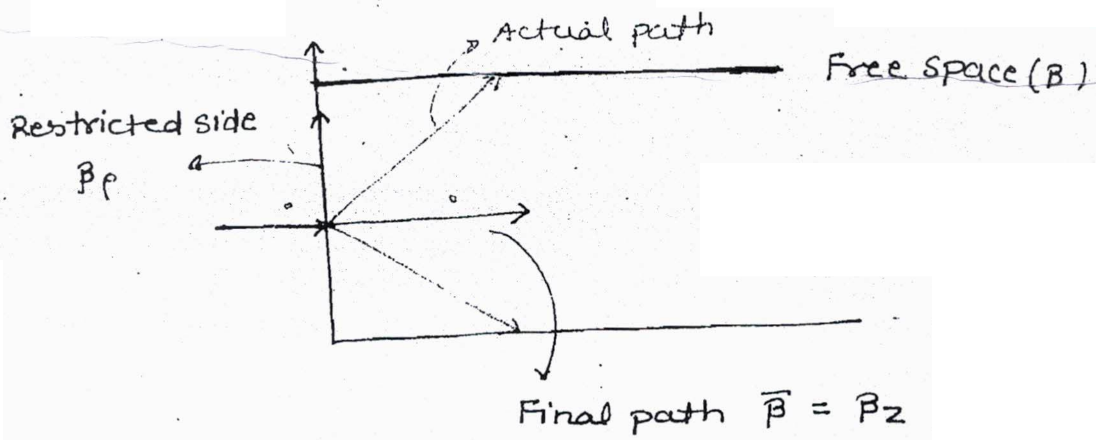
where n = order of Bessel function with $n = 0, 1, 2, 3, \ldots$











$$\beta = \omega\sqrt{\mu_0 \epsilon_0} = \sqrt{\bar{\beta}^2 + \beta_\rho^2}$$

$$\boxed{\bar{\beta} = \sqrt{\omega^2 \mu_0 \epsilon_0 - \beta_\rho^2}}$$

→ The TM waves with $H_z = 0$, the axial component E_z exists as

$$E(\rho, \phi, z, t)_z = E_{z0} \cdot J_n(\beta_\rho \cdot \rho)\, e^{-\bar{\gamma} z}\, e^{j\omega t}\, a_z$$

$$E_\phi = C_1 \frac{\partial E_z}{\partial \phi} \qquad H_\rho = C_2 E_\phi$$

$$E_\rho = C_3 \frac{\partial E_z}{\partial \rho} \qquad H_\phi = C_4 E_\rho$$

→ Applying boundary conditions,

$$E(\rho = a)_z = 0$$

$$J_n(\beta_\rho a) = 0$$

$$\Rightarrow \beta_\rho a = X_{np}$$

$$\Rightarrow \boxed{\beta_\rho = \frac{X_{np}}{a}}$$

where X_{np} = p^{th} root of n^{th} order Bessel's Harmonic

$$\bar{\beta} = \sqrt{\omega^2 \mu_0 \epsilon - \left(\frac{X_{np}}{a}\right)^2}$$

With $\bar{\beta} = 0$ for cut-off frequency

$$\boxed{\omega_c = \frac{X_{np} \cdot c}{a}}$$

→ Roots of Bessel Harmonics of n-order (X_{mp}) (TM)

p ↓ \ n →	0	1	2	3	4	5
1	2.40	3.83	5.13	6.38	7.58	8.7
2	5.52	7.10	8.41	9.76	11.06	12.34
3	8.64	10.17	11.62	13.01	14.37	
4	11.79	13.32	14.79			

