Reflector Antennas :

* The Reflector antennas are used in microwave radiation applications.

* In Reflector antennas another antenna is required to excite it. Antenna such as dipole, horn or slot is used to excite the reflector antenna, hence called as **primary antenna**, while reflector antenna is called **secondary antenna**.

* Reflector antenna can be represented in any geometrical configuration but the most commonly used are plane reflector, corner reflector and curved or parabolic reflectors.

* Using reflectors the radiation pattern of a radiating antenna can be modified.

* Different types of reflector antennas are shown in fig below.

* The simplest type of the reflector antenna is a large flat sheet reflector as shown in Fig (a). A linear dipole antenna is placed infront of a large flat reflector such that backward radiations are eliminated.

* Even if the size of the sheet is reduced, the

properties of large sheet remains as in Fig (b).

* If the size of the sheet is further reduced, it turns to a thin linear reflector antenna as shown in Fig(c)

* The main difference between large sheets and thin reflectors is that the large sheets are not sensitive to a small freq variations while thin reflectors are highly sensitive to freq. changes.

* when 2 flat sheets are arranged such that they intersect each other at an angle $\alpha < 180°$, then we get a corner reflector as shown in Fig (d) and (e).

* The radiation pattern obtained from corner reflector is more sharper compared to pattern obtained with flat sheet reflector.

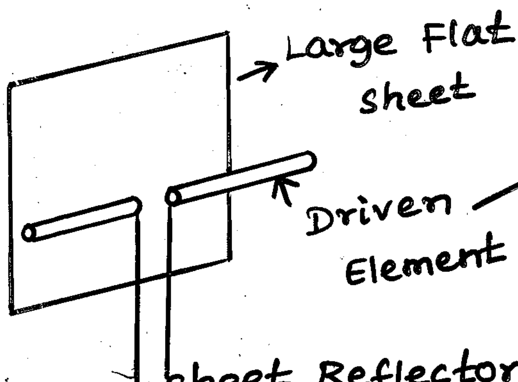
* A corner reflector with feeding or exciting antenna is called <u>active corner reflector</u> (fig (d)). and corner reflector without any exciting antenna is called <u>Passive corner reflector</u> (fig (e)).

* In Active corner reflector, the aperture is 1λ to 2λ in length and in passive corner reflector, the aperture length is multiples of λ and the angle between 2 sheets is always 90°.

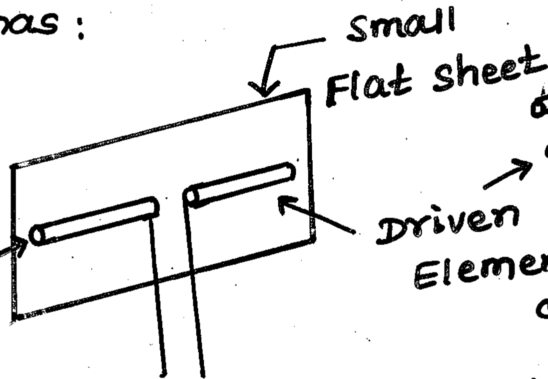
* Passive reflector is also called as <u>retroreflector</u>.

Reflector Antennas

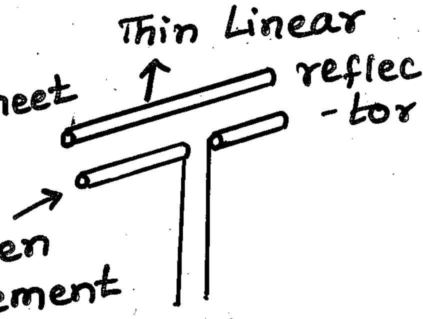
Types of Reflector Antennas :



