APERTURE ANTENNAS

Reflector antennas
Lens antennas
Horn antennas
(large compared to a wavelength)

INTELSAT VII

What is an antenna?

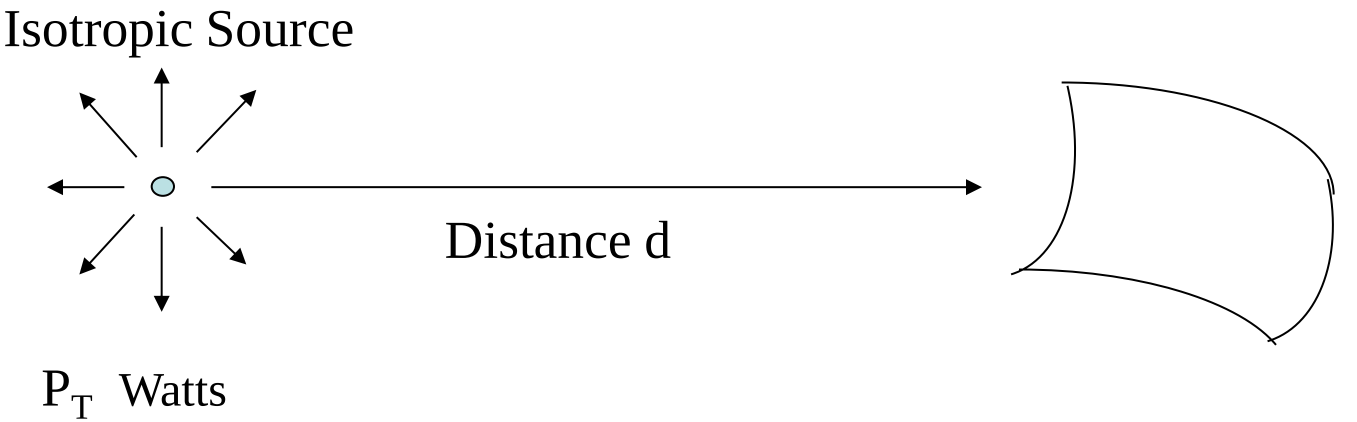
- Provides a transition between guided wave and free space propagation
- Receives an incoming wave and passes it into a transmission line (receiving case)
- Launches waves from a guiding structure into space (transmitting case)
- Reciprocal device
- Passive

Basic Antenna Parameters

- Beamwidth: *The angle between the two directions in which the radiated power is half of the maximum value of the beam.*
- Bandwidth: *Half-power frequency band.*
- Radiation pattern: *The relative distribution of radiated power as a function of direction in space – an (hypothetical) isotropic antenna radiates equally in all directions.*
- Gain *G* : *The ratio of the radiated power in the maximum direction to the radiated power of an isotropic antenna. The gain of an antenna represents the ability to focus its beam in a particular direction – an isotropic antenna has a gain of 0 dB.*
- Polarization: *The direction of the E-field.*

Isotropic Radiator

- Consider an Isotropic Source (point radiator) radiating P_T Watts uniformly into free space.
- At distance d, the area of the spherical shell with center at the source is $4\pi d^2$
- Power flux at distance d is given by $$P = \frac{P_T}{4\pi d^2}$$



Antenna Gain G

- Often use large antennas to focus the power in a wanted direction.
- Define Gain of antenna as increase in power in a given direction compared to isotropic antenna.

$$G(\theta) = \frac{P(\theta)}{P_0/4\pi}$$

- $P(\theta)$ is variation of power with angle.
- $G(\theta)$ is gain at the direction θ.
- P_0 is total power transmitted.
- sphere = 4π solid radians

For an Isotropic radiator G = 1 = 0 dBi

End 5 2009

- Antenna has gain in every direction.
- “Gain” usually denotes the maximum gain of the antenna.
- The direction of maximum gain is called “boresight”.

