Notes on

Wave Propagation and Broadband Communication

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Transmission Line

* Fundamentals

→ These are used commonly for power distribution (at low freq.) and in communication (at high freq.).

→ The transmission line basically consists of two or more parallel conductors are used to connect source to load.

Types :- co-axial cable, parallel wire, & microstrip line.

* Characteristics

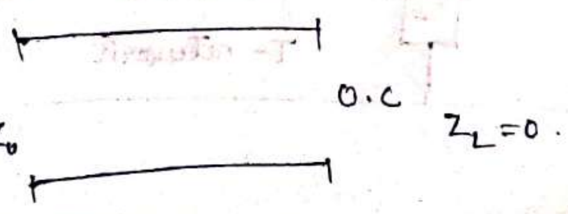
(i) Attenuation

(ii) Power handling capability

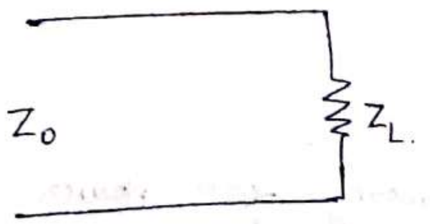
→ There should be minimum attenuation and maximum power handling capability.

→ There are also two types transmission line based on load termination.

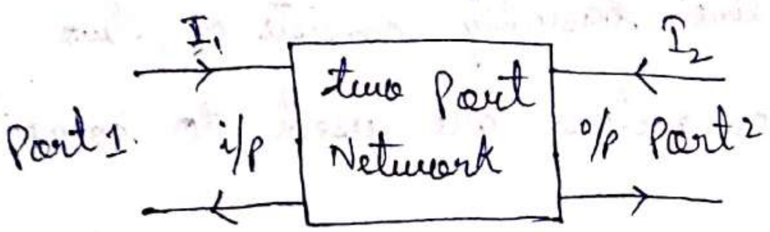
(a) Resonant Transmission Line ($Z_0 \mp Z_L$)



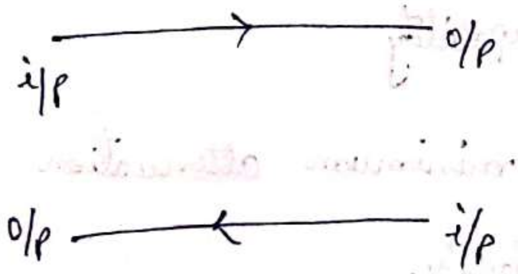
(b) Non - Resonant Transmission Line ($Z_0 = Z_L$)



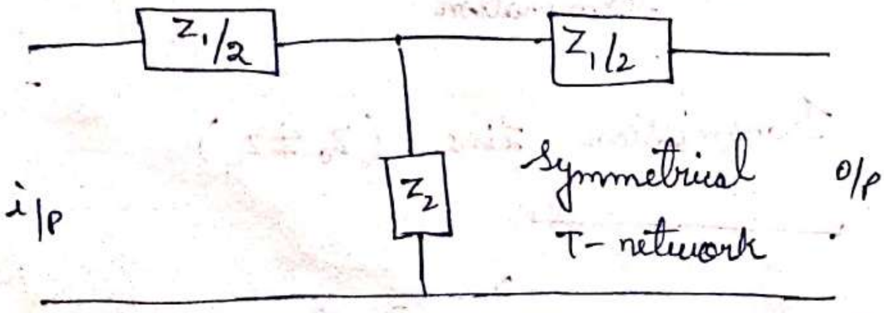
→ A Port is a Pair of terminals

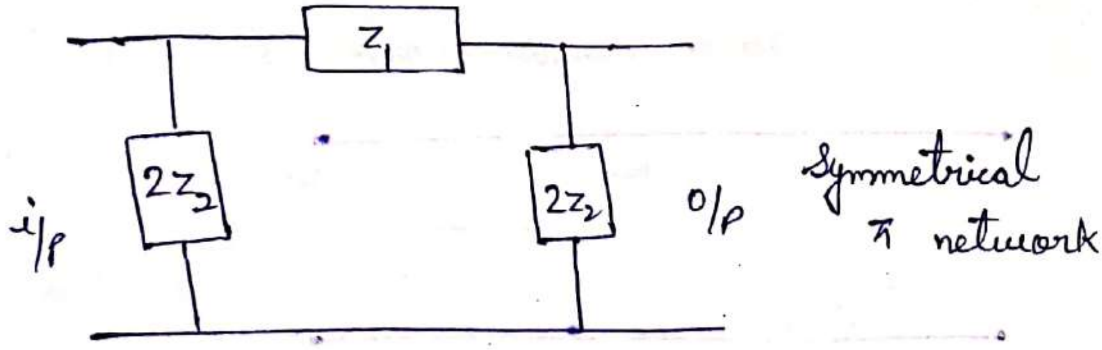


→ If i/p & o/p Ports are interchanged and electrical Properties of the network are not change then that network is Symmetrical network.



→ Entering current = o/p current for symmetrical network.

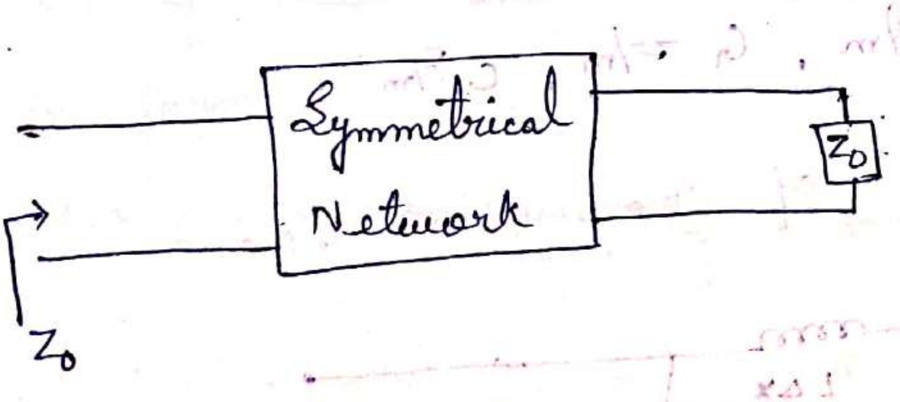




* Definition of characteristic impedance 'Z_0'

→ If infinite no of identical symmetrical network are connected in cascade then the impedance seen at i/p of the first network is called characteristics impedance 'Z_0'.

→ When a symmetrical network is terminated by characteristic impedance then the impedance seen at input of network is equals to characteristics impedance 'Z_0'.



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I/p end (or) transmitting end (or) source end (or) Sending end

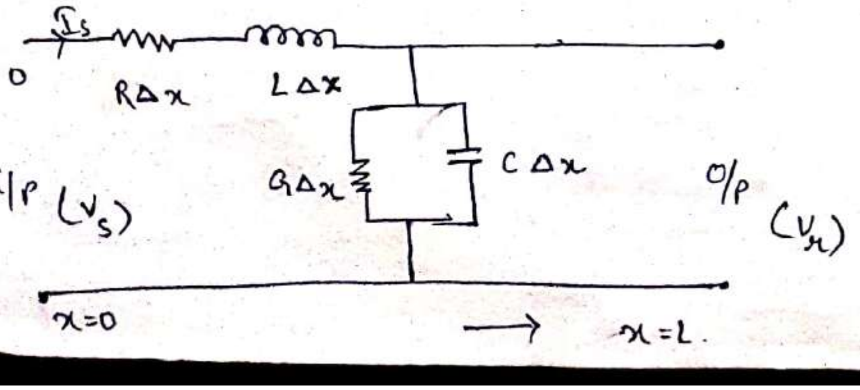
O/p end (or) Receiving end (or) Load end (or) Terminating end.

→ R, L, G, C are distributed throughout the transmission line. These are not physically present. So transmission lines are distributed network.

→ If R, L, G, C are distributed uniformally then transmission line is uniform transmission line.

→ R Ω/m, L H/m, G ℧/m, C F/m.

* Equivalent ckt of Transmission Line



x is length of transmission line.

* Transmission Line Equation

$$\frac{\partial^2 V_s(x)}{\partial x^2} - \gamma^2 . V_s(x) = 0 \rightarrow (1)$$

$$\frac{\partial^2 I_s(x)}{\partial x^2} - \gamma^2 . I_s(x) = 0 \rightarrow (2)$$

γ = Propagation constant

$$\gamma = \alpha - j\beta$$

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

where,

α = Attenuation constant = Re (γ)

β = Phase constant = I_m (γ)

* Solutions of Transmission Line Equation

→ Solutions of these differential homogeneous equation are in form of :

$$V_s(x) = V_0^+ . e^{-\gamma x} + V_0^- . e^{\gamma x} \rightarrow (3)$$

$$I_s(x) = I_0^+ . e^{-\gamma x} + I_0^- . e^{\gamma x} \rightarrow (4)$$

V_0^+, V_0^-, I_0^+, I_0^- are wave amplitude

V_0^+, I_0^+ travels are in (+)ve direction.

V_0^-, I_0^- travels in (-ve) direction.

$$V = V_S \cdot \cosh \gamma x - I_S \cdot Z_0 \sinh \gamma x.$$

$$I = I_S \cdot \cosh \gamma x - \frac{V_S}{Z_0} \cdot \sinh \gamma x.$$

V and I are the voltage and current in terms of V_s and I_s at any position of transmission line. (At $x = 0$ to L).

* Characteristic Impedance

→ It is the ratio of positively (negatively also) travelling voltage wave to current wave at any point on transmission line.

$$Z_0 = \frac{V_0^+}{I_0^+}$$ if positively

$$Z_0 = \frac{V_0^-}{-I_0^-}$$ [$-I_0$ due to reflection]

$$Z_0 = -\left(\frac{V_0^-}{I_0}\right)$$

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

Question

A transmission line contains R, L, G, C parameter where;

$R = 8\ \Omega/m$, $L = 8$ nH/m, $G = 0.8$ m mho/m, $C = 0.20$ PF,

$f = 4$ GHz.

Calculate

(a) Characteristics impedance

(b) Propagation constant

Ans

Given data,

$R = 8\ \Omega/m$

$G = 0.8\ m\mho/m = 0.8 \times 10^{-3}\ \mho/m$

$L = 8\ nH/m = 8 \times 10^{-9}\ H/m$

$C = 0.20\ PF = 0.20 \times 10^{-12}\ F$

$f = 4\ GHz = 4 \times 10^{9}\ Hz.$

$\therefore\ \omega = 2\pi f$

$= 2\pi \times 4 \times 10^{9}$

$= 25.12 \times 10^{9}$ rad/s $= 25.12$ G rad/sec.

(a) Characteristics impedance

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

$$= \sqrt{\frac{8 + j(25.12 \times 10^{9})(8 \times 10^{-9})}{0.8 \times 10^{-3} + j(25.12 \times 10^{9})(0.20 \times 10^{-12})}}$$

$$= \sqrt{\frac{8 + j200.96}{8 + 10^{-2} + j50 \times 10^{-12}}}$$

$$= \sqrt{\frac{201.2 \angle 87.7^\circ}{10^{-2} \times 50.6 \angle 80.9}}$$

$$= \sqrt{397.6 \angle 6.8^\circ} = 19.99 \angle 3.4^\circ$$

(b) **Propagation constant**

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

$$= \sqrt{(201.2 \angle 87.7^\circ)(50.6 \times 10^{-2} \angle 80.9^\circ)}$$

$$= 100.9 \times 10^{-1} \angle 84.3^\circ$$

By calculator

$(3 + j4) = 5 \angle 53.13^\circ$ or $3 + j4 = a + jb$.

$= r \angle \theta \quad [r = \sqrt{a^2 + b^2}]$

$= \sqrt{3^2 + 4^2} = 5$

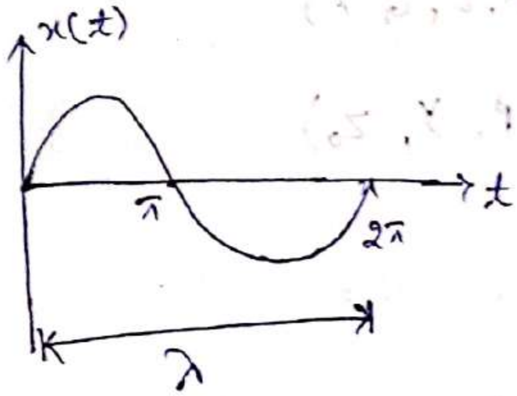
$\theta = \tan^{-1}(b/a)$

$= \tan^{-1}(4/3)$

$= 53.13^\circ$.

* Wavelength, Velocity of Propagation :

→ A wavelength is distance travelled by the wave along line when the phase angle changes to 2π radians.



$$\lambda = \frac{2\pi}{\beta}$$, $$\text{Velocity } (v) = \frac{\omega}{\beta}$$

$$\text{Velocity } (V) = \frac{1}{\sqrt{LC}}$$

For any medium $$(v) = \frac{1}{\sqrt{\mu \cdot \epsilon}}$$

$$\mu = \mu_0 \cdot \mu_r \quad , \quad \epsilon = \epsilon_0 \cdot \epsilon_r$$

For air medium $$(v) = \frac{1}{\sqrt{\mu_0 \cdot \epsilon_0}}$$

$$= 3 \times 10^8 \ m/s$$

$$\mu_0 = 4\pi \times 10^{-7} \ H/m.$$

$$\epsilon_0 = 8.854 \times 10^{-12} \ F/m.$$

→ $v = \omega/\beta = \frac{1}{\sqrt{LC}}$ (In transmission line).

$$\boxed{\beta = \omega . \sqrt{LC}}$$

* Relation between Primary and Secondary Parameters

Primary Parameter (R, L, G, C).

Secondary Parameter $(\alpha, \beta, \gamma, Z_0)$.

Case 1 : For loss less line

Defⁿ :- A transmission line is loss less when diaelectric medium between them is loss less and conductance is very high. $(\sigma_c = \infty)$.

Condition :- $R = G = 0$ for loss less line

$$\therefore \boxed{Z_0 = \sqrt{L/C}}$$

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

$$= \sqrt{(j\omega)^2 . LC}$$

Put $R = G = 0$ in above

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

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

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

$= 0 + j\omega \sqrt{LC}$

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

$$\boxed{v_p = \text{Phase velocity} = \frac{1}{\sqrt{LC}}}$$

Case 2 :- For distortion less line attenuation constant(α) is independent of frequency and phase constant is proportional to frequency.

Condition :- $\frac{R}{L} = \frac{G}{C}$

$R = \alpha . Z_0 \ \Omega/m$; $L = \frac{Z_0}{v_p} H/m$

$G = \frac{\alpha}{Z_0} \ ℧/m$; $C = \frac{1}{Z_0 . v_p} F/m.$

Delay $= \sqrt{LC}$ sec/m

$$\boxed{\alpha = R . \sqrt{\frac{C}{L}}} \quad \text{or} \quad \boxed{G\sqrt{\frac{L}{C}} = \alpha}$$

Ques

An airline has characteristic impedance of 70Ω & phase const. 3 rad/m at 100 MHz. calculate

(i) Inductance/m.

(ii) Capacitance/m.

Ans: Assume an airline be loss less line ($\Rightarrow \sigma = 0$).

So $R = G = 0$ & $\alpha = 0$.

$Z_0 = \sqrt{\frac{L}{C}}$; $\beta = \omega\sqrt{LC}$

Given data,

$Z_0 = 70\,\Omega$, $\beta = 3$ rad/m.

$f = 100\,MHz = 100 \times 10^6\,Hz$

$\therefore Z_0 = \sqrt{L/C}$ $\quad \omega = 2\pi f = 2\pi \times 100 \times 10^6 = 200\pi \times 10^6\,Hz$.

~~$= 2\pi \times 100 \times 10^6 = 200\pi \times 10^6\,Hz$.~~

$\Rightarrow 70 = \sqrt{L/C}$

$\Rightarrow \frac{L}{C}(70^2) = 4900$

$\Rightarrow L = 4900\,C$.

$\therefore \beta = \omega\sqrt{LC}$ $\quad \Rightarrow \sqrt{LC} = \frac{3}{200\pi \times 10^6}$

$\Rightarrow 3 = 200\pi \times 10^6 \sqrt{LC}$

$\Rightarrow 70\,C = \frac{3}{200\pi \times 10^6}$

$\Rightarrow C = \frac{3 \times 10^{-6}}{200 \times 3.14 \times 70} = 6.82 \times 10^{-5} \times 10^{-6}$.

$\Rightarrow C = 8.2 \times 10^{-12}\,F = 68.2\,pF/m$.

$\therefore L = 4900\,C = 4900 \times 68.2 \times 10^{-12}$

$= 334.2\,nH/m$.

* Reflection co-efficient of Transmission Line :-

If Z_L is load impedance of T.L, Z_0 is ch/as impedance of T.L then,

Voltage reflection co-efficient (K_v).

$$K_v = \frac{\text{Reflected Voltage wave}}{\text{Incident voltage wave}}$$

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

→ Similarly current reflection co-efficient (K_i).

$$K_i = \frac{\text{Reflected current wave}}{\text{Incident current wave}}$$

$$K_i = -(K_v)$$

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

* Transmission co-efficient (T) :-

$$T = \frac{\text{Transmitted Voltage wave}}{\text{Incident voltage wave}} = \frac{V_{tr}}{V_{inc}}$$

$$T = \frac{\text{Transmitted current wave}}{\text{Incident current wave}} = \frac{I_{tr}}{I_{inc}}$$

$$T = 1 + K_v$$

Transmission co-efficient (T) = 1 + Voltage Reflection co-efficient.

$$T = \frac{2Z_L}{Z_L + Z_0}$$

$$= 1 + K_v$$

$$= 1 + \frac{Z_L - Z_0}{Z_L + Z_0}$$

$$= \frac{Z_L + Z_0 + Z_L - Z_0}{Z_L + Z_0} = \frac{2Z_L}{Z_L + Z_0}$$

Ques

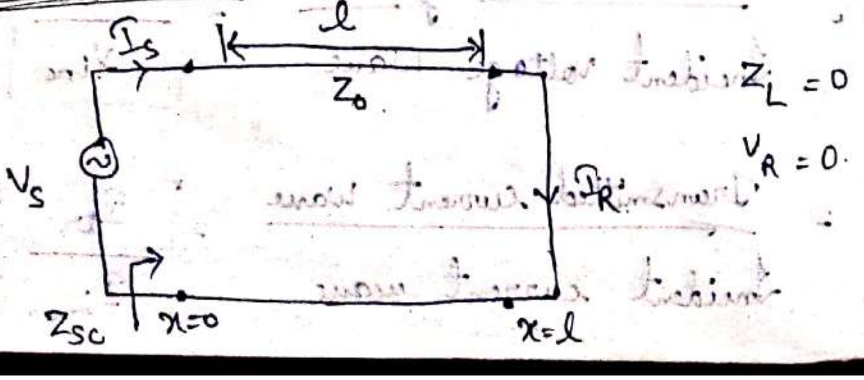
If the length of T.L. is $\frac{\lambda}{8}$, Find the electrical length.

Ans Electrical length $= \beta . l$.

$$= \frac{2\pi}{\lambda} . \frac{\lambda}{8}$$

$$= \frac{2\pi}{8} = \pi/4.$$

* Short circuit Line



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$$Z_{SC} = \frac{V_S}{I_S}.$$

→ When a finite length T.L is terminated by short circuit then that line is short ckt line.

$V(\text{at } x = l) = V_R = 0$

$= V_S \cdot \cosh \gamma l - I_S \cdot Z_0 \cdot \sinh \gamma l.$

$$\Rightarrow \boxed{\frac{V_S}{I_S} = Z_0 \cdot \tanh \gamma l.}$$

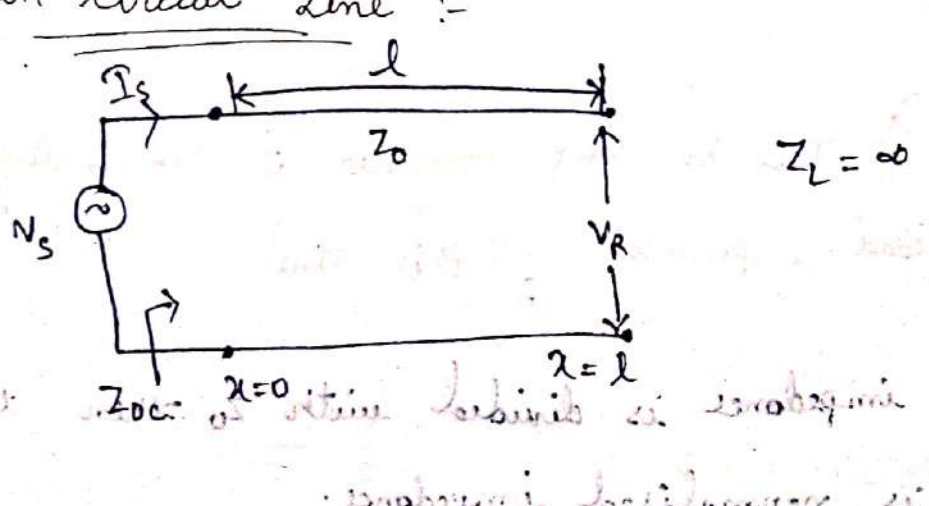
$Z_{SC} = V_S / I_S$ = i/p impedance of short ckt T.L.

→ If T.L is loss less, $\alpha = 0$; $\gamma = j\beta$.

$\therefore Z_{SC} = Z_0 \cdot \tanh (j\beta) l$

$$\boxed{Z_{SC} = j Z_0 \cdot \tan \beta l.}$$

* Open circuit Line :-



→ When a finite length of T.L is open circuited at terminating end then it is called open ckt line.

→ The impedance seen at the i/p of the line is Z_{oc}.

$\therefore \hat{I}$ (at $x = l$) $= \hat{I}_R = 0$

$\therefore \hat{I}_s \cosh \gamma l - \frac{V_s}{Z_0} \sinh \gamma l$

$$\Rightarrow \frac{V_s}{\hat{I}_s} = Z_0 . \coth \gamma l .$$

$$\Rightarrow \boxed{Z_{oc} = Z_0 \cdot \coth \gamma l}$$

For a loss less line

$$\boxed{Z_{oc} = -jZ_0 . \cot \beta l}$$

NOTE :- A section of loss less T.L either it is open circuited or short circuited that can act as a ckt reactive element (or) ckt susceptive element.

Ques

A loss less $\frac{\lambda}{8}$ T.L is sort circuited at terminating end. Find normalised impedance of this line.

Ans If any impedance is divided with Z_0 then that impedance is normalised impedance.

Here loss less T.L length $l = \lambda/8$

Z_{sc} = i/p impedance of short ckt T.L.

$= jZ_0 \cdot \tan \beta l$

$\therefore \frac{Z_{sc}}{Z_0} = j \tan \frac{2\pi}{\lambda} \cdot \frac{\lambda}{8} = j \cdot 1 = j$

⇒ Normalised Impedance = 1 = |j|.

This indicates an inductive reactance.

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$Z_{oc} \cdot Z_{sc} = Z_0^2$

Ques :-

A distortionless transmission line has α = 20 mnP/m (milli Neper/mtr), Phase velocity $v_p = 0.6 \times 3 \times 10^8$ m/sec i.e., 0.6 times the velocity of light. Assume $Z_0 = 50\,\Omega$. Find the Primary constants and delay in the T.L.

Ans

$\alpha = 20 \times 10^{-3}$ nP/m.

$v_p = 0.6 \times 3 \times 10^8$ m/sec

$Z_0 = 50\,\Omega$

$R = \alpha Z_0 = 20 \times 10^{-3}$ nP/m $\times 50\,\Omega$

$= 1\,\Omega/m.$

$G = \frac{\alpha}{Z_0} = \frac{20 \times 10^{-3} \text{ nP/m}}{50\,\Omega} = 0.4$ m℧/m.

$L = Z_0/v_p = \frac{50\,\Omega}{0.6 \times 3 \times 10^8 \text{ m/sec}} = 0.27\ \mu H/m.$

$C = \frac{1}{Z_0 \cdot v_p} = \frac{1}{50\,\Omega \times 0.6 \times 3 \times 10^8 \text{ m/sec}} = 0.11$ G F/m.

* Input Impedance of a Transmission Line :-

If a transmission line has length 'l' and its characteristics impedance is Z_0 then i/p impedance of transmission line is :

$$Z_{in} = Z_0 \cdot \frac{Z_L + Z_0 \tanh \gamma l}{Z_0 + Z_L \tanh \gamma l} \rightarrow (5)$$

Z_L = load impedance i.e., the T.L is terminated at Z_L.

→ If T.L is lossless line $\alpha = 0$, $\gamma = j\beta$, then i/p impedance,

$$Z_{in} = Z_0 \cdot \frac{Z_L + jZ_0 \cdot \tan\beta l}{Z_0 + jZ_L \tan\beta l} \rightarrow (6)$$

NOTE :- When a T.L is terminated by $Z_L = Z_0$, then the impedance seen at any point in the T.L is Z_0, and the i/p impedance of T.L is also Z_0 wheather the line is lossless (or) lossy, and irrespective of the length of the line.

* Properties of $\lambda/2$ line

Length of T.L $l = \lambda/2$, consider T.L is lossless.

$$Z_{in} = Z_0 \cdot \frac{Z_L + jZ_0 \tan\beta l}{Z_0 + jZ_L \tan\beta l}$$

$$Z_{in} = Z_0 \cdot \frac{Z_L + jZ_0 \tan \frac{2\pi}{\lambda} \cdot \lambda/2}{Z_0 + jZ_L \tan 2\pi/\lambda \cdot \lambda/2}$$

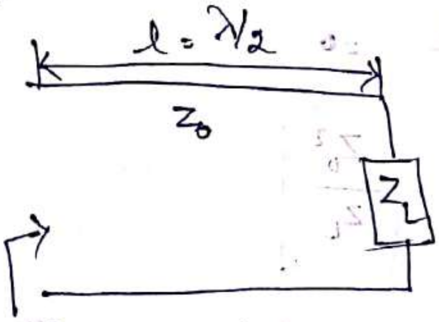
$$= Z_0 \cdot \frac{Z_L + jZ_0 \tan 0}{Z_0 + jZ_L \tan 0}$$

$$= Z_0 \cdot \frac{Z_L + 0}{Z_0 + 0}$$

$$\therefore \boxed{|Z_{in}| = |Z_L|}$$

i.e.,

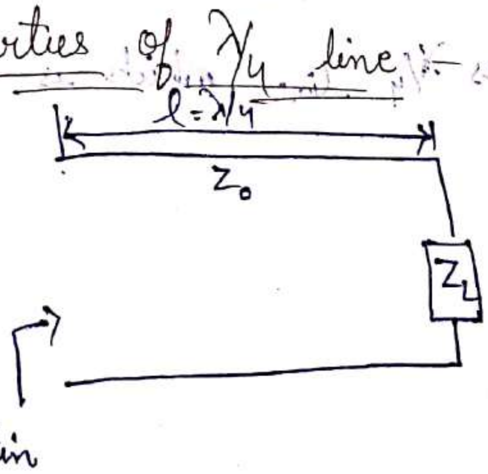
Input impedance of $\lambda/2$ line is same as load impedance.



$Z_{in} = Z_L$

→ Input impedance of $n\frac{\lambda}{2}$ line (length of T.L $l = n\lambda/2$), where $n = 1, 2, 3 \ldots$, is same as $\lambda/2$ line & it is equal to load impedance.

* Properties of $\lambda/4$ line



$$\tan \beta l = \tan \frac{2\pi}{\lambda} \cdot \frac{\lambda}{4}$$

$$= \tan \pi/2 = \infty \quad \text{(In radian)}.$$

Let, the transmission line ($l = \lambda/4$) is lossless line.

$$Z_{in} = Z_0 \cdot \frac{Z_L + jZ_0 \cdot \tan \beta l}{Z_0 + jZ_L \tan \beta l}$$

$$= Z_0 \cdot \frac{\tan \beta l \left(Z_L/\tan \beta l + jZ_0 \right)}{\tan \beta l \left(Z_0/\tan \beta l + jZ_L \right)}$$

$$\Rightarrow \frac{Z_L}{\tan \beta l} = \frac{Z_L}{\infty} = 0.$$

$$\Rightarrow Z_{in} = Z_0 \cdot \frac{jZ_0}{jZ_L} = \boxed{\frac{Z_0^2}{Z_L}}$$

→ If $Z_L = 0\,\Omega$ then $Z_{in} = \infty\,\Omega$ & $Z_L = \infty\,\Omega$, then $Z_{in} = 0\,\Omega$.

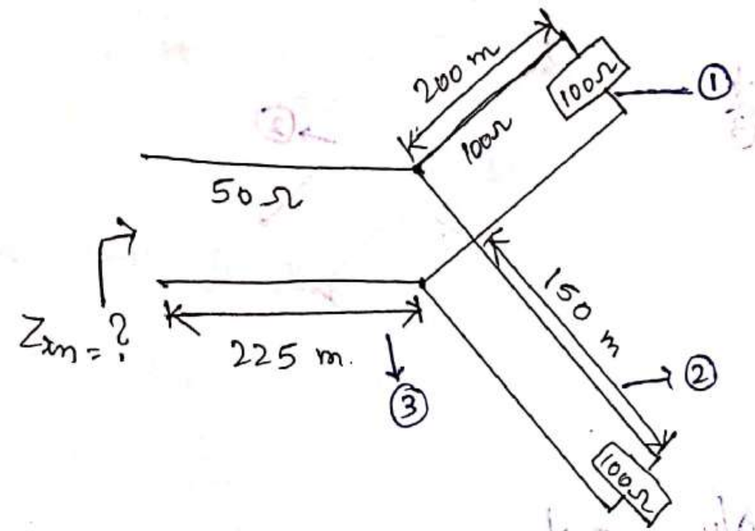
→ A quarter wave line ($l = \lambda/4$) also named as impedance T/F because it transforms high impedance to low impedance & vice versa.

→ The i/p impedance of a $n\lambda/4$ line (where n is add i.e., $n = 1, 2, 3 \ldots$) same as $\lambda/4$ line which is equal to $\frac{Z_0^2}{Z_L}$.

Ques

Find i/p impedance of the following T.L.

(i) Assume T.L are loss less lines.



Ans For line ①

$Z_0 = Z_L = 100\,\Omega$

$\Rightarrow Z_{in_1} = 100\,\Omega$.

For line ②; $Z_0 = Z_L = 100\,\Omega$.

$\Rightarrow Z_{in_2} = 100\,\Omega$

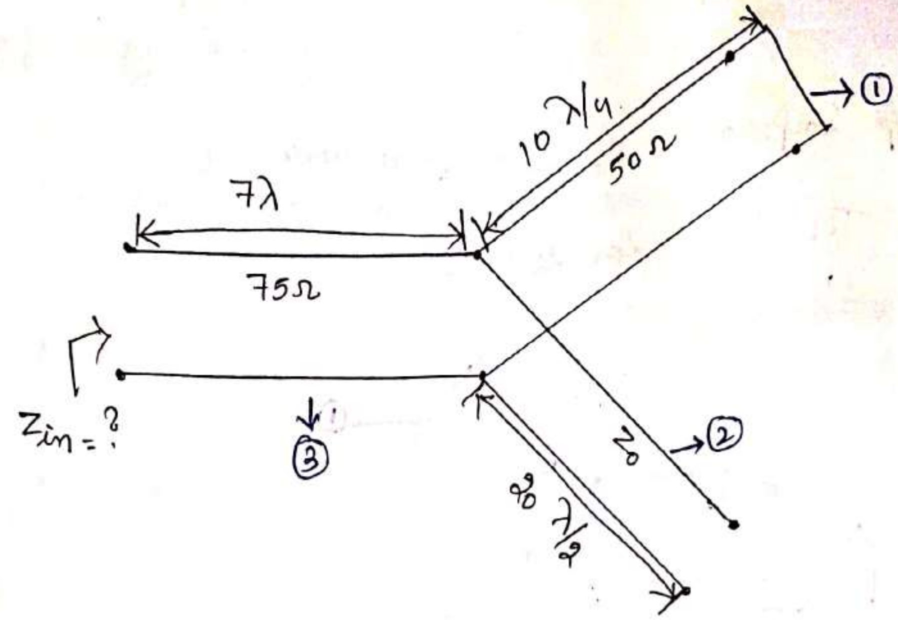
Line ① & line ② are parallel to each other, so their effective i/p impedance is

$Z_{in} = Z_{in_1} \,||\, Z_{in_2}$

$= 100\,\Omega \,||\, 100\,\Omega = 50\,\Omega$.

For line ③ $Z_0 = Z_L = Z_{in} = 50\,\Omega$.

(ii)



Ans For line ①

$l = 10\lambda/4 = 5\lambda/2$.

$Z_L = 0\,\Omega \Rightarrow Z_{in_1} = 0\,\Omega = Z_L$

For line ② $l = 20\lambda/2$

$Z_{L_2} = \infty\,\Omega \Rightarrow Z_{in_2} = Z_{L_2} = \infty\,\Omega$

Line ① & line ② are Parallel.

$Z_{in} = Z_{in_1} \parallel Z_{in_2}$

$= 0 \parallel \infty$

$= 0$

For line ③.

$l = 7\lambda = 14 \cdot \lambda/2$

$Z_{L_3} = 0\,\Omega$

$Z_{in} = Z_{L_3} = 0\,\Omega$.

For $n\lambda/2$ line, i/p impedance is load impedance.

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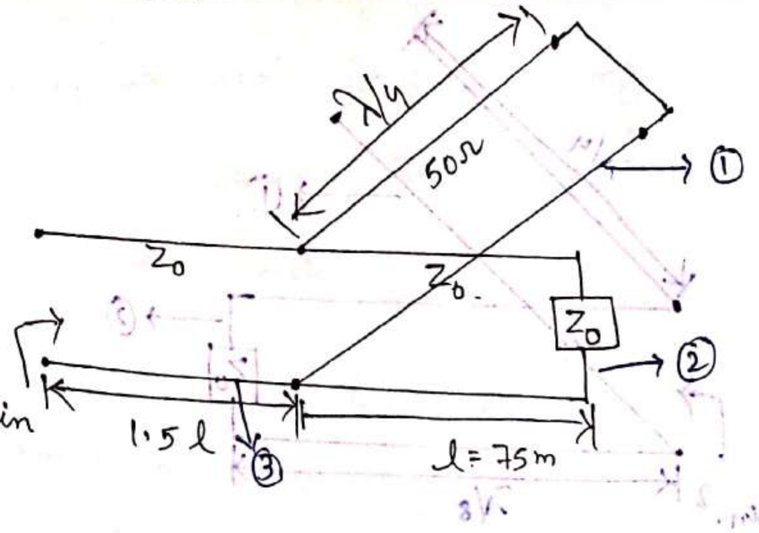
(iii)



<u>Ans</u>

For line ① $l = \lambda/4$, $Z_{L_1} = 0\Omega$

$Z_{in_1} = \infty\ \Omega$

$\left[\because Z_{in} = \frac{Z_0^2}{Z_L} = \frac{50^2}{0} = \infty\right]$. For λ/4 line

For line ② $Z_{L_2} = Z_0 \Rightarrow Z_{in_2} = Z_0$

line ① // line ②

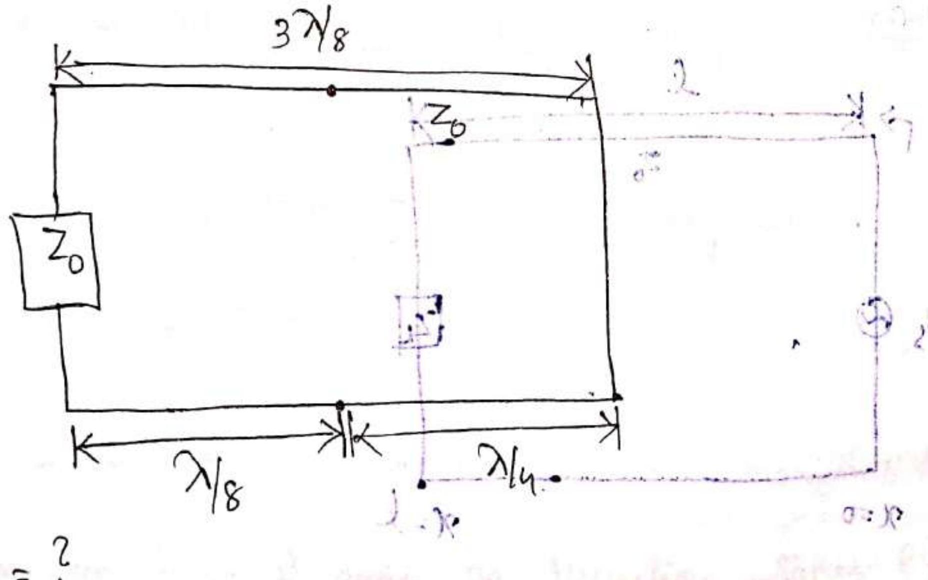
$Z_{in} = Z_{in_1} \parallel Z_{in_2}$

$= \infty \parallel Z_0 = Z_0$

For line ③ $Z_{L_3} = Z_0$

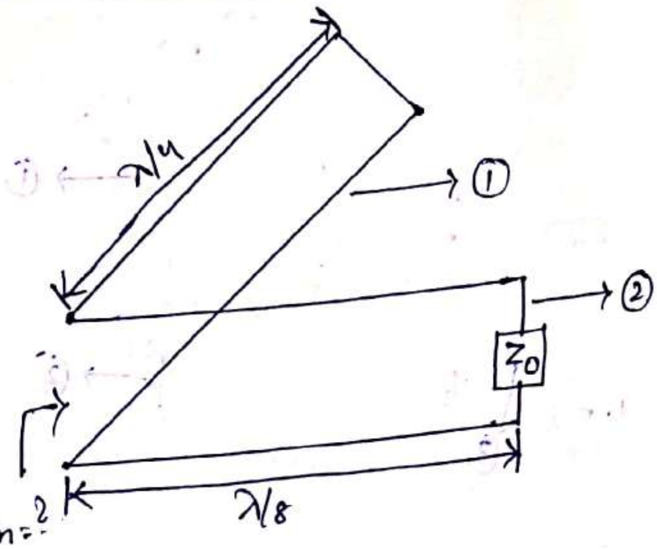
$\therefore Z_{in} = Z_{L_3} = Z_0$

(iv)



$Z_{in} = ?$

Ans



For line ①; $l = \lambda/4$, $Z_{L_1} = 0\,\Omega$.

$$\Rightarrow Z_{in_1} = \infty \left[\because Z_{in} = \frac{Z_0^2}{Z_L}\right]$$

For line ②; $l = \lambda/4$, $Z_{L_2} = Z_0$.

$$\Rightarrow Z_{in_2} = Z_0.$$

Line ① // line ②

$$Z_{in} = Z_{in_1} // Z_{in_2}$$
$$= \infty // Z_0$$
$$= Z_0.$$

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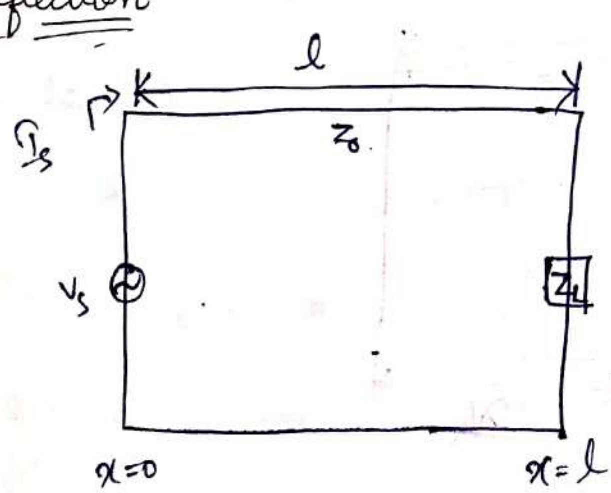
* Reflection



→ When $Z_L = Z_0$ at that time the impedance at any Point of the transmission line is same as Z_0. This is called impedance matching.

