UNIT-I

1. **Enumarate basic advantages, disadvantages and applications of microwave engineering.**

(Or)

What is a Microwave band spectrum bands? Explain briefly the applications of microwaves at various frequency bands.

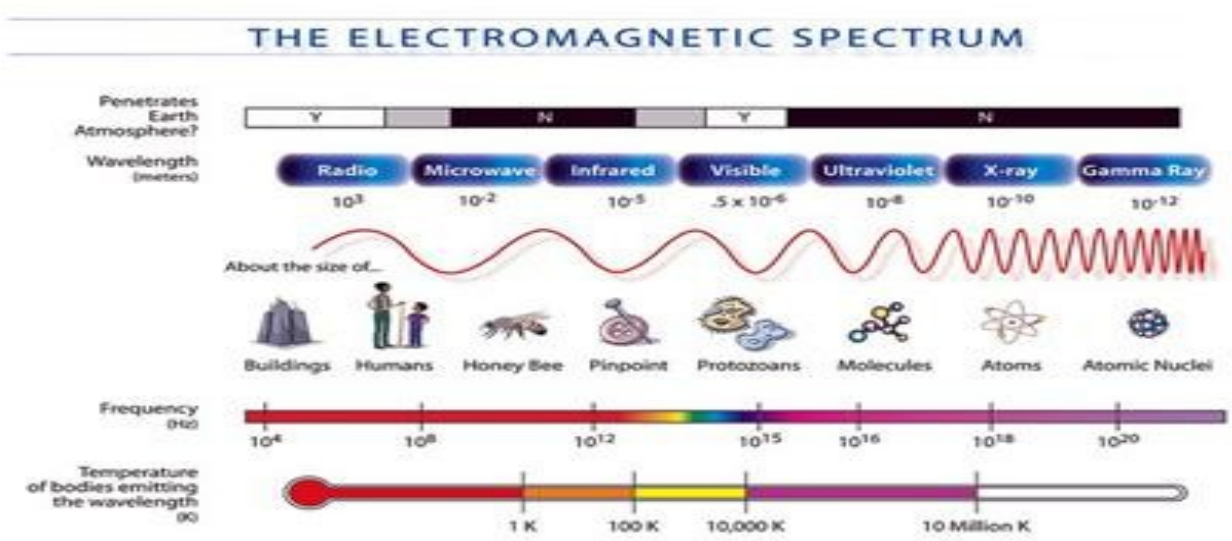
Ans:

Microwaves refer to the electromagnetic rays with frequencies between 300MHz and 300GHz in the electromagnetic spectrum. Microwaves are small when compared with the waves used in radio broadcasting. Their range is in between the radio waves and infrared waves. Microwaves travel in straight lines and they will be affected lightly by the troposphere. They don't require any medium to travel. Metals will reflect these waves totally. Non metals such as glass and particles are partially transparent to these waves.

Microwaves are suitable for wireless transmission of signals of having larger bandwidth. Microwaves are most commonly used in satellite communications, radar signals, phones, and navigational applications. Other applications where the microwaves used are medical treatments, drying materials, and in households for the preparation of food.

Practically a microwave technique tends to move away from the resistors, capacitors, and inductors used with lower-frequency radio waves. Instead, distributed and transmission-line theory are more useful methods for design and analysis. Instead of open-wire and coaxial lines used at lower frequencies, waveguides are using. And lumped elements and tuned circuits are replaced by cavity resonators or resonant lines. Even at higher frequencies, where the wavelength of the electromagnetic waves becomes small when compare to the size of the structures used to process them, microwave has become a latest technology, and the methods of optics are used. High-

power microwave sources use specialized vacuum tubes to generate microwaves.



Advantages:

1. It does not require any cable connection.
2. They can carry high quantities of information due to their high operating frequencies.
3. We can able to access more numbers of channels.
4. Low cost land purchase: each tower occupies small area.
5. High frequency/short wavelength signals require small antenna.

Disadvantages:

1. Attenuation by solid objects: birds, rain, snow and fog.
2. It's much expensive to build long towers.
3. Reflected from flat surfaces like water and metal.
4. Diffracted (split) around solid objects.
5. Refracted by atmosphere, thus causing beam to be projected away from receiver.

Microwave Bands:

Microwaves are found at the higher end of the radio spectrum, but they are commonly different with radio waves based on the technology using them. Microwaves are divided into sub-bands based on their wavelengths which are providing different information. The frequency bands of microwaves are as follows:

Band	Frequency Range (GHz)
L	1 to 2
S	2 to 4
C	4 to 8
X	8 to 10
Ku	12 to 18
K	18 to 26.5
Ka	26.5 to 40
Q	30 to 50
U	40 to 60
V	50 to 75
E	60 to 90 (millimeter waves)
W	75 to 110
F	90 to 140
D	110 to 170

L-Band:

L bands are having the frequency rage between 1 GHz to 2 GHz and their wavelength in free space is 15cm to 30cm. These ranges of waves are used in navigations, GSM mobile phones, and in military applications. They can be used to measure the soil moisture of rain forests.

S-Band:

S band microwaves are having the frequency range between 2 GHz to 4 GHz and their wavelength range is 7.5cm to 15 cm. These waves can be used in navigation beacons, optical communications, and wireless networks.

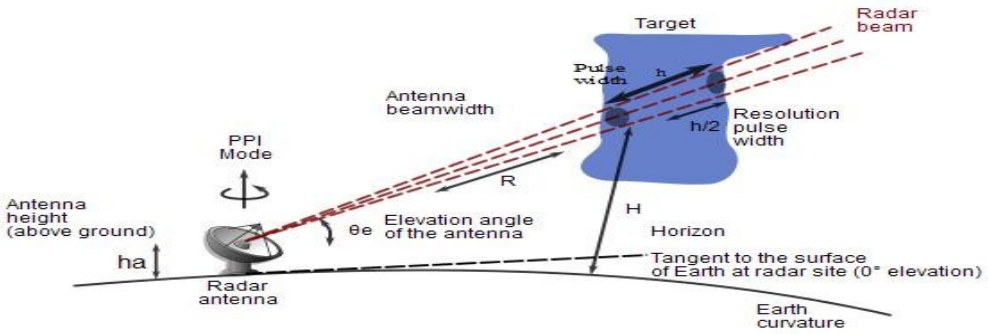
C-Band:

C band waves are having the range between 4 GHz to 8 GHz and their wavelength is in between 3.75 cm to 7.5 cm. C band microwaves penetrate clods, dust, smoke, snow, and rain to reveal the earth's surface. These microwaves can be used in long-distance radio telecommunications.

X-Band:

The frequency range for S-band microwaves is 8 GHz to 12 GHz having the wavelength in between 25 mm to 37.5 mm. These waves are used in satellite

communications, broadband communications, radars, space communications and amateur radio signals.



Ku-Band:



These waves are occupying the frequency range between 12 GHZ to 18 GHz and having the wavelength in between 16.7 mm to 25 mm. “Ku” refers to Quartz-under. These waves are used in satellite communications for measuring the changes in the energy of the microwave pulses and they can determine speed and direction of wind near costal areas.

K-Band and Ka-Band:

The frequency range for K band waves in between 18 GHz to 26.5 GHz. These waves are having the wavelength in between 11.3 mm to 16.7 mm. For Ka band the frequency range is 26.5 GHz to 40 GHz and they are occupying the wavelength in between 5 mm to 11.3 mm. These waves are used in satellite communications, astronomical observations, and radars. Radars in this frequency range provide short range, high resolution and high amount of data at the renewing rate.

V-Band:

This band stays for a high attenuation. Radar applications are limited for a short range of applications. The frequency range for these waves is 50 GHz to 75 GHz. The wavelength for these microwaves is in between 4.0 mm to 6.0 mm. There are some

more bands like U, E, W, F, D, and P having very high frequencies which are used in several applications.

Propagation of TM waves in Rectangular Waveguides:-

For a TM wave $H_z = 0$, $E_z \neq 0$

2. Derive TE_{mn} mode field equation in Rectangular Waveguide.

The wave equation of a TM wave is

$$\frac{\partial^2 E_z}{\partial x^2} + \frac{\partial^2 E_z}{\partial y^2} + h^2 E_z = 0 \quad \text{---(1)}$$

Let us assume $E_z = XY$

X is a function of 'x' & Y is a function of 'y'

X & Y are independent variables

$$\frac{\partial^2 E_z}{\partial x^2} = \frac{\partial^2 (XY)}{\partial x^2} = Y \frac{\partial^2 X}{\partial x^2}$$

$$\frac{\partial^2 E_z}{\partial y^2} = \frac{\partial^2 (XY)}{\partial y^2} = X \frac{\partial^2 Y}{\partial y^2}$$

Now

$$(1) \Rightarrow \quad Y \frac{\partial^2 X}{\partial x^2} + X \frac{\partial^2 Y}{\partial y^2} + h^2 XY = 0$$

$$\frac{1}{X} \frac{\partial^2 X}{\partial x^2} + \frac{1}{Y} \frac{\partial^2 Y}{\partial y^2} + h^2 = 0$$

Let $\frac{1}{X} \frac{\partial^2 X}{\partial x^2} = -B^2$ ---(2) $\quad \frac{1}{Y} \frac{\partial^2 Y}{\partial y^2} = -A^2$ ---(3)

$$-B^2 - A^2 + h^2 = 0 \Rightarrow h^2 = A^2 + B^2$$

Equations (2) & (3) are 2nd order differential equations, the solutions are

$$X = C_1 \cos Bx + C_2 \sin Bx$$

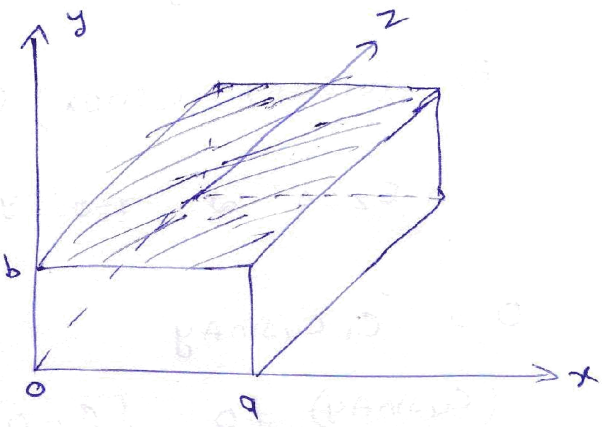
$$Y = C_3 \cos Ay + C_4 \sin Ay$$

C_1, C_2, C_3, C_4 are constants can be calculated by using boundary conditions.

The Complete Solution is $E_z = XY$

$$E_z = (C_1 \cos Bx + C_2 \sin Bx)(C_3 \cos Ay + C_4 \sin Ay) \quad \text{---(4)}$$

Boundary conditions:- The entire surface of a rectangular waveguide acts as a short circuit (or) ground for electric field, $E_z = 0$ all along the boundary walls of the waveguide



1st boundary condition:-

Bottom Plane (or) wall

we know $E_z = 0$, all along the bottom wall

that is $E_z = 0$ at $y = 0$ $\forall$ $x \to 0$ to a.

2nd boundary condition:

Left side Plane (or) wall

$E_z = 0$ at $x = 0$ $\forall$ $y \to 0$ to b.

3rd boundary condition:- TOP Plane (or) wall

$E_z = 0$ at $y = b$ $\forall$ $x \to 0$ to a

4th boundary condition:- Right side plane (or) wall

$E_z = 0$ at $x = a$ $\forall$ $y \to 0$ to b.

Substituting 1st boundary in eqn (4) then

$$E_z = (C_1 \cos Bx + C_2 \sin Bx)(C_3 \cos Ay + C_4 \sin Ay)$$

$E_z = 0$ at $y = 0$ $\forall$ $x \to 0$ to a

$$0 = (C_1 \cos Bx + C_2 \sin Bx)(C_3 \cos 0 + C_4 \sin 0)$$

$$0 = C_3 (C_1 \cos Bx + C_2 \sin Bx)$$

$x \to 0$ to a so $(C_1 \cos Bx + C_2 \sin Bx) \neq 0$

then $\boxed{C_3 = 0}$

Now

$$E_z = (C_1 \cos Bx + C_2 \sin Bx)(C_4 \sin Ay) \quad \text{— (5)}$$

Now apply ②nd boundary in eqn ⑤ then

$$E_z = (C_1 \cos Bx + C_2 \sin Bx)(C_4 \sin Ay)$$

$E_z = 0$ at $x = 0$ $y \to 0$ to b

$$0 = C_1 C_4 \sin Ay$$

$(C_4 \sin Ay) \neq 0$, $\boxed{C_1 = 0}$

Now

$$E_z = C_2 C_4 \sin Bx \sin Ay \quad \text{—— ⑥}$$

Sub ③rd condition in ⑥ then

$E_z = 0$, at $y = b$ $\forall$ $x \to 0$ to a

⑥ $\Rightarrow$ $0 = C_2 C_4 \sin Bx \sin Ab$

$\sin Bx \neq 0$, $C_4 \neq 0$, $C_2 \neq 0$ $\sin Ab = 0$

$\sin Ab = 0$

$Ab =$ a multiple of π

$Ab = n\pi$

$$\boxed{A = \frac{n\pi}{b}}$$

Sub ④th condition in eqn ⑥

$E_z = 0$ at $x = a$, $\forall$ $y \to 0$ to b

⑥ $\Rightarrow$ $0 = C_2 C_4 \sin Ba \sin Ay$

$C_2 \neq 0$, $C_4 \neq 0$ $\sin Ay \neq 0$

$\sin Ba = 0$

$Ba = n\pi$

$$\boxed{B = \frac{n\pi}{a}}$$

The Complete Solution using eqn (6) is

$$E_z = C_2 C_4 \sin\beta x \sin Ay$$

$$E_z = C_2 C_4 \sin\left(\frac{m\pi}{a}\right) x \sin\left(\frac{n\pi}{b}\right) y \quad e^{-\gamma z} e^{j\omega t}.$$

$e^{-\gamma z}$ = Propagation along z-direction.

$e^{j\omega t}$ = Sinusoidal Variation w.r.t 't'.

Let $C = C_2 C_4$

$$E_z = C \sin\left(\frac{m\pi}{a}\right) x \sin\left(\frac{n\pi}{b}\right) y \; e^{j\omega t - \gamma z}$$

we know

$$\vec{E_x} = \frac{-\gamma}{h^2} \frac{\partial \vec{E_z}}{\partial x} - \frac{j\omega\mu}{h^2} \frac{\partial \vec{H_z}}{\partial y}$$

FOR TM wave $\vec{H_z} = 0$

$$\vec{E_x} = \frac{-\gamma}{h^2} \frac{\partial \vec{E_z}}{\partial x}$$

$$= \frac{-\gamma}{h^2} C \frac{\partial}{\partial x} \left(\sin\left(\frac{m\pi}{a}\right) x \sin\left(\frac{n\pi}{b}\right) y\right) e^{j\omega t - \beta z}$$

$$\boxed{\vec{E_x} = \frac{-\gamma}{h^2} C \left(\frac{m\pi}{a}\right) \cos\left(\frac{m\pi}{a}\right) x \sin\left(\frac{n\pi}{b}\right) y \; e^{j\omega t - \gamma z}}$$

$$\vec{E_y} = \frac{-\gamma}{h^2} \frac{\partial \vec{E_z}}{\partial y} + \frac{j\omega\mu}{h^2} \frac{\partial \vec{H_z}}{\partial x} = \frac{-\gamma}{h^2} \frac{\partial \vec{E_z}}{\partial y}$$

$$\boxed{\vec{E_y} = \frac{-\gamma}{h^2} C \left(\frac{n\pi}{b}\right) \sin\left(\frac{m\pi}{a}\right) x \cos\left(\frac{n\pi}{b}\right) y \; e^{j\omega t - \gamma z}}$$

$$\vec{H_x} = \frac{-\gamma}{h^2} \frac{\partial H_z}{\partial x} + \frac{j\omega\varepsilon}{h^2} \frac{\partial \vec{E_z}}{\partial y} = \frac{j\omega\varepsilon}{h^2} \frac{\partial \vec{E_z}}{\partial y}$$

$$\vec{H_x} = \frac{j\omega\varepsilon}{h^2} c\left(\frac{n\pi}{b}\right) \sin\left(\frac{m\pi}{a}\right)x \cos\left(\frac{n\pi}{b}\right)y \; e^{j\omega t - \gamma z}$$

$$\vec{H_y} = \frac{-\gamma}{h^2} \frac{\partial \vec{H_z}}{\partial y} + \frac{j\omega\varepsilon}{h^2} \frac{\partial \vec{E_z}}{\partial x}$$

(10)

Propagation of TE waves in Rectangular Waveguides: The TEmn modes in rectangular waveguides can be characterized by $H_z = e^{j\omega t - \gamma z}$

$$\nabla^2 H_z = -\omega^2 \mu\varepsilon H_z$$

TM modes: $\frac{\partial^2 H_z}{\partial x^2} + \frac{\partial^2 H_z}{\partial y^2} + \frac{\partial^2 H_z}{\partial z^2}$ rectangular waveguides: $\left\{\because \frac{\partial^2}{\partial z^2} = \gamma^2\right\}$

Depending on $\frac{\partial^2 H_z}{\partial x^2} + \frac{\partial^2 H_z}{\partial y^2} + h^2 H_z = 0$ values of m and n we have various modes in TM waves.

Various TM$_{mn}$ modes $\frac{\partial^2 H_z}{\partial x^2} + \frac{\partial^2 H_z}{\partial y^2} + h^2 H_z = 0$

Assume a solution $H_z = XY$

① TM$_{00}$ mode :- $m=0$ & $n=0$

$Y\frac{\partial^2 X}{\partial x^2} + X\frac{\partial^2 Y}{\partial y^2} + h^2 XY = 0$

If $m=0$, $n=0$ are substituted in E_x, E_y, H_x, H_y all will become

so TM$_{00}$ mode $\frac{1}{X}\frac{\partial^2 X}{\partial x^2} + \frac{1}{Y}\frac{\partial^2 Y}{\partial y^2}$ not h^2 exist.

② Let TM$_{01}$: $\frac{1}{X}\frac{\partial^2 X}{\partial x^2} = -B^2$ & $\frac{1}{Y}\frac{\partial^2 Y}{\partial y^2} = -A^2$

$E_x = 0$, $E_y = 0$, $H_x = 0$, $H_y = 0$ so TM$_{01}$ also

Gn't $-B^2 - A^2 + h^2 = 0$

③ TM$_{10}$: $h^2 = A^2 + B^2$

Solving for $m=1$ & $n=0$ by separation of variable method

④ TM$_{11}$:- $X = C_1 \cos Bx + C_2 \sin Bx$ $m=1, n=1$

$Y = C_3 \cos Ay + C_4 \sin Ay$

H_z M$_{11}$ XY exists and for all higher values of m and n.

$H_z = (C_1 \cos Bx + C_2 \sin Bx)(C_3 \cos Ay + C_4 \sin Ay)$ ——— (A)

Components exist.

C_1, C_2, C_3, C_4 are constants which can be evaluated by applying boundary conditions all higher order modes exist.

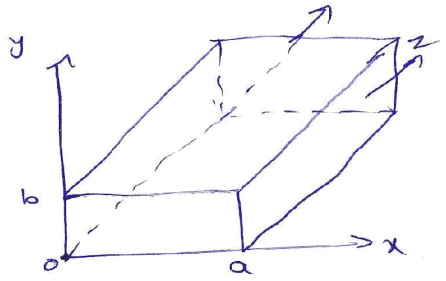
3. Derive TE$_{mn}$ mode field equation in Rectangular Waveguide.

Boundary conditions :- For TE waves also we have four boundary conditions. For TE waves $E_z = 0$ but we have components along x & y

directions

$E_x = 0$ all along bottom and top walls of the waveguide.

$E_y = 0$ all along left and right walls of the waveguide.



① $E_x = 0$ at $y = 0$ $\forall$ $x \to 0$ to a (bottom wall)

② $E_x = 0$ at $y = b$ $\forall$ $x \to 0$ to a (top wall)

③ $E_y = 0$ at $x = 0$ $\forall$ $y \to 0$ to b (left side wall)

④ $E_y = 0$ at $x = a$ $\forall$ $y \to 0$ to b (Right wall).