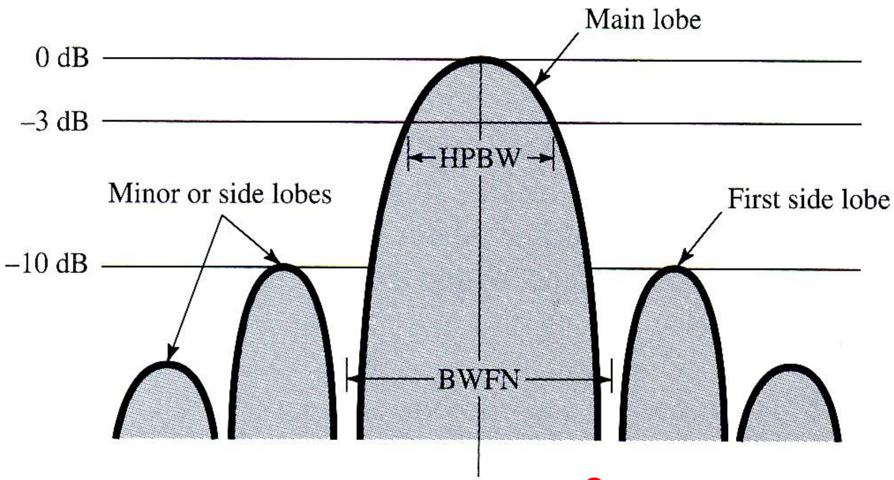
Gain is a ratio but it is usually expressed in Decibels (dB)

G [dB] = 10 $\log_{10}$ (G ratio)

If a transmitting antenna gain G_T radiates power toward a receiving antenna then power density at receiver is given by

$$P_A = PG_T = \frac{P_T G_T}{4\pi d^2} \qquad \text{(Eqn1)}$$

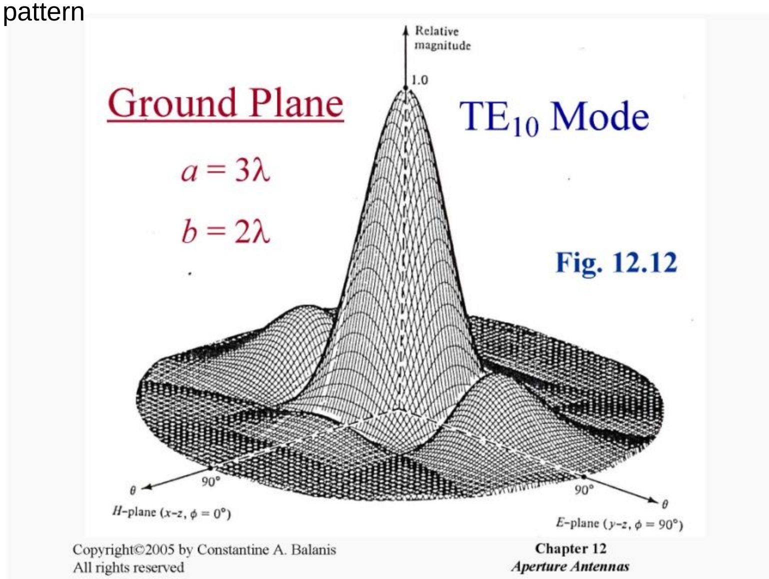
Radiation Pattern

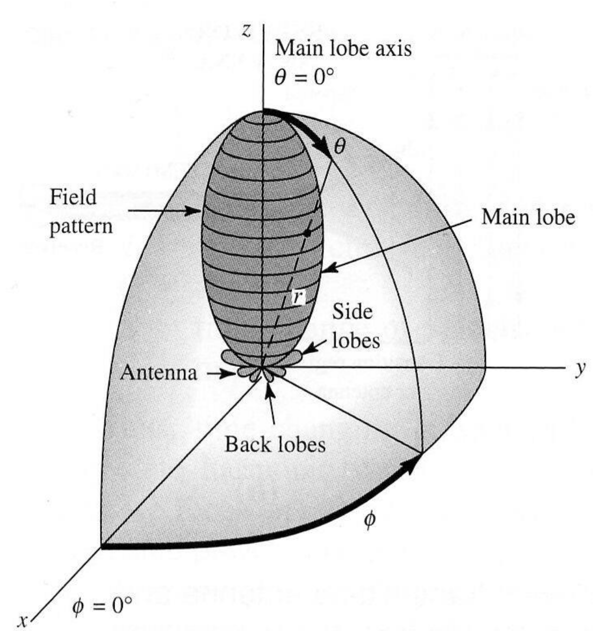


θ →

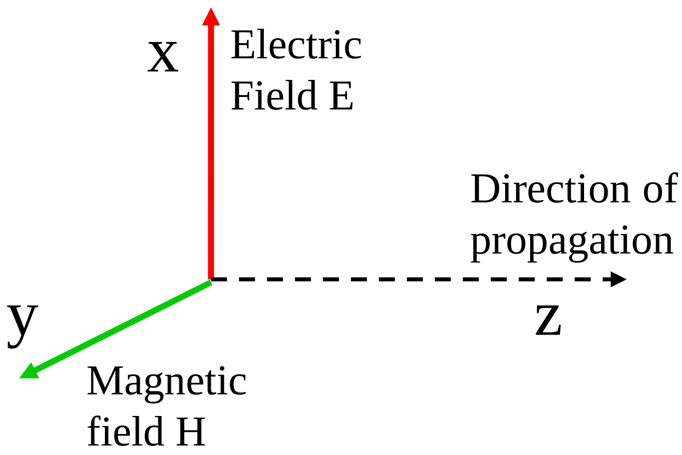
- Gain & Directivity
- Beam width
- Nulls (positions)
- Side-lobe levels (envelope)

