MODULE 5

Loop and Horn Antennas

SEVENTH SEMESTER

MICROWAVES AND ANTENNAS

17EC71

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Introduction: Loop Antenna

Loop antenna is simple conductor in loop to which we are feeding with transmission line

Loop antennas are also simple, cheap, and very versatile.

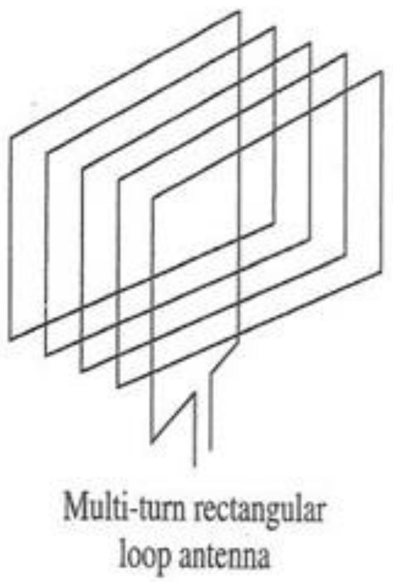
Loop antenna

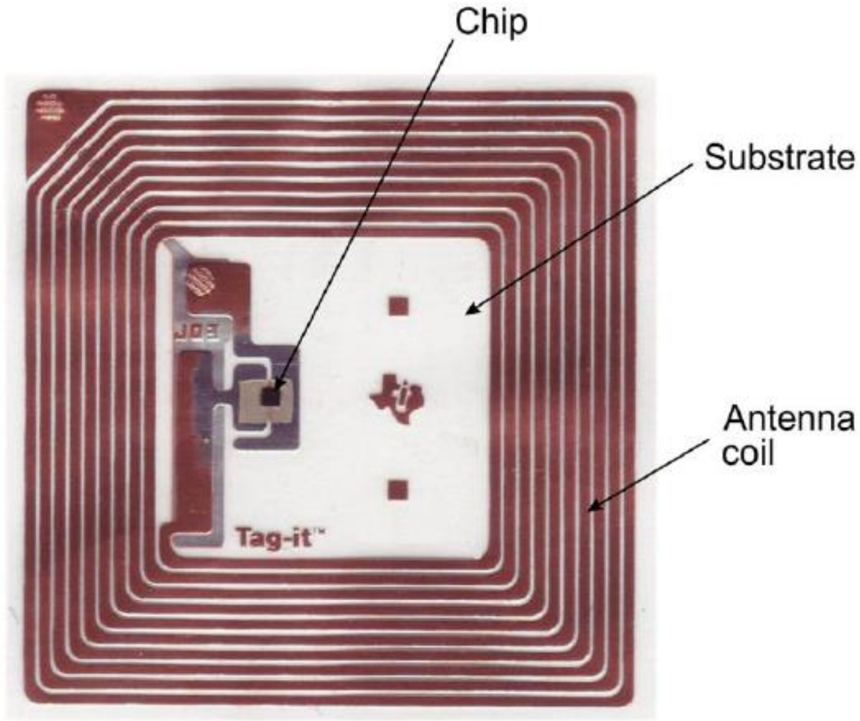
- An antenna constructed in a form of a loop
- Loops may vary in shape: square, circular, elliptical
- Can be classified as electrically small or electrically large
  - Based on circumference/ perimeter:
    - Small loop: C< $\lambda/10$
    - Large loop: $C \sim \lambda$ (free space wavelength)
- Common band of application
  - HF (3–30 MHz)
  - VHF (30–300 MHz)
  - UHF (300–3,000 MHz)
  - Microwave bands

Small loops

A short wave loop antenna

Application of multi-turn small loop antenna-RFID



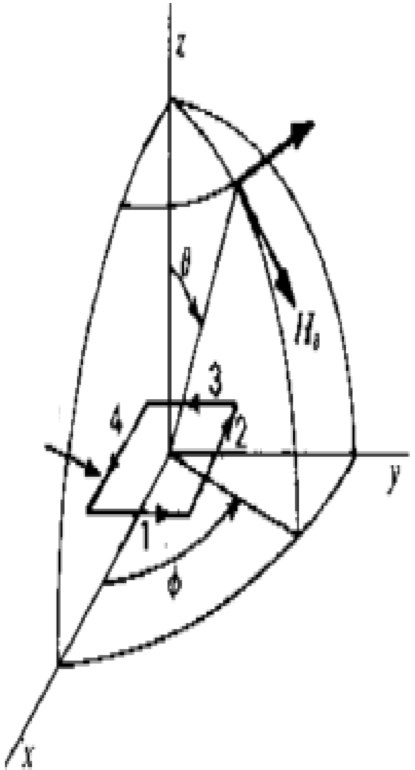


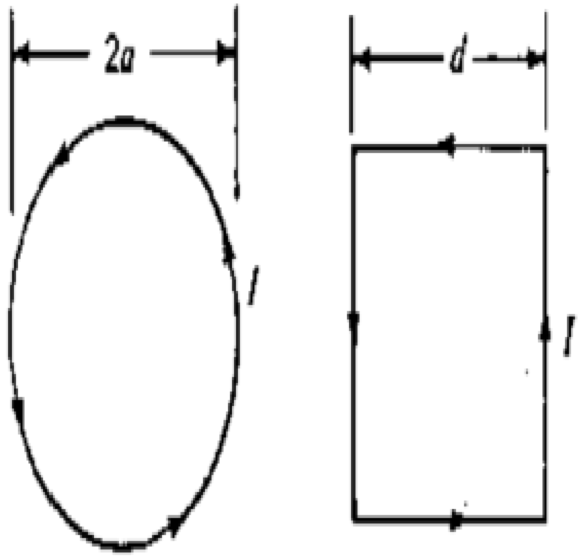
RFID Tag

Loop antennas

Loop antennas can have circular, rectangular, triangular

or any other shape. It can have number of turns and can be wrapped in the air or around dielectric (solid or hollow) or ferrite material.





Circular Loop

Square Loop

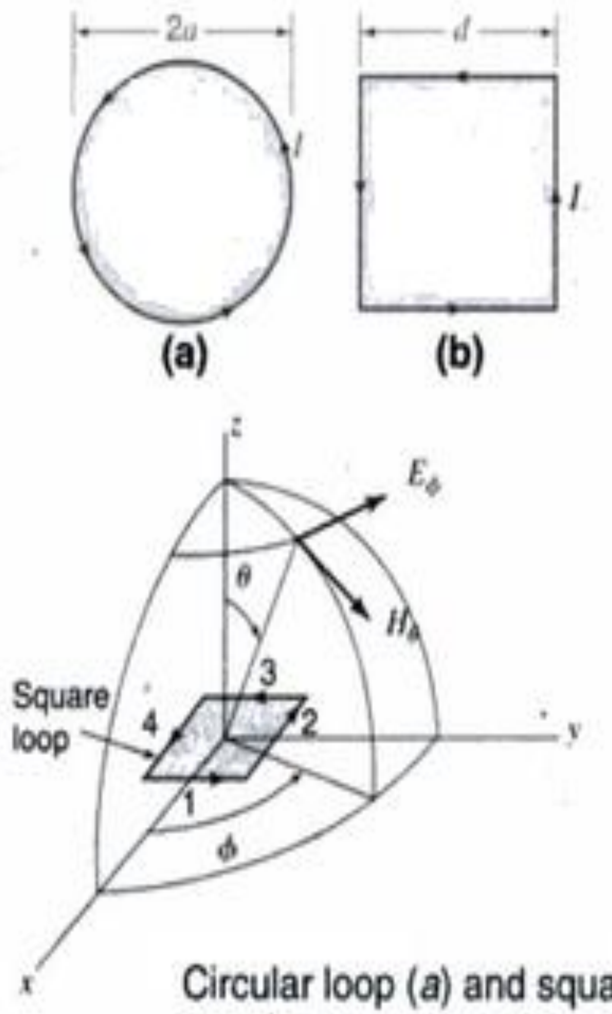
A small electric loop is equivalent to a small linear magnetic dipole of constant current amplitude I_m.

Small loop

The field pattern of a small circular loop of radius 'a' may be determined by considering a square loop of the same area.

$d^2 = \pi a^2$, where d is the side length of the square loop.

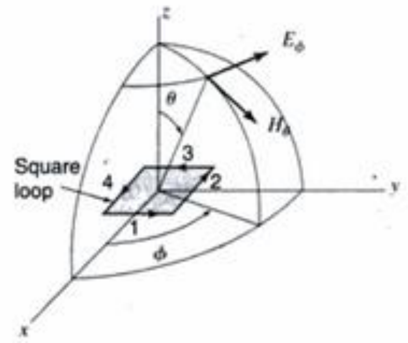
It is assumed that the loop dimensions are small compared to the wavelength. It can be seen that the far-field patterns of circular and square loops of the same area are the same when the loops are small but different when they are large in terms of the wavelength.

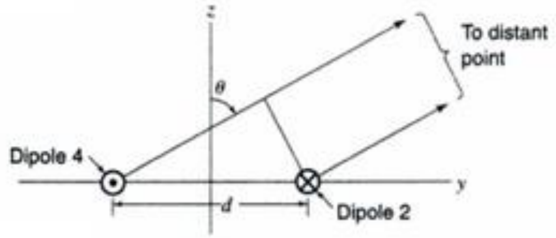


Circular loop (*a*) and square loop (*b*) of equal area.

Small loop

If the loop is oriented as shown, its far electric field has only an E_ϕ component. To find the far field pattern, in the yz plane, we should consider plane. So consider only two of the small linear dipoles, namely 2 and 4 . A cross section of the loop in the yz plane is also shown. Since the individual small dipoles 2 and 4 are nondirectional in the yz plane, the field patternof the loop in this plane is the same as that f or two isotropic point sources .





Electric field is given as

$$E\phi = -E_{\phi 0} e^{j\psi/2} + E_{\phi 0} e^{-j\psi/2} \longrightarrow (1)$$

Where $E\phi_0$: Electric field from indivi-
-dual dipole

$$\psi = \beta d \sin\theta = \frac{2\pi}{\lambda} d \sin\theta \longrightarrow (2)$$

$$\therefore \quad E\phi = -E\phi_0 \cdot 2j \sin(\psi/2) \quad \left\{ \sin\theta = \frac{e^{j\theta} - e^{-j\theta}}{2j} \right.$$

$$= -E_{\phi 0} \cdot 2j \sin\left[\frac{\beta d}{2} \sin\theta\right] \longrightarrow (3)$$

If $d << \lambda$ then equation (3) can be writtenas

$$E\phi = -j E\phi_0 \cdot \cancel{2}j \cdot \frac{\beta d}{\cancel{2}} \sin\theta$$

$$E_\phi = -jE_{\phi 0}\, d_r \sin\theta \qquad \{\beta d = d_r\}$$

→ The far field of individual dipole is given as

$$E_{\phi 0} = \frac{j60\pi [I] L}{r\lambda} \longrightarrow (4)$$

Where [I] is retarded current at distance r from dipole

Substitute equation (4) in equation 3,

$$E_\phi = -jd_r\left(\frac{j60\pi[I]L}{r\lambda}\right)\sin\theta$$

$$E_\phi = \frac{60\pi[I]L}{r\lambda} d_r \sin\theta \longrightarrow (5)$$

If $L = d$, then area of the loop is d^2, then equation (5) becomes

$$E_\phi = \frac{60\pi\,[I]\cdot d \cdot \frac{2\pi}{\lambda} d \ \sin\theta}{r\lambda}$$

$$= \frac{120\pi^2\,[I]\,d^2}{r\lambda^2} \sin\theta$$

$$\boxed{E_\phi = \frac{120\pi^2\,[I]}{r} \sin\theta \,\frac{A}{\lambda^2}} \longrightarrow (6)$$

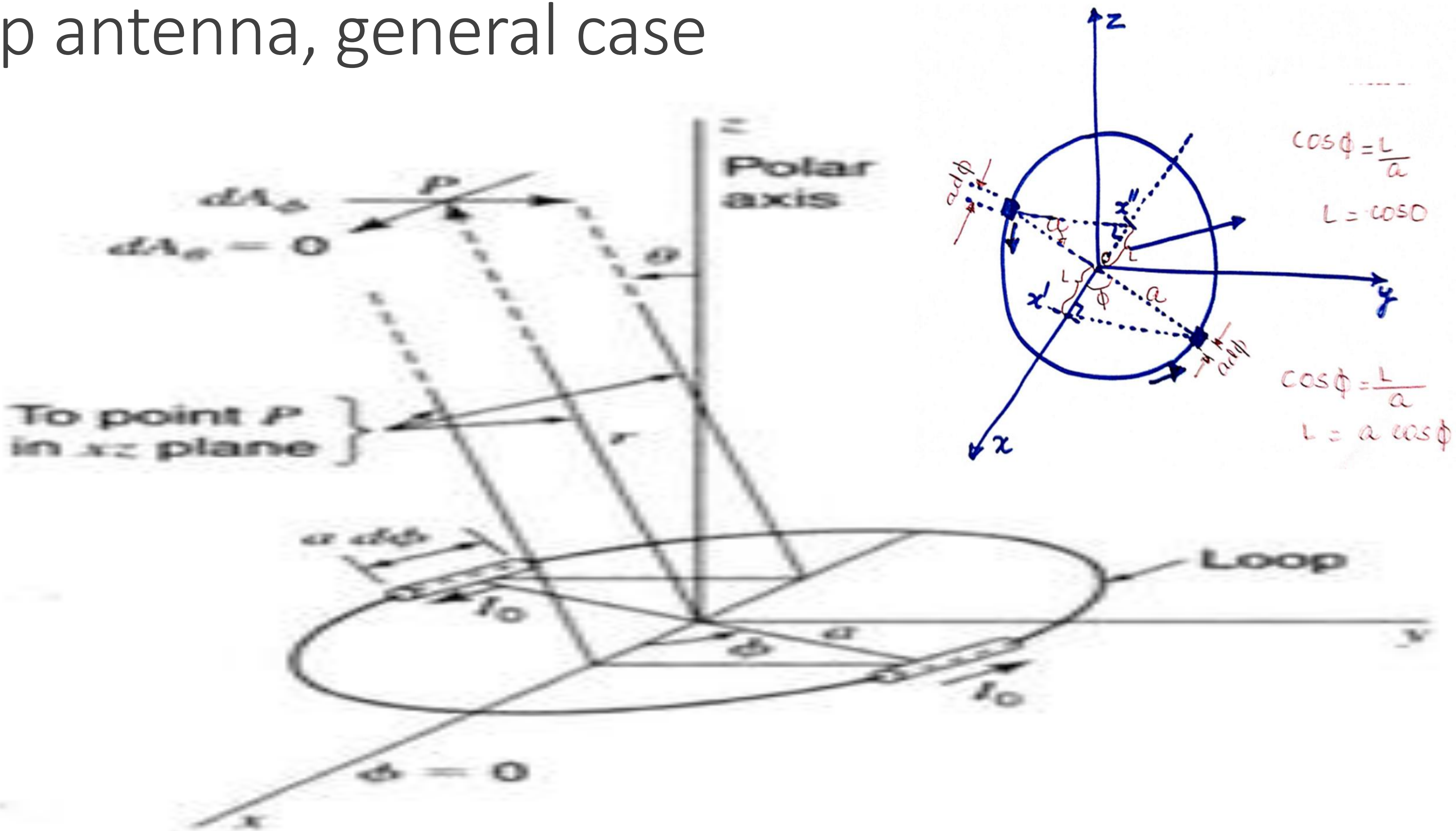
$$H_\theta = \frac{E_\phi}{120\pi} = \frac{\pi \sin\theta \cdot [I]}{r} \frac{A}{\lambda^2} \longrightarrow (7)$$

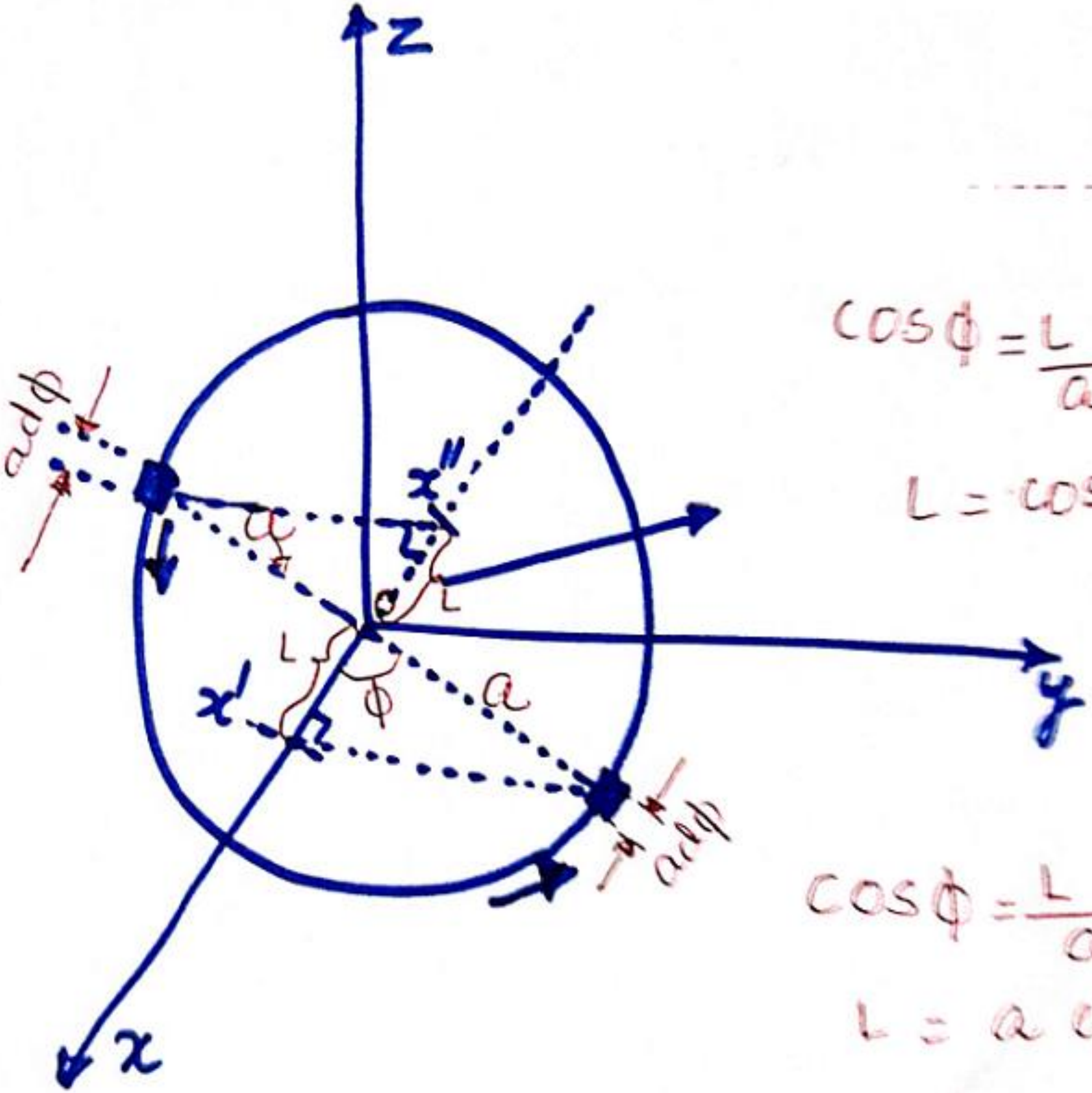
Small loops

Far fields of small electric dipoles and loops

Field	Electric dipole	Loop
Electric	$E_\theta = \frac{j60\pi[I]\sin\theta}{r}\frac{L}{\lambda}$	$E_\phi = \frac{120\pi^2[I]\sin\theta}{r}\frac{A}{\lambda^2}$
Magnetic	$H_\phi = \frac{j[I]\sin\theta}{2r}\frac{L}{\lambda}$	$H_\theta = \frac{\pi[I]\sin\theta}{r}\frac{A}{\lambda^2}$

Loop antenna, general case





$\cos\phi = \frac{L}{a}$

$L = \cos\theta$

$\cos\phi = \frac{L}{a}$

$L = a\cos\phi$

Distance between x' and x'' is

$2L$

i.e. $2a\cos\phi$

Total phase difference is

$\lambda - 2\pi$

$2a\cos\phi - ?$

$= 2a\cos\phi \left(\frac{2\pi}{\lambda}\right)$ — β

$= 2a\beta\cos\phi$

Loop antenna, general case

Since the current is confined to the loop, the only component of the vector potential having a value is A_ϕ. The other components are zero: $A_\theta = A_r = 0$. The infinitesimal value at the point P of the ϕ component of A from two diametrically opposed infinitesimal dipoles is

$$dA_\phi = \frac{\mu \, dM}{4\pi r}$$

where dM is the current moment due to one pair of diametrically opposed infinitesimal dipoles of length, $a\,d\phi$. In the $\phi = 0$ plane the ϕ component of the retarded current moment due to one dipole is

$$[I]a\,d\phi\cos\phi$$

where $[I] = I_0 e^{j\omega[t-(r/c)]}$ and I_0 is the peak current in time on the loop.

Loop antenna, general case

cross section through the loop in the xz plane

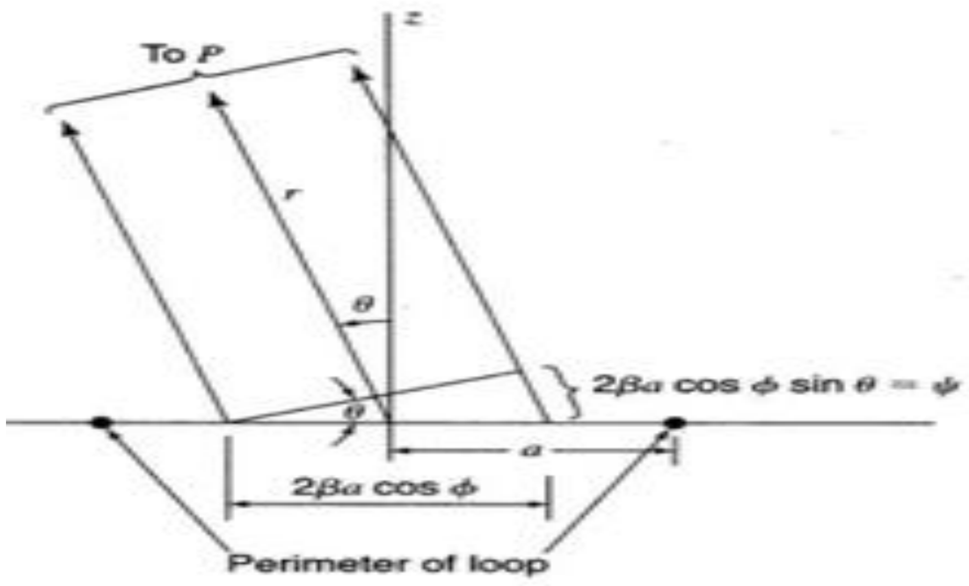
the resultant moment dM at a large distance due to a pair of diametrically opposed dipoles is

$$dM = 2j[I]a\,d\phi\cos\phi\sin\frac{\psi}{2}$$

where $\psi = 2\beta a\cos\phi\sin\theta$ radians

Introducing this value for ψ we have

$$dM = 2j[I]a\cos\phi[\sin(\beta a\cos\phi\sin\theta)]\,d\phi$$



Cross section in xz-plane through loop

We know that

$$dA_\phi = \frac{\mu}{4\Pi r} dM$$

$$dA_\phi = \frac{\mu}{\cancel{4}_2 \pi r} \cdot 2j[I]\, a \cos\phi [\sin(\beta a \cos\phi \sin\theta] d\phi$$

$$A_\phi = \int_0^\pi dA_\phi$$

$$A_\phi = \frac{j\mu[I]a}{2\pi r} \int_0^\pi \sin(\beta a \cos\phi \sin\theta) \cos\phi \, d\phi$$

or

$$A_\phi = \frac{j\mu[I]a}{2r} J_1(\beta a \sin\theta)$$

where J_1 is a Bessel function of the first order and of argument $(\beta a \sin\theta)$. The integration is performed on equivalent dipoles which are all situated at the origin but have different orientations with respect to ϕ. The retarded current $[I]$ is referred to the origin and, hence, is constant in the integration.

