UNIT IV

SPECIAL ANTENNAS

Principle of frequency independent antennas –Spiral antenna, Helical antenna, Log periodic. Modern antennas- Reconfigurable antenna, Active antenna, Dielectric antennas, Electronic band gap structure and applications, Antenna Measurements-Test Ranges, Measurement of Gain, Radiation pattern, Polarization, VSWR

PRINCIPLES OF FREQUENCY INDEPENDENT ANTENNAS

4.1 LOG PERIODIC ANTENNA

- ✓ A log periodic antenna is a broad band narrow beam antenna.
- ✓ It is a frequency independent antenna.

Frequency-Independent Concept

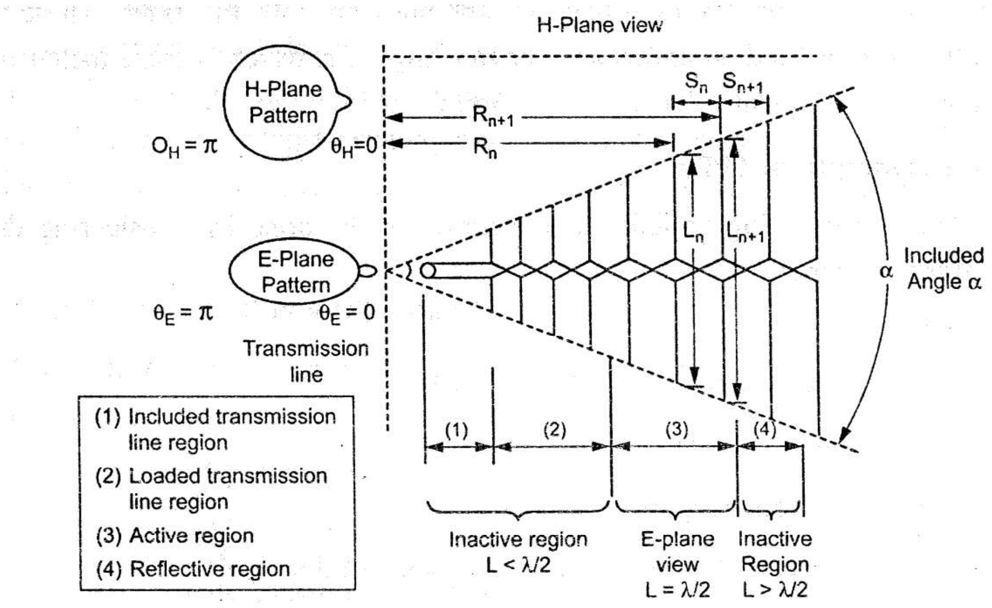
If the structure of the antenna is defined in terms of angles only, then it comes under the category of frequency independent antenna, ***e.g., Log periodic antenna, Spiral antenna***. In any frequency independent antenna, the characteristics like impedance and radiation pattern are independent of frequency. This frequency independent concept can be obtained by adjusting the antenna structure (either expanded or contracted) in proportion to the wavelength. If it is not possible to adjust the antenna mechanically, then the size of active (or) radiating region should be proportional to the wavelength.

Log-Periodic Concept

Here, the geometry of the antenna structure is adjusted such that all the electrical properties of the antenna are repeated periodically with the logarithm of the frequency. For every repetition, the structure size changes by a constant scale factor by which the structure can either expanded or contracted. The log periodic principle can be understood with the help of the array of log periodic antenna known as **Log Periodic Dipole Array (LPDA)**

Construction of LPDA

A typical log periodic dipole array is shown in Fig.4.1. It consists of number of dipoles of different lengths and spacings. The array is fed using a balanced transmission line which is connected at narrow end or apex of the array. Also the transmission line is transposed between each adjacent pairs of terminals of dipoles. The length of the dipoles increases from feed point towards other end such that the included angle a remains constant.



(b) Radiation pattern of a LPDA in E-plane and H-plane

(a) A log periodic dipole array with main region of operation

Fig 4.1. LPDA and its radiation pattern

The dipole lengths and the spacings between two adjacent dipoles are related through parameter called design ratio (or) scale factor denoted by $\boldsymbol{\tau}$.

Thus the relationship between S_n and S_{n+1} and L_n and L_{n+1} is given by

$$\frac{\boldsymbol{S_n}}{\boldsymbol{S_{n+1}}} = \frac{\boldsymbol{L_n}}{\boldsymbol{L_{n+1}}} = \boldsymbol{\tau}$$

τ is also called periodicity factor which is always less than 1. The same expression can be written in terms of constant k as

$$\frac{R_{n+1}}{R_n} = \frac{S_{n+1}}{S_n} = \frac{L_{n+1}}{L_n} = \frac{1}{\tau} = k; \quad k > 1$$

The ends of the dipoles lie along straight lines on both the sides. These two straight line meet at feed point (or) apex having angle 2α which is angle included by two straight line. (Typical value of $\alpha = 30°$ and $\tau = 0.7$)

Working principle of LPDA

The analysis of a log periodic dipole array can be done by considering three region of the antenna:

They are

1. Inactive transmission line region ($L < \lambda/2$)
2. Active region $L \approx \lambda/2$
3. Inactive reflective region ($L > \lambda/2$) These regions are classified according to the length of the dipoles.

1. Inactive transmission line region ($L < \lambda/2$)

It is the region in which the length of the dipoles is less than the resonant length $\lambda/2$. Therefore the elements present a relatively high capacitive impedance (like director in yagi-uda array). The spacing between the elements is comparatively smaller.

The current in the region are very small and hence it is considered as inactive region. These currents lead the voltage supplied by the transmission line. Transposition of transmission introduces 180° phase shift between adjacent dipoles.

Hence currents in elements of these region are small and hence small radiation in backward direction (towards left).

2. Active region $(L \approx \lambda/2)$

In this region, the dipole length are approximately equal to the resonant length ($\lambda/2$). Therefore the dipoles in this region offer resistive impedance. Thus the element currents are of large value and in phase with the base voltage. Hence there is strong radiation towards left in backward direction and a little radiation towards right.

3. Inactive reflective region (L >λ/2)

The element (dipoles) lengths are longer than the resonant length (i.e., L >λ/2). Hence the dipoles offers inductive impedance, (like reflector in yagi-uda antenna). The base voltage supplied by transmission line is now very much small as almost all the energy transmitted down the line has been attracted and radiated by the active region. Therefore the currents are smaller in this region and also lag the base voltage. This region presents a large reactive impedance to the line and thus any small amount of incident wave from active region is reflected back towards backward direction.

The performance of a log periodic dipole array depends on the following parameters.

(i) Apex angle (∝)
(ii) Design ratio (τ)
(i) Spacing factor (σ)

To find the relationship among α, τ and σ

Consider a part of a log periodic array as shown in the Fig.4.2

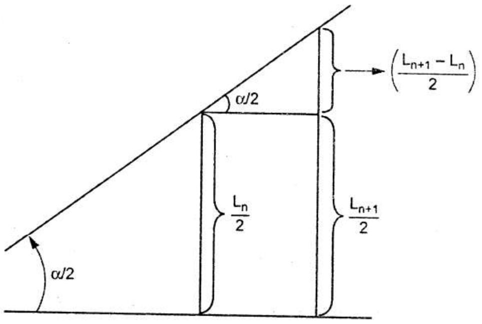


Fig .4.2 : Geometry of log-periodic arrray

From Fig.4.2

$$\tan\left(\alpha/2\right) = \frac{\frac{L_{n+1}-L_n}{2}}{S} \qquad \text{..................(4.38}$$

$$\tan\left(\alpha/2\right) = \frac{L_{n+1}-L_n}{2S}$$

$$= \frac{L_{n+1}\left[1-\frac{L_n}{L_{n+1}}\right]}{2S}$$

But $\frac{L_{n+1}}{L_n} = k$

i.e $\frac{L_n}{L_{n+1}} = \frac{1}{k}$

$$\therefore \quad tan\left({}^{\alpha}/_{2}\right) = \frac{\left(1-\frac{1}{l}\right)L_{n+1}}{2S}$$

For active region $L_{n+1} = {}^{\lambda}/_{2}$

$$\therefore \quad tan\,{}^{\alpha}/_{2} = \frac{\left(1-\frac{1}{k}\right){}^{\lambda}/_{2}}{2S}$$

$$tan\left({}^{\alpha}/_{2}\right) = \frac{\left(1-\frac{1}{k}\right)}{4\left(\frac{S}{\lambda}\right)}$$

$$\tan\left({}^{\alpha}/_{2}\right) = \frac{\left(1-\frac{1}{k}\right)}{4\sigma}$$

Where $\sigma = \frac{S}{\lambda}$, called spacing factor

α = apex angle

k = scale factor

But $\tau = \frac{1}{k}$

$$\therefore tan\left({}^{\alpha}/_{2}\right) = \frac{1-\tau}{4\sigma} \qquad \text{……..(4.39)}$$

From equation (4.39), σ can be obtained as

$$\sigma = \frac{1-\tau}{4tan\,{}^{\alpha}/_{2}} \qquad \text{……..(4.40)}$$

$$tan\left({}^{\alpha}/_{2}\right) = \frac{1-\tau}{4\sigma}$$

$$ {}^{\alpha}/_{2} = tan^{-1}\left(\frac{1-\tau}{4\alpha}\right)$$

$$\alpha = 2tan^{-1}\frac{1-\tau}{4\sigma} \qquad \text{……(4.41)}$$

Out of the three parameters (σ, τ and α) two are specified and the third is determined.

General Characteristics of Log Periodic Antennas

- ✓ Log periodic antenna or array is excited from the high frequency end (small end) for one active region and at the centre for the two active region. Both are fed by a balanced two wire transmission line.
- ✓ There are an infinite variety of log periodic structures possible but not all structures would be frequency independent. A successful and most practical structures are few. Broadband will be with those log periodic antennas which have small variation in periodicity properties.

- ✓ For unidirectional log periodic antenna, the structure fires in backward direction. For bidirectional log periodic antenna, the maximum radiation is in the broadside direction (normal to the surface of antenna). For both the cases, the radiation in the forward direction along the surface of the antenna must be zero or very small.
- ✓ Transmission line inactive region must have proper characteristic impedance with negligible radiation.
- ✓ In active region, current magnitude and phasing should be proper so that strong radiation occur along backward direction and zero or negligible radiation along forward direction. Typical values are A-/4 spacing and 90° phase (zero phase for bidirectional).
- ✓ In inactive reflective region, there should be rapid decay of current. ^

REASON FOR FEEDING FROM END WITH SHORTER DIPOLES

When the log periodic antenna is operated at a given frequency, it is observed that all the structure does not radiate but only a certain portion known as active region radiates. Active region is the region in which the dipoles have nearly resonant length ($\lambda/2$). For high frequency application, the active region is towards apex end (shortest end). Because if frequency (f) increases, wavelength (λ) will decrease to maintain the ratio $C = f\lambda$.

Similarly for intermediate frequencies, the active region is at middle and for lower frequencies, the active region is at longest end. In other words, phase centre of the antenna shifts from shortest end to longest end as the frequency changes from maximum to minimum. The maximum to minimum ratio of frequencies determines the bandwidth. Therefore for high frequency application, it is necessary to feed the antenna from end with shorter dipoles.

NEED FOR TRANSPOSING THE LINE

In log periodic antenna, it is necessary to introduce a 180° phase reversal between elements. This is accomplished by using a twisted transmission line (transposed lines) as shown in Fig.4.19.

In the inactive transmission line region ($L < \lambda/2$), the spacing between the dipoles is very small. Therefore the transmission provides 180° phase shift between adjacent dipoles. Hence the radiation is very small in backward direction.

