Program : **B.Tech**

Subject Name: **Antenna & Wave Propagation**

Subject Code: **EC-602**

Semester: **6th**

Unit 3

Syllabus: Types of antennas

Log periodic antenna, loop antenna, helical antenna, biconical antenna, folded dipole antenna, Yagi-Uda antenna, lens antenna, turnstile antenna. Long wire antenna: resonant and travelling wave antennas for different wave lengths, V-antenna, rhombic antenna, beverage antenna.

Log Periodic Antenna:

It is a broadband antenna in which 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. Thus the basic geometry structure is repeated with the structure size changed.

The basic realization of the log periodic antenna is as shown in figure 3.1. This is a planer structure which consists two edge shaped metallic structure with teeth cut into themselves along circular arc.

The main feature of the above structure is that the radii of the arm which define location of successive teeth are with constant ration given by

$$\tau = \frac{R_n + 1}{R_n}$$

This ratio also defines lengths and widths of the successive teeth along radii. When such antenna is energized at the vertex, the properties exhibited by the structure at frequency f will repeated at all frequencies given by $\tau^n . f$ where n is integer. When these frequencies are plotted on logarithmic scale, it is observed that all are spaced equally with period equal to logarithmic of τ. Because of such a unique property, antenna is named as log-periodic antenna or logarithmically periodic antenna.

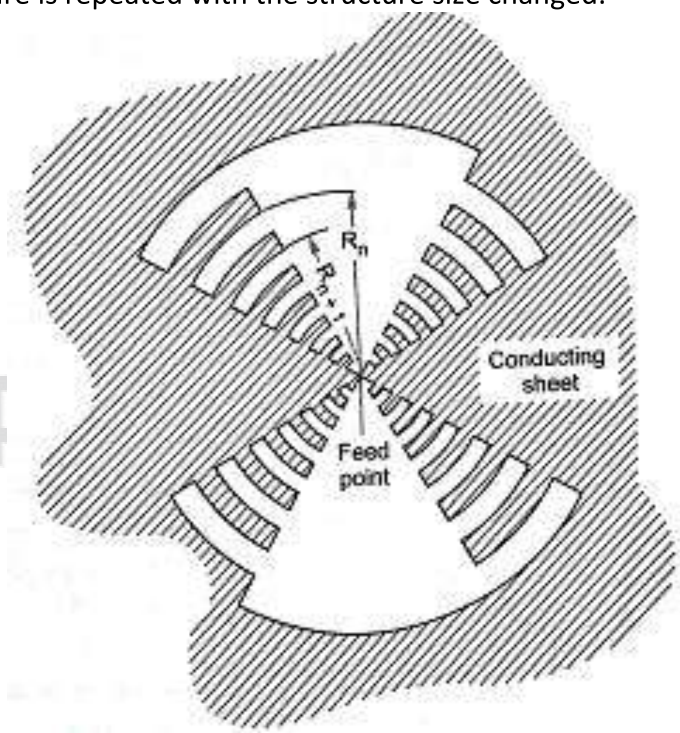


Figure 3.1 Planer log periodic antenna structure

Log Periodic Dipole Array:

In log-periodic antenna the basic geometric structure is repeated with the structure size changed. For every repetition, the structure size changes by a constant scale factor,, with which the structure can either be expand or contract.

A typical Log Periodic Dipole Array (LDPA) consists number of dipoles of different lengths and spacing. A typical arrangement is shown in figure 3.2.

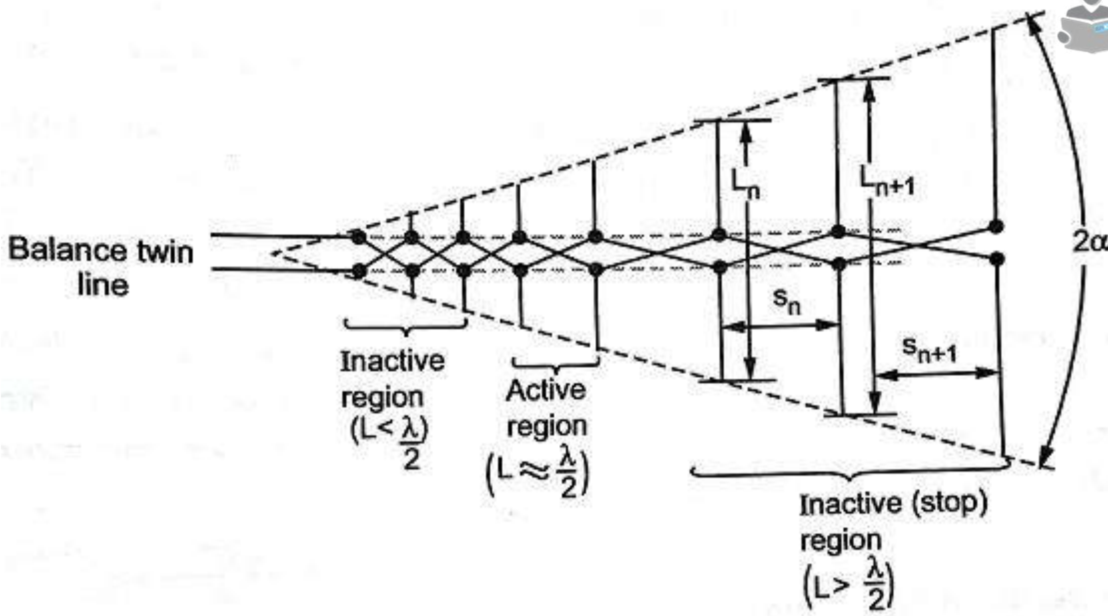


Figure 3.2 Log Periodic Dipole Array (LDPA)

The length of the dipoles increases from the feed point towards the other end such that the included angle α remains constant. The increase in the length of the dipole (L) and the spacing in the wavelength between two dipoles(s) are adjusted such that the dimensions of the adjacent dipoles possess certain ratio with each other. The dipole lengths and the spacing between two adjacent dipoles are related through parameter called design ratio or scale factor which is denoted by τ. Thus the relationship between s_n and s_{n+1} and L_n and $L_{n+1}$is given by

$$\frac{s_n}{s_{n+1}} = \frac{L_n}{L_{n+1}} = \tau$$

This $\tau$is also called periodicity factor which is always less than 1. Equation 3.5.1 can also be written as

$$\frac{s_{n+1}}{s_n} = \frac{L_{n+1}}{L_n} = \frac{1}{\tau} = K$$

Depending upon the length of the dipoles we get the three regions as under:

(i) Inactive Transmission Line Region$(\boldsymbol{L} < \lambda/2)$**:**

In this region the length of the dipoles is less than $\lambda/2$. The elements in this region provide capacitive impedance. The element spacing in this region is comparatively smaller. The currents in this region are very small therefore it is considered as inactive region. These currents lead the voltage supplied by the transmission line.

(ii) Active Region$(\boldsymbol{L = \lambda/2})$**:**

In this region the length of the dipoles are approximately equal to $\lambda/2$ (resonant length). This is the central region of the array from where maximum radiations take place. In this region the dipoles offer resistive impedance. The currents are of large value and are in phase with the base voltage.

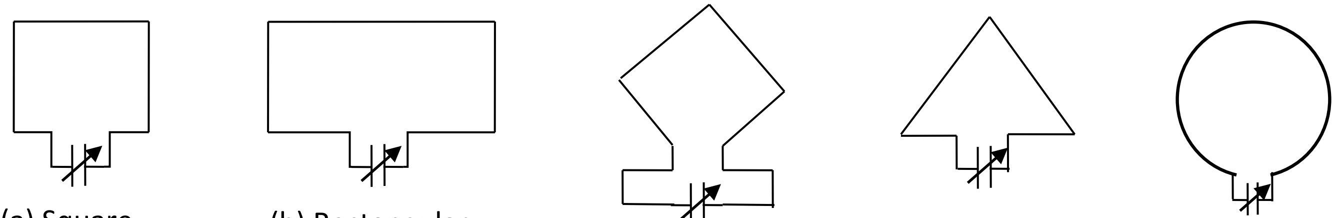
(iii) Inactive Stop Region$(\boldsymbol{L} > \lambda/2)$**:**

In this region the lengths of the dipoles are greater than $\lambda/2$ i.e. greater than the resonant lengths. The dipoles offer inductive impedance. The currents are smaller in this region and also lag base voltage. This is also called the reflective region.