→ When $Z_L \neq Z_0$ at that time the impedance changes from Point to Point on the T.L. This is called impedance mismatching (or) impedance is discontinous (or) irregular (or) mismatch (or) non. uniform. Here reflection takes place.

→ The Voltage at any Point on T.L is vectorial sum of incident wave Voltage & reflected wave voltage at some locations on T.L. If these two voltages add in phase at that time voltage maxima will be observed. $V_{max} = |V_i| + |V_r|$

→ But at some location on T.L these two voltages add in out of phase. So in voltage minima is observed in T.L. $V_{min} = |V_i| - |V_r|$

→ Therefore a voltage across T.L may swing between V_{max} to V_{min} and vice versa.

→ But when $Z_L = Z_0$, there are no maximas & no minimas in T.L. Because, no reflection takes place in T.L

→ Voltage standing wave ratio (V_{SWR}) or

$$S = \frac{V_{max}}{V_{min}} = \frac{|V_i| + |V_r|}{|V_i| - |V_r|}$$

$$= \frac{1 + \frac{V_r}{V_i}}{1 - \frac{V_r}{V_i}} = \frac{1 + |K|}{1 - |K|}$$

where,

K = reflection co-efficient $= \frac{V_r}{V_i}$

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

$K \rightarrow |K| \angle\theta$

θ is phase angle of K.

$|K|_{max} = 1$; $|K|_{min} = 0$

$S_{min} = 1$; $S_{max} = \infty$

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→ The successive distance between two voltage minimas (or) two maximas is $\lambda/2$

→ The successive distance between voltage minima to maxima (or) vice versa is $\lambda/4$.

Location of

$V_{max} \leftrightarrow Z_{max} \leftrightarrow I_{min}$

Location of

$V_{min} \leftrightarrow Z_{min} \leftrightarrow I_{max}$

* **Location of V_{max} :-**

$$2\beta y_{max} - \phi = 2n\pi$$

n = 0 for 1st maxima

n = 1 for 2nd maxima

⋮

so on.

* **Location of V_{min} :-**

$$2\beta y_{min} - \phi = (2n+1)\pi$$

n = 0 for 1st minima

n = 1 for 2nd minima

⋮

so on

y → Distance measured from load end.

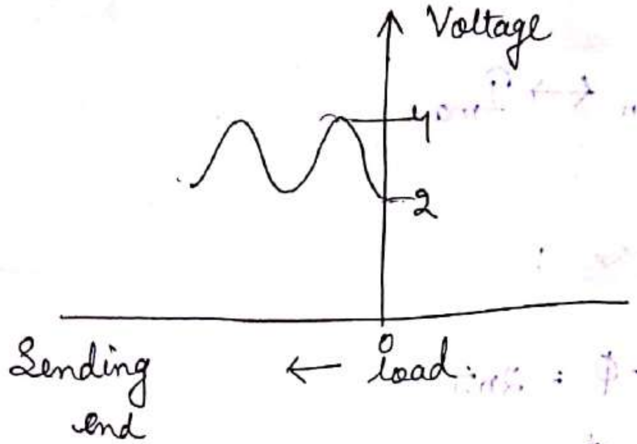
$Z_{max} = S.Z_0$; $Z_{min} = \frac{Z_0}{S}$

S = standing wave ratio

Z_0 = characteristic impedance

Ques

A certain T.L is terminated by an unknown load impedance. The voltage standing wave pattern is shown in figure. Calculate SWR, reflection co-efficient & also find load impedance. Given that $Z_0 = 100\,\Omega$.



Ans $V_{max} = 4$, $V_{min} = 2$

$\therefore$ SWR (S) $= \dfrac{V_{max}}{V_{min}} = 4/2 = 2.$

At the load V_{min} [i.e., 2] is observed. So the load impedance is Z_{min}

$\therefore Z_{min} = \dfrac{Z_0}{S} = \dfrac{100}{2} = 50 = Z_L$

* Reflection co-efficient

$$K = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{50-100}{50+100} = \frac{-50}{150}$$

$$= -1/3 = -0.33 = 0.33\angle 180^\circ$$

$$|K| = \frac{S-1}{S+1} = \frac{2-1}{2+1} = 1/3 = 0.33.$$

At the load, V_{min} is observed i.e., at $y=0$

1^{st} V_{min} is observed ..

$$2\beta y_{min} - \phi = (2n+1)\pi$$

$n = 0$ for 1^{st} minima

$\Rightarrow 2.\beta(0) - \phi = (2.0+1)\pi$

$\Rightarrow -\phi = \pi \Rightarrow \phi = -\pi \qquad \Rightarrow \pi = -180 = 180°$

* Impedance Matching :-

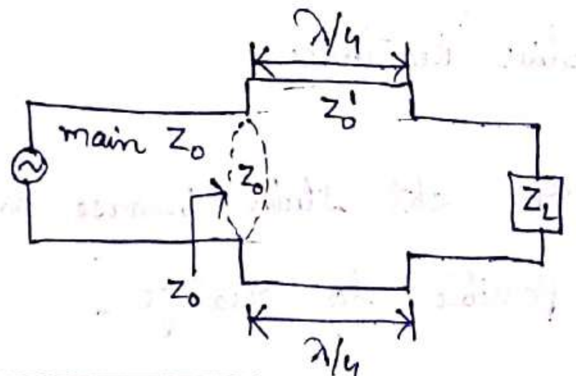
→ This technique is used for avoiding reflections.

→ Two types of impedance matching technique

(i) Quarter wave T/F.

(ii) Stub matching.

(i) Quarter Wave Transformer Matching :-



$$Z_0' = \sqrt{Z_0 . Z_L}$$

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→ Characteristics impedance of this quarter wave line (Z_0') is geometric mean of Z_0 & Z_L.

$$Z_0 = \frac{(Z_0')^2}{Z_L}$$

* **Disadvantage** :- When freq. of operation changes, length of quarter wave line has to be readjusted by disconnecting from the main line. So we use stub matching.

* Stub Matching :-

→ A section of a loss less T.L is either short circuited (or) open circuited can act as a ckt reactive element (or) circuit susceptible element and desired reactance (or) suspectance can be achieved by properly choosing length of T.L.

→ These are used in impedance matching technique. Hence, the name is stub matching.

$X_L = \omega L$ = Inductive Reactance

$X_C = \frac{1}{\omega C}$ = capacitive Reactance

→ We don't prefer open ckt stubs because an ideal open ckt is not possible to realize.

→ For example :- When a T.L is open circuited, it is indirectly terminated by air impedance.

→ For free space air impedance is 120π (or) $377\,\Omega$.

(Or)

→ A section of T.L can be used in shunt (or) parallel with main line as impedance matching by inserting it between the load & source is known as stub.

→ The process of impedancing by the stub is called stub matching.

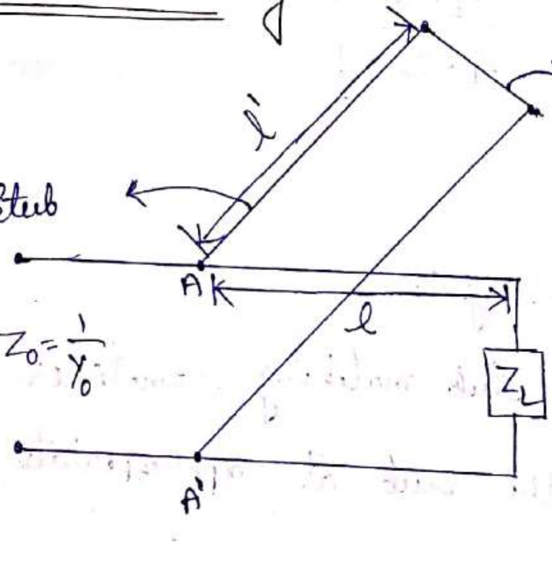
* Advantages :-

(i) Length of main T.L remains unchanged.

(ii) Z_0 of T.L remains constant.

(iii) At higher freq. the stub may be adjusted to a variable load & it is operated over a wide range of freq.

(1) Single Stub Matching :-



$$\text{Impedance}_{(Z)} = \frac{1}{\text{Admittance}(Y)}$$

$Z = R + jX_L$ = Resistance + j reactance

$Y = G + jb$ = conductance + j suspectance.

Here, in main T.L is $Z_L \neq Z_0$ then by inserting single stub we can match the impedance i.e., $Z_L = Z_0$.

→ Take 'l' is the distance from the load, where if we locate the stub then impedance matching occurs. Then that distance.

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

→ Take 'l_s' is the length of stub that to be placed at a distance 'l' from the load for impedance matching ($Z_L = Z_0$).

→ Then length of short circuit stub is

$$l_s = \frac{\lambda}{2\pi} \cdot \tan^{-1} \frac{Z_L \cdot Z_0}{Z_L - Z_0}$$

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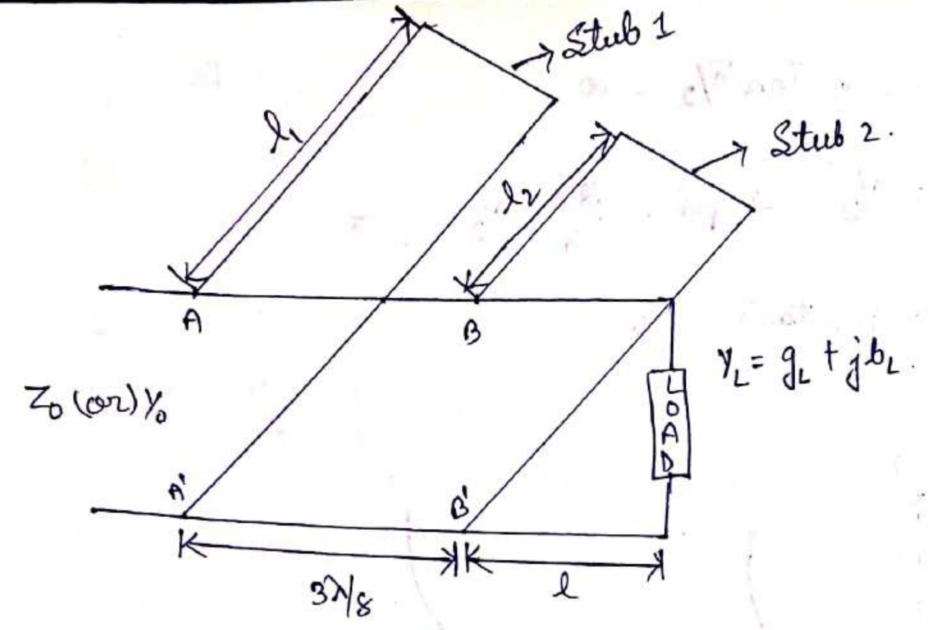
* Double Stub Matching :-

→ In case of single stub matching sometimes it is very difficult to put the stub at appropriate position along a T.L.

→ So, in this situation double stub matching is preferred.

→ In double stub matching two stubs having length l_1 & l_2 are used & those are placed at a fixed position AA' & BB' aparting a distance $3\lambda/8$.



→ The stub nearer to the load is adjusted to make the real part of resulting admittance at point AA' is equal to characteristic conductance of T.L = 1.

→ In the absence of 2nd stub at BB' (or) reflection co-efficient (Γ) is not fully negligible, in that case the stub at AA' is adjusted to produce the zero susceptance at AA'.

→ So in this way matching is done.

* Short circuit line

$$Z_{SC} = jZ_0 . \tan \beta l$$

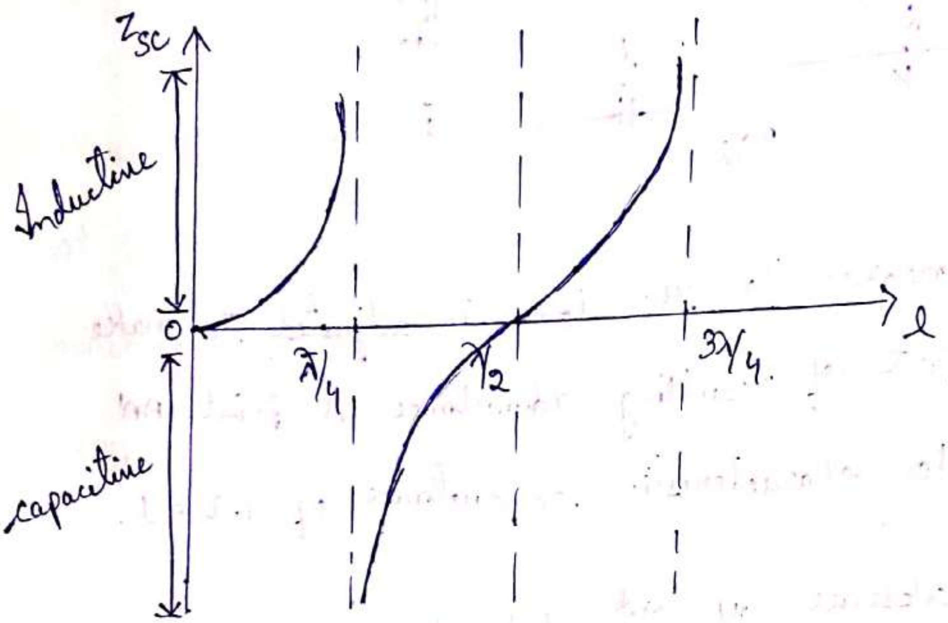
① If $l = \lambda/4$

$$\Rightarrow \beta l = \frac{2\pi}{\lambda} . \lambda/4 = \pi/2.$$

$\Rightarrow Z_{SC} = jZ_0 . \tan \pi/2 = \infty .$

② If $l = \lambda/2 \Rightarrow \beta l = \frac{2\pi}{\lambda} . \lambda/2 = \pi .$

$\Rightarrow Z_{SC} = jZ_0 \tan \pi = 0$



→ In T.L, in loss less condition for length 'l' varies from 0 to $\lambda/4$, the short ckt i/p impedonce is inductive in nature.

→ For length 'l' varies from $\lambda/4$ to $\lambda/2$ the short ckt i/p impedonce is capacitive in nature.

* Open circuit Line :-

$$\boxed{Z_{OC} = -jZ_0 . \cot \beta l .}$$

① If $l = \lambda/4$

$\Rightarrow \beta l = \frac{2\pi}{\lambda} . \lambda/4 = \pi/2 .$

$\Rightarrow Z_{OC} = -jZ_0 \cot \pi/2$

$= -jZ_0 \, 0$

$= 0.$

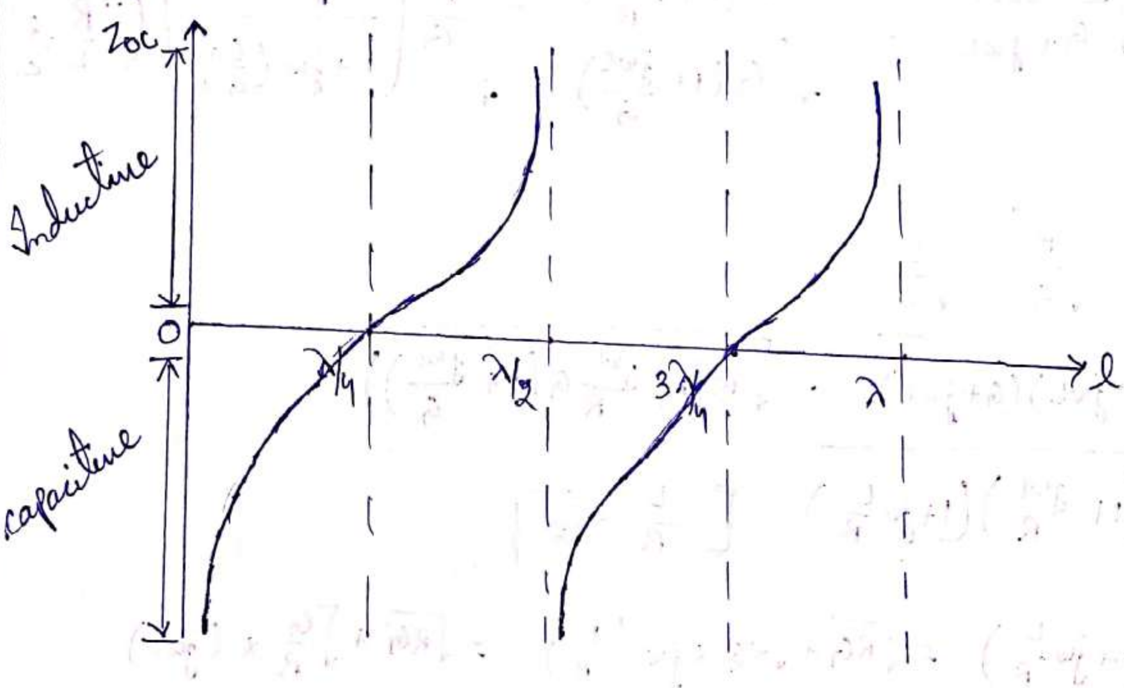
② If $l = \lambda/2$

$\Rightarrow \beta l = \frac{2\pi}{\lambda} \cdot \frac{\lambda}{2} = \pi.$

$\Rightarrow Z_{OC} = -jZ_0 \cot \pi$

$= -jZ_0 \infty$ $\left[\because \cot \pi = \frac{1}{\tan \pi} = \frac{1}{0} = \infty \right]$

$= \infty.$



→ The T.L in loss less condition for length 'l' varies from 0 to λ/4, the open ckt i/p impedance is capacitive in nature.

→ For length 'l' varies from λ/4 to λ/2, the open circuit i/p impedance is inductive in nature.

* Smith chart

→ In T.L equation, the solutions are complicated and computations are also difficult.

→ To overcome this problem, we use Smith chart.

* Relationship between primary & secondary parameters

Case 2 :-

$$Z_0 = \sqrt{\frac{R+j\omega L}{G+j\omega L}} = \sqrt{\frac{R\left(1+\frac{j\omega L}{R}\right)}{G\left(1+\frac{j\omega C}{G}\right)}} = \sqrt{\frac{R}{G}\left(\frac{1+j\omega\left(\frac{C}{G}\right)}{1+j\omega\left(\frac{C}{G}\right)}\right)} \left(\because \frac{R}{L} = \frac{G}{C}\right)$$

$$= \sqrt{\frac{R}{G}}$$

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

$$\therefore \gamma = \sqrt{(R+j\omega L)(G+j\omega C)} = \sqrt{R\left(1+\frac{j\omega L}{R}\right)G\left(1+\frac{j\omega C}{G}\right)}$$

$$\therefore \gamma = \sqrt{RG\left(1+\frac{j\omega L}{R}\right)\left(1+j\omega\frac{L}{R}\right)} \quad \left[\frac{L}{R} = \frac{C}{G}\right]$$

$$= \sqrt{RG}\left(1+j\omega\frac{L}{R}\right) = \sqrt{RG}+\sqrt{RG}\times j\omega\left(\frac{L}{R}\right) = \sqrt{RG}+\sqrt{\frac{G}{R}}\times(j\omega L)$$

$$= \sqrt{RG}+\sqrt{\frac{C}{L}}\times j\omega L = \sqrt{RG}+j\omega\sqrt{LC} \quad [\because \alpha + j\beta]$$

where, $\boxed{\alpha = \sqrt{RG} \ \& \ \beta = \omega\sqrt{LC}, \ \text{So}, \ \gamma = \sqrt{RG}+j\omega\sqrt{LC}}$

$$v_p = \frac{\omega}{\beta} = \frac{\omega}{\omega\sqrt{LC}} = \frac{1}{\sqrt{LC}}$$

Case 3 At high frequency when $(R \ll \omega L \ \& \ G \ll \omega C)$

$$\therefore \gamma = \sqrt{(R+j\omega L)(G+j\omega C)} = \sqrt{j\omega L\left(1+\frac{R}{j\omega L}\right)\left(1+\frac{G}{j\omega C}\right)j\omega C}$$

$$= j\omega\sqrt{LC}\left(1+\frac{R}{j\omega L}\right)^{1/2}\left(1+\frac{G}{j\omega C}\right)^{1/2} = j\omega\sqrt{LC}\left(1+\frac{R}{j\omega L}\right)\left(1+\frac{1}{2}\times\left(\frac{G}{j\omega C}\right)\right)$$

$$= j\omega\sqrt{LC}\left(1+\frac{G}{2j\omega C}+\frac{R}{2j\omega L}+\frac{RG}{4j^2\omega^2 LC}\right) \quad [\because \omega C >> G \text{ \& } \omega L >> R].$$

$[\because (1+a_x)^n \simeq 1+nax$ when $|a|<1$, here $a = \frac{R}{j\omega L}$

$\Rightarrow a << 1 \; ; \; \omega L >> R].$

$$= j\omega\sqrt{LC} + \frac{G}{2C}\sqrt{LC} + \frac{R}{2L}\times\sqrt{LC} = j\omega\sqrt{LC} + \frac{G}{2}\sqrt{\frac{L}{C}} + \frac{R}{2}\sqrt{\frac{C}{L}}$$

$$= \left[\frac{R}{2}\left(\sqrt{\frac{C}{L}}\right) + \frac{G}{2}\left(\sqrt{\frac{L}{C}}\right)\right] + j\omega\sqrt{LC} \simeq \alpha + j\beta.$$

By similar Process for $Z_0 = \sqrt{\frac{R+j\omega L}{G+j\omega C}} = \frac{\sqrt{j\omega L}\left(\frac{R}{j\omega L}+1\right)^{1/2}}{\sqrt{j\omega C}\left(\frac{G}{j\omega C}+1\right)^{1/2}}$

$$\Rightarrow Z_0\sqrt{\frac{L}{C}}\left(1+\frac{R}{2j\omega L}\right)\left(1-\frac{1}{2j\omega C}\right)$$

$$\therefore \alpha = \left(\frac{R}{2}\sqrt{\frac{C}{L}} + \sqrt{\frac{L}{C}}\frac{G}{2} \quad \& \quad \beta = \omega\sqrt{LC}\right.$$

$$\therefore u = \frac{\omega}{\beta} = \frac{1}{\sqrt{LC}}$$

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1) An open wire T.L has the following primary constants

$R = 4 \Omega/Km$, $L = 2.5$ mH/Km

$C = 0.009 \mu f/Km$, $G = 0.29 \mu mho/Km$

Frequency of operation = 1 KHz.

Find :- (a) Z_0

(b) Phase constant

(c) Attenuation const.

(d) Phase velocity

A) Given data

$R = 4\Omega/Km$, $L = 2.5$ mH/Km $= 2.5 \times 10^{-3}$ H/Km

$C = 0.009 \mu F/Km = 0.009 \times 10^{-6}$ F/Km

$G = 0.29 \mu ℧/Km = 0.29 \times 10^{-6}$ ℧/Km

$f = 1$ KHz $= 10^3$ Hz.

$\omega = 2\pi f = (2\pi \times 10^3)$ rad/s.

(a) $Z_0 = \sqrt{\dfrac{R + j\omega L}{G + j\omega C}} = \sqrt{\dfrac{4 + j2\pi \times 10^3 \times 2.5 \times 10^{-3}}{0.29 \times 10^{-6} + j2\pi \times 10^3 \times 0.009 \times 10^{-6}}}$

$= \sqrt{\dfrac{4 + j22}{(0.29 + j56.5) \times 10^{-6}}} = 10^3 \sqrt{\dfrac{22.4 \angle 79.3^\circ}{56.5 \angle 90^\circ}}$

$= 630 \angle 10.7^\circ \Omega$

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

$$= \sqrt{(4+j22)(0.29+j56.5)\times 10^{-6}}$$

$$= \sqrt{(22.4\angle 79.3)(10^{-6}\times 56.5\angle 90^\circ)} = 0.36\angle 84.65^\circ$$

$$= 0.36\cos 84.65^\circ + j\,0.36\sin 84.65$$

[$\alpha + j\beta$ form]

(b) β = Phase constant

$$= 0.36 \sin 84.65^\circ = 0.358 \text{ rad/sec}$$

(c) $$\alpha = 0.36\cos 84.65^\circ$$

$$= 0.033 \text{ rad/sec.}$$

(d) Phase Velocity $= u = \dfrac{\omega}{\beta}$

$$= \frac{2\pi\times 10^{3}}{0.358} = 17.55 \text{ km/sec}$$

Or

take

$$Z = R + j\omega L = (4 + j2\pi 10^{3})\times(2.5\times 10^{-3})$$

$$= 4 + j22$$

$$= 22.4\angle 79.3^\circ$$

$$Y = G + j\omega C = (0.29\times 10^{-6}) + (j2\pi\times 10^{3}\times 0.009\times 10^{-6})$$

$$= (0.29 + j56.5)\times 10^{-6}$$

$$= 56.5\times 10^{-6}\angle 90^\circ$$

$$\therefore Z_0 = \sqrt{\frac{R+j\omega L}{G+j\omega C}} = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{22.4\angle 79.3}{56.5\times 10^{-6}\angle 90^\circ}} = 630\angle -5.3^\circ$$

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

$$= \sqrt{(22.4\angle 79.3^\circ)(56.5\times10^{-6}\angle 90^\circ)} = 0.037\angle 84.65^\circ.$$

Q2) A T.L has characteristic impedance of $(75+j0.01)\Omega$ & is terminated in load impedance of $(70+j50)\Omega$, compute

(a) The reflection co-efficient

(b) Transmission co-efficient

(c) Show that $T = 1+\Gamma$.

A) Given that,

$$Z_L = (70+j50)\Omega \,, \quad Z_0 = (75+j0.01)\Omega.$$

(a) Reflection co-efficient means voltage reflection constant.

$$\Gamma_V = \frac{Z_L - Z_0}{Z_L + Z_0} = \frac{(70+j50)-(75+j0.01)}{(70+j50)+(75+j0.01)}$$

$$= \frac{50.24\angle 95.71^\circ}{153.38\angle 19.03^\circ} = 0.33\angle 76.68^\circ = 0.08+j0.32$$

(b) Transmission co-efficient = T.

$$T = \frac{2Z_L}{Z_L+Z_0} = \frac{2(70+j50)}{(70+j50)+(75+j0.01)}$$

$$= \frac{172\angle 35.54^\circ}{153.38\angle 19.03^\circ} = 1.12\angle 16.51^\circ = 1.08+j0.32.$$

(c) $T = 1+\Gamma$

$$= 1+(0.08+j0.32)$$

$$= 1.08+j0.32.$$

Q3) A. T.L has a $Z_0 = (50 + j0.01)\Omega$ & its terminated in a load impedance of $(73 - j42.5)\Omega$ calculate (a) Γ (b) SWR.

A) $Z_0 = 50 + j0.01\,\Omega$; $Z_L = 73 - j42.5\,\Omega$.

(a) $\Gamma = \dfrac{Z_L - Z_0}{Z_L + Z_0} = \dfrac{(73 - j42.5) - (50 + j0.01)}{(73 - j42.5) + (50 + j0.01)}$

$= 0.377 \angle -42.7^\circ$

(b) $SWR = S = \dfrac{1 + |\Gamma|}{1 - |\Gamma|} = \dfrac{1 + 0.377}{1 - 0.377} = 2.21$

Q4) A lossless T.L of $Z_0 = 100\Omega$ is terminated by an unknown impedance. The termination is found to be at a max. of volt. standing wave & VSWR is 5. what is the value of terminated impedance?

A) Given, $Z_0 = 100\Omega$

$S = 5$, $Z_L = ?$

$S = \dfrac{Z_L}{Z_0}$ $\Big|$ $(Z_{in})_{max} = SZ_0$ $\Rightarrow Z_L = SZ_0$ [$\because$ Z_L is found at max. of volt. standing wave].

when Z_L & Z_0 are real $S = \dfrac{Z_L}{Z_0}$ & will be a number only (no fractional).

Q5) A 50Ω lossless line connect a signal of 300 KHz to a load of 100Ω. If load power is 50 mW. Determine

i) VSWR, (ii) V_{min} & V_{max}.

(iii) Position of V_{max} & V_{min}.

A) Given, $Z_0 = 50\Omega$, $Z_L = 100\Omega$.

$f = 300\,kHz = 300 \times 10^3\,Hz$.

Power $= P = 50\,mW = 50 \times 10^{-3}\,W$.

(a) $\Gamma = \dfrac{Z_L - Z_0}{Z_L + Z_0} = \dfrac{100 - 50}{100 + 50} = 1/3$.

$S = \dfrac{1+|\Gamma|}{1-|\Gamma|} = \dfrac{1+1/3}{1-1/3} = 4/3 \times 3/2 = 2$.

(b) $P = \dfrac{V^2_{max}}{Z_L} = 50 \times 10^{-3}$ ($\because V_{max}$ is located at the load $Z_L > Z_0$ & real).

$\Rightarrow V^2_{max} = 50 \times 10^{-3} Z_L$

$\Rightarrow V^2_{max} = 50 \times 10^{-3} \times 100$

$\Rightarrow V^2_{max} = 5 \quad \Rightarrow V_{max} = 2.24\,v$.

$S = \dfrac{V_{max}}{V_{min}} \Rightarrow V_{min} = \dfrac{V_{max}}{S}$

$\Rightarrow V_{min} = \dfrac{2.24}{2} = 1.12\,v$.

(c) V_{max} is located at the load ($\because Z_L > Z_0$ & real).

V_{min} is located at $\lambda/4$ from load $= \frac{100}{4} = 50$ from load.

$\left[\lambda = \dfrac{c}{f} = \dfrac{3 \times 10^8}{300 \times 10^3} = 10^3\,m\right]$.

* Different Losses in Transmission Line

(i) Attenuation Loss :-

→ It happens due to absorption of signal / in T.L. It is also called dielectric loss.

→ $$\text{Loss} = 10 \log \left[\frac{E_i - E_r}{E_t} \right]$$

where,

E_i = Energy of i/p signal

E_r = Energy of reflected signal

E_t = Total energy in incident signal.

→ Energy (E) ∝ (voltage)^2. $(V)^2$

$E_i \propto (V_i)^2$ $\quad E_t \propto (V_t)^2$

$E_r \propto (V_r)^2$

$$\text{Loss} = 10 \log \left[\frac{|V_s^2| - |V_r^2|}{|V_s^2| - |V_r^2| e^{-2.\alpha.l}} \right]$$

α = Attenuation co-efficient

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

$= 20 \alpha l \left(\log e \right)$

$= 8.686 \alpha l.$

(ii) Reflection Loss :-

→ It is present due to mismatch of T.L.

$$L_{Ref} = 10 \log \left[\frac{E_i}{E_i - E_r} \right].$$

$$= 10 \log \left[\frac{|V_i^2|}{|V_i^2| - |V_r^2|} \right]$$

$$= 10 \log \left[\frac{1}{1 - \left| \left(\frac{V_r}{V_i}\right)^2 \right|} \right]$$

$$= 10 \log \left[\frac{1}{1 - |K|^2} \right]$$; K = Reflection constant $\left(\frac{V_r}{V_i}\right)$.

(iii) Transmission Loss :-

→ It is associated with a loss in T.L.

$$\boxed{L_{tran} = 10 \log \left[\frac{E_i}{E_t} \right]}$$

$$= 10 \log \left[\frac{E_i}{E_i - E_r} \times \frac{E_i - E_r}{E_t} \right].$$

$$= 10 \log \left[\frac{E_i}{E_i - E_r} \right] + 10 \log \left[\frac{E_i - E_r}{E_t} \right]$$

$$= L_{ref} + L_{attenuation}$$

$$= 10 . \log \left[\frac{1}{1 - |K|^2} \right] + 8.686 \alpha l$$

(iv) Return Loss :-

→ It is associated with impedance mismatch to the point.

$$\boxed{L_{return} = 10 \log \left[\frac{E_i}{E_r} \right]}.$$

$$= 10 \log \left[\frac{|V_i|^2}{|V_r|^2} \right]$$

$$= 10 \log \left[\frac{1}{|K|^2} \right] = -20 \log |K|.$$

(v) Insertion Loss :-

→ It is associated with device insertion.

$$L_{ins} = 10 \log \left[\frac{E_1}{E_2} \right]$$

where,

E_1 = Energy received without device

E_2 = Energy received with device.

NOTE :-

→ Two wire line, coaxial cable, strip line etc are supporting Transverse Electro Magnetic (TEM) mode of wave propagation.

→ T.L supports TEM mode of wave propagation.

→ TEM mode wave Propagation means both electric, magnetic field are ⊥r to each other as well as they are also ⊥r to direction of propagation.

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Microwave

→ Microwave means very small wave, wavelength of this wave is very small.

→ So, frequency is very high. Microwave frequency range is 0.3 GHz to 300 GHz.

1) Very Low frequency (VLF) = 3 KHz to 30 KHz

2) Low frequency (LF) = 30 KHz to 300 KHz.

3) Medium frequency (MF) = 300 KHz to 3MHz

4) High frequency (HF) = 3MHz to 30 MHz.

5) Very High frequency (VHF) = 30 MHz to 300 MHz

6) Ultra High frequency (UHF) = 300 MHz to 3GHz

7) Super high frequency (SHF) = 3GHz to 30 GHz

8) Extra high frequency (EHF) = 30GHz to 300 GHz.

L - Band = 1 GHz to 2 GHz

S - Band = 2 GHz to 4 GHz

C - Band = 4 GHz to 8 GHz

X - Band = 8 GHz to 12 GHz

* Advantages of Microwave :-

(i) Wide Bandwidth

Microwave signals have large bandwidth which makes it Possible to use Various multiplexing technique to transmit more information.

(ii) Improved Directive Properties

As frequency increases directivity increases & beam-width decrease which is required properties for a Antenna to get more gain.

(iii) Less Fading

Since low frequency signals becomes weaker for a long distance transmission i.e., called fading. But microwave signals are high frequency signal, so less fading occurs.

(iv) Reliability and Transparency

Microwave frequency signals are capable of freely propagating through ionized layers surrounding the earth where as it is not possible for less frequency signals.

* Disadvantages :-

-> Conventional resistors, inductors, capacitors can't be operated in very high freq. like microwave frequency range

-> The simple LCR ckt behaves as complex ckt.

-> So lumped components are not used in this frequency that's why distributed ckt elements are used where T.L is the example of it which is used in microwave frequency.

→ Due to microwave signals are very high frequency signals, so snow, fog, rain, etc. affects more during transmission.

* Applications :-

(i) Telephone communication

(ii) In Radar Communication

(iii) Cable T.V

(iv) Satellite communication

(v) Used for heating purpose where very common example is microwave oven, etc.

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Waveguide

* Definition

→ It is a medium which contains a hollow metallic tube which guides the wave (or signal) in a proper direction from source to load.

→ It is operated in very high frequency, so it is capable of handling very large power.

→ Waveguide consists metallic tube with rectangular (or) circular cross section.

→ There is no loss due to radiation & dielectric losses are negligible, because waveguides are air filled (non-conducting, linear, homogenous, isotropic and charge free medium)

→ Tangential components of electric fields & normal component of magnetic field vanishes (i.e., 0) across the conductor interfaces.

→ waveguides are cylindrical in structural & the preferred cross sections are rectangular, circular & elleptical.

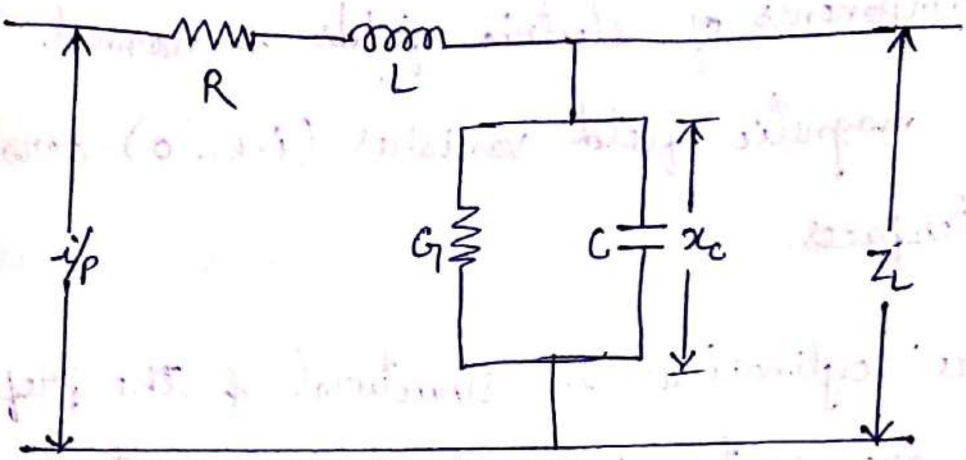
→ The wave is propagating through waveguide by reflection from the wall of waveguide.