While in active region, the spacing between the dipoles is sufficiently large and the transmission provides 90° phase shift. When the field radiated from element $(n + 1)$ reaches n^{th} element, the phase advances by 90° and field of n^{th} element adds to that of $(n + 1)^{th}$ element in phase. Thus a large field is resulted towards left (Backward direction). So it is-necessary to feed the neighboring dipoles at opposite phase and this is accomplished by transposing the transmission line.

EFFECTS OF DECREASING α

From equation (4.42), we can write

$$\alpha = 2tan^{-1}\frac{1-\tau}{4\sigma} \qquad ....(4.42)$$

Where $\sigma \rightarrow$ spacing factor

$\alpha \rightarrow$ apex angle

$\tau \rightarrow$ scale factor $= \frac{L_n}{L_{n+1}}$

From equation (4.42), it is clear that $\propto$ and σ are inversely proportional. when α (apex angle) is reduced, it will increase the spacing factor (σ).

From equation (4.42), it is clear that a and a are inversely proportional. When a (apex angle) is reduced, it will increase the spacing factor (σ).

But $\sigma = \frac{S}{\lambda}$

Therefore increase in spacing factor (σ) will increase the spacing between the dipoles (or) decrease the length of the dipole. This in turn will increase the number of dipoles and they will become more closer to each other. For this type of design, more number of dipoles comes in active region. Hence the radiation efficiency is increased with increased gain and directivity.

But the difficulty in reducing the apex angle ($\propto$) is that compactness of the structure is affected and the space required to install the antenna is large.

USES OF LOG PERIODIC ANTENNA

- ✓ It is mainly used in the field of HF communication where multiband steerable and fixed antennas are generally used. It has advantage that no power is wasted in terminating resistance.
- ✓ It is used for TV reception. Only one log periodic design will suffice for all the channels even upto UHF band.
- ✓ It is best suited for all round monitoring, i.e., a single log periodic antenna will cover all the higher frequencies bands if the cost of the installation is no problem.

4.2 SPIRAL ANTENNA

It is a frequency independent antenna. It radiates a bi-directional main lobe perpendicular to the plane of the antenna. It produces a circularly polarized waves within the band of operation. Outside the band of operation, the radiation is elliptically polarized.

The frequency independent antennas arc governed by Rumsey's principle. It states that the impedance and pattern properties of an antenna will be frequency independent if the antenna shape is specified only in terms of angles.

A spiral is a geometrical shape found in nature and it can be geometrically described using polar co-ordinates (r, θ) The spiral antenna has two geometrical Shapes. They are:

1. Logarithmic or equiangular spiral antenna
2. Conical equiangular spiral antenna

LOGARITHMIC (or) EQUIANGULAR SPIRAL ANTENNA

A Logarithmic or equiangular spiral antenna can be described by the equation

$$r = r_0 \; e^{a\theta} \;\ldots\ldots(4.71)$$

Where r_0, a →positive constants

r and θ→ conventional polar co- ordinates.

Here the constant 'a' indicates the rate of expansion. Fig.4.3 shows an equiangular spiral for $r_0 = 1$ and $a = 0.4$.

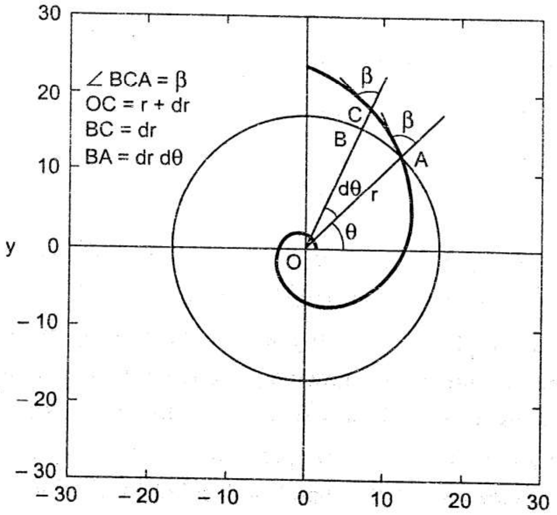


Fig 4.3. Logarithmic spiral

Taking natural logarithm on both sides of equation .(4.71)

$$Inr = Inr_0 + a\theta$$

Differentiating with respect to θ

$$\frac{1}{r}\frac{dr}{d\theta} = a \qquad ....(4.72)$$

From Δ ABC in Fig .4.3,

$$tan\beta = \frac{BA}{BC} = \frac{rd\theta}{dr} = \frac{1}{a} \qquad .....(4.73)$$

$$\because \left[\frac{dr}{rd\theta}\right] = a$$

Therefore, the angle between the tangent at any point on the spiral and the radial line from the origin to that point (denoted as β) is the same for all points on the spiral. Therefore the name equiangular spiral and it is represented by the equation (4.71),

Consider a spiral described by

$$r_1 = r_0 \; e^{a\theta} \qquad .... (4.74)$$

Now the dimensions of an antenna designed to operate at a frequency, $'f_0'$can be defined in terms of this equation (4.74).

If we scale this antenna by a factor K, it would be the same radiation and input properties at a frequency f_0/K. Multiplying equation (4.74) by a factor 'K', we have

$$r_2 = Kr_0 \; e^{a\theta} \qquad \dots\dots(4.75)$$

Expressing $K = e^{a\delta}$, we can reduce equation (4.75) to

$$r_2 = e^{a\delta} r_0 e^{a\theta} = r_0 \; e^{a(\theta+\delta)} \qquad \dots\dots(4.76) \;..$$

This show that the scaled antenna is obtained by rotating the original antenna structure by an angle δ. But the structure is unchanged. Hence the radiation pattern alone rotates by an angle 'δ', keeping all the other properties remains the same. Therefore this type of antenna is known as frequency-independent antenna. For structures that are finite in size, the frequency invariance property is exhibited over a limited range of frequencies. The lower end of this band is decided by the largest dimension of the spiral and the upper end by the smallest dimension.

Now to construct an antenna using this spiral shape, consider a thin conducting strip of variable width with the edges defined by the following two equations.

$$r_1 = r_0 e^{a\theta} \qquad \dots.(.4.77)$$

and $$r_2 = r_0 e^{a(\theta-\delta)} \qquad \dots\dots(4.78)$$

These two edges are shown in Fig.4.4 for 0 $\geq \theta \leq$ 2.25 π and $\delta \geq \theta \leq (2.25\,\pi + \delta)$

A second conductor can be obtained by rotating the first spiral by 180°. Now the edges of the second spiral are given by

$$r_3 = r_o e^{a(\theta+\pi)}$$

and $$r_4 = r_o e^{a(\theta+\pi-\delta)}$$

where, δ →determines the width of the arm

r_0 → determines the radius of the feed region

a → rate of growth of the spiral and

$\theta_{\max}$ →determines the maximum radius of the spiral

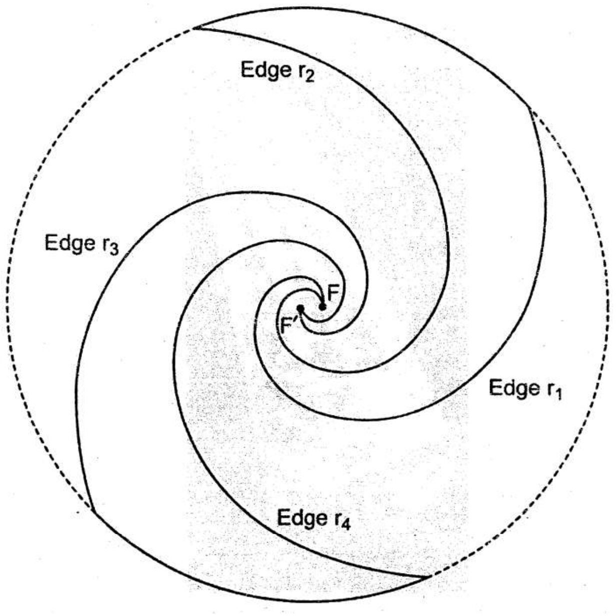


Fig 4. 4. An Antenna based on logarithmic spiral

These edges, edge r_3 and edge r_4 are shown in Fig.4.4 for $-\pi \geq \theta \leq 1.25\,\pi$ and $(-\pi + \delta) \geq \theta \leq (1.25\,\pi + \delta)$ The voltage is applied between the 2 conductors (arms) F and F' in such a way that the arms are balanced to ground. The currents flow outward along the spiral arms with small attenuation until a region of certain size in wavelengths is reached. This region is known as the active or radiating region where all of the power guided along the spiral arms is radiated.

Beyond this region, the presence or absence of the arms is of little consequence. Because the radiating region has fixed dimension in wavelength, it moves inward (or) outward as the frequency is raised or lowered. Therefore, the size of the effective radiating aperture automatically adjusts or scales with frequency to produce an antenna that has the same pattern and impedance at all frequencies. This remarkable property of scaling or automatic adjustment of the size of the radiating region to suit the frequency of oration is characteristics of all successful frequency-independent antennas.

CONICAL EQUIANGULAR SPIRAL ANTENNA

The special feature of this antenna is that it produces a unidirectional radiation pattern. This could be obtained when the balanced spiral arms were wrapped on the surface of a cone. For conical angles less than 45 degrees and appropriately chosen rates of spiral, this antenna produces a single broad lobed beam towards the apex of the cone with maximum along the axis.

The conical equiangular spiral antenna is a balanced structure which may be fed at the apex by means of a balanced transmission line. The transmission line is carried up to the apex inside the cone along the axis of the cone. In conical antennas also, circularly polarized wave is obtained and relatively constant impedances over the bandwidth are presented.

The input impedance of the conical spiral antenna - ranges between 100 to 150 Ω for pitch angle $\alpha = 17°$. The bandwidth depends on the ratio of base diameter to the truncated apex diameter and this ratio may be chosen arbitrarily large such as 5 : 1 or more.

4.3 HELICAL ANTENNA

- ✓ Helical antenna is a broadband VHF and UHF antenna to provide circular polarization characteristics.
- ✓ Since it provides circularly polarized waves, it is used in extra terrestrial communications where satellite relays are involved.

Construction

Helical antenna consists of a helix of thick copper wire (or) tubing wound in the shape of a screw thread and used with a flat metal called a ground plane (or) ground plate. The structure of the helical antenna is shown in Fig.4.5.

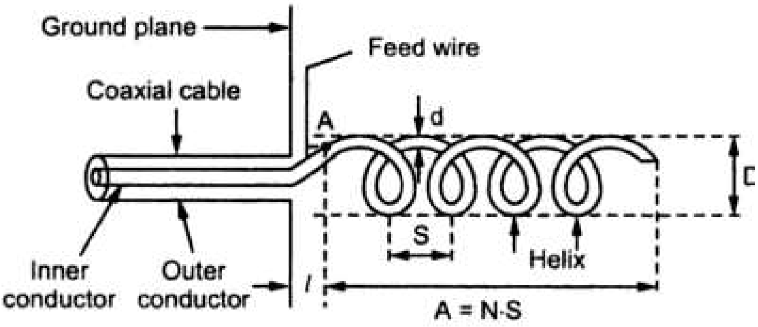


Fig 4.5 Structure of helical antenna

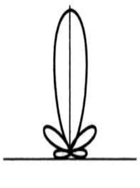


Fig 4.6 Radiation pattern of helical antenna in axial mode

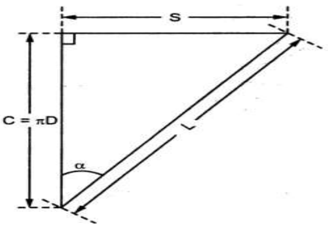


Fig 4.7 inter relation between circumference , spacing , turn length and pitch angle

- ✓ The helix is fed by a co- axial cable and is connected between helix and ground.
- ✓ i.e., One end of the helix is connected to the centre conductor of the cable and the outer conductor is connected to the ground plane.
- ✓ The mode of radiation depends on the diameter of the helix "D" and turn spacing "S" (turn spacing is a measure between two centers of the turns).

