UNIT-II

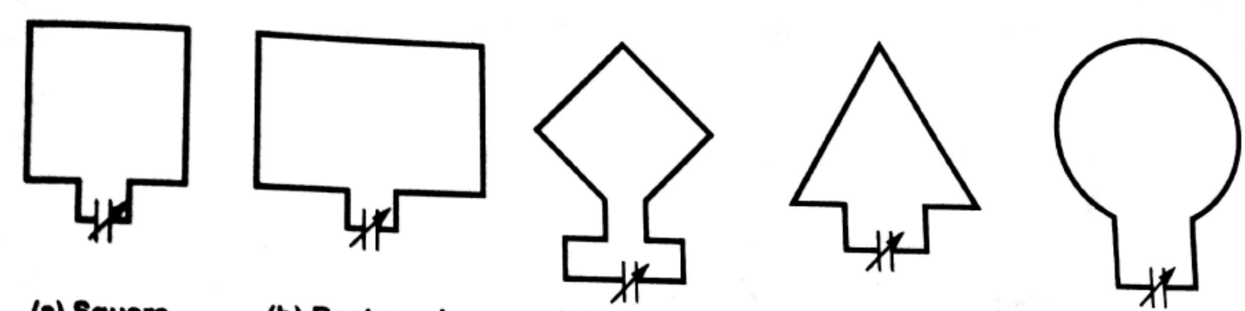
VHF, UHF and Microwave Antennas-I

Introduction: The antennas which are operated between the frequency ranges from 30MHz to 3000MHz are known as VHF and UHF antennas respectively. The antennas operating above the 3000MHz frequency are called microwave antennas. In VHF and UHF bands, the arrays are constructed using elevated wire and tubing rods of copper. This increases the directivity of the antenna.

The most commonly used antennas in VHF and UHF bands are Yagi-Uda antennas, folded dipole antennas, plane and corner reflector antennas.

The most commonly used antennas in Microwave frequency range are parabolic reflector antennas, horn antennas and lens antennas.

Loop Antennas: The loop antenna is a radiating coil of any shape with one or more turns carrying a r.f current. The loop antenna may assume any shape like a rectangular, square, triangular, ellipse, circle, and any other configuration. Loop antennas are extensively used in radio receivers, aircraft, receiver's direction finding and UHF transmitters. A loop of more than one turn is often called frame.



The Small Loop: The field pattern of a small circular loop of radius *a* may be determined very simply by considering a square loop of the same area, that is, $d^2=\pi a^2$ ---------(1)
where d = side length of square loop as shown in fig

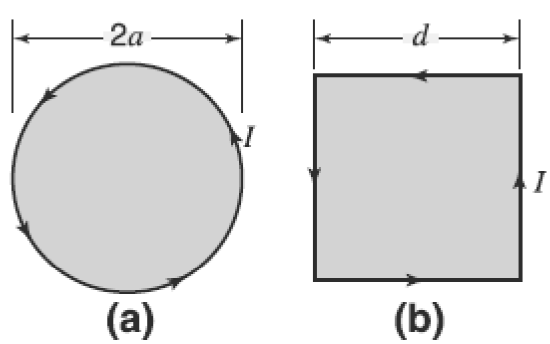


Fig (a) Circular loop (b) Square loop of Equal area

It is assumed that the loop dimensions are small compared to the wavelength. It will be shown that the far-field patterns of circular and square loops of the same area are the same when the loops are small but different when they are large in terms of the wavelength. If the loop is oriented as in Fig.2, its far electric field has only an E_ϕ component.

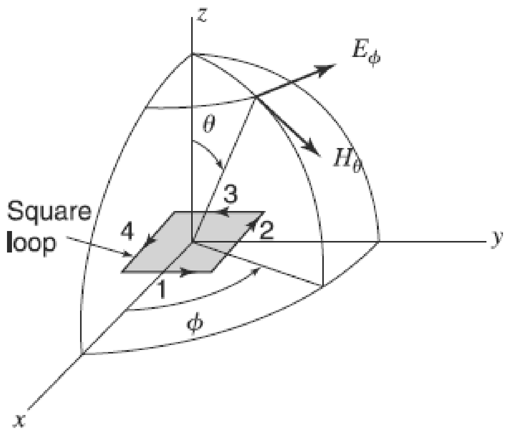


Fig.2.Relation of square loop to coordinates.

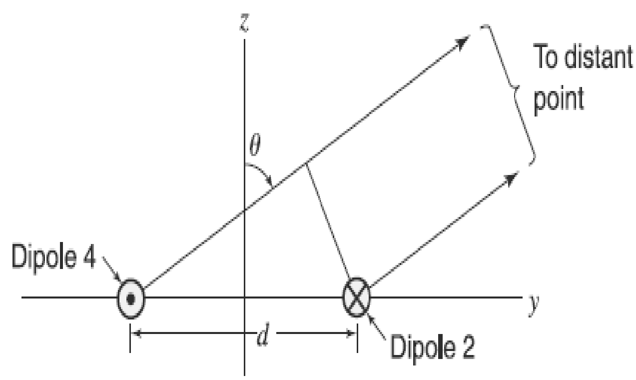


Fig 3.Construction for finding far field of Dipoles 2 and 4 of square loop.