Thus for a wavelength λ, the radiation occurs from the active region which is in the middle of the array. When the wavelength increases the radiation zone moves towards right side of the active region and vice versa.

Loop Antenna:

A loop antenna is a radiating coil of any shape with one or more turns carrying an R.F. current. The loop antenna may be of one of the any shape shown below.

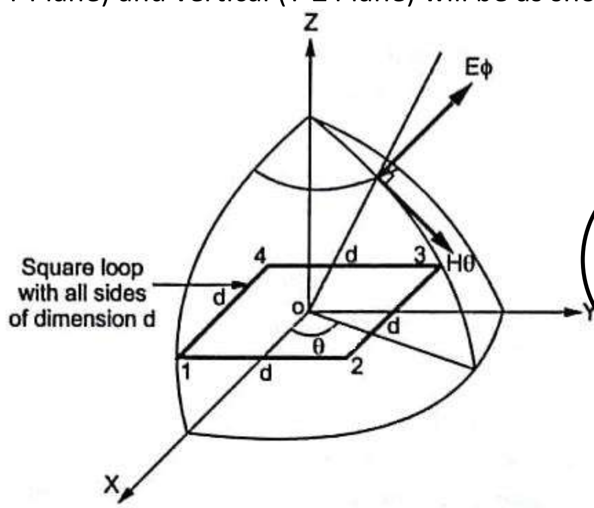


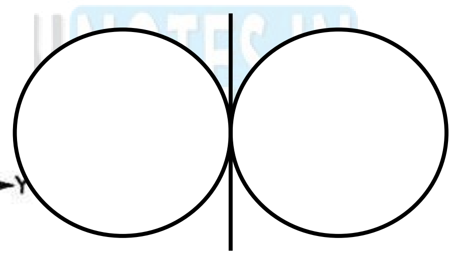
(a) Square (b) Rectangular (c) Rhombic (d) Triangular (e) Circular

Figure 3.3 Different shapes of loop antenna

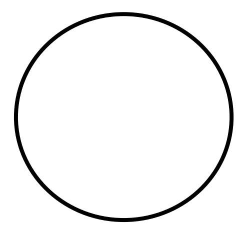
Generally a loop may consist one turn or more turns on a ferrite or air core. If a loop consists more than one turn then it is called as frame. For small loop antennas the radiation pattern is similar to the Hertzian dipole, with only difference that the electric field and the magnetic fields are interchanged. It means that the loop antenna is surrounded by the magnetic field which is at the right angles to the loop. Therefore small loop antennas are also called magnetic dipole.

Consider that the square loop is located at the center of the coordinate system as shown in figure 3.4 (a). The far field will have only $E_\phi$component. To find the far field rather than considering the four short dipoles, it is sufficient to consider only two short dipoles such as sides 14 and 23. Then the radiation pattern of these two short dipoles in the horizontal plane(X-Y Plane) and vertical (Y-Z Plane) will be as shown in figure 3.4 (b) and (c).





(b) Radiation pattern in horizontal plane



(c) Radiation pattern in vertical plane

Figure (a) Square loop at the centre

Figure 3.4 Square loop antenna at the centre of co-ordinate system & Radiation pattern

From figure (b) it is clear that the radiation pattern in the Y-Z plane for both the short dipoles is circular. We can say that the dipoles 1,4 and 2,3 are behaving like isotropic point sources in Y-Z plane as both radiating uniformly in all directions.

The far field radiation due to the two point sources with reference to centre O can be given as

$$E_\phi = \text{Field component due to dipole } 1,4 + \text{ Field component due to dipole } 2,3$$

From figure 3.5 it is clear that dipole 1,4 will take more time to reach point P than dipole 2,3. This path difference is given by

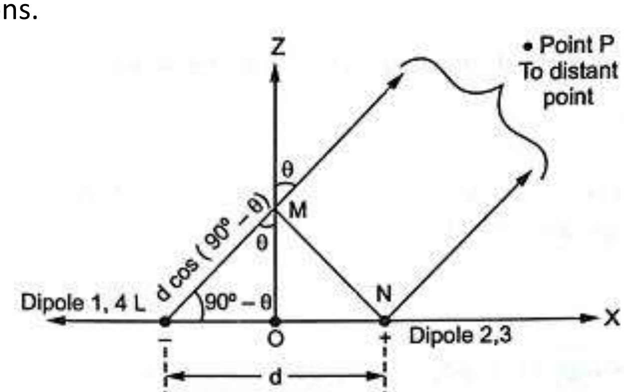


Figure 3.5 Dipoles in Y-Z plane as isotropic point

$\therefore Path\ Difference$ **source**

$= d\cos(90^0 - \theta)$

In terms of wavelength,

$\therefore Path\ Difference$

$= \frac{d\cos(90^0 - \theta)}{\lambda}$

The phase angle is given by

$$Phase\ angle = \psi = 2\pi \times Path\ difference$$

$$\psi = 2\pi \times \frac{d\,cos(90^0 - \theta)}{\lambda}$$

But $\cos(90^0 - \theta) = \sin\theta$, then phase angle is given by,

$$\psi = \frac{2\pi}{\lambda} d\,sin\,\theta$$

In general the field component for any dipole is given by

$$Field\ component = Magnitude \times e^{j(phase\ angle)}$$

Far field radiations due to the square loop antenna are

$$E_\phi = -j2\,E_0\,sin\left[\frac{\beta d\,sin\,\theta}{2}\right]\,V/m = \frac{120\,\pi^2[I]\,A\,sin\,\theta}{r\lambda^2}$$

$$H_\phi = \frac{-jE_0}{60\pi} sin\left[\frac{\beta d\,sin\,\theta}{2}\right]\,A/m = \frac{\pi[I]\,A\,sin\,\theta}{r\lambda^2}$$

The radiation resistance of the loop antenna is given by

$$R_{rad} = 3720\left(\frac{a}{\lambda}\right)\Omega$$

Where a, is the radius of the loop of the loop antenna.

Similarly the directivity of the circular loop antenna is defined as the ratio of maximum radiation intensity to the average radiation intensity.

$$D = \frac{Maximum\ radiation\ intensity}{Average\ radiation\ intensity} = \frac{P_r(r^2)}{\left(\frac{P}{4\pi}\right)}$$

$$D \approx 0.682\left(\frac{C}{\lambda}\right)\ For\ large\ loop\ \frac{C}{\lambda} \geq 5$$

$$D \approx \frac{3}{2} For\ smallloop\ \frac{C}{\lambda} < \frac{1}{3}$$

Applications of loop antenna:

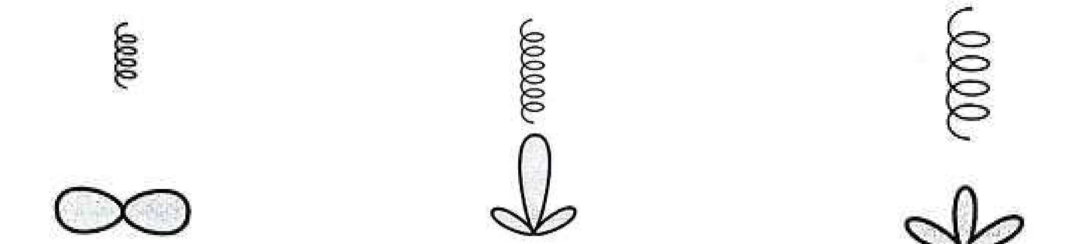
1. Small loop antenna is used as a source for Paraboloid in many applications.
2. Large loop antenna can be used as direction finder.
3. In many applications, loops are mounted at the top of the towers and can be used as omnidirectional systems.