  The dimension of the helix are

C →Circumference of helix (πD)

d → Diameter of helix conductor

A →Axial length = NS

N →Number of turns

L →Length of one turns

I →pacing of helix from ground plane

∴The total length of antenna = NS. If one turn of helix is unrolled, then circumference (π D), spacing S, turn length "L" and pitch angle a are related by the triangle shown in Fig

$$L\sqrt{S^2 + C^2} = \sqrt{S^2 + (\pi D)^2} \quad …….(4.27)$$

Pitch Angle (∝)

Pitch angle is the angle between a line tangent to the helix wire and the plane normal to the helix axis

$$tan\alpha = \frac{S}{C} = \frac{S}{\pi D}$$

$$\alpha = tan^{-1}\left(\frac{S}{\pi D}\right) \qquad .....(4.28)$$

The different radiation characteristics are obtained by changing the above parameter in relation to wave length.

- ✓ After the point "A" the conductor lies in the surface of imaginary helix cylinder. The axial length of the helix starts from here.
- ✓ The component of the feed wire length parallel to the axis length is "/". This length is equal to S/2
- ✓ The antenna terminals are considered fct the point "B" and all the impedances are referred to this point.
- ✓ The variation of feed wire geometry affects the input impedances of the antenna.

Modes of Radiation

- ✓ In general, a helical antenna can radiate in many modes. But the most important modes of radiation are as follows.
    - Normal mode (or) perpendicular mode.
    - Axial (or) End fire (or) Beam mode of radiation.

NORMAL MODE OF RADIATION

- ✓ In this normal mode of radiation, the radiation field is maximum in broad way (i.e.,) in the direction normal to the helix axis and is circularly polarized waves.
- ✓ Here the dimensions of the helix is small compared with wavelength (i.e.,)NL<<λ.
- ✓ Here the radiation pattern is a combination of the equivalent radiation from a short dipole (positioned on the same helix axis) and a small loop which is also coaxial with helix axis.
- ✓ When $\alpha = 0°$ helix corresponds to a loop and $\alpha = 90°$ becomes a linear dipole as shown in Figure.4.8.
- ✓ If S = 0, helix collapse to a loop and if S = constant and D = 0, the helix straightens into a linear conductor.

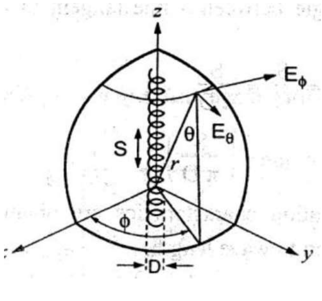


Fig 4.8. Helix in 3 dimensional spherical coordinate

- ✓ The radiation pattern of the above two are the same but the polarization are at right angle and phase angles at any point in space are at 90° apart..
- ✓ The resultant field is either circularly polarized (or) elliptically polarized depending upon the field strength ratio (or) Amplitudes of the two components which depend on pitch angle α.
- ✓ If α is small, loop type of radiation pre-dominates.

  If α is very large, the dipole polarization pre-dominates.

  In between values of a, the polarization is elliptical and the polarization is circular at a particular value of a.
- ✓ Helix antenna may be considered to be having a number of small loops and jsh-it dipoles connected in series in which loop diameter is same as helix diameter and helix spacing "S" is same as dipole length.

The far field of the small loop is given by

$$E_\phi = \frac{120\pi^2[I]sin\theta}{r}.\frac{A}{\lambda^2} \qquad \text{.........(4.29)}$$

where, [I]→Retarded current
r→Distance
A→ Area of loop $=\frac{\pi D^2}{4}$

The far field of a short dipole is given by

$$E_\theta = \frac{j60\pi[I]sin\theta}{r}.\frac{S}{\lambda}$$

Where , S =L= length of dipole

The axial ratio (AR) of Elliptical polarization is given by

$$AR = \frac{E_\theta}{E\phi} = \frac{\left|\frac{j60\pi[I]sin\theta.S}{\lambda.r}\right|}{\frac{120\pi^2[I]sin\theta.A}{r\lambda^2}}$$

$$= \frac{S\lambda}{2\pi A} = \frac{2S\lambda}{\pi^2D^2} \qquad \text{where } A = \frac{\pi D^2}{4}$$

$$AR = \frac{2S\lambda}{\pi^2D^2} = \text{Axial ratio} \qquad \text{......(4.31)}$$

- When axial ratio is zero, then elliptical polarization becomes linear horizontal polarization.

- When axial ratio is infinity, then elliptical polarization becomes linear vertical I polarization.
- When axial ratio is unity, then elliptical polarization becomes circular polarization.

  ∴ For circular polarization ,$AR = 1 = \frac{E_{\theta}}{E_{\phi}}$ (or)

  $|E_{\theta}| = |E_{\phi}|$

$$\therefore |2S\lambda| = |\pi^2 D^2$$

$$S = \frac{\pi^2 D^2}{2\lambda} = \frac{C^2}{2\lambda}$$

where $C = \pi D$ ……(4.32)

Substituting equation (4.32) into equation (4.28)

$$\alpha = tan^{-1}\left(\frac{S}{\pi D}\right) = tan^{-1}\frac{\frac{\pi^2 . D^2}{2\lambda}}{\pi D}$$

$$\alpha = tan^{-1}\left(\frac{\pi D}{2\lambda}\right) = tan^{-1}\left(\frac{C}{2\lambda}\right)$$

$\alpha = tan^{-1}\left(\frac{C}{2\lambda}\right)$ is the condition for pitch angle to get circular polarization

Conclusion

- ✓ This mode (Normal mode) of operation is very narrow in bandwidth and its radiation efficiency is very small.
- ✓ Also this mode of operation is limited and it is hardly used

AXIAL (or) BEAM MODE OF RADIATION

The radiation field is maximum along the helical axis and the polarization is circular (or) nearly circular.

This mode occurs when the helix circumference (D) and spacing (S)are appreciable of the order of one wavelength.

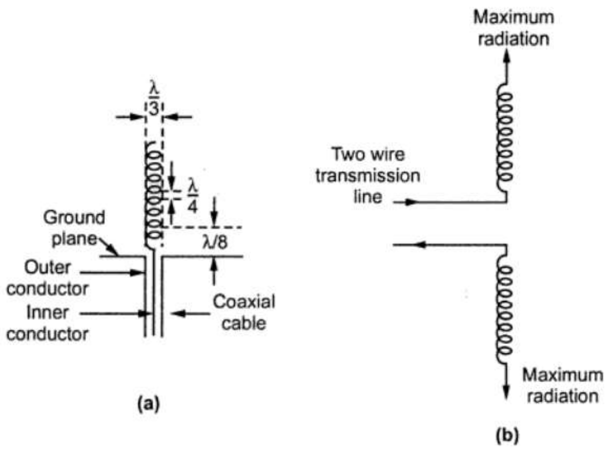


Fig4.9 : Helical antenna in axial mode

This mode is more interesting as it produces a broad and fairly directional beam in the axial direction with minor lobes at oblique angles.

Because of this features, helical antenna is used for many practical applications.

This mode is obtained by raising helix circumference (C/λ) of the order of one wavelength and spacing approximately of X/4.

✓ The helix is operated in conjunction with a ground plane and is fed by a coaxial cable. The ground plane is at least half wavelength in diameter.

✓ Pitch angle "a" varies from 12° to 18° and about 14° is optimum pitch angle. The antenna gain and beam width depends upon the helix length (NS).

✓ The terminal impedance is 100 Q resistive, at frequency C = A, and at higher and lower frequencies, the resistive value changes followed by reactive components.

✓ In general, terminal impedance of helical antenna lies between 100 Q to 200 Q pure resistive. Within 20% approximation, the terminal impedance is given by

$$R = \frac{140C}{2\lambda} \text{ ohms} \qquad \ldots\ldots\ldots(4.33)$$

HPBW (Beam width between half power points) is given by

$$(HPBW) = \frac{52}{C}\sqrt{\frac{\lambda^3}{NS}} \text{ degrees} \qquad \ldots\ldots(4.34)$$

Where λ = free space wave length

C = Circumference

N = Number of turns

S = Spacing

The beam width between first nulls is given by

$$BWFN = \frac{115}{C}\sqrt{\frac{\lambda^3}{NS}} = \text{degree} \qquad \ldots..(4.35)$$

The maximum directive gain (directivity) is given by (axial mode)

$$D = \frac{15NSC^2}{\lambda^3} \qquad \ldots\ldots(4.36)$$

Axial ratio $AR = 1 + \frac{1}{2N}$ …..(4.37)

and the normalized far field pattern is given by

$$E = sin\left(\frac{\pi}{2N}\right) cos\theta.\left(\frac{\frac{N\varphi}{2}}{sin\frac{\varphi}{2}}\right)$$

Where , $\varphi = 2\pi\left[\frac{S}{\lambda}(cos\theta) + \frac{1}{2N}\right]$

With $\alpha = 12° \text{ to } 15°\ N \geq 3, NS \leq 10$ and

$C = \frac{3}{4}\lambda \text{to} \frac{4}{3}\lambda$

ADVANTAGE OF HELICAL ANTENNA

N-turn helix is an end fire array of "n" sources.

Helix not only have a nearly uniform resistance input over a wade bandwidth, but it also operates as a super gain end fire array over the same bandwidth.

IIt is non critical with respect to conductor size and turn spacing, therefore can achieve circular polarization over a wide bandwidth.

IIt is easy to use in arrays because of almost negligible mutual impedance.

Because of circular polarization, helical antenna is capable of receiving signals of arbitrary polarization.

APPLICATION OF HELICAL ANTENNA

- ✓ Wide bandwidth, simplicity, highest directivity and circular polarization of helical beam antenna have made it indispensable for space communication application like telemetry, radio astronomy, satellite and space communications.

MODERN ANTENNAS

4.4 Reconfigurable Antenna

A **reconfigurable antenna** is an antenna capable of modifying dynamically its frequency and radiation properties in a controlled and reversible manner. In order to provide a dynamical response, reconfigurable antennas integrate an inner mechanism (such as RF switches, varactors, mechanical actuators or tunable materials) that enable the intentional redistribution of the RF currents over the antenna surface and produce reversible modifications over its properties. Reconfigurable antennas differ from smart antennas because the reconfiguration mechanism lies inside the antenna rather than in an external beam forming network. The reconfiguration capability of reconfigurable antennas is used to maximize the antenna performance in a changing scenario or to satisfy changing operating requirements.

Types of antenna reconfiguration

Reconfigurable antennas can be classified according to the antenna parameter that is dynamically adjusted, typically the frequency of operation, radiation pattern or polarization.

Frequency reconfiguration

Frequency reconfigurable antennas can adjust dynamically their frequency of operation. They are particularly useful in situations where several communications systems converge because the multiple antennas required can be replaced by a single reconfigurable antenna. Frequency reconfiguration is generally achieved by modifying physically or electrically the antenna dimensions using RF-switches, impedance loading or tunable materials.

Radiation pattern reconfiguration

Radiation pattern reconfigurability is based on the intentional modification of the spherical distribution of radiation pattern. Beam steering is the most extended application and consists in steering the direction of maximum radiation to maximize the antenna gain in a link with mobile devices. Pattern reconfigurable antennas are usually designed using movable/rotatable structures or including switchable and reactively-loaded parasitic elements.

