UNIT-II

VHF, UHF AND MICROWAVE ANTENNAS -I

The antennas which are operated between the frequency ranges 30 to 300 MHz are VHF antennas, 300 to 3000 MHz are known as UHF antennas. Typically the antennas is operating over 3000 MHz are called Microwave Antennas. In UHF and VHF bands, the arrays are constructed using elevated wires and tubing rods of copper or aluminium. This increase directivity of antenna.

Frequency Range	Antenna	Application
→ 30-300 MHz	→ VHF antennas	Eg:- yagi-uda Antennas, Folded dipole antennas,
→ 300-3000 MHz	→ UHF antennas	grounded plane corner reflector antennas etc.
→ ~~3000~~-30000 MHz	→ Microwave Antennas	
→ 3000-30000 MHz	→ SHF antennas.	Applns:- Landline commn, public & industry.

→ In this band, the radio waves are propagated by space wave propagation. The antenna works satisfactorily if it is mounted at the top of vertical masts or towers for ground to ground commn.

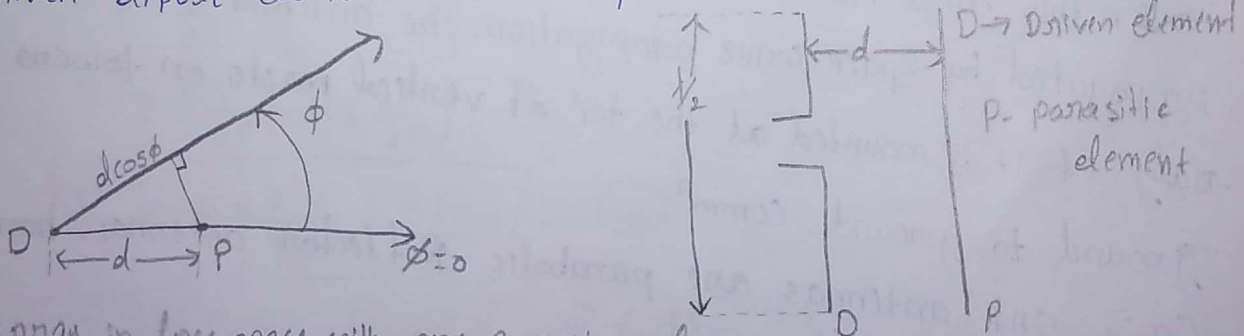
Eg:- SHF antennas are parabolic Reflector antennas, horn antennas, Lens antennas.

ARRAYS WITH PARASITIC ELEMENTS

→ In broadband array, End fire array and Hansen-woodyard end fire array etc. In all above these arrays all the elements are driven by a source. All individual elements are supplied with a power by means of transmission line. Such directional arrays can be constructed by using some other elements in which the currents are induced due to the fields of driven element. in other elements is called parasitic element such elements do not require transmission line connection for supplying power.

One or more parasitic elements coupled magnetically with the driven element forms an array of parasitic elements. It is also called parasitic antenna. It is important to study the parasitic element because its presence effects the directional pattern. The effect of parasitic element on the directional pattern of the antenna depends on the directional pattern of the antenna depends on magnitude and the phase of the induced current in the parasitic element. Thus ultimately "the effect of the directional pattern depends on the spacing b/w antenna elements and turning of the parasitic element.

To study the quantitative relations b/w voltages and currents of a parasitic antenna let us consider an array in the free space consisting only two elements such as one $\lambda/2$ driven dipole elements and one parasitic element.



Array in free space with one parasitic element and one driven $\lambda/2$ dipole element.

Let both the elements be vertical and parallel to each other such that azimuth angle ϕ. Let the two elements seperated by distance d. Let I_1 be current in the driven element D. Similarly I_2 be the current induced in the parasitic element P. The relation between voltages and currents can be written on the basis of circuit theory as

$$V_1 = Z_{11} I_1 + Z_{12} I_{12} \quad \text{---} (1)$$

$$0 = Z_{21} I_1 + Z_{22} I_2 \quad \text{---} (2)$$

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Note that as parasitic element P is not excited the applied voltage V_2 is written zero. V_1 is the applied voltage to the driven element. The impedances Z_{11} and Z_{22} are the self impedances of the driven element D and the parasitic element P. The impedances Z_{12} and Z_{21} is the mutual impedence b/w the two elements such that, $Z_{12} = Z_{21} = Z_M$

let $Z_M = R_M + jX_M = R_{12} + jX_{12} = |Z_{12}| \angle \theta_M$

where $|Z_{12}| = \sqrt{R_{12}^2 + X_{12}^2}$ and $\theta_M = \tan^{-1}\left(\frac{X_{12}}{R_{12}}\right)$

let $Z_{22} = R_{22} + jX_{22} = |Z_{22}| \angle \theta_2$

where $|Z_{22}| = \sqrt{R_{22}^2 + X_{22}^2}$, $\theta_2 = \tan^{-1}\left(\frac{X_{22}}{R_{22}}\right)$

from eqn-②, the current in element 2 is given by,

$$I_2 = -\frac{Z_{21}}{Z_{22}} I_1 = \frac{-Z_{12}}{Z_{22}} I_1 \quad \text{— ③} \qquad [\because Z_{12} = Z_{21}]$$

→ substituting values of Z_{12} and Z_{22} in eqn-③, we get

$$I_2 = \frac{-|Z_{12}| \angle \theta_M}{|Z_{22}| \angle \theta_2} I_1 \Rightarrow I_2 = -I_1 \left[\left| \frac{Z_{12}}{Z_{22}} \right| \angle (\theta_M - \theta_2) \right]$$

Eliminating -ve sign, we can write, $\boxed{I_2 = I_1 \left[\left| \frac{Z_{12}}{Z_{22}} \right| \angle \xi \right]}$

$\xi = \pi + (\theta_M - \theta_2)$

from eqns ① & ②, the driving point impedence is given by $Z_1 = \frac{V_1}{I_1}$

$$Z_1 = \frac{V_1}{I_1} = Z_{11} - \frac{Z_{12}}{Z_{22}}$$

$$Z_1 = Z_{11} - \frac{|Z_{12}|^2 \angle 2\theta_M}{|Z_{22}| \angle \theta_2} \quad \text{— ④}$$

The real part of the driving point impedence can be written as,

$$\boxed{R_1 = R_{11} - \left[\left| \frac{Z_{12}^2}{Z_{22}} \right| \cos(2\theta_M - \theta_2) \right]} \quad \text{— ⑤}$$

$$R_1 = R_{11} + R_{1loss} - \left[\left| \frac{Z_{12}^2}{Z_{22}} \right| \cos(2\theta_M - \theta_2) \right] \quad \text{—(6)}$$

If P_{in} be the i/p power to the driven element. we can express interms of i/p current as, $P_{in} = I_1^2 \cdot R_1 \Rightarrow I_1 = \sqrt{P_{in}/R_1}$

Substituting value of R_1 from eq^n —(6)

we get,

$$\boxed{I_1 = \sqrt{\frac{P_{in}}{\left[R_{11} + R_{1loss} - \left|\frac{Z_{12}^2}{Z_{22}}\right| \cos(2\theta_M - \theta_2)\right)}}}$$

In general, the E at a larger distance away from an array is a function of azimuth angle ϕ, hence we can write for field $\bar{E}$ is

$$E(\phi) = k[I_1 + I_2 \angle d_r \cos\phi) \text{ and } d_r = \beta d = \left(\frac{2\pi}{\lambda}\right)\phi$$

substituting the value of I_2 in above eq^n —(a)

we get, $E(\phi] = k \left[I_1 + I_1 \left\{ \left| \frac{Z_{12}}{Z_{22}} \right| \angle \xi \right\} \angle d_r \cos\phi \right]$

Simplifying above eq^n we get,

$$\boxed{E(\phi] = kI_1 \left[1 + \left| \frac{Z_{12}}{Z_{22}} \right| \angle \xi + d_r \cos\phi \right]}$$

putting the value of I_1 in the above eq^n. we get,

$$E(\phi] = k \sqrt{\frac{P_{in}}{R_{11} + R_L - \left|\frac{Z_{12}^2}{Z_{22}}\right| \cos(2\theta_M - \theta_2)]}}$$

Now, assume that the parasitic element is not present and the same i/p power P_{in} is applied to $\lambda/2$ dipole driven element, then E field at same distance is given by,

$$E_{HW}(\phi] = kI_0 = k\sqrt{\frac{P_{in}}{R_0 + R_{0loss}}}.$$

Where R_0 = self resistance of $\lambda/2$ dipole element alone.

R_{0loss} = Loss resistance of $\lambda/2$ dipole element

→ To analyze the performance of the array with parasitic element along with one driven element, it gain must be compared with the gain of the single $\lambda/2$ dipole antenna with the same i/p power. The gain in field intensity as a function of ϕ can be obtained by taking, eqⁿ – $E(\phi)$ and $EHW(\phi)$.

$$G_f(\phi)\left[\frac{A}{HW}\right] = \sqrt{\frac{R_{11} + R_{1Loss}}{R_{11} + R_{1loss} - \left|\frac{Z_{12}}{Z_{22}}\right|^2 \cos(2\theta_M - \theta_2)}\left[1 + \left|\frac{Z_{12}}{Z_{22}}\right|^2\right]}$$

Where $R_0 = R_{11}$ and $R_{0loss} = R_{1loss}$.

→ If X_{22} is made very large, then the value of Z_{22} becomes large and reduces to unity. Thus, we can conclude that with above equation reducing to unity for large Z_{22}, the field of array with one driven $\lambda/2$ dipole element and one parasitic element is same as that due to single $\lambda/2$ dipole element (without parasitic element).

Making value of reactance very small or very large is called detuning of the parasitic element. The amplitude of the current in the parasitic element as well as its phase relation with the current in the driven element depends on the tuning of parasitic element. There are 2 methods in tuning the parasitic element.

→ The parasitic element is kept same as $\lambda/2$ dipole element and tuning is carried out by connecting a lamped reactance in series with antenna at its centre.

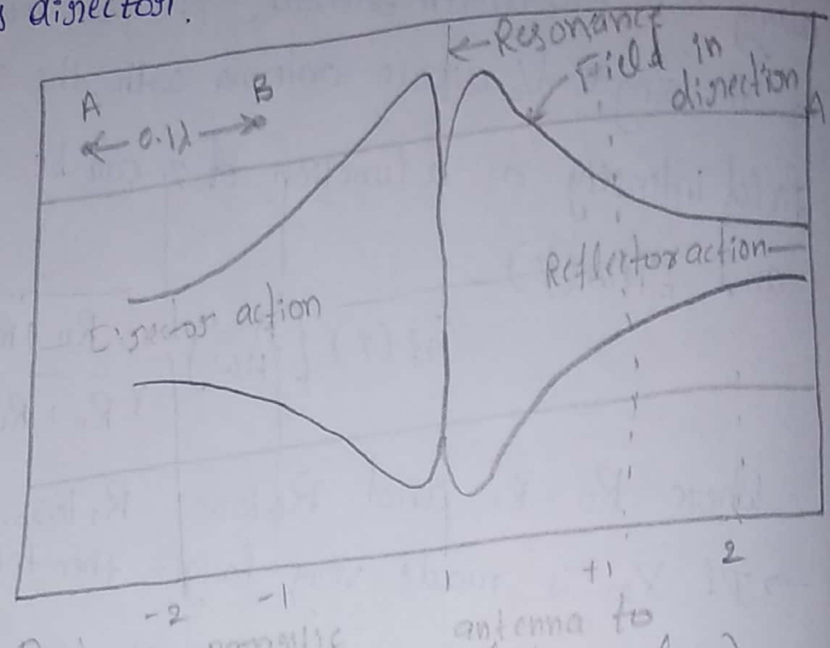
→ In 2nd method, the parasitic element is continuous (without any series reactance) and tuning is carried out by adjusting its length.

The second method is more simpler to achieve proper tuning but slightly difficulty from analysis of point view.

→ When the $\lambda/2$ parasitic element is ~~giv~~ larger than its resonant length, it is inductive in nature. Then parasitic element acts as reflector.

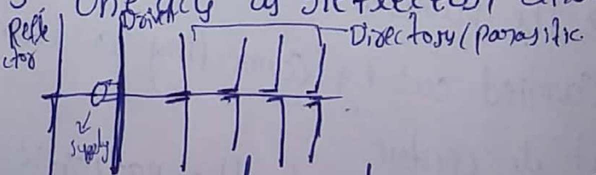
→ similarly when $\lambda/2$ < resonant length. it is capacitive in nature. Then it acts as director.

Element parasitic array



Reactance parasitic antenna to resonant frequency (relative values)

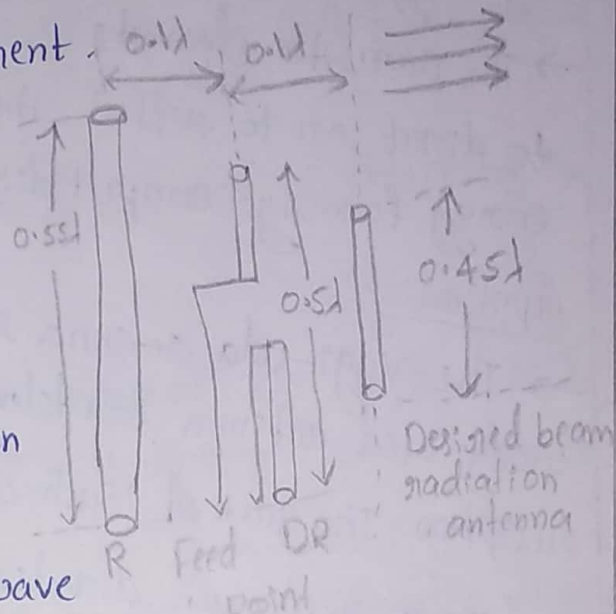
If the driven element and the parasitic element are very close to each other (say $d = 0.1\lambda$) and parallel, then the current induced in the parasitic antenna is such that the strength of the radiation in the direction of antenna reduces if the parasitic element is resonant at lower frequencies where it acts as reflector. If the parasitic element is resonant at higher frequencies, then it acts as director and tend to concentrate field in the direction of antenna. We can construct a parasitic array with one $\lambda/2$ dipole element and two parasitic elements. One acts as reflector and other acts as director.



YAGI-UDA ANTENNA

yagi-uda arrays or yagi-uda antennas are high gain antennas. The antenna was first invented by prof. H. yagi. He measured gains and patterns with single parasitic reflector, single parasitic director and reflector and as many as 30 directors.