To find the far-field pattern in the *yz* plane, it is only necessary to consider two of the four small linear dipoles (2 and 4). A cross section through the loop in the *yz* plane is presented in Fig. 3.Since the individual small dipoles 2 and 4 are nondirectional in the *yz* plane, the field pattern of the loop in this plane is the same as that for two isotropic point sources . Thus,

$$\mathbf{E_\phi = E_{\phi0}\, e^{-j\psi/2} - E_{\phi0}\, e^{j\psi/2}}$$

$$\mathbf{E_\phi = -2jE_{\phi0} \sin\frac{\psi}{2}} \text{ -----------(2)}$$

Where $E\phi_0$ = electric field from individual dipole .
The path difference from fig.3 is given by =d cos(90-θ)=d sinθ
The corresponding phase difference is given by

$$\boldsymbol{\psi = \frac{2\pi d}{\lambda} \sin\theta = d_r \sin\theta} \text{ -------------------(3)}$$

$$\text{where } d_r = \frac{2\pi d}{\lambda}$$

Substitute equation (3) in equation in equation in (2), than It follows that

$$\mathbf{E_\phi = -2jE_{\phi0} \sin\left(\frac{d_r}{2}\sin\theta\right)} \text{ ------------(4)}$$

The factor *j* in (4) indicates that the total field $E\phi$ is in phase quadrature with the field $E\phi_0$ of the individual dipole. Now if $d << \lambda$, the equation(4) can be written

$$\mathbf{E_\phi = -jE_{\phi0} dr \sin\theta} \text{ ------------(5)}$$

The far field of the individual dipole was given by

$$\mathbf{E_{\phi0} = \frac{j60\pi[I]L\sin\theta}{r\lambda} = \frac{j60\pi[I]L}{r\lambda}} \text{ -----------------(6)}$$

In developing the dipole formula, the dipole was in the *z* direction, whereas in the present case it is in the *x* direction, hence θ=90 degrees. Where [I] is the retarded current on the dipole and r is the distance from the dipole. Substituting (6) in (5) then gives

$$\mathbf{E_\phi = \frac{60\pi[I]L\, d_r \sin\theta}{r\lambda}} \text{ --------------------(7)}$$

However, the length L of the short dipole is the same as d, that is, L = d and dr = 2πd/λ. the area A of the loop is d^2, then Equation (7) becomes

$$\boxed{\textit{Small loop}\quad E_\phi = \frac{120\pi^2[I]\sin\theta}{r}\frac{A}{\lambda^2}\qquad \textit{Far field}\ E_\phi} \text{ ----------------(8)}$$

This is the instantaneous value of the E_ϕ component of the far field of a small loop of area *A*. The peak value of the field is obtained by replacing [I] by I_0, where I_0 is the peak current in time on the loop.
Similarly the other component of far field is given by

$$\boxed{H_\theta = \frac{E_\phi}{\eta} = \frac{\pi[I]\sin\theta}{r}\frac{A}{\lambda^2}}$$

Comparison of Far Fields of Small Loop and Short Dipole:

Comparison of Far Fields of Small Loop and Short Dipole is made in the following table 1.
The presence of the operator *j* in the dipole expressions and its absence in the loop equations indicate that the fields of the electric dipole and of the loop are in time-phase quadrature, the current *I* being in the same phase in both the dipole and loop. This quadrature relationship is a fundamental difference between the fields of loops and dipoles.

Table 1 Far fields of small electric dipoles and loops

Field	Short dipole	Loop
Electric Field	$E_\theta \cong j\eta\frac{\beta I_o L e^{-j\beta r}}{4\pi r}\sin\theta$	$E_\phi = \frac{120\pi^2[I]\sin\theta}{r}\frac{A}{\lambda^2}$
Magnetic Field	$H_\phi \cong j\frac{\beta I_o L e^{-j\beta r}}{4\pi r}\sin\theta$	$H_\theta = \frac{\pi[I]\sin\theta}{r}\frac{A}{\lambda^2}$

Radiation Resistance of Loops:

To find the radiation resistance of a loop antenna, the Poynting vector is integrated over a large sphere yielding the total power P_{rad} radiated. This power is then equated to the square of the effective current on the loop times the radiation resistance Rr

$$P_{rad} = \frac{1}{2}I_o^2R_r \text{ -----------------(1)}$$

The average Poynting vector of a far field is given by

$$P_{avg} = \frac{1}{2}\eta|H_\theta|^2$$

$$P_{avg} = \frac{1}{2}\eta\left(\frac{\pi A}{r\lambda^2}\right)^2 I_o^2\sin^2\theta$$

The total power radiated P_{rad} is the integral of P_{avg} over a large sphere; that is

$$P_{rad} = \oint\!\!\oint P_{avg}\,dS$$

$$P_{rad} = \frac{1}{2}\eta\left(\frac{\pi A}{\lambda^2}\right)^2 I_o^2\int_0^{2\pi}d\phi\int_0^{\pi}\sin^3\theta\, d\theta$$

$$\mathbf{P}_{rad} = \frac{1}{2}\eta\left(\frac{\pi A}{\lambda^2}\right)^2 I_o^2 2\pi\frac{4}{3}$$

$$\mathbf{P}_{rad} = \frac{4}{3}\eta\pi^3\left(\frac{A}{\lambda^2}\right)^2 I_o^2 \quad \text{-----------------(2)}$$

From equations (1) and (2) the radiation resistance of the small loop antenna is given by

$$\mathbf{R}_r = \frac{8}{3}\eta\pi^3\left(\frac{A}{\lambda^2}\right)^2 = 320\pi^4\left(\frac{A}{\lambda^2}\right)^2$$

$$\mathbf{R}_r = 31,171\left(\frac{A}{\lambda^2}\right)^2 = 31,171\left(\frac{\pi a^2}{\lambda^2}\right)^2 = \frac{31,171}{16\pi^2}\left(\frac{16\pi^4 a^4}{\lambda^4}\right) = 197\left(\frac{C}{\lambda}\right)^4 = 197C_\lambda^4 \quad (\Omega)$$

Where the perimeter of the circle is $C=2\pi a$ and $A = \pi a^2$ and $C_\lambda = \frac{C}{\lambda}$

The radiation resistance of the small circular loop antenna is given by

$$\mathbf{R}_r \cong 31,200\left(\frac{A}{\lambda^2}\right)^2 \qquad (\Omega)$$

The radiation resistance of a small loop consisting of one or more turns is given by

$$\mathbf{R}_r \cong 31,200\left(n\frac{A}{\lambda^2}\right)^2 \qquad (\Omega)$$

<u>Directivity of small loop antenna :</u>

The directivity of antenna is given by $\mathbf{D} = 4\pi\frac{U_{max}}{P_{rad}}$