Polarization reconfiguration

Polarization reconfigurable antennas are capable of switching between different polarization modes. The capability of switching between horizontal, vertical and circular polarizations can be used to reduce polarization mismatch losses in portable devices. Polarization reconfigurability can be provided by changing the balance between the different modes of a multimode structure.

Compound reconfiguration

Compound reconfiguration is the capability of simultaneously tuning several antenna parameters, for instance frequency and radiation pattern. The most common application of compound reconfiguration is the combination of frequency agility and beam-scanning to provide improved spectral efficiencies. Compound reconfigurability is achieved by combining in the same structure different single-parameter reconfiguration techniques or by reshaping dynamically a pixel surface.

Reconfiguration Techniques:

Six major types of reconfiguration techniques are used to implement reconfigurable antennas, as indicated in fig.

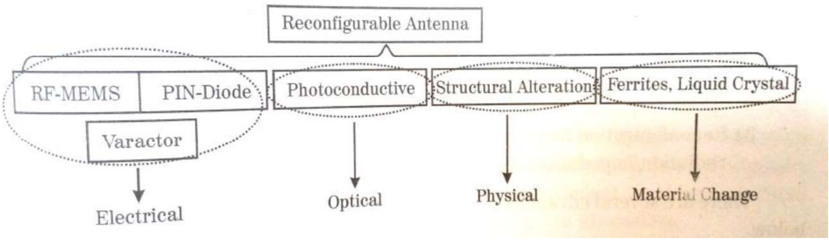


Fig :4.10

Antennas based on radio-frequency microelectromechanical systems RF –MEMS, PIN diodes , and varactors to redirect their surface currents are called electrically reconfigurable. Antennas that rely on photoconductive switching elements are called optically reconfigurable antennas. A description of the operation of the switches is summarized in Table. Physically reconfigurable antennas can be achieved by altering the structure of the antenna. Finally , reconfigurable antennas can be implemented through the use of smart materials such as ferrites and liquid crystals.

RF MEMS: They use mechanical movement to achieve a short circuit or an open circuit in a surface current path of an antenna structure. The forces required for the mechanical movement can be obtained using electrostatic, magneto static, piezoelectric or thermal designs.

PIN Diodes: They operate in two modes. The ON state, where the diode is forward biased and the OFF state, where the diode is not biased.

Varactors: They consist of a p-n junction diode. As the bias voltage applied to the diode is varied, the varactor capacitance is going to be changed. Typical values are from tens to hundreds of picofarads.

Photoconductive Elements: The movement of electrons from the valence band to the conduction band allows the switch to go from OFF state to ON state. This is achieved by illuminating the switch by light of appropriate wavelength from a laser diode.

Challenges to be addressed while designing reconfigurable antenna.

Three challenges that have to addressed while designing reconfigurable antenna

1. Reconfigurable property (e.g., frequency, radiation pattern, or polarization) that needs to be modified.
2. Different radiating elements of the antenna structure that have to be reconfigured to achieve the required property
3. Reconfiguration technique that minimizes negative effects on the antenna radiation/impedance characteristics.

There are several advantages in using reconfigurable antennas as summarized below.

1. **Ability to support more than one wireless standard**
    a) Minimizes cost
    b) Minimizes volume requirement
    c) Simplifies integration
    d) Good isolation between different wireless standards.
2. **Lower front end processing**
    a) No need for front end filtering
    b) Good out – of- band rejection
3. **Best candidate for software – defined ratio**
    a) Capability to adapt and learn

   b) Automated via a microcontroller or a field programmable gate array (FPGA)

4. **Multifunctional capabilities**
   a) Change functionality as the mission changes.
   b) Act as a single element or as an array
   c) Provide narrow band or wideband operation.

4.5 ACTIVE ANTENNAS

An **active antenna** is an antenna that contains active electronic components, as opposed to typical passive components. A passive antenna typically resembles a dipole antenna.

An active design allows the construction of antennas of limited size and / or wide frequency range, and are primarily used in situations where a simpler and more receptive large antenna is either impractical (inside a portable radio) or impossible (suburban residential area that disallows use of large outdoor low-frequency antennas).

Most active antennas use antenna parts of minimal conducting area, e.g., a small whip, connected to the active component (usually a FET). The signal attenuation caused by the antenna-size-to-wavelength mismatch is compensated by an active circuit. The active circuit consists of an impedance translating stage and an optional amplification stage. This arrangement is especially useful for constructing compact low frequency antennas which, due to budgetary, spatial, or practical requirements (e.g., installation in vehicles), must be downsized. Low frequency signal wavelengths range from one to ten kilometers.

Power for the active components may be supplied by batteries, a filtered power supply, or through the signal feeder itself (phantom power). Antennas containing active impedance translating and optionally amplifying stages are usually used only for receiving, since operation of such stages is unidirectional.

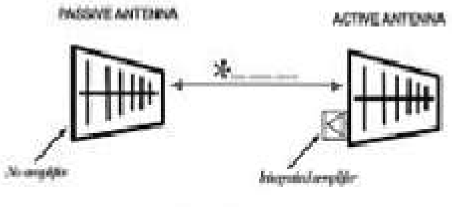


Fig 4.10

An antenna includes two amplifiers, one for the downlink and one for the uplink. The amplifier are located very close to the antenna. The purpose of the downlink amplifier is to maintain the best possible signal quality at reception . The purpose of the uplink amplifier is to deliver the needed RF power into the antenna. Without these amplifiers , the loss of the coaxial cable will have a severe impact on performance. With an active antenna , it is possible to use long cables and still maintain performance. Passive antenna includes only an antenna element, no amplifiers. A passive antenna is useful only for short runs of coaxial cable. Cable loss will deteriorate system performance.

Passive antennas are antennas that have no amplification stages as shown in Figure whereas, active antennas are any antennas with integrated signal amplifiers as shown in Figure. An active antenna is a passive antenna that simply includes an onboard amplifier. There is no difference between the antenna element of an active or passive antenna of the same type; the only difference is whether an amplifier is included.

Active antennas can be used for both receiving and transmitting applications, but they are most often seen as receiving antennas. When used to receive signal, the integrated amp boosts the RF picked up by the antenna and allows much longer remote cable runs.

When used as a transmitting antenna, active antennas increase the RF power above and beyond whatever output power the transmitting device is using. The only practical reason to use an active antenna is to compensate for cable loss in receive applications. All RF signal loses strength (attenuates) as it passes through coaxial cable. The longer the cable run, the larger the loss.

There may be a loss of -8 to -11 dB, in a 100 feet cable, depending on a few factors, like frequency. The amplifiers on active antennas are designed to compensate for this losss by boosting the signal right behind the antenna before sending it down the line, so the gain at the receiver is closer to unity gain.

It is important to note that active receive antennas do not increase directional gain. i.e., the amplifier has no effect on the electrical characteristics of the antenna, and therefore no effect on an antenna's fundamental ability to pick up RF energy floating through the air.

Active antennas can be built for any frequency range, but they are more commonly used from VLF (10KHz or so) to about 30MHz. The reason for that is because full-size antennas for those frequencies are often much too long for the available space. At higher frequencies, it is quite easy to design a relatively small high-gain antenna.

4.6 DIELECTRIC LENS ANTENNA:

- ✓ It is an antenna which consists of electromagnetic lens with a feed.
- ✓ It converts spherical wave from a point source(feed) into a flat plane wave. It acts like a **glass lens** in **optics.**
- ✓ The design of lens antenna is based on the law of refraction.
- ✓ Parabolic reflector discussed in the last chapter can be applied to low frequency range.

- ✓ The lens antenna are classified according to the material used to construct the lens or according to the geometrical shape of the lens.
- ✓ Basically lens antennas can be classified as
    - i) Delay lens
    - ii) Fast lens

i) Delay lens:

It is the antenna in which the electrical path length is increased by the lens medium and the wave is retared.

Ex: Dielectric lenses
H-plane metal plate lenses

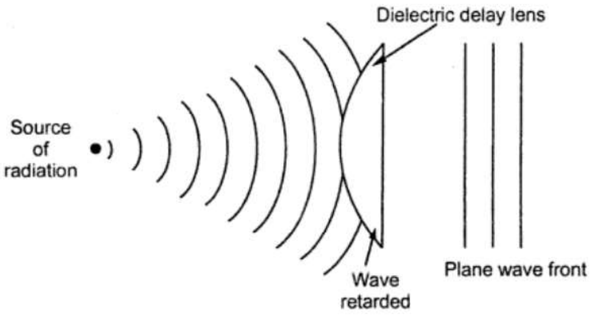
- ✓ The dielectric lenses are further classified on the basis of the dielectric used.

ii) Fast lens:

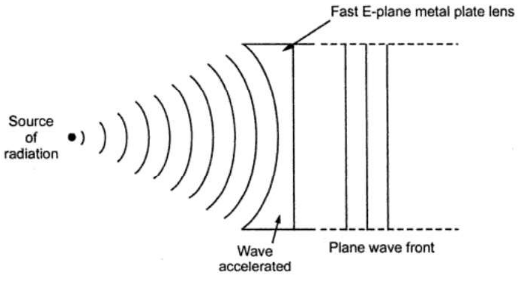
It is the antenna in which the electrical path length is decreased by the lens medium and he wave is **accelerated.**

Ex: E-plane metal plate lenses.

The action of delay lens and fast lens antenna are as shown in fig 4.11.



(a) Delay lens antenna



(b) Fast lens antenna

Fig 4.11 Delay and fast lens antennas

PRINCIPLES OF LENS ANTENNA:

- ✓ The main application of lenses is to **collimate** the incident divergent energy there by preventing it from spreading in undesired directions.
  A lens antenna in association with a primary feed antenna in transmitting mode is shown in fig 4.12

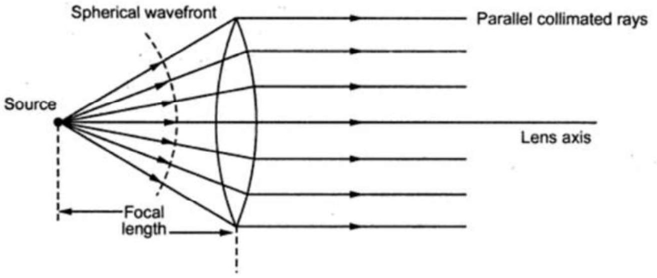


Fig 4.12 : Lens antenna in transmitting mode

- ✓ When the feed antenna is kept at the focal point of the lens antenna, the diverging rays are collimated forming a plane wave front after their incidence on the lens and passing through it.
- ✓ Collimation occurs because of refraction mechanism. The refraction is more at the edges than at the center.
- ✓ The lens antenna in receiving mode is shown in the fig 3.36. Here, the incoming parallel rays coverage at the focal point after passing through the lens due to refraction mechanism.
- ✓ This is an indication of the reciprocity theorem.
- ✓ Collimation is also possible if the lens has refractive index less than unity.
- ✓ Lens antennas are used with in association with a point source.

DIELECTING LENS (DELAY LENS):

- ✓ To operate a lens at radio frequencies, a dielectric lens is perferred.

Salient features of dielectric lens:

- ✓ They are usually made of polystyrene or Lucite and polyethylene.
- ✓ They are bulky and heavy for $f < 3$ GHZ.
- ✓ Uniform illumination for lens antennas is better if focal length is long.
- ✓ At GHz, the lens become excessively and undesirably thick.
- ✓ This can be avoided by zoned or stepped dielectric lens as shown in fig 4.13.