Salient Features of Loop Antenna:

1. The loop antennas with circumference of loops less than 0.1λ at highest frequency are called small loop antennas. They can be used up to 30 MHz.
2. In practical applications, vertical loop antenna is most widely used for direction finding applications. If it is not shielded it receives bidirectional signal and if the antenna is shielded, it receives unidirectional signal. Due to electrostatic shielding, the directional characteristics are improved.
3. The loop antennas are most widely used in LF, MF, HF, VHF and UHF ranges and it shows doublet shaped radiation pattern.
4. The loop antennas when used with ferrite core, effective diameter of a loop can be increased and such loop antenna can be used as broadcast receiver.
5. When the loop circumference is small and if current is uniform then the radiation pattern of such loop antenna is similar to that of a magnetic dipole.

Helical Antenna:

It is basically a simple broadband VHF and UHF antenna which provides circular polarization. It consists of a thick copper wire wound in the form of a screw thread forming a helix. The wire is wounded in such a way that it is wounded as if on a uniform cylinder. When it is observed from any end, the shape observed is circular.



(a) Normal Mode (b) Axial Mode (c) Conical Mode

Figure 3.6 Different Modes of Helical Antenna

Though it can radiate in many modes, two important are axial mode and normal mode. In axial mode, the maximum radiation is along the helix axis under the condition that the circumference of the helix is of the order of one wavelength as shown in figure 3.6(b). In normal mode the maximum radiation is along the broadside to the helix axis under the condition that the circumference of the helix is smaller with respect to one wavelength as shown in figure 3.6(a). When the dimensions of the helix exceed those required for normal mode and axial mode, a multi-lobed pattern is observed as shown in figure 3.6(c), called conical mode.

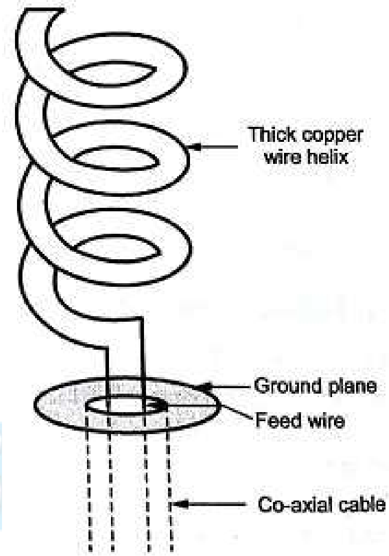


Figure 3.7 Helical Antenna

Helical Antenna Structure & Helical Geometry:

The structure is shown in figure 3.7 The helical antenna can operate in many modes but two important are normal and axial modes of operation.

This mode is called broadside mode. In axial mode, the field radiated by the antenna is maximum in the plane along the axis as in the end fire mode. Consider a helix antenna as shown in figure 3.8 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 ground plate.

The helix can be described by using following symbols.

N= Number of Turns
D= Diameter of the Helix
C= Circumference of Helix =πD
S= Space between two turns
A= Axial length
λ= Length of one turn
α= Pitch Angle
d= Diameter of conductor

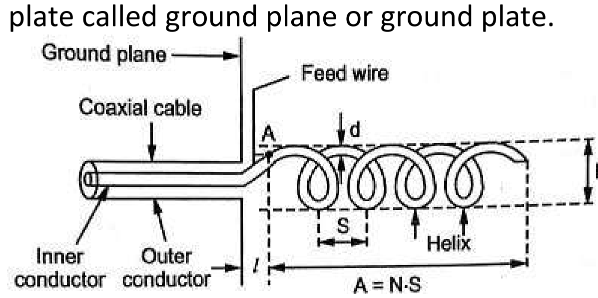


Figure 3.8 Helical Antenna Structure

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 the 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., the spacing between the turns S which is measure between two centers of the turns. The pitch angle is given by

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

Salient features of the Helical Antenna:

1. It is used for the circular polarization.

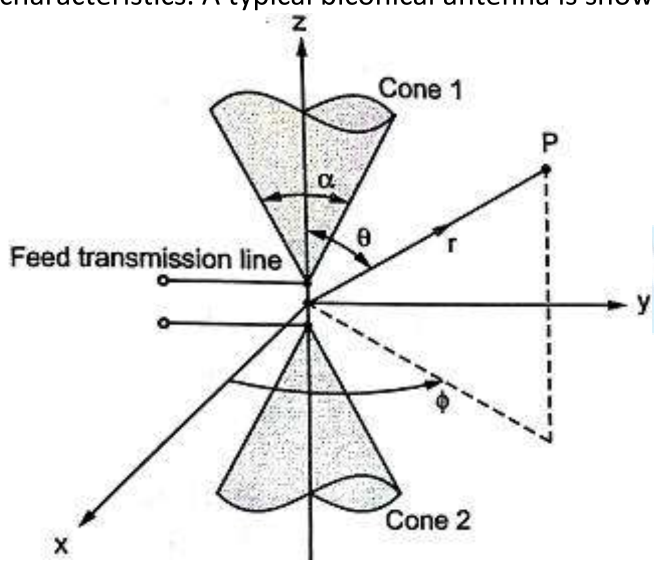
2. It is used most widely in VHF and UHF bands.
3. The axial mode of helical antenna is most widely used.
4. The antenna in axial mode has larger bandwidth but in normal mode bandwidth and efficiency are small.
5. Its construction is simple and directivity is higher.

Applications of Helical Antenna:

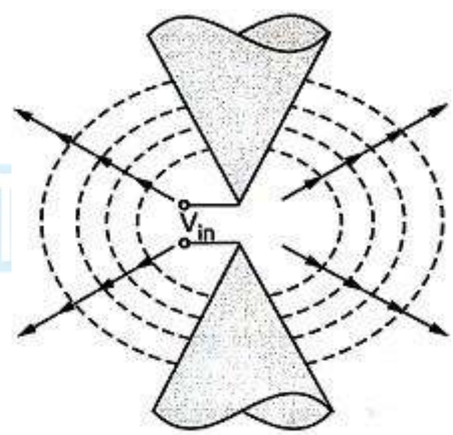
1. The axial mode helical antennas are used to achieve circularly polarized waves over extremely wide bandwidth.
2. As the axial mode helical antennas have wide bandwidth, the directivity and gain are greater. Also they are able to produce circularly polarized waves over greater bandwidth; they are extensively used in the space communication systems, such as transmitting telemetry data from moon to the earth.
3. A single helical antenna or an array of helical antennas are useful in transmitting or receiving VHF signals through the ionosphere.