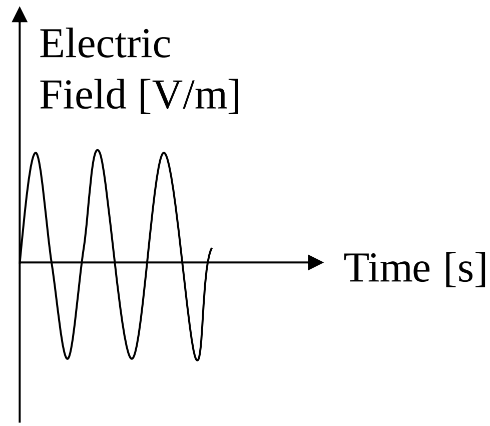
3D pattern

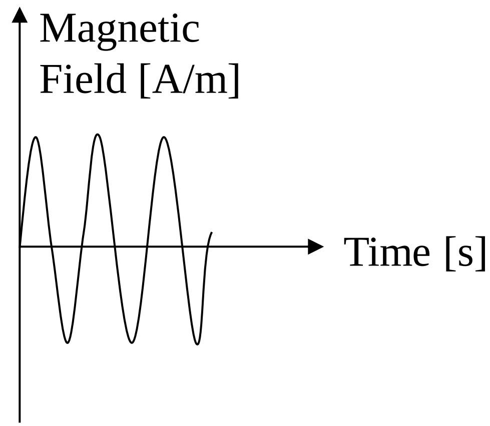




Free space electromagnetic wave







- Velocity of light (~300 000 000 m/s)
- E and H fields are orthogonal
- E and H fields are in phase
- Impedance, Z_0: 377 ohms = 120π

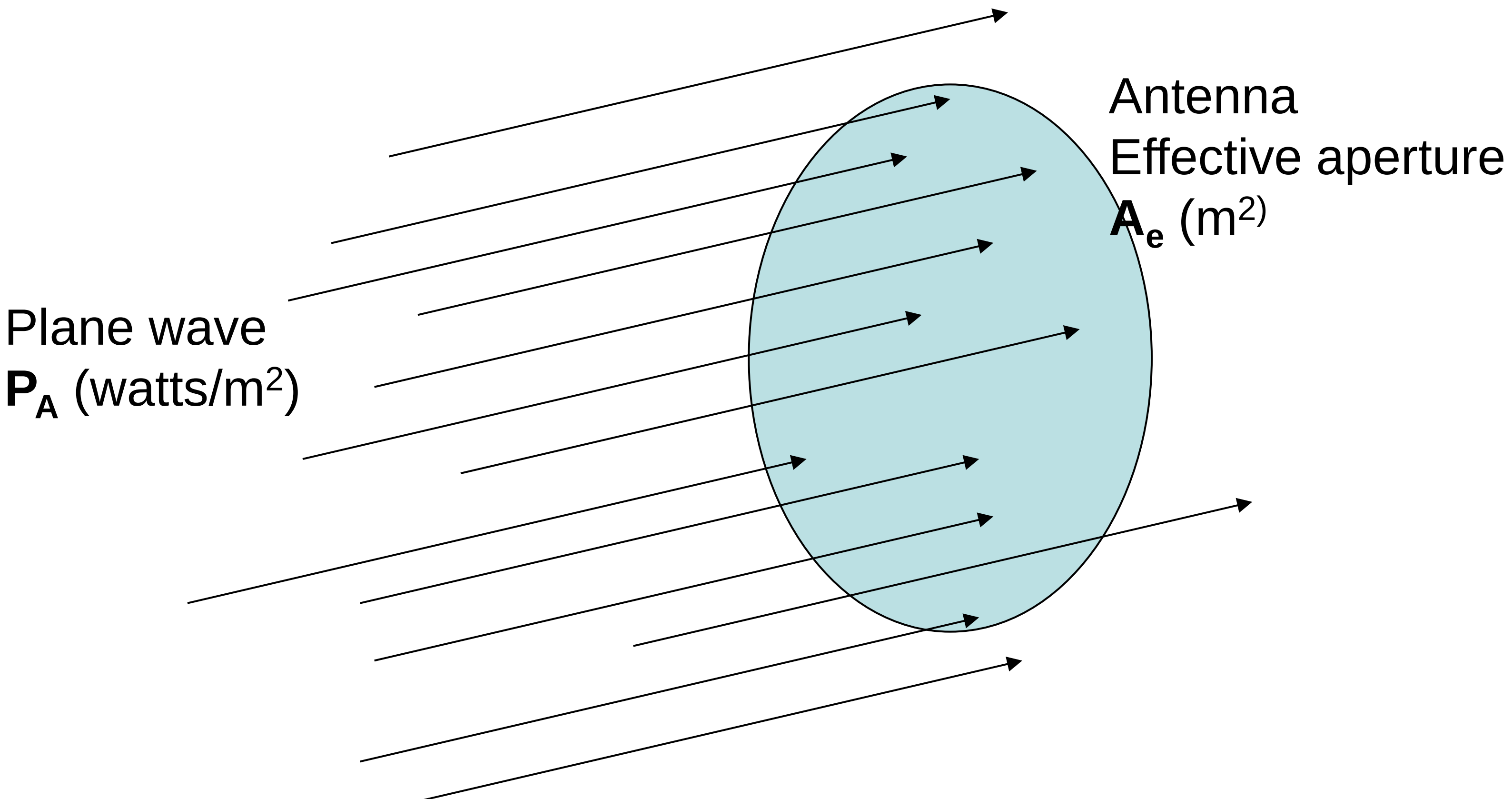
Pointings vector - power in an EM wave is P_A (W/m^2) (Power Density)

