Antenna

By

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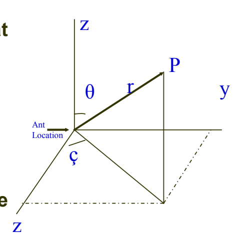
Antenna

- Antennas form a very important element in communication system, either terrestrial or extra terrestrial, depending on the mission type and requirements
- "That part of a transmitting or receiving system which is designed to radiate or to receive electromagnetic waves".
- we use antennas to overcome our inability to lay a physical interconnection between two remote locations or an antenna can also be viewed as a transitional structure (transducer) between free-space and a transmission line (such as a coaxial line).
- Antennas cannot add power, instead they can only focus and shape the radiated power in space e.g. it enhances the power in some wanted directions and suppresses the power in other directions

Some Basic Definitions

- Suppose we have an antenna located at the origin of a spherical co-ordinate system, further assume that the antenna is transmitting and the observations are made for a very large distance;
- Let P_o (Watts) be the accepted power in the antenna and P_r (Watts) be the radiated power, then the radiating efficiency ή as;
  - ή = P_r / P_o



Radiation Intensity

- We define Radiation Intensity f (θ,Φ) or Θ(θ,Φ) (watts/steradians)

$$P_r = \int_0^{2\pi} \int_0^{\pi} f(\theta, \varphi) \sin\theta \, d\theta \, d\varphi$$

- The Average radiation intensity is;

  $\Theta_{avg} = P_r / 4\pi$

Antenna Directivity

(Measure of the focusing property of an antenna)

- "The directivity of an antenna is defined as the ratio of the radiation intensity in a given direction from the antenna, to the radiation intensity averaged over all directions.
- This average radiation intensity is equal to the total power of the antenna divided by (4 pi). If the direction is not specified, the directivity refers to the direction of maximum radiation intensity".

$$D(\theta,\Phi) = \{\Theta(\theta,\Phi) / \Theta_{avg}\}$$

or

$$D(\theta,\Phi) = 4\pi \{\Theta(\theta,\Phi) / P_r\}$$

  - θ is the elevation angle
  - ϕ is the azimuth
- where D is the directivity. Generally D > 1, except in the case of an isotropic antenna for which D = 1. An antenna with directivity D >> 1 is called a directive antenna.

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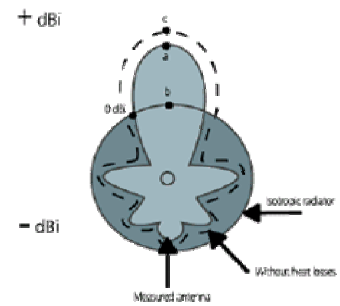

Gain (Measure of Directivity)

- The Gain $G(\theta,\phi)$ is the ability to concentrate the power accepted by the antenna in a particular direction. It is related to the Directivity and Power Radiation efficiency or in other words Power Radiation Intensity as follow;

$$G(\theta,\phi) = ή\, D(\theta,\phi)$$

for loss less antenna ή =1

$$G(\theta,\phi) = 4\pi\{\Theta(\theta,\Phi) / P_r\}$$

- With respect to the antenna's dimensions,

$$G = ή\{4\pi A / \lambda 2\}$$

A is the aperture area of the antenna

λ is the wavelength of the operational frequency

η is the antenna efficiency (usually between 50% and 70%)

Cont…

- Basically there are only two types of antennas:
  - dipole antenna (Hertzian)
  - vertical antenna (Marconi)
- All antennas can be broken down to one of these types (although some say that there is only one - the dipole)
- In addition to this we have a theoretical perfect antenna (non-existent) that radiates equally in all directions with 100% efficiency. This antenna is called an isotropic radiator.

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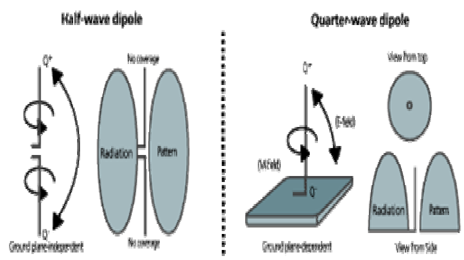
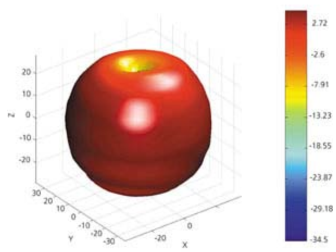
(Basic Antenna types)



Gain presented as 3D gain



The gain can also be presented as a 3D gain. The radius of the spheroid is proportional to the antenna gain.

