6.9 DIPOLE ARRAYS

An array antenna is one which consists of a group of elements arranged linearly or in a plane. When an antenna element is bi-directional or multi-directional in its radiation characteristics, an array of such elements yields a uni-directional pattern. An array is said to be linear if the elements are arranged along a straight line with equal spacing. Arrays are divided into:

1. Broadside array
2. End-fire array.

6.10 BROADSIDE ARRAY

Broadside array is an array which gives a radiation pattern whose main beam is perpendicular to the axis of the array.

In a wider sense, broadside array is a linear or a planar array antenna whose direction of maximum radiation is perpendicular to the line or plane of the array.

Salient features of broadside arrays

1. A number of dipoles of equal size are used.
2. The elements are spaced equally.
3. All the dipoles are fed in the same phase.
4. Null-to-Null beam width of broadside array.

   Beam width between first Nulls

   $$= \frac{2\lambda}{Nd} \qquad \text{...(6.3)}$$

   where λ = wavelength
   N = number of elements
   d = spacing between the elements.
5. The length of the broadside array can be 2 to 10λ.
6. Typical spacing between the elements vary from $\frac{\lambda}{2}$ to λ.
7. The number of elements to be used depends on the beam width requirement, cost and space available.
8. A broadside array is often used along with a reflector antenna. The back lobe is now reflected forward and adds to the forward lobe.
9. When a broadside array is used with a reflector, it is possible to improve its gain and directivity and the broadside array becomes uni-directional.
10. This array is often used in overseas broadcast systems.

11. It is used for LF, MF, HF and higher band of frequencies. A typical broadside array is shown in Fig. 6.11.

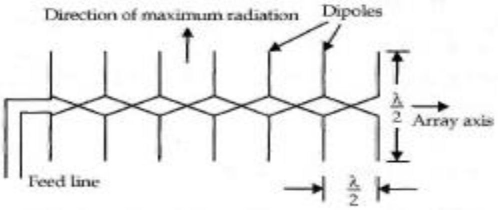


Fig. 6.11 *Broadside array*

12. A typical radiation pattern of a broadside array is shown in Fig. 6.12.

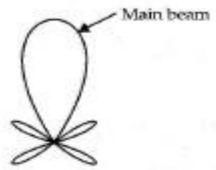


Fig. 6.12 *Radiation pattern of broadside array*

6.11 END-FIRE ARRAY

End-fire array is an array which gives a radiation pattern whose main beam is along the axis of the array.

In a wider sense, end-fire array is a linear or planar antenna whose direction of maximum radiation is along the line or in the plane of the array.

Salient features of end-fire array

1. A number of dipoles or elements of equal size are used.
2. The elements are equally spaced.
3. The elements are fed with different phases.
4. The additional phase for each element is given by

$$\alpha_{N-1} = (N-1)\, kd \cos\phi$$

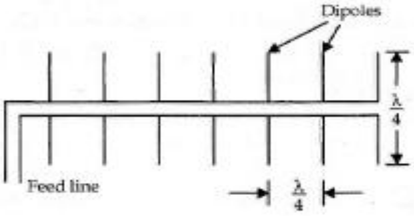
where $k = \frac{2\pi}{\lambda}$, d = spacing, ϕ is the angle between the line of observation and axis of the array.

Null-to-Null to beam width of an end-fire array is

$$\text{B.W.F.N.} = 2\sqrt{\frac{2\lambda}{Nd}} \qquad \text{...(6.4)}$$

6. In this, the pattern is uni-directional.
7. The physical arrangement of the elements in the end-fire array is the same as that of broadside array.
8. The number elements to be used depends on the beam width requirements, cost and space available.
9. These are often used in LF, MF, HF and higher band of frequencies.
10. These arrays are used for point-to-point communications and in overseas broadcasting systems.
11. In this array, the elements are spaced at $\frac{\lambda}{4}$ or $3\frac{\lambda}{4}$.

A typical end-fire structure is shown in Fig. 6.13 and its radiation pattern is shown in Fig. 6.14.



6.12 FOLDED DIPOLE

It is an antenna composed of two or more parallel and closely spaced dipole antennas connected together at their ends with one of the dipole antennas being centre fed.