Transmission Line (T.L)	Wave Guide (W.G)
→ It is operated in limited range of freq.	It is used in very high freq.
→ It can transmit dc signals also.	It operates after certain cutoff freq.
→ It acts as LPF.	It acts as HPF.
→ It supports TEM mode	It does not support TEM mode. But it supports TE, TM modes.
→ It is not capable of handling large powers as W.G	It is capable of handling large power.
→ Transmission loss is more	W.G has less loss.
→ Metal conductors are used	metal hollow tube is used to avoid loss.

Ques

How T.L acts as one type of low pass filter (LPF)?

Ans



→ T.L cannot be operated at high frequency due to skin effect.

Skin Effect

$x_c = \frac{1}{2\pi f c}$, At very high freq., $f \cong \infty$.

$\Rightarrow x_c = \frac{1}{\infty} = 0$.

→ The reactance path will be short circuited, so the signal pass through the short ckt path instead of passing to load, loss occurs.

→ But, T.L can be operated in some limited freq. (0 to f). So, it acts as LPF.

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* Modes In Rectangular Waveguide :-

→ The distinct field pattern is called mode - 4 types of modes available.

① TEM Mode (Transverse Electro-Magnetic Mode) :-

→ If the wave is propagating along z-direction then $E_z = H_z = 0$

→ There is no electric field & magnetic field along z-direction.

② TE Mode (Transverse Electric Mode) :-

→ If the wave is propagating along z-direction, then in TE Mode ; $E_z = 0$, but $H_z \neq 0$.

→ That means there is no electric field component along z-direction.

③ TM Mode (Transverse Magnetic Mode) :-

→ In this mode there is no magnetic field component exist along direction of propagation of the wave. i.e., $H_z = 0$ but $E_z \neq 0$.

④ HE Mode (Hybride Mode) :-

→ Here neither electric (or) magnetic field component along propagationg direction are zero.

$$E_z \neq 0, H_z \neq 0.$$

→ Transverse Electromagnetic field is impossible to exist through waveguide having any crossection.

→ TE_{mn} modes, TM_{mn} modes exists in waveguide.

where,

m & n are integers.

* TM_{mn} Waves :-

→ If the wave is propagating along z-direction in waveguide.

→ (+z).

$$\frac{E_x}{H_y} = \eta TM_{mn} = -\frac{E_y}{H_x}.$$

ηTM_{mn} is characteristics wave impedance for TM_{mn} waves.

$$E_x = E_{x_0} \cdot \cos\left(\frac{m\pi}{a}\right)x \cdot \sin\left(\frac{n\pi}{b}\right)y \cdot e^{-\gamma z}$$

$$H_x = -\frac{E_y}{\eta TM_{mn}}$$

a, b are rectangular waveguide dimensions.

$$E_y = E_{y_0} \cdot \sin\left(\frac{m\pi}{a}\right)x \cdot \cos\left(\frac{n\pi}{b}\right)y \cdot e^{-\gamma z}$$

$$H_y = \frac{E_x}{\eta TM_{mn}}$$

$$E_z = E_{z_0} \cdot \sin\left(\frac{m\pi}{a}\right)x \cdot \sin\left(\frac{n\pi}{b}\right)y \cdot e^{-\gamma z}$$

$$H_z = 0$$

* TE_{mn} Waves :-

→ If the wave is propagating along z-direction in wave guide, then

→ (+z).

$$\frac{E_x}{H_y} = \eta TE_{mn} = \frac{-E_y}{H_x}$$

ηTE_{mn} is characteristic wave impedance for TE_{mn} waves.

$$E_x = E_{x0} \cos\left(\frac{m\pi}{a}\right)x \cdot \sin\left(\frac{n\pi}{b}\right)y \cdot e^{-\gamma z}$$

$$H_x = \frac{-E_y}{\eta TE_{mn}}$$

$$E_y = E_{y0} \sin\left(\frac{m\pi}{a}\right)x \cdot \cos\left(\frac{n\pi}{b}\right)y \cdot e^{-\gamma z}$$

$$H_y = \frac{E_x}{\eta TE_{mn}}$$

$$E_z = 0$$

$$H_z = H_{z0} \cos\left(\frac{m\pi}{a}\right)x \cdot \cos\left(\frac{n\pi}{b}\right)y \cdot e^{-\gamma z}$$

* Characteristics of TE_{mn} & TM_{mn} Waves :-

→ In the process of derivation we get the following equation :-

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

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

γ = Propagation constant

α = Attenuation constant

β = Phase shift constant

m, n : Integers

a, b : cross sectional dimensions

μ, ϵ : Medium properties → linear, homogenous, isotropic, charge free, non-conducting.

$\omega = 2\pi f$.

↳ freq. of wave which is progressing through the wave guide.

→ At high freq.

$$\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2 < \omega^2 \mu\epsilon$$

So γ = propagation constant is imaginary

$= j\beta$.

$\alpha = 0$.

So wave propagation takes place along wave guide at high frequency.

→ So wave guide acts as high pass filter. we define a limiting freq. (or) cut off freq. beyond that propagation takes place.

$$f_c = \frac{1}{2\pi\sqrt{\mu\epsilon}} \cdot \left[\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2\right]^{1/2}$$

→ At $f = f_c$, $\gamma = 0$.

→ In free space $\mu = \mu_0$, $\epsilon = \epsilon_0$.

∴ velocity of wave in air

$$\boxed{v = \frac{1}{\sqrt{\mu_0 \cdot \epsilon_0}}} = 3 \times 10^8 \text{ m/sec.}$$

→ So, cut off freq. of a waveguide will depend upon physical properties of wave guide.

→ $$\boxed{\text{cut off wavelength } \lambda_c = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}}}$$

→ $\lambda = \frac{c}{f} = \frac{\text{Velocity}}{\text{freq.}}$ = wavelength.

→ For $f > f_c$ (or) $\lambda < \lambda_c$

Propagation is allowed through the waveguide.

→ For $f < f_c$ (or) $\lambda > \lambda_c$

Propagation is not allowed through the waveguide.

→ $\beta = \frac{2\pi}{\lambda}$ = Phase shift const.

→ Phase velocity $v_p = \omega/\beta$, it is the velocity at which wave propagates in a wave guide.

$$\boxed{v_p = \frac{c}{\sqrt{1 - \left(\frac{f_c}{f}\right)^2}}}, \quad c = \text{light velocity.}$$

→ Phase velocity (v_p) > c (light velocity), which violate Einstein's Relativity theory.

→ But signal wave in a wave guide does not travel in phase velocity. Actually signal travels in a group velocity (v_g).

* Group Velocity (v_g)

→ Group of signals travel in a waveguide in this velocity which is less than light velocity.

$$\boxed{v_g < c}$$

→ The velocity of modulation envelope is called group Velocity.

$$\boxed{v_g = c \cdot \sqrt{1 - \left(\frac{F_c}{F}\right)^2}}$$

$$\boxed{v_p \times v_g = c^2}$$

→ $$\eta_{TE} = \frac{\eta}{\sqrt{1 - (f_c/f)^2}} \ \Omega$$

→ $$\eta_{TM} = \eta \cdot \sqrt{1 - \left(\frac{f_c}{f}\right)^2} \ \Omega.$$

η = Intrinsic impedance of the medium.

$$= \sqrt{\mu/\epsilon}$$

For air $\eta = \sqrt{\frac{\mu_0}{\epsilon_0}} = 377\ \Omega$ or 120π.

→ $$\boxed{\eta_{TE} \times \eta_{TM} = \eta^2}$$

→ At $f = f_c$, $\eta_{TE} = \infty$ & $\eta_{TM} = 0$.

→ Guided wave length

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

where, λ_0 = wavelength in space

λ_c = cutoff wavelength

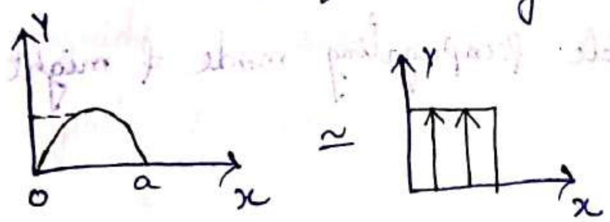
* Significance of m, n :-

m :- no. of half field variation along x.

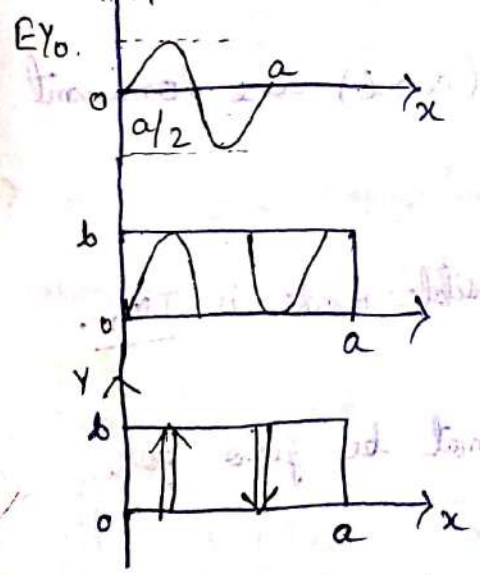
n :- no. of half field variation along y.

They indicates field variations in the transverse plane.

TE_{10} :- No. of half field along x is 1.

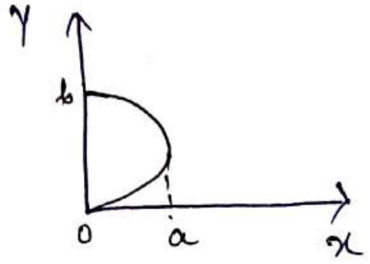


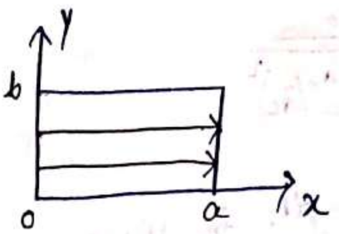
TE_{20} :- No. of half fields along x = 2.



$\underline{TE_{01}}$:- $(m = 0, n = 1)$

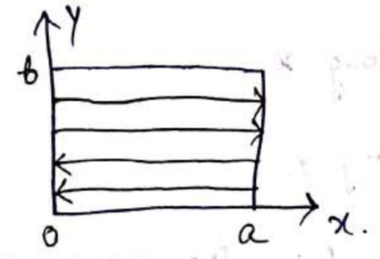
No. of half fields along Y-axis = 1.





$\underline{TE_{02}}$:- $(m = 0, n = 2)$

No. of half field variations along Y-axis = 2.



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* Dominant Mode :-

→ It is the lowest possible propagating mode & might have lowest cutoff freq.

→ In the dominant mode, it is possible to transfer maximum energy from sending end to receiving end.

→ In case of rectangular waveguide $(a > b)$ the dominant mode is $\underline{TE_{10}}$.

→ For TM_{mn} mode, the lowest possible mode is $\underline{TM_{11}}$.

→ For TM_{mn} mode, m & n values cannot be zero for rectangular waveguide.

* Degenerate Mode :-

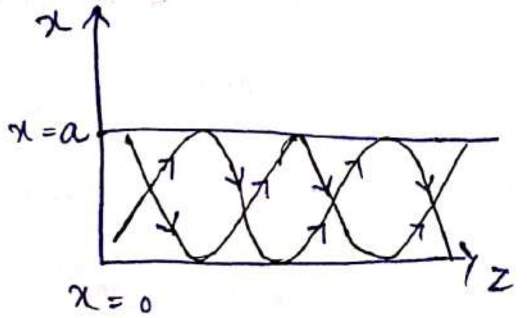
→ If two different modes are having same cutoff freq. then those modes.

→ Examples of degenerate modes are TE_{11}, TM_{11} & TE_{21}, TM_{21}. These modes are two different modes but having same cutoff freq. So these modes are degenerate mode.

→ The modes which are not possible in a wave-guide are called evanescent waves (or) evanescent modes.

→ Ex:- For rectangular wave guide TM_{10} is evanescent mode.

→ The waveguide is operated in dominant mode & this waveguide is used for x-band frequencies. The waveguide is air-filled.



→ The wave propagation through the waveguide is by means of total internal reflection between the walls.

→ Phase constant

$$\boxed{\beta = \beta' \sqrt{1-(f_c/f)^2}}, \quad \boxed{\beta' = \omega\sqrt{\mu\epsilon}}$$

where,

β = phase constant in presence of waveguide

β' = Phase constant in absence of waveguide

f_c = cutoff frequency.

f = Operating frequency.

→ For rectangular waveguide in dominant mode TE_{10}, the cutoff freq. $f_c = \frac{c}{2a}$.

→ In dominant mode TE_{10}, the cutoff wavelength $\lambda_c = 2a$.

where,

c = Velocity of light = 3×10^8 m/sec

a = Length of waveguide.

Q1) A rectangular wave guide for which $a = 1.5$ cm, $b = 0.8$ cm, $\sigma = 0$ & $\mu_0 = \mu$ & $\epsilon = 4\epsilon_0$, $H_x = 2\sin\left(\frac{\pi x}{a}\right)\cos\left(\frac{3\pi}{b}\right)\sin(\pi\times10^{11}t - \beta z)$ A/m

Determine

(a) The mode of operation

(b) The cutoff frequency

(c) The phase constant

(d) The propagation constant

(e) The Intrinsic wave impedance (η).

A) $H_x = H_0 \sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right)\sin(\omega t - \beta z)$.

where,

$m = 1$, $n = 3$ & $\omega = \pi\times10^{11}$ rad/sec.

(a) Means waveguide is operating at TM_{13} or TE_{13} mode

(b) If we take TM_{13}

$$f_{c_{max}} = f_{c_{13}} = \frac{u'}{2}\sqrt{\frac{m^2}{a^2}+\frac{n^2}{b^2}}$$

$$\left[\therefore u' = \frac{1}{\sqrt{\mu\epsilon}} = \frac{1}{\sqrt{\mu_0 4\epsilon_0}} = \frac{1}{\sqrt{4}\sqrt{\mu_0\epsilon_0}} = \frac{c}{2}, \because c = \frac{1}{\sqrt{\mu_0\epsilon_0}}\right]$$

$$= \frac{\left(\frac{c}{2}\right)}{2}\sqrt{\left(\frac{1}{a^2}+\frac{9}{b^2}\right)} = \frac{3\times10^8}{4}\sqrt{\frac{1}{(1.5\times10^{-2})^2}+\frac{9}{(0.8\times10^{-2})^2}} = \underline{10.625\ GHz.}$$

(c) $\beta = \omega\sqrt{\mu\epsilon}\sqrt{1-(f_c/f)^2}$

$$\left[\because \omega = \pi\times10^{11}\right.$$

$$\Rightarrow f = 50\ GHz \ \&\ \mu\epsilon = \sqrt{\mu_0 4\epsilon_0} = 2\sqrt{\mu_0\epsilon_0} = \frac{2}{c}$$

$$\left. = \frac{2}{3\times10^8}\right].$$

$$= (\pi\times10^{11})\left(\frac{2}{3\times10^8}\right)\sqrt{1-\left(\frac{10.625\times10^9}{50\times10^9}\right)^2} = 2.046\ \text{k rad/m}.$$

(d) $\gamma = j\beta$

$= j\,2.046\times10^3$

(e) Intrinsic wave impedance

$$\eta'_{TM_{13}} = \eta'\sqrt{1-(f_c/f)^2}$$

$$\left[\eta' = \sqrt{\frac{\mu}{\epsilon}} = \sqrt{\frac{\mu_0}{4\epsilon_0}} = \frac{1}{2}\sqrt{\frac{\mu_0}{\epsilon_0}} = \frac{1}{2}\times377\right]$$

$$= \frac{377}{2}\sqrt{1-\left(\frac{10.625\times10^9}{50\times10^9}\right)^2} = 184.19\ \Omega.$$

Q2) A standard air filled rectangular waveguide with dimensions $a = 8.6$ cm & $b = 4.3$ cm is fed by a 4 GHz carrier from co-axial cable. Determine if a TE_{10} mode will be propagated. If so, calculate phase velocity & group velocity.

A) TE_{10} mode $f_{c_{10}} = \frac{u'}{2}\sqrt{\frac{m^2}{a^2} + \frac{n^2}{b^2}}$ $[m=1, n=0]$...

$= \frac{u'}{2a} = \frac{c}{2a}$ [$\because$ $u' = c$, due to air filled guide].

$= \frac{3 \times 10^8 \times 10^2}{2 \times 8.6} = 1.74\ GHz.$

$f = 4\ GHz > f_c$ means TE_{10} mode will propagate

($\because$ operating freq. should be greater than cut off freq).

Phase velocity $(v_p) = \frac{u'}{\sqrt{1-\left(\frac{f_c}{f}\right)^2}} = \frac{3 \times 10^8}{\sqrt{1-\left(\frac{1.7}{4}\right)^2}} = 0.33\ G\ m/s.$

Group velocity $(v_g) = \frac{u'^2}{v_p}$ $[\because v_p \cdot v_g = v'^2]$

$= \frac{(3 \times 10^8)^2}{0.33 \times 10^9} = 0.27\ G\ m/s.$

Q3) A rectangular wave guide with dimension 3 cm x 2 cm operates in TM_{11} mode at 10 GHz. Determine characteristic wave impedance.

A) Given, $f = 10\ GHz$, $a = 3\ cm$, $b = 2\ cm$.

$TM_{11} = f_{c_{11}} = \frac{u'}{2}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}$ [assume air as dielectric $\Rightarrow u' = c$].

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

$= \frac{3 \times 10^8}{2}\sqrt{\frac{1}{(3 \times 10^{-2})^2} + \frac{1}{(2 \times 10^{-2})^2}} = 9.01\ GHz.$

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$\eta_{TM_{11}} = \eta\sqrt{1-\left(\frac{f_c}{f}\right)^2} = 377\sqrt{1-\left(\frac{9.01\times10^9}{10\times10^9}\right)^2} = 163.54\ \Omega.$

Q4) Determine the cutoff wavelength for dominant mode in a waveguide of 10 cm x 10 cm. For a 2.5 GHz signal propagated in this waveguide in the dominant mode. Calculate the guide wavelength, groups & phase velocity?

A) For dominant mode TE_{10}.

(a) The cutoff length of wave $(\lambda_c) = 2a$.

$$\left[\because f_c = \frac{u'}{2a} = \frac{c}{2a}\ \{\because m=1, n=0\}\right.$$
$$\left.\Rightarrow \lambda_c = \frac{c}{f_c} = \frac{c}{c/2a} = 2a.\right]$$

$= 2\times10\ cm = 20\ cm.$

(b) λ_g (guide wavelength) $= \frac{\lambda_0}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}}$ $\left[\because \lambda_0 = \frac{c}{f} = \frac{3\times10^8}{2.5\times10^9} = 0.12\ m = 12\ cm\right]$

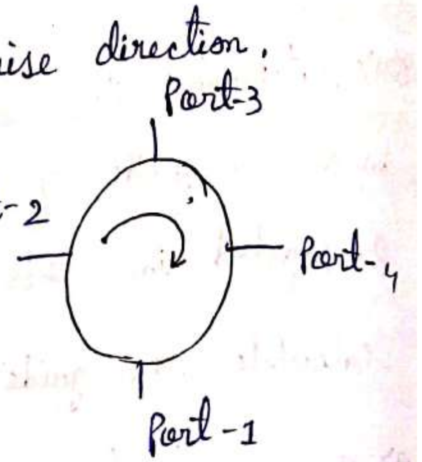
$$= \frac{12}{\sqrt{1-\left(\frac{12}{20}\right)^2}} = 15\ cm.$$

(c) Phase velocity $(v_p) = \frac{c}{\sqrt{1-\left(\frac{\lambda_0}{\lambda_c}\right)^2}} = \frac{3\times10^8}{\sqrt{1-\left(\frac{12}{20}\right)^2}} = 3.75\times10^{10}\ cm/s.$

v_g (group velocity) $= \frac{c^2}{v_p} = 2.4\times10^6\ cm/s$. $[c^2 = v_p v_g]$.

* Circulator :-

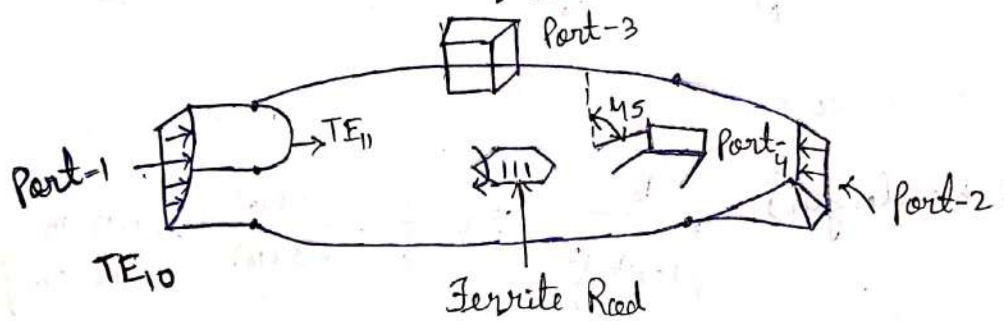
→ Here signal is circulated in clockwise direction.



→ If we apply signal at Port-1, O/p will be forwarded to Port-2 & at Port-3, port-4 O/p = 0.

→ If we give i/p at port-2, then o/p will circulate to Port-3 & at port-4, port-1 o/p = 0.

* Internal Structure of 4-Port circulator :-



→ If we apply i/p at port-1 in TE_{10} mode, inside it is translated to circular waveguide & TE_{11} mode is o/p of Port-1.

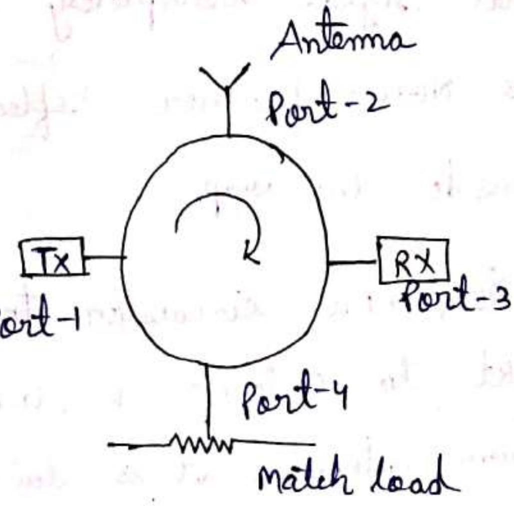
→ Orientation of Port-1 & Port-3 are out of phase. So signal is not transferred to Port-3.

→ Ferrite Rod is in betⁿ port-3 & Port-4. It circulate the signal to 45° in clockwise direction.

→ At Port-2 o/p is available.

* Application of circulator :-

circulator as Duplexers :-



→ At Port-1 Tx (transmitter) is connected. At Port-2 Antenna is connected.

→ Duplexer aim is to use transmitting & receiving at single antenna.

→ Transmitting ckt. functions as Mega Watt (MW) in radar. Receiving ckt functions as Milli Watt (mW) in radar.

→ Transmitting ckt radiates extremely high Power to the antenna & receiving ckt receives extremely low power from the antenna.

→ So, it is very essential to isolate these two ckts & signal transmits at Port-1 & at Port-2 antenna receives.

→ Then from Port-2 signal is transmitted to Port-3. Due to mismatch in receiving ckt of antenna signal from Port-3 is Propagated to Port-4.

Scanned with CamScanner

→ If we provide match termination at Port-4 then that signal completely absorbed at match termination. So Now further reflections will not propagate inside the loop.

→ So, here circulator transfer signal from transmitter ckt. to antenna & receiver receives the signal from antenna. It is doing double job of isolation and duplexer.

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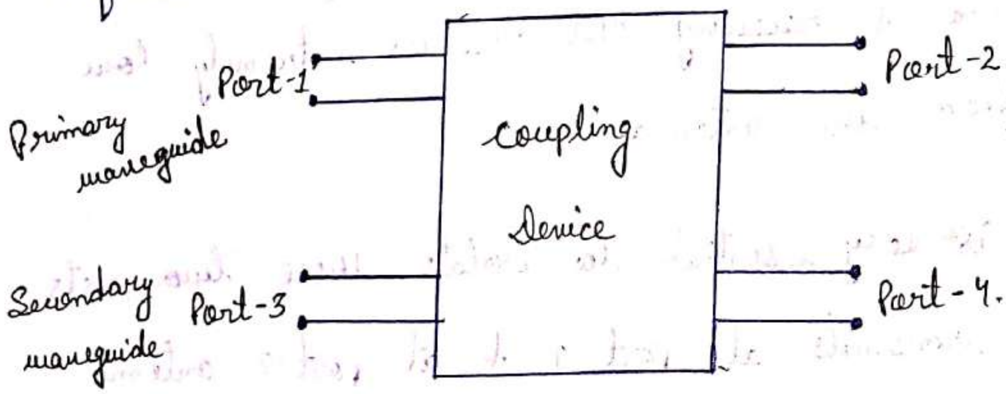
* Directional Coupler

→ It is 4-Port waveguide junction through which the i/p at one Port directed to other port for o/p without reflection.



→ Construction

→ It consists of Primary & Secondary of total 2-wave guide.
Primary wave guide is Port-1 & Port-2
Secondary wave guide is Port-3 & Port-4.

→ All ports are terminated in their characteristic impedances.

→ There is free transmission & no-reflection between Port-1 & port-2. But there is no direct transmission between Port-1 & Port-3 or Port 2 & Port-4, due to coupling is done in that system.

→ The o/p ports are port-3 & Port-4, but main port is Port-4

→ Characteristics

→ Directional coupler's characteristics is expressed in terms of coupling factor & directivity.

→ coupling factor is a measure of how much of incident power is sampled.

→ Directivity is measure of how well it distinguishes between forward & reverse travelling power.

$$\text{Coupling factor } (C)_{dB} = 10 \log_{10}(P_1/P_4)$$

$$\text{Directivity } (D)_{dB} = 10 \log_{10}(P_4/P_3)$$

where, P_1 → Power i/p to Port-1.

P_3 → Power o/p from Port-3

P_4 → Power o/p from Port-4 → actual o/p Port.

→ So, if coupling factor & P_4 is known. We can calculate i/p power means P_1.

→ Similarly in directivity case if directivity & P_3 are known, so easily o/p power P_4 can be calculated.

In ideal case

→ Directivity (D) is ∞ (⇒ for this case P_3 should be zero).

→ But practical value $D_{dB} = (30 \to 40)$ dB.

→ So for better directivity, P_3 should be less. That's why in case of 2-hole direction coupler have P_3 is less.

* Isolator (Ferrite Isolator)

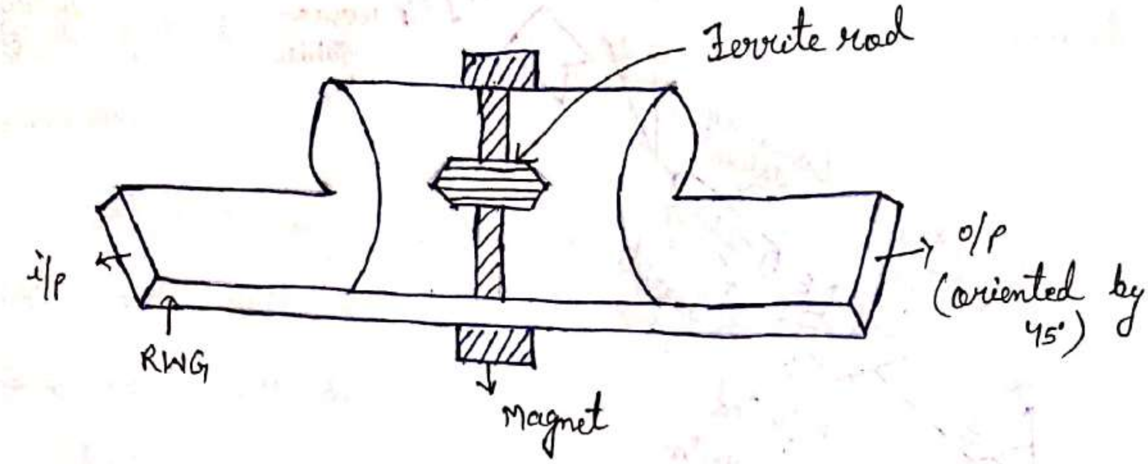
→ It is a device used to isolate one component from reflections of other components in T.L.

→ It absorbs the reflected energy in one direction & provides lossless transmission in opposite direction. So isolator is called unline.

→ Generally isolator is used to improve the frequency stability of microwave generators like Klystron & magnetrons. In this case isolator is placed between generator & load. The reflection part from load is absorbed by isolator & i/p signal is transmitted from generator to load in other direction.

→ Due to absorption of reflection signal, it eliminates the interferrence of i/p signal frequency & refleition signal freq. So, it increases the freq. stability.

Construction



→ It consists of two rectangular waveguide at beginning and end side & a circular waveguide is middle position between two rectangular wave guide.

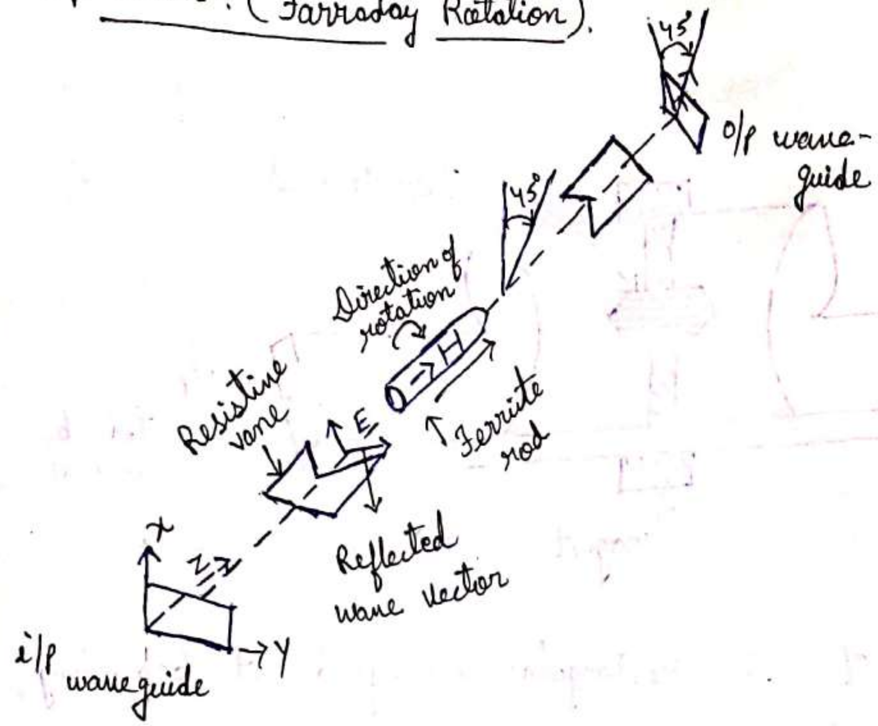
→ The rectangular waveguide supports TE_{10} dominating mode & the circular waveguide supports TE_{11} dominating mode.

→ A pencil shaped ferrite rod is located inside the circular waveguide is surrounded by permanent magnet.

→ So ferrite rod & magnet both have repulsion magnetic field. Due to repulsion any signal passes through its field direction changes some angle i.e, 45° taken generally as standard value.

→ (Ferrites are example of $ZnFe_2O_3$ or $MnFe_2O_3$ are high resistive means insulator & these have magnetic properties due to 'Fe'. These ferrites are non-reciprocal devices because these support farrday rotation).

Operation : (Farraday Rotation).



→ All devices are on one axis.

→ When a signal enters to i/p waveguide at that time the $\vec{E}$ field is ⊥r to first i/p resistive vane.

→ But due to ferrite rod is affected by a permanent magnet due to magnetic property of ferrite in the rod. So the o/p of resistive vane is through ferrite rod is changed to 45° Polarization (because of Faraday Rotation).

→ The changed field is passed through to second resistive vane as normal because the second vane is set like such way that the resultant will be normal to it.

→ So, finally we will get 45° polarised signal at o/p of rectangular waveguide that means transmission occurs without attenuation.

→ But if some reflection occurs, so the reflected signal will be 45° changed towards left and to pass through ferrite rod. So result will be again 45° change means the signal will be parallel to its resistive vane which indicates absorption.

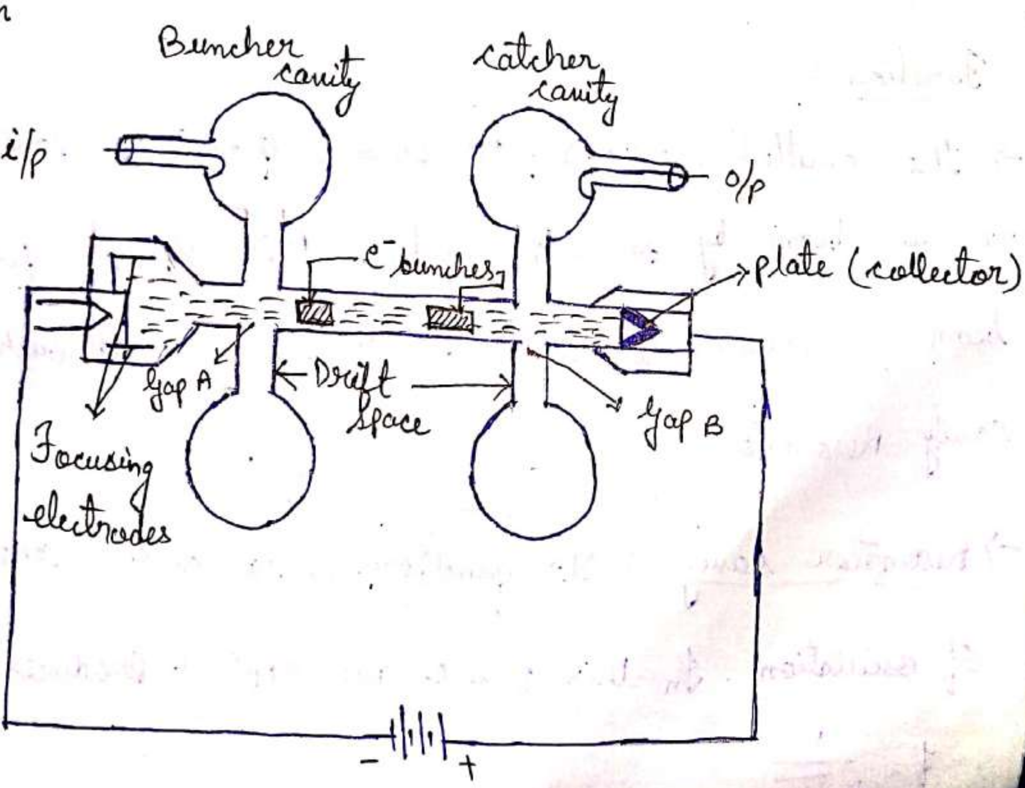
→ Because when any signal passes parallel to resistive vane that signal will be absorbed by that vane. So, no interference will be occured means reflection signal will no interfere with incident signal.

→ Attenuator :- These are devices which are used for reducing the microwave power (or for controlling power).

* Klystron (Two-cavity Klystron)

→ It is a microwave vacuum tube using cavity resonator to produce velocity modulation of election beam & to produce amplification.

Construction



Operation

(i) Filament :- Its function is to heat the cathode.

(ii) Cathode :- Its function is to emit electrons (after heated by filament).

(iii) Focusing Anode :- Its function is to pass the electrons into a narrow beam.

(iv) Buncher Cavity

→ It is the i/p cavity at which electrons are bunched & passed towards right.

→ Also microwave signal is given at the i/p path of ~~cah~~ cavity.

(v) Catcher Cavity : It is the o/p cavity at which the o/p is taken which is at the end side of tube.

(vi) Plate (collector) :- It is connected to +ve voltage side & its function is to collect the electrons.

Function :

→ The emitted electrons (are from cathode) are passed to a narrow beam by focusing anode. This sharply focused beam of electrons is then forced to pass through 1st cavity Resonator.

→ Resonator cavity : Its function is to control the freq. of oscillation. In this L & C are kept & produces a freq.

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

→ The microwave signal is given at i/p side of buncher cavity. Due to this signal there is the +ve half cycle & -ve half cycle.

→ During +ve half cycle the focused e⁻ speed up & in -ve half cycle slow down. This speeding & slowing process is called velocity modulation. And this process is happened at i/p cavity, so this cavity is called buncher cavity.

→ These bunched e⁻ are attracted by +ve plate because the plate is connected +ve terminal voltage.

→ So this attraction results in to pass the e⁻ through the o/p path in 2nd cavity. So this cavity is called catcher cavity.

→ But another RF field is maintained at catcher cavity, So these bunch e⁻ of RF signal increases. As more speeded bunch e⁻ interact, they release energy & more amplification occurs at catcher cavity.

→ Means more amplified energy is extracted from this cavity outlet & e⁻ after releasing energy attracted to +ve plate & complete a path. So 2-cavity Klystron is called an Amplifier.

* Magnetron Oscillator

Basics :-

→ It is high Power Vacuum tube.

→ It is multi-cavity device.

→ Frequency is from 0.6 GHz to 30 GHz.

→ It works with fix frequency constructively.

→ It is available with 8 to 20 cavity.

→ It works self exited microwave Oscillator.

Advantages

→ The magnetron is high Power microwave generator.

→ With antennas it can be easily installed.

→ The magnetron is a fairly efficient device.

Disadvantages

→ It is costly device.

→ Device cannot tune wide range of frequency.

→ Resonance is based on dimension & it is fix.

Operational steps of Magnetron :-

→ Generation of e^- from cathode.

→ Velocity modulation.

→ Formation of e^- bunch.

→ Reducing (or) transferring energy.

* Travelling Wave Tube (TWT) :-

Basics :-

-> It is a specialized vacuum tube i.e., used in electronics to amplify audio freq. signals in microwave range.

-> It belongs to category of linear beam tubes, such as Klystron.