The average Poynting vector of a small loop is given by

$$\mathbf{P}_{avg} = \frac{1}{2}\eta\left(\frac{\pi A}{r\lambda^2}\right)^2 I_o^2 \sin^2\theta$$

The radiation intensity *U* which is given by $\mathbf{U} = r^2 P_{avg} = \frac{1}{2}\eta\left(\frac{\pi A}{\lambda^2}\right)^2 I_o^2 \sin^2\theta$

$$\mathbf{U}_{max} = \frac{1}{2}\eta\left(\frac{\pi A}{\lambda^2}\right)^2 I_o^2$$

The total power radiated P_{rad} is given by $\mathbf{P}_{rad} = \frac{4}{3}\eta\pi^3\left(\frac{A}{\lambda^2}\right)^2 I_o^2$

$$\mathbf{D} = 4\pi\frac{U_{max}}{P_{rad}} = \frac{3}{2} = 1.5 \; or \; 1.76dB$$

The maximum effective aperture is given by $\boxed{A_e = \left(\frac{\lambda^2}{4\pi}\right)D = \frac{3\lambda^2}{8\pi}}$

It is observed that the directivity and the maximum effective area, of a small loop is the same as that of an infinitesimal electric dipole. This should be expected since their patterns are identical.

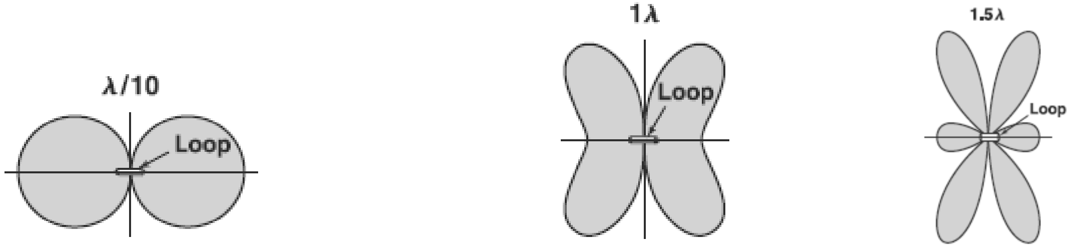
<u>The loop antenna Types:</u>

1. Small loop antenna.
2. Large loop antenna.

Small loop antenna: The loop antenna satisfies the condition $C_\lambda < \frac{1}{3}$, then we can treat it as small loop antenna.

Large loop antenna: The loop antenna satisfies the condition $C_\lambda > 5$, then we can treat it as large loop antenna.

Radiation Patterns of small and large loop antenna:



Large loop $C_\lambda \geq 5$ $\quad R_r = 60\pi^2 C_\lambda = 592 C_\lambda = 3720\dfrac{a}{\lambda}$ $\quad$ *Radiation resistance*

Large loop $C_\lambda \geq 2$ $\quad D = 0.68 C_\lambda$ $\quad$ *Directivity*

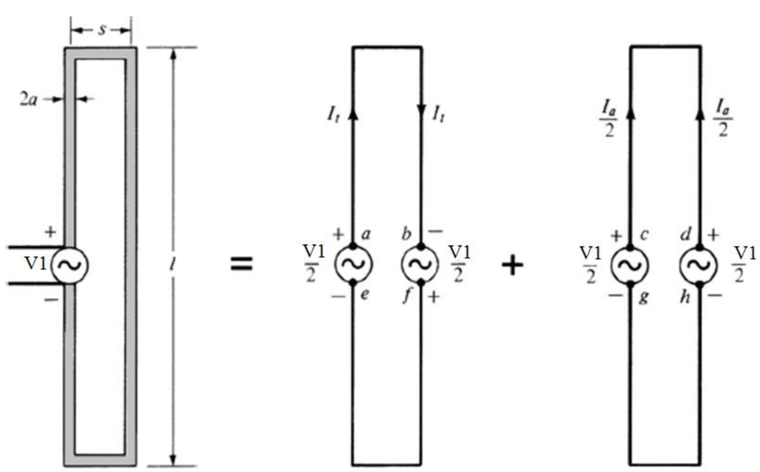
Folded dipole antenna:

A simple $\lambda/2$ dipole has a terminal resistance of about 73 Ω so that an impedance transformer is required to match this antenna to a 2-wire line of 300Ω to 600Ω characteristic impedance. However, the terminal resistance of the modified $\lambda/2$ dipole shown in Fig.1 (a) is nearly 300 Ω so that it can be directly connected to a 2-wire line having a characteristic impedance of the same value. This "ultra closed-spaced type of array" is called a *folded dipole*. The antenna consists of 2 closely spaced λ/2 elements connected together at the outer ends. The currents in the elements are substantially equal and in phase.

A simple folded dipole can be formed by folding two half wave dipoles and joining them together as shown in figure. The folded dipole which is splitted at the center is fed with a balanced transmission line. So that the voltage at the end of two dipoles is same and radiation fields are parallel.

The radiation pattern of the folded dipole is exactly same as the conventional dipole, but input impedance and band width of folded dipole are much higher.

If the conductors of the folded dipoles are of same radii, then the currents with equal in magnitude and phase flows through the two dipoles.