→ For TE waves where $E_z = 0$, the axial component H_z exists as

$$H(\rho, \phi, z, t)_z = H_{z0} J_n(\beta_\rho \cdot \rho) \cdot \cos(n\phi)\, e^{-\gamma z} \cdot e^{j\omega t} \cdot a_z$$

$$E_\phi = C_1 \frac{\partial H_z}{\partial \rho} \qquad H_\rho = C_2 E_\phi$$

$$E_\rho = C_3 \frac{\partial H_z}{\partial \phi} \qquad H_\phi = C_4 E_\rho$$

Applying boundary conditions, $E(\rho = a)_\phi = 0$

$$J_n'(\beta_\rho \cdot a) = 0$$

$$\beta_\rho \cdot a = X'_{np}$$

where X'_{np} is p^{th} root of the Bessel Harmonics derivative

$$\boxed{\beta_\rho = \frac{X'_{np}}{a}}$$

Finally - $\boxed{\omega_c = \dfrac{X'_{np}\, c}{a}}$

Roots of Bessel Harmonics Derivative (X'_{mp}) → TE

p ↓ / n →	0	1	2	3	4	5
1	3.83	1.84	3.05	4.20	5.31	6.41
2	7.10	5.33	6.70	8.01	9.28	10.52
3	10.17	8.53	9.96	11.34	12.68	13.98
4	13.32	11.70	13.17			

Summary :-

Rectangular Waveguides

$$f_c = \left(\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}\right)\frac{c}{2}$$

For TE & TM both

The modes are assigned as TE_{mn} & TM_{mn}

2. The dominant mode is :- TE_{10} or TE_{01}

3. The modes TM_{m0} and TM_{0n} do not exist physically and are said to be Evanescent modes

Cylindrical Waveguides

1. $$f_c = \frac{X_{np} \cdot c}{2\pi a} \rightarrow TM$$

$$f_c = \frac{X'_{np}\, c}{2\pi a} \rightarrow TE$$

The modes are assigned as TE_{np} or TM_{np}

2. The dominant mode is TE_{11} with $X'_{np} = 1.84$

3. The TE_{n0} and TM_{n0} modes do not exist and are Evanescent modes.

Rectangular Waveguides:

4. All TE_{mn} and TM_{mn} are de-generate for a given m and n values

5. The increasing order of f_c for modes is

a > b

TE_{10}

TE_{01}

TE_{11} / TM_{11}

TE_{20}

TE_{02}

Cylindrical Waveguides:-

4. All TE_{op} and TM_{1p} are de-generate for a given p values.

5. The modes in increasing order of f_c is

TE_{11}, $X'_{11} = 1.84$

TM_{01}, $X_{01} = 2.40$

TE_{21}, $X'_{21} = 3.05$

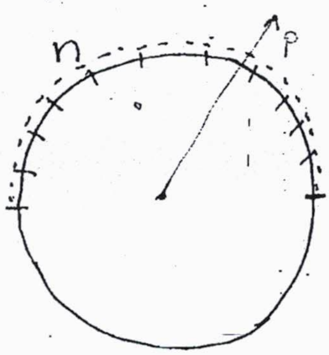
TE_{01}/TM_{11}, $X'_{01} = X_{11} = 3.83$

Lecture - 2

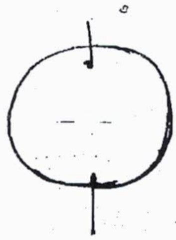
Feeds and Modes in Waveguides :-

n = No. of out of phase feed points in ϕ direction with $\phi = [0, \pi]$, with the feed at $\phi = 0$ or π not counted

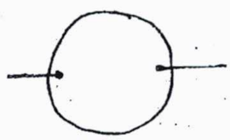
p = No. of feed points in the ρ direction with $\rho = [0, a]$