The far electric field of the loop has only a ϕ component given by

Loop antenna, general case

$$E_\phi = -j\omega A_\phi$$

Substituting the value of A_ϕ yields

For all loops	$E_\phi = \frac{\mu\omega[I]a}{2r} J_1(\beta a \sin\theta)$ or $E_\phi = \frac{60\pi\beta a[I]}{r} J_1(\beta a \sin\theta)$	***Far fields***

This expression gives the instantaneous electric field at a large distance r from a loop of any radius a. The peak value of E_ϕ is obtained by putting $[I] = I_0$, where I_0 is the peak value (in time) of the current on the loop. The magnetic field H_θ at a large distance is related to E_ϕ by the intrinsic impedance of the medium, in this case, free space. Thus,

$$H_\theta = \frac{\beta a[I]}{2r} J_1(\beta a \sin\theta)$$

This expression gives the instantaneous magnetic field at a large distance r from a loop of any radius a.

Far field patterns of circular loop antennas with uniform current

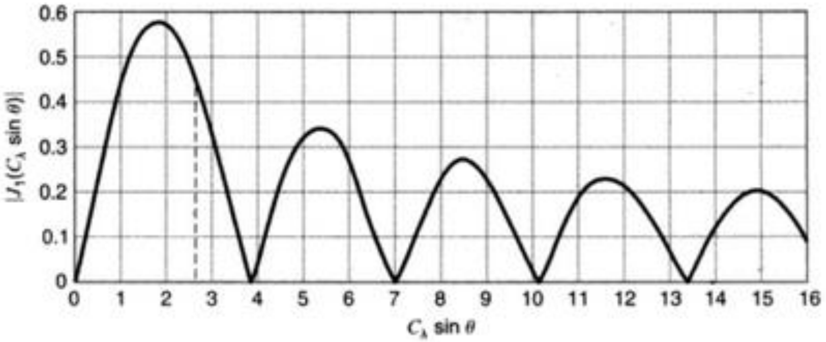
For a loop of a given size, βa is constant and the shape of the far-field pattern is given as a function of θ by

$$J_1(C_\lambda \sin\theta)$$

where C_λ is the circumference of the loop in wavelengths. That is,

$$C_\lambda = \frac{2\pi a}{\lambda} = \beta a$$

The value of $\sin\theta$ as a function of θ ranges in magnitude between zero and unity. When $\theta = 90^\circ$, the relative field is $J_1(C_\lambda)$, and as θ decreases to zero, the values of the relative field vary in accordance with the J_1 curve from $J_1(C_\lambda)$ to zero.



Rectified first-order Bessel curve for patterns of loops.

The small loop as a special case

For small arguments of the first-order Bessel function, the following approximate relation can be used:

$$J_1(x) = \frac{x}{2}$$

where x is any variable. When $x = \frac{1}{3}$, the approximation is about 1 percent in error. The relation becomes exact as x approaches zero. Thus, if the perimeter of the loop is $\lambda/3$ or less ($C_\lambda < \frac{1}{3}$), with an error which is about 1 percent or less.

Small loop

$$E_\phi = \frac{60\pi\beta a[I]\beta a \sin\theta}{2r} = \frac{120\pi^2[I]\sin\theta}{r}\frac{A}{\lambda^2}$$

$$H_\theta = \frac{\beta a[I]\beta a \sin\theta}{4r} = \frac{\pi[I]\sin\theta}{r}\frac{A}{\lambda^2}$$

Far fields

Radiation Resistance of Loops

→ Total power radiated by an antenna is given by

$$P = \frac{I_0^2 R_r}{2} \quad \text{.........} \quad (1)$$

→ According to Poynting vector, power density at any point is given by

$$S_r = \frac{1}{2} H^2 Re(Z) \quad \text{......} \quad (2)$$

H = Absolute value of magnetic field

$$= \frac{\beta a[I]}{2r} J_1(\beta a \sin\theta) \quad \text{.......} \quad (3)$$

Z = Intrinsic impedance of medium $= 120\pi$

→ Substitute equation (3) in equation (2), we get

$$S_r = \frac{1}{2}\left[\frac{\beta a[I]}{2r} J_1(\beta a \sin\theta)\right]^2 \cdot 120\pi$$

$$S_r = \frac{1}{\cancel{8}r^2}(\beta a I_0)^2 J_1^2(\beta a \sin\theta) \cdot \overset{15}{\cancel{120}}\pi$$

$$= \frac{15\pi(\beta a I_0)^2}{r^2} J_1^2(\beta a \sin\theta)$$

→ The total power radiated P is the integral of S_r, over a large sphere ;

$$P = \iint S_r \, ds$$

$$= 15\pi (\beta a I_0)^2 \int_{\phi=0}^{2\pi} \int_{\theta=0}^{\pi} J_1^2(\beta a \sin\theta) \sin\theta \, d\theta \, d\phi \longrightarrow (4)$$

$$= 15\pi\,(\beta a I_0)^2\,(2\pi)\int_0^{\pi} J_1^2(\beta a \sin\theta)\,\sin\theta\, d\theta$$

$$= 30\pi^2\,(\beta a I_0)^2\int_0^{\pi} J_1^2(\beta a \sin\theta)\sin\theta\, d\theta \quad \to (5)$$

→ For small loop $J_1(x) = \frac{x}{2}$

∴ Equation (5) reduces to

$$P = 30\pi^2\,(\beta a I_0)^2\int_0^{\pi}\left(\frac{\beta a \sin\theta}{2}\right)^2 \sin\theta\, d\theta$$

$$= \frac{30\pi^2 \beta^4 a^4 I_0^2}{4} \int_0^{\pi} \sin^3\theta \, d\theta$$

$$= \frac{\overset{10}{\cancel{30}}\pi^2 \beta^4 a^4 I_0^2}{\cancel{4}} \cdot \frac{\cancel{4}}{\cancel{3}}$$

$$= 10\pi^2 \left(\frac{2\pi}{\lambda} \cdot a\right)^4 I_0^2$$

$$= 10\beta^4 A^2 I_0^2 \text{ ——— } (6)$$

$$= 10\pi^2 C_\lambda^4 I_0^2 \cdots (7) \left\{ A = \pi a^2 \right.$$

Where C_λ : Circumference of loop in wavelength.

→ Equating equation(6) to equation (1)

$$R_r \frac{I_0^2}{2} = 10\beta^4 A^2 I_0^2$$

$$R_r = 31171\left(\frac{A}{\lambda^2}\right)^2 = 197\, C_\lambda^4$$

DIRECTIVITY OF LOOPS

$$\text{DIRECTIVITY} = \frac{\text{max. radiation intensity}}{\text{Avg. radiation intensity}}$$

→ max. radiation intensity for a loop antenna is given by

$$= 15\pi(\beta a I_0)^2 J_1^2(\beta a \sin\theta) \longrightarrow ①$$

→ Avg. radiation intensity for loop antenna is given by

$$= \frac{30\pi^2(\beta a I_0)^2}{4\pi} \int_0^{\pi} J_1(\beta a \sin\theta) \sin\theta \, d\theta \longrightarrow ②$$

→ We have,

$$\int_0^{\pi} J_1(x \sin\theta)\sin\theta \, d\theta = \frac{1}{x}\int_0^{2x} J_2(y)\,dy$$

Where : Y is any function

$\therefore$

$$= \frac{30\pi^2(\beta a I_0)^2}{4\pi} \cdot \frac{1}{\beta a}\int_0^{2\beta a} J_2(y)\,dy$$

∴ We can write equation for directivity of loop antenna as

$$D = \frac{\cancel{15}^{1} \cancel{\pi} \cancel{(\beta a I_0)^2} J_1(\beta a \sin\theta)}{\frac{\cancel{2}\cancel{30}\cancel{\pi^2}\cancel{(\beta a I_0)^2}}{\cancel{4\pi}_{2}} \cdot \frac{1}{\beta a} \int_0^{2\beta a} J_2(y)\,dy}$$

$$= \frac{2\beta a\, J_1(\beta a \sin\theta)}{\int_0^{2\beta a} J_2(y)\,dy}$$

$$D = \frac{2C_\lambda \left[J_1^2(C_\lambda \sin\theta)\right]_{max}}{\int_0^{2C_\lambda} J_2(y)\,dy} \longrightarrow (3)$$

In equation-3, angle θ is the value for which the field is a maximum.

→ For loop ($C_\lambda < \frac{1}{3}$), the directivity expression reduces to

$$D = \frac{3}{2} \sin^2\theta = \frac{3}{2}$$

→ For large loop ($C_\lambda > 2$), $D = 0.68 C_\lambda$

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 radiated. This power is then equated to the square of the effective current on the loop times the radiation resistance R_r

$$P = \frac{I_0^2}{2} R_r$$

where I_0 = peak current in time on the loop. The radiation resistance so obtained is the value which would appear at the loop terminals connected to the twin-line, and coaxial line It is assumed that the current is uniform and in phase for any radius a, this condition being obtained by means of phase shifters, multiple feeds or other devices The average Poynting vector of a far field is given by

$$S_r = \tfrac{1}{2}|H|^2 \operatorname{Re} Z$$

where $|H|$ is the absolute value of the magnetic field and Z is the intrinsic impedance of the medium, which in this case is free space. Substituting the absolute value of H_θ yields

$$S_r = \frac{15\pi(\beta a I_0)^2}{r^2} J_1^2(\beta a \sin\theta)$$

The total power radiated P is the integral of S_r over a large sphere; that is,

$$P = \iint S_r\, ds = 15\pi(\beta a I_0)^2 \int_0^{2\pi}\int_0^{\pi} J_1^2(\beta a \sin\theta) \sin\theta \, d\theta \, d\phi$$

Radiation resistance of loops

$$P = 30\pi^2(\beta a I_0)^2 \int_0^{\pi} J_1^2(\beta a \sin\theta)\sin\theta\, d\theta$$

In the case of a loop that is small in terms of wavelengths,

$$P = \frac{15}{2}\pi^2(\beta a)^4 I_0^2 \int_0^{\pi} \sin^3\theta\, d\theta = 10\pi^2\beta^4 a^4 I_0^2$$

Since the area $A = \pi a^2$,

$$P = 10\beta^4 A^2 I_0^2$$

Radiation resistance of loops

Assuming no antenna losses, this power equals the power delivered to the loop terminals Therefore,

$$R_r \frac{I_0^2}{2} = 10\beta^4 A^2 I_0^2$$

and

Small loop	$R_r = 31{,}171 \left(\frac{A}{\lambda^2}\right)^2 = 197 C_\lambda^4 \quad (\Omega)$ or $R_r \simeq 31{,}200 \left(\frac{A}{\lambda^2}\right)^2 \quad (\Omega)$	***Radiation resistance***

This is the radiation resistance of a small single-turn loop antenna, circular or square, with uniform in-phase current. The relation is about 2 percent in error when the loop perimeter is $\lambda/3$. A circular loop of this perimeter has a diameter of about $\lambda/10$. Its radiation resistance is nearly 2.5 Ω.

Radiation resistance of loops

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

$$\boxed{\textbf{\textit{Small loop}} \qquad R_r = 31{,}200\left(n\frac{A}{\lambda^2}\right)^2 \qquad (\Omega) \qquad \textbf{\textit{Radiation resistance}}}$$

where n = number of turns

Let us now proceed to find the radiation resistance of a circular loop of any radius a.

$$\int_0^{\pi} J_1^2(x\sin\theta)\sin\theta\, d\theta = \frac{1}{x}\int_0^{2x} J_2(y)\, dy$$

where y is any function

Radiation resistance of loops

$$P = 30\pi^2 \beta a I_0^2 \int_0^{2\beta a} J_2(y)\, dy$$

putting $\beta a = C_\lambda$ yields

$$R_r = 60\pi^2 C_\lambda \int_0^{2C_\lambda} J_2(y)\, dy \qquad (\Omega)$$

This is the radiation resistance as given for a single-turn circular loop with uniform in-phase current and of any circumference C_λ.

When the loop is large ($C_\lambda \geq 5$), we can use the approximation

$$\int_0^{2C_\lambda} J_2(y)\, dy \simeq 1$$

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

For a loop of 10λ perimeter, the radiation resistance is nearly 6000 Ω.

For values of C_λ between $\frac{1}{3}$ and 5 the integral can be evaluated using the transformation

$$\int_0^{2C_\lambda} J_2(y)\, dy = \int_0^{2C_\lambda} J_0(y)\, dy - 2J_1(2C_\lambda)$$

Radiation resistance of loops

For perimeters of over 5λ ($C_\lambda > 5$) one can also use the asymptotic development,

$$\int_0^{2x} J_2(y)\,dy \simeq 1 - \frac{1}{\sqrt{\pi x}}\left[\sin\left(2x - \frac{\pi}{4}\right) + \frac{11}{16x}\cos\left(2x - \frac{\pi}{4}\right)\right]$$

where $x = \beta a = C_\lambda$.

For small values of x, one can use a series obtained by integrating the ascending power series for J_2. Thus,

$$\int_0^{2x} J_2(y)\,dy = \frac{x^3}{3}\left(1 - \frac{x^2}{5} + \frac{x^4}{56} - \frac{x^6}{1080} + \frac{x^8}{31{,}680} - \cdots\right)$$

When $x = C_\lambda = 2$ (perimeter of 2λ), the result with four terms is about 2 percent in error. This same percentage error is obtained with one term when the perimeter is about $\lambda/3$.

Directivity of circular antennas with uniform current

The directivity D of an antenna is the ratio of maximum radiation intensity to the average radiation intensity.

$$D = \frac{2C_\lambda[J_1^2(C_\lambda \sin\theta)]_{max}}{\int_0^{2C_\lambda} J_2(y)\,dy}$$

This is expression for the directivity of a circular loop with uniform in-phase current of any circumference C_λ. The angle θ is the value for which the field is a maximum.

For a small loop ($C_\lambda < \frac{1}{3}$), the directivity expression reduces to

$$\boxed{\textbf{Small loop } C_\lambda \leq 1/3 \qquad D = \tfrac{3}{2}\sin^2\theta = \tfrac{3}{2} \qquad \textbf{Directivity}}$$

since the field is a maximum at $\theta = 90°$. The value of $\frac{3}{2}$ is the same as for a short electric dipole. This is to be expected since the pattern of a short dipole is the same as for a small loop.

For a large loop ($C_\lambda > 5$),

$$D = 2C_\lambda J_1^2(C_\lambda \sin\theta)$$

for any loop with $C_\lambda \geq 1.84$, the maximum value of $J_1(C_\lambda \sin\theta)$ is 0.582. Thus, the directivity expression for a large loop becomes

$$\boxed{\textbf{Large loop } C_\lambda \geq 2 \qquad D = 0.68C_\lambda \qquad \textbf{Directivity}}$$

SUMMARY

Loop antennas are radiating coils of one or more turns.

Loop antenna has a continuous conducting path leading from one conductor of a two-wire transmission line to the other conductor.

Loop antennas Can be used as:

- Self contained antennas in themselves
- Elements in an array
- Feeds for corner reflectors, lenses or parabolic reflectors.

Both ferrite and air cored loops are commonly used in Radio Rx in LF & MF bands

Wide applications in direction finders, a/c Rxs an UHF Txs.

Loops may be small (a or d <<λ), or large (a or d $\approx$ λ) or medium.

Loops may be circular, square, triangular or of hexagonal shape

Small loops are assumed to have uniform current distribution.

Large loops may have uniform or non-uniform current distribution

Assumed current may be in-phase or out of phase

Small loops are $\cong$ to magnetic dipoles.

All planar loops are directional with sharp nulls, and have a radiation pattern similar to that of dipole antenna with E and H fields interchanged.

When loops are small ($A < \lambda^2/100$) the far fields of circular and square loops are same and are different when loops are large.

Radiation properties depend only on loop area and shape of loop has no effect for small loops .

When loops are large the pattern of:

- **Circular loop of any size is a function of θ**
- **Square loop is a function of both θ and ϕ**

For smallness $2a \approx \lambda/10$ for loop and $L \approx \lambda/10$ are the good approximations

Small loops

A loop is considered a *small* if its circumference is less than λ/4.

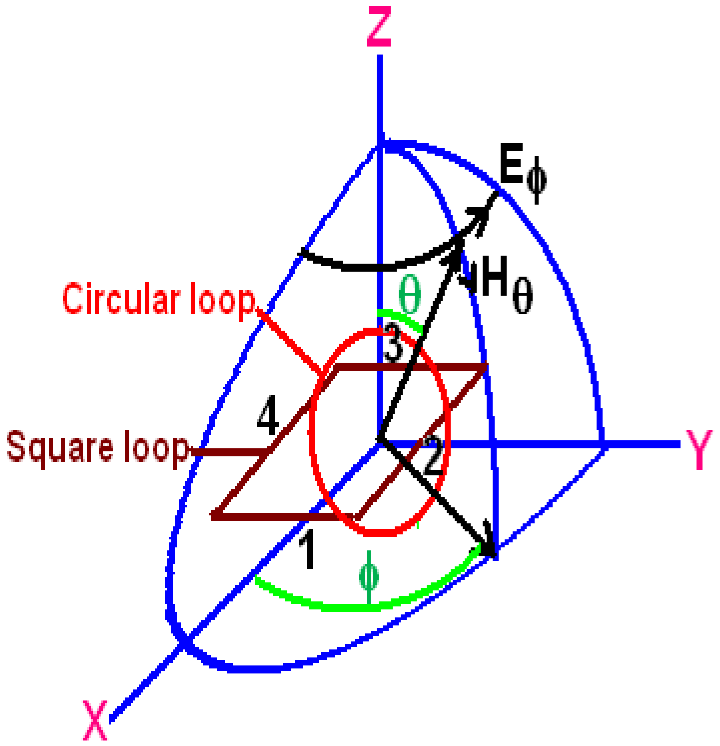
Most directional Rxg loops are about λ/10.

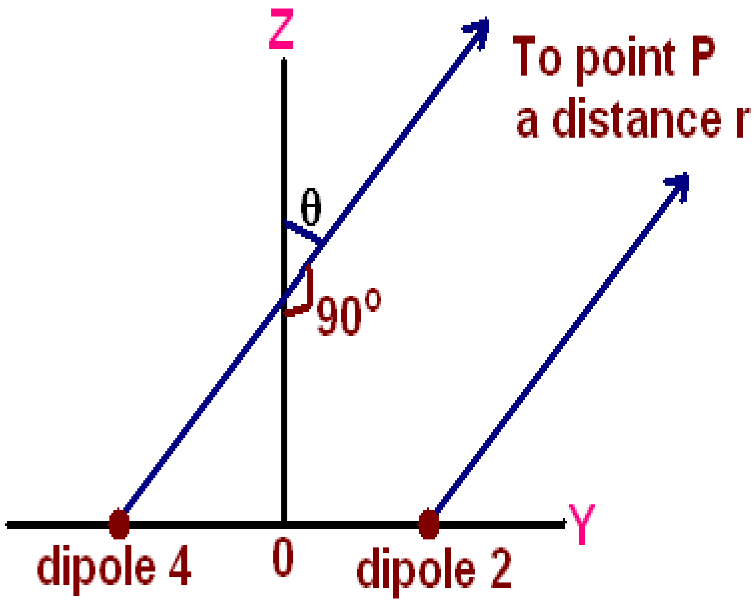
Small loop is also called the magnetic loop

because it is more sensitive to H component of em wave.

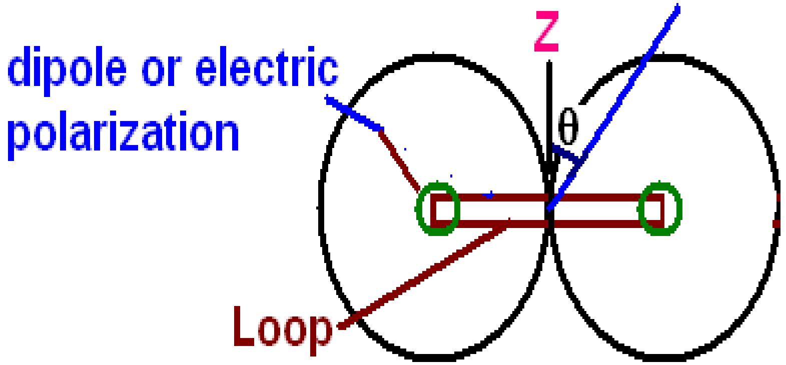
It is less sensitive to near E field noise when properly shielded.

Its received voltage can be increased by bringing the loop into resonance with a tuning capacitor.





With the illustrated orientation $E = E_\phi a_\phi$ only



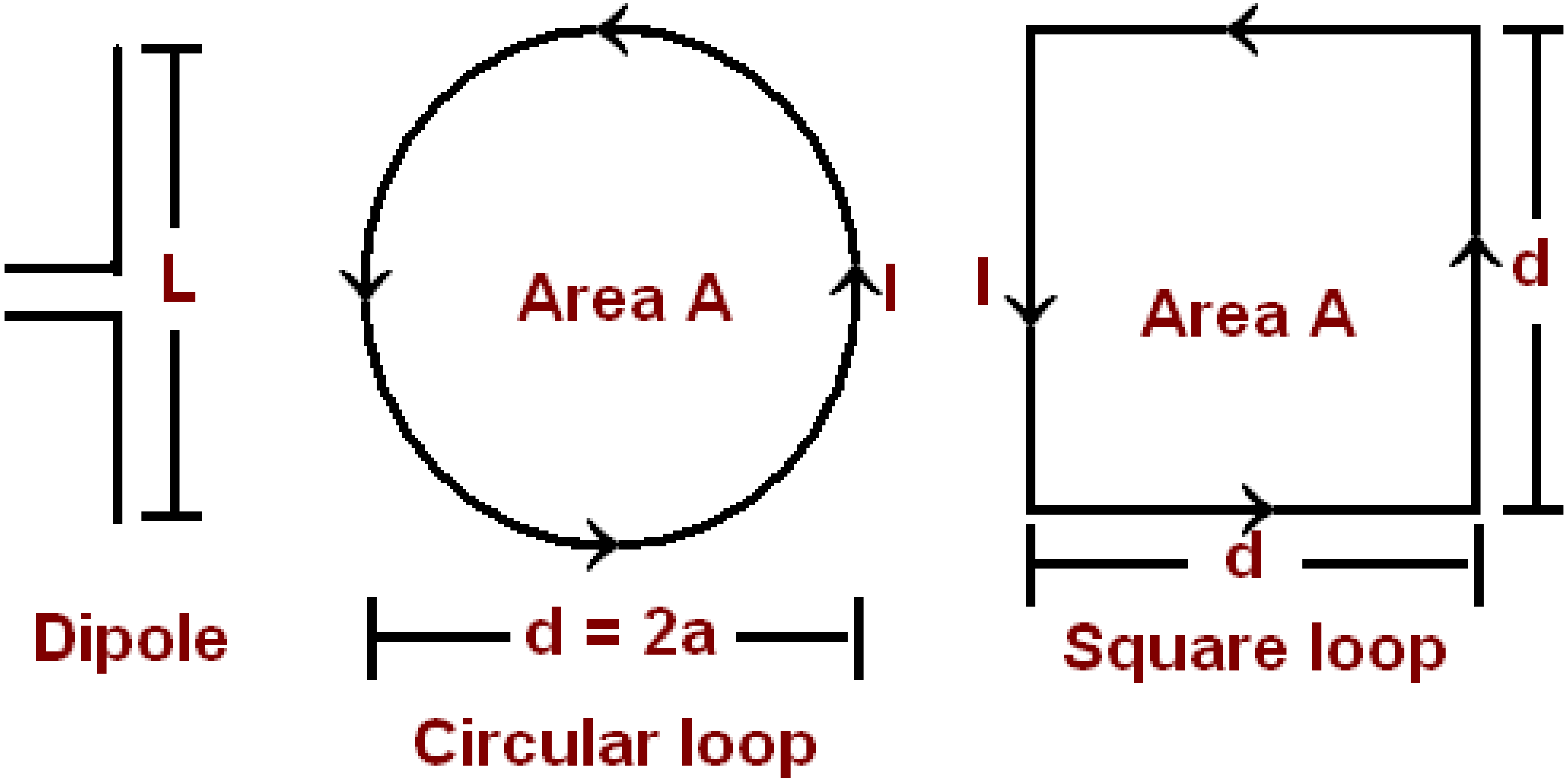
Far field pattern of a small loop and an electric dipole oriented normal to the plane of loop with E & H fields interchanged

	Electric Dipole	Small Loop
Electric Field	$E_\theta = j\ 60\pi\lvert I\rvert\ \{\sin\theta/r\}\ (L/\lambda)$	$E_\phi = 120\pi^2\lvert I\rvert\ \{\sin\theta/r\}\ (A/\lambda^2)N$
Magnetic Field	$H_\phi = j\ \lvert I\rvert\ \{\sin\theta/2r\}\ (L/\lambda)$	$H_\theta = \pi\ \lvert I\rvert\ \{\sin\theta/r\}\ (A/\lambda^2)N$

If |I| is the retarded current, N is the number of turns and other parameters shown in figure far field expressions given in table are obtained.