Gain in theory

- **Since all real antennas will radiate more in some directions than in others, you can say that gain is the amount of power you can reach in one direction at the expense of the power lost in the others. When talking about gain it is always the main lobe that is discussed**
- **Gain may be expressed as dBi or dBd. The first is gain compared to the isotropic radiator and the second gain is compared to a half-wave dipole in free space (0 dBd=2.15 dBi)**

Power Density

- **The power density $P(\theta,\phi)$ is related to radiation intensity as follows;**

$$P(\theta,\phi)= \{\Theta(\theta,\Phi) / r^2\}$$

or

$$P(\theta,\phi)= \{G(\theta,\Phi)\ P_o / 4\pi r^2\}$$

- **The factor $P_o / 4\pi r^2$ represent the power density that results if the power accepted by the antenna were radiated by loss-less isotropic antenna**

Equivalent Isotopic Radiated Power (EIRP)

- The maximum power flux density at some distance “r” from a transmitting antenna of gain “G” is;

$$\psi_M = \frac{GP_S}{4\pi r^2}$$

- An isotropic radiator with input power equal to GP_S would produce the same flux density. Hence,

$$EIRP = GP_S$$
$$[EIRP]_{dB} = [P_S]_{dB} + [G]_{dB}$$
$$G = \eta \frac{4\pi A}{\lambda^2} = \eta \left(\frac{\pi Df}{c} \right)^2$$

Antenna Effective Area

- Measure of the effective absorption area presented by an antenna to an incident plane wave.
- Depends on the antenna gain and wavelength

$$A_e = \frac{\lambda^2}{4\pi} G(\vartheta, \varphi) \ [\mathrm{m}^2]$$

- Aperture efficiency: $\eta_a = A_e / A$
  A: physical area of antenna’s aperture, (m^2)

Transmission losses

- Free Space Transmission [FSL]
  - More to follow
- Feeder Losses [RFL]
  - Between the receive antenna and the receive proper
- Antenna Misalignment Losses [AML]
- Fixed Atmospheric & Ionospheric Losses
  - Absorption losses
  - Depolarization losses

Power transfer between two antennas

- For two antennas in free space separated by large distance R
- The received power is equal to a product of power density of the incident wave and the effective aperture area of the receiving antennas

$Pr = PA_e$

or

$Pr = \{(G_t P_t G_r \lambda^2) / (16\pi^2 R^2)\}$

Antenna Bandwidth

- The bandwidth of an antenna is defined as "The range of frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard".
- The reason for this qualitative definition is that all the antenna parameters are changed with frequency and the importance of the different parameters as gain, return loss, beamwidth, side-lobe level etc. much depends on the application.
- For example, the bandwidth of an antenna for gain (-1dB from the maximum) is defined as

$$Bandwidth(\%) = \frac{f_U - f_L}{f_C} \times 100$$

- where f_U is the upper frequency, f_L is the lower frequency, and f_C is the center frequency. Another example is the bandwidth related to the mismatch loss defined by the SWR.

Reciprocity

- **ALL the major properties of a linear passive antenna are identical whether it is used in transmit or receive mode. There is only one exception to this rule called "reciprocity", and that is when the antenna contains magnetically biased magnetic materials such as ferrites with resonantly rotating electron spin systems.**
- **The physical reason for reciprocity is that the only difference between outgoing and incoming waves lies in the arrow of time. Since the electromagnetic equations are invariant except for the signs of magnetic fields and currents, under time reversal, there can be no difference between transmit and receive mode in the physical current and field distributions. However, if we have a magnet providing a steady bias field, under time reversed conditions we would have to reverse the direction of this bias field. But for incoming and outgoing waves, the bias field direction remains the same. Thus it is possible for the system to be non-reciprocal.**

Cont…

- Of course, antennas containing amplifiers, or diodes, or spark gaps, may well not be reciprocal for obvious reasons. Also, practical antenna installations having metal-oxide-metal contacts, "rusty bolts", dry soldered joints and other electrical contact imperfections are also likely to behave differently under transmit and receive modes of operation

Radiation Parameters

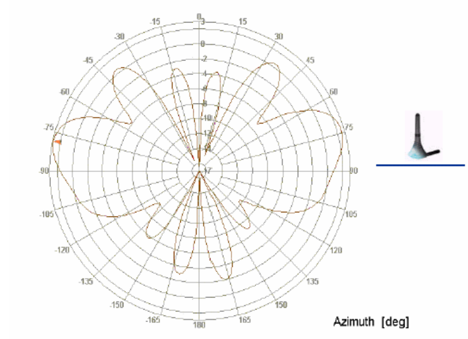
- **Radiation Pattern measurement**
  - Graphical representation of the field magnitude at a fixed distance from an antenna as a function of direction i.e. angular variation of the test antennas radiation.
- **Gain measurement**
  - Absolute measurement that gives the angular variation of the test antenna's radiation. Needed to fully characterize the radiation properties of the test antenna.

Radiation Parameters

- **Polarization**
  - Defined as the polarization of the electromagnetic wave radiated by the antenna along a vector originating the antenna along the primary direction of propagation. The direction of the oscillating electrical field vector i.e. orientation of the E-filed.
  - **Four basic types of polarization**

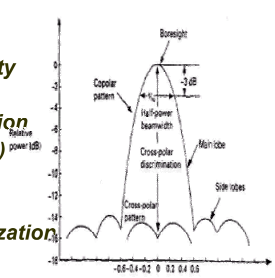
    Vertical-, horizontal-linear polarization and Left-hand elliptical, Right-hand elliptical polarization.