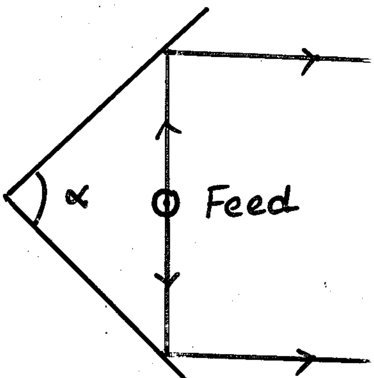
a) Large sheet Reflector



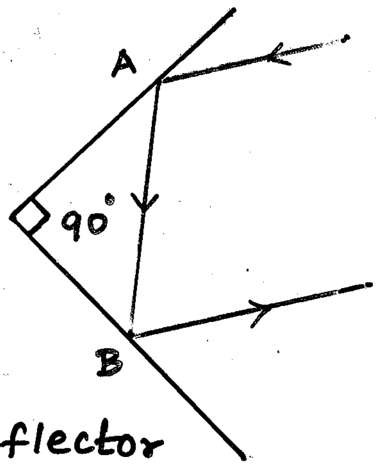
b) small sheet reflector



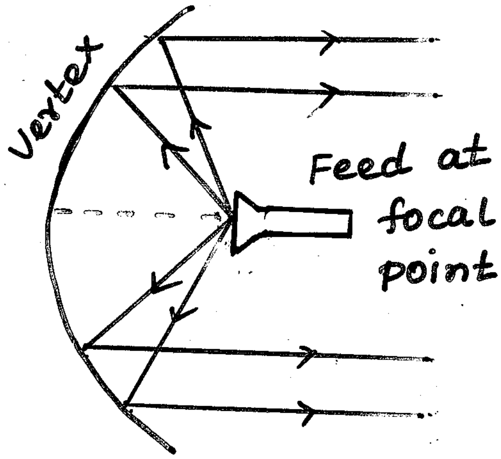
c) Thin linear reflector



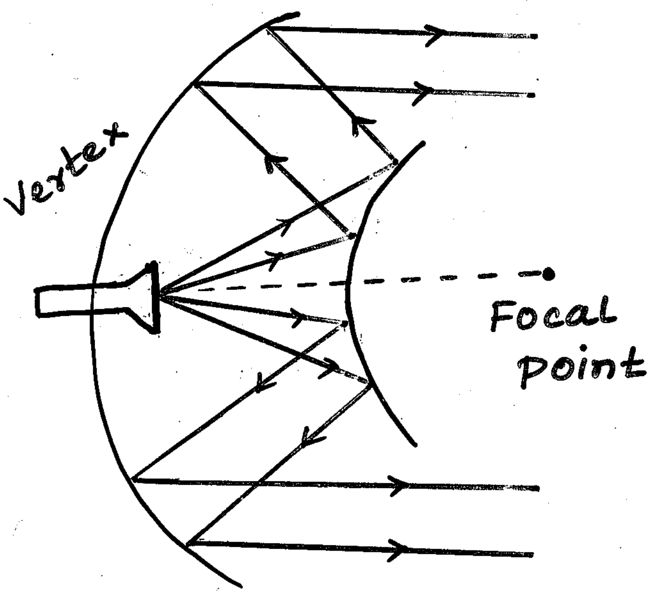
d) Active corner reflector



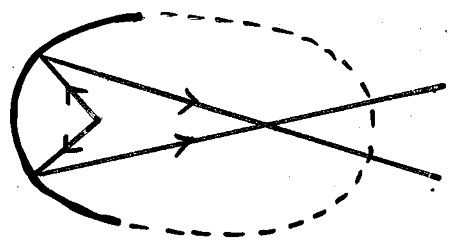
e) passive corner reflector



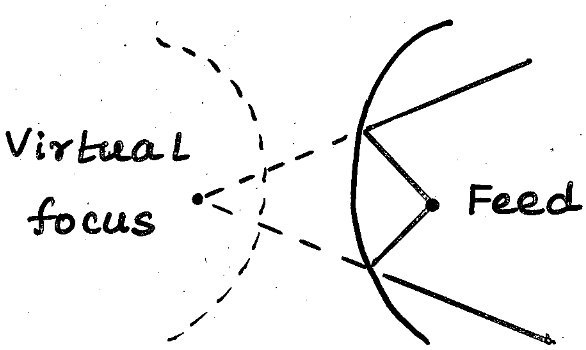
f) Curved Reflector with Front Feed



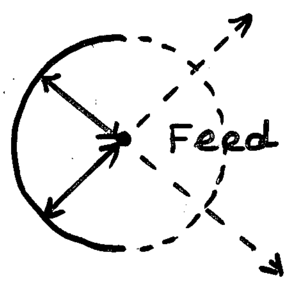
g) curved reflector with cassegrain Feed



h) Elliptical reflector



i) Hyperbolic reflector



j) circular reflector

* when it is possible to build antenna with aperture of many wavelengths, the curved reflectors as shown in Fig (f) and (g) are suitable. These are also called <u>parabolic reflector</u>.

* Parabolic reflectors are highly directional.

* parabolic reflectors transforms curved wavefront into plane wavefront.

* An elliptical reflector as shown in Fig (h) produces a beam diverging out passing thro' second focus of ellipse.

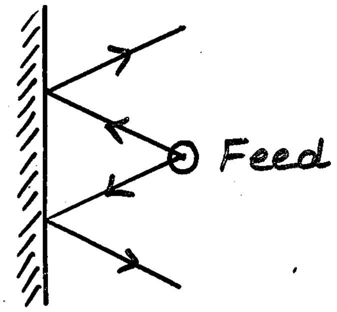
* The other types of reflector are hyperbolic reflector (Fig (i)) and circular reflector (Fig (j)).

Plane Reflectors or Flat sheet Reflectors :

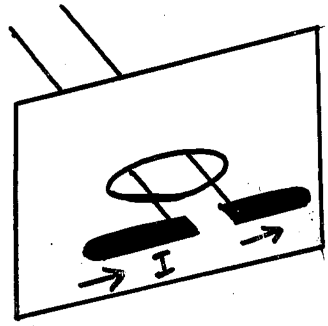
* The plane reflector is the simplest form of the reflector antenna. when the plane reflector is kept infront of the feed, the energy is radiated in the desired direction.

* The plane reflector is shown in Fig. below.

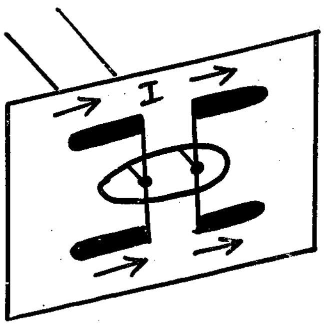
* To increase the directivity of the antenna, a large flat sheet can be kept as plane reflector infront of a half dipole as shown in Fig (b)



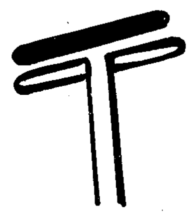
a) plane reflector



b) Half wave dipole with plane reflector



c) Half wave dipole array with plane reflector



d) Half wave dipole with reflector element

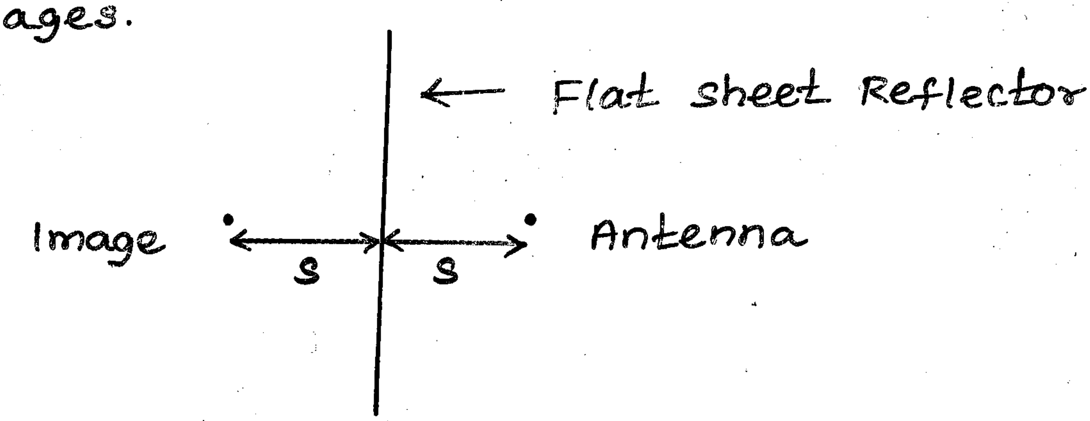
* The main advantage of the plane reflector is that for the dipole backward radiations are reduced and the gain in the forward direction is increased.

* To increase directivity further, we can use array of 2 half wave dipoles infront of flat plane reflector as shown in fig (c).

* The Flat sheet is less sensitive to Freq. than the thin element. Hence only a reflector element can be used to increase directivity as shown in Fig (d)

* 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.



Antenna with Flat sheet Reflector

* In this method, the reflector is replaced by an image of the antenna at a distance 2s from the antenna as in Fig above. Assuming zero reflector losses, the gain in field intensity of a $\lambda/2$ dipole antenna at a distance 's' from an infinite plane reflector is given by

$$G_f(\phi) = 2\sqrt{\frac{R_{11}+R_{Loss}}{R_{11}+R_{Loss}-R_{12}}}\;\left|\sin(S_r\cos\phi)\right| \rightarrow ①$$

