16. Ground and surface waves are best received in upper HF band.
17. Arrays can be used for high gain.
18. It is not preferred for transmitting purposes.
19. Its radiation pattern contains high side lobes.

6.15 RHOMBIC ANTENNA

This is an antenna which is in the shape of a rhombus. It is usually terminated in a resistance. The side of the rhombus, the angle between the sides, the elevation, termination and height above the earth are chosen to obtain the desired radiation characteristics. A typical Rhombic antenna and radiation pattern are shown in Fig. 6.26.

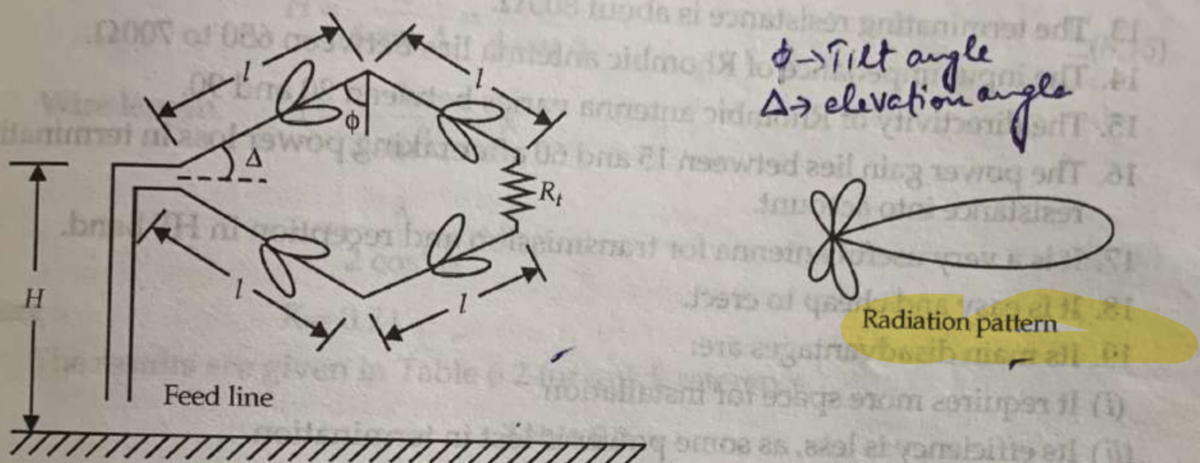


Fig. 6.26 *Rhombic antenna and radiation pattern*

Salient features of Rhombic antenna

1. It is a long wire antenna and consists four non-resonant wires.
2. It provides greater directivity than *V* antenna.
3. Its band width is high.
4. It is a HF non-resonant antenna.
5. It is very useful for point-to-point communications.
6. It is a travelling wave antenna and there are no reflections.
7. It also finds wide applications where the angle of elevation of the main lobe (measured from the plane of the antenna to the radiation axis) is less than 30°.
8. At elevation angle above 30°, the gain is very low for practical applications.
9. The directivity of each wire is

$$D(\theta) = \frac{60I}{r} \sin\theta \left[\frac{\sin\left[\frac{\pi l}{\lambda}(1-\cos\theta)\right]}{(1-\cos\theta)} \right] \quad ...(6.11)$$

where I = the magnitude of the current in element
θ = the polar angle
λ = wavelength
l = length of the radiator
r = the distance from the radiator to the elevation point.

The total directivity of the Rhombic antenna is the vector sum of directivity of each wire.

10. The length of equal radiators vary from 2 to 8λ.
11. The tilt angle, ϕ varies between $40°$ and $75°$.
12. ϕ is determined from leg length.
13. The terminating resistance is about $800\,\Omega$.
14. The input impedance of Rhombic antenna lies between 650 to $700\,\Omega$.
15. The directivity of Rhombic antenna varies between 20 and 90.
16. The power gain lies between 15 and 60 after taking power loss in terminating resistance into account.
17. It is a very useful antenna for transmission and reception in HF band.
18. It is easy and cheap to erect.
19. Its main disadvantages are:
(*i*) It requires more space for installation.
(*ii*) Its efficiency is less, as some power is lost in termination.
20. Its radiation pattern in a vertical plane is shown in Fig. 6.27.

