

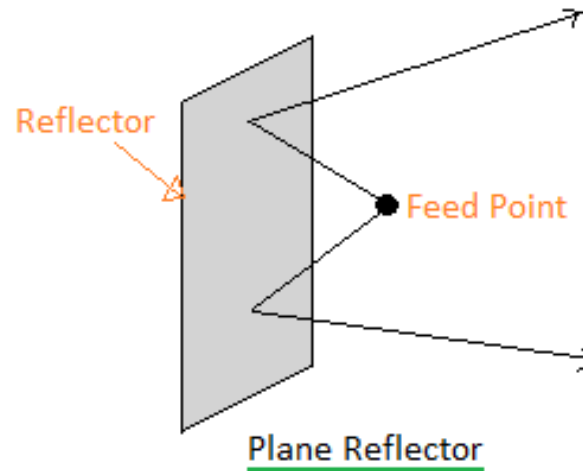
# Reflector Antennas

- Designing reflectors of many various for use in radio astronomy, microwave communication, and satellite tracking resulted in spectacular progress in the development of sophisticated analytical and experimental techniques in shaping the reflector surfaces and optimizing illumination over their apertures so as to maximize the gain.
- Although reflector antennas take many geometrical configurations, some of the most popular shapes are the plane, corner, and curved reflectors (especially the paraboloid) .

## Types of reflectors antenna

- **Plane Reflector**
- **Corner Reflector**
- **Parabolic Reflector**
- **Spherical Reflector**

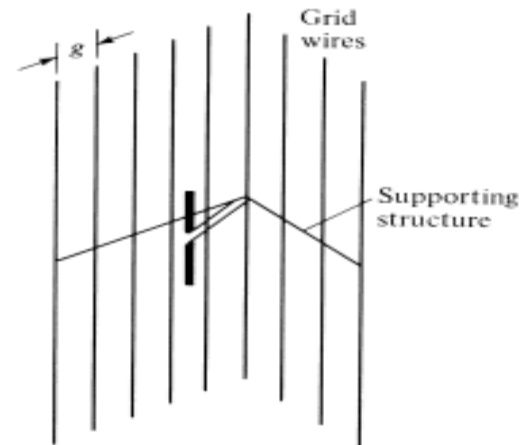
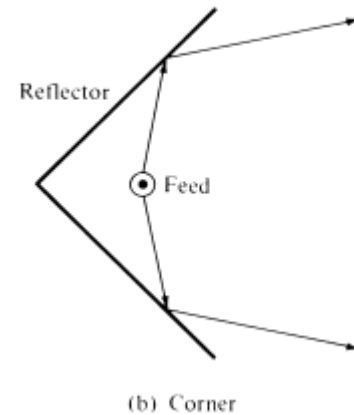
# Plane Reflector



- The simplest type of reflector is a plane reflector . It consists of primary antenna and reflecting surface introduced to direct energy in a desired direction.
- Position of radiating source and it's relative to the reflecting surface can be used to control the radiating properties (pattern, impedance, directivity) of the overall system.
- Image theory has been used to analyze the radiating characteristics of such a system.
- Disadvantage of this type that not possible to collimate energy in forward direction.

# Corner Reflector

- To better collimate the energy in the forward direction, the geometrical shape of the plane reflector itself must be chosen to prohibit radiation in the back and side directions.
- It consists of two plane reflectors joined so as to form a corner
- The feed element for a corner reflector is almost always a dipole or an array of collinear dipoles placed parallel to the vertex a distance  $s$  away
- Greater bandwidth is obtained when the feed elements are cylindrical or biconical dipoles instead of thin wires.
- In many applications, especially when the wavelength is large compared to tolerable physical dimensions, the surfaces of the corner reflector are frequently made of grid wires rather than solid sheet metal. One of the reasons for doing that is to reduce wind resistance and overall system weight.
- **The spacing ( $g$ )** between wires is made a small fraction of a wavelength (usually  $g \leq \lambda/10$ ). For wires that are parallel to the length of the dipole, the reflectivity of the grid-wire surface is as good as that of a solid surface.

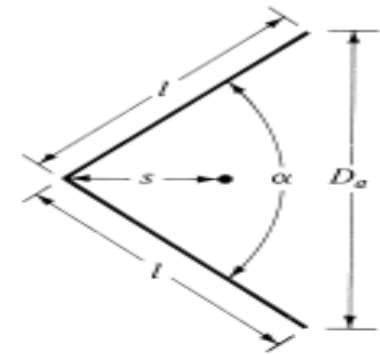


# Practicle design for Corner Reflector

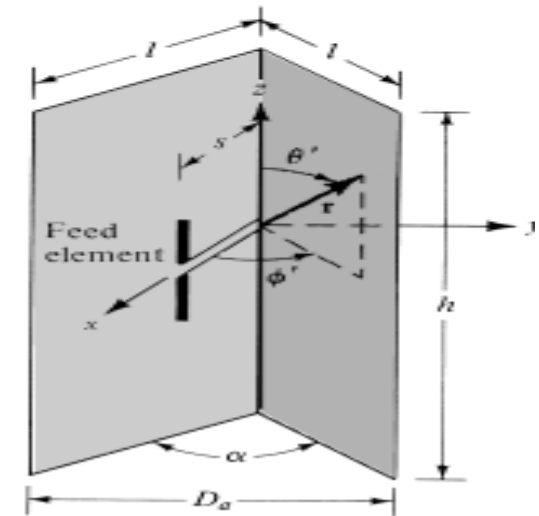
Typically:

- $\lambda < D_a < 2\lambda$
- $l \approx 2s$  ( $\alpha = 90^\circ$ )
- $l > 2s$  ( $\alpha < 90^\circ$ )
- $\lambda/3 < s < 2\lambda/3$
- $h > (1.2-1.5) \times \text{Length of feed element}$

- inorder to reduce radiation toward the back region from the ends.