$P_A = E \times H$

$P_A = E^2/377 = E^2/Z_o = E^2/120\pi$

Antenna Effective Collecting Area

- Measure of the effective absorption area presented by an antenna to an incident plane wave.
- Power collected (absorbed) $P_R = P_A A_e$



Power received by an antenna P_R

For a plane wave $P_A = E^2/377 = E^2/Z_o$

Power received by antenna $P_R = P_A\ A_e = A_e\ E^2/120\pi$

A_e is the effective aperture of the antenna (collecting area)

A_e is related to the gain of the antenna G as

(G dependent on angle of wave)

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

$$\therefore P_R = \frac{E^2 G \lambda^2}{480\pi^2} \qquad \text{(Eqn2)}$$

Received signal strength E

For a plane wave $P_A = E^2/120\pi = E^2/Z_o$

And from eqn1 $$P_A = PG_T = \frac{P_T G_T}{4\pi d^2}$$

Hence $$E = \frac{\sqrt{30 P_T G_T}}{d}$$

And received power (eqn 2) $$\therefore P_R = P_T G_T G_R \left(\frac{\lambda}{4\pi d} \right)^2$$

This is the Friis formula for propagation through free space.

The inverse of the term at the right is the Path Loss Lp

$$P_L = \frac{P_T}{P_R} = 20\log_{10}\left(\frac{4\pi d}{\lambda} \right) \text{dB}$$

Example 1

What is the path loss when two isotropic antennas are separated by d = 1λ?

i.e. only of the power radiated by the transmitting antenna is received!

In practice the power can be increased by having antennas with gains >> 1 but the received power is still very small.

Example 2

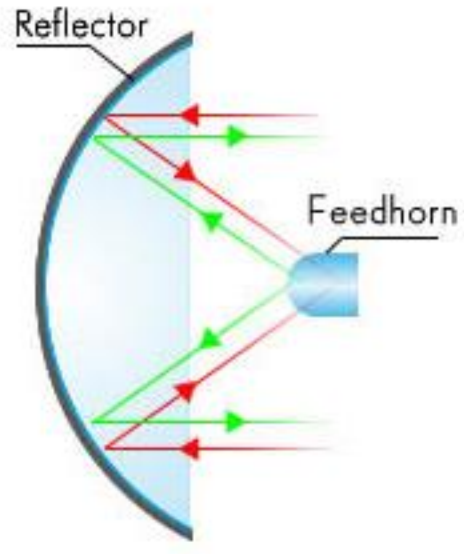
A satellite at a distance of 40,000 km from the receiving earth station operates at 11 GHz. What is the free space path loss?

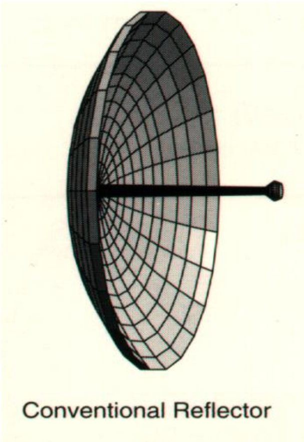
$$P_L = 20\log_{10}\left(\frac{4\pi d}{\lambda}\right)$$

i.e. 1 watt transmitted results in watts at the earth station.

