* Microwave $freq^n$ band range :- 1 GHZ to 300 GHZ

L	:-	1 to 2 GHZ
S	:-	2 to 4 GHZ
C	:-	4 to 8 GHZ
X	:-	8 to 12 GHZ
Ku	:-	12 to 18 GHZ
K	:-	18 to 27 GHZ
Ka	:-	27 to 40 GHZ

* ISM :- Industrial scientific medical band

Bluetooth = 2.4 GHZ

Wifi = 5.2 GHZ

AM = 0.45 MHZ to 1.60 MHZ

FM = 88 MHZ to 108 MHZ

Q. * Explain Advantage of microwave

1. extremelly high B.W due to $freq^n$ range is 1 GHZ to 300 GHZ

2. Directivity :- for microwave $freq^n$ due to high $freq^n$ it is used to Satellite $comm^n$

Beam width < 1°

$B = \dfrac{140}{D/\lambda}$ D = diameter of reflector antenna.

$B = 1^\circ$, $f = 1\,GHZ$

$\lambda = \dfrac{C}{f} = \dfrac{3 \times 10^8}{10^9}$

$= 0.3m$

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$$D = \frac{140\lambda}{\beta} = \frac{140 \times 0.3}{1} = 42m$$

$B = 1^0$, $f = 10$ GHZ

$\lambda = 0.03m$

$$D = \frac{140\lambda}{\beta} = 4.2m$$

3. Transperancy property :- signal is externelly transperent so it is benifit for space commⁿ

4. less feeding :- Because of line of sight commⁿ

- Transmitted power is inversly perposnal of square of freqⁿ
- power transmission requirement less in µwave commⁿ

Q. * explain application of microwave.

1) ~> * military application (ex = Radar)
2) ~> * Telecommunication (cellular system , GSM)
3) ~> commercial application (bluetooth, zig-bee , wi-fi)
4) ~> microwave owen (food processing)

5) * In EMI [electro magnetic interference] &
EMC [electro magnetic compactibility]

6) * TEMODE [Transverce electric mode]
TEM MODE [Transverce electro - magnetic mode]

Q * defined TEMODE & TMMODE & TEMMODE

* Transmission line
- co - axial Transmission line
- Two - wire parallel x'mission line
- microstrip x'mission line.

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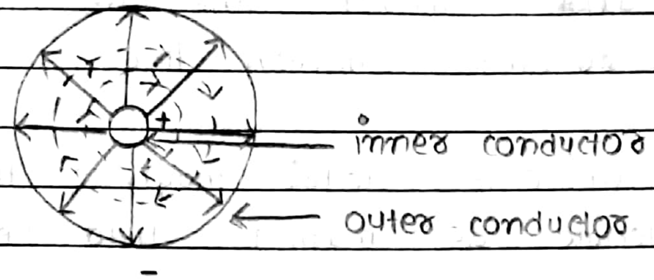
→ co-axial Transmission line

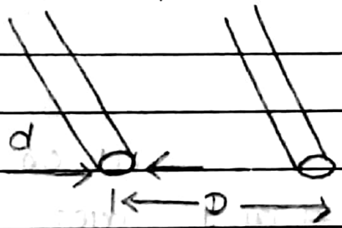


→ electric field

--→ magnetic field

- Here current is going inside the page

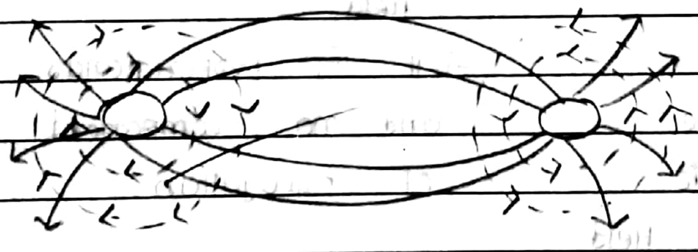
→ Two - wire parallel Transmission line



d = diameter of wire

D = spacing between two wire

R & G = 0 for ideal x'mission line



$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

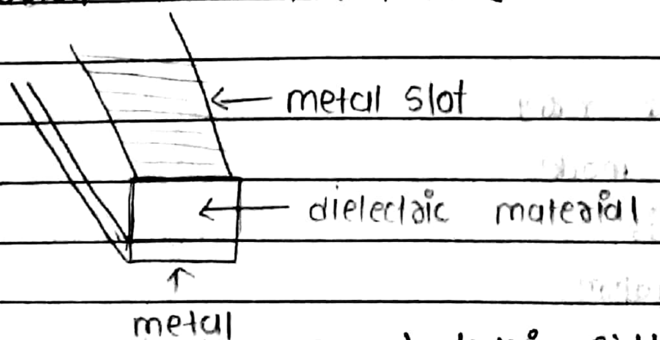
$$C = \frac{\pi \epsilon}{\ln\left(\frac{2D}{d}\right)}$$

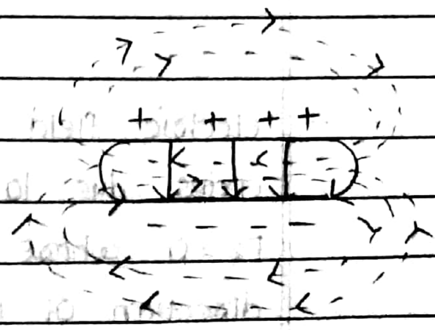
→ electric field

--→ magnetic field

$$L = \frac{\mu}{\pi} \ln\left(\frac{2D}{d}\right)$$

→ microstrip Transmission line



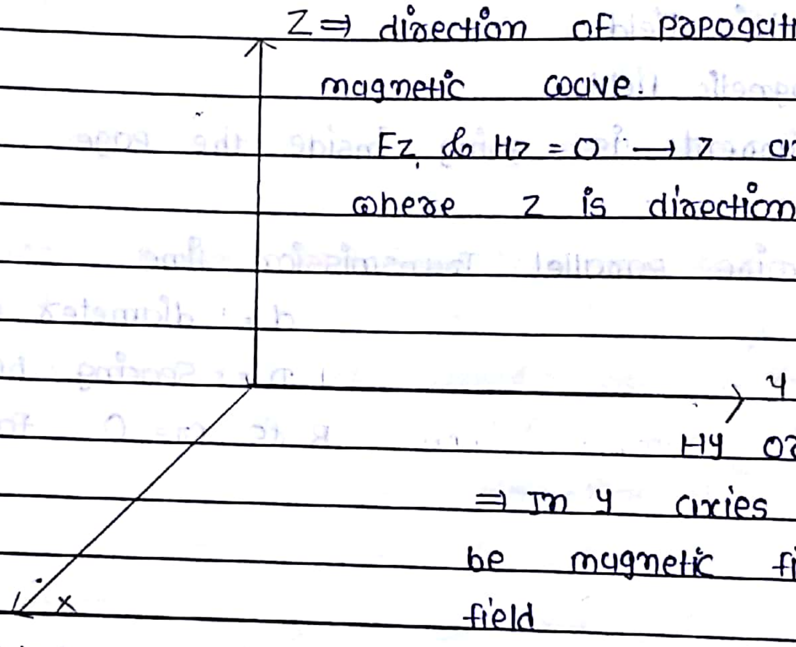


→ electric field , --→ magnetic field

Q. * explain and draw electric field & magnetic field in coaxial x'mission line & two wire parallel & micro-strip x'mission line ?

2-7

* TEM MODE [Transverse electric magnetic mode]
it's means electric & magnetic field perpendicular to propogation.



Z ⇒ direction of propogation electric & magnetic wave.

E_z & H_z = 0 → Z axies
where Z is direction OF propogation

Y

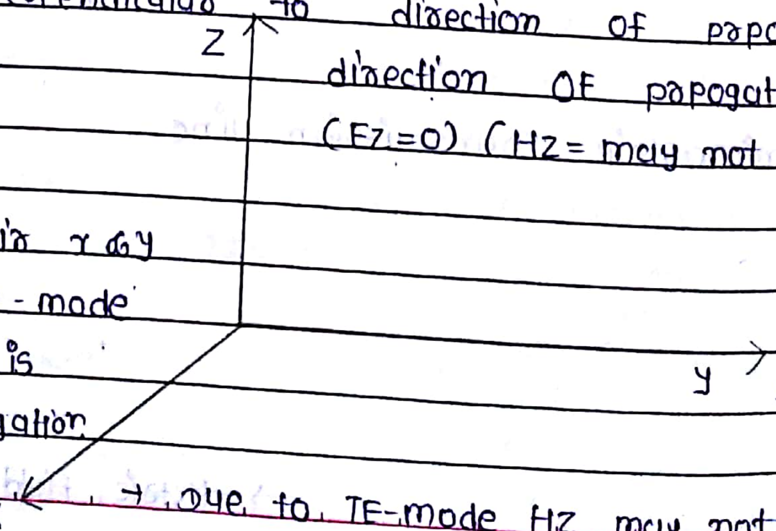
Hy or Ey
⇒ In y axies there could be magnetic field or electric field

X

Ex or Hx
In x axies there could be electric field & magnetic field

⇒ it is perpendicular each other and no component in direction OF propogation

* TE - mode [Transverse electric mode]
electric field perpendicular to direction of propogation,



Z

direction OF propogation
(E_z=0) (H_z = may not be zero)

– electric field their x & y axies due to TE-mode
E_z = 0 where z is direction OF propogation

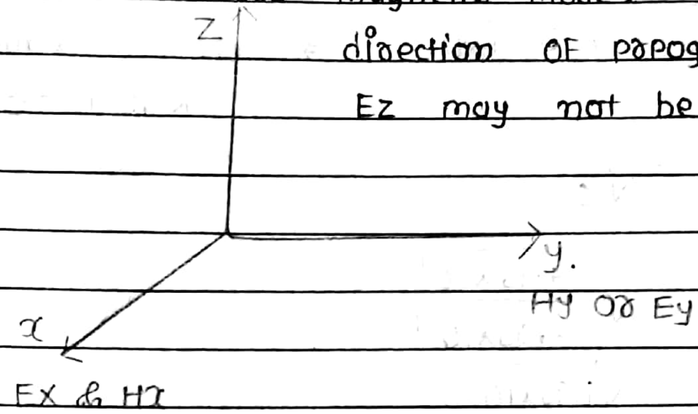
Y Hy or Ey

X → due to TE-mode HZ may not be zero.

* TM Mode :- (Transverse magnetic mode)

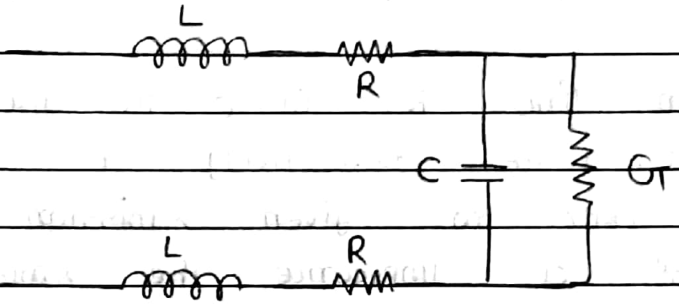
direction of propogation $H_z = 0$

E_z may not be zero



* equivalent circuit of Transmission line.

3-1



Ex If two parallel wire x'mission line separated by 2mm and diameter of wire is 0.1 mm is given for loss less x'mission line calculate
1) L 2) C 3) ch^r impedance

$$L = \frac{\mu}{\pi} \ln\left(\frac{2D}{d}\right)$$

$$= \frac{4\pi \times 10^{-7}}{\pi} \ln\left(\frac{2 \times 2 \times 10^{-3}}{0.1 \times 10^{-3}}\right)$$

$$= 14.75 \times 10^{-7}\ H$$

$$C = \frac{\pi \epsilon}{\ln\left(\frac{2D}{d}\right)} = \frac{\pi \times 8.85 \times 10^{-14}}{\ln(40)}$$

$$= 7.53 \times 10^{-14}\ F$$

$$Z = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$ ⇒ loss less x'mission line

R & $G = 0$

$$= \sqrt{\frac{L}{C}}$$

$$= \sqrt{\frac{14.75 \times 10^{-7}}{7.33 \times 10^{-14}}}$$

$$= \sqrt{1.95 \times 10^{7}}$$

$$= \sqrt{19.5 \times 10^{6}}$$

$$= 4.41 \times 10^{3}\ \Omega$$

Ex for x'mission line R, L, G, C is given by 5 Ω, 15 mH, 0.1 ℧, 1 μF respectively if operation freq^n is 1 KHZ for given x'mission line calculate ch^r of impedance the x'mission line

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

$$= \sqrt{\frac{5 + j\,(1 \times 10^{3} \times 2\pi \times 15 \times 10^{-3})}{0.1 + j\,(1 \times 10^{3} \times 2\pi \times 1 \times 10^{-6})}}$$

$$= \sqrt{\frac{5 + 30\pi j}{0.1 + 0.002\pi j}}$$

$$= \sqrt{\frac{94.38 \angle 86.96}{0.100 \angle 3.5}}$$

[POL(5, 30π) = 94.38
Alpha (tan) = 86.96]

94.38 ÷ 0.100
86.96 − 3.5

$$= \sqrt{9.438 \angle 83.46 / 2}$$

$$= \sqrt{943.8} \angle 41.73$$

$$= 30.72 \angle 41.73$$

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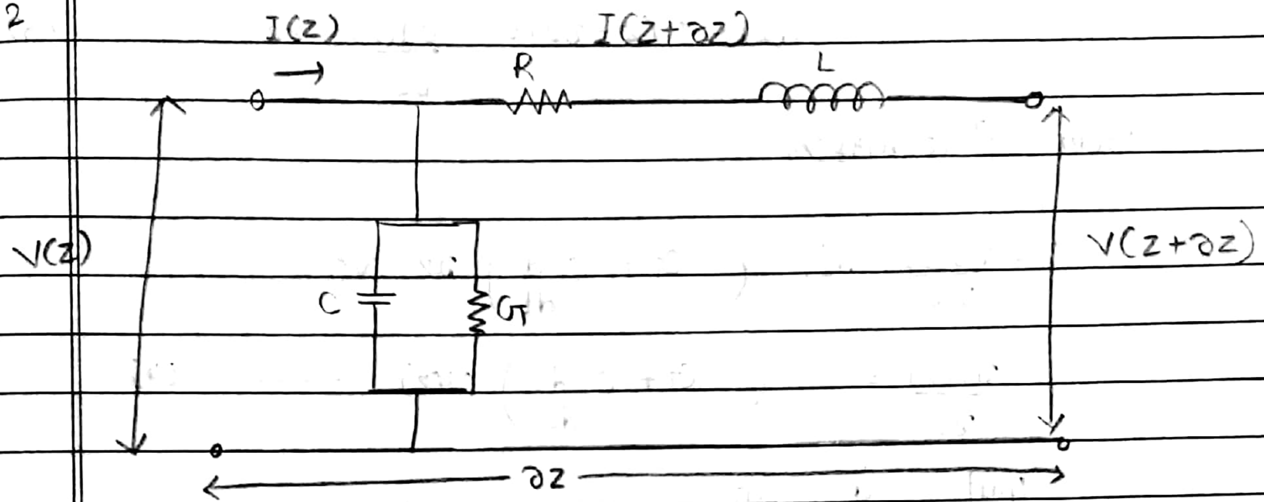
Rec (30.78 , 41.73) = Real

$Z_0 = 22.91 + i\, 20.44$ ← Alpha (tan) - imagnery

✱ Second order differential eq^n for x'mission line

3.2



Voltage drop across small x'mission line path

$$V(z) - V(z+\partial z) = R\,\partial z\, I(z+\partial z) + L\,\partial z \frac{dI(z+\partial z)}{dt}$$

$$V(z) - V(z+\partial z) = \left(R + L \frac{d}{dt} \right) \partial z\; I(z+\partial z) \quad \text{------} (1)$$

current drop across small differential length x'mission line

$$I(z) - I(z+\partial z) = G\,\partial z\, V(z) + C\,\partial z \frac{dV(z)}{dt}$$

$$I(z) - I(z+\partial z) = \left(G + C \frac{d}{dt} \right) \partial z\; V(z) \quad \text{-----} (2)$$

∂z is small differential eliment
for partial differential eq^n

$$I(z+\partial z) = I(z) + \partial I(z)$$

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we multiply & divide ∂z

$$I(z) - I(z+\partial z) = I(z+\partial z) = I(z) + \frac{\partial I(z)}{\partial z}\partial z$$

$$I(z) - I(z+\partial z) = -\frac{\partial I(z)}{\partial z}\partial z \quad \text{-----} (3)$$

from eq^n (2) & (3)

$$-\frac{\partial I(z)}{\partial z}\cancel{\partial z} = \left(\sigma + C\frac{d}{dt}\right)\cancel{\partial z}\, V(z)$$

$$\frac{\partial I(z)}{\partial z} = -\left(\sigma + C\frac{d}{dt}\right)V(z) \quad \text{------} (4)$$

that $\frac{d}{dt} = j\omega$

$$\frac{\partial I(z)}{\partial z} = -(\sigma + j\omega C)V(z) \quad \text{------} (5)$$

Similarly

$$\frac{\partial I(z)}{\partial z} = -(\sigma + Cj\omega)V(z)$$

$$\frac{\partial V(z)}{\partial z} = -(R + j\omega L)I(z) \quad \text{-----} (6)$$

By differentiator eq^n (6) w.r.t z

$$\frac{\partial^2 V(z)}{\partial z^2} = -(R + j\omega L)\frac{\partial I(z)}{\partial z}$$

From eq^n (5)

$$\boxed{\frac{\partial^2 V(z)}{\partial z^2} = (R + j\omega L)(\sigma + j\omega C)V(z)} \quad \text{-----} (7)$$

This eq^n is similar to propagation eq^n.

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$$\boxed{\frac{\partial^2 V}{\partial z^2} = \gamma^2 V} \quad ---- \quad 8$$

γ = propogation constant

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$$

- propogation constant have two arbitrary value α (real) & β (imagnerary)

α = attenuation constant

β = phase constant

$$\gamma = \alpha + j\beta$$

$$\gamma = V_1 e^{-\gamma z} + V_2 e^{+\gamma z}$$

$$= V_1 e^{-(\alpha + j\beta)z} + V_2 e^{(\alpha + j\beta)z}$$

$$= \underbrace{V_1 e^{-\alpha z} e^{-j\beta z}}_{\text{incident wave}} + \underbrace{V_2 e^{\alpha z} e^{j\beta z}}_{\text{Reflected wave}}$$

- j increase = $(V_1 e^{-\alpha z} e^{-j\beta z})$ decrease

$$\gamma = \underbrace{I_1 e^{-\gamma z}}_{\text{incident}} + \underbrace{I_2 e^{\gamma z}}_{\text{Reflected}}$$

Ex:- R = 5Ω

L = 15mH

G = $0.1℧$

C = $1\mu F$

F = 1KHZ

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$$

$$= \sqrt{(5 + j(2\pi \times 1 \times 10^3 \times 15 \times 10^{-3}))(0.1 + j(2\pi \times 1 \times 10^3 \times 1 \times 10^{-6})}$$

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$= \sqrt{(5 + j30\pi)(0.1 + j0.002\pi)}$

$= \sqrt{(94.38 \angle 86.96)\ (0.100 \angle 3.59)}$

94.38 × 0.100

86.96 + 3.59

$= \sqrt{9.438 \angle \frac{90.55}{2}}$

$= (3.072 , 45.27)$ Rec (3.072 , 45.27)

$= 2.13 + j\,2.18$ Alpha (tan)

$\boxed{\alpha = 2.13}$ $\boxed{\beta = 2.18}$

E.X R, L, G, C are given by 5 Ω, 1 mH, 0.1 ℧, 1 μF respectively find the ch^{a} impedance, propogation constant, α, β if frequency is 1 MHZ

$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$

$= \sqrt{(5 + j \times 2\pi \times 10^{6} \times 1 \times 10^{-3})\ (0.1 + j \times 2\pi \times 10^{6} , \times 10^{-6})}$

$= \sqrt{(5 + \overset{2000}{\cancel{0.002}} j\pi)(0.1 + j2\pi)}$

~~$= \sqrt{(5 \angle 0.071)\ (6.28 \angle 89)}$~~

~~$= (5.6 \angle 44.53)$~~

~~$= (3.99 \angle 3.92)$~~

$= \sqrt{(6283.18 \angle 89.95)\ (6.28 \angle 89)}$

$= 198.64 \angle 89.47$

$= (1.83$

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$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

$$= \sqrt{\frac{5 + j(2\pi \times 10^6 \times 10^{-3})}{0.1 + j(2\pi \times 10^6 \times 10^{-6})}}$$

$$= \sqrt{\frac{6283 \angle 89.94}{6.28 \angle 89.08}}$$

$$= 31.63 \angle 0.75 \ \Omega$$

propogation constant

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$$

$$= \sqrt{(6283 \angle 89.94)(6.28 \angle 89.08)}$$

$$= 198.56 \angle 89.51$$

$$= \underbrace{1.69}_{\alpha} + j\,\underbrace{198.5}_{\beta} \qquad \alpha = 1.69 \quad \beta = 198.5$$

Ex A x'mission line having following parameter $R = 2\ \Omega/m$, $G = 0.5\ m℧/m$, $L = 8\ nH/m$, $C = 0.23\ PF$, $f = 1\ GHz$ ch^r impedance, γ, α, β

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

$$= \sqrt{\frac{2 + j \times 2\pi \times 10^9 \times 8 \times 10^{-9}}{10^{-3} \times 0.5 + j \times 2\pi \times 10^9 \times 0.23 \times 10^{-12}}}$$

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$$= \sqrt{\frac{(2 + j16\pi)}{(0.0005 + j\,0.00046\pi)}}$$

$$= \sqrt{\frac{50.30 \angle 87.72}{0.00152 \angle 70.91}}$$

$$= 181.91 \angle 8.40$$
$$= (179.95 + j\,26.57)$$

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$$

$$= \sqrt{(50.30 \angle 87.72)(0.00152 \angle 70.91)}$$

$$= (0.276 \angle 79.31)$$
$$= (0.051 + j\,0.271)$$

$$\text{Phase Velocity} = \frac{\omega}{\beta}$$

$$= \frac{2\pi \times 10^9}{0.271} = 23.17 \times 10^9$$

Ex $R = 6\,\Omega / 1\,\text{km}$, $L = 2.2\,\text{mH}$, $C = 0.005\,\mu\text{F}/\text{km}$, $G = 0.005\,\mu\mho/\text{km}$, $f = 1\,\text{KHZ}$ find α, β, γ phase velocity.

