UNIT-III
VHF,UHF And Microwave Antenna-II

Micro strip Antennas- Introduction, features, advantages and limitations, Rectangular patch antennas- Geometry and parameters, characteristics of Micro strip antennas, Impact of different parameters on characteristics, reflector antennas - Introduction, Flat sheet and corner reflectors, parabola reflectors- geometry, pattern characteristics, Feed Methods, Reflector Types -Related Features, Lens Antennas - Geometry of Non-metallic Dielectric Lenses, Zoning , Tolerances, Applications, Illustrative Problems.

Micro strip Antennas:

A Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure

The patch is generally made of conducting material such as copper or gold and can take any possible shape.

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape as shown in Figure

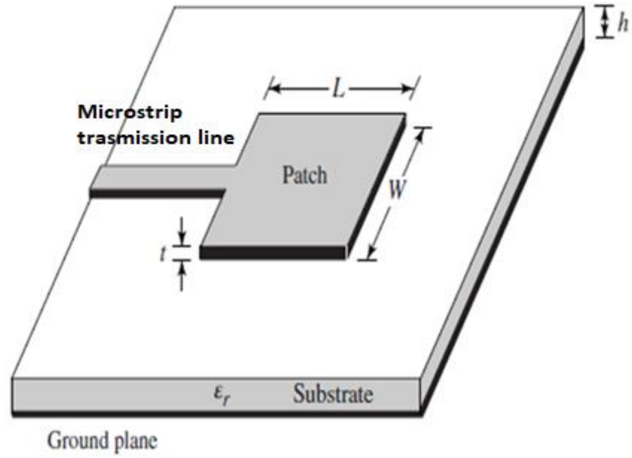


Fig. Microstrip antennas.

Advantages:

The principal advantages are given below:

- Light weight, smaller size and low volume.
- Low profile planar configuration which can be easily made conformal to host surface.
- Low fabrication cost, hence can be manufactured in large quantities.
- Supports both, linear as well as circular polarization.
- Can be easily integrated with microwave integrated circuits (MICs).
- Capable of dual and triple frequency operations.
- Mechanically robust when mounted on rigid surfaces.
- With the microstrip antennas it is easy to form large arrays with half-wavelength or lesser spacing.

Limitations:

Microstrip patch antennas suffer from a number of disadvantages as compared to conventional antennas. Some of their major disadvantages are given below:

- Narrow bandwidth
- Low efficiency
- Low Gain
- Extraneous radiation from feeds and junctions
- Poor end fire radiator except tapered slot antennas
- Low power handling capacity.
- Surface wave excitation
- The size of a microstrip antenna is inversely proportional to its frequency. At lower frequencies the size of antenna becomes large.
- The design complexity gets enhanced due to their smaller size.

Applications:

- Wireless applications
- Mobile phones and Pagers
- Radars
- Satellite communication
- Radio altimeter
- The telemetry and communication antennas on missiles
- Feed elements in complex antennas
- Satellite navigation receiver
- Biomedical radiator

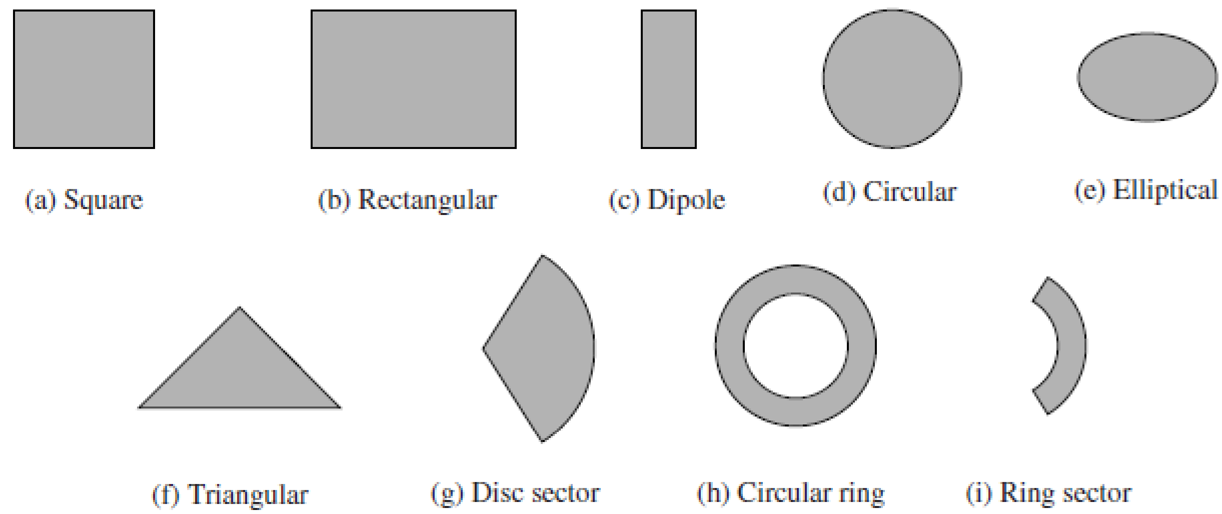
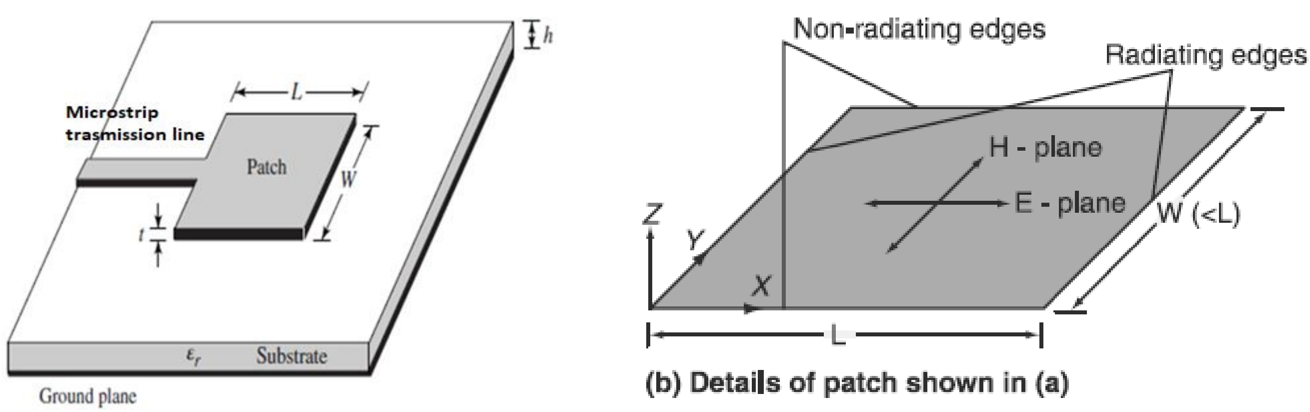


Fig . Representative shapes of microstrip patch elements.

Rectangular Microstrip Antennas:

The rectangular shape is the simplest and most widely used configuration for fabrication of microstrip antennas. The basic structure of the rectangular microstrip antenna is shown in figure (a). The length L causes resonance at its half-wavelength frequency.

The two ends of the length 'L' are called radiating edges and other two are called non-radiating edges. The radiating edges produce single polarized waves and non-radiating edges produce cross polarization.



(a) Rectangular microstrip antenna

Fig.1 Basic structure of a rectangular microstrip antenna.

The field variations of the rectangular patch antenna for both sinusoidal and uniform variations are given below.

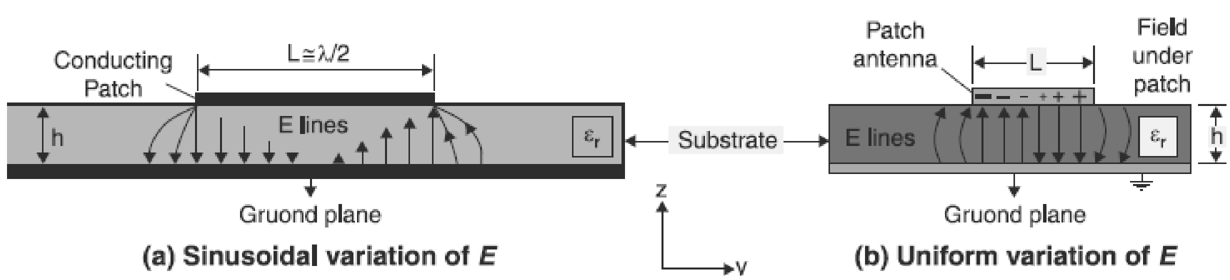


Fig 2. Patch antenna with E field distribution.

Due to the half wave length of the patch, the fields under the L-edges are of opposite polarity and when the fields curved out and finally propagates out into the direction normal to the substrate and the radiation from the two sides are added up because the fields are in phase (both facing left).
The radiation intensity goes on decreasing as fields move away from the edges and cancel due to out of phase.

For effective radiation from a microstrip antenna

1. The structure needs to be a half-wavelength resonator ($L=\lambda/2$)
2. The dielectric substrate should be sufficiently thicker and with low dielectric constant
3. The height of the substrate needs to be a fraction of the wavelength.

Let us consider the microstrip antenna fed by a microstrip transmission line as shown in fig. The microstrip or patch antenna, microstrip transmission line and the ground plane are made of a high-conductivity metal. The patch is of length L, width W, and sitting on top of a dielectric substrate of thickness h with permittivity ε_r.

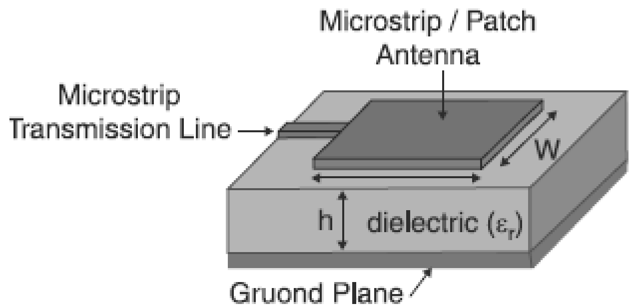


Fig.3.Geometry of a microstrip patch antenna.