Biconical Antenna:

It is formed by placing two cones of infinite extent together. It gives the broadband characteristics. A typical biconical antenna is shown in figure 3.9(a)



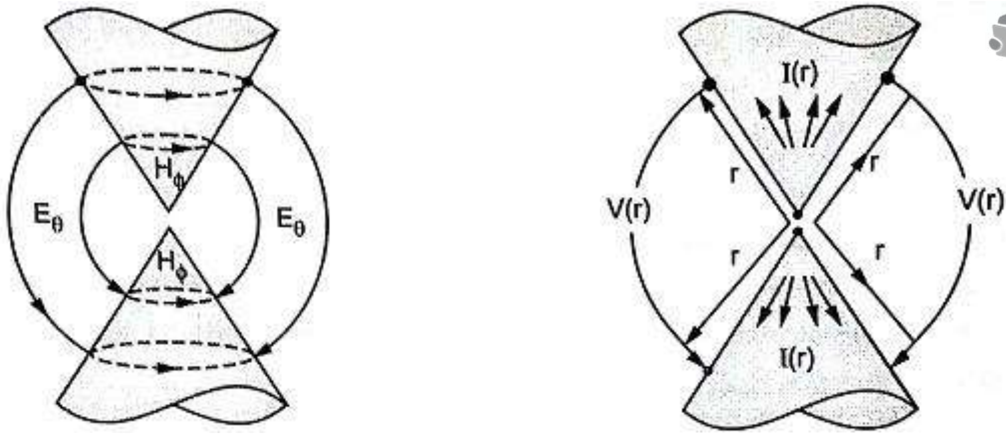
(a) Biconical Antenna Structure



(b) Spherical Waves due to voltage V_{in}

Figure 3.9 Biconical Antenna

The biconical antenna can be imagined as a properly uniformly tapered transmission line. When a voltage V_{in} is applied at the input terminals, the antenna produces spherical waves which are outgoing as shown in the figure 3.9(b). These spherical waves at any point on the surface of the cone produces current I along surface and voltage V between the cones. The corresponding electric and magnetic fields are shown in figure 3.10 (a). The proportional voltages and currents are represented in figure 3.10(b).



(a) Representation of electric and magnetic field

(b) Representation of voltage and current at distance r

Figure 3.10 Electric and magnetic fields and relative currents and voltages of biconical antenna

The relative electric and magnetic fields of biconical antenna are given by

$$H_\emptyset = \frac{1}{r\sin\theta}H_m e^{-j\beta r}$$

$$E_\theta = \eta H_\emptyset = \eta\frac{H_m e^{-j\beta r}}{r\sin\theta}$$

And the corresponding voltages and currents are given by

$$V(r) = 2\eta H_m e^{-j\beta r}\,ln\left(cot\frac{\alpha}{4}\right)$$

$$I(r) = 2\pi H_m e^{-j\beta r}$$

The input impedance of the biconical antenna is given by

$$Z_{in} = \frac{\eta}{\pi}ln\left(\frac{4}{\alpha}\right)\Omega$$

The radiated power and the radiation resistance is given by the following expressions:

$$P_{rad} = 2\pi\eta H_m^2\,ln\left(cot\frac{\alpha}{4}\right)$$

$$R_{rad} = \frac{\eta}{\pi}ln\left(cot\frac{\alpha}{4}\right)\Omega$$

Thus we can say that the radiation resistance of the conical antenna is identical to the input impedance of the antenna.

<u>Salient Features of the Biconical Antenna:</u>

The Salient Features of the Biconical Antenna are as follows:

1. It consists of two identical large cones arranged with axes in line while vertices infinitesimally at a large distance.
2. The two cones are fed with a balanced transmission line.
3. The input impedance of the biconical antenna is independent of the frequency.
4. It has large bandwidth.
5. It has omnidirectional radiation pattern.
6. It is most extensively used for broadcast applications.

<u>Folded Dipole Antenna</u>:

A simple $\lambda/2$ antenna has a terminal resistance of about 73Ω so that an impedance transformer is required to match this antenna with the transmission feeder lines having nominal characteristics impedance of 300Ω, which is the most common impedance level used for television receivers.

However the modified $\lambda/2$ dipole i.e. folded dipole shown in figure 3.11 has radiation resistance of 292Ω and it can be connected to two wire line directly.

The folded dipole antenna consists of two half wave radiators very close to each other and connected together at top and bottom. As far as antenna current or radiating currents are concerned the two elements are in parallel and if the diameters are the same, the current in the elements will be equal and in the same direction. The reason for this is strong mutual coupling between the two closely spaced conductors.

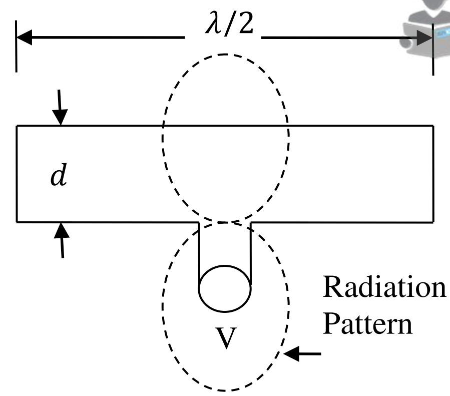


Figure 3.11 Folded Dipole Antenna

Radiation Resistance/ Terminal Impedance:

The equivalent circuit of the two element folded dipole is shown in figure 3.12. If V is the applied EMF at the antenna terminals it will be divided between the two dipoles equally as shown in the figure.

Then

$$\frac{V}{2} = Z_{11}I_1 + Z_{12}I_2$$

Where I_1= Current at the terminals of dipole 1

I_2= Current at the terminals of dipole 2

Z_{11}= Self impedance of the dipole 1

Z_{22}= Self impedance of the dipole 2

Z_{12}= Mutual impedance of the dipole 1 and 2

Since $I_1 = I_2$ equation 3.9.1 becomes

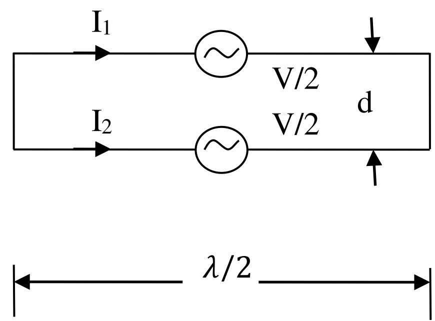


Figure 3.12 Equivalent Circuit

$$V/2 = I_1(Z_{11} + Z_{12})$$
$$V = 2I_1(Z_{11} + Z_{12})$$

Since the two dipoles are close together and d is of order of $\lambda/100$, then we can consider that the self impedance is equal to the mutual impedance between the dipoles 1 and 2.

$$\text{i. e. } Z_{11} \approx Z_{12}$$

Then $$V = 2I_1(Z_{11} + Z_{11})$$

∴ $$V = 4I_1Z_{11}$$

Then $$Z = V/I_1 = 4Z_{11}$$

The self-impedance of dipole 1 of length $\lambda/2$ is nothing but its radiation resistance which is of value 73 Ω.

∴ $$Z = 4(73) = 292\ \Omega$$

Thus the input impedance of two wire folded dipole of length $\lambda/2$ is equal to 292 Ω.

Salient Features of Folded dipole antenna:

- It is basically a single antenna consisting two or three elements. The first is fed directly while second and/or third elements are coupled inductively at the ends.
- In a straight dipole the current is I. But in folded dipole if current fed is I, then the current in each arm is I/2 with condition that both arms are of same dimensions.
- The input impedance of a folded dipole antenna is 4 times that of a straight dipole antenna. i.e.

∴ $$R_{rad} = 4(73) = 292\ \Omega$$

- By using different diameters of two arms of folded dipole, the impedance can be transformed by factor ranging from 1.5 to 25.
- The folded dipole arrangement increases the bandwidth of an antenna, an important consideration in FM and TV application.

- By varying the ratio of the conductor diameter, impedance of an antenna can be changed.
- In certain type of dipole arrays, the dipole antenna impedance is considerably reduced because of the mutual coupling. The higher impedance of the folded dipole helps to offset this decrease.
- Its geometrical arrangement tends to behave as a short parallel stub line which attempt to cancel the off resonance reactance of a single dipole.

Advantages of Folded dipole antenna:

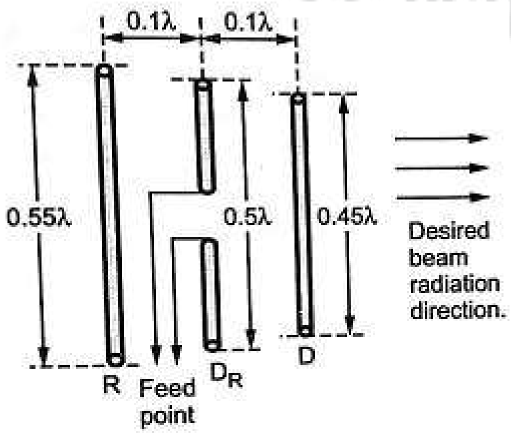
- High input impedance,
- Greater Bandwidth,
- It acts as built in reactance compensation network,
- Simple in construction and cheaper,
- Better impedance matching characteristic.