→ He found that highest gain is possible with the reflector of length equal length to $\lambda/2$ located at a distance $\lambda/4$ from the driven element, along with the director of length approximately 10% less than $\lambda/2$ located at a distance $\lambda/3$ from the driven element.



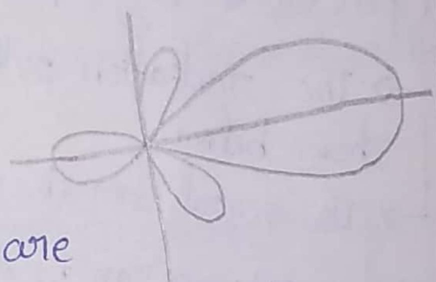
Construction:-

→ A Basic yagi-uda antenna consists a driven element one reflector and one or more directors.

→ Basically it is an array of one driven element and one of parasitic elements.

→ The driven element is a resonant half wave dipole made of a metallic rod.

→ The parasitic elements which are continuous are arranged parallel to the driven elements and at the same line of sight. All the elements are placed parallel to each other and close to each other.



→ The parasitic element receive excitatation through the induced e.m.f. as current flows in the driven element. The phase and amplitude of the currents through the parasitic element mainly depends on the length of the elements and spacing between the elements. Generally the spacing b/w the driven element and parasstic elements is kept nearly 0.1λ to 0.15λ.

→ A yagi-uda antenna uses both the reflector (R) and the director (D) elements in the same antenna. The Antenna at the back side of the driven element is the reflector. It is of the length compared with remaining elements. The element infront of the driven element is the director which is of lowest length in all the three elements. The lengths of the different elements can be obtained by using formula.

Reflector length = $\frac{152}{f(MHz)}$ meter

Driven element length = $\frac{143}{f(MHz)}$ m.

Director length = $\frac{137\ m}{f(MHz)}$

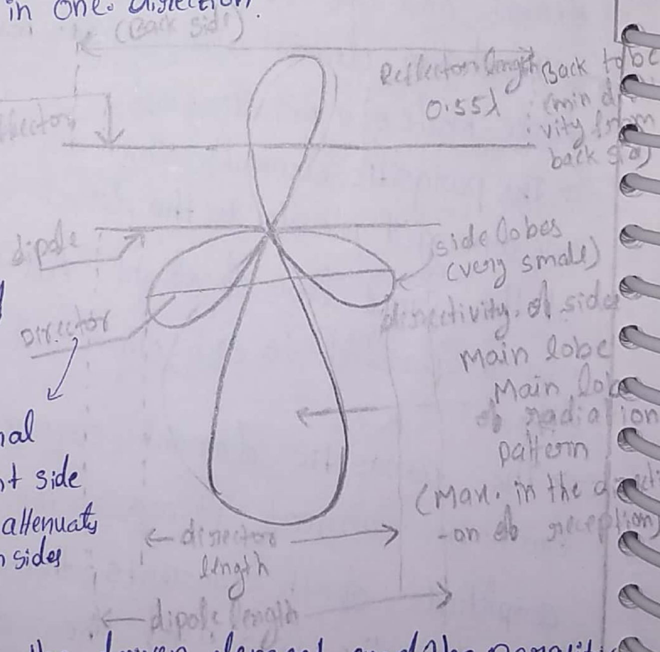
→ The parasitic elements is used either to direct or to reflect, the radiated energy forming compact directional antenna.

Application:-

→ The yagi-uda antenna is the most widely used antenna for television signal reception. The gain of such antenna is very high and the radiation pattern is very much directive in one direction.

→ The radiation pattern is as shown below.

→ The signal strength of the yagi uda antenna can be increased by increasing (signals from) the no. of directors in antenna.



Retransmits the signal collected from front side towards dipole. It attenuates the signal coming from sides and back sides.

Disadvantages:- When the spacing b/w the driven element and the parasitic element (and more director is commonly called beam Antenna) is reduced driven element gets loaded which reduces the i/p impedence at the terminal of the driven element. To overcome this the drive element used in the folded dipole antenna which maintains the impedance at the i/p terminals.

i) Gain is limited. ii) Bandwidth is limited.

iii) Gain of antenna increases with reflector and director.

Characteristics of yagiuda Antenna:

1) The yagi-uda antenna with the three elements including one reflector, one driven element and one director is commonly called beam antenna.

2) It is generally a fixed frequency operated unit. This antenna is frequency sensitive and the bandwidth of 3% can be easily obtained. Such bandwidth is sufficient for television reception.

3) The bandwidth of 2% to 3% can be easily achieved if the spacing b/w the elements is 0.1λ to 1.5λ.

4) The gain of yagi-uda antenna is about 7 to 8 dB. Its FBR is 20dB.

5) This antenna gives a radiation beam which is unidirectional with a moderate directivity.

6) The yagi-uda Antenna is light weight, low cost and simple in feeding with signal

7) To achieve greater directivity more no. of directors are used. The no. of directors may range from 2 to 40.

8) The yagi-uda antenna provides high gain and beamwidth greater than that is obtainable from the uniform distribution. Thus, yagiuda antennas are called superdirective or super gain antennas.

Yagi-uda Antenna calculations:-

To design yagi-uda antenna properly it is important to know the wavelength of EM wave. The wavelength of EM wave can be obtained by $\lambda = c/f$.

we know that the length of the dipole is $L = \lambda/2$

then $L = \frac{c/f}{2} = \frac{3\times10^8 / f(MHz)}{2} = \frac{150}{f} m$

$$\boxed{L = \frac{150}{f(MHz)} \text{ meter}}$$

Due to electrical characteristics of the antenna material it is found that the antenna elements should be 5% to 7% shorter in practice than those obtained using exact forwards. Hence

For dipole: $L = \frac{143}{f(MHz)}$ m $L = \frac{475}{f(MHz)}$ feet

The lengths of the reflector and first director are given, for reflector:

$L = \frac{152}{f(MHz)}$ m. $L = \frac{500}{f(MHz)}$ feet

For 1st director $D_1 : L = \frac{137}{f(MHz)}$ m $L = \frac{455}{f(MHz)}$ feet

The spacing b/w reflector R and dipole DR is given by $0.25\lambda = \frac{75}{f(MHz)}$ m

→ spacing b/w dipole DR and director D_1 is given by $= \frac{40}{f(MHz)}$ m.

→ spacing b/w directors D_1 & D_2 is given by, $\frac{38}{f(MHz)}$ m.

Advantages of yagi uda Antenna:

→ It has excellent sensitivity

→ Its FBR ratio is excellent

→ It is useful as transmitting antenna at high frequency for TV reception

→ It has almost unidirectional radiation pattern.

→ Due to use of folded dipole, the yagi-uda antenna is broadband.

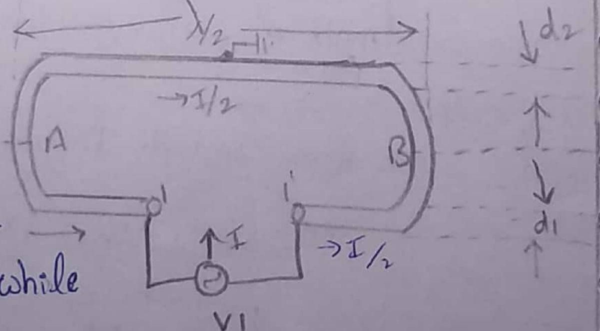
Disadvantages:-

→ Gain is limited.

→ Bandwidth is limited.

→ The gain of antenna ↑ses with reflector and director.

FOLDED DIPOLE ANTENNA

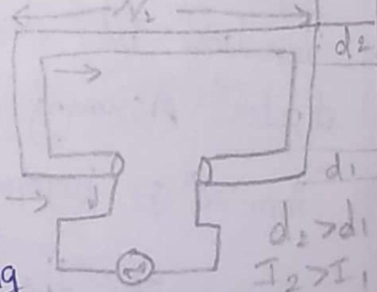


→ It is the modification of conventional half wave dipole in which the two half wave dipoles have been folded and joined.

→ one of the half dipoles in continuous while other is split at the centre

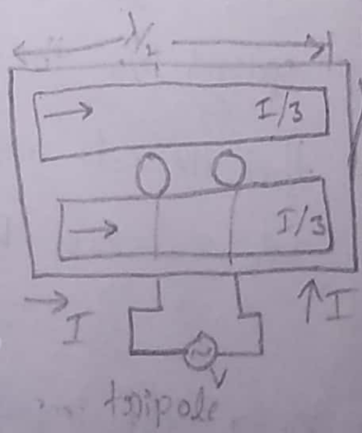
→ The folded dipole which is splitted at the centre is fed with the balanced transmission line. As a result the voltages at the ends of two dipoles are same

→ The radiation pattern of the conventional half wave dipole and that of the folded dipole are exactly same.
→ The directivity and bandwidth of conventional half wave dipole and folded dipole are differ.
→ If the conductors of folded dipoles are of same radii, then the currents with equal in magnitude and phase flows through the two dipoles.
→ Consider that the folded dipole has 2 dipoles, the total current flowing into terminals 1-1' is I. Now if the radii of the conductors are equal then the conductors will carry equal currents of magnitude I/2. Now if the radii of the conductors are equal then the had been a straight dipole the total current would flow in first only dipole arm. Now if the power applied is same, only half of the current flows in first dipole. As the power is $P = I^2R$, the i/p impedence is 4 times that of the straight dipole.
→ As the transmission line is delivering the same power but at only half of the current. Hence for the line impedance is higher. Hence, Radiation resistance is of folded dipole becomes,



$$R_{rad} = (2)^2 73 = 4(73) = 292\Omega$$

Thus folded dipole can be fed with a conventional 300Ω open wire transmission line without any matching device. If three wire folded dipole, commonly called tripole, then only 1/3rd of the radiating current would be supplied at i/p terminals.

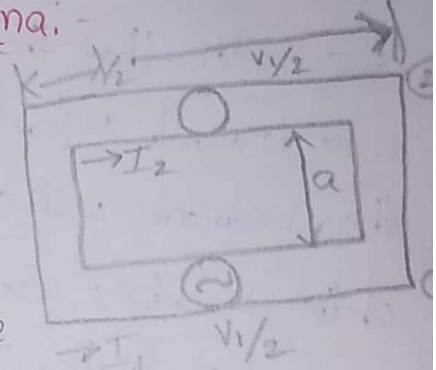


→ The i/p or R_{rad} of tripole is $R_{rad} = (3)^2 73$
$R_{rad} = 657\Omega$. It says that tripole can be convention used with 600Ω open wire transmission line
→ The impedence transformation/changing if impedence can be done by changing radii of the conductors in the folded dipole itself. When the radii of two

dipoles are different, the current flowing through the dipoles are different practically for the unequal radii dipoles, the transformation ratio of 1.5 to 20 can be achieved and it can be further enhanced by increasing no. of dipoles.

→ A folded dipole can be designed with a length other than $\lambda/2$ length. Typically an i/p impedence of 2 conductor folded dipole of $3\lambda/8$ is $225\,\Omega$, while that of 2 conductor folded dipole of length $3\lambda/4$ is $450\,\Omega$.

Derivation for i/p Impedance of Folded dipole Antenna.



Let us Consider a folded dipole the equivalent ckt of two wire folded dipole of length $\lambda/2$.

The applied voltage V_1 which is applied across terminals 1-1' gets equally devided in each dipole as voltage $V_1/2$. Then equation can be written as,

$$\frac{V_1}{2} = Z_{11} I_1 + Z_{12} I_2 \quad \text{——} (1)$$

Note that Z_{11} is the self impedance of dipole and Z_{12} is the mutual impedance b/w dipoles (1) & (2). The currents I_1 & I_2 through the respective dipoles. Assuming both the dipoles of equal radii, we have Cond^n $I_1 = I_2$

then eq^n (1) becomes, $\frac{V_1}{2} = (Z_{11} + Z_{12}) I_1$ —— (2)

If the two dipoles are very close to each other such that spacing b/w the two is of the order of $\lambda/100$ then we can approximate that the self impedance is equal to the mutual impedance b/w the dipoles. i.e, $Z_{11} = Z_{12}$. Hence, eq^n (2) becomes.

$$\frac{V_1}{2} = (Z_{11} + Z_{11}) I_1 \Rightarrow \frac{V_1}{2} = 2(Z_{11}) \Rightarrow \boxed{V_1 = 4 Z_{11} I_1}$$

Z_{11} → Self impedance of one dipole of length $\lambda/2$ is nothing but radiation resistance $= 73\,\Omega$.

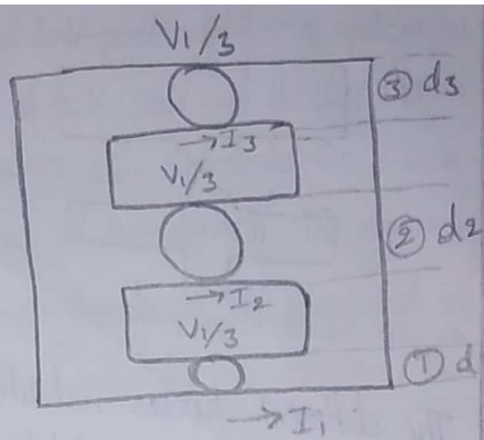
$$Z = 4(73) = 292\,\Omega$$

Thus, the i/p impedance of 2 wire folded dipole of length $\lambda/2 = 292\,\Omega$

Zin of Tripole:-

The voltage for tripole can be written as, $V_1/3$,

$\frac{V_1}{3} = (Z_{11} + Z_{12} + Z_{13}) I_1$, As $I_1 = I_2 = I_3$.



Now consider all the elements are placed very close to each other. Thus $Z_{12} = Z_{13} = Z_{11}$. Then, we get, $\frac{V_1}{3} = (3Z_{11}) I_1$

$$\boxed{V_1 = (9Z_{11}) I_1}$$

we have $Z_{11} = 73$, then, $\boxed{V_1 = 657\Omega}$

→ If the radii are made are unequal, then the general expression for the i/p impedance is given by,

$$\boxed{Z_2 = Z_{11}\left[1 + \frac{r_2}{r_1}\right]^2 = 73\left[1 + \frac{r_2}{r_1}\right]^2}$$

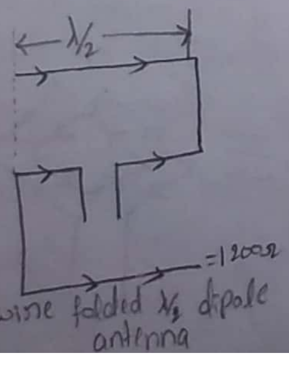
r_1 = Radius of dipole 1
r_2 = Radius of dipole 2

If we select $r_2 = 2r_1$, then $Z = 73\left[1 + \frac{(2r_1)}{r_1}\right]^2 = 9(73) = 657\Omega$.