The frequency of operation of the patch antenna is determined by the length L and is given by

$$f_c \cong \frac{c}{2L\sqrt{\varepsilon_r}} = \frac{1}{2L\sqrt{\varepsilon_0 \varepsilon_r \mu_0}}$$

According to the recent inventions the frequency of operation will also depends on the width 'w' and the relation is given by,

$$f_{r,nm} = \frac{c}{2\sqrt{\varepsilon_{r,eff}}}\left[\left\{\frac{n}{L+2\Delta L}\right\}^2 + \left\{\frac{m}{W+2\Delta W}\right\}^2\right]^{1/2}$$

The expression for dominant mode (n=1 and m=0) is given by.

$$f_{r,nm} = \frac{c}{2(L+2\Delta L)\sqrt{\varepsilon_{r,eff}}}$$

In the above equations, ΔL and ΔW are the incremental length and width which account for the fringing of field at the respective edges.
The width 'w' is an important parameter because it controls the input impedance of the antenna. When the width is increased the input impedance of the antenna will decrease. The width of the patch also controls the radiation pattern of the antenna.
The normalized pattern of the antenna can be obtained by plotting the fields E_θ and E_ϕ which is approximately given as

$$\mathbf{E}_{\boldsymbol{\theta}} = \frac{\sin[(\boldsymbol{\beta\omega}\sin\boldsymbol{\theta}\sin\boldsymbol{\phi})/2]}{[(\boldsymbol{\beta\omega}\sin\boldsymbol{\theta}\sin\boldsymbol{\phi})/2]}\cos[(\boldsymbol{\beta L}/2)\sin\boldsymbol{\theta}\cos\boldsymbol{\phi}]\cos\boldsymbol{\phi}$$

$$\mathbf{E}_{\boldsymbol{\phi}} = -\frac{\sin[(\boldsymbol{\beta\omega}\sin\boldsymbol{\theta}\sin\boldsymbol{\phi})/2]}{[(\boldsymbol{\beta\omega}\sin\boldsymbol{\theta}\sin\boldsymbol{\phi})/2]}\cos[(\boldsymbol{\beta L}/2)\sin\boldsymbol{\theta}\cos\boldsymbol{\phi}]\sin\boldsymbol{\phi}$$

The net magnitude of electric field at any point is a function of θ and ϕ and is given by

$$E(\theta,\phi) = \sqrt{(E_\theta^2 + E_\phi^2)}$$

The radiation patterns obtained for a specific case of $W = L = \lambda/2$ in $\phi = 0$ and $\phi = 90°$ plane are illustrated in Fig. 4

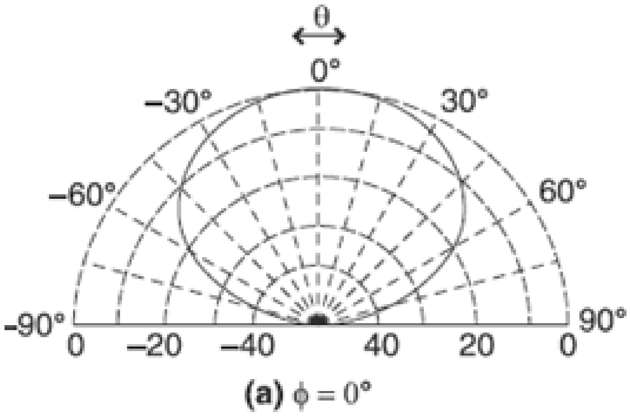


Fig 4. Radiation patterns of MSA

Feed Methods:

Microstrip patch antennas can be fed in a variety of ways. These feeding methods can be classified under the categories of (a) contacting, and (b) non-contacting feeds.

In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line or a coaxial cable.

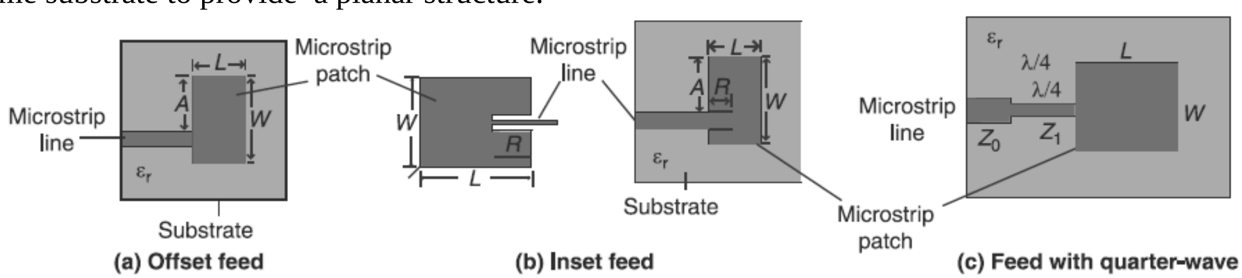
In the non-contacting scheme, electromagnetic coupling is used to transfer the power between the feed line and the radiating patch.

Some of most popular feed techniques include (i) microstrip line, (ii) coaxial probe, (iii) aperture coupling, and (iv) proximity coupling.

The first two techniques are contacting feeds, and the last two are non-contacting schemes.

(a).Microstrip Feed

In this technique, a conducting strip is connected directly to the edge of the microstrip patch. The conducting strip is much smaller in width as compared to the width of the patch. The advantage is that the feed can be etched on the same substrate to provide a planar structure.



(a) Offset feed (b) Inset feed (c) Feed with quarter-wave matching section

(b)Coaxial Feed:

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As shown in Figure the inner conductor of the coaxial connector is connecting to the radiating patch, while the outer conductor is connected to the ground plane.

The main advantage of this type of feed scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance.

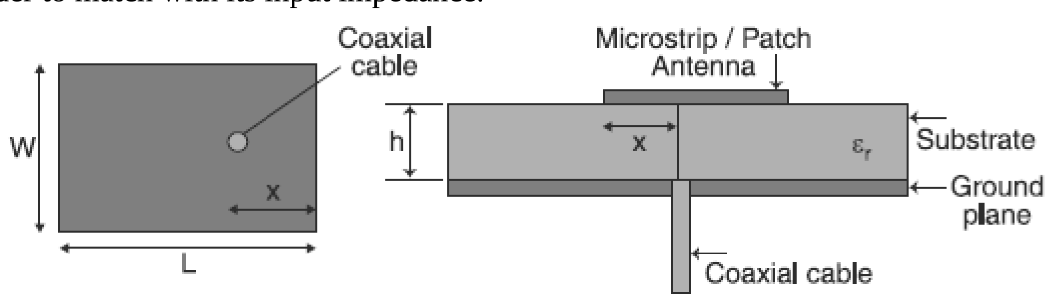


Fig.(a) coaxial feed

(c) Aperture-Coupled Feed:

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Fig(b). Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.

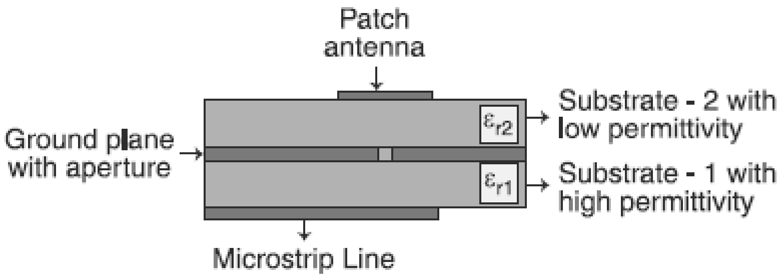


Fig.(b) **Aperture-Coupled Feed**

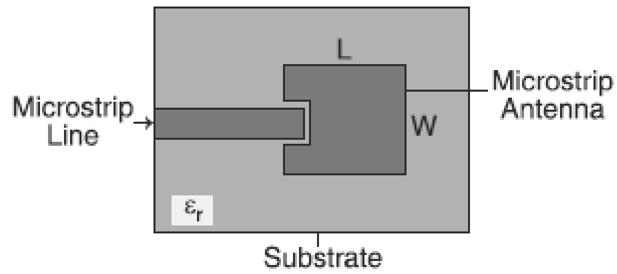


Fig.(c) **Proximity Coupled Feed**

(d). Proximity Coupled Feed: Proximity Coupled Feed is shown in the above fig(c).

Characteristics of Microstrip Antennas:

(a).Radiation Pattern: Two radiation patterns in $\phi = 0$ (i.e., in azimuth) and $\phi = 90^\circ$ (in elevation) are shown in figure (a) and (b).

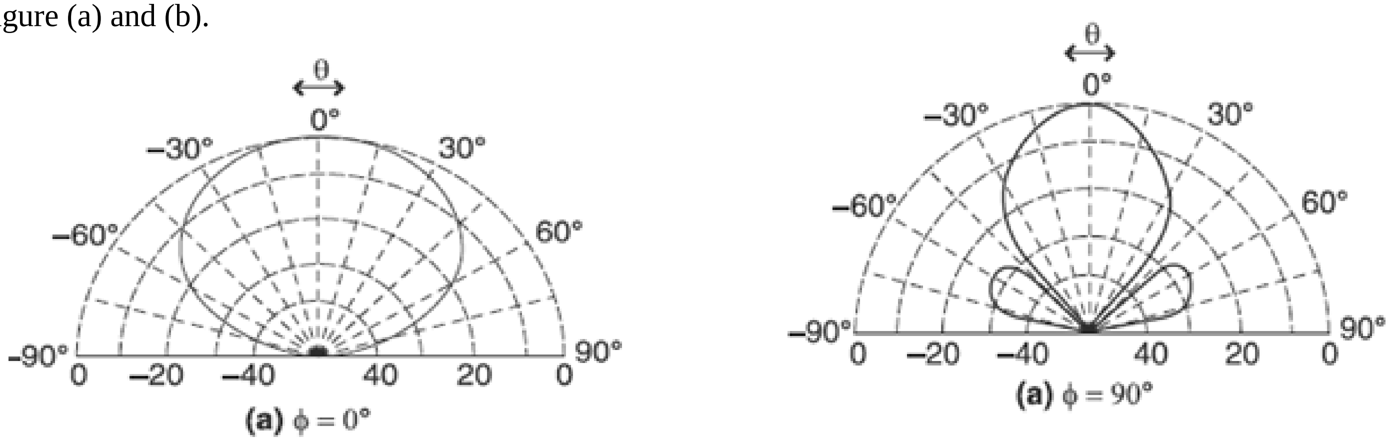


Fig. (a) and (b) Normalized Radiation pattern

Fringing field is responsible for the radiation. The smaller the ε_r more the fringing field . Therefore, use of a substrate with smaller ε_r yields better radiation.

(b).Beam Width: From radiation pattern figure , it can be noted that MSA's generally have a very wide beam width, both in azimuth and elevation.

(c).Directivity: The directivity of microstrip patch antenna is given by

$$D = \frac{2h^2 E_0^2 W'^2 K_0^2}{P_r \pi \eta_0}$$

(d).Gain:

Gain of a rectangular microstrip patch antenna with air dielectric is roughly estimated between 7–9 dB

(e).Bandwidth:

The *impedance bandwidth* of a patch antenna is strongly influenced by the spacing between the patch and the ground plane. As the patch is moved closer to the ground plane, less energy is radiated and more energy is stored in the patch capacitance and inductance: that is, the quality factor Q of the antenna increases and impedance bandwidth decreases.

The bandwidth decreases with the increase of Q roughly in proportion to the dielectric constant of the substrate.

$$Bandwidth = \frac{S-1}{Q_0\sqrt{S}}$$

As S (VSWR) increases, the impedance bandwidth increases.

(f).Quality Factor:

Microstrip patch antennas have a very high quality factor. The quality factor '*Q*' represents the losses associated with the antenna. A large *Q* leads to narrow bandwidth and a low efficiency. *Q* can be reduced by increasing the thickness of the dielectric substrate. But as the thickness increases, a large fraction of the total power delivered by the source transforms into a surface waves. The surface waves can be minimized by using EBG structures.

Problems of low gain and low power handling capacity can be overcome by employing array configurations.

(g).Efficiency: The efficiency of microstrip antenna is given by

$$\eta = \frac{P_r}{P_c + P_d + P_r}$$

where *Pr* is the radiated power, *Pc* is the power dissipated due to conductor loss, and *Pd* is the power dissipated due to the dielectric.