Applications:

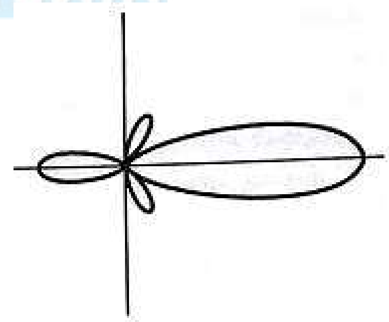
- As a feed element of TV antennas such as Yagi Antennas.
- Feed element for the antennas with very low and very high terminal impedances so that no impedance matching required.

Yagi-Uda Antenna:

These antennas has high antenna gains. A basic Yagi antenna consist of a driven element, one reflector and one or more directors. Basically it is an array of one driven element and one or more parasitic elements. The driven element is a resonant half wave dipole made of metallic rod. The parasitic elements which are continuous arranged parallel to the driven element and at the same line of sight. All the elements are parallel to each other and placed close to each other as shown in figure 3.13.



(a)



(b) Radiation Pattern

Figure 3.13 Yagi-Uda Antenna

Generally the spacing between the driven and the parasitic elements is kept nearly 0.1λ to 0.15λ. The length of the 9ifferent elements can be obtained by the following formula:

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

$$Driven\ Element\ Length = \frac{143}{f(MHz)}\ meter$$

$$Director\ Length = \frac{137}{f(MHz)}\ meter$$

Working of Yagi-Uda Antenna:

The parasitic elements are used either to direct or to reflect the radiated energy. If the parasitic element is greater than length $\lambda/2$, i.e. reflector, it is inductive in nature. Hence the phase of the current lags the induced voltage. While if the parasitic element is less than the resonant length $\lambda/2$, i.e. director, it is capacitive in nature. Hence the phase of the current in the director leads the induced voltage. The directors adds the field of the driven element in the direction away from the driven element. In case of an array, more than one directors are used, then the first one excites the next one and so on. Whereas the properly spaced reflector adds the field of the driven element in the direction towards the driven element from the reflector. To increase the gain of the Yagi antenna, the number of directors is increased. To get good excitation, the elements are closely spaced.

The radiation is in the direction front to rear. Part of this radiation induces currents in the parasitic elements which actually radiate almost all directions. With the proper length of the parasitic elements and the spacing between the elements, the backwards radiation is cancelled and the radiated energy is added in front.

The Yagi antenna is the most widely used antenna for the TV signal reception. The gain of such antenna is very high and the radiation pattern is very much directive in one direction. The signal strength of the antenna can be increased by increasing the number of directors in antenna.

General Characteristics of the Yagi-Uda Antenna:

1. The Yagi Antenna with three elements including one reflector, one driven element and one director is commonly known as Beam Antenna.
2. It is generally operated at a fixed frequency. This antenna is frequency sensitive and the bandwidth of 3% can be easily obtained. Such bandwidth is sufficient for TV reception.
3. The bandwidth of 2% to 3% can be easily achieved if the spacing between the elements is between 0.1λ to 0.5λ.
4. The gain of the antenna is about 7 to 8 dB. Its front to back ratio is 20 dB.
5. The antenna gives a radiation beam which is unidirectional with a moderate directivity.
6. It is light weight, low cast and simple in feeding with signal.
7. To achieve more directivity more number of directors are used. The number of directors may range from 2 to 40.
8. It provides high gain and beam width greater than that obtainable from the uniform distribution. Thus Yagi-Uda Antennas are also called Super directive or super gain antennas.

Yagi-Uda Antenna Calculations:

To design the Yagi antenna the wavelength of the EM wave must be known.

We know the length of the dipole $\mathrm{L} = \lambda/2$. Now $\lambda = \mathrm{c/f}$ where $\mathrm{c} = 3 \times 10^{8}\mathrm{m/sec}$, and $\mathrm{f} =$ Freq of EM wave in MHz,

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

Due to electrical characteristic of the antenna material it is found that the antenna elements should be 5% to 7% shorter in practice than those given in the formula. Then,

$$\text{For Dipole L} = \frac{143}{\mathrm{f(MHz)}} \text{ meter}$$

The length of the reflector and first director is given by.

$$\text{For Reflector L} = \frac{152}{\mathrm{f(MHz)}} \text{ meter}$$

and
$$\text{For first director: L} = \frac{137}{\mathrm{f(MHz)}} \text{ meter}$$

The spacing between reflector R and dipole D_R is given by.

$$\text{Spacing between R and } D_R = 0.25\lambda = \frac{75}{\mathrm{f(MHz)}} \text{ meter}$$

Similarly the spacing between dipole D_R and director D_1 is given by.

$$\text{Spacing between } D_R \text{ and } D_1 = 0.13\lambda = \frac{40}{\mathrm{f(MHz)}} \text{ meter}$$

The spacing between directors D_1 and director D_2 is given by.

$$\text{Spacing between } D_1 \text{ and } D_2 = \frac{38}{\text{f(MHz)}} \text{ meter}$$

Salient features of Yagi-Uda Antenna:

The salient feature of Yagi-Uda antenna are as follows.

(i) The Yagi-Uda antenna consists folded dipole as driven element along with a reflector and one or more directors. The director and reflectors are straight conductors which are called parasitic elements. The directors are placed in front of driven element while the reflector is placed behind the driven element. The length of folded dipole is $\lambda/2$ while length of director is less than $\lambda/2$ and that of reflector is greater than $\lambda/2$.

(ii) The radiation pattern of the Yagi-Uda antenna is almost unidirectional. There is a back lobe which can be reduced by placing the elements dose to each other.

(iii) The folded dipole element resonates at a frequency of resonance but reflector resonates at frequency lower than resonant frequency while director resonates at frequency greater than resonant frequency.

(iv) The current through director is leading current while that through reflector is lagging current.

The mutual impedance of antenna depends not only on length but also spacing between elements.

Advantages of Yagi-Uda Antenna

(i) It has excellent sensitivity.

(ii) Its front to back ratio is excellent.

(iii) It is useful as receiving antenna at high frequency for TV reception.

(iv) It has almost unidirectional radiation pattern.

(v) Due to use of folded dipole, the Yagi-Uda antenna is broadband.

Disadvantages of Yagi-Uda Antenna

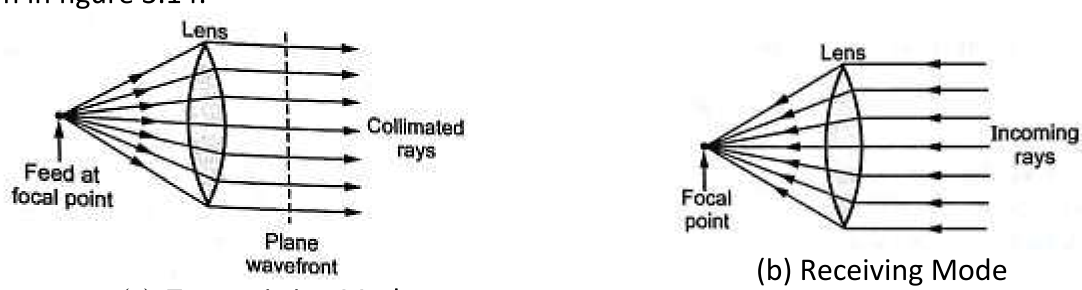
(i) Gain is limited,

(ii) Bandwidth is limited,

(iii) The gain of antenna increases with reflector and director

Lens Antenna:

A Lens antenna is an antenna consisting an EM lens with a feed. It is a three dimensional EM device having refractive index n other than unity. Its operation is similar to glass lens used in optics. The lens antenna can be used in transmitting mode and in receiving mode both as shown in figure 3.14.