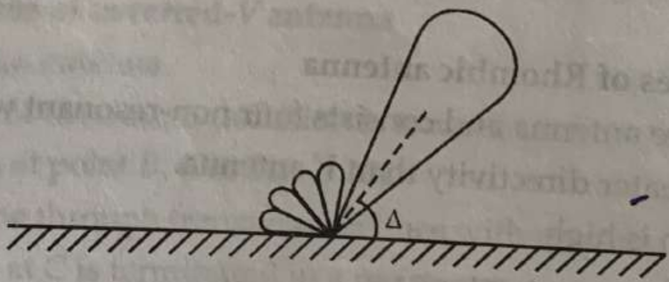


Fig. 6.27 *Radiation pattern of Rhombic antenna in vertical plane*

In the design of Rhombic antennas the maximum point of the main lobe of the radiation pattern is aligned with the desired angle of elevation. The angle of elevation is also called angle of radiation.

The **design parameters** of Rhombic antenna are:

1. Rhombic height, H
2. Angle of elevation, Δ
3. Wire length, l.

The design equations are

$$H = \frac{\lambda}{4 \sin \Delta} \quad \ldots(6.12)$$

Δ = elevation angle

Δ is complement of tilt angle, ϕ

$(\sin\phi = \cos\Delta)$

$$l = \frac{\lambda}{2\cos^2\phi} = \frac{\lambda}{2\sin^2\Delta} \quad \text{...(6.13)}$$

Alignment design equations.

Tilt angle, $\phi = 90^\circ -$ elevation angle

$$= 90^\circ - \Delta \quad \text{...(6.14)}$$

Rhombic height,

$$H = \frac{\lambda}{4\sin\Delta} = \frac{\lambda}{4\cos\phi} \quad \text{...(6.15)}$$

Wire length, $$l = \frac{\lambda}{2\sin^2\Delta} \times K$$

$$= \frac{\lambda}{2\cos^2\phi} \times K \quad \text{...(6.16)}$$

where $K = 0.74$

The results are given in Table 6.2 for quick reference.

Table 6.2

Frequency, f = 30 MHz, λ = 10 m					
Angle of elevation, Δ	***Tilt angle ϕ***	***Rhombic height H in λ***	***H in meters***	***Wire length, l in λ***	***Wire length in meters***
10°	80°	1.439	14.39	16.58	165.8
15°	75°	0.966	9.66	7.46	74.6
20°	70°	0.730	7.30	4.27	42.7
25°	65°	0.591	5.91	2.79	27.9
30°	60°	0.500	5.00	2.00	20.0
35°	55°	0.435	4.35	1.52	15.2
40°	50°	0.320	3.90	1.21	12.1

6.16 YAGI-UDA ANTENNA

This antenna was developed by Prof. Yagi and Prof. Uda. It is an array antenna which consists of one active element and a few parasitic elements. The active element consists of a folded dipole whose length is $\lambda/2$. The parasitic elements consist of one reflector and a few directors. The length of the reflector is greater than $\lambda/2$. It is located behind the active element. The length of each director is less than $\lambda/2$ and they are placed in front of the active element. The spacing between each element is not identical and hence it can be considered as a non-linear array. The number of directions in the antenna depends on the gain requirements. The impedance of the active element is resistive. The impedance of the reflector is

The average characteristic impedance, $(z_0)_{av}$ is

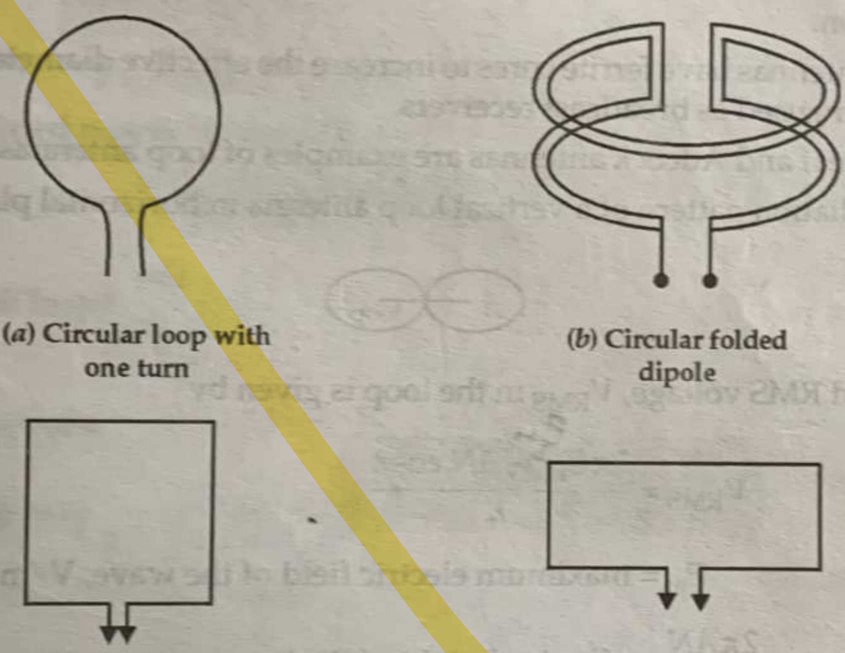
$$(z_0)_{av} = 120\left[ln\left(\frac{L_n}{d_n} - 2.25\right)\right]$$