Apply ① in eqn Ⓐ then

we know $\vec{E_x} = \frac{-j\omega\mu}{h^2}\frac{\partial H_z}{\partial y} - \frac{\gamma^2}{h^2}\frac{\partial E_z}{\partial x}$

Since $E_z = 0$

$$\vec{E_x} = \frac{-j\omega\mu}{h^2}\frac{\partial}{\partial y}\left[(C_1\cos Bx + C_2\sin Bx)(C_3\sin Ay + C_4\cos Ay)\right]$$

$$\vec{E_x} = \frac{-j\omega\mu}{h^2}(C_1\cos Bx + C_2\sin Bx)(-AC_3\sin Ay + AC_4\cos Ay)$$

Now substitute ① boundary

$$0 = \frac{-j\omega\mu}{h^2}(C_1\cos Bx + C_2\sin Bx)(AC_4)$$

$(C_1\cos Bx + C_2\sin Bx) \neq 0$ $\quad A \neq 0$ $\quad \boxed{C_4 = 0}$

$$H_z = (C_1\cos Bx + C_2\sin Bx)(C_3\cos Ay)$$

we know $E_y = \frac{-\gamma}{h^2}\frac{\partial E_z}{\partial y} + \frac{j\omega\mu}{h^2}\frac{\partial H_z}{\partial x}$

$E_z = 0$

$$E_y = \frac{j\omega\mu}{h^2}\frac{\partial H_z}{\partial x} = \frac{j\omega\mu}{h^2}\frac{\partial}{\partial x}(C_1\cos Bx + C_2\sin Bx)(C_3\cos Ay)$$

$$E_y = \frac{j\omega\mu}{h^2}\left(-BC_1\sin Bx + BC_2\cos Bx\right) C_3\cos Ay$$

Substitute 3rd boundary $E_y = 0$ at $x = 0$

$$0 = \frac{j\omega\mu}{h^2}\left(BC_2\cos Bx\right) C_3\cos Ay$$

$\cos Ay \neq 0$, $B \neq 0$ $C_3 \neq 0$

$$\boxed{C_2 = 0}$$

$$H_z = C_1 C_3 \cos Bx \cos Ay$$

we know $E_x = -\frac{\gamma}{h^2}\frac{\partial E_z}{\partial x} - \frac{j\omega\mu}{h^2}\frac{\partial H_z}{\partial y}$

$E_z = 0$

$$E_x = -\frac{j\omega\mu}{h^2}\frac{\partial}{\partial y}\left(C_1 C_3 \cos Bx \cos Ay\right)$$

$$E_x = \frac{j\omega\mu}{h^2} C_1 C_3 A \cos Bx \sin Ay$$

Substitute 2nd boundary $E_x = 0$ at $y = b$

$$0 = \frac{j\omega\mu}{h^2} C_1 C_3 A \cos Bx \sin Ab$$

$\cos Bx \neq 0$, $C_1 \neq 0$, $C_3 \neq 0$

$\sin Ab = 0 \Rightarrow Ab = n\pi \Rightarrow A = \frac{n\pi}{b}$

we know

$$E_y = -\frac{\gamma}{h^2}\frac{\partial E_z}{\partial y} + \frac{j\omega\mu}{h^2}\frac{\partial H_z}{\partial x}$$

$E_z = 0$

$$E_y = \frac{j\omega\mu}{h^2}\frac{\partial H_z}{\partial x}$$

$$E_y = \frac{j\omega\mu}{h^2}\frac{\partial}{\partial x}(C_1C_3 \cos Bx \cos Ay)$$

$$E_y = -\frac{j\omega\mu}{h^2} C_1C_3 B \sin Bx \cos Ay$$

Substitute (4)th boundary

$$0 = -\frac{j\omega\mu}{h^2} C_1C_3 B \sin Ba \cos Ay$$

$$C_1 \neq 0,\ C_3 \neq 0 \quad \cos Ay \neq 0$$

$$\sin Ba = 0$$

$$Ba = m\pi$$

$$B = \frac{m\pi}{a}$$

$$H_z = C_1C_3 \cos Bx \cos Ay$$

$$H_z = C_1C_3 \cos\left(\frac{m\pi}{a}\right)x \cos\left(\frac{n\pi}{b}\right)y$$

$$C_1C_3 = C = \text{constant}$$

$$\boxed{H_z = C \cos\left(\frac{m\pi}{a}\right)x \cos\left(\frac{n\pi}{b}\right)y\, e^{(j\omega t - \gamma z)}}$$

Field Components

$$E_x = -\frac{\gamma}{h^2}\frac{\partial E_z}{\partial x} - \frac{j\omega\mu}{h^2}\frac{\partial H_z}{\partial y}$$

$$E_x = -\frac{j\omega\mu}{h^2}\frac{\partial}{\partial y}\left(C \cos\left(\frac{m\pi}{a}\right)x \cos\left(\frac{n\pi}{b}\right)y\, e^{j\omega t - \gamma z}\right)$$

$$\boxed{E_x = \frac{j\omega\mu}{h^2} C \cdot \left(\frac{n\pi}{b}\right) \cos\left(\frac{m\pi}{a}\right)x \cos\left(\frac{n\pi}{b}\right)y\, e^{(j\omega t - \gamma z)}}$$

$$E_y = -\frac{\gamma}{h^2}\frac{\partial E_z}{\partial y} - \frac{j\omega\mu}{h^2}\frac{\partial H_z}{\partial x}$$

$$E_y = -\frac{j\omega\mu}{h^2} C\left(\frac{m\pi}{a}\right) \sin\left(\frac{m\pi}{a}\right)x \cos\left(\frac{n\pi}{b}\right)y \, e^{j\omega t - \gamma z}$$

By $H_x = \frac{\gamma}{h^2} C\left(\frac{m\pi}{a}\right) \sin\left(\frac{m\pi}{a}\right)x \cos\left(\frac{n\pi}{b}\right)y \, e^{j\omega t - \gamma z}$

$$H_y = -\frac{\gamma}{h^2} C\left(\frac{n\pi}{b}\right) \cos\left(\frac{m\pi}{a}\right)x \sin\left(\frac{n\pi}{b}\right)y \, e^{j\omega t - \gamma z}$$

TE modes in Rectangular waveguide :-

(a) TE_{00} mode :- $m=0, n=0$

$E_x=0, E_y=0, H_x=0, H_y=0$

All field components which this mode don't exist.

(b) TE_{01} mode :- $m=0, n=1$

$E_y=0, H_x=0$ E_x & H_y exist.

(c) TE_{10} mode $m=1, n=0$

$E_x=0, H_y=0$, E_y & H_x exist.

(d) TE_{11} mode :- $m=1, n=1$

This also exist.

4. **What are dominant and degenerate modes? What is the significance of dominant modes? Indicate the dominant mode in Rectangular waveguide and calculate f_c for the same.**

Ans:

Dominant Mode: The mode having the lowest cutoff frequency is called dominant mode. The dominant mode for parallel plate waveguide is TEM**.**

Significance of Dominant mode It is useful in finding the lowest cutoff frequency for any waveguide.

Degenerative mode

TE_{10} and TE_{01} modes are degenerate modes (**modes with same cut off frequency**) for square wave guide. The rectangular waveguide allows one to operate at a frequency above the cutoff of the dominant TE_{10} mode but below that of the next highest mode to achieve single mode operation.

A waveguide operating at a frequency where more than one mode propagates is said to be ***overmoded***

Dominant TE and TM mode in rectangular waveguides are **TE_{10}** and **TM_{11}** respectively.

TE_{10} mode is the dominant mode in rectangular waveguide, its E field is polarized
in one direction and it has the lowest attenuation of all modes in rectangular waveguide.

$$f_c = \frac{1}{2\sqrt{\varepsilon\mu}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}\ (Hz)$$

The cutoff frequency for the dominant mode of a Rectangular Waveguide is m= 0 and n=1 then

$$f_c = \frac{c}{2a}$$

5. Define TEM wave. Why is TEM mode not supported by waveguide?

(or)

State the characteristics of TEM waves.

The TEM wave in which both electric and magnetic fields are tranverse entirely but have no component of Ez and Hz.(Hz& Ez= 0). It is referred to as principal waves. The properties are

1. The TEM wave is independent of frequency

2.The cut-off frequency of TEM is zero ($f_c = 0$) .This means that all frequencies down to zero can propagate.

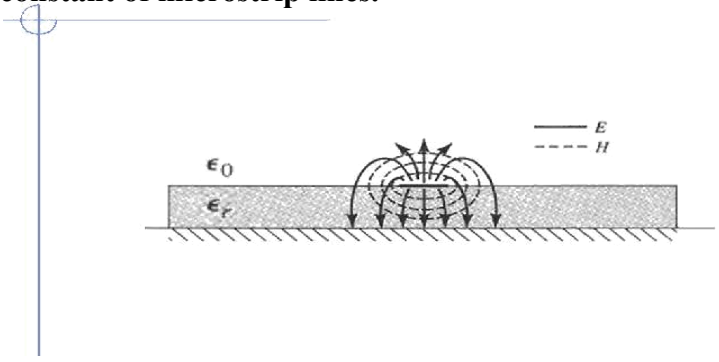
According to Maxwell's equation $\nabla \times \mathbf{H} = \mathbf{J} + \partial \mathbf{D} / \partial t$. To have H lines there must be an axial current in the inner conductor. In a Hallow waveguide, no inner conductor. Also electric field E should be axial direction. But E_{axial} is not present in TEM waves. Hence TEM wave cannot exist in waveguide.

6. Explain the wave impedance of a rectangular waveguide and derive the expression for it of TE and TM modes.

Ans: Wave impedance is the ratio of transverse components of Electric to Magnetic field Strength. Wave impedance: The intrinsic impedance or wave impedance is defined as when looking in the direction of propagation, that is, along the z axis .It is defined as the ratio of transverse component of electric and magnetic fields.

$$\eta 0 = E/H$$

7. Derive the expression for the characteristic impedance and effective dielectric constant of microstrip lines.



For thin conductors (i.e., $t \rightarrow 0$), closed-form expression (error ≤ 1 %):

W/h ≤ 1:

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left\{\left(1 + 12\frac{h}{W}\right)^{-0.5} + 0.04\left(1 - \frac{W}{h}\right)^2\right\}$$

$$Z_c = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}} \ln\left(\frac{8h}{W} + 0.25\frac{W}{h}\right)$$

For thin conductors (i.e., t → 0), more accurate expressions:

Effective dielectric constant (error ≤ 0.2 %):

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10}{u}\right)^{-ab}$$

$$a = 1 + \frac{1}{49}\ln\left(\frac{u^4 + \left(\frac{u}{52}\right)^2}{u^4 + 0.432}\right) + \frac{1}{18.7}\ln\left[1 + \left(\frac{u}{18.1}\right)^3\right]$$

For thin conductors (i.e., t → 0), closed-form expression (error ≤ 1 %):

W/h ≤ 1:

$$\varepsilon_{re} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + 12\frac{h}{W}\right)^{-0.5}$$

$$Z_c = \frac{\eta}{\sqrt{\varepsilon_{re}}}\left\{\frac{W}{h} + 1.393 + 0.677\ln\left(\frac{W}{h} + 1.444\right)\right\}^{-1}$$

For thin conductors (i.e., $t \rightarrow 0$), more accurate expressions:

Characteristic impedance (error ≤ 0.03 %):

$$Z_c = \frac{\eta}{2\pi\sqrt{\varepsilon_{re}}} \ln\left[\frac{F}{u} + \sqrt{1+\left(\frac{2}{u}\right)^2}\right]$$

$$F = 6 + (2\pi - 6)\exp\left[-\left(\frac{30.666}{u}\right)^{0.7528}\right]$$

8. A wave is propagated in the dominant mode in a parallel plane waveguide. The frequency is 6 GHz and the plane separation is 4 Cm. Calculate the cutoff wavelength and the wavelength in the waveguide. [May/June,2014]

Given:

f = 6 G Hz

a = 4 cm= $4x10^{-2}$ m c = $3x10^8$ m/s

consider dominant mode TE_{10} where m=1 n=0

$f_c = mc/2a$

$= 3x10^8 /2 \times 4x10^{-2}$

$=$ 3.75 G Hz

$\lambda_c = C/ f_c = 3x10^8/3.75x10^9 =$ **0.08 m**

(or) λ_c **=2a/m =0.08m**

9. **A wave is propagated in a parallel plane wave guide. The frequency is 6 G Hz and the plane separation is 3 cm. Determine the group and phase velocities for the dominant mode. [Nov/Dec,2013] [Nov-2010,R8]**

UNIT-2.

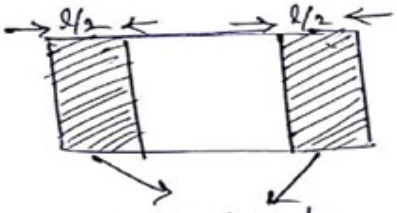
LONG ANSWER QUESTIONS

1. **Explain about Waveguide Windows.**

impedance matching in the waveguides. Three types (2)
of windows are available.

1) Inductive window
2) Capacitive window
3) Resonant windows.

→ 1) Inductive windows:-



Projection from side walls of guide.

* An inductive window allows the current flow where non-flown before.

* Conducting diaphragm extending in a waveguide from side walls. have the effect of adding an inductive susceptance across the waveguide at the point at which diaphragms are placed.

* These diaphragms ~~are~~ has to be placed in a position where magnetic field is strong and electric field is relatively weak.

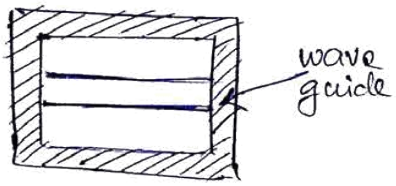
* The electric field that advanced before now has a conducting surface in its plane, which permits current flow.

* Thus some energy is stored in the magnetic field which leads to an increased inductance at that point of the waveguide.

→ 2) Capacitive windows:-

Conducting diaphragms extending in a waveguide from top and bottom walls have the effect

of adding a capacitive susceptance across the waveguide at the point at which diaphragms are placed.



capacitive windows.

* In capacitive fan's a potential which had existed earlier between the top and bottom walls of waveguide now exists between surfaces that are closer. This results in an increased capacitance at that points.

⇒3) Resonant windows:-

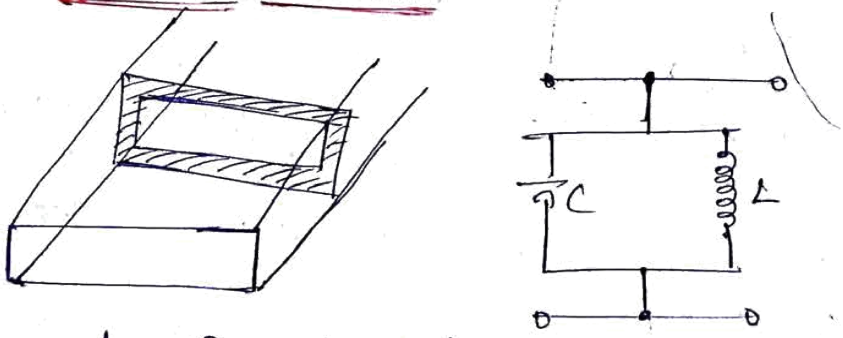


fig:- Resonant window.

* A conducting diaphragm of the form shown in figure gives the effect of a parallel tuned circuit connected across the guide at point where diaphragm is placed.

A resonant window may be considered as a combination of an inductive and capacitive window; at the same point in the waveguide.

If the inner dimensions of aperture are properly chosen, the frequency range covered is large

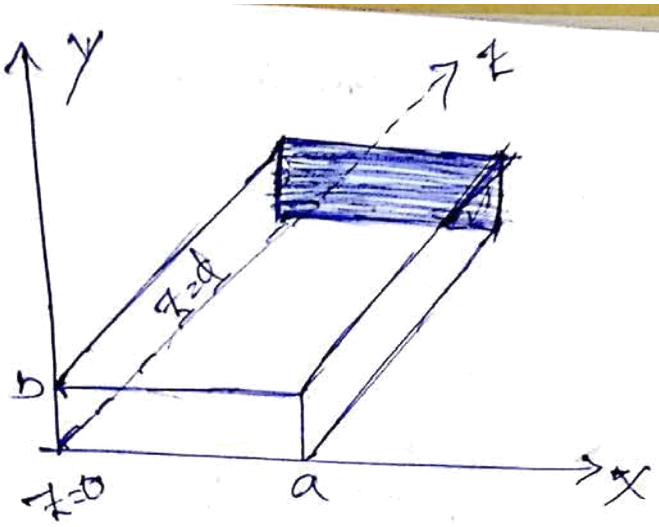
However a limit of minimum aperture size prevents any further changes.

2. What is meant by a Cavity Resonator? Derive the expression for the resonant frequency of the rectangular cavity resonator.

Rectangular Cavity Resonator:-

* The electromagnetic field inside the cavity should satisfy Maxwell's equations, subject to the boundary conditions that the electric field tangential to and the magnetic field normal to the metal walls must vanish. The geometry of a rectangular cavity is given in fig(b).

* A rectangular ~~wave~~ cavity resonator may be viewed as a rectangular waveguide shorted at both ends. The cavity is resonant at frequencies, where "d" is a multiple of $\lambda_g/2$, λ_g being the guide wavelength for propagation along the z-axis. To verify this, consider the rectangular guide to be shorted at $z = d$ but not at $z = 0$ as shown in figure.



* A signal entering at $z=0$ produces a standing wave pattern. Because of short, the transverse electric field (E_x and E_y) is zero at $z=d$ and at multiples of a half wavelength along the z axis.

* At certain frequencies an electric field null occurs at $z=0$. Two such cases are shown in the figure below.

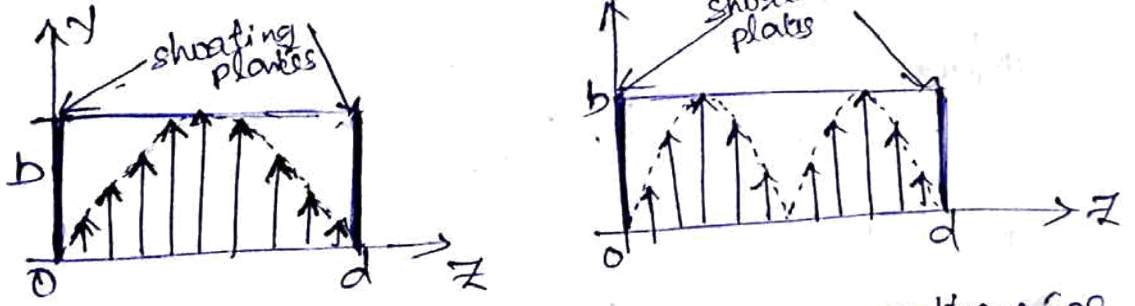


fig.(c): Electric field standing wave patterns for a shorted Rectangular wave guide.

* Since the transverse electric field is zero at $z=0$ plane, the introduction of a shorting plate at that point i.e., at $z=0$ (as shown in fig(b)) does not disturb the standing wave pattern. Thus at selected frequencies, the electromagnetic field within

the cavity can be sustained even in the absence of a signal source.

* The resonant condition is therefore given by.

* $\boxed{d = P\frac{\lambda g}{2}}$.

* where P is a positive integer.