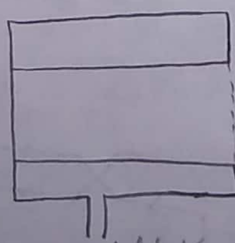
→ The ratio of antenna i/p impedence Z to the self impedance of dipole, then the ratio is called Impedance transformation Ratio (ITR) or Impedance setup ratio.

$$\boxed{ITR = \frac{Z}{Z_{11}} = \left[1 + \frac{\log(a/r_1)}{\log(a/r_2)}\right]^2 = Z_r}$$

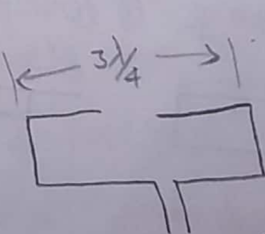
Types of Folded dipole antenna:-



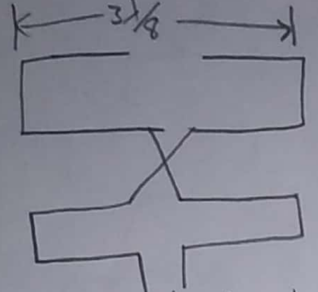
3 wire folded λ/2 dipole antenna



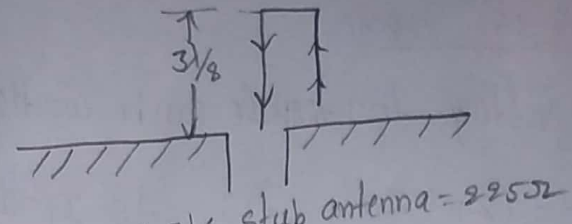
4 wire folded (1400Ω) λ/2 dipole antenna



2 wire folded 3λ/4 dipole antenna = 450Ω



4-wire folded 3λ/8 dipole antenna $= 225\Omega$



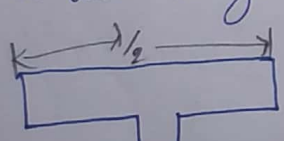
2 wire 3λ/8 stub antenna $= 225\Omega$.

The different dipoles indicates dipoles of different length.

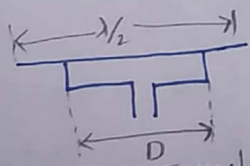
→ Another important folded dipole antenna is planar folded dipoles. Such planar folded dipole may be categorized as symmetrical planar folded dipole and Asymmetrical planar folded dipole. Such antennas are fabricated using PCB using strips on the PCB. By adjusting the widths of the strips, a wide range of the i/p impedance values can be easily achieved. Moreover, the antenna impedance can be matched with the characteristic impedance of the transmission line on printed ckt with 4:1 impedance ratio.

Modifications of Folded Dipole Antenna.

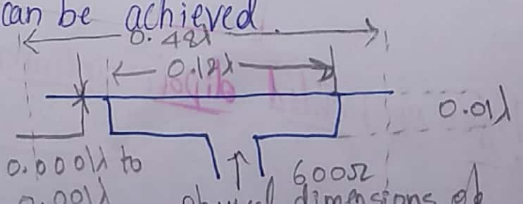
The terminal impedence of a general 2-wire folded $\lambda/2$ dipole antenna is 292Ω or approximately 300Ω. By modifying one of the dipoles we can achieve the terminal impedance of value 600Ω. Such folded dipole antenna is called T-match Antenna. The typical dimensions of T-match antenna to achieve terminal impedence of 600Ω are as shown below. By simply selecting different values of D a wide range of terminal impedence can be achieved.



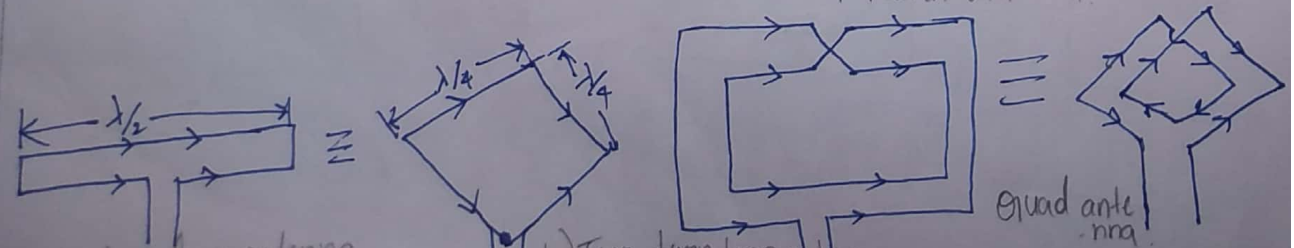
2 wire folded dipole antenna



4 wire T-match antenna



Physical dimensions of T-match antenna



Single turn loop antenna

b) Two turn Loop antenna

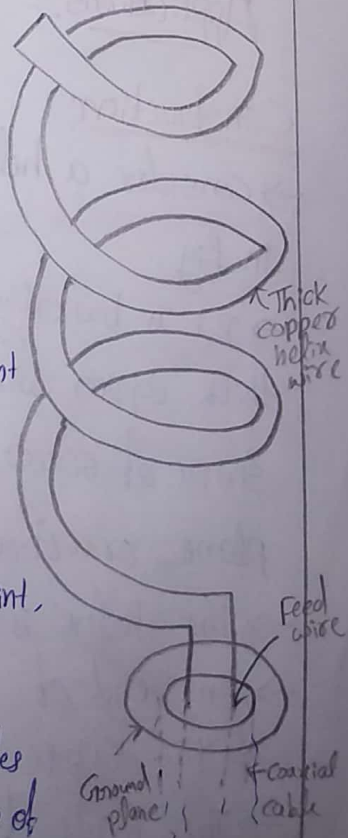
Quad antenna

The single turn loop antenna can be obtained by pulling the $\lambda/2$ dipoles of two wire dipole apart at the center. The length of each side of the loop becomes half of that of the dipole length. That means length becomes $\lambda/4$. Similarly the 2-turn loop antenna is obtained by pulling the dipoles apart at the center. The significance of the loop antennas obtained is that they have terminal impedances less than that of those of the original dipole antennas from which loop antennas are obtained. The two turn loop antenna is popularly known as Quad antenna.

* Applications of Folded Dipole Antenna:-

→ A basic two wire folded dipole antenna is most extensively used as a feed element of TV antennas such as Yagi-uda antennas. The bandwidth characteristic of a folded dipole antenna is far better than that of the single dipole of the same size. As the terminal impedance of the folded dipole antenna can be adjusted over a wide range of impedances using different techniques it can be used as feed element for the antennas with very low and very high terminal impedance so that no impedance matching is required.

* HELICAL ANTENNA:-



→ Helical antenna is basic, simple broadband VHF and UHF antenna which provides circular polarization.

→ It consists of thick copper wire wound in the form of a screw thread forming helix.

→ In general, helix is used with ground planes. These are different forms such as flat ground plane, cylindrical cavity. In general helical antenna is fed with coaxial transmission line in which the central conductor is connected to the helix of the feed point, while the outer conductor is attached to the ground plane.

Operating Modes:- The helical antenna can operate in many modes but the two important modes are normal mode and axial mode of operation. In normal mode, the field radiated by the antenna is max. in a plane normal to the axis of helix and min. along the axis. This mode is also termed as <u>broadside mode</u>.

Axial mode:- In the axial mode, the field radiated by the antenna is max. in the plane along the axis. In axial mode there is only one major lobe with max. intensity along the axis of the helix.

→ The axial mode is the practical mode and it is also known as <u>Endfire mode</u>.

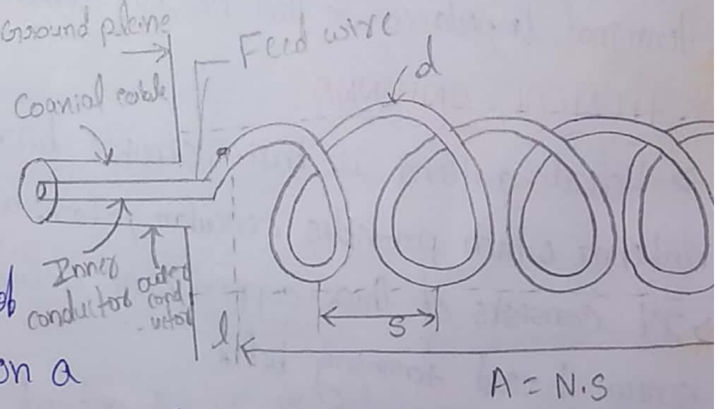
→ The dimensions of the helix in the axial mode are not critical. Hence the endfire or axial helical antenna can be used to achieve circular polarization over a wider bandwidth.

→ For the space commn applications, the helical antennas are most suitable as they have <u>wide bandwidth</u>, <u>higher directivity</u> and <u>circular polarization</u>.

To transmit or receive VHF signals through ionosphere generally an array of helical antennas is used.

Applications:- The helical antenna is used for space and satellite commns

Construction:-



→ Consider a helical antenna as shown in fig.

→ It is basically consists of a helix of thick copper wire or tubing wound on a shape of screw thread and used with a flat metal plate called Ground plane or Grounded plate

→ The helix is fed by a coaxial cable.

→ one end of the helix is connected to the centre or inner conductor of the cable and outer conductor is connected to the ground plane.

→ The mode of the radiation of the antenna depends on the diameter of the helix. i.e. D, the spacing between turns S which is measur between two centres of the turns. The circumference of the helix is denoted by C and it is equal to πD. Then the pitch angle α is give by. $\alpha = \tan^{-1}\left[\frac{S}{\pi D}\right]$ 9

→ For N turns of the helix, the total length of the antenna is equal to N-S while the circumference equals to πD. If we unroll one term of helix on a plane surface, then the circumference, spacing between terms (S), turn length (L) and pitch angle (α) can be related to each other. Then we can write,

$$L = \sqrt{S^2 + C^2} = \sqrt{S^2 + (\pi D)^2}$$

Pitch angle:- It is defined as angle b/w a line tangential to a helix wire and the plane normal to the axis of helix.

→ The pitch angle then can be expressed as, $\tan\alpha = \frac{S}{C} = \frac{S}{\pi D}$

$$\boxed{\alpha = \tan^{-1}\left[\frac{S}{\pi D}\right]}$$

→ In general, a helical antenna can radiate in many modes. But the most important modes of radiation are as follows.

(i) Normal or perpendicular mode of radiation.

(ii) Axial or End fire or beam mode of radiation.

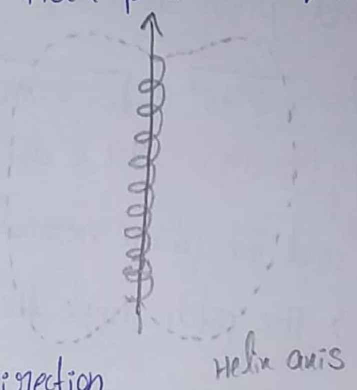
(a) Normal or perpendicular Mode of Radiation:-

In this mode of helical antenna, the radiation is max. in boundary broadway direction. Normal or perpendicular to the axis of the helix, hence the mode is called normal or perpendicular mode of radiation. The radiation in the direction normal to the helix axis is circularly polarized wave.

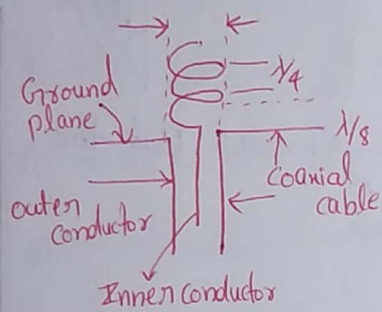
→ This mode of radiation can be obtained if the helix dimensions are made very small as compared with radiation is $N \cdot S << \lambda$. But with this mode of radiation, the bandwidth of antenna becomes narrow and radiation efficiency also becomes very less.

→ The Radiation pattern of helical antenna in a normal mode is a combin-ation of the equivalent radiation from a short dipole located on the same helix axis and form a small which is coaxial with the same helix axis.

→ Thus, the resultant radiation pattern for the helical antenna in the normal mode can be obtained by superimposing the field patterns of the loop and the dipole for circular polarization as shown below.



b) AXIAL OR END FIRE MODE OF RADIATION

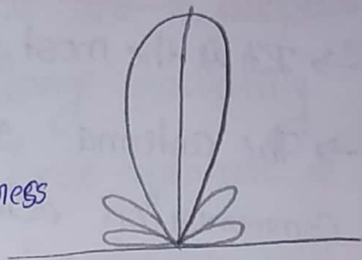


The helical antenna radiating field max. in the end fire direction. i.e, along the axis of helix is called axial mode or end fire mode helical antenna. with the axial mode of radiation, the polarization of the wave is either circular or nearly circular. The main difference in the radiation pattern of the normal mode and axial mode is that in the axial mode, radiation is max. along the helix axis while in normal mode, radiation is max. in the direction normal to the helix axis.

The two parameters of the helical antenna which decide the mode of radiation are spacing b/w two turns(s) and diameter of helix (D). With these two parameters are of the order of one wavelength to achieve the axial mode of radiation. Note that in the normal mode, the dimension $N.s << \lambda$. The axial mode radiation of the helical antenna is more important because of the helical antenna is more im) practical antennas. similar radiation patterns with the features like broad and directional beam in axial direction and minor lobes at oblique angle.

→ For the axial mode, the pitch angle α varies from $12°$ to $18°$. The optimum pitch angle is $14°$. The terminal impedance is resistance at resonant frequency and it becomes reactive at higher and lower frequencies.

→ The terminal Impedance, $\boxed{R = \frac{140C}{\lambda}}$



R.P of helical antenna in axial mode

$HPBW = \frac{52}{C}\sqrt{\frac{\lambda^3}{N \cdot S}}$ degrees, $BWFN = \frac{115}{C}\sqrt{\frac{\lambda^3}{N.S}}$ degrees

$GD = \frac{15NSC^2}{\lambda^3}$, $\boxed{\text{Axial ratio (AR)} = 1 + \frac{1}{2N}}$

→ The helix can have either right handed pitch or left handed pitch. Then accordingly circular polarization may be right handed or left handed. Moreover, a receiver helical antenna with right handed pitch cannot receive left handed circularly polarized wave.