where d_n = diameter of the n^{th} dipole.

6.18 LOOP ANTENNA

It is an antenna which is in the form of a loop.

An antenna which consists of one or more turns of wire forming a DC short circuit is called a loop antenna. The loop antenna can be of circular, square or rectangular shape. Typical loop antennas are shown in Fig. 6.32.



(a) Circular loop with one turn

(b) Circular folded dipole

(c) Square loop

(d) Rectangular loop

Fig. 6.32 *Loop antennas*

Small vertical loops are used for finding the direction. The loop is oriented until a null or zero field is obtained. This gives the direction of the received signal.

Loop antennas have advantage over the other antennas in direction-finding as they are small in size. These are more suitable for mobile communication applications.

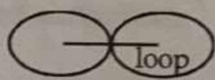
The polarisation of the loop antenna is the same as that of a short dipole.

Horizontal loop antenna produces horizontal polarisation and vertical loop produces vertical polarisation.

Salient features of loop antenna

1. Small loops, whose circumferences are less than 0.1λ at the highest frequencies, are suitable for receiving signals upto about 30 MHz.
2. The loop antennas are characterised by a null along the axis of the loop.

3. Directional characteristics of loop antennas are improved by shielding them electrostatically.
4. A vertical loop antenna is popular and it receives bi-directional signals.
5. A vertical loop antenna, if shielded, receives uni-directional signals.
6. It has excellent directivity.
7. Vertical loop antennas are very useful for direction-finding applications.
8. These are suitable for LF, MF, HF, VHF and UHF ranges.
9. The radiation pattern is in the shape of a doublet.
10. The directional patterns of loop antennas are independent of the exact shape of the loop.
11. In direction-finding applications, a small vertical loop is rotated about the vertical axis. The plane of the loop is perpendicular to the direction of radiation.
12. Loop antennas have ferrite cores to increase the effective diameter of the loop. These are used as broadcast receivers.
13. Cloverleaf and Adcock antennas are examples of loop antennas.
14. The radiation pattern of a vertical loop antenna in horizontal plane is



15. Induced RMS voltage, V_{RMS} in the loop is given by

$$\boxed{V_{RMS} = \frac{2\pi \overset{E_m}{E_{RMS}} AN \cos\phi}{\lambda}} \qquad ...(6.36)$$

Here, E_m = maximum electric field of the wave, V/m

$\frac{2\pi AN}{\lambda}$ = effective height of the loop

λ = wavelength, m

A = area of the loop, m^2

N = number of turns

ϕ = angle between plane of the loop and direction of incident wave.

16. The radiation efficiency of a small loop antenna is poor.
17. The dimensions of the antenna should be of the order of λ for using as transmitters.
18. The field expressions of small loop antennas are:

$$E_\phi = \frac{120\pi^2 IA \sin\theta}{r\lambda^2}, \text{ V/m} \qquad ...(6.37)$$

$$H_\theta = \frac{\pi I \sin\theta A}{r\lambda^2}, \text{ V/m} \qquad ...(6.38)$$

Here, I = retarded current

$$= I_0 e^{j\omega(t - r/v_0)} \quad ...(6.39)$$

19. The radiation resistance of small loop antenna

$$R_r \approx 31{,}171 \left(\frac{NA}{\lambda^2}\right)^2 \Omega \quad ...(6.40)$$

Here N = number of turns

A = area of the loop

λ = wavelength.

20. Radiation resistance of a loop antenna is

$$R_r = 3{,}720 \frac{a}{\lambda}, \Omega$$

where a = radius of the loop.