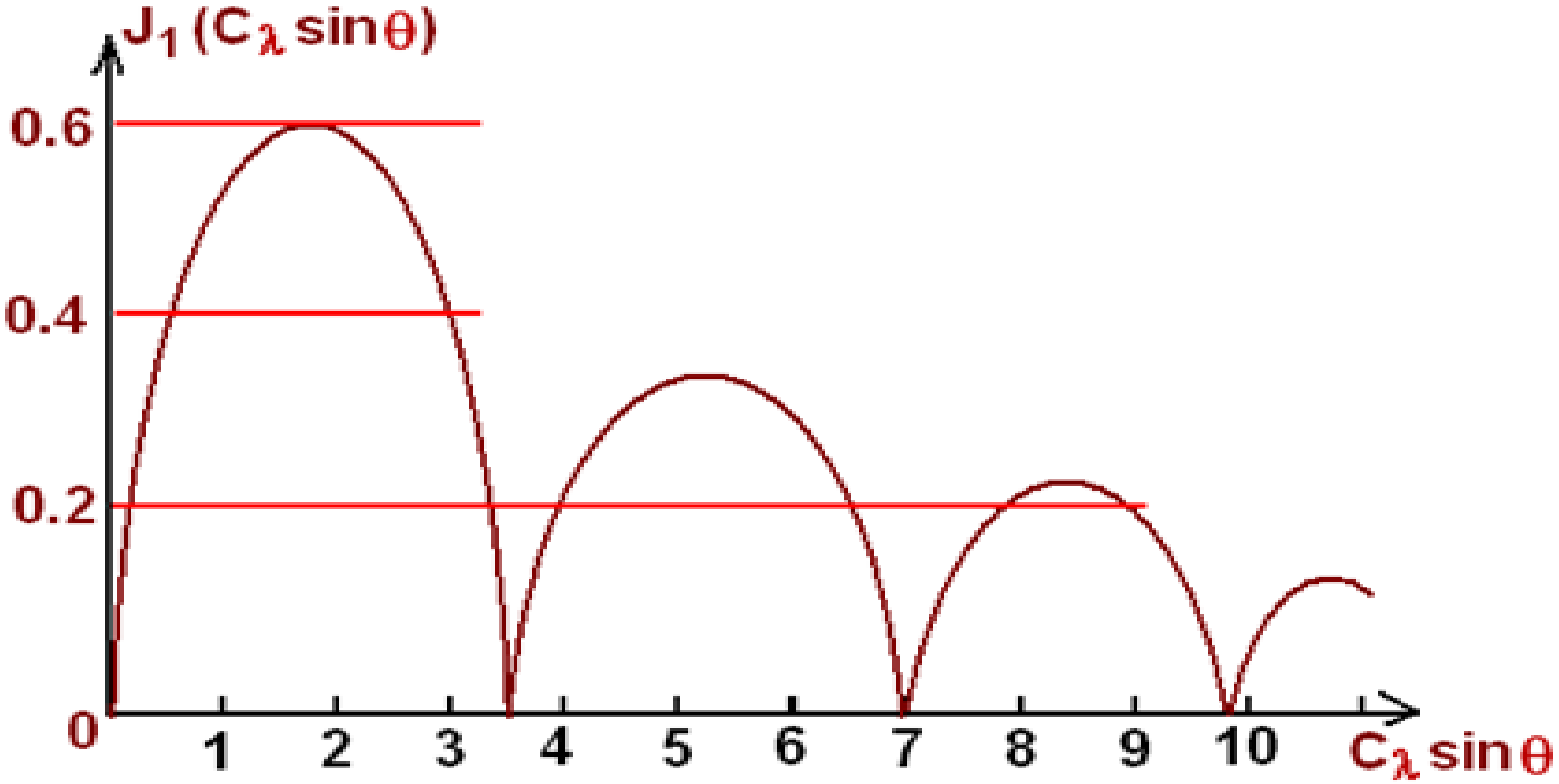
Given mathematical relations apply for orientation shown and for vanishingly small diploes and circular loops.

These equations are valid for any arbitrary loop cross-section if current is uniform and loop dia is small ($a < \lambda/6$) and for dipole ($L < \lambda/10$)

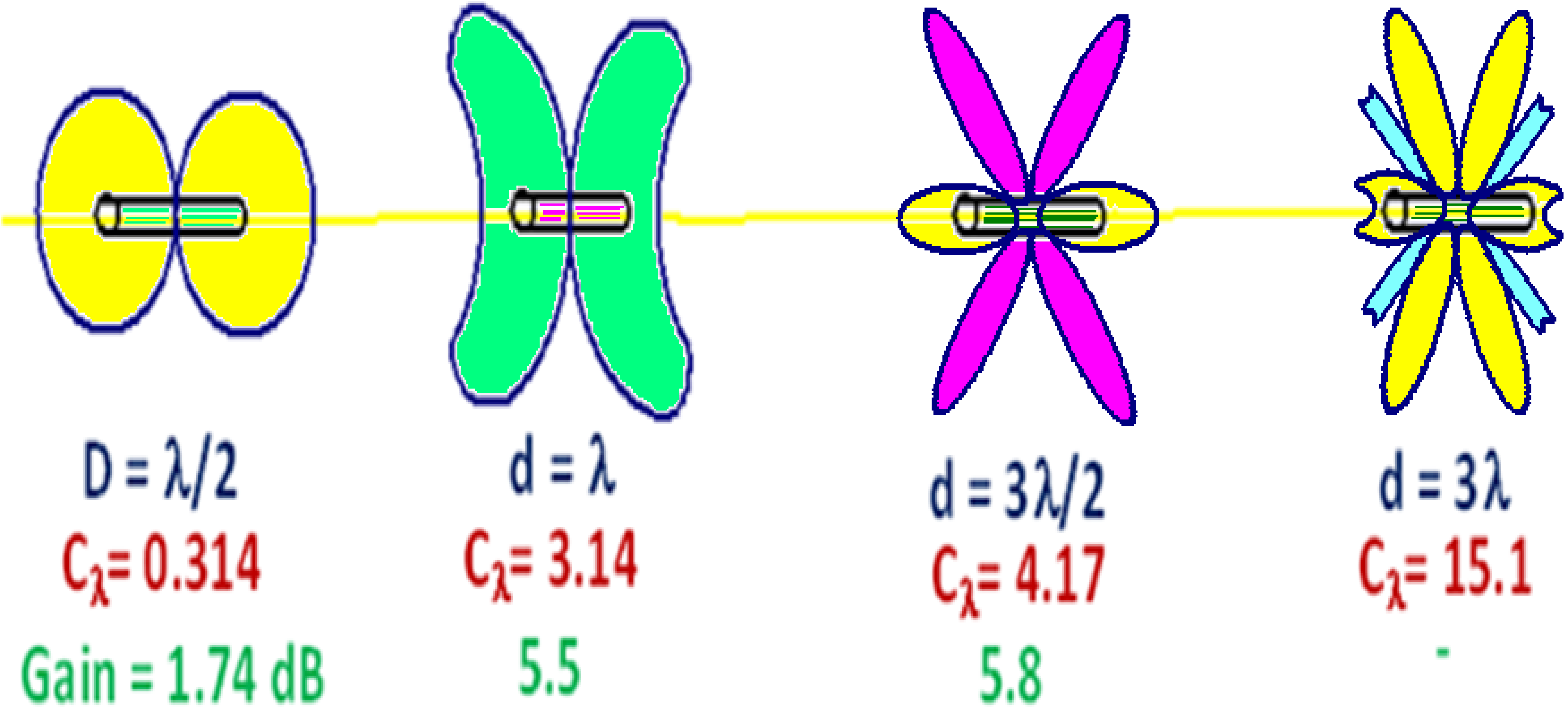


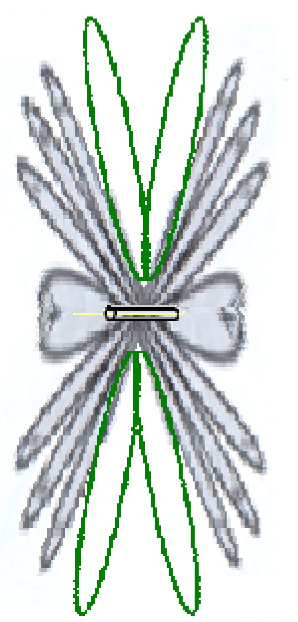
$$\boxed{\text{For the same area } A = \pi a^2 = d^2}$$

The shape of a far field pattern is given by a function of θ expressed in terms of Bessel's function: $J_1(C_\lambda \sin\theta)$,
where C_λ is the circumference of loop in wavelength. $C_\lambda = 2\pi a/\lambda = \beta a$, $\beta = 2\pi/\lambda$



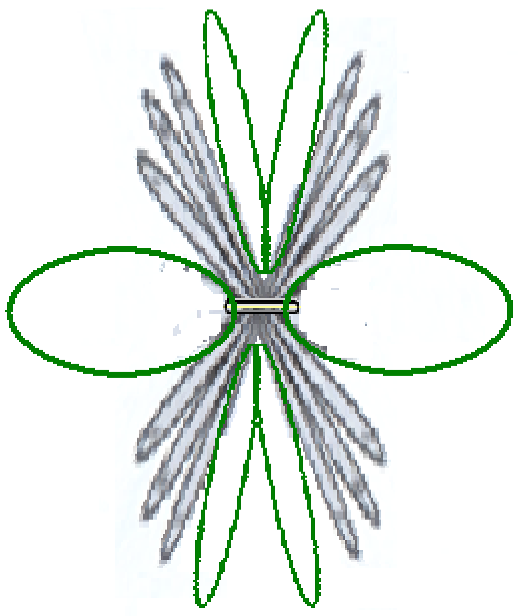
Radiation patterns of loop ant. For different values of diameter d are shown below





$d = 5\lambda$

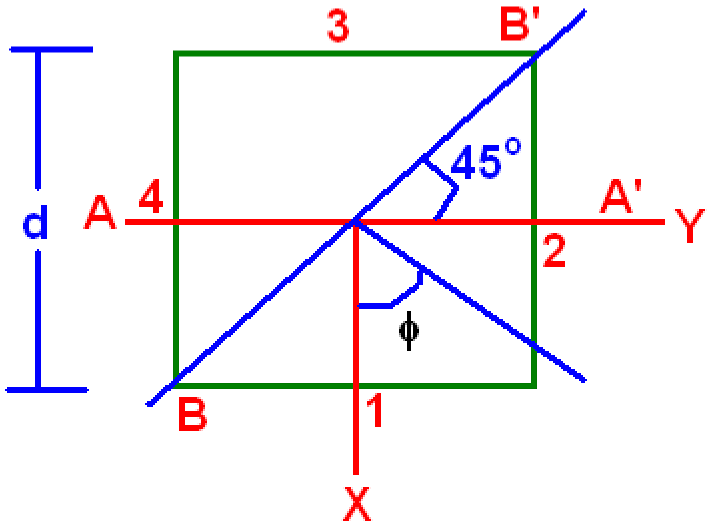
Circular loop



$d = 4.4\lambda$

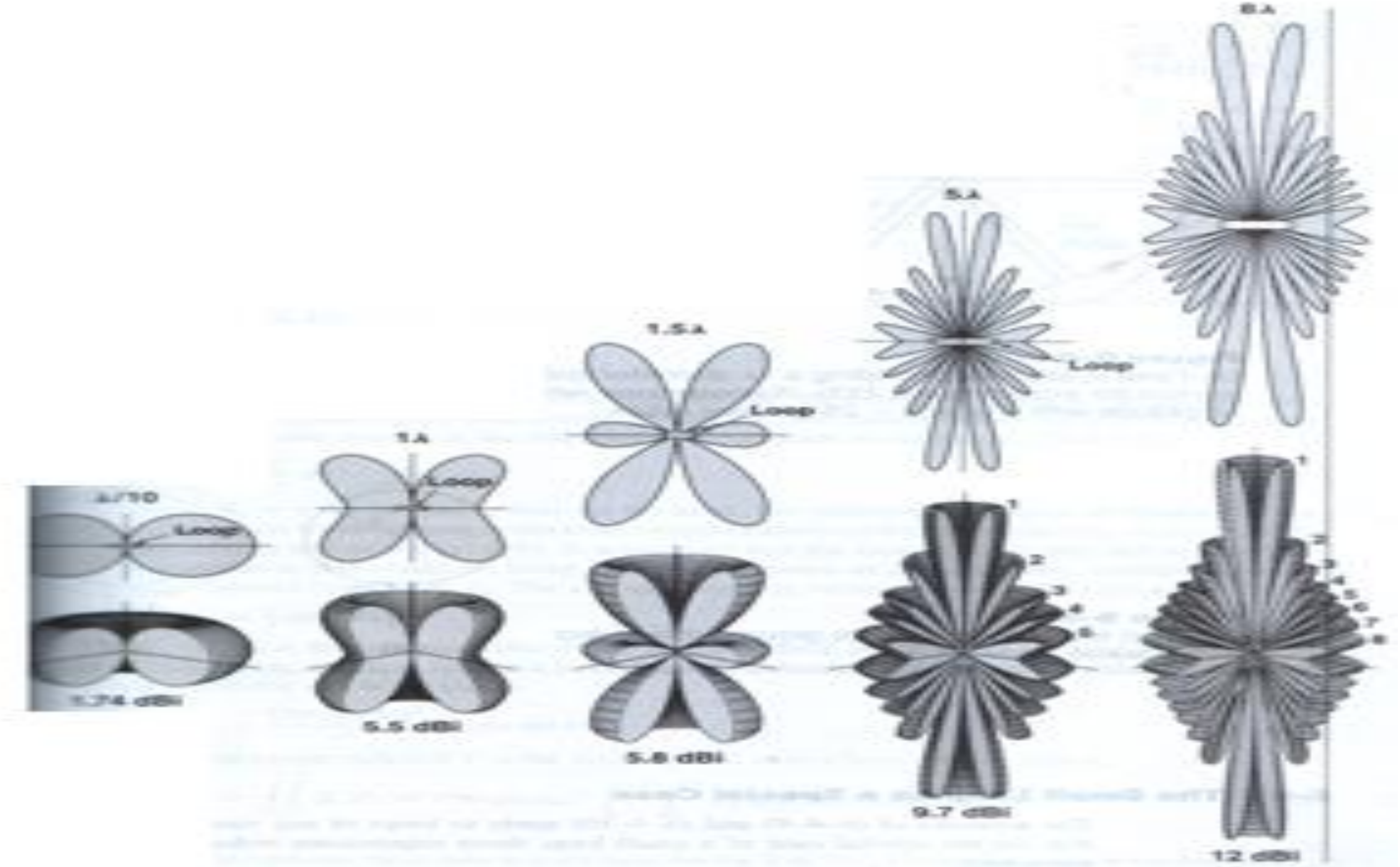
Square loop

A large square loop

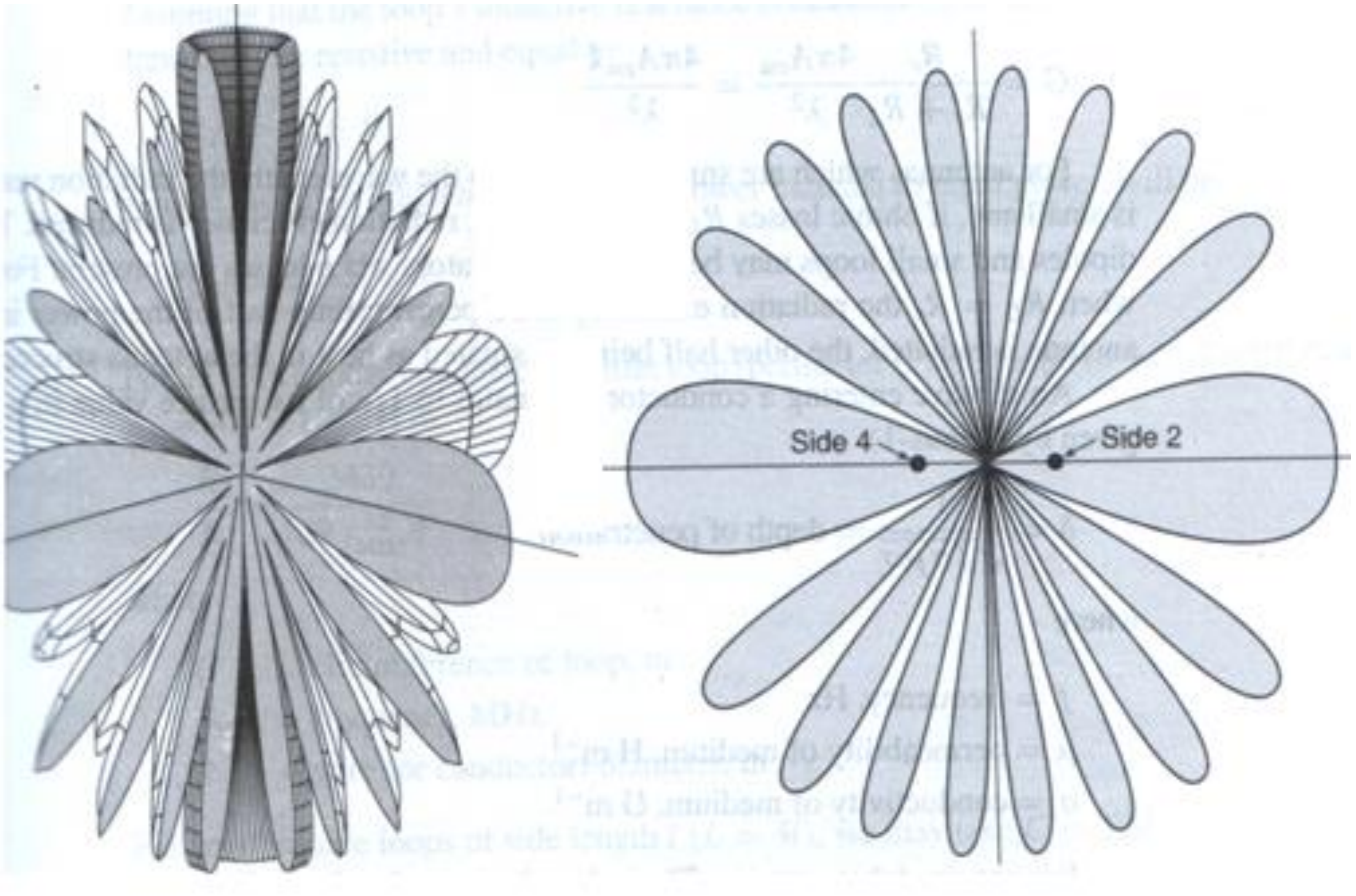


Polar plot for square loop is in a plane perpendicular the plane of loop and throgh line AA'

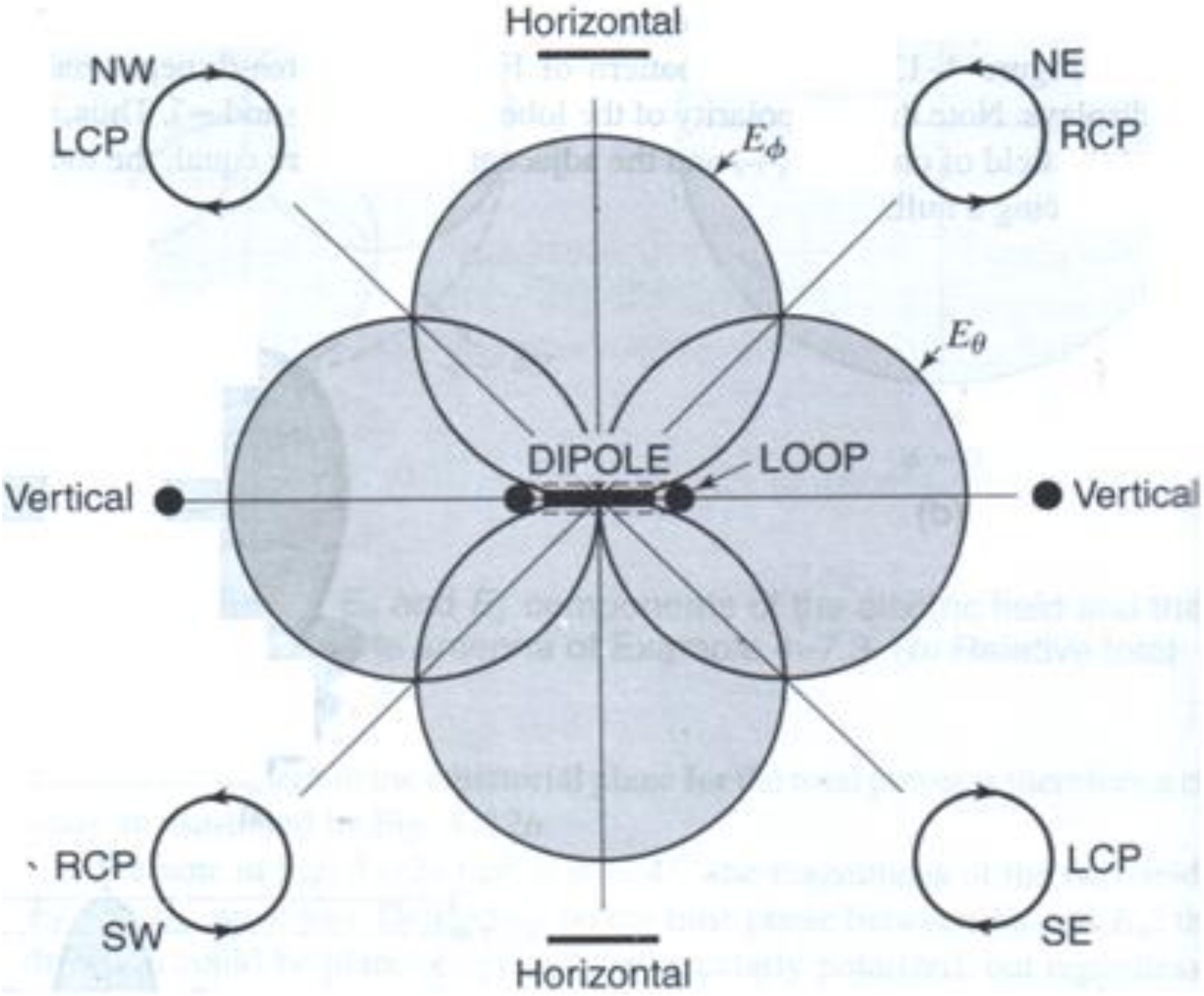
Difference in RPs of large circular and square loops can be observed from above



Circular loops of 0.1, 1, 1.5, 5 and 8 wavelengths diameters



Square loop of 4.44 wavelength side with uniform in phase current


Horizontal
NW
LCP
NE
RCP
E_ϕ
E_θ
DIPOLE
LOOP
Vertical
Vertical
RCP
SW
LCP
SE
Horizontal

Radiation resistance

$R_{rad} = 320\ \pi^4 A^2 N^2 / \lambda^2$ ohms for small air loop

$R_{rad} = 19000\ N^2 (D/\lambda)^4$ ohms for circular loop of dia $D = 2a$

$R_{rad} = 3720\ N (a/\lambda)$ ohms for $C_\lambda = 5$, large loop

In order to be below resonance, the dia of simple loop fed from a simple point must be $< \lambda/2$

If $D = \lambda/10$, $R_{rad} = 1.9$ ohms

$R_{rad} = 320\ N^2 \sin(\pi L/\lambda)$, $L=4d$ = perimeter for square loop whose dimensions are comparable to λ

For d =λ/4, N = 1, R_{rad} = 160$\sqrt{2}$

In radio Rx if N= 50 and D/λ = 10^{-3},

R_{rad} = 50μOhms (actual 47.5μOhms).