The folded dipole antenna is shown in Fig. 6.15.

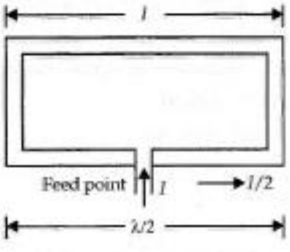


Fig. 6.15 *Folded dipole antenna*

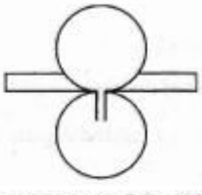
Salient features of folded dipole

1. It is a single antenna, but consists of two elements.
2. The first is fed directly and the second is inductively coupled at the ends.
3. Its radiation pattern is the same as that of a straight dipole.
4. If the current fed is I, then the current in each arm is $\frac{I}{2}$, provided the two arms have the same dimensions. If it is a straight dipole, the total current I flows.
5. When the same power is applied, only half of the current flows in the first arm. Therefore, the input impedance is four times that of the straight dipole. That is,

$$R_r = 4 \times 73 = 292\Omega.$$

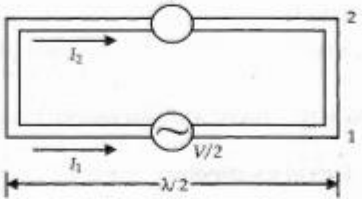
6. If the diameters of the two arms of folded dipole are different, impedance transformation of 1.5 to 25 is achievable.
7. The spacing between the arms is very small and is of the order of $\frac{\lambda}{100}$.
8. Folded dipole is used in Yagi-Uda antenna as an active element.
9. It has the advantages of high input impedance, greater band width, ease and low cost of construction with better impedance-matching characteristics.

A typical radiation pattern of a folded dipole is shown in Fig. 6.16.



Proof The equivalent diagram of the folded dipole of Fig. 6.15 is shown in Fig. 6.17.

When a voltage V is applied to the folded dipole, it is divided equally in each arm of the dipole. That is, the voltage in each dipole is $\frac{V}{2}$. Hence, we have



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

Here, I_1 = current in (1) and I_2 is current in (2)

Z_{11} = self impedance of dipole (1)

Z_{12} = mutual impedance between (1) and (2)

For equal dimensions of the dipoles

$$I_1 = I_2 = I$$

So $$\frac{V}{2} = I\,(Z_{11} + Z_{12})$$

As the two dipoles are very close and the spacing is very small,

$$Z_{11} = Z_{12}$$

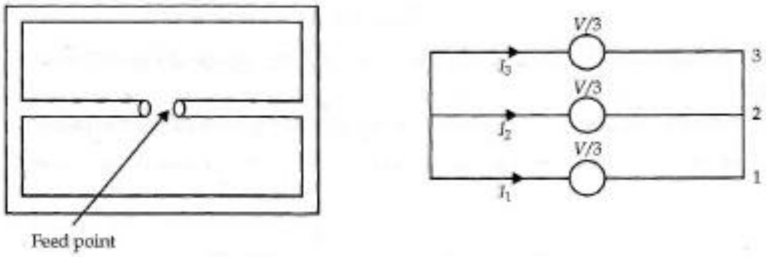
or $$\frac{V}{2} = I\,(2Z_{11})$$

or $$Z = \frac{V}{I} = 4Z_{11}$$

$$= 4 \times 73 = 292\,\Omega$$

$R_i = Z_r$ = terminal or input or radiation resistance = $292\,\Omega$

Proof The three armed folded dipole is shown in Fig. 6.18 (*a*) and its equivalent diagram is shown in Fig. 6.18 (*b*).



(*a*) Three armed folded dipole

(*b*) Equivalent diagram of three armed folded dipole

Fig. 6.18 *Folded dipole and equivalent diagram*

For equal dimensions of the dipoles,

$$I_1 = I_2 = I_3 = I$$

So $$\frac{V}{3} = I\,(3Z_{11})$$

r $$\frac{V}{I} = 3 \times 3Z_{11} = 9z_{11}$$

$$= 9 \times 73 = 657\,\Omega$$

That is, $Z_i = R_r = 657\,\Omega$

r, in general $R_r = Z_i = K^2 \times 73\,\Omega$

here K = number of arms.