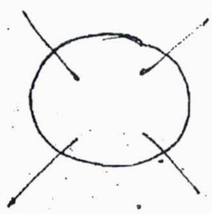
eg:-



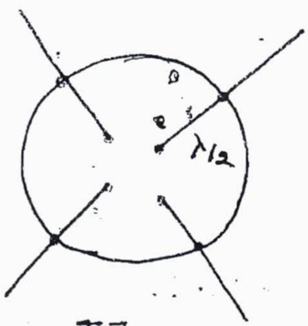
TE_{11}



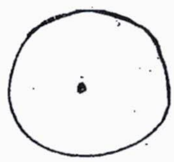
TE_{01}



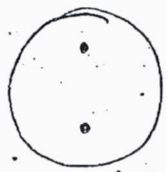
TE_{21}



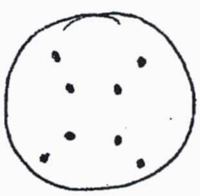
TE_{22}



TM_{01}



TM_{11}



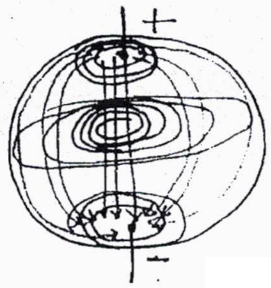
TM_{22}

Field line Representation of guided Waves :-

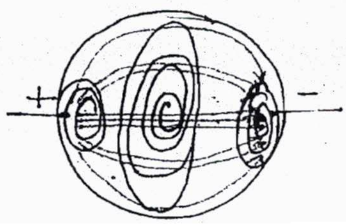
TE Waves (E_ρ, E_ϕ) :- $E(\rho,\phi,z,t)_{(\rho,\phi)}$, H_ρ, H_ϕ, H_z

$H(\rho,\phi,z,t)_{(\rho,\phi,z)}$

TE_{11}



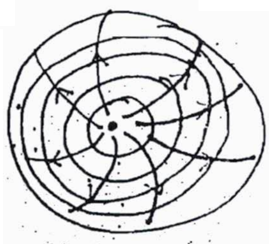
TE_{01}



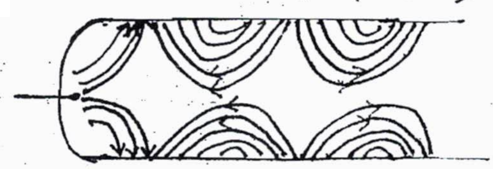
TM Waves :-

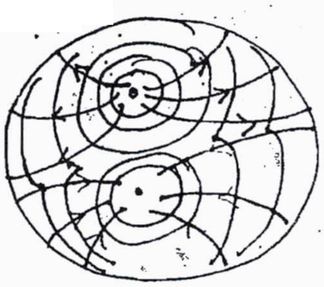
E_ρ, E_ϕ, E_z & $E(\rho,\phi,z,t)_{(\rho,\phi,z)}$