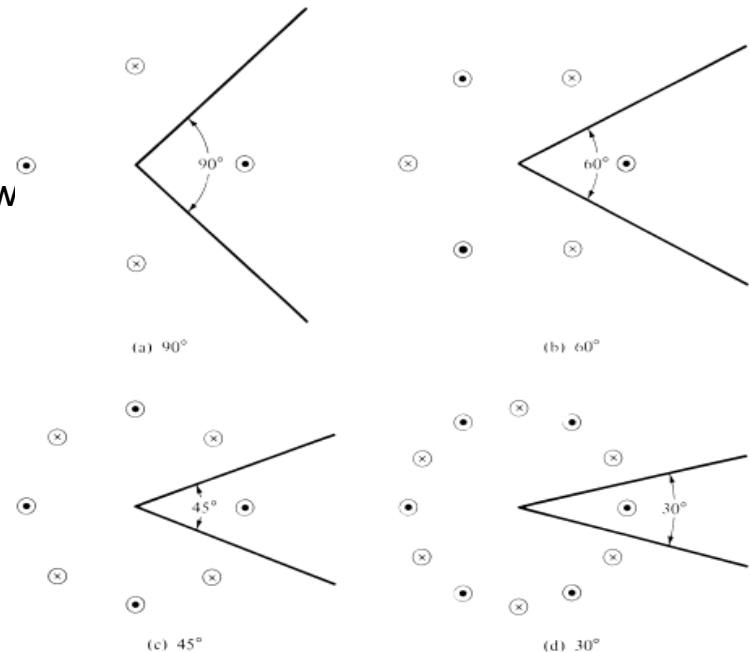
(a) Side view



(c) Perspective view

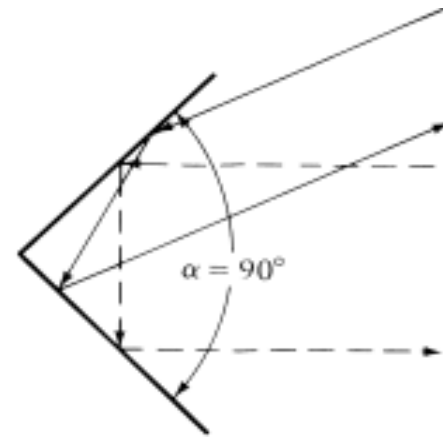
# Practicle design for Corner Reflector

- The length of the sides for reflectors with smaller included angles, the sides are made larger.
- For each reflector, there is an **optimum feed-to-vertex spacing**. If the spacing becomes too small, **the radiation resistance** decreases and becomes comparable to the loss resistance of the system which leads to an **inefficient antenna**. For very large spacing, the system produces undesirable multiple lobes, and it loses its directional characteristics.
- increasing the size of the sides does not greatly affect **the beamwidth and directivity**, but it increases the bandwidth and radiation resistance.
- The analysis for the field radiated by a source in the presence of a corner reflector is facilitated when the included angle ( $\alpha$ ) of the reflector is  $\alpha = \pi/n$ , where  $n$  is an integer ( $\alpha = \pi, \pi/2, \pi/3, \pi/4$ , etc.). For those cases ( $\alpha = 180^\circ, 90^\circ, 60^\circ, 45^\circ, \dots$ )
- **To maintain a given system efficiency**, the spacing between the vertex and the feed element must increase as the included angle of the reflector decreases, and vice versa. For reflectors with infinite sides, the gain increases as the included angle between the planes decreases
- **The number of images**, polarity, and position of each is controlled by the included angle of the corner reflector and the polarization of the feed element.



# 90° Corner Reflector

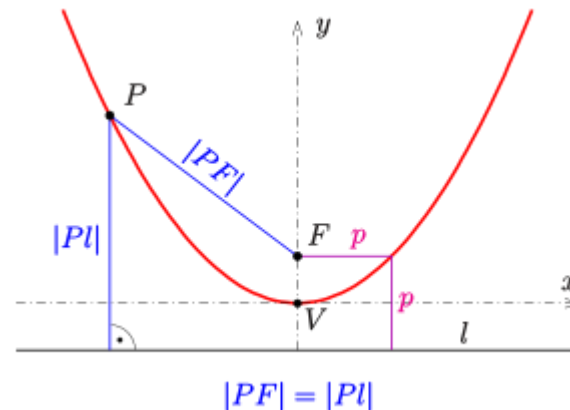
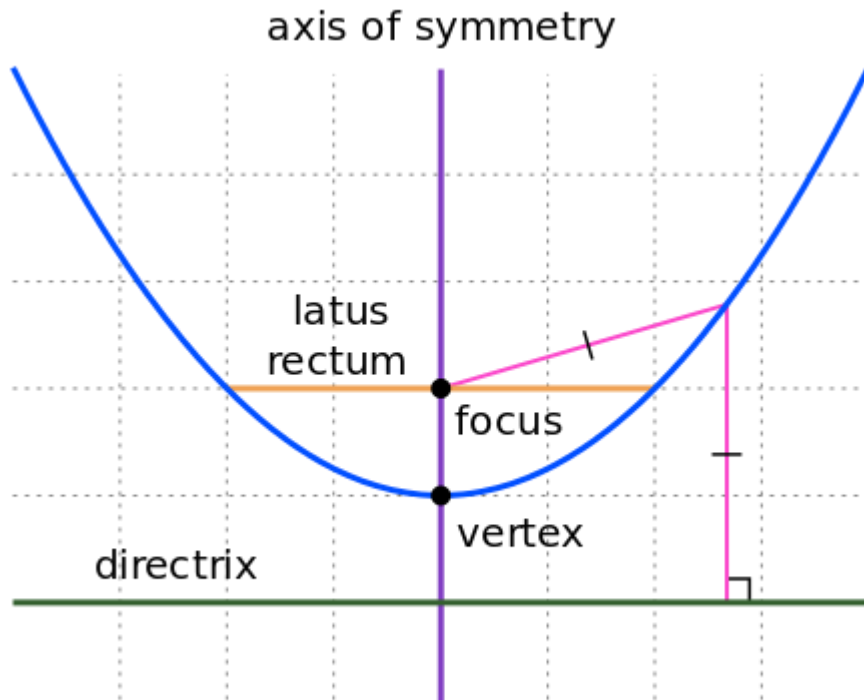
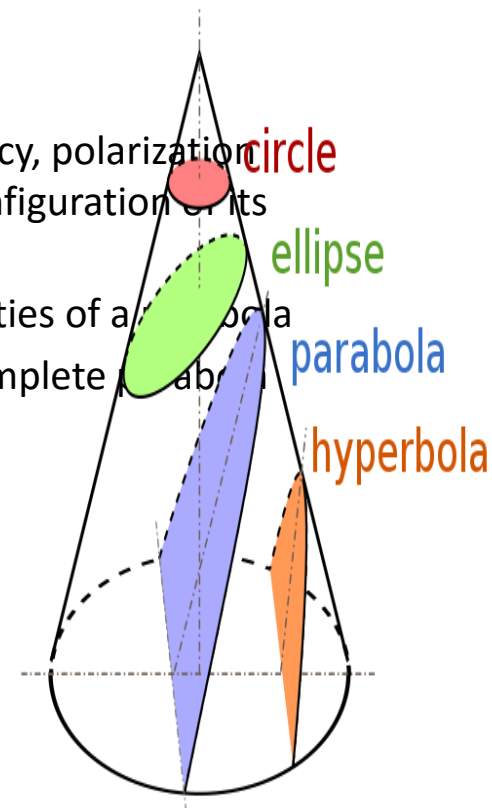
- In most practical applications, the included angle formed by the plates is usually 90°.
- Because its radiation characteristics are the most attractive, it has become the most popular.
- Because of its simplicity in construction, it has many unique applications. For example, if the reflector is used as a passive target for radar or communication applications, it will return the signal exactly in the same direction as it received it when its included angle is 90°.