* Expression for "f_0" in a Rectangular waveguide cavity resonator :-

* For a rectangular waveguide.

$$\boxed{k^2 = \gamma^2 + \omega^2\mu\varepsilon} \quad -(1) \text{ and.}$$

$$\boxed{k^2 = A^2 + B^2} \quad -(2)$$

$$\Rightarrow \boxed{k^2 = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2} \quad -(3)$$

* from (1) and (3)

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

* for wave propagation

$$\boxed{\gamma = j\beta}.$$

$$\Rightarrow \gamma^2 = j^2\beta^2 = -\beta^2$$

$$\Rightarrow \boxed{\omega^2\mu\varepsilon = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \beta^2} \quad -(4)$$

* If a wave has to exist in a cavity resonator there must be a phase change corresponding to a given wavelength. $\boxed{\beta = 2\pi/\lambda g}$. The condition for the resonator to resonate is $\boxed{d = P\frac{\lambda g}{2}}$.

$$\Rightarrow d = \frac{2\pi}{2\beta} p \Rightarrow d = p\frac{\pi}{\beta} \Rightarrow \boxed{\beta = \frac{p\pi}{d}} \quad -(5)$$

* By substituting eq'n (5) in eq'n (4), we get

$$\omega_0^2 \mu\varepsilon = \left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 + \left(\frac{p\pi}{d}\right)^2$$

$$\therefore \boxed{f_0 = \frac{c}{2}\left[\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{p}{d}\right)^2\right]^{1/2}}$$

* General modes of propagation in a cavity resonator is TE_{mnp} (or) TM_{mnp}

* Where:

- $m = 0, 1, 2, 3$ ---- represents the no. of half-wave variation in the x-direction
- $n = 0, 1, 2, 3$ ---- represents the no. of half-wave variation in the y-direction
- $p = 0, 1, 2, 3$ ---- represents half wave variations in the z-direction
- a = wider dimensions (length along x-axis i.e., breadth)
- b = narrow dimension (length along y-axis i.e. width)
- d = resonator length (length along z-axis i.e., length)

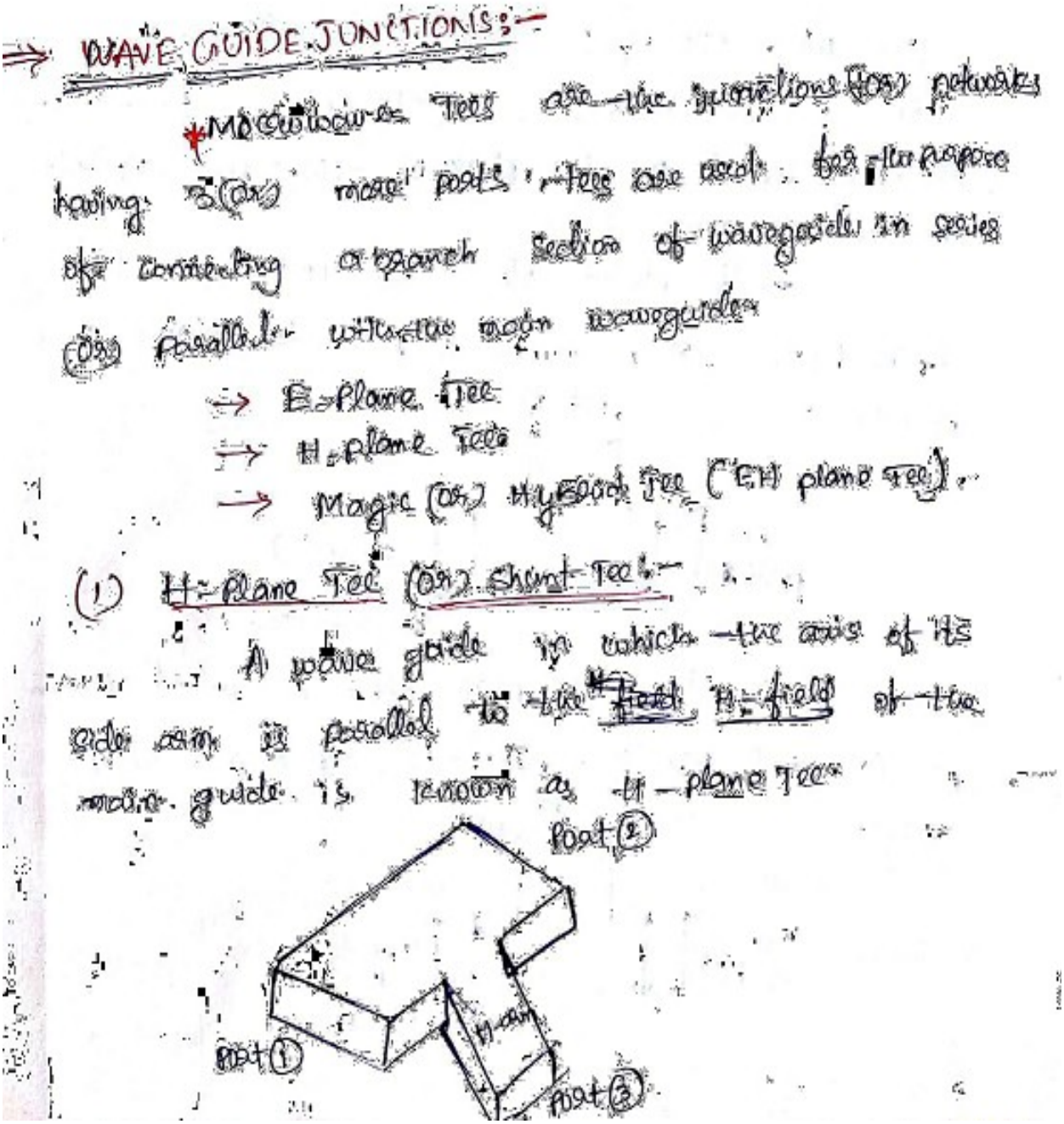
→ a) Dominant Mode:-

* The mode having the lowest resonant fq is called "dominant mode". The dominant modes of a rectangular cavity resonator are.

$\boxed{TE_{101}}$ and $\boxed{TM_{111}}$.

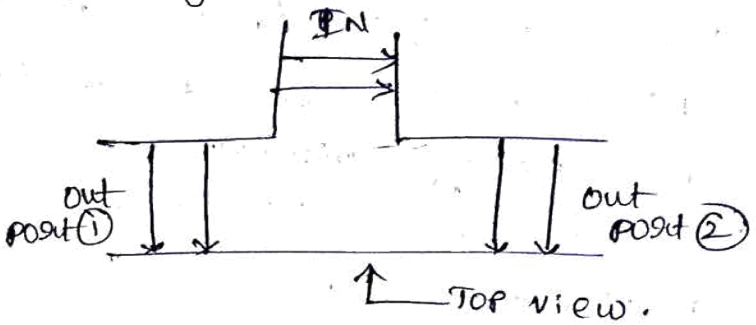
→ Degenerate Mode:- The modes having same resonant frequency are said to be "degenerate mode".

3. Explain the properties of microwave junctions.



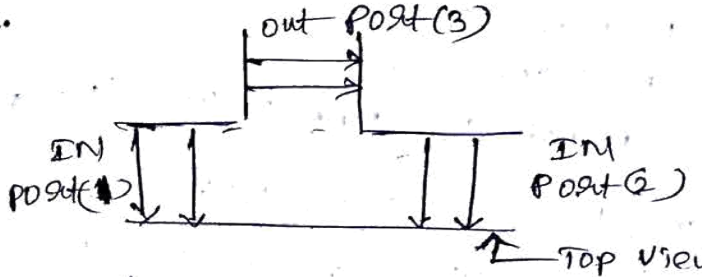
Properties :—

(i) When the i/p is applied at the side arm i.e, at the port (3), the o/p's are obtained from the collinear arms i.e., port (1) and port (2). and are equal magnitude and phase.

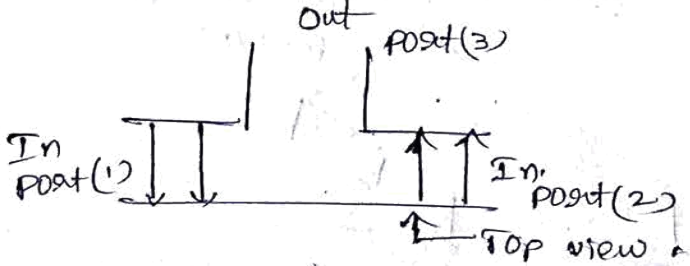


(ii) When the i/p is applied at collinear arms i.e, at port (1) & (2), the o/p obtained from the side arm depends on the phase of the inputs applied at collinear arms i.e,

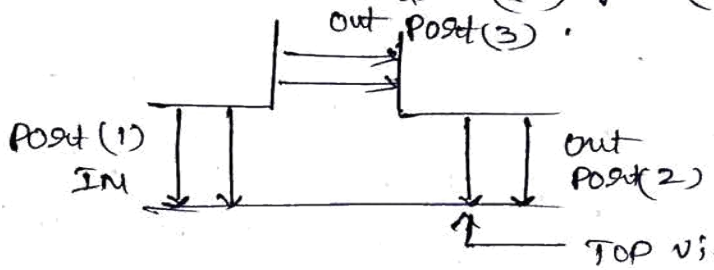
→ If phased i/p's are applied at port (1) & port (2) then maximum power is obtained at port (3).



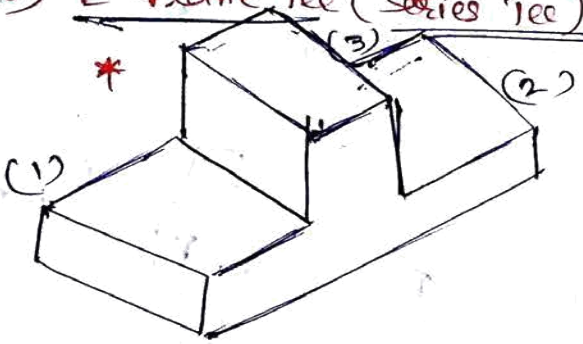
→ If a 180° phase shift is applied between port (1) and port (2), then the o/p at port (3) is zero.



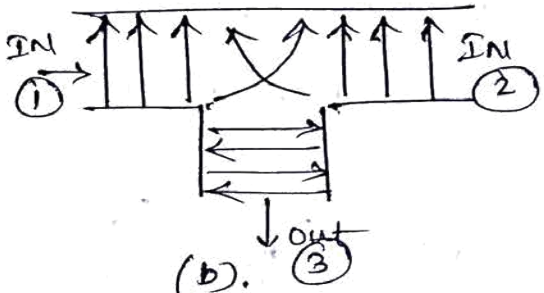
(iii) when the I/P is applied at one of collinear arms i.e., port(1) (or) port(2), the respective o/p's are obtained at port(3) (or) port(1) and side arm.



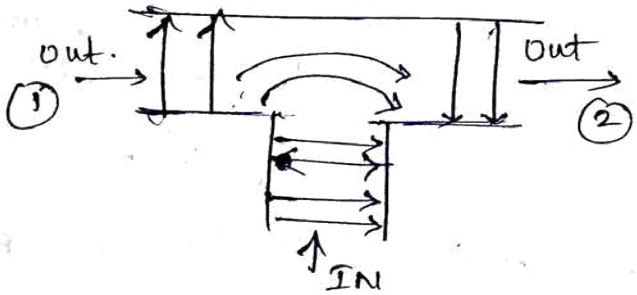
⇒ 2) E-plane Tee (Series Tee):-



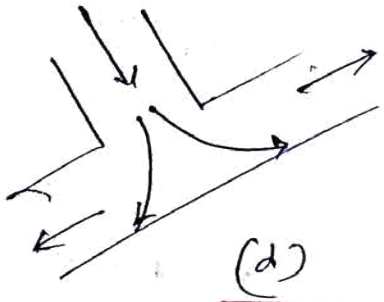
(a)



(b).



(c)(3)



(d)

* If the input arm of tee comes from broadwall then the junctions is called an "E-plane tee."

* E plane tee is a voltage (or) series junction symmetric about the centre arm. so the signal to be split up is fed to it.

* The waves entering the junction from side arm split up and leaves the main arm with equal magnitude and but of opposite phase as shown in fig (b).

* Similarly, the wave entering the junction from main arm leaves the side arm, the resulting field being proportional to the difference between instantaneous field entered the junctions from opposite directions as shown in fig (b) and (c).

⇒ Hybrid Junction (or) Magic Tee :—

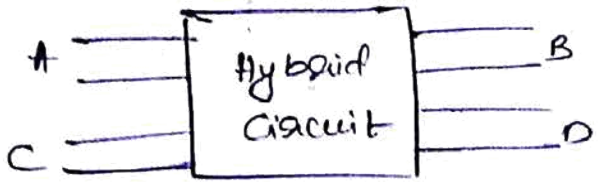


fig (a)

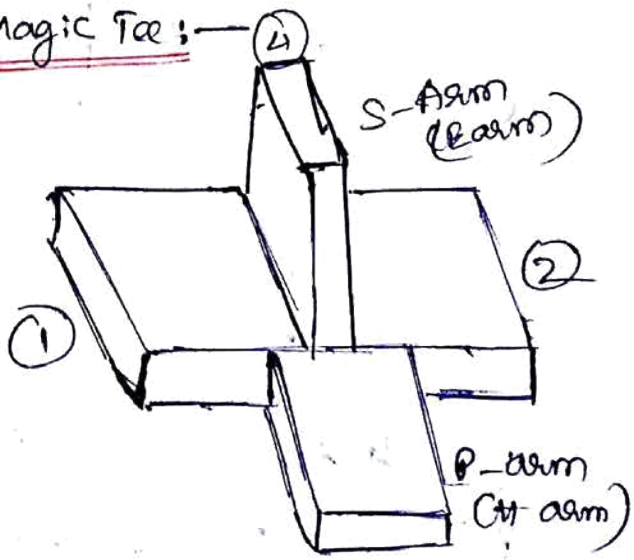


fig (b).

* A magic tee is a combination of E-plane tee and H-plane tee. It acts as a 4-port circuit as shown in fig a. If power enters through arms A and C, then the power is delivered entirely to arms B and D. with no power transmission from port A and C and vice versa.

* Similarly, power entering B (or) D is delivered entirely to arms A (or) C, with no power transmission

→ Operation of Magic Tee:-

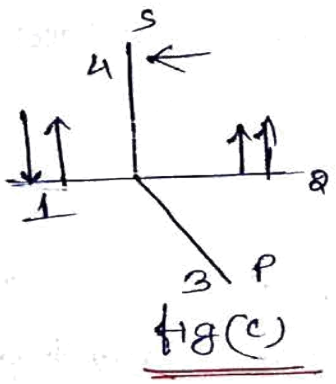
* H field in parallel arm 'P' is normal to 'E'-field in series arm
* There is no different direct transmission between series and parallel arms.
* When waves of equal amplitude and phase enter 'P' and 'S' arms the E-fields cancel in one of the side arms and add in the other as shown in fig(b).
* The energy applied to 'P' (or) 'S' arm is divided equally between 1 and 2 arms $1/\sqrt{2}$ as shown in figure (c) and (d)

⇒ Effects of reflections:-

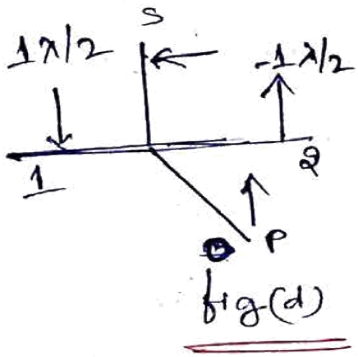
*Power will not divide equally between side arms 1 and 2. when power enters through S (or) P.

*Imbalance exists between arms 1 and 2

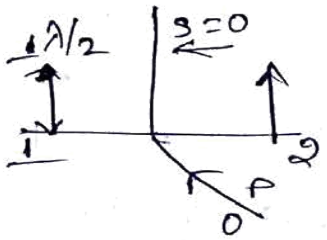
*Reflections must be avoided (or) compensated.



fig(c)



fig(d)



fig(e)

→ Applications of Magic Tee:-

→ As an isolator

→ As a matching device

4. Explain Directional Coupler .Explain about types of it.

Directional Coupler :-

* A directional coupler is a useful microwave guide joint which couples power in an auxiliary wave guide arm in one direction.

* It is a 4 port device but one of the port is terminated into a matched load.

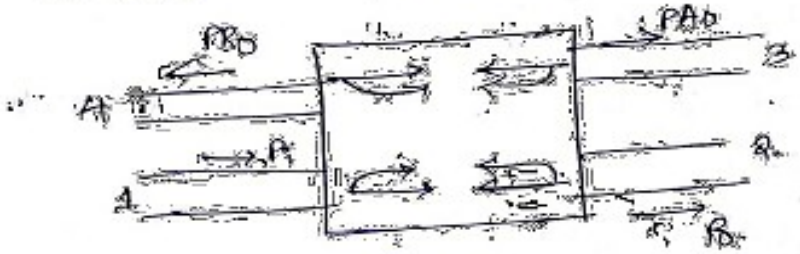


fig:- Directional coupler as a 4 port device.

→ Characteristics of a directional coupler :-

* An ideal bidirectional coupler has the following characteristics :

(1) If power is fed into port (1) it is power is coupled in ports (2) and (3) i.e. power flows in the forward direction but no power couples in port (4) i.e. in backward direction. similarly power fed in (2) couples in ports (1) and port (4) not in (3)

* The important parameters of a directional couples are:

(a) coupling factor (b) coefficient.

(c) directivity (d) Bandwidth

(e) Insertion loss (f) Frequency sensitivity.

→ **Coupling factor:-** It is the ratio of power supplied to the main line input (P_i) to the forward power to (P_f) at the auxiliary line output.

$$C = 10 \log (P_i / P_f) \text{ db}$$

→ **Directivity:-** It is the ratio of forward power to the backward power.

$$D = 10 \log (P_f / P_b)$$

→ **Types of couplers:-**

1) Bethe hole directional coupler (single hole)
2) Long slot directional couples.
3) Schwinger reverse phase couples
4) Capacitance - loop directional couples.
5) Double- hole; (or) multi- hole couples.

→ **Bethe hole couples:-**

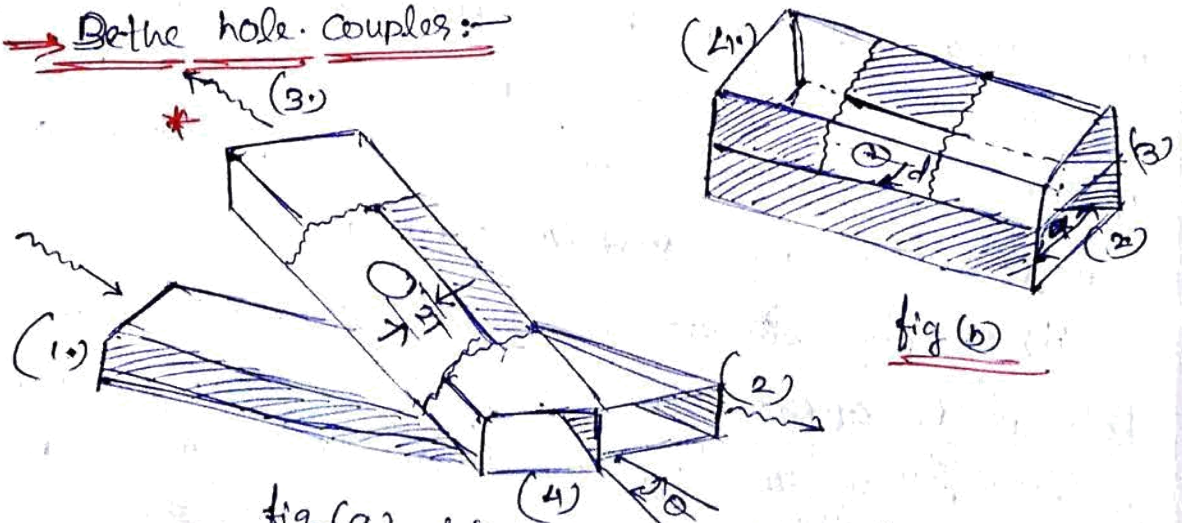


fig (a) & (b) Bethe-hole directional couples.

* It consists of two rectangular waveguides coupled by means of a circular aperture located at the centre of the common board wall. To achieve directional coupling the axes of the 2 wave guides are inclined at an angle θ. Fig. (a) shows determined by frequency and the dimensions of the hole. If θ is zero then hole is to be taken offset and not at the centre. This construction can be understood by considering TE10 mode incident on port 1, produces a normal electric dipole in the aperture plus a tangential magnetic dipole, whose direction is same as that of the incident wave and magnitude proportional to the incident wave strength.

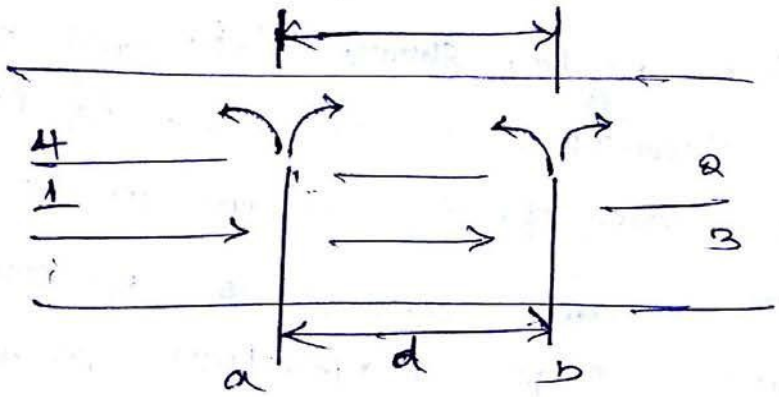
* Now in the auxiliary arm (upper waveguide) the normal electric dipole and axial component of magnetic dipole radiate symmetrically in both the directions. But the transverse component of magnetic dipole radiates anti symmetrically.