(h).Polarization:

Patch antennas can be designed to have vertical, horizontal, right hand circular (RHCP) or left hand circular (LHCP) polarizations, using multiple feed points.

(i).Return Loss:

The *return loss* is defined as the ratio of the Fourier transforms of the incident pulse and the reflected signal.

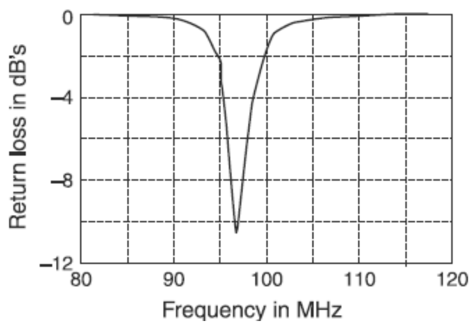


Fig Return loss.

The bandwidth and resonance frequency of the patch antenna can be calculated from return loss figure.

(j).Radar Cross-section:

The GPS guidance systems require low *radar cross-section* (RCS) platforms. The RCS of a conventional patch antenna is high. The patch is covered with a magnetic absorbing material to reduce the RCS of a conventional patch antenna.

Impact of Different Parameters on Characteristics: The parameters (L, W, h, A and ε_r) of the rectangular patch antennas control the antenna properties. The length *L* and the width *W* of the patch, controls the resonant frequency.The width *W* controls the input impedance and the radiation pattern. The wider the patch becomes, the lower will be the input impedance and higher will be the radiation.

The best choice for the dimension *W* is given by

$$W = c/[2 f_0 \sqrt{\{(\varepsilon_R + 1)/2\}}]$$

The permittivity εr of the substrate controls the fringing field. Lower the εr, wider will be the fringing and better will be the radiation. Higher values of permittivity result in 'shrinking' of the patch antenna.

$$L \approx 1/2 f_c \sqrt{\varepsilon_0 \varepsilon_r \mu_0}$$

If the effective permittivity is increased by a factor of 4, the required length decreases by a factor of 2.

The dependence of bandwidth on various parameters is given by.

$$B \propto \frac{(\varepsilon_r - 1)}{\varepsilon_r^2} \frac{W}{L} h$$

A decrease in εr also increases the antenna bandwidth. The efficiency of the antenna also increases with the lower value of εr . The impedance of the antenna increases with the ε_r.

Reflector antennas:

Reflectors are widely used to modify the radiation pattern of a radiating element. For example, the backward radiation from an antenna may be eliminated with a plane sheet reflector of large enough dimensions. In the more general case, a beam of predetermined characteristics may be produced by means of a large, suitably shaped, and illuminated reflector surface.

Several reflector types are illustrated in Fig.

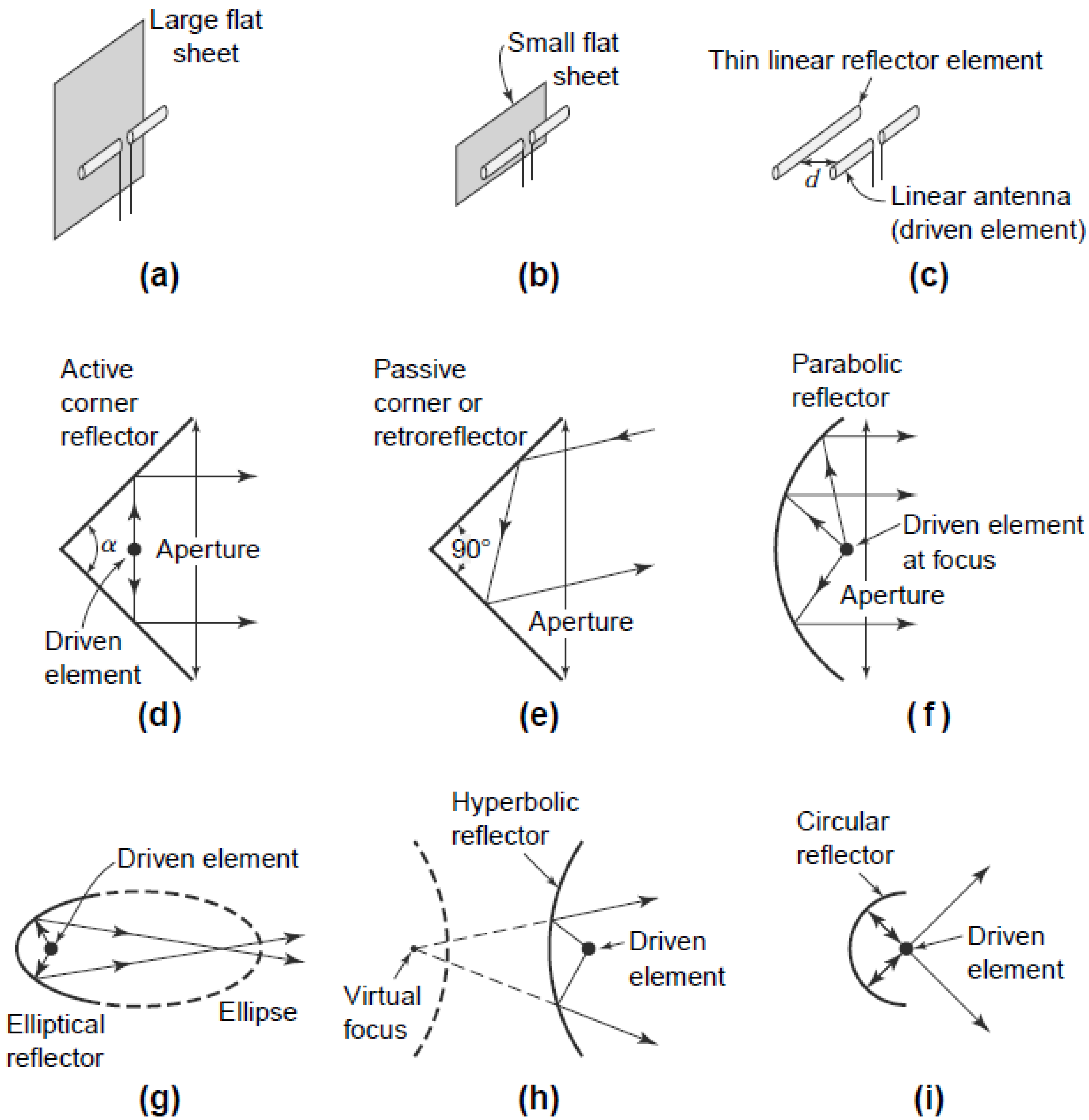


Fig Reflectors of various shapes

1.A corner reflector with two flat conducting sheets at a corner angle α and a driven antenna is called active corner reflector.

2. A corner reflector without an exciting antenna can be used as a *passive reflector* or target for radar waves.

3. In this application the aperture may be many wavelengths, and the corner angle is *always* 90◦. Reflectors with this angle have the property that an incident wave is reflected back toward its source as in Fig. 9–1*e*, the corner acting as a *retroreflector*.

Flat Sheet Reflectors: The plane reflector is the simplest form of the reflector antenna. Plane reflector can be considered to be made up of two flat sheets intersecting each other at an angle α=180˚.

The flat sheet reflector near a linear dipole antenna is used to reduce the backward radiation as shown in fig.(a)

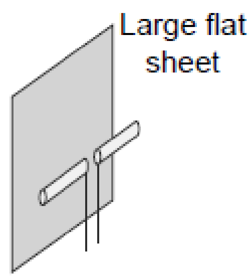


Fig.1.(a).Antenna with flat sheet reflector

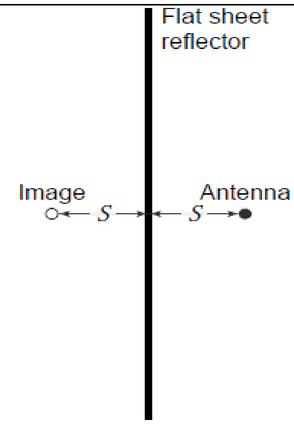


Fig.1.(b). antenna with its image

The problem of an antenna at a distance S from a perfectly conducting plane sheet reflector of infinite extent is readily handled by the method of images. In this method the reflector is replaced by an image of the antenna at a distance $2S$ from the antenna, as in Fig.(b). This situation is identical with a horizontal antenna above ground. Assuming zero reflector losses, the gain of a $\lambda/2$ dipole antenna at a distance S from an infinite plane reflector is

$$G_f(\phi) = 2\sqrt{\frac{R_{11} + R_L}{R_{11} + R_L - R_{12}}}\,|\sin(S_r \cos\phi)| \quad ----(1)$$

where $S_r = 2\pi S/\lambda$

The gain in (1) is expressed relative to a $\lambda/2$ antenna in free space with the same power input. The field patterns of $\lambda/2$ antennas at distances $S = \lambda/4$, $\lambda/8$ and $\lambda/16$ from the flat sheet reflector are shown in Fig. 2. These patterns are calculated from (1) for the case where $R_L = 0$.

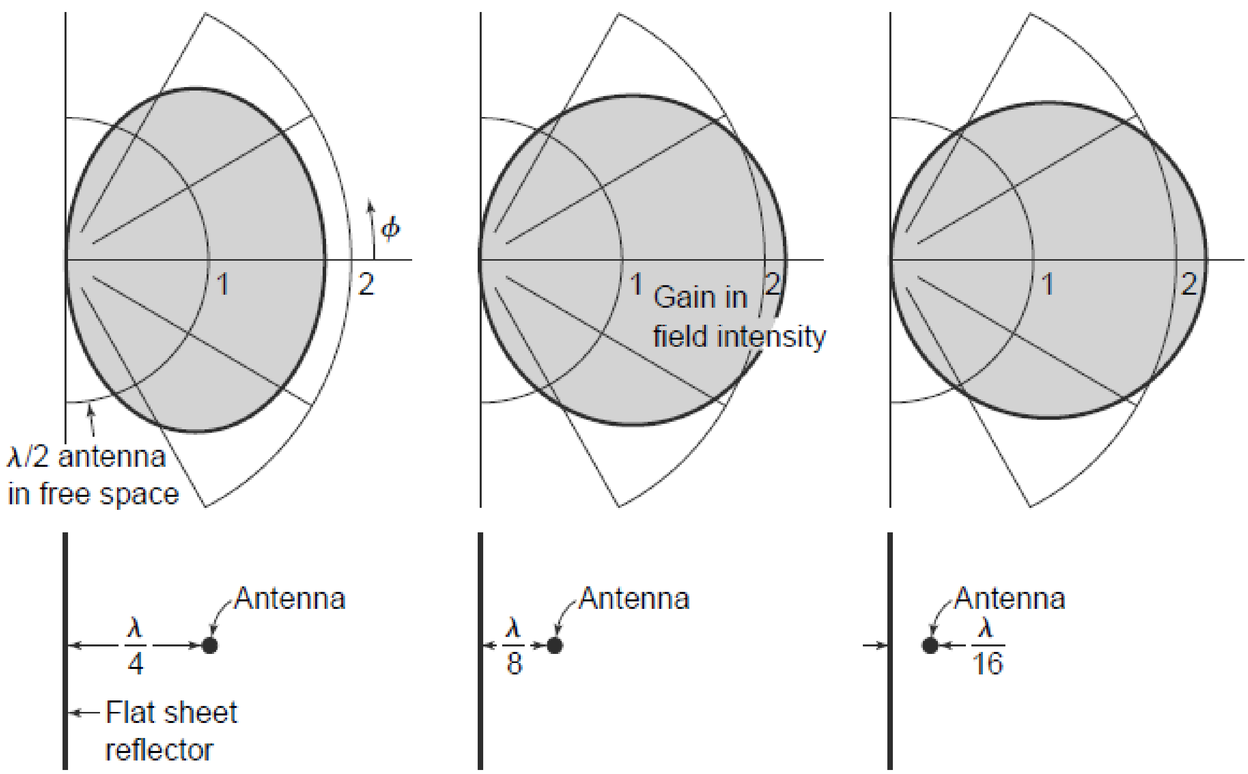


Fig 2. Field patterns of a $\lambda/2$ antenna at spacings of $\lambda/4$, $\lambda/8$ and $\lambda/16$ from an infinite flat sheet reflector.