and $S_r = \left(\frac{2\pi}{\lambda}\right)\cdot s \quad \rightarrow ②$

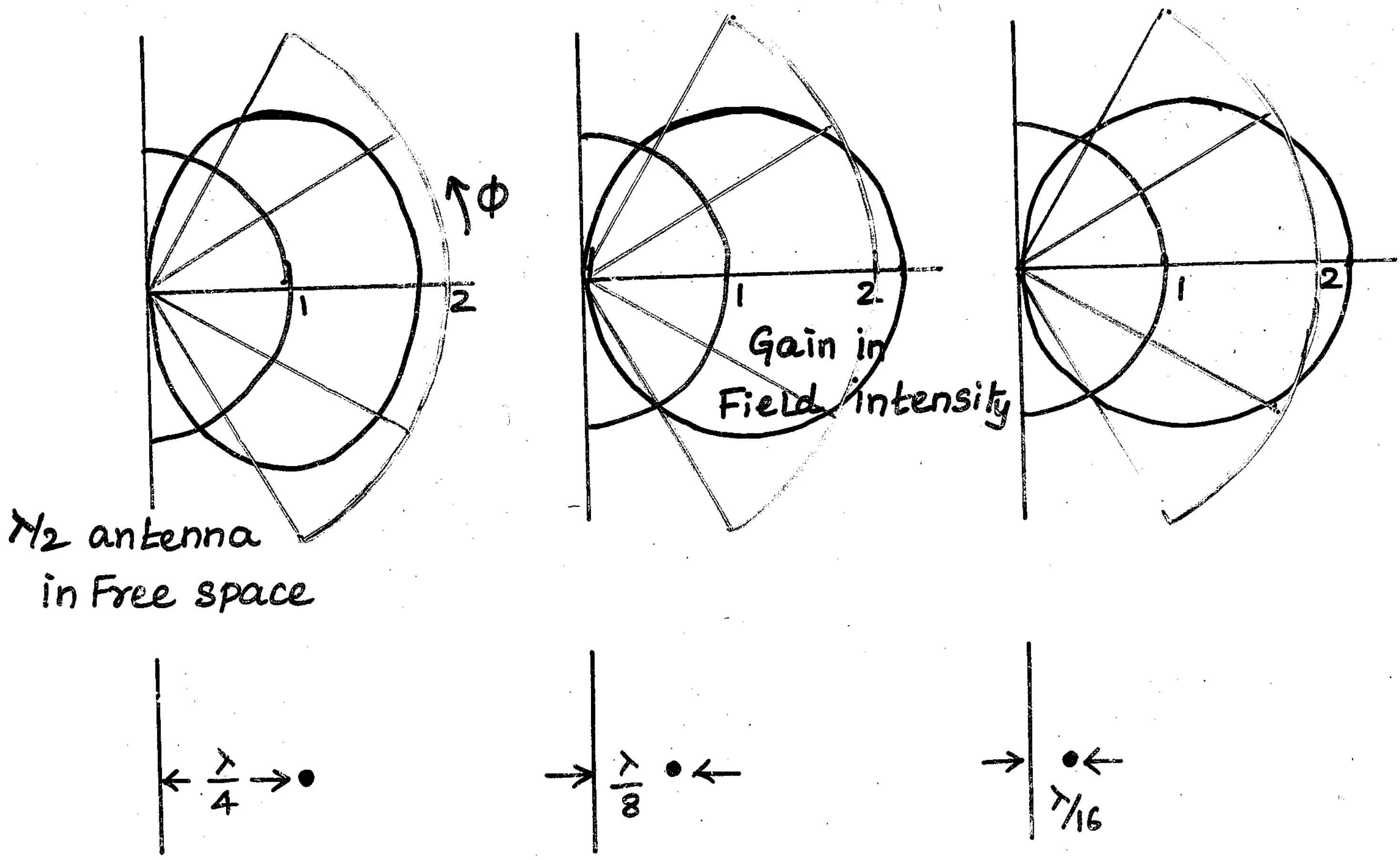
where,

R_{11} → self Resistance of one element

R_{12} → mutual " B/w element 1 and element 2

R_{Loss} → Loss resistance

* From equ ① it is clear that the gain of reflector relative to half wave dipole antenna is a function of the spacing between flat sheet and half wave dipole antenna.

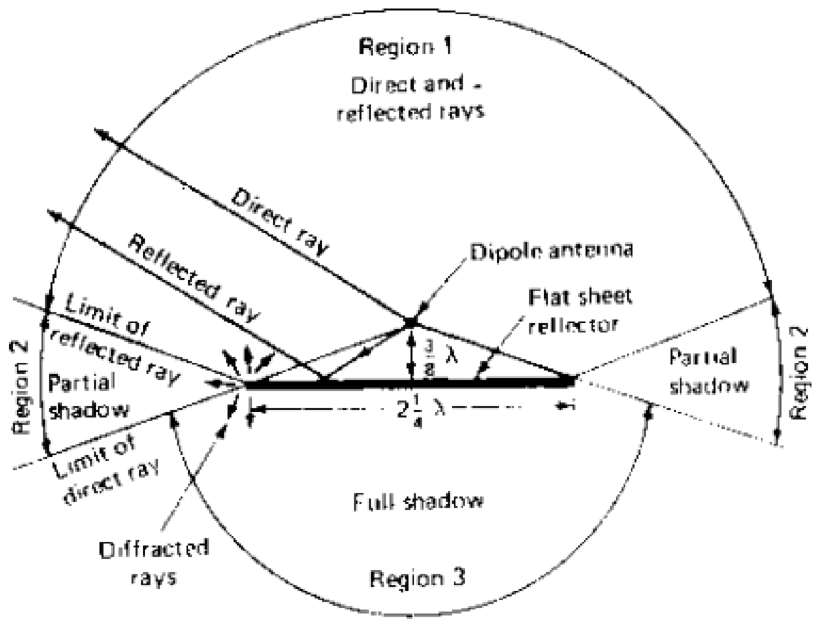


* When the spacing between the half wave dipole and infinite sheet decreases, the gain increases.

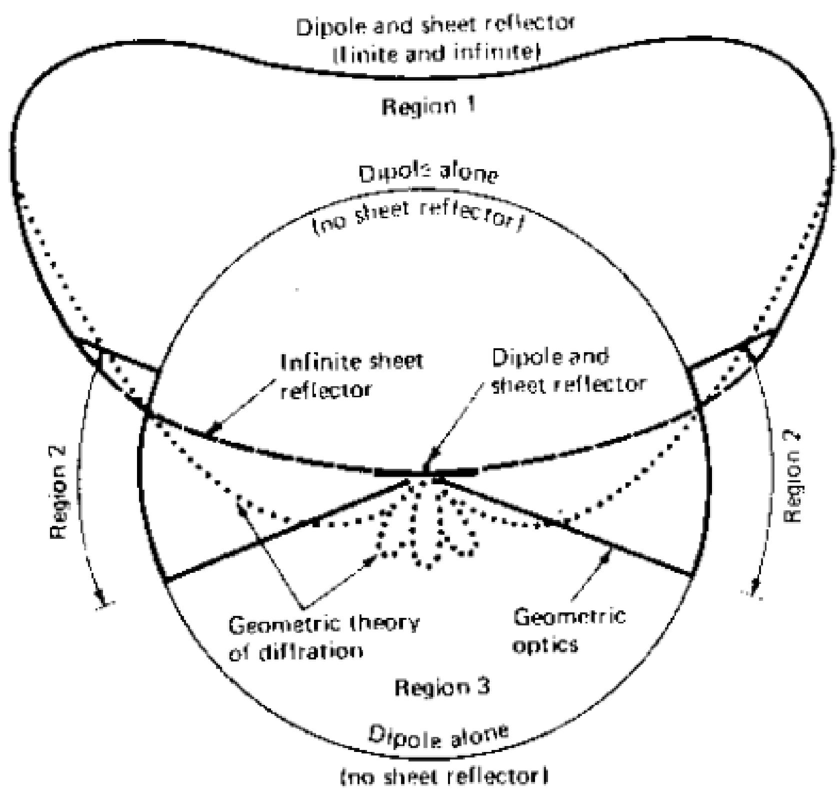
* When the reflecting sheet is reduced in size, the analysis is simple. There are 3 principle angular regions.