This is << Ohmic resistance of the wire.

In this case the loop is feeding a high impedance input and induced voltage is the quantity of great importance.

To increase R_{rad}, D must be increased while current distribution is maintained to be uniform

Directivity D of Circular loop with uniform current distribution is given by:

$$D = 2C_\lambda[\{J_1^2(C_\lambda \sin\theta)\}_{max}] / [\int_0^{2C_\lambda} J_2(y)\,dy]$$

$D = 3/2$ for $C_\lambda \leq 1/3$ and

$D = 0.68\, C_\lambda$ for $C_\lambda \geq 2$

Gain G: G = D, where K is the radiation efficiency

$K = R_r / (R_r + R_L)$

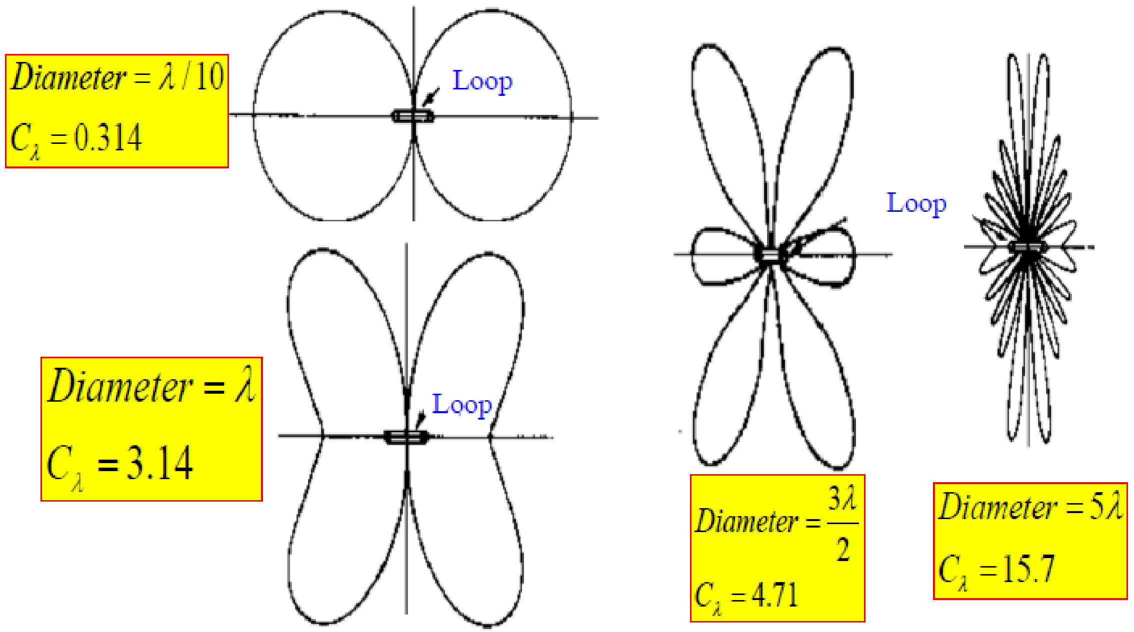
R_r is the radiation resistance and

R_L is the loss resistance

K = 1 for lossless antennaK

Loop antenna radiation pattern

Radiation pattern of circular loop antenna of different diameter assuming uniform current distribution along the loop



Loop antenna radiation resistance

For Single Turn Small Loop Antenna

$$\boxed{R_r = 20\pi^2 \left(\frac{C}{\lambda}\right)^4}$$

where C = 2 π a is circumference of the Loop Antenna

For N turns $\boxed{R_r = 20\pi^2 N^2 \left(\frac{C}{\lambda}\right)^4}$

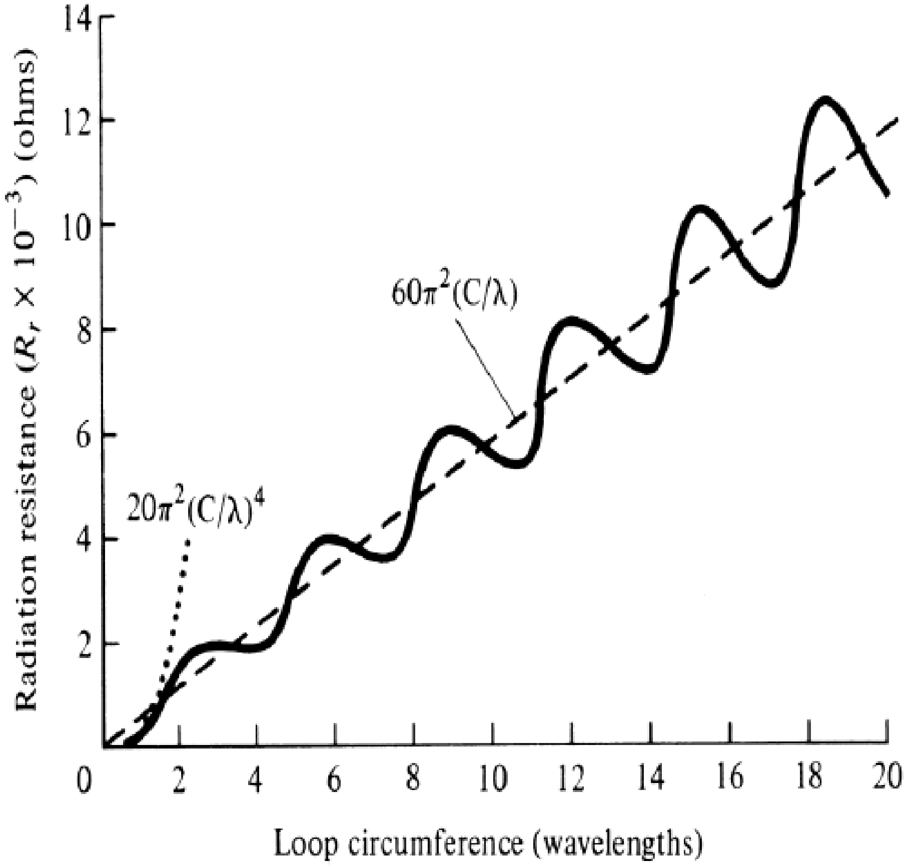
For large loop($C \geq 3.14\lambda$) antenna $\boxed{R_r = 60\pi^2 \left(\frac{C}{\lambda}\right)}$

Example: If $\frac{C}{\lambda} = 0.1 \rightarrow R_r = 20\pi^2 \left(\frac{C}{\lambda}\right)^4 = 20\pi^2 \times (0.1)^4 = 0.02\Omega$(very small)

For N = 50

$R_r = 20\pi^2 N^2 \left(\frac{C}{\lambda}\right)^4 = 20\pi^2 \times (50)^2 x (0.1)^4 = 50\Omega$

Radiation resistance vs loop circumference



Radiation resistance of loop antenna on ferrite

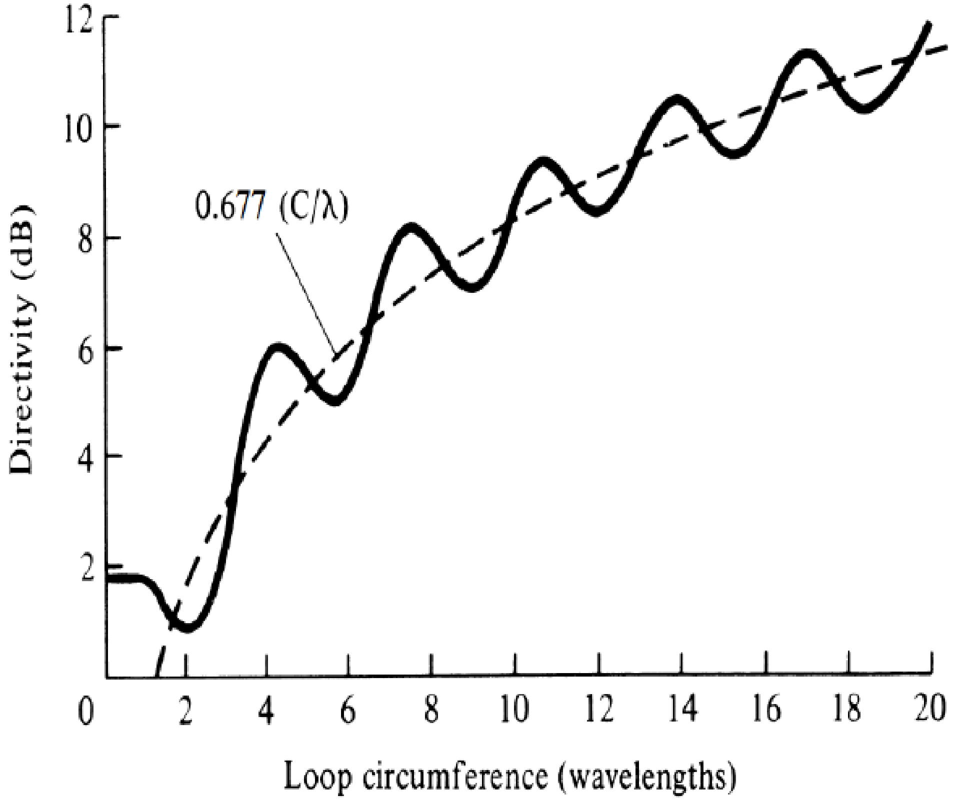
$$R_f = \mu_{cer}{}^2 R_r = \left(\frac{\mu_{ce}}{\mu_0}\right)^2 R_r$$
$$= 20\pi^2 \left(\frac{C}{\lambda}\right)^4 \left(\frac{\mu_{ce}}{\mu_0}\right)^2 N^2$$

Example: A N-turn circular loop antenna has a diameter of 2 cm, and the wire diameter is 1 mm. It is wound on the ferrite core, whose effective permeability is 10. How many turns are required to obtain R_{in} = 50 ohm at 3MHz.

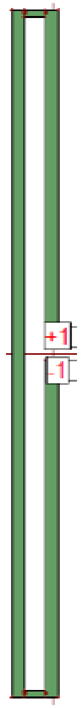
$$N^2 = \frac{R_{in}}{\mu_{cer}{}^2 20\pi^2 \left(\frac{C}{\lambda}\right)^4} = \frac{50}{10^2 20\pi^2 \left(\frac{\pi \text{ x } 2}{10000}\right)^4}$$

$$N = 127485$$

Directivity of circular loop antenna



Folded dipole vs rectangular loop antenna



Z_{in} of Folded Dipole Antenna = 4 x Z_{in} of Dipole Antenna

Connecting Strip Length (mm)	Zin (Ω)	**Resonance Frequency (GHz)**
Dipole Antenna	70.3	1.495
3	286.9	1.405
6	292.6	1.396
10	297 .0	1.381
20	303 .0	1.340

As connecting strip length increases, resonance frequency decreases and input impedance increases because rectangular loop length increases (circumference is approximately equal to λ)

Length of the each segment of dipole = 50mm, width = 2mm, air-gap = 2mm
Length of the folded arm = 102mm, connecting strip width = 1mm

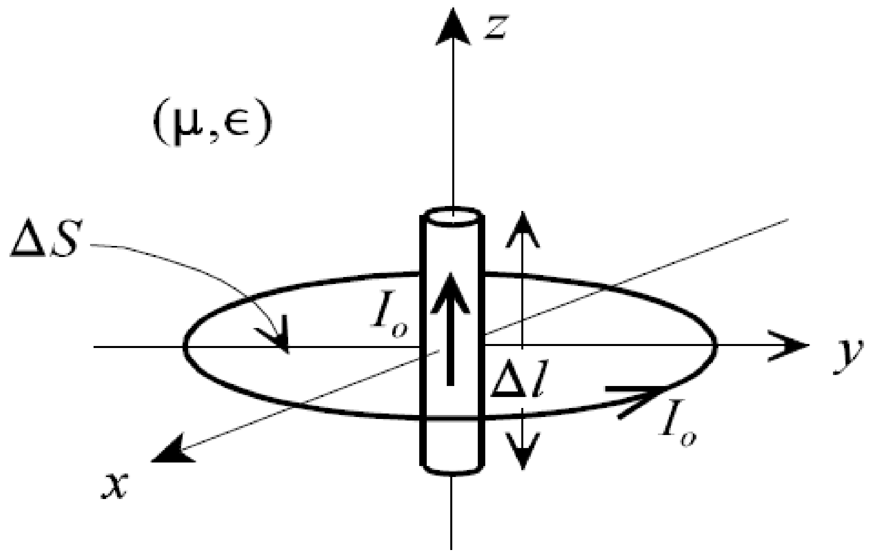
Small loops

Loop antennas are usually classified as either electrically small or electrically large based on the circumference of the loop.

$$\text{electrically small loop} \quad \Rightarrow \quad \text{circumference} \leq \lambda/10$$

$$\text{electrically large loop} \quad \Rightarrow \quad \text{circumference} \approx \lambda$$

Comparing small loop and dipole

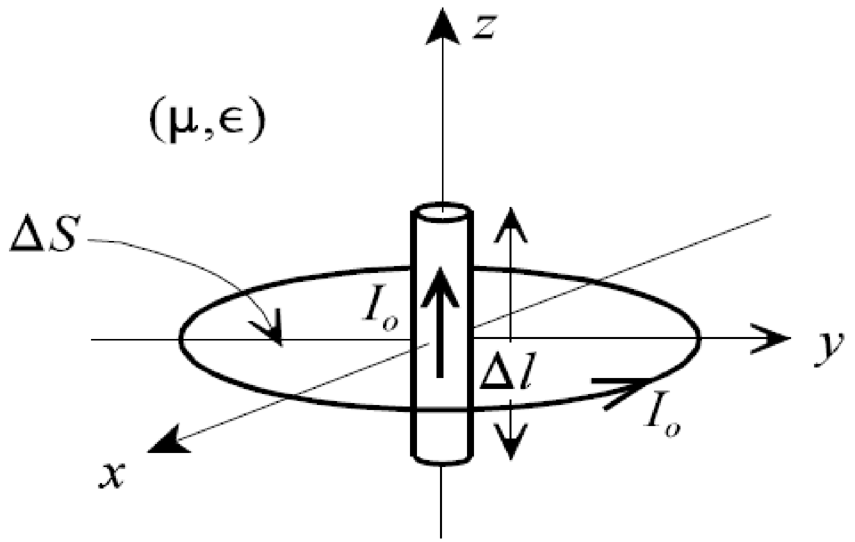


$$E_{loop} = H_{dipole}$$
$$H_{loop} = E_{dipole}$$
(far fields)

Comparing small loop and dipole

The electrically small loop antenna is the dual antenna to the electrically short dipole antenna when oriented as shown. That is,

the far-field electric field of a small loop antenna is identical to the far-field magnetic field of the short dipole antenna and the far-field magnetic field of a small loop antenna is identical to the far-field electric field of the short dipole antenna.



Comparing small loop and dipole

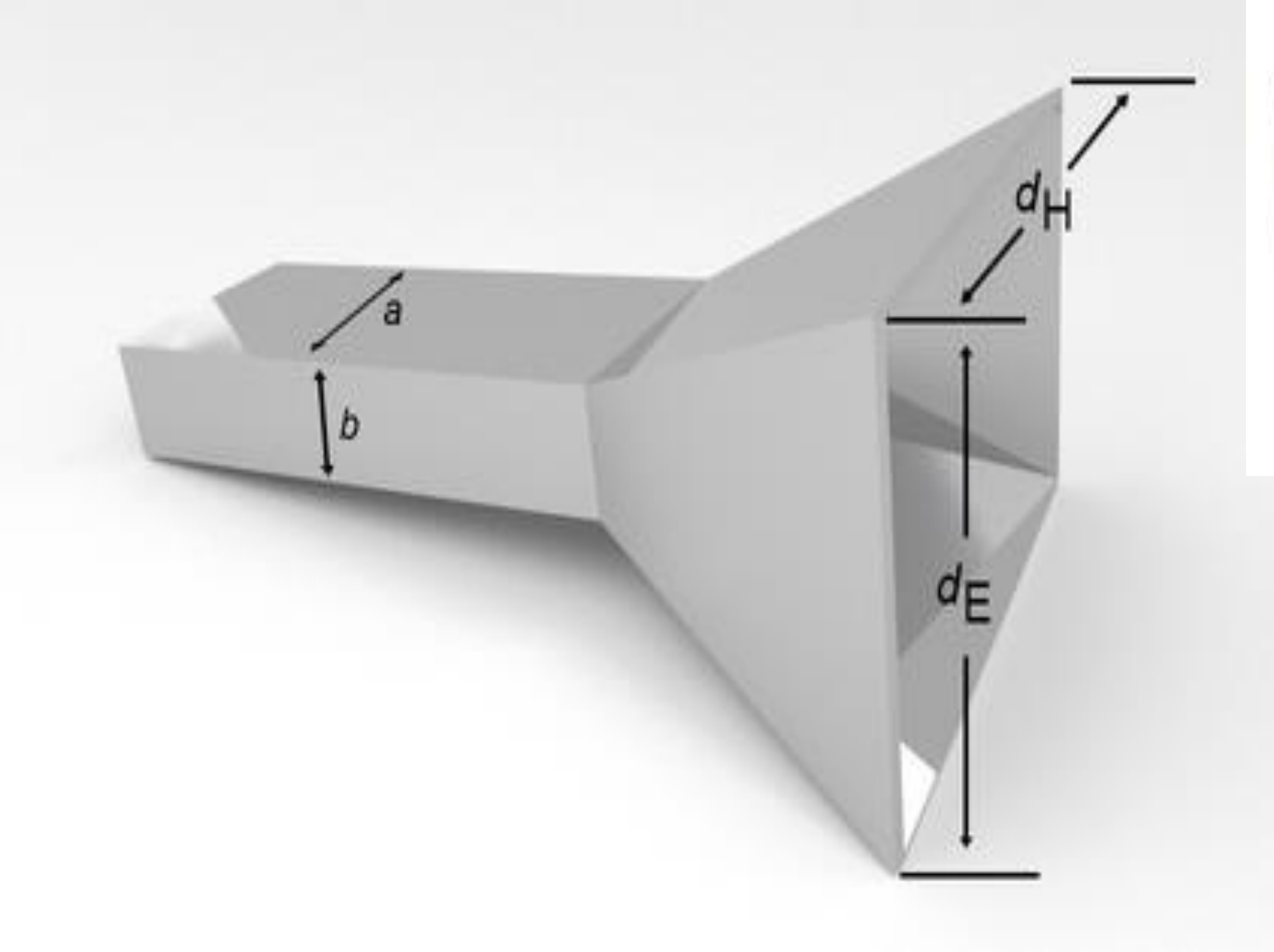
Given that the radiated fields of the short dipole and small loop antennas are dual quantities, the radiated power for both antennas is the same and therefore, the radiation patterns are the same. This means that the plane of maximum radiation for the loop is in the plane of the loop. When operated as a receiving antenna, we know that the short dipole must be oriented such that the electric field is parallel to the wire for maximum response. Using the concept of duality, we find that the small loop must be oriented such that the magnetic field is perpendicular to the loop for maximum response.

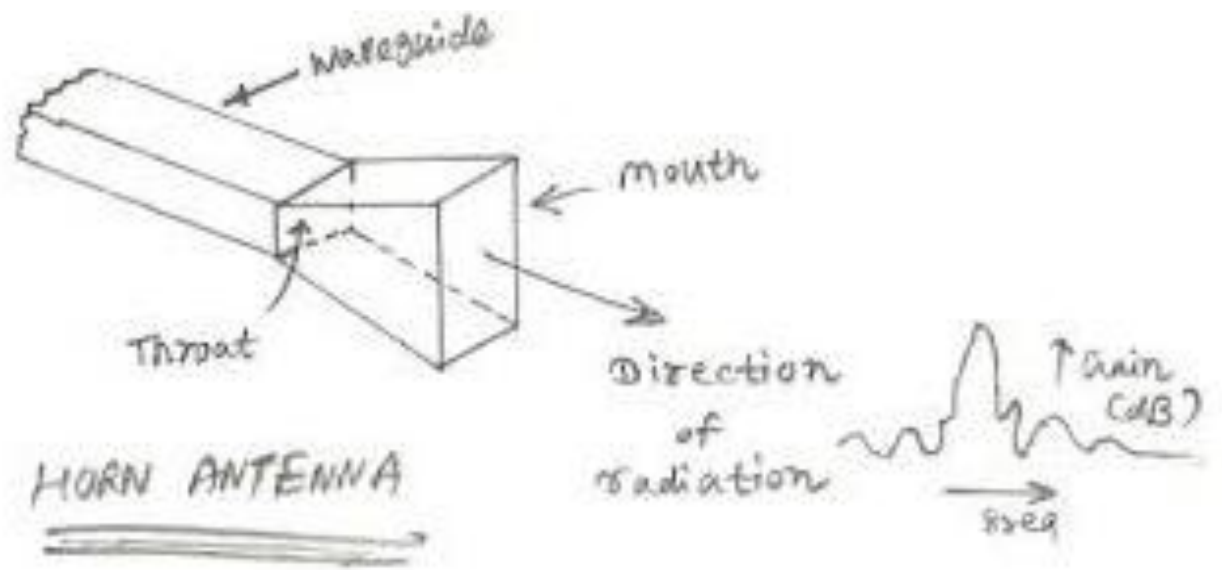
Comparing small loop and dipole

The radiation resistance of the small loop is much smaller than that of the short dipole. The loss resistance of the small loop antenna is

frequently much larger than the radiation resistance. Therefore, the small loop antenna is rarely used as a transmit antenna due to its extremely small radiation efficiency. However, the small loop antenna is acceptable as a receive antenna since signal-to-noise ratio is the driving factor, not antenna efficiency. The fact that a significant portion of the received signal is lost to heat is not of consequence as long as the antenna provides a large enough signal-to-noise ratio for the given receiver. Small loop antennas are frequently used for receiving applications such as pagers, low frequency portable radios, and direction finding. Small loops can also be used at higher frequencies as field probes providing a voltage at the loop terminals which is proportional to the field passing through the loop.

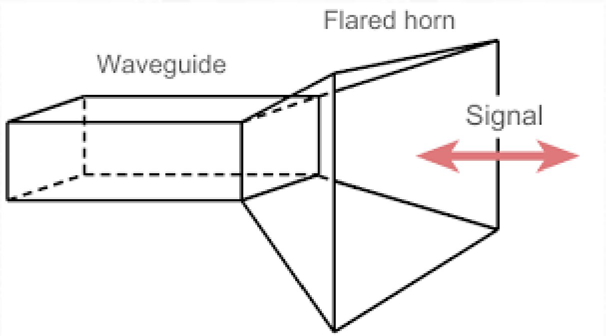
HORN ANTENNA





What Is Horn Antenna?

- A **Horn Antenna** or microwave **Horn** is an **antenna** that consists of a flaring metal waveguide shaped like a **Horn** to direct radio waves in a beam.
- **Horns** are widely used as **antennas** at UHF and microwave frequencies, above 300 MHz
- A Horn Antenna is used to transmit radio waves from a waveguide(a metal pipe used to carry radio waves) out into space, or collect radio waves into waveguide for reception.
- Extension of waveguide in form of horn is called Horn Antenna.