The gain as a function of the spacing S is presented in Fig. 3 for assumed antenna loss resistances R_L = 0 ,1 and 5 Ω.

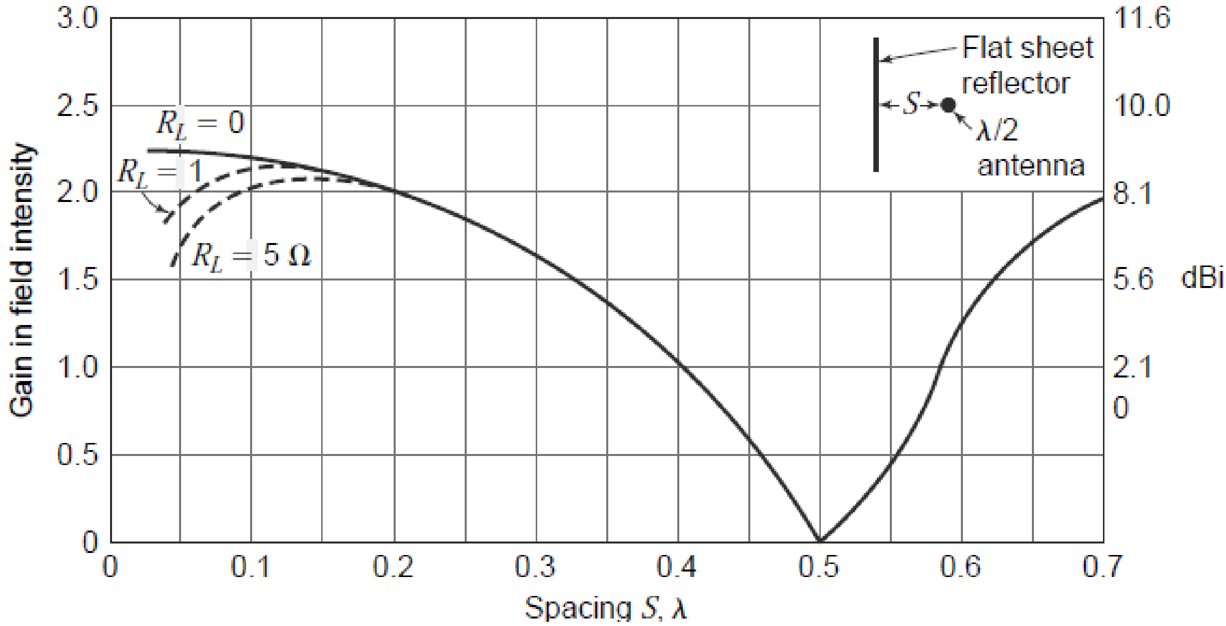
As spacing increases the bandwidth increases but gain decreases.

A large flat sheet reflector can convert a bidirectional antenna array into a unidirectional system.

To increase directivity further, we can use array of two half wave dipoles in front of a flat sheet reflector.

The Gain verses spacing plot is shown in fig

Fig .3. Gain verses spacing plot



Corner Reflectors: In flat sheet reflector there is radiation in side and back side. The shape of the flat sheet reflector is modified to get radiation in the forward direction only.
When two flat sheets are arranged such that they intersect each other at an angle $\alpha < 180^\circ$,then the corner reflector is formed as shown in fig.1. a sharper radiation pattern than from a flat sheet reflector ($\alpha = 180^\circ$) can be obtained. α is called include angle.

When the corner angle $\alpha = 90^\circ$, the sheets intersect at right angles, forming a square-corner reflector. Corner angles both greater or less than 90˚ can be used although there are practical disadvantages to angles much less than 90◦. A corner reflector with $\alpha = 180^\circ$ is equivalent to a flat sheet reflector.
Assuming perfectly conducting reflecting sheets of infinite extent, the *method of images* can be applied to analyze the corner reflector antenna for angles $\alpha = 180^\circ/n$, where n is any positive integer.
The number of images is equal to $N = (360/\alpha) - 1 = 2n - 1$.
Corner angles of 180◦, 90◦, 60◦, etc., can be treated in this way.

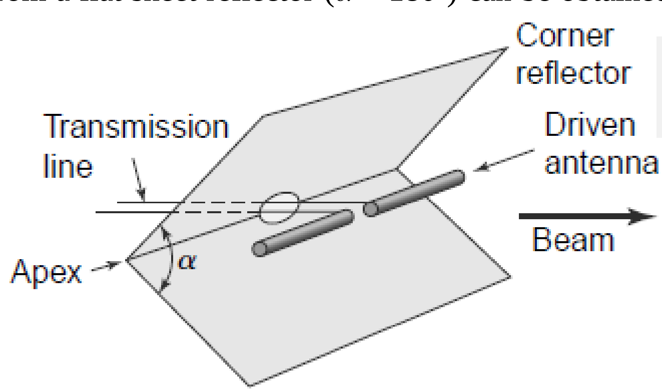


Fig .(1). Corner reflector antenna

In the analysis of the 90◦ corner reflector there are 3 image elements, 2, 3 and 4, located as shown in Fig.2. The driven antenna 1 and the three images have currents of equal magnitude. The phase of the currents in 1 and 4 is the same. The phase of the currents in 2 and 3 is the same but 180◦ out of phase with respect to the currents in 1 and 4. All elements are assumed to be $\lambda/2$ long.

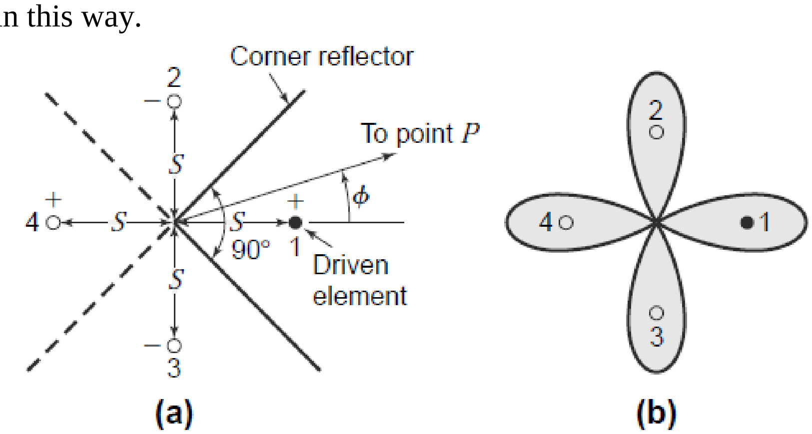


Fig .(2). (a) Square-corner reflector with images used in analysis
(b) 4-lobed pattern of driven element and images

At the point P at a large distance D from the antenna, the field intensity is

$$\mathbf{E(\phi) = 2KI_1|[\cos(S_r \cos\phi) - \cos(S_r \sin\phi)]|} \quad \text{----------------------- } \mathbf{(1)}$$

Where

I_1 = current in each element

S_r = spacing of each element from the corner, rad=$2\pi(S/\lambda)$

k = constant involving the distance D, etc.

The emf $V1$ at the terminals at the center of the driven element is

$$V_1 = I_1Z_{11} + I_1R_{1L} + I_1Z_{14} - 2I_1Z_{12} \quad \text{----------------- (2)}$$

Where

Z_{11} = self-impedance of driven element

R_{1L} = equivalent loss resistance of driven element

Z_{12} = mutual impedance of elements 1 and 2

Z_{14} = mutual impedance of elements 1 and 4

If P is the power delivered to the driven element, then

$$I_1 = \sqrt{\frac{P}{R_{11} + R_{1L} + R_{14} - 2R_{12}}} \quad \text{-------------------- (3)}$$

Substituting (3) in (1) yields

$$E(\phi) = 2k\sqrt{\frac{P}{R_{11} + R_{1L} + R_{14} - 2R_{12}}}|[\cos(S_r \cos\phi) - \cos(S_r \sin\phi)]| \quad \text{---- (4)}$$

When the reflector is removed, then no image antenna can exit i.e R_{12}=R_{14}=0 .The field intensity due to isolated half wave dipole is given by

$$E_{HW}(\phi) = k\sqrt{\frac{P}{R_{11} + R_{1L}}} \quad \text{---------------------- (5)}$$

Where k = the same constant as in (1) and (4)

The gain of a square-corner reflector antenna in field intensity over a single $\lambda/2$ antenna in free space with the same power input is obtained by dividing (4) by (5).

$$\begin{aligned} G_f(\phi) &= \frac{E(\phi)}{E_{HW}(\phi)} \\ &= 2\sqrt{\frac{R_{11} + R_{1L}}{R_{11} + R_{1L} + R_{14} - 2R_{12}}}|[\cos(S_r \cos\phi) - \cos(S_r \sin\phi)]| \end{aligned}$$

Where

$$\sqrt{\frac{R_{11} + R_{1L}}{R_{11} + R_{1L} + R_{14} - 2R_{12}}}$$ is coupling factor

$|[\cos(S_r \cos\phi) - \cos(S_r \sin\phi)]|$ is pattern factor which is function of ϕ and S.

The field pattern consists of 4 lobes, out of these only one lobes is real.