* So, proper adjustments of the axes of two wave guide at an angle θ cause the complete cancellation of backward power in the auxiliary arm. This cancellation may also be achieved by offsetting the hole as shown in fig (b).

→ Two Hole (or) multiple hole couplers:-

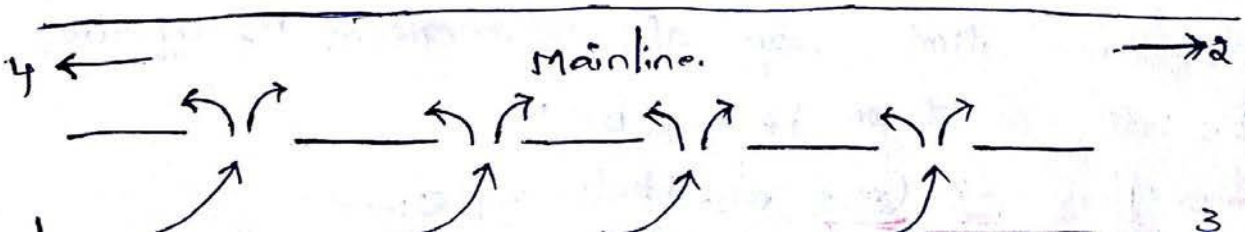
* Two hole couples are constructed by coupling two identical rectangular wave guides by means of a

identical apertures spaced by a distance of $\lambda_g/4$, i.e., quarter guide wavelength apart. In this type of coupler as shown in fig(a) the signal which travels back to the first hole from the second hole is 180° out.



fig(a): Two hole type Couplers

of phase and so the 2 signals tend to cancel in the backward direction. The signals in the forward directions are in phase and hence they add together. If the distance between the holes is other $\lambda_g/4$, the said characteristics of coupling and directivity cannot be achieved and so this type of coupler is a narrow band coupler. It is to be noted that directivity and coupling parameters are the sum of inherent property of the single hole and the one associated with arrays.



* Multi hole couplers. fig(b) operate on the same basic principles as a hole coupler. the coupling array holes are each separated by a distance of $\lambda g/4$.

* The hole dimensions are so varied so that a wide frequency band is covered. these coupling versus frequency variations are + or - 0.5db over the entire wave guide range.

* The holes are drilled in the narrow side of the wave guide for high power operation.

5. Explain Faraday Rotation in Ferrites

Faraday Rotation in Ferrites:

Consider an infinite lossless medium. A static field B_0 is applied along the z-direction. A plane TEM wave that is linearly polarized along the x-axis at $t = 0$ is made to propagate through the ferrite in the z-direction.

The plane of polarization of the wave will rotate while moving, a phenomenon known as "Faraday rotation".

Any linearly polarized wave can be regarded as the vector sum of two counter rotating circularly polarized waves (Left & right vectors shown in figure (a)). The ferrite material offers different characteristics to these waves with the result that the phase change of the wave is larger than the other wave resulting

in rotation 'θ' of the linearly polarised wave at $z = l$.

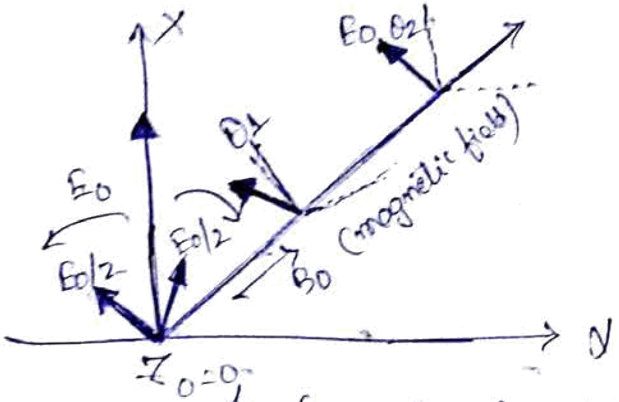


fig (a) Faraday rotation.

* It is observed that a rotation of 100 degrees (or) more per cm of ferrite length is typical for ferrites at a frequency of 10GHz. If the direction of propagation is reversed, the plane of polarization continues to rotate in the same direction i.e., $z = l$ to $z = 0$, the wave will arrive back at $z = 0$ polarized at an angle 2θ relative to x-axis.

* In fact the angle of rotation 'θ' given by

$$\theta = \frac{l}{2}(\beta_+ - \beta_-)$$

* where l = length of the ferrite rod

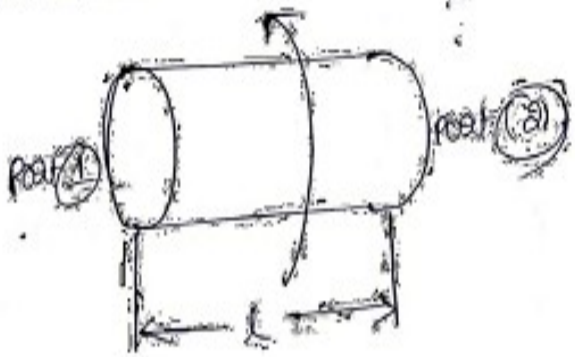
β_+ = phase shift for the right circularly polarised (Component in clockwise direction) wave w.r.to some reference.

β_- = phase shift for the left circularly polarised (Component in anticlockwise direction) wave w.r.to the same reference.

* In a ferrite medium, there will be finite losses. The propagation constant for circularly polarised

wave will have unequal attenuation constants and unequal phase constant. Due to this, the direction of faraday rotation will be different in the two regions above and below the resonant frequency (f_{res}).

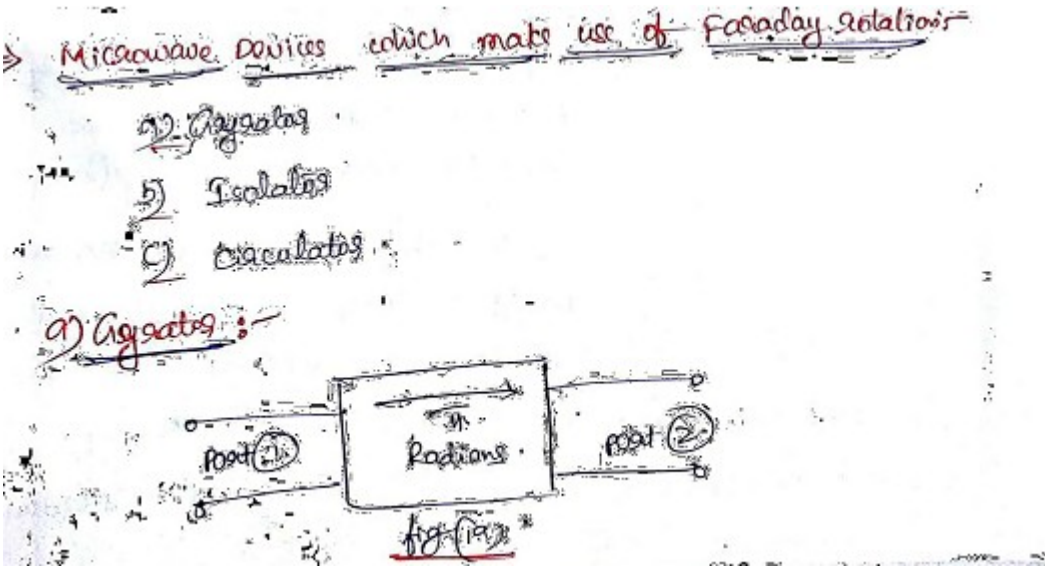
* A two port reserve device is shown in fig(2). When a wave is transmitted from port (1)

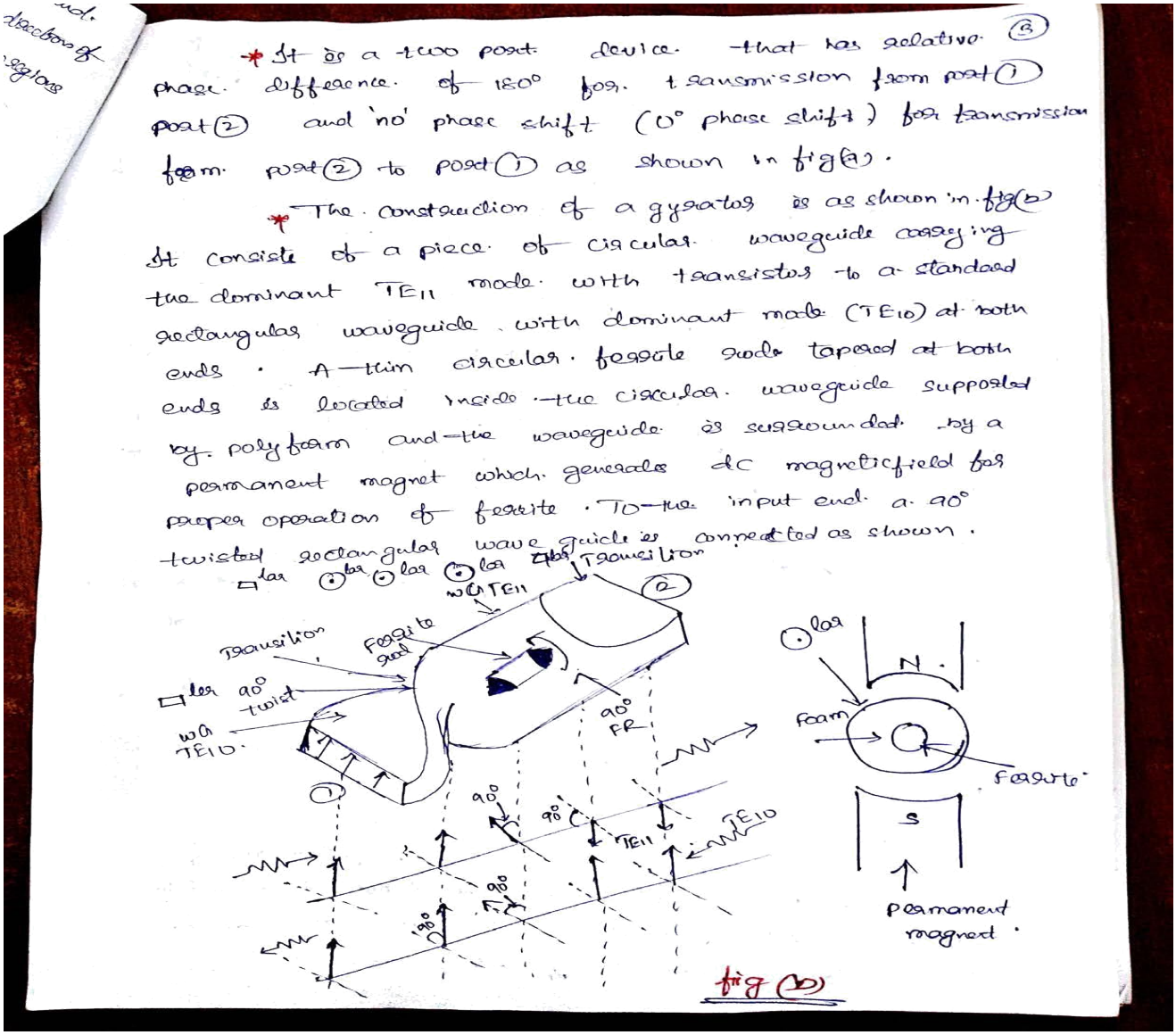


fig(2):

port (2) it undergoes rotation in the anticlockwise direction as shown. Even if the same wave is allowed to propagate from port (2) port (1), it will undergo rotation in the same direction (anticlockwise). Hence the direction of rotation of linearly polarized wave is independent of the direction of propagation of the wave.

6 . Explain the Operation of i)Gyrator ii) isolator iii) circulator





⇒ Operation :-

* When a wave enters port (1) its plane of polarization rotates by 45° because of the twist in the waveguide. It again undergoes faraday rotation through 90° because of ferrite rod and the wave which comes out of port (2) will have a phase shift of 180° compared to wave entering the port (1)

* But when the same wave enters port (2) (TE10 mode signal), it undergoes faraday rotation through 90° in the same anticlockwise direction. Because of the twist, this wave gets rotated back by 90° comes out of port (1) with 0° phase shift. as shown in fig (a) Hence a wave at port (1) undergoes a phase shift of π radians (or 180°) but a wave fed from port (2) does not change its phase in aggregate.

~~⇒ Isolator :-~~

⇒ Isolator :-

* An isolator is a 2 port device which provides very small amount of attenuation for transmission from port (1) to port (2) but provides maximum attenuation for transmission from port (2) to port (1) This requirement is very much desirable when we want to match a source with a variable load.

* In most MW generators the o/p amplitude and frequency tend to fluctuate very significantly with changes in load impedance. This is due to mismatch of generator o/p to the load. resulting in reflected wave from load. But these reflected waves should not be allowed to reach the MW generator, which will cause amplitude and frequency instability of MW generator.

* When an isolator is placed b/n generator & load, the generator is coupled to the load with '0' attenuation and any reflections from load are absorbed by the isolator without effecting generators O/P. Hence acts as matched for all loads with no change in fq and O/P power.

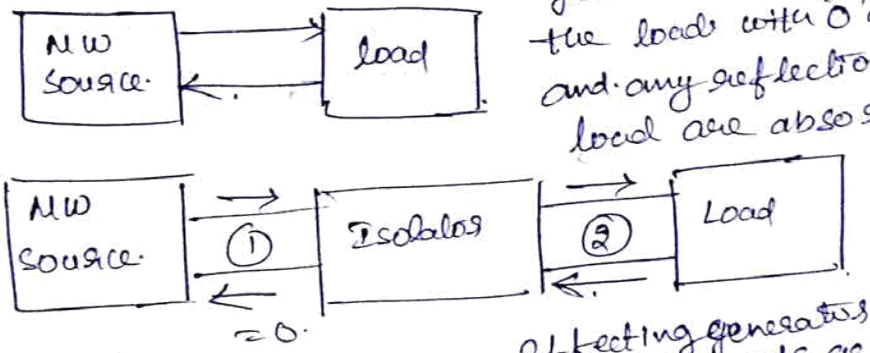


fig (a)

Construction:—

* The construction of isolator (fig (b)) is similar to gyrator except that in isolator makes use of 45° twisted R.W.C (Rectangular W.G) → and 45° faraday rotation ferrite rod a resistive card is placed along the longer dimension of the □lar W.G. So as to absorb a wave whose plane of polarisation is parallel to the plane of resistive card. The resistive card does not absorb any wave whose plane of polarization is perpendicular to its own plane

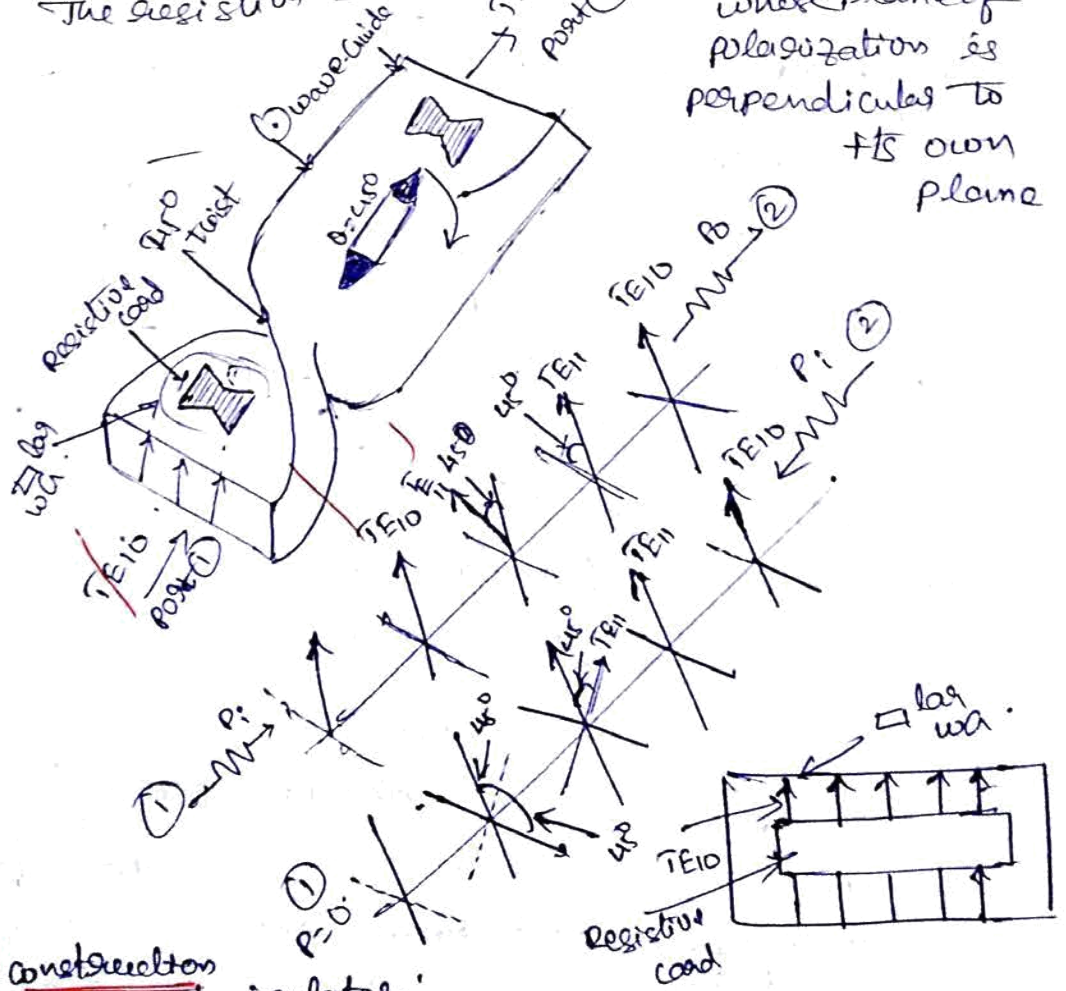


fig (b) construction of isolator

* Operation :-

* A TE10 wave passing from port (1) through the resistive card and is not attenuated. After coming out of the card, the wave gets shifted by 45° because of the twist in anticlockwise direction and then by another 45° in clockwise direction because of the ferrite rod and hence comes out of port (2) with the same polarization as port (1) without any attenuation.

* But a TE10 wave fed from P (2) gets a pass from the resistive card placed near P (2) since the plane of polarization of wave is ⊥ar to the plane of resistive card. Then the wave gets rotated by 45° due to faraday rotation in clockwise direction and further get rotated by 45° in clockwise direction due to the twist in the waveguide.

* The plane of polarization of the wave will be parallel to with that of the resistive card and hence the wave will be completely absorbed by the Resistive card. and the o/p at port (1) will be zero. This power is dissipated in the card as heat

⇒ Circulator :-

* A circulator is a four port NW device which has a peculiar property that each terminal is connected only to the next clock wise terminal i.e., port (1) is connected to port (2) only. and not to port (3) and (4) and port (2) is connected only to port (3) etc This is shown in fig (a) Although there is no restriction on the number of ports, four ports are most commonly commonly used. They are useful parametric amplifiers, tunnel diodes.

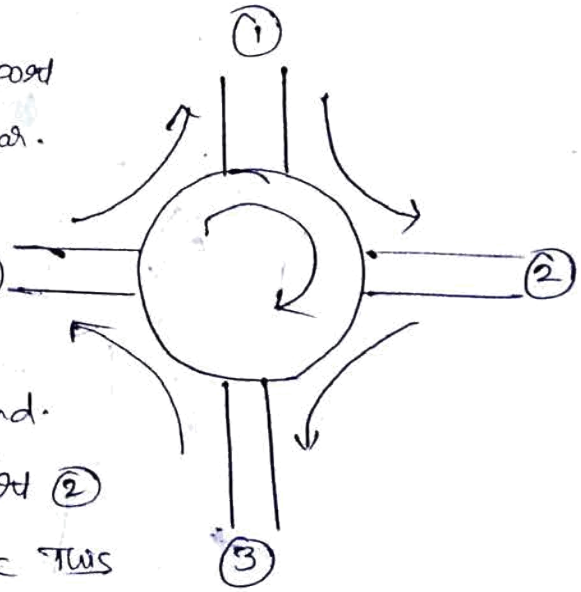


fig (a)

amplifiers, and multipliers in radars.