- To improve the radiation efficiency and directivity of the beam, the wave guide should be provided with an extended aperture to make the abrupt discontinuity of the wave into a gradual transformation. So that all the energy in the forward direction gets radiated. This can be termed as **Flaring**. Now, this can be done using a horn antenna.

Frequency Range

The operational frequency range of a horn antenna is around **300MHz to 30GHz**. This antenna works in **UHF** and **SHF** frequency ranges.

Construction & Working of Horn Antenna

The energy of the beam when slowly transform into radiation, the losses are reduced and the focussing of the beam improves. A **Horn antenna** may be considered as a **flared out wave guide**, by which the directivity is improved and the diffraction is reduced.

There are several horn configurations out of which, three configurations are most commonly used.

(1) Sectoral horn

This type of horn antenna, flares out in only one direction. Flaring in the direction of Electric vector produces the **sectorial E-plane horn**. Similarly, flaring in the direction of Magnetic vector, produces the **sectorial H-plane horn**.

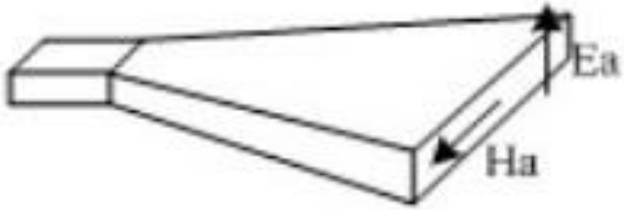
(2) Pyramidal horn

This type of horn antenna has flaring on both sides. If flaring is done on both the E & H walls of a rectangular waveguide, then **pyramidal horn antenna** is produced. This antenna has the shape of a truncated pyramid.

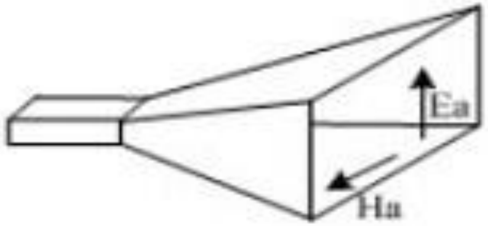
(3) Conical horn

When the walls of a circular wave guide are flared, it is known as a **conical horn**. This is a logical termination of a circular wave guide.

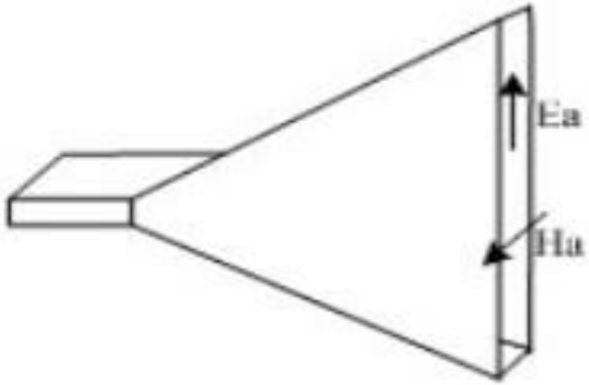
DIFFERENT TYPES OF HORN ANTENNA



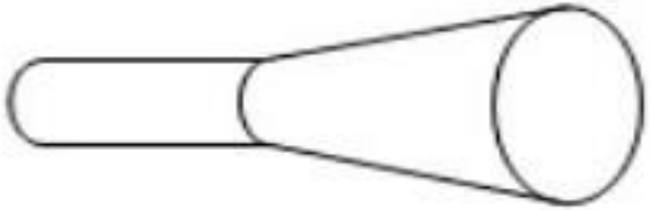
H-plane sectoral horn



Pyramidal horn



E-plane sectoral horn



Conical Horn Antenna

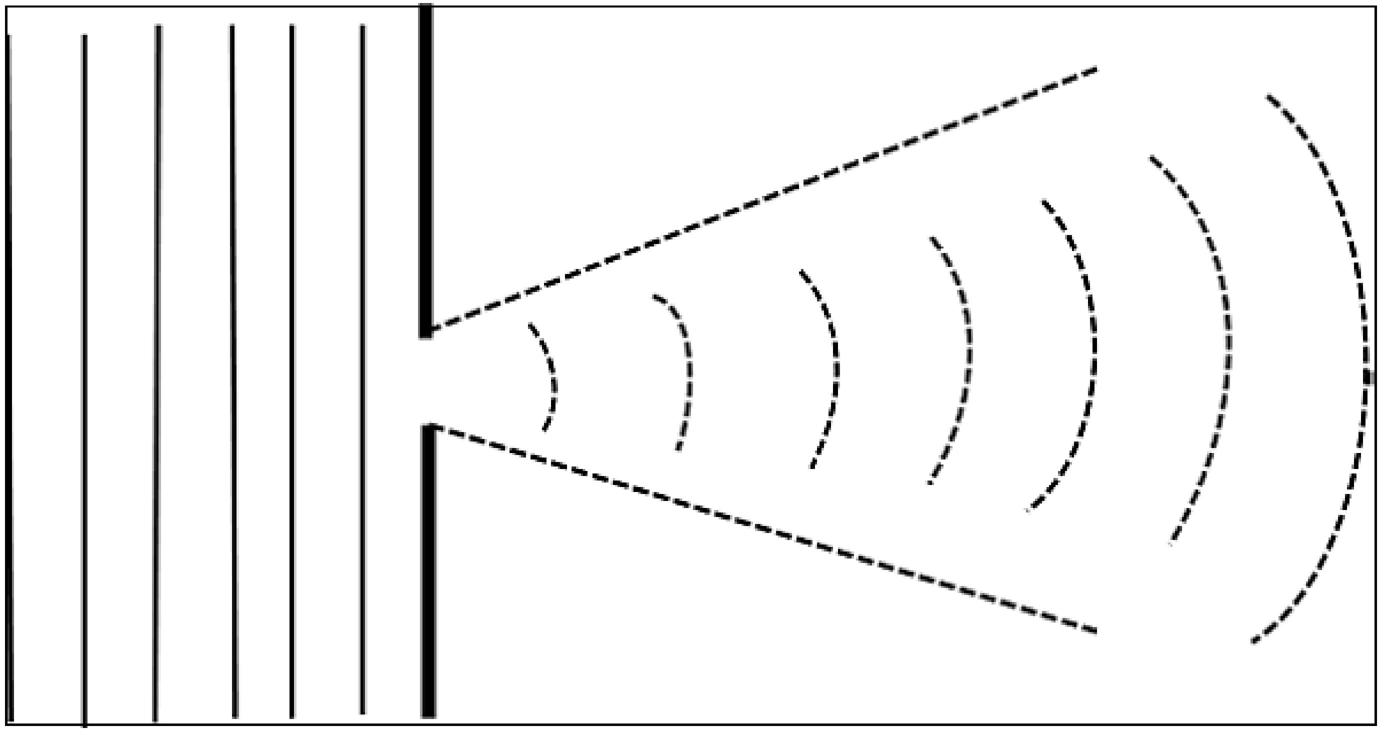
HORN ANTENNA

- **FLARING HELPS TO MATCH THE ANTENNA IMPEDANCE WITH THE FREE SPACE IMPEDANCE FOR BETTER RADIATION. IT AVOIDS STANDING WAVE RATIO AND PROVIDES GREATER DIRECTIVITY AND NARROWER BEAM WIDTH. THE FLARED WAVE GUIDE CAN BE TECHNICALLY TERMED AS <u>ELECTROMAGNETIC HORN RADIATOR.</u>**

- **FLARE ANGLE, Φ OF THE HORN ANTENNA IS AN IMPORTANT FACTOR TO BE CONSIDERED. IF THIS IS TOO SMALL, THEN THE RESULTING WAVE WILL BE SPHERICAL INSTEAD OF PLANE AND THE RADIATED BEAM WILL NOT BE DIRECTIVE. HENCE, THE FLARE ANGLE SHOULD HAVE AN OPTIMUM VALUE AND IS CLOSELY RELATED TO ITS LENGTH.**

Radiation Pattern

The radiation pattern of a horn antenna is a Spherical Wave front. The following figure shows the **radiation pattern** of horn antenna. The wave radiates from the aperture, minimizing the diffraction of waves. The flaring keeps the beam focussed. The radiated beam has high directivity.



Directivity of Horn antenna

$$D = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi \varepsilon_{ap} A_p}{\lambda^2} \quad \text{—— (1)}$$

Where A_e : Effective aperture

A_p : Physical aperture

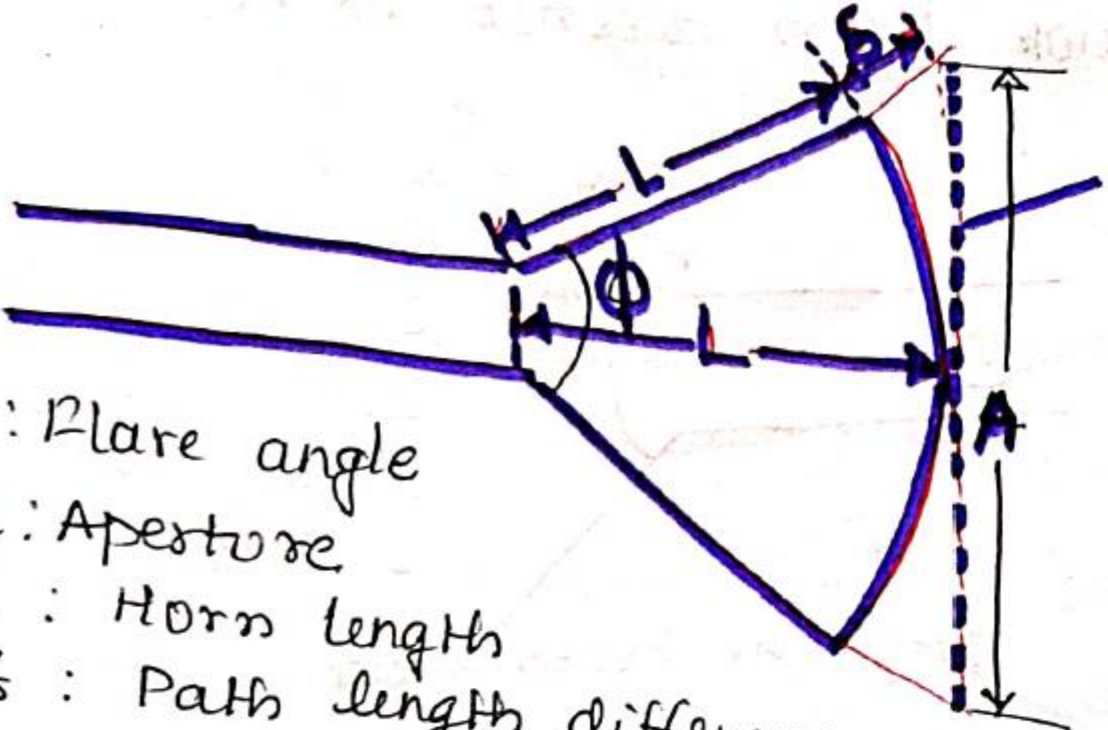
ε_{ap} : Aperture efficiency

λ : Wavelength.

→ For a rectangular horn $A_p = a_E a_H$ & for a conical horn $A_p = \pi r^2$, where r = aperture radius. It is assumed that a_E, a_H or r are all at least 1λ. Taking $\varepsilon_{ap} \simeq 0.6$, equation-(1) becomes

$$D \simeq \frac{7.50 A_p}{\lambda^2}$$

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



ϕ : Flare angle

A : Aperture

L : Horn length

δ : Path length difference.

$$\cos \phi/2 = \frac{L}{L+\delta}$$

$$\sin \phi/2 = \frac{a}{2(L+\delta)}$$

$$\tan \phi/2 = \frac{A}{2L}$$

From geometry, $L = a^2/8\delta$ $[\delta << L]$

$$\phi = 2\tan^{-1}\left(\frac{A}{2L}\right) = 2\cos^{-1}\left(\frac{L}{L+\delta}\right)$$

Applying Pythogorus theorem, we get

$$(L)^2 + (A/2)^2 = (L+\delta)^2$$

$$\cancel{L^2} + \frac{A^2}{4} = \cancel{L^2} + \delta^2 + 2L\delta \qquad \delta \text{ is very small } \delta \simeq 0$$

$$\frac{A^2}{4} = 2L\delta$$

$$\therefore \boxed{\frac{A^2}{8\delta} = L} \qquad D \simeq \frac{7.5\,A}{\lambda^2}$$

→ In the E plane of the horn, δ is usually held to 0.25λ or less, for H-plane δ can be larger or about 0.4λ.

→ The Optimum horn antenna are given by

$$\delta_0 = \frac{L}{\cos(\theta/2)} - L \quad = \text{Optimum } \delta$$

$$L = \frac{\delta_0 \cos\theta/2}{1-\cos\theta/2} \quad = \text{Optimum length.}$$

- **<u>Advantages</u>**

The following are the advantages of Horn antenna –

Small minor lobes are formed

Impedance matching is good

Greater directivity

Narrower beam width

Standing waves are avoided

- <u>Disadvantages</u>

The following are the disadvantages of horn antenna –

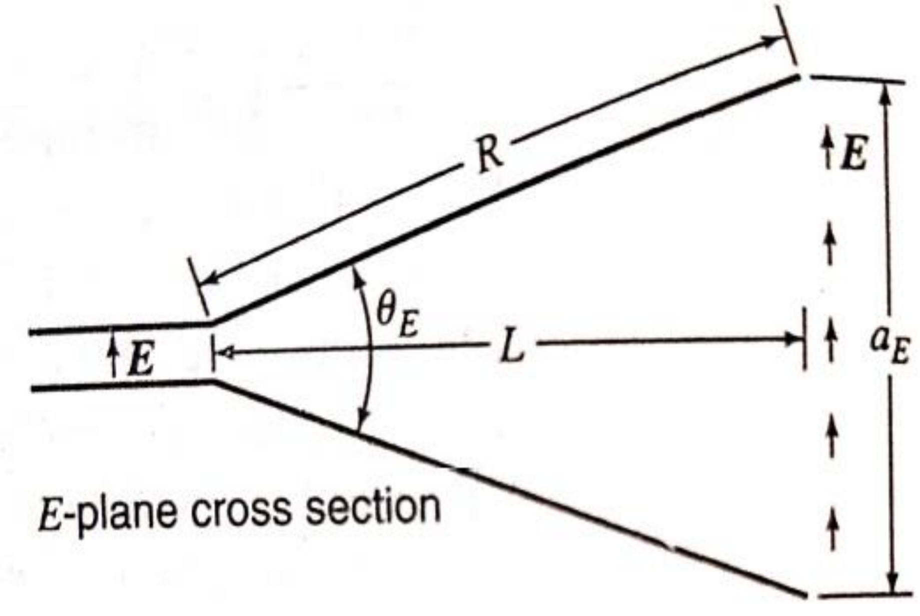
- Designing of flare angle, decides the directivity
- Flare angle and length of the flare should not be very small

Applications of horn antenna

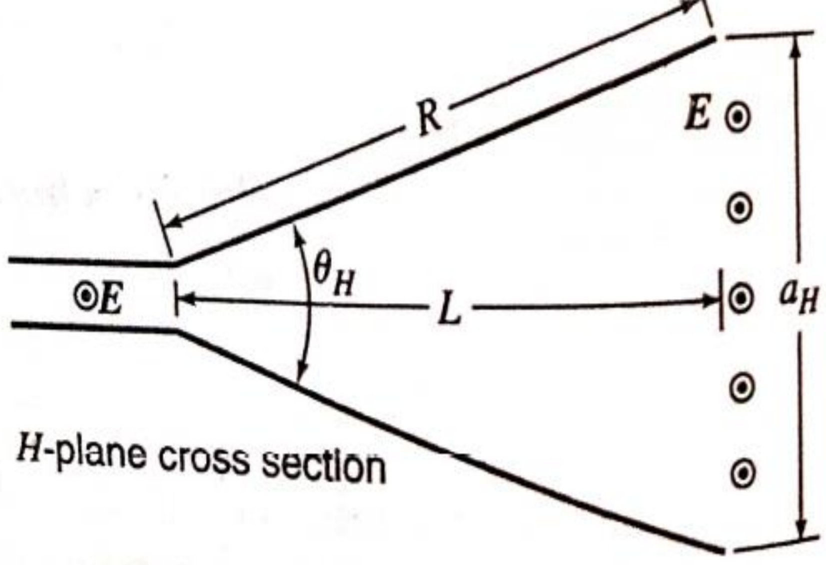
THE FOLLOWING ARE THE APPLICATIONS OF HORN ANTENNA –

1. USED FOR ASTRONOMICAL STUDIES
2. USED IN MICROWAVE APPLICATIONS

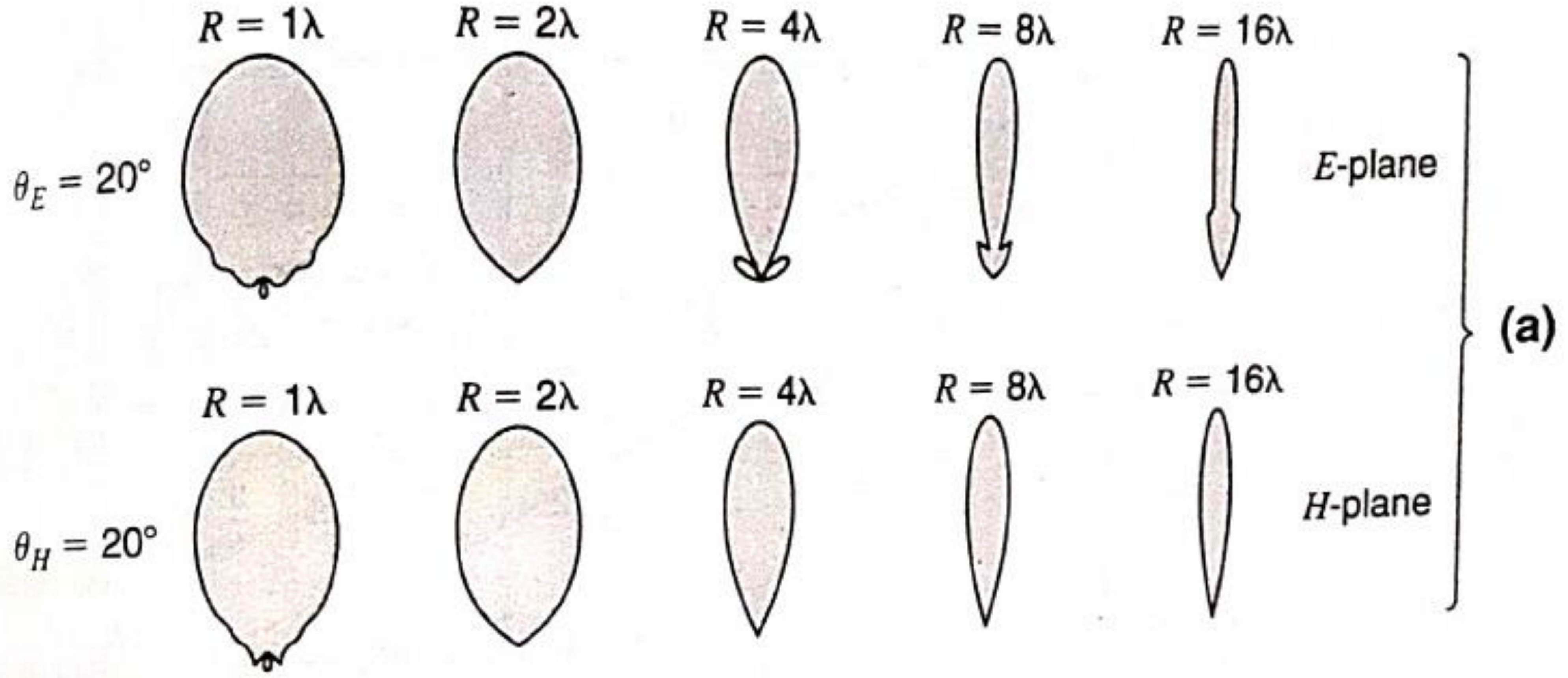
Rectangular Antenna



(a)



(b)



R = 1λ
R = 2λ
R = 4λ
R = 8λ
R = 16λ
θ_E = 20°
E-plane
(a)
R = 1λ
R = 2λ
R = 4λ
R = 8λ
R = 16λ
θ_H = 20°
H-plane

Helical Antenna

A helical antenna is an antenna consisting of one or more conducting wires wound in the form of a helix. The frequency range of operation of helical antenna is around 30MHz to 3GHz. This antenna works in VHF and UHF ranges.

- **Helical antenna** or helix antenna is the antenna in which the conducting wire is wound in helical shape and connected to the ground plate with a feeder line.

- It consists of a helix of thick copper wire or tubing wound in the shape of a screw thread used as an antenna in conjunction with a flat metal plate called a ground plate. One end of the helix is connected to the center conductor of the cable and the outer conductor is connected to the ground plate.

- It is the simplest antenna, which provides **circularly polarized waves**. It is used in extra-terrestrial communications in which satellite relays etc., are involved.

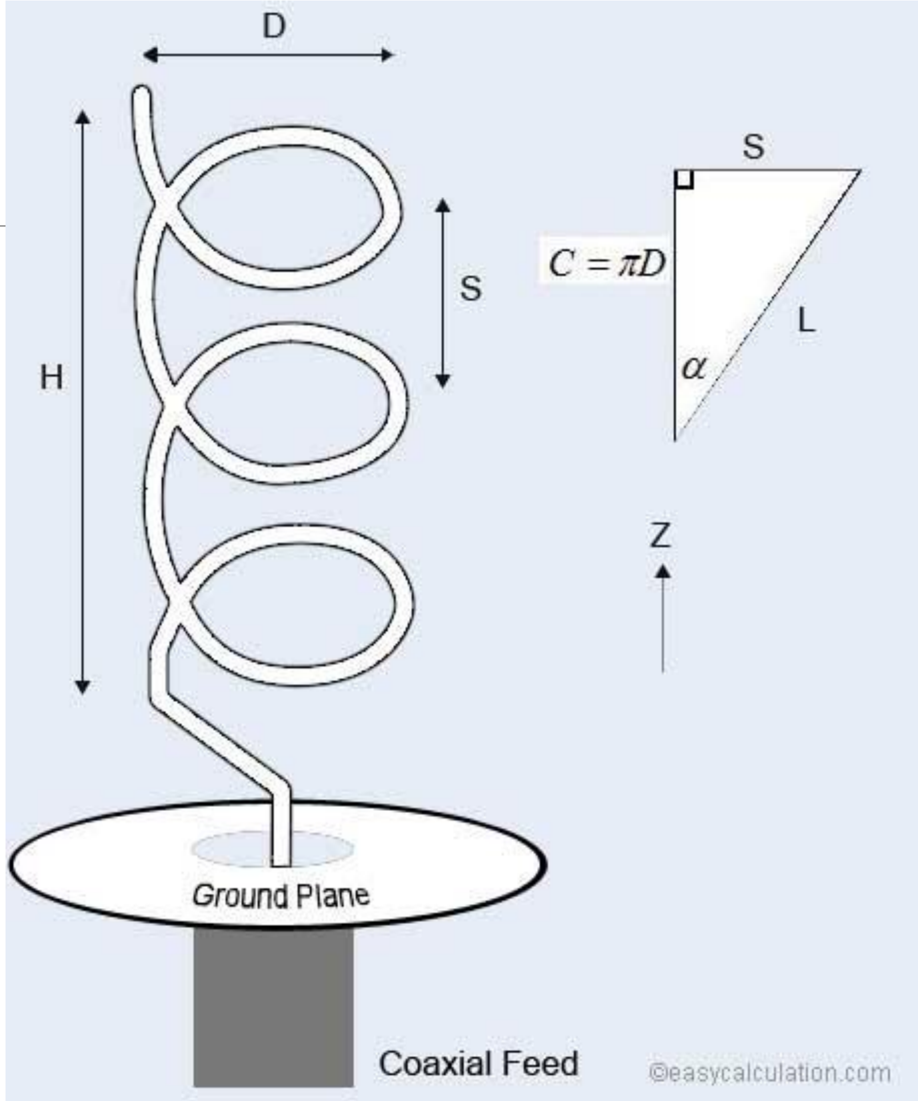
- The radiation of helical antenna depends on the diameter of helix, the turn spacing and the pitch angle.