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

$$= \sqrt{\frac{6 + j\,2\pi \times 10^3 \times 2.2 \times 10^{-3}}{0.005 \times 10^{-6} + j \times 2\pi \times 10^3 \times 0.005 \times 10^{-6}}}$$

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0.0000005

$$= \sqrt{\frac{6 + j\,4.4\pi}{(5\times10^{-8} + j\pi\times10^{-5})}}$$

$$= \sqrt{\frac{(15.06 \angle 66.53)}{(3.14\times10^{-5} \angle 89.08)}}$$

$$= 692.54 \angle -11.28$$

$$\gamma = \sqrt{(R + j\omega L)(G + j\omega C)}$$

$$= \sqrt{(15.06 \angle 66.53)(3.14\times10^{-5} \angle 89.08)}$$

$$= 0.0217 + j\,77.80$$

$$= \alpha = 0.0217 \;,\; \beta = 77.80$$

phase velocity $= \frac{\omega}{\beta}$

$$= \frac{2\pi\times10^{3}}{77.80}$$

$$= 0.08076$$

Ans $694 \angle -11.72$

EX:- A x'mission line has $R = 8\,\Omega/km$, $L = 2mH/km$, $C = 0.002\mu F/km$, $G = 0.07\,\mu\mho/km$, $f = 2KHZ$, find $\alpha, \beta, \gamma, Z_0, V_p$

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

$$= \sqrt{\frac{8 + j(2\pi\times2\times10^{3}\times2\times10^{-3})}{0.07\times10^{-6} + j(2\pi\times10^{3}\times2\times0.002\times10^{-6})}}$$

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$$= \sqrt{\frac{8 + j8\pi}{7\times10^{-8} + j8\times10^{-3}\pi}}$$

$$= \sqrt{\frac{26.37 \angle 72.34}{2.5\times10^{-5} \angle 89.84}}$$

$$= 1024.8 \angle -8.75$$

$$\gamma = \sqrt{(26.36\angle 72.34)(2.51\times10^{-5}\angle 89.94)}$$

$$= 0.025\angle 81.13$$
$$= 3.98\times10^{-3} + j\,0.019$$

$$V_p = \frac{\omega}{\beta} = \frac{2\times\pi\times2\times10^{3}}{0.025}$$
$$= 5.02\times10^{5}\ \text{km/s}$$

3.7 * ch^r impedance of x'mission line :-

we have seen x'mission line eq^n

$$\frac{dV}{dz} = -(R + j\omega L)\,I$$

we have seen sol^n of propogation x'mission line

$$V = V_1 e^{-\gamma z} + V_2 e^{\gamma z}$$
$$= \underbrace{V_s e^{-\gamma z}}_{\text{Incident}} + \underbrace{V_0 e^{\gamma z}}_{\text{Reflected}}$$

differential V w.r.t z

$$\frac{dV}{dz} = -\gamma V_s e^{-\gamma z} + \gamma V_0 e^{\gamma z}$$

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$$= \gamma \left(-V_s e^{-\gamma z} + V_r e^{\gamma z} \right)$$

$$\therefore \gamma \left(-V_s e^{-\gamma z} + V_r e^{\gamma z} \right) = -(R + j\omega L) I$$

$$I = \frac{\gamma \left(-V_s e^{-\gamma z} + V_r e^{\gamma z} \right)}{-(+R + j\omega L)}$$

$$= \frac{-\gamma \left(V_s e^{-\gamma z} - V_r e^{\gamma z} \right)}{-(R + j\omega L)}$$

$$= \frac{\gamma \left(V_s e^{-\gamma z} - V_r e^{\gamma z} \right)}{R + j\omega L}$$

$$\frac{\sqrt{(R + j\omega L)(G + j\omega C)} \left(V_s e^{-\gamma z} - V_r e^{\gamma z} \right)}{R + j\omega L}$$

$$= \sqrt{\frac{G + j\omega C}{R + j\omega L}} \left(V_s e^{-\gamma z} - V_r e^{\gamma z} \right)$$

$$= \frac{1}{Z_0} \left(V_s e^{-\gamma z} - V_r e^{\gamma z} \right)$$

$$\boxed{I = \frac{1}{Z_0} \left(V_s e^{-\gamma z} - V_r e^{\gamma z} \right)}$$

$$\therefore Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

- Here R & G represent lossy component of x'mission line
- It is impedance measured from two ends of x'mission line provided length of x'mission line is ∞
- x'mission line is loss less R & $G = 0$

$$Z_0 = \sqrt{\frac{L}{C}}$$

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Value OF L & C depend upon dimension & not OF x'mission line
dimension is not change so ch$^{\sigma}$ impedance is constant still freq^{n} is change.

- R & G present freq^{n} change ch$^{\sigma}$ impedance change in x'mission line.

- R & G = 0 , $\alpha = 0 \Rightarrow$ attenuation is zero

- $$\gamma = \underset{\substack{\Downarrow \\ 0}}{\alpha} + \underset{\substack{\Downarrow \\ \omega\sqrt{LC}}}{j\beta}$$

$$\gamma = \sqrt{(R+j\omega L)(G+j\omega C)}$$ R & G = 0

$$= \sqrt{j^2\omega^2 LC}$$

$$\gamma = j\omega\sqrt{LC}$$

$$\boxed{\alpha = 0 \quad , \quad \beta = j\omega\sqrt{LC}}$$

- Phase velocity $V_P = \frac{1}{\sqrt{LC}}$ for loss less x'mission line

- for two parallel wire x'mission line

$$L = \frac{\mu}{\pi} \ln\left(\frac{2D}{d}\right)$$

$$C = \frac{\pi\epsilon_0}{\ln\left(\frac{2D}{d}\right)}$$

L & C is put in $V_P = \frac{1}{\sqrt{LC}}$

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$$V_P = \frac{1}{\sqrt{\mu\epsilon_0}}$$

for air $\mu_r = 1$ $\quad \epsilon_r = 1$

$\mu = \mu_0 \mu_r$ $\qquad \epsilon = \epsilon_0 \epsilon_r$

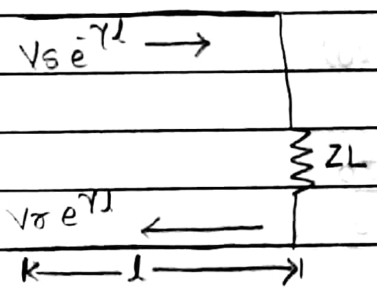
$= 4\pi \times 10^{-7} \times 1$ $\qquad = 8.85 \times 10^{-14} \times 1$

$= 4\pi \times 10^{-7}$ $\qquad = 8.85 \times 10^{-4}$

$$V_P = \frac{1}{\sqrt{4\pi \times 10^{-7} \times 8.85 \times 10^{-14}}}$$

$$V_P = 3 \times 10^{8} \text{ m/s}$$

Ex:- consider x'mission line length l (Reflection co-efficient)



- for x'mission line voltage

$$V_L = V_s e^{-\gamma l} + V_r e^{\gamma l}$$

- for load current OF x' line

$$I_l = \frac{1}{Z_0}\left[V_s e^{-\gamma l} - V_r e^{\gamma l} \right]$$

$$\Longrightarrow Z_l = \frac{V_L}{I_L} = Z_0 \left(\frac{V_s e^{-\gamma l} + V_r e^{\gamma l}}{V_s e^{-\gamma l} - V_r e^{\gamma l}} \right)$$

- Reflection coefficient

$$\rho = \frac{V_r}{V_s} = \frac{V_r e^{\gamma l}}{V_s e^{-\gamma l}}$$

$$= \left(\frac{V_r}{V_s}\right) e^{2\gamma l}$$

$$= |\rho| e^{j\psi}$$

$$Z_L = Z_0 \left(\frac{1 + \frac{V_r}{V_s} e^{2\gamma l}}{1 - V_r/V_s \, e^{2\gamma l}} \right)$$

$$Z_L = Z_0 \left(\frac{1+\rho}{1-\rho} \right)$$

$$Z_L (1-\rho) = Z_0 (1+\rho)$$

$$\rho (Z_L + Z_0) = (Z_L - Z_0)$$

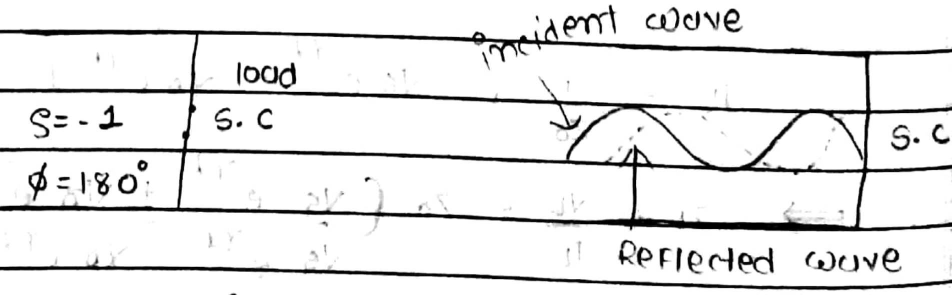
$$\boxed{\rho' = \frac{Z_L - Z_0}{Z_L + Z_0}}$$

$Z_L = 0$ $\quad \rho = -1 \quad$ phase $= +180^\circ$

$Z_L = \infty$ $\quad \rho = 1 \quad$ phase $= 0^\circ$

<u>case</u> 1 :- load is short circuit

$Z_L = 0 \quad \rho = -1 \quad$ Phase $= 180^\circ$



<u>case</u> 2 : load is open circuit

$Z_L = \infty \quad \rho = 1 \quad$ Phase $= 0^\circ$

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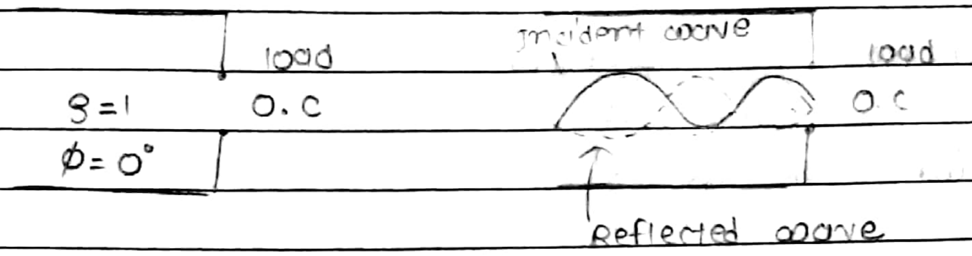

Ex:- $Z_L = 50 + j25$

$Z_0 = 75\,\Omega$

$\rho = ?$

$\rightarrow$ $\rho = \dfrac{Z_L - Z_0}{Z_L + Z_0} = \dfrac{50 + j25 - 75}{50 + j25 + 75} = \left(\dfrac{-25 + j25}{125 + j25}\right)$

$= \left(\dfrac{35.35 \angle 135}{127.47 \angle 11.30}\right)$

$= \underset{\text{reflection}}{0.277} \angle \underset{\text{phase}}{123.7}$

$Z_L = Z_0 \Rightarrow \rho = 0$

$VSWR = \dfrac{1 + \rho}{1 - \rho}$

$\rho = \dfrac{VSWR - 1}{VSWR + 1}$

Ex:- consider Z_L ~~the~~

$VSWR = \dfrac{1 + \rho}{1 - \rho}$

$= \dfrac{1 + 0.277}{1 - 0.277}$

$=$ ~~0.323~~ 1.766

$=$ ~~0.506~~

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Ex:- consider $Z_L = 100 + j25$

$Z_0 = 50\Omega$

find VSWR & ρ

$$\rho = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$= \frac{100 + j25 - 50}{100 + j25 + 50}$$

$$= \frac{50 + j25}{150 + j25}$$

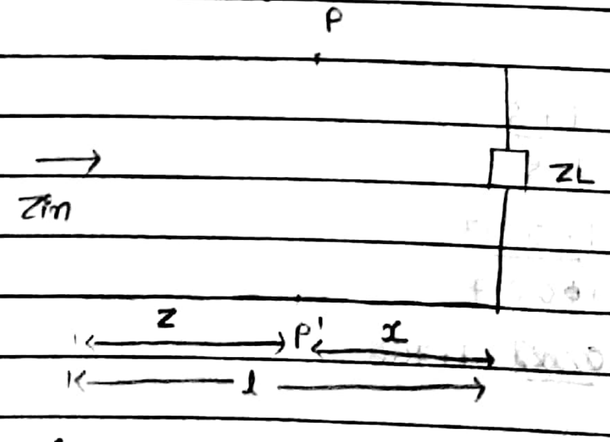
$$= \frac{55.90 \angle 26.56}{152.06 \angle 9.462}$$

$$= 0.367 \angle 17.098$$

$$VSWR = \frac{1+\rho}{1-\rho}$$

$$= \frac{1 + 0.36}{1 - 0.36} = \frac{1.36}{0.64} = 2.125$$

* line impedance & i/p impedance OF x'mission line



line impedance

$$Z_P = \frac{V_P}{I_P}$$ $$V_P = V_S e^{-\gamma x} + V_r e^{\gamma x}$$

$\text{sinc} = \frac{\sin x}{x}$

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$$= Z_0 \left(\frac{V_s e^{-\gamma x} + V_r e^{\gamma x}}{V_s e^{-\gamma x} - V_r e^{\gamma x}} \right)$$

$$= Z_0 \left(\frac{e^{-\gamma x} + V_r/V_s \, e^{\gamma x}}{e^{-\gamma x} - V_r/V_s \, e^{+\gamma x}} \right)$$

Here $\rho = \frac{V_r}{V_s}$

$$Z_P = Z_0 \frac{(e^{-\gamma x} + \rho e^{\gamma x})}{(e^{-\gamma x} - \rho e^{\gamma x})}$$

Here $\rho = \frac{Z_L - Z_0}{Z_L + Z_0}$

$$Z_P = Z_0 \left(\frac{e^{-\gamma x}(Z_L + Z_0) + (Z_L - Z_0) e^{\gamma x}}{e^{-\gamma x}(Z_L + Z_0) - (Z_L - Z_0) e^{\gamma x}} \right)$$

$$= Z_0 \left(\frac{Z_L (e^{-\gamma x} + e^{\gamma x}) + Z_0 (e^{-\gamma x} - e^{\gamma x})}{Z_L (e^{-\gamma x} - e^{\gamma x}) + Z_0 (e^{-\gamma x} + e^{\gamma x})} \right)$$

$\times \left\{ S = Z_0 \left(\cancel{Z_L} \right\} \right.$ Here $\frac{e^{-\gamma x} + e^{\gamma x}}{2} = \cosh \gamma x$

$$\frac{e^{-\gamma x} - e^{\gamma x}}{2} = \sinh \gamma x$$

$$Z_P = Z_0 \left(\frac{Z_L \cosh \gamma x + Z_0 \sinh \gamma x}{Z_L \sinh \gamma x + Z_0 \cosh \gamma x} \right)$$

$$Z_P = Z_0 \left(\frac{Z_L + Z_0 \tanh \gamma x}{Z_L \tanh \gamma x + Z_0} \right)$$

⟹ if $x = l$, $Z_P = Z_{in}$

$$Z_{in} = Z_0 \left(\frac{Z_L + Z_0 \tanh \gamma l}{Z_L \tanh \gamma l + Z_0} \right)$$

Here $\frac{Z_{in}}{Z_0} = \mathcal{Z}_{in}$, $\frac{Z_L}{Z_0} = \mathcal{Z}_L$

$$\boxed{\mathcal{Z}_{in} = \frac{\mathcal{Z}_L + \tanh \gamma l}{\mathcal{Z}_L \tanh \gamma l + 1}}$$

1 - for load to be short circuit

$\mathcal{Z}_L = 0$ $\qquad \mathcal{Z}_{in} = \tanh \gamma l$

2 - for load to be open circuit

$\mathcal{Z}_L = \infty$ $\qquad \mathcal{Z}_{in} = \coth \gamma l$

3. - for loss less x'mission line

$\alpha = 0$, $\gamma = \alpha + j\beta$

$= j\beta$

$$\mathcal{Z}_{in} = \frac{\mathcal{Z}_L + \tanh j\beta l}{\mathcal{Z}_L \tanh j\beta l + 1}$$

$$= \frac{\mathcal{Z}_L + j \tanh \beta l}{1 + j\mathcal{Z}_L \tanh \beta l}$$

open circuit, $\mathcal{Z}_L = \infty$

$$\mathcal{Z}_{in} = -j \cot h \beta l$$

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- Short circuit $Z_L = 0$

$$Z_{in} = j \tanh \beta l$$

- length of x'mission line $\lambda/4$

$$Z_{in} = \infty$$

$$Z_{in} = \frac{\frac{Z_L}{\tanh j\beta l} + 1}{Z_L + \frac{1}{\tanh j\beta l}}$$

$$Z_{in} = \frac{1}{Z_L}$$

* Voltage standing wave ratio (VSWR)

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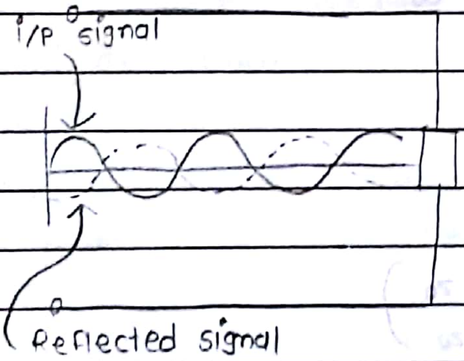
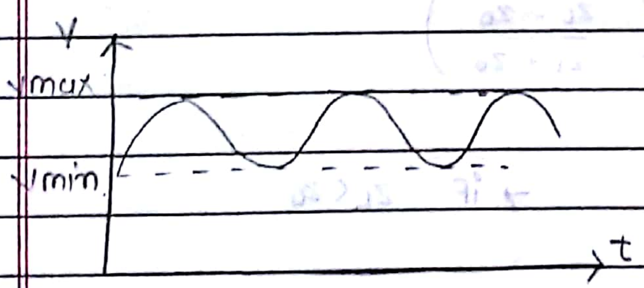


+ve +ve } in phase
-ve -ve

+ve -ve } out of phase.



if i/p voltage is V1
& Reflected voltage is V2

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$$V_{max} = V_1 + V_2 = V_1 \left(1 + \frac{V_2}{V_1} \right) = V_1 (1 + |\rho|)$$

$$V_{min} = V_1 - V_2 = V_1 \left(1 - \frac{V_2}{V_1} \right) = V_1 (1 - |\rho|)$$

$$VSWR = \frac{V_{max}}{V_{min}}$$

$$= \frac{V_1 (1 + |\rho|)}{V_1 (1 - |\rho|)}$$

$$= \frac{1 + |\rho|}{1 - |\rho|}$$

$\rho = 0$, $VSWR = 1$

$\rho = 1$, $VSWR = \infty$

VSWR range 1 to ∞

$$\rho = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$VSWR = \frac{1 + \left(\frac{Z_L - Z_0}{Z_L + Z_0} \right)}{1 - \left(\frac{Z_L - Z_0}{Z_L + Z_0} \right)}$$

→ if $Z_L > Z_0$

$$VSWR = \frac{Z_L}{Z_0}$$

→ if $Z_L < Z_0$

$$VSWR = \frac{Z_0}{Z_L}$$

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*

$$Z_{max} = \frac{V_{max}}{I_{min}}$$

$$= \frac{V_s(1+|\rho|)}{\frac{1}{Z_0} V_s(1-|\rho|)}$$

$$= \frac{Z_0 (1+|\rho|)}{\cancel{V_s}(1-|\rho|)}$$

$$\boxed{= Z_0 (VSWR)}$$

$$Z_{min} = \frac{V_{min}}{I_{max}}$$

$$= \frac{V_s(1-|\rho|)}{\frac{1}{Z_0} V_s(1+|\rho|)}$$

$$= Z_0 \left(\frac{1-|\rho|}{1+|\rho|}\right)$$

$$\boxed{= \frac{Z_0}{VSWR}}$$

Ex:- if $Z_L = 60\,\Omega$ & $Z_0 = 50\,\Omega$ then find Reflection co-effiecent, VSWR, Zmax, Zmin. if i/p voltage is 1 V then find Vmax, Vmin, Imax, Imin.

→

$$\rho = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$= \frac{10}{110}$$

$$= 0.090$$

$$VSWR = \frac{1+|\rho|}{1-|\rho|}$$

$$= \frac{1+0.09}{1-0.09}$$

$$= \frac{1.09}{0.91} = 1.19$$

$$Z_{max} = Z_0 (VSWR)$$

$$= 59.5$$

$$Z_{min} = \frac{Z_0}{VSWR}$$

$$= \frac{50}{1.19} = 42$$

$VS = 1\,V$

$$\rho = \frac{VR}{VS}$$

$VR = \rho \times VS$

$= 0.09 \times 1$

$= 0.09\,V$

$V_{max} = VS + Vr$

$= 1 + 0.09$

$= 1.09\,V$

$V_{min} = Vs - VR$

$= 1 - 0.09$

$= 0.91\,V$

$$I_{max} = \frac{V_{min}}{Z_{min}}$$

$$= \frac{0.91}{42}$$

$= 0.021$

$= 21\,mA$

$$I_{min} = \frac{V_{max}}{Z_{max}}$$

$$= \frac{1.09}{60}$$

$= 0.018\,A$

$18\,mA$

* losses in x'mission line :-

- Attenuation loss
- Reflection loss
- return loss
- x'mission loss
- insertion loss

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1. Attenuation loss :- This loss happen because of absorbtion of signal while it propogation through x'mission line.

$$L_{at} = 10 \log \left(\frac{E_i - E_r}{E_t} \right)$$

Here E_i = energy of incident signal
E_r = " " Reflected "
E_t = Total energy of propogated signal

- energy is propostional to square of voltage

$$= 10 \log \left(\frac{V_s^2 - V_r^2}{(V_s^2 - V_r^2)\, e^{-2\alpha l}} \right)$$

$$= 10 \log \left(\frac{1}{e^{-2\alpha l}} \right)$$

$$= 10 \log (e^{2\alpha l})$$

$$= 20 \log e^{\alpha l}$$

$$= 20 \alpha l \log e$$

Attenuation loss $= 8.686\, \alpha l$

2. Reflection loss :- This loss happen because of missmatch of signal & x'mission line

$$L_{Ref} = 10 \log \left(\frac{E_i}{E_i - E_r} \right)$$

$$= 10 \log \left(\frac{V_s^2}{V_s^2 - V_r^2} \right)$$

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$$= 10 \log \left(\frac{1}{1 - \left(\frac{V_r}{V_s}\right)^2} \right)$$

$$= 10 \log \left(\frac{1}{1 - |S|^2} \right)$$

3) X'mission loss :- A loss associated with signal transmitted from i/p to o/p

$$L_{trans} = 10 \log \frac{E_i}{E_t}$$

$$= 10 \log \left(\frac{E_i}{(E_i - E_r)} \times \frac{(E_i - E_r)}{E_t} \right)$$

$$= 10 \log \left(\frac{E_i}{E_i - E_r} \right) + 10 \log \left(\frac{E_i - E_r}{E_t} \right)$$

$$= L_{ref} + L_{at}$$

$$= 10 \log \left(\frac{1}{1 - |S|^2} \right) + 8.686 \alpha l$$

4) Return loss :- This loss happen because of mismatch of load to the x'mission line

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$$l_{ret} = 10 \log \frac{E_i}{E_r}$$

$$= 10 \log \frac{V_i^2}{V_r^2}$$

$$= 10 \log \frac{1}{|S|^2}$$

$= -10 \cdot \log |\rho|^2$

$L_{ret} = -20 \log \rho$

5) insertion loss :- This loss happen because of x'mission line inserted.

$$L_{ins} = 10 \log \frac{E_1}{E_2}$$

here E_1 = energy with x'mission line
E_2 = " without " "

EX for a x'mission line ch^r impedance is 75 Ω & load impedance is 50 + j50 if length of x' line to be 10 m calculate.