(b)  $\alpha = 90^\circ$

# Parabolic Reflector

- The overall radiation characteristics (antenna pattern, antenna efficiency, polarization discrimination, etc.) of a reflector can be improved if the structural configuration of its surface is upgraded.
- This type of reflector has shape of paraboloid and hence it has properties of a parabola
- Part of a parabola (blue), with various features (other colours). The complete parabola has no endpoints. In this orientation, it extends infinitely to the left, right, and upward.



# Parabolic Reflector

- Parabolic antenna focal

One important element of the parabolic reflector antenna theory is its focal length.

To ensure that the antenna operates correctly, it is necessary to ensure that the radiating element is placed at the focal point. To determine this it is necessary to know the focal length.

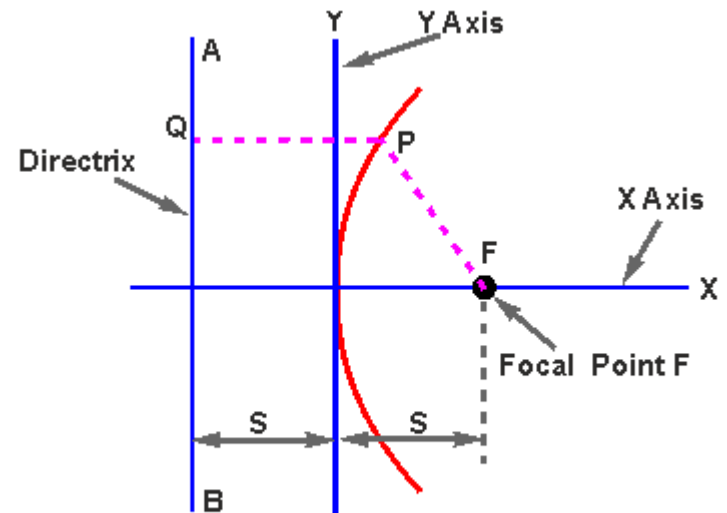
**Where:**

**f** is the focal length

**D** is the diameter of the reflector

**c** is the depth of the reflector

In addition to this the  $f/D$  ratio is important. As the  $f/D$  ratio is often specified along with the diameter, the focal length can be obtained very easily by multiplying its  $f/D$  ratio by the specified diameter  $D$ .



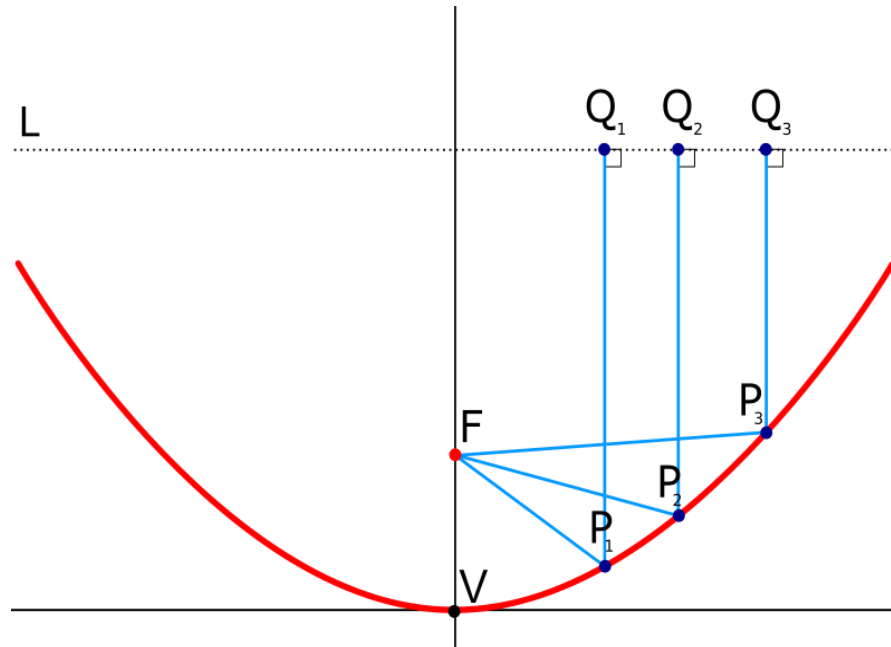
The parabolic curve and its details

$$\text{Focal length } f = \frac{D^2}{16c}$$



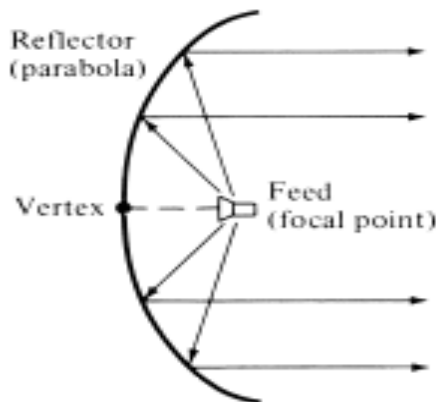
# Parabolic Reflector

- It has been shown by geometrical optics that if a beam of parallel rays is incident upon a reflector whose geometrical shape is a parabola, the radiation will converge (focus) at a spot which is known as **the focal point**. In the same manner, if **a point source** is placed at the focal point, the rays reflected by a parabolic reflector will emerge as a parallel beam.
- Rays that emerge in a parallel formation are usually said to be *collimated* .
- In practice, collimation is often used to describe the highly directional characteristics of an antenna even though the emanating rays are not exactly parallel.