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

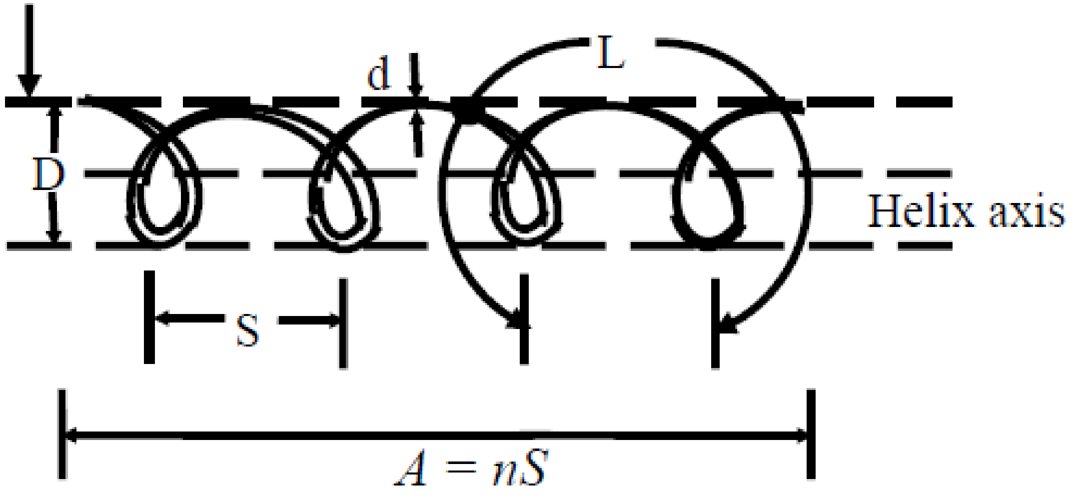
D is the **diameter** of helix.

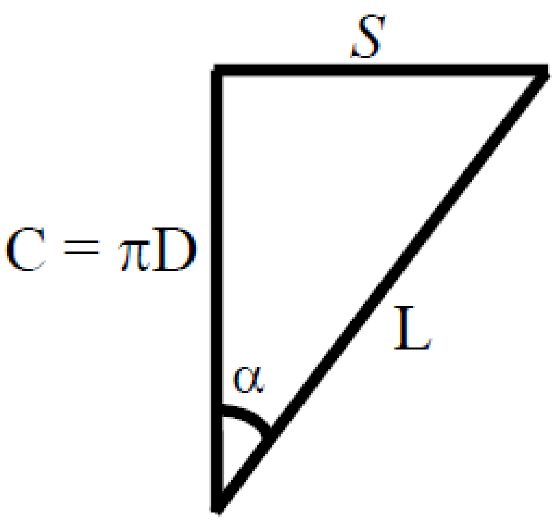
S is the **turn spacing** (centre to centre).

α is the **pitch angle**.



Helical Antenna





Total Length of wire = nL

Total axial length (A) = nS

$$L = \sqrt{S^2 + C^2}$$

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

Special Cases of Helical Antenna:

Case 1: $\alpha = 0°$ $\Rightarrow$ S = 0 $\Rightarrow$ Loop Antenna

Case 2: $\alpha = 90°$ $\Rightarrow$ D = 0 $\Rightarrow$ Linear Antenna

The parameters of Helical Antenna

The parameters of the helix antenna are defined below.

D - Diameter of a turn on the helix antenna.

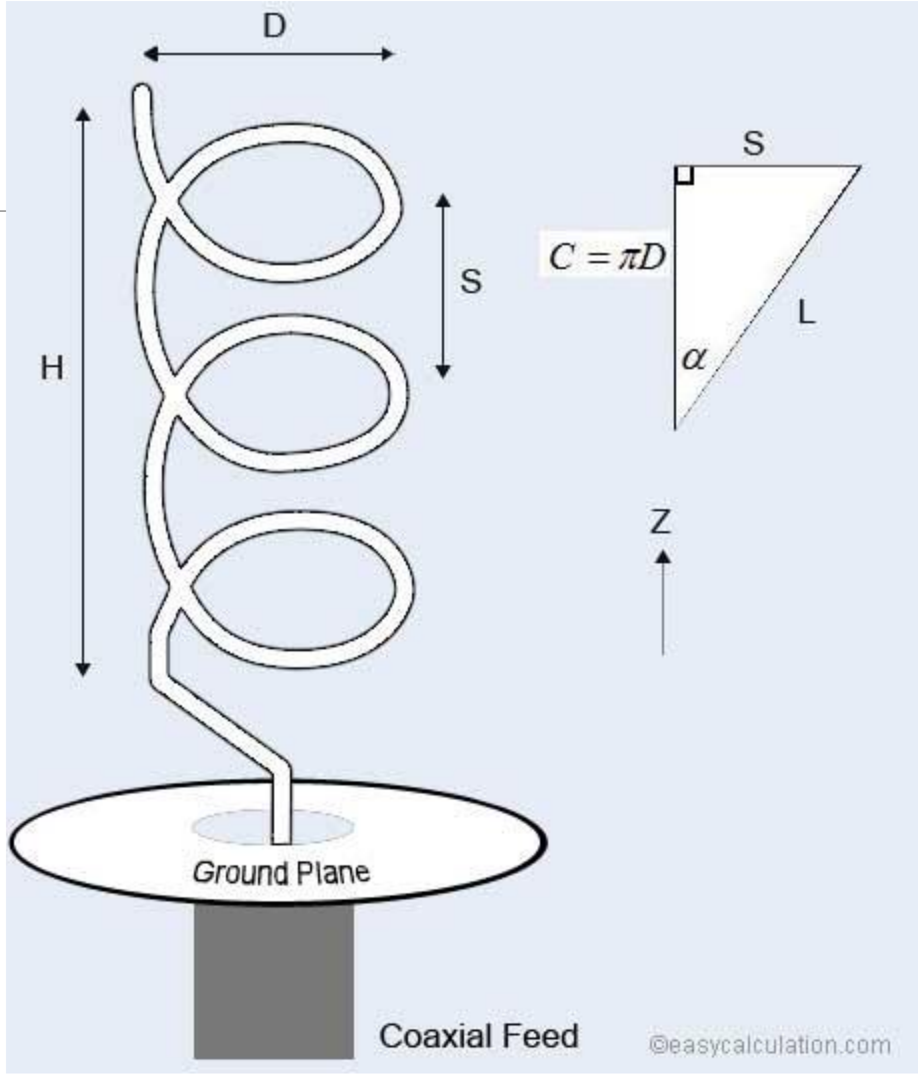
C - Circumference of a turn on the helix antenna (*C*=pi**D*).

S - Vertical separation between turns for helical antenna.

 - pitch angle, which controls how far the helix antenna grows in the z-direction per turn, and is given by

N - Number of turns on the helix antenna.

H - Total height of helix antenna, *H*=*NS*.

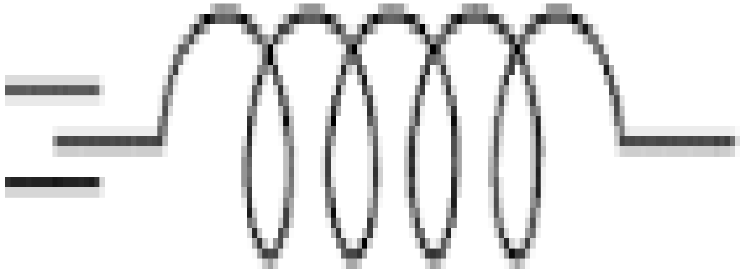


Modes of Operation

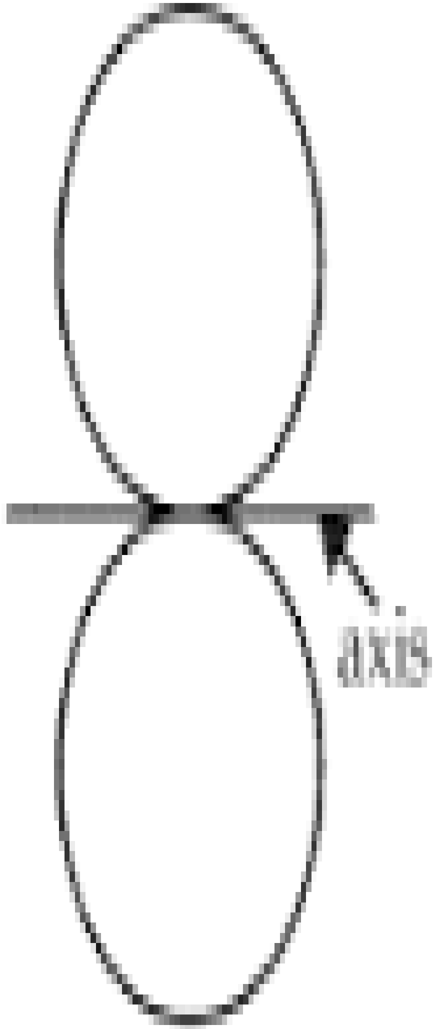
The predominant modes of operation of a helical antenna are −

- **Normal** or perpendicular mode of radiation.
- **Axial** or end-fire or beam mode of radiation.
- **Normal mode:** in normal mode of radiation, the radiation field is **perpendicular** to the helix axis. The radiated waves are circularly polarized. This mode of radiation is obtained if the dimensions of helix are small compared to the wavelength. The radiation pattern of this helical antenna is a combination of short dipole and loop antenna.

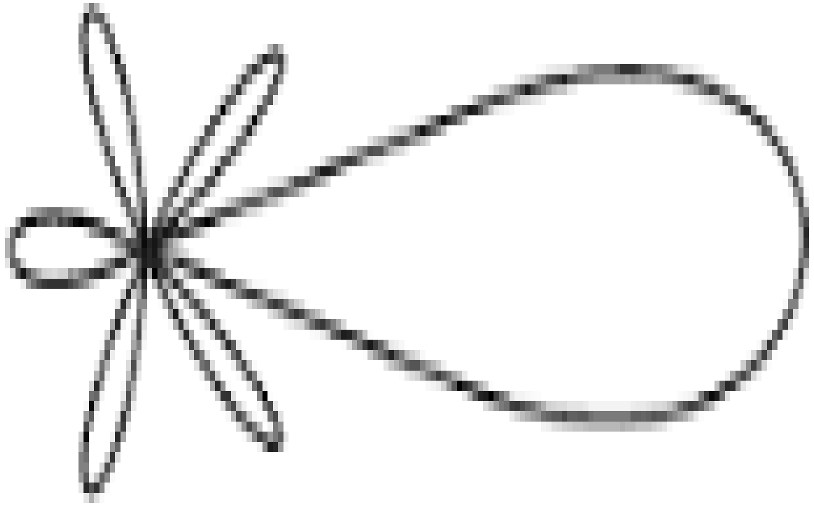
- **Axial mode** of radiation, the radiation is parallel to the direction of axis of helix. This mode of operation is obtained by raising the circumference to the order of one wavelength **(λ)** and spacing of approximately **λ/4**. The radiation pattern is broad and directional along the axial beam producing minor lobes at oblique angles.



(a) Helical antenna



(b) Normal mode



(c) Axial mode

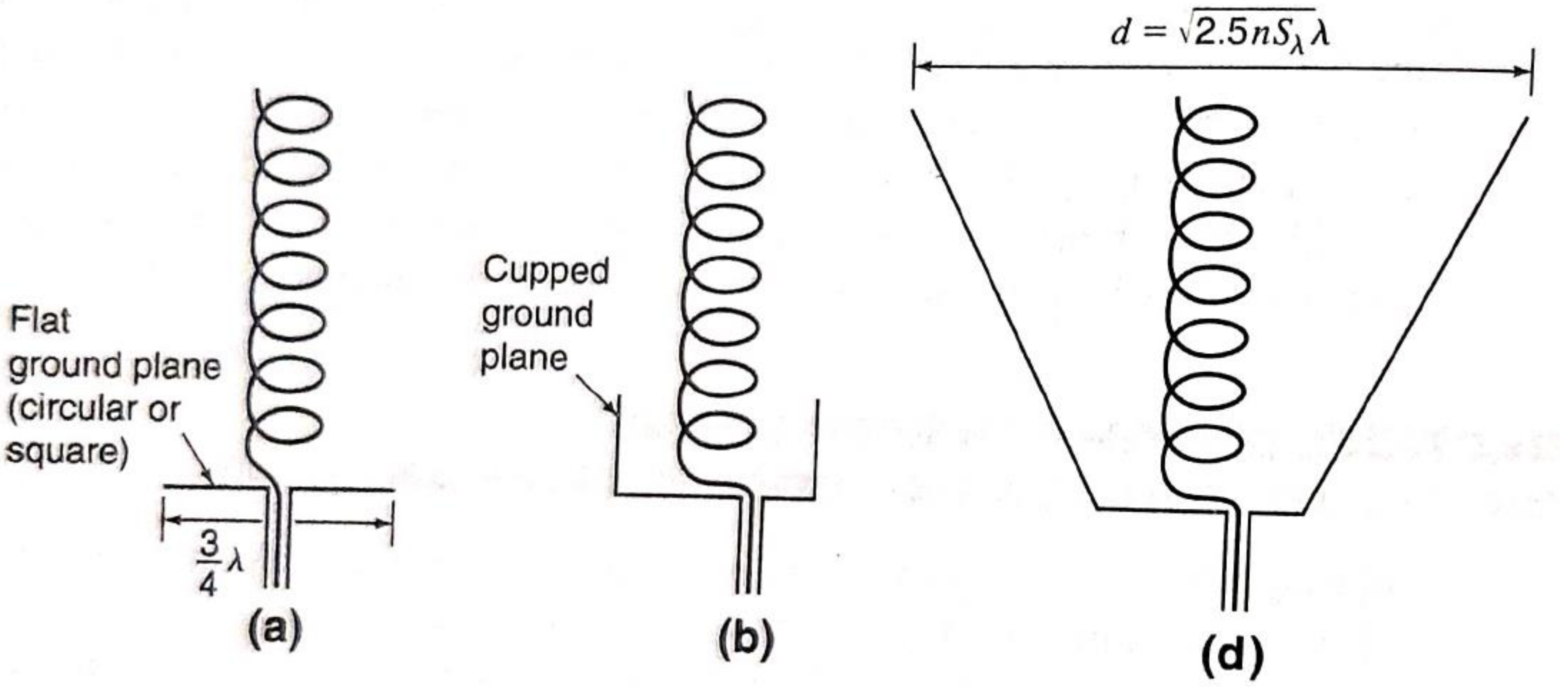
The important parameter which decide the performance are:

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

These parameters are functions of the **number of turns, the turn spacing and frequency.**

These parameters are also functions of the ground plane size and shape, the helical conductor diameter and feed arrangement.

The ground plane may be flat with a diameter or side dimension of at least ¾ lambda or the ground plane may be cup shaped forming a shallow cavity.



$d = \sqrt{2.5 n S_\lambda} \lambda$
Flat
ground plane
(circular or
square)
$\frac{3}{4}\lambda$
(a)
Cupped
ground
plane
(b)
(d)

- **Advantages**

  1.**Simple design**
  2.Highest directivity
  3.Wider bandwidth
  4.Can achieve circular polarization
  5.Can be used at HF & VHF bands

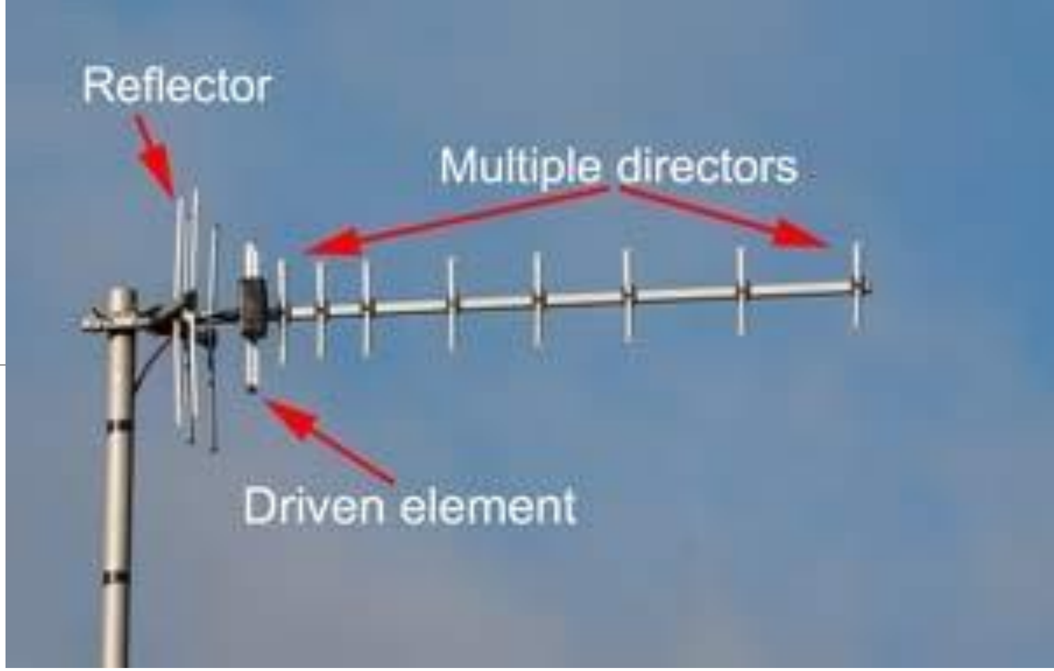
  Disadvantages

  1.Antenna is larger and requires more space
  2. Efficiency decreases with number of turns

  Applications

  1.A single helical antenna or its array is used to transmit and receive VHF signals
  2.Frequently used for satellite and space probe communications
  3.Used for telemetry links with ballastic missiles and satellites at Earth stations
  4.Used to establish communications between the moon and the Earth
  5.Applications in radio astronomy

YAGI-UDA ANTENNA



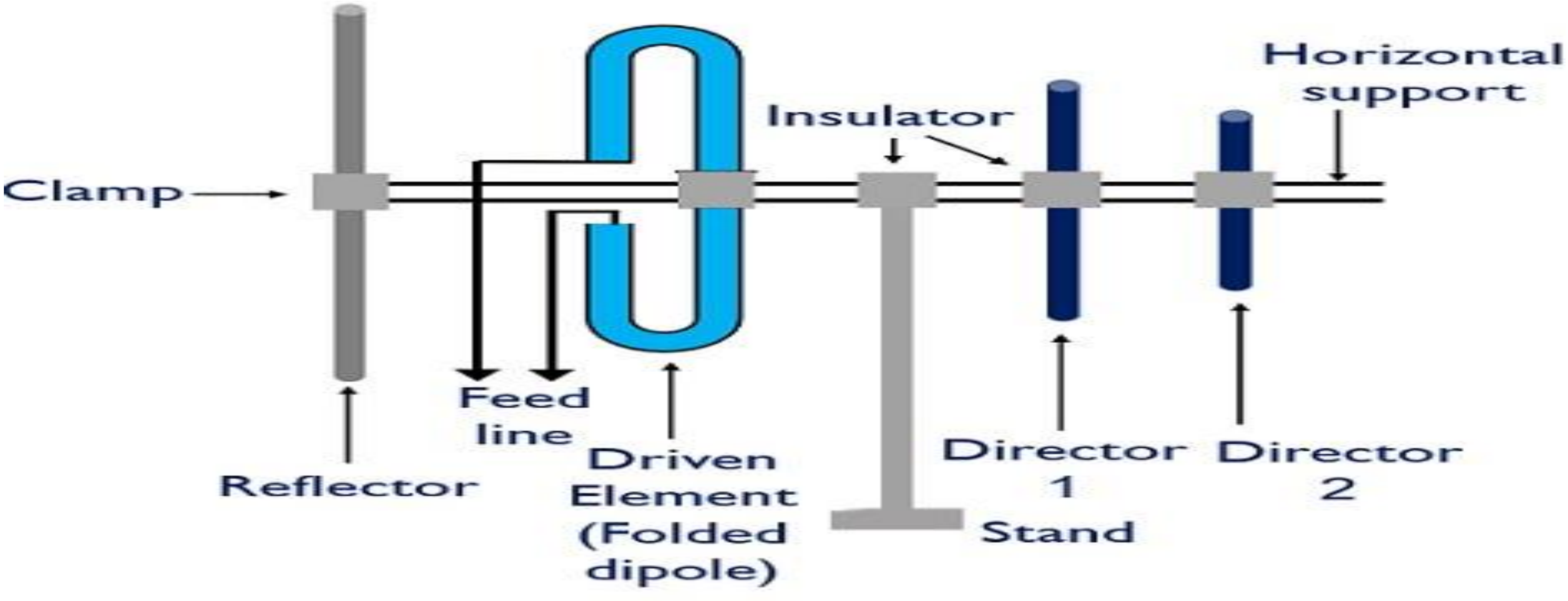
History of Yagi-Uda Antenna

The yagi antenna was invented in japan, with results first published in 1926. The work was originally done by shintaro uda, but published in japanese. The work was presented for the first time in english by yagi (who was either uda's professor or colleague, my sources are conflicting), who went to america and gave the first english talks on the antenna, which led to its widespread use. Hence, even though the antenna is often called a yagi antenna, Uda probably invented it.

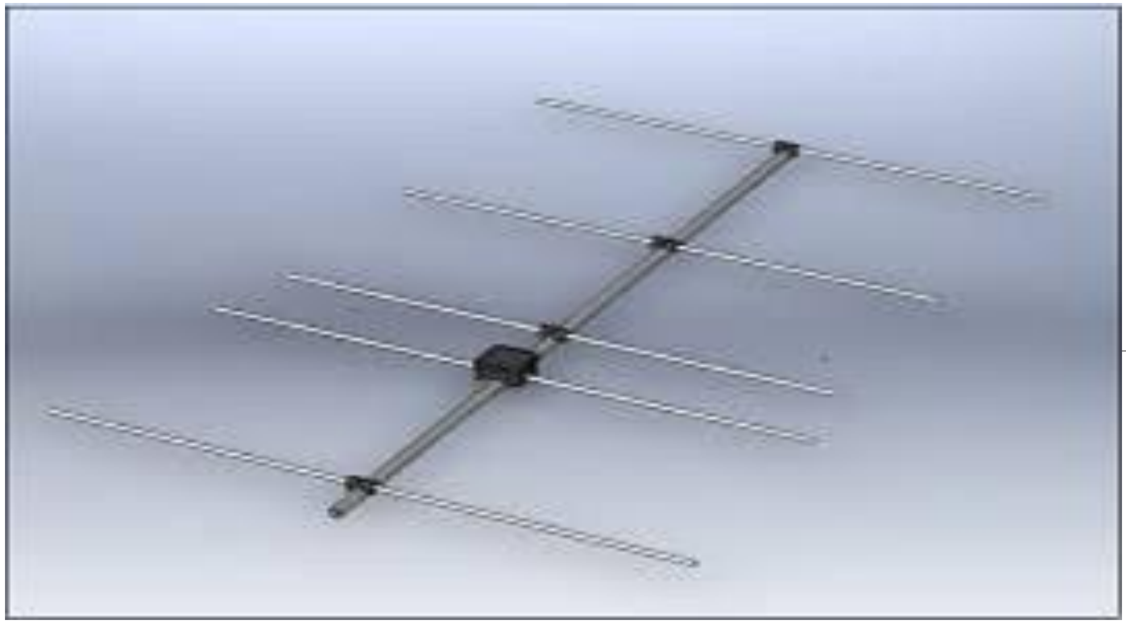
Yagi-Uda antenna is the most commonly used type of antenna for TV reception over the last few decades. It is the most popular and easy-to-use type of antenna with better performance, which is famous for its high gain and directivity

Frequency range

The frequency range in which the Yagi-Uda antennas operate is around **30 MHz to 3GHz** which belong to the **VHF** and **UHF** bands.