21. The radiated power of loop antenna is

$$P_T = 10K^4 A^2 I_m^2, \text{ watts.}$$

22. For small loop $\left(\frac{2\pi a}{\lambda} < \frac{1}{3}\right)$

The directivity, $D = \frac{3}{2} = 1.5$

For large loop, $C = 2\pi a \geq 5\lambda$

$$D = 4.25 \left(\frac{a}{\lambda}\right).$$

23. The maximum effective aperture for small loop antenna is

$$A_{em} = \frac{3\lambda^2}{8\pi}.$$

24. The maximum effective aperture is given by

$$A_{em} = 0.341\lambda a \text{ m}^2$$

25. Loop antennas are used extensively in radio receivers, aircraft receivers, for direction-finding and also in UHF transmitters.

26. If the current in the loop is uniform and the loop circumference is small compared to the operating wave length, its radiation pattern is almost like that of a magnetic dipole.

6.18.1 Radiation Resistance, R_r of Loop Antenna

Consider a circular loop antenna of Fig. 6.33.

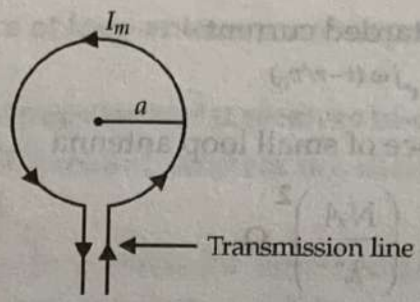


Fig. 6.33 *Loop antenna with feed line*

By definition, radiation resistance is

$$R_r \equiv \frac{\text{radiated power}}{I_{\text{RMS}}^2}$$

$$= \frac{2 \times \text{total radiated power}}{I_m^2} = \frac{2P_T}{I_m^2} \quad \text{...(6.41)}$$

where I_m = maximum current in the antenna.

Total radiated power,

$$P_T = \iint_S (P_r)_{av}\, ds \quad \text{...(6.42)}$$

Here, $(P_r)_{av}$ = average radiated power density, watts/m^2

$$= \frac{1}{2} H^2 \eta_0 \quad \text{...(6.43)}$$

where $H = |\mathbf{H}|$, η_0 = intrinsic impedance of free space.

For a loop antenna in y-z plane with its centre at the origin, the radiation fields consist of E_ϕ and H_θ components. H_θ is given by

$$H_\theta = \frac{kaI_m}{2r} J_1 (ka \sin\theta) \quad \text{...(6.44)}$$

where $J_1 (ka \sin\theta)$ = Bessel function of the first kind

$$\approx \frac{ka \sin\theta}{2} \text{ for small loops} \quad \text{...(6.45)}$$

$$H_\theta = k \times \frac{aI_m}{2r} \times \frac{ka \sin\theta}{2}$$

$$= \frac{k^2 a^2 I_m \sin\theta}{4r} \quad \text{...(6.46)}$$

$$(P_r)_{av} = \frac{1}{2} H^2 \eta_0$$

$$= \frac{1}{2} \frac{\eta_0 k^4 a^4 I_m^2 \sin^2\theta}{16r^2}$$

$$= \frac{120\pi \times k^4 a^4 I_m^2 \sin^2\theta}{32r^2}$$

$$= \frac{15\pi}{4} \frac{k^4 a^4 I_m^2 \sin^2\theta}{r^2} \qquad ...(6.47)$$

$$P_T = \iint (P_r)_{av}\, ds$$

$$= \int_0^{2\pi}\int_0^{\pi} \frac{15\pi}{4} \frac{k^4 a^4 I_m^2 \sin^2\theta}{r^2} r^2 \sin\theta \, d\theta \, d\phi$$

$$= \int_0^{\pi} \frac{15\pi^2}{2} k^4 a^4 I_m^2 \sin^3\theta \, d\theta$$

$$= 10\pi^2 k^4 a^4 I_m^2 \qquad ...(6.48)$$

But the area of the loop is given by

$$A = \pi a^2 \qquad ...(6.49)$$

So $$P_T = 10k^4 A^2 I_m^2 \qquad ...(6.50)$$

From Equations (6.41) and (6.50), we have

$$R_r = \frac{2P_T}{I_m^2}$$

$$= \frac{2}{I_m^2} 10k^4 A^2 I_m^2 \qquad ...(6.51)$$

But $$k = \frac{2\pi}{\lambda}$$

So $$\boxed{R_r = 31{,}171 \left(\frac{A}{\lambda^2}\right)^2, \Omega} \qquad ...(6.52)$$