Reflector antenna

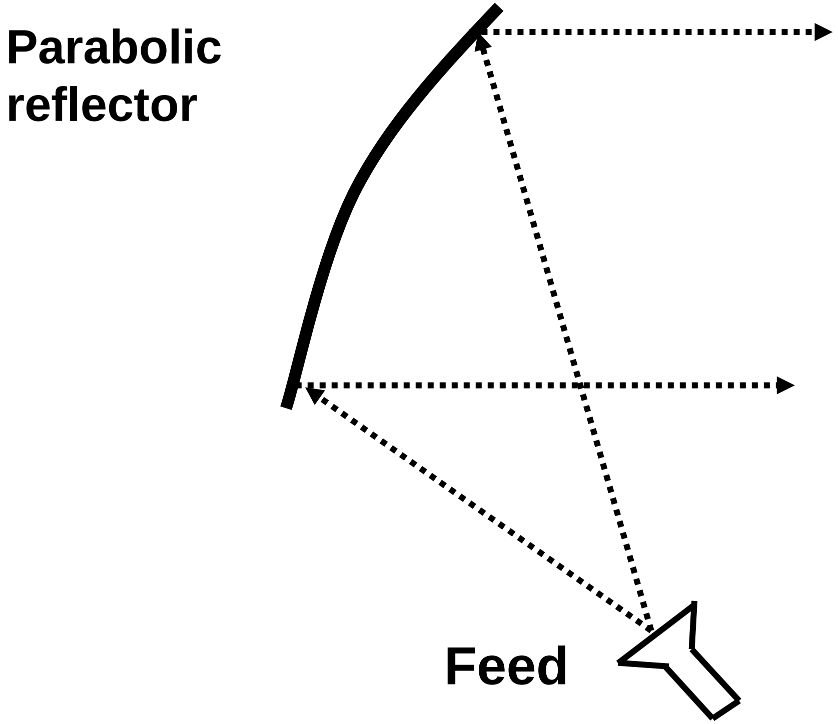
- Shaped reflector: parabolic dish
  - Reflector acts as a large collecting area and concentrates power onto a focal region where the feed is located
- Cassegrain reflector - two mirrors are used to bring the focus to a location where the feed including the transmitter/receiver can be installed more easily.