(a) Transmitting Mode

(b) Receiving Mode

Figure 3.14 Lens Antenna operation modes

Functions of Lens Antenna:

(i) It controls illumination of aperture.

(ii) It collimates the EM rays.

(iii) It produces directional characteristics.

(iv) In receiving mode, it converges the incoming wavefront at its focus or focal point.

(v) It produces plane wavefront from a spherical wavefront.

Principle of Lens Antenna:

Consider an optical concave lens. If a point source is placed at the focal point of lens which is along the axis of the lens, a focal distance away from the lens as shown in figure 3.15.

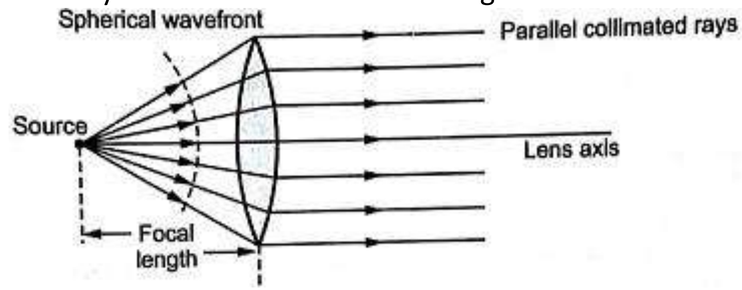


Figure 3.15 Principle of operation of Lens

Due to radiation from the point source, we get the spherical wavefront. When the waves travel to the lens, refraction takes place due to the refraction index of the lens and thus rays are collimated to obtain plane wavefront of parallel rays. The refraction is more at the edges than at the centre.

To operate the lens at radio frequencies, dielectric lens are preferred. If the parallel rays are incoming to the lens, then these rays will converge at a point at the focal length of the antenna.

Advantages of the Lens Antenna:

The advantages of lens antennas are as follows,

(1) In lens antenna, the rays are transmitted away from the feed system, hence the aperture is not obstructed due to the feed and feed support.

(2) In lens antenna, as the waves enter from one side and leaves out from other end, greater extent of wrapping and twisting is possible without disturbing electrical path length.

(3) Lens antenna can be used to feed at a point off the axis; so it is most extensive used in the applications where beam is needed to be moved angularly with respect to axis.

Disadvantages of Lens Antenna:

The disadvantages of the lens antennas are as follows,

(1) Lens antennas are bulkier.

(2) The design of lens antennas is complicated.

(3) Compared with reflectors, the lens antennas are expensive for the same gain and bandwidth requirements.

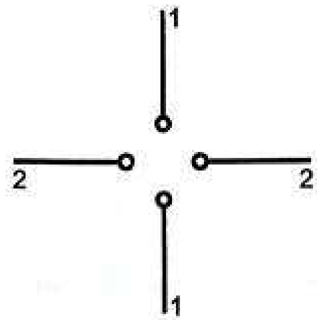
Applications of Lens Antennas:

(1) As lens antenna is a microwave antenna, it is most widely used at a microwave frequency above 3000MHz.

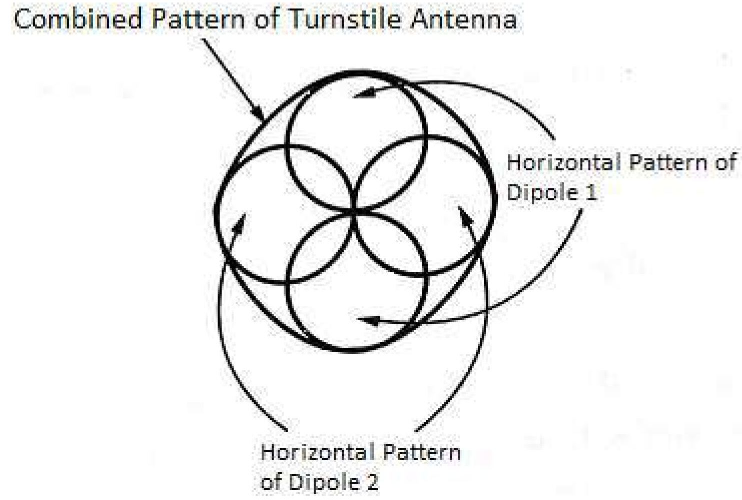
(2) For larger bandwidth requirements, unstepped dielectric lens are used because its shape is not dependent on wavelength. For narrow bandwidth applications, the dielectric lens antennas are used.

Turnstile Antenna:

It is most widely used primarily for omnidirectional VHF communications. It consists of two half wave dipoles at right angle to each other in the same horizontal plane as shown in figure 3.16.



(a) Two Half wave dipole at 90^0 from each other



(b) Radiation Pattern

Figure 3.16 Turnstile Antenna

Both the dipoles carry current equal in magnitude but 90^0 out of phase. When the two half wave dipoles are excited with the equal magnitude, 90^0 out of phase currents, the typical figure eight pattern if both the antennas merge to get almost circular pattern as shown in figure 3.16(b). The main advantage of such a pattern is that it is polarized in the same horizontal plane. Thus when the antenna is mounted in the horizontal plane, it will radiate horizontally polarized wave equally in all directions along the ground.

When the greater directivity is needed, number of turnstile antennas are stacked together on a vertical mast. This mast is coincident with the axis of the turnstile. The distance between the two elements is typically of $\lambda/2$. Such an arrangement is called 4-bay turnstile. Each pair of turnstile antenna is called a bay. The corresponding elements are excited in phase. Due to this part of the vertical radiation from each bay is cancelled by the vertical radiation of the other bay. Thus it decreases the energy radiated in the vertical direction and increases the energy radiated in the horizontal direction.

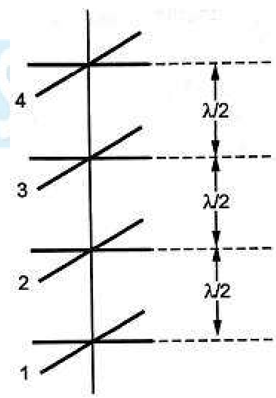


Figure 3.17 4-Bay Turnstile Antenna with half wave dipoles

The main disadvantage of the turnstile antenna is that it radiates the power 3dB less than that would be by a half wave dipole. This limitation can be overcome by using super turnstile antenna.

Salient Features of the turnstile antenna:

The Salient Features of the turnstile antenna are as under:

(1) The radiation pattern produced is almost unidirectional.

(2) It produces horizontal polarization and it is thus mostly useful for TV and FM broadcasting in VHF and UHF band.

(3) It is useful to match 70Ω dual co-axial line.

(4) To increase the antenna directivity, an array of turnstile antennas is used.

Introduction to Long Wire Antenna:

The antennas which operate in frequency range 3-30MHz are called High Frequency (HF) antennas. The simplest practical antenna that can be used in the HF band is the horizontal antenna $\lambda/2$ dipole. Basically a single half wave dipole horizontal antenna is a simple type but with no directional properties. Therefore to achieve higher directive properties, two or more antennas are connected together to form an array of horizontal antennas. For point to point communication in HF band an antenna with large aperture producing a beam of radiation is used. Such antenna is either a resonant i.e. periodic or non-resonant i.e. aperiodic antenna. The non-resonant antenna is commonly called travelling wave antenna.

- A long wire antenna is a linear wire antenna which is many wavelength long. It can be considered as an array of $\lambda/2$ elements connected in a continuous linear way such that each element acts as radiator and transmission line both.
- A long wire antenna is defined as a single long wire, typically n times $\lambda/2$ long at the operating frequency. The higher value of n, the directivity is better.
- Long wire antenna can be considered as resonant antenna and non-resonant antenna. The resonant antenna means the antenna is open at load end whereas non-resonant antenna means the antenna which is terminated in the characteristics impedance of the line i.e. Z_0.