1) Reflection co-efficent
2) VSWR
3) Zmax
4) Zmin
5) Attenuation loss
6) Reflection "
7) x'mission "
8) Return "

given $\alpha = 0.02$ (attenuation constant)

$$\rho = \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$= \frac{50 + j50 - 75}{50 + j50 + 75}$$

$$= \frac{-25 + j50}{125 + j50}$$

$$= \frac{55.90 \angle 116.56}{134.62 \angle 21.80}$$

$$= 0.415 \angle 94.76$$

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$\rightarrow$ $VSWR = \dfrac{1+S}{1-S}$

$= \dfrac{1+0.415}{1-0.415} = \dfrac{1.415}{0.585} = \underline{\underline{2.41}}$

$\rightarrow$ $Z_{max} = Z_0 (VSWR)$

$= 75 (2.41)$

$= 181.41$

$Z_{min} = \dfrac{Z_0}{VSWR}$

$= \dfrac{75}{2.41} = 31.12$

$\rightarrow$ $L_{at} = 8.686 \alpha l$

$= 8.686 \times 0.02 \times 10$

$= 1.73$ dB

$\rightarrow$ $L_{Ref} = 10 \log \left(\dfrac{1}{1-S^2} \right)$

$= 10 \log \left(\dfrac{1}{1-(0.415)^2} \right)$

$= 10 \log (1.2)$

$= 0.82$ dB

$\rightarrow$ R $L_{trans} = 10 \log \left(\dfrac{1}{1-|S|^2} \right) + 8.686 \alpha l$

$= 0.82 + 1.73$

$= 2.55$ dB

$\rightarrow$ $L_{Ret} = -20 \log S$

$= -20 \log (0.415)$

$= 7.64$ dB

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* Impedance Matching :- it is essentiale to power x'fer theorem

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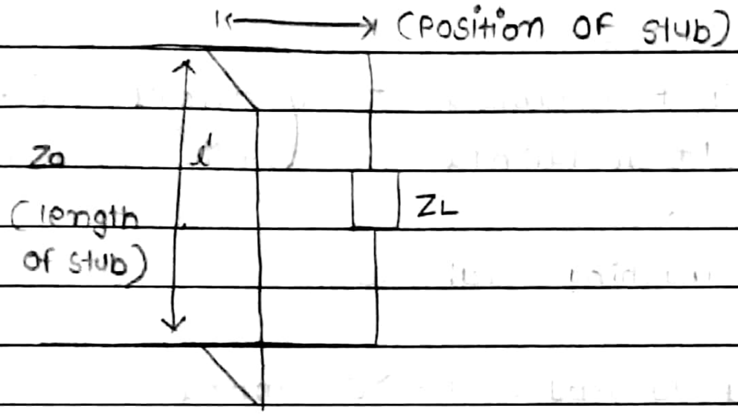
- Based on proper tuning of impedance power get x'fer
- Reflection from line & load depends on calibration of impedance



→ input impedance of x' line

$$Z_{in} = Z_0 \left(\frac{Z_L + Z_0 \tanh \gamma l}{Z_0 + Z_L \tanh \gamma l} \right)$$

By translating this eq^n admittiance

$$Y_{in} = Y_0 \left(\frac{Y_L + Y_0 \tanh \gamma l}{Y_0 + Y_L \tanh \gamma l} \right)$$

Here $\frac{y_L}{y_0} = Y_L$, $\frac{y_{in}}{y_0} = Y_{in}$

$$Y_{in} = \frac{Y_L + \tanh \gamma l}{1 + Y_L \tanh \gamma l}$$

for lossless x'mission line

$\gamma = \alpha + j\beta$

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$$\alpha = 0 , \quad \gamma = j\beta$$

$$Y_{in} = \frac{Y_L + j \tanh \beta l}{1 + j Y_L \tanh \beta l}$$

$$Y_{in} = \frac{Y_L + j \tanh \beta l}{1 + j Y_L \tanh \beta l} \times \frac{1 - j Y_L \tanh \beta l}{1 - j Y_L \tanh \beta l}$$

$$Y_{in} = \frac{Y_L + Y_L \tan^2 h \beta l}{1 + Y_L^2 \tan^2 h \beta l} + j\left(\frac{\tanh \beta l - Y_L^2 \tanh \beta l}{1 + Y_L^2 \tan^2 h \beta l}\right)$$

for impedance matching real parts

all are Y_L capital

$$Y_L + Y_L \tan^2 h \beta l = 1 + Y_L^2 \tan^2 h \beta l$$

$$Y_L - 1 = \tan^2 h \beta l \,(Y_L^2 - Y_L)$$

$$Y_L - 1 = Y_L (Y_L - 1) * \tan^2 h \beta l$$

$$\tan^2 h \beta l = 1 / Y_L$$

$$\tanh \beta l = \frac{1}{\sqrt{Y_L}}$$

$$\tanh \beta l = \sqrt{\frac{Y_0}{Y_L}}$$

By conversion from admittance to impedance.

$$\tanh \beta l = \sqrt{\frac{Z_L}{Z_0}}$$

$$\beta l = \tan^{-1} \sqrt{\frac{Z_L}{Z_0}}$$

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$(\beta = \frac{2\pi}{\lambda})$

$$\boxed{l = \frac{\lambda}{2\pi} \tan^{-1} \sqrt{\frac{Z_L}{Z_0}}}$$

$$b = \frac{\tanh \beta l - y_L^2 \tanh \beta l}{1 + y_L^2 \tanh^2 \beta l}$$

$$b = \frac{\tanh \beta l \, (1 - y_L^2)}{1 + y_L^2 \tan^2 h \, \beta l}$$

$$b = \frac{1/\sqrt{y_L} \, (1 - y_L^2)}{1 + y_L^2 \left(\frac{1}{y_L}\right)}$$

$$= \frac{1 + y_L^2}{y_L}$$

$$b = \frac{1 - y_L^2}{\sqrt{y_L}\,(1 + y_L)}$$

$$\frac{y_L + y_L^2}{y_L} = (1 + y_L)$$

$$b = \frac{1 - y_L}{\sqrt{y_L}}$$

- Transforming eq^n from admittance to impedance

$$b = \frac{1 - 1/z_L}{\sqrt{\frac{1}{z_L}}}$$

$$b = \frac{z_L - 1}{\sqrt{z_L}}$$

Here $z_L = \frac{Z_L}{Z_0}$

$$b = \frac{Z_L - Z_0}{\sqrt{Z_L Z_0}}$$

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from exprimnet value of b is $\cot \beta l'$

$$\cot \beta l' = \frac{Z_L - Z_0}{\sqrt{Z_L Z_0}}$$

$$\tan \beta l' = \frac{\sqrt{Z_L Z_0}}{Z_L - Z_0}$$

$$~~l' = \frac{\lambda}{2\pi} \tan^{-1}\left(\frac{\sqrt{Z_L Z_0}}{Z_L - Z_0}\right)~~$$

Ex:- If ch^r impedance of x'line is 50 Ω terminated by load to be 60 Ω if operating freq^n is 1 GHz then find length & position of stub to have a proper impedance matching.

→ $Z_0 = 50\Omega$ $f = 1\,GHz$

$Z_L = 60\Omega$

$$f = \frac{c}{\lambda} \qquad \lambda = \frac{c}{f}$$

$$= \frac{3\times10^8}{10^9}$$

$$= 0.3\,m$$

$$l = \frac{\lambda}{2\pi} \tan^{-1}\sqrt{\frac{Z_L}{Z_0}}$$

$$= \frac{0.3\times10}{2\pi} \tan^{-1}\sqrt{\frac{60}{50}}$$

$$= 0.039\,m\,(rad)$$

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$$l'' = \frac{\lambda}{2\pi} \tan^{-1}\left(\frac{\sqrt{Z_L \times Z_0}}{Z_L - Z_0}\right)$$

$$= \frac{0.9}{2\pi} \tan^{-1}\left(\frac{\sqrt{3000}}{10}\right)$$

$$\boxed{= 0.066\ m\ (rad)}$$

Ex If x'line operating at 0.1 m terminated by 90 Ω load having ch^r impedance of 100 Ω calculate length & position of stub to have proper impedance matching

$\lambda = 0.1$

$Z_L = 90\ \Omega$

$Z_0 = 100\ \Omega$

$$l = \frac{\lambda}{2\pi} \tan^{-1}\sqrt{\frac{Z_L}{Z_0}}$$

$$= \frac{0.1}{2\pi} \tan^{-1}\sqrt{\frac{90}{100}}$$

$$= 0.012\ m$$

$$l' = \frac{\lambda}{2\pi} \tan^{-1}\left(\frac{\sqrt{Z_L Z_0}}{Z_L - Z_0}\right)$$

$$= \frac{0.1}{2\pi} \tan^{-1}\left(\frac{\sqrt{9000}}{-10}\right) \qquad \frac{0.1}{2\pi}\left[\pi - \tan^{-1}(9.48)\right]$$

$$= 0.0266\ m$$

Ex :- For x'line R L G C are given by 5 Ω, 1 μH, 2 PF, 0.1 ℧ Respectively for 1 MHz freq^n calculate

1) ch^r imepedance Z_0 3) attenuation constant α

2) propogation constant γ 4) phase constant β

5) phase velocity

6) If load is terminated by 50 Ω then calculate Reflection co-efficient, VSWR, Zmax, Zmin

→

$R = 5\,\Omega$, $L = 1\times10^{-6}\,H$, $\sigma = 0.1\,℧$, $C = 2\times10^{-12}\,F$

→ $Z_0 = \sqrt{\dfrac{R + j\omega L}{\sigma + j\omega C}}$

$= \sqrt{\dfrac{5 + (j2\pi\times10^6\times1\times10^{-6})}{0.1 + (j2\pi\times10^6\times2\times10^{-12})}}$

$= \sqrt{\dfrac{8.029\angle 51.48}{0.1\angle 0.0071}}$

$= 8.96\angle 25.73$

$= 8.07\angle 3.88$

→ $\gamma = \sqrt{(R + j\omega L)(\sigma + j\omega C)}$

$= \sqrt{(8.029\angle 51.48)(0.1\angle 0.0071)}$

$= 0.89\angle 25.74$

$= \underbrace{0.80}_{\alpha} + j\underbrace{0.38}_{\beta}$

→ $V_p = P.V = \dfrac{\omega}{\beta}$

$= \dfrac{2\pi\times10^6}{0.38}$

$= 16.53$ MV

8 07 + j3.88

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→ $\rho = \frac{Z_L - Z_0}{Z_L + Z_0}$

$= \frac{50 - 8.07 - j3.88}{50 + 8.07 + j3.88}$

$= \frac{42.15 \angle -5.28}{58.18 \angle 3.82}$

$= 0.724 \angle -9.1$

→ $VSWR = \frac{1+\rho}{1-\rho}$

$= \frac{1+0.724}{1-0.724}$

$= 6.24$

→ $Z_{max} = Z_0(VSWR)$

$= 8.96(6.24)$

$= 55.91$

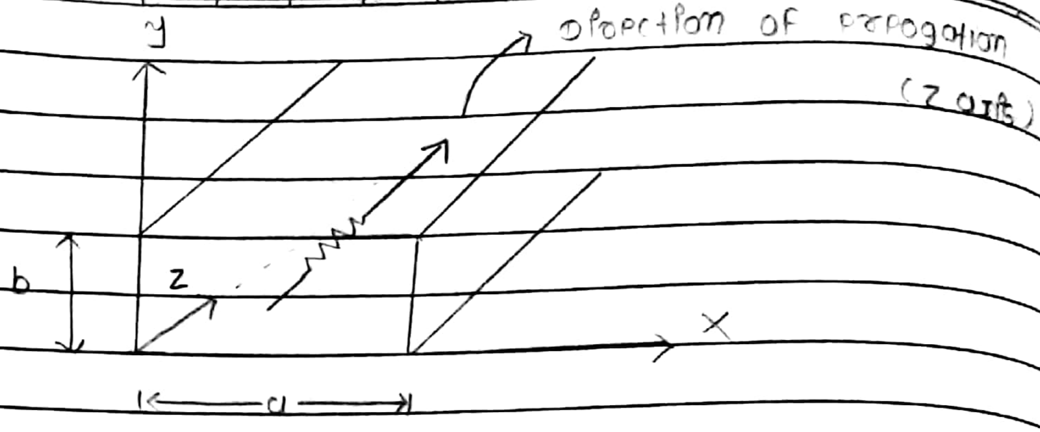
→ $Z_{min} = \frac{Z_0}{VSWR}$

$= \frac{8.96}{6.24} = 1.43$

* Rectangular waveguide & it's propogation eq^n

or

why TEM mode is not possible to rectangular waveguide



→ for TE mode $E_z = 0$

$$\nabla^2 H_z = -\omega^2 \mu \epsilon H_z \qquad ---- (1)$$

→ for TM mode , $H_z = 0$

$$\nabla^2 E_z = -\omega^2 \mu \epsilon E_z \qquad ---- (2)$$

→ From eq^n (1)

$$\frac{\partial^2 H_z}{\partial x^2} + \frac{\partial^2 H_z}{\partial y^2} + \frac{\partial^2 H_z}{\partial z^2} = -\omega^2 \mu \epsilon H_z \quad ---- (3)$$

Here propagation is along with z

$$\text{So,} \quad \frac{\partial^2}{\partial z^2} = \gamma^2 \qquad ---- (4)$$

$$\frac{\partial^2 H_z}{\partial x^2} + \frac{\partial^2 H_z}{\partial y^2} + \gamma^2 H_z + \omega^2 \mu \epsilon H_z = 0$$

$$\frac{\partial^2 H_z}{\partial x^2} + \frac{\partial^2 H_z}{\partial y^2} + (\gamma^2 + \omega^2 \mu \epsilon) H_z = 0$$

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→ consider $\gamma^2 + \omega^2 \mu \epsilon = h^2$

$$\boxed{\frac{\partial^2 H_z}{\partial x^2} + \frac{\partial^2 H_z}{\partial y^2} + h^2 H_z = 0} \quad ----- \langle 9 \rangle \qquad eq\ (1)$$

→ Similarly, TM mode

$$\boxed{\frac{\partial^2 E_z}{\partial x^2} + \frac{\partial^2 E_z}{\partial y^2} + h^2 E_z = 0} \quad ------ \langle 6 \rangle \qquad (2)$$

→ As per Maxwell's eq^n

$$\nabla \times \vec{H} = j\omega\epsilon \vec{E}$$

$$= \begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ H_x & H_y & H_z \end{vmatrix} = j\omega\epsilon (E_x \hat{i} + E_y \hat{j} + E_z \hat{k})$$

$$\boxed{\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} = j\omega\epsilon E_x} \qquad (3)$$

$$\boxed{\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} = j\omega\epsilon E_y} \qquad (4)$$

$$\boxed{\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} = j\omega\epsilon E_z} \qquad (5)$$

→ As per maxwell's eq^n

$$\nabla \times \vec{E} = -j\omega\mu \vec{H}$$

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$$\begin{vmatrix} \hat{i} & \hat{j} & \hat{k} \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ E_x & E_y & E_z \end{vmatrix} = -j\omega\mu \vec{H} = -j\omega\mu (H_x \hat{i} + H_y \hat{j} + H_z \hat{k})$$

$$\boxed{\frac{\partial E_z}{\partial y} - \frac{\partial E_y}{\partial z} = -j\omega\mu H_x} \quad (6)$$

$$\boxed{\frac{\partial E_x}{\partial z} - \frac{\partial E_z}{\partial x} = -j\omega\mu H_y} \quad (7)$$

$$\boxed{\frac{\partial E_y}{\partial x} - \frac{\partial E_x}{\partial y} = -j\omega\mu H_z} \quad (8)$$

⇒ Solution:

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

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

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

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

– In TEM mode, popogation is peependiculaa

$E_z, H_z = 0$

~~TEM~~ TEM

- if $E_z, H_z = 0$ then $\Rightarrow E_x, E_y, H_x, H_y = 0$
- Hence nothing can papogate in TEM mode for rectangular mode

⇒ Dominal mode - TE_{10} mode $m = 1$, $n = 0$

$$\lambda_c = \frac{2ab}{\sqrt{m^2b^2 + n^2a^2}}$$

⇒ guided wavelength :-

- distance maxima bet^n two maxima $= \frac{\lambda g}{2}$

- maxima minima $= \frac{\lambda g}{4}$

- minima minima $= \frac{\lambda g}{2}$

→ operating wave-length

$$\lambda_0 = \frac{c}{f_0}$$

→ cutoff wavelength

$$\lambda_c = \frac{2ab}{\sqrt{m^2b^2 + n^2a^2}}, \quad TE_{mn}$$

→ guided wave-length

$$\lambda_g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$$

→ phase Velocity

$$V_p = \frac{c}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$$

→ guided velocity

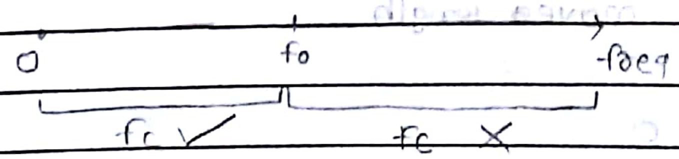
$$V_p V_g = c^2$$

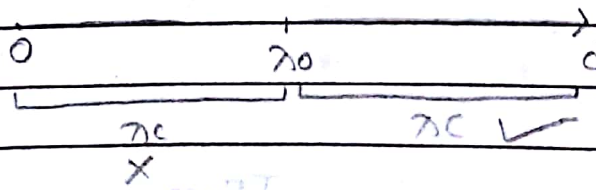
phase Velocity > light Velocity in rectangular waveguide.

for propogation in rectangular waveguide

$\lambda_c > \lambda_0$

$f_c > f_0$





Ex:- when the dominal mode is propogated in air field rectangular waveguide the guide wavelength for a freq^n of 9000 mHZ is 4 cm calculate the dimension of waveguide.

→ $\lambda g = 4cm$

$f = 9000\ mHZ$

→ $\lambda o = \frac{c}{fo}$

$= \frac{3\times10^{8}}{9000\times10^{6}}$

$= 3.33\times10^{-2}$

$= 3.33\ cm$

→ $\lambda g = \frac{\lambda o}{\sqrt{(1-(\frac{\lambda o}{\lambda c})^2}}$

$\lambda g^2 = \frac{\lambda o^2}{1-(\frac{\lambda o}{\lambda c})^2}$

$\cancel{S} = \frac{(3.33\times10^{-2})^2}{1-(3.33\times10^{-2}}$

$(4\times10^{-2})^2 = \frac{(3.33\times10^{-2})^2}{1-(\frac{3.33\times10^{-2}}{\lambda c})^2}$

$1-(\frac{3.33\times10^{-2}}{\lambda c})^2 = \frac{(3.33\times10^{-2})^2}{(4\times10^{-2})^2}$

$1-(\frac{3.33\times10^{-2}}{\lambda c})^2 = 0.693$

$1-0.693 = (\frac{3.33\times10^{-2}}{\lambda c})^2$

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$$0.3069 = \frac{(3.33 \times 10^{-2})^2}{\lambda c^2}$$

$$\lambda c^2 = \frac{(3.33 \times 10^{-2})^2}{0.3069}$$

$$= 36.1269$$

$$\lambda c = \underline{6.01 \text{ cm}}$$ $\lambda c = (5.08 \text{ cm})$

→ $$V_p = \frac{c}{\sqrt{1-\left(\frac{\lambda_0}{\lambda c}\right)^2}}$$

$$V_p = \frac{c}{\sqrt{1-\left(\frac{\lambda_0}{\lambda c}\right)}}$$

$$= \frac{(3 \times 10^8)}{\sqrt{1-\left(\frac{3.33 \times 10^{-2}}{6.01 \times 10^{-2}}\right)}}$$

$$= \frac{3 \times 10^8}{0.8324}$$

$$V_p = 3.60 \times 10^8 \text{ m/s}$$ $\boxed{3.97 \times 10^8 \text{ m/s}}$

$$V_p V_g = c^2$$

→ $$V_g = \frac{c^2}{V_p}$$

$$= \frac{(3 \times 10^8)^2}{(3.97 \times 10^8)}$$

$$= 2.26 \times 10^8 \text{ m/s}$$

$\lambda c = 5.84 \text{ cm}$. $V_p = 3.64 \times 10^8$ m/s

$a = 2.92$ $V_g = 2.26 \times 10^8$

$b = 1.46$

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Ex determine the λc for dominal mode in rectangular waveguide is 10 cm for 2.5 GHZ signal propagated in this waveguide in dominal mode. calculate λg, VP, Vg,

$a = 10\,cm$

→ $fo = 2.5 \times 10^9$

→ $\lambda o = \frac{c}{fo}$

$= \frac{3 \times 10^8}{2.5 \times 10^9}$

$= 0.12\,m$

→ $\lambda c = 2 \times a$

$= 2 \times 10$

$= 20\,cm$

$= 0.2\,m$

→ $\lambda g = \frac{\lambda o}{\sqrt{1 - \left(\frac{\lambda o}{\lambda c}\right)^2}}$

$= \frac{0.12\,m}{\sqrt{1 - \left(\frac{0.12}{0.2}\right)^2}}$

$= 0.15\,m$

→ $VP = \frac{c}{\sqrt{1 - \left(\frac{\lambda o}{\lambda c}\right)^2}}$

$= \frac{3 \times 10^8}{\sqrt{1 - \left(\frac{0.12}{0.2}\right)^2}}$

$= 3.75 \times 10^8\,m/s$

→ $Vg = \frac{c^2}{Vp} = 2.4 \times 10^8\,m/s$

$\frac{(3 \times 10^8)^2}{(3.75 \times 10^8)}$

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Ex The dimensions of waveguide are $2.5 \times 1 cm^2$
$f_0 = 8.6$ GHz
1) find possible modes — TE10 mode
2) cutoff freq^n
3) guided waveguide.

$a = 2.5 \qquad b = 1 cm^2$
$f_0 = 8.6 \times 10^9$

$$\lambda_0 = \frac{c}{f_0} = \frac{3 \times 10^8}{8.6 \times 10^9}$$
$$= 0.03 m$$

1) TE10 mode

$$\lambda c = \frac{2ab}{\sqrt{m^2b^2 + n^2a^2}} = \frac{2 \times 2.5 \times 1}{1}$$

$$= 5 cm$$

→ $$\lambda g = \frac{\lambda_0}{\sqrt{1 - \left(\frac{\lambda_0}{\lambda c}\right)^2}}$$

$$= \frac{0.034}{\sqrt{1 - \left(\frac{0.034}{5 \times 10^{-2}}\right)^2}}$$

$$= 4.63 cm$$

$$\lambda c = \frac{c}{fc}$$

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$$f_c = \frac{c}{\lambda_c} = \frac{3\times10^8}{0.04635\times10^{-2}} = 64.79\times10^8 = 6\ GHz$$

2) TE11 mode

$$\lambda_c = \frac{2ab}{\sqrt{a^2+b^2}}$$

$$= \frac{\cancel{2a}\times 5}{\sqrt{6.25+1}}$$

$$= 1.85\ cm$$

$\lambda_0 > \lambda_c$ it is not possible

Ex:- A Rectangular waveguide have dimension $4\times3\ cm^2$ $f_0 = 5\ GHz$ calculate all possible mode & for those mode calculate λ_g & f_c

→ $$\lambda_0 = \frac{c}{f_0}$$

$$= \frac{3\times10^8}{5\times10^9}$$

$$= 0.06\ m$$

1) for TE10 mode

$$\lambda_c = 2a$$

$$= 2\times4$$

$$= 8cm$$

$\lambda_c < \lambda_0$

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$$\lambda g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda c}\right)^2}}$$

$$fc = \frac{c}{\lambda c}$$

$$= \frac{3\times 10^8}{8\times 10^{-2}}$$

$$= \frac{0.06}{\sqrt{1-\left(\frac{0.06}{8\times10^{-2}}\right)^2}}$$

$$= 3.75 \text{ GHz}$$

$$= 9.07 \text{ cm}$$

2) for TE11 mode

$$\lambda c = \frac{2ab}{\sqrt{a^2+b^2}}$$

$$= \frac{2\times4\times3}{\sqrt{16+9}}$$

$$= 4.8 \text{ cm}$$

$\lambda c < \lambda_0$ is not possible

Ex for TE_{10} mode propogaten in rectangular waveguide of dimension 6×4 cm^2 by means of traveling detector the distance betn maxima & minima founded to be 4.55cm find the freqn of waveguide.