(a) Folded dipole (b) Transmission-line mode (c) Antenna mode

Input impedance of folded dipoles: The equivalent circuit of two wire folded dipole of length λ/2 as shown in the fig.1(b). The applied voltage V_1 which is applied across terminals gets equally divided in each dipole as voltage $\frac{V_1}{2}$. Then

$$\frac{\mathbf{V_1}}{\mathbf{2}} = \mathbf{Z_{11}I_1} + \boldsymbol{Z_{12}}\mathbf{I_2}$$

Where Z_{11}=Self impedance of the dipole (1) and Z_{12}=Mutual impedance between dipoles 1 and 2. I_1 and I_2 are the currents through antennas 1 and 2. $I_1=I_2$ as the dipoles have equal radii.

$$\frac{\mathbf{V_1}}{\mathbf{2}} = (\mathbf{Z_{11}} + \boldsymbol{Z_{12}})\ \mathbf{I_1}$$

As the dipoles are very close then the self-impedance is equal to the mutual impedance.
$Z_{11}=Z_{12}$. Therefore

$$\frac{\mathbf{V_1}}{\mathbf{2}} = (\mathbf{2Z_{11}})\ \mathbf{I_1}$$

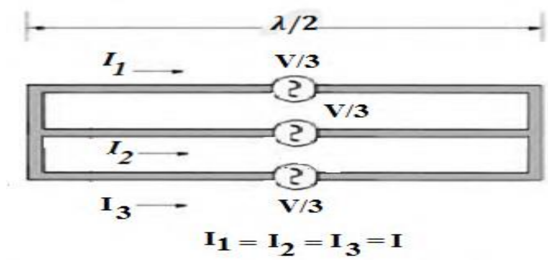
$$\mathbf{V_1} = \mathbf{2}(\mathbf{2Z_{11}})\ \mathbf{I_1} = \mathbf{4Z_{11}I_1}$$

Thus the input impedance of the antenna is given

$$\frac{\mathbf{V_1}}{\mathbf{I_1}} = \mathbf{4Z_{11}}$$

The self impedance of dipole 1 of half wave length is 73 Ω.
Therefore Z=4(73)=292 Ω
Therefore the input impedance of two wire folded dipole of length λ/2 is equal to 292 Ω.

Let us consider three half wave dipoles are folded to form a three-wire folded dipole or tri-pole as shown in fig.



The voltage equation is given by

$$\frac{\mathbf{V_1}}{\mathbf{3}} = \mathbf{Z_{11}I_1} + \boldsymbol{Z_{12}}\mathbf{I_2} + \mathbf{Z_{13}I_3}$$

As $I_1=I_2=I_3$ and $Z_{11}=Z_{12}=Z_{13}$ therefore

$$\frac{\mathbf{V_1}}{\mathbf{3}} = (\mathbf{3Z_{11}})\ \mathbf{I_1}$$

$$\mathbf{V_1} = \mathbf{3}(\mathbf{3Z_{11}})\ \mathbf{I_1} = \mathbf{9Z_{11}I_1}$$

$$\frac{\mathbf{V_1}}{\mathbf{I_1}} = \mathbf{9Z_{11}}$$

The self impedance of dipole 1 of half wave length is 73 Ω.
Therefore, the input impedance of a three-wire folded dipole is Z=9(73)=657 Ω
The general expression for the impedance of n-wire folded dipole can be written as

$$\boldsymbol{Z} = \boldsymbol{n^2Z_{11}}\ \boldsymbol{\Omega}$$

The folded dipole has ability of transforming impedance to desired value.
If the radii of the two dipoles are made unequal, then the general expression for the input impedance is given by

$$\boldsymbol{Z} = \boldsymbol{Z_{11}}\left[\mathbf{1} + \frac{\mathbf{r_2}}{\mathbf{r_1}}\right]^{\mathbf{2}} = \mathbf{73}\left[\mathbf{1} + \frac{\mathbf{r_2}}{\mathbf{r_1}}\right]^{\mathbf{2}}\ \boldsymbol{\Omega}$$

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

If we select $r_2=2r_1$ then $\boldsymbol{Z} = \mathbf{73}\left[\mathbf{1} + \frac{\mathbf{2r_1}}{\mathbf{r_1}}\right]^{\mathbf{2}} = \mathbf{657\Omega}$

Advantages:
1) The input impedance of folded dipole is high.
2) The bandwidth of the folded dipole is wider than simple dipole.
3) The folded dipole acts as a built in reactance compensation network.
4) The construction of folded dipole is simple and low cost.
5) The impedance matching characteristics of the folded dipole is much better than others.

Applications:
1) The two wire folded dipole is extensively used in T.V antennas as feed element such as Yagi-Uda antenna
2) The impedance matching characteristics of the folded dipole is much better. So, folded dipoles are used with very low and high terminal impedances.
3) The folded dipole bandwidth is far better than the single dipole of same size. So, it can be used in wide band applications.

Yagi - Uda Antenna:

Yagi-Uda antennas or Yagi-Uda arrays are high gain antennas. These antennas are first invented by a Japanese professor S.Uda in 1920's. Later it was described in English by professor H.Yagi and become popular as Yagi-Udaantenna.

A Yagi-Udaantenna consists of a driven element, reflector and one or more directors. The driven element is a resonant half wave dipole made of metallic rod or tube. The reflector and directors are arranged parallel to the driven element at the same line of sight.as shown below.