If there are N number of turns in the loop antenna,

$$\boxed{R_r = 31{,}171 \left(\frac{NA}{\lambda^2}\right)^2, \Omega} \qquad ...(6.53)$$

As the circumference of the loop is $2\pi a$,

$$\boxed{R_r \approx 197 \left(\frac{C}{\lambda}\right)^4} \qquad ...(6.54)$$

or

$$R_r \approx 3{,}720 \left(\frac{a}{\lambda}\right) \quad \text{...(6.55)}$$

The **directivity** for small loop antenna ($C < 0.33\lambda$)

$$D = 3/2 \quad \text{...(6.56)}$$

and for large loop ($C > 5\lambda$)

$$D = 4.25 \left(\frac{a}{\lambda}\right) \quad \text{...(6.57)}$$

The **maximum effective aperture** is given by

$$A_{em} = 0.341\lambda a,\ \text{m}^2 \quad \text{...(6.58)}$$

The **maximum effective aperture** for small loop antennas,

$$A_{em} = \frac{3\lambda^2}{8\pi}$$

For a **square loop of side** a, the **radiation resistance** is given by

$$R_r = 31{,}171 \left(\frac{a}{\lambda}\right)^4,\ \Omega. \quad \text{...(6.59)}$$

6.19 HELICAL ANTENNA

It is an antenna which is in the shape of a helix.

Its polarisation and radiation properties depend on the diameter, pitch, number of turns, wavelength, excitation and spacing between the helical loops.

A typical structure of helical antenna is shown in Fig. 6.34.

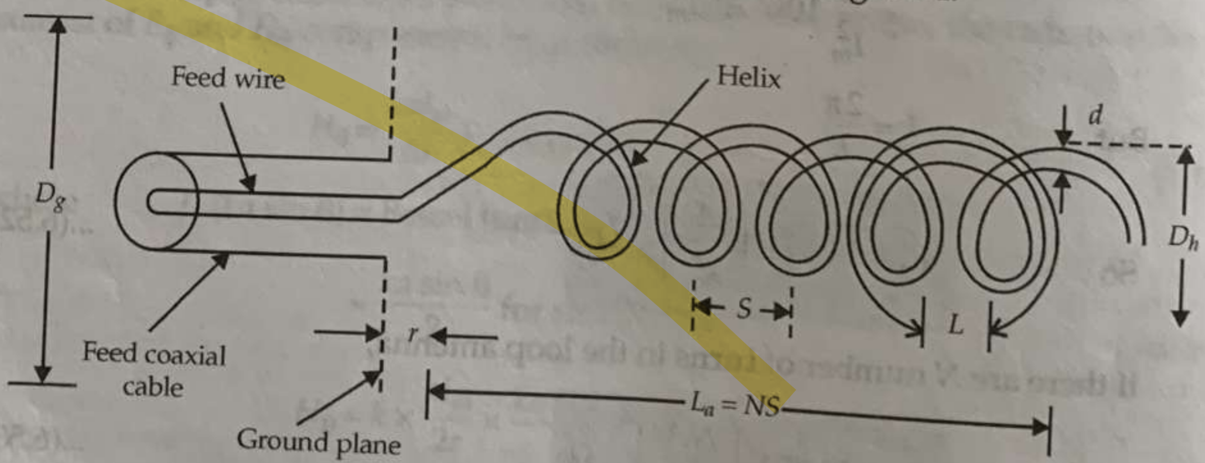


Fig. 6.34 *Helical antenna*

Helical antenna consists of helical loops made of a thick conductor which have the appearance of a screw thread. It is associated with a ground plane made of the conductor. The ground plane is often made of screen or sheet or of radial and

2. It is used for the following communications:
   (*a*) Satellite, space communications.
   (*b*) Space telemetry at HF and VHF bands
   (*c*) Radio astronomy.

6.20 WHIP ANTENNA

It is a short vertical monopole used for mobile communication purposes. A few typical whip antenna structures are shown in Fig. 6.37.