SALIENT FEATURES OF HELICAL ANTENNA:-

→ Helical Antenna is used in circular polarization.

→ mostly used in VHF and UHF bonds.

→ Axial mode of helical antenna is most widely used.

→ The antenna in axial mode has larger bandwidth but normal mode bandwidth and efficiency both are Small.

→ Its Construction is simpler and directivity is higher.

→ If axial ratio AR=0, linear horizantal polarisation is resulted. For AR=∞, linear vertical polarisation is resulted. For AR=1, Circular polarization is resulted.

* Applications of Helical Antennas:-

→ Used to achieve circularly polarized waves are extremely wide-band width.

→ Used in space Commⁿ systems.

→ Transmitting telemetry data from moon to earth.

→ used in transmitting or receiving VHF signals through the Ionosphere.

→ Used in space probe communication.

* HORN ANTENNAS :-

→ It is the most widely used simplest form of microwave antenna.

→ The antenna serves as a fed element for large radio Astronomy, Communication dishes and satellite tracking throughout the world.

→ As it is widely used at uwave frequencies, it may be considered as aperture antenna.

→ The horn antenna can be considered as a waveguide with hollow pipe of different cross-sections which is flared or tapered into large opening. With one end of the waveguide is excited while other end is kept open, it radiates in open space in all directions. As compared with the radiation through the waveguide is large. The waveguide, the small amount of the power in the Incident wave is radiated, while due to the open circuit at other end large amount of power is reflected back. As one end of the waveguide is open circuited, the impedance matching with the free space is not perfect. At the edges of the waveguide, diffraction takes place, which results in poor radiation. Also the radiation pattern is non directive.

In order to overcome these limitations, the mouth of the waveguide is flared or opened out such that it shapes like horn. When the transmission line is opened out, dipole is obtained. The advantage of terminating the waveguide into an electromagnetic horn is that instead of open circuit at one end of the waveguide, properly shaped gradual transition takes place. Under the condition of proper Impedance matching, the total power incident will be radiated in forward direction. Thus the radiation is increased. As the edges are flared out the diffraction at the edges reduces and thus directivity improves.

→ A horn antenna is an aperture antenna which is used to properly match the waveguide or any guiding system to a large radiating aperture by shaping the transition gradually. The large aperture is necessary to improve directivity and to produce efficient radiation with proper matching with free space. The horn antenna is most useful for broadband signals.

TYPES OF HORN ANTENNAS:-

→ The horn antenna is nothing but a flared out or opened out waveguide. The main function of the horn antenna is to produce a uniform phase front with a aperture larger than waveguide to give higher directivity.

→ Basically, the horn antennas are classified are classified is Rectangular Horn antennas or circular horn Antennas. The rectangular horn antennas are fed with the rectangular waveguide. While the circular horn antennas are fed with circular waveguide.

→ Depending upon the direction of flaring, the rectangular horns are further classified as sectoral horn and pyramidal horn.

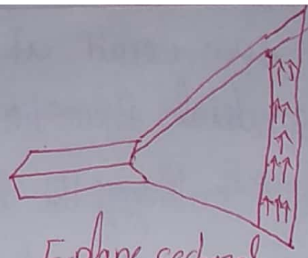
→ It is brodband antenna.

→ It is Microwave antenna and it is nothing but waveguide antenna.

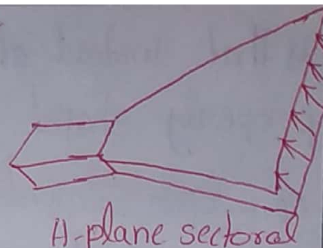
→ It is having larger Aperture Area.

SECTORAL HORN:-

→ A sectoral horn is obtained if flaring (tapering) is done in one direction only.



E-plane sectoral horn



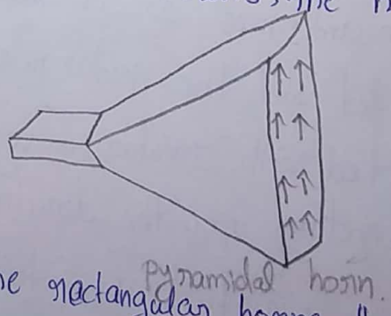
H-plane sectoral horn

→ A sectoral horn is ~~E-p~~ further classified as E-plane sectoral horn and H-plane sectoral horn. E-plane sectoral horn is obtained when the flaring is done in the direction of the Electric field vector. The H-plane sectoral horn is obtained when the flaring is done in the direction of Magnetic field vector. In both the E-plane and H-plane sectoral horns, the flaring is done along the single wall of the rectangular waveguide in one direction.

In both the cases, the arrows indicate the direction of E and the lengths of the arrows indicate the direction approximate magnitude of the field Intensity.

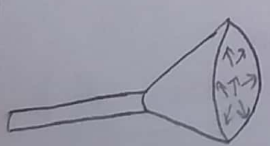
Pyramidal horn → It is most widely used electromagnetic horn which has characteristics as a combination of E-plane and H-plane sectoral horns.

When the flaring is done along both the walls of the rectangular waveguide in both the direction of E and H field vectors, the horn obtained is called pyramidal horn.



Pyramidal horn.

Circular Horn antennas:-



Conical horn

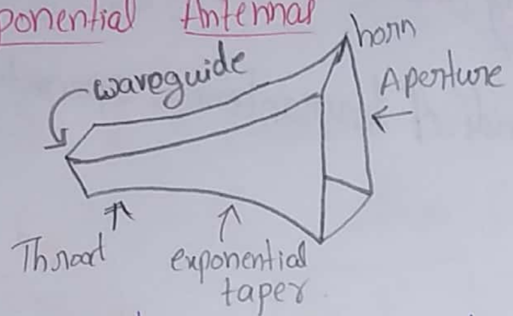
Biconical horn

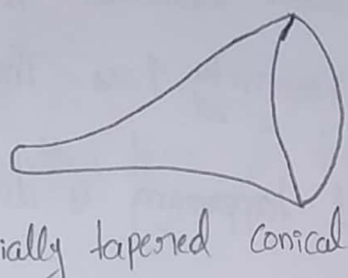
Similar to the rectangular horns, the circular horn antennas can be obtained by flaring the walls of the circular waveguide.

→ The circular horn antennas namely conical horn and biconical horn antenna.

Many times, the transition region b/w the throat of the waveguide and the aperture is tapered with a gradual exponential taper. This minimizes the reflections of the guided wave.

Exponential Antennas





Exponentially tapered conical

→ Horn antenna is the aperture antenna which is having larger aperture antenna to increase the radiations and directivity in desired direction

→ This is also called waveguide antenna because, as the incident wave travelling in the one end.

Eg:- open pipe. the incident wave at open end, only some radiations occur outside and some are radiated back. So inorder to ↑se the radiations the structure at open end should enlarge i.e, large appertore area, threeby no radians and reflected back, and complete wave guide is converted into free space waves. Thats why it is called waveguide antenna.

Depending on direction of flowing/tappering, horn antenna is classified as below.

Horn Antenna

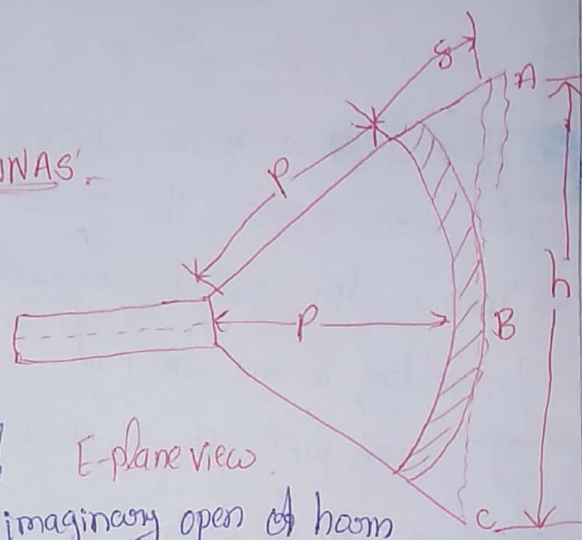
- Rectangular Horn Antenna (feed with rectangular waveguide)
  - sectoral HA (flaring is done in only one direction) (or)
  - pyramidal HA (flaring is done in two direction)
- circular horn antenna (feed with circular waveguide)
  - conical horn
  - Biconical horn
  - Exponential taper
  - Exponentially taper Conical

Tappering / flaring:-

Rato of magnitude of current of center element to edge element in binomial Antenna. Generally, the binomial antenna has max. radiations at center and min. radiations at end side. so, as the tappering ratio increases. The radiations in desired direction increase, Therefore. Directivity ↑ses. This indirectly indicates the max. aperture area.

So, if tappering is done open ends of horn antenna, operature area increases.

DESIGN EQUATIONS OF HORN ANTENNAS.



Consider E-plane sectoral horn
The EM horn produces uniform phase front with the larger aperture as compared with the waveguide. Because of this the directivity increases. Consider an imaginary open of horn. Assume that their exists a line source which radiates cylindrical waves.

E-plane view

→ The constant or uniform wavefronts are cylindrical as the waves propagate in the direction radially outwards. At any point on the aperture the phase is different that of origin. The reason of the difference in phase is that the wave traces different distances from apex to the aperture. Let δ be the difference in the path of travel.

From the geometry, $\cos\theta = \frac{\rho}{\rho+\delta}$, $\tan\theta = \frac{h/2}{\rho} = \frac{h}{2\rho}$

hence, we can write,

$$\cos\theta = \frac{\rho}{\rho+\delta} \Rightarrow \theta = \cos^{-1}\left[\frac{\rho}{\rho+\delta}\right] \quad -(1) \qquad \theta = \tan^{-1}\left[\frac{h}{2\rho}\right] \quad -(2)$$

Equate ① & ②, $\boxed{\theta = \cos^{-1}\left[\frac{\rho}{\rho+\delta}\right] = \tan^{-1}\left[\frac{h}{2\rho}\right]}$ — ①

From right angle triangle OBA, $(\rho+\delta)^2 = \rho^2 + \left(\frac{h}{2}\right)^2$

$(\rho+\delta) = \sqrt{\rho^2 + (h/2)^2}$ (from hypoteneuse theorem).

$(\rho^2 + 2\rho\delta + \delta^2)^2 = \rho^2 + \frac{h^2}{4}$.

As δ is fractional, δ^2 will be smaller than δ, hence neglecting

$\therefore 2\rho\delta = \frac{h^2}{4}$, where $\delta \ll \rho$.

$$\boxed{\rho = \frac{h^2}{8\delta}} — ②$$

eqⁿ ① & ② are called design eqⁿs of horn antenna.

→ Flare angle can be easily adjusted in this antenna only.

→ When θ decreases, ρ increases, length of aperture decreases, Beamwidth increases, as beam width $\propto \frac{1}{\text{Directivity}}$. Directivity decreases. So ρ should be min. in such a way, because the radiations must be near the aperture area.

So, flare angle should be selected in such away that ρ should be min.

→ optimum ρ, θ means the values at which the radiations are max. in particular desired direction upto a certain level. Half power bandwidth for optimum flare horn.

$a_E \rightarrow$ E-plane aperture
$a_H \rightarrow$ H plane aperture.

$$\theta_H = \frac{67^\circ \lambda}{a_H}, \quad \theta_E = \frac{56^\circ \lambda}{a_E}$$

As we know that $A_E = \frac{D.\lambda^2}{4\pi} \Rightarrow D = A_E \cdot \frac{4\pi}{\lambda^2}$.

$A_e = E_{ap} \cdot A_e \left[E_{ap} = \frac{A_e}{A_{ep}}\right]$ E_{ap} – Aperture efficiency
A_{ep} – physical aperture.

At optimum value, $E_{ap} \simeq 0.6$

$$D = \frac{4\pi (0.65)(A_{ep})}{\lambda^2} \Rightarrow \boxed{D = \frac{7.5 A_{ep}}{\lambda^2}}$$

Case(i):- Directivity of Rectangular Horn Antenna

$A_{ep} = A_E \times a_H$

$$\boxed{D \cong \frac{7.5 (a_E \times a_H)}{\lambda^2}}$$

Features of Horn Antenna.

→ Horn antenna is used with waveguide if it is used as radiator. Generally used with paraboloidal antenna as primary antenna.

Case(ii) Directivity of pyramidal horn antenna:

$A_{ep} = \pi r^2$

$$\boxed{D \simeq \frac{7.5 \pi r^2}{\lambda^2}}$$

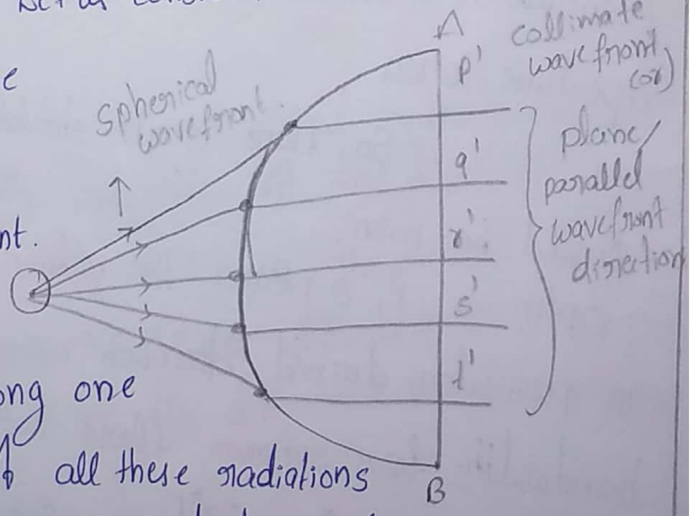
→ For pyramidal horn the directivity is if the flare of the horn is in more than one radiation.

* FERMATS PRINCIPLE / PRINCIPLE OF EQUALITY OF PATH LENTHS

Fermats principle:-

It says that the distance travelled by the radiating source from the focal point to the mouth of direction is same.

Consider concave lens antenna. Let us consider the focus point and lf be the focal distance. The radiating source is placed as a focal point. Then there source radiates radiations and there are along one directions. Hence, combination of all these radiations are called spherical wavefront. The radiations from P,q,r,s,t to the end (mouth) of distrix and they are radiated outside.