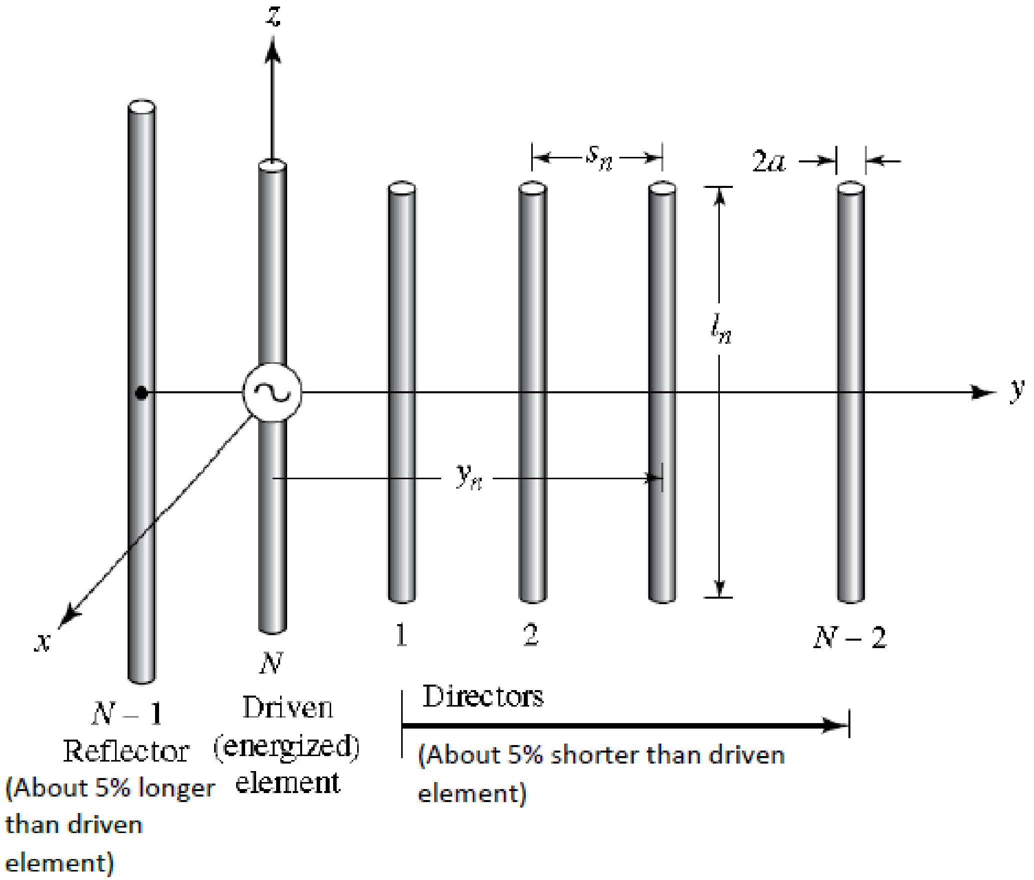


Structure of Yagi-Uda Antenna



- The figure shows a **Yagi-Uda antenna**. It is seen that there are many directors placed to increase the directivity of the antenna. The feeder is the folded dipole. The reflector is the lengthy element, which is at the end of the structure.

- The figure depicts a clear form of the Yagi-Uda antenna. The center rod like structure on which the elements are mounted is called as **boom**. The element to which a thick black head is connected is the **driven element** to which the transmission line is connected internally, through that black stud. The single element present at the back of the driven element is the **reflector**, which reflects all the energy towards the direction of the radiation pattern. The other elements, before the driven element, are the **directors**, which direct the beam towards the desired angle.



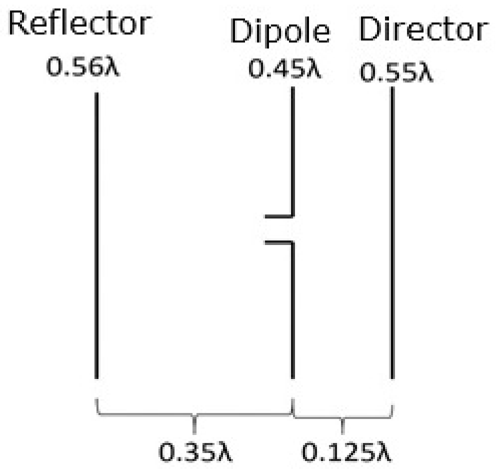
There are three types of element within a Yagi antenna:

(i) Driven element: The driven element is the Yagi antenna element to which power is applied. It is normally a half wave dipole or often a folded dipole.

(ii) Reflector : The Yagi antenna will generally only have one reflector. This is behind the main driven element, i.e. the side away from the direction of maximum sensitivity. Further reflectors behind the first one add little to the performance. However many designs use reflectors consisting of a reflecting plate, or a series of parallel rods simulating a reflecting plate. This gives a slight improvement in performance, reducing the level of radiation or pick-up from behind the antenna, i.e. in the backwards direction. Typically a reflector will add around 4 or 5 dB of gain in the forward direction.

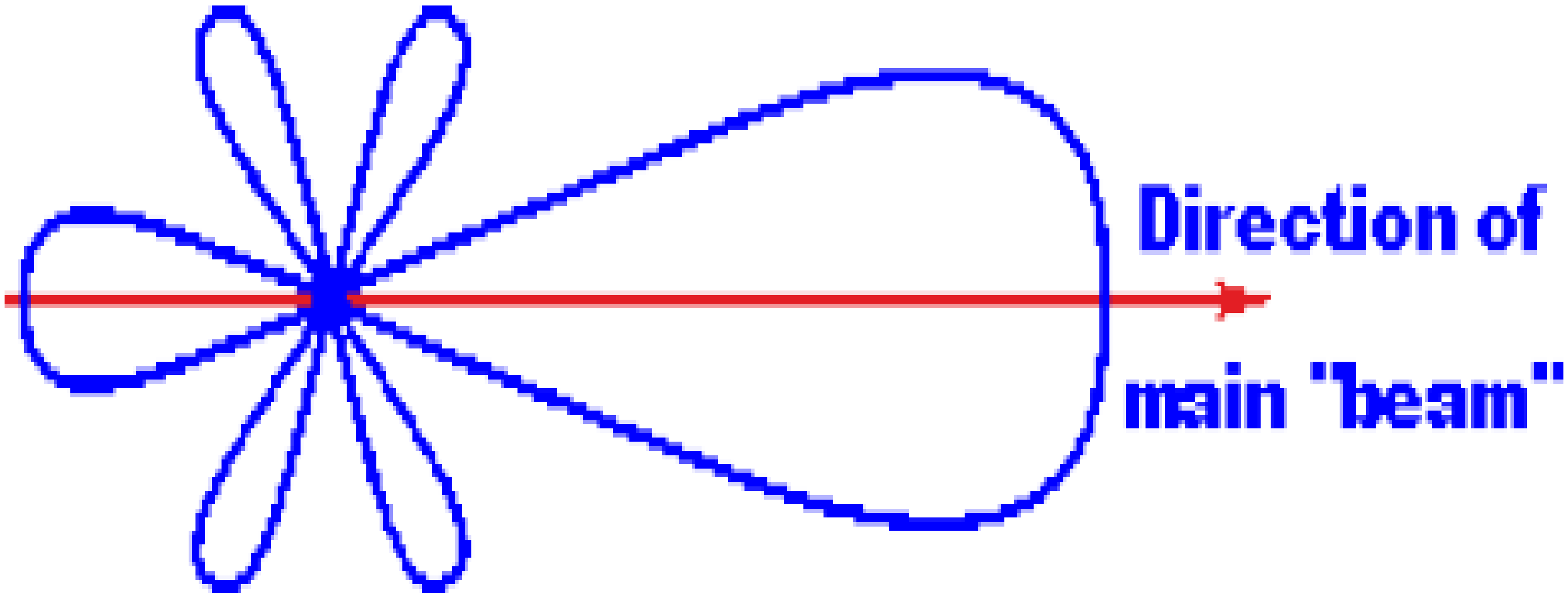
(iii) Director: The director or directors are placed in front of the driven element, i.e. in the direction of maximum sensitivity. Typically each director will add around 1 dB of gain in the forward direction, although this level reduces as the number of directors increases.

Designing



ELEMENT	SPECIFICATION
Length of the Driven Element	0.458λ to 0.5λ
Length of the Reflector	0.55λ to 0.58λ
Length of the Director 1	0.45λ
Length of the Director 2	0.40λ
Length of the Director 3	0.35λ
Spacing between Directors	0.2λ
Reflector to dipole spacing	0.35λ
Dipole to Director spacing	0.125λ

Radiation pattern of Yagi-Uda Antenna



Advantages

1.High gain is achieved.
2.High directivity is achieved.
3.Ease of handling and maintenance.
4.Less amount of power is wasted.
5.Broader coverage of frequencies.
6. Simpler in design and light in weight.
7. Less costly

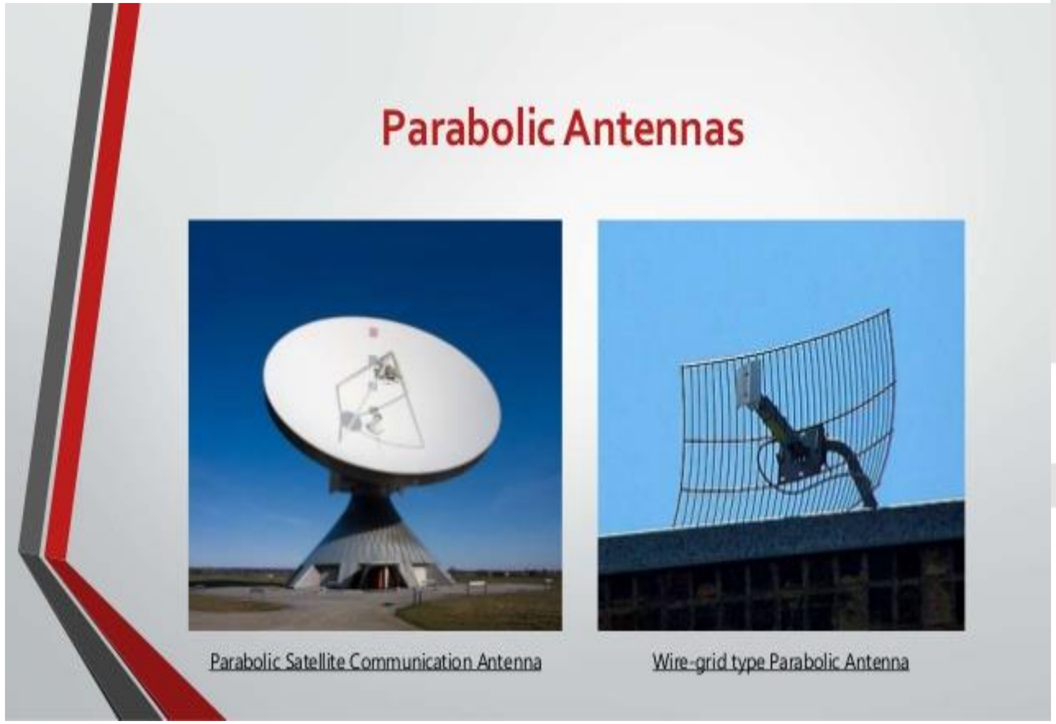
Disadvantages

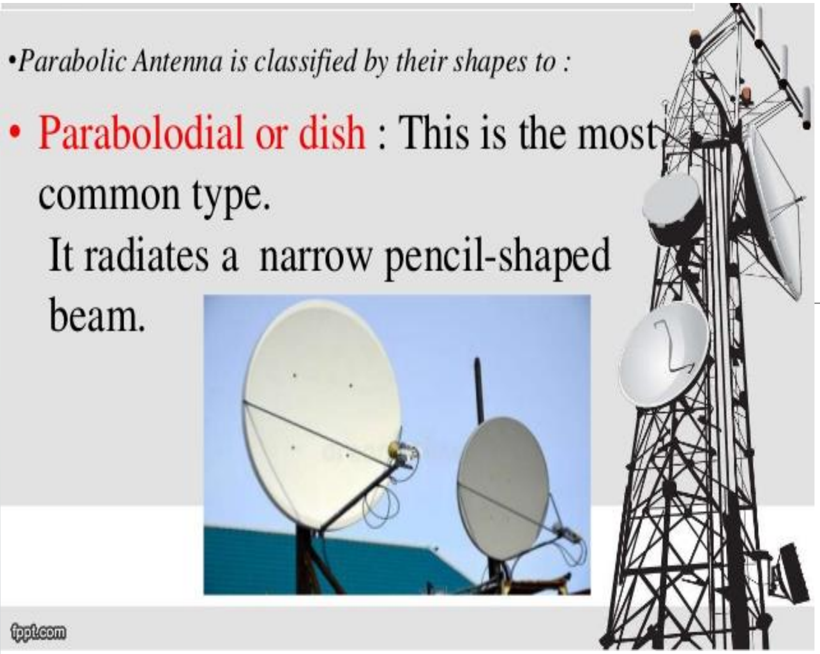
1.Prone to noise.
2.Prone to atmospheric effects.

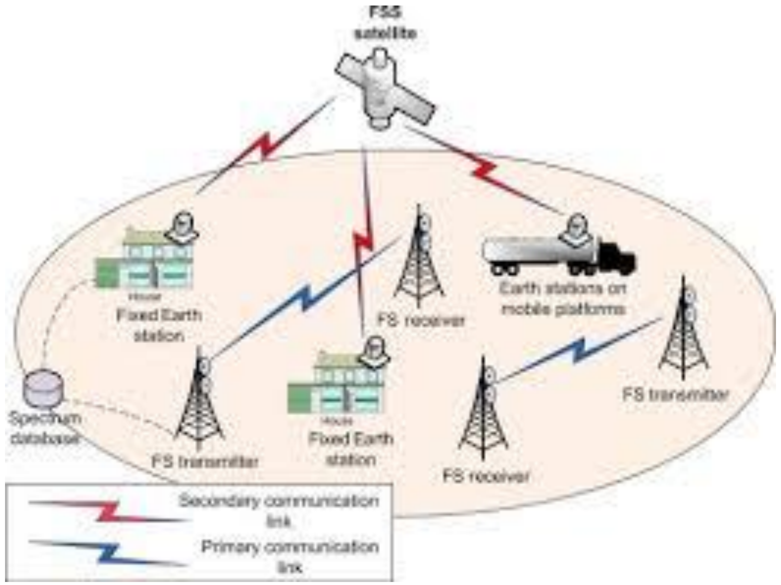
Applications

1.Mostly used for TV reception.
2.Used where a single-frequency application is needed.

Parabolic antenna

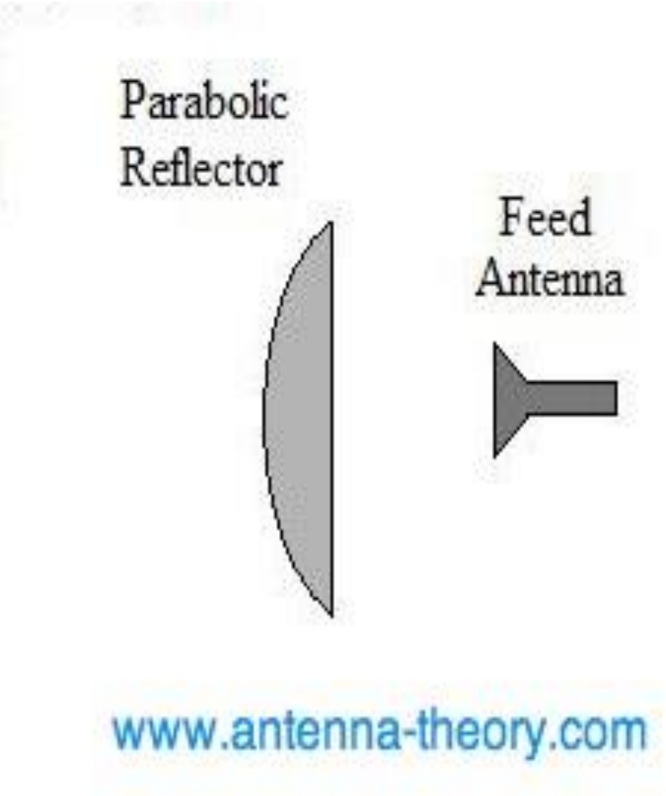






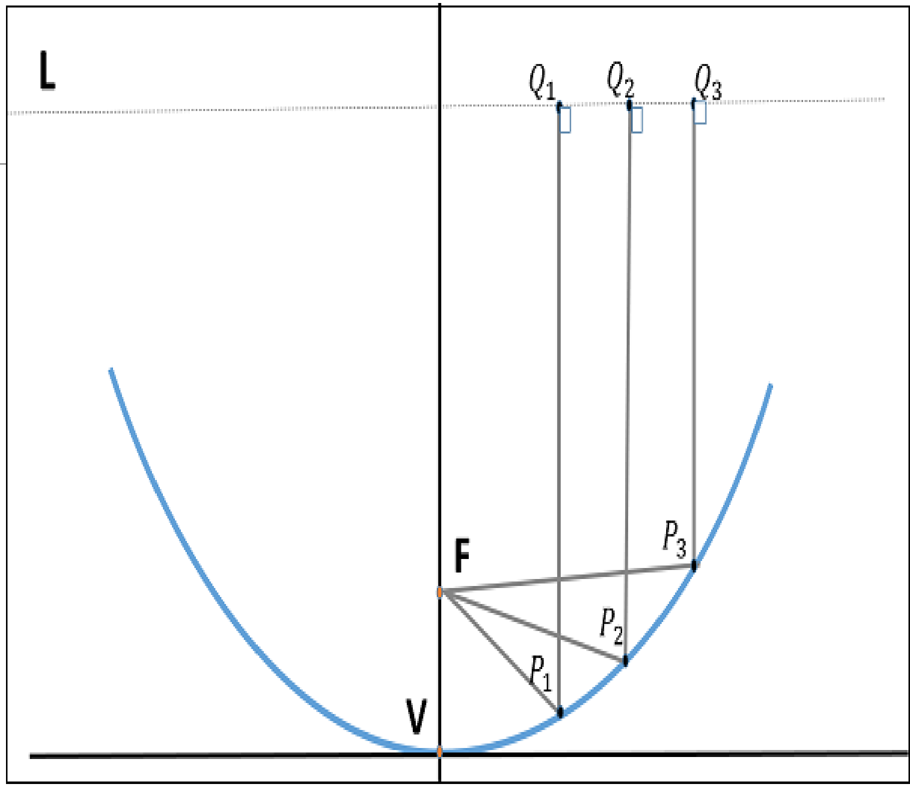
Parabolic antenna

- It was invented by german physicist heinrich Hertz during his discovery of radio waves in 1887.
- A **parabolic antenna** is an antenna that uses a parabolic reflector, a curved surface with the cross-sectional shape of a parabola, to direct the radio waves. The most common form is shaped like a dish and is popularly called a **dish antenna** or **parabolic dish**.
- It functions similarly to a searchlight or flashlight reflector to direct the radio waves in a narrow beam, or receive radio waves from one particular direction only.
- The main advantage of a parabolic antenna is that it has high directivity
- The smaller dish antennas typically operate somewhere between 2 and 28 ghz. The large dishes can operate in the VHF region (30-300 mhz), but typically need to be extremely large at this operating band.
- Parabolic antennas have some of the highest gains, meaning that they can produce the arrowest beamwidths, of any antenna type.



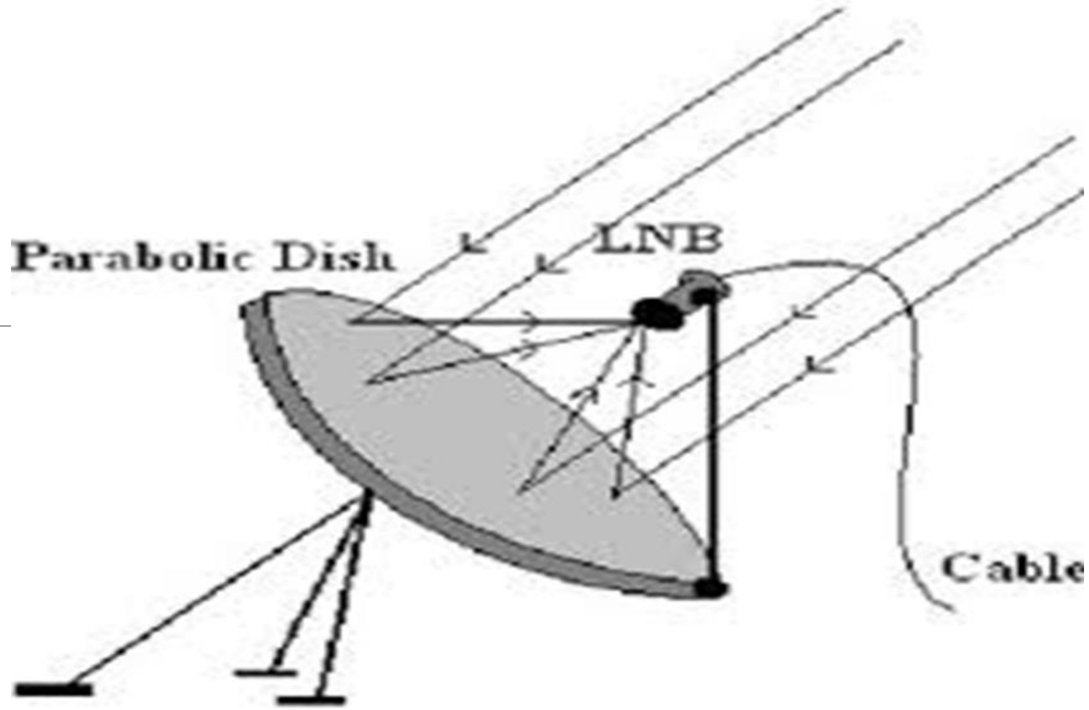
Principle of Operation

- The standard definition of a parabola is - Locus of a point, which moves in such a way that its distance from the fixed point (called **focus**) plus its distance from a straight line (called **directrix**) is constant.
- This figure shows the geometry of parabolic reflector. The point **F** is the focus (feed is given) and **V** is the vertex. The line joining F and V is the axis of symmetry. PQ are the reflected rays where **L** represents the line directrix on which the reflected points lie (to say that they are being collinear). Hence, as per the above definition, the distance between F and L lie constant with respect to the waves being focussed.
- The reflected wave forms a colllimated wave front, out of the parabolic shape. The ratio of focal length to aperture size (ie., f/D) known as **"f over D ratio"** is an important parameter of parabolic reflector. Its value varies from **0.25 to 0.50**.
- The law of reflection states that the angle of incidence and the angle of reflection are equal. This law when used along with a parabola, helps the beam focus. The shape of the parabola when used for the purpose of reflection of waves, exhibits some properties of the parabola, which are helpful for building an antenna, using the waves reflected.



Properties of Parabola

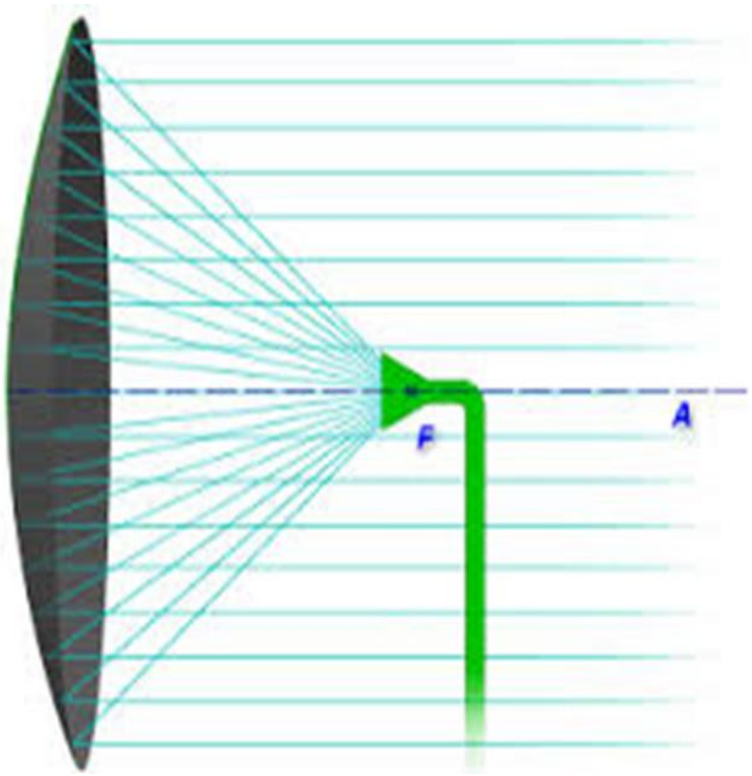
- All the waves originating from focus, reflects back to the parabolic axis. Hence, all the waves reaching the aperture are in phase.
- As the waves are in phase, the beam of radiation along the parabolic axis will be strong and concentrated.