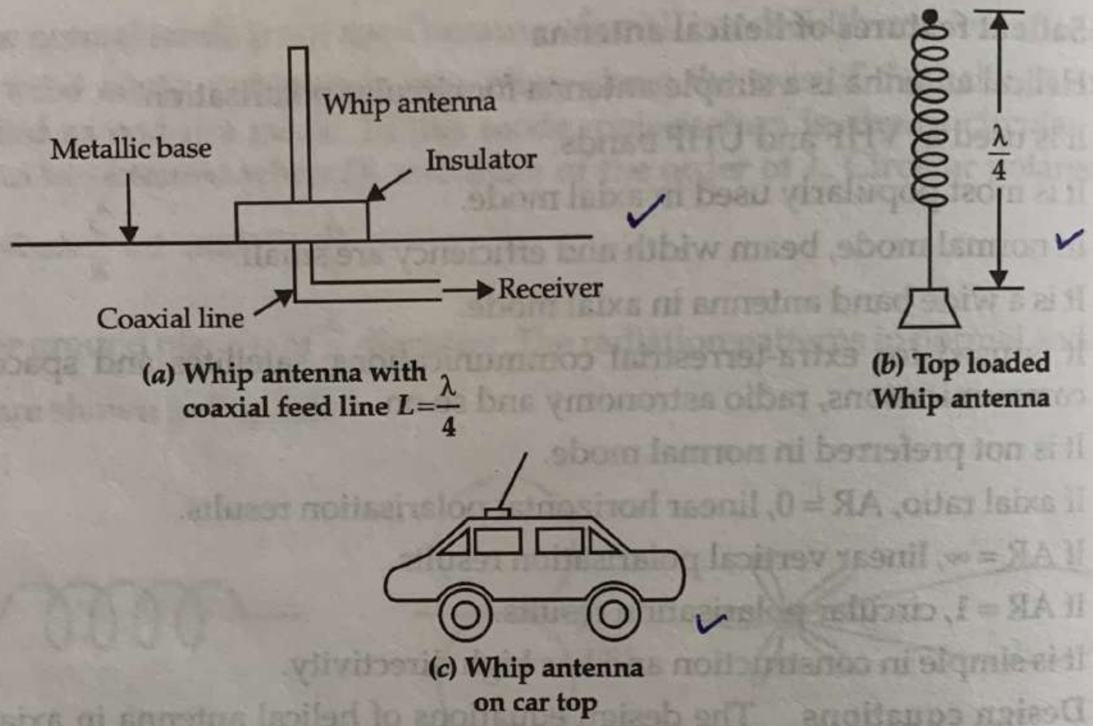


Fig. 6.37 *Whip antennas*

Salient features of whip antenna

1. It gives a gain of three with respect to isotropic radiator in a direction perpendicular to its axis.
2. Its length can be reduced by loading.
3. It can be used in HF and VHF bands.
4. It is used mostly for mobile communications.
5. A continuously wound step tapered helical conductor with a uniform current distribution gives a 50Ω match at its resonant frequency. Its standard length is 4 feet for most of the applications.

6.21 FERRITE ROD ANTENNA

It is an antenna which consists of a ferrite rod on which a coil with a number of turns are wound. A typical structure is shown in Fig. 6.38.

This is commonly used in all transistorised radio receivers. It has a ferrite rod with one or more coils. A typical structure of ferrite rod antenna is shown in Fig. 6.38.