$a=6$, $b=4$ mode = TE_{10}

for TE10 mode $\lambda c = 2a$

$= 2\times6$

$= 12$ cm

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maxima , minima $= \frac{\lambda g}{4}$

$$4.55 = \frac{\lambda g}{4}$$

$$\lambda g = 18.2 cm$$

$$\lambda g = \frac{\lambda o}{\sqrt{1-\left(\frac{\lambda o}{\lambda c}\right)^2}}$$

$$\lambda g^2 = \frac{\lambda o^2}{1-\left(\left(\frac{\lambda o}{\lambda c}\right)^2\right)}$$

$$\lambda o = \lambda g\left(\sqrt{1-\left(\frac{\lambda o}{\lambda c}\right)^2}\right)$$

$$\left(\frac{\lambda o}{\lambda g}\right)^2 = 1-\left(\frac{\lambda o}{\lambda c}\right)^2$$

$$\frac{\lambda o^2}{(18.2)^2} = 1 - \frac{(\lambda o)^2}{(12)^2}$$

$$\lambda o^2 = 331.24 - 2.3\lambda o^2$$

$$3.3\lambda o^2 = 331.24$$

$$\lambda o = 10 cm$$

$$f_0 = 3 \text{ GHZ}$$

<u>Ex:-</u> The dimension of waveguide are $2.5 \times 1 cm^2$
$f_0 = 8.6$ GHZ , $\epsilon_r = 3$

1) find possible modes
2) cutoff freq^n
3) guided waveguide

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$$\lambda_0 = \frac{c}{f_0} = \frac{3\times10^8}{8.6\times10^9}$$

$$= 0.035\ m$$

→ for TE10 mode

$$\lambda c = \frac{2ab\sqrt{\varepsilon r}}{\sqrt{m^2b^2+n^2a^2}}$$

$$= 2\times2.5\times\sqrt{3}$$

$$= 8.66\ cm$$

$$= 0.086\ m$$

$\lambda c > \lambda 0$, so TE10 is possible

$$\lambda g = \frac{\lambda 0}{\sqrt{1-\left(\frac{\lambda 0}{\lambda c}\right)^2}}$$

$$= \frac{0.035}{\sqrt{1-\left(\frac{0.035}{0.086}\right)^2}}$$

$$= 0.038\ m$$

$$fc = \frac{c}{\lambda c}$$

$$= \cancel{848.83}\ GHZ$$
3.4883

→ for TE11 mode

$$\lambda c = \frac{2ab\sqrt{\varepsilon r}}{\sqrt{a^2+b^2}}$$

$$= \frac{2\times2.5\times1\times10^{-4}\ \sqrt{3}}{\sqrt{(2.5)^2_{\times10^{-2}}+(1)^2_{\times10^{-2}}}} = 3.21\ cm$$

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$\lambda_c < \lambda_0$. so TE_{11} mode is not possible.

Ex A Rectangular waveguide have dimension $4 \times 3 \ cm^2$ $f_0 = 5$ GHZ calculate all possible mode & for those mode calculate λ_g & f_c , $\varepsilon_r = 3$

$$\lambda_0 = \frac{c}{f_0} = 6 \text{ cm}$$

for TE_{10} mode

$$\lambda_c = 2a\sqrt{\varepsilon_r}$$
$$= 13.85 \text{ cm}$$

$$\lambda_g = \frac{\lambda_0}{\sqrt{1 - \left(\frac{\lambda_0}{\lambda_c}\right)^2}}$$

$$= \frac{6}{\sqrt{1 - \left(\frac{6}{13.85}\right)^2}}$$

$$= 6.65 \text{ cm}$$

$$\lambda_g = 0.0665 \text{ m}$$

$$f_0 = \frac{c}{\lambda_c}$$
$$= \frac{3 \times 10^8}{13.85 \times 10^{-2}}$$
$$= 2.16 \text{ GHZ}$$

for TE_{11} mode.

$$\lambda_c = \frac{2ab\sqrt{\varepsilon_r}}{\sqrt{m^2b^2 + n^2a^2}}$$

$$= \frac{2 \times 4 \times 3 \times \sqrt{3}}{\sqrt{(4)^2 + (3)^2}}$$

$$= 8.31 \text{ cm}$$

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$$\lambda g = \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda c}\right)^2}}$$

$$= \frac{6}{\sqrt{1-\left(\frac{6}{8.31}\right)^2}}$$

$= 8.66$ cm

$= 0.0866$ cm

$$fc = \frac{c}{\lambda c} = \frac{3\times10^8}{8.3\times10^{-2}}$$

$= 3.61$ GHz

for TE_{12} mode

$$\lambda c = \frac{2ab\sqrt{\varepsilon r}}{\sqrt{m^2b^2+n^2a^2}}$$

$$= \frac{2\times4\times3\times\sqrt{3}}{\sqrt{9+64}}$$

$$= \frac{41.56}{\sqrt{73}}$$

$= 4.86$ cm

$\lambda_0 > \lambda c$ is not possible (TE_{12})

* circular waveguide :- for dominal mode is TE_{11} mode

$$\lambda c = \frac{2\pi r}{1.841}$$

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Ex for radius of 2 cm of circular waveguide operating dominal mode working at 9 GHZ of freq^n calculate cut - off wavelength, guided wavelength, guided velocity, phase velocity

$$\lambda c = \frac{2\pi r}{1.841}$$

$$= \frac{2\pi \times 2}{1.841}$$

$$= 0.068 m$$

$$= 0.07 m$$

$$\lambda o = \frac{c}{fo}$$

$$= \frac{3 \times 10^8}{9 \times 10^9}$$

$$= 0.033 m$$

$$\lambda g = \frac{\lambda o}{\sqrt{1-\left(\frac{\lambda o}{\lambda c}\right)^2}}$$

$$= \frac{0.033}{\sqrt{1-\left(\frac{0.033}{0.07}\right)^2}}$$

$$= 0.037 m$$

$$Vp = \frac{c}{\sqrt{1-\left(\frac{\lambda o}{\lambda c}\right)^2}}$$

$$= \frac{3 \times 10^8}{\sqrt{1-\left(\frac{0.033}{0.07}\right)^{-2}}} = 3.4 \times 10^8 \ m/s$$

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$$v_p \cdot v_g = c^2$$

$$v_g = \frac{(3\times10^8)^2}{(3.40\times10^8)}$$

$$= 2.64\times10^8 \text{ m/s}$$

Ex if Diameter of waveguide is 3 cm then can it be possible to use operating freq^n of 1 GHZ ?

if ~~km~~ m what are the possible solution.

$d = 3\text{cm}$

$r = 1.5\text{cm}$

$= 0.015\text{m}$

$$\lambda c = \frac{2\pi r}{1.841} \qquad \lambda_0 = \frac{c}{f_0}$$

$$= \frac{2\pi\times0.015}{1.841} \qquad = \frac{3\times10^8}{1\times10^9}$$

$$= 0.051\text{ m} \qquad = 0.3\text{m}$$

$\lambda_0 > \lambda c$ it is not possible

2> $\varepsilon_r = 36$

$= \left(\frac{\lambda_0}{\lambda c}\right)^2$ - Dielectric constant (ε_r)

$$\varepsilon_r = \left(\frac{0.3}{0.051}\right)^2$$

$$= 34.6$$

To have $\lambda c > \lambda_0$, present $\left(\frac{\lambda_0}{\lambda c}\right)^2 = 34.60$

that equal to ε_r

so ε_r value should be greater than 34.6.

So that ~~we~~ this waveguide operate at 7 GHz freq^n.

Ex Dimension of rectangular waveguide 4×2 cm^2 if operating freq^n is 20 GHz. calculate possible mode from propagate through waveguide.

→ TE_{10}

1) $\lambda_0 = \frac{c}{f} = \frac{3 \times 10^8}{20 \times 10^9}$

$= 0.15 \times 10^{-1}$

$= 0.015$ m

2) $a = 4$ cm $\quad b = 2$ cm

$a = 0.04$ m $\quad b = 0.02$ m

$\lambda c = \frac{2ab}{\sqrt{m^2b^2 + n^2a^2}}$

$= 2 \times 0.04$

$= 2a$

$= 8$

$= 0.08$ m

$\lambda c > \lambda 0$ this mode is possible.

→ TE_{11}

$\lambda c = \frac{2ab}{\sqrt{m^2b^2 + n^2a^2}}$

$= \frac{2 \times 4 \times 2}{\sqrt{20}} = 0.036$ m

10
11
12
21
22

31
32
33

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$\lambda_c > \lambda_o$ this mode is possible

→ TE_{12}

$$\lambda_c = \frac{2ab}{\sqrt{m^2 b^2 + n^2 a^2}}$$

$$= \frac{2 \times 4 \times 2}{\sqrt{4 + 64}}$$

$$= \frac{16}{\sqrt{68}}$$

$= 0.019\ m$ $\lambda_c > \lambda_o$ this mode is possible

→ TE_{21} =

$$\lambda_c = \frac{2 \times 4 \times 2}{\sqrt{4 + 16}}$$

$= 0.028m$

TE_{31}

$$\lambda_c = \frac{2 \times 4 \times 2}{\sqrt{36 + 16}}$$

$= 0.022m$

→ TE_{22} = $\lambda_c = \frac{2 \times 4 \times 2}{\sqrt{16 + 64}}$

$= 0.017\ m$

TE_{32}

$$\lambda_c = \frac{16}{\sqrt{4 + 144}}$$

$= 0.013m$

→ TE_{33} $\lambda_c = \frac{2 \times 4 \times 2}{\sqrt{144 + 36}}$

$= 0.011$

$\lambda_c < \lambda_o$ is not possible

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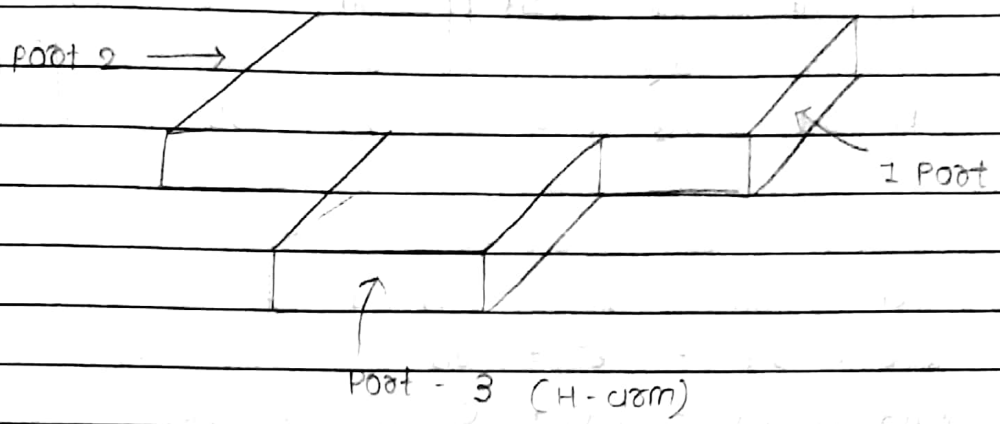
* H plane Tee :-



$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$$

- port - 3 is perfectly matched

$$S_{33} = 0$$

- port - 1 & 2 are inphase with port 3 with Same magnitude

$$S_{13} = S_{23}$$

- it follows Symetricity

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

$$S_{12} = S_{21} \ , \ S_{13} = S_{31} \ , \ S_{23} = S_{32}$$

- Identity

$$[S] \ [S^*] = [I]$$

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$$\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix} \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & S_{13} \\ S_{13} & S_{13} & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$R_1C_1 : S_{11}^2 + S_{12}^2 + S_{13}^2 = 1$ ——— (1)

$R_2C_2 : S_{12}^2 + S_{22}^2 + S_{13}^2 = 1$ ——— (2)

$R_3C_3 : S_{13}^2 + S_{13}^2 + 0 = 1 \Rightarrow S_{13} = \frac{1}{\sqrt{2}}$

from (1) & (2) compare

$S_{11} = S_{22}$

→ R_1C_3

$S_{11} S_{13} + S_{12} S_{13} = 0$

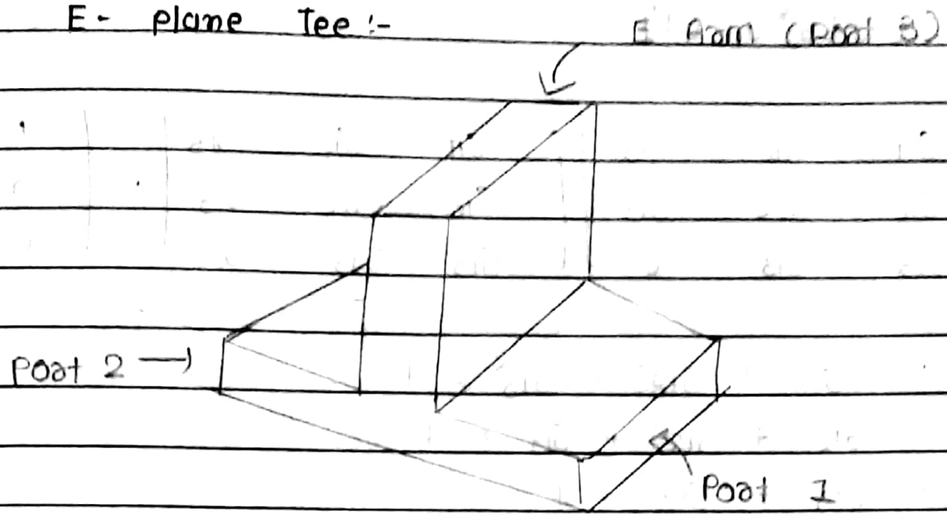
$S_{11} = -S_{12}$

$S_{11} = 1/2$

$S_{12} = -1/2$

$$[S] = \begin{bmatrix} 1/2 & -1/2 & 1/\sqrt{2} \\ -1/2 & 1/2 & 1/\sqrt{2} \\ 1/\sqrt{2} & 1/\sqrt{2} & 0 \end{bmatrix}$$

* E - plane Tee :-



- In E plane tee
E - arm is perfectly ~~method~~ matche
$S_{33} = 0$

- if i/p is at port -3 (E - arm)
o/p at 1 & 2 is Same & out of phase

$S_{13} = - S_{23}$

- As per Symmetricity

$S_{ij} = S_{ji}$

$S_{12} = S_{21}$, $S_{13} = S_{31}$, $S_{32} = S_{23}$

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & -S_{13} \\ S_{13} & -S_{13} & 0 \end{bmatrix}$$

- As per identity

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$[S][S^*] = [I]$

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & -S_{13} \\ S_{13} & -S_{13} & 0 \end{bmatrix}\begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{12} & S_{22} & -S_{13} \\ S_{13} & -S_{13} & 0 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

R_1C_1 : $S_{11}^2 + S_{12}^2 + S_{13}^2 = 1$

R_2C_2 : $S_{12}^2 + S_{22}^2 + S_{13}^2 = 1$

$R_3C_3 = S_{13}^2 + S_{13}^2 = 1$

$2 S_{13}^2 = 1$

$S_{13} = \frac{1}{\sqrt{2}}$

from R_1C_3 : $S_{13}(S_{11} - S_{12}) = 0$

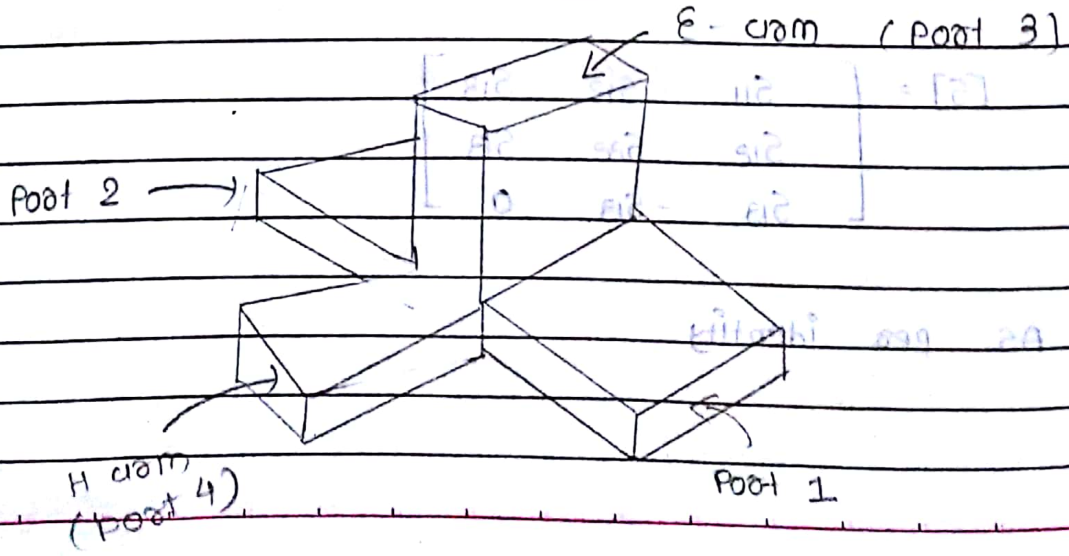
$\Rightarrow S_{11} = S_{12}$

from above eqn

$S_{11} = S_{12} = S_{22} = \frac{1}{2}$

$$[S] = \begin{bmatrix} 1/2 & 1/2 & 1/\sqrt{2} \\ 1/2 & 1/2 & -1/\sqrt{2} \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 \end{bmatrix}$$

* E - H plane Tee or Magic Tee



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- Here E arm & H arm in magic Tee is perfectly matched

So,

S_{33} & $S_{44} = 0$, $S_{33} = S_{44} = 0$

- port 3 & port 4 is issolated to each other
- Here E arm & H arm is perfectly isolated to each other

$S_{34} = S_{43} = 0$

- if i/p is given to port 3 (E arm)
- O/P at port 1 & 2 is will be same & out of phase

$S_{13} = -S_{23}$

- if i/p is given to port 4 (H arm)
- O/P at port 1 & 2 will be same & in phase

$S_{14} = S_{24}$

- Symmetricity property

$S_{ij} = S_{ji}$

$S_{12} = S_{21}$, $S_{23} = S_{32}$, $S_{34} = S_{43}$
$S_{31} = S_{13}$, $S_{24} = S_{42}$, $S_{14} = S_{41}$

$$[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & -S_{13} & S_{14} \\ S_{13} & -S_{13} & 0 & 0 \\ S_{14} & S_{14} & 0 & 0 \end{bmatrix}$$

identity property

$[S][S^*] = [I]$

$$\begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & -S_{13} & S_{14} \\ S_{13} & -S_{13} & 0 & 0 \\ S_{14} & S_{14} & 0 & 0 \end{bmatrix} \begin{bmatrix} S_{11} & S_{12} & S_{13} & S_{14} \\ S_{12} & S_{22} & -S_{13} & S_{14} \\ S_{13} & -S_{13} & 0 & 0 \\ S_{14} & S_{14} & 0 & 0 \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

$R_1C_1 \div \quad S_{11}^2 + S_{12}^2 + S_{13}^2 + S_{14}^2 = 1$

$R_2C_2 \div \quad S_{12}^2 + S_{22}^2 + S_{13}^2 + S_{14}^2 = 1$

$R_3C_3 : \quad S_{13}^2 + S_{13}^2 = 1$

$2S_{13}^2 = 1$

$S_{13} = \frac{1}{\sqrt{2}}$

$R_4C_4 :- \quad S_{14}^2 + S_{14}^2 = 1$

$S_{14} = \frac{1}{\sqrt{2}}$

$\because \quad R_2C_2 = \quad S_{12}^2 + S_{22}^2 = 0$

$R_1C_1 = \quad S_{11}^2 + S_{12}^2 = 0$

$S_{11} = S_{12} = S_{22} = 0$

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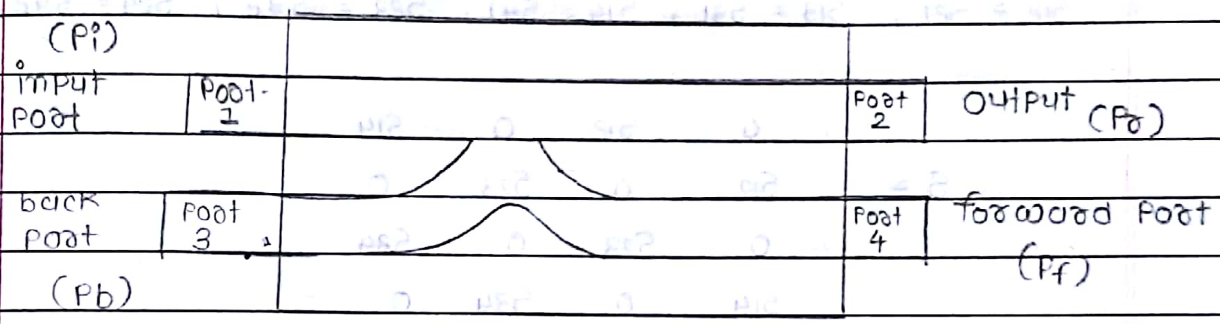
$$[S] = \begin{bmatrix} 0 & 0 & 1/\sqrt{2} & 1/\sqrt{2} \\ 0 & 0 & -1/\sqrt{2} & 1/\sqrt{2} \\ 1/\sqrt{2} & -1/\sqrt{2} & 0 & 0 \\ 1/\sqrt{2} & 1/\sqrt{2} & 0 & 0 \end{bmatrix}$$

* Directional Coupler :-



→ coupling factor

$$C = 10 \log\left(\frac{P_i}{P_f}\right)$$

→ Directivity

$$D = 10 \log\left(\frac{P_f}{P_b}\right)$$

→ isolation factor

$$I = 10 \log\left(\frac{P_i}{P_b}\right)$$

→ All ports are matched Port

$$S_{11} = S_{22} = S_{33} = S_{44} = 0$$

- ideally back power should be zero

$$S_{31} = 0, \quad S_{42} = 0$$

- As per Symmetricity

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

$S_{12} = S_{21}$, $S_{13} = S_{31}$, $S_{14} = S_{41}$, $S_{23} = S_{32}$, $S_{24} = S_{42}$, $S_{34} = S_{43}$

$$S = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{12} & 0 & S_{23} & 0 \\ 0 & S_{23} & 0 & S_{34} \\ S_{14} & 0 & S_{34} & 0 \end{bmatrix}$$

→ As per identity property

$$[S][S^*] = [I]$$

$R_1C_1 \Rightarrow S_{12}^2 + S_{14}^2 = 1$
$R_2C_2 \Rightarrow S_{12}^2 + S_{23}^2 = 1$ → $S_{23} = S_{14}$
$R_3C_3 \Rightarrow S_{23}^2 + S_{34}^2 = 1$
$R_4C_4 \Rightarrow S_{14}^2 + S_{34}^2 = 1$

from (2) & (3)
$S_{12} = S_{34}$

from (1) & (4)
$$S_{12} = S_{34}$$

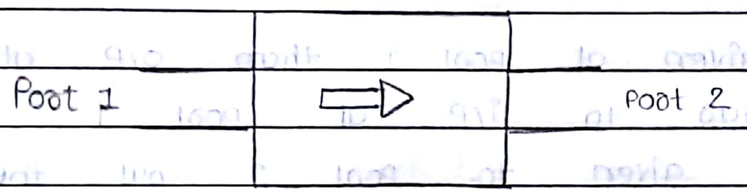
$$S = \begin{bmatrix} 0 & S_{12} & 0 & S_{14} \\ S_{12} & 0 & S_{14} & 0 \\ 0 & S_{14} & 0 & S_{12} \\ S_{14} & 0 & S_{12} & 0 \end{bmatrix}$$