-> Two major categories of TWT are :- Helix TWT, coupled cavity TWT.

-> The major advantage of TWT w.r.t other microwave tube is to amplify a wide range of frequencies.

-> TWT accounts 50% of microwave total tubes.

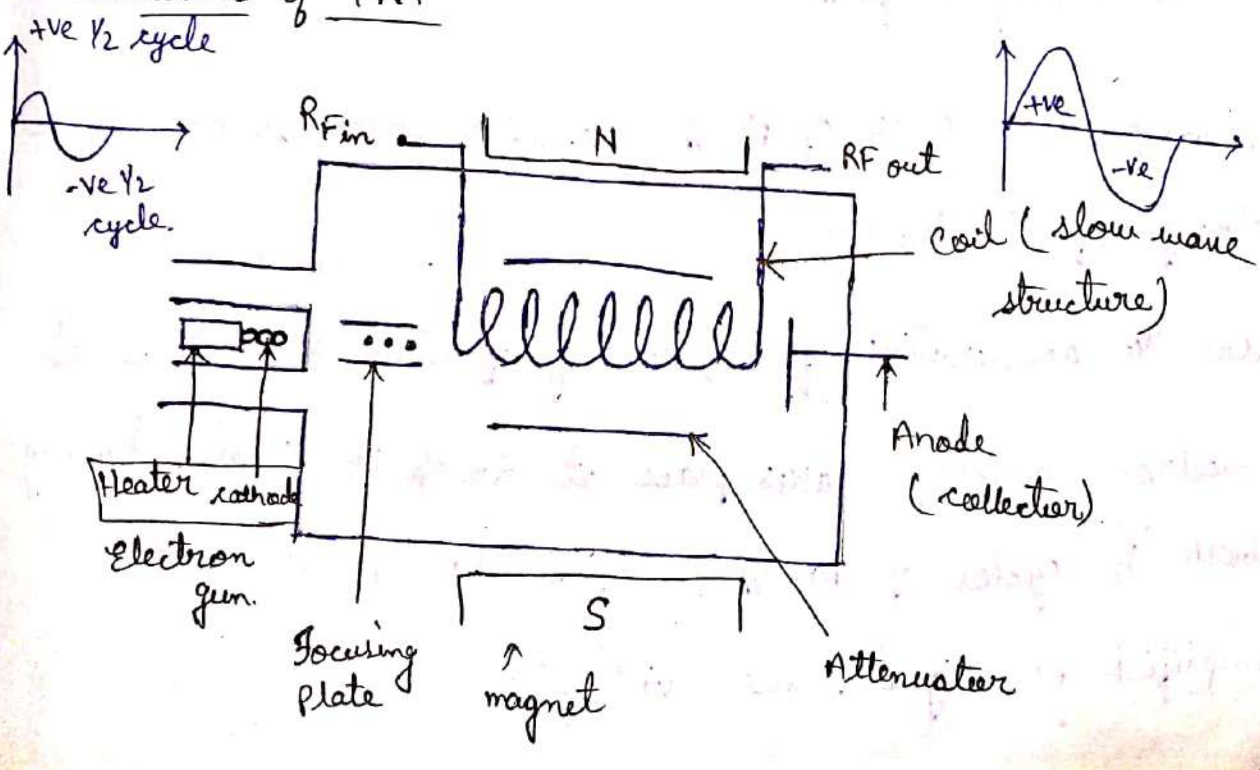
Operational Parameters of TWT

-> It's operating freq. range is from 300 MHz to 50 GHz.

-> Power gain 40 to 70 dB. Generally 60 dB.

-> O/P Power ranges from few watt to megawatts.

Structure of TWT



→ Anode collects e^- and cathode generates e^-. -ve terminal of battery is connected to e^- gun & +ve terminal of battery is connected to anode.

→ Focusing plates focuses the electrons i.e., generated by e^- gun.

→ Electrons travels through coil, attenuator bounds the focusing e^- through coil.

→ Magnet generates magnetic field i.e., used to amplify RF i/p signal & amplified signal is collected at RF o/p terminal.

→ When we give RF i/p, during +ve ½ cycle the e^- get accelerated.

→ Magnetic field directions from north to south.

→ In +ve ½ cycle the force on e^- is accelerative force

i.e., $F = q\,(V \times B)$.

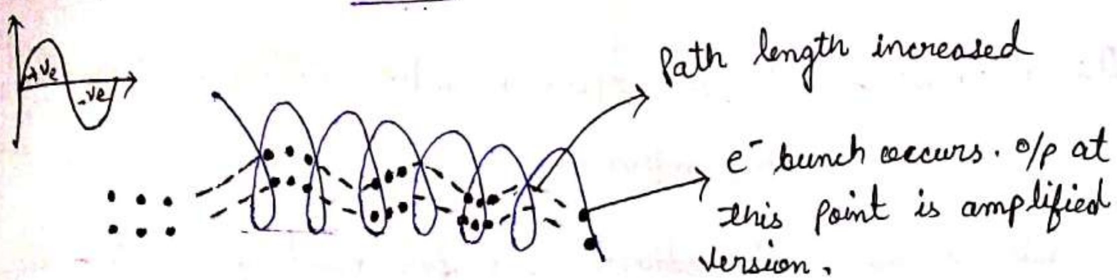
where,
V = Velocity of e^-
q = charge of e^-
B = Magnetic field

→ During -ve ½ cycle of RF i/p, resistive force is on e^-, so velocity of e^- decreases.

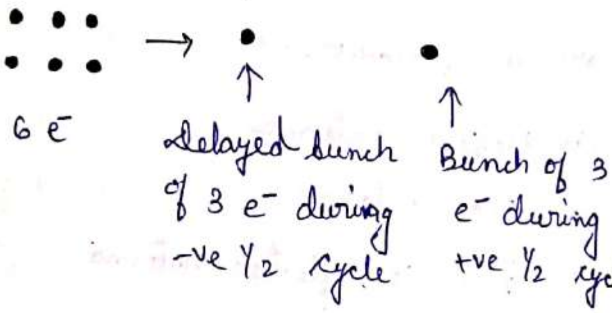
→ Due to accelerative force, velocity of e^- increases.

→ Electron bunching takes place at RF o/p terminal. During both ½ cycles of RF i/p. So, at RF o/p terminal amplified AC signal, we will get.

Top View



-> While travelling the e⁻, the distance between the e⁻ decreases.



-> These bunching e⁻ results amplification at RF o/p.

-> Because of e⁻ path length increases, so it is makes slow wave structure.

-> Electron motion completely based on force & that force drives the e⁻ from cathode to anode.

Applications

-> It is used in o/p tube in radar. Generally in pulse radar system.

-> It is used in microwave amplifier

-> It is used in microwave high power generator

-> It is used in satellite communication.

Application of Magnetron Oscillator

-> In radar

-> In heating (microwave oven)

-> In lighting (Sulphur lamp)

-> Microwave generator.

2/9

Antenna

→ The antennas which are operated under microwave frequencies are called microwave antennas.

→ An antenna is a transducer used for matching the T_x - line (or wave guide) to surrounding medium & vice versa.

→ The types of antenna are as follows :-

(i) Microstrip Antenna
(ii) Lense Antenna
(iii) Horn Antenna
(iv) Helical Antenna
(v) Slot Antenna
(vi) Parabolic reflector Antenna.

→ Horn antenna & Parabolic antenna are used in microwave freq.

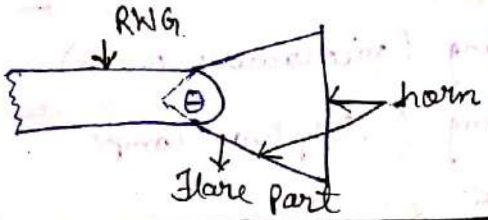
* Horn Antenna

→ The most widely used microwave antenna is horn antenna

→ It is nothing but a flared wave guide. The horn exhibits gain & directivity.

→ Generally the signal is transmitted through T.L or W.G. But W.G in high freq. cases is efficient. So rectangular W.G is used.

→ But problem is a rectangular W.G as radiator has poor impedance matching with space (or medium). This mismatch causes standing waves & reflection which indicates powerloss of original signal.



→ This mismatch can be overcome by flaring the end of rectangular wave guide. This flaring portion is called horn.

→ The more and gradual the flare (horn), the better impedance match or lower the loss. So horn antenna exhibits excellent gain & directivity.

→ The types of Horn antenna are as follows:-

(i) Sectoral horn

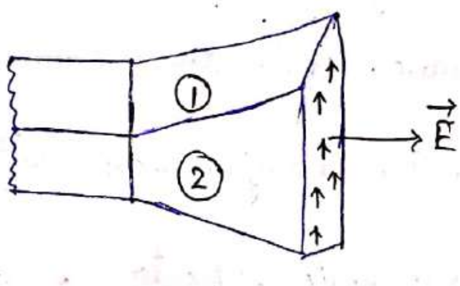
(ii) Pyramidal horn

(iii) Conical horn.

Sectoral horn :- When the flaring is done only in one direction then it is called sectoral horn. It is of two type namely. sectoral E-plane & sectoral H-plane.

Sectoral E-plane horn :-

→ [a_e → Aperature of E-plane horn. Aperature Area (A_p) = (height) (breadth)].



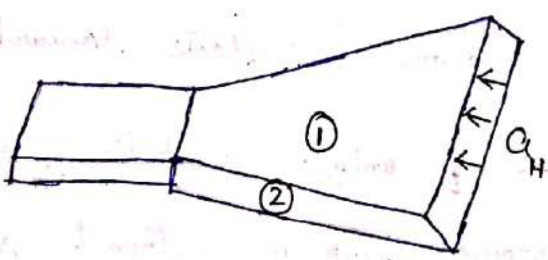
→ In this side (2) is flared only. The flaring is done in direction of $\vec{E}$ field.

Sectoral H-plane horn

→ a_H → Aperature of H-plane of horn.

→ In this side (1) is flared.

→ The flaring is done in direction of $\vec{H}$ field.

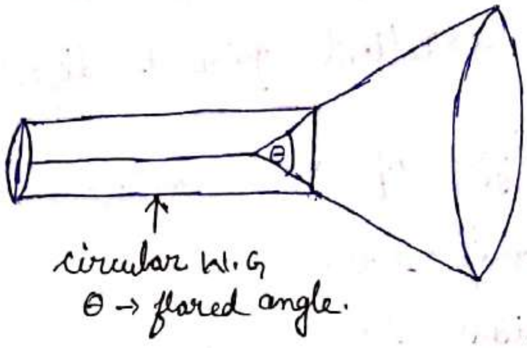


Pyramidal Horn Antenna

→ When flaring is done along both walls of W.G is called Pyramidal horn antenna.

Conical Horn Antenna

→ When one side (end portion) is flared of circular W.G is called conical horn antenna.



* Parabolic Reflector Antenna

→ When a horn antenna is in conjunction with Parabolic reflector is called Parabolic Reflector Antenna.

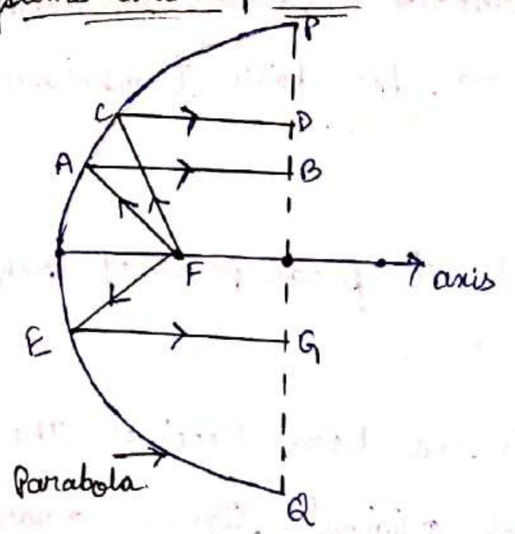
→ Horn antennas are used in many microwave (μw) application, but many times more Power gain & more directivity are desirable. And this can be easily obtained by using a horn in conjunction with Parabolic reflector.

→ A Parabolic reflector is a large dish-shaped structure made of metal.

→ The energy is radiated by the horn is pointed to the reflector which focuses the radiated energy into a narrow beam & reflects towards its destination.

→ Because of unique Parabolic shape the electromagnetic waves are narrowed into a extremely small beam which indicates extremely high gains.

Systems and operation



→ 'F' point → focal point of parabola.

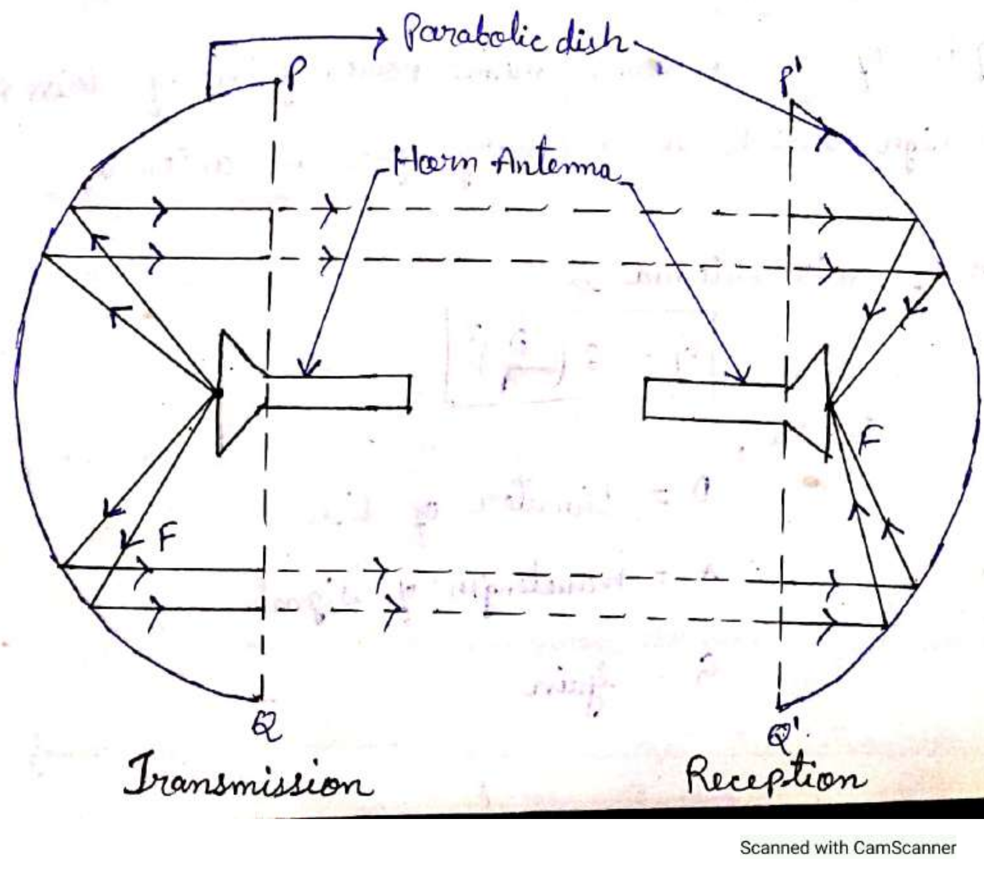
→ 'PQ' → end line (end points) of parabola.

→ Parabola's unique characteristic is distance between focal point to parabola and to vertical dashed line are same.

i.e., (FA + AB) = (FC + CD) = (FE + EG)

→ This system of effects results the electromagnetic waves to pass a narrow beam.

Operation



→ The figure shows how a parabolic reflector is used in conjuction with horn antenna, for both transmission and reception.

→ The horn antenna is placed at focal point of each side (T_x & R_x side).

→ In T_x side (transmitting side) the horn receives the original signal & radiates that original signal towards reflector which bounces the signal wave & passes them in to parallel narrow beam.

→ When used for receiving, the reflector picks up the electromagnetic signal which are from T_x - Antenna & bounces the signal towards antenna at focal point at (R_x - side).

→ Practically it is seen that the result is an extremely high gain & it is narrow beamwidth antenna.

→ The gain of the Antenna means Power gain of this antenna is very high which is necessary for an antenna.

Gain of this antenna is

$$G = 6\left(\frac{D}{\lambda}\right)^2$$

where,

D = Diameter of dish

λ = Wavelength of signal

G = Gain

Gain when expressed in dB (decibel)

$$G_{dB} = 10 \log_{10}(G)$$

uses:-

-> In satellite communication

-> One example dish TV & (DTH)

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* Rhombic Antenna

Basics

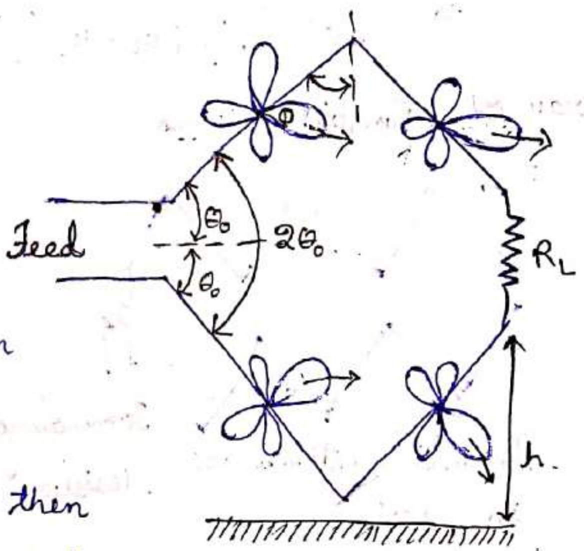
-> It's name comes from its diamond shaped layout.

-> It is array of four inter-connected long wire antennas.

-> It is also called as double V antenna.

-> It needs 600 Ω to 800 Ω terminator resistance to minimize reflection loss.

Structure of Rhombic Antenna



ϕ = Tilt Angle

$2\theta_0$ = Apex angle

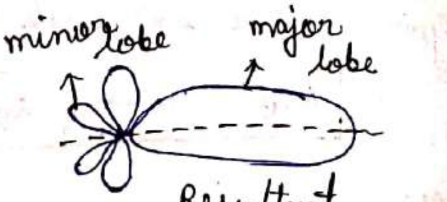
-> If we have very long wire then we will not use R_L

-> But if we have limited wire then we will use R_L to minimize reflection loss.

Radiation Pattern

-> It is due to long wires is given above. By addition of those four wire radiations, resultant radiation is formed.

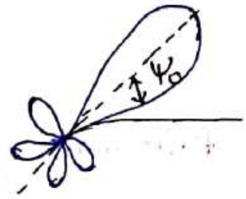
→ If we place rhombic antenna nearer to ground with height h, then resultant radiation will shift by an angle ψ_0.



Resultant radiation pattern

Design of Rhombic antenna

ψ_0 = Direction of major lobe



→ To obtain major lobe direction ψ_0, we need to calculate height.

$$\boxed{\frac{h_m}{\lambda_0} = \frac{m}{4\cos'(90-\psi_0)}},$$ where h_m is min. height for $m = 1$.

→ For a symmetrical rhombus all leg lengths are equal.

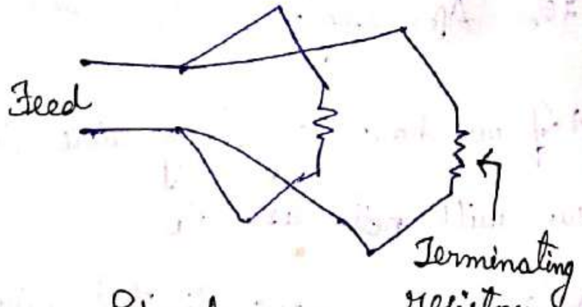
$$\frac{l}{\lambda_0} = \frac{0.371}{1-\sin(90-\psi_0)\cos\theta_0}$$

where, $2\theta_0$ = Apex angle.

$$\theta_0 = \cos^{-1}[\sin(90-\psi_0)]$$

Array of Rhombic Antenna :-

Rhombic antenna are in Series



Rhombic antenna are in Parallel.

Advantages

→ Simple & cheap

→ Vertical radiation is low, hence it is suitable for long distance F-layer propagation.

→ Short wave antennas of this type require low height.

→ Small variation of i/p impedance that results of wide range frequencies.

Disadvantages

→ It occupy large space.

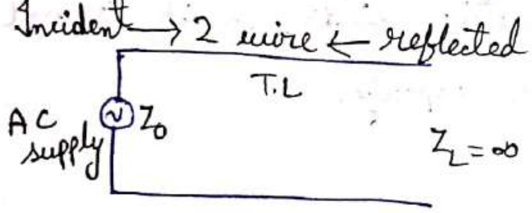
→ It has minor lobes that reduce transmission efficiency.

→ Half power is wasted in terminating resistor.

* Dipole Antenna :-

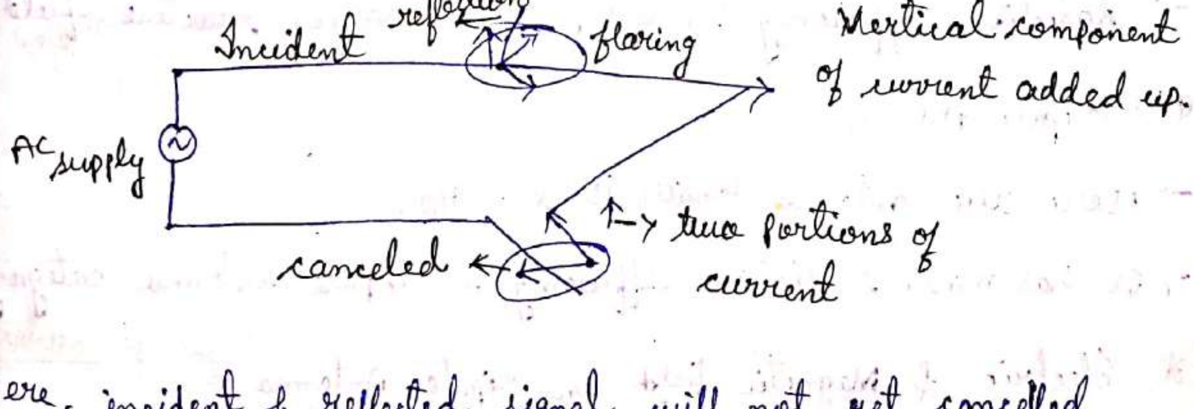
case-1

→ In a normal, T.L when $Z_L = \infty$ i.e., T.L is opened then reflection occurs i.e., max. reflection & min. radiation occurs.



case 2

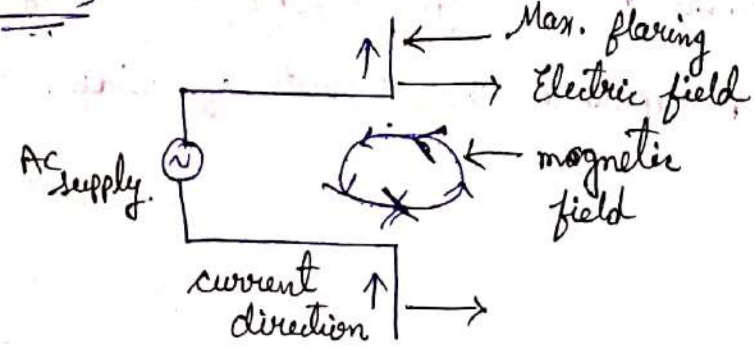
→ When we start increasing flaring in T.L then reflected signal decreases & T.L start to radiate.



→ Here, incident & reflected signal will not get cancelled completely.

→ So, the partial vertical component of signal is radiated in the space.

Case-3



→ Flaring in T.L is dipole antenna.

→ At max. flaring, max. radiation happen.

Types of Dipole Antenna

(i) Hertzian Dipole (Infinitisinal small dipole):-

→ Here length of dipole antenna is $l < \lambda/50$.

→ Min. use, higher loss, radiation efficiency is less.

→ It has larger region of reactive fields, so it is not commercial used in larger capacity.

(ii) Small Dipole Antenna

→ Here, the antenna length is $\lambda/50 < l < \lambda/10$.

→ Less use, higher losses.

→ Radiation efficiency is less, it has larger reactive field.

(iii) Dipole Antenna

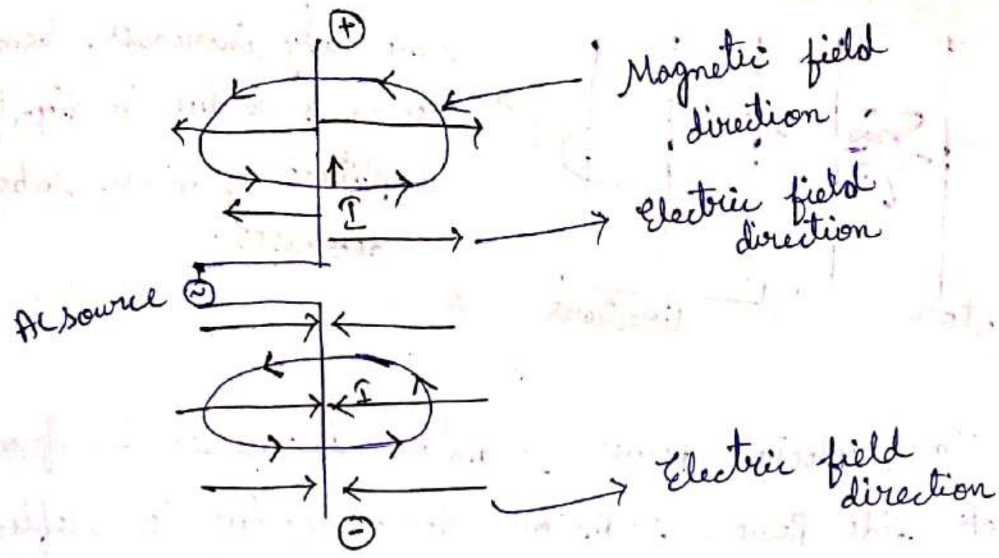
→ Here the antenna length is $l = \lambda/2$.

→ It has max. radiation efficiency in dipole antenna category.

* Electric & Magnetic field in Dipole Antenna :-

→ Electric field is away from +ve dipole & E-field direction is in the -ve dipole.

→ Magnetic field is circulating along the dipole antenna.



→ For -ve 1/2 cycle of AC signal, the direction of E-field & M-field will be reverse.

* Yagi Uda Antenna

Basics

→ It is directional antenna. It has operating frequency < 10MHz.

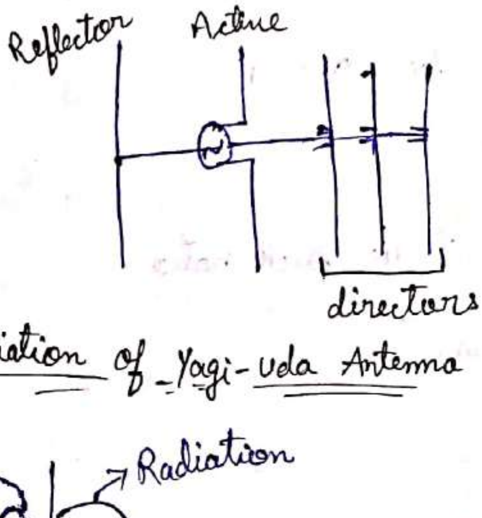
→ It can be used for 40 to 60 Km distance.

→ It has two types of elments :-

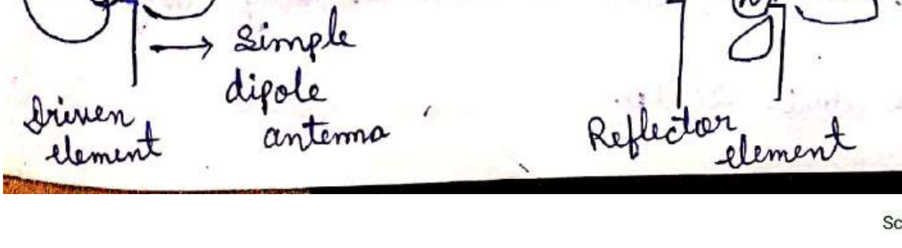
i) Active element [driven element] :- it is connected to power supply.

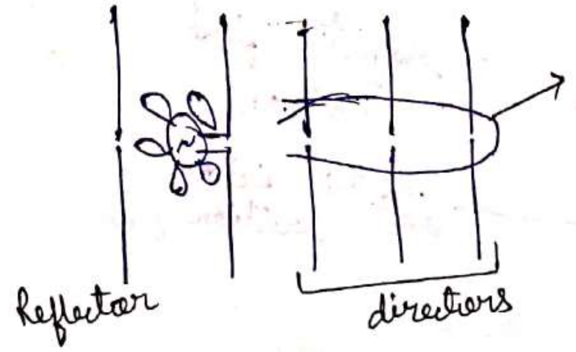
ii) Parasitic element [reflector, directors] :- it is not " " " "

→ Structure of Yagi Uda Antenna :-



Radiation of Yagi-Uda Antenna





Directivity increases, beam width decreases & due to directors, amplitude of minor lobe decreases.

→ Due to reflector power radiation increases in front side. In back side power radiation decreases, due to reflector back side radiated field reflected.

Designing of 3-element Yagi-Uda Antenna :-

→ Length of active element.

$$L_a = \frac{478}{f\,(MHz)} \text{ (feet)}.$$

→ Length of reflector element

$$L_R = \frac{492}{f\,(MHz)} \text{ (feet)}$$

→ Length of director element.

$$L_D = \frac{461.2}{f\,(MHz)} \text{ (feet)}.$$

→ Spacing between elements should be 0.25λ.

Advantages of Yagi-Uda Antenna :-

→ High gain about 9 dB, high front to back ratio.

→ Cheap, it is light weight antenna.

Disadvantages

→ For high gain level the antenna becomes very long.

→ Gain limitation is about 20 dB.

Applications

-> It is used in HF (3-30 MHz), VHF (30-300 MHz), UHF (300-3000 MHz)

-> Home TV receiver.

-> For point to point communication.

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* Directivity

-> It refers to the ability of an antenna to send or receive signals over a narrow ~~hoz~~ horizontal direction range.

-> It means how much it directional in physical orientation towards the signal source.

* Beam Width

-> It refers to angle of radiation pattern over which transmitter's energy is transmitted or received.

-> The measure of an antenna's directivity is beam width.

-> The angle formation by the two 3-dB down point from centre of graph is beam width.

-> Less beam width ⇒ more gain ⇒ more directivity

* Duct Propagation (Super Refraction) (SR)

-> The VHF, UHF & microwaves are neither reflected by Ionosphere nor propagated along earth's surface. But due to the refraction of such high freq. waves in the troposphere, the transmission occurs much beyond of LOS surface.

-> Due to water, vapour, temp. the refraction occurs i.e., S.R

* Critical Frequency

→ The sky wave propagation due to reflection from Ionosphere occurs in HF range of frequencies.

→ As the freq. is increased at some point, the wave is not reflected by Ionosphere & instead it pierces through the Ionosphere.

→ This freq. known as Critical freq. (f_c), where, is
$f_c = \sqrt{N_{max}}$ & N_{max} is max. e^- density in m^{-3} which varies with time.

* MUF

→ It stands for Max. Usable Freq.

→ It is highest freq., that is bent back by Ionosphere layer & depends on angle of incident ray.

→ $f_{muf} = (9\sqrt{N}) \sec\theta$; where, N → e^- density; θ → angle made by incident ray in ionised layer.

* Fading

→ If the intensity (strength) of received signal decreases when the transmitted signal travels in different by covering long distance to reach at receiver is called fading.

→ Fading depends upon wind flow, temp., humidity of air, etc.

→ Types of fading are namely of interference, selective, absorption, skip & polarization.

* Propagation

→ The propagation of microwave signal means travelling of EM waves from transmitter to receiver through channel. (i.e., may be free space).

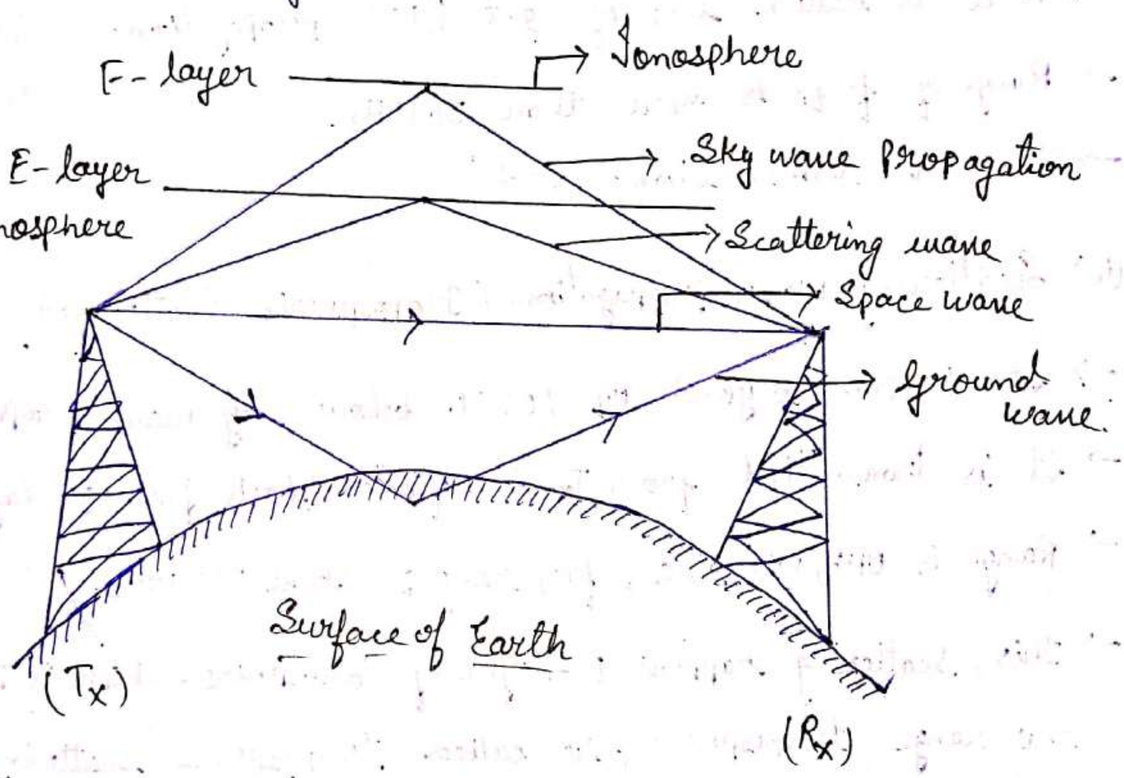
→ Types of propagation are namely :-

(i) Ground wave propagation

(ii) Sky-wave propagation

(iii) Space wave propagation

(iv) Scatter wave propagation



(i) Ground wave propagation

→ In this mode of propagation, the signal travels very close to surface of earth.

→ The ground wave actually follows the curvature of earth & travel long distances beyond the horizon.

→ Freq. range is 30 KHz - 3 MHz

→ Ex:- All medium broadcasting, telephone communication.

(ii) Sky-Wave Propagation :-

→ In this mode the waves are reflected back from transmitting antenna to receiving antenna through F - layer of ionosphere.

→ Rang of freq. is 3 MHz - 30 MHz.

→ Ex :- Point to point communication of large distance radio communication and short wave radio communication.

(iii) Space Wave Propagation (LOS)

→ The wave Propagates from T_x to R_x in direct path wave. So it is called line of sight (LOS) propagation.

→ Range of freq. is more than 30 MHz.

→ Ex :- TV transmission.

(iv) Scattering Wave propagation (Tropospheric Scattering)

→ It happens beyond of LOS & below sky wave propagation.

→ It is transmitted from T_x & reflected back from E - layer.

→ Range is UHF, VHF, uw, freq rang is above 300 MHz.

→ This scattering happens E - layer of ionosphere which is in the range triopospher, so called troposphere scattering.

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Antenna

→ An antenna is a coupling device. It couples transmitter to space & space to receiver.

→ It radiates & receives EM waves. It is a tuned element and passive element.

* Isotropic Radiator :-

→ It is a fictious antenna (or) impractical antenna. It is capable of radiating uniformly in all directions.

Ex:- Point source.

* Omnidirectional Antenna :-

→ This antenna is capable of radiating uniformly in Azimuthal plane & having non-uniform radiation in the elevation plane.

Ex:- Dipole Antenna

Azimuthal Angle (0° to 180°); Elevation angle (0° to 360°).

* Directional Radiator

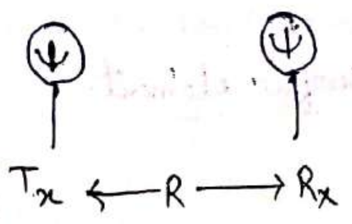
→ All practical antennas are directional radiators i.e., they are capable of radiating & receiving EM waves through some particular direction.

* Radiation Pattern :-

→ It is the locus of received field strength (or) power at a fixed far distance as a function of space co-ordinates.

→ If received quantity is field strength then it is called field strength pattern.

→ If the received quantity is power then it is called power pattern.



→ If $R > \frac{2D^2}{\lambda}$, then this zone is Fraunhofer far field Zone.

→ In this zone the radiated fields are active field & it is used for radiation purpose.

→ If $R < \frac{2D^2}{\lambda}$, then it is called Fraunhofer near field zone

→ In this zone the fields are reactive fields & it is not used for radiation purpose.

λ = operating wavelength

D = diameter of antenna

→ All the antennas are intended to be operated in the Fraunhofer far field zone only.

30/9

* Average Radiation Density :-

→ It is defined as average power radiated per unit area.

$$P_{avg} = P_{rad} = \frac{1}{2} \times \vec{ES} \times \vec{HS}^* \ W/m^2.$$

→ This is avg Poynting vector. $\vec{ES}$, $\vec{HS}$ are phasor form of the electric field ($\vec{E}$ field) & Magnetic field ($\vec{H}$ field).

* Average Radiated Power (W_{rad}) :-

→ It is an average power radiated by an antenna.

$$W_{rad} = \oint_s P_{avg} \cdot ds \text{ watt.}$$

$\vec{ds}$ is the vector differential surface element.

* Average Radiation Intensity ($\vec{U}$) :-

→ It is defined as average power radiated per unit solid angle.

$\vec{U} = r^2 . \vec{P}_{avg}$ w/steradian.