→ Construction :-

A four port Faraday rotation circulator is shown in fig(b). The power entering port (1) is TE_{10} mode and is converted to TE_{11} mode because of gradual rectangular to circular transition. This power passes port (3) unaffected since the electric field is not significantly cut and is rotated through 45° due to the ferrite, passes port (4) uneffected (for the same reason as it passes port (3)) and finally emerges out of port (2). Power from port (2) will have plane of polarization already tilted by 45° with respect to port (1). This

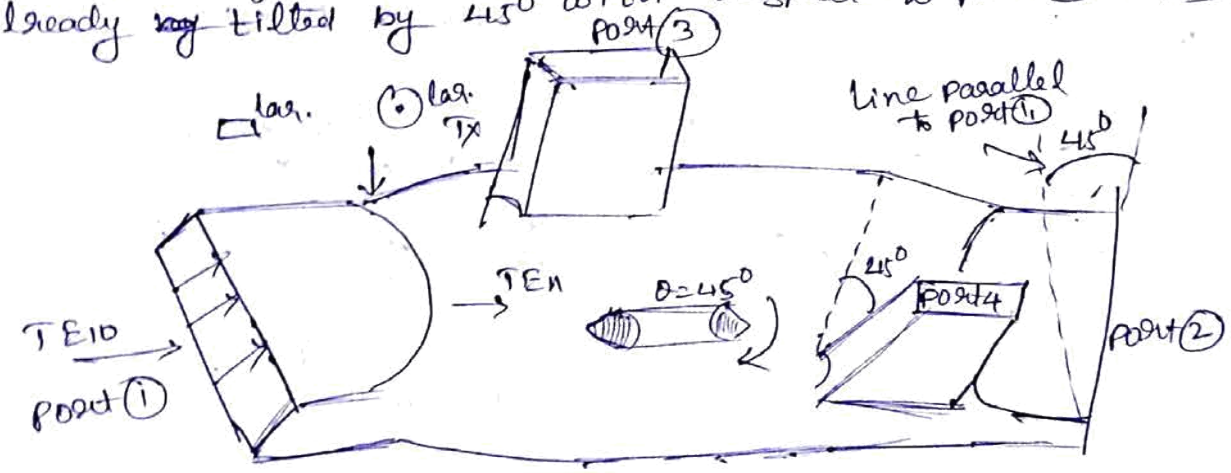


fig. (b): Four port circulator

power passes port (4) uneffected because again the electric field is not significantly cut. This wave gets rotated by another 45° due to ferrite rod in the clockwise direction. This power whose plane of polarization is tilted through 90° finds port (3) suitably aligned and emerges out of it. similarly P(3) is coupled only to port (4) and P(4) to P(1).

→ Applications :-

1)

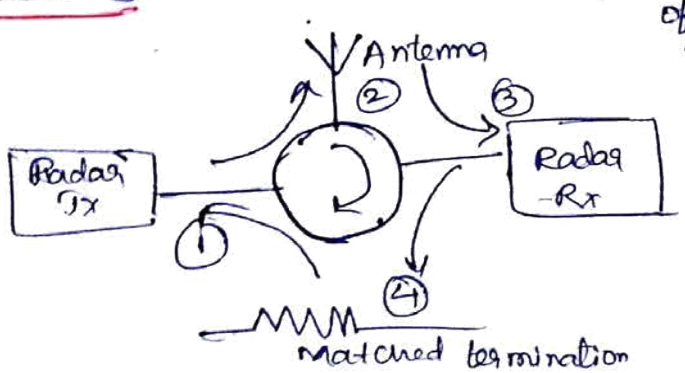
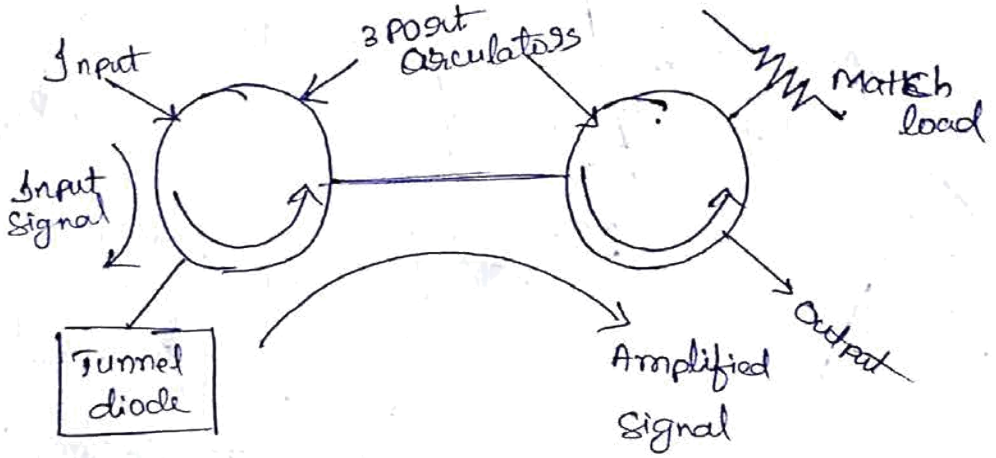


fig (a).

A circulator can be used as a duplexer for a radar antenna system as shown in fig(a).

1) Transmitter feeds the antenna while the received energy is directed to the receiver. The powerful radar transmitter is isolated from the sensitive receiver and also the same antenna can be used for both transmission and reception. This is the duplexer action being performed by a circulator.

2) We can have three port circulators, strip lines circulators that can have several applications. Two-three port circulators can be used in tunnel



fig(b).

diode. (or) parametric amplifier as shown in fig(b).

3) Circulators can be used as low power devices as they can handle low powers only.

Short Answers

1. **What are the two types of terminations.**

Matched load

Variable short circuit

2. **What are ferrites and give its properties?**

Ferrites are ceramic like materials. These are maby by sintering a mixture of metallic oxides Properties Specific resistivitieis may be used as much as 1014 greater than that of metals Dielectric constants around 10to 15 or greaterRelative permeability is 1000

3 .Give some examples of ferrite devices?

Isolator Circulator Phaseshifters, Modulators, Power limiters

4.List two microwave devices using faraday rotation principles

Isolator, Circulator

5.What are powere dividers?

Power dividers are used to divide the input power into a number of smaller amounts of power for exciting the radiating elements in an array antenna

6. Give the differences between Isolator and Circulator

Si.no	Isolator	Circulator
1	It is a 2 port device	It is a 3 port device
2	It cannot be used as circulator	It is used as isolator by terminating one port
3	If input is given in port 1,output is obtained at port 2 and vice versa	Each terminal is connected only to the next terminal

7.Give an example for a two port MW device

Isolator is an example for a 2 port MW device

8.Give the applications of directional coupler

1.Unidirectional power measurement

2.SWR measurement

3.Unidirectional wave launching

4.Reflectometer

5.Balanced duplexer

9.What is Faraday's rotation law?

If a circulary polarised wave is made to pass through a ferrite rod which has been influenced by an axial magnetic field B ,then the axis of polarization gets tilted in clockwise direction and amount of tilt depends upon the strength of magnetic field and geometry of the ferrite.

10.Define VSWR

Voltage standing wave ratio is defined as the ratio of maximum voltage to the minimum vottage VSWR=Vmax/Vmin

11.What is Gyrator?

Gyrator is a two port device which provides a relative phase shift of 180 degree for transmission from port 1 to port 2 as compared to the phase for transmission from Port2 to port 1.

12.What is the principle of Microwave phase shifter?

When a wave propagates on a line,a phase difference prevails between any two arbitary points along its paths.The phase difference between two points.

13.what are junctions?Give some examples

A microwave circuit consists of several microwave devices connected in some way to achieve the desired transmission of MW signal.The interconnection of two or more microwave may be regarded as MW junction.

Eg:Magic Tee,Hybrid Ring

14.What is Tee junction?Give two examples

In MW circuits a wave guide or coaxial junction with three independent ports is referred to as tee junction.

Eg: E- Plane Tee,H-plane Tee

15.What is the other name for magic TEE?

Hybrid Tee

16.What is hybrid ring?

Hybrid ring consists of an annular line of proper electrical length to sustain standing waves,to which four arms are connected at proper intervals by means of series or parallel junctions.

17.What is the other name for Hybrid ring?

Rat-race circuit.

18.Name some wave guide components used to change the direction of the guide through an arbitrary angle.

Wave guide corner,Bend and twist

19.What are the different types of Directional coupler?

1.Two hole directional coupler

2.Be the hole directional coupler

3.Four hole directional coupler

20.What are hybrid couplers?

Hybrid couplers are interdigitated microstrip couplers consisting of four parallel striplines with alternate lines tied together,It has four ports.This type of coupler is called Lange hybrid coupler.

21. What are nonreciprocal devices? Give two examples

The devices which are having the property that the forward characteristics are not equal to the reverse characteristics are called non reciprocal devices.

22.Why isolators are called uniline?

An ideal isolator completely absorbs the power for propagation in one direction and provides lossless transmission in the opposite direction. Thus isolators are called uniline

23.Give some coupling parameters of directional coupler?

Coupling coefficient, Directivity, Insertion loss, Isolation

UNIT-3

Long Answer Questions

1. **Explain the principle of working for two cavity klystron with velocity diagram.**

Microwave Engineering deals with the design of microwave circuits, systems & components. Various fundamental principle are used for the analysis and design purpose with the application of field measurement techniques. Reflex klystron is a microwave device that works on principle of velocity modulation in addition to current modulation. Reflex klystron is also known as a 'Sutton' klystron. This name is given by the name of its inventor Robert Sutton, It allow the passage of electron beam through a single resonant cavity. Now understand the concept of Reflex klystron in microwave engineering in details through following questions and answers.

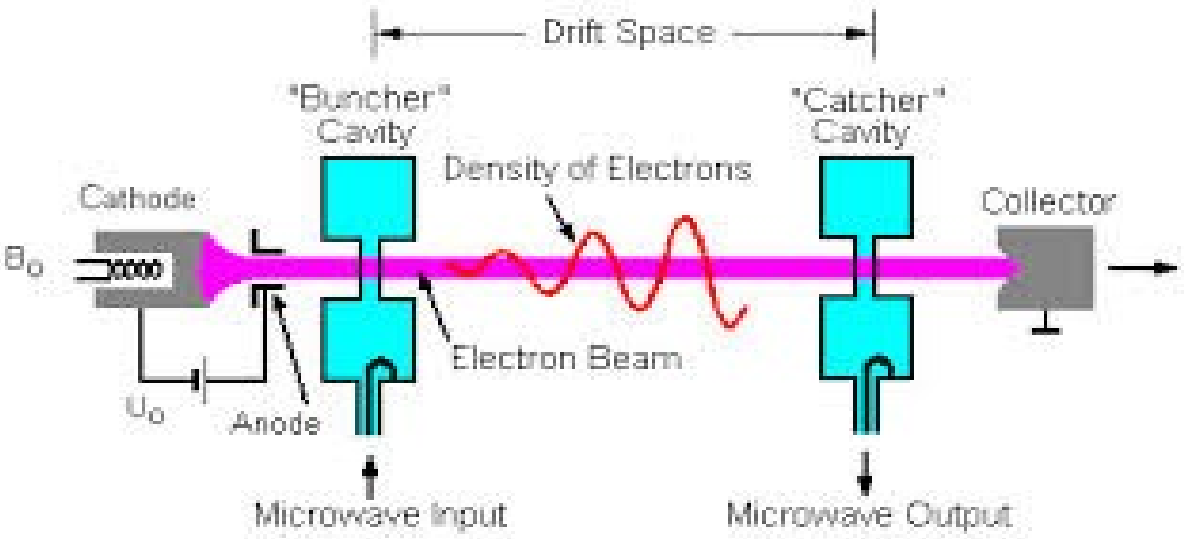
In this section and in the next, we present the theory behind the principal formulae used in the design of amplifier klystrons. The intent is to provide the student or engineer with the assumptions used in their derivations so that he or she can use them correctly. These assumptions result in the approximations necessary to derive analytical expressions for the gain and bandwidth of klystrons at low rf signal levels (small-signal). The "Mathcad" code, which is discussed in a later lecture, contains such formulae. The theory below is included because it is incompletely covered in textbooks, and because there is widespread confusion on how to properly treat coupling coefficients and beam loading in complex cavities. This is a problem, particularly at millimeter wave frequencies, where extended interaction cavities are likely to be used.

Other codes, such as AJ-disk and MAGIC, simulate klystron performance using first principles (electron dynamics and Maxwell's equations). These codes are approximate only to the extent that they are either one-dimensional (or two dimensional), or employ too coarse a grid, or contain other approximations. Later lectures describe these codes, as well as two working klystron examples, in one case comparing actual performance to results from three different codes. This is essential information, since klystron design in the 21st century is being carried out almost entirely on computers (i.e. with little, or no "cold-testing" or "beam testing").

The kinematic (no space charge) analysis below follows several authors who published books on klystrons shortly after WW2. The velocity modulation (or

"bunching") 2-cavity theory that follows immediately is the only large signal analytical treatment of klystrons in this chapter. It leads to the Bessel function coefficients of the current harmonics and a calculation of two- cavity amplifier efficiency. The subsequent derivation of the coupling coefficient and the statement of the beam-loading formulae are based on small signal approximations, which are valid for all but the final cavities of a multicavity klystron. Neither treatment takes space charge into account. This is done in the third lecture of the series.

Consider a klystron consisting of two cavities, a "buncher" and a "catcher," both gridded. (Fig.1). Let a beam of electrons, which has been accelerated by a potential V_o to a velocity u_o, traverse the first pair of grids, where it is acted upon by an rf voltage $V_1 \sin\omega t$, reduced by a "coupling coefficient" M. The latter modifies the voltage across the grids to produce the effective voltage modulating the electron beam. Expressions for the coupling coefficient M (always less than 1) will be derived later.



The electrons in the beam enter the gridded gap with energy,

$$\frac{1}{2}mu_o^2 = eV_o$$

where the electron charge e does not carry its own negative sign. The electron energy is modified by the rf field at the gap and the following relationship can be written for the exit velocity u:

$$\frac{1}{2}mu^2 - \frac{1}{2}mu_0^2 = eMV_1 \sin \omega t$$

$$u = u_0 \sqrt{1 + \frac{MV_1}{V_0} \sin \omega t}$$

Principle

- Velocity modulated tube
- High velocity electron beam is generated by an electron gun and sent down along a gas tube through an input cavity (BUNCHER), drift space (FIELD FREE) and an output cavity (CATCHER) to a collector electrode anode.
- The anode is kept positive to receive the electrons, while the output is taken from the tube via resonant cavities with the aid of coupling loops
- Two grids of the buncher cavity are separated by a small gap A while the two grids of the catcher cavity are separated by a small gap B.

OPERATION

The input buncher cavity is exited by the RF signal, (the signal to be amplified) which will produce an alternating voltage of signal frequency across the gap A.

- This voltage generated at the gap A is responsible to produce bunching of electrons or velocity modulation of the electron beam.

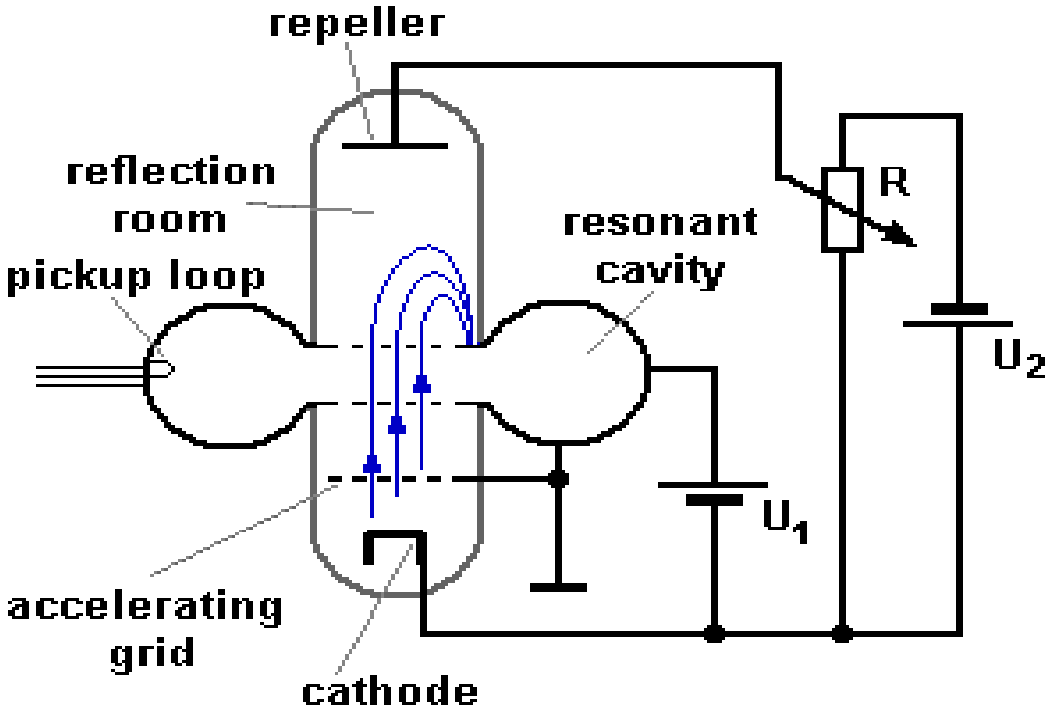
2. **Explain the operation of Reflex Klystron.**

- The reflex klystron has been the most used source of microwave power in laboratory applications. A reflex klystron consists of an electron gun, a cavity with a pair of grids and a repeller plate as shown in the above diagram.
- In this klystron, a single pair of grids does the functions of both the buncher and the catcher grids.
- The main difference between two cavity reflex klystron amplifier and reflex klystron is that the output cavity is omitted in reflex klystron and the repeller or reflector electrode, placed a very short distance from the single cavity, replaces the collector electrode.

Working:

- The cathode emits electrons which are accelerated forward by an accelerating grid with a positive voltage on it and focused into a narrow beam.
- The electrons pass through the cavity and undergo velocity modulation, which produces electron bunching and the beam is repelled back by a repeller plate kept at a negative potential with respect to the cathode.
- On return, the electron beam once again enters the same grids which act as a buncher, therby the same pair of grids acts simultaneously as a buncher for the forward moving electron and as a catcher for the returning beam.
- The feedback necessary for electrical oscillations is developed by reflecting the electron beam, the velocity modulated electron beam does not actually reach the repeller plate, but is repelled back by the negative voltage.
- The point at which the electron beam is turned back can be varied by adjusting the repeller voltage.
- Thus the repeller voltage is so adjusted that complete bunching of the electrons takes place at the catcher grids, the distance between the repeller and the cavity is chosen such that the repeller electron bunches will reach the cavity at proper time to be in synchronization.

- Due to this, they deliver energy to the cavity, the result is the oscillation at the cavity producing RF frequency.



Performance Characteristics:

1. Frequency: 4 – 200 GHz
2. Power: 1 mW – 2.5 W
3. Theoretical efficiency : 22.78 %
4. Practical efficiency : 10 % - 20 %
5. Tuning range : 5 GHz at 2 W – 30 GHz at 10 mW

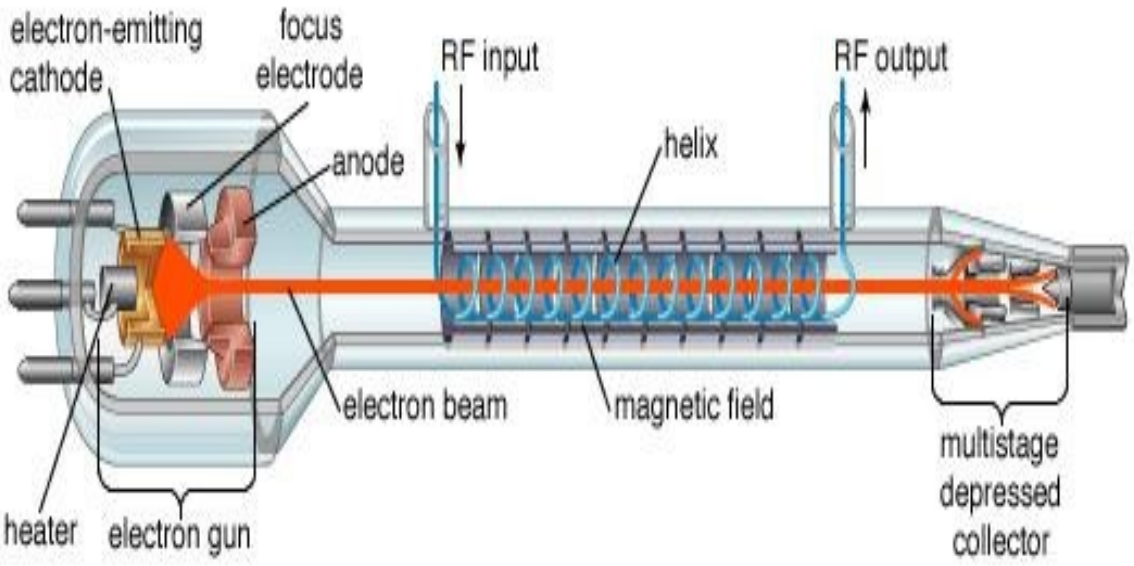
Applications:

- The reflex klystrons are used in

1. Radar receivers
2. Local oscillator in microwave receivers
3. Signal source in microwave generator of variable frequency
4. Portable microwave links
5. Pump oscillator in parametric amplifier

3. Explain the operation of TWT.

Traveling Wave Tube (TWT) is the most versatile microwave RF power amplifiers. The main virtue of the TWT is its extremely wide band width of operation.