The impedance of the dipole depends on

1. spacing between dipoles and
2. radius of the dipoles.

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 inductive. The impedances of the directors are capacitive. A typical structure of Yagi-Uda antenna is shown in Fig. 6.28.

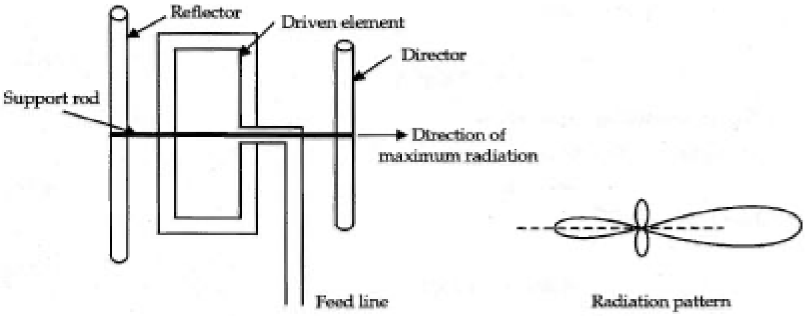


Fig. 6.28 *Yagi-Uda antenna and radiation pattern*

Salient features of Yagi-Uda antenna

1. It consists of a driven element, a reflector and one or more directors.
2. Driven element is usually a folded dipole which is excited. Director is a straight conductor placed in front of the driven element towards transmitter. Reflector is also a straight conductor placed behind the driven element.
3. Directors and reflector are called parasitic elements.
4. The length of the folded dipole is about $\frac{\lambda}{2}$ and it is at resonance. Length of the director is less than $\frac{\lambda}{2}$ and length of the reflector is greater than $\frac{\lambda}{2}$.
6. Its radiation pattern is almost uni-directional and gives a gain of about 7 dB.
7. It is used as a transmitting antenna at HF and used for TV reception at VHF.
8. Back lobe can be reduced by bringing the elements closer. This reduces the input impedance of the antenna and hence there will be a mismatch.
9. The effect of parasitic elements depends on their distance and tuning. In other words, the effect depends on the magnitude and phase of the current induced in them.

6.17 LOG-PERIODIC ANTENNA

A typical structure of log-periodic antenna is shown in Fig. 6.30.

It is an array antenna which has structural geometry such that its impedance is periodic with the logarithm of the frequency.

It is a non-linear array in which the spacing of the elements as well as their dimensions are unequal. However, excitation is uniform. It is basically called a frequency-independent antenna. It can be used to receive a good number of TV channels without any deterioration of the received field strength.

Salient features

1. It is a frequency-independent antenna.
2. The input impedance variation of the antenna with the log of frequency is periodic and hence the name. This is shown in Fig. 6.31.

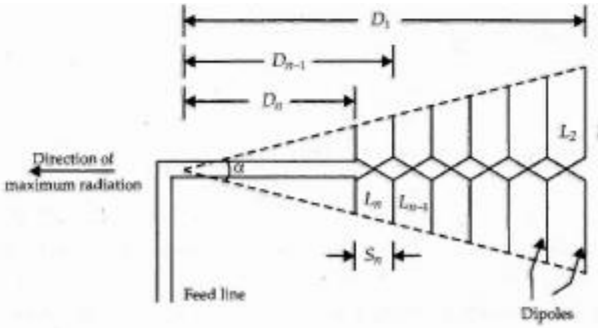


Fig. 6.30 *Log-periodic antenna or array*

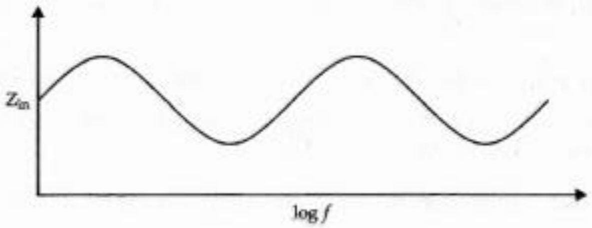


Fig. 6.31 *Impedance characteristics of log-periodic antenna*

3. It is an array of non-identical dipoles which are all excited equally.
4. It is a non-uniform array where the spacing between the elements is unequal.
5. Its impedance, directional patterns and directivity are constant with frequency.
6. The gain of a well-designed antenna lies between 7.5 and 12 dB_i.
7. It is a broad band antenna.
8. It has uni-directional characteristics.
9. There are a variety of log-periodic structures and all of them are not frequency-independent.
10. They are used in VHF and UHF bands.
11. They are used for TV reception and can receive a number of channels.