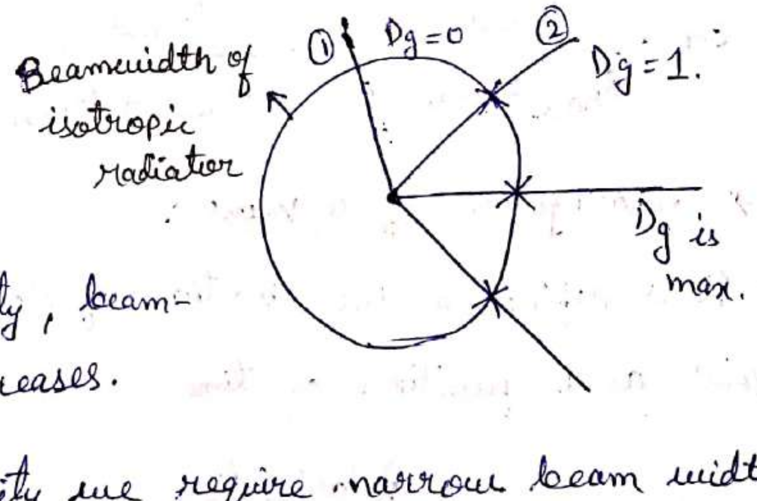
* Directive Gain (D_g) :-

→ It is in a given direction is the ratio of radiation intensity of the practical antenna whose directive gain (D_g) you want to calculate to the radiation intensity of the reference antenna.

$$D_g = \frac{\text{Radiation Intensity of the practical Antenna whose } D_g \text{ you want to calculate}}{\text{Radiation Intensity of reference antenna.}}$$

→ This reference antenna is being choosen as isotropic radiator.

→ Isotropic radiator directive gain is zero.



→ By increasing directivity, beam-width of antenna decreases.

→ For larger directivity we require narrow beam width. for smaller directivity we require larger beam width.

→ For Broadcast application an antenna has low directivity.

→ For Point to point communication the antenna must have very high directivity.

$$\boxed{D_g = 4\pi . \frac{U_{max}}{W_{rad}}}$$

→ **Power gain (G_P) = $4\pi \cdot \frac{U}{W_{in}}$**

W_{in} = Power in to the antenna

$W_{in} = W_{rad} + W_{loss}$

- W_{loss}:
  - I^2R loss (Power loss)
  - Reflection loss
  - Dielectric loss.

→ Max. Power Gain.

$$G_0 = 4\pi \cdot \frac{U_{max}}{W_{in}}$$

* Total Efficiency of an antenna :-

$$e_t = \frac{\text{Gain}}{\text{Directivity}} \quad ; \quad \text{Directivity} = \frac{\text{Gain}}{\text{Efficiency}}$$

$$e_t = \frac{R_{rad}}{R_{rad} + R_{loss}} \quad ; \quad = \frac{W_{rad}}{W_{rad} + W_{loss}}$$

1/10 ## * Polarization of a Wave :-

→ It is defined as the direction of electric field at a given point as a function of time.

Polarization

- Linear Polarization.
  - Horizontal
  - Vertical
  - Theta
- circular
- Elliptical

* Linear Polarization :-

→ $\vec{E}$ field remain along a straight line as a function of time at some point in the medium.

→ When wave travels in Z-direction both $\vec{E_S}$ & $\vec{H_S}$ lying in X-Y plane.

If (i) $E_{YS} = 0$ & E_{XS} is present [X-Polarised or Horizontal]

(ii) $E_{XS} = 0$ & E_{YS} is present [Y-Polarised or vertical polarised].

(iii) E_{XS} & E_{YS} is present & in phase [θ-polarised ; $\theta = \tan^{-1}\frac{E_Y}{E_X}$]

* Circular Polarization :-

→ In this polarization $\vec{E}$ (Electric field) traces a circle.

→ Here, Electric field ($\vec{E}$) has 2 components E_{XS} & E_{YS} have equal magnitude & a 90° phase difference.

→ The locus of the resultant $\vec{E}$ field is a circle & the wave is a circle & the wave is circularly polarized.

$$E_{XS}^2 + E_{YS}^2 = E_K^2$$

where,

K represents the direction of propagation & it is generally in Z- direction.

* Elliptical Polarization :-

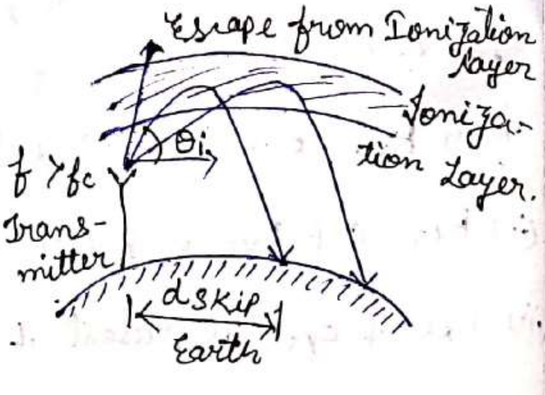
→ Here, $\vec{E}$ has 2 components E_{XS} & E_{YS} are not equal in magnitude & they differ by 90° phase, then the tip of the resultant electric vector traces an ellipse. The wave is said to be elliptically polarized.

$$\frac{E_{XS}^2}{a^2} + \frac{E_{YS}^2}{b^2} = 1$$

* Skip Distance

→ It is the shortest distance from a transmitter measured along earth's surface at which sky wave has fixed frequency ($f > f_c$) will be returned to the earth.

→ A θ_i angle of radiation the signal comes to the earth by reflecting in ionization layer.



→ So we can say the sky wave propagation is possible for greater than skip distance.

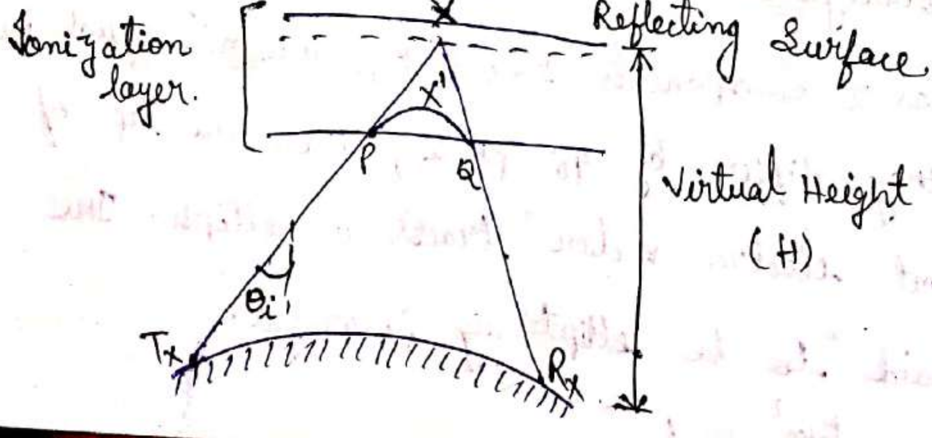
→ Equation of MUF & critical freq. is

$$\Rightarrow f_{muf} = f_c \sqrt{1+\left(\frac{d}{2H}\right)^2}$$

$$\Rightarrow d_{skip} = 2H \cdot \sqrt{\left(\frac{f_{muf}}{f_c}\right)^2 - 1}$$

* Virtual Height :-

→ It is that height from which a wave sent up at an angle appears to be reflected.



→ Due to gradual change in refractive index actual path is $T_X - P - X' - Q - R_X$. And virtual path is $T_X - P - X - Q - R_X$.

→ The height associated with virtual path is virtual height.

→ To measure the virtual height, the instrument used is ionospheric sound is also called as Ionosonde.

→ The transmitter antenna sends vertically upward radio-wave of pulse duration 150 μs.

→ The receiver antenna (R_X) is placed close to transmitter antenna (T_X) & receives reflected signal.

→ If the duration of transmitter (T_X) & receiver (R_X) signal difference is T, then distance = velocity × time,

$$\Rightarrow 2H = C \times T \quad \Rightarrow H = \frac{C \times T}{2}$$

↓

(Sending distance H, receiving distance is H by reflection. So total distance is 2H).

* <u>Actual Height</u> :-

→ The height associated with actual path is actual height.

3/10

Television

* SMPS :-

→ SMPS stands for Switch Mode Power Supply.

→ It is a device which provides power to any electrical load and involves some kind of switching action.

→ Previously linear power supplies become very bulky with increase in its current ratings. So, we need something which will allow us to handle large amount of currents without taking a lot of space. So we use SMPS as a solution for that.

→ SMPs works on a very high frequencies as compared to linear power supplies & as the size of transformer reduces with increase in frequency, the overall size of an SMPS become very small as compared to linear power supplies.

→ There are basically five blocks in SMPS namely :-

(i) Input rectifier & filter.

(ii) Chopper (It is used to convert DC signal to Pulsnating DC).

(iii) Transformer (It steps down the volt. to required level).

(iv) Output rectifier and filter (constant DC o/p voltage is obtained).

(v) Feedback circuit (This circuit has to maintain the o/p voltage to a desired value).

* Working of SMPS

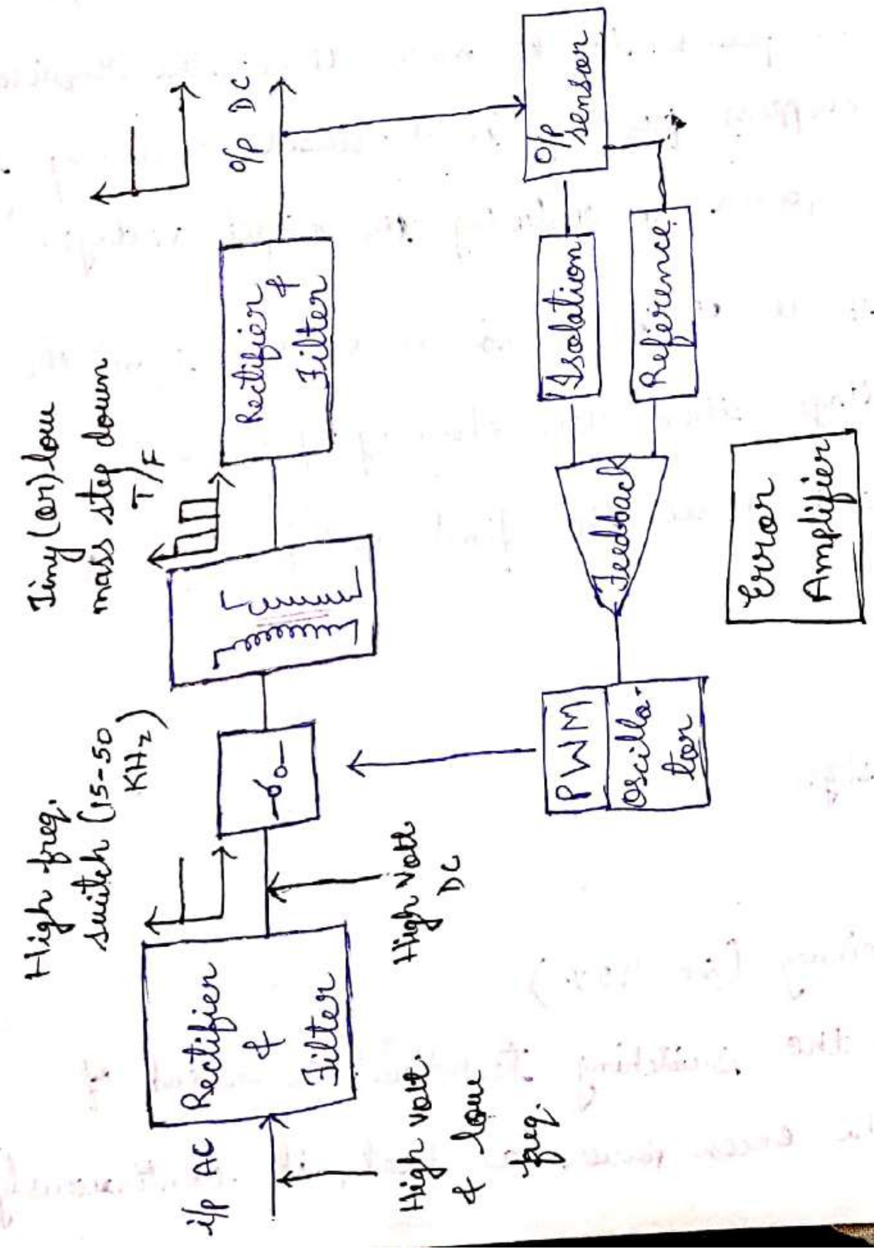
→ SMPS works on high frequencies.

→ We need to increase the frequency of 50 Hz i/p.

→ So, we have to convert the ac i/p to d.c first & then chop it at high frequency to get the pulsating dc o/p which is then applied to rectifiers & filters.

→ Feedback helps to maintain the level of o/p signal.

* Block Diagram of SMPS :-



→ Isolation unit is used to separate the high current from damaging the primary side circuitory.

→ Transformer steps down the pulsating DC signal and it is applied to o/p rectifier & filter circuit to get a constant DC o/p.

* Feedback circuit

→ Output sensor of the feedback unit senses the o/p voltage and then compares with reference voltage. The error voltage is used to control the chopping frequency.

→ If the o/p is found to be more than the required value, the chopping frequency is decreased, reducing the total output power so reducing the output voltage.

→ Similarly if the o/p is found to be less than the required voltage then the chopping frequency is increased, and hence the final voltage level is maintained.

* Advantages :-

(i) Small in size

(ii) Less noise.

(iii) High efficiency (80-95%)

SMPS uses the switching technique. So instead of dissipating the excess power as heat, it continuously switches its i/p to control the o/p power contribute to linear power supplies. This increases overall efficiency of SMPS.

* Disadvantage :-

→ SMPS has high complexity as it involves so many stages of operation.

→ It operates at high freq. which causes generation of EMI that can damage the sensitive instruments.

Antenna

* Total efficiency of an antenna (e_t) :-

→ $e_t = \frac{W_{rad}}{W_{in}} = \frac{\text{gain } (G_0)}{\text{directivity } (D_0)}$

⇒ Directivity = $\frac{\text{gain}}{\text{efficiency}}$; D_0 = directivity = $4\pi \cdot \frac{U_{max}}{W_{rad}}$

$$\text{Efficiency } (e_t) = \frac{W_{rad}}{W_{rad} + W_{loss}} = \frac{R_{rad}}{R_{rad} + R_{loss}}$$

* Effective Aperture Area (A_e) :-

→ It refers to physical size of the antenna. Large antennas will have larger aperture area & vice versa.

→ If the antenna dimensions are less than λ, then they are called small antennas & vice versa.

$$A_e = \frac{\text{Average Power received}}{\text{Avg. Power density of the incident wave}}$$

$$A_e = \frac{Watt}{(Watt/mtr)^2} = mtr^2$$

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

→ A_e ↑ (increase), D_o ↑, Beamwidth(↓), A_e ↓, D_o ↓, Beamwidth (↑)

* Hertzian Dipole :-

$$H \text{ (magnetic field)} = \frac{I \cdot \beta \cdot l \cdot \sin\theta}{4\pi r}$$

E (Electric field) $= \eta \cdot H$ [∵ η = Impedance]

Radiation Resistance $(R_{rad}) = 80 \cdot \pi^2 \left(\frac{l}{\lambda}\right)^2$

Radiated Power $(W_{rad}) = 80 \cdot \pi^2 (l/\lambda)^2 \cdot I_{eff}^2$

I_{eff} = Effective current of antenna
$= I/\sqrt{2}$

* Intrinsic / Input Impedance :-

→ It is the ratio of electric field (E) to magnetic field (H)

$$\eta = \frac{E}{H} \text{ in } \Omega \quad \text{or} \quad \sqrt{\frac{\mu}{\epsilon}}, \text{ for free space.}$$

→ If the wave is moving along Z-direction then,

$$\frac{E_x}{H_y} = \eta = -\frac{E_y}{H_x}$$

$$\frac{E_x}{H_y} = -\eta = -\frac{E_y}{H_x} \quad \text{(for -ve Z direction)}$$

→ If the wave is moving along x-direction then,

$$\frac{E_y}{H_z} = \eta = -\frac{E_x}{H_y}$$

$$\frac{E_y}{H_z} = -\eta = -\frac{E_x}{H_y}$$ (If the wave move & along -ve z-direction).

→ If the wave is moving along y-direction then,

$$\frac{E_z}{H_x} = \eta = -\frac{E_x}{H_z}$$

$$\frac{E_z}{H_x} = -\eta = -\frac{E_x}{H_z}$$ (for -ve y-direction).

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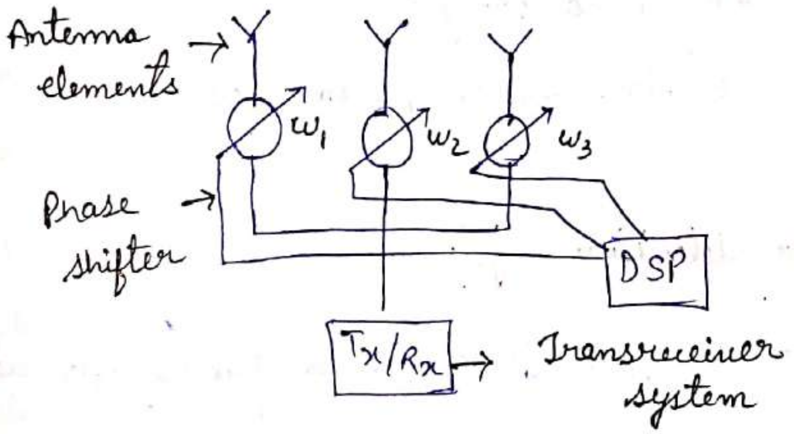
* Smart Antenna

→ It is the combination of antenna phased array and DSP processors.

Structure of Smart Antenna



→ Phase of the phase shifter is controlled by DSP Processor. By controlling the phase of phase shifter antenna is steered.

→ Antenna elements radiates in desired direction only. It has minimum interference. Each antenna element is connected with phase shifter & then it is connected with trans-receiver system. Smart antenna has higher gain in desired direction.

Definition :- A smart antenna system combines multiple antenna elements with signal processing capability to optimize the radiation and/or reception pattern automatically in response to the signal environment.

Benefits :-

(i) It has higher gain for the desired signal.

(ii) Interference Rejection.

(iii) Increase system capacity.

Applications :-

(i) It is used in acoustic signal processing.

(ii) It is used in tracking of RADAR.

(iii) It is used in radio astronomy.

(iv) It is used in cellular system, radio telescopes.

17/10

* Introduction to Television system :-

→ The word television has its origin in two greek words 'tele' & 'vision'. Tele means 'at distance' & vision means 'seeing'.

→ Earlier selenium photosensitive cells were used for converting light from pictures into electrical signals. (i.e., Conversion of optical signal to electrical signal).

→ First camera tube is iconoscope. In 1935 TV broadcasting started. In 1959 TV came to India.

* Evolution of TV :-

Black & white TV → color TV → plasma TV → 3D TV → HD TV.

* Aspect Ratio :-

→ Width to height ratio of a picture frame is called aspect ratio. Width is kept longer than height because of the following facts:-

i) Horizontal dimension of a scene is generally more than its vertical dimension.

ii) Eyes can move with more ease & comfort in the horizontal plane than in vertical.

(iii) The fovea, the surface of max. senstivity & resolution at the centre of the retina in the eye has greater width than height. Hence, the longer width of the image ensures more efficient use at the fovea.

(iv) As a result of intensive subjective tests by the cinema people, aspect ratio of 4:3 was found to be most pleasing aesthetically & less fatiguing to the eyes.

* Details & Resolution :-

→ Closely spaced small objects (or) small distinct features in a picture form details.

→ Smaller the objects (or) features visible distinctly, higher is the resolution of the details (or) finer are the details being seen.

→ The ability to see the fine details in a Picture is called resolution.

* **Flicker :-**

→ Time of Persistence of vision is more for darkness than for bright light. This results in a phenomenon called flicker.

→ It means dark intervals between bright pictures become visible for a very short time & appear as a flicker.

* **Scanning :-**

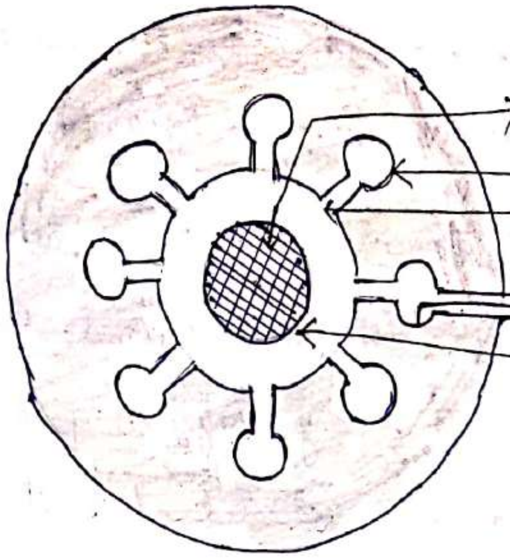
→ Optical information is converted into electrical form and transmitted element by element, one at a time in a sequential manner to cover the entire scene to be televised.

→ Scanning is done at very fast rate.
→ It is repeated a no. of times per second to create an illusion of simultaneous pick up.

* **Magnetron :-**

→ It is a combination of a simple diode vacuum tube with built in cavity resonators & an extremely Powerful magnet.

Construction



→ A Magnetron is a called a cross field device, because there is a magnet outside of the magnetron.

→ Due to e^- move, there is a electric field. But the magnetic field & electric field acts in Perpendicular.

→ The two fields crossed each other so it is called cross field device.

$$F = \bar{B} \times e\bar{v} = Bev \sin\theta$$

$$\Rightarrow F = B_{ev} \quad [\text{when } \theta = 90^\circ \text{ means perpendicular}]$$

$\sin\theta = 1$; B → Mag. field.

→ There are even no. of cavities. Every Portion is indicated as cathode, e^- path, interaction space, outlet. The o/p is taken from one of the cavities.

→ Cathode :- Its function is to emit e^-. Here ~~is~~ cathode is a circular cathode.

→ Interaction space :- At which e^- moves & magnetic & electric fields act.

Operation

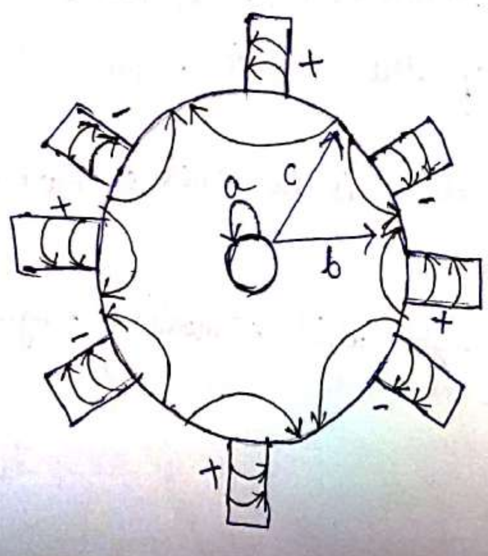
→ When heated the cathode emits e^-. So the e^- want to move towards +ve anode. Due to anode is connected DC supply

→ If e^- move directly towards the anode, anode current will flow. But it is not happened. ~~But~~ Because the system is Kept in a strong magnetic field, when e^- move also a magnetic field is created but it is small compare to outside magnetic field. So repulsion occurs.

→ Due to this repulsion the e^- moves in a (curved path) or circular path instead of directly towards the anode.

→ The magnetic field for which e^- return back to cathode without reaching the anode for which anode current is zero, that magnetic field is called critical magnetic field. (B_c).

→ For zero anode current applied magnetic field (B) should be greater than B_c.



→ Input is applied to one anode cavity. It is circulated to other cavities by making 180° phase shift.

→ There is +ve & -ve polarity for each cavity. $\vec{E}$ is always +ve to -ve potential.

→ For 'b' e^- $\vec{E}$ & e^- movement direction same means velocity of e^- increases. But 'c' e^- $\vec{E}$ & e^- movement opposite means velocity of e^- decreases.

→ So velocity modulation occurs & e^- move up & down & releases energy as a result oscillation occurs.

→ So from one cavity the oscillated e^- are taken. That's why magnetron is called oscillator.

COMPOSITE VEDEO SIGNAL :-

BASICS :- → In TV, picture signal is a combination of multiple signals.

(i) camera signal :- corresponding to the variation of light of given picture.

(ii) Synchronization pulse :- To provide synchronization

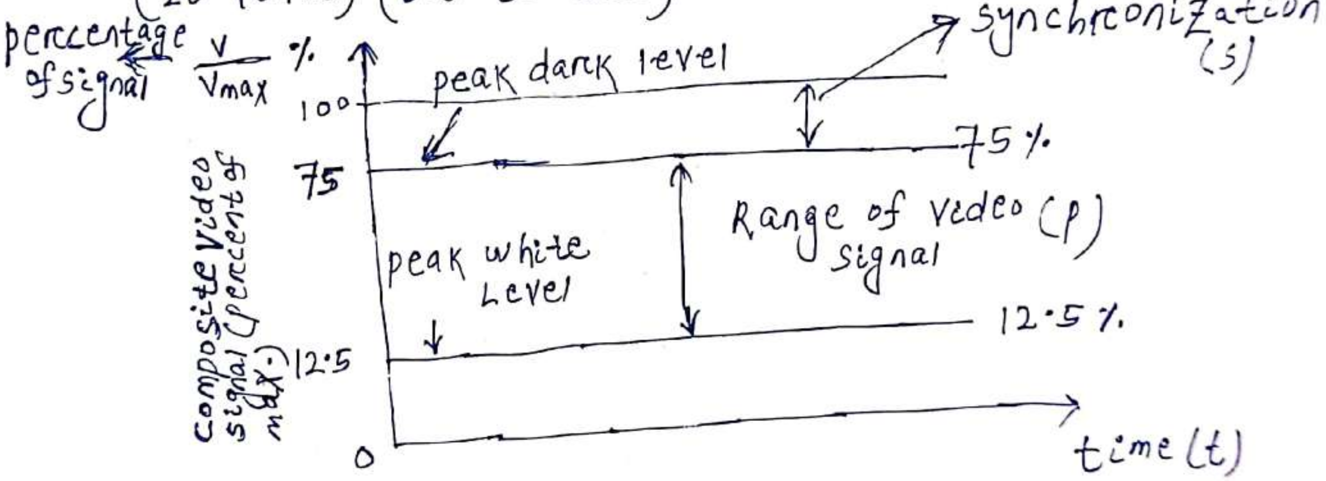
(iii) Blanking pulse :- To make retraces invincible.

→ In TV, There are 625 lines in one frame.

→ one frame is divided in two fields, 1 to 312.5 lines and 312.5 to 625 lines.

→ In 1st field from 1 to 312.5 again divided into trace (292.5 lines) (1 to 292.5) and Retrace (20 lines) (292.5 to 312.5).

→ In 2nd field from 312.5 to 625 lines again divided in to trace (292.5 lines) (312.5 to 605) and retrace (20 lines) (605 to 625).



→ If the signal is brightest then 12.5% of voltage available similarly for darkest signal maximum 75% of voltage available. In between 12.5% to 75% of voltage Level video signal voltage range exist.

→ In camera Video signal we sent blanking pulse and synchronization pulse. synchronization is always provided in between 75 to 100%.

→ $\frac{P}{S}$ ratio should be maintained to $\frac{10}{4}$. ($\frac{\text{Video signal voltage}}{\text{synchronization signal voltage}}$)

If P/S ratio > $\frac{10}{4}$ then cost of synchronization occurs.

If $\frac{P}{S}$ ratio < $\frac{10}{4}$ then it will be cost of picture data.

Camera signal :- ↳ Lowest Amplitude at 12.5%, shows whitest part of the picture. ↳ Highest Amplitude at 75%, shows darkest part of the picture.
↳ Signal Transmission is done by Negative polarity Transmission.

Horizontal Blanking pulse :- ↳ Horizontal Blanking pulse (12 μsec) has 3 portion.
(i) Front porch (1.5 μsec) [Fly back initiated with black level.]
(ii) Horizontal synchronization pulse (4.7 μsec) [synchronization is done to Transmitter to Receiver by pulse.]
(iii) Back porch (5.8 μsec) [Fly back completed with black level.]

Vertical sync pulse :- (i) It is of 2.5 line duration.
(ii) so its Time period is 2.5 × 64 μs = 160 μs.
(iii) At the end of first field vertical synch pulse is added at (312.5 to 315) (2.5 lines).
(iv) At the end of second field again vertical sync pulse is added at (1 to 2.5) (2.5 lines).
(v) one vertical sync pulse ends at half line period and one ends at full line period.

Vertical Blanking period :- (i) It is the period during which picture information is completely suppressed and flyback retrace of field is initiated and completed.
(ii) It is of 20 lines duration. so Time will be 20 × 64 μsec = 1.28 msecond

↳ Composite video signal is formed by (i) Electrical signal corresponding to the picture information.
(ii) Lines scanned in TV camera pickup Tube.
(iii) Introduced sync signals.

↳ Three components of composite video signal. (i) camera signal. (ii) synchronizing pulses. (iii) Blanking pulses.

Horizontal Blanking period :- ↳ It is part of each line during which line sync pulse is inserted.

↳ During This period :- (i) Flyback is initiated and completed. (ii) Beam cutoff by the black level amplitude of video signal.

↳ Horizontal Blanking period = 0.19 H, Here H = 64 μs
= 0.19 × 64 μs
= 12 μs

Horizontal sync pulse :- ↳ short pulse sent from Transmitter to Receiver. ↳ Sync pulse is used to synchronize Transmitter and receiver. ↳ width = 0.07 × H = 0.07 × 64 μsec
= **4.7 μsecond**

Front porch :- ↳ sync pulse does not coincide with blanking pulse but it follows after about 2% of the line period. This short period is called front porch.

↳ Front porch = 2.5% width H = 1.5 μsecond

Back porch :- ↳ At the blanking level allows plenty of time for retrace to be completed.

↳ Back porch period is 5.8 μsecond.

↳ permits time for the horizontal time base circuit to reverse direction of current for the initialization of scanning for next time. ↳ It provides amplitude and enables to preserve the DC content of picture information at Transmitter.

↳ Amplitude = Blanking Level.
↳ At Receiver Blanking Level is independent of the picture details. This picture details is utilized in Automatic Gain control (AGC) circuits. AGC circuits develop AGC voltage proportional to the signal strength picked up at the antenna.

Details of Horizontal scaning

Total line period (H) → 64 µsecond.
Horizontal Blanking → 12 µsecond.
Horizontal sync pulse → 4.7 µsecond.
Front porch → 1.5 µsecond.
Back porch → 5.8 µsecond.

~~Vertical sync pulse:~~

— x —

BASICS OF PIXELS IN TV :- ↳ conversion of light beam in to video is done by scanning process.

↳ smallest part of picture element covered by light beam is referred as pixel.

↳ For aspect ratio 4:3 [Number of pixels in horizontal lines are $\left(\frac{4}{3}\right)$th times compared to pixels in vertical lines.]

↳ For aspect ratio 16:9 [Number of pixels in horizontal lines are $\left(\frac{16}{9}\right)$th times compared to pixels in vertical lines.]

pixels lost in vertical Blanking :-

↳ As we have seen in interlaced scanning, in first field of vertical trace 292.5 Active lines are there and in first field of vertical retrace 20 inactive lines are there. similarly for second field of vertical trace another 292.5 active lines are there and in second field of vertical of retrace 20 inactive lines are there.

↳ So in one frame, 585 Active lines are there with vertical trace and 40 inactive lines are there with vertical retrace.

↳ So during vertical retrace, pixels are lost due to screen is blank.

↳ So number of active lines are given by

$$N_a = \text{Total no. of lines } (N_t) - \text{Inactive Lines } (N_I)$$

$$= 625 - 40 = 585$$

Pixels lost due to Kell effect :- (i) Arrangement of pixels is uneven and random in nature. (ii) During scanning process, scanning beam may miss some pixels. (iii) In General, 70% of pixels are reproduced during scaning process, so 30% of pixels may get lost during scanning. This effect is referred as Kell effect.

↳ so, The number of active lines actually reproducing pixels can be calculated by multiplying active lines by a Kell factor (K), whose value is choosen (0.7).

↳ Total pixels in vertical direction = $N_a \times K$ (↓ Active Lines)

$= 585 \times 0.7 = 410$

RESOLUTION :- (i) Resolution means ability to differentiate between nearly spaced pixels.

(ii) In Gross structure of TV, we have already discussed that horizontal resolution is always higher than vertical resolution in TV. Because, horizontal dimension is greater than that of vertical dimension.

(iii) Vertical resolution is given by $R_V = N_a \times K$

$= 585 \times 0.7 = 410$

(iv) Horizontal resolution is given by $R_H = R_V \times a$

a = Aspect Ratio (4/3)

$\Rightarrow R_H = 410 \times 4/3$

$= 546$

(v) Resolution is always expressed by vertical resolution. Example :- 1080p, 720p, 144p, 240p.

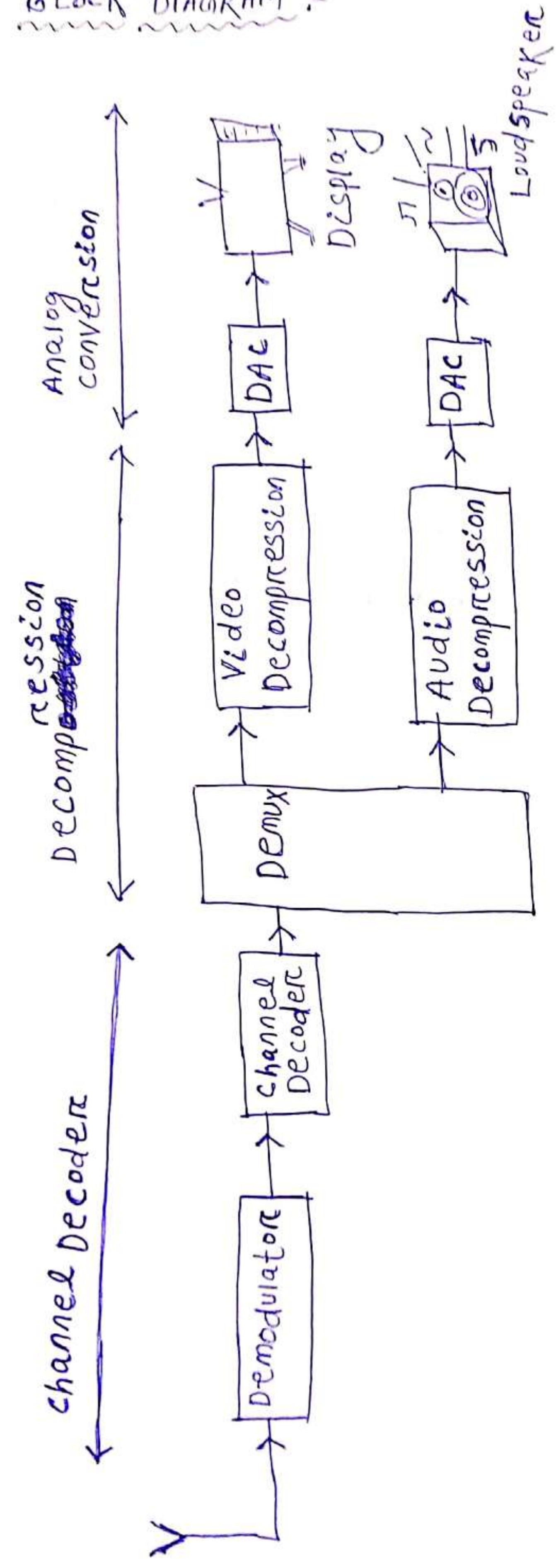
BANDWIDTH :- Bandwidth means the highest video Frequency related to the time taken in scanning two nearly spaced pixels.

Let R_H pixels scanned in t second. so 2 pixels are scanned in $T = \frac{2 \cdot t}{R_H}$ second. Bandwidth $= \frac{1}{T} = \frac{R_H}{2 \cdot t}$

As smaller is the size pixels, less would be the time taken in scanning two adjacent pixels, better will be the resolution and hence higher will be the bandwidth.

DIGITAL TV RECEIVER :-

BLOCK DIAGRAM :-



Basics of Digital TV Receiver :-

↳ Digital TV signal Receiver can be sub divided in to three (3) parts.

(1) Channel Decoding :- (i) Demodulation of received signal. (ii) Error Detection and correction.

(2) Digital Decompression :- (i) Video and Audio Decompression. (ii) MPEG decoder decompress digital video. (iii) Expanding (Non Linear Dequantization) to decompress audio.