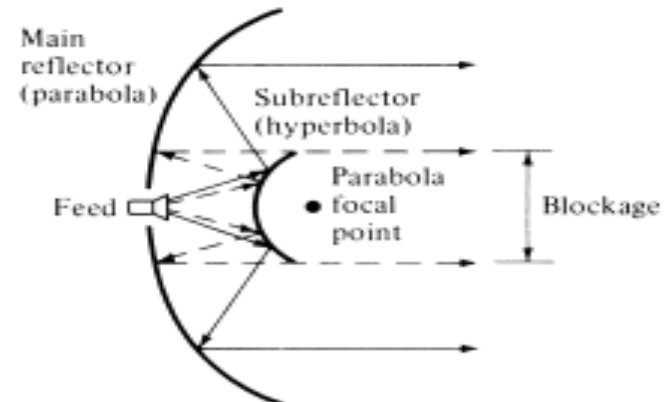


# Parabolic Reflector

- Since the transmitter (receiver) is placed at the focal point of the parabola, the configuration is usually known as **front fed**.
- Another arrangement that avoids placing the feed (transmitter and/or receiver) at the focal point is that as the **Cassegrain feed**.
- In cassegrain feed the incident parallel rays can be focused to a point by utilizing two reflectors. To accomplish this, the main(primary) reflector must be a **parabola**, the secondary reflector (subreflector) a **hyperbola**, and the feed placed along the axis of the parabola usually at or near the vertex. **Cassegrain** used this scheme to construct optical telescopes.
- **Cassegrain designs**, employing dual-reflector surfaces, are used in applications where **pattern control is essential**, such as in satellite ground-based systems, and have efficiencies of **65–80%**. They supersede the performance of the single-reflector front-fed arrangement by about 10%.



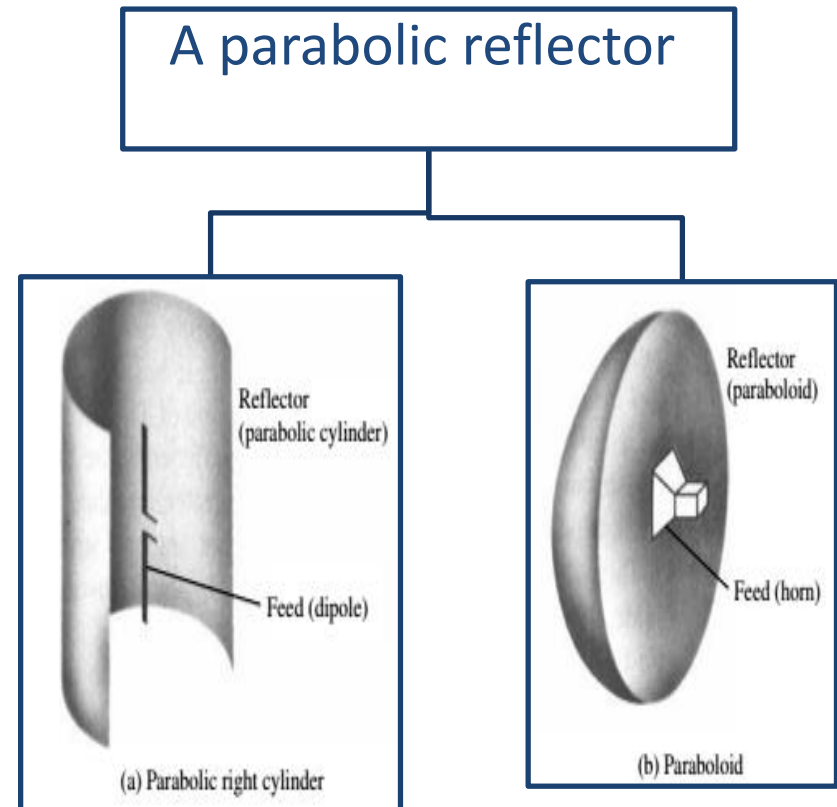
(c) Curved (front-fed)



(d) Curved (Cassegrain feed)

# Parabolic Reflector

- In **parabolic right cylinder**, The most widely used feed for this type of a reflector is a linear dipole, a linear array, or aslotted waveguide.
- In **a paraboloid**, A pyramidal or a conical horn has been widely utilized as a feed for this arrangement.
- **Paraboloidal reflectors** are the most widely used large aperture ground-based antennas and widely used for low-noise applications, such as in radioastronomy
- This type Produce a high-gain pencil beam with low side lobes
- 



# paraboloidal reflectors

- *Surface Geometry*

$$OP + PQ = \text{constant} = 2f$$

$$OP = r'$$

$$PQ = r' \cos \theta'$$

$$r'(1 + \cos \theta') = 2f$$

$$r' = \frac{2f}{1 + \cos \theta'} = f \sec^2 \left( \frac{\theta'}{2} \right) \quad \theta \leq \theta_0$$