Design Equations The design equations are:

Scale factor, $\tau = \dfrac{D_n}{D_{n-1}} = \dfrac{L_n}{L_{n-1}}$, $n = 1, 2, 3$

Spacing factor, $\sigma = \dfrac{S_n}{2L_n} = \dfrac{S_n}{S_{n-1}}$

$$S_n = D_{n-1} - D_n$$

where α = wedge angle or included angle $= 2\tan^{-1}\left(\dfrac{1-\tau}{4\sigma}\right)$

Here, B = desired bandwidth

Total length of the array is

$$L = \frac{\lambda_{\max}}{4}\left(1 - \frac{1}{B_d}\right)\cot\frac{\alpha}{2}$$

Here, $\lambda_{\max} = 2l_{\max} = \dfrac{v_0}{f_{\min}}$

The number of elements in the array is

$$N = 1 + \frac{\ln(B_d)}{\ln(1/\tau)}$$

7.5 PARABOLIC REFLECTOR

It is a reflector antenna which has the shape of paraboloid and employs the properties of parabola.

It can also be defined as a reflector which is part of a paraboloid of revolution.

The parabola, it is a plane curve obtained by the locus of a point which moves so that its distance from another point, called the focus, plus its distance from a straight line, called directrix, is constant.

A paraboloid is a three dimensional surface obtained by revolving the parabola about its axis. The paraboloid is called the parabolic reflector or dish antenna.

The geometry of a parabolic reflector in transmitting mode is shown in Fig. 7.3.

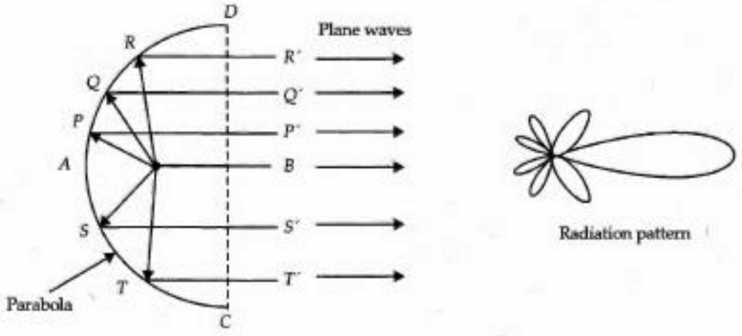


Fig. 7.3 *Geometry of parabolic reflector in transmitting mode and its radiation pattern*

Here AB = axis of the parabola
CD = mouth diameter, D_a
AF = focal length = l_f
A = vertex
F = focus
CAD = parabola
The line CD = directrix
AF/CD = aperture of the parabola

Operation of parabolic reflector If a feed antenna is placed at the focus, all the waves are incident on the reflector and they are reflected back, forming a plane wave front. By the time the reflected waves reach the directrix, all of them will be in phase, irrespective of the point on the parabola from which they are reflected. Hence the radiation is very high and is concentrated along the axis of the parabola. At the same time, waves will be cancelled in other directions as a result of path and phase differences.

The main purpose of the parabolic reflector is to convert a spherical wave into a plane wave.

The difference between the plane wave and spherical wave are shown in Fig. 7.5.

If the primary or feed antenna is non-directional or isotropic, the beam width of the radiation pattern of the paraboloid is given by:

HPBW, $= \phi = \frac{70\lambda}{D_a}$

BWFN, $\phi_0 = 2\phi = \frac{140\lambda}{D_a}$ ...(7.5)

Directivity, $$D = 9.87\left(\frac{D_a}{\lambda}\right)^2$$

Here,

ϕ = half-power beam width, in degrees

ϕ_0 = beam width between first nulls, in degrees

λ = wavelength, m

D_a = mouth diameter, m.