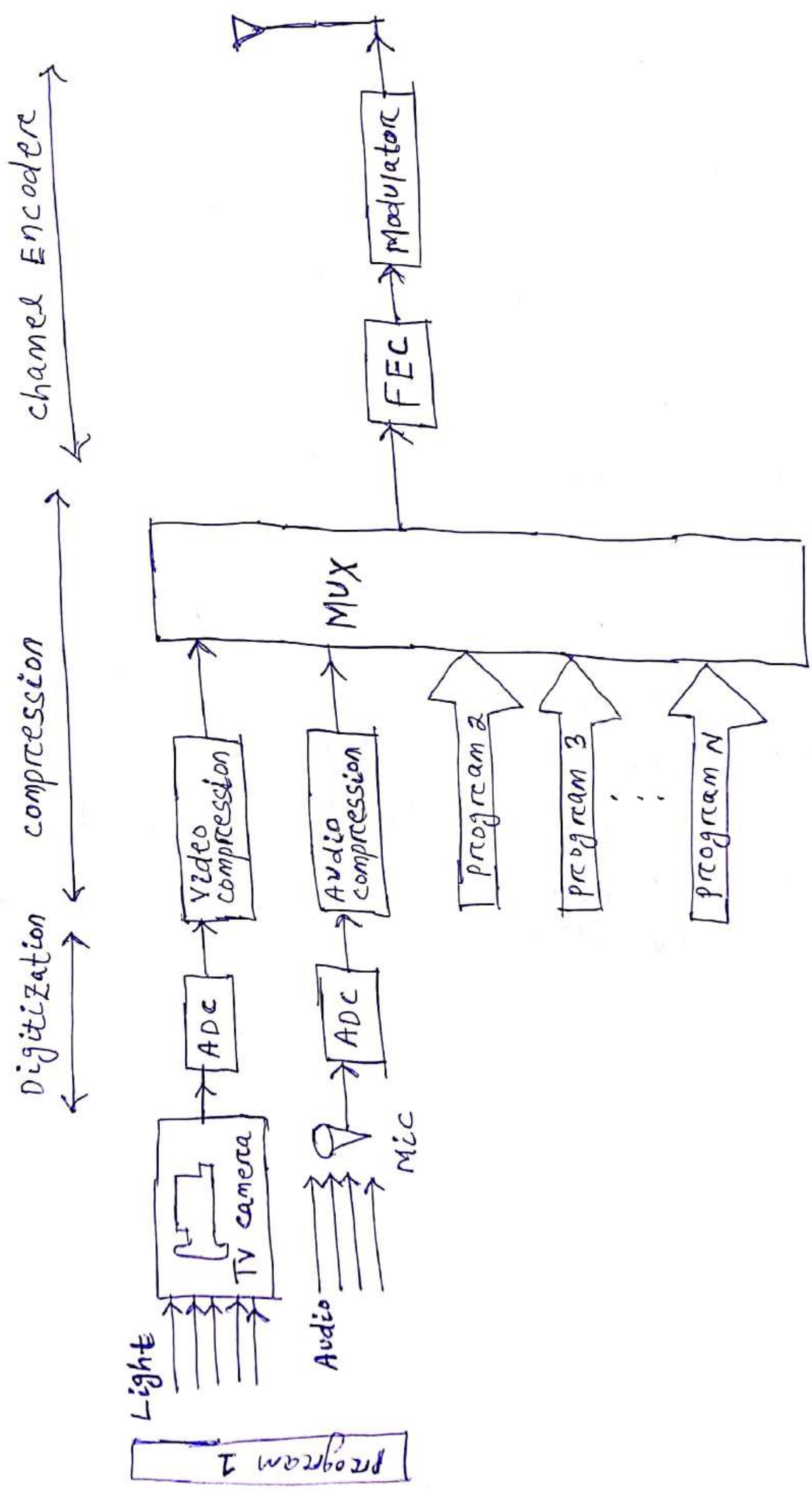
(3) Analog Conversion :- (i) Digital data converted into analog signal to display TV program on Television.

↳ At Receiver side we use QPSK demodulator.

↳ Channel Decoder corrects the digital error which occurs in the channel.

DIGITAL TV TRANSMITTER :-

BLOCK DIAGRAM :-



Basics of Digital TV Transmitter :-

↳ Digital TV signal Transmission can be sub divided into three (3) parts.

① Digitization :- (i) conversion of Analog signal in-to digital signal. (ii) ADC converter has sampling, quantization and encoding process.

② Digital compression :- (i) Video and Audio compression digitally. (ii) MPEG encoder compress digital Video. (iii) Nonlinear quantization used to compress audio (companding)

③ Channel Encoding :- (i) It has forward error correction and Modulation (ii) For HDTV broadcasting QPSK Modulator is used.

↳ The output signal of TV camera is available in Three formats. i.e. YUV format, YIQ format, $YC_b r_b$ format.

↳ In YUV format signal :- Y represents Luminance signal, UV represents Color signal.

$Y = 0.299R + 0.587G + 0.114B$, $U = 0.492(B-Y)$,
$V = 0.877(R-Y)$.

↳ In digital TV transmission system we use YUV format only.

— x — x — x — x —

LIQUID CRYSTAL DISPLAY (LCD) :-

→ Liquid crystal referes to compounds which are in crystalline arrangement, but can flow like liquid. The light source passes through a liquid-crystal material that can be aligned to either block (or) transmit the light. 2 glass plates, each containing a light polarizer at right angles to the other, sandwich a liquid crystal material. Rows of horizontal transparent conductors are built into one glass page. columns of vertical conductors are put in to the other plate.

→ The intersection of 2 conductors define a pixel position. passive Matrix LCD in the "on" state, polarized light passing through the material is twisted so that it will pass through the opposite polarizer. Different materials can display different colors. By placing thin film transistors at pixel locations, voltage at each pixel can be controlled. Active-Matrix LCD.

MONOCHROME TV TRANSMITTER :- (1)

Basics :- Monochrome TV means Black and White TV.

→ Elementary area of picture is broken in to "picture Element" (or) "pixels". There are almost infinite elements/pixels in any picture, so information of picture is very complex. Each element/pixel has different level of brightness.

→ Information is given as a function of two variables space and time.

→ Ideally, There is infinite elements/pixels of information in optical domain.

→ practically, conversion of optical elements in to electrical form is done and its Transmission is carried out element by element.

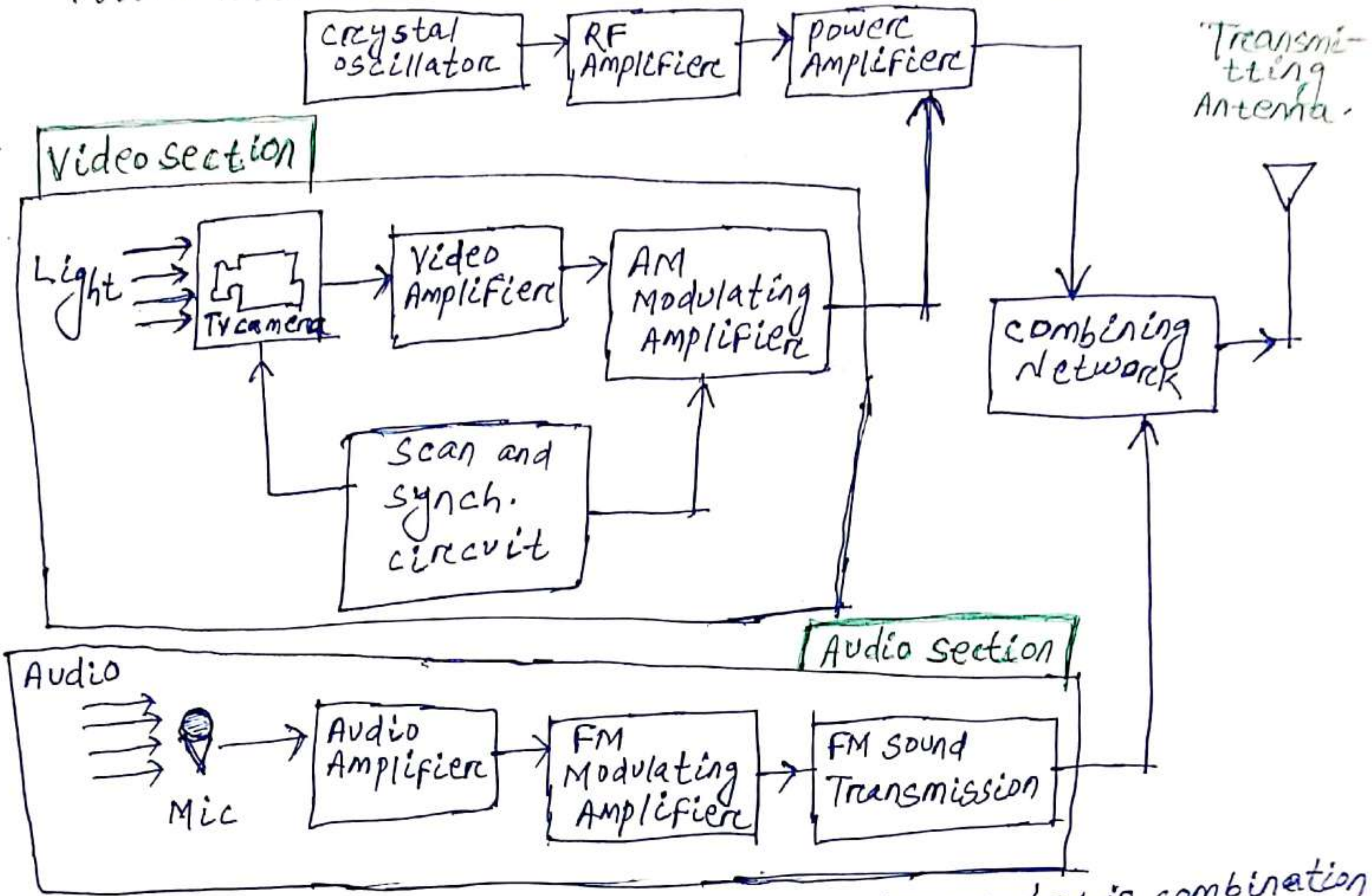
→ Scanning of elements is done at a very fast rate and this process is repeated a large number of times per second to create an illusion of simultaneous pick up and transmission of picture details.

parameters of Monochrome TV Transmitter :-

→ It has a video information, in between black and white with the shades of gray. → It transmits on channels in the VHF (Very High Frequency) and UHF (ultra High Frequency). → picture and sound signals are modulated on RF carrier to reduce antenna size.

BLOCK DIAGRAM EXPLANATION :- (i) In Monochrome TV transmitter there are Two sections, video section and Audio section. (ii) TV camera will capture the video which is in optical domain. TV camera again translate video information to Electrical signal. (iii) After that electrical domain of video will be given to video Amplifier and then

BLOCK DIAGRAM OF MONOCHROME TV TRANSMITTER :-



we will give it to AM Modulating Amplifier. (It is combination of AM Modulator and Amplifier). (iv) Scan & synch. circuit is used to provide synchronisation of video information in proper sequence. (v) Bandwidth of Monochrome TV transmitter for video section is about 5MHZ. (vi) In Audio section we will having mic first that convert Audio signal to Electrical signal of sound then it is given to Audio Amplifier and then it is given to FM Modulating Amplifier. In Audio section Available bandwidth is about 20KHZ.

↳ our aim is to transmit both video section and Audio section through same antenna. ~~So~~ Since Audio section frequency is very low (20KHZ) so it is very difficult to transmit low frequency signal through Antenna. so we will convert Low frequency signal to High frequency signal. For that we will have crystal oscillator first and then it is given to RF Amplifier. RF frequency is there in VHF & UHF Band. combining network will combine both video section and Audio section signal and ~~it is given~~ ~~trans~~ both signal is transmitted through transmitting Antenna.

Scanned by CamScanner

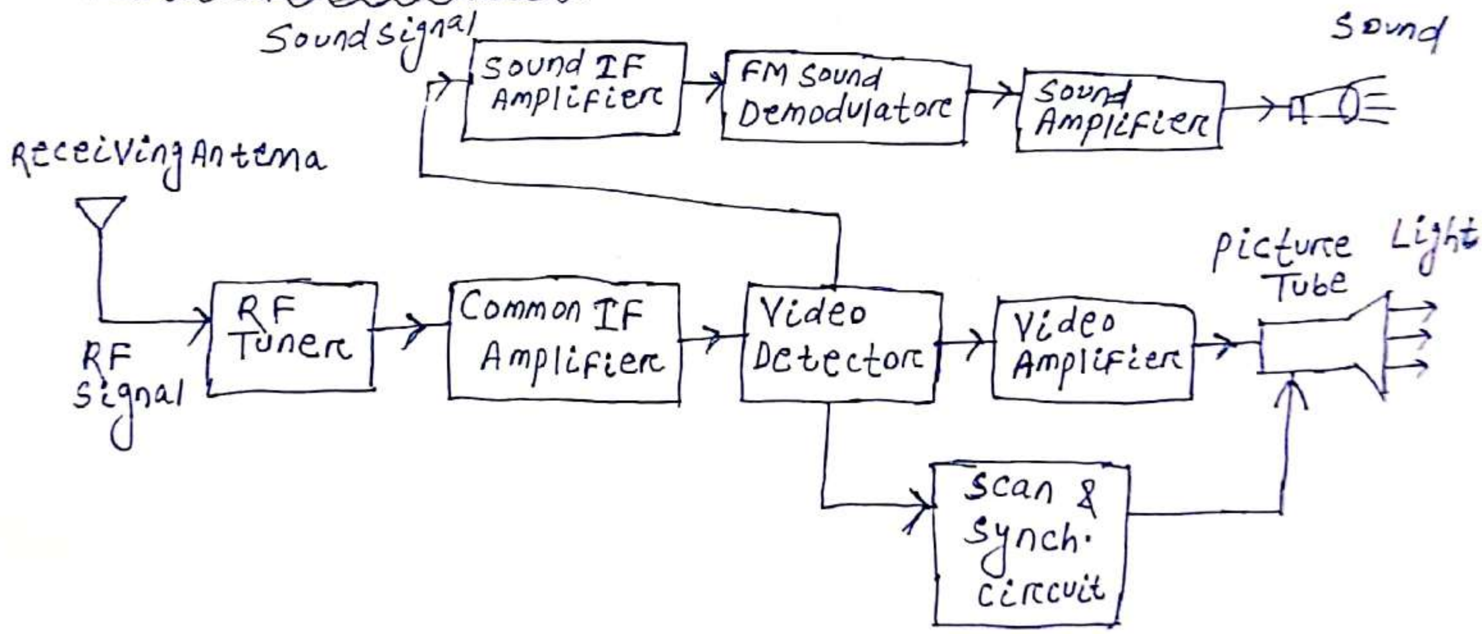
MONOCHROME TV RECEIVER

Basics :- (i) Data Transmitted by Monochrome TV transmitter antenna will be received by Monochrome TV receiver.

(ii) Here, our agenda is
- ↳ Receive Electromagnetic (EM) signal by Antenna at Receiver.
- ↳ convert that signal in to Electrical signal.
- ↳ Separate sound and video signals.
- ↳ play Sound by Speaker and play Video by tube.

(iii) In Monochrome TV, display will be black and white with the shades of gray (brightness).

BLOCKDIAGRAM :-



↳ Receiving Antenna receives EM Signal. So Antenna converts EM signal in RF electrical signal.

↳ RF Tuner translates RF Frequency to Intermediate Frequency (IF Frequency). As per basic standard of Monochrome TV, IF Frequency for sound is 33.4 MHz, IF frequency for video = 38.9 MHz

↳ Common IF Amplifier picture commonly amplifying picture IF Frequency as well as sound IF Frequency.

↳ Video Detector having AM Demodulator in video side.

↳ In picture Tube Two types of scanning is done ① Vertical scanning ② Horizontal scanning.

↳ In Audio side we are having FM Demodulator.

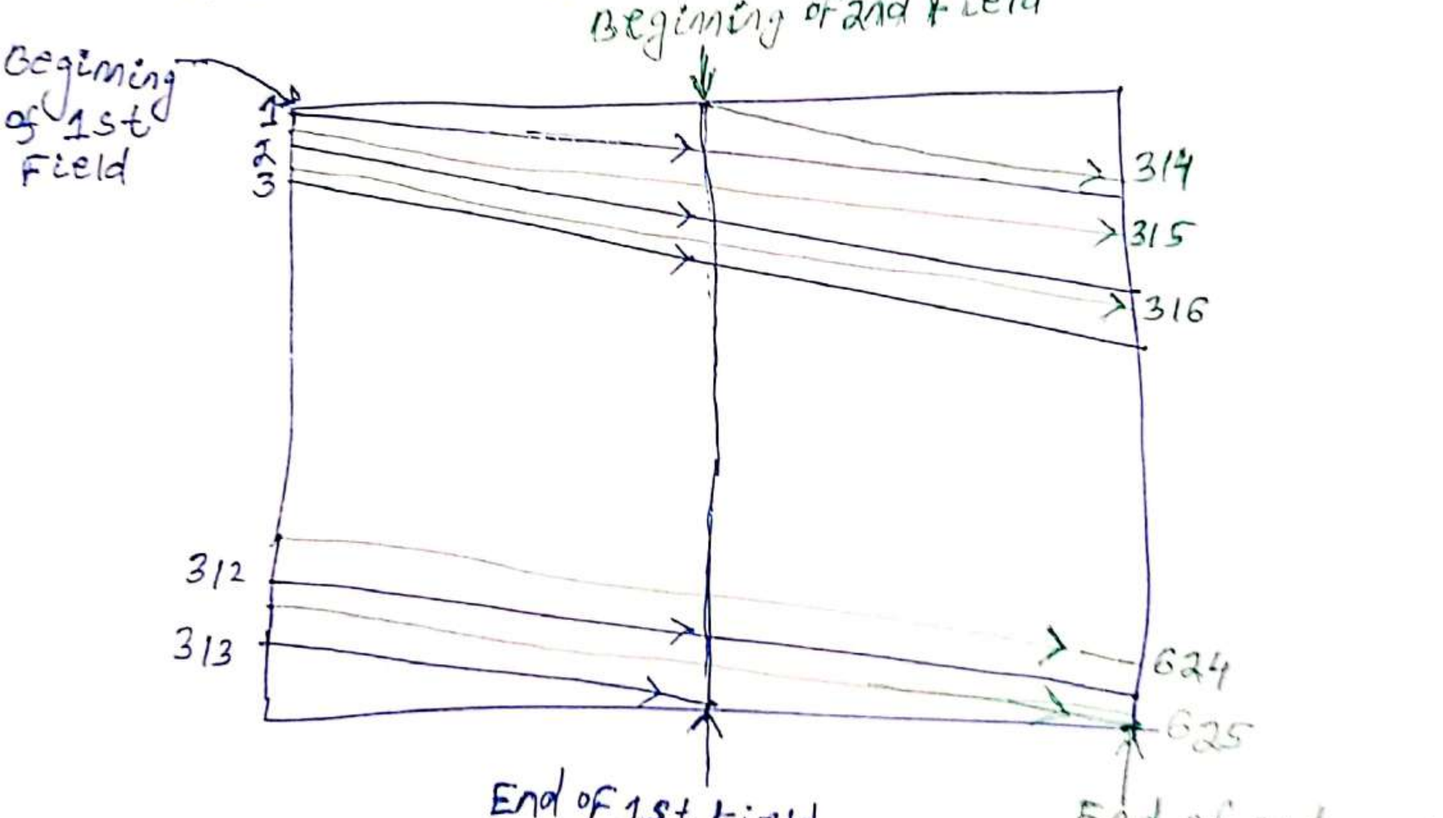
↳ picture Bandwidth over here around 5 MHZ (megahertz) and sound Bandwidth over here around 20 KHZ (Kilo hertz.)

Parameters of Monochrome TV Receiver :- ① It has a video information, in between black and white with the shades of gray. i.e. Brightness will justify video information.

(ii) It Receives channels in the VHF and UHF. (iii) picture and sound signals are demodulated from RF carrier received from antenna.

FLICKER (OR) INTERLACED SCANNING :- (1)

- IN TV picture, 24 pictures per second we can see and 25 frames are scanned per second.
- But some time They are not rapid and blank screen produce some successful frames. This is called Flicker.
- To solve flicker problem each picture show twice i.e. 48 view of the scene show together per second. Each picture is scanned twice.
- In Interlaced scanning, 50 vertical scanning per second is done to reduce flicker.
- Each picture has 625 lines That is divided in to set of 312.5 line in Two field.



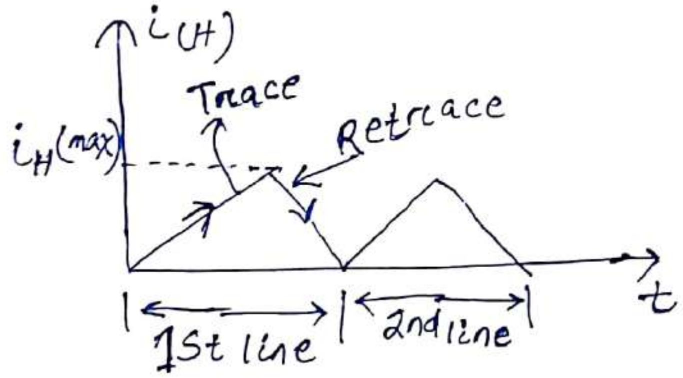
- To achieve horizontal sweep oscillator work frequency 15625 HZ ($312.5 \times 50 = 15625$)
  - ↓ Frequency of Electrical Home Supply 50 HZ in INDIA.

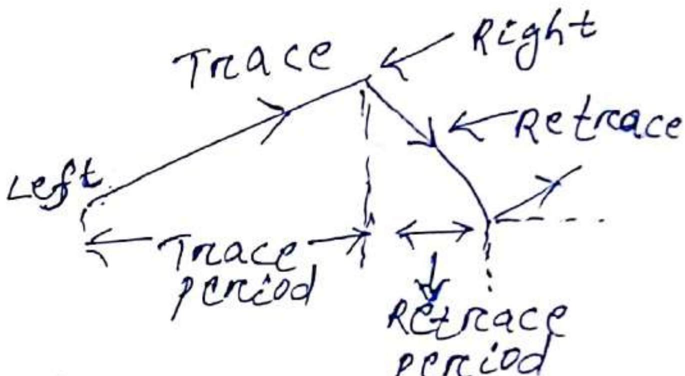
Scan no. of Line per frame $\left(\frac{15625}{25} = 625 \text{ lines}\right)$

→ Vertical sweep oscillator run frequency 50Hz (312×50 = 15625)

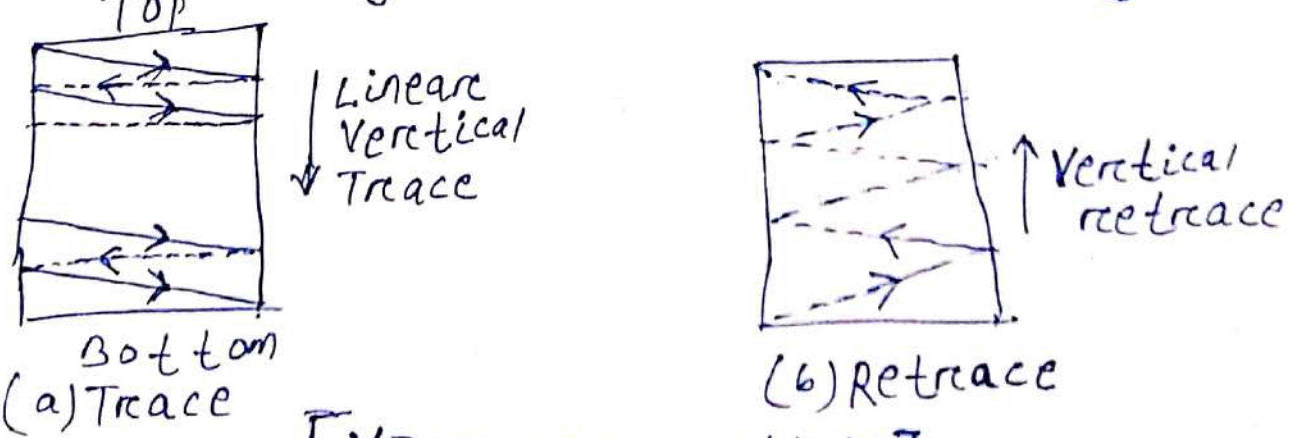
→ The division of picture in to many horizontal lines is called scanning. The flickering effect can be minimized by using interlaced scanning. From the point of view of flicker, it is observed that 50 picture frames per second is the minimum requirement in Television scanning.

→ Horizontal line scanning frequency of (15625+15625 = 31625 HZ) is required for a 625 line system with a period of (64 μs/2 = 32 μs).



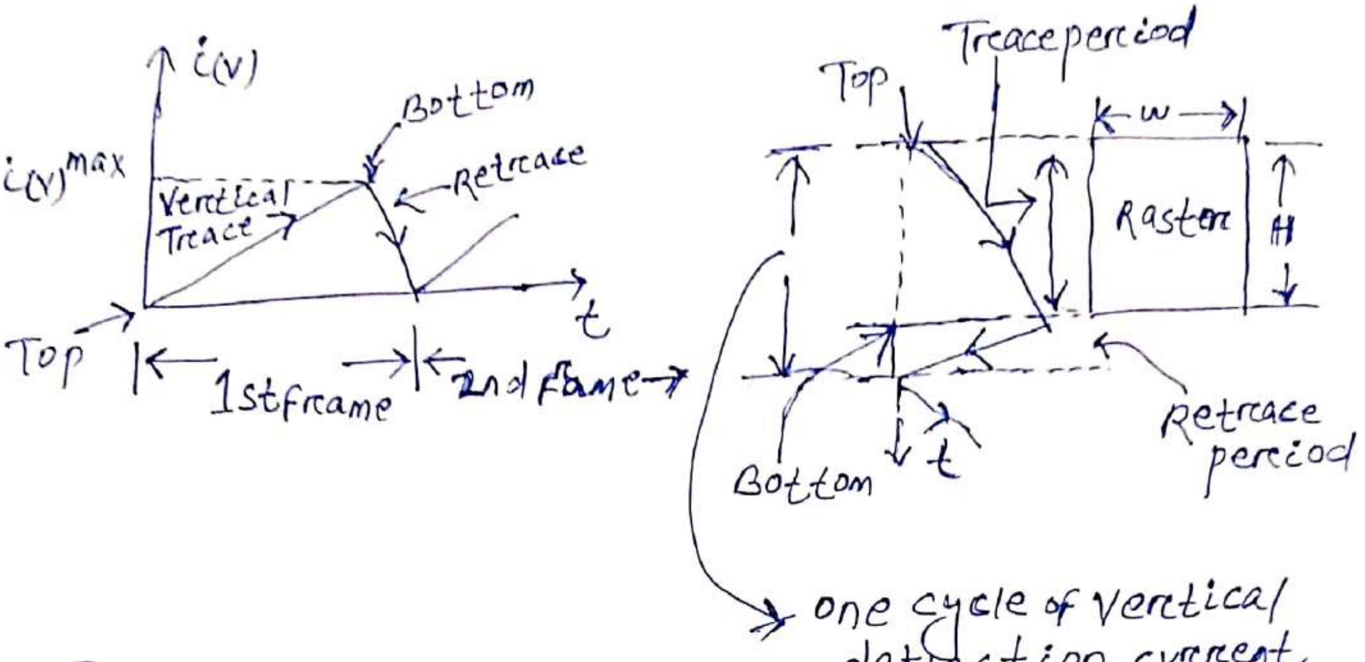


[waveform of current in the horizontal deflection coils producing linear (constant velocity) scanning in the horizontal direction.]



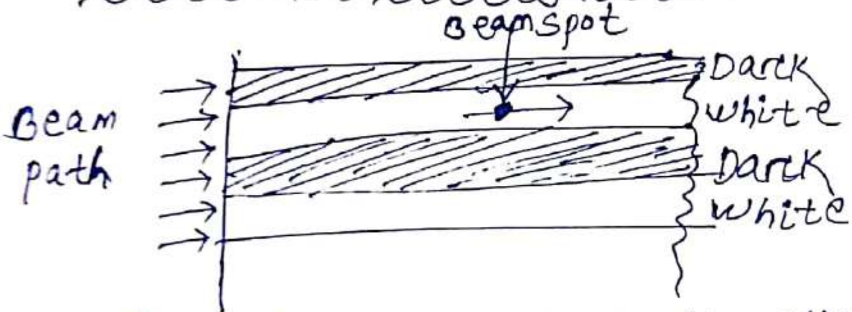
(a) Trace (b) Retrace

[VERTICAL SCANNING]



[current wave form in vertical deflection coils.]

Number of scanning lines :-



[Scanning spot perfectly aligned with black and white lines]

↳ Alternate lines are black and white. The electrical information corresponding to the brightness of each bar will be correctly reproduced during the scanning process.

↳ If (1) Thickness of scanning beam = width of each white and black bar.

(2) Number of scanning lines = Number of bars.

↳ The maximum number of alternate light and dark elements (lines) which can be resolved by the eye is given by

$$N_V = \frac{1}{\alpha \cdot \rho} \quad \text{--- (1)}$$

where,

N_V = Total number of lines (elements) to be resolved in the vertical direction.

Scanned by CamScanner

α = Minimum resolving angle of the eye expressed in radians $\left(\frac{\pi}{180} \times \frac{1}{60}\right)$.

$\rho = \frac{D}{H}$ = viewing distance / picture Height = (standard Value = 4)

putting these values in eqn-①

$$N_V = \frac{1}{(\pi/180 \times \frac{1}{60}) \times 4} = 860$$

→ A distinct pickup of the picture information results

(i) Total number of scanning lines = 860.

(ii) The scanning beam just passes over each bar (line)

Interlaced scanning :-

→ In Television pictures an effective rate of 50 vertical scans per second is utilized to reduce flicker. This is accomplished by increasing the downward rate of travel of the scanning electron beam. so that every alternate line gets scanned instead of every successive line. Thus the total number of lines are divided in to two groups called 'fields'. Each field is scanned alternately this method of scanning is known as interlaced scanning.

→ For successful interlaced scanning, the 625 lines of each frame (or) picture are divided in to sets of 312.5 lines.

→ To achieve this the horizontal sweep oscillator is made to work at a frequency of 15625 HZ. (312.5 X 50 = 15625)

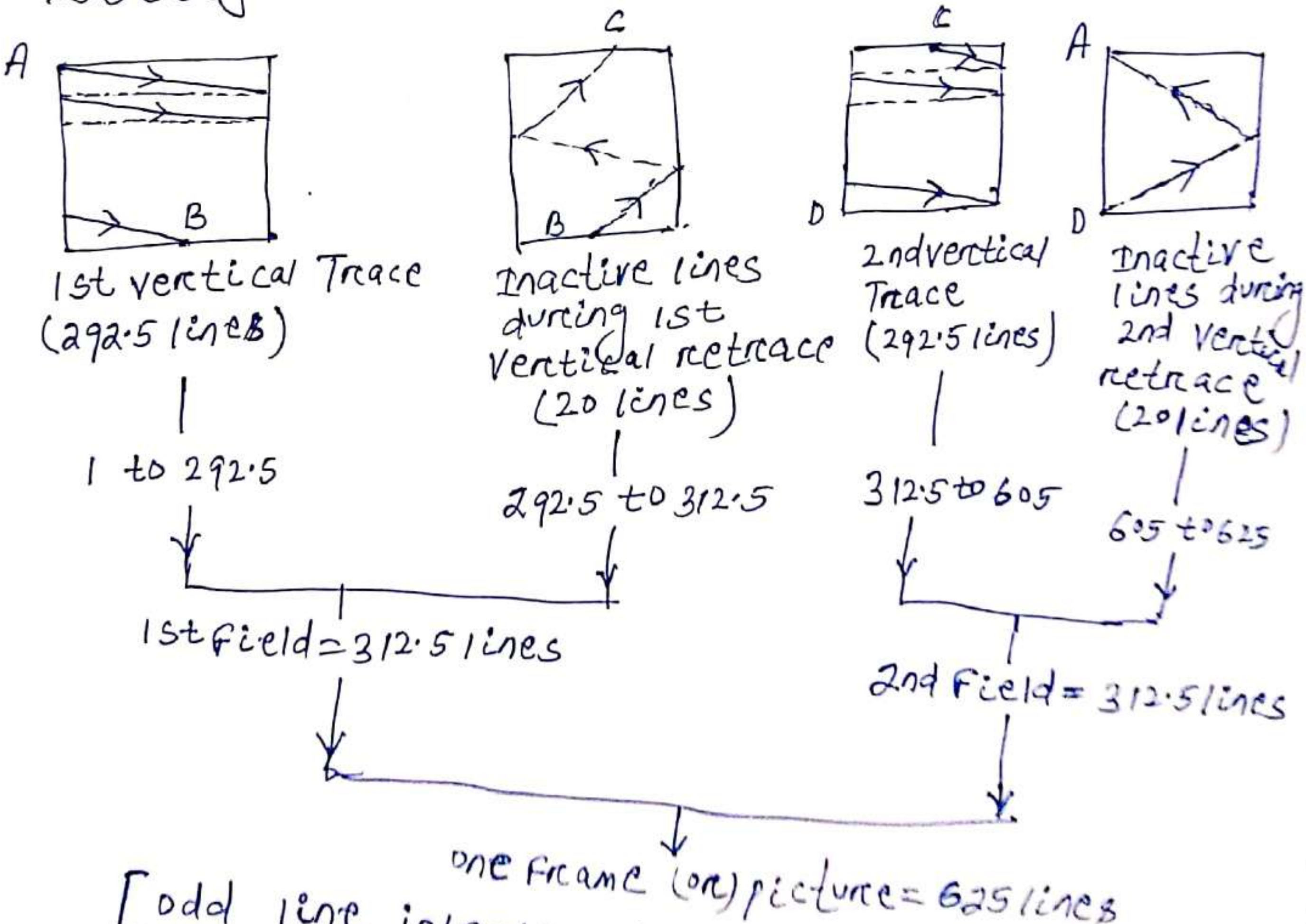
→ Two scanning periods are available i.e For Horizontal deflection current and For vertical deflection current. For Horizontal deflection current Time period (Trace Time + Retrace Time) is 64 MS and having frequency 15625 HZ.

For vertical deflection current Total Time period (Trace Time + Retrace Time) is 20ms and having frequency 50HZ.

↳ The horizontal and vertical sweep oscillators operate continuously to achieve the fast sequence of interlaced scanning $20\left(\frac{1280 \mu s}{64 \mu s}\right)$ horizontal lines.

↳ This leaves the active number of lines, Na, for scanning the picture details equal to $625 - 40 = 585$, instead of the 625 lines actually scanned per frame.

Scanning sequence



[odd line interlaced scanning procedure.]

ADVANTAGES:- (i) Avoids flicker (ii) It is better than sequential scaning. (iii) conserves Bandwidth.

Scanned by CamScanner

Progressive Scanning	Interlaced Scanning
(1) In this every successive line is being scanned.	(1) In this the electron beam first scans odd lines from top to bottom and then it scans the lines those are skipped in the previous scanning.
(2) The effective no. of pictures scaned per second are 25 frames/second.	(2) The effect no. of fields scanned per second are 50 frames/second.
(3) Flicker problem well occur.	(3) Flicker problem is avoided.
(4) Total no. of lines scanned at a time from top to bottom are 625 lines.	(4) Total no. of lines scanned at a time from top to bottom are 312.5 lines.

—xx— xx—

INTRODUCTION TO TELEVISION SYSTEM:-

↳ The word television has its origin in two Greek words 'tele' and 'vision'. Tele means 'at distance' and vision means 'seeing'.

↳ Earlier selenium photosensitive cells were used for converting light from pictures in to electrical signals. (i.e. conversion of optical signal to electrical signal.)

↳ First camera tube is iconoscope. In 1935 TV broadcasting started. In 1959 TV came to India.

Evolution of TV :-

① Black and white TV → ② color TV → ③ plasma TV → ④ 3D TV → ⑤ HD TV

Intensity of Light in a picture :- The intensity of illumination can vary from darkness (light of faint stars in the universe, which is taken as reference = 0dB) to light of bright. Sun on snow is 110dB.

ASPECT RATIO :- width to Height ratio of a picture frame is called Aspect ratio. width is kept longer than height because of the following facts:-

① Horizontal dimension of a scene is generally more than its vertical dimension.

(2) Eyes can move with more ease and comfort in the horizontal plane than in the vertical.

(3) The fovea, the surface of maximum sensitivity and resolution at the centre of the retina in the eye has greater width than height. Hence, the longer width of the image ensures more efficient use at the fovea.

(4) As a result of intensive subjective tests by the cinema people, aspect ratio of 4:3 was found to be most pleasing aesthetically and less fatiguing to the eyes. The same ratio was accepted by the television engineers as the cinema films formed a major part of the TV programmes. This enabled direct transmission of films without wastage of any film area.

↳ Dimension of a TV receiver are specified by the diagonal length of the screen, when the width is $4x$ and height is $3x$ and the diagonal length would be $5x$.

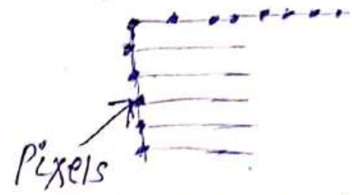
ex:- If TV screen of size 30cm

$\Rightarrow 5x = 30\text{cm} \Rightarrow x = 6\text{cm}$

Hence height $= 3x = 18$ cm and

width $= 4x = 24$ cm

picture Elements :- For analysis and processing, an image can be considered to be consisting of tiny areas (dots), called picture elements (PELS) (or) more popularly pixels.



(pixels on a vertical Line and on a Horizontal Line on a screen.)

→ The maximum number of pixels that can appear on a vertical line on the screen will be equal to number of Horizontal Lines. Here in given figure 6 horizontal Lines.

So 6 pixels on a vertical Line.

As the Aspect Ratio is 4:3 so $6 \times \frac{4}{3} = 8$ pixels on a horizontal Line. Total number of pixels on the screen is $6 \times 8 = 48$

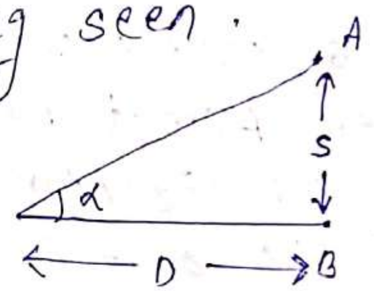
Details and Resolution :- closely spaced small objects (or) small distinct features in a picture form details. smaller the objects (or) features visible distinctly, higher is the resolution of the details (or) finer are the details being seen. The ability to see the fine details in a picture is called Resolution.

Example :- wrinkles on a face, hair of the eye brows, veins on a leaf and similar closely spaced but distinct features should be clearly visible in a reproduced picture for good resolution. A pixel in a picture represents a very small area (almost point size) which possesses the characteristics brightness and color at that point.

Visual Acuteness and Viewing Distance :-

Human eye has resolution of 1 minute (or 1/60 degree). It means that if two closely spaced objects form a minimum angle of 1 minute at the eye, they would be distinctly visible. For smaller angles, the two objects would appear as merged with each other. The angle subtended at the eye will depend on two factors.

1. The space, S, between the objects.
2. The distance, D, from which the objects are being seen.



Let the two closely spaced but distinct objects be A and B. Angle α subtended by A and B at the eye E = S/D radians

As 1 radian = $\frac{180}{\pi}$ degrees, angle $\alpha = \frac{180}{\pi} \times \frac{S}{D}$ degrees

For clear resolution, this angle should be $= \frac{1}{60}$ degree. Hence $\frac{180 \times S}{\pi \times D} = \frac{1}{60}$ (or)

$$\frac{S}{D} = \frac{\pi}{180 \times 60}$$

Example-1 :- calculate the minimum distance between adjacent pixels for the viewing distance equal to 2.5 mtr.