- The basic structure of a TWT consists of a cathode and filament heater plus an anode that is biased positively to accelerate the electron beam forward and to focus it into a narrow beam.
- The electrons are attracted by a positive plate called the collector, which has given a high dc voltage.
- The length of the tube is usually many wavelengths at the operating frequency.

- Surrounding the tube are either permanent magnets or electromagnets that keep the electrons tightly focused into a narrow beam.

Features:

- The unique feature of the TWT is a helix or coil that surrounds the length of the tube and the electron beam passes through the centre or axis of the helix.
- The microwave signal to be amplified is applied to the end of the helix near the cathode and the output is taken from the end of the helix near the collector.
- The purpose of the helix is to provide path for RF signal.
- The propagation of the RF signal along the helix is made approximately equal to the velocity of the electron beam from the cathode to the collector

Functioning:

The passage of the microwave signal down the helix produces electric and magnetic fields that will interact with the electron beam..The electromagnetic field produced by the helix causes the electrons to be speeded up and slowed down, this produces velocity modulation of the beam which produces density modulation.Density modulation causes bunches of electrons to group together one wavelength apart and. these bunch of electrons travel down the length of the tube toward the collector.

- The electron bunches induce voltages into the helix which reinforce the voltage already present there. Due to that the strength of the electromagnetic field on the helix increases as the wave travels down the tube towards the collector.
- At the end of the helix, the signal is considerably amplified. Coaxial cable or waveguide structures are used to extract the energy from the helix.

Advantages:

1. TWT has extremely wide bandwidth. Hence, it can be made to amplify signals from UHF to hundreds of gigahertz.
2. Most of the TWT's have a frequency range of approximately 2:1 in the desired segment of the microwave region to be amplified.

3. The TWT's can be used in both continuous and pulsed modes of operation with power levels up to several thousands watts.

Performance Characteristics:

1. Frequency of operation : 0.5 GHz – 95 GHz
2. Power outputs:

   5 mW (10 – 40 GHz – low power TWT)

   250 kW (CW) at 3 GHz (high power TWT)

   10 MW (pulsed) at 3 GHz

3. Efficiency : 5 – 20 % (30 % with depressed collector)

Applications:

1. Low noise RF amplifier in broad band microwave receivers.
2. Repeater amplifier in wide band communication links and long distance telephony.
3. Due to long tube life (50,000 hours against ¼th for other types), TWT is power output tube in communication satellite.
4. Continuous wave high power TWT's are used in troposcatter links (due to larger power and larger bandwidths).
5. Used in Air borne and ship borne pulsed high power radars.

Short Answers

1.What is transit time?

A:It is the time taken by the electrons to travel from cathode to anode.

2.What is the operating principle of reflex klystron?

A:It works on the principle of velocity modulation and current modulation.

3. What is velocity and current modulation in a reflex klystron?

A:Variation in velocities of the electrons in the electron beam is called velocity modulation; variation in the current density of the electron beam is referred to as current modulation.

4. How does bunching occur in a reflex klystron?

A:A reference electron passing the gap when the gap voltage is zero travels with no change in velocity. An electron leaving the gap earlier during slightly positive voltage would travel further into repeller space and hence would take longer time then the reference electron to return to the gap. An electron leaving the gap later will face slightly negative voltage and gets retarded. So it returns back after a shorter travel in the repeller space. Thus all the electrons would arrive back to the gap in bunches. Bunching around reference electron takes place once per cycle of RF oscillations.

5. Why do different modes of operation exist for a reflex klystron?

A:There are several combinations of repeller voltage and anode voltage that provide favorable conditions for bunching. Accordingly there are several modes of operation, expressed by N + ¾ where N is an integer.

6. What modes are generally used in a reflex klystron?

A:1 ¾ and 2 ¾ are the most commonly used modes in a practical reflex klystron.

7. What is the operating frequency and power output of a reflex klystron?

A:Frequency range: 4GHz – 200GHzOutput power: maximum 3W in X-band to 10mW at220GHz

8. What is the maximum theoretical efficiency of the reflex klystron?

A:22.7% for 1 ¾ mode.

9. What is mechanical tuning and electronic tuning in a reflex klystron?

A:Variation in frequency of resonance of cavity by varying its dimension by a mechanical method like adjusting screws is called mechanical tuning. Variation of frequency by adjusting repeller voltage is called electronic tuning.

10. What are the high frequency effects in conventional tubes?

The high frequency effects in conventional tubes are

i) Circuit reactance

a)Inter electrode capacitance

b) Lead inductance

ai) Transit time effect

bi) Cathode emission

iv) Plate heat dissipation area

v) Power loss due to skin effect, radiation and dielectric loss.

11. What are the assumptions for calculation of RF power in Reflex Klystron?

a. Cavity grids and repeller are plane parallel and very large in extent.

ai) No RF field is excited in repeller space

bi) Electrons are not intercepted by the cavity anode grid. iv) No debunching takes place in repeller space.

v) The cavity RF gap voltage amplitude V, is small compared to the dc beamvoltage VO

12. What is the condition for oscillation in Reflex klystron ?

The necessary condition for oscillation is that the magnitude of the negative real part of the electronic admittance should not be less than the total conductance of the cavity circuit i.e. _-Ge__G.

Where 1

G=Gc + Gb +G1 = ------Rsh

Rsh _ effective shunt resistance Gc _ copper losses of cavity Gb _ beam loading conductance G1 _ load conductance

13. Give the drawbacks of klystron amplifiers.

1. As the oscillator frequency changes then resonator frequency also changes and the feedback path phase shift must be readjusted for a positive feedback.
2. The multicavity klystron amplifiers suffer from the noise caused because bunching is never complete and electrons arrive at random at catcher cavity. Hence it is not used in receivers.

14. What is the effect of transit time?

There are two effects.

1) At low frequencies, the grid and anode signals are no longer 180O out of phase, thus causing design problems with feedback in oscillators.
2) The grid begins to take power from the driving source and the power is absorbed even when the grid is negatively biased.

15. What are the applications of reflex klystron ?

i. Signal source in MW generator
ii. Local oscillators in receivers
iii. It is used in FM oscillator in low power MW links.
iv. In parametric amplifier as pump source.

16. What is the purpose of slow wave structures used in TWT amplifiers?

Slow wave structures are special circuits that are used in microwave tubes to reduce wave velocity in a certain direction so that the electron beam and the signal wave can interact. In TWT, since the beam can be accelerated only to velocities that are about a fraction of the velocity of light, slow wave structures are used.

17. How are spurious oscillations generated in TWT amplifier? State the method to suppress it.

In a TWT, adjacent turns of the helix are so close to each other and hence oscillations are likely to occur. To prevent these spurious signals some form of attenuator is placed near the input end of the tube which absorb the oscillations.

18.State the applications of TWT.

1) Low power, low noise TWT's used in radar and microwave receivers
2) Laboratory instruments
3) Drivers for more powerful tubes
4) Medium and high power CWTWT'S are used for communication and radar.

19.How the klystron amplifier can act as klystron oscillator? What are the applications of klystron amplifier?

When the klystron amplifier is given a positive feedback such that the overall phase shift becomes zero 360° and __Av _= I then klystron amplifier acts as an oscillator.

Applications:

(1) UHF TV Transmitters
(2) Long ranger radar
(3) Linear particle accelerator
(4) Troposcatter links
(5) Earth station transmitter.

20.Define phase focusing effect.

The bunching of electrons in known as " Phase focusing effect" This effect is important because without it, favoured electrons will fall behind the phase change of electric field across the gaps. Such electrons are retarded at each interaction with the R.F field in magnetron.

21.What do you mean by O-type tubes? Name some O-type tubes.

In O – type tube a magnetic field whose axis coincides with that electron beam is used to hold the beam together as it travels the length of the tube. It is also called as linear beam tube.

i) Helix Traveling wave tube
ii) Coupled cavity TWT
iii) Forward wave amplifier
iv) Backward wave amplifier
v) Backward wave oscillator

22.Define Transit time in Reflex klystron.

The time taken by the electron to travel into the repeller space and back to the gap. T =n + ¾

23.Write the parameters on which bunching depend on?

i) Drift space should be properly adjusted.
ii) D.C anode voltage
iii) Signal amplitude should be such that proper bunching takes place.

24.Compare TWTA Klystron amplifier

Klystron amplifier	TWTA
1. Linear beam or 'O' type device.	Linear beam or 'O' type device
2.Uses cavities for input and Output circuits.	Use non resonant wave circuit.
3.Narrow band device due to resonant cavities.	Wide band device because use of use of Non-resonant wave circuit.

25. Give the performance Specification of Reflex klystron?

Frequency range: 2- 200 GHz
Band width: + 30 MHz for _ VR = +
10 V Power output: 10 mw – 2.5W
Efficiency: 20 to 30%

26. What is CFA? State the applications of CFA.

CFA _Cross Field Amplifier

CFA is a microwave power amplifier. It is a cross between TWT and magnetron in its operation. i.e., it has a magnetron structure to provide an interaction between crossed dc electric and magnetic fields on one hand and an RF field on the other hand. It also uses a slow wave structure as in TWT to provide a continuous interaction between the electron beam and a moving RF field.

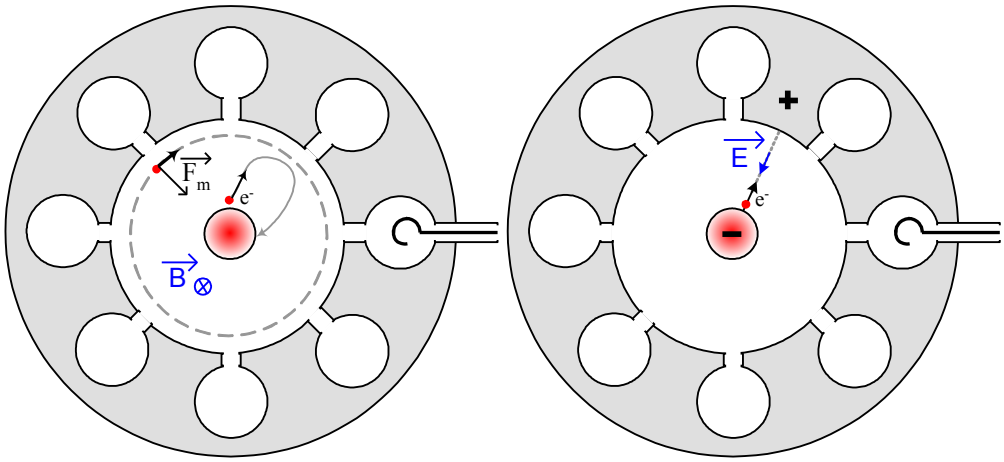
Applications:
(1) Radar system
(2) Electronic counter measure.

UNIT-4

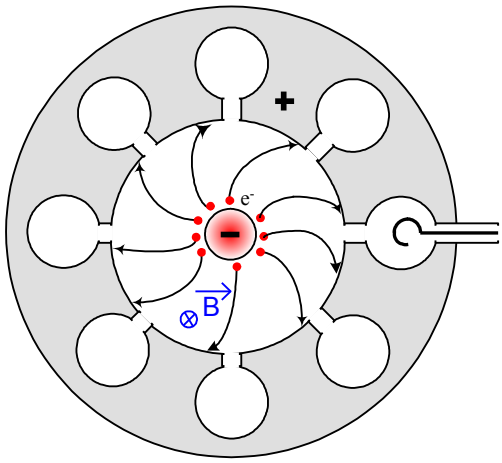
1. Explain the operation of Magnetron.

- A magnetron is a high-powered vacuum tube that generates non consistent microwaves with built-in resonators or by special oscillators or solid-state devices to control the frequency.

- The electromagnetic energy created from a magnetron can travel at the speed of light and is the same type of energy used in radio and television broadcasting.



Effect of electric field **Effect of magnetic field**



Effect of Crossed-Fields

As shown in the figure, a cavity magnetrons consist of a hot filament (cathode) kept at, or pulsed to, a high negative potential by a high-voltage, direct-current power supply. The cathode is built into the center of an evacuated, lobed, circular chamber.

A magnetic field parallel to the filament is imposed by a electro-magnet. The magnetic field causes the electrons, attracted to the (relatively) positive outer part of the chamber, to spiral outward in a circular path rather than moving directly to this anode**.**

Spaced around the rim of the chamber are cylindrical cavities. The cavities are open along their length and connect the common cavity space. As electrons sweep past these openings, they induce a resonant, high-frequency radio field in the cavity, which in turn causes the electrons to bunch into groups.

A portion of this field is extracted with a short antenna that is connected to a waveguide (a metal tube usually of rectangular cross section). The waveguide directs the extracted RF energy to the load, which may be a cooking chamber in a microwave oven or a high-gain antenna in the case of radar.

Applications:

1. In radar devices the waveguide is connected to an antenna. The magnetron is operated with very short pulses of applied voltage, resulting in a short pulse of high power microwave energy being radiated. As in all radar systems, the radiation reflected off a target is analyzed to produce a radar maponascreen.

2. In microwave ovens the waveguide leads to a radio frequency-transparent port into the cooking chamber. It is important that there is food in the oven when it is operated so that these waves are absorbed, rather than reflecting into the waveguide where the intensity of standing waves can cause arcing. The arcing, if allowed to occur for long periods, will destroy the magnetron.

3. In microwave-excited lighting systems, such as Sulphur Lamps, a magnetron provides the microwave field that is passed through a waveguide to the lighting cavity containing the light-emitting substance (e.g. Sulfur, metal halides etc.)

Disadvantages:

- They are costly and hence limited in use.

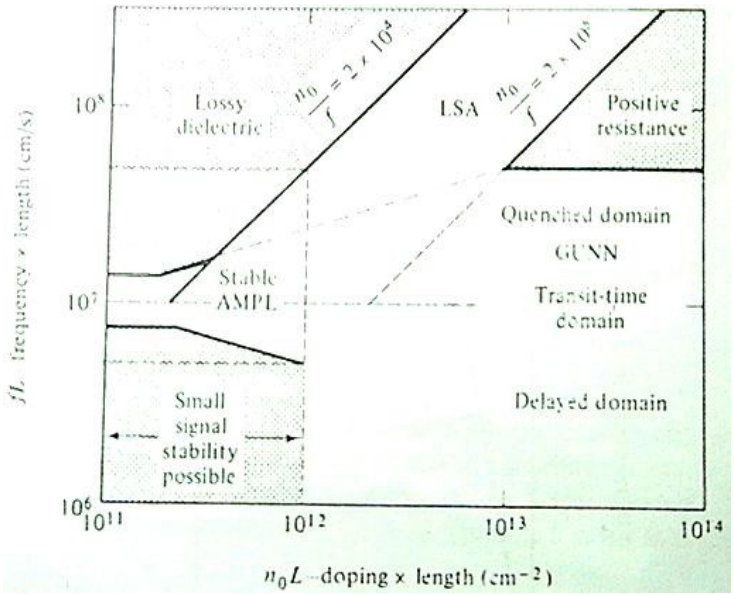
- Although cavity magnetron are used because they generate a wide range of frequencies , the frequency is not precisely controllable.

- The use in radar itself has reduced to some extent, as more accurate signals have generally been needed and developers have moved to klystron and traveling-wave tube systems for accurate frequencies.

2. Explain about several modes of operation of Gunn Diode.

Since Gunn first announced his observation of microwave oscillation in the n-type GaAs and n-type InP diodes in 1963, various modes of operation have been developed, depending On the material parameters and operation conditions. The formation of a strong space-charge instability depends on the

conditions that enough charge is available in the crystal and that the specimen is long enough so that the necessary amount of space charge can be built up within the transit time of the electrons. This requirement sets up a criterion for the various modes of operation of bulk negative-differential-resistance devices. Copeland proposed four basic modes of operation of uniformly doped bulk diodes with low-resistance contacts as shown in the figure below.



Gunn oscillation mode: this mode is defined in the region where the product of frequency multiplied by length is about 10^7cm/s and the product of doping multiplied by length is greater than 10^{12} cm^{-2}. In this region the device is unstable because of the cyclic formation of either the accumulation layer or the high-field domain. In a circuit with relatively low impedance the device operates in the high-field domain mode and the frequency of oscillation is near the intrinsic frequency. When the device is operated in a relatively high-Q cavity and coupled properly to the load, the domain is quenched or delayed (or both) before nucleating. In this case, the oscillation frequency is almost entirely determined by the resonance frequency of the cavity and has a value of several times the intrinsic frequency.

Stable amplification mode: This mode is defined in the region where the product of frequency times length is about 10^7 cm/s and the product of doping times length is between 10^{11} and 10^{12} cm^{-2}.

LSA oscillation mode: This mode is defined in the region where the product of frequency times length is above 10^7 cm/s and the quotient of doping divided by frequency is between 2×10^4 and 2×10^5.

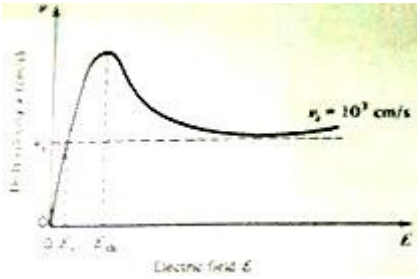
Bias-circuit oscillation mode: This mode occurs only when there is either Gunn or LSA oscillation, and it is usually at the region where the product of frequency times length is too small to appear in the figure. When a bulk diode is biased to threshold, the average current suddenly drops as Gunn oscillations begin. The drop in current at the threshold can lead to oscillations in the bias circuit that are typically 1 kHz to 100 MHz.

Gunn Oscillation Modes ($10^{12}/cm^2 < (n0L) < 10^{14}/cm^2$)

Most Gunn-effect diodes have the product of doping and length (n_0L) greater than $10^{12}/cm^2$. However, the mode that Gunn himself observed had a product (n_0L) that was much less. When the product of (n_0L) is greater than $10^{12}/cm^2$ in GaAs, the space-charge perturbations in the specimen increase exponentially in space and time in accordance with Q(X,t). Thus a high-field domain is formed and moves from the cathode to the anode as described earlier. The frequency of oscillation is given by the relation $f = \frac{U_{dom}}{L_{eff}}$, where υ_{dom} is the domain velocity and L_{eff} is the effective length that the domain travels from the time it is formed until the time that a new domain begins to form.

Gunn described the behaviour of Gunn oscillators under several circuit configurations. When the circuit is mainly resistive or the voltage across the diode is constant, the period of oscillation is the time required for the domain to drift from the cathode to the anode. This mode is not actually typical of microwave applications. Negative conductivity devices are usually operated in resonant circuits, such as high-Q resonant microwave cavities. When the diode is in a resonance circuit, the frequency can be tuned to a range of about an octave without loss of efficiency.

As described previously, the normal Gunn domain mode (or Gunn oscillation mode) is operated with the electric field greater than the threshold field ($E > E_{th}$). The high-field domain drifts along the specimen until it reaches the



anode or until the low field value drops below the sustaining field E_S required to maintain υ_s as shown in the figure. The sustaining drift velocity for GaAs is $\upsilon_s = 10^7$ cm/s. Since the electron drift velocity υ varies with the electric field, there are three possible domain modes for the Gunn oscillation mode.

Transmit time domain mode ($fL \approx 10^7$ cm/s): When the electron drift velocity is equal to the sustaining velocity υ_s, the high-field domain is stable. In other words, the electron drift velocity is given by $\upsilon_d = \upsilon_s = fL \approx 10^7$ cm/s. Then the oscillation period is equal so the transit time--that is, $\tau_0 = \tau_t$. This situation is shown in figure below (a). The efficiency is below 10% because the current is collected only when the domain arrives at the anode.