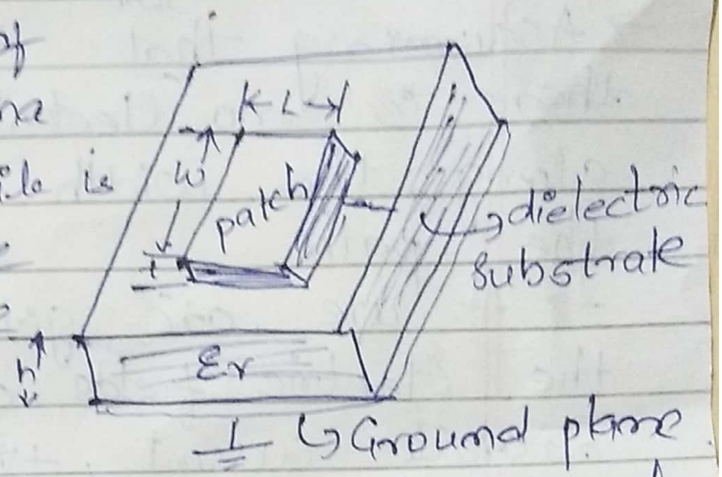
Hence the distance, $OPP' = OqQ' = Orr' = Oss' = Ott'$

Where $OP \neq Oq \neq$ or $\neq Os \neq Ot$.

Microstrip Antennas / Patch Antenna

A metal microstrip antenna consists of a radiating metal patch on one side of a dielectric substrate which has a ground plane on the other side.

It is a kind of Internal antenna because as mobile is very compact we can easily place this antenna.



→ The patch is made up of conducting material such as Copper (or) Gold.

→ It is available in any shape

→ The radiating patch and the feed lines are photo-etched on the dielectric substrate.

Radiation Mechanism

Consider the rectangular patch [RMSA] Rectangular Microstrip Antenna. For a rectangular patch,

→ $0.3333\lambda_0 < L < 0.5\lambda_0$

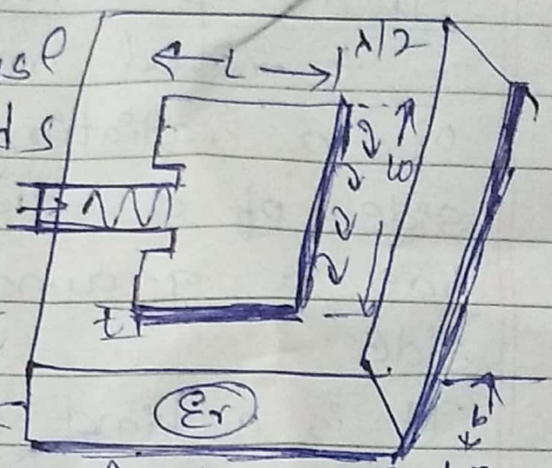
→ $t << \lambda_0$

→ Height of the dielectric substrate

$0.003\lambda_0 \leq h \leq 0.05\lambda_0$

$2.2 < \varepsilon_r \leq 12$.

→ Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane



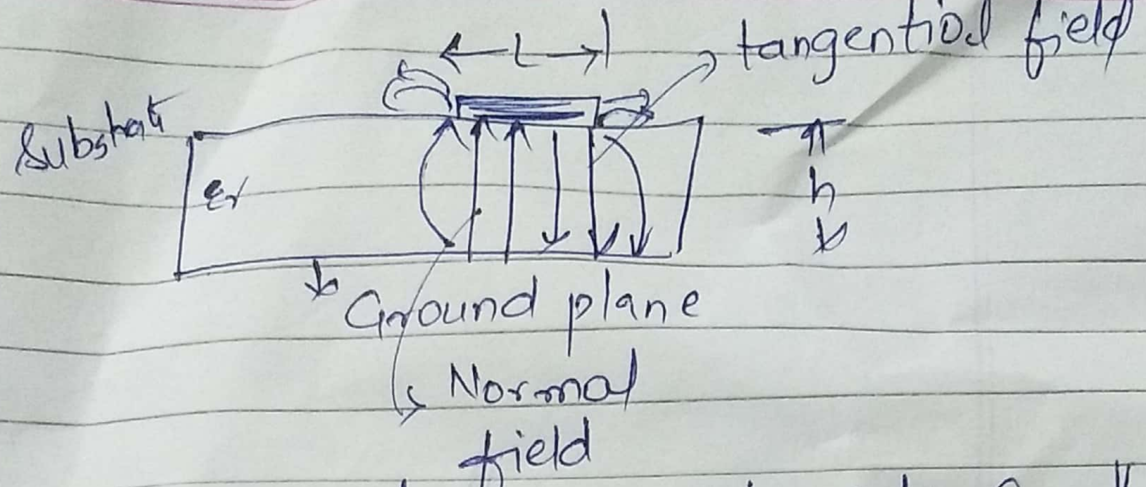
→ Assuming that there is no electric field variation along the width and thickness of the path.

→ As we are giving i/p to this line the Electric fields created as like a alternate current, +ve & -ve. So, it starts radiating /oscillating /vibrating inside this metal pad. At the last slot, the signal can be radiated as fringing effect. Here, there is no Electric field variation along width and thickness. There is a field variation along length of patch only.

→ The field at the end can be resolved into normal and tangential components with respect to ground plane.

→ The normal components are out of phase.

Therefore, the far field cancels in the normal direction



The normal Compoments gets Cancelled but tangential Compoments are in phase and the resulting fields Combine to give max. radiated field. The max. radiation occurs ||ar / normal to patch Antenna

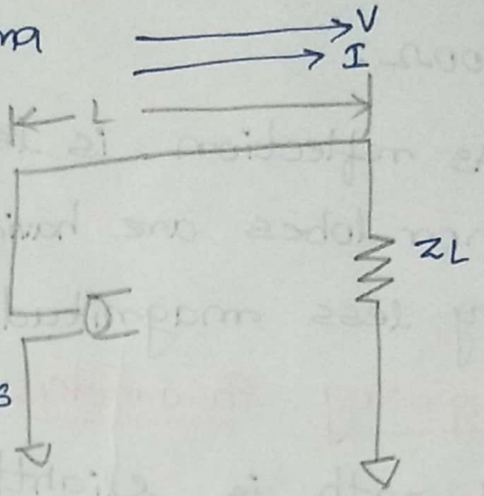
Trade off b/w Antenna dimensions and performance

→ Thick dielectric Substrat having a low dielectric constant makes good antenna performance. i,e Better radiation but larger bandwidth, high Gain. But, it leads to larger antenna size. So, we cannot make use this as Internal antenna.

→ So, in order to design Compact patch antenna, Substrates with high dielectric constant must be used. But, this will provide low antenna performance. So, we need to select

Travelling Wave Antenna

→ Non Resonant Antenna



Structure:-

We connect load at the end in non resonant category. As load is connected, the reflections are less. The load is matching with the antenna. In resonant antenna, incident and reflected waves are there. and standing waves are produced. If the wire is less, the characteristic Impedance of wire should be equal to the load. If the wire is so long, the load should simply connected with Z_0. Now if we follow this case, standing pattern is generated.

Basics of Travelling Wave Antenna:-

→ It is long wire antenna at far end terminated by matched load.

→ So, there is less reflection, ideally no standing pattern.

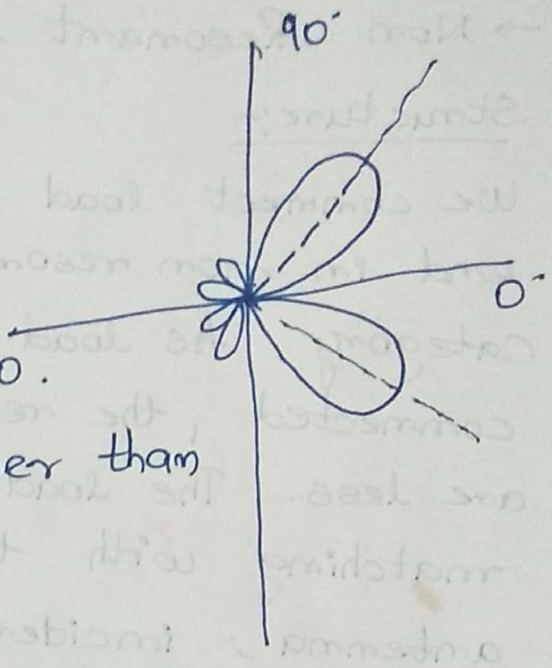
→ Length may or may not be $(n\lambda/2)$. It's somewhat less than H.

→ Due to termination by matched load, unidirectional radiation pattern.

→ Angle of lobes vary with frequency.

→ characteristic Impedance is found to be 600Ω.

→ As reflection is less, minor lobes are having very less magnitude



Designing Parameters

(1) Length is slightly lower than $\left(\frac{n\lambda}{2}\right)$

→ Load Resistance

$$R_L = 138 \log\left(\frac{4h}{d}\right)$$

where h is height of wire from Ground

d — diameter of wire

Advantages:-

→ Very simple
→ Economical
→ Effective in the MF (300k - 3M) and (3 - 30M)
→ properities enhance when used in array

Disadvantages:-

→ Major lobe ~~is~~ is little inclined at an angle and controlled by its length.
→ Poor directivity.
→ Power density in Minor lobe.

Long wire Antenna

There are two types of Long wire antenna

1) Resonant Long wire Antenna
2) Non Resonant Long wire antenna / Travelling wave Antenna

Basics of Resonant Long wire antenna

→ When the length of antenna is integral multiple of half wavelength the antenna is said to be resonant Long wire Antenna.

→ In this case both incident and reflected waves are present on the long wire, resulting in standing waves on the wire.

→ Two waves in opposite direction results in a bidirectional radiation pattern

V- Antenna

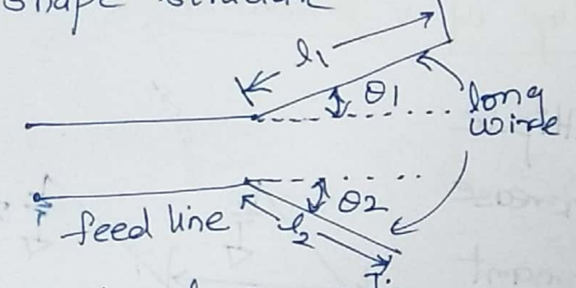
As we know the long wire antenna are having simple structure but for some applications, it is not practically used because of following reasons. They are

→ Low directivity, high side lobes, Angle of beam based on length.

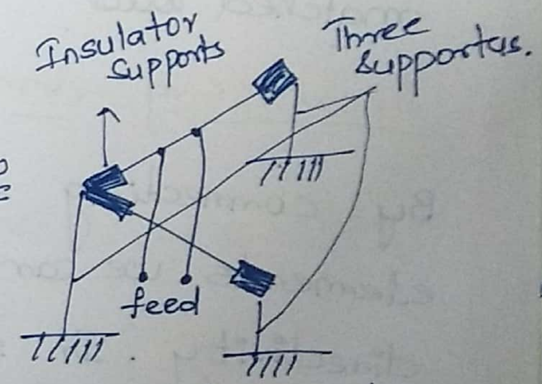
These are avoided with the help of V-antenna.

Structure of V- antenna

This is so called V-antenna because it has V-shape structure



Electrical Connection structure

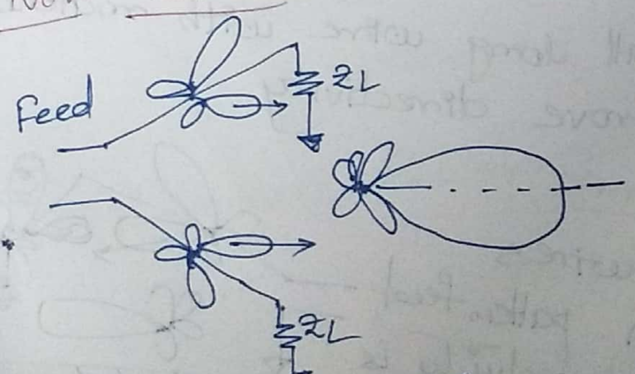


physical structure

Types of V Antenna

→ Resonant V, Non resonant V, Inverted V.

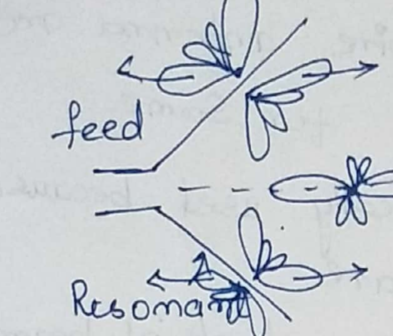
Non Resonant V



The two long wire antennas are terminated with a matched load. The above are the radiation patterns for individual long wire antennas

As the two radiation pattams are in the forward direction the resultant radiation pattern will be also in forward direction. As the two long wires are connected to a matched load, those are known non resonant V antenna.

Resonant V



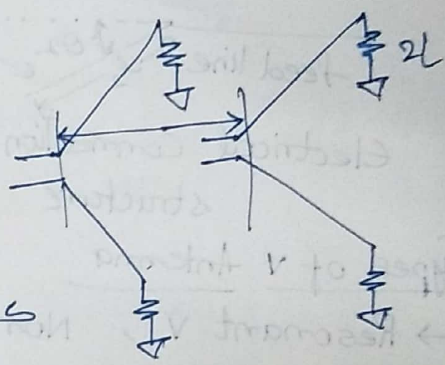
It is so called because, the long wires are not terminated with a matched load. The individual radiation patterns are as shown aside. It has four major lobes. So, resonant V antenna will have major lobes in opposite direction also.

≅

So, these two are differed based on the matched load.

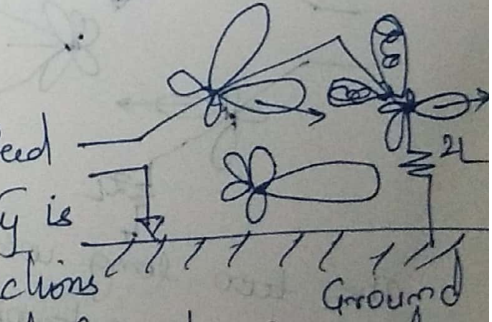
Increasing directivity of V-antenna

By connecting multiple elements we can increase directivity. In resonant type, there are two major lobes, but in non resonant, there is single major lobe.



→ By terminating all long wire with matched load we can improve directivity.