Soln :- $S = \frac{2.5 \times \pi}{180 \times 60} = 73 \times 10^{-5}\,m = 0.073\,cm$

— x —

Example-2:- calculate the number of pixels in 50 cm size TV Screen for Example-1.

soln:- for 50 cm size screen, width = 40 cm, height = 30 cm

Therefore No. of pixels in width = $\frac{40}{0.073}$

and No. of pixels in height = $\frac{30}{0.073}$

Hence Total number of pixels = $\frac{40}{0.073} \times \frac{30}{0.073}$

$= 225000$

—x—x—xx—

Persistence of vision and flicker :- when the eye sees light, it continues to see it for about 60ms after the light source is removed. This property of eye is called persistence of vision. It has been possible to see movie picture because of this property.

FLICKER :- Time of persistence of vision is more for darkness than for bright light. This results in a phenomenon called flicker. It means dark intervals between bright pictures become visible for a very short time and appear as a flicker.

BRIGHTNESS :- Brightness in TV pictures is the average intensity of light. It determines the background level of illumination in the reproduced picture. The eye adapts itself to the average prevailing brightness and sees all variations with respect to this adapted value.

ELEMENTS OF A TV SYSTEM :-

↳ picture Transmission. ↳ Sound Transmission

↳ picture Reception. ↳ Sound Reception.

↳ synchronization. ↳ Receiver controls.

↳ Colour Television.

PICTURE TRANSMISSION :-

Fundamental Aim :- To extend the sense of sight beyond its natural limit along the sound associated with the scene. → (Black and white TV)

↳ In 625 line monochrome system :- picture signal is Amplitude modulated and Sound signal is Frequency modulated, carrier frequencies are suitably spaced and modulated outputs radiated through a common antenna.

↳ picture information is optical in nature. It assembly of a large number of bright and dark areas, each representing a picture element. Infinite number of pieces existing simultaneously.

↳ Information is a function of two variables Time and Space.

↳ Instead of using infinite number of channels simultaneously, we use scanning.

scanning :- optical information is converted in to electrical form and transmitted element by element, one at a time in a sequential manner to cover the entire scene to be televised.

↳ scanning is done at very fast rate. It is repeated a number of times per second to create an illusion of simultaneous pick up.

TV camera :- ① Heart of a TV camera is a Camera tube.

② Camera Tube converts optical information in to corresponding electrical signal.

③ Amp Here Amplitude is proportional to brightness.

④ optical image is focused by a lens assembly to a rectangular glass face plate.

⑤ Transparent conductive coating at the inner side of the glass is face plate,

⑥ on which a thin Layer of photoconductive material is coated and it is having a very high resistance when no light falls on it.

⑥ Resistance decreases when the intensity increases.

⑦ Electron Beam is used to pick up the picture information available on the target plate interms of varying resistance.

⑧ Beam is formed by an electron gun and the beam is deflected by a pair of deflection coils kept mutually perpendicular on the glass plate to achieve scanning of the entire target area.

↳ ⑨ Video signal is amplified. Amplitude Modulated with channel picture carrier frequency. It is fed to the transmitter antenna for radiation along with the sound signal.

Advantages :- (i) structure is very simple. (ii) It is economical. (iii) It is effective in the medium ~~freq~~ frequency MF (300K-3MHz) and HF (3-30 MHz.) (iv) properties of radiation can enhance when used in array.

Disadvantages :- (i) Major Lobe is little inclined at an angle and controlled by its Length. (ii) poor directivity. (iii) power density in minor lobes.

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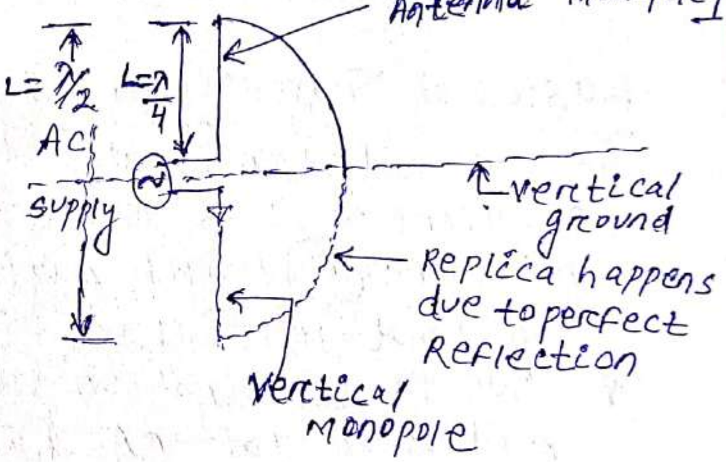
MONOPOLE ANTENNA :-

↳ Physical Length of monopole Antenna is $\frac{\lambda}{4}$.

↳ Dipole Antenna having Length is $\lambda/2$.

↳ Monopole Antenna has Lower radiation efficiency with respect to Dipole Antenna.



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BASICS OF ANTENNA ARRAY :-

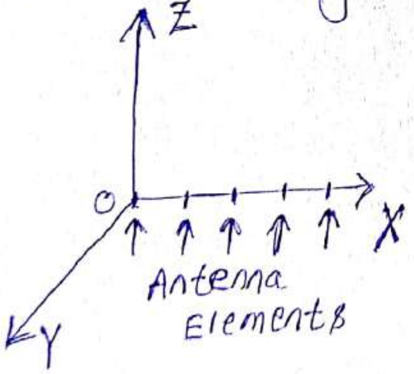
↳ In some wireless communication applications, we need to have narrow beam for large distance communication. So it is possible by 2 ways. ① Increasing the size of Antenna. ② Using Antenna array. These are used (i) To increase gain of Antenna. (ii) To have narrow beam.

ANTENNA ARRAY :- ↳ Antenna formed by multiple elements of Antenna is antenna array.

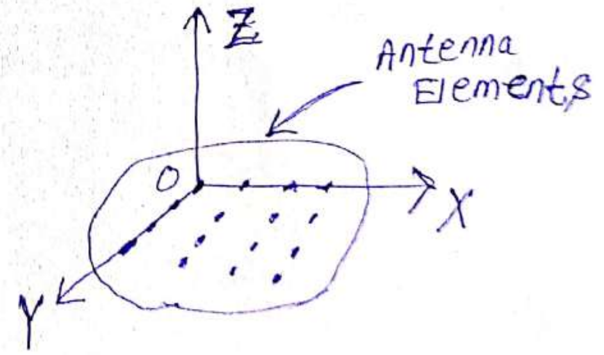
↳ In most cases elements of an array are identical. This is not necessary but it is convenient, simpler and more practical.

↳ If array arranged in one axis (X, Y or Z) then it is said to be single dimensional array (or) Linear array.

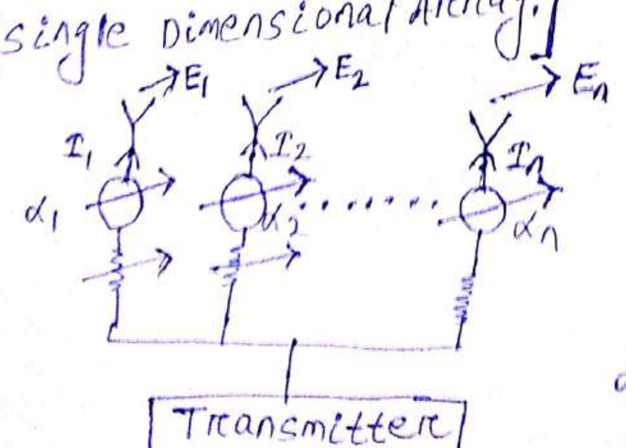
↳ If Array arranged in plane (XY, YZ or XZ) then it is said to be two dimensional array (or) plannar array.



[Single Dimensional Array.]



[Plannar Array.]



Y → Antennas, ⏀ → phase shifter

→ Attenuator

α_1 = Phase Difference of 1st element.

α_2 = " " " 2nd " .

α_n = " " " nth " .

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↳ Electric field by different element is given by

$\vec{E_1} = E_1 \cdot e^{j\psi_1}$, $\vec{E_2} = E_2 \cdot e^{j\psi_2}$, ... , $\vec{E_n} = E_n \cdot e^{j\psi_n}$

ψ_1 = phase Angle of 1st element, ψ_2 = Phase Angle of 2nd element

ψ_n = phase Angle of nth element.

↳ current supplied to different element is given by

$I_1 = I_1 \cdot e^{j\alpha_1}$, $I_2 = I_2 \cdot e^{j\alpha_2}$ ... $I_n = I_n \cdot e^{j\alpha_n}$

↳ So, Total Electric field is

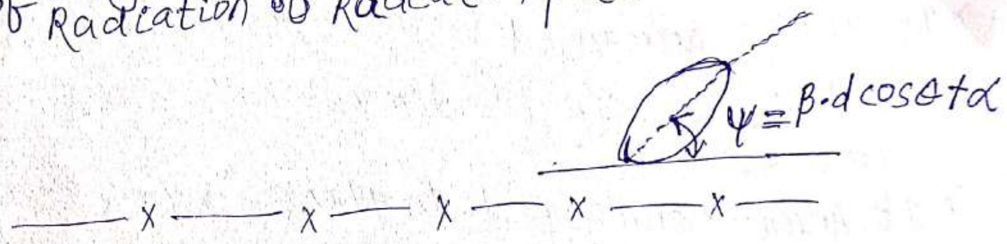
$$\vec{E} = \vec{E_1} + \vec{E_2} + \cdots + \vec{E_n} = E_1 \cdot e^{j\psi_1} + E_2 \cdot e^{j\psi_2} + \cdots + E_n \cdot e^{j\psi_n}$$

where $\psi = \beta \cdot d + \alpha = \left(\frac{2\pi}{\lambda}\right) \cdot d + \alpha$

d = Spacing between Elements, α = Initial phase

λ = wavelength.

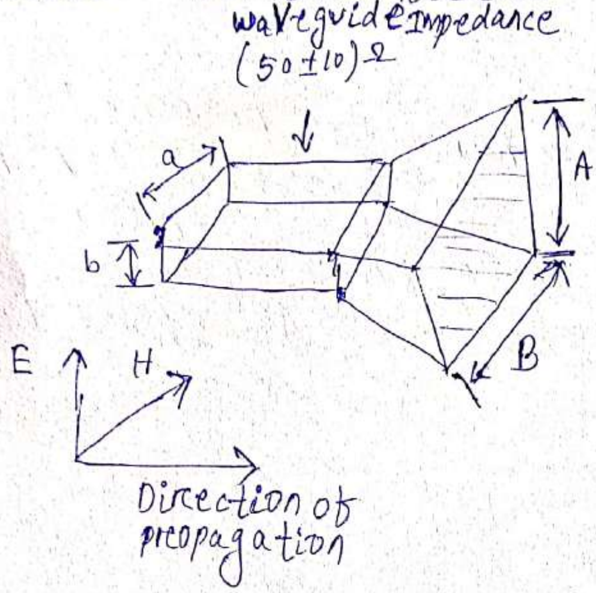
ψ = Angle of Radiation of Radiation pattern.

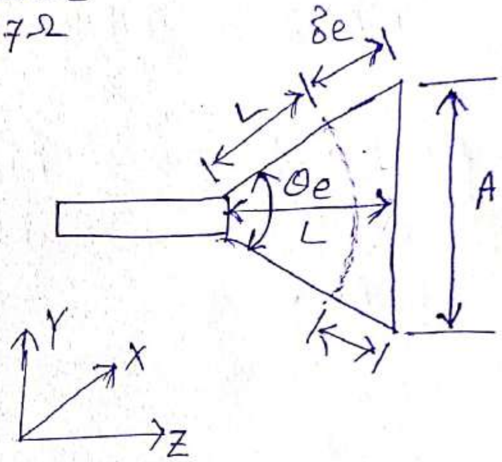


HORN ANTENNA :-

Basics :- (i) Horn Antennas are constructed by flaring of waveguide. (ii) It increases the directivity. (iii) It improves the impedance Matching. (iv) It is directional Antenna, so it can be utilized for long distance communications.

Structure of Horn Antenna :-





L = Flaring Length

θ_e = flaring angle with E-plane.

δe = E-plane flaring Difference.

↳ By Pythagores Theorem

$$(L+\delta e)^2 = L^2 + (A/2)^2$$

$$\Rightarrow L^2 + 2\cdot\delta e\cdot L + (\delta e)^2 = L^2 + \frac{A^2}{4}$$

$$\Rightarrow 2\cdot\delta e\cdot L + (\delta e)^2 = A^2/4$$

↳ By neglecting $(\delta e)^2$ we have

$$\Rightarrow \boxed{L = \frac{A^2}{8\cdot\delta e}}$$

$$\left(\begin{matrix}\delta_E \leq 0\cdot 25\,\lambda \\ \delta_H \leq 0\cdot 4\,\lambda\end{matrix}\right)$$

Types of Horn Antenna :- (i) sectoral E-plane Horn. (Flaring is done along E-field) (ii) sectoral H-plane Horn. (Flaring is done along H-field). (iii) pyramidal Horn (Flaring is done along both E-field and H-field). (iv) In circular wave guide flaring is done in circular dimension that is called Conical Horn.

Designing of Horn Antena :-

$$HPBW(E\text{-plane}) = \frac{56^\circ}{A_\lambda} (deg) \quad \left(A_\lambda = \frac{A}{\lambda}\right)$$

$$HPBW(H\text{-plane}) = \frac{67^\circ}{B_\lambda} (deg) \quad \left(B_\lambda = B/\lambda\right)$$

$$FNBW(E\text{-plane}) = \frac{115^\circ}{A_\lambda} (deg)$$

$$FNBW(H\text{-plane}) = \frac{170^\circ}{B_\lambda} (deg)$$

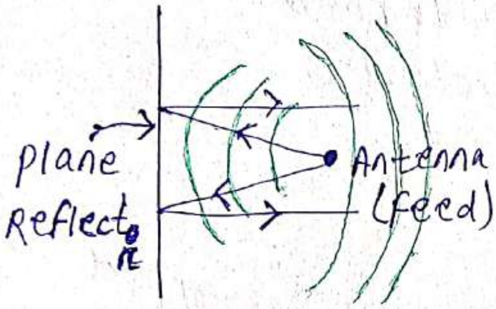
Gain $G = \frac{4\pi A_e}{\lambda^2} \times \eta$, where η = Antenna Efficiency
A_e = Effective Aperature Area.

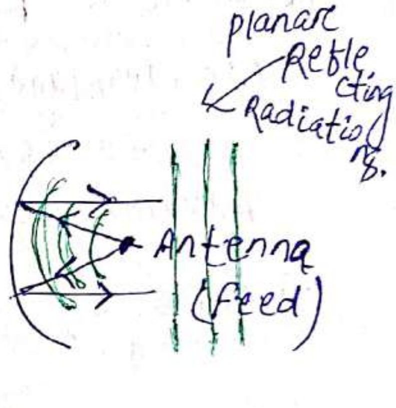
Applications :- (i) Microwave Engineering.
(ii) Feed for parabolic Reflector. (iii) Short Range RADAR.

REFLECTOR ANTENNA :-

Basics :- (i) It is highly directional Antenna. (ii) It is used to very long distance communication, such as satellite communications. (iii) It is applicable to Microwave frequency range (1-100 GHz) and beyond that.
(iv) It consists of two types of elements.
→ Active Element (Feed Antenna). → parasitic Element (Reflector)

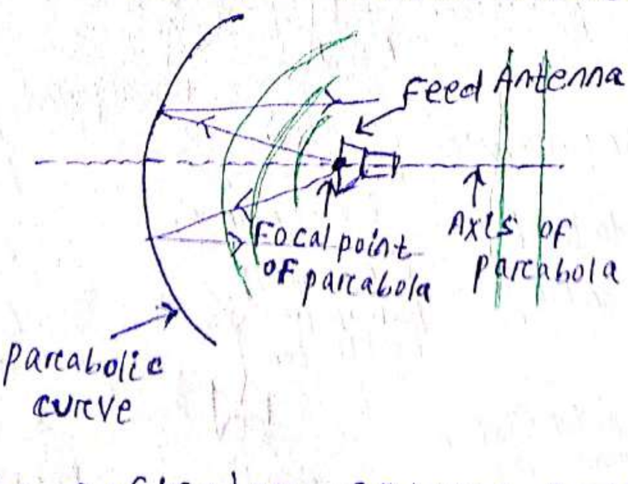
Types of Reflector Antenna :-





plane Reflector	corner Reflector	curved Reflector (or) parabolic Reflector.
→ plane Reflector has less directivity.	→ Here Directivity is little more than plane Reflector.	→ Here Directivity is High.

working of parabolic curved Reflector :-



→ parabolic Reflector antenna converts spherical wavefronts into planar wavefronts. Due to this it is highly directive antenna.

Applications:- (i) Radio Astronomy. (ii) Microwave communication. (iii) Satellite communication. (iv) Deep space communication.

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Feeding Mechanism of parabolic Reflector:- Types of Feeding. (i) center feed parabolic Reflector. (ii) offset Feed parabolic Reflector. (iii) cassergain feed (center) (iv) cassergain offset feed.

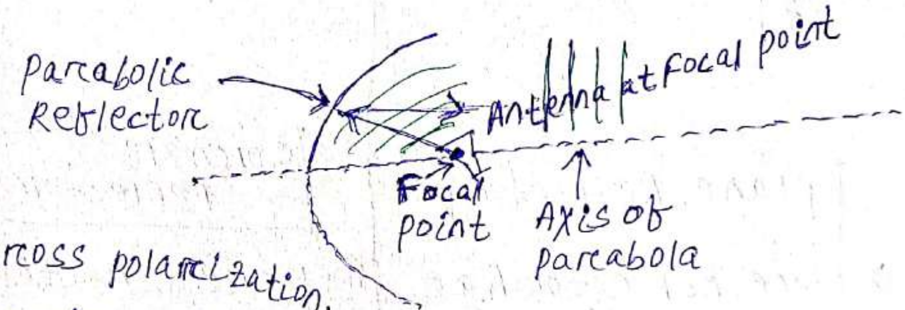
(1) center feed parabolic Reflector:-

Disadvantages:- (i) It is difficult to use for Low noise application due to isolation. (ii) Blockage due to feed.

Advantages:- (i) It has less cross polarization.

(2) offset Fed parabolic Reflector:-

Advantage:-
(i) No blockage due to Feed.

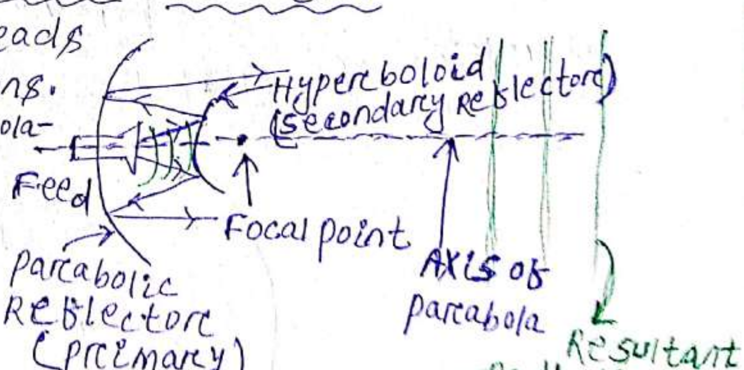


Disadvantages:- (i) cross polarization.

(3) center Feed cassergain parabolic Reflector:-

Advantage:- (i) Isolation of Feed Leads it's use in Low noise applications. (ii) Directivity is high. (iii) Low cross polarization.

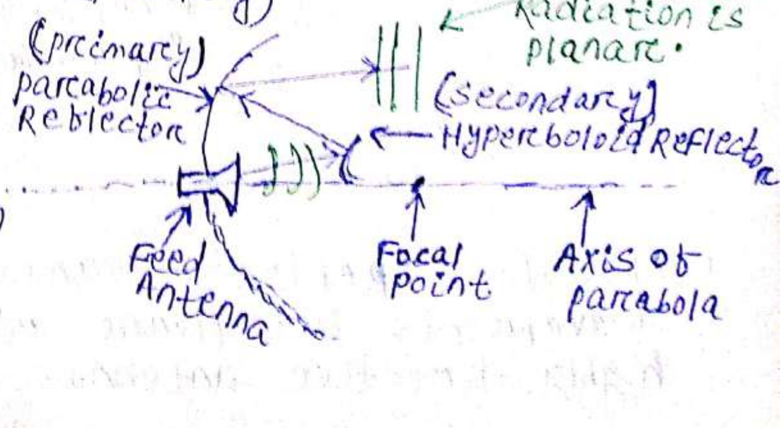
Disadvantage:- (i) Blockage due to secondary Reflector.



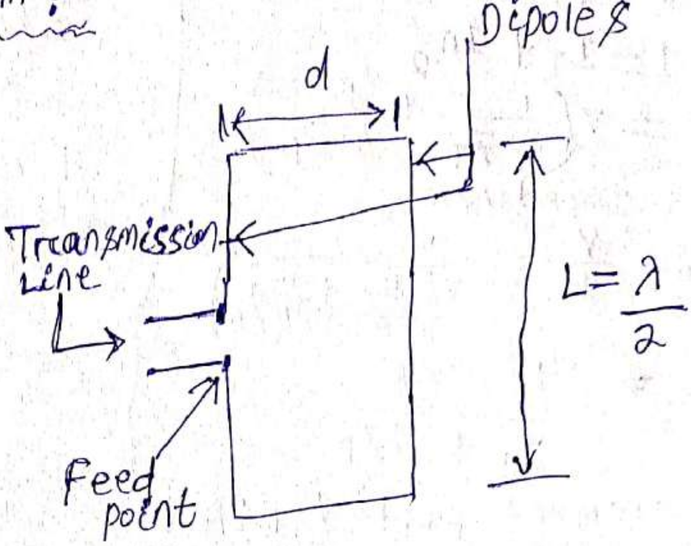
(4) Offset feed cassergain parabolic Reflector:-

Advantage:- (i) Isolation to feed Antenna. (ii) No blockage due to secondary Reflector.

Disadvantage:- (i) cross polarization occurs. Because not symmetric with respect to Axis of parabola.



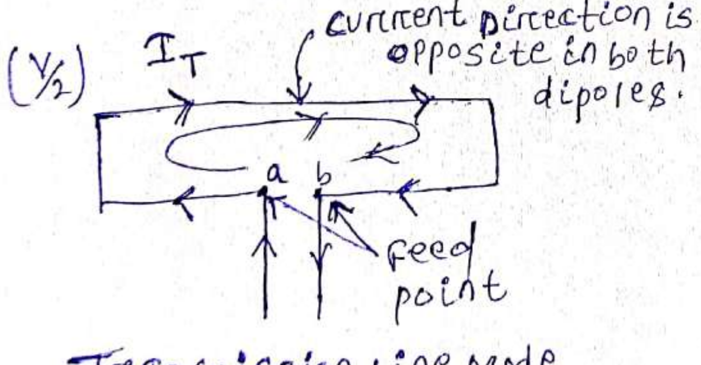
FOLDED DIPOLE ANTENNA :-



Basics :-

- It consists of two parallel dipoles connected at the ends forming a narrow wire loop.
- Length of dipole $L = \frac{\lambda}{2}$ and separation between two dipole is d which is very smaller than λ and L.
- It has high input impedance than half wave dipole.
- It has high bandwidth than half wave dipole antenna. It is utilized for 300Ω Transmission Line.

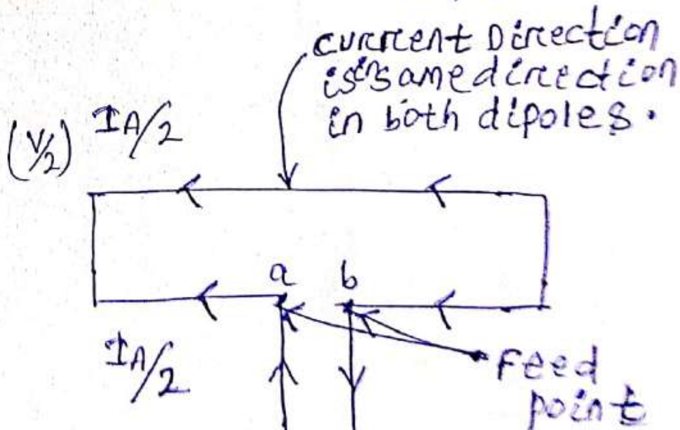
Operation of Folded Dipole :- It is operated in two different modes. (i) Transmission Line Mode. (ii) Antenna Mode.



Transmission Line Mode

↓

It does not radiates because current direction is opposite in both dipoles. So Electric field cancels.



Antenna Mode

↓

It does Radiates.

Derivation of Input Impedance

- Current in Transmission Line

$$I_T = \frac{V/2}{Z_T} = \frac{V}{2 \cdot Z_T}$$

- Current in Antenna Mode

$$I_A = \frac{V/2}{Z_D} = \frac{V}{2 \cdot Z_D}$$

- For Dipole Length $L = \lambda/2$

$$Z_T = j Z_0 \cdot \tan\left(\beta \cdot (L/2)\right)$$

$$= j Z_0 \cdot \tan\left[\frac{2\pi}{\lambda} \cdot \frac{\lambda}{4}\right]$$

$$= j Z_0 \cdot \tan(\pi/2) = \boxed{\infty}$$

↳ Total current through single dipole

$$I = I_T + I_A/2$$

$$= V\left(\frac{1}{2 \cdot Z_T} + \frac{1}{4 \cdot Z_D}\right)$$

↳ Input Impedance

$$Z_{in} = \frac{V}{I} = \frac{V}{V\left(\frac{1}{2Z_T} + \frac{1}{4 \cdot Z_D}\right)}$$

$$\Rightarrow Z_{in} = \frac{4 Z_T \cdot Z_D}{Z_T + 2 \cdot Z_D}$$

↳ So input Impedance

$$Z_{in} = \frac{4 \cdot Z_D}{1 + \left(\frac{2 \cdot Z_D}{Z_T}\right)} = \frac{4 \cdot Z_D}{1+0} = 4 \cdot Z_D$$

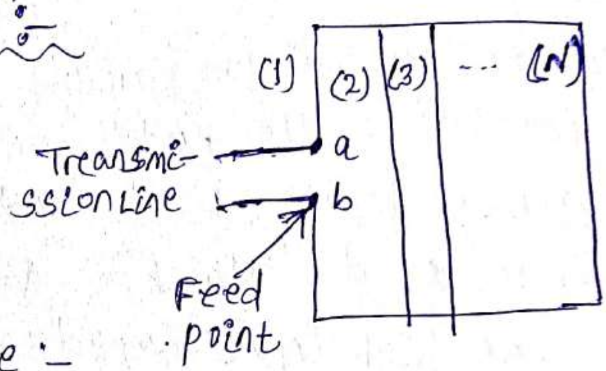
Here $Z_D \approx 73\ \Omega$

$\Rightarrow$ $Z_{in} \approx 300\ \Omega$

N-element folded Dipole :-

For N-elements

$$Z_{in} = N^2 \cdot Z_D$$



Applications of Folded Dipole :-

↳ FM broadcast band receiving Antenna.
↳ TV Antenna.
↳ Driving element in Yagi-uda Antenna.
↳ Matching Network of Antenna.

— x —

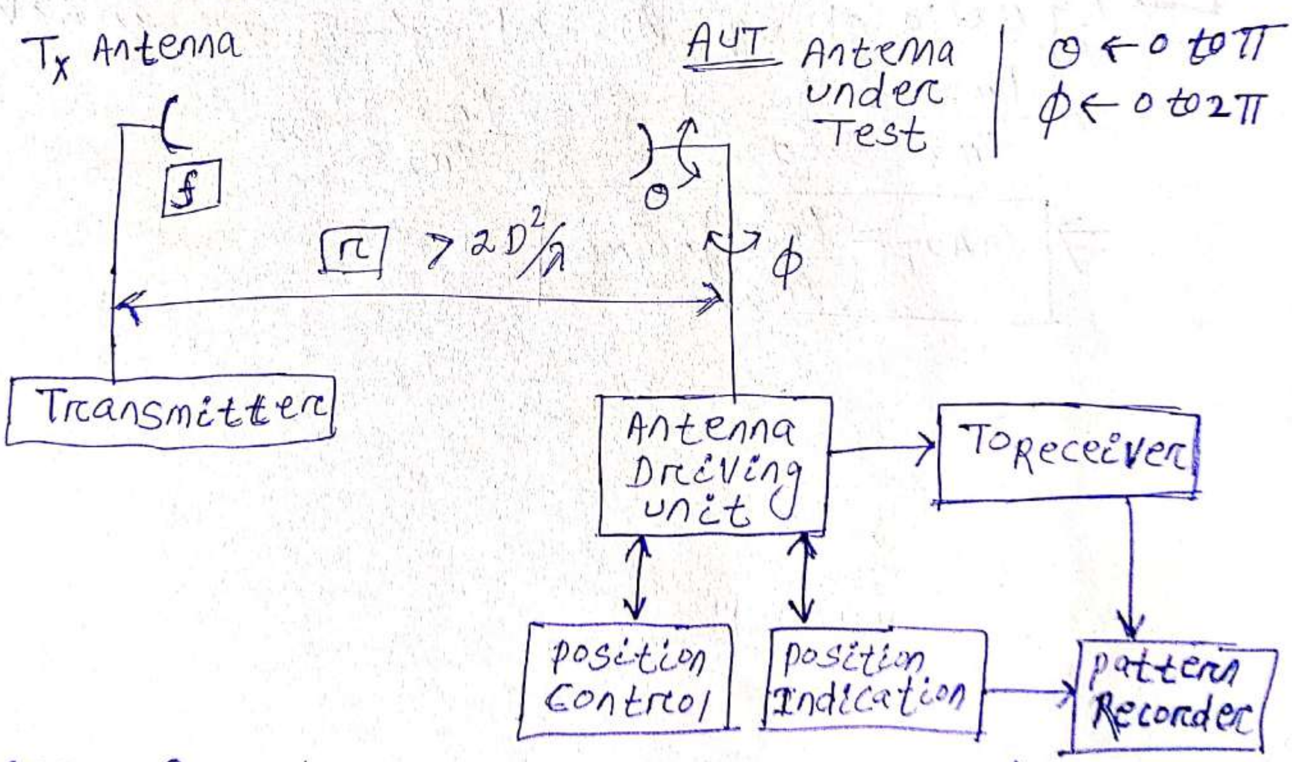
RADIATION PATTERN MEASUREMENT :-

Basics:- (i) It is measured at fix distance r and at fixed frequency f. (ii) Here angle θ varies from 0 to π. (iii) Here angle ϕ varies from 0 to 2π.

Definition:- (i) A plot of radiation characteristics of Antenna as a function of θ and ϕ for constant radial distance r and frequency f is called as the Radiation pattern of the Antenna.

parameteres of Radiation patteren:-

↳ First Null Beam width (FNBW). ↳ Half power Beam width (HPBW). ↳ Major Lobe. ↳ Side Lobes. ↳ Nulls. ↳ Maxima. ↳ Front to back ratio.



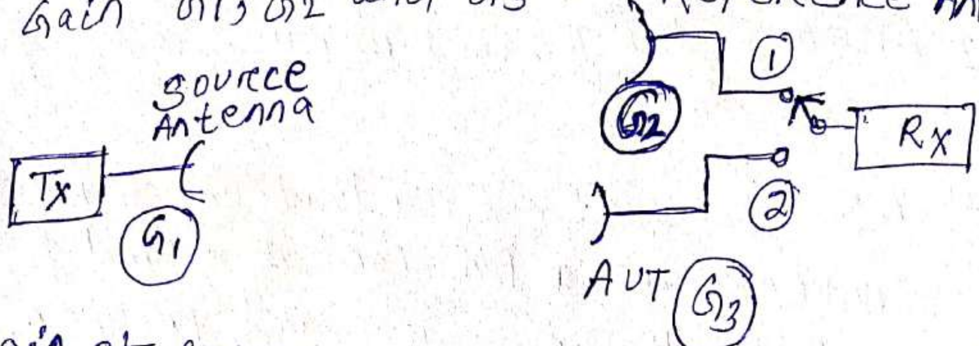
↳ Here f and r is constant. r should be $> \frac{2D^2}{\lambda}$.

↳ pattern Recorder ~~measures~~ stores Amplitude and Angle.

— x —

GAIN MEASUREMENT (continued) :-

(2) Comparision Method :- ↳ It requires three antenna of Gain G_1, G_2 and G_3.



↳ Gain of Reference antenna is known gain G_2.

↳ By keeping switch at position (1)

$$P_{r2} = P_T \cdot G_1 \cdot G_2 \cdot \left(\frac{\lambda}{4\pi R}\right)^2 \quad \text{—— (A)}$$

↳ By keeping switch at position (2)

$$P_{r3} = P_T \cdot G_1 \cdot G_3 \cdot \left(\frac{\lambda}{4\pi R}\right)^2 \quad \text{—— (B)}$$

↳ By ratio of eqn (A) and eqn (B) we can have

$$\frac{P_{r2}}{P_{r3}} = \frac{G_2}{G_3} \Rightarrow G_3 = \left(\frac{P_{r3}}{P_{r2}}\right) \cdot G_2$$

$$\Rightarrow \boxed{G_{AUT} = \left(\frac{P_{r3}}{P_{r2}}\right) \cdot G_{ref}}$$

—— x ——

ANTENNA FIELD ZONES :-

↳ Field zone means how antenna radiates with respect to its position. There are three antenna field zone (1) Reactive near field region. (2) Radiating near field region. (3) Far field region

(1) Reactive Near Field Region :-

↳ It is that portion of the near field region immediately surrounding the antenna where in the reactive field predominates.

↳ For most of the antennas, The outer boundary of this region is

$$R = 0.62\sqrt{\frac{L^3}{\lambda}}$$

↳ But for a very short dipole radiator, the outer boundary is

$$R < \frac{\lambda}{2\pi}$$

↳ In general, objects within this region will result in coupling with the antenna and distortion of the ultimate far field antenna pattern.

↳ Large conductor within this distance will couple with the antenna and "detune" it. The result can be an altered resonant frequency, radiation resistance and radiation pattern.

(2) Radiating Near field Region :-

↳ It is that region of the field of an antenna between the Reactive near field region and the far field region. ↳ For This region, the distance from the antenna R is

$$0.62\sqrt{\frac{L^3}{\lambda}} < R < \frac{2 \cdot L^2}{\lambda}.$$

↳ This region is also called the Transition region.

↳ properties of this region are :- (i) The Antenna pattern is taking shape but it is not completely formed.

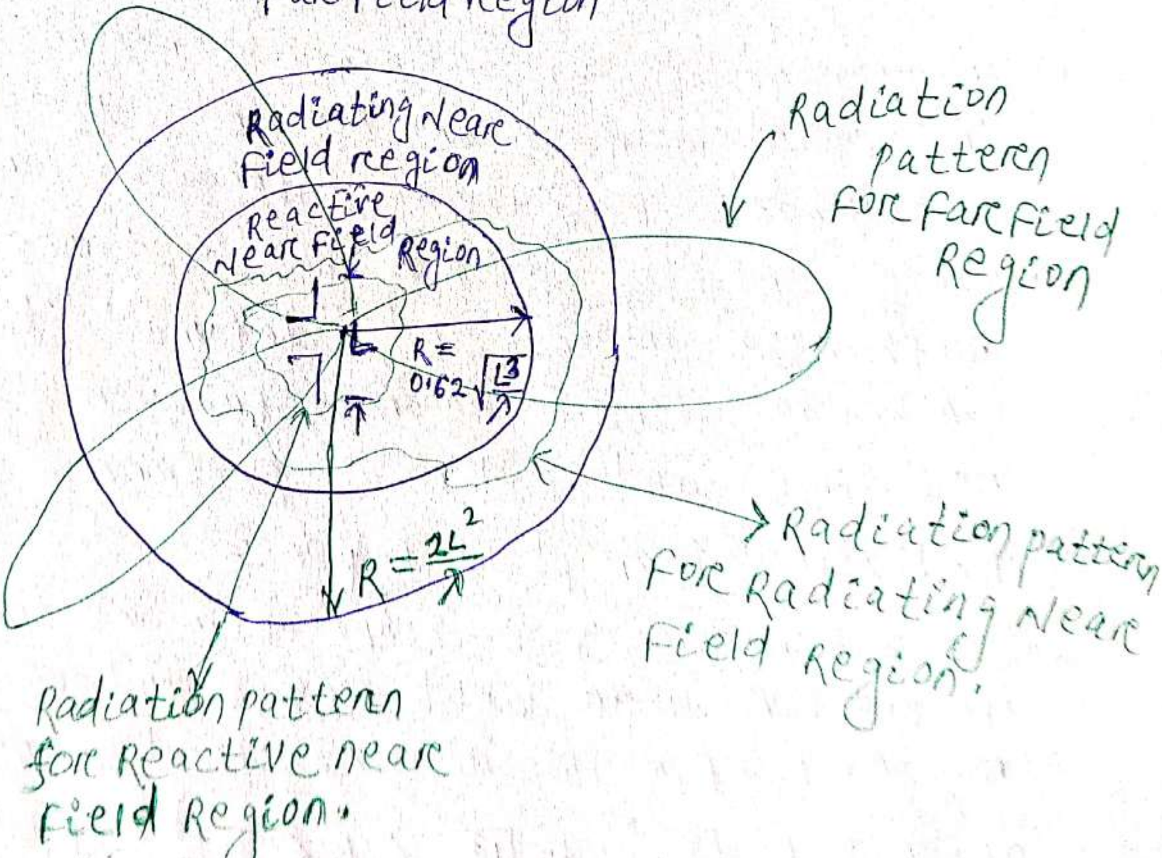
(ii) The radiation field predominates the reactive field. (iii) The radiated wave front is still clearly curved. (iv) The Electric and Magnetic field vectors are not orthogonal.