* <u>Region 1</u> (above or infront of the sheet). In this region, the radiated field is given by the resultant of the direct field of the dipole and the reflected field from the sheet.

* <u>Region 2</u> (above and below at the sides of the sheet) In this region there is only the direct field from the dipole. This region is in the shadow of the reflected field.



Dipole Antenna with 2.25λ flat sheet reflector with 3 Regions of radiation according to Geometric optics



Field pattern of Dipole and sheet Reflector according to Geometric optics (Solid Line) and according to Geometry theory of Diffraction (Dotted Line)

* Region 3 (Below or behind the sheet). In this region the sheet acts as a shield producing a full shadow (no direct or reflected fields, only diffracted fields).

* If the sheet is 1λ or 2λ in width and the dipole is close to it, image theory accounts adequently for the radiation pattern in region 1.

* In region 2, the distant field is dominated by the direct ray from the dipole.

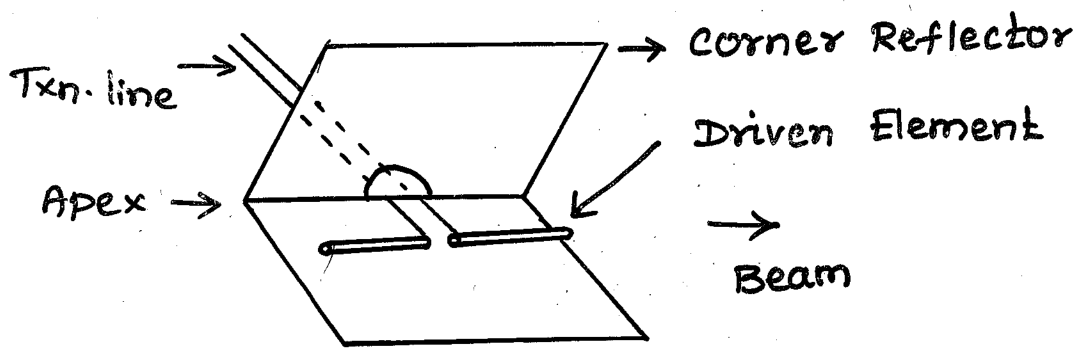
* In region 3, the geometrical theory of diffraction (GTD) must be used.

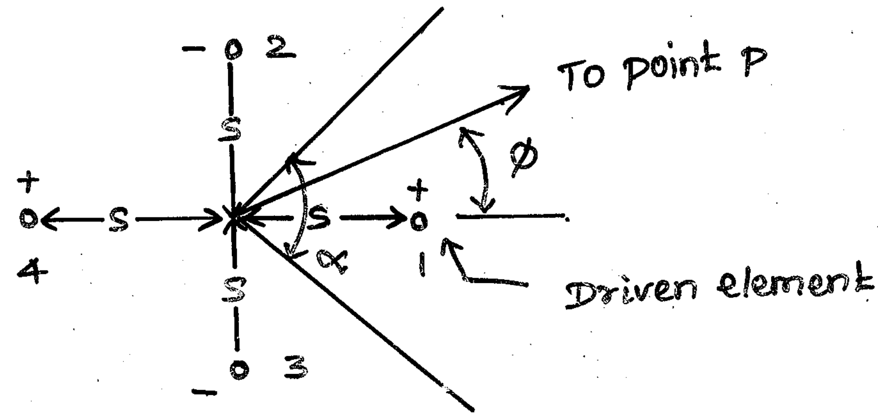
Corner Reflector :-

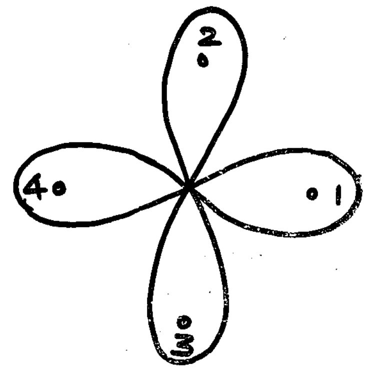
* The radiation from a diapole parallel to a flat sheet can be replaced by its image.

* Assuming perfectly conducting reflecting sheets of infinite extent, the method of images can be applied to analyze the corner reflector antenna for angles $\alpha = 180°/n$ where, $n \rightarrow$ any +ve integer.

* In the analysis of 90° corner reflector, there are 3 image elements 2, 3 and 4 located as shown in fig. below.







* The driven antenna 1 and the 3 images have current of equal magnitude.

* The phase of the currents in 1 and 4 is the same and the phase of the currents in 2 and 3 are 180° out of phase w.r.to currents in 1 and 4.

* All elements are assumed to be $\lambda/2$ long.

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

$$E(\phi) = 2KI_1 \left| \left[\cos(S_r \cos\phi) - \cos(S_r \sin\phi) \right] \right| \quad \rightarrow (1)$$

where, I_1 → current in each element

S_r → Spacing of each element from the corner $= 2\pi(S/\lambda)$

K → constant involving the distance D

* The emf V_1 at the terminals of the driven element is

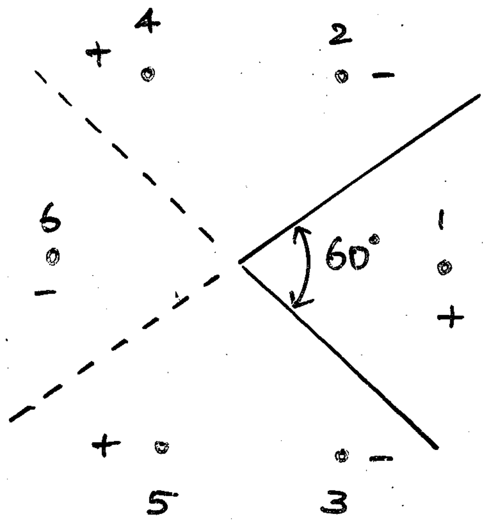
$$V_1 = I_1 Z_{11} + I_1 R_{1L} + I_1 Z_{14} - 2I_1 Z_{12} \rightarrow (2)$$