Delayed domain mode (10^6 cm/s < f_L < 10^7 cm/s): When the transit time is chosen so that the domain is collected While E < E_{th} as shown in figure (b), a new domain cannot form until the field rises above threshold again. In this case, the oscillation period is greater than the transit time—that is, $\tau_0 > \tau_t$. This delayed mode is also called inhibited mode. The efficiency of this mode is about 20%.

Quenched domain mode ($f_L > 2 \times 10^7$ cm/s): If the bias field drops below the sustaining field E_s during the negative half-cycle as shown in figure (c), the domain collapses before it reaches the anode. Then the bias field swings back above threshold, a new domain is nucleated and the process repeats. Therefore the oscillations occur at the frequency of the resonant circuit rather than at the transit-time frequency. It has been found that the resonant frequency of the circuit is several times the transit-time frequency, since one dipole does not have enough time to readjust and absorb the voltage of the other dipoles. Theoretically, the efficiency of quenched domain oscillators can reach 13%.

A typical n-type GaAs Gunn diode has the following parameters:

Threshold field E_{th} = 200 V/cm

Applied field E = 3200 V/cm

Device length L = 10 μm

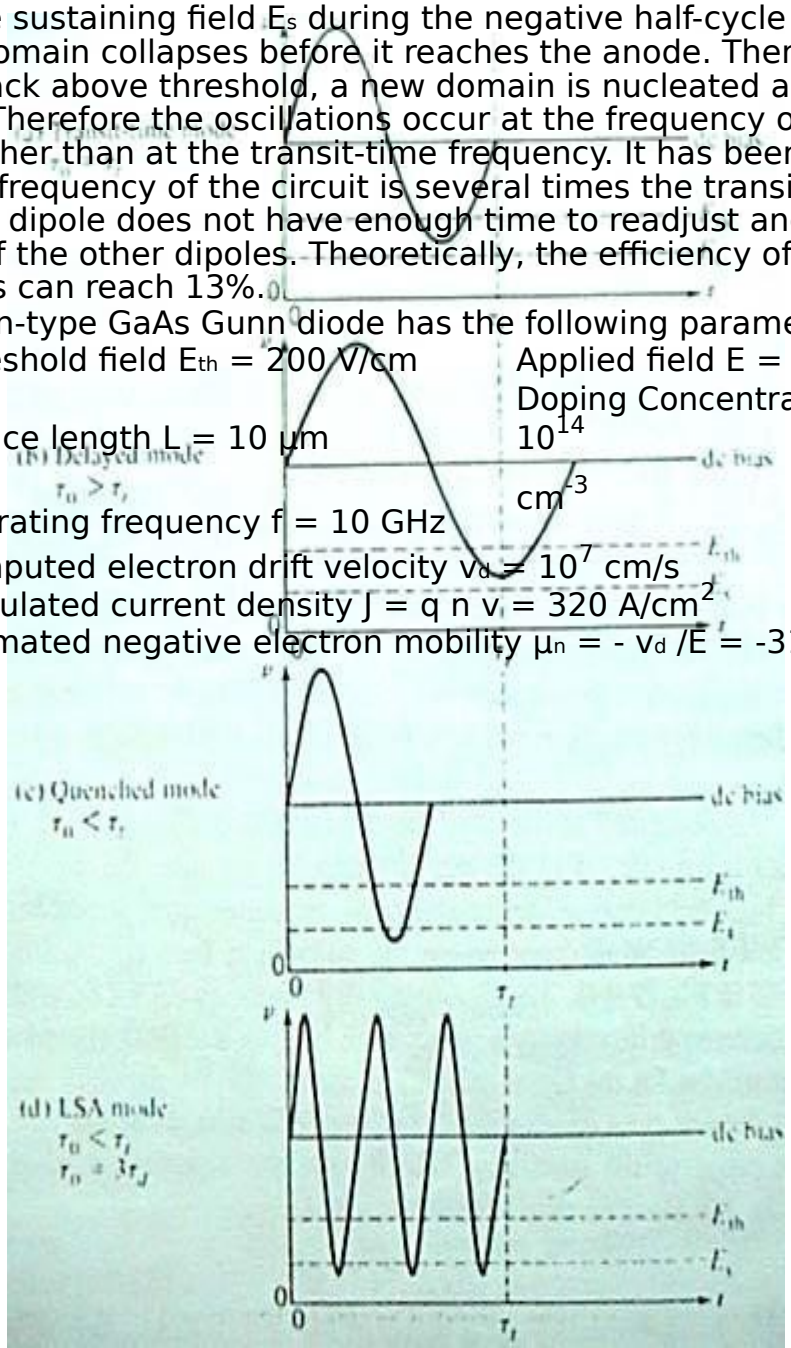
Doping Concentration $n_0 = 2 \times 10^{14}$ cm^{-3}

Operating frequency f = 10 GHz

Computed electron drift velocity $v_d = 10^7$ cm/s

Calculated current density $J = q\, n\, v_i = 320$ A/cm^2

Estimated negative electron mobility $\mu_n = - v_d / E = -3100$ cm^2/V s

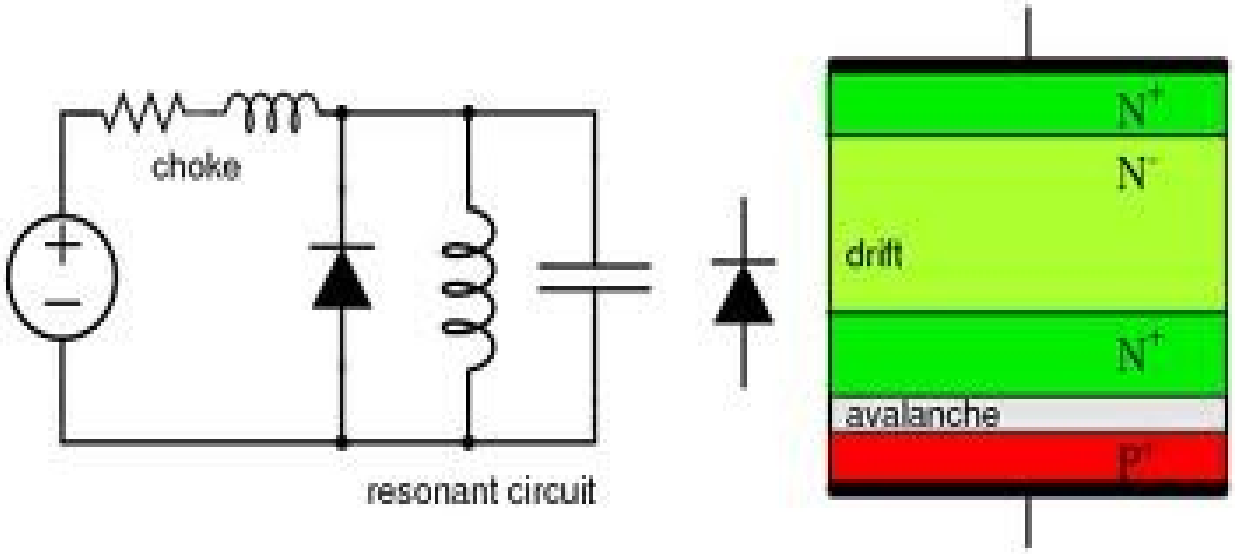


4.

3. Explain the operation of IMPATT Diode.

Form of high power diode used in high frequency electronics and microwave devices Typically made from silicon carbides due to their high breakdown fields. 3 to 100 GHz High power capability From low power radar systems to alarms Generate high level of phase noise – avalanche process.

IMPATT Diode as Oscillator



The IMPATT diode family includes many different junctions and metal semiconductor devices. The first IMPATT oscillation was obtained from a simple silicon p-n junction diode biased into a reverse avalanche break down and mounted in a microwave cavity.

Electron–hole pairs are generated in the high field region. The generated electron immediately moves into the N region, while the generated holes drift across the P region. The time required for the hole to reach the contact constitutes the transit time delay.

The original proposal for a microwave device of the IMPATT type was made by Read.

The Read diode consists of two regions (i) The Avalanche region (a region with relatively high doping and high field) in which avalanche multiplication occurs and (ii) the drift region (a region with essentially intrinsic doping and constant field) in which the generated holes drift towards the contact.Read diode is the basic type in the IMPATT diode family

IMPACT IONIZATION

If a free electron with sufficient energy strikes a silicon atom, it can break the covalent bond of silicon and liberate an electron from the covalent bond.If the electron liberated gains energy by being in an electric field and liberates other electrons from other covalent bonds then this process can cascade very quickly into a chain reaction producing a large number of electrons and a large current flow.

This phenomenon is called impact avalanche.

$$n^+\text{-}p\text{-}i\text{-}p^+$$

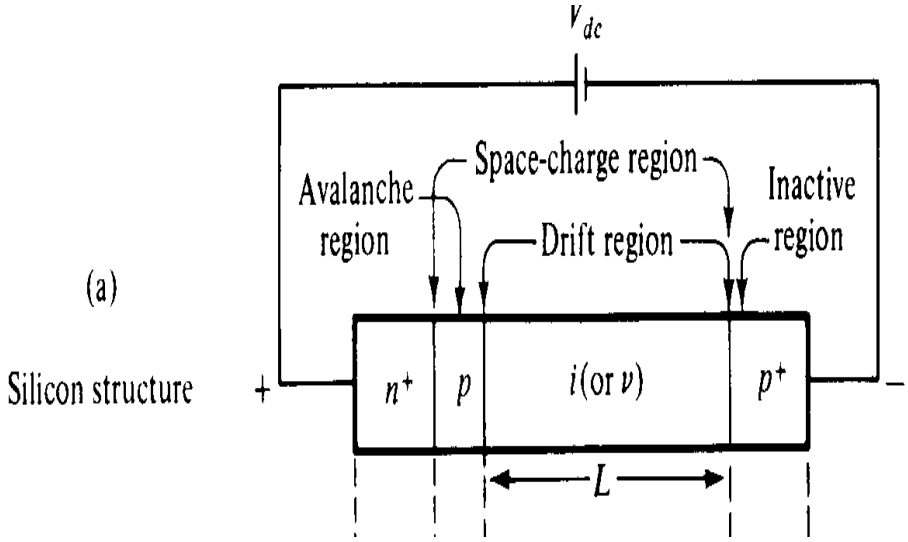
+ very high doping

i or v intrinsic material

Two regions

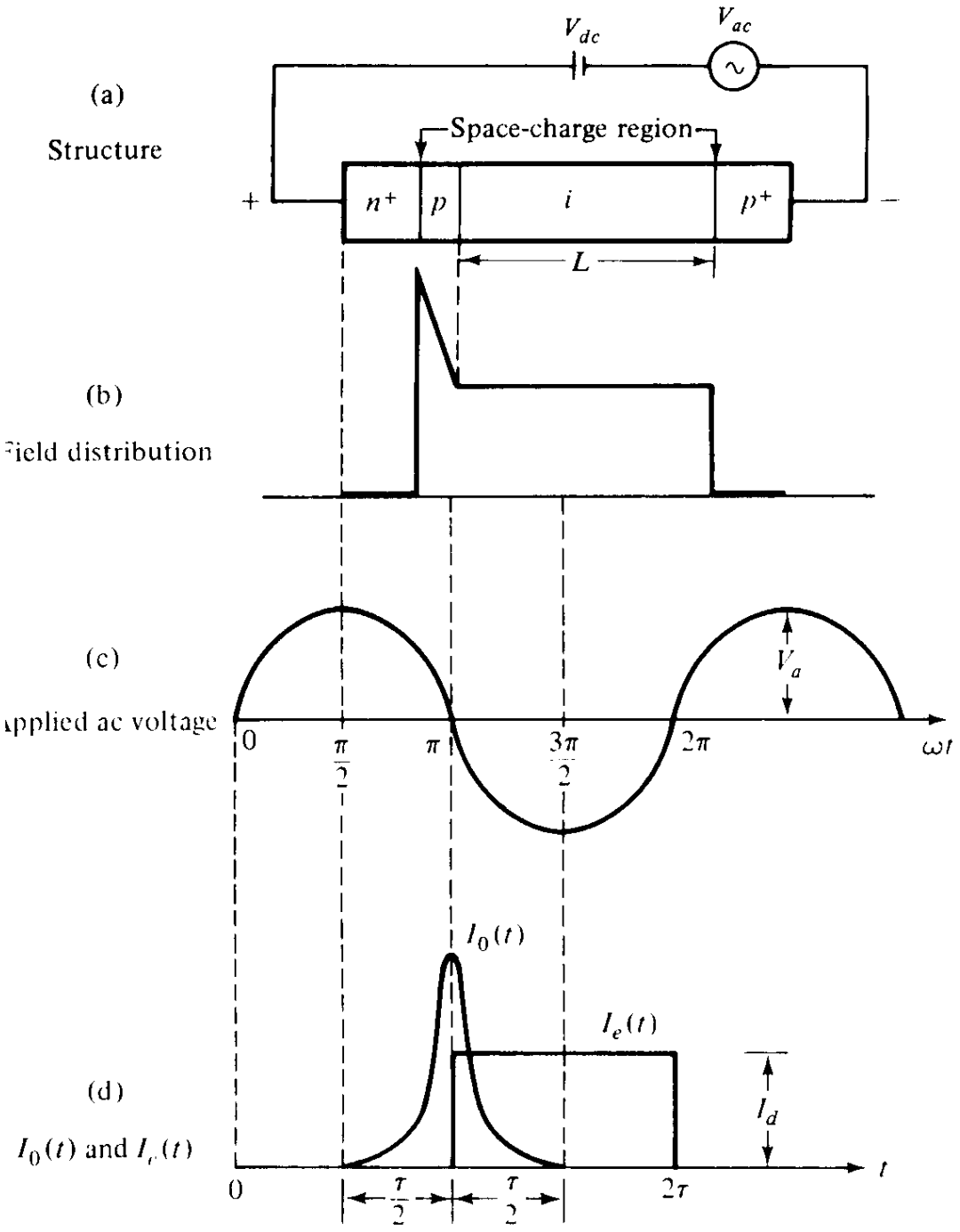
1) Thin p region (High field/Avalanche region) – avalanche multiplication occurs

2) Intrinsic region (Drift region) – generated holes must drift towards the p+ contact



The space between n+ -p junction and the i –p+ junction is called the space charge regionThe diode is reverse biased and mounted in a microwave cavity. The impedance of the cavity is mainly inductive which is matched with the capacitive impedance of the

diode to form a resonant circuit.Such device can produce a negative ac resistance that in turns delivers power from the dc bias to the oscillation



Short Answer Questions

1. **State the characteristics of magnetron and of 2-cavity klystron amplifier.**
   Magnetron:

   Operating frequencies _ 70 GH
   z Output power _ 40 MW
   Efficiency _ 40 to 70%

   2-cavity
   klystron:
   Efficiency _
   40%

   Power output _ average power _> 500
   KW Pulsed power _> 30 MW
   Power gain _ about 30 db.
2. **What are the advantages of TWT?**
   1. Bandwidth is large.
   2. High reliability
   3. High gain
   4. Constant Performance in space
   5. Higher duty cycle.

3. **What is meant by strapping?**

The magnetron has eight or more coupled cavity resonators and hence several modes of oscillation are possible. The oscillating frequency of different modes are not same and are quite close to each other which results in mode jumping. i.e., a 3 cm πmode oscillation which is normal for a particular magnetron

3 π

Could become a 3.05 cm------- mode oscillation. This result

in 4

oscillations of reduced power at wrong frequency. To prevent this.Strapping is used. It consists of two rings of heavy gauge wire connecting alternate anode poles. It provides a phase difference 0f 2 π radians for the modes other π mode and thus preventing the occurrence of other modes, except the π-mode .

4. **State the applications of magnetrons. why magnetron is called as cross filed device?**

1) Pulse work in radar

2) Linear particle accelerators.

In cavity magnetron, there exists a radial electric field and an axial magnetic field perpendicular to each other and hence magnetron is called as a cross filed device.

5. What is BWO? State the applications of BWO.

A backward wave oscillator (BWO) is microwave cw oscillator with an enormous tuning and ever all frequency coverage range.

Applications:

(i) It can be used as signal source in instruments and transmitters.

(ii) It can be used as broad band noise sources which used to confuse enemy radar.

6. . What is hull cutoff condition?

In a magnetron, the electron will just graze the anode and return towards the cathode depends on Vo and Bo . The hull cut of magnetic equation is

$$Boc = (8Vo\ m / e)^{1/2}$$

$$b(1- a^2 / b^2)$$

If B0>BOe for given Vo.the electrons will not reach anode.

If Vo < Voc for a given Bo the electrons will not reach the anode.

7. What are the principal limitations of conventional negative grid electron tubes?

a. Electron transit time becomes a noticeable proportion at high frequencies.

b. Lumped electrical reactance and low Q resonant circuit.

8. What is frequency pulling and frequency pushing in magnetrons?

Frequency pulling is caused by changes in the load impedance reflected into the cavity resonators. Frequency pushing is due to the change in anode voltage which alters the orbital velocity of electron clouds.

9. .What are the applications of High Q-oscillators and amplifier circuits?

They are used in

a)Low power transmitters
b)Parametric amplifier pumps
c)Police radars and intrusion alarms.

10 .What are the Key phenomenon taking place in TRAPATT diode?

The Key phenomena are

a)Carrier generation by impact ionization producing a current pulse of phase delay of 90 degree. b)An additional phase shift introduced by the drift of carriers.

11.What is the operating frequency of TRAPATT devices?

TRAPATT devices operate at frequencies from 400 MHz to about 12GHz.

12. What are the applications of TRAPATT devices?

The applications are

a)Phased-array Radar systems
b)Intermediate frequency transmitters. c)Proxity fuse sources
d)Radio altimeters
e)Microwave landing systems.

13. What are the applications of Tunnel Diode?

a)used in self excited mixers

b)High speed switching and logic operations c)Low power oscillators.

14 .What are the elements that exhibit Gunn effect?

The elements are

a)Gallium arsenide
b)Indium phosphide
c)Cadmium telluride d)Indium arsenide.

15.What are the applications of Gunn Diode?

The applications are

a. Low and medium power oscillators
b. Used in high pump frequencies
c. Burglar alarms and aircraft rate-of-climb indicators.

16..What is negative resistance?

Negative resistance is defined as that property of a device which causes the current through it to be 180 degree out of phase with the voltage across it.

17.What are the applications of Backward diode?

a. Video detection
b. Doppler radar

18.Why are FET's preferred to bipolar transistor at high frequencies?

FET's are preferred over Bipolar transistors at high frequencies as they easily lend themselves more readily to intrgration.

19.What is the main advantage of TRAPATT over IMPATT?

TRAPATT diode has much greater efficiency than IMPATT.

20. Define GUNN EFFECT.

Guneffect was first observed by GUNN in n_type GaAs bulk diode.according to GUNN,above some critical voltage corresponding to an electric field of 2000-4000v/cm,the current in every specimen became a fluctuating fuction of time.The frequency of oscillation was determined mainly by the specimen and not by the external circuit.

21. What is MESFET?

If the field effect transistor is constructed with metal semiconductor schottky barrier diode,the device is called metal-semiconductor field effect transistor.

22..Explain stable amplification mode.

When 'n0l'product of the device is less than about 10 ^(12)/cm^2 the device exhibits amplification at transit time frequency rather than spontaneous oscillation. This is called stable amplification mode.Here n0 is the amount of doping and 'L' is the length.

23.What are the factors reducing efficiency of IMPATT diode?

1)Space charge effect
2)Reverse saturation current effect
3)High frequency skin effect
4)Ionization saturation effect.

24.Explain plasma formation in TRAPATT diode.

During the operation of the diode a high field avalanche zone propagates through the depletion region and fills the layer with a dense plasma of electrons and holes which get trapped in the low field region behind the zone.

25..What is negative resistance in gunn diode?

The carrier drift velocity increases linearly from 0 to maximum when the electric field is increased from 0 to threshold value in gunndiodes.When the electric field is beyond the threshold value of 3000v/cm the drift velocity is decreased and the diode exhibit negative resistance.

26.What are the applications of GaAsMESFET.?

a,Used in microwave integrated circuits for high power, low noise applications. b.Used in broadband amplifier application.

27.What are the applications of TRAPATT?

a)Used in airborne
b)Marine radars.