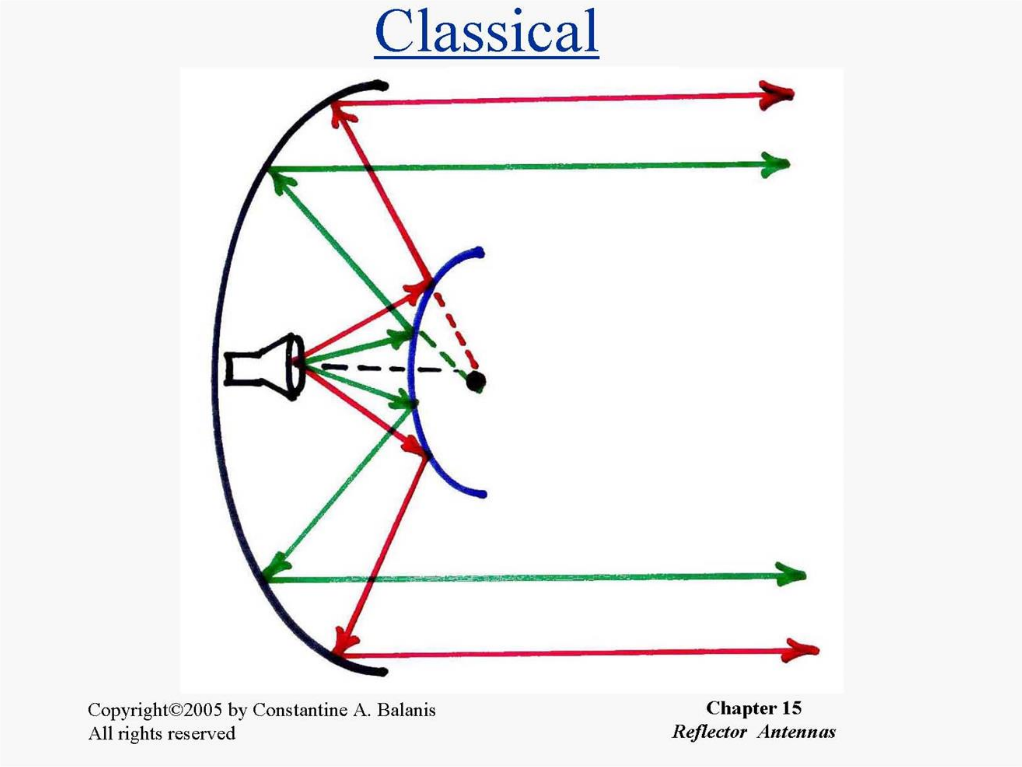


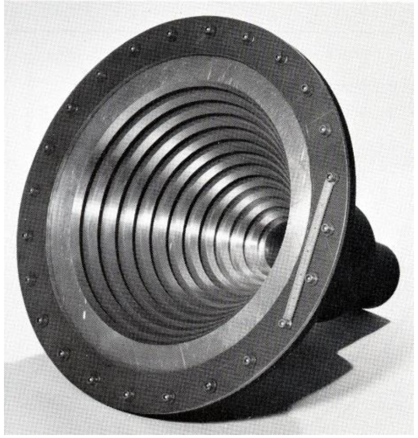
TV Reception Antenna (SKY)

Offset reflector



Cassegrain reflector





Large main reflector is a paraboloid
Small secondary reflector is a hyperboloid

Cassegrain antenna

- Less prone to back scatter than simple parabolic antenna (reduces noise)
- Much more compact for a given f/D ratio
- Gain depends on diameter, wavelength, illumination
- Effective aperture is limited by surface accuracy, blockage
- Loss in aperture efficiency due to:
  - Tapered illumination
  - Spillover (illumination does not stop at the edge of the dish)
  - Blockage of secondary mirror, support legs
  - Surface irregularities (effect depends on wavelength)