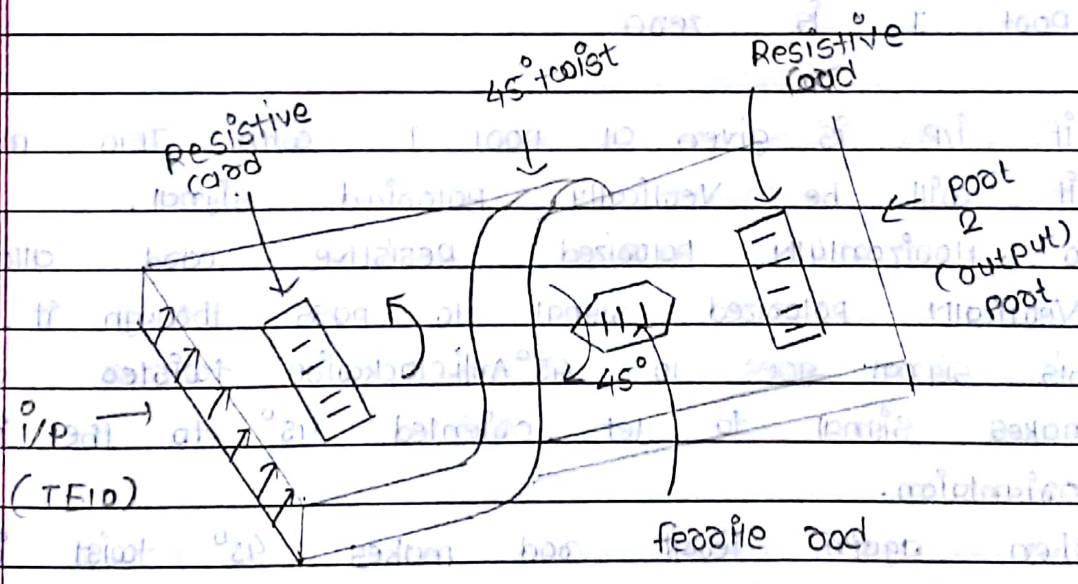
- Received position $S_{12} = P$

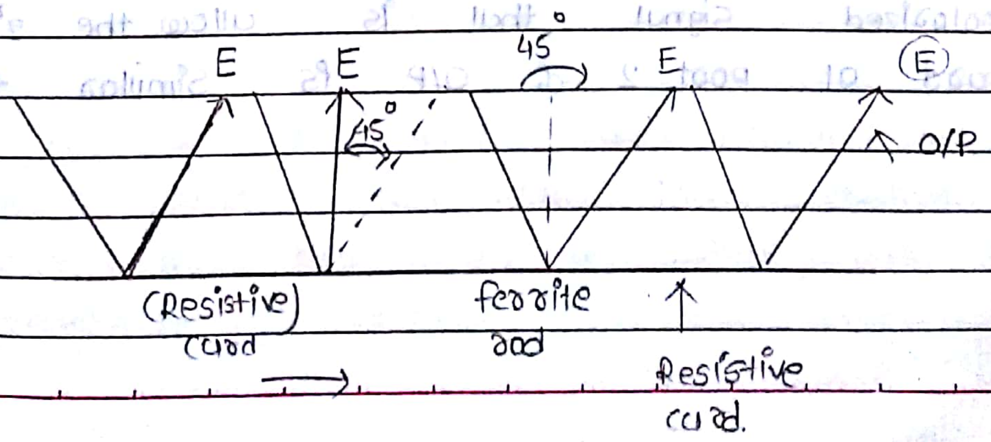
forward (coupled) $S_{14} = Q$

$$\begin{bmatrix} 0 & P & 0 & Q \\ P & 0 & Q & 0 \\ 0 & Q & 0 & P \\ Q & 0 & P & 0 \end{bmatrix}$$

* isolator :-







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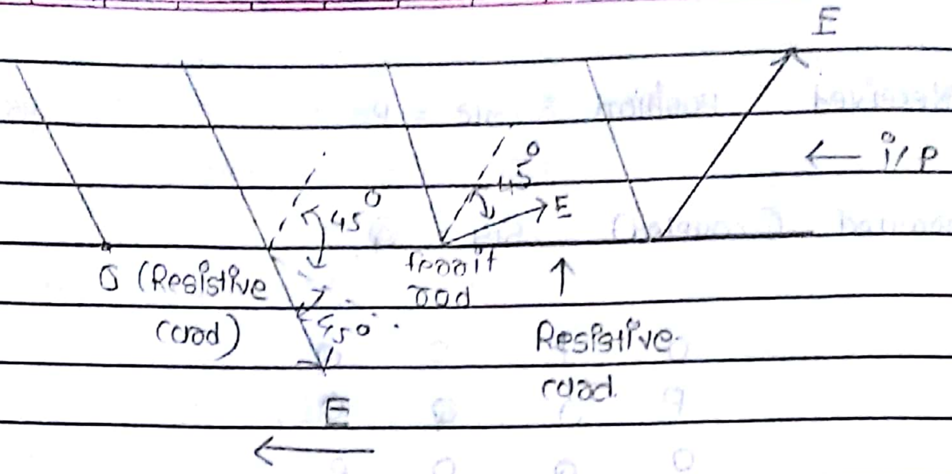

isolator is a device which is been used to isolate i/P with respect to O/P

Working :-
i/P is given at port 1 then O/P at port 2 is similar to i/P at port 1 but it i/P is given to port 2 but the O/P at port 1 is zero

if i/P is given at port 1 with TE10 mode it will be Vertically polarized signal. So Horizontally polarized Resistive card allows Vertically polarized signal to pass through it. then this signal goes to 45° Anti-clockwise twister which makes signal to get oriented 45° to the initial oriantaion.
then again ferrit rod makes 45° twist in clockwise direction makes it to vertical polarized signal that is allow the 2nd Resistive card at port 2 & O/P is Simillar to i/P

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if i/p is given at port 2 with TE10 mode which is vertically polarizes signal this signal allow pass through resistive card at port 2 then signal is get twisted due to ferrit rod in 45° clockwise. & again it is getting twisted. by twisted in 45° clockwise which makes that signal orintation horizontal polarized signal. which is getting absorb at Resistive card placed at port 1 so o/p the port 1 is minimum

- Scattering matrix:

$$S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

$$= \begin{bmatrix} 0 & 1 \\ 0 & 0 \end{bmatrix}$$ port 1 & port 2 is perfectly matched

So $S_{11} = S_{22} = 0$

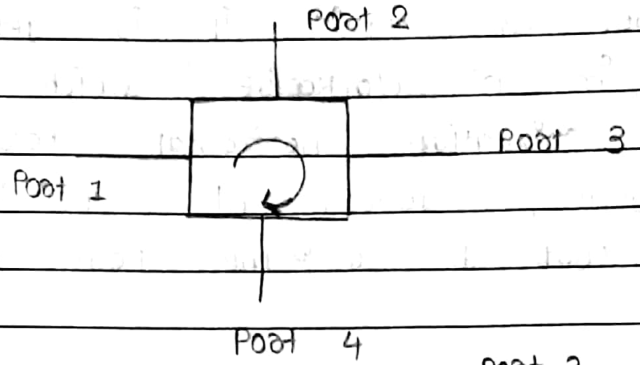
i/p at port 1 reaches the o/p at port 2 but at i/p port 2 not reaches to at o/p at port 2

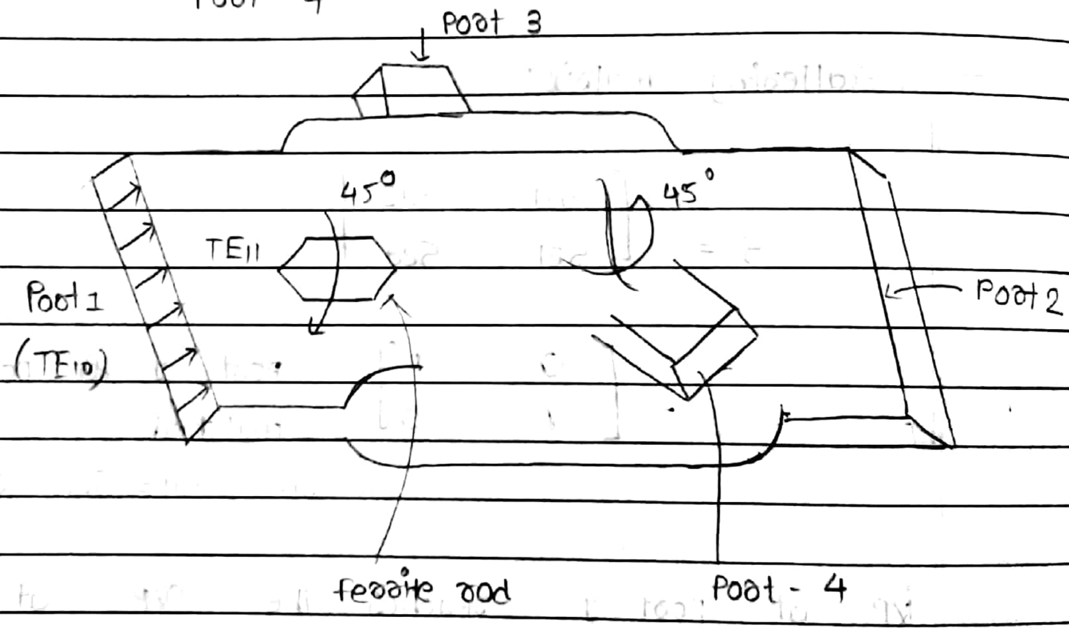
$S_{12} = 1, S_{21} = 0$

* Circulator :-

It is a device where signal is getting x'fer from one port to another port either it clock wise or Anti clock wise direction.

here if i/p is port 1 then o/p will be port 2 and other port will be zero similarly for other port signal is getting x'fered to next successive port





If we insert signal at port - 1 for rectangular waveguide dominal mode is TE10. Now then that signal is x'fer to cylindrical waveguide mode is converted from TE10 to TE11 mode.

- Now signal is getting oriented 45° from initial position by ferrite rod is out of phase to port - 3 & again anti clockwise 45° twister making it to original orientation out of

→ duplexer : it is transmitte & receive the signal at same time & also isolate the signal

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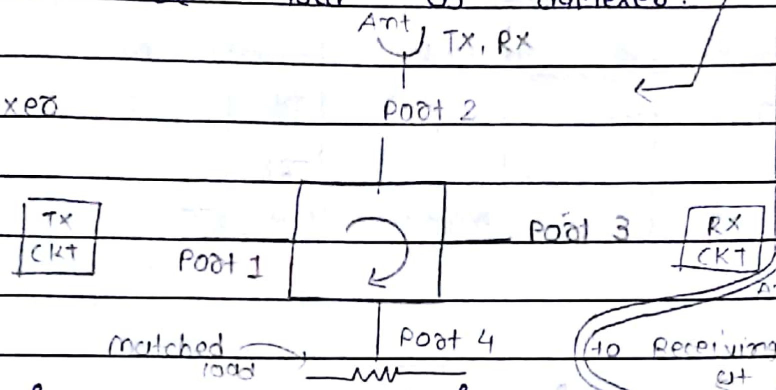
phase to port-4 & in completely in phase to port-2 So signal can x'fer from port 1 to 2 not to other ports.

Application:- it can be used as duplexer.

Signal is given at port 1 from x'mitting ckt will be x'mitted by at port 2 Received signal at port 2 by Ant will get x'fer at port 3 to Receiving ckt, Reflected signal at port 3 will get terminated port 4 by mathed load

* duplexer



→ Scattering parameter of circulator :-

- All ports are matched ports

so. $S_{11} = S_{22} = S_{33} = S_{44} = 0$

In clockwise circulator signal x'fer from 1 to 2, 2 to 3 & 3 to 4 and 4 to 1

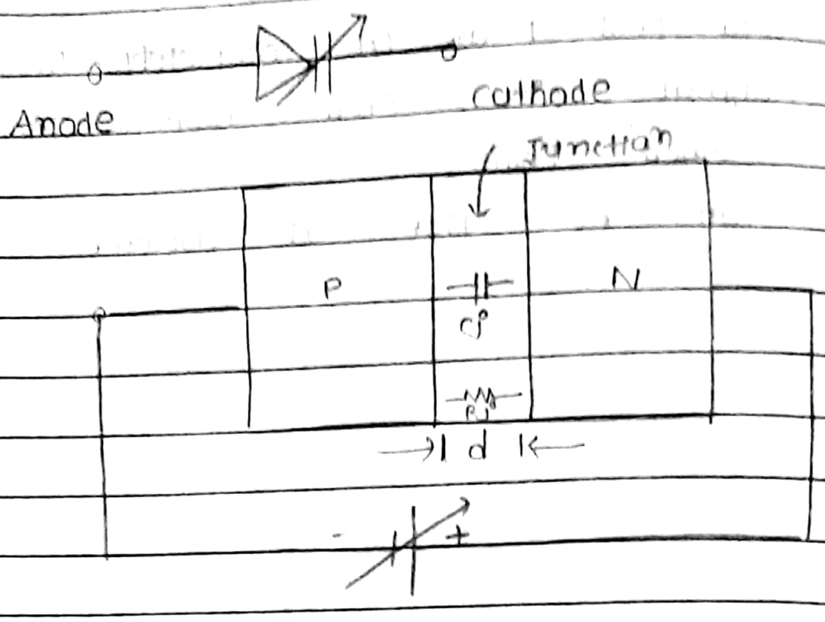
- $S_{21}, S_{32}, S_{43}, S_{14} = 1$

$$S = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}$$

mid-sem

* Varycap diode (variable capacitor diode)

- Working principle :
it is working based on Reverse bias Voltage where it capacitor will get change w.r.t Reverse bias Voltage.



- junction capacitence C_j depends on width d of jy^n

$$C_j = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

- Reverse bias voltage is directly proposonal to width OF jy^n

$$V_r \propto d$$

$$C_j \propto \frac{1}{d}$$

$$C_j \propto V_r^{-1}$$

- operating freq^n OF LC ckt

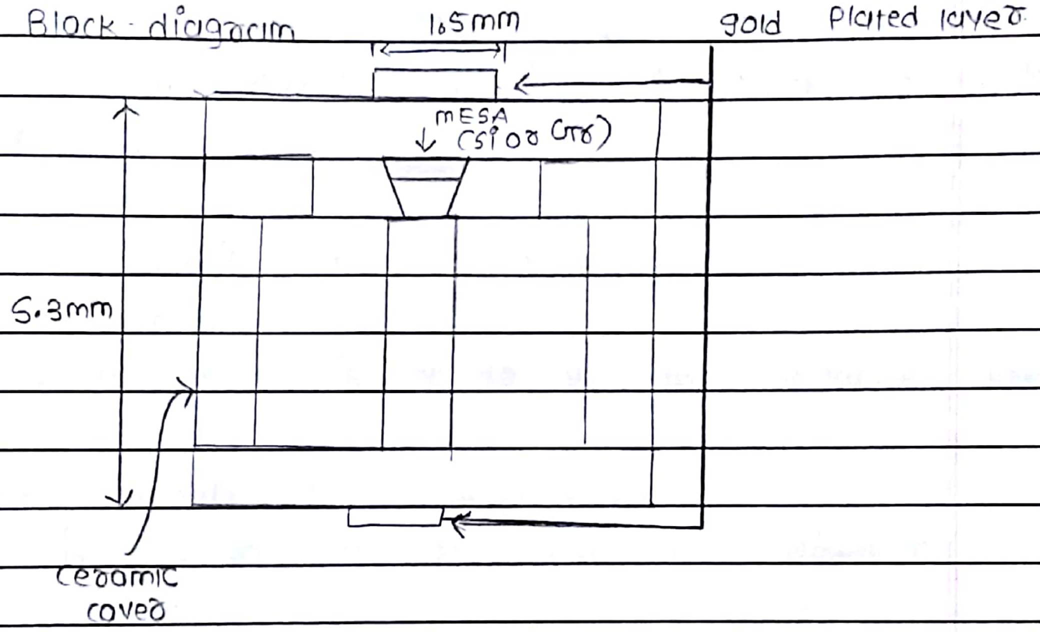
$$f = \frac{1}{2\pi\sqrt{LC}}$$

$$f \propto \sqrt{V_r}$$

V_r = Reverse bias voltage

for low freq^n operation structure of Varycap diode is very simple with p & n type material but to achieve freq^n we need extremly small reverse recovery time for high freq^n switching. so there is possible extremly high doping of impurities in semiconductor.

Block diagram



- Varycap diode working at 25 GHZ.
- it could be made of silicon.
- To have 90 GHZ vary-cap diode GaAs material is used (Gallium Arsenide)

- Application.
- tuning circuit
- Active filter
- Oscillator
- freq^n multipler

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Ex:8

step :1 :- draw Unit circle

step : 2 :- point Z_L

step 3 :- identify y_L

step 4 :- identify y_1

from y_L in clockwise direction intersection to unit circle y_1

step 6 :- identify y_e

step 5 indentify l

length of l is y_L to y_1 in clockwise direction.

step 7 :- identify l'

l' is Z_{max} to y_e clock wise direction

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velocity :- 10^6 m/s
drift " :- m/s = 0

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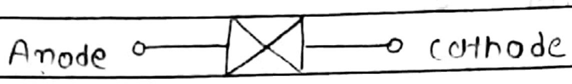
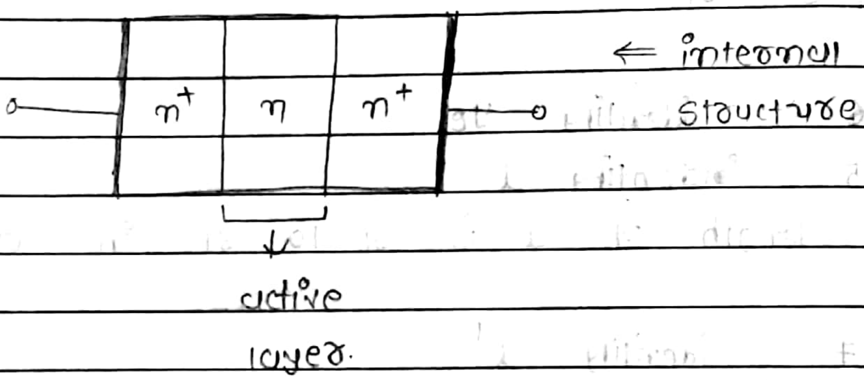
Reverse recovery time :- it required the device turn OFF to on

* Gunn diode :-

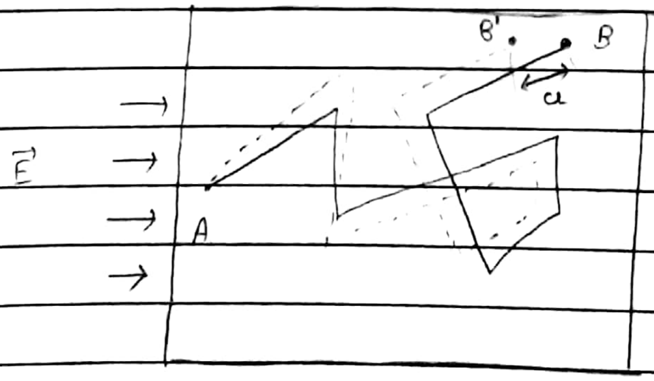
- Gunn diode does not have P-N ju^n
- it contains two N types layer
  1) N layer
  2) N^+ layer

Symbol





- internal structure consist of the n^+, n, n^+ layer
- n layer is active layer



- drift velocity

$$V_d = \frac{\Delta l}{\Delta t}$$

- mobility

$$\mu = \frac{V_d}{E}$$

μ is +ve . electron flow ← e + Resistance
μ is -ve . electron flow → e , - Resistance

mobility = $\frac{V_d}{E}$ ... field $E \uparrow$ = speed of electron ↑

mobility ↑, resistance ↑

mobility ↓, " ↓

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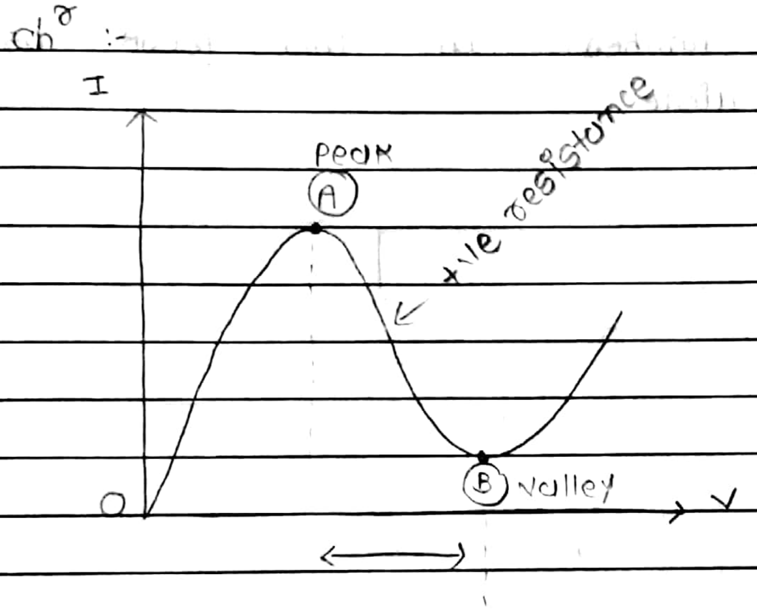
Operation :-

- Gunn as done experiment on ~~GaAs~~ & ~~done~~ once signal is be beyond threshold to the GaAs we observe groove oscillation that ~~is~~ b'coz of -ve Resistance ch^r & that device is called as Gunn diode

→ ch^r :-



- In Gunn diode majority carrier is electron

- ch^r = In ch^r

1) O to A :- In O to A voltage ↑, current ↑ and it will reaches point A it's called peak point in O to A mobility (μ) is equal to positive $\mu = \frac{+dV_d}{dE}$

2) A to B :- once it is reaches to peak point & we further ↑ voltage, current will further ↓ gradully up to point B that point is called valley point

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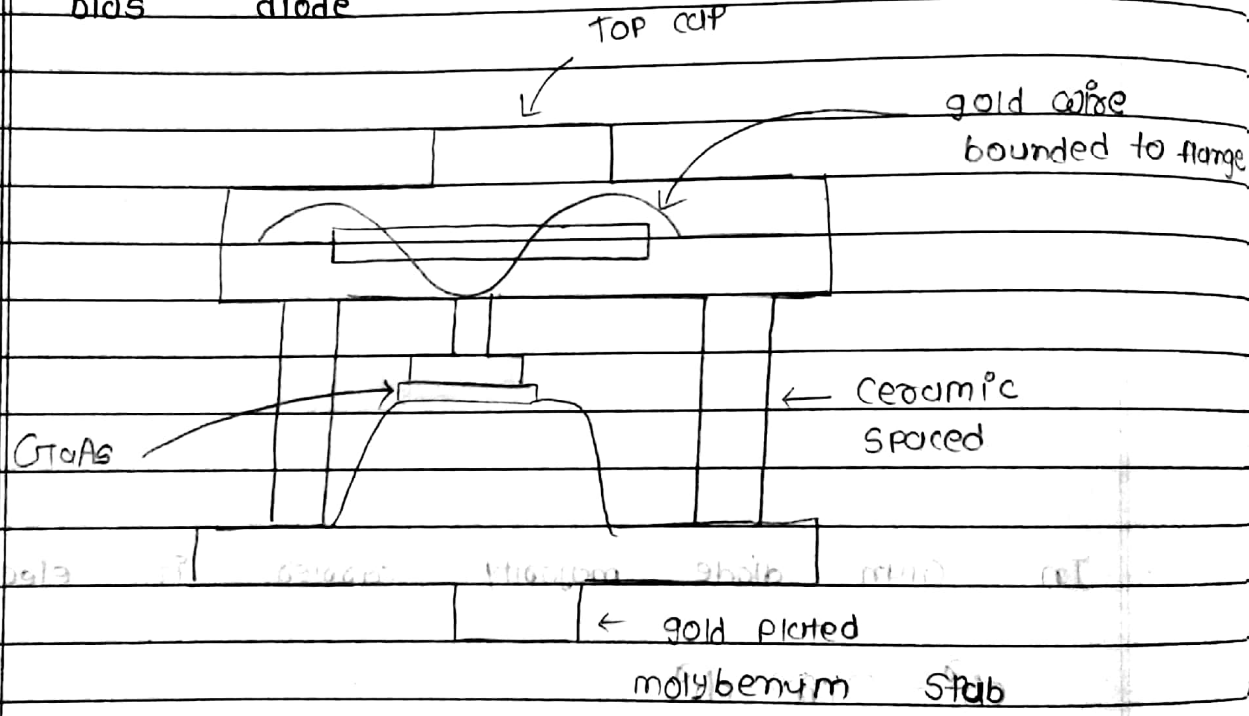
A to B exibits -ve resistance ch^r & that happen bcoz of -ve mobility

$$\mu = -\frac{dvd}{dE}$$

3) B to further : In this work as a forward bias diode



→ Application :-
- wave generator
- Oscillator
- Amp^r
- Radar x'mitter

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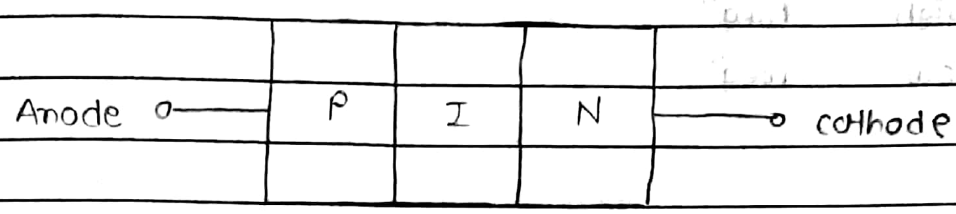
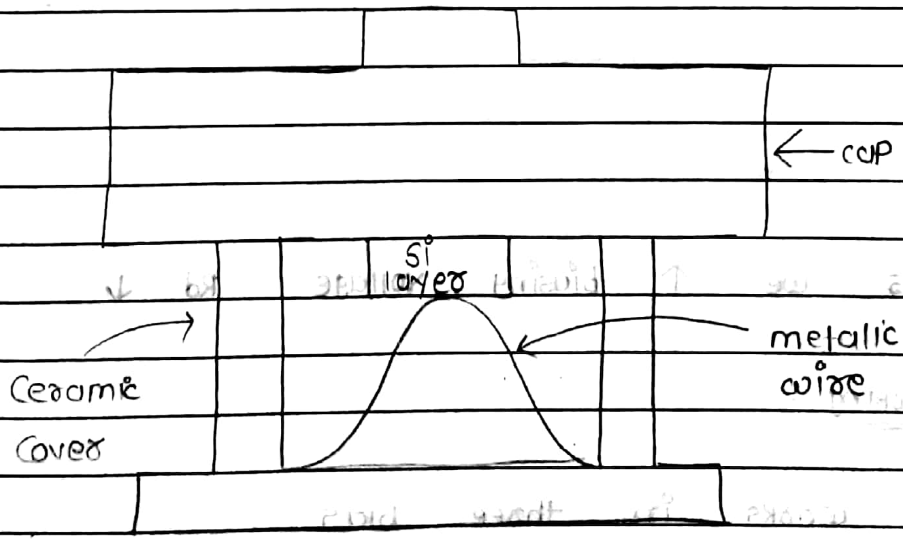
* PIN diode :- current control device

PIN diode means P → P type material
I → Intrensic materiat
N → N type material



it is three layer diode
1) P. type
2) Intrensic (pure silicon)
3) N - type

Resistivity OF I- layer is extremally high that utilize in groove layer.