$$\alpha = \beta = \frac{\theta'}{2} \quad \text{Snell's Law}$$

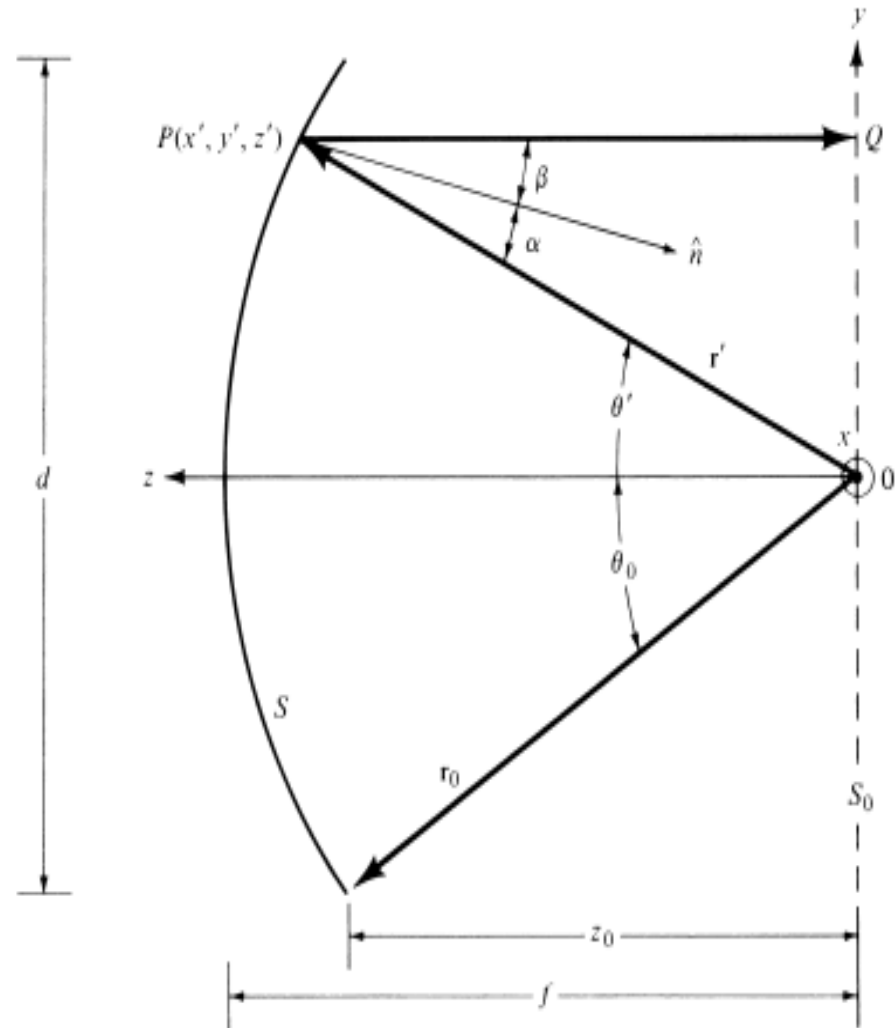


Figure 15.10 Two-dimensional configuration of a paraboloidal reflector.

# paraboloidal reflectors

$$\theta_0 = \tan^{-1} \left( \frac{d/2}{z_0} \right) \quad (15-22)$$

$$z_0 = f - \frac{x_0^2 + y_0^2}{4f} = f - \frac{(d/2)^2}{4f} = f - \frac{d^2}{16f}$$

$$\theta_0 = \tan^{-1} \left[ \frac{\frac{d}{2}}{f - \frac{d^2}{16f}} \right] = \tan^{-1} \left[ \frac{\frac{1}{2} \left( \frac{f}{d} \right)}{\left( \frac{f}{d} \right)^2 - \frac{1}{16}} \right]$$

$$f = \frac{d}{4} \cot \left( \frac{\theta_0}{2} \right)$$

$$\frac{f}{d} = \frac{1}{4} \cot \left( \frac{\theta_0}{2} \right)$$

$\theta_0$ (degrees)	$f/d$
10°	2.857
20°	1.418
30°	0.933
40°	0.687
50°	0.536
60°	0.433
70°	0.357
80°	0.298
90°	0.250
100°	0.210
120°	0.144

# Analysis Method

- It was pointed out earlier that the two most commonly used techniques in analyzing the radiation characteristics of reflectors are the **aperture distribution** and the **current distribution methods**.

## 1- Induced Current Density

-To determine the radiation characteristics (pattern, gain, efficiency, polarization, etc.) of a parabolic reflector, the current density induced on its surface must be known. The current density  $\mathbf{J}_s$  can be determined by using

$$\mathbf{J}_s = \hat{\mathbf{n}} \times \mathbf{H} = \hat{\mathbf{n}} \times (\mathbf{H}^i + \mathbf{H}^r)$$

- If the reflecting surface can be approximated by an *infinite plane surface* (this condition is met locally for a parabola),

$$\hat{\mathbf{n}} \times \mathbf{H}^i = \hat{\mathbf{n}} \times \mathbf{H}^r$$

- $\eta$  is the intrinsic impedance of the medium,
- $\hat{\mathbf{s}}^i$  and  $\hat{\mathbf{s}}^r$  are radial unit vectors
- along the ray paths of the incident and reflected waves

$$\mathbf{J}_s = 2\hat{\mathbf{n}} \times \mathbf{H}^i \simeq \frac{2}{\eta} [\hat{\mathbf{n}} \times (\hat{\mathbf{s}}_i \times \mathbf{E}^i)]$$

$$\mathbf{J}_s = 2\hat{\mathbf{n}} \times \mathbf{H}^r \simeq \frac{2}{\eta} [\hat{\mathbf{n}} \times (\hat{\mathbf{s}}_r \times \mathbf{E}^r)]$$

$$\mathbf{J}_s = \hat{\mathbf{n}} \times (\mathbf{H}^i + \mathbf{H}^r) = 2\hat{\mathbf{n}} \times \mathbf{H}^i = 2\hat{\mathbf{n}} \times \mathbf{H}^r$$

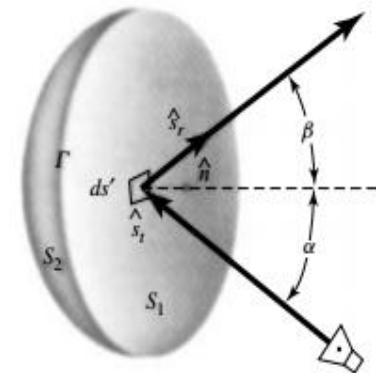


Figure 15.11 Reflecting surface with boundary  $\Gamma$ .