For a large, uniformly illuminated rectangular aperture,

HPBW $= \phi = \dfrac{57.5\lambda}{L}$ (degrees)

BWFN $= \phi_0 = \dfrac{115\lambda}{L}$ (degrees) ...

Directivity, $D = \dfrac{4\pi A}{\lambda^2}$

Here,

L = length of the aperture, in λ

A = aperture area, m^2.

7.7 FEED SYSTEMS FOR PARABOLIC REFLECTORS

It is possible to feed the reflector in several ways. Some of them are:

1. Half-wave dipole
2. An array of collinear dipoles
3. Yagi-Uda antenna
4. Centre-fed with spherical reflector
5. Horn
6. Cassegrain feed.

7.7.1 Half-Wave Dipole Feed

This has bi-directional radiation characteristics. Ideally, uni-directional antenna is required as feed antenna. In this case the reflected rays will interfere with the backward radiated rays and disturb the plane wave–front because of phase difference.

7.7.2 Yagi-Uda Antenna Feed

Although this produces a uni-directional pattern, the size of the antenna is a common problem. It blocks the reflected rays.

7.7.3 Array of Collinear Dipoles Feed

This is another possible primary feed antenna. But feeding with a dipole array involves changing from unbalanced system to a balanced system.

7.7.4 Centre-fed with Spherical Reflector

This is shown in Fig. 7.10.

Salient features of centre-fed with spherical reflector

1. The primary antenna is kept at the focus of the paraboloid for better reception or transmission.
2. Direct radiation from the feed spoils the directivity. To prevent direct radiation, a small spherical reflector is used which redirects the direct radiations back to the paraboloid.
3. The spherical shell obstructs the reflected rays. But this is not high. If a spherical shell of diameter 2 cm is placed at the focus of 2 m paraboloid, the obstruction is only one percent.

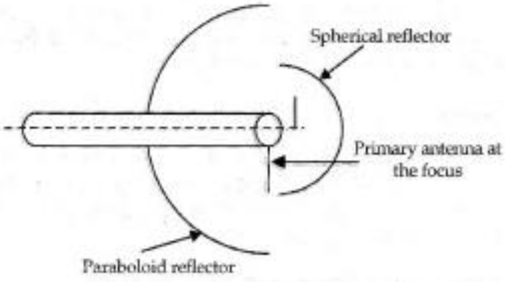


Fig. 7.10 *Centre-fed with spherical reflector*

7.7.5 Horn Feed

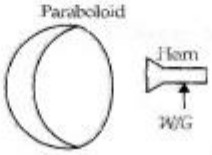


Fig. 7.11 *Horn feed*

Salient features of horn feed

1. Horn has moderate directional characteristics towards the reflector.
2. There is no direct radiation.
3. Horn obstructs the reflected rays when it is placed at the focus. But obstruction is not high. It may be one or two percent of the total reflected energy.

7.7.6 Cassegrain Feed

It is named after the early eighteenth century astronomer. The feed mechanism is shown in Fig. 7.12. It uses:

- a parabolic reflector,
- a hyperbolic reflector and
- a feed antenna, horn with waveguide.

One of the foci of the hyperbolic reflector coincides with the focus of the paraboloid. When electromagnetic rays from a horn antenna are incident on the hyperboloid reflector, they are reflected back and are then incident on the paraboloid. These incident rays are reflected and propagate as a plane wave front.

Hyperbola is a curve traced by a point which moves so that its ratio of the distance from a fixed point, the focus to its distance from a fixed straight line, the directrix is a constant and is greater than unity. The hyperboloid is a three dimensional surface obtained by revolving the hyperbola about its axis. The size of

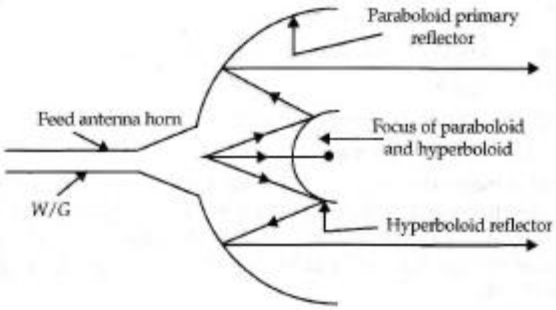


Fig. 7.12 *Cassegrain mechanism in transmission mode*

the hyperboloid depends on its distance from the primary feed antenna, mouth diameter of horn and the frequency of operation.