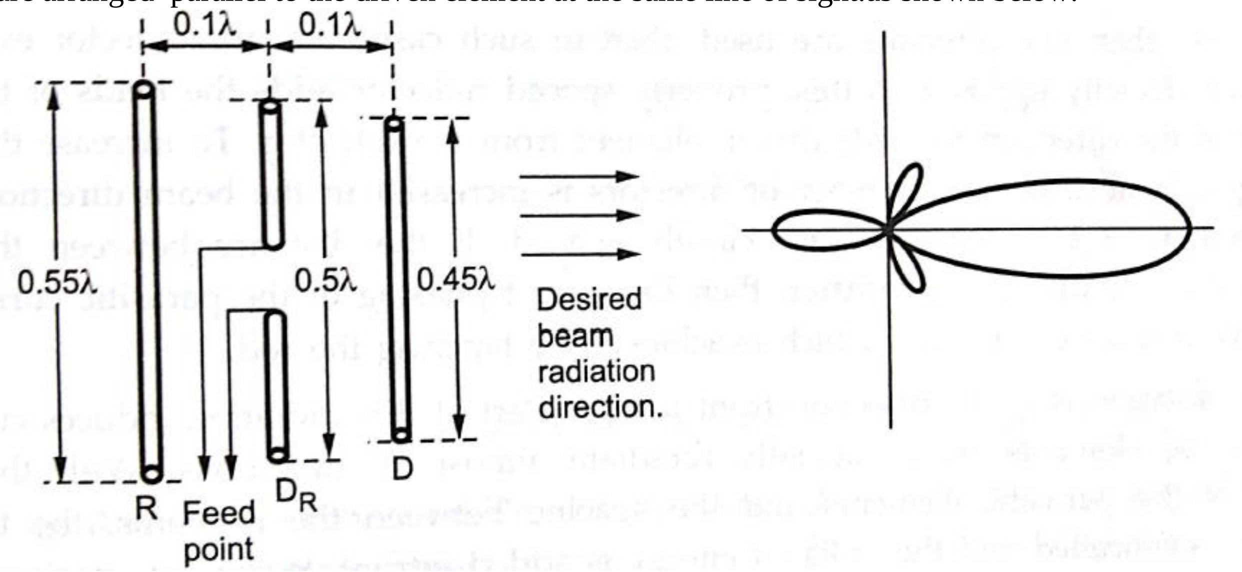


Fig. Three element Yagi-uda antenna

The driven element is an active antenna where the power from transmission line is fed. The half wave dipole is used as a driven element. The reflector and directors are parasitic elements which are not connected directly to the transmission line but these are electrically coupled to the driven element.

The phase and amplitude of the currents through the parasitic elements depend on the lengths and spacing between the elements.

The element at the back side of the driven element is called as reflector and it is large in length compared with the other two elements. The element in front of the driven element is the director, which is shortest in all the three elements. Generally the half wave dipole is used as a driven element. The reflector is inductive in nature and it adds up the fields of driven element from reflector to the direction towards the driven element. In reflector the current lags the induced voltage. The director is capacitive in nature and it adds the fields of driven element in the direction away from the driven element.

In director the current leads the induced voltage. The antenna design equations are as shown below.

$$Driven\ element\ length\ \ L = \frac{143}{f(in\ MHz)}\ \ meters$$

$$Reflector\ length\ \ L = \frac{152}{f(in\ MHz)}\ \ meters$$

$$Director\ length\ L = \frac{137}{f(in\ MHz)}\ meters$$

When more number of directors are required then the lengths of the subsequent directors shortens by 2.5 %

To get the better results the ratio between lengths to diameter of the elements must be in the range of 200 to 400.

The spacing between the elements must be from 0.1 λ to 0.35 λ. The gain of the antenna can be improved by increasing the no of directors.

The distance between the elements can be reduced to improve the gain of the antenna which causes a great fall in the input impedance up to 25 Ω. To avoid such problems either shunt feed or folded dipoles are used to raise the impedance to a suitable level. TheYagi-Uda antenna with folded dipole as driven element and more number of directors is as shown below.

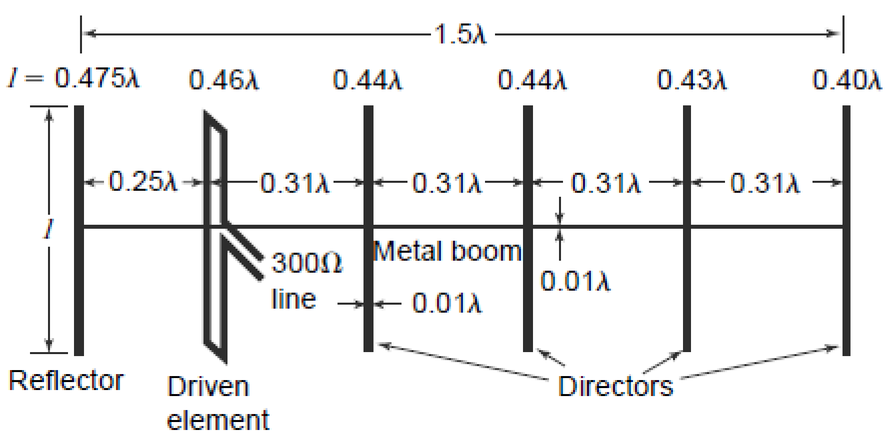


Fig. 6-element Yagi-Uda antenna with dimensions.

Advantages:

1. The sensitivity of this antenna is excellent.
2. The front to back ratio of this antenna is excellent.
3. It has almost unidirectional pattern.
4. It is useful at high frequency TV reception.
5. Due to folded dipole , the yagi-uda antenna is broadband

Disadvantages:

1. The bandwidth is limited.
2. The gain is limited.
3. Require more directors to improve the directivity.

Helical antenna: Helical antenna is a broadband VHF and UHF antenna which provides elliptical polarized waves. This antenna consists of a thick copper wire wound in a shape of screw thread forming helix. The helix of helical antenna combines three different geometric shapes like straight line, circle, and cylinder.

Helical antenna modes:

The helical antenna radiates in many modes, but there are two important modes called normal mode and axial mode.

In normal mode the maximum radiation is along the broad side to helix axis under the condition that the circumference of the helix is smaller with respect to one wavelength.

In axial mode the maximum radiation is along the axis of the helix under the condition that the circumference of the helix is of the order of one wavelength.

Helical antenna geometry: The geometry of the helical antenna is as shown below. The helical antenna consists of a thick copper wire wound in a shape of screw thread forming helix. In general, the helix is used with a ground plane. The ground plane can take different forms such as flat, cylindrical cavity and frustrum cavity. In general the helical antenna is fed with coaxial transmission line in which the central conductor is conned to the helix at the feed point ,while the outer conductor is attached to the ground.