# Analysis Method

## 2- Aperture Distribution Method

- For the aperture distribution method, the field reflected by the surface of the paraboloid is first found over a plane which is normal to the axis of the reflector. Geometrical optics techniques (ray tracing) are usually employed to accomplish this.
- In most cases, the plane is taken through the focal point, and it is designated as the *aperture plane*, as shown in Figure Equivalent sources are then formed over that plane. Usually it is assumed that the equivalent sources are zero outside the projected area of the reflector on the aperture plane. These equivalent sources are then used to compute the radiated fields utilizing the aperture techniques.

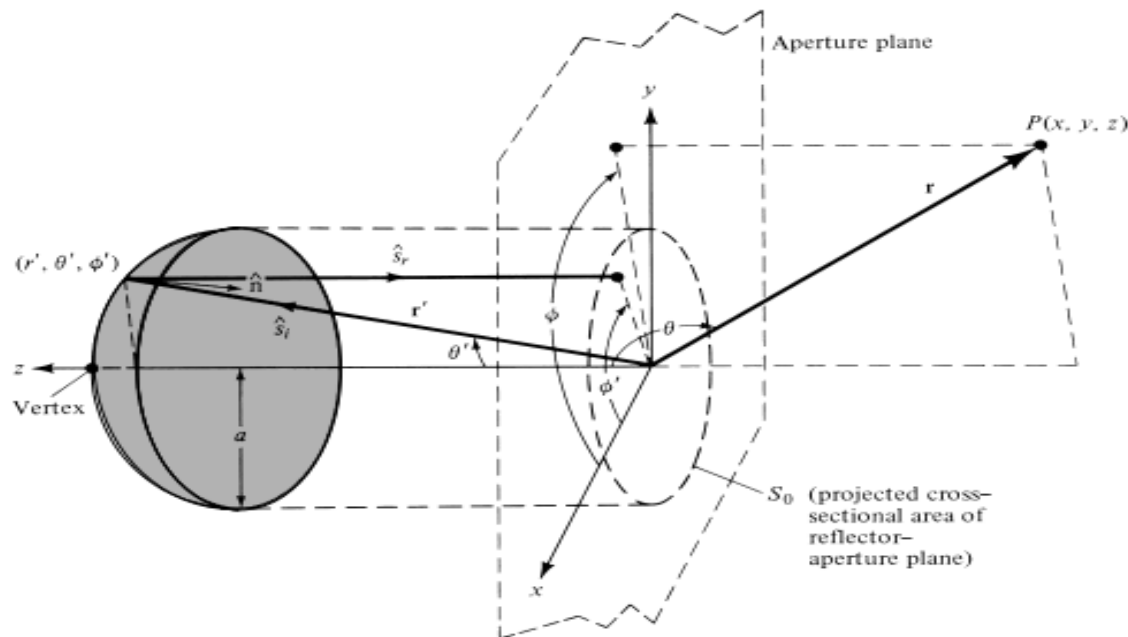


Figure 15.12 Three-dimensional geometry of a paraboloidal reflector system.

# Analysis Method

- Let us assume that a y-polarized source with a gain function of  $G_f(\vartheta, \varphi)$  is placed at the focal point of a paraboloidal reflector. The radiation intensity of this source is given by
- where  $P_t$  is the total radiated power. at a point  $r'$  in the far-zone of the source

$$U(\theta', \phi') = \frac{P_t}{4\pi} G_f(\theta', \phi') \quad U(\theta', \phi') = \frac{1}{2} \text{Re}[\mathbf{E}^o(\theta', \phi') \times \mathbf{H}^{o*}(\theta', \phi')] = \frac{1}{2\eta} |\mathbf{E}^o(\theta', \phi')|^2$$

$$|\mathbf{E}^o(\theta', \phi')| = [2\eta U(\theta', \phi')]^{1/2} = \left[ \eta \frac{P_t}{2\pi} G_f(\theta', \phi') \right]^{1/2}$$

- The incident field, with a direction perpendicular to the radial distance, can then be written as

$$\mathbf{E}^i(r', \theta', \phi') = \hat{\mathbf{e}}_i \left[ \sqrt{\frac{\mu}{\epsilon}} \frac{P_t}{2\pi} G_f(\theta', \phi') \right]^{1/2} \frac{e^{-jkr'}}{r'} = \hat{\mathbf{e}}_i C_1 \sqrt{G_f(\theta', \phi')} \frac{e^{-jkr'}}{r'} \quad (15-32)$$

$$C_1 = \left( \frac{\mu}{\epsilon} \right)^{1/4} \left( \frac{P_t}{2\pi} \right)^{1/2} \quad (15-32a)$$

$$\mathbf{J}_s = 2\sqrt{\frac{\epsilon}{\mu}} [\hat{\mathbf{n}} \times (\hat{\mathbf{s}}_i \times \mathbf{E}^i)] = 2\sqrt{\frac{\epsilon}{\mu}} C_1 \sqrt{G_f(\theta', \phi')} \frac{e^{-jkr'}}{r'} \mathbf{u}$$

$$\mathbf{u} = \hat{\mathbf{n}} \times (\hat{\mathbf{a}}_r' \times \hat{\mathbf{e}}_i) = (\hat{\mathbf{n}} \cdot \hat{\mathbf{e}}_i) \hat{\mathbf{a}}_r' - (\hat{\mathbf{n}} \cdot \hat{\mathbf{a}}_r') \hat{\mathbf{e}}_i$$



# Analysis Method

-where  $\hat{e}_i$  is a unit vector perpendicular to  $\hat{a}_r$  and parallel to the plane formed by  $\hat{a}_r$  and  $\hat{a}_y$   
 which reduces to

$$\mathbf{u} = \left[ -\hat{\mathbf{a}}_x \sin \theta' \sin \left( \frac{\theta'}{2} \right) \sin \phi' \cos \phi' \right. \\ \left. + \hat{\mathbf{a}}_y \cos \left( \frac{\theta'}{2} \right) (\sin^2 \phi' \cos \theta' + \cos^2 \phi') \right. \\ \left. - \hat{\mathbf{a}}_z \cos \theta' \sin \phi' \sin \left( \frac{\theta'}{2} \right) \right] / \sqrt{1 - \sin^2 \theta' \sin^2 \phi'}$$