Expressions for the gain in field intensity of corner reflectors with corner angles of 60◦, 45◦, etc., can be obtained in a similar manner. For the 60◦ corner the analysis requires a total of 6 elements, 1 actual antenna and 5 images as in Fig. The gain of a 60° corner reflector antenna in field intensity is given by

$$2\sqrt{\frac{R_{11}+R_{1L}}{R_{11}+R_{1L}+2R_{14}-2R_{12}-R_{16}}} \times \left|\{\sin(S_r\cos\phi)-\sin[S_r\cos(60^\circ-\phi)]-\sin[S_r\cos(60^\circ+\phi)]\}\right|$$

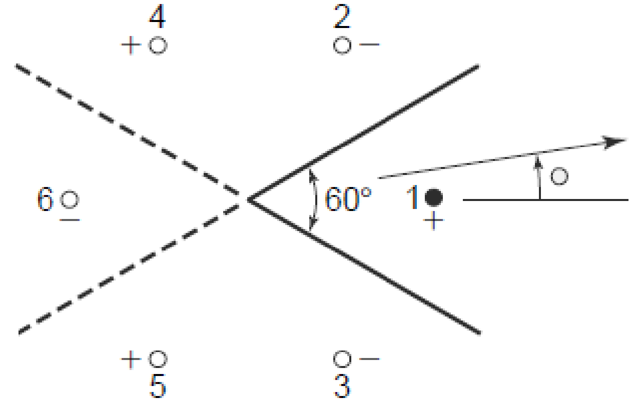


Fig.3. A 60° corner reflector with images

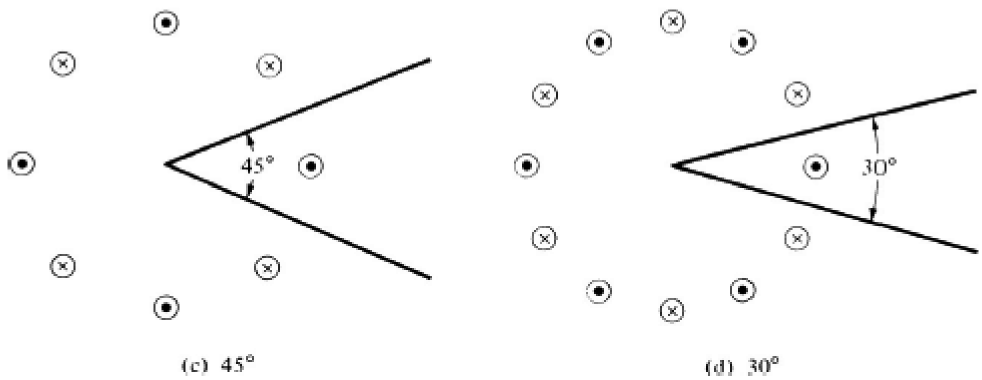


Fig.4. 30° and 45° corner reflectosr with images

PARABOLIC REFLECTOR: The overall radiation characteristics of a reflector can be improved if the structural configuration of reflector is parabolic. The parabolic reflector is used at microwave frequencies.

A parabola may be defined as the 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.

A parabola with focus F and vertex O is shown in fig.1(a).

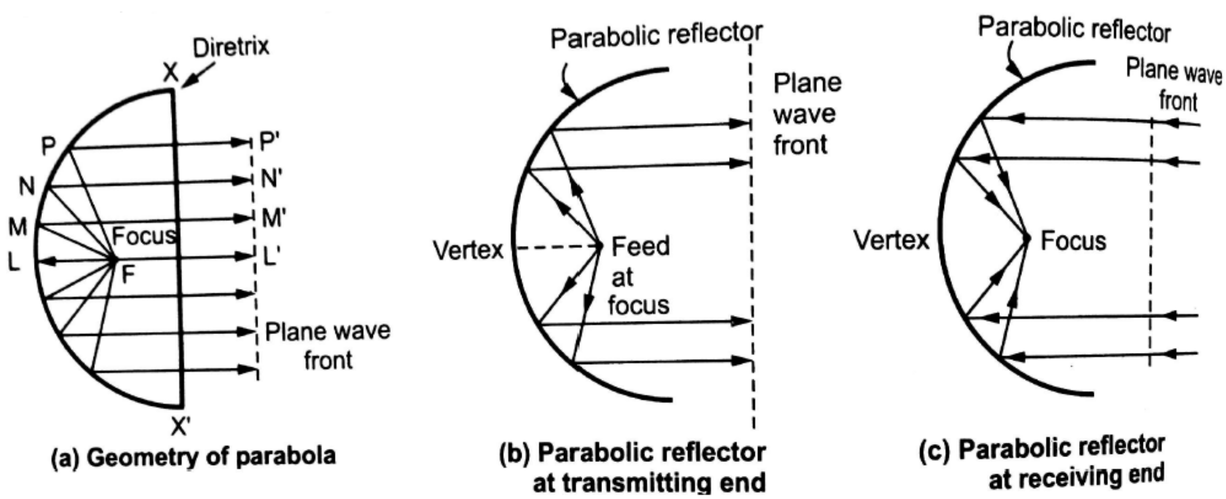


Fig .1. Parabolic reflector principle

The parabola is a two dimensional plane curve.

By definition of parabola $\mathbf{LF + LL' = MF + MM' = NF + NN' = PF + PP' = constant}$

The principle of equality of path length is used in parabolic reflector.

The equation of parabolic reflector is given by $\mathbf{Y^2 = 4fX}$

The open mouth(d) of parabola is known as Aperture .

The ratio of focal length to aperture size is known as f/d ratio or f over d ratio. Its value lies between 0.25 to 0.50.

If a point source is placed at the focal point, the rays reflected by a parabolic reflector will emerge as a parallel wave front. This principle is used in transmitting antenna as shown in fig.1(b).
Similarly if a beam of parallel rays is incident on a reflector, the radiation will converge (focus) at a spot which is known as the focal point as shown in fig.1(c). This principle is used in receiving antenna.
The maximum radiation is along the axis of the parabola.
The antenna placed at the focus of the parabola is called primary radiator and the parabolic reflector is called secondary radiator.
Paraboloidal Reflector: The three dimensional structure of the parabolic reflector can be obtained by rotating the parabola around its axis and it is called paraboloidal reflector.

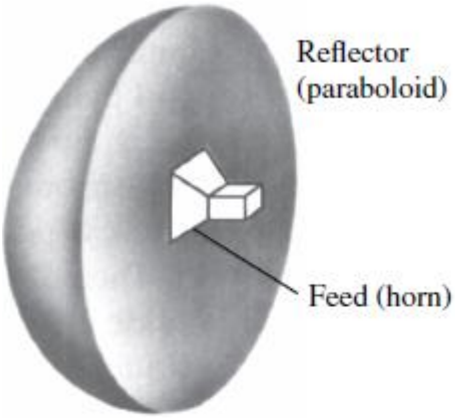


Fig .2.(a) paraboloid with horn as feed

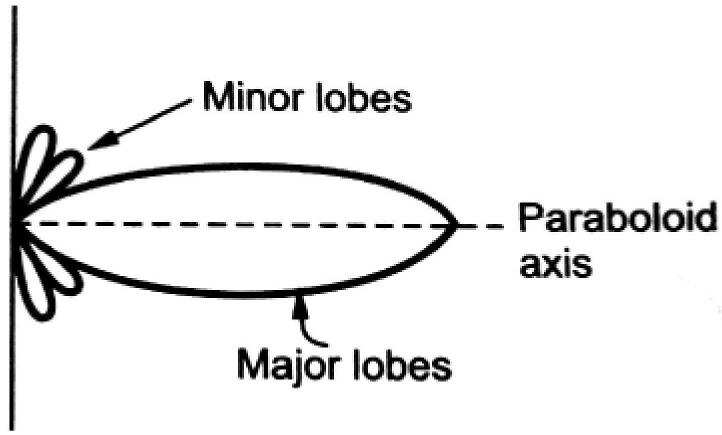


Fig.2.(c). Radiation pattern

Assuming large circular aperture ,the beam width between first nulls can be expressed as

$$\mathbf{FNBW = \frac{140\lambda}{d}\ Degrees}$$

Where λ=Free space wavelength and d=Diameter of aperture
The Half power Beam Width for large circular aperture can be expressed as

$$\mathbf{HPBW = \frac{58\lambda}{d}\ Dgress}$$

The beamwidth between first nulls for a large uniformly illuminated rectangular aperture is

$$\mathbf{FNBW = \frac{115\lambda}{d}\ Degrees}$$

The Half power Beam Width for rectangular aperture can be expressed as

$$\mathbf{HPBW = \frac{51\lambda}{d}\ Degrees}$$

The directivity D of a large uniformly illuminated aperture is given by

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

For a circular aperture $\mathbf{A}_{\boldsymbol{e}} = \boldsymbol{\pi}\frac{\boldsymbol{d}^2}{\mathbf{4}}$

$$\mathbf{D = \frac{4\pi}{\lambda^2} A_e = \frac{4\pi}{\lambda^2}}\boldsymbol{\pi}\frac{\boldsymbol{d}^2}{\mathbf{4}} = \boldsymbol{\pi}^2\left(\frac{\boldsymbol{d}}{\boldsymbol{\lambda}}\right)^2$$

$$\mathbf{D = 9.87}\left(\frac{\boldsymbol{d}}{\boldsymbol{\lambda}}\right)^2$$

The power gain *G* of a circular aperture over a *λ*/2 dipole antenna is

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

Where A_e is the effective aperture which is less than the phyisical area A_p of the mouth and is given by A_e=K A_p

Where K=Aperture efficiency and is 0.65

$$G = \frac{4\pi}{\lambda^2} A_e = \frac{4\pi}{\lambda^2} KA_p = \frac{4\pi}{\lambda^2} \times 0.65 \times \pi \frac{d^2}{4}$$

$$G = 6\left(\frac{d}{\lambda}\right)^2$$

f/d ratio:

The ratio of focal length to aperture size is known as f/d ratio or f over d ratio. Its value lies between 0.25 to 0.50. The paraboloid can be designed to obtain pencil shape radiation beam by keeping the diameter of the aperture fixed and changing the focal length.

The three possible cases are as follows.

1.Focal point inside the aperture of paraboloid.

2. Focal point along the plane of the aperture of paraboloid.

3. Focal point beyond the aperture of paraboloid.

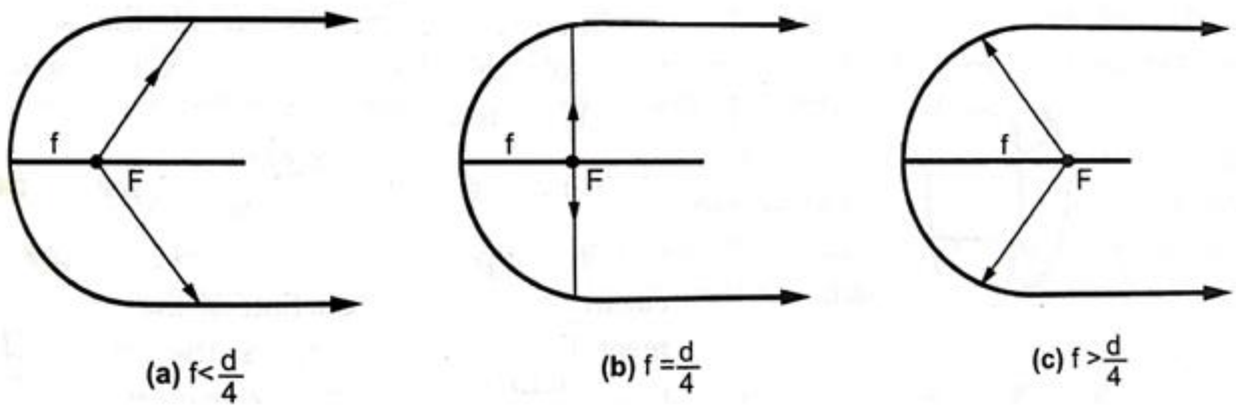


Fig .3. Effect of variation of focal length f keeping diameter fixed

In case 1 ,it is very difficult to obtain uniform illumination over a wide angle .In case 2 gives maximum gain pencil shaped radiation equal in horizontal and vertical plane. In case 3 ,it is difficult to direct all the radiation from the source on the reflector.