* If 'P' is the power delivered to the driven element

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

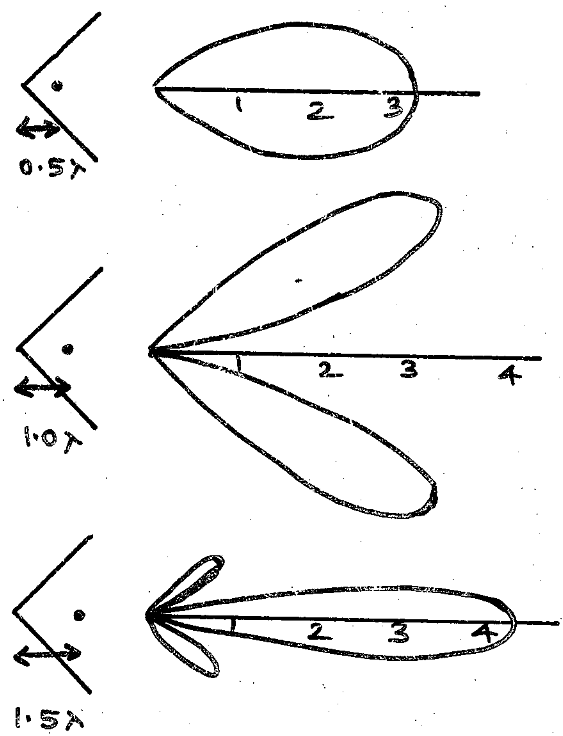
sub (3) in (1)

$$E(\phi) = 2K\sqrt{\frac{P}{R_{11}+R_{1L}+R_{14}-2R_{12}}} \cdot \left|\left[\cos(S_r \cos\phi) - \cos(S_r \sin\phi)\right]\right| \rightarrow (4)$$



A 60° corner reflector with Images

* The Calculated Pattern of a 90° corner reflector with different antenna-to-corner spacing is shown in fig.



* when $s = 0.5\lambda$, a single lobed pattern with 12dB is obtained.

* when $s = 1.0\lambda$, multilobed Pattern is obtained and when $s = 1.5\lambda$, major lobe with some minor lobe is obtained.

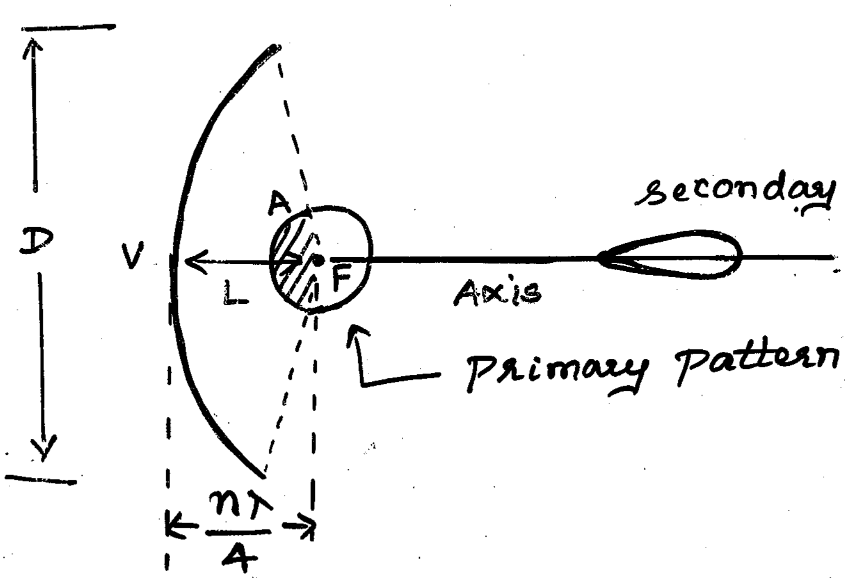
Paraboloidal Reflector :

* The surface generated by the revolution of a Parabola around its axis is called a paraboloid.

* If an isotropic source is placed at the focus of a paraboloidal reflector, a portion 'A' of the source radiation that is intercepted by the paraboloid is reflected as a plane wave.

* If the distance 'L' between the focus and vertex of the paraboloid is an even number of $\lambda/4$, the direct radiation in the axial direction from the source will be in opposite phase and will tend to cancel the central region of the reflected wave.

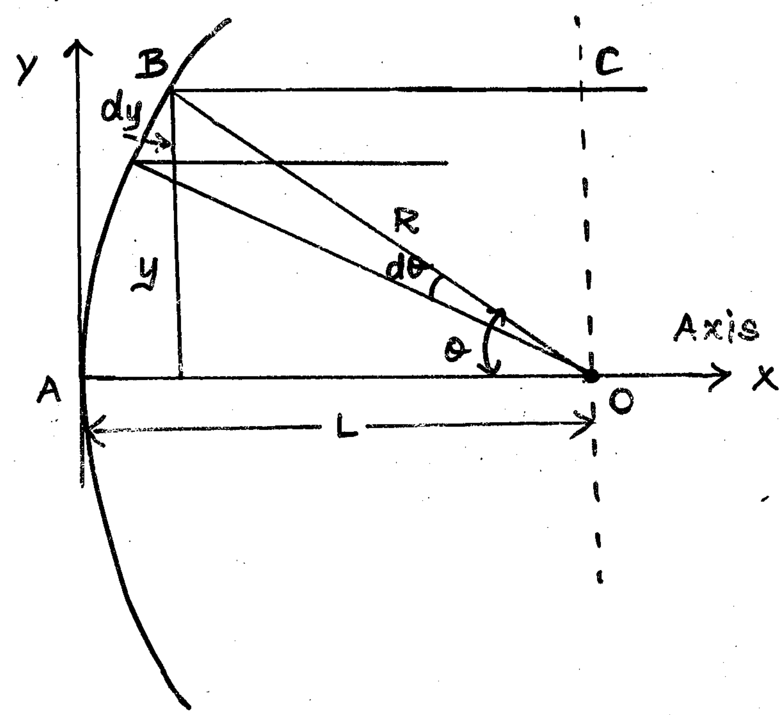
$$L = \frac{n\lambda}{4} \rightarrow (1)$$



* when $n = 1, 3, 5 \ldots$ the direct radiation in the axial direction from the source will be in the same phase and will tend to reinforce the central region of the reflected wave.

* An expression for the field distribution across the aperture of a parabolic reflector is derived as below.