For the half wavelength long wire antenna, the physical length is given by

$$\text{Length} = \frac{492(n-0.05)}{\text{f(MHz)}} \text{ feet}$$

Where n is the number of integer multiple half wavelength. The radiation resistance of resonant long wire antenna of n wavelength is given by

$$R_{rad} = 73 + 69 \log_{10} n\,\Omega$$

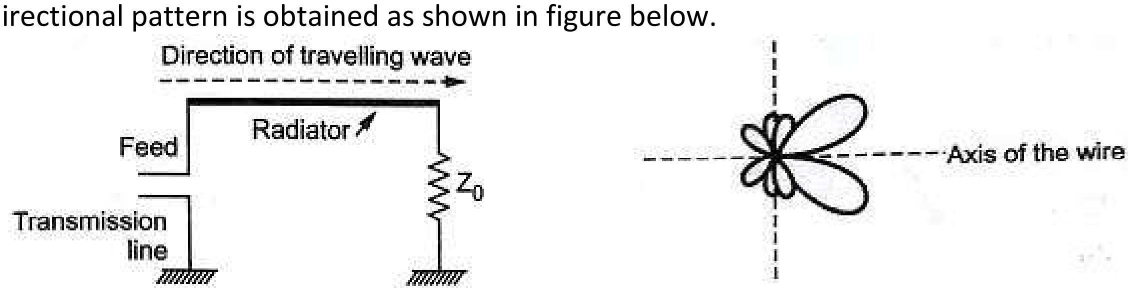
The angle of maximum radiation is given by

$$\theta_{max} = cos^{-1}\left(\frac{n-1}{n}\right)$$

Travelling Wave Antenna:

The antenna in which the standing wave does not exist along the length of the antenna is called Travelling Wave Antenna. The travelling wave antenna is non-resonant type antenna or aperiodic antenna.

For larger bandwidth condition, the travelling wave antennas are the best option. In this antenna one end is terminated into the characteristics impedance Z_0, while the other end is connected to the input signal. Due to proper termination, reflections are avoided and thus the unidirectional pattern is obtained as shown in figure below.



(a) Travelling wave antenna arrangement (b) Unidirectional Radiation Pattern

Figure 3.18 Travelling wave antenna and its radiation pattern

The long wire radiator can be assumed to be made up of number of Hertzian dipoles connected back to back. The phase of the current is changing progressively with distance as in end fire array case of Hertzian dipole. The radiation pattern will be as shown in figure 3.18(b). The strength of the electric field at a distance r from the radiator is given by,

$$E = \frac{60 I_{r.m.s.}}{r} . \left(\frac{\sin\theta}{1-\cos\theta}\right) . \sin\left(\frac{\pi L}{\lambda}[1-\cos\theta]\right)$$

Where r=distance of the point from radiator

L=Length of the wire or radiator.

The angle of the major lobe and the amplitude of the major lobe depends on the length of the wire. As the length of the wire increases, the angle of the major lobe decreases with respect to the axis of the wire. Also with increase in the length the amplitude increases. It is shown in the table 3.1.

Table 3.1

Length of the travelling wave	Angle of major lobe (β)	Amplitude of major lobe
$L = \lambda/2$	68^0	1.25
$L = \lambda$	48^0	2.0
$L = 2\lambda$	35^0	2.9
$L = 4\lambda$	24^0	4.2
$L = 8\lambda$	17^0	5.8

Advantages:

(1) Standing waves do not exist.
(2) Bandwidth is more compared to the single wire antenna.
(3) Less power dissipation.
(4) Shows sharp null in forward direction.
(5) With increasing length, the major lobes becomes narrower and closer.
(6) Useful in radio communication applications

V-Antenna:

The V antenna is made up of two long wire antennas which are arranged in the form of the horizontal V and it is fed at the apex by the transmission feed line. The long wire antennas are called the legs of the V antenna. A typical arrangement of the resonant V antenna is shown in figure 3.19.

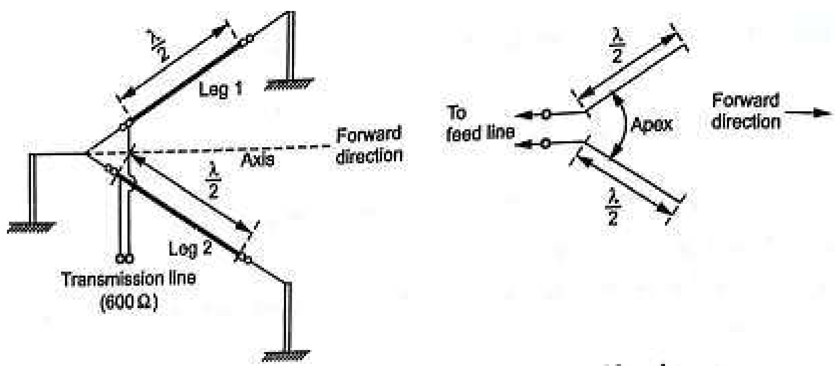


Figure 3.19 Arrangements for high frequency V antenna

The angle made by the two legs is called the apex angle and it is denoted by the "α". To increase the gain and the directivity in the desired direction, the lengths of the legs are increased in the proportion. Because of this the side lobes are cancelled out and the major lobes are added together. Thus the radiation pattern obtained is much sharper than that obtained with the same length single long wire antenna.

The directivity of the V antenna can be increased further by using an array of resonant V antennas in a stacked form one above another. To make the pattern unidirectional, one more V antenna is stacked at a distance of odd multiple of $\lambda/4$ in the back and exciting the next with certain phase difference of 90^0.

Therefore the resonant V antenna is found to be the cheapest transmitting and receiving antenna at high frequency which provides a low angle beam along the axis for fixed frequency operation. The main drawback of the V antenna is that the minor or side lobes are also of high strength.

Salient Features of V antenna:

1. It consist of two long wire antennas arranged in V shape and is fed at apex.
2. It can be a resonant or non-resonant type antenna.
3. Its gain and directivity increases as the length of each wire is increased.
4. It is used for HF band frequency applications.

5. The radiation pattern of the resonant type V antenna is bidirectional while that of the non-resonant type is unidirectional.
6. Typically the gain of the V antenna is two times the gain of the single long wire antenna. For each wire of length 8λ, the gain achieved is about 12dB.
7. It is possible to conduct end fire and broadside arrays using V antenna.
8. It is easy to construct and cheapest high frequency antenna.

Rhombic Antenna:

It is based on the principal of travelling wave radiator or travelling wave antenna. In this four long wires are connected together in such a way to form a diamond or rhombus shaped structure in the horizontal plane above the ground. It can be considered as two inverted V antennas connected in series end to end forming abtuse angles. It is also known as diamond antenna. Each side of the rhombic antenna formed by the wires is called the leg of the antenna.

A rhombic antenna of four wires each of length L and installed horizontally over the ground or earth at the height h is shown in figure 3.20.

As a transmitting antenna, one end of the antenna is fed through the balanced transmission line as feeder, while the other end of the antenna is terminated into the non-inductive resistor. The value is adjusted such that the travelling waves are set in all the four legs with no reflection and hence no standing waves exists in any of the legs.