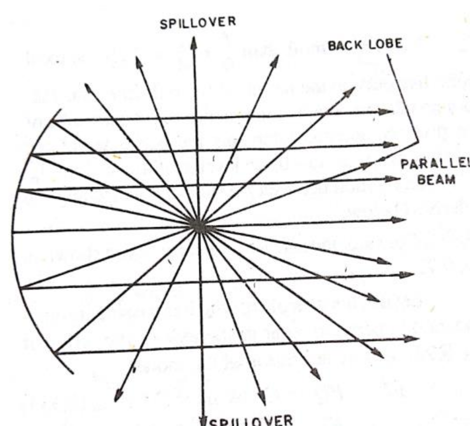


Fig. Spillover and backlobe.

Spill Over: Practically it is observed that some of the rays are not fully captured by the reflector, such non captured rays form spill over. While receiving spill over , the noise pick up increases which is troublesome.

Back lobe radiation: In addition to this, few radiations originated from the primary source are observed in forward direction such radiations get added with desired parallel beam .This is called back lobe radiation as it originated from the back lobe of the primary source. Obviously the back lobe radiations are unwanted as they considerably affect the reflected beam.

Types of paraboloid reflectors:

Depending on the use the paraboloid is modified in various types of the structur**es.**

1. Cylindrical parabola:

This is generated by moving the parabola parallel to itself. This structure has focal line instead of a focal point and similarly a vertex line instead of vertex. It provides a rectangular mouth. In practice, a linear dipole or linear array or a slotted waveguide is used as feed antenna. This configuration can be used to generate fan beam required in search radars.

2. paraboloidal reflector:

Fig.4.(b) represents a conventional and most commonly used paraboloidal reflector. It is fed by a point source– normally, a wave-guide horn. It generates a pencil beam. The paraboloidal reflector has a 3-dimensional curved surface generated by rotating a parabola about its own axis.

3. Truncated paraboloid:

This type of the paraboloid is formed by cutting some portions of the paraboloid to meet requirements.

It is used to generate fan beams in azimuth or elevation depending on the location of asymmetry.

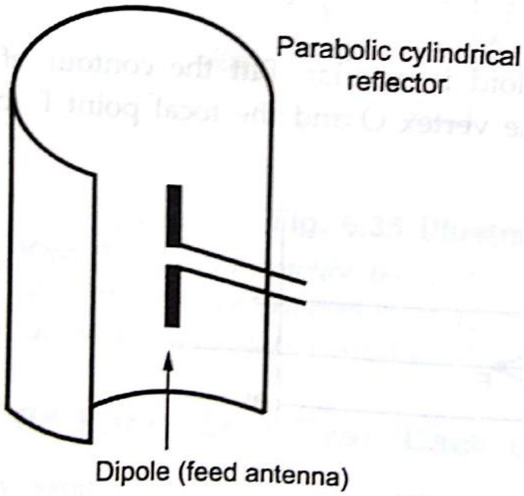


Fig .4.(a) parabolic cylinder

Fig.4.(b). paraboloidal reflector

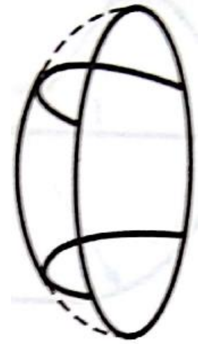


Fig.4.(c) Truncated praboloid

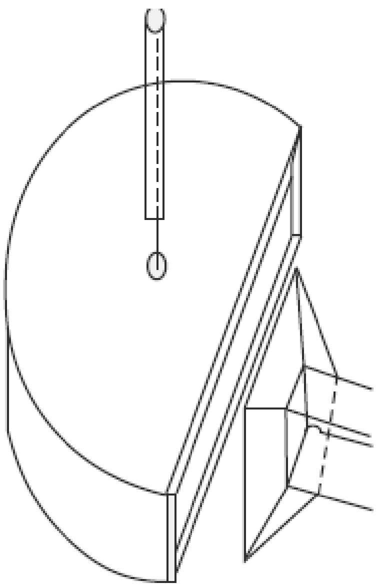


Fig 4.(*d*).Short cylinder with plates (pill box antenna)

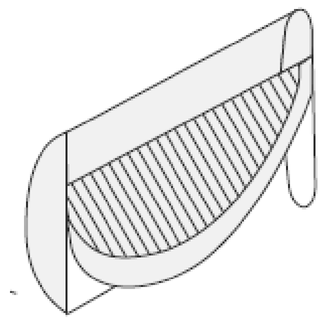


Fig.4. (*e*) Cheese antenna.

4 . Short cylinder with plates (pill box antenna): Fig.4.(*d*) represents a cylinder that is short in axial direction and provided with conducting end plates. It is also sometimes called pillbox. It can be fed simply by a probe or by extending the inner conductor of a coaxial cable to the space between plates. It can also be fed by a waveguide horn or by a waveguide itself. This type of antenna can be used to generate a fan beam.

5. Cheese antenna: Fig.4.(e) illustrates a cheese antenna, which is a combination of a pillbox and a parabolic cylinder. It is also called parabolic torus.

Feed Methods for Parabolic Reflectors:

The source placed at focus is commonly called feed antenna or simple feed.

The different types of Feeds to the parabolic reflectors are given below.

1.Dipole antenna: The simplest feed used in parabolic reflector is a half wave dipole antenna with a small ground plane as shown in fig.5.(a).

2. Dipoles with Parasitic Reflectors:

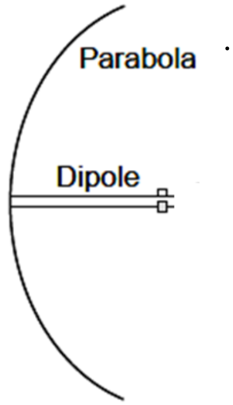
These *parasitic reflectors* may be of the following types: (a) Another dipole (b) A plane sheet (c) Half cylinder (d) A hemisphere

Disadvantages of the above feeds are

(a) Radiates along length only

(b) Poor polarization characteristics

(c) Gain reduces due to cross polarization when part of radiation is normal to the primary pattern



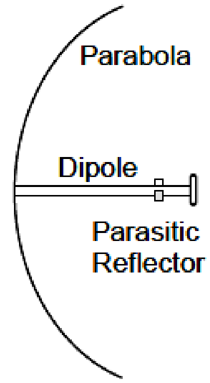


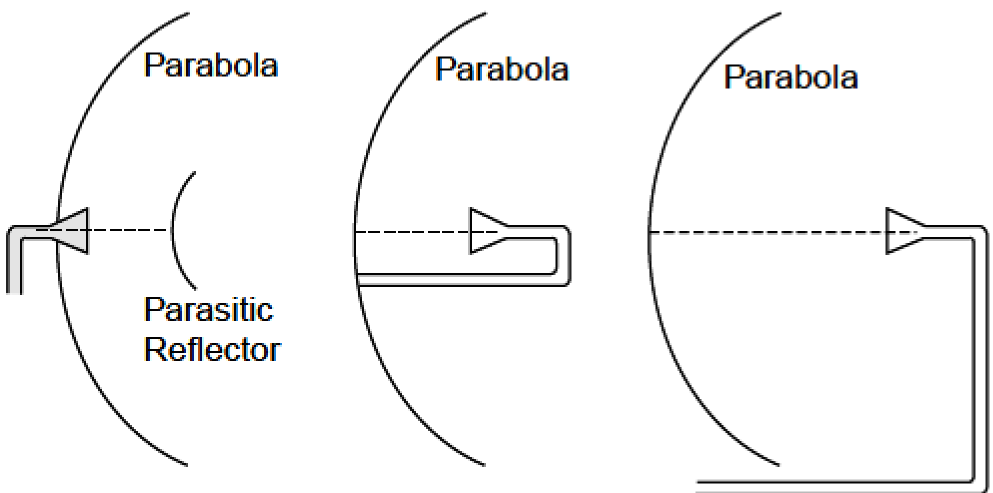
Fig.5.(a) Dipole feed   Fig.5(b).Dipole with parasitic reflector

3.Open-Ended Waveguide Better phase characteristics

(a) More energy is directed in forward direction
(b) Circular paraboloid is fed by circular waveguide in TE11mode
(c) Rectangular waveguide feed is good for generating fan beam

3. Waveguide Horns:

(a) More directivity
(b) Acts as point source with large reflectors
(c) The ratio f/d should be large for uniform illumination
(d) Due to spill over, overall efficiency is reduced.
(f) Spill over is can be reduced by increasing f/d ratio thereby efficiency but the aperture efficiency decreases



5.(c) **Rear feed using horn**   **Front feed using horn**

The parabolic reflectors can be fed in different ways by using horn antenna. These methods include rear feed, front feed and offset feed.

(a).Rear Feed:

(a)In rear feed the feed antenna is placed at vertex.
(b) Asymmetrical pattern as transmission line is not in center
(c) It forms a compact system
(d) Minimum length of transmission line is required resulting in less line loss

(b).Front Feed:

(a) In front feed the feed antenna is placed at the focal point
(b) Aperture blocking
(c) Impedance mismatch in feed results
(d) Due to reflections in the dish, standing waves are produced in the line decreasing transmitter efficiency
(e) By using impedance matching and apex matching plates mismatch can be reduced, results in lower gain

(c). Offset Feed:

(a) In offset feed the feed antenna is placed offset to the axis of the parabola
(b) Only half of the parabola is used
(c) No aperture blocking
(d) No impedance mismatch
(e) Seriously affects performance
(f) More difficult to scan
(g) Normally hog horn is employed in place of conventional pyramidal horn

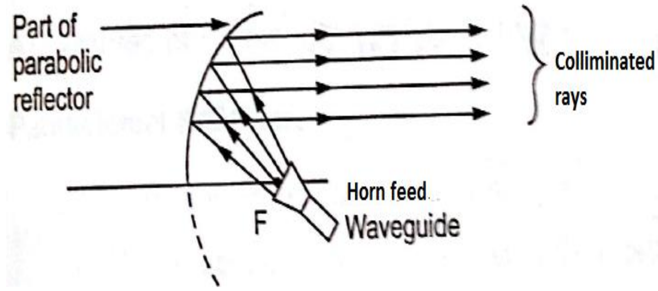


Fig.5.(d). Offset feed

5.Cassegrain feed system:

This system of feeding paraboloid reflector is named after a mathematician prof . cassegrain.
The feed mechanism is shown in below figure.