Applications of Cassegrain feed

1. It is used when it is required to keep the primary antenna in a convenient position.
2. It is used when it is desired to use a short transmission line or waveguide for connecting the receiver or transmitter to the primary antenna.
3. It is used for low-noise receiver applications.

If the active part of the transmitter or receiver is kept at the focus, it is possible to reduce power loss. But the size of the transmitter or receiver prohibits such a placing. This is the reason why Cassegrain feed is best suited for low-noise applications.

7.9 HORN ANTENNA

It is a radiating element which has the shape of a horn. It is a waveguide one end of which is flared out.

A waveguide, when excited at one end and open at the second end, radiates. However, radiation is poor and non-directive pattern results because of the mismatch between the waveguide and free space. The mouth of the waveguide is flared out to improve the radiation efficiency, directive pattern and directivity.

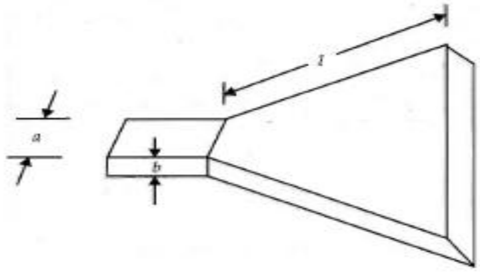


Fig. 7.20 *Sectoral H-plane horn*

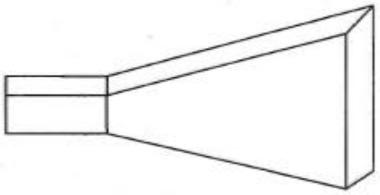


Fig. 7.21 *Sectoral E-plane horn*

Sectoral horn is a horn in which flaring exists only in one direction.

If flaring is along the direction of electric field, it is called **sectoral *E*-plane horn.**

If flaring is along the direction of magnetic field, it is called **sectoral *H*-plane horn.**

If flaring is along E and H, the horn is called **pyramidal horn.** It has the shape of a truncated pyramid.

If the walls of a circular waveguide are flared out, a **conical horn** is obtained.

$$\theta = 2\tan^{-1}\left(\frac{d}{2l}\right)$$

$$= 2\cos^{-1}\left(\frac{l}{l+\delta}\right)$$

and

$$l = \frac{d^2}{8\delta}$$

Half-power beam width of optimum flared horns are

$$\phi_E = \frac{56\lambda}{d_E} \text{ degrees}$$

$$\phi_H = \frac{67\lambda}{d_H} \text{ degrees}$$

The directivity of horn is $D = \dfrac{7.5A_a}{\lambda^2}$

Power gain, $g_p = \dfrac{4.5A}{\lambda^2}$

Applications of horns

1. Horns are used at microwave frequencies where moderate gains are sufficient.
2. They are used as feed elements.
3. They are often used in laboratories for the measurement of different antenna parameters.

Salient features of horns

1. Horn becomes small if the flare angle is small. Its radiation pattern is directive, wave front is spherical, mouth area is small and its directivity is small.
2. Flare angle is related to axial length.
3. If $\theta = 15°$, when $l/\lambda = 50$, the beam width is 23° and directivity is 120.
4. Directivity of pyramidal horn is more as the flare is in more than one direction.
5. Its directivity is not as high as that of paraboloid.
6. It is used as radiator.
7. It is easy to use with the waveguide.
8. It is used as primary antenna for paraboloid.
9. The gain of the conical antenna is optimum for a given slant length of flare, l and

$$d \approx \left(\frac{3}{\lambda}\right)^{1/2} \qquad \text{...(7.14)}$$

Here, d = diameter of the aperture.