(3) Far-Field Region :- ↳ It is that region of the field of an Antenna where the angular field distribution is essentially independent of the distance from the antenna.

↳ For this region, the distance from the antenna R is

$$R > \frac{2L^2}{\lambda}$$

↳ properties of this region are :- (i) The wavefront becomes approximately planner. (ii) The Radiation pattern is completely formed and does not vary with distance. (iii) E-field and H-field vectors are orthogonal to each other.



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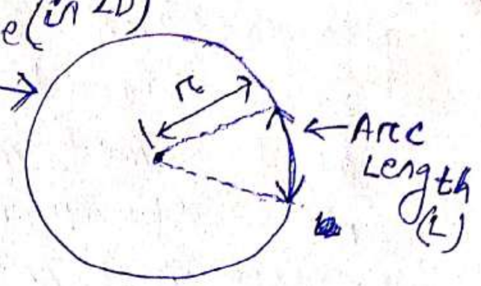
Angle [Radian] :-



It is arc Length per unit radius.

$$\theta = \frac{\text{Arc Length}}{\text{Radius}} = \frac{L}{r} \text{ [in radian]}$$

↳ For complete circle, Arc Length $= 2\pi r$

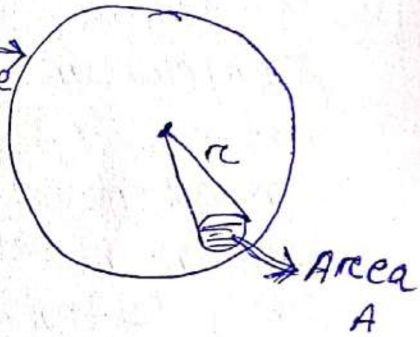
$$\theta = \frac{2\pi r}{r} = 2\pi \text{ (Radian)}$$

↳ Radian is measured in 2-Dimension (2D).

Solid Angle [steradian] :-

↳ It is amount of area per square of radius.

$$\text{Solid Angle}(\phi) = \frac{\text{Area}}{(\text{Radius})^2} \text{ (in sr)}$$



↳ for complete sphere, surface area is $= 4\pi r^2$

Now solid Angle $\phi = \frac{4\pi r^2}{r^2} = 4\pi$ sr (in steradian)

↳ solid angle is angle measurement in 3D.

Relation between Radian and steradian :-

↳ 1 steradian $= 1 \text{ rad} \times 1 \text{ rad} = 1 \text{ rad}^2$

$$= \left(\frac{180}{\pi}\right)^2 (\text{deg})^2 = 3286.13 \text{ (degree)}^2$$

↳ For complete Sphere

$$\text{Solid angle} = 4\pi \text{ (s}_o) = 4\pi \times 3286.13$$

$$= 41273.88 \text{ (degree)}^2$$

——x—— x ——xx——

ANTENNA TEMPERATURE :-

Basics :- (i) Antenna Temperature T_a is a parameter that describes how much noise an antenna produces in a given environment.

(ii) This Temperature is not the physical temperature of the antenna. (iii) Moreover, an antenna does not have an intrinsic "antenna Temperature" associated with it; rather the temperature depends on its gain pattern and the thermal environment that it is placed in. (iv) Antenna Temperature is also sometimes referred to as Antenna Noise Temperature.

Definition of Antenna Temperature :- (i) The noise Temperature is mathematically defined as

$$T_A = \frac{1}{4\pi} \int_0^{2\pi} \int_0^{\pi} R(\theta,\phi) \cdot T(\theta,\phi) \cdot \sin\theta \cdot d\theta \cdot d\phi$$

(ii) where, $R(\theta,\phi)$ is Radiation pattern of Antenna. $T(\theta,\phi)$ is Temperature distribution.

(iii) To define the environments, we will introduce a Temperature distribution - This is the Temperature in every direction away from the antenna in spherical co-ordinates. For instance, the night sky is roughly 4 Kelvin; The value of the temperature pattern in the direction of the Earth's ground is the physical temperature of the Earth's ground.

Noise power By Antenna as per Antenna Temperature:-

→ Noise power $\boxed{P_{TA} = K \cdot T_A \cdot B}$, where T_A is Antenna Temperature, (in Kelvin) K is Boltzmann's constant, B is Bandwidth.

Gain with respect to Temperature :-

↳ A parameter often encountered in specification sheets for antennas that operate in certain environments is the ratio of gain of the antenna divided by the antenna temperature (or system temperature if a receiver is specified). This parameter is written as G/T, and has units of dB/Kelvin.

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RADIATION RESISTANCE IN ANTENNA :- (R_r)

↳ The antenna is a radiating device, which radiates Electromagnetic wave (EM wave) in the space.

↳ If we supply I current to antenna, then power dissipated by antenna is $P = I^2 \cdot R$.

↳ The energy supplied to antenna is dissipated in two ways.
① Radiated power (P_{rad}) ② Due to ohmic Loss (P_{Loss})

↳ So, Total power $P = P_{rad} + P_{Loss} = I^2 \cdot R_r + I^2 \cdot R_L$

$$= I^2 \cdot (R_r + R_L)$$

R_r = Radiation Resistance

↳ Radiation efficiency $\epsilon_{rad} = \frac{R_r}{R_r + R_L}$

If R_r is high then ϵ_{rad} is high.

↳ Radiation resistance depends upon following parameters.
① configuration Antenna. ② Ratio of Length to Diameter of conductor used in antenna. ③ It depends upon point where radiation resistance is considered. ④ Location of antenna with respect to ground and other objects. ⑤ corona discharge.

↳ Basically Radiation Resistance is associated with amount of power radiated by antenna in the space as Electromagnetic waves. So higher the Radiation Resistance, indicates higher the radiated power by antenna. And higher the Radiation Resistance, highere the Radiation efficiency of antenna.

DIRECTIVITY OF ANTENNA :- ① The directivity of an antenna is defined as the ratio of radiation intensity in a given direction from the antenna to the radiation intensity average over all direction.

$$D = \frac{U_{given\ direction}}{U_{avg.}}, \quad U = \text{Radiation Intensity}$$

↳ Average radiation Intensity $U_{avg} = \frac{P_{rad}}{4\pi}$

$$\Rightarrow D = \frac{4\pi \cdot U}{P_{rad}}$$

↳ Maimum Directivity has to be calculated in case of direction is not given. So Maximum Directivity is defined as the ratio of radiation Intensity in maximum direction to the readiation Intensity of Isotropic Source. Isotropic source radiates equally in all direction.

↳ Approximated Directivity $(D) = \frac{4\pi}{\theta_{HP} \cdot \phi_{HP}}$

Here θ_{HP} = Half power Beamwidth (HPBW) in E-plane.

ϕ_{HP} = Half power Beamwidth (HPBW) in H-plane.

—x— x—

Example:– The radiation Intensity of a unidirectional Antena is given by $U = U_m \cdot \cos\theta$, where $0 \leq \theta \leq \frac{\pi}{2}$, $0 \leq \phi \leq 2\pi$. Find Directivity.

Soln:– Directivity $D = \frac{4\pi \cdot U_m}{P_{rad}} = \frac{4\pi \cdot U_m}{U_m \cdot \pi} = 4$

Radiated power $P_{rad} = \int U \cdot d\Omega = \int_{\theta=0}^{\pi/2} \int_{\phi=0}^{2\pi} (U_m \cdot \cos\theta) \cdot \sin\theta \cdot d\theta \cdot d\phi$

$= \frac{U_m}{2} \cdot \int_{\phi=0}^{2\pi} d\phi \cdot \int_{\theta=0}^{\pi/2} 2 \cdot \cos\theta \cdot \sin\theta \cdot d\theta = \frac{U_m (2\pi)}{2} \cdot \int_{\theta=0}^{\pi/2} \sin 2\theta \cdot d\theta$

$= U_m \cdot \pi \left[-\frac{\cos 2\theta}{2} \right]_0^{\pi/2} = \frac{U_m \cdot \pi}{2} \cdot [-\cos\pi + \cos 0]$

$= \frac{U_m \cdot \pi}{2} \cdot [1+1] = \boxed{U_m \cdot \pi}$

put This value in above equation.

—x— x—

RADIATION DENSITY AND RADIATED POWER :-

↳ when Electromagnetic wave travels in space, the power density of radiation by antenna related to Electric and Magnetic field is given by

$$\vec{w} = \vec{E} \times \vec{H} \quad (\text{watt}/\text{metre}^2)$$

↳ so, for Instantaneous power $P_{int} = \oint \vec{w} \cdot \vec{ds}$

↳ Average power density $w_{avg.} = \frac{1}{2} \text{Re} [\vec{E} \times \vec{H}]$

↳ so, radiated power / Average power by Antenna is

$$\boxed{P_{rad} = \oint_S \vec{w}_{avg} \cdot \vec{ds}} = \oint_S \left[\frac{1}{2} \text{Re}(\vec{E} \times \vec{H})\right] \cdot \vec{ds}$$

$$= \frac{1}{2} \oint_S \text{Re}(\vec{E} \times \vec{H}) \cdot ds$$

↳ Relationship between $\vec{E}$ and $\vec{H}$ is $H = \frac{E}{\eta}$ (or)

$$\vec{E} = \eta \cdot \vec{H}$$

$$\Rightarrow \vec{w}_{avg} = \frac{E^2}{2\eta} \cdot \vec{a_r} = \frac{\eta H^2}{2} \cdot \vec{a_r}$$

$$P_{rad} = \frac{1}{2\eta} \oint_S E^2 \, \vec{a_r} \cdot \vec{ds}$$

—xx— x —x—

Example on Radiated power :-

Que:- The power density of an antenna is expressed as

$$\vec{W}_{rad} = \frac{A_0 \cdot \sin\theta}{r^2} \cdot \hat{a}_r \quad (\text{watt}/\text{metre}^2)$$

Find the Radiated power

→ In Intensity we don't multiply r^2.

Sol:- $P_{rad} = \oint W_{rad} \cdot \vec{ds} = \int_\phi \int_\theta W_{rad} \cdot r^2 \sin\theta \cdot d\theta \cdot d\phi$

we multiply with r^2 only in case of power Density.

$$= \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} \frac{A_0 \cdot \sin\theta}{r^2} \cdot r^2 \sin\theta \cdot d\theta \cdot d\phi$$

$$= \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} A_0 \sin^2\theta \cdot d\theta \cdot d\phi = A_0 \cdot \int_{\phi=0}^{2\pi} d\phi \cdot \int_{\theta=0}^{\pi} \sin^2\theta \cdot d\theta$$

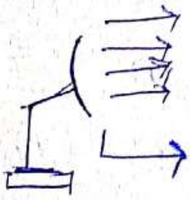
$$= A_0 \cdot (2\pi) \cdot \int_{\theta=0}^{\pi} \left(\frac{1 - \cos 2\theta}{2}\right) \cdot d\theta$$

$$= A_0 \pi \int_{\theta=0}^{\pi} (1-\cos 2\theta) \cdot d\theta = A_0 \cdot \pi \left[\theta - \frac{\sin 2\theta}{2} \right]_{\theta=0}^{\pi}$$

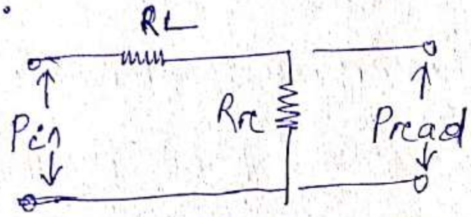
$$= A_0 \pi \left[(\pi - 0) - (0-0) \right] = \boxed{A_0 \cdot \pi^2} \text{ watt.}$$

---x---

ANTENNA RADIATION EFFICIENCY :-



↳ If loss power is more then Radiated power (Prad) will be less.



R_r = Radiation Resistance

R_L = Loss Resistance

↳ Radiation Efficiency $= \frac{P_{rad}}{P_{in}} = \frac{R_r}{R_r + R_L} = \epsilon_{rad}$

↳ By increasing Radiation Resistance, we can increase radiation efficiency.

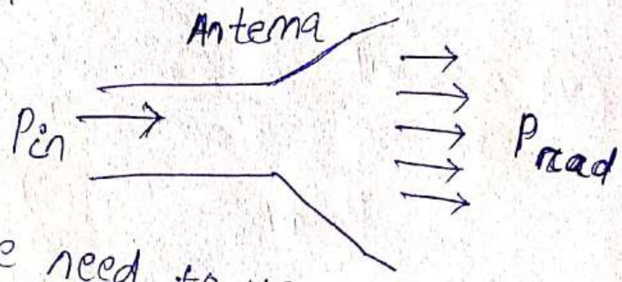
Example:- If $R_L = 10\Omega$, $R_r = 10\Omega$

$\epsilon_{rad} = \frac{R_r}{R_r + R_L} = \frac{10}{20} = 0.5$

If $R_L = 10\Omega$, $R_r = 40\Omega$

$\epsilon_{rad} = \frac{40}{50} = 0.8$

ANTENNA GAIN :- (i) we have seen Directivity of Antenna is $D = \frac{4\pi \cdot U_m}{P_{rad}}$ —— (1)



(ii) For Gain of Antenna we need to use P_{in} instead of P_{rad} in directivity.

$G = \frac{4\pi U_m}{P_{in}}$ —— (2)

(iii) Efficiency of Antenna $K = \frac{P_{rad}}{P_{in}}$

(iv) Equation-(2)/Equation-(1) is $\frac{G}{D} = \frac{4\pi U_m/P_{in}}{4\pi U_m/P_{rad}} = \frac{P_{rad}}{P_{in}} = K$

$\Rightarrow$ $\boxed{G = K \cdot D}$

(v) Gain of Antenna can be measured by Antenna under Test with respect to reference antenna.

$\Rightarrow$ $\boxed{G = \frac{U_{AUT}}{U_{Ref.}}}$ = $\frac{\text{Radiation Intensity of Antenna under Test}}{\text{Radiation Intensity of reference Antenna}}$

reference Antenna ↓ (Isotropic Antenna)

$U_{Ref.} = \frac{P_{in}}{4\pi}$

So, $G = \frac{U_{AUT}}{P_{in}/4\pi} = \boxed{\frac{4\pi \cdot U_{AUT}}{P_{in}}}$

—— x —— x ——

RADIATION INTENSITY :- (i) Radiation Intensity is amount of power radiated by antenna per unit solid angle.

(ii) unit of Radiation Intensity is watt/steradian.

$U = w \cdot r^2$

(iii) w (power density) $= \frac{E^2}{2\cdot\eta}$

(iv) So, Radiation Intensity $= \frac{r^2 \cdot E^2}{2\cdot\eta}$

(v) Based on Radiation Intensity, Radiated power can be calculated by

$$P_{rad} = \int U \cdot d\Omega = \oint_S \vec{W} \cdot d\vec{s}$$

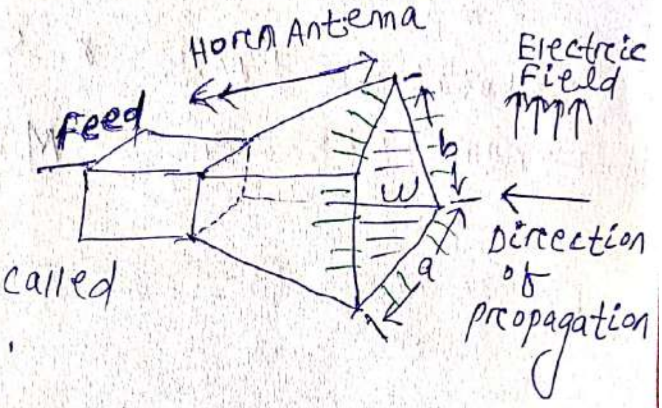
$$= \int_\theta \int_\phi U \cdot \sin\theta \cdot d\theta \cdot d\phi$$

—— x —— x ——

ANTENNA APERATURES :-

↳ Aperature means Area. With each Antenna, we can associate a number of equivalent areas. These are used to describe the power capturing characteristics of antenna. Different aperatures are ① Physical Apereature, ② Effective Aperature ③ Scattering Aperature ④ Loss Aperature ⑤ Collecting Aperature.

① Physical Aperature :-



↳ Rectangular horn antenna with dimensions a and b is given. The area of opening called as Physical aperature A_p.

$$\boxed{A_p = a \times b}$$

↳ If Incident wave has power density w. Then Received power $\boxed{p = w \cdot A_p \text{ (in watts.)}}$.

② Effective Aperature :- ↳ When we receive power, it is Less than we calculate. It is happening due to following reasons. (i) Horn is not uniform over opening.
(ii) Electric field ($\vec{E}$ field) at wall must be zero but practically not.
(iii) Due to teppering loss. (iv) Due to conduction loss.

↳ So to understand effective aperature we need to calculate aperature efficiency.

$$\epsilon_{ap} = \frac{A_e}{A_p} = \frac{\text{Effective Aperature}}{\text{Physical Apereature}}$$

↳ Scattering Aperature occurs Due to edges of Antenna. If edges are not proper then there will be scattering from edges of any antenna.

↳ Loss will occure due to conductive material as a horn, so E-field is not zero at the wall.

↳ collecting Aperature will indicate how much ElectroMagnetic wave it will collect at the opening of Antenna.

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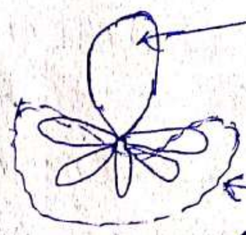
BEAM EFFICIENCY



Ω_M = Solid Angle for Major lobes

Ω_m = Solid Angle for Minor lobes

↳ Total Solid Angle $\Omega_A = \Omega_M + \Omega_m$

↳ Beam Efficiency $\epsilon_M = \frac{\Omega_M}{\Omega_A} = \frac{\Omega_M}{\Omega_M + \Omega_m}$

↳ stray factor $\epsilon_m = \frac{\Omega_m}{\Omega_A} = \frac{\Omega_m}{\Omega_M + \Omega_m}$

↳ Beam Efficiency + stray Factor = 1

—x—

BASICS OF RADIATION PATTERN :-

① HPBW (Half power Beam width) :-

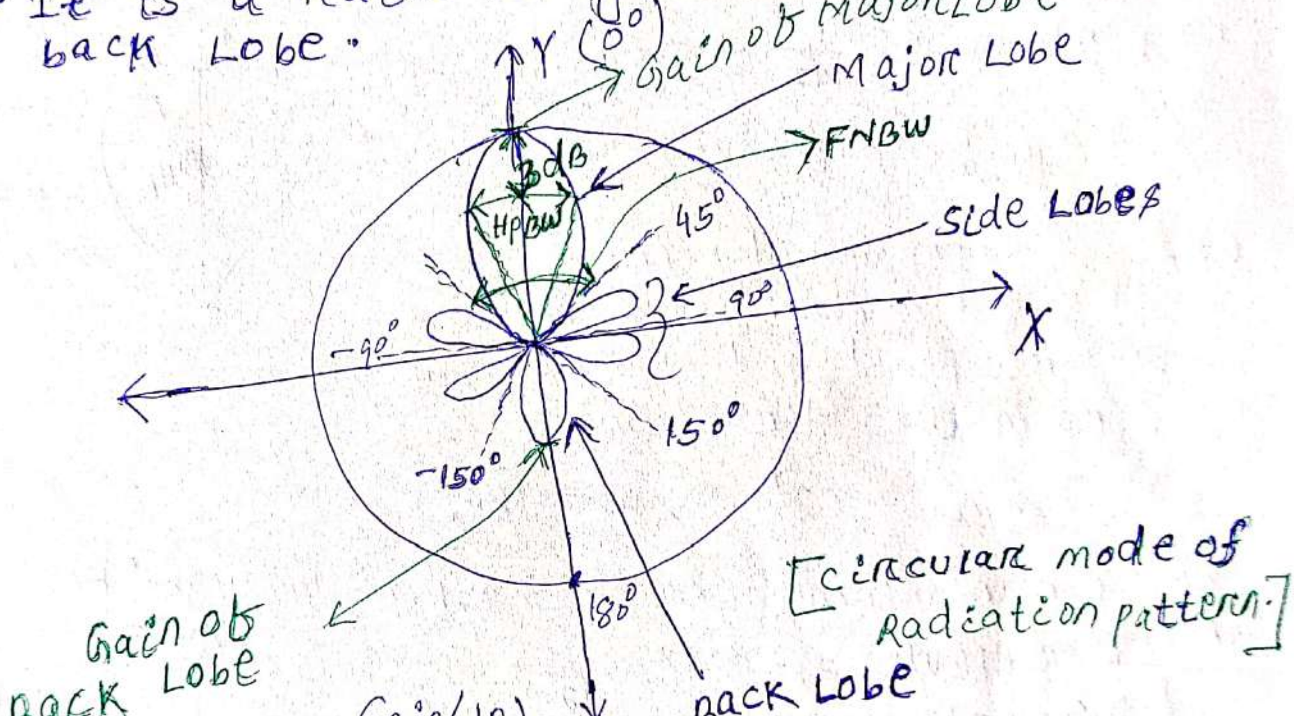
↳ It is a angular width of major lobe, from maximum to 3-dB down.

② FNBW (First Null Beam width) :-

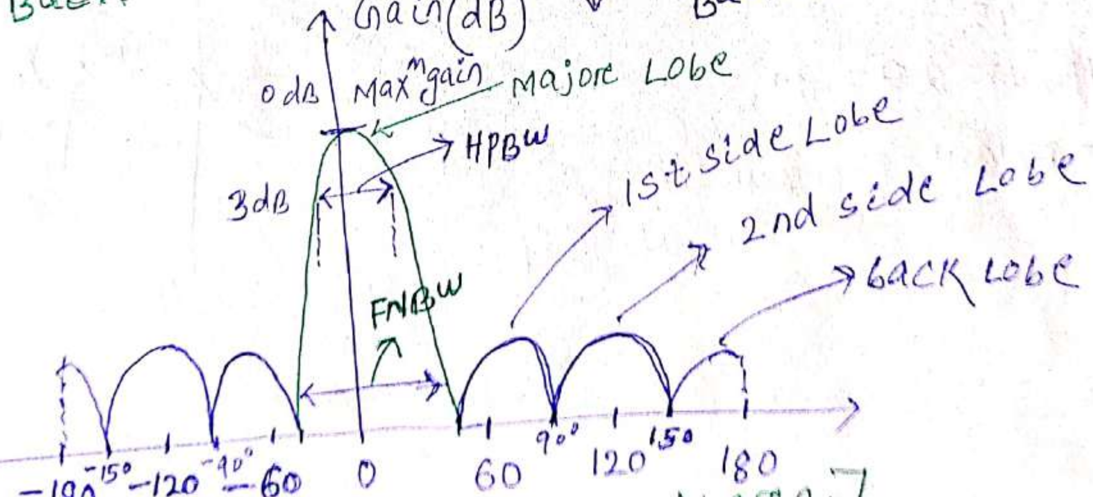
↳ It is a width of Major lobe.

③ Front to Back ratio :-

↳ It is a ratio of gain from major Lobe to back Lobe.



[circular mode of Radiation pattern.]



[Axial Mode of Radiation pattern.]

↳ In above diagram An Antenna is radiating in X-Y plane.

↳ Major Lobe Angle with X-axis is 45° and with Y-axis is 0°.

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Examples on HPBW and FNBW:-

Que:- An Antenna is having a field patteren given by $E(\theta) = \cos\theta$, for $0 \leq \theta \leq 90^\circ$. Find Half power Beam width and FNBW.

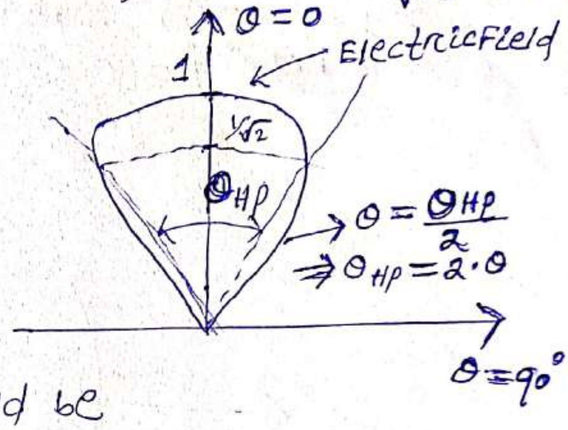
Ans:- HPBW is width of beam of major lobe and power is half. we know power(P) $\propto E^2$ (square of Electric Field.)

$\Rightarrow E \propto \sqrt{P}$

↳ At Half power Beam width power is half, and at the same time Electric field (E-field) should be $\frac{1}{\sqrt{2}}$ of maximum E-field.

↳ $E(\theta) = \cos\theta = \frac{1}{\sqrt{2}} \Rightarrow \theta = 45^\circ$

$\Rightarrow \theta_{HPBW} = 2 \cdot \theta = 90^\circ$



↳ First Null Beamwidth (FNBW) is based on Null. Null means Electric field and power should be zero in that direction.

$\Rightarrow \theta_{FNBW} = 2\theta' = 2 \times 90 = 180^\circ$

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Que-2 For an antenna $E(\theta) = \sin\theta$. Find HPBW and FNBW.

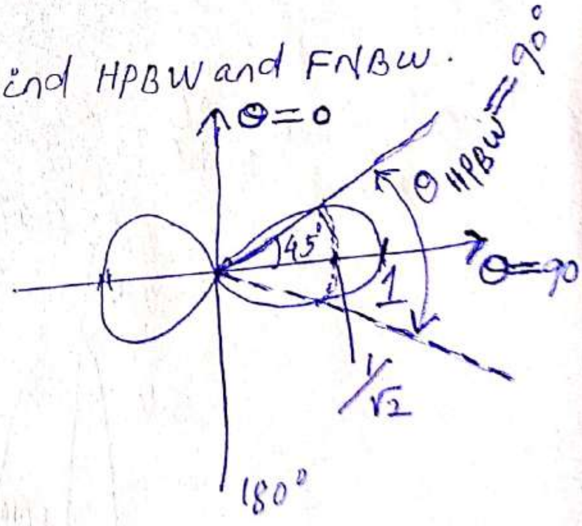
Ans:- For HPBW, $E(\theta) = \sin\theta = \frac{1}{\sqrt{2}}$

$\Rightarrow \theta = 45^\circ$

$\Rightarrow \theta_{HPBW} = 2\theta = 90^\circ$

↳ For FNBW, $\theta_{FNBW} = 180^\circ - 0^\circ$

$= \boxed{180^\circ}$



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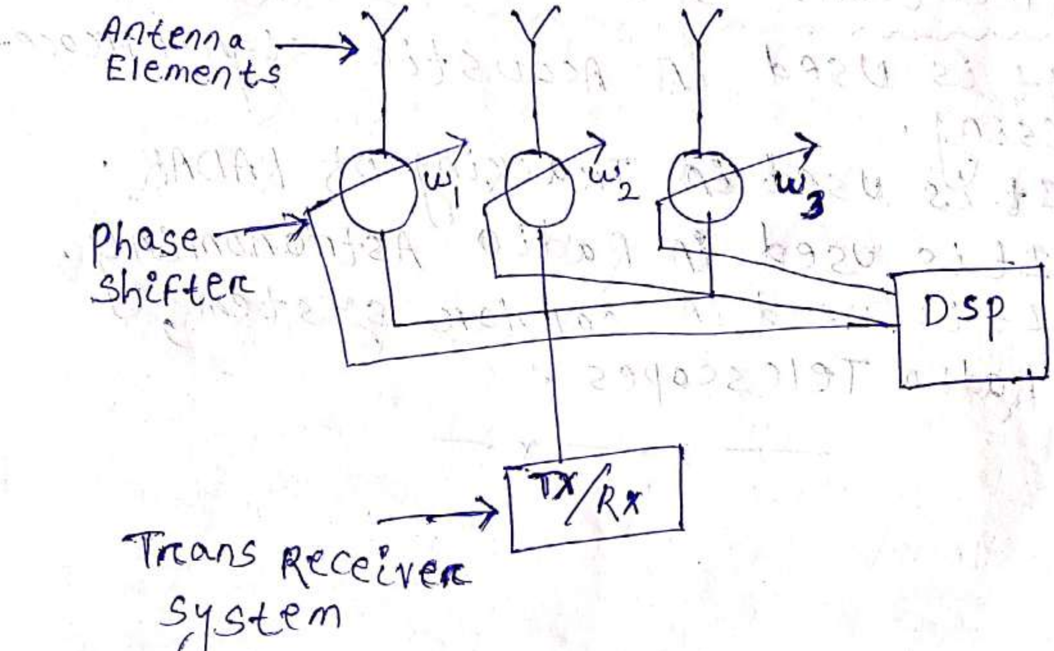
SMART ANTENNA :-

↳ It is the combination of Antenna phased Array and DSP processors.

STRUCTURE OF SMART ANTENNA :-



↳ phase of the phase shifter is controlled by DSP processor. By controlling the phase of phase shifter Antenna is steered.

↳ Antenna Elements radiates in desired direction only. It has minimum intereference. Each Antenna element is connected with phase shifter and then it is connected with Trans-Receiver system. Smart Antenna has higher gain in desired direction.

Definition :- A smart Antenna system combines multiple antenna elements with signal processing capability to optimize the radiation and/or reception pattern automatically in response to the signal environment

Smart Antenna Benefits :- ① It has higher gain for the desired signal.
② Interference Rejection.
③ Increase system capacity.

Applications of smart Antenna :-

① It is used in Acoustic signal processing.
② It is used in Tracking of RADAR.
③ It is used in Radio Astronomy.
④ It is used in cellular system, Radio Telescopes.

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ZERO MODE and PI MODE IN MAGNETRON:-

→ If ϕ represents the relative phase change of the AC electric field across adjacent cavities then

$$\phi = \frac{2\pi n}{N}, \text{ where } n = 0, \pm 1, \pm 2, \ldots \pm \frac{N}{2}$$

→ It means $\frac{N}{2}$ number of modes of resonance can exist if N is an even number.

If n = 0, then $\phi = 0$, so it is zero mode

If $n = \frac{N}{2}$ then $\phi = \pi$, so it is called PI MODE magnetron.

PI MODE in MAGNETRON :-

→ In this mode, adjacent anode cavity have 180° phase difference. pi mode is most commonly used more in magnetron.

→ A magnetron when operated under pi mode, it gives maximum output power and desired frequency.

→ Since magnetron has 8 coupling cavity resonators, several different modes of oscillation is possible.

→ The oscillation frequency corresponding to the different modes are quite close to one another, so that a pi mode oscillation which is normal for magnetron.

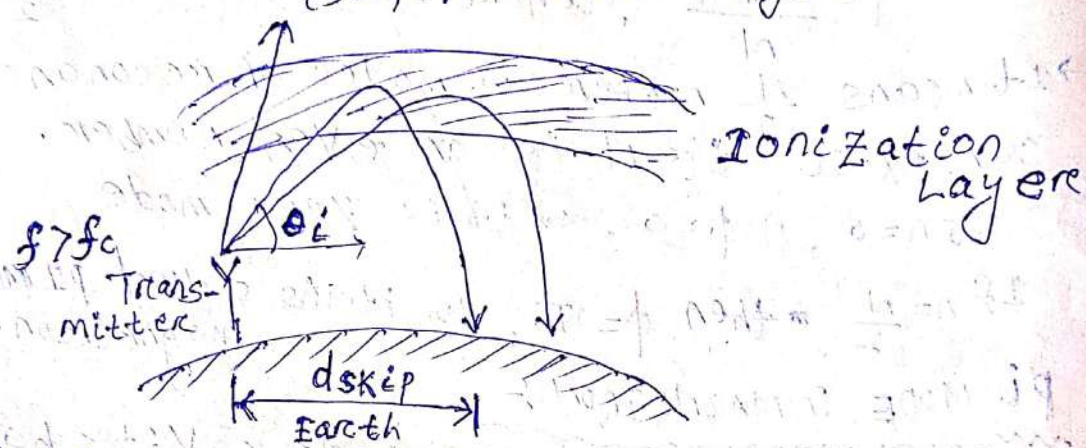
→ The modes which are close to pi mode, switching occurs between thes modes. This is called mode jumping.

strapping in MAGNETRON :-

→ In order to avoid mode jumping strapping is used.

→ strapping consists of two rings of heavy gauge wire connecting alternate anode poles. These are the poles that should be in phase with each other for pi mode. Phase other than pi is rejected.

SKIP DISTANCE :- The skip Distance is the shortest distance from a Transmitter measured along earth's surface at which sky wave at fixed frequency ($f > f_c$) will be returned to the earth.



↳ A θi Angle of Radiation the signal comes to the earth by reflecting in Ionization Layer.

↳ So we can say the sky wave propagation is possible for greater than skip distance.

↳ Equation of maximum usable frequency (f_{muf}) and critical frequency (f_c) is

$$\Rightarrow f_{MUF} = f_c \cdot \sqrt{1 + \left(\frac{d}{2H}\right)^2}$$

$$\Rightarrow d_{skip} = 2H \cdot \sqrt{\left(\frac{f_{MUF}}{f_c}\right)^2 - 1}$$

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CRITICAL FREQUENCY :- For any given time, each Ionospheric Layer has a maximum frequency at which radio waves can be transmitted vertically and reflected back to the earth. This frequency is known as critical frequency.

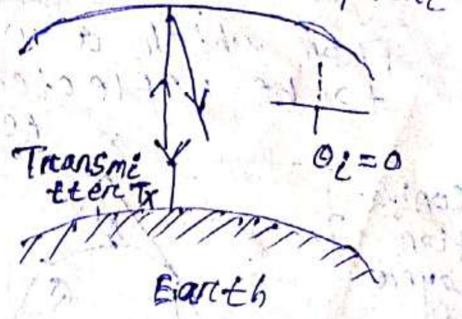
↳ For Ionosphere Layer $\mu = \sqrt{1 - \frac{81N}{f^2}}$, where

μ = Refractive Index of Ionospheric Layer.

N = Number of Electron Density.

From Snell's Law,

$$\mu = \frac{\sin\theta_i}{\sin\theta_t} = \sqrt{1-\frac{81N}{f^2}}$$



→ For $f = f_c$ (critical frequency), $\theta_i = 0$,

$$\Rightarrow 0 = \sqrt{1-\frac{81N}{f^2}}$$

$$\Rightarrow f_c = 9\sqrt{N}$$

→ For D-Layer in Ionosphere critical frequency $f_c = 100$ KHZ.

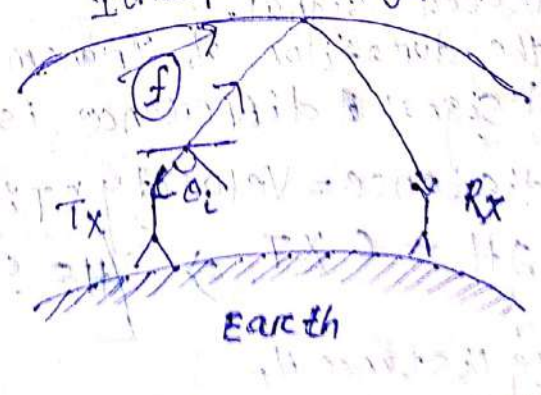
For E-Layer → $f_c = 3$ to 5 MHZ

For F_1-Layer → $f_c = 5$ to 7 MHZ

For F_2-Layer → $f_c = 10$ MHZ

MAXIMUM USABLE FREQUENCY (MUF) :-

→ In sky wave propagation the maximum usable frequency is defined as the highest frequency that can be used for sky wave communication between two given points on earth.



CASE-1 :-

→ for $\theta_i = 90°$,

$f = f_c = f_{MUF}$

$$f_{MUF} = 9\sqrt{N}$$

CASE-2 :-

for $\theta_i < 90°$, $\mu = \sin\theta_i = \sqrt{1-\frac{81N}{f^2}}$

→ After the range of maximum usable frequency, the signal is penetrated into ionosphere.

→ Here frequency is variable.

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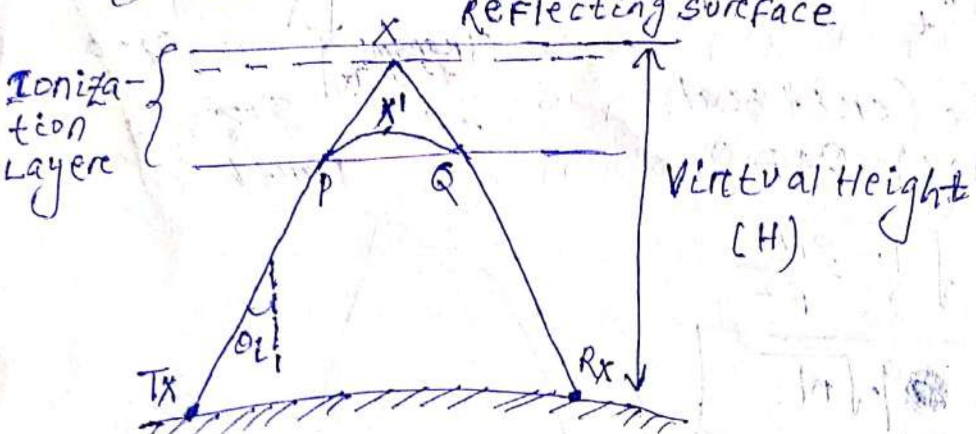
VIRTUAL HEIGHT :- The Virtual height is that height from which a wave sent up at an angle appears to be reflected.



↳ Due to Gradual change in Refractive Index actual path is $T_x - P - X' - Q - Rx$. And virtual path is $T_x - P - X - Q - Rx$.

↳ The height associated with virtual path is virtual height.

↳ To measure the virtual height, the instrument used is ionospheric sound is also called as IONOSONDE.

↳ The Transmitter Antenna sends vertically upward radio wave of pulse duration 150 Micro second (MS).

↳ The Receiver Antenna (Rx) is placed closed to Transmitter Antenna (T_x) and receives ~~reflected~~ reflected signal.

↳ If the duration of Transmitter (T_x) and Receiver (Rx) signal difference is T. Then,

distance = Velocity × Time

$$\Rightarrow 2H = c \times T \Rightarrow \boxed{H = \frac{c \times T}{2}}$$

(Sending Distance H, Receiving distance is H by Reflection. So Total Distance is 2H)

↳ The height associated with Actual path is Actual height.