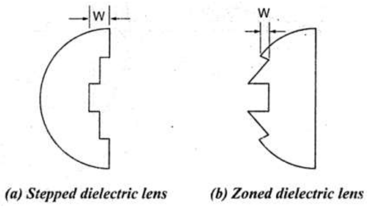


Fig 4.13

- ✓ The width ‘w’ of a stepped lens is w=$\frac{\lambda}{\lambda-1}$
- ✓ The zoned lens is mechanically stable.
- ✓ Weight of stepped lens is less.power dissipation is also less.
- ✓ The bandwidth of the zoned lens is

  Bandwidth = $\frac{50n}{1+kn}$ [k = number of zones]

Dielectric lens are of two types.

(i) Non-metallic dielectric type

(ii)Metallic type

Non-metallic dielectric lens:

- ✓ Dielectric lens used as antenna is identical to the optical lens.

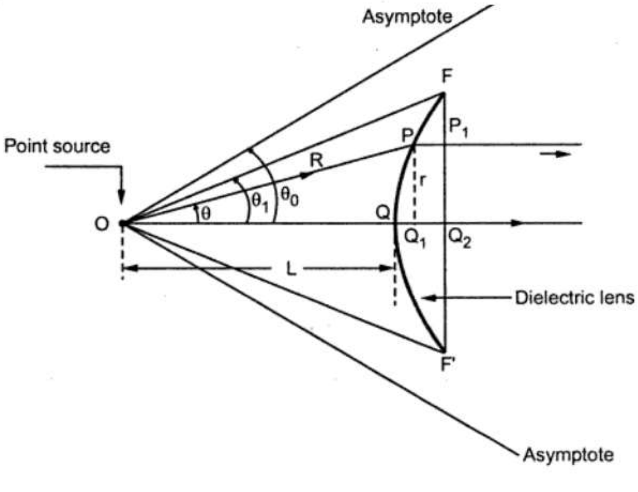


Fig 4.14 Path lengths in plane convex lens

- ✓ Consider that a isotropic point source is placed at focal point ‘O’ as shown in fig 4.14. this is acting as primary antenna. It produces spherical wave front. This is called **principle of equality of path length (or) fermat’s principle.**

Let l -> focal length
Now according to the principle of equality of path length,
Electrical path OPP_1 = electrical path of OQQ_1Q_2
from fig 4.14

let OP = R
OQ = L
QQ_1 = x
OP = $OQ+QQ_1$

Expressing the above equation in terms of time [$\frac{Distance}{Veocity}$ = time]

$$\frac{R}{V_o} = \frac{L}{V_O} + \frac{X}{V_O}$$

$$R = L + \left(\frac{V_O}{V}\right)x \qquad \text{…….(a)}$$

But the refractive index

$$n = \frac{V_O(velocity\ of\ free\ space)}{V(velocity\ in\ the\ medium)}$$

∴ Equation (a) becomes

$$R = L + nx \qquad \text{………….(b)}$$

$$x = OQ_1 - OQ \qquad \text{……………..(c)}$$

From triangle ∠ OQ_1P,

$$OQ_1 = R\cos\theta \qquad [\because \cos\theta = \frac{OQ_1}{R}]$$

∴ equation (c) becomes

$$x = R\, cos\theta - L \qquad \text{…….(d)}$$

Substituting equation (c) in (b)

$$R = L + n(R\, cos\theta - L)$$

$$= L + n\, R\, cos\theta - nL$$

$$R - n\, R\, cos\theta = L - nL$$

$$R(1 - n\cos\theta) = L(1 - n)$$

$$R = \frac{L(1-n)}{(1-n\cos\theta)}$$

$$R = \frac{L(n-1)}{n\cos\theta - 1}$$

Where L = focal length of the lens

- The above Equation represents the equation for the shape of the lens.
- R = L (n-1) if θ is small.
- The asymptotes of hyperbola are at an angle, with respect to the main axis. This angle can be determined by letting R =∞

$$n\cos\theta - 1 = \frac{L(n-1)}{R} = \frac{L(n-1)}{\propto} = \frac{Finite}{\propto} = 0$$

$$\therefore \cos\theta = \frac{1}{n}$$

Uses of dielectric lens antenna:

- Unstepped dielectric lens antenna is wide-band and its shape does not depend on wavelength.
- Typical bandwidth of unstepped and stepped lens antenna are 12% and 5% respectively.
- As lens antenna is a microwave device, it is most widely used at a microwave frequency above 3000 MHZ.

E-PLANE METAL PLATE LENS ANTENNA:

- This antenna is constructed using parallel metal-plates spaced suitably to support the TE mode of propagation.

Design of metal plate lens:

- A metal plate lens makes use of waveguide theory which states that the guide wavelength $\lambda\lambda_{g_g}$ is related to the free-space wavelength λ via

$$\frac{1}{\lambda_g^2} = \left(\frac{1}{\lambda_o}\right)^2 - \left(\frac{1}{2a}\right)^2 \qquad \text{…………(e)}$$

Where , λ_g = Guide wavelength

λ_o = free space wavelength

a = wider internal dimension of the rectangular waveguide or spacing between two plates

- ✓ The phase velocity of the wave in a rectangular guide is always greater than velocity of wave in free space($i.e., C = 3 \times 10^8 m/s$) and is given by

$$V_p = \frac{C\lambda_g}{\lambda_o}$$

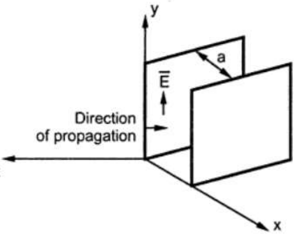


Fig 4.15: Propagation through metal plates of E plane metal lens

Let us consider a wave propagates between two infinite parallel plates spaced a distance **'a'** as shown in fig 4.15. the electric field vector is parallel to the plates. This may be regarded as a part of a rectangular waveguide waveguide wirth its other dimension 'b' infinitely large. But the wavelength 'λ_g' is dependant only on the dimension "a" .

A structure consisting of many such parallel plates with spacing **'a'** can be regarded as a uniform medium.Its effective refractive index is given by

$$n = \frac{C}{V_p} = \frac{C}{C\lambda_g/\lambda_o} = \frac{\lambda_o}{\lambda_g}$$

Where λ_o = free space wavelength

λ_g = guide wavelength

Multiplying equation (e) by λ_o^2 , we get

$$\lambda_o^2\left(\frac{1}{\lambda_g}\right)^2 = \lambda_o^2\left(\frac{1}{\lambda_o}\right)^2 - \lambda_o^2\left(\frac{1}{2a}\right)^2$$

$$i.e., \left(\frac{\lambda_o}{\lambda_g}\right)^2 = \left(\frac{\lambda_o}{\lambda_o}\right)^2 - \left(\frac{\lambda_o}{2a}\right)^2$$

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

But $\frac{\lambda_o}{\lambda_g} = n$

$$\therefore n = \sqrt{1 - \left(\frac{\lambda_o}{2a}\right)^2} \qquad \ldots\ldots..(f)$$

The value of ***n*** is less than unity

- ✓ The spacing between the plates **'a'** for which the refractive index becomes zero is called **critical spacing between plates.**
  Therefore equation (f) becomes

$$0 = \sqrt{1 - \left(\frac{\lambda_o}{2a}\right)^2}$$

Squaring on both the sides

$$0 = 1 - \left(\frac{\lambda_o}{2a}\right)^2$$

$$1 = \left(\frac{\lambda_o}{2a}\right)^2$$

$$(2a)^2 = \lambda_o^2$$

$$a^2 = \frac{\lambda_o^2}{4}$$

$$a = \frac{\lambda_o}{2} \qquad \rightarrow Critical\ spacing$$

Construction of metal plate lens antenna:

- ✓ This antenna is constructed using parallel metal plates to support the TE mode of propagation.
- ✓ The phase velocity of this mode in a parallel-plate waveguide is greater than the free-space phase velocity, C. $V_p = C/\sqrt{\varepsilon_r}$
- ✓ Therefore its dielectric constant is less than unity. Hence a lens made of such a medium with dielectric constant less than unity must have a ***concave refracting surface.***
- ✓ This configuration retains most of the advantages of a lens antenna while reducing the weight of the antenna.
- ✓ Zoning is also used here to reduce the depth of the lens.
- ✓ A convergent E-plane metal plate lens antenna is shown in fig 4.16.

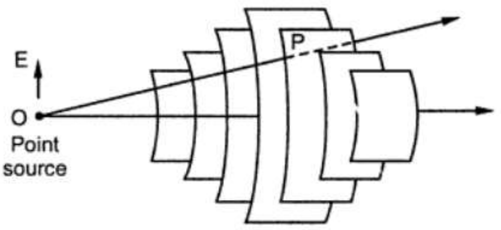


Fig 4.16 : Convergent E plane metal plate lens

Equation for the shape of the plate:

- ✓ Now consider a plate which is on the axis of the lens as shown in fig 4.17

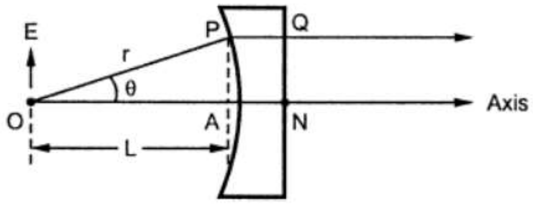


Fig 4.17 : Metal plate of lens on the axis of the lens

- ✓ The shape of the plate can be determined by the principle of ***equality of electrical path length*** according to **fermat's principle**.
- ✓ According to the equality of the electrical path length

$$OPQ = OAN$$

$$i.e., OP + PQ = OB + BN$$

$$r + PQ = L + AB \qquad (\because AB \approx BN)$$

$$r + 2AB = L + AB \qquad (\because PQ = AN = 2AB) \ldots\ldots\ldots.(g)$$

From right angled $\triangle\, OAP, COS\theta = \frac{OA}{r}$

$$OA = rCOS\theta$$

$$AB = OB - OA = L - rCOS\theta$$

Therefore equation (g) becomes

$$r + 2(L - rCOS\theta) = L + L - L - rCOS\theta$$

$$r + L - rCOS\theta = L$$

$$L = (L - rCOS\theta) + r$$

Writing the above equation in terms of time

$$\frac{L}{\lambda_O} = \frac{r}{\lambda_O} + \frac{L - rCOS\theta}{\lambda_g}$$

$$\left(\because time = \frac{Distance}{velocity} = \frac{Distance}{f\lambda}\right)$$

$$L = r + \tfrac{\lambda_O}{\lambda_g}(L - rCOS\theta)$$

$$L = r + n(L - rCOS\theta)$$

$$r = \frac{L(1-n)}{1-nCOS\theta}$$

With n<1, the above equation is an equation of ellipse. So we can achieve three dimensional concave surface of the concave lens by rotating the center plate on the axis.

Disadvantage of E-plane metal plate lens:

The major drawback of the E-plane metal plate lens antenna compared with the dielectric lens antenna is that the bandwidth of the metal plate lens antenna is relatively smaller.

Advantages of lens antenna:

- ✓ Feed and feed support do not obstruct the aperture.
- ✓ Tolerance in the design of lens antenna is more, greater extent of wrapping and twisting is possible without disturbing electrical path length.
- ✓ Feeding at a point away from the axis is possible.

Disadvantages of lens antenna:

- ✓ Lens antennas are expensive for similar gain and bandwidth in comparison with reflector antennas.
- ✓ The design of lens antennas is complicated.
- ✓ Lens antennas are bulkier.

Luneburge Lens:

- ✓ The luneburge lens is basically a delay type lens and it is spherically symmetric.
- ✓ Here in this lens, the refractive index of the dielectric(n) varies as a function of radius.

$$n = \sqrt{2 - \left(\frac{r}{R}\right)^2}$$

Where R = radius of the sphere

r = radial distance from the center of the sphere r

when R = r

n = $\sqrt{2-1}$ =1

- ✓ At the centre of the sphere r = 0. Then the maximum value of the refractive index at the center of the sphere is given by

$$\eta_{max} = \sqrt{2-0} = \sqrt{2} = 1.412$$

- ✓ The basic Luneburg lens is as shown in the fig 4.18, which indicates its basic property.