The following symbols are used to describe a helix

D = diameter of helix (center to center)

C = circumference of helix = πD

S = spacing between turns (center to center)

α = pitch angle = arctan $S/\pi D$

L_o = length of 1 turn

N = number of turns

L = axial length = NS

d = diameter of helix conductor

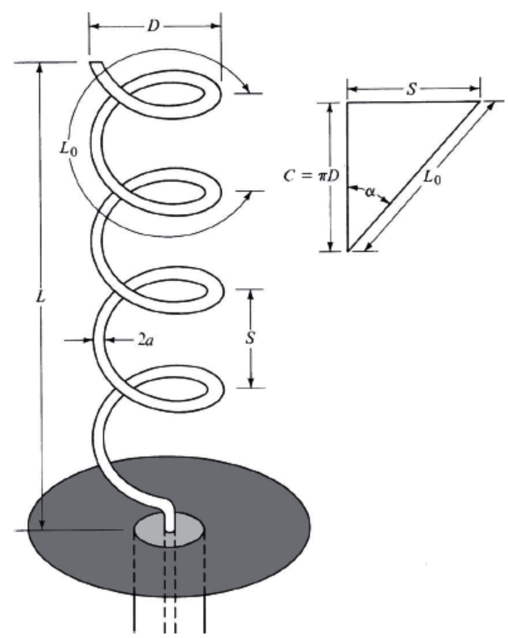


Fig. Helical antenna with ground plane.

If 1 turn of a circular helix is unrolled on a flat plane, the relation between the spacing S, circumference C, turn length L_o and pitch angle α is as illustrated by the triangle in Fig.

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

When the spacing is zero, α =0 and the helix becomes a loop of n turns. On the other hand, when the diameter is zero, α =90◦ and the helix becomes a linear conductor (short dipole).
When **0◦<α < 90◦**, then a true helix is formed with a circumference greater than zero.
The radiation characteristics of the antenna can be varied by controlling the size of its geometrical properties compared to the wavelength.

Helical antenna modes:

In general, the helical antenna radiates in many modes, but there are two important modes called normal mode and axial mode.

Normal Mode : In normal mode the maximum radiation is along the broad side to helix axis. It is also called broad side mode. To achieve the normal mode of operation, the dimensions of the helix are usually small compared to the wavelength (NS ,C<< λ). The radiation efficiency and band width of this mode are very less. As the dimensions are very less the radiation pattern of the normal mode can be analyzed by considering the antenna as a combination of small loop and short dipole.
The far field of the small loop has only an E_ϕ component and is given by

$$E_\phi = \frac{120\pi^2[I]\sin\theta}{r}\frac{A}{\lambda^2}$$

where the area of the loop A = $\pi D^2/4$
The far field of the short dipole has only an E_θ component and is given by

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

Where *S* has been substituted for *L* as the length of the dipole.
Comparing (1) and (2), the *j* operator in (2) and its absence in (1) indicates that E_ϕ and E_θ are in phase quadrature.

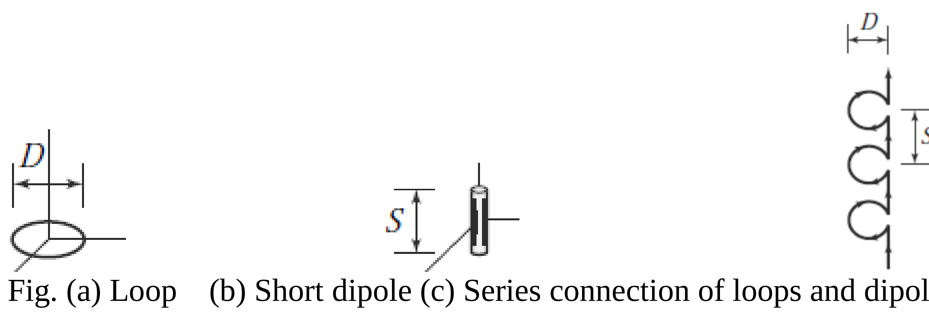


Fig. (a) Loop (b) Short dipole (c) Series connection of loops and dipole

The **axial ratio** which determines the polarization of the radiation is the ratio between the fields of short dipole and small loop.

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

If the axial ratio AR = 0, linear horizontal polarization.
AR = ∞, linear vertical polarization.
AR = 1, circular polarization.
Otherwise elliptical polarization

The condition for circular polarization is given by AR=1

$\mathbf{2S\lambda = \pi^2 D^2}$ or $\mathbf{C = \sqrt{2S\lambda}}$

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

The radiation resistance of antenna in normal mode

$$\mathbf{R_r = 640\left(\frac{h}{\lambda}\right)^2\ \Omega}$$

Axial (end-fire) mode:

In axial mode the maximum radiation is along the axis of the helix. The axial (end-fire) mode is usually the most practical because it can achieve circular polarization over a wider bandwidth (usually 2:1) and it is more efficient. To excite this mode, the diameter *D* and spacing *S* must be large fractions of the wavelength, i.e the circumference of the helix must be in the $\frac{3}{4} < \frac{C}{\lambda} < \frac{4}{3}$ range , N > 3 and the spacing about S= $\lambda/4$. The pitch angle is usually $12^\circ \leq \alpha \leq 14^\circ$. Most often the antenna is used in conjunction with a ground plane,whose diameter is at least $\lambda/2$, and it is fed by a coaxial line.

The terminal impedance (resistive) is given by $\mathbf{R = \frac{140D}{\lambda}}$

Half power beam width (HPBW) is given by $\mathbf{HPBW} = \frac{52}{C}\sqrt{\frac{\lambda^3}{N.S}}$ **degrees**

The Beam width between first nulls is given $\mathbf{FNBW} = \frac{115}{C}\sqrt{\frac{\lambda^3}{N.S}}$ **degrees**

The Directivity is given by $\mathbf{D = \frac{15NSC^2}{\lambda^3}}$

The gain is given by $\boxed{G = 6.2\frac{NSC^2}{\lambda^3}}$

The axial ratio is given by $\mathbf{AR = 1 + \frac{1}{2N}}$

the normalized far-field pattern by

$$E = \sin\left(\frac{\pi}{2N}\right)\cos\theta\,\frac{\sin[(N/2)\psi]}{\sin[\psi/2]}$$ where $\boldsymbol{\psi = \beta s \cos\theta}$

<u>Practical Design considerations for Monofilar Helical Antenna in Axial:</u>

The monofilar axial-mode helical antenna is very simple and easy to build.

The important parameters are:

1. Beamwidth
2. Gain
3. Impedance
4. Axial ratio

Gain and *beamwidth,* which are interdependent [*G α (*1/HPBW2*)*], and the other parameters are all functions of the number of turns, the turn spacing (or pitch angle) and the frequency.