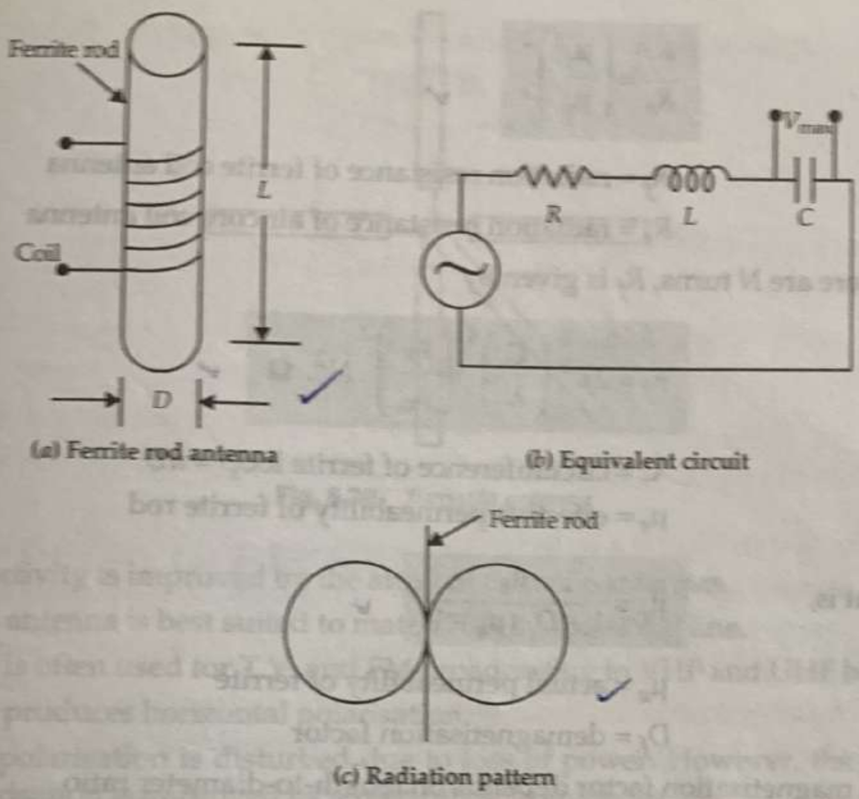


Fig. 6.38 *Ferrite rod antenna with equivalent circuit and radiation pattern*

flux density

$\because \frac{E}{H} = \eta$

$V = \omega B A N f \mu_r$
$= (2\pi f)\cdot(\mu_0 H) A N f \mu_r$
$2\pi f \cdot \mu_0 \frac{E}{\eta} \cdot A N f \mu_r$
$\frac{2\pi c}{\lambda} \cdot \mu_0 \frac{E}{\eta} A N f \mu_r$
$\frac{2\pi}{\lambda} \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \cdot \frac{\mu_0 E A N f \mu_r}{\sqrt{\frac{\mu_0}{\varepsilon_0}}}$

$\because \eta = \sqrt{\frac{\mu_0}{\varepsilon_0}}$

$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}}$

In the Fig. 6.38,

D = diameter of the ferrite rod

L = length of the rod

The induced voltage is given by

$$V = \frac{2\pi}{\lambda} E S N K \mu_r, \text{ volt} \quad ...(6.72)$$

where E = electric field present at antenna, V/m

μ_r = permeability of the rod

K = modifying factor which takes care of coil length

= 1 for short coils

= 0.7 for coils of full length of rod

S = cross-sectional area of the rod

N = number of turns in the coil.

Effective length of the antenna is defined as

$$l_{\text{eff}} = \frac{V}{E} = \frac{2\pi}{\lambda} S K \mu_r, \text{ m} \quad ...(6.73)$$

$l_{eff} = \frac{V}{E} = \frac{2\pi}{\lambda} A N f \mu_r$ meters

The relation between radiation resistance of the ferrite coil and that of air core coil is

$$\frac{R_f}{R_r} = \left(\frac{\mu_e}{\mu_o}\right)^2 \quad \text{...(6.74)}$$

where R_f = radiation resistance of ferrite coil antenna

R_r = radiation resistance of air core coil antenna

If there are N turns, R_f is given by

$$R_f = 2\lambda^2 \left(\frac{C}{\lambda}\right)^4 \left(\frac{\mu_e}{\mu_o}\right)^2 N^2, \ \Omega \quad \text{...(6.76)}$$

where C = circumference of ferrite loop = πD

μ_e = effective permeability of ferrite rod

That is,

$$\mu_e = \frac{\mu_a}{1 + D_f(\mu_a - 1)} \quad \text{...(6.76)}$$

μ_a = actual permeability of ferrite

D_f = demagnetisation factor

The magnetisation factor depends on length-to-diameter ratio.

Salient features of ferrite rod antenna:

1. It is used in all radio receivers.
2. It is compact.
3. Its quality factor, Q is very high. It exhibits high selectivity and more induced voltage.

6.22 TURNSTILE ANTENNA

It is an antenna composed of two dipole antennas perpendicular to each other. They intersect at their mid-points. The currents on the two dipoles are equal and in phase quadrature.

Salient features of turnstile antenna:

1. Turnstile antenna consists of two half-wave dipoles which are perpendicular to each other. The dipoles are excited with a phase difference of 90° (phase quadrature) with equal currents.
2. A typical antenna is shown in Fig. (6.39).
3. The excitation is provided by different non-resonant lines of unequal length.
4. It produces almost an omni-directional pattern.
5. The electric field of turnstile antenna is given by

$$E(\theta) = \frac{\cos\left(\frac{\pi}{2}\sin\theta\right)}{\cos\theta}\sin\omega t + \frac{\cos\left(\frac{\lambda}{2}\cos\theta\right)}{\sin\theta}\cos\omega t \quad \text{...(6.77)}$$