* consider a cylindrical parabolic reflector with line source as in fig below. The line source is isotropic in a plane perpendicular to its axis



* For a unit distance in the z-direction, the power P in a strip of width dy is

$$P = dy \cdot S \rightarrow (1)$$

↑ power density at y (W/m²)

also,

$$P = d\theta \cdot U \rightarrow (2)$$

↑ power per unit length in z direction

$$dy \cdot S = d\theta \cdot U$$

$$\frac{S}{U} = \frac{d\theta}{dy} = \frac{1}{(dy/d\theta)}$$

$$\frac{S}{U} = \frac{1}{\frac{d}{d\theta}(R\sin\theta)} = \frac{1}{R} \rightarrow (3)$$

$(\because \sin\theta \approx \theta)$

* According to Fermat's principle,

$$OA + AO = OB + BC$$

$$L + L = R + R\cos\theta$$

$$2L = R(1+\cos\theta)$$

$$\therefore R = \frac{2L}{1+\cos\theta} \rightarrow (4)$$

sub (4) in (3)

$$\therefore \frac{S}{U} = \frac{1+\cos\theta}{2L} \rightarrow (5)$$

* The ratio of power density S_θ at θ to the power density S_0 at $\theta = 0$ is given by the ratio of (5) when $\theta = \theta$ to equ (5) when $\theta = 0°$.

$$\therefore \frac{S_\theta}{S_0} = \frac{1+\cos\theta}{2} \rightarrow (6)$$

$$S_\theta = \frac{1+\cos\theta}{2L} \cdot U$$

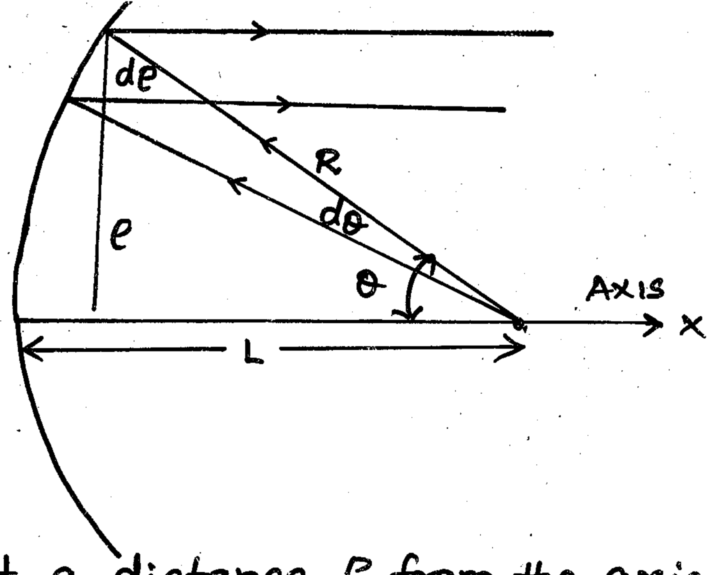
At $\theta = 0$,

$$S_0 = \frac{U}{L}$$

* The field intensity ratio in the aperture plane is equal to the square root of the power ratio.

$$\frac{E_\theta}{E_0} = \sqrt{\frac{1+\cos\theta}{2}} \rightarrow (7)$$

Paraboloid of Revolution :



The total power 'P' thro' the annular section of radius ρ and width $d\rho$ is

$$P = 2\pi\rho \, d\rho \cdot S \quad \rightarrow (8)$$

where, $S \rightarrow$ Power density at a distance ρ from the axis.

This power must be equal to the power radiated by the isotropic source over the solid angle $2\pi \sin\theta \, d\theta$.

Thus, $P = 2\pi \sin\theta \, d\theta \, U \quad \rightarrow (9)$

(U ← Radiation intensity)

$$\therefore \cancel{2\pi}\rho \, d\rho \cdot S = \cancel{2\pi} \sin\theta \, d\theta \, U$$

$$\therefore \frac{S}{U} = \frac{\sin\theta}{\rho (d\rho/d\theta)} \quad \rightarrow (10)$$

From Fig, $\rho = R\sin\theta$ and $R = \frac{2L}{1+\cos\theta}$

$$\therefore \frac{S}{U} = \frac{\cancel{\sin}\theta}{R\cancel{\sin}\theta \left(\frac{\partial}{\partial\theta} R\sin\theta\right)} \qquad \because \sin\theta \approx \theta$$

$$\frac{S}{U} = \frac{1}{R^2}$$

$$\therefore S = \frac{1}{\left(\frac{2L}{1+\cos\theta}\right)^2} \cdot U = \frac{(1+\cos\theta)^2}{4L^2} \cdot U \quad \rightarrow (11)$$

The ratio of power density S_θ at an angle 'θ' to the power density S_0 at $\theta = 0$ is

$$\frac{S_\theta}{S_0} = \frac{(1+\cos\theta)^2}{4} \quad \rightarrow (12)$$

The field intensity ratio in the aperture plane is equal to the square root of the power ratio.

$$\frac{E_\theta}{E_0} = \frac{1+\cos\theta}{2} \rightarrow (13)$$

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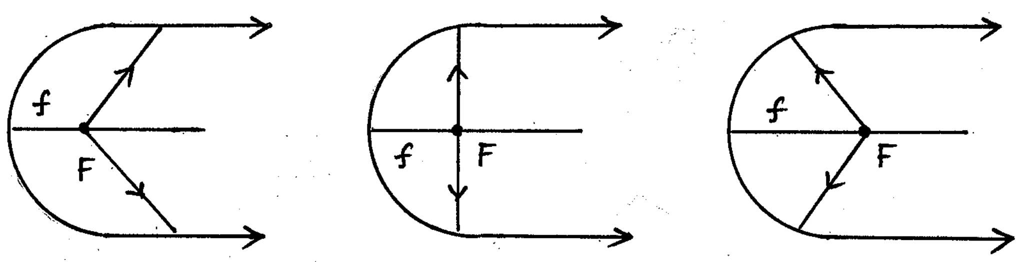
f/d Ratio, Spill over, Back Lobe :-

* In paraboloid reflector, the ratio of focal length 'f' to the diameter of aperture is another important design constraint.

* The 3 possible cases are,

1. Focal point inside the aperture of paraboloid
2. Focal point along the plane of aperture of paraboloid
3. Focal point beyond the aperture of Paraboloid



$f < \frac{d}{4}$ $\quad$ $f = \frac{d}{4}$ $\quad$ $f > \frac{d}{4}$

* when the focal length is very small, the focal point lies inside the aperture (open mouth) of paraboloid.

• It is difficult to obtain uniform illumination over a wide angle.

* when the focal length is one fourth of the aperture 'd', the focal point lies on the plane of the open mouth of the paraboloid.

• This condition gives uniform radiation in horizontal and vertical plane.

* when the focal length is too large $(f > \frac{d}{4})$, the focal point lies beyond the open mouth of the paraboloid.

• It is difficult to direct all the radiations from the source on the reflector.

• For practical applications, the f/d ratio lies in between 0.25 and 0.5.

Spill Over :-

* The reflector focuses all the parallel rays to the focal point or develops a parallel beam from the radiations originated from the focal point. But, there are some rays that are not fully captured by reflector, such non-captured rays form spill over.

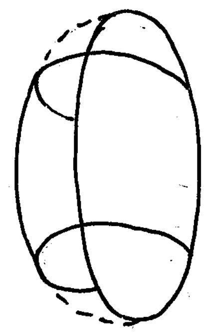
Back Lobe :-

* The radiations originated from the primary

radiators and the non-captured rays are observed in forward direction, such radiations get added with desired parallel beam. This is called back lobe radiation as it originates from the back lobe of primary radiator.