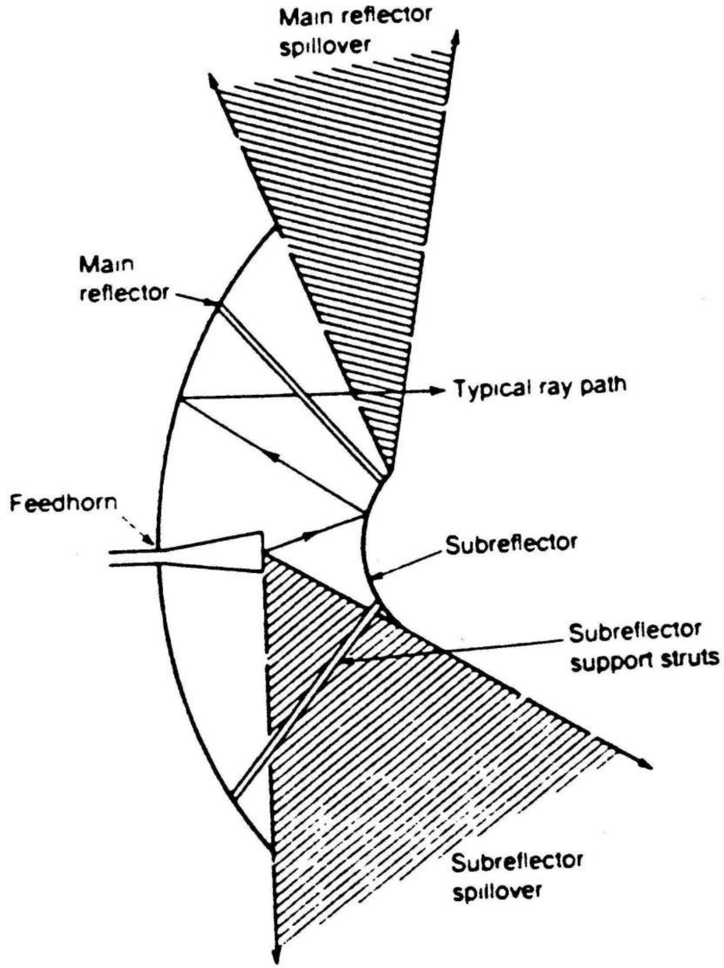
High performance

$$\text{taper efficiency}: \ \varepsilon_{\mathrm{t}} = 0.87$$

$$\text{spillover efficiency}: \ \varepsilon_{\mathrm{s}} = 0.94$$

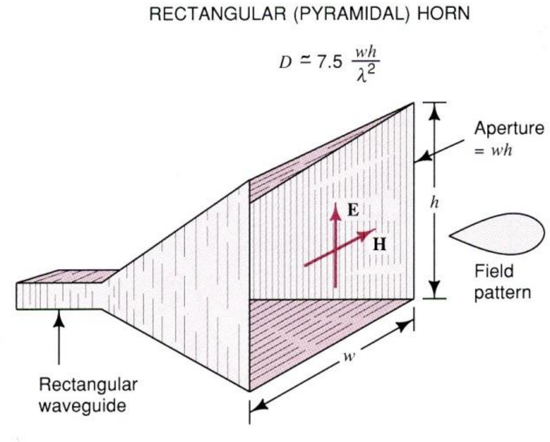
$$\text{blockage efficiency}: \ \varepsilon_{\mathrm{b}} = 0.96$$

SPILLOVER

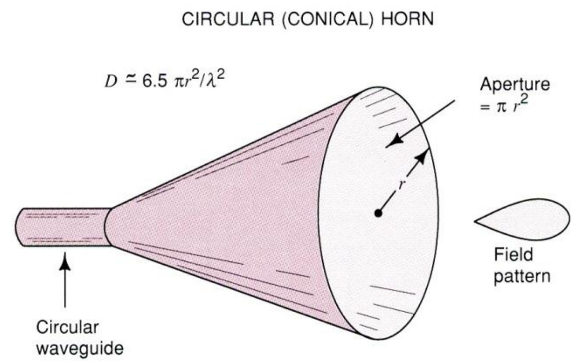


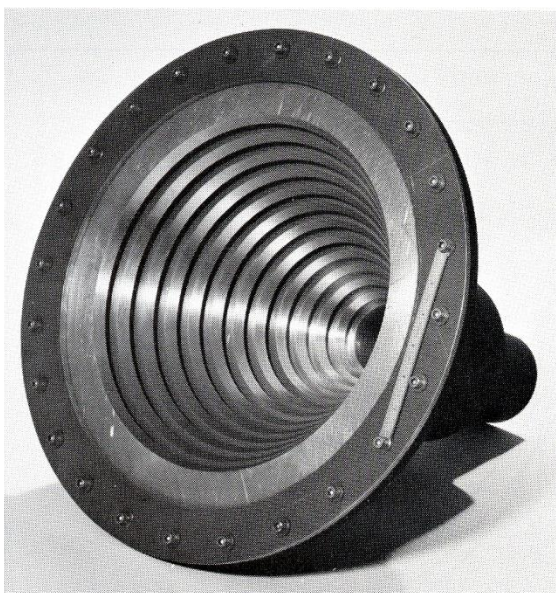
Geometry of the Cassegrain antenna.

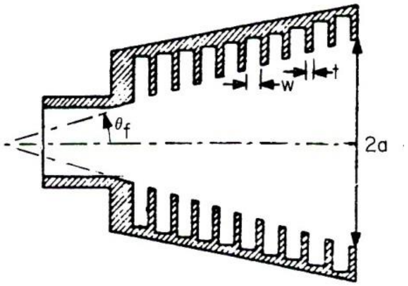
Horn antenna



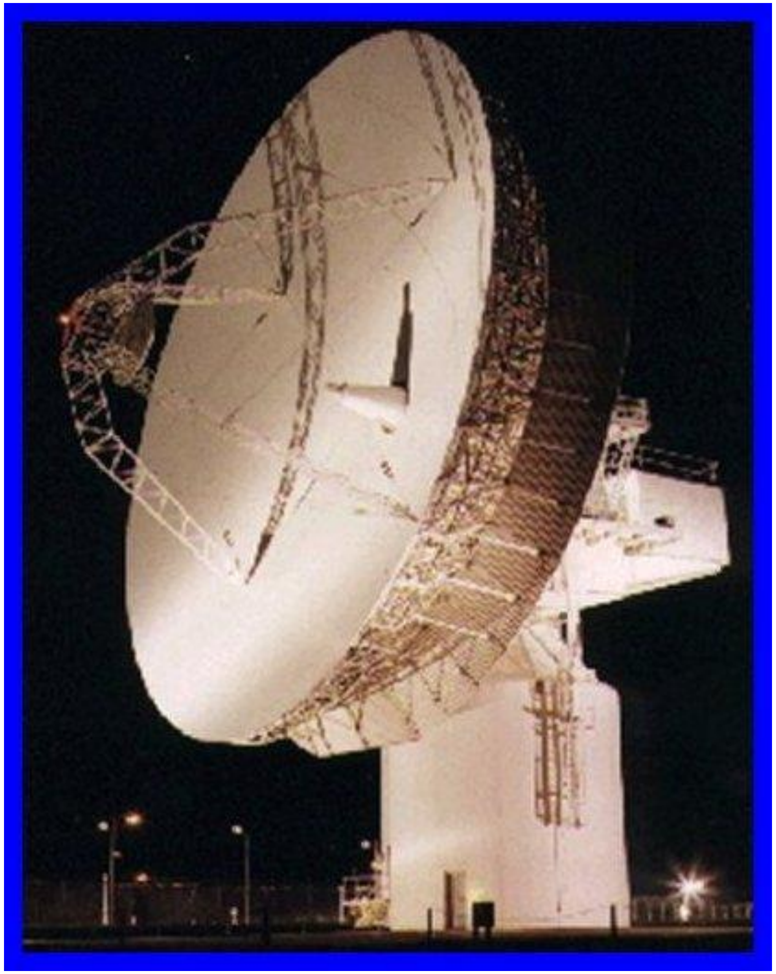
- Rectangular or circular waveguide flared up
- Spherical wave fronts from phase centre
- Flare angle and aperture determine gain