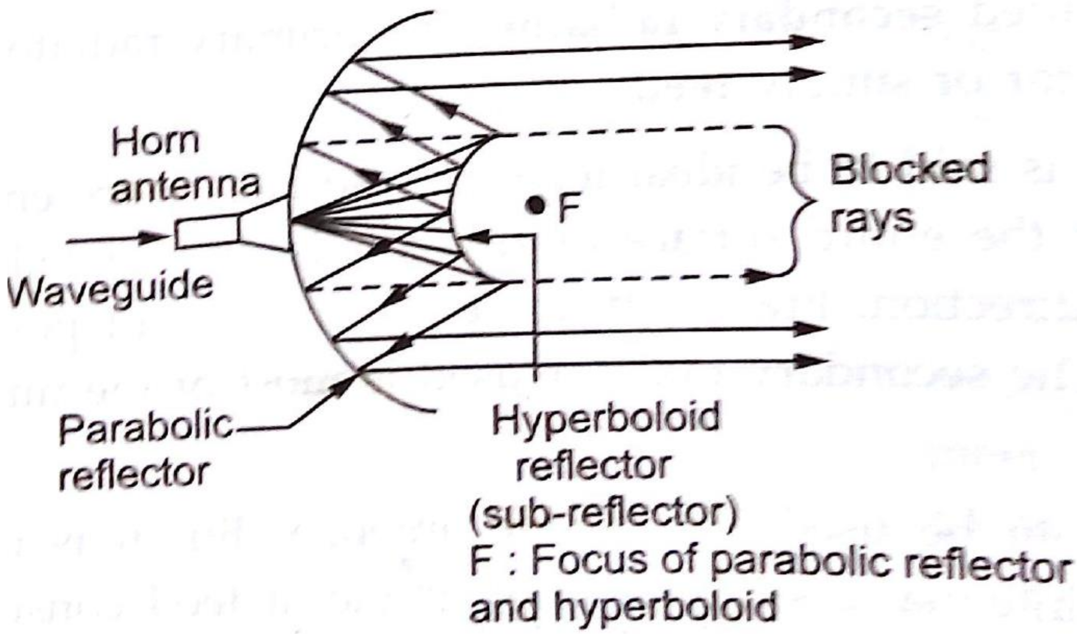


Fig.5.(d) Cssegrain feed

It uses: 1. A parabolic reflector 2.A hyperboloid reflector 3. A feed antenna

In all the feed systems discussed earlier the feed is located at the focus , But in cassegrain feed system ,The feed antenna is placed at the vertex of the parabolic reflector instead of placing it at the focus.This system uses a hyperbolic reflector placed such that its one of the foci coincides with the focus of the parabolic reflector. This hyperboloid reflector is called cassegrain secondary reflector or sub reflector.

The primary feed antenna used is generally a horn antenna with waveguide. The feed antenna is aimed at the secondary hyperboloid reflector.The radiation emitted from feed radiator are reflected from cassegrain secondary reflector which illuminates the main paraboloid reflector similar to the radiations from the feed placed at the focus. Then the paraboloid reflector colliminates all the radiations as usual.

Applications:

1. Widely used in telescope design and monopulse tracking
2. It is used when it is required to keep the primary antenna in a convenient position.

Advantages:

1. Permits greater flexibility in design of feed system and eliminates the need for long transmission lines
2. It reduces the spill over and thus minor lobes radiation.
3. Ability to get an equivalent focal length much greater than the physical length.
4. The system has ability to place a feed at convenient place.
5. Capability for scanning or broadening of beam by moving one of the reflecting surfaces.

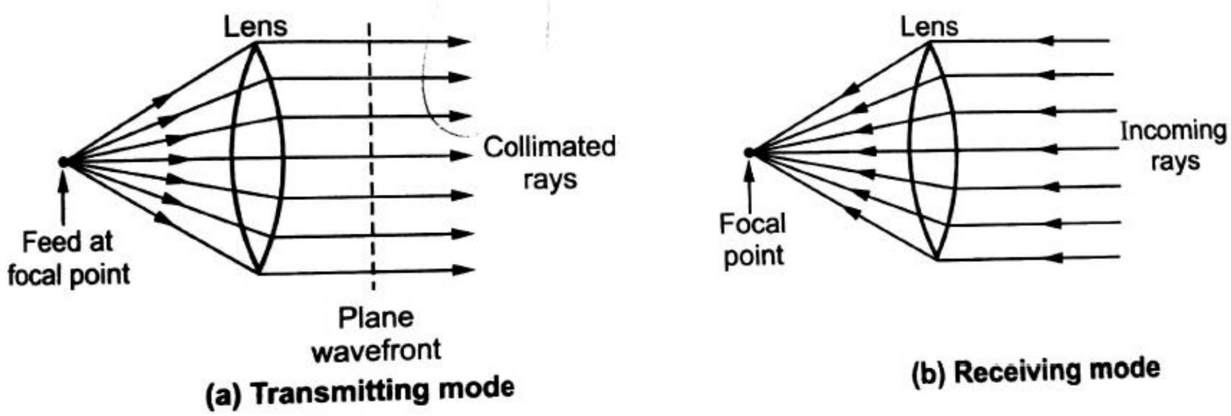
Disadvantages:

1. The main disadvantage of the casssegrain feed is the Aperture blocking..

Aperture blocking can also decreased by increasing size of the parabolic reflector.

Lens Antenna:

A lens antenna is an antenna consisting an electromagnetic lens with a feed. In other words, it is a three dimensional electromagnetic device having refractive index n other than unity. Its operation is similar to a glass lens used in optics. Lenses are primarily used to collimate incident divergent energy to prevent it from spreading in undesired directions. The divergent beam is collimated because refraction takes place as a results of which ray at the center are refracted less than at the edges. Lens antenna can transform various forms of divergent energy into plane waves. The lens antenna can be used in transmitting and in receiving mode as shown in figure.

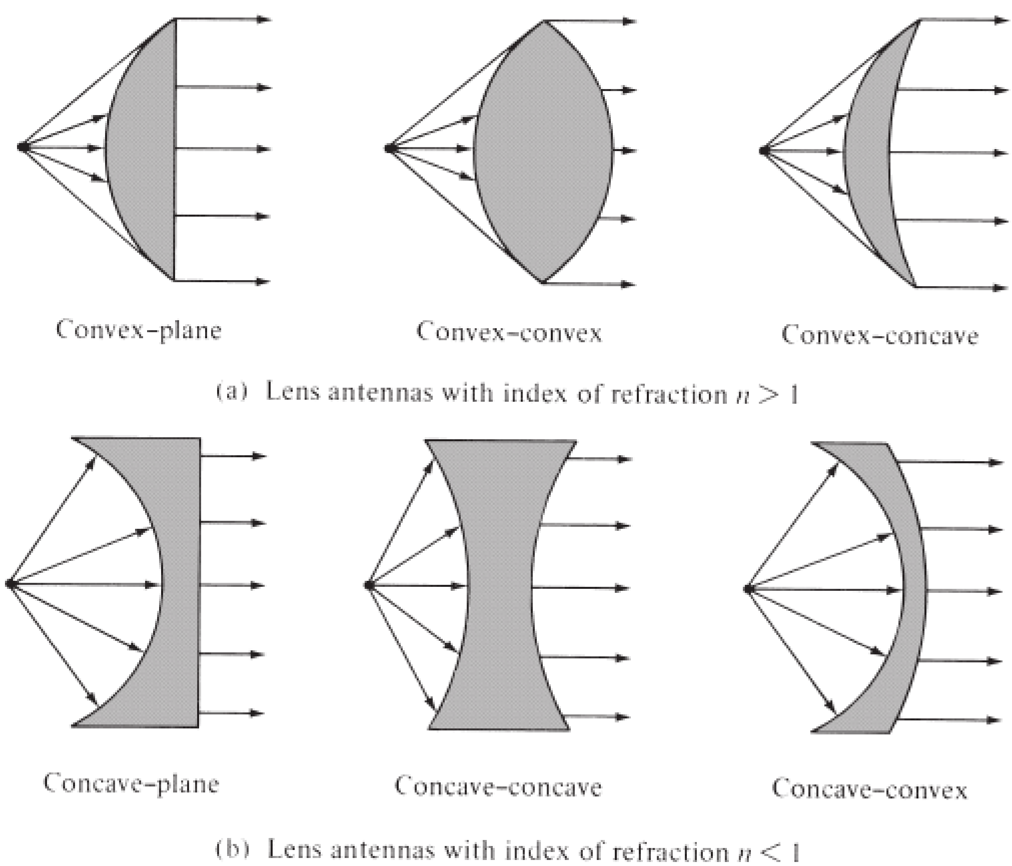


(a) Transmitting mode (b) Receiving mode

In general, the function of the lens antennas are as follows.

1. It controls the illumination of aperture.
2. It colliminates the electromagnetic rays.
3. It produces direction characteristics.
4. In receiving mode, it converges the incoming wave front at its focal point.
5. It produces plane wave front from a spherical wave front in transmitting mode.
6.

Lens antennas are generally used at higher frequencies, because their dimensions and weight become extremely large at lower frequencies. Lens antennas are classified according to the material from which they are constructed, or according to their geometrical shape. Some forms are shown in Figure.



(a) Lens antennas with index of refraction $n > 1$

(b) Lens antennas with index of refraction $n < 1$

Types of lens antenna:

Lens antennas may be divided into two distinct types:

(1) delay lenses, in which the electrical path length is increased by the lens medium. the wave is retarded .

(2) fast lenses, in which the electrical path length is decreased by the lens medium. the wave is accelerated.

Dielectric lenses and *H*-plane metal plate lenses are the delay lens antennas.

E-plane metal plate lenses are the fast lens antennas.

The actions of a dielectric lens and an *E*-plane metal-plate lens are compared in Fig.