To find the aperture field  $E_{ap}$  at the plane through the focal point, due to the reflector currents, the reflected field  $E_r$  at  $r'$  (**the reflection point**) is first found. This is of the form

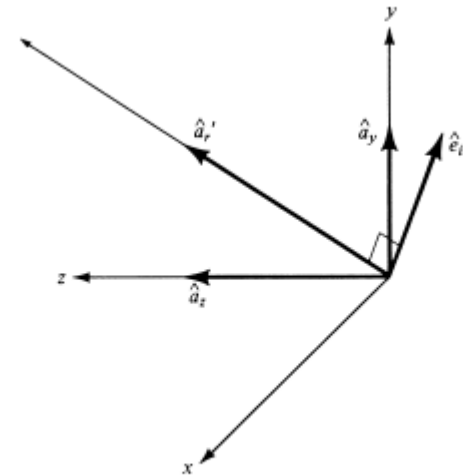


Figure 15.13 Unit vector alignment for a paraboloidal reflector system.

$$\mathbf{E}^r = \hat{\mathbf{e}}_r C_1 \sqrt{G_f(\theta', \phi')} \frac{e^{-jkr'}}{r'}$$

$$\hat{\mathbf{e}}_r = \frac{\hat{\mathbf{a}}_y \sin \phi' \cos \phi' (1 - \cos \theta') - \hat{\mathbf{a}}_z (\sin^2 \phi' \cos \theta' + \cos^2 \phi')}{\sqrt{1 - \sin^2 \theta' \sin^2 \phi'}}$$

# Analysis Method

- At the plane passing through the focal point, the field is given by

$$\mathbf{E}_{ap} = \hat{\mathbf{e}}_r C_1 \sqrt{G_f(\theta', \phi')} \frac{e^{-jkr'(1+\cos\theta')}}{r'} = \hat{\mathbf{a}}_x E_{xa} + \hat{\mathbf{a}}_y E_{ya}$$

- where ***Exa* and *Eya*** represent the x- and y-components of the reflected field over the aperture. Since the field from the reflector to the aperture plane is a **plane wave**
- Using the reflected electric field components (*Exa* and *Eya*), an equivalent is formed at the aperture plane. That is

$$\mathbf{J}'_s = \hat{\mathbf{n}} \times \mathbf{H}_a = -\hat{\mathbf{a}}_z \times \left( \hat{\mathbf{a}}_x \frac{E_{ay}}{\eta} - \hat{\mathbf{a}}_y \frac{E_{ax}}{\eta} \right) = -\hat{\mathbf{a}}_x \frac{E_{ax}}{\eta} - \hat{\mathbf{a}}_y \frac{E_{ay}}{\eta}$$

$$\mathbf{M}'_s = -\hat{\mathbf{n}} \times \mathbf{E}_a = +\hat{\mathbf{a}}_z \times (\hat{\mathbf{a}}_x E_{ax} + \hat{\mathbf{a}}_y E_{ay}) = -\hat{\mathbf{a}}_x E_{ay} + \hat{\mathbf{a}}_y E_{ax}$$

$$E_{\theta s} = \frac{jke^{-jkr}}{4\pi r} (1 - \cos\theta) \iint_{S_0} (-E_{ax} \cos\phi - E_{ay} \sin\phi) \times e^{jk(x' \sin\theta \cos\phi + y' \sin\theta \sin\phi)} dx' dy'$$

$$E_{\phi s} = \frac{jke^{-jkr}}{4\pi r} (1 - \cos\theta) \iint_{S_0} (-E_{ax} \sin\phi + E_{ay} \cos\phi) \times e^{jk(x' \sin\theta \cos\phi + y' \sin\theta \sin\phi)} dx' dy'$$

# Parabolic reflector antenna

- A **parabolic antenna** is antenna that uses a [parabolic reflector](#), a curved surface with the cross-sectional shape of a [parabola](#), to direct the [radio waves](#).
- The most common form is shaped like a [dish](#) and is popularly called a **dish antenna** or **parabolic dish**.
- used in the high frequency part of the [radio spectrum](#), at [UHF](#) and [microwave \(SHF\)](#) frequencies, at which the wavelengths are small enough that conveniently-sized reflectors can be used.
- Parabolic antennas have some of the highest [gains](#), meaning that they can produce the narrowest [beamwidths](#), of any antenna type.(achieve narrow beamwidths, the parabolic reflector must be much larger than the [wavelength](#) of the radio waves used).
- **Factors affect on dish antenna**
  - 1-aperature efficiency
  - 2-frequency
  - 3-diameter
  - 4-accuracy of dish surface
  - 5-pattern of feed antenna

# Parabolic reflector antenna

- To make Design for parabolic reflector antenna

## 1-Gain

$$G = \frac{4\pi A}{\lambda^2} e_A = \left( \frac{\pi d}{\lambda} \right)^2 e_A$$

where:

- $A$  is the area of the antenna aperture, that is, the mouth of the parabolic reflector. For a circular dish antenna,  $A = \pi d^2/4$ , giving the second formula above.
- $d$  is the diameter of the parabolic reflector, if it is circular
- $\lambda$  is the wavelength of the radio waves.
- $e_A$  is a dimensionless parameter between 0 and 1 called the *aperture efficiency*. The aperture efficiency of typical parabolic antennas is 0.55 to 0.70.

# Parabolic reflector antenna

- **Aperture efficiency  $e_A$**  is a catchall variable which accounts for various losses that reduce the gain of the antenna from the maximum that could be achieved with the given aperture. The major factors reducing the aperture efficiency in parabolic antennas are:
  - 1-Feed spillover
  - 2-Feed illumination taper
  - 3-Aperture blockage
  - 4-Shape errors

## **2-Beamwidth**

-The angular width of the beam radiated by high-gain antennas is measured by the half-power beam width (HPBW), which is the angular separation between the points on the antenna radiation pattern at which the power drops to one-half (-3 dB) its maximum value.