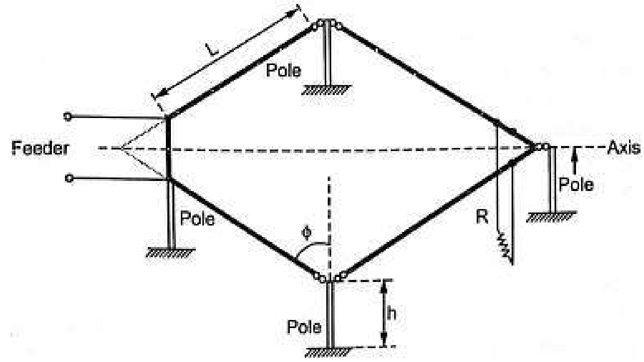
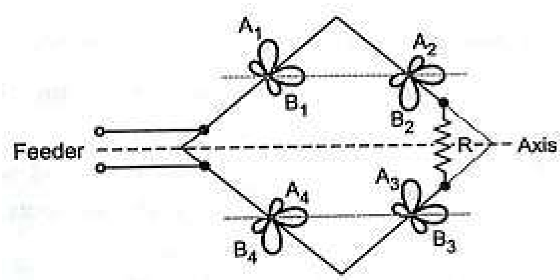
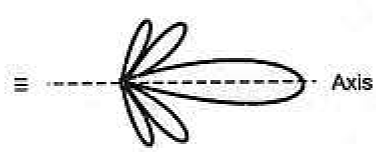


Figure 3.20 Arrangement for Rhombic Antenna

The line joining the feed point and the termination point is called the axis of the antenna. When the four legs are terminated in the resistor equal to the characteristic impedance, it gives a non-resonant condition, thus the legs provided unidirectional distribution. With a proper design, it provides the maximum radiation along the axis of the antenna as shown in figure 3.21.



(a) Radiation pattern in each leg



(b) Unidirectional resultant radiation pattern

Figure 3.21 Radiation pattern of properly terminated rhombic antenna

Advantages of Rhombic Antenna:

1. The input impedance and radiation patterns do not vary very rapidly over a considerably large range.
2. Due to high efficiency it is highly used for radio communication.
3. It can be used for short wave applications with very low height.
4. Its construction is simple and cost is low.
5. Its input impedance is twice as that of single side radiator.

Disadvantage:

1. It requires very large space for installation.

2. It produces number of side lobes along with the highly directive major lobe.
3. It dissipates half of the output power in the terminating impedance, hence the transmission efficiency is poor.

Salient features of the Rhombic Antenna:

1. It is a high Frequency non resonant antenna consisting four non resonant wires.
2. It shows higher directivity and bandwidth as compared to V antenna.
3. It is basically a travelling wave antenna without any reflections used for transmission and reception in HF band.
4. It is very useful antenna for point to point communication.
5. The terminating resistance lies between 600 to 800Ω while its input impedance lies between 650 to 700 Ω.
6. Its directivity lies between 20 to 90, while the power gain lies between 15 to 60.
7. The angle of elevation of major lobe is typically less than 30^0. Practically if the angle of elevation is greater than 30^0, then the gain reduces.

Beverage antenna:

The Beverage antenna or "wave antenna" is a long-wire receiving antenna mainly used in the low frequency and medium frequency radio bands, invented by Harold H. Beverage in 1921. A Beverage antenna consists of a horizontal wire from one-half to several wavelengths long (hundreds of feet at HF to several kilometers for long wave) suspended above the ground, with the feed line to the receiver attached to one end and the other terminated through a resistor to ground. The antenna has a unidirectional radiation pattern with the main lobe of the pattern at a shallow angle into the sky off the resistor-terminated end, making it ideal for reception of long distance sky wave (skip) transmissions from stations over the horizon which reflect off the ionosphere. However the antenna must be built so the wire points at the location of the transmitter.

The advantages of the Beverage are excellent directivity and a wider bandwidth than resonant antennas. Its disadvantages are its physical size, requiring considerable land area, and inability to rotate to change the direction of reception. Installations often use multiple antennas to provide wide azimuth coverage.

The Beverage antenna consists of a horizontal wire one-half to several wavelengths long, suspended close to the ground, usually 10 to 20 feet high, pointed in the direction of the signal source. At the end toward the signal source it is terminated by a resistor to ground approximately equal in value to the characteristic impedance of the antenna considered as a transmission line, usually 400 to 800 ohms. At the other end it is connected to the receiver with a transmission line, through a balun to match the line to the antenna's characteristic impedance as shown in figure 3.22.

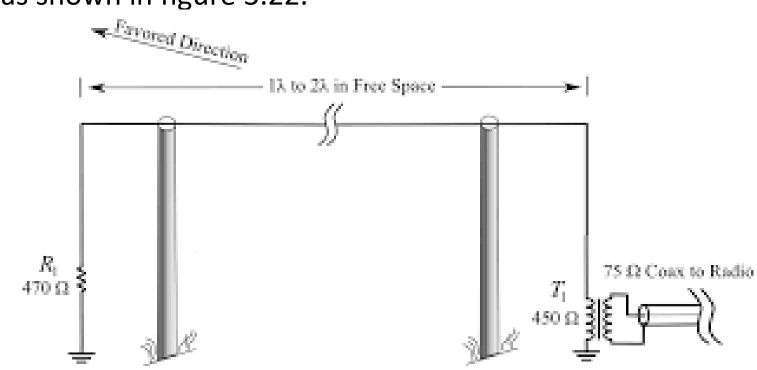


Figure 3.22 Beverage antenna

Operation/working:

Unlike other wire antennas such as dipole or monopole antennas which act as resonators, with the radio currents traveling in both directions along the element, bouncing back and forth between the ends as standing waves, the Beverage antenna is a traveling wave antenna; the radio frequency current travels in one direction along the wire, in the same direction as the radio waves. The lack of resonance gives it a wider bandwidth than resonant antennas. It receives vertically polarized radio waves, but unlike other vertically polarized antennas it is suspended close to the ground, and requires some resistance in the ground to work.

The Beverage antenna relies on "wave tilt" for its operation. At low and medium frequencies, a vertically polarized radio frequency electromagnetic wave traveling close to the surface of the earth with finite ground conductivity sustains a loss that causes the wavefront to "tilt over" at an angle. The electric field is not perpendicular to the ground but at an angle, producing an electric field component parallel to the Earth's surface. If a horizontal wire is suspended close to the Earth and approximately parallel to the wave's direction, the electric field generates an oscillating RF current wave traveling along the wire, propagating in the same direction as the wavefront. The RF currents traveling along the wire add in phase and amplitude throughout the length of the wire, producing maximum signal strength at the far end of the antenna where the receiver is connected.

The antenna wire and the ground under it together can be thought of as a "leaky" transmission line which absorbs energy from the radio waves. The velocity of the current waves in the antenna is less than the speed of light due to the ground. The velocity of the wavefront along the wire is also less than the speed of light due to its angle. At a certain angle θmax the two velocities are equal. At this angle the gain of the antenna is maximum, so the radiation pattern has a main lobe at this angle. The angle of the main lobe is

$$\theta_{max} = \cos^{-1}\left(1 - \frac{\lambda}{2L}\right)$$

L=length of antenna wire

λ=wavelength.

The antenna has a unidirectional reception pattern, because RF signals arriving from the other direction, from the receiver end of the wire, induce currents propagating toward the terminated end, where they are absorbed by the terminating resistor.

Features:

While Beverage antennas have excellent directivity, because they are close to lossy Earth, they do not produce absolute gain; their gain is typically from −20 to −10 dBi. This is rarely a problem, because the antenna is used at frequencies where there are high levels of atmospheric radio noise. At these frequencies the atmospheric noise, and not receiver noise, determines the signal-to-noise ratio, so an inefficient antenna can be used. The antenna is not used as a transmitting antenna since, to do so, would mean a large portion of the drive power is wasted in the terminating resistor.

Directivity increases with the length of the antenna. While directivity begins to develop at a length of only 0.25 wavelengths, directivity becomes more significant at one wavelength and improves steadily until the antenna reaches a length of about two wavelengths. In Beverages longer than two wavelengths, directivity does not increase because the currents in the antenna cannot remain in phase with the radio wave.

END OF UNIT 3