Inverted V type Antenna



As both the long wires are having radiation pattern in same direction, directivity is high. Inverted V antenna functions based on Imaginary Ground Concept. The feed line and load are connected to Ground. The mirror Image will be formed as Imaginary in ~~it~~ below the Ground.

Design parameters of Resonant Wire antenna

→ length of Resonant wire antenna

$$L = \frac{n\lambda}{2} = \frac{492\,(n - 0.05)}{2} \quad (\text{ft})$$

→ Electric field

$$\vec{E} = \frac{60 I_{rms}}{r}\left[\frac{\cos\left(\frac{n\pi}{2}\cos\theta\right)}{\sin\theta}\right] \quad n \text{ is odd}$$

$$= \frac{60 I_{rms}}{r}\left[\frac{\sin\left(\frac{n\pi}{2}\cos\theta\right)}{\cos\theta}\right] \quad n \text{ is even}$$

→ Maximum angle Radiation

$$\cos\theta_{max} = \frac{n-1}{n}$$

→ Radiation Resistance

$$R_r = 73 + 69 \log n.$$

→ These are mostly used in robot application because the orientation of radiation pattern is easily changed as long wire antenna is changed accordingly. Therefore, these long wire antennas are used in small scale applications

Disadvantage of V Antenna

→ The radiation pattern will have many considerable minor lobes.

→ These lobes results in horizontally polarized waves transmitted in some directions. Thus Inverted V antenna will receive horizontally polarized waves from these directions.

Long wire Antenna

There are two types of Long wire antenna

1) Resonant Long wire Antenna

2) Non Resonant Long wire antenna / Travelling wave Antenna

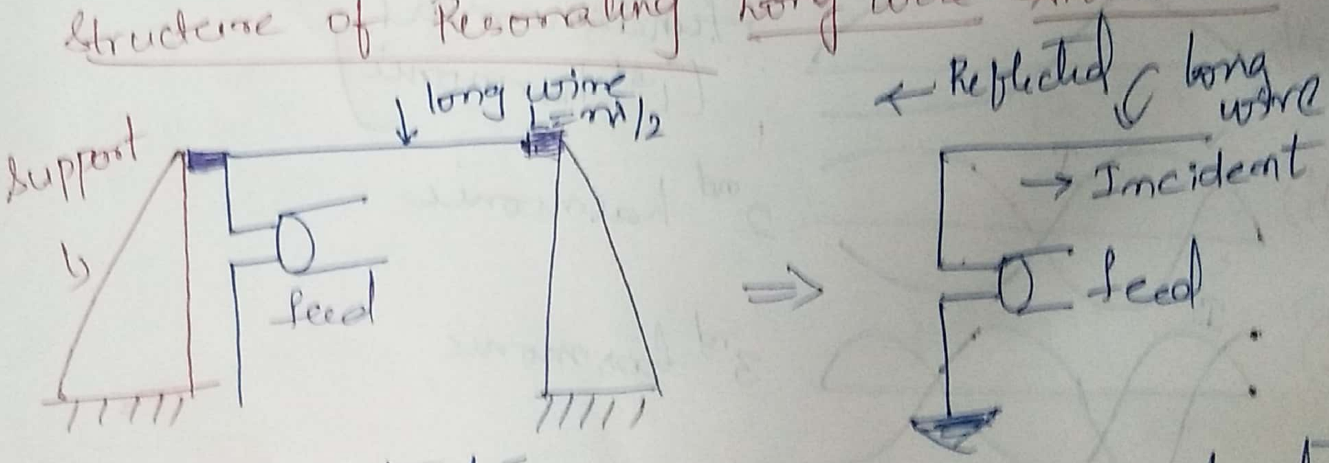
Basics of Resonant Long wire antenna

→ When the length of antenna is integral multiple of half wavelength the antenna is said to be resonant Long wire Antenna.

→ In this case both incident and reflected waves are present on the long wire, resulting in standing waves on the wire.

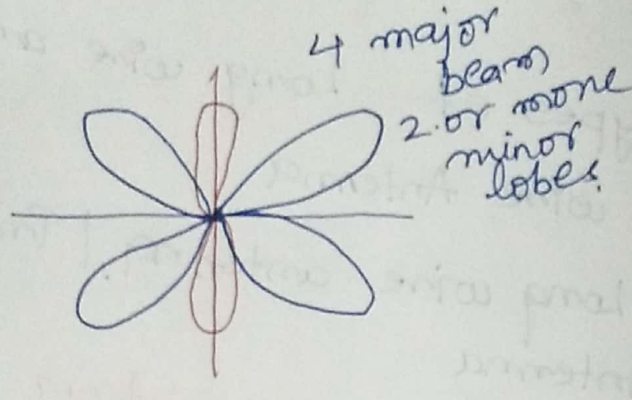
→ Two waves in opposite direction results is a bidirectional radiation pattern

Structure of Resonating long wire Antenna



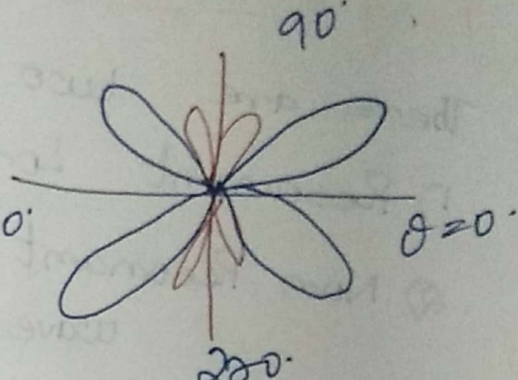
physical structure   Electrical structure

At one end feed is provided with respect to Ground. Because of Incident and reflected waves standing waves are generated and bidirectional pattern is observed.

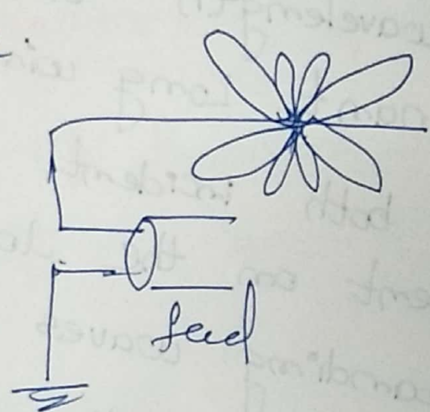


$m=3$, $L=\frac{3\lambda}{2}$

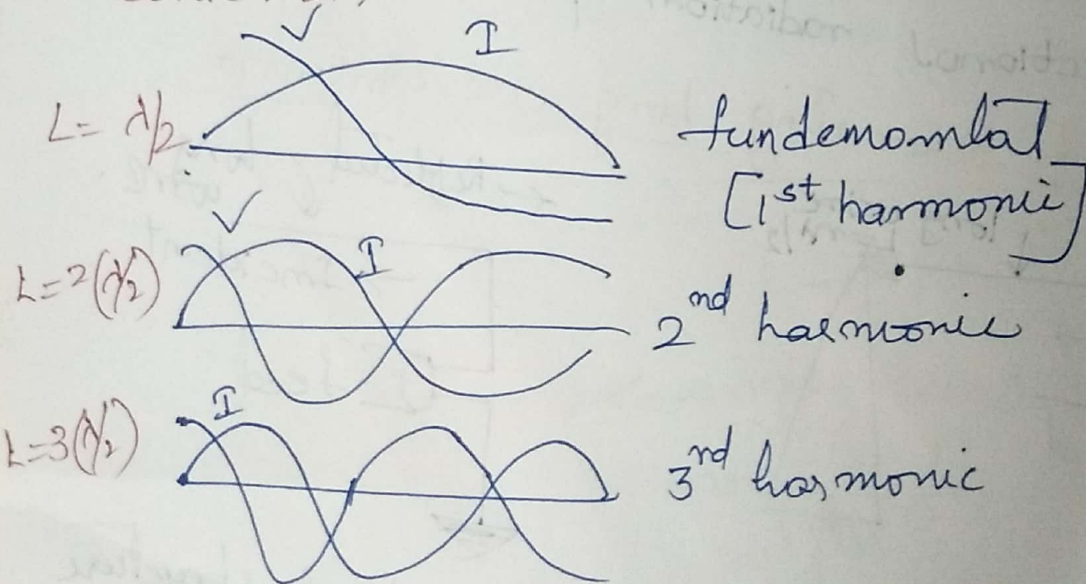
Because of $L=\frac{3\lambda}{2}$
2 minor lobes are there.



$m=4$, $L=\frac{4\lambda}{2}$,
4 minor lobes



Resonant long wire antenna as harmonic antenna.



Q Rhombic Antenna

Basics:-

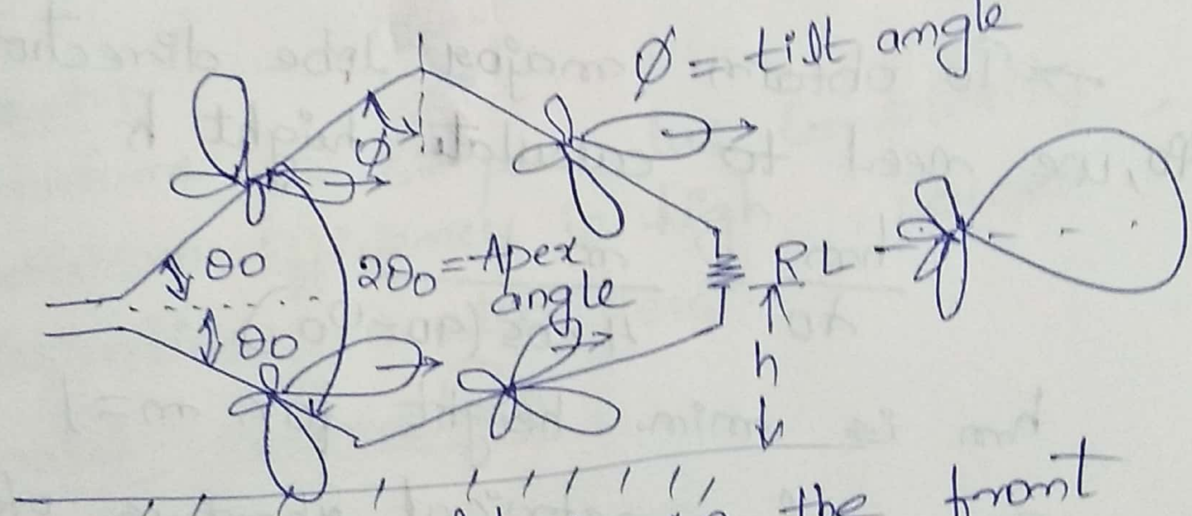
→ It's name comes from, its diamond - shaped layout.

→ It is array of four Interconnected long wire antennas.

→ It is also called as double V antenna (Inverted)

→ It needs 600-800Ω terminator resistance to minimize radiation loss, reflection loss.

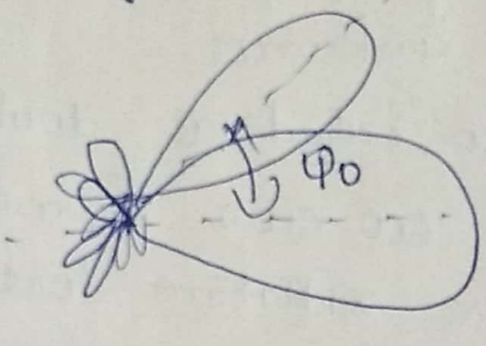
Structure of Rhombic Antenna



The no. of lobes in the front direction are high when compared to other directions. The 4 major lobes algebraically forms one of the other major lobe in front direction and minor lobes in the other direction.

If there is a ground with respect to Ground, the path gets tilted.

If Ground is placed nearer to rhombic antenna, the radiation pattern gets tilted and gets shifted with an angle of φ_0 direction φ_0



<u>Design of Rhombic Antenna</u>

→ To obtain major lobe direction φ_0, we need to calculate height h.

$$\frac{h_m}{\lambda_0} = \frac{m}{4\cos(90-\varphi_0)}.$$

h_m is min. height for $m=1$

→ For a symmetrical rhombus of leg lengths l are equal

$$\frac{l}{\lambda_0} = \frac{0.371}{1-\sin(90-\varphi_0)\cos\theta_0}$$

$2\theta_0$ = Apex Angle

Hence,

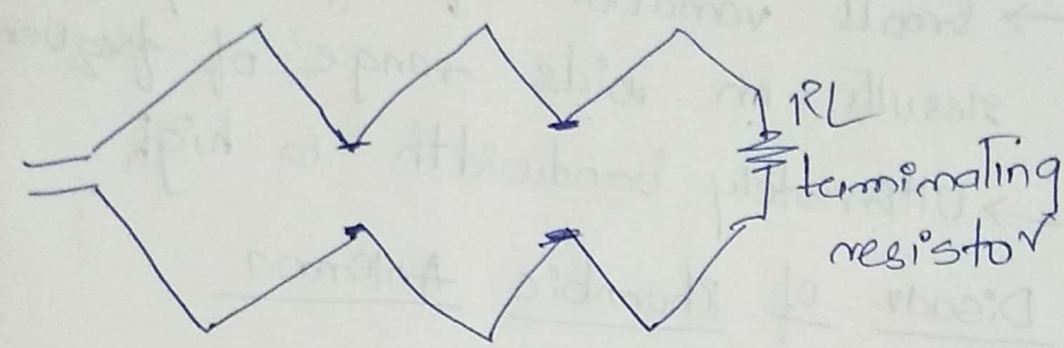
$$\theta_0 = \cos^{-1}\left[\sin(90-\varphi_0)\right]$$

φ_0 = Angle of radiation / direction of Major lobe.