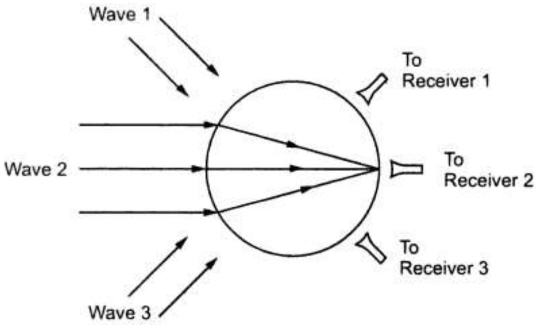


Fig 4.18 : Luneburg lens

- ✓ When a plane wave is incident on one side of the lens, then the waves are brought into the focus at a point on opposite of the sphere.
- ✓ The Luneburg lens can receive signal from any direction in the space around the lens.
- ✓ At the other side, we may use single conical horn or many conical horns to steer the single beam by switching.
- ✓ The obtain variable refractive index, an artificial dielectric material can be used, otherwise concentric shells of different refractive indices may be used in the sphere.
- ✓ The luneberg lens provides beam steering in both polar coordinates θ and ϕ equally.
- ✓ When the Luneburg spherical lens is cut in exactly two pieces at centre and if a reflecting sheet is placed at the flat side of the half Luneburg lens, then it is called Luneburg reflector type lens antenna. This focus the incoming waves incident at angle $\theta = \theta_i$; into angle of reflection $\theta_r = \theta_i$.

Application of Luneburg lens:

Luneburg lens is used in variety of applications like

- ✓ Ground navigation
- ✓ Air navigation
- ✓ It is used to enhance the radar visibility of a target.

4.7 ANTENNA MEASUREMENTS

Antenna measurements are useful for the application oriented specific designs of the antennas. There are some complex antenna structures which cannot be studied and analytically investigated. For such complex antennas, the experimental results are necessary to validate the theoretical data.

In general, the antenna measurements are carried out using the test antenna in the receiving mode. It is beneficial if the test antenna is reciprocal because the receiving mode characteristics of such reciprocal antennas are identical to the characteristics in the transmitting mode. For ideal far-field radiation characteristic measurements, the test antenna is illuminated by uniform plane waves.

But such ideal conditions are difficult to achieve, thus the conditions are approximated by separating the test antenna and the illuminating antenna by a distance greater than or equal to $2\ d^2/\lambda$. Additionally the illumination to the test antenna is affected due to the reflections from the ground and nearby objects such as tall buildings, trees, hills, etc. Following are some of the drawbacks of the experimental investigations.

1. In some cases, the size, weight and volume of antenna makes it impractical to move it from operating environment to the measuring site.
2. For large antennas, at higher frequencies the pattern measurement becomes very difficult because distance to the far-field region ($r > 2d^2/\lambda$) becomes too large for even outside ranges.
3. It is very difficult to keep the reflections from ground and other objects below acceptable levels.
4. The outside measuring equipments are not capable of handling uncontrolled all-weather environment.
5. The enclosed measuring systems for compact ranges cannot accommodate large antenna systems including ships, aircrafts, spacecrafts, etc.
6. In some cases, the time required to measure antenna characteristics is uncontrollable, (e.g., phased arrays)
7. The cost factor in the measurement techniques is too high.

But some of the drawbacks have been overcome or simplified now-a-days by the use of special techniques such as far-field pattern prediction by extrapolation of the near-field measurements, scale model measurements, using modern commercial equipments and computer assisted techniques.

MEASUREMENT OF RADIATION PATTEN

The radiation capabilities of an antenna are characterized by the characteristics of an antenna such as the radiation pattern (including amplitude and phase patterns), polarization and gain.

All these quantities are measured on the surface of a sphere with constant radius. Any point P on such sphere can be described using spherical co-ordinate system as shown in the Fig. 4.19.

Basically for representation of a point on the surface, only θ and ϕ specifications are sufficient because sphere with constant radius is considered. Thus the radiation characteristics of the antenna as a function of θ and ϕ for constant radius and frequency is called radiation pattern of an antenna. Basically it is a three dimensional representation. But due to the practical difficulty, number of two dimensional patterns are measured and from that the three dimensional pattern is constructed

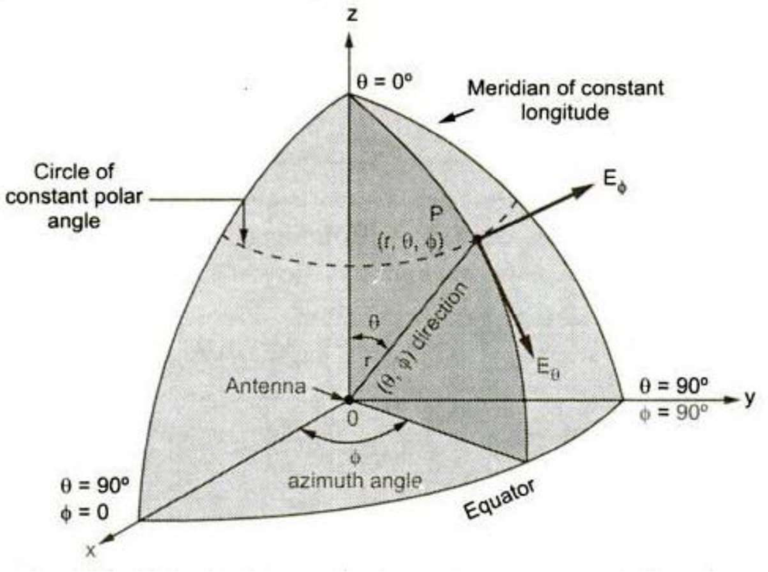


Fig .4.19: Spherical co-ordinate system representation for radiation pattern measurement

.

In general, the minimum number of patterns required to construct a three dimensional pattern is 2 and they are selected as principle E-plane and H-plane patterns. The two dimensional pattern is generally called pattern cut. Generally the pattern cuts can be obtained for one of the angles (θ or (ϕ)) constant and varying the other. In most of the cases, the required patterns are patterns in horizontal plane i.e., x-y plane and vertical pattern in x-y plane. (Refer Fig.4.33). For horizontal antenna following patterns are required.

(i) The ϕ component of electric field as a function of ϕ is measured in x-y plane (θ = 90°).

The field component can be then represented as E_ϕ (θ = 90°, ϕ) and it is called ***E-plane pattern***.

(ii) The ϕ component of electric field as a function of θ is measured in x-z plane (ϕ = 0°). It is represented as E_ϕ (θ, ϕ = 90°) and it is called ***H-plane pattern.***

The two patterns bisect the major lobe in mutually perpendicular planes providing sufficient information for the measurement.

For the ***vertical antenna*** following patterns are required.

(i) The θ component of the electric field is measured in x-y plane (θ = 90°) as a function of ϕ .The field component can be represented as E_θ (θ = 90°, ϕ) and it is called ***H-plane*** **pattern.**

(ii) The θ component of the electric field is measured as a function of ϕ in the x-z plane (ϕ = 90°). Then the field component can be represented as E_θ (θ, ϕ = 90°) and it is called ***E-plane pattern***.

For the antennas which are circularly or elliptically polarized, the measurement of all these four patterns is necessary. However the patterns in one plane provides sufficient information for the measurement. For example, for broadcasting applications and earth to earth communications, the horizontal plane patterns are sufficient. While for earth to space communications such as radar, radio astronomy etc., the vertical plane patterns are sufficient.

The radiation pattern of an antenna can be measured either in transmitting mode or receiving mode. For reciprocal antennas, even any mode is sufficient, receiving mode is selected.

BASIC PROCEDURE FOR RADIATION PATTERN MEASUREMENT

For the measurement of radiation pattern of antenna, two antennas are required. One of the antennas in the system is the antenna under test, while the other illuminates the antenna under test and it is located away from the antenna under test.

Thus one antenna is used in the transmitting mode, while other in the receiving mode. But according to- the reciprocity principle, the radiation pattern will be same irrespective of the mode in which antenna is used. The antenna under test is usually referred as primary antenna, while the other one as secondary antenna. Note that these are called primary or secondary antennas irrespective of the antenna mode i.e., either transmitting or receiving

The procedures for measuring the radiation pattern in a particular plane are as follows.

A) In the first procedure, the antenna under test i.e., primary antenna is kept stationary, while the secondary antenna is moved around the primary antenna along a circular path with uniform radius. If the secondary antenna is directional one, it is always aimed at the primary antenna. In this procedure, usually the primary antenna is transmitting. At different points, along the circular path, the readings of the field strength and direction with respect to the primary antenna are recorded. Then from these readings a plot of the radiation pattern of a primary antenna is plotted either as rectangular plot or polar plot.

B) In the second procedure, both the antennas are kept stationary with a suitable spacing between them. The secondary antenna is aimed at the primary antenna. The primary antenna is rotated about a vertical axis. In this procedure, the secondary antenna is used in the transmitting mode, so that the field strength reading and direction of the primary antenna with respect to the secondary antenna is made. The continuous readings at different points during rotation can be made using pattern recorder.

Generally at low frequency, first procedure is used while at high frequency second one is preferred.

SET UP FOR MEASUREMENT OF RADIATION PATTERN OF AN ANTENNA

The simple arrangement for the radiation pattern measurement consists of primary antenna is transmitting mode, secondary antenna as antenna under test. The secondary antenna is coupled with the rotating shaft and it is rotated using antenna rotator mechanism. To measure the relative amplitude of the received field an indicator is using along with the receiver as shown in the Fig.4.20.

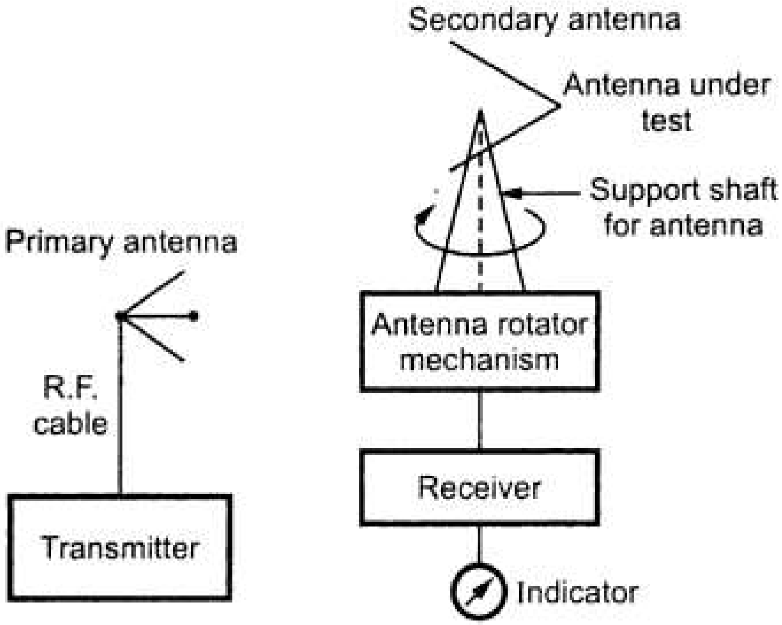


Fig 4.20. Measurement set up for radiation pattern

Usually the antenna under test is used in the receiving mode. It is properly illuminated by the stationary primary antenna. The secondary antenna is rotated about vertical axis. For E-plane pattern measurement, the antenna support shaft is rotated with both the antennas horizontal. While for H-plane pattern measurement, the shaft is rotated with both the antennas vertical.