TM_{01}



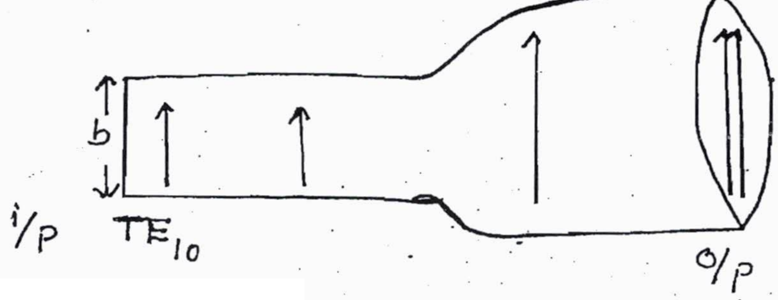
→ z axis



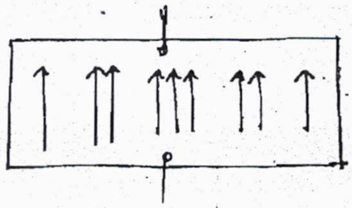


Guide Transformations :-

Case -(1) :-

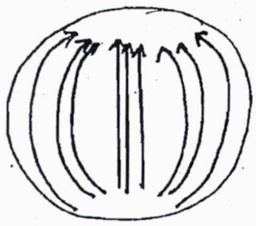


i/p



TE$_{10}$

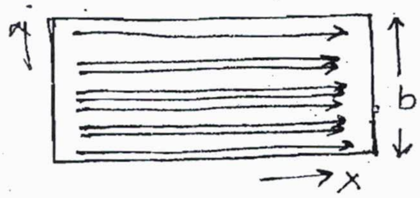
o/p



TE$_{11}$

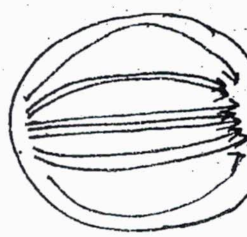
Case – (II) : –

i/p

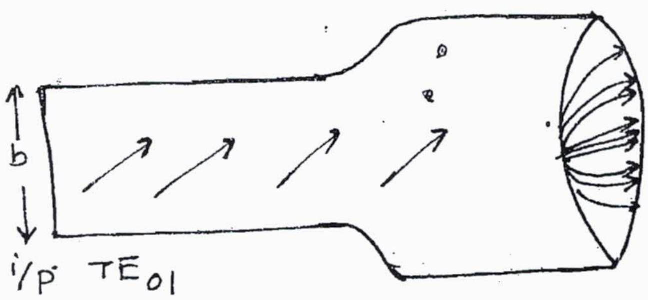


TE$_{01}$

o/p



TE$_{01}$



i/p TE$_{01}$

Case – (III) : –

o/p feed

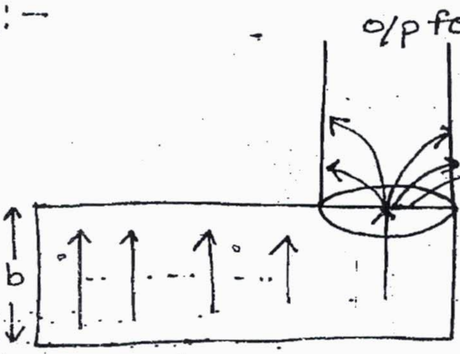
TM$_{01}$

CWG

(Radiation slot)

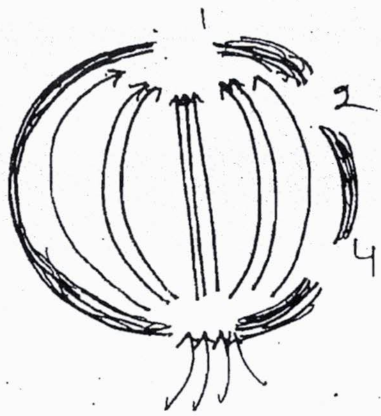
Iris Aperture

i/p TE$_{10}$



RWG

Workbook :-



1, 3 → Radiation slot

2. $f_c = \frac{X_{11} \cdot c}{2\pi a} = \frac{c}{\lambda_c} \Rightarrow \lambda_c = \frac{\pi \cdot D}{X_{11}} = \frac{3.14}{3.83} \cdot D$

3. TM_{01} Note :-

→ The conducting wires filter out the mode whose electric field is parallel to those conducting wires, i.e. the mode having an electric field pattern as shown is likely to be filtered i.e. TM_{01}

4. → TE_{11} $X'_{np} = 1.84$

$$f_{c_1} = \frac{X'_{np}\, c}{2\pi a} = \frac{1.84 \times 3 \times 10^8}{2 \times 3.14 \times 10^{-2}} = 8.8 \text{ GHz}$$

→ TM_{01} $X_{np} = 2.40$

$$f_{c_2} = \frac{2.40 \times 3 \times 10^8}{2 \times 3.14 \times 10^{-2}} = 11.46 \text{ GHz}$$

→ TE_{21} $X'_{np} = 3.05$

$$f_{c_3} = \frac{3.05 \times 3 \times 10^8}{2 \times 3.14 \times 10^{-2}} = 14.57 \text{ GHz}$$

→ TE_{01}/TM_{11} $X_{np} = X'_{np} = 3.83$

$$f_{c_4} = 18.3 \text{ GHz}$$