Scanned with CamScanner

Array of Rhombic Antenna

Series Connection

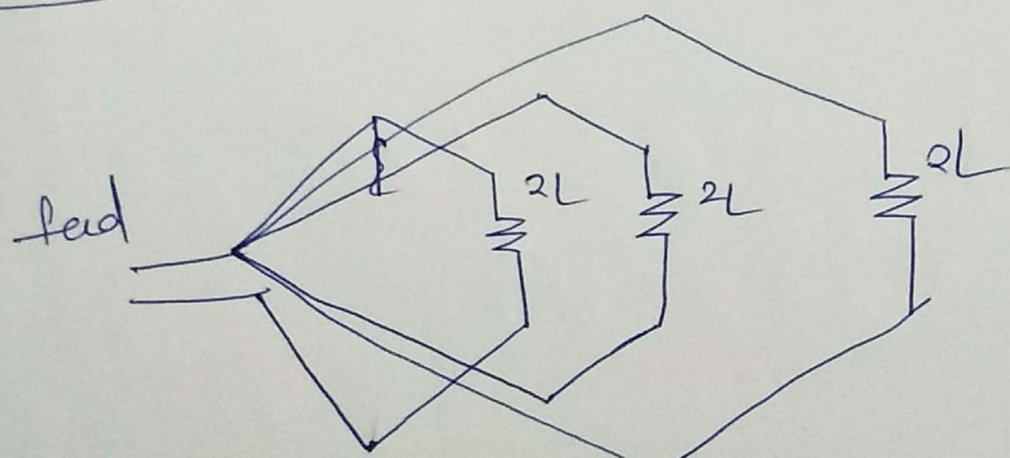


disadv:-

→ It takes more space

adv:-
structure is simple, less complexity, radiation efficiency is high, power dissipation is also less.

Parallel Connection



Adv. of Rhombic Antenna

→ simple and cheap
→ Vertical radiation is low, hence it is suitable for long distance communication F layer propogation

→ short wave antennas of this type require low height

→ Small variation of i/p impedance results in wide range of frequency.

→ Ultimately bandwidth is high

Disadv. of Rhombic Antenna

→ Large space.

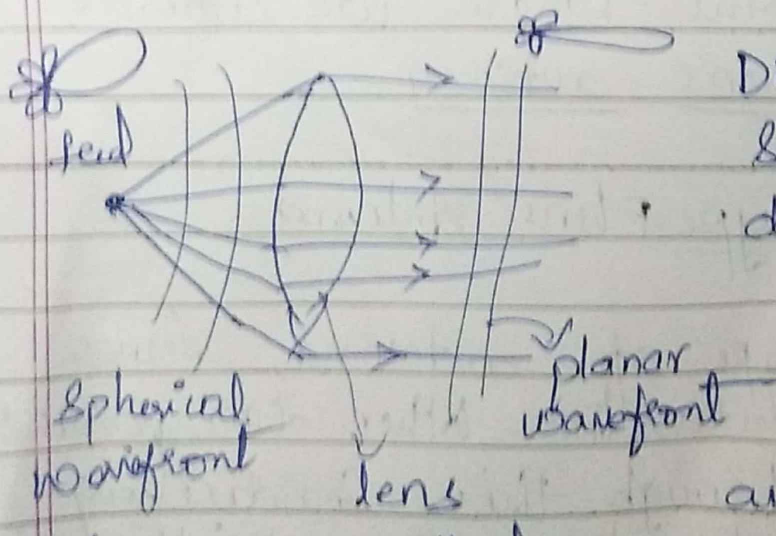
→ Minor lobes reduce transmission efficiency.

→ Half power is wasted in terminating resistor.

Lens Antenna:

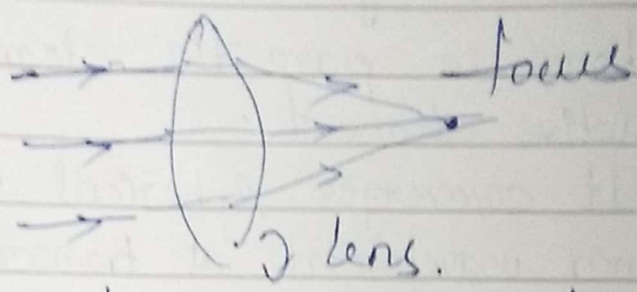
(1) It is an antenna which consists an Electromagnetic lens with feed.
(2) Lens is parasitic element and feed is active element.
(3) It converges Spherical wavefront into planar wavefront at transmitting side and planar wavefront to spherical at receiver side.
(4) It is typically thicker, heavier and more difficult to construct.
(5) It has one advantage over reflector antenna, blockage is not happening.

Principle of lens antenna



Directivity increases So, radiation in desired direction increases. So, shape of major lobe changes and beamwidth ↓ses

Lens is called parasitic element bcz, we are not directly providing feed to lens. When lens used as receiving antenna, the incoming signal is planar of wavefront and converted to Spherical wavefront and that is going to focused at feed.

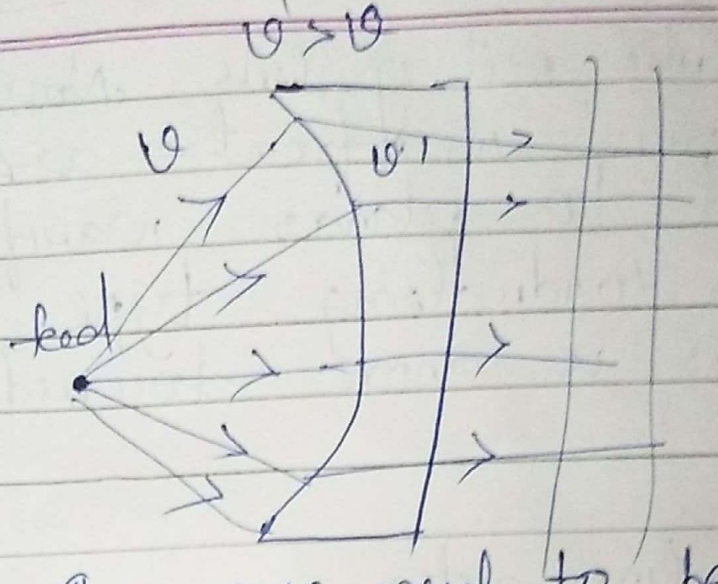


If feed aperture is less, then also it receives higher amount of power. Lens is not basically only single antenna. Along with other antenna, lens should be used. And lens is also one of the parasitic element which is used to increase its radiation characteristics. So, lens converges and also provides focused wavefront at focal point where we connect feed.

Types of Lens antenna.

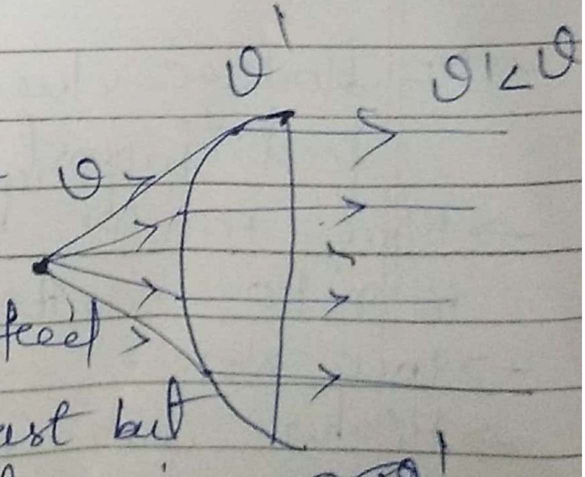
Conducting type E lens Antenna

In this type of antenna, lens working as accelerator. When Em waves propogates through this conducting material, it travels with velocity v before the wave travels with velocity v in free space. That means the velocity of charges ↑ses and it acts as accelerator.



The wave need to be accelerated because as spherical wavefront should be converted into planar because at some places higher pathlengths are required and at some places lower pathlengths are required to meet planar wavefronts.

Dielectric Type

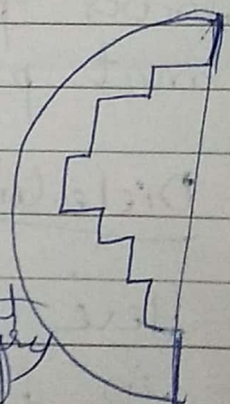


Here, the wave in free space at ϑ velocity. At centre, the waves reaches fast but as thickness of lens is high the waves takes large time as deacceleration takes place. But at ends, the wave reaches slow but bcz of less thickness of lens, inside lens less time will take. Finally, the waves will come at

Same time out of lens. Now, the Spherical wavefronts are converted to planar wavefronts. But in conducting type lens, thickness is more towards edge.

Zoned lens antenna

As lens antenna is bulky, to radiate its waves difficultly. So, the lens will be cutted into required shaped and this is so called Zoned lens antenna



Adv of lens Antenna

→ No blockage due to feed and feed support but feed is not b/w primary & secondary
→ More Em can be received w.r.to parabolic Reflector
→ Low Noise
→ Higher Gain Compared to reflector antenna

Disadv

→ lens are heavy
→ Complex to Construct
→ Costlier as Compared to reflector

Appns

→ for narrow beamwidth
→ Microwave Transmission

~~Sources of Error in Gain Measurement~~

Antenna Measurements:-

There are two ways to measure gain

(1) Absolute Method → Two antenna Method
→ Three antenna Method.

(2) Comparison Method

Two-Antenna Method:-

In this method, two identical antennas are considered. From friis transmission formulae.

$$P_R = P_T \cdot G_T \cdot G_R \left(\frac{\lambda}{4\pi R}\right)^2 \text{ — } (1)$$

$\lambda \rightarrow$ operating wavelength

$R \rightarrow$ Spacing b/w two elements

By taking log at both sides

$$\frac{P_R}{P_T} = G_T \cdot G_R \cdot \left(\frac{\lambda}{4\pi R}\right)^2$$

$$10 \log\left[\frac{P_R}{P_T}\right] = 10\log[G_T] + 10\log[G_R] + 20\log\left(\frac{\lambda}{4\pi R}\right)$$

$$10\log\left[\frac{P_R}{P_T}\right] = (G_T)dB + (G_R)dB + 20\log\left(\frac{\lambda}{4\pi R}\right)$$

$$10\log\left[\frac{P_R}{P_T}\right] + 20\log\left(\frac{4\pi R}{\lambda}\right) = (G_T)_{dB} + (G_R)_{dB} \text{ — } (a)$$

Since, two antennas are same and they are Identical

$$(G_T)dB = (G_R)dB \text{ — } (b)$$

From Eq^n (a) & (b)

$$2(G)_{dB} = \left[20\log\left(\frac{4\pi R}{\lambda}\right) + 10\log\left(\frac{P_R}{P_T}\right)\right]$$

$$(G)_{dB} = \frac{1}{2}\left[20\log\left(\frac{4\pi R}{\lambda}\right) + 10\log\left(\frac{P_R}{P_T}\right)\right]$$

Three Antenna Method

→ If we don't have two identical antenna, then we can use three different Antenna of Gain G_1, G_2 and G_3. Now Combine any two antennas and make them as transmitting antenna.

→ If we combine 1 & 2.

$$(G_1)_{dB} + (G_2)_{dB} = 20\log\left(\frac{4\pi R}{\lambda}\right) + 10\log\left(\frac{P_{R2}}{P_{T1}}\right) \quad \text{—(x)}$$

→ If we combine antenna 1 & 3.

$$(G_1)_{dB} + (G_3)_{dB} = 20\log\left(\frac{4\pi R}{\lambda}\right) + 10\log\left(\frac{P_{T3}}{P_{T1}}\right) \quad \text{—(y)}$$

P_{R1} → Power received at antenna

P_{t2} → Power transmitted at antenna 2

→ Combining 2 & 3, we get

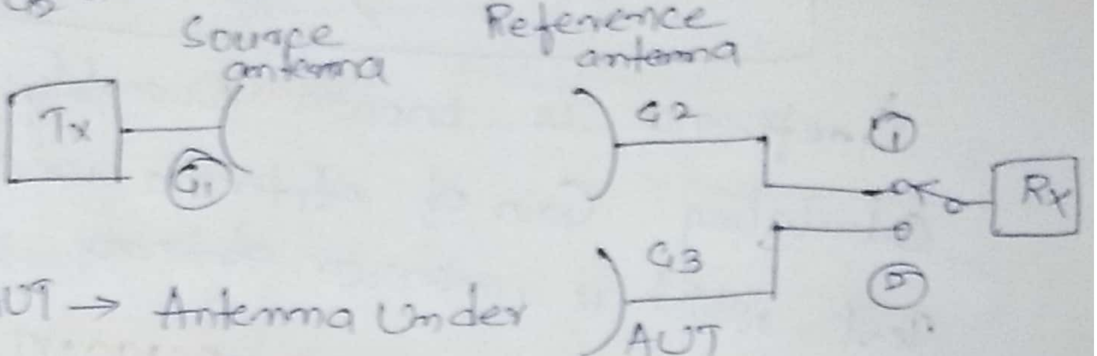
$$(G_2)_{dB} + (G_3)_{dB} = 20\log\left(\frac{4\pi R}{\lambda}\right) + 10\log\left(\frac{P_{R2}}{P_{T3}}\right) \quad \text{—(3)}$$

In all the three equations, the unknown values are G_1, G_2 and G_3 only.

As we 3 eqn's, if we solve x, y, z, we will get G_1, G_2 and G_3.

Comparison Method

→ It requires three antenna of gain G_1, G_2 and G_3.



AUT → Antenna Under Test

G_1 → Gain of Source antenna

G_3 → Antenna Under Test Gain

G_2 → Reference antenna Gain.

G_2 is considered which is known antenna. Hence, Gain also known.

① By keeping switch at position ①

$$P_{R2} = P_T G_1 G_2 \left(\frac{\lambda}{4\pi R}\right)^2 \text{ — (A)}$$

P_{R_2} → Power received at antenna 2

If switch is connected at position ②

$$P_{R3} = P_T . G_1 G_3 \left(\frac{\lambda}{4\pi R}\right)^2 \text{ — (B)}$$

By ratio of (A) and (B)

$$\frac{P_{R2}}{P_{R3}} = \frac{G_2}{G_3}$$

Here, unknown Gain is G_3

$$G_3 = \left(\frac{PR3}{PR2}\right) G_2$$

$$\boxed{G_{AUT} = \left(\frac{PR3}{PR2}\right) G_{reference}}$$

$G_{reference}$ is known Quantity and Calculating Gain of Antenna under Test which is unknown Antenna

RADIATION PATTERN MEASUREMENT OF ANTENNA

Basics:-

(A) Radiation pattern is measured by taking following step.