UNIFORM DISTANCE REQUIREMENT

For accurate far-field radiation pattern, the distance between the primary and secondary antenna must be very large. If this distance is smaller, then the near-field radiation pattern is obtained. The basic requirement for the far-field pattern, the secondary antenna must be illuminated by a plane wave front. The plane wave front is possible only at infinite distance. Thus the limit specified is that the phase difference between the centre and the edge of the antenna should not be greater than λ/16.

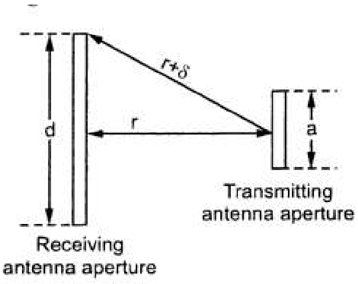


Fig 4.21. Phase different between centre and edge of the receiving antenna for uniform distance requirement

But according to standard condition , the distance between the two antennas should be

$$r \geq \frac{2d^2}{\lambda} \qquad \text{.......(4.80)}$$

Where r = Distance between transmitter and receiver

λ = wave length

d = Maximum dimension of the antenna

From Fig 4.35 ,we can write

$(r+\delta)^2 = \left(\frac{d}{2}\right)^2 + r^2$, where δ is phase difference error

$$\therefore \quad r^2 + 2r\delta + \delta^2 = \frac{d^2}{4} + r^2$$

As δ is very small , neglecting δ^2,we can write

$$2r\delta = \frac{d^2}{4}$$

$$\therefore \quad r = \frac{d^2}{8\delta} \qquad \text{.....(4.81)}$$

From above equation it is clear that minimum distance required depends on the aperture of the receiving antenna and wavelength λ. The reduction in the value of ***r*** yields broader radiation patterns and higher minor lobes and the increase in the value of r, directive pattern is obtained with minimum or reduced minor lobes.

UNIFORM AMPLITUDE REQUIREMENT

For the accurate field radiation pattern, another requirement is of uniform amplitude. The transmitting antenna i.e., primary antenna should produce a plane wave with uniform amplitude and phase over distance r. As far as possible, the interference between direct rays and indirect reflected rays should be minimized. Along with this, reflections from tall buildings, trees should also be avoided. For this both the antennas must be mounted on higher towers or tops of the tall building. Also both the antennas must be highly directional

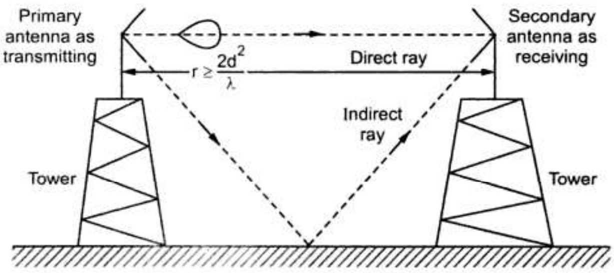


Fig 4.21 : Uniform amplitude requirement

MEASUREMENT OF PHASE OF AN ANTENNA

The phase of an antenna is periodic quantity and it is defined in multiples of 360°. Basically phase is a relative quantity. Hence for the measurement of a phase of an antenna, some reference is necessary so that the measurement of this relative quantity is carried out by the comparison with reference.

The basic near field phase measurement system is shown in the Fig.4.22.

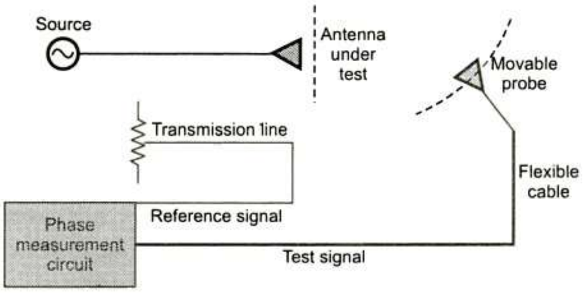


Fig 4.22: Near field phase pattern for measuring system

For near-field phase pattern measurements, the reference signal is coupled from the transmission line. The received signal is compared with the reference signal using appropriate phase measurement circuit. Thus this method uses a technique in which direct of comparison of the phase of the received signal with that of the reference is carried out.

For far-field phase pattern measurement, this direct phase comparison technique is not possible. The far-field phase pattern measurement set up is as shown in the Fig.4.23.

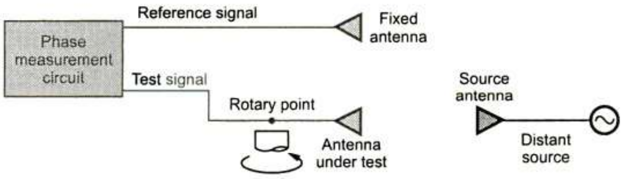


Fig 4.23: Far field phase pattern for measuring system

The signal transmitted by the source antenna, fed with distant source, is received by the fixed antenna and the antenna under test simultaneously. Then the antenna under test is rotated but the fixed antenna is kept steady. This fixed antenna serves as a reference. Using dual channel heterodyne system as the phase measuring circuit, the phase pattern of the antenna under test is measured by comparing it with the reference phase pattern.

4.8 MEASUREMENT OF GAIN OF AN ANTENNA

The performance of any antenna can be described in terms of figure of merit i.e., gain of an antenna. Depending upon the frequency of operation various methods can be used for the measurement of gain of an antenna. Typically to measure gain above 1 GHz, free space ranges are used. In addition to this, the microwave techniques using waveguides can also be used for the gain measurements. At lower frequencies, due to the longer wavelength, it is very difficult to achieve free space conditions. Hence between 0.1-1 GHz range, the ground-reflection ranges are conveniently used. Usually below 1 MHz frequency, antenna gains are not measured. In such cases the measurements are done with the field strength of the radiated ground wave.

Basically there are two standard methods used for the measurement of gain of an antenna such as

(i) Gain-transfer (or gain-comparison) method or direct comparison method, and
(ii) Absolute-gain method.

Basically absolute-gain method is useful in calibrating antennas that can be used as standard gain antennas for the measurement of gain. While the gain-comparison method is used including the standard gain antennas to measure the absolute gain of the antenna.

The most widely used standard gain antennas are half wave dipole, with 2.1 dB gain and pyramidal horn antennas, with 12-25 dB gain. Both the antennas have linear polarizations. In free space, the polarization purity is highest for the dipole. But the polarization is affected by the surrounding environment as it has very broad pattern. While for the horn antennas, the polarization is elliptical. But in the free space, the polarization of these antennas is not affected because the pattern is highly directive.

GAIN MEASUREMENT BY DIRECT COMPARISON METHOD

At high frequencies, the gain measurement is done using direct comparison method. In this method, the gain measurement is done by comparing the strength of the signals transmitted or received by the antenna under test and the standard gain antenna. The antenna whose gain is accurately known and can be used for the measurement of gain of other antennas is called standard gain antenna. At high frequency the universally accepted standard gain antenna is the horn antenna.

The set up of gain measurement by the comparison method is as shown in the Fig.4.24.

This method uses two antennas termed as primary antenna and secondary antenna. The secondary antenna is arbitrary transmitting antenna. The knowledge of gain of the secondary antenna is not necessary. The primary antenna consists of two different antennas separated through a switch SW.

The first primary antenna is the standard gain antenna (i. e., horn antenna in above case) and the subject antenna under test. The two primary antennas are located with sufficient distance of separation in between so as to avoid interference and coupling between the two antennas. While the primary and secondary antennas are separated with a distance greater than or equal to $2\ d^2/\lambda$ to minimize the reflection between them to great extent.

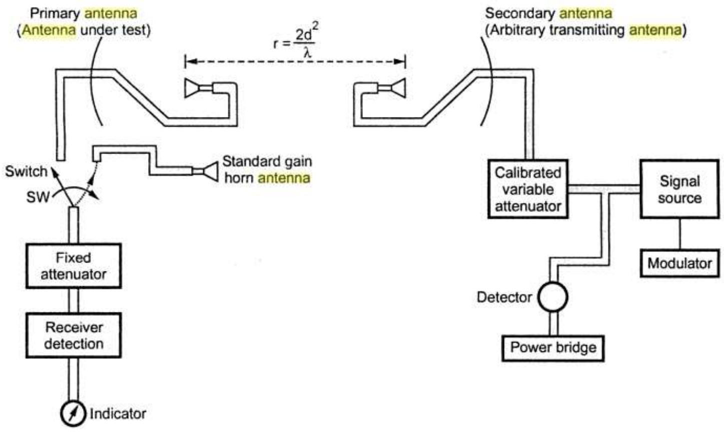


Fig . 4.24. Set up of gain measurement by gain comparison method

At the input of receiver, attenuation pad i.e., fixed attenuator is inserted for matching load conditions. This method demands that throughout the gain measurement process the frequency of radiated power in the direction of the primary antenna should remain constant. To ensure utmost frequency stability at the transmitter, the power bridge circuit is used.

The gain measurement by the gain-comparison method is two step procedure.

1. Through the switch SW, first standard gain antenna is connected to the receiver. The antenna is adjusted in the direction of the secondary antenna to have maximum signal intensity. The input connected to the secondary or transmitting antenna is adjusted to required level. For this input corresponding primary antenna reading at the receiver is recorded. Corresponding attenuator and power bridge readings are recorded as $A_1$and P_1
2. Secondly the antenna under test is connected to the receiver by changing the position of the switch SW. To get the same reading at the receiver (obtained with the standard gain antenna), the attenuator is adjusted. Then corresponding attenuator and power bridge readings are recorded as A_2 and P_2

Now consider two different cases.

Case I: If $P_1 = P_2$, then no correction need to be applied and the gain of the subject antenna under test is given by,

Power gain = $G_p = \frac{A_2}{A_1}$where A_1 and A_2 are relative power levels

Taking logarithms on both the sides, we get,

$$\log_{10} G_P = \log_{10}\left(\frac{A_2}{A_1}\right) = \log_{10} A_2 - \log_{10} A_1$$

$$\boxed{\text{i.e.} \underset{(dB)}{G_p} = \underset{(dB)}{A_2} - \underset{(dB)}{A_1}}$$