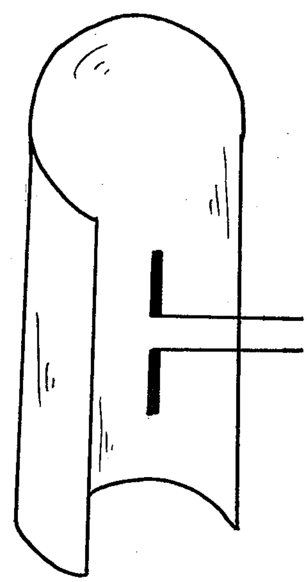
Types of Paraboloid Reflectors :-

a) Truncated paraboloid or cut paraboloid :



* This type of paraboloid is formed by cutting some of the portion of paraboloid.

b) Parabolic Right cylinder :



* This type of paraboloid is obtained by moving the parabola in side ways.

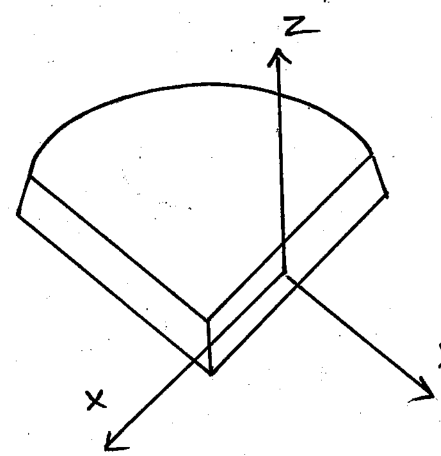
* This parabolic structure has focal line instead of a focal point and similarly a vertex line instead of a vertex.

* In this paraboloid, the energy is collimated at a line which is parallel to the axis through the focal point of the reflector.

c) Pill box or cheese antenna :-

* It is a short parabolic right cylinder enclosed by parallel plates as shown in fig.

* This antenna is useful in producing wide beam in one of the planes while a narrower beam in other plane.



Feed systems of paraboloid Reflector Antenna :-

* The paraboloid reflector antenna consists of 2 parts namely a source and a reflector.

* The source placed at the focus is called as primary radiator or feed radiator or simply feed. while the reflector is called as secondary radiator.

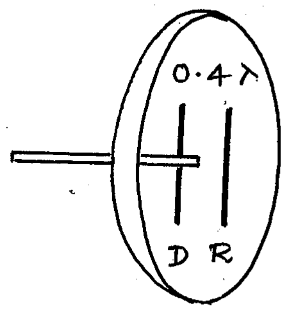
* The various types of feed used in reflector antenna are,

1. Dipole Feed
2. End Fire Feed
3. Horn antenna Feed
4. cassegrain Feed
5. Offset Feed

1. Dipole Feed :-

* The simplest type of feed that can be used is a dipole antenna.

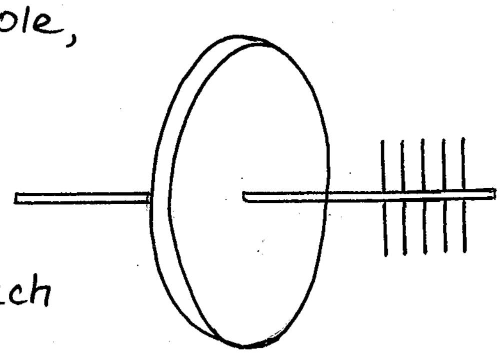
* Instead of only dipole, a feed consisting dipole with reflectors can be used as a feed system.



* The spacing between the dipole and reflector is 0.125λ. In some cases a dipole along with a plane reflector spaced 0.4λ apart from the dipole is used.

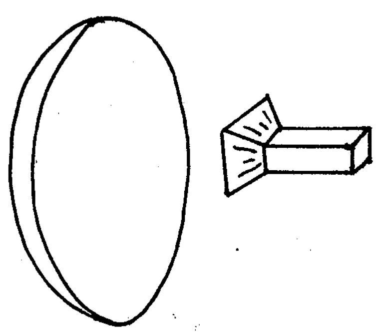
2. End Fire Feed :-

* Instead of using single dipole, an array of dipoles are used as feed radiator.



* The dipoles are spaced in such a way that the end fire pattern of an array illuminates reflector.

3. Horn Feed :-



* The most widely used feed system in the parabolic reflector antenna is horn antenna.

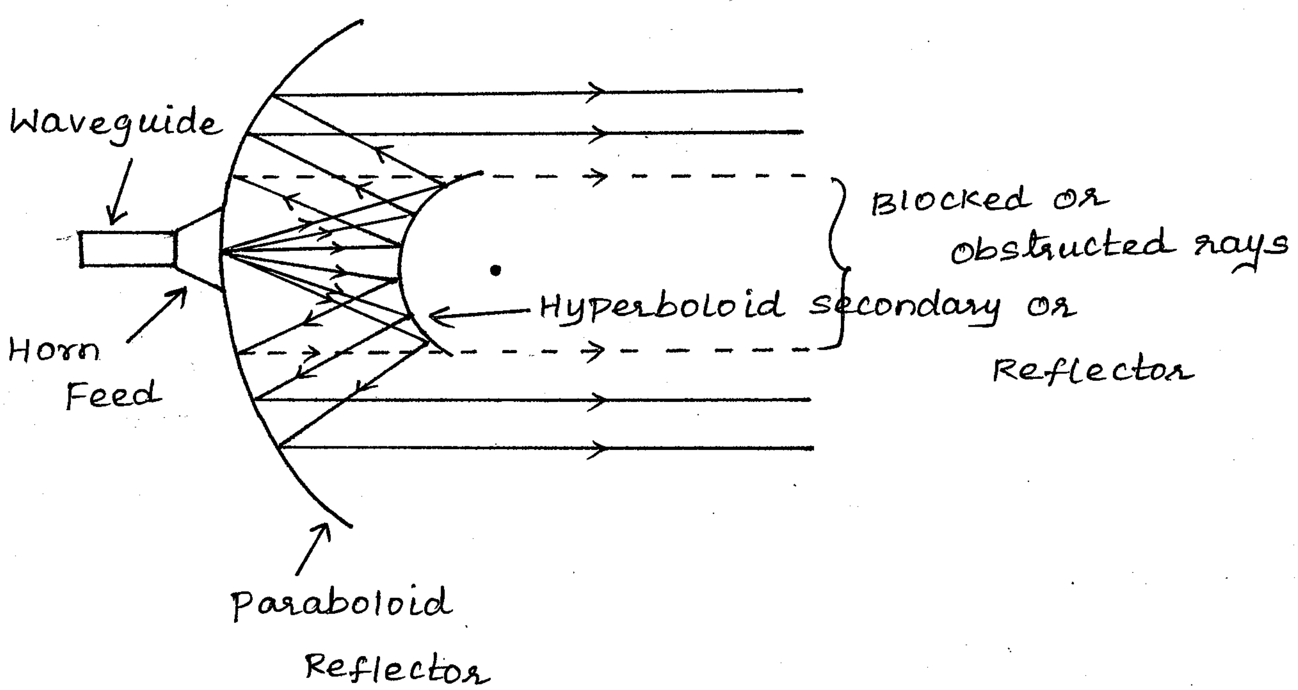
* The horn antenna is fed with a waveguide.