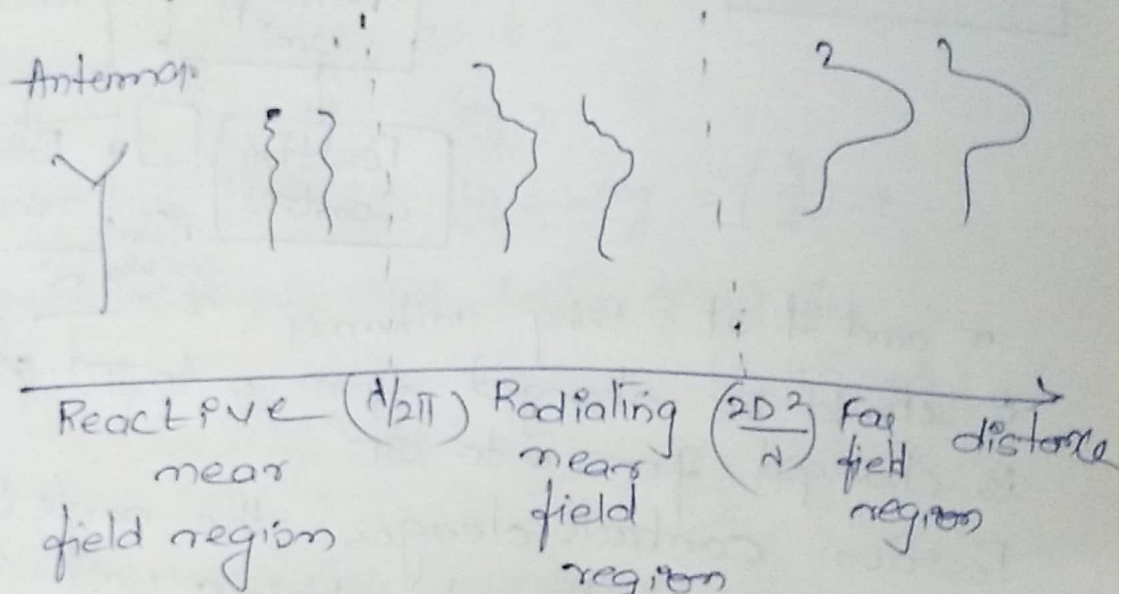
1. It is measured at fixed distance r and at fixed frequency f
2. Angle θ varies from 0 to π
3. Angle ϕ varies from 0 to 2π.

Definition

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 Antenna

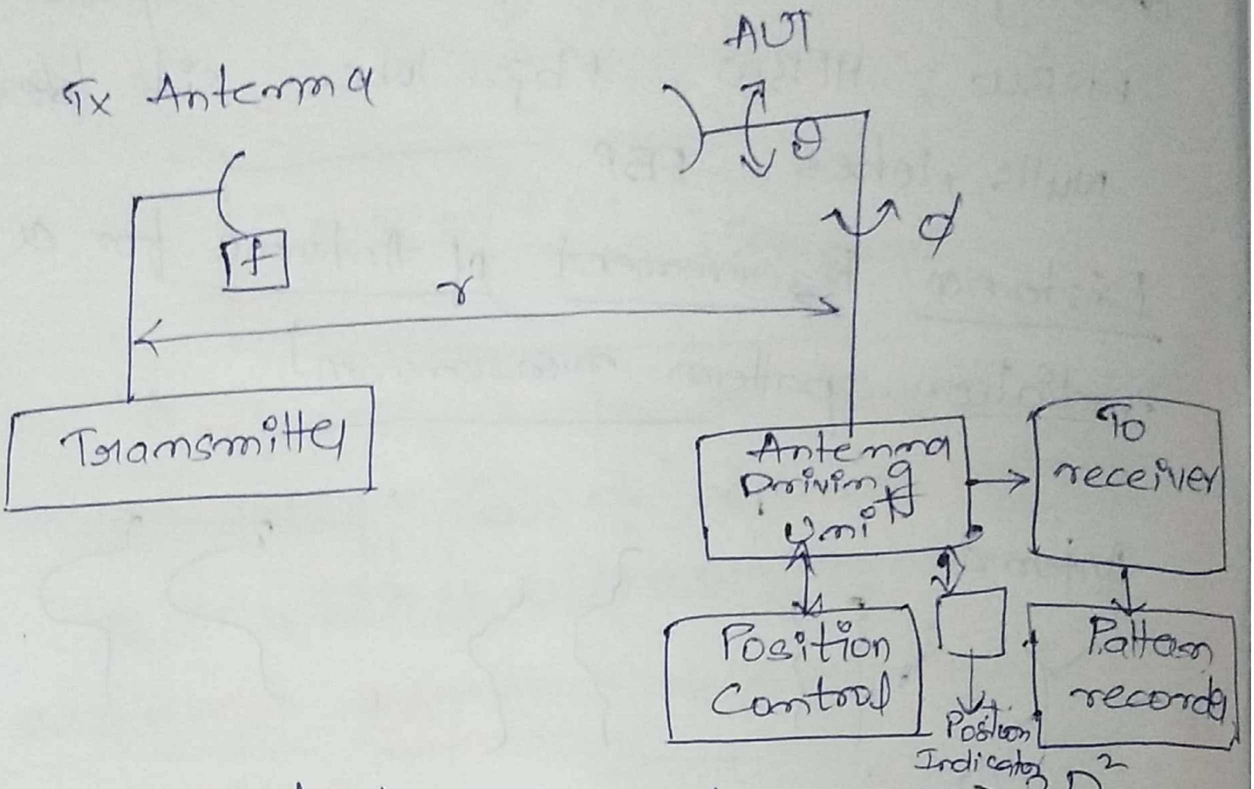
The following parameters are considered during measurement of radiation pattern. FNBW, HPBW, Major lobes, side lobes, Nulls, lobes, FBR.

<u>Distance Requirement of Antenna for a radiation pattern measurement</u>



From antenna to distance ($\lambda/2\pi$) we don't find proper radiation pattern. As we move fartherly, the radiation is getting into some shape but not accurate. In the distance ($\frac{2D^2}{\lambda}$) far distance, pattern of radiation will get properly. So, whenever we are measuring radiation pattern at a distance greater than ($\frac{2D^2}{\lambda}$), we can measure the radiation pattern properly. So, distance should be min as $\frac{2D^2}{\lambda}$.

Method



r and f at Txing antenna,
θ should be changed from 0 to π. ϕ is changed from 0 to 2π.
Position control changes the angle θ which is done through driving unit. The receiver receive magnitude of radiation and pattern recorder will recording the pattern of radiation by changing position control θ & ϕ are changed. θ and ϕ variations are shown by position Indicator.

Source of Error in Gain Measurement

Absolute and Comparison Gain measurements are there for antenna measurements.
→ Error in calculation will be there in Gain measurements. And the sources for these Gain's measurement are the following.

→ Polarization Mismatch
→ Impedance mismatch
→ Due to misalignment of antenna
→ frequency should be stable when we measure Gain of antenna
→ Multipath problem
→ Proximity Effect.

In Comparison Method, coupling happens automatically between first and second Antenna.

9.6 Friss Free Space Equation

In general, when the power is radiated by the antenna in the free space, the radio energy may be absorbed or radiated by the objects in the region. So it becomes essential to calculate the loss during radio transmission. This is nothing but **radio transmission loss.** The basic definition of radio transmission loss is the ratio of the radiated power to the received power. This loss is based on the concept of the inverse square law in optics applied to radio transmission.

For the **isotropic radiator,** the radiation is uniform in all the directions. Hence the power density is same everywhere at all the points on the surface of a sphere with radius r. Thus the **average power** can be expressed interms of radiated power as,

$$P_{avg} = \frac{P_{rad}}{4\pi r^2} \text{ W/m}^2 \quad \text{... (1)}$$

The **maximum directive gain** or **directivity** of the test antenna is given by,

$$\left(G_{D\,max}\right)_t = \frac{P_{d\,max}}{\frac{P_{rad}}{4\pi r^2}}$$

$$\therefore \quad P_{d\,max} = G_{D\,max} \cdot \frac{P_{rad}}{4\pi r^2} \quad \text{... (2)}$$

Now the receiving antenna is placed such that ideally it receives total power from the radio waves. Let P_{rec} be the maximum power delivered by the receiving antenna to the receiver load under matched load conditions. Let $(A_e)_r$ be the effective aperture of receiving antenna. Then we can write

$$P_{rec} = P_{d\,max} (A_e)_r$$

$$\therefore \quad P_{rec} = \left(G_{D\,max}\right)_t \frac{P_{rad}}{4\pi r^2} (A_e)_r \quad \text{... (3)}$$

But in general, the directivity and effective aperture area for any antenna are related as,

$$G_{D\,max} = \frac{4\pi}{\lambda^2}(A_e)$$

Let $(G_{D\,max})_r$ be the directivity of the receiving antenna, then we can write,

$$(G_{D\,max})_r = \frac{4\pi}{\lambda^2}(A_e)_r$$

$$\therefore \quad (A_e)_r = \frac{\lambda^2}{4\pi}(G_{D\,max})_r$$

Substituting value of $(A_e)_r$ in equation (3), we get,

$$P_{rec} = (G_{D\,max})_t \cdot \frac{P_{rad}}{4\pi r^2}\left[\frac{\lambda^2}{4\pi}(G_{D\,max})_r\right]$$

$$\therefore \quad \boxed{\frac{P_{rec}}{P_{rad}} = (G_{D\,max})_t\,(G_{D\,max})_r\left(\frac{\lambda}{4\pi r}\right)^2} \quad \text{... (6)}$$

Above equation called **fundamental equation for free space propagation.** This is also called **Friss free space equation.**

The factor $\left(\frac{\lambda}{4\pi r}\right)^2$ is called **free space path loss.** This indicates the loss i.e. attenuation of signal as the power spreads with distance r. The path loss can be expressed as

$$\therefore \quad \boxed{P_{Loss} = 10\log_{10}\left(\frac{4\pi r}{\lambda}\right)^2 \text{ dB}} \quad \text{... (7)}$$

The alternate forms of the equation are as follows.

$$\boxed{\frac{P_{rec}}{P_{rad}} = (G_{D\,max})_t\,(G_{D\,max})_r \cdot \left(\frac{\lambda}{4\pi r}\right)^2} \quad \text{... (8)}$$

We can express power received by antenna at receiving end interms of the power radiated and the directivities of receiving and transmitting antennas as,

$$\boxed{P_{rec} = P_{rad}\frac{(G_{D\,max})_t\,(G_{D\,max})_r}{\left(\frac{4\pi r}{\lambda}\right)^2}} \quad \text{... (9)}$$

From equation (9) it is clear that, if the value of denominator term increases, the power received decreases. The term is called **spatial attenuation** and it is denoted by L_s. It is given by,

$$L_s = \left(\frac{4\pi r}{\lambda}\right)^2 \quad \text{... (10)}$$

Consider equation (8), we can express the ratio in dB as,

$$10\log_{10}\left(\frac{P_{rec}}{P_{rad}}\right) = 10\log_{10}\left[\left(G_{D\,max}\right)_t\right] + 10\log_{10}\left[\left(G_{D\,max}\right)_r\right] + 10\log_{10}\left[\left(\frac{\lambda}{4\pi r}\right)^2\right] \quad \text{... (11)}$$

Similarly, we can write the received power in dB, using equation (9) as,

$$\boxed{\underset{(dB)}{P_{rec}} = \underset{(dB)}{P_{rad}} + \underset{(dB)}{\left(G_{D\,max}\right)_t} + \underset{(dB)}{\left(G_{D\,max}\right)_r} - \underset{(dB)}{L_s}} \quad \text{... (12)}$$

where $\quad \underset{(dB)}{L_s} = 10\log_{10}\left(\frac{\lambda}{4\pi r}\right)^2 = 20\log_{10}\left(\frac{\lambda}{4\pi r}\right)$

Simplifying,

$$\boxed{\underset{(dB)}{L_s} = 32.45 + 20\log_{10} r + 20\log_{10} f} \quad \text{... (13)}$$

In equation (14), generally distance r is expressed in kilometer while frequency f is expressed in MHz. This indicates loss due to wave spreading taking place when it propagates out of the source. Alternatively the spatial attenuation is sometimes called transmission path loss. At microwave frequencies absorption in atmosphere results in comparatively greater value of the spatial attenuation.

We can obtain expression for the field strength (generally electric field) at receiving antenna using Poynting theorem. According to Poynting theorem,

$$\bar{P} = \bar{E} \times \bar{H}$$

Thus the magnitude of the power delivered can be obtained as,

$$P_{dmax}(E)\left(\frac{E}{\eta_0}\right) = \frac{E^2}{\eta_0} \quad \text{... (14)}$$

$$\therefore \quad E^2 = P_{dmax}\,\eta_0$$

$$\therefore \quad E = \sqrt{P_{dmax}\cdot\eta_0}$$

But η_0 = Intrinsic impedance of free space = $120\pi\ \Omega \approx 377\ \Omega$. Substituting value P_{dmax} from equation (2), we get

$$E = \sqrt{\frac{G_{Dmax}\,P_{rad}}{4\pi r^2}(120\pi)}$$

$$\therefore \quad E = \sqrt{\frac{30\,G_{Dmax}\,P_{rad}}{r^2}}$$

$$\therefore \quad \boxed{E = \frac{\sqrt{30\,G_{Dmax}\,P_{rad}}}{r}\ \text{V/m}} \quad \text{... (1}$$

Above equation represents expression for field strength at the receiving antenna for the wave propagation in free space.

9.6.1 Inverse Square Law

Consider an isotropic radiator radiates the EM waves in all the direction as shown in the Fig. 9.7.

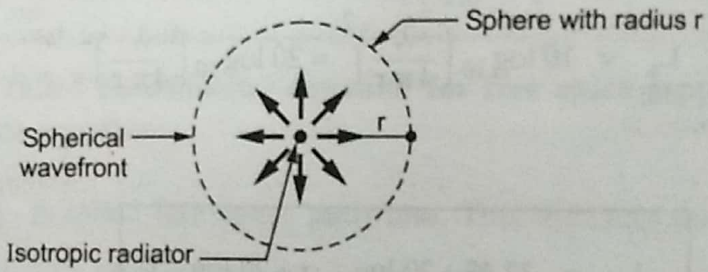


Fig. 9.7 Isotropic radiator and spherical wavefront

At a distance r from the source, the total radiated power P_{rad} distributes equally over the area of sphere with radius r.

The average power at a distance r from the isotropic radiator can be given as,

$$P_{avg} = \frac{P_{rad}}{4\pi r^2} \quad \text{... (1)}$$

But according to the Poynting theorem, the average power is given by,

$$P_{avg} = \frac{E^2}{\eta_0} = \frac{E^2}{120\pi} \quad \text{... (2)}$$

where, $\eta_0 = 120\pi = 377\ \Omega$ = Intrinsic impedance of free space.

Equating equation (2) with equation (1),

$$\frac{E^2}{120\pi} = \frac{P_{rad}}{4\pi r^2}$$