-For parabolic antennas, the HPBW  $\vartheta$  is given by

$$\theta = k\lambda/d$$

# Parabolic reflector antenna

- where  $k$  is a factor which varies slightly depending on the shape of the reflector and the feed illumination pattern.
- For an ideal **uniformly illuminated** parabolic reflector and  $\vartheta$  in degrees,  $k$  would be **57.3** (the number of degrees in a radian). For a "typical" parabolic antenna  $k$  is approximately **70**.
- It can be seen there is an inverse relation between gain and beam width.

$$G = \left( \frac{\pi k}{\theta} \right)^2 e_A$$

# Parabolic reflector antenna

- Feeding Types

1-Axial feed

$k=55\% : 60\%$ .

2-offset feed

used in satellite and home tv .

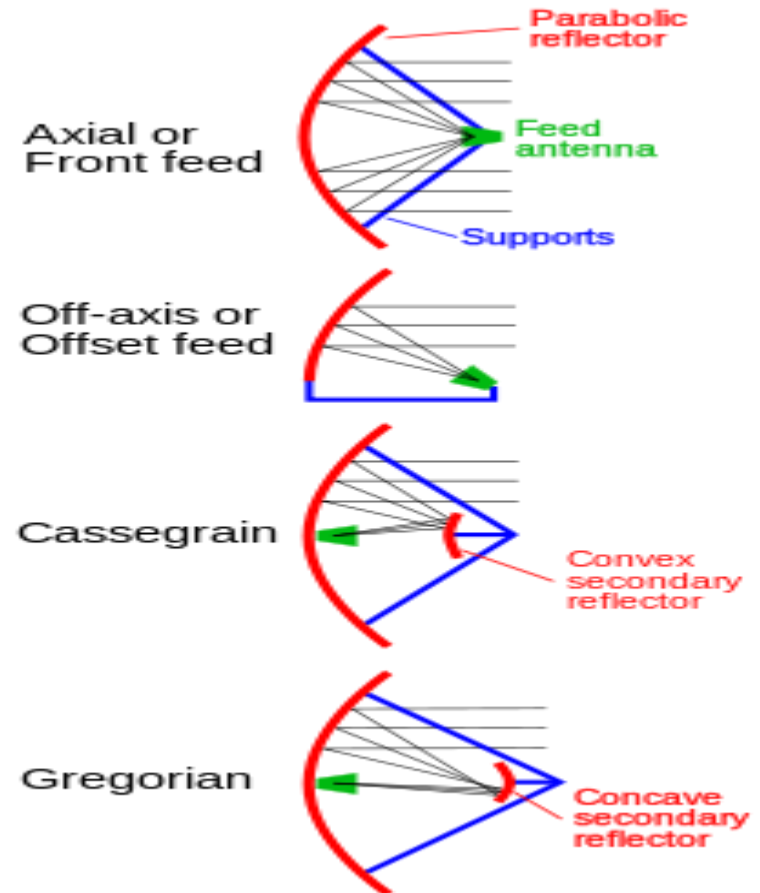
3-cassegrain

$k=65\%:70\%$

Used in radio telescope.

4-gregorian

$K>70\%$



# Spherical reflector

-a point source is placed at the focus of the sphere, it does not produce plane waves. The departure of the reflected wavefront from a plane wave is known as **spherical aberration**, and it depends on the diameter and focal length of the sphere.

-plane waves incident on a spherical reflector surface parallel to its axis do not converge at the focus  
-A caustic is a point, a line, or a surface through which all the rays in a bundle pass and where the intensity is infinite.

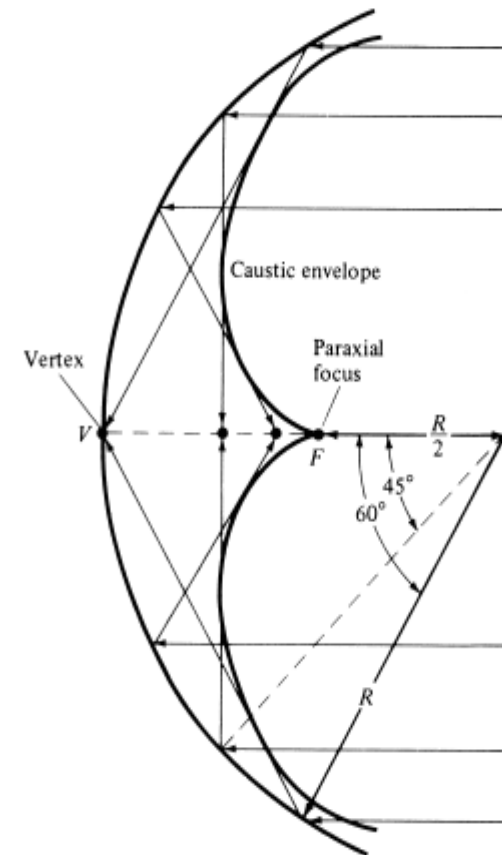


Figure 15.32 Spherical reflector geometry and rays that form a caustic.



# Spherical reflector

- to reduce spherical aberration and to minimize path error by placing a point-source feed not at the paraxial focus  $F$  (half radius of the sphere), as taught in optics, but displaced slightly toward the reflector. For an aperture of diameter  $d$ , the correct location for placing a point source is a distance  $f_0$  from the vertex such that the maximum path error value is

$$\left| \Delta_{\max} \simeq \frac{d^4}{2000 f_0^3} \right|$$

The optimum focal length is

$$\underline{f_{op} = \frac{1}{4}(R + \sqrt{R^2 - a^2})}$$

where

$R$  = radius of the spherical reflector

$a$  = radius of the utilized ap

# Spherical reflector

- for a given maximum aperture size there exists a maximum value of total allowable phase error, and it is given by

where  $(\Delta/\lambda)$  is the total phase error in wavelengths.

$$\left(\frac{a}{R}\right)_{\max}^4 = 14.7 \frac{(\Delta/\lambda)_{\text{total}}}{(R/\lambda)}$$

## Example 15.4

A spherical reflector has a 10-ft diameter. If at 11.2 GHz the maximum allowable phase error is  $\lambda/16$ , find the maximum permissible aperture.

*Solution:* At  $f = 11.2$  GHz

$$\lambda = 0.08788 \text{ ft}$$

$$\left(\frac{a}{R}\right)_{\max}^4 = 14.7 \left(\frac{1/16}{56.8957}\right) = 0.01615$$

$$a^4 \simeq 10.09$$

$$a = 1.78 \text{ ft}$$