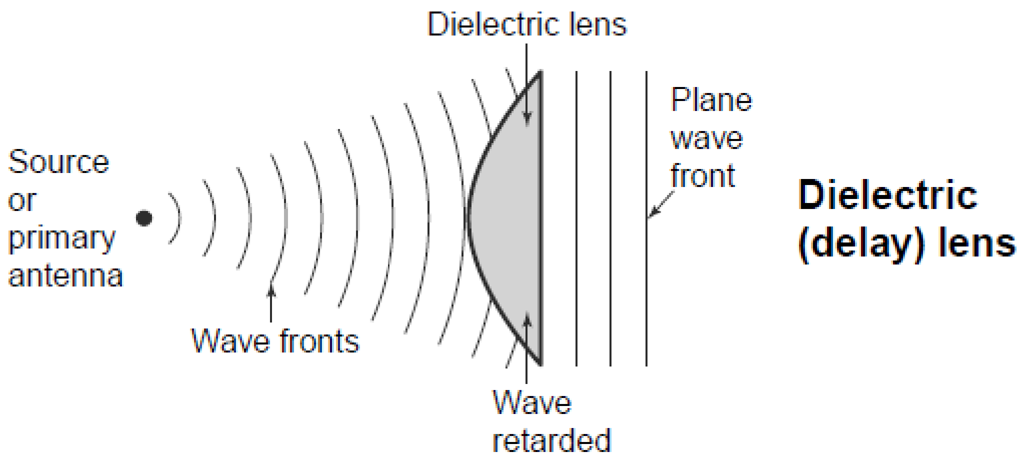


Fig.(a) Delay lens

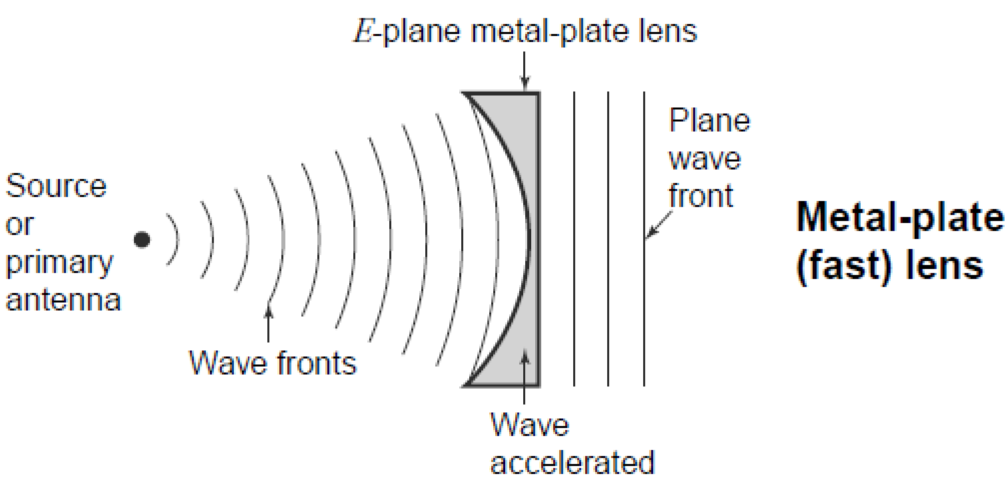


Fig.(b) Fast lens

The dielectric lenses may be divided into two groups:

1. Lenses constructed by using nonmetallic dielectrics, such as lucite or polystyrene.
2. Lenses constructed by using metallic or artificial dielectrics.

Advantage of lens antenna:

1. In lens antenna, the rays are transmitted away from the feed system, hence no aperture blocking due to the feed and feed support.
2. In lens antenna, as the waves enter from one side and leaves out from other side, hence Greater extent of wrapping and twisting is possible without disturbing electrical path length.
3. At millimeter wavelengths low-loss dielectric lens antennas are competitive in weight and performance with reflector antennas .

Disadvantages:

1. Lens antennas are usuallu bulky and heavier at low frequencies .
2. The design of lens antenna is complicated.
3. Costlier for the same gain and beam width in comparison with parabolic reflector.

Applications:

1. As lens antenna is a microwave antenna, it is most widely used at microwave frequencies above 3000MHz.
2. For larger bandwidth requirements, unstepped dielectric lens are used as its shape is independent of wavelength.
3. For narrow bandwidth applications, dielectric lens antennas are used.

Nonmetallic Dielectric Lens Antennas. Fermat's Principle (Equality of Path Length):

It may be designed by the ray analysis methods of geometrical optics. As an example, let us determine the shape of the plano-convex lens of Fig.(a) for transforming the spherical wave front from an isotropic point source or primary antenna into a plane wave front. The field over the plane surface can be made everywhere in phase by shaping the lens so that all paths from the source to the plane are of equal electrical length. **This is the principle of equality of electrical path length** (**Fermat's principle**). Thus, in Fig. the electrical length of the path OPP′ must equal the electrical length of the path OQQ′Q″, or more simply OP must equal OQ′.

$\mathbf{OP + PP' = OQ + OQ' = OQ + QQ' + Q'Q''}$ and $\mathbf{OP = OQ'}$

$$\mathbf{OP = OQ + QQ'}$$

Let OQ = L, OP = R and , $\boldsymbol{QQ' = OQ' - OQ = R\cos\theta - L}$ and let the medium surrounding the lens be air. Then

$$\frac{\boldsymbol{R}}{\boldsymbol{\lambda_o}} = \frac{\boldsymbol{L}}{\boldsymbol{\lambda_o}} + \frac{\boldsymbol{R\cos\theta - L}}{\boldsymbol{\lambda_d}} \quad ------(\mathbf{1})$$

Where

λ_0 = wavelength in free space

λ_d = wavelength in the lens

Multiplying (1) by λ_0,

$$\boldsymbol{R = L + n(R\cos\theta - L)} \quad ----(\mathbf{2})$$

$$Refractive\ index\ n = \frac{\nu_o}{\nu_d} = \frac{\lambda_o}{\lambda_d} = \sqrt{\varepsilon_r}$$

From equation (2)

$$\boldsymbol{R = \frac{(n-1)L}{n\cos\theta - 1}} \quad ---(\mathbf{3})$$

This equation gives the required shape of the lens. It is the equation of a hyperbola.

Referring to Fig.(a) the distance *L* is the focal length of the lens.

The asymptotes of the hyperbola are at an angle θ_0 with respect to the axis.

The angle θ_0 may be determined from (3) by letting $R = \infty$. Thus,

$$\theta_0 = \arccos\frac{1}{n}$$

The point O is at one focus of the hyperbola.

The other focus is at O′.

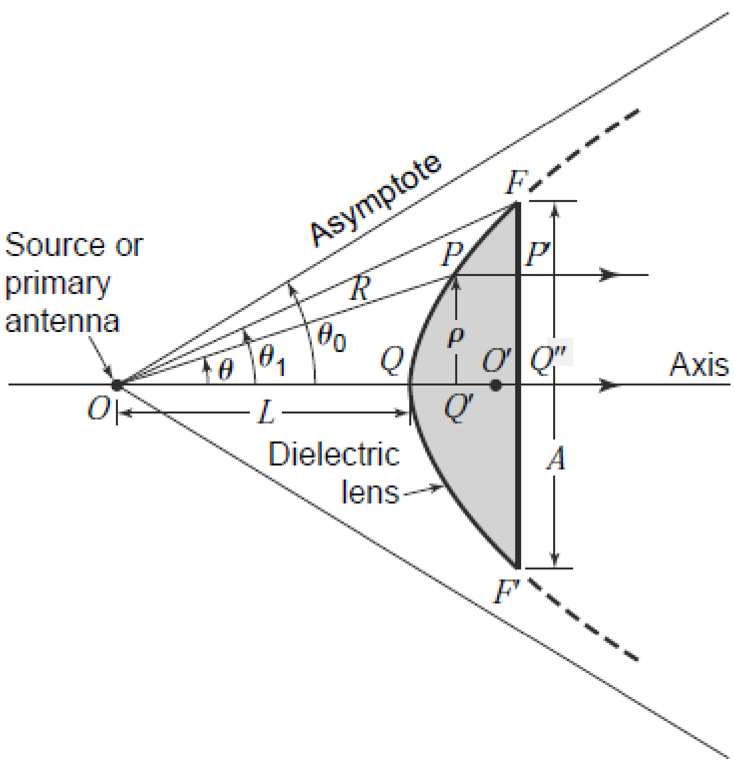


Fig.(a) Path lengths in dielectric lens.

The plane wave emerging from the right side of the lens produces a secondary pattern with maximum radiation in the direction of the axis. The shape of the secondary pattern is a function of both the aperture *A* and the type of illumination.

Zoning of Lens:

The weight of the lens can be reduced by removing sections or zones of lens, which is called zoning of the lens. The geometry of the zones being such that the lens performance is unaffected at the design frequency.

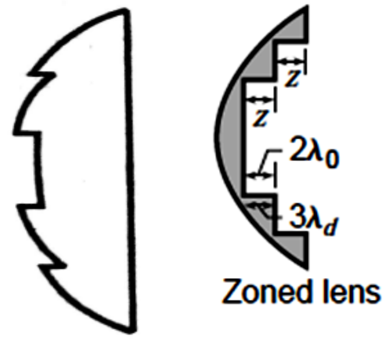
The unzoned lens is not frequency sensitive, Where as the zoned lens is frequency dependent, and this may be a disadvantage.

The thickness z of a zone step is such that the electrical length of z in the dielectric is an integral number of wavelengths longer than the electrical length of *z* in air. That means z in dielectric may be 3 λ_d and z in air is2 λ_o , where λ_d and λ_o are the wavelengths in the dielectric and air respectively.

Thus, for a 1λ difference,

$$\frac{z}{\lambda_d} - \frac{z}{\lambda_o} = 1 \qquad \text{or } z = \frac{\lambda_o}{n-1}$$

Where refractive index $n = \frac{\lambda_o}{\lambda_d}$



The zoning can be classified as

(a). Curved surface zoning (b). Plane surface zoning

S.no	Curved surface zoning	Plane surface zoning
1	In curved, zoning is done to the curved surface of lens antenna.	In plane surface zoning, zoning is done to the plane surface.
2	Thickness of curved surface zoned lens is z	Thickness of plane surface zoned lens is z
3	Curved surface zoned lens is mechanically stronger than the plane surface zoned lens.	Plane surface zoned lens is less strong .
4	Curved surface zoning lens antennas have less weight and less power dissipation	Here the power dissipation is more.

Tolerances on Lens Antennas:

In a dielectric lens, differences in the path length may be caused by

1.deviations in thickness from the ideal contour

2. variations in the index of refraction

Let us assume that the maximum allowable variations in both the parameters to be $\lambda_0/32$ r.m.s Then the thickness Tolerance(Δt) is given by

$$\frac{\Delta t}{\lambda_d} - \frac{\Delta t}{\lambda_o} = \frac{1}{32} \quad \Longrightarrow \quad \Delta t = \frac{\lambda_o}{32(n-1)} = \frac{0.03\lambda_o}{(n-1)} \;----(1)$$

For n=1.5 then $\Delta t = 0.06\lambda_o$

Now For the tolerance of n, we can write $\Delta nt = \frac{\lambda_o}{32}$

$$\Delta n = \frac{\lambda_o}{32t}$$

$$\Delta n = \frac{1}{32t_\lambda} \quad --- \quad (2)$$

Where t_λ = thickness of lens in free-space wavelengths

Dividing (2) by *n*,

$$\frac{\Delta n}{n} = \frac{0.03}{nt_\lambda} = \frac{3}{nt_\lambda}\ \% \;---(3)$$

If n=1.5 and t=4 λ_o $\Delta n/n$=1/2 %

In an *E-plane metal-plate lens* the path length may be affected by both the thickness of the lens and the spacing *b* between lens plates. So again assuming maximum allowable variation of $\lambda_0/32$, the thickness tolerance is given

$$\triangle \mathbf{t} = \frac{\boldsymbol{\lambda_o}}{\mathbf{32(1-n)}} = \frac{\mathbf{0.03\lambda_o}}{\mathbf{(1-n)}} \quad ----(\mathbf{4})$$

and for the tolerance on the spacing b between plates is given by

$$\frac{\boldsymbol{\Delta b}}{\boldsymbol{b}} = \frac{\boldsymbol{3n}}{\boldsymbol{(1-n^2)t_\lambda}} \ (\%) \quad ----(\mathbf{5})$$

As compared to large parabolic reflector antenna , for lens antenna , a relatively large amount of warping or twisting can be tolerated. The thickness tolerance on a lens refers only to the thickness dimension.