28.What is Transferred electron effect?

Some materials like GaAs exhibit negative differential mobility,when biased above a threshold value of the electric field.This behaviour is called transferred electron effect.

29.What are time parameter for TED'S

a)Domain growth time constant
b)Dielectric relaxation time
c)transit time.

30.What are the various modes of transferred electron oscillators?

a)Transit time mode
b)Quenched and delayed domain modes
c)limited space charge accumulation mode.

31.List the type of circuit used for IMPATT diode circuits.

a)Broadly tunable circuits
b)Low
'Q'circuits
c)high
'Q'circuits

32.What are the applications of low Q-oscillators and amplifier circuits?

a)Final output stage of FM telecommunication transmitter

b)Up converter pump
c)CW Doppler radar transmitter.

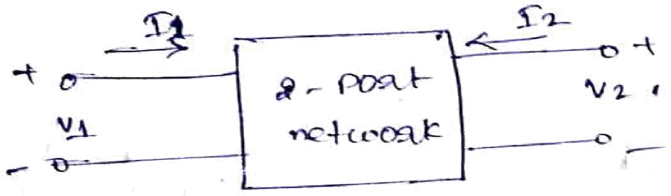
33.List some of power detecting elements?

1.Schottky diode
2.baretter
3.thermistor
4.thermocouple

and the remaining port may be one out of port (1) if due to mismatch between port (1) and microwave junction

→ Scattering (or) (S) Parameters :—

* Low frequency circuits can be described by two port networks and their parameters such as Z, Y, H, ABCD etc.) as per network theory. these the network parameters relate the total voltages and total currents as shown in fig (3)



fig(3)

* In a similar way at low frequencies, we talk of travelling waves with associated power instead of voltages and currents and the microwave junction can be defined by what are called as S-parameters (or) Scattering parameters as shown in fig (4) it can be seen that for an input at one port, we have four outputs. Similarly if we apply inputs to all the ports we will have 16 outputs. which are represented in a matrix. form and the matrix is called as a scattering matrix.
* It is a square matrix which gives all the combinations of power relations between the various input and output ports of a microwave junction.

UNIT-5

Long Answer Questions

1. **What is a scattering matrix? Discuss the importance of S-parameters. List the properties of S-matrix (Or)**

   Derive the S-Parameters for a two-port microwave Junction.

* The elements of matrix are called scattering coefficients (or) scattering (S) parameters.

* To obtain the relationship between the scattering matrix and the input / output powers at different ports consider a junction of 'n' number of transmission lines. wherein the 'i'th line is terminated in a source as shown in fig (4):

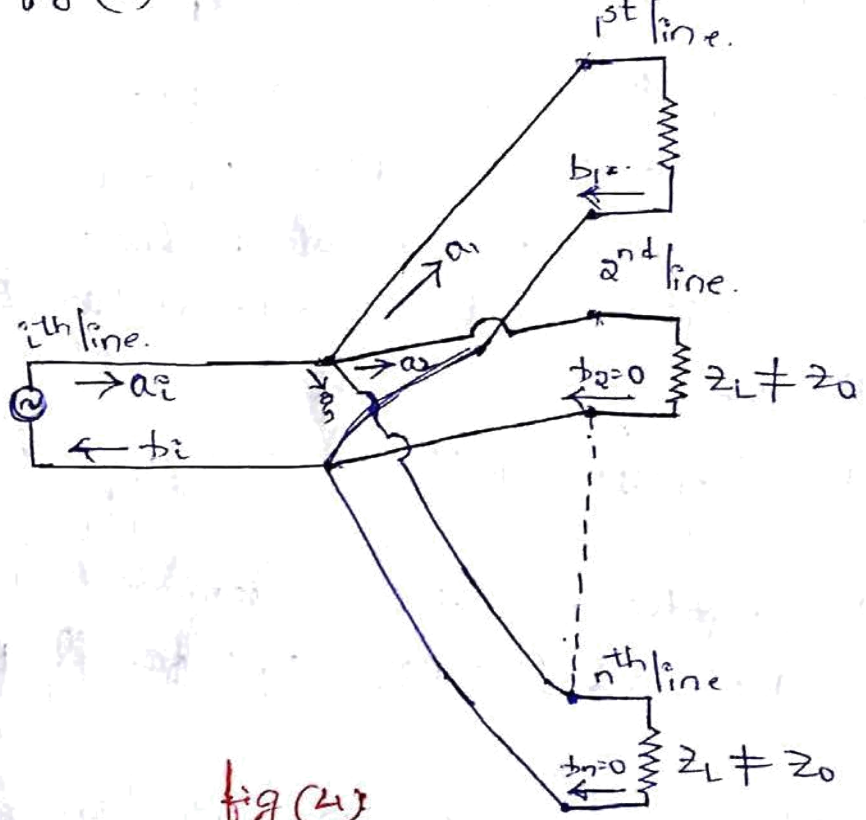


fig (4)

Case (1) :- Let the first line be terminated in an impedance other than the characteristic impedance (i.e., ~~(i.e.,~~ Z_L $(Z_L \neq Z_0)$ and all the remaining lines (from 2nd to nth line) in an impedance equal to Z_0 (i.e., $Z_L = Z_0$).

* If a_i be the incident wave at the junction due to a source at ith line, then it divides itself among (n-1) number of lines as $a_1, a_2, \ldots a_n$ as shown

in fig(4). There will be no reflections from 2nd to nth line and the incident waves are absorbed since their impedances are equal to characteristic impedance (Z_0). But there is a mismatch at the 1st line. and hence there will be a reflected wave b_1 going back into the junction.

b_1 is related to a_1 by

b_1 = (reflection coefficient) $a_1 = S_{11} a_1$

* where S_{11} = reflection coefficient of 1st line.

1 → reflection from 1st line and

i → source connected at ith line.

* Hence, the contribution to the outward travelling wave in the ith line is given by

$b_i = S_{i1} a_1$ ($\because b_2 = b_3 = \cdots = b_n = 0$).

Case(2):— Let all the (n-1) lines be terminated in an impedance other than Z_0 (i.e.) $Z_L \neq Z_0$ for all the lines)

* Then there will be reflections into the junction from every lines and hence the total contribution to the outward travelling wave in the i^{th} line is given by

$b_i = S_{i1} a_1 + S_{i2} a_2 + S_{i3} a_3 + \cdots + S_{in} a_n$

* i = 1 to n. since 'q' can be any line from 1 to n

Therefore, we have

$b_1 = S_{11} a_1 + S_{12} a_2 + S_{13} a_3 + \cdots + S_{1n} a_n$

$b_2 = S_{21} a_1 + S_{22} a_2 + S_{23} a_3 + \cdots + S_{2n} a_n$

$$b_n = S_{n1}a_1 + S_{n2}a_2 + S_{n3}a_3 + \cdots + S_{nn}a_n$$

* In matrix form:

$$\begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & \cdots & S_{1n} \\ S_{21} & S_{22} & \cdots & S_{2n} \\ \vdots & \vdots & & \vdots \\ S_{n1} & S_{n2} & \cdots & S_{nn} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_n \end{bmatrix} \quad -(2)$$

Column matrix [b] corresponding to reflected waves (or) o/p

Scattering coloumn Matrix [S] of order n×n

Matrix [a] corresponding to Incident waves (or) Input

$$\therefore [b] = [S][a] \quad -(3)$$

* When a junction of n number of waveguides is considered:

→ a's represent inputs to particular ports

→ b's represent outputs out of various ports

→ S_{ij} represents scattering coefficients resulting due to i/p at i^{th} port and output taken out of j^{th} port.

→ S_{ii} denotes how much of power is reflected back from the junction into the i^{th} port when i/p power is applied at the i^{th} port itself.

→ Properties of S-Matrix:-

1) [S] is always a square matrix of order (n×n)

2) [S] is asymmetric matrix

$$S_{ij} = S_{ji}$$

3) [S] is a unitary matrix.

i.e., $[S][S]^* = [I]$

where $[S]^*$ = complex conjugate of [S]

[I] = unit matrix or Identity matrix of the same order as that of [S]

4) The sum of the products of each term of any row (or) column multiplied by the complex conjugate of the corresponding terms of any other row (or) column is zero.

i.e., $\sum_{i=1}^{n} S_{ik} S^*_{ij} = 0 \quad k \neq j \quad \begin{pmatrix} k = 1, 2, 3, \ldots n \\ j = 1, 2, 3 \ldots n \end{pmatrix}$

5) If any of the two terminal (say reference plane (say kth port) are moved away from the junction by an electric distance $\beta_k l_k$, each of the coefficients S_{ij} involving ik will be multiplied by the factor $e^{-j\beta_k l_k}$

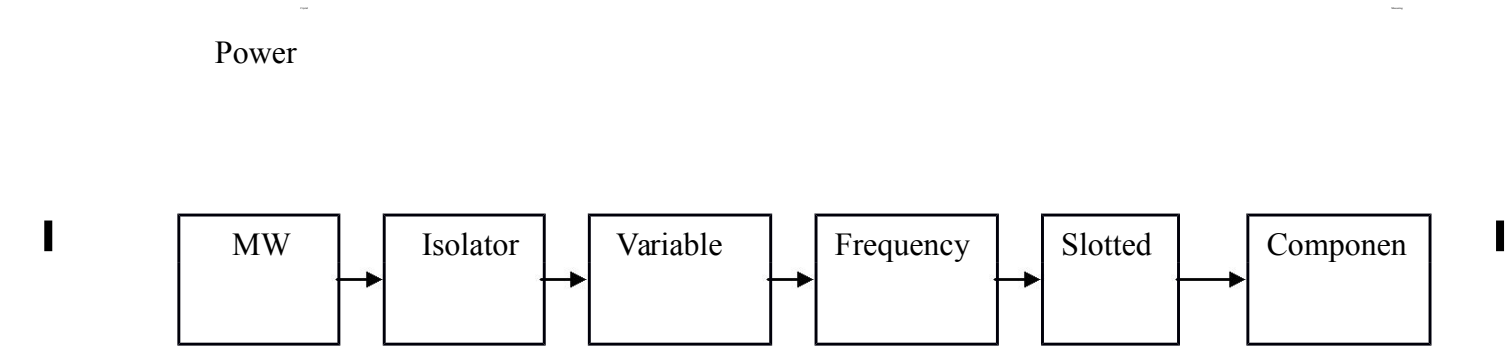
2. Explain Microwave Bench Setup.

Introduction:

Electrical measurements encountered in the microwave region of the electromagnetic spectrum are discussed through microwave measurement techniques. This measurement technique is vastly different from that of the more conventional techniques. The methods are based on the wave character of high frequency currents rather than on the low frequency technique of direct determination of current or voltage. For example, the measurement of power flow in a system specifies the product of the electric and magnetic fields .Where as the measurement of impedance determines their ratio .Thus these two measurements indirectly describe the distribution of the electric field and magnetic fields in the system and provides its complete description .This is ,in fact ,the approach to most of the measurements carried out in the micro wave region of the spectrum.

Microwave Bench:

The micro wave test bench incorporates a range of instruments capable of allowing all types of measurements that are usually required for a microwave engineer .The bench is capable of being assembled or disassembled in a number of ways to suit individual experiments .A general block diagram of the test bench comprising its different units and ancillaries are shown bellow.



1. Klystron Power Supply:

Klystron Power Supply generates voltages required for driving the reflex Klystron tube like 2k25 .It is stable, regulated and short circuit protected power supply. It has built on facility of square wave and saw tooth generators for amplitude and frequency modulation. The beam voltage ranges from 200V to 450V with maximum beam current.50mA. The provision is given to vary repeller voltage continuously from-270V DC to -10V.

2. Gunn Power Supply:

Gunn Power Supply comprises of an electronically regulated power supply and a square wave generator designed to operate the Gunn oscillator and PIN Modulator. The Supply Voltage ranges from 0 to 12V with a maximum current, 1A.

Reflex Klystron Oscillator:

At high frequencies , the performance of a conventional vacuum tube is impaired due to transit time effects, lead inductance and inter-electrode capacitance. Klystron is a microwave vacuum tube employing velocity modulation and transit time in achieving its normal operation. The reflex type known as reflex klystron, has been the most used source of microwave power in laboratory (fig.1).It consists of an electron gun producing collimated electron beam. The electron beam is accelerated towards the reflector (repellor) by a dc voltage V0, while passing through the positive resonator grids. The velocity of the electrons in the beam will be

$$v_0 = \sqrt{\frac{2eVo}{m}}$$

e = electron charge
m = mass of the electron

The repeller, which is placed at a short distance from the resonator grids, is kept at negative potential with respect to cathode. And consequently it retards and finally reflects the electrons which then turn back through the resonator grids.

Power Frequency Characteristics:

The cavities used in reflex klystrons do not have infinite Q, as such each mode of operation will be spread over a narrow range of repeller voltages. Fig.3 shows the variation of frequency and power output versus repeller voltages along with mode number. . It should, however, be noted that repeller voltage - mode number correspondence is valid only at the center of mode (maximum power) of operation. That is, the repeller voltage needed for the calculations should measure only at the peak (top) of the mode. The variation in repeller voltage from the peak of the mode causes change in transit time, as a result the bunch is either not properly formed or starts de-bunching, thereby decreasing output power and also a slight change in frequency observed.

3. Gunn oscillator:

Gunn oscillator uti1izes Gunn diode which works on the principle that when a DC voltage is applied across a sample of n-type Gallium Arsenide; the current oscillates at .microwave frequencies. This does not need high voltage as it is necessary for Klystrons and therefore solid state oscillators are now finding wide applications. Normally, they are capable of delivering 0.5 watt at 10GHz, but as the frequency of operation is increased the microwave output power gets considerably reduced.

Gunn oscillators can also be' used as modulated microwave sources. The modulation is generally provided by means of a PIN diode. PIN diode is a device whose resistance varies with the bias applied to it. When waveguide line is shunted with PIN diode and the diode is biased positively, it presents a very high impedance thereby not affecting the line appreciably. However, it is negatively biased, it offers a very low impedance, almost short-circuit thereby reflecting the microwave power incident on it. As impedance varies with bias, the signal is amplitude modulated as the bias varies. Since heavy-power is reflected during the negative biasing of PIN diode, so an isolator or an attenuator should invariably be used to isolate PIN diode and avoid overloading of the latter. Gunn oscillator can also be pulse – modulated, but it is accompanied by the frequency modulation and frequency modulation is not good, so separate PIN modulation is preferred.

4. Isolator:

This unattenuated device permits un attenuated transmission in one direction (forward direction) but provides very high attenuation in the reverse direction {backward direction). This is generally used between the source and rest of the set up to avoid overloading of the source due to reflected power.

5. Variable Attenuator:

The device that attenuates the signal is termed as attenuator. Attenuators are categorized into two categories namely, the fixed attenuators and variable attenuators. The attenuator used in the microwave set is of variable type. The variable attenuator consists of a strip of absorbing material which is arranged in such a way that its profusion into the guide is adjustable. Hence, the signal power to be fed to the microwave set up can be set at the desired level.

6. Frequency Meter:

It is basically a cavity resonator. The method of measuring frequency is to use a cavity where the size can be varied and it will resonate at a particular frequency for given size. Cavity is attached to a guide having been excited by a certain microwave source and is tuned to its resonant frequency. It sucks up some signal from the guide to maintain its stored energy. Thus if a power meter had been monitoring the signal power at the resonating condition of the cavity it will indicate a sharp dip. The tuning of the cavity is achieved by a micrometer screw and a curve of frequency versus screw setting is provided. The screw setting at which the power indication dip is noted and the frequency is read from the curve.

7. Slotted Section:

To sample the field with in a wave guide, a narrow longitudinal slot with ends tapered to provide smoother impedance transformation and thereby providing minimum mismatch, is milled on the top of broader dimension of wave guide. Such section is known as slotted wave guide section. The slot is generally so many wave lengths long to allow many minima of standing wave pattern to be covered. The slot location is such that its presence does not influence the field configurations to any great degree. On this Section a probe inserted with in a holder, is mounted on a movable carriage. The output is connected to detector and indicating meter. For detector tuning a tuning plunger is provided instead of a stub.

8. Matched Load:

The microwave components which absorb all power falling on them are matched loads. These consist of wave guide sections of definite length having tapered resistive power absorbing materials. The matched loads are essentially used to test components and circuits for maximum power transfer.

9. Short Circuit Termination:

Wave guide short circuit terminations provide standard reflection at any desired, precisely measurable positions. The basic idea behind it is to provide short circuit by changing reactance of the terminations.

10. VSWR meter:

Direct-reading VSWR meter is a low-noise tuned amplifier voltmeter calibrated in db and VSWR for use with square law detectors. A typical SWR meter has a standard tuned frequency of 100-Hz, which is of course adjustable over a range of about 5 to 10 per cent, for exact

matching in the source modulation frequency. Clearly the source of power to be used while using SWR meter must be giving us a 1000-Hz square wave modulated output. The band width facilitates single frequency measurements by reducing noise while the widest setting accommodates a sweep rate fast enough for oscilloscope presentation.

For precise attenuation measurements, a high accuracy 60 db attenuator is included with an expand offset feature that allows any 2 db range to be expanded to full scale for maximum resolution. Both crystal and bolometer may be used in conjunction with the SWR meter. There is provision for high (2,500-10,000 ohm) and low (50-200 ohm) impedance crystal inputs. This instrument is the basic piece of equipment in microwave measuring techniques and is used in measuring voltage peaks valleys, attenuation, gain and other parameters determined by the ratio of two signals.

11. Crystal Detector:

The simplest and the most sensitive detecting element is a microwave crystal. It is a nonlinear, non reciprocal device which rectifies the received signal and produces a current proportional to the power input. Since the current flowing through the crystal is proportional to the square of voltage, the crystal is rejoined to as a square law detector. The square law detection property of a crystal is valid at a low power levels (<10 mw). However, at high and medium power level (>10 mw), the crystal gradually becomes a linear detector.

Short Answer Questions

1. Define s-matrix

In a microwave junction there is intersection of three or more components.There will be an output port ,in addition there may be reflection from the junction of other ports.Totally there may be many combinations,these are represented easily using a matrix called S matrix.

2. What are the .Properties of s-matrix?

1.It possess symmetric property sij =sji

2.It possess unitary property [s][s]*=[i]

3.Why is s-matrix used in MW analysis?

S matrix is used in MW analysis to overcome the problems which occurs when H,Y,& Z parameters are used in high frequencies.

1.Equipment is not readily available to measure total voltage &total current at the ports of the network.

2.Short and open circuits are difficult to achieve over a broad band of frequencies.

3.Active devices,such as power transistor &tunnel diodes,frequently won't have stability for a short or open circuit.

4.Give ABCD matrix for a two port network

V1=A B V2
I1= C D -I2

5.What is ABCD matrix?

ABCD matrix is a transmission matrix.these parameters express voltage and current at output in terms of those at input port.
V1=AV2-BI2
I1=CV2-DI2

6.What are the advantages of ABCD matrix?

1.They are used in power transmission lines.
2.They are very helpful in the case of cascade networks.

7.What is the Scattering matrix for N port device?

[S]= S11 S12 S13…… S1n
S21 S22 ……S2n
S31 S32 ……S3n
. .
. .
Sm1 Sm2 ……...Smm

8.Give the S matrix of uniform transmission line $S = \begin{matrix} 0 & e^{-jbl} \\ e^{-jbl} & 0 \end{matrix}$

9.Give the properties of impedence [x]&admittance[y] matrix?

1.For a lossless junctionary y and z are symmetric .
2.[y]=[z] -1
3.Elements of matix [Z] &matrix [Y] are Frequency dependent.

10.What are the properties of scattering matrix for a lossless junctoion?

1.The product of any column of the S-matrix with conjugate of this column equals unity.
2.The product of any column of the scattering matrix with the complex conjugate of any other column is zero.

11.What is transmission matrix?

When a number of microwave devices are connected in cascade.Each junction is represented by a transmission matrix which gives the output quantities interms of input quantities.

12.Define one port circuit.Give two examples.

A one port circuit is a circuit for which power can enter or leave through a single wave Guide or transmission line.

Examples:

1.Short-circuited co-axial line

13.Write the voltage matrix for an N-port microwave

circuits. V1 Z11 Z12 ….. Z1N I1

V2 Z12 Z22 …… Z2N I2

. = . . …… …. .

.

VN ZN1 ZN2 . ZNN IN

Where Zij=Elements of impedence matrix. [Z]=Impedence martrix