In PIN diode I- layer is Sandwiched in betⁿ P- type & N type layer

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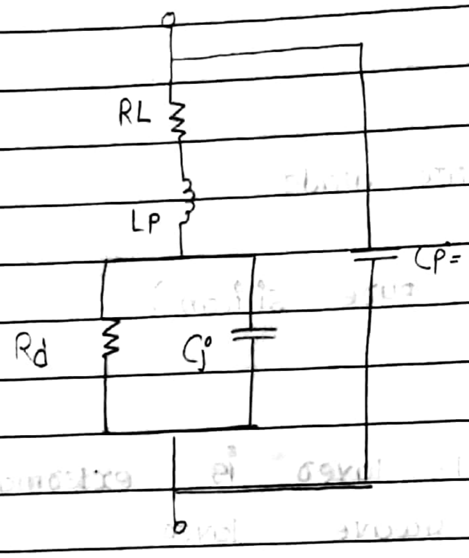
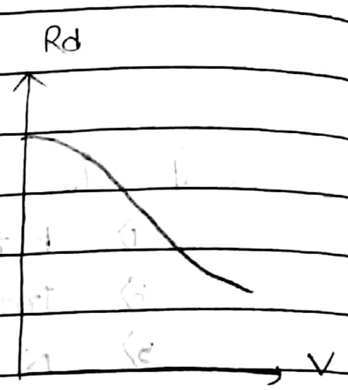
- Two operation
- high freq^n resistance will decrease w.r.t increase in potential voltage

→ Two operation
1. high freq^n
2. low freq^n





Cj = ju^n capacitance
CP = packet capacitace
Rd = diode Resistance
LP = packet inductance
RL = lead Resistance

- as we ↑ biasing voltage , Rd ↓

→ Working :-

it works in three bias
1) no bias
2) forward bias
3) reverse bias

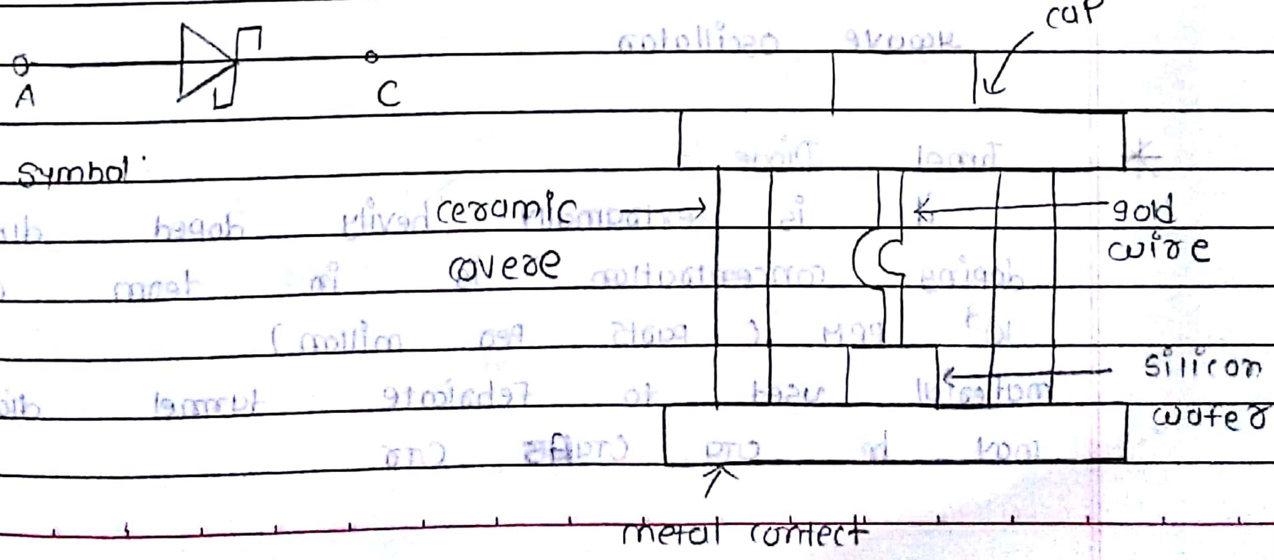
1) no bias :- (zero bias) :- in that P type material contain +ve charge carrier & N- type material contain -ve charge carrier but I- layer contain exterme high resistance

2) forward bias :- To have in diode F.B P is connected to +ve terminal of battery & N is connected to -ve terminal of battery which leads to decreasing width of depletion region & conduction will happen.

3) Reverse bias :- P with -ve terminal of battery & N is +ve terminal of battery which leads to increasing depletion region & that offers exteromilly high resistance.

→ Application
- High freq^n switch
- Amplitude modulation
- phase shifter
- impedance matching n/w

* Schottky barrier diode :- (SBD)

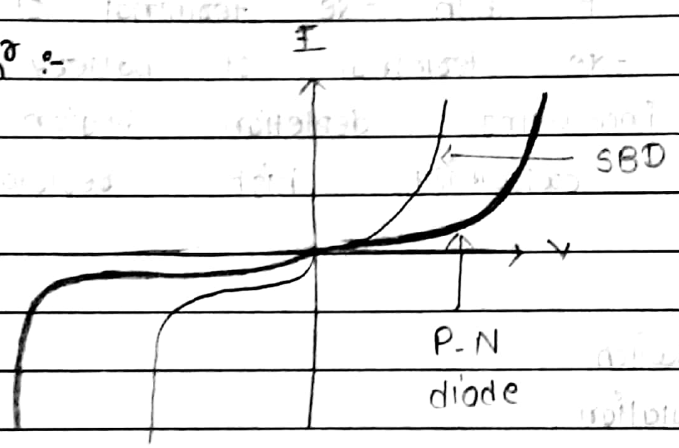


SBD is having very less Reverse recovery time due to Removel potential barrier

so its structure it contains metal contect on n type material so there is no PN Jy^n. which results in to use OF SBD at µwave (100 GHZ)

Working :- SBD is having less forward drop Voltage w.r.t which result into heat loss

Ch^r :-



Application
- mixter
- fast Switching device
- Oscillator
- µwave oscillator

* Tunel Diode :-

it is extraomally hevily doped diode & doping concentration is in team OF 10^3 PPM (parts Per milion)
material used to febaicate tunnel diode may be Ga, GaAs, Gr

depletion region = Space Charge region

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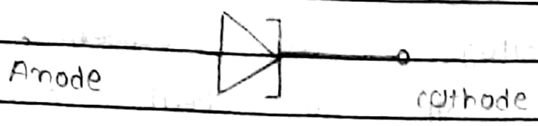
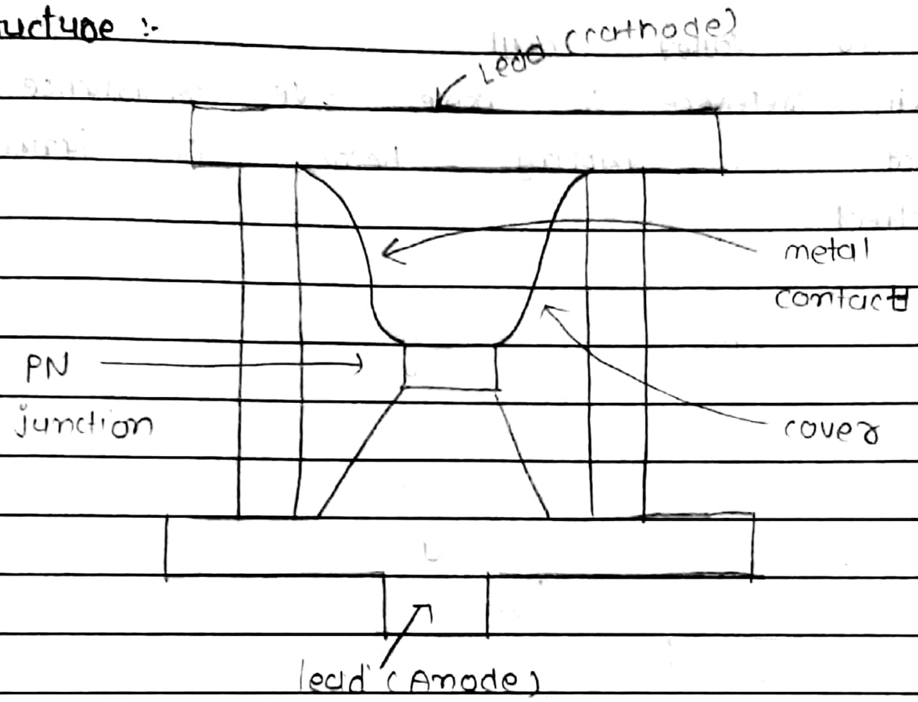
Symbol :-

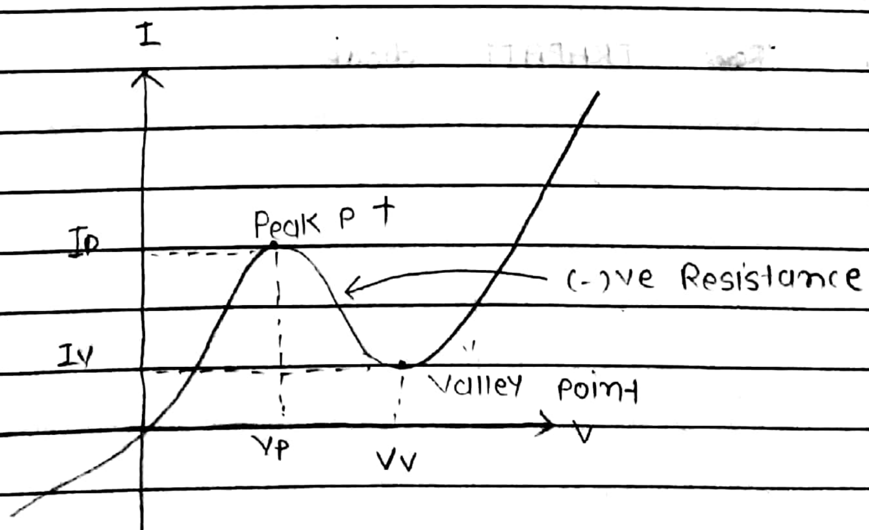


Structure :-



This tunnel diode could be utilized for fast switching device due to very narrow depletion width that ju^n is having width is in terms of $100\,A^\circ$ (100×10^{-8})

ch^r :-



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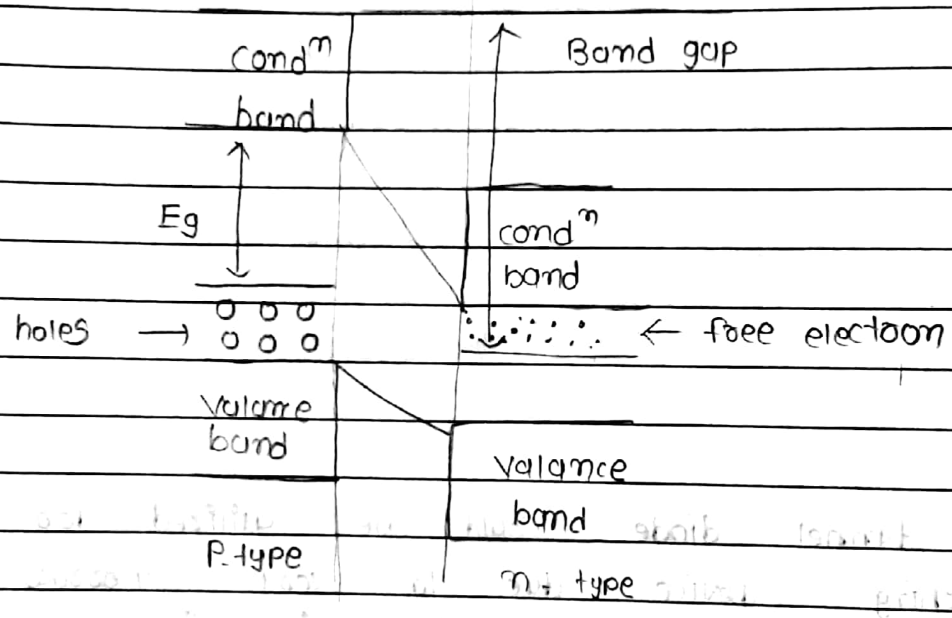
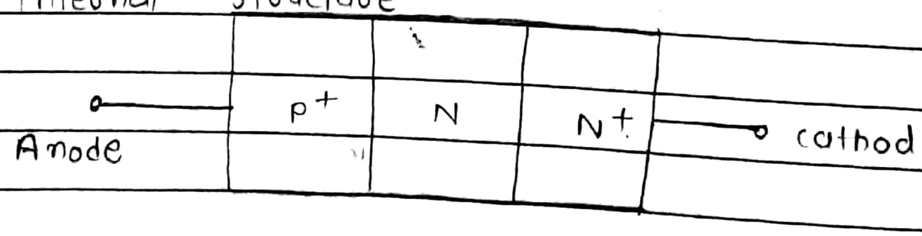
Usually we used tunnel diode in F.B & initially voltage & current increasing linearly up to peak point and than as we increase voltage, current is ↓ up to valley point
which reference to have -ve resistance ch^r & that is happing becoz of tunneling effect



→ Energy band diagram

* TRAPATT diode :-
[Traped plasma Avalanch triggered transiant diode]

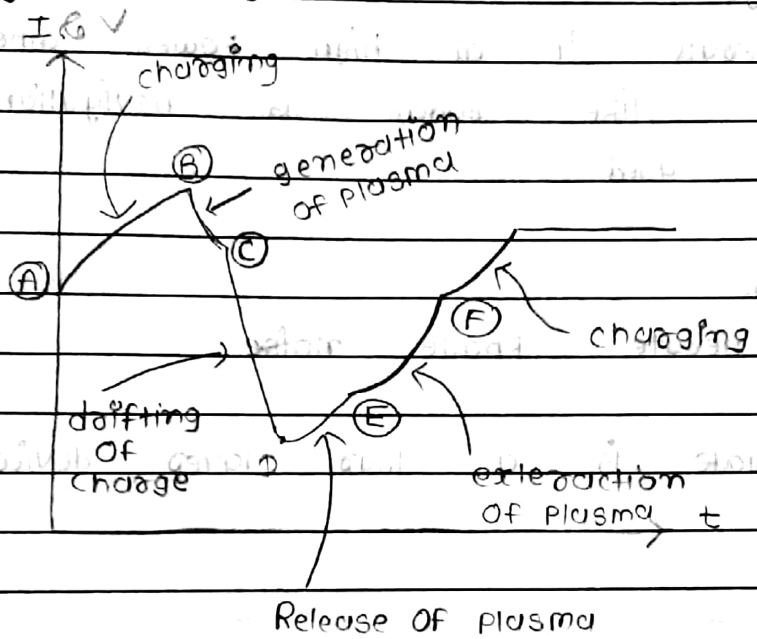
⟹ internal structure



Battery :- 3000 mAh

$= 3000 \times 10^{-3} \times \frac{C}{m\cancel{s}} \times 3600\ \cancel{sec}$

charge = 10800 C



→ **Structure** :-

it is made of a Ge or Ga for TRAPATT ~~trapped~~ working at below 0.5 GHZ

So to have extreme high $freq^n$ up to 50 GHZ it to be made of GaAs

This is very highly doped diode & it has switching period in terms of 100 ps (10 GHZ)

* IMPATT diode

(impact ionization Avalanch transient time diode)

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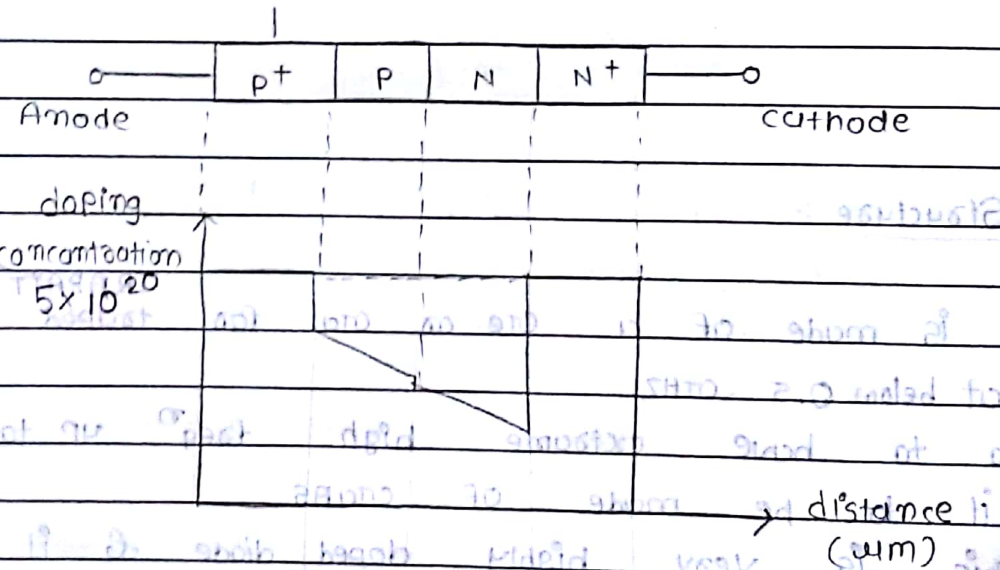
This diode is having high Switching Speed & it operates at 3 to 100 GHz.

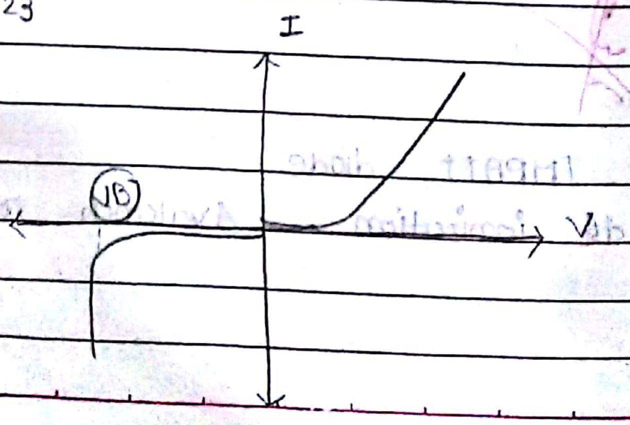
→ Advantage :
to operate it at high power where some application like radar & navigational application could be used

→ Disadvantage :
it generate phase noise

⇒ This diode is a four layer device



$$= \frac{5 \times 10^{20}}{6.23 \times 10^{23}} = 1000 \text{ PPM}$$



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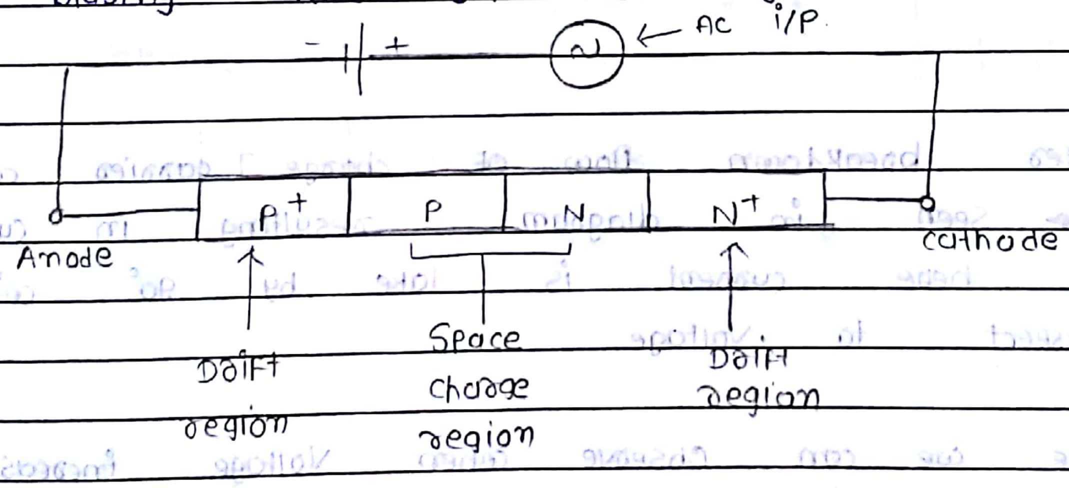
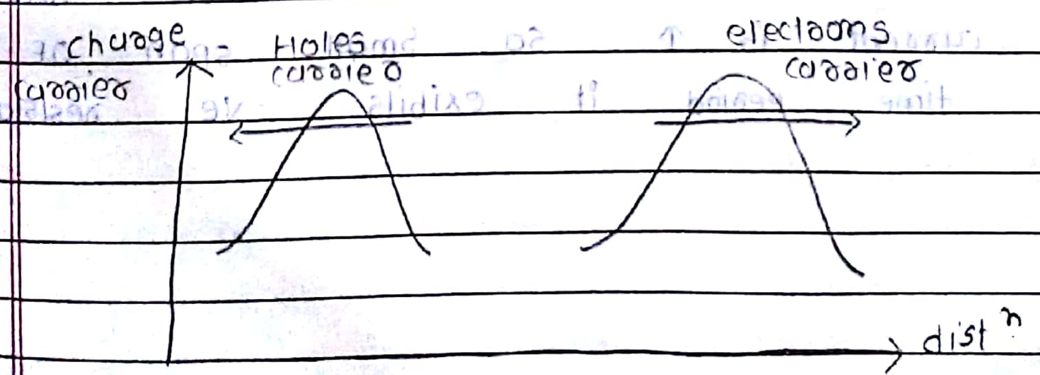
- for forward bias it starts to conduct after voltage greater than potential barrier voltage and in Reverse bias it flow minor current due to space charge region after avalanch breakdown high current following due to multiplication of charge carrier even it is called as avalanch in charge multiplication.