For a given number of turns the behavior of the *beamwidth, gain, impedance* and *axial ratio* determines the useful *bandwidth*.

The terminal impedance (resistive) is given by $\mathbf{R} = \frac{\mathbf{140D}}{\boldsymbol{\lambda}}$

Half power beam width (HPBW) is given by $\mathbf{HPBW} = \frac{\mathbf{52}}{\mathbf{C}}\sqrt{\frac{\boldsymbol{\lambda}^3}{\mathbf{N.S}}}$ **degrees**

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The Directivity is given by $\mathbf{D} = \frac{\mathbf{15NSC^2}}{\boldsymbol{\lambda}^3}$

The gain is given by $\boxed{\mathrm{G} = 6.2\frac{\mathbf{NSC^2}}{\boldsymbol{\lambda}^3}}$

The axial ratio is given by $\mathbf{AR} = \mathbf{1} + \frac{\mathbf{1}}{\mathbf{2N}}$

the normalized far-field pattern by

$$E = \sin\left(\frac{\pi}{2N}\right)\cos\theta\,\frac{\sin[(N/2)\psi]}{\sin[\psi/2]}$$

where $\boldsymbol{\psi} = \boldsymbol{\beta s}\cos\boldsymbol{\theta}$

<u>Applications of Helical antenna:</u>

1. The helical antenna is used for space telemetry applications of satellites, space probes, and ballistic missiles to transmit or receive signals.
2. It is used for circular polarization.
3. It is widely used in VHF and UHF Bands.

<u>Horn Antennas:</u> The horn antenna is most widely used microwave antenna.

A horn antenna may be regarded as a flared-out (or opened-out) waveguide. The function of the horn is to produce a uniform phase front with a larger aperture than that of the waveguide and hence greater directivity. Several types of horn antennas are illustrated in Fig which are classified as rectangular and circular horn antennas. The rectangular horn antennas are feed with rectangular waveguide while circular horn antennas are feed with circular waveguide.

To minimize reflections of the guided wave, the transition region or horn between the waveguide at the throat and free space at the aperture could be given a gradual exponential taper as in Fig. 1*a* or *e*. However, it is the general practice to make horns with straight flares as in Fig.1 b,c and d.

Depending upon the direction of flaring ,the rectangular horn antennas are further classified as sectoral horn and pyramidal horn. A sectoral horn is obtained if the flaring is done only in one direction. There are two types of sectoral horns which are H-plane sectoral horn and E-plane sectoral horn. The H-plane sectoral horn is obtained when flaring is done in the direction of the magnetic field vector (H-plane) as shown in fig.1(b) .

The E-plane sectoral horn is obtained when flaring is done in the direction of the electric field vector (E-plane) as shown in fig.1(c) . A rectangular horn with flare in both planes, as in Fig. 1(*d*) is called a *pyramidal horn*.

The rectangular waveguide is fed with a TE10 mode wave electric field (**E** in the y direction).

The arrows indicate the direction of the electric field **E**, and their length gives an approximate indication of the magnitude of the field intensity.

The horn shown in Fig.1.f is a conical horn antenna which is obtained by flaring circular waveguide. It is fed with a circular guide carrying a TE11 mode wave. The horns in Fig.1.(g and h) are biconical types. The biconical antennas are excited by TEM and TE_{01} modes.

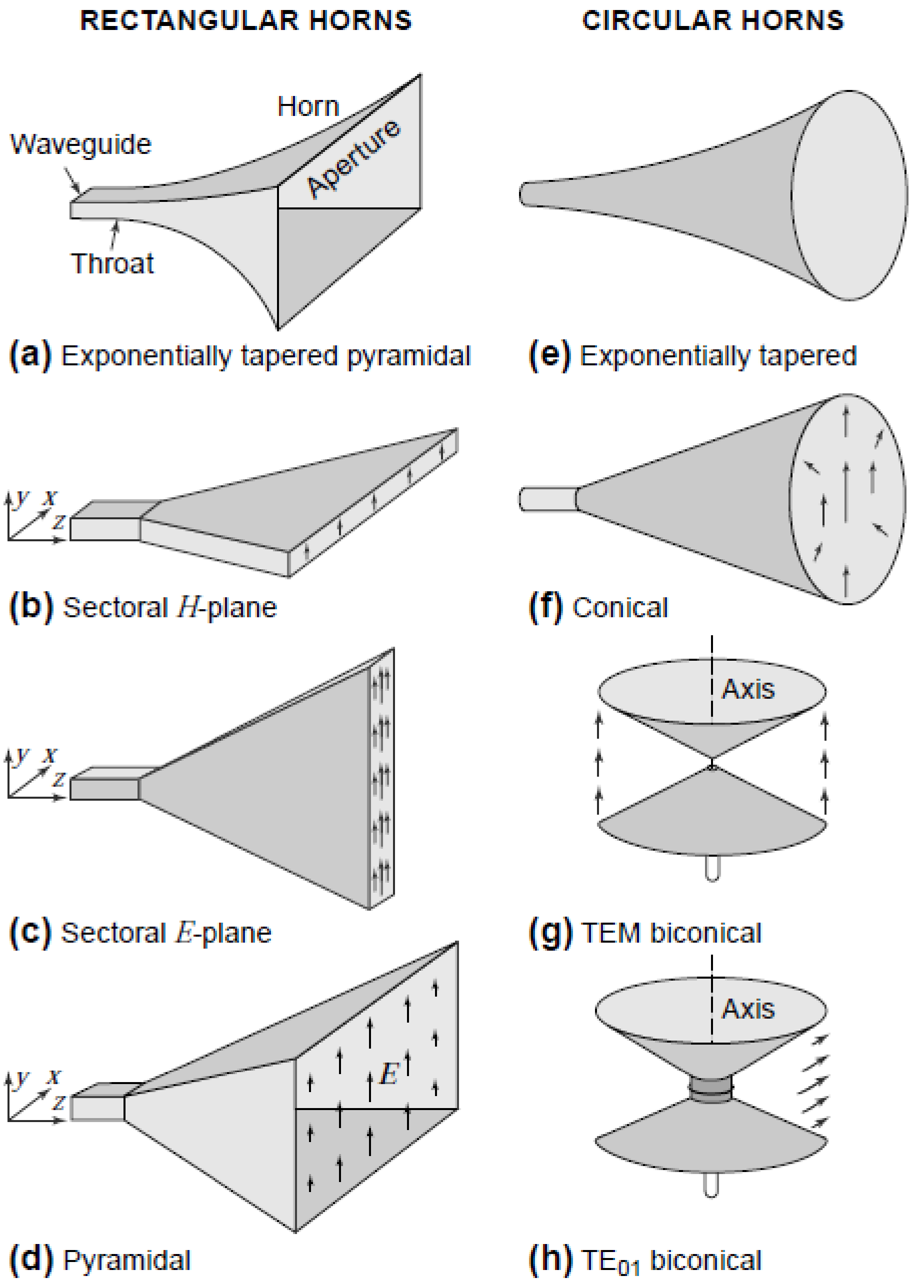
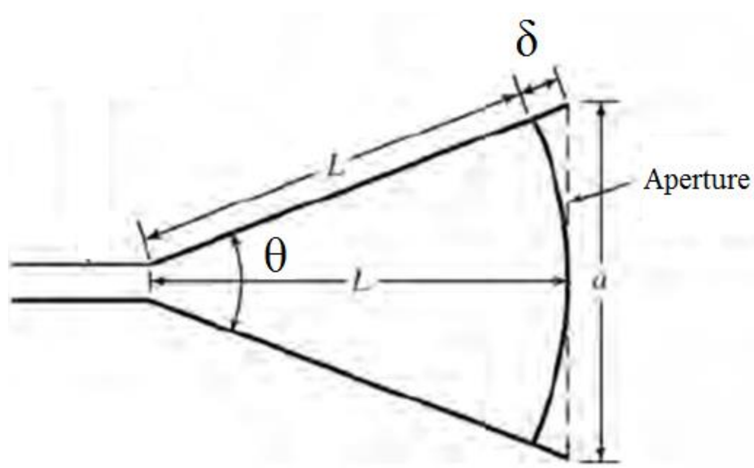