Case II: If $P_1 \neq P_2$, then the correction need to be included

$$\text{Let} \qquad \frac{P_1}{P_2} = P, \qquad \text{then}$$

$$log_{10}\frac{P_1}{P_2} = P_{(dB)}$$

Hence power gain is given by

$$G = G_p \times \frac{P_1}{P_2} = \frac{A_2}{A_1}\cdot\frac{P_1}{P_2}$$

$$\text{i.e. } G = G_p\cdot\frac{P_1}{P_2}$$

Taking logarithms on both the sides

$$log_{10}G = log_{10}\left(G_p\cdot\frac{P_1}{P_2}\right) = log_{10}G_p + log_{10}\left(\frac{P_1}{P_2}\right)$$

$$\text{i.e. } G_{(dB)} = G_{p(dB)} + P_{(dB)}$$

MEASUREMENT OF ABSOLUTE GAIN

Consider two identical antennas separated by distance ***r*** **.**Let the transmitted power be denoted by P_t and the received power be P_r. Let the effective apertures of the transmitting and receiving antennas be A_{et} and A_{er} respectively. As the two antennas are identical, we can write,

$$A_{et} = A_{er} = \frac{G_D\lambda^2}{4\pi}$$

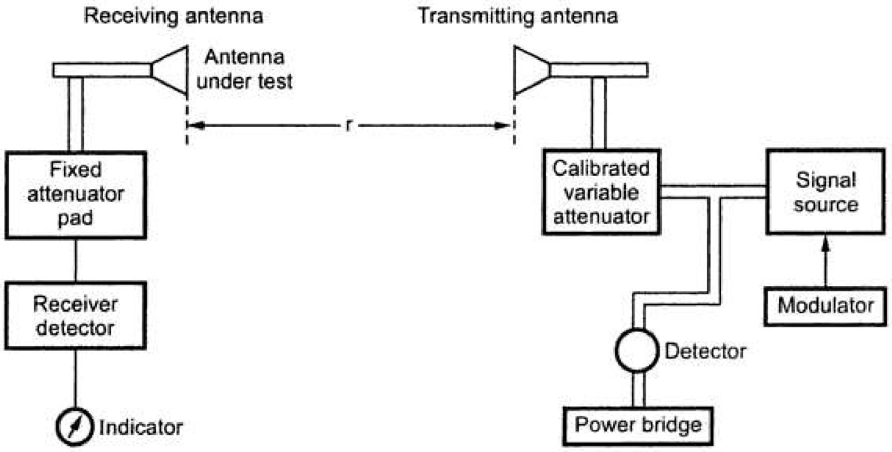


Fig 4.25 : Transmitting and receiving antennas for absolute gain measurement

From Friis's transmission equation , we can write,

$$\frac{P_r}{P_t} = \frac{A_{er} . A_{et}}{\lambda^2 . r^2} = \left(\frac{G_D \lambda^2}{4\pi}\right)\left(\frac{G_D \lambda^2}{4\pi}\right)\frac{1}{\lambda^2 r^2}$$

$$\therefore \quad \frac{P_r}{P_t} = \left(\frac{G_D \lambda}{4\pi}\right)^2$$

$$\therefore \quad \frac{G_D \lambda}{4\pi r} = \sqrt{\frac{P_r}{P_t}}$$

$$G_D = \frac{4\pi r}{\lambda}\sqrt{\frac{P_r}{P_t}}$$

By knowing wavelength λ distance between two antennas *r,* and measuring the radiated and received powers, the absolute gain of the antenna can be obtained.

First the antennas are oriented for maximum signal. Using the calibrated variable attenuator, the input signal level of the transmitting antenna is adjusted. Then corresponding receiver reading is recorded. The corresponding attenuator and power bridge readings are recorded as A_1 and P_{t1} respectively. Then the transmitter is disconnected from the antenna and is connected to the receiver through pad providing fixed attenuation. Again attenuator dial is adjusted to get same reading at the receiver as obtained in first step. Again corresponding attenuator and power bridge readings are recorded as A_2 and P_{t2}.

If $P_{t1} = P_{t2}$, no connection need to be included and gain can be calculated by using equation (4.85) in which A_1 and A_2 correspond to the relative transmitted and received powers respectively.

4.9 MEASUREMENT OF POLARAISATION OF ANTENNA:

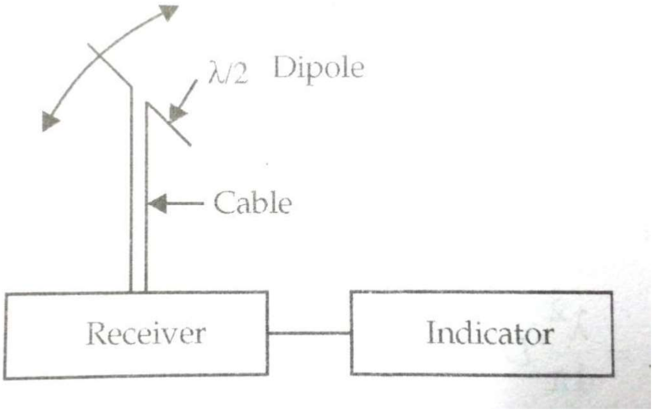
Polarization of the antenna is defined as the polarization of its radiated wave . The polarization of electromagnetic wave is the direction of its electric field . in general , the direction of electric field with time forms an ellipse. The ellipse has either clockwise or anti-clock sense. When the ellipse becomes a circle ,the polarization is circular. When the ellipse becomes a straight line, the polarization is linear. The clockwise rotation of electric field with time is called right-hand polarization and anti- clockwise rotation of electric field is called left-hand polaraisation.

The electric field consists of both E_θ and E_ϕ components. The direction of rotation along the direction of propagation represents the sense of polarization. The axial ratio and tilt angle describes the ellipse.

The methods of measurement of polarization are:

1. Polarization pattern method
2. Linear component method
3. Circular component method
4. Power measurement method.

1. Polarization pattern method



A rotatable half-wave dipole is connected to a calibrated receiver. The dipole is rotated and incident field coming from AUT is measured. AUT is used in transmitting mode. If the variation of received signal forms an ellipse as in fig. The AUT is said to be elliptically polarized. The sense of polarization is obtained by using two antennas. Here one is right – hand circular polarized and the other left-hand circular polarized. The antenna which receives a large signal gives the sense of polaraisation.

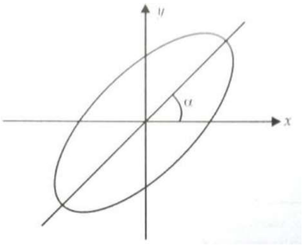


Fig2.26 :Tilted ellipse

2. **Linear component method**

The AUT is used in transmitting mode. The signal coming from AUT is measured by vertical antenna as in fig. Let the signal be E_v.

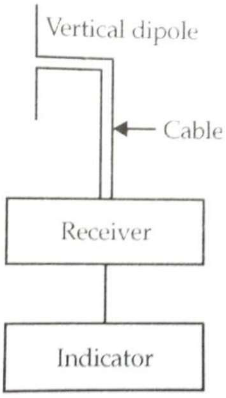


Fig : 2.27 Vertical dipole with receiver

Now the vertical dipole is connected in horizontal position and the signal is measured. Let the signal be E_H.

$$\text{Then } E_x = E_v \sin(\omega t - \beta z)$$

$$E_y = E_H \sin(\omega t - \beta z + \alpha)$$

α = phase difference between the two signals

$\beta = \frac{2\pi}{\lambda}$; ω = angular frequency.

The phase difference α is measured by a phase comparative method. The signal from the vertical antenna is measured as in step 2. But the signal from the horizontal antenna is connected to a matched terminated slotted line. The probe in the slotted line is connected to the receiver as in below fig.

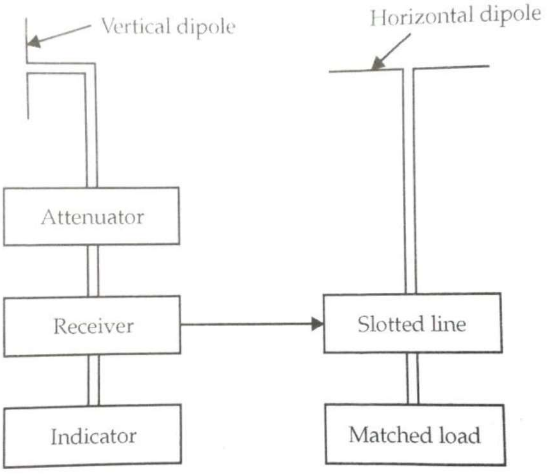


Fig 2.28: Phase comparison

If α lies in $0 < \alpha < 180^0$, the direction of rotation is clockwise. If α lies in $0 < \alpha < -180^0$, the direction of rotation is anticlockwise. The angle of tilt ϕ_t is given by

$$\phi_t = \frac{1}{2}\tan^{-1}\left(\frac{2E_1E_2 cos\alpha}{E_1^2 - E_2^2}\right)$$

3.Circular component method

In this method, two circularly polarized antennas of opposite sense , for example, left and right hand helical antennas, are used to receive the signals E_L and E_R from AUT. The set up for measurement using this method is shown in fig.

The axial ratio is given by

$$AR = \frac{E_R + E_L}{E_R - E_L}$$

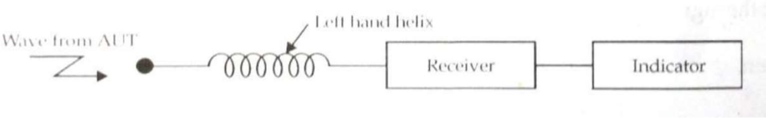
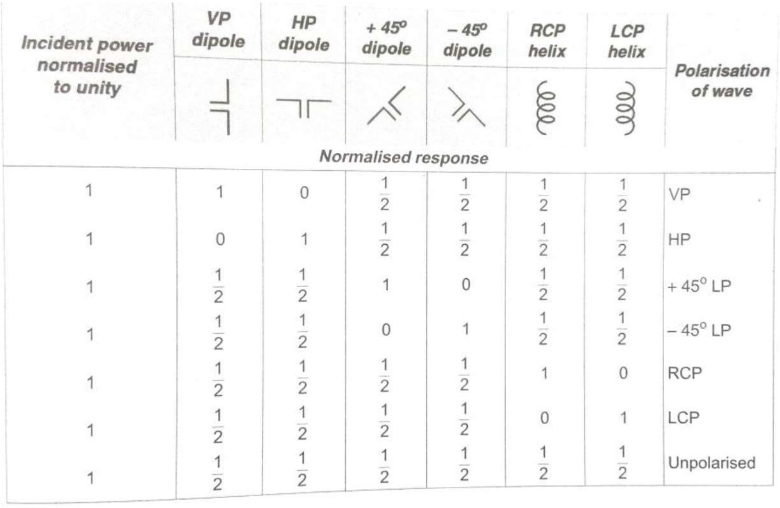


FIG2.29 : POLARISATION MEASUREMENT BY CIRCULAR COMPONENT METHOD

4.Power measurement method.

AUT is used in the transmitting mode. Six types of antennas, namely vertical dipole , horizontal dipole, a dipole with an inclination of $+45^0$, a dipole with an inclination of -45^0, right circularly polarized helix and left circularly polarized helix are used to measure the incident power. Tabulate the responses as in below table. From the response of the six antennas, the polarization of the antenna is decided as shown in the last column of table.



Incident power normalised to unity	VP dipole	HP dipole	+ 45° dipole	− 45° dipole	RCP helix	LCP helix	Polarisation of wave
	Normalised response						
1	1	0	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	VP
1	0	1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	HP
1	$\frac{1}{2}$	$\frac{1}{2}$	1	0	$\frac{1}{2}$	$\frac{1}{2}$	+ 45° LP
1	$\frac{1}{2}$	$\frac{1}{2}$	0	1	$\frac{1}{2}$	$\frac{1}{2}$	− 45° LP
1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	1	0	RCP
1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0	1	LCP
1	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	Unpolarised

Table: Polarization measurement by power measurement

Here VP = vertical polarization

HP = horizontal polarization

LP = linear polarization

RCP = right circular polarization

LCP = left circular polarization

It is well known that waves are completely polarized in communication. The waves from celestial sources are partially polarized in radio astronomy. The waves are completely un-polarized in many cases.

TWO MARK QUESTION

1.Define lens antenna?

An antenna which collimates the incident divergent energy to prevent it from spreading in undesired directions is called as lens antenna.

2.What are the different types of lens antenna?

Lens antenna can be divided into two types.

1) Dielectric lens H-plane metal plate lens
2) E-plane metal plate lens antenna

3.State the merits and demerits of lens antenna?

Merits:

1. Flexible in design
2. Feed and feed support do not obstruct the aperture.
3. Used for wide frequency range.
4. It has greater design tolerance , larger amount of wrapping and twisting is possible in lens antenna as wave enters from one side and emerges at the other side maintaining the electrical path length.
5. It can be used to feed at off the optical axis and hence useful in applications where beam is required to be moved angularly with respect to axis.

Demerits:

1. Lenses are heavy and provide design complication
2. High cost.

4. What is the difference between planar and conical spiral antenna ?