- Basically impatt diode is use in R.B & biasing or operating point is their verge of avalanch Break-down

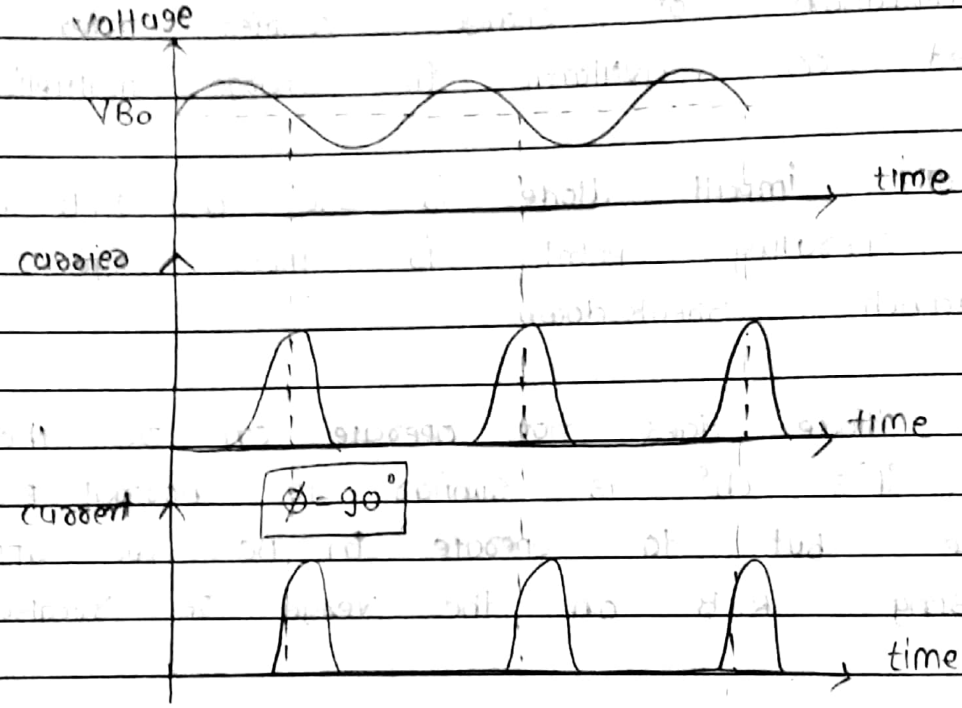
- This diode does not operate on DC the reason is it's chr is similar to normal P-N jun diode but to operate in AC we apply biasing R.B on the verge of Breakdown





breakdown ↑

if signal increased to greater than avalanch charges are generated the charges greater than out of which holes are attracted towards p type material & electron material toward N type material



After breakdown flow of charge carrier can be seen in diagram resulting in current & here current is lake by 90° with respect to Voltage.

here we can observe when Voltage increase current is not that but when Voltage ↓ current is ↑ so Small span of that time period it exibits -ve resistance ch^r

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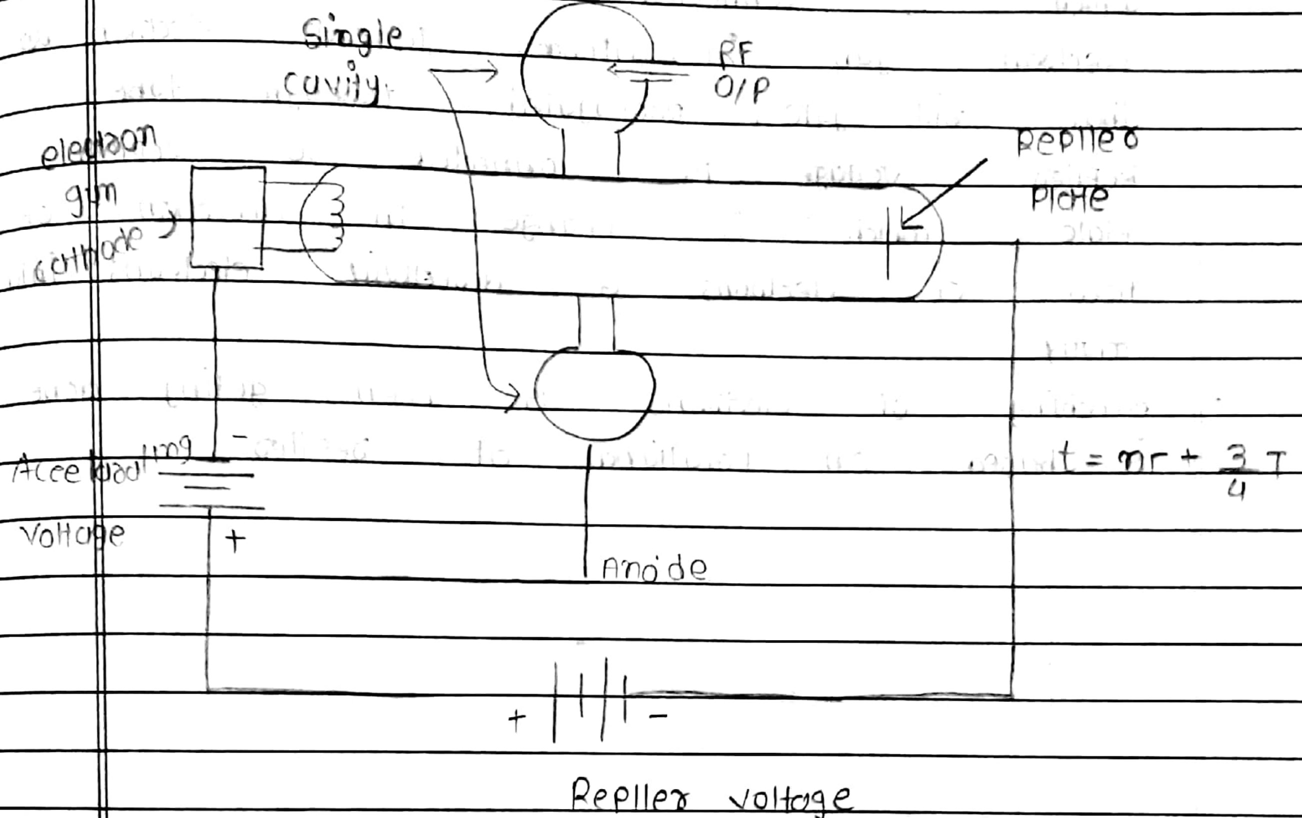
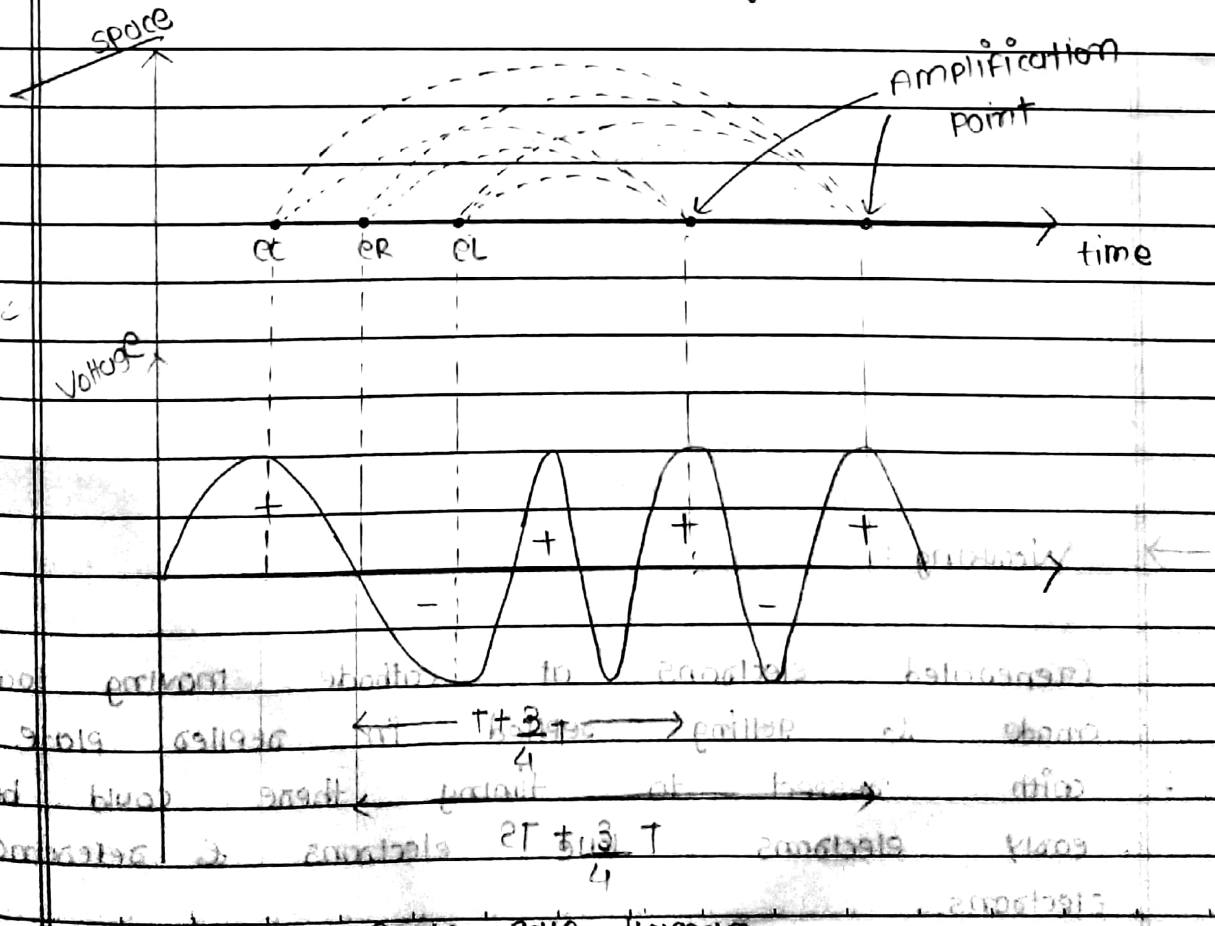
* Reflex Klystron (Applifier)





Apple gate diagram

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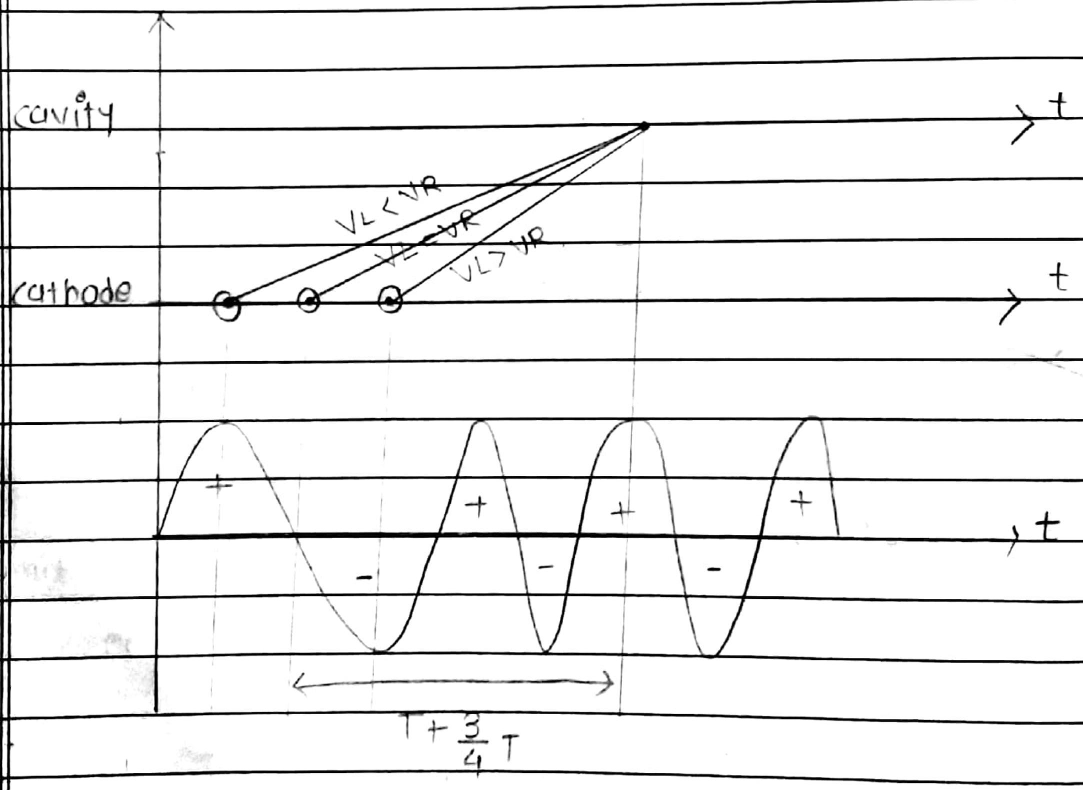
- In reflect klystron single cavity is there which is connected to anode
- electron gun in (cathode) generat electron & that will gate, propagated through tube
- Repller voltage is connected to repller plate which is change in direction of flow of electrons & directivity electrons into cavity
- bunching of electrons is been geting done is based on potational at repller



→ Working :

- Generated electrons at cathode moving towards anode & getting repplied in repller plate
- with respect to timing there could be early electrons late electrons & refearnce electrons.

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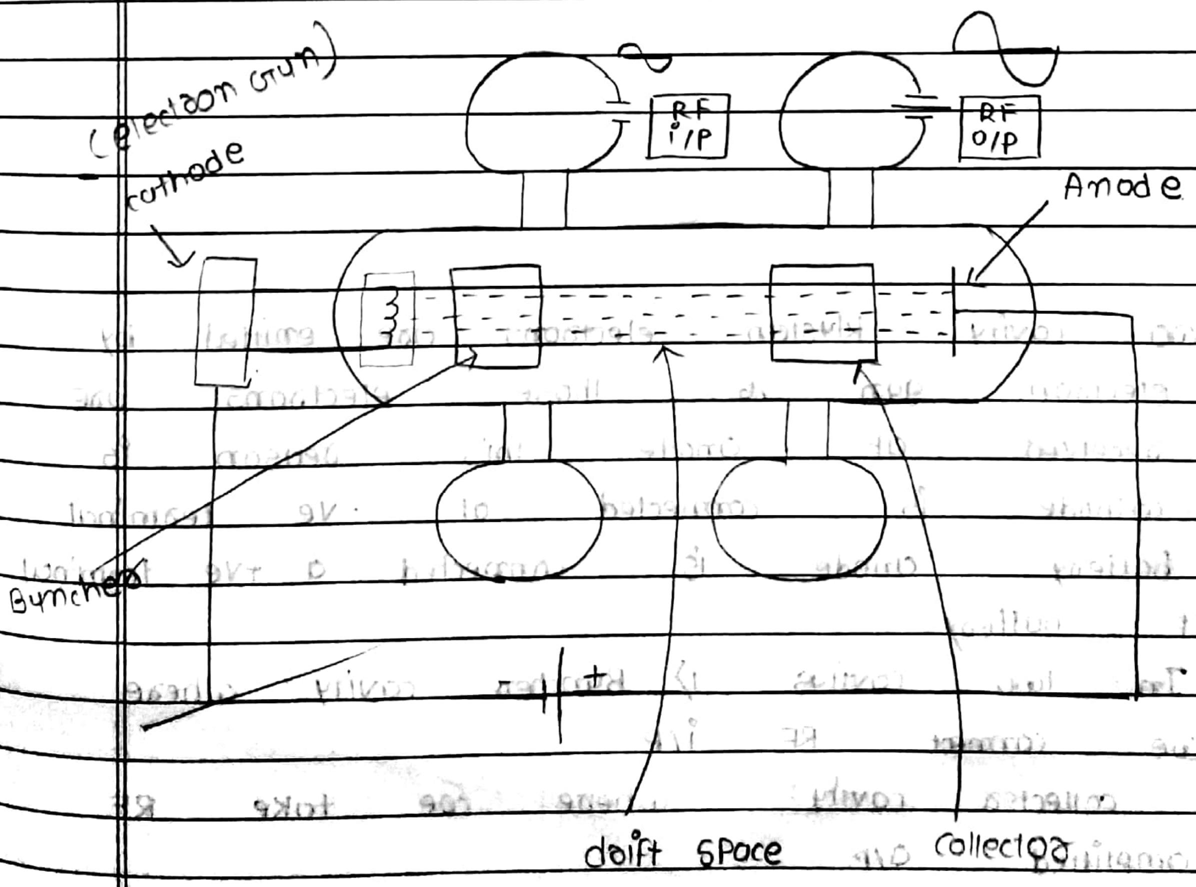
- To combine all together we need higher velocity in with late electron & lower velocity with early electron is called as velocity modulation
- which is been based on repller potentional & mode of operation.
- Transiance time T for bunching of electrons is be defined by

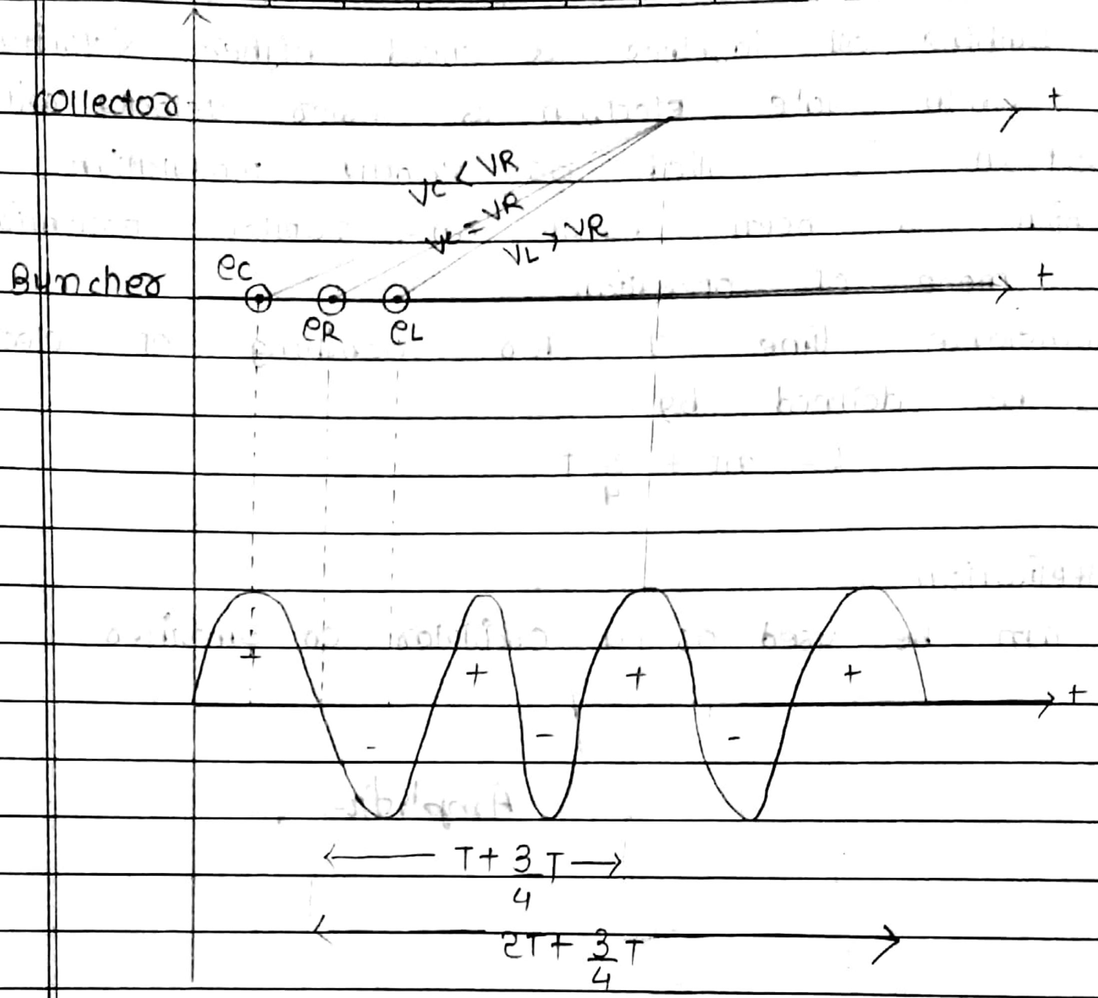
$$t = nT + \frac{3}{4}T$$

⟹ Application

It can be used as a oscillator or amplifier

* Two cavity klystone Amplifier.