Fig .Types of rectangular and circular horn antennas. Arrows indicate **E**-field directions.

<u>Design considerations of Pyramidal Horns:</u> The *principle of equality of path length (Fermat's principle)* is applicable to the horn design. Instead of requiring a constant phase across the horn mouth, the requirement is relaxed to one where the phase may deviate, but by less than a specified amount δ, equal to the path length difference between a ray traveling along the side and along the axis of the horn. From Fig.2



$$\cos\frac{\theta}{2} = \frac{L}{L+\delta} \tag{1}$$

$$\sin\frac{\theta}{2} = \frac{a}{2(L+\delta)} \tag{2}$$

$$\tan\frac{\theta}{2} = \frac{a}{2L} \tag{3}$$

where

θ = flare angle (θ_E for E plane,θ_H for H plane), deg
a = aperture (a_E for E plane, aH for H plane),m
L = horn length, m
δ = path length difference, m
From the geometry we have also that

$$(L+\delta)^2 = L^2 + \frac{a^2}{4}$$

$$(L+\delta)^2 = L^2 + 2L\delta + \delta^2 = L^2 + \frac{a^2}{4}$$

$$L = \frac{a^2}{8\delta} \qquad (\delta \ll L) \tag{4}$$

and

$$\theta = 2\tan^{-1}\frac{a}{2L} = 2\cos^{-1}\frac{L}{L+\delta} \tag{5}$$

Optimum Horns:

To obtain as uniform an aperture distribution as possible, a very long horn with a small flare angle is required. However, from the standpoint of practical convenience the horn should be as short as possible. An *optimum horn* is between these extremes and has the minimum beamwidth without excessive side-lobe level (or most gain) for a given length. Thus, from (1) the optimum horn dimensions can be related by

Optimum horn dimensions

$$\delta_0 = \frac{L}{\cos(\theta/2)} - L = \text{optimum } \delta \tag{6}$$

$$L = \frac{\delta_0 \cos(\theta/2)}{1-\cos(\theta/2)} = \text{optimum length} \tag{7}$$

The directivity (or gain, assuming no loss) of a horn antenna can be expressed in terms of its effective aperture. Thus,

$$D = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi \varepsilon_{ap} A_p}{\lambda^2}$$

Where A_e = effective aperture, m2

Ap = physical aperture, m2
εap = aperture efficiency = Ae/Ap
λ = wavelength, m
For a rectangular horn Ap = $a_E a_H$ and for a conical horn Ap = πr^2, where r =aperture radius. It is assumed
that aE, aH or r are all at least 1λ. Taking εap = 0.6, The directivity becomes

$$D \simeq \frac{7.5A_p}{\lambda^2}$$

or

$$D \simeq 10\log\left(\frac{7.5A_p}{\lambda^2}\right) \qquad \text{(dBi)}$$

For a pyramidal (rectangular) horn (3) can also be expressed as

$$D \simeq 10\log(7.5a_{E\lambda}a_{H\lambda})$$

where
$a_{E\lambda}$ = E-plane aperture in λ
$a_{H\lambda}$ = H-plane aperture in λ

$$\text{HPBW } (E \text{ plane}) = \frac{56^\circ}{a_{E\lambda}}$$

$$\text{HPBW } (H \text{ plane}) = \frac{67^\circ}{a_{H\lambda}}$$

Prob. (a) Determine the length L,H-plane aperture and flare angles θ_E and θ_H (in the E and H planes, respectively) of a pyramidal horn for which the E-plane aperture a_E = 10λ. The horn is fed by a rectangular waveguide with TE_{10} mode. Let δ = 0.2λ in the E plane and 0.375λ in the H plane. (b) What are the beamwidths? (c) What is the directivity?