* In case if circular polarization is required, then in place of a rectangular horn, a conical horn or helix antenna is used at the focus.

4. cassegrain Feed system :-

* In cassegrain feed system, the feed radiator is placed at the vertex of the parabolic reflector, instead of placing it at the focus.

* This system uses a hyperboloid 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.



* Horn antenna is used as primary radiator. It aims at the sub-reflector.

* When the feed radiator (Horn antenna) radiates towards the sub-reflector, it reradiates all the radiations and due to these radiations, the parabolic reflector gets illuminated.

Advantages :-

1. It reduces the spill over and minor lobe radiations
2. The system has ability to place a feed at convenient place.
3. Increases Effective aperture and directivity.
4. Beam can be broadened by adjusting one of the reflector surfaces.

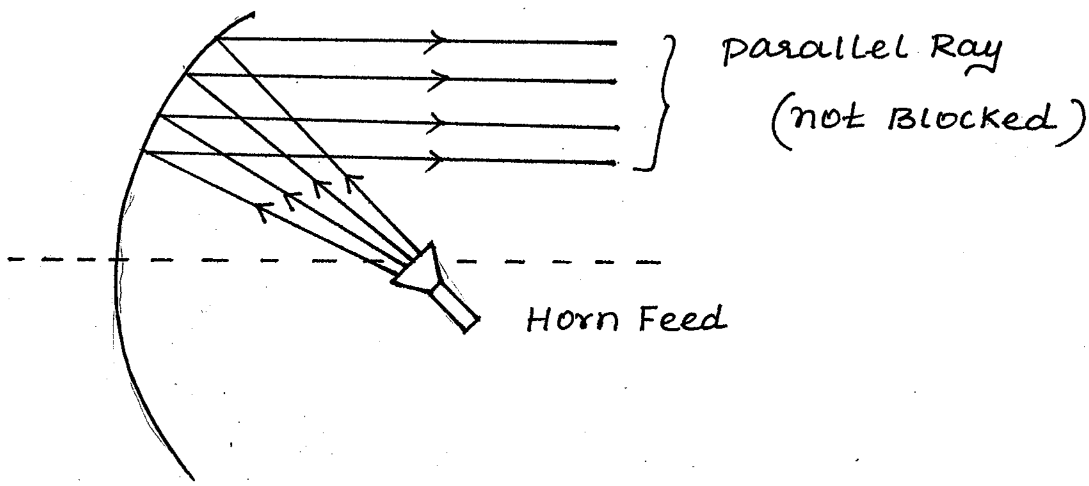
Disadvantages :-

1. Some of the radiation from the parabolic reflector are blocked by the hyperboloid reflector creating region of blocked rays.

5. Offset Feed system :-

By suitably selecting primary antenna, correct directional pattern for any arrangement can be obtained.

* To over come the aperture blocking effect due to the dependence of the secondary reflector dimension on the distance between feed and sub-reflector, the offset feed system is used.



* The feed radiator is placed at the focus as shown in above figure.

* With this system all the rays are properly collimated without forming Blocked rays.

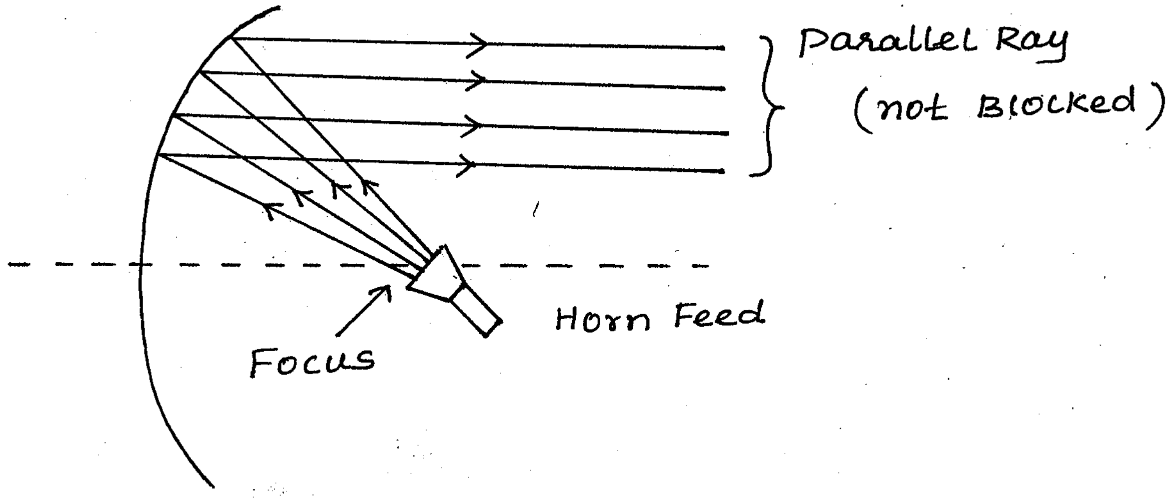
Aperture Blockage :-

* It is also called as feed Blockage.

* It refers to the part of the feed energy that is reflected back into feed antenna and does not contribute to form the main beam. This is due to shadowing by feed and sub-reflector.

* Aperture Blockage reduces power radiated and

scatter some of the power into the side lobe region of the main aperture. To achieve low side lobe level, this has to be avoided.



* To avoid aperture blockage, feed is usually placed away from the axis of the parabola or focus point. This is called off set feed.

Beamwidth Directivity and Gain of Parabolic Reflectors

Beamwidth :

For rectangular aperture,

$$BWFN = \frac{115\lambda}{L} \text{ degree}$$

For circular aperture,

$$BWFN = \frac{140\lambda}{Dia} \text{ degree}$$

$$HPBW = \frac{58\lambda}{Dia} \text{ degree}$$

where, Dia → Diameter of the aperture in metre.

Directivity :

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

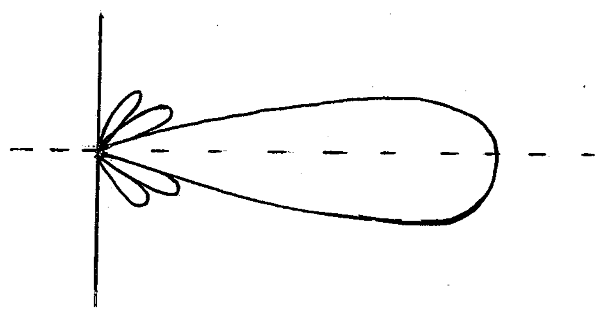
For circular aperture, $A_e' = \frac{\pi Dia^2}{4}$

$$\therefore \; D = \frac{9.87 \, Dia^2}{\lambda^2}$$

Gain :

$$G = \frac{6 \, Dia^2}{\lambda^2}$$

Radiation Pattern :-



Applications of parabolic reflectors :-

1. Satellite communication
2. Radio Telescopes & Radio Astronomy
3. Parabolic microphones
4. Microwave links
5. Direct Broadcast Television