[apple - gate diagram]

→ Construction :-

Two cavity klystron electrons are emitted by electron gun & those electrons are received at anode this's reason is cathode is connected at -ve terminal battery anode is connected a +ve terminal of battery

In two cavitys 1) Buncher cavity :- where we connect RF i/p

2) collector cavity :- where we take RF amplified o/p

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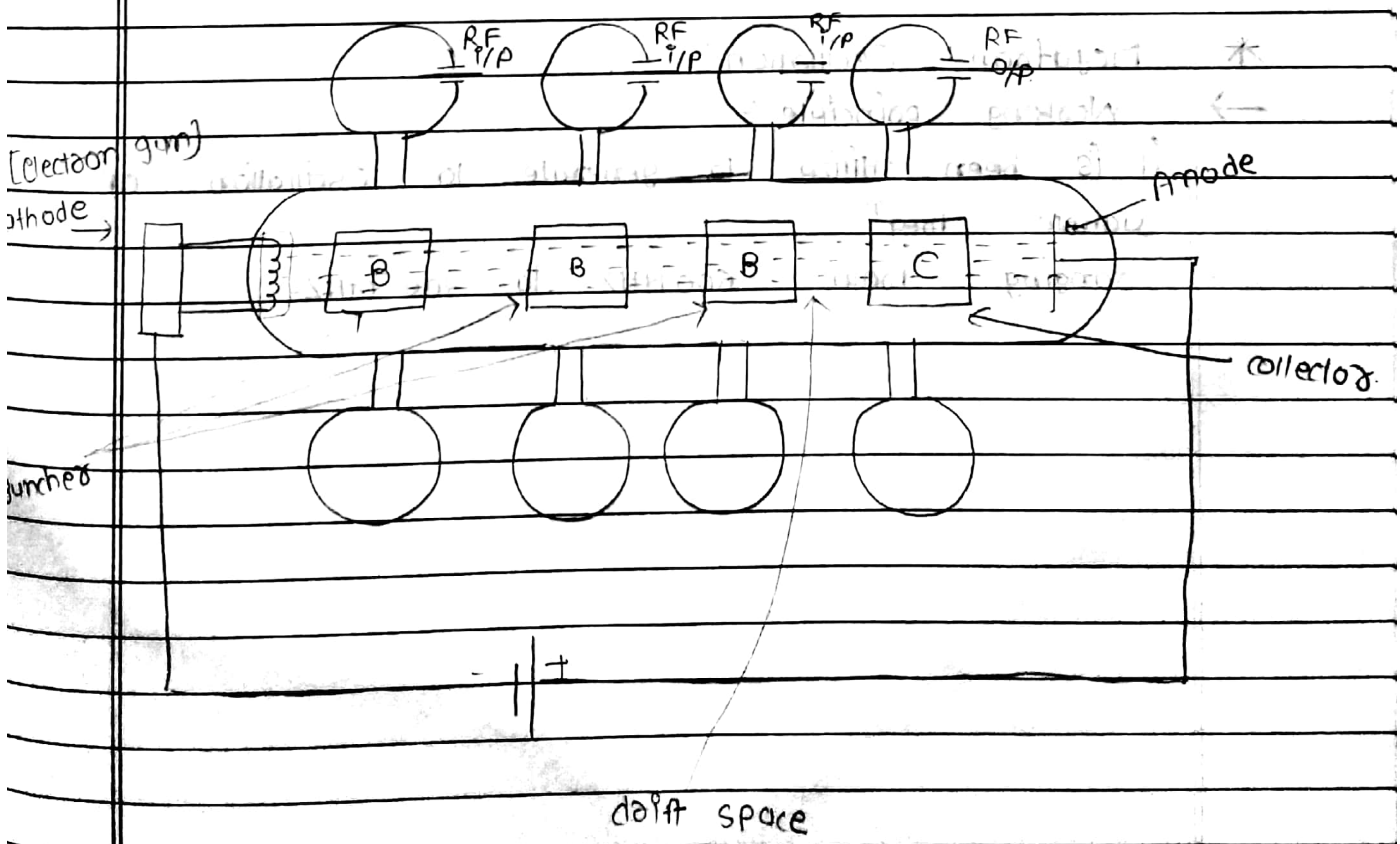
Working :-

- Generated electron from electron gun moves toward anode & during the motion by velocity modulation electrons are getting bunched & collected at 2^{nd} cavity

- velocity modulation :- electrons which are generated early noted early electron and the electrones are generated late are noted at late electrons.

and to receive at same time early electrone should have low velocity & late electrone should have heigher velocity this phenomena is called as velocity modulation

✱ multi cavity klystone :-



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- multi cavity klystron electron emitted by electron gun & those electrones received at anode the reason is anode is connected +ve & cathode is connected -ve terminal of battery

- n-1 cavity is buncher cavity where we connect RF i/p
- N^{th} cavity is a collector cavity where we take RF amplified o/p

→ Working :-
generated electrones from electron gun move towards anode & during the motion by velocity modulation electrones are getting bunch & collected at N^{th} cavity.

* Megatron Oscillation :- Magnetron
→ Working principle :-
it is been utilize to generate to Oscillation of microwave $freq^n$
- ranging from 600 MHZ to 300 GHZ

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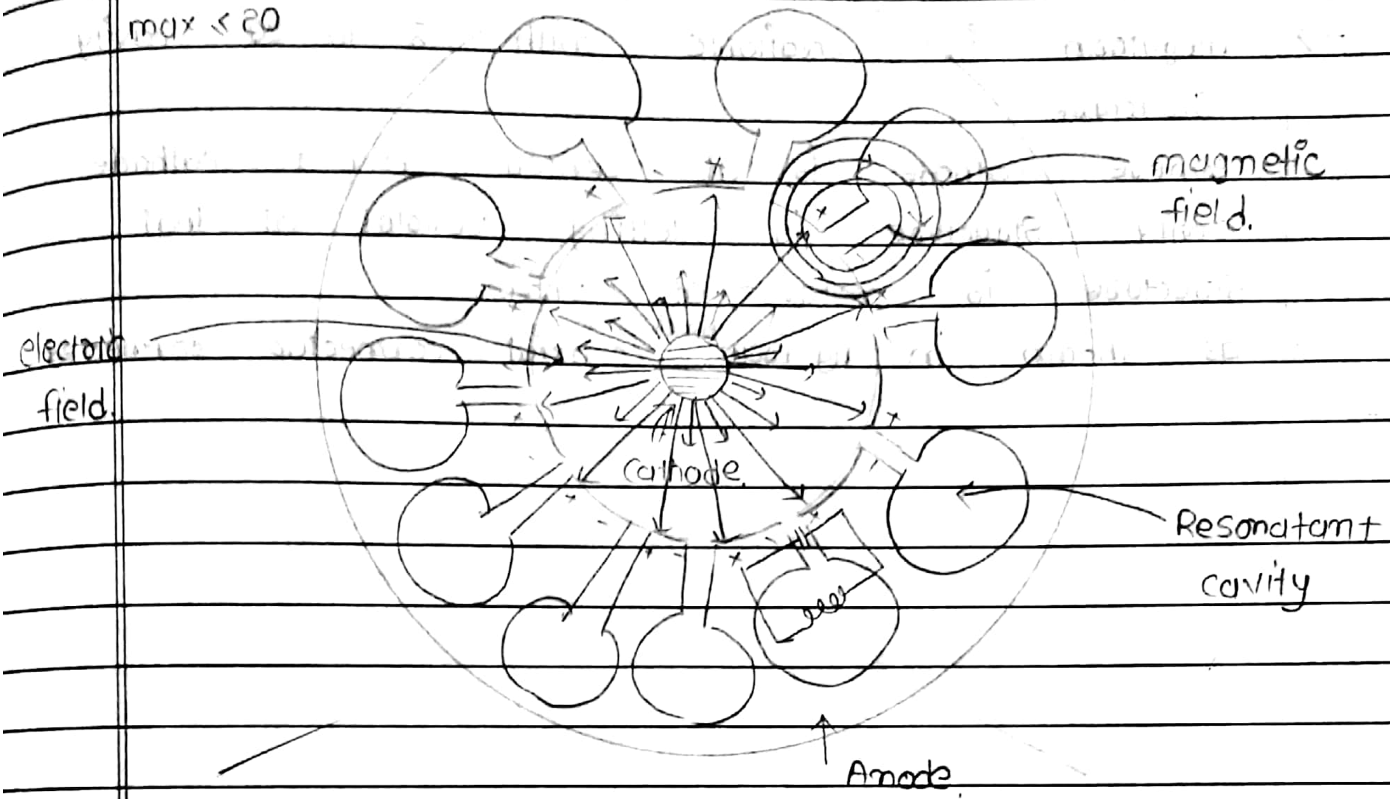
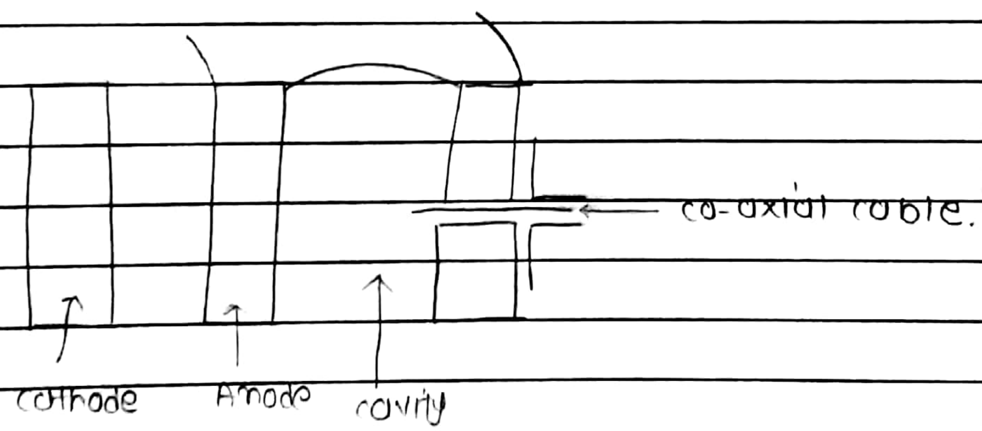
→ Stoucture.

min = 8

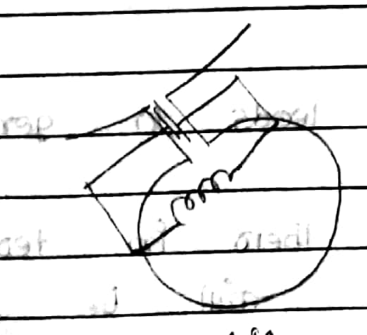
max ≤ 20



→ [TOP view OF megatoon]



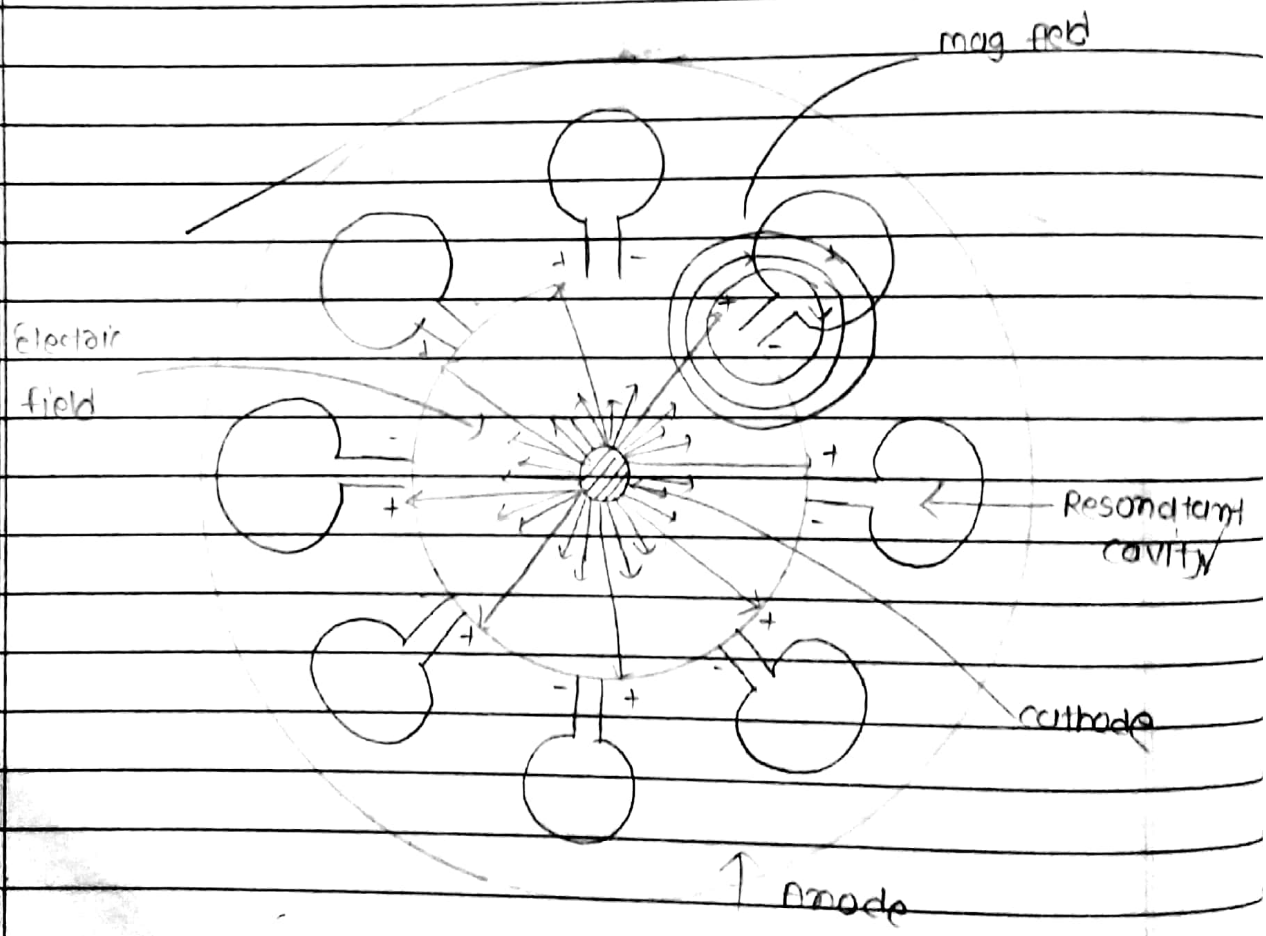
→ [cross section view]



→ [equivalent ckt OF cavity]

- internal cavity structure :

→ megatron is available with 8 to 20 cavity structure
- where cathode is at center w.r.t cathode cavity structure is getting revolved at that structure is noted at anode.
- as shown in fig from which co-axial connector connected



- tank circuit oscillation leads to generation of electric & mag field
- range of freq^n in their in terms of micro wave freq^n which will be detected by coaxial cable.

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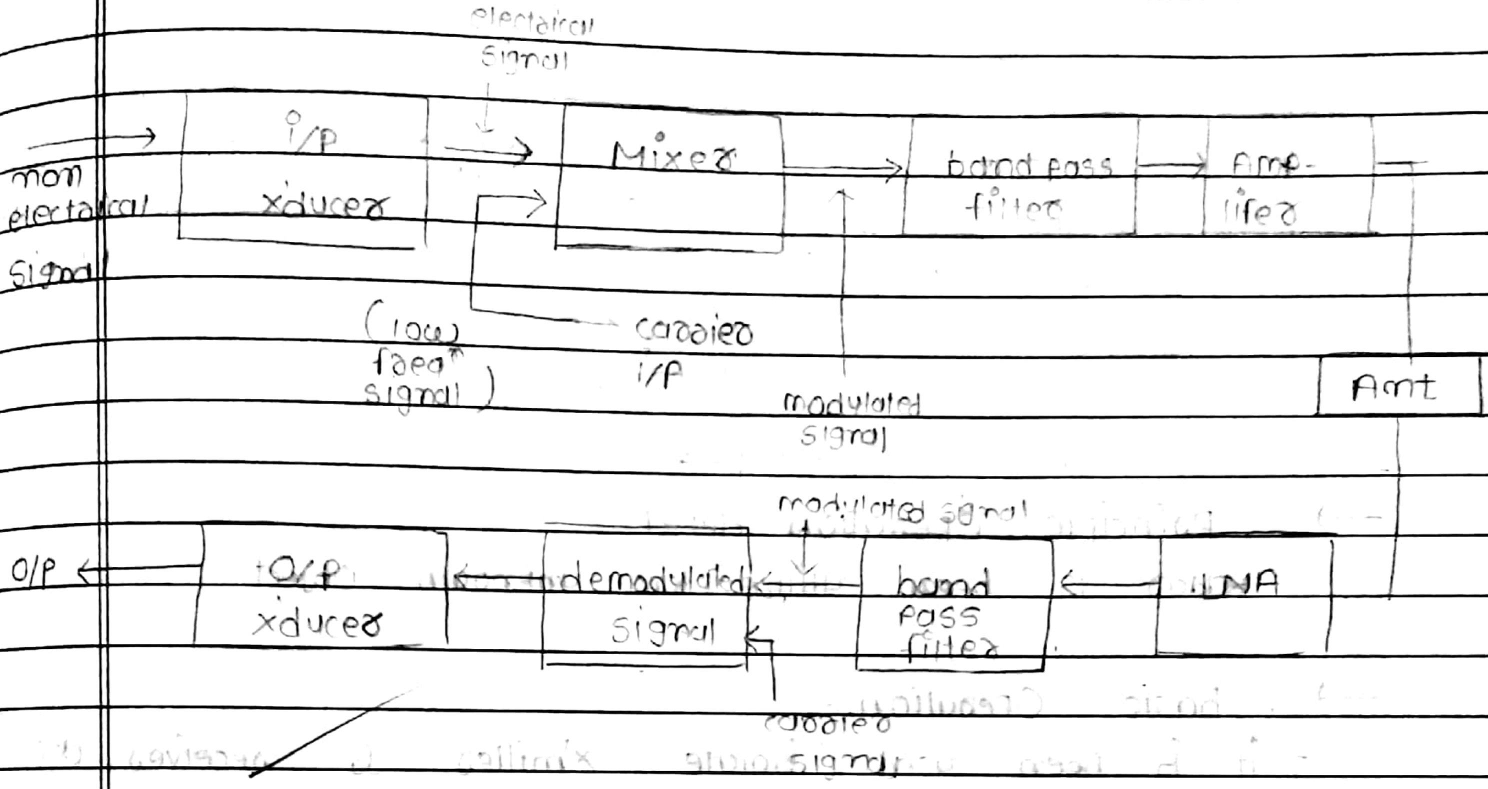
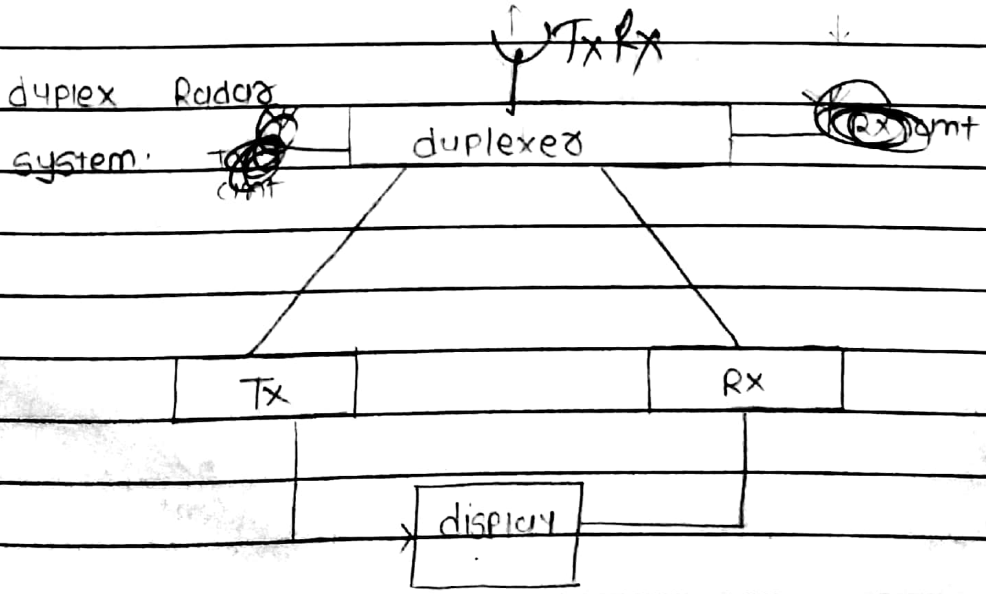
* communication System.



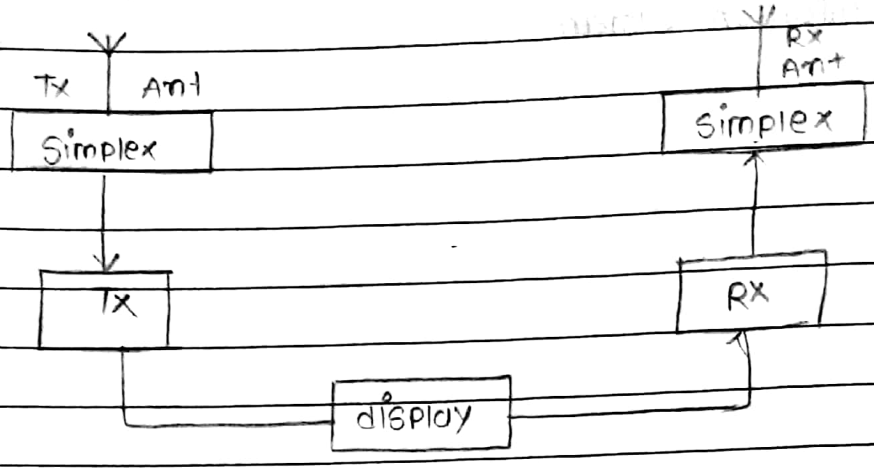
⇒ Noise figure (1) = $\frac{\text{Signal to noise ratio at O/P}}{\text{Signal to noise ratio at i/p}}$

$= \frac{\text{Signal at O/P}}{\text{Noise at O/P}} \times \frac{\text{Noise at i/p}}{\text{Signal at i/p}}$

* duplex Radar system.



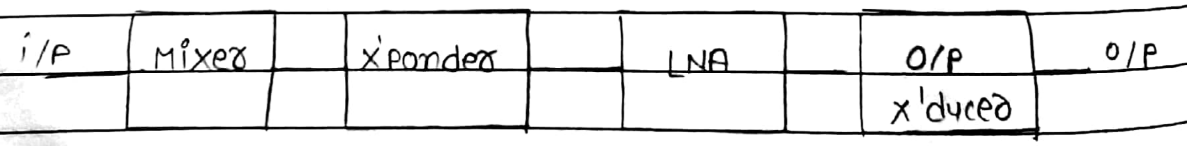
* Simplex Radar System

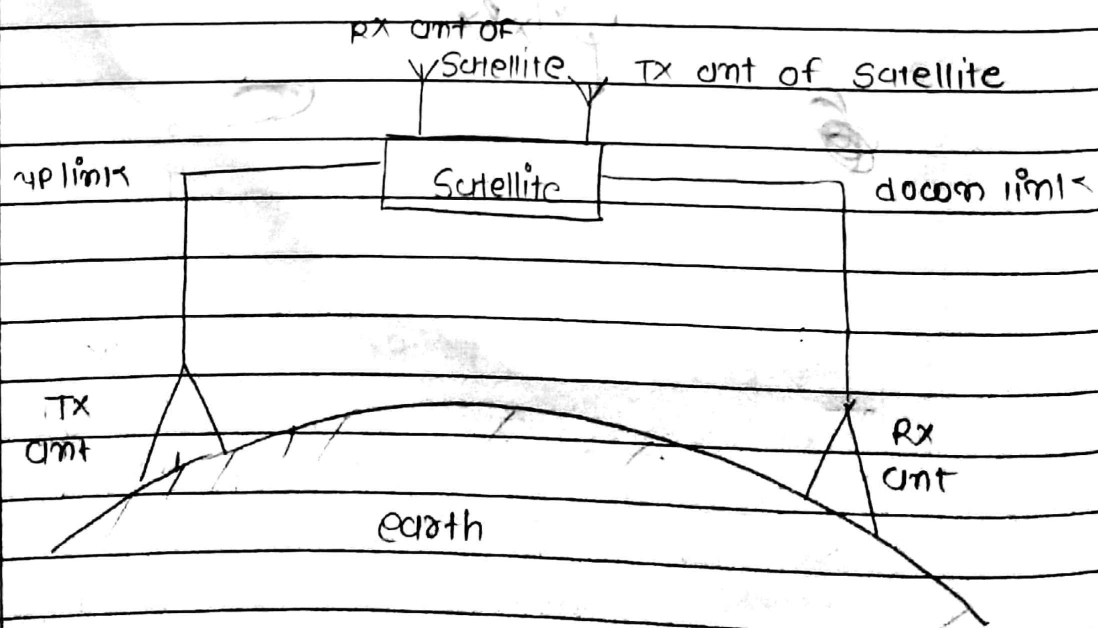


→ Principle Operation :- detect
Radar is been utilize for unknown Object.

→ Basic Operation :-
it is been used isolate x'mitter & receiver ckt

* Satellite communication system





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- in figure we show that the non electrical signal x'mit to x'mitter antenna
- using X'mitter ant signal x'mit earth to satellite can receive signal
- Mixer process on i/p signal & carrier i/p
- Transmitter ant of satellite x'mit ant to earth & at earth station receiver ant receive the signal
- uplink freq^n is higher than the downlink freq.

* Microwave imaging & it's application

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* Aids of navigation :

→ The compass :-

- A compass is a navigational instrument that shows directions in a frame of reference that is stationary relative to surface of the earth.
- It four cardinal directional (North, South, east, west)

→ The chronometer :-

- a chronometer is a clock that is precise and accurate enough to be used as a portable time std. It can therefore be used to determine longitude by means of celestial navigation

→ The sextant :-

- It used to measure the angle betn any two visible objects.

→ The Theodolite :-

measuring angles in the horizontal & vertical planes.

* Navigation :-

The art of directing the movements of a craft (object) from one point to another along a desired path is called navigation

- In short navigation is process to finding a short & secure path to travel.