10. The directivity of a loss-less horn antenna is its gain and it is given by

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

$$= \frac{4\pi\eta_a}{\lambda^2} A_a$$

Here, A_e is effective aperture, m^2

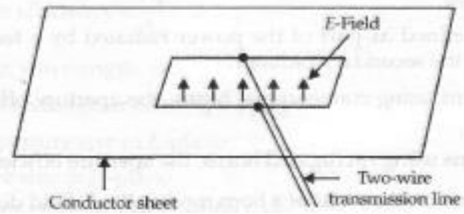
A_a is actual area or physical area, m^2

7.11 SLOT ANTENNA

It is a radiating element formed by a slot in a metallic surface. An opening cut in a conducting sheet or in one of the walls of the waveguide acts as the antenna. It is excited suitably either by a co-axial cable or through the waveguide.

Salient features of slot antennas

1. A basic slot has a length of $\frac{\lambda}{2}$ and its width is much less than $\frac{\lambda}{2}$.
2. Slots are usually excited by a co-axial cable at a distance of about 0.05λ from one end of the slot to get reasonable impedance properties.
3. A horizontal slot with such an excitation produces vertical polarisation and vice-versa. In fact, the slot radiates from both sides.
4. If the slot is boxed with an internal dimension of $d = \frac{\lambda}{4}$, the radiation is outward from the opening of the box.
5. A slot and a dipole of $\frac{\lambda}{2}$ length have similar gain and radiation characteristics. But there is a difference in polarisation.
6. In order to increase the gain and directivity, array of slots is used.
7. Cylindrical arrays of slots are found to produce omni-directional radiation in the horizontal plane with horizontal polarisation.
8. When a high frequency field exists across a thin slot in a conducting plane, it radiates.
9. A slot excited by a two-wire line is shown in Fig. 7.26. The electric field in the $\frac{\lambda}{2}$ slot is sinusoidal.



7.19 MICROSTRIP OR PATCH ANTENNAS

These are antennas made from patches of conducting material on a dielectric substrate above a ground plane.

Construction It consists of a very thin ($l << \lambda$) metallic strip called a patch placed above a ground plane. The strip and ground plane are separated by a dielectric sheet called substrate as shown in Fig. 7.45. The radiating element and feed lines are usually photoetched on the dielectric substrate. The wide use of printed circuits led to the construction of radiating elements and inter-connecting transmission lines using similar technology.

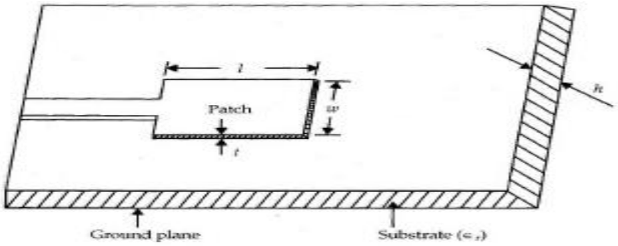
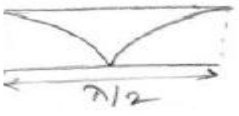
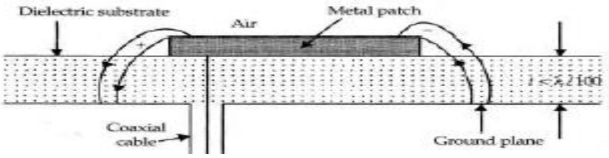


Fig. 7.45 *Microstrip antenna*





Applications

1. They are used in spacecrafts and aircrafts.
2. They are used in applications where aerodynamic drag due to antennas should be nil.
3. They are used in telemetry, satellite communications and defence radar systems to operate over a frequency range of 1 to 10 GHz.

Advantages

1. Small size.
2. Low weight.
3. Low cost.
4. Ease of installation.
5. It does not give rise to aerodynamic drag when used in aircrafts.
6. These are low profile antennas.
7. These antennas can be flush mounted to a metallic conductor or to other surfaces. They do not require space for feed line. The feed line can be placed behind the ground plane.

Disadvantages

1. Their efficiency is less.
2. Their band width is small and is typically a few percent.