LARGE EARTH STATION



Transmit high power signal to satellite
Receive very low power signal from satellite

G/T = 40.7 dB
Noise temp T = 28K

Reflectors efficiency 80%
26m in diameter – 0.2º beamwidth
Track satellite to a fraction of a degree
±0.04º even in a hurricane

Effective Aperture

- Real antennas have effective power collecting areas which are **LESS** than the physical aperture area.

- Define Effective Aperture Area A_e:

$$A_e = A_{phy} \text{ x } \eta$$

where A_{phy} is actual (physical) aperture area.

η = <u>aperture efficiency</u>

$\left\{ \begin{array}{l} \text{Very good: 75\%} \\ \text{Typical: 55\%} \end{array} \right.$

$$Gain = \frac{4\pi A_e}{\lambda^2} = \frac{4\pi A_{phy}}{\lambda^2} \times \eta \qquad Gain = \left(\frac{\pi D}{\lambda}\right)^2 \times \eta$$

Reflector Antenna

A rule of thumb to calculate a reflector **antenna beamwidth** in a given plane as a function of the antenna dimension in that plane is given by:

$$\theta_{3dB} \cong \frac{75\lambda}{D} \quad \text{degrees}$$

The approximation above, together with the definition of gain (previous page) allow a gain approximation (for reflectors only):

$$Gain \cong \eta \left(\frac{75\pi}{\theta_{3dB}} \right)^2 = \eta \frac{(75\pi)^2}{\theta_{3dBH}\theta_{3dBE}}$$

Assuming for instance a typical aperture efficiency of 0.55 gives:

$$Gain \cong \frac{30{,}000}{(\theta_{3dB})^2} = \frac{30{,}000}{\theta_{3dBH}\theta_{3dBE}}$$

MAPSAR Proposed Antenna Concept

Antenna Trade-Off Result:

Elliptical parabolic main reflector

7,5 m length (azimuth)

5 m width (range)

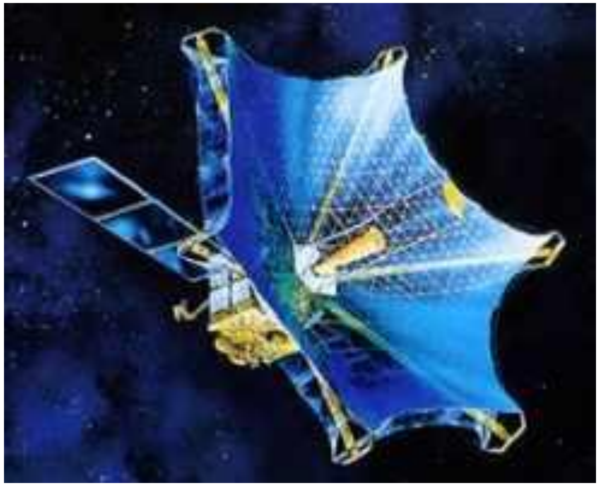
Cassegrain type subreflector

67 cm length (azimuth)

93 cm width (elevation)

Distance to main reflector: 2,8 m.

Feed type: horn antenna



Technology Example:

HALCA (MUSES-B), the first astronomical satellite dedicated to Very-Long Baseline Interferometry (VLBI), was launched from Kagoshima Space Center on February 12, 1997.

Operating frequency 1.6-1.73 GHz

Reflector diameter 8 m

Satellite System Antennas – Summary

Reflector antennas used mainly
Offset for efficiency
Shaped to provide efficient power footprints on earth
Large antenna gives narrow beam and small footprint