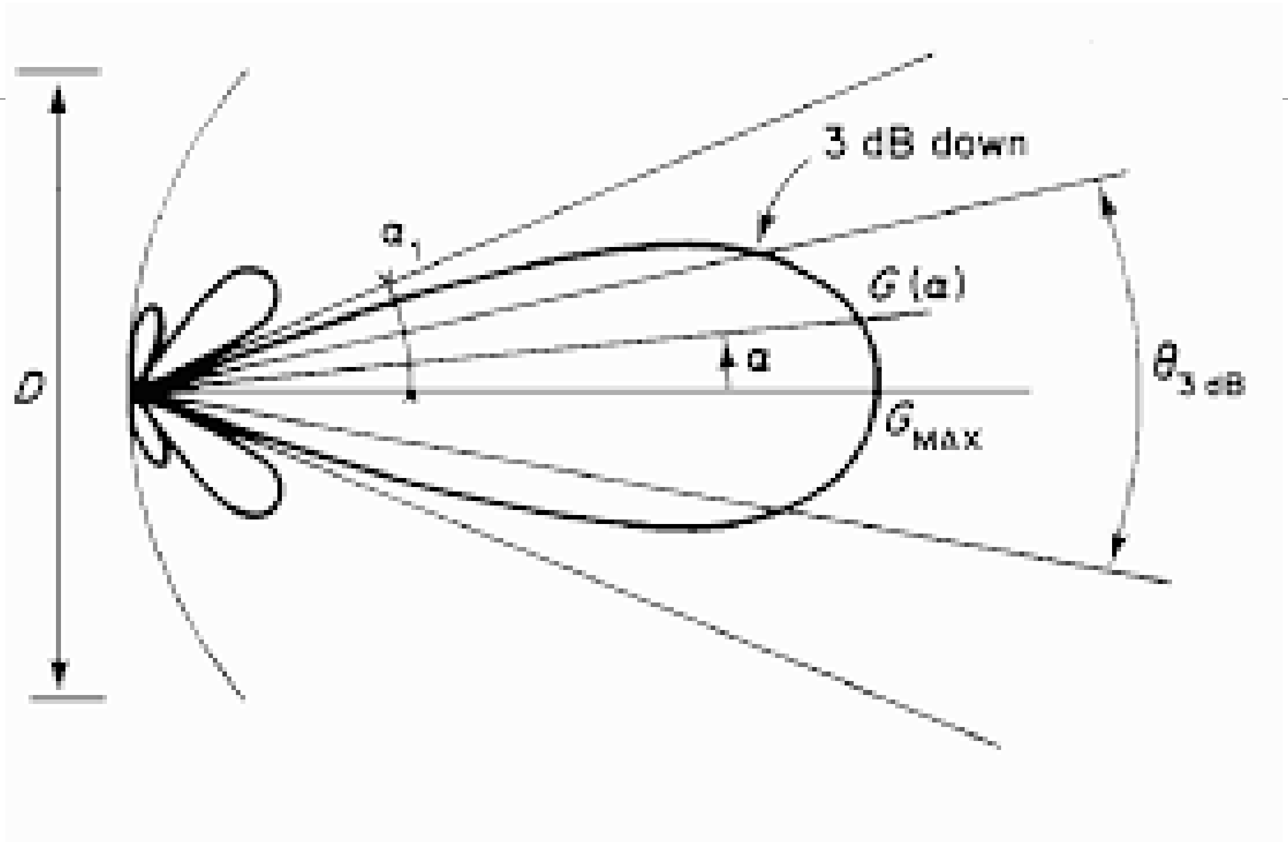
Working of a Parabolic Reflector

- If a Parabolic Reflector antenna is used for transmitting a signal, the signal from the feed, comes out of a dipole or a horn antenna, to focus the wave on to the parabola. It means that, the waves come out of the focal point and strike the Paraboloidal reflector. This wave now gets reflected as **collimated wave front.**

- The same antenna is used as a receiver. When the electromagnetic wave hits the shape of the parabola, the wave gets reflected onto the feed point. The dipole or the horn antenna, which acts as the receiver antenna at its feed, receives this signal, to convert it into electric signal and forwards it to the receiver circuitry.



Radiation pattern of parabolic antenna



Advantages:

High gain: parabolic reflector antennas are able to provide **very high levels of gain**. The larger the 'dish' in terms of wavelengths, the higher the gain.

High directivity: as with the gain, so too the parabolic reflector or dish antenna is able to provide **high levels of directivity**. The higher the gain, the narrower the beamwidth. This can be a significant advantage in applications where the power is only required to be directed over a small area.

Disadvantages

Requires reflector and drive element: the parabolic reflector itself is only part of the antenna. It requires a feed system to be placed at the focus of the parabolic reflector.

Cost : the antenna needs to be manufactured with care. A paraboloid is needed to reflect the radio signals which must be made carefully. In addition to this a feed system is also required. This can add cost to the system

Size: the antenna is not as small as some types of antenna, although many used for satellite television reception are quite compact.

Applications of parabolic antenna

1.Direct broadcast television: Direct broadcast or satellite television has become a major form of distribution for television content. The wide and controllable coverage areas available combined with the much larger bandwidths enable more channels to be broadcast and this makes satellite television very attractive.

2. ***Microwave links:*** Terrestrial microwave links are used for many applications. Often they are used for terrestrial telecommunications infrastructure links. One of the major areas where they are used these days is to provide the backhaul for mobile telecommunications systems.

3.Satellite communications: Many satellite uplinks, or those for communication satellites require high levels of gain t ensure the optimum signal conditions and that transmitted power from the ground does not affect other satellites in close angular proximity. Again the ideal antenna for most applications is the parabolic reflector antenna.

4.Radio astronomy: Radio astronomy is an area where very high levels of gain and directivity are required. Accordingly the parabolic reflector antenna is an ideal choice.

Portion for IA-2

MODULE-4-PART (A):LINEAR ARRAYS OF N ISOTROPIC POINT SOURCES OF EQUAL AMPLITUDE AND SPACING. ,

(PART B) **ELECTRIC ANTENNA**: INTRODUCTION, SHORT ELECTRIC DIPOLE, FIELDS OF A SHORT DIPOLE (GENERAL AND FAR FIELD ANALYSES), RADIATION RESISTANCE OF A SHORT DIPOLE, THIN LINEAR ANTENNA(FIELD ANALYSES), RADIATION RESISTANCES OF LAMBDA/2 ANTENNA.

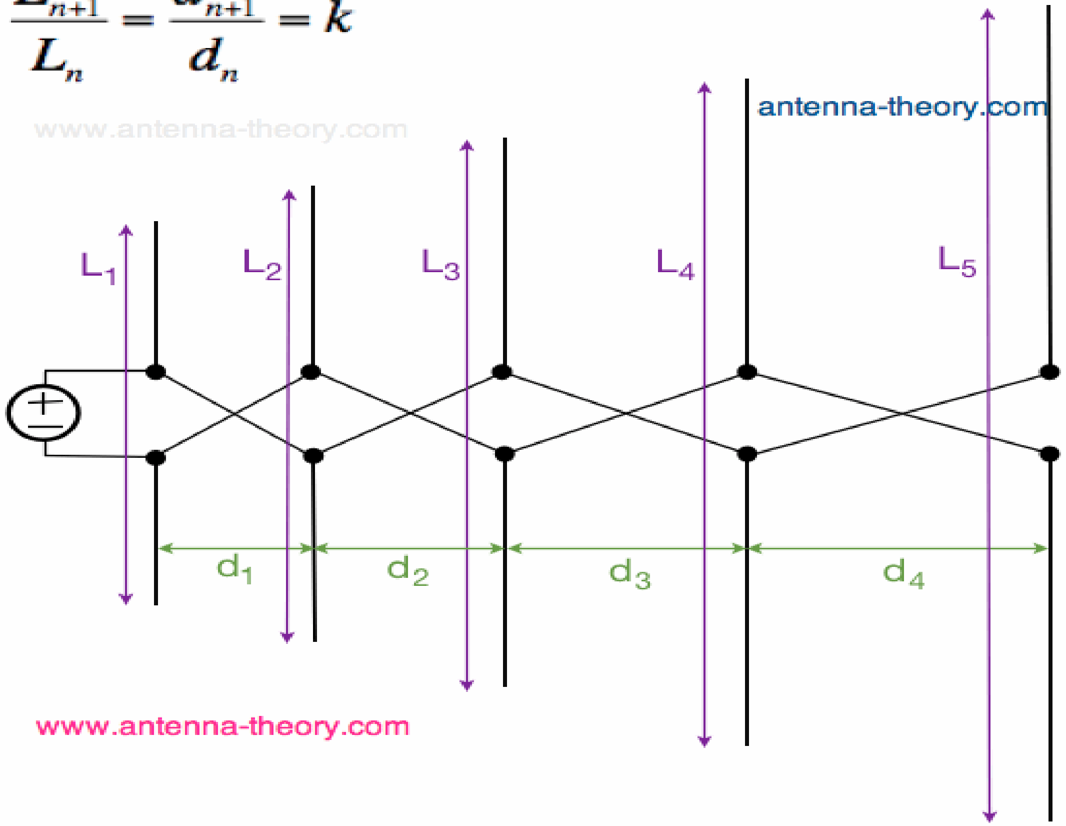
MODULE-5

PART (A)LOOP AND HORN ANTENNA:INTRODUCTION, SMALL LOOP, COMPARISON OF FAR FIELDS OF SMALL LOOP AND SHORT DIPOLE, THE LOOP ANTENNA GENERAL CASE, FAR FIELD PATTERNS OF CIRCULAR LOOP ANTENNA WITH UNIFORM CURRENT, RADIATION RESISTANCE OF LOOPS, DIRECTIVITY OF CIRCULAR LOOP ANTENNAS WITH UNIFORM CURRENT, HORN ANTENNAS RECTANGULAR HORN ANTENNAS. **PART (B) ANTENNA TYPES:**HELICAL ANTENNA, HELICAL GEOMETRY, PRACTICAL DESIGN CONSIDERATIONS OF HELICAL ANTENNA, YAGI-UDA ARRAY, PARABOLA GENERAL PROPERTIES, LOG PERIODIC ANTENNA.

LOG-PERIODIC ANTENNA

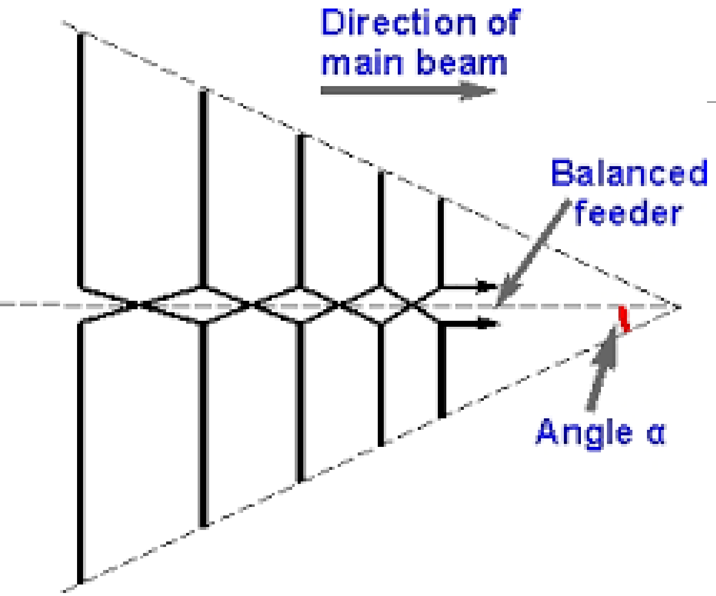
LOG-PERIODIC ANTENNA: Log of impedance, log of directivity or log of beam width vary periodically with respect to frequency hence called log periodic antenna.

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



- *LOG PERIODIC ANTENNA : is an antenna whose characteristic vary periodically with respect to frequency Eg: At 1GHz, 10GHz, 100GHz characteristic repeats.*
- *The log periodic antenna or aerial often called the LPDA (***log-periodic dipole array***)is a wideband directional antenna that provides gain and directivity combined over a wide band of frequencies*.
- *Usually log-periodic antenna are considered as frequency independent antenna. i.e. all the characteristics are independent of frequency and it is dependent on the angle (i.e. it works in wider band width).*
- The LPDA consists of a number of half-wave dipole driven elements of gradually increasing length, each consisting of a pair of metal rods. The dipoles are mounted close together in a line, connected in parallel to the feedline with alternating phase. Electrically, it simulates a series of two or three-element Yagi antennas connected together, each set tuned to a different frequency.
- Adding elements to a Yagi increases its directionality, or gain, while adding elements to a LPDA increases its frequency response, or bandwidth.
- **Frequency range:**The frequency range, in which the log-periodic antennas operate is around **30 MHz to 3GHz** which belong to the **VHF** and **UHF** bands.

α = the angle of the line of the elements to the line drawn through the centre of the elements



- The construction and operation of a log-periodic antenna is similar to that of a Yagi-Uda antenna. The main advantage of this antenna is that it exhibits constant characteristics over a desired frequency range of operation. It has the same radiation resistance and therefore the same SWR.

- The log periodic dipole array consists of a number of dipole elements. These progressively reduce in size from the back to the front – the direction of maximum radiation is from the smaller front.

- Each dipole element of the LPDA is fed, but the phase is reversed between adjacent dipole elements – this ensures that the signal phasing is correct between the different elements. It also means that a feeder is required along the length of the antenna. Normally this is arranged so that it forms part of the mechanical structure of the array.

1. Find radiation resistance of a circular loop antenna of radius 0.3183m operating at 1MHz. The radius of a wire used is 0.4mm, conductivity of the wire is 57 mS/m and $\mu_r = 1.0$.

Sol: For a circular loop, radiation resistance is

$$R_r = 197\left(\frac{C}{\lambda}\right)^4$$

$$C = 2\pi a = 2 \times \pi \times 0.3183 = 2m$$

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{1\times10^6} = 300m$$

$$\therefore R_r = 197\left(\frac{2}{300}\right)^4 = 0.3891 \times 10^{-6}\,\Omega = 0.3891\,\mu\Omega$$

2. The diameter of a circular loop antenna is 0.04λ. How many turns of the antenna will give a radiation resistance of $36\,\Omega$?.

Sol: Area of loop $= A = \pi a^2 = \pi\left(\frac{d}{2}\right)^2 = \pi\left(\frac{0.04\lambda}{2}\right)^2 = 0.001256\lambda^2$

If $\frac{A}{\lambda^2} < 0.01$ the loop is said to be small loop.

Since $\frac{A}{\lambda^2} = 0.001256 < 0.01$, loop is considered to be small loop.

$\therefore R_r = 31200\left(\frac{A}{\lambda^2}\right)^2 N^2$

$\Rightarrow 36 = 31200\left[\frac{0.001256\cancel{\lambda^2}}{\cancel{\lambda^2}}\right]^2 N^2$

$\therefore N^2 = 731.5205$

$\Rightarrow N = 27.04 \simeq 27$

3. Find radiation resistance of a loop antenna with diameter 0.5m operating at 1MHz

Sol: Area of loop $= A = \pi a^2 = \pi\left(\frac{d}{2}\right)^2 = \pi\left(\frac{0.5}{2}\right)^2 = 0.1963 > 0.01$

Therefore it is large loop

$$\lambda = \frac{c}{f} = \frac{3\times10^8}{1\times10^6} = 300m$$

$$R_r = 3720\left(\frac{a}{\lambda}\right) = 3720\left(\frac{0.25}{200}\right) = 3.1\Omega$$

4. Determine directivity of loop antenna having radius of 1.0m when it is operated at 0.9MHz

Sol:- $\lambda = \frac{c}{f} = \frac{3\times10^8}{0.9\times10^6} = 333.33\ m$

$$\frac{C}{\lambda} = \frac{2\pi a}{\lambda} = \frac{2\pi\times1}{333.33} = 0.01885 < 1/3 \quad [\text{Small loop}]$$

If $\frac{C}{\lambda} < \frac{1}{3}$, directivity of loop antenna is given by

$\therefore \quad D = \frac{3}{2} = 1.5$

5. Find directivity and radiation resistance of loop antenna with diameter of 1.5λ.

Sol: Radius $= a = \frac{d}{2} = \frac{1.5\lambda}{2} = 0.75\lambda$

$$\frac{c}{\lambda} = \frac{2\pi a}{\lambda} = \frac{\pi d}{\lambda} = \frac{\pi(1.5\cancel{\lambda})}{\cancel{\lambda}} = 1.5\pi > 1/3 \quad [\text{large loop}]$$

If $\frac{c}{\lambda} > \frac{1}{3}$, radiation resistance is given by

$$R_r = 3720\left(\frac{a}{\lambda}\right) = 3720\left(\frac{0.75\cancel{\lambda}}{\cancel{\lambda}}\right) = 2790\,\Omega$$

1. Directivity of large loop antenna is given by

$$D = 0.682\left(\frac{c}{\lambda}\right) = 0.682\,(1.5\pi) = 3.21385$$

6. Determine length ρ of the horn, H-plane aperture and flare angles θ_E and θ_H in (E and H planes respectively) of a pyramidal horn for which E plane aperture is 10λ. The horn is fed with a rectangular waveguide with TE_{10} mode. Let $\delta = 0.2\lambda$ in E plane and 0.375λ in H plane. Calculate beamwidth and directivity.

Sol: For E-plane $\delta = 0.2\lambda$

$$\therefore \rho = \frac{a^2}{8\delta} = \frac{a_E^2}{8\delta} = \frac{(10\lambda)^2}{8 \times 0.2\lambda} = 62.5\lambda$$

Flare angle in E-plane is

$$\theta_E = 2\tan^{-1}\left(\frac{a_E}{2\rho}\right) = 2\tan^{-1}\left(\frac{10\lambda}{2 \times 62.5\lambda}\right) = 9.147^\circ$$

Flare angle in H-plane is

$$\theta_H = 2\cos^{-1}\left(\frac{\rho}{\rho+\delta}\right) = 2\cos^{-1}\left(\frac{62.5\lambda}{62.5\lambda + 0.375\lambda}\right) = 12.521^\circ$$

H-plane aperture is

$$a_H = 2\rho\tan\left(\frac{\theta_H}{2}\right) = 2(62.5\lambda)\tan\left(\frac{12.521}{2}\right) = 13.7129\lambda$$

HPBW in E-plane is given by

$$(HPBW)_{E\text{-plane}} = \frac{56^\circ\lambda}{a_E} = \frac{56^\circ\lambda}{10\lambda} = 5.6^\circ$$

HPBW in H-plane is given by

$$(HPBW)_{H\text{-plane}} = \frac{67^\circ\lambda}{a_H} = \frac{67^\circ\lambda}{13.7129\lambda} = 4.8857^\circ$$

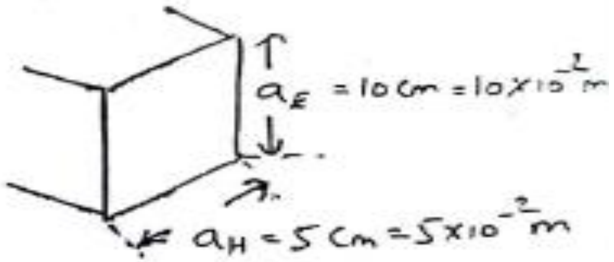
Directivity in dB is

$$D_{(dB)} = 10\log\left(\frac{7.5A}{\lambda^2}\right) = 10\log\left(\frac{7.5\,a_E a_H}{\lambda^2}\right)$$

$$\therefore D_{(dB)} = 10\log\left(\frac{7.5 \times 10\lambda \times 13.7129\lambda}{\lambda^2}\right) = 30.1219\ dB$$

7. The dimensions of an aperture of a pyramidal horn are 10 × 5 cm. It is operated at 6 GHZ frequency. Find beamwidth, power gain and directivity.

Sol:- $f = 6 \times 10^9\ HZ$



$$\therefore \lambda = \frac{c}{f} = \frac{3 \times 10^8}{6 \times 10^9} = 0.05\,m$$

$$HPBW_{(E\text{-plane})} = \frac{56^\circ \lambda}{a_E} = \frac{56^\circ \times 0.05}{10 \times 10^{-2}} = 28^\circ$$

$$HPBW_{(H\text{-plane})} = \frac{67^\circ \lambda}{a_H} = \frac{67^\circ \times 0.05}{5 \times 10^{-2}} = 67^\circ$$

The power gain is given by

$$G_p = \frac{4.5A}{\lambda^2} = \frac{4.5\, a_E a_H}{\lambda^2} = \frac{4.5\,(10 \times 10^{-2})(5 \times 10^{-2})}{(0.05)^2} = 9$$

$$(G_p)_{dB} = 10 \log 9 = 9.5424\,dB$$

Directivity $$D = \frac{7.5A}{\lambda^2} = \frac{7.5\, a_E a_H}{\lambda^2} = \frac{7.5\,(10 \times 10^{-2})(5 \times 10^{-2})}{(0.05)^2} = 15$$

$$(D)_{dB} = 10 \log 15 = 11.761$$

8. Find the power gain in dB of a square horn antenna with aperture size 8.5λ.

Sol:- Power gain $G_P = \frac{4.5 A}{\lambda^2} = \frac{4.5\, a_E\, a_H}{\lambda^2} = \frac{4.5 a^2}{\lambda^2} = \frac{4.5(8.5\lambda)^2}{\lambda^2} = 325.125$

$$(G_P)_{dB} = 10 \log 325.125 = 25.1205 \text{ dB}$$

9. Calculate directivity of 20 turn helix with $\alpha = 12°$ and circumference equal to one wavelength.

Sol:- Directivity $D = \frac{15 n S C^2}{\lambda^3}$ $\left[\because C_\lambda = \frac{C}{\lambda} \text{ and } S_\lambda = \frac{S}{\lambda}\right]$

$n = 20$, $C = \lambda$

To find S, we know

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

$$\Rightarrow S = C \tan\alpha = \lambda \tan 12° = 0.2125\lambda$$

$$\therefore D = \frac{15 \times 20 \times 0.2125\cancel{\lambda} \times \cancel{\lambda^2}}{\cancel{\lambda^3}} = 63.75$$

11. A right handed monofilar helical antenna has 10 turns, 100mm diameter and 70mm turn spacing. Calculate the far field pattern at $f = 1GHz$, HPBW and gain.

Sol:
$$\alpha = \tan^{-1}\left(\frac{S}{\pi D}\right) = \tan^{-1}\left(\frac{70\times10^{-3}}{\pi\times100\times10^{-3}}\right) = \tan^{-1}\left(\frac{7}{10\pi}\right) = 12.56^\circ$$

$$\lambda = \frac{c}{f} = 0.3m$$

$$HPBW = \frac{52^\circ}{\frac{C}{\lambda}\sqrt{\frac{nS}{\lambda}}} = \frac{52^\circ}{\left(\frac{\pi\times100\times10^{-3}}{0.3}\right)\left(\sqrt{\frac{10\times70\times10^{-3}}{0.3}}\right)} = 32.5^\circ$$

$$Gain = 15 C_\lambda^2 n S_\lambda = \frac{12\times(\pi\times100\times10^{-3})^2\times10\times70\times10^{-3}}{(0.3)^3} = 38.38$$

$$(Gain)_{dB} = 10\log 38.38 = 15.84dB$$

This completes module-5