Radiation Parameters



Radiation Pattern

- **Radiation pattern characteristics/parameters:**
  - ***Half-power beam width***
  - ***Main lobe***
  - ***Side lobes***
  - ***Antenna directivity***
  - ***Gain function***
  - ***Boresight (Direction of maximum gain)***
  - ***Polarization***
  - ***Distortion***
  - ***XPD(cross polarization Discrimination)***



Radiation Pattern

- Antenna radiation pattern is three-dimensional, but is needed to describe them as two-dimensional paper. The most popular technique is to record signal level along great circle or conical cuts through the radiation pattern. In other words, one angular coordinate is held fixed, while the other is varies.
- **Radiation Pattern = Radiation Intensity as function of the azimuth/ elevation angles**

  or

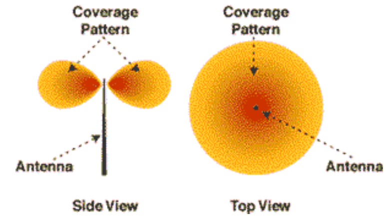
  In different words when power radiation intensity and power density are presented as relative scale, they are referred to as antenna radiation pattern.
- A family of such two-dimensional patterns then can be used to describe the complete three dimensional patterns
- The main lobe of the radiation pattern is in the direction of maximum gain

Radiation Pattern

- There are many types of antenna radiation patterns, most common are;
  - Omnidirectional (azimuthal plane) beam
  - Pencil beam
  - Fan beam
  - Shaped beam

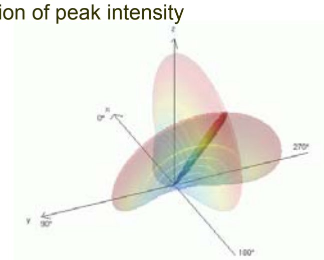
Omnidirectional Antenna and Coverage Patterns

The Omnidirectional beam is most popular in communication and broadcast applications. The azimuthal pattern is circular, but the elevation pattern will have some directivity to increase the gain in the horizontal directions



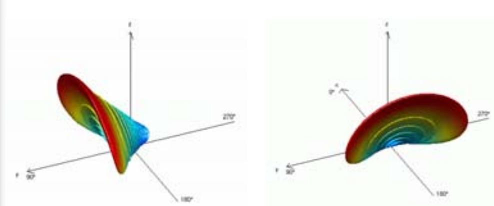
Pencil Beam

Pencil beam is applied to a highly directive antenna pattern consisting of a major lobe contained with in it cone of small solid angle. Usually the beam is circularly symmetric about the direction of peak intensity



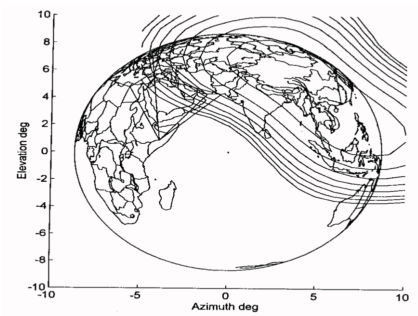
Fan Beam

A fan beam is narrows in one direction and wide in the other. A typical use of a fan beam would be in search or surveillance radar



Shaped Beam

Shaped beams are also used in search and surveillance



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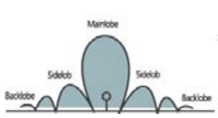
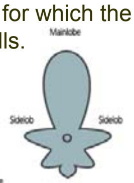
- Radiation patterns generally defined as the far field power or field strength produced by the antenna as a function of the direction (Azimuth and elevation) measured from the antenna position. The behavior of the fields is changed with the distance from the antenna, and generally three regions are defined:
- **Reactive near-field region** - The region in the space immediately surrounding the antenna in which the reactive field dominated the radiating field ($d < \lambda/(2\pi)$).
- **Radiating near-field region** - Beyond the former region and for which $d < 2D^2/\lambda$ where r is the distance from the antenna, D is the largest dimension of the antenna and λ is the wavelength. This region is called also Fresnel region. In this region the radiating field begins to dominate.
- **Far-field region** - Beyond this region, the reactive field become negligible and also the radial part of the fields. This region is called also Fraunhofer region.
  - Generally measurements are taken in the far field region. In case of large planar antennas it is more convenient to make near field measurements and to calculate the far field.

Antenna Radiation Pattern Lobes and Nulls

- A radiation lobe can be defined as a portion of radiation pattern bounded by regions of relatively weak radiation intensity. The main lobe is a high radiating energy region. Other lobes are called sidelobes, and the lobe radiating in the counter direction to the desired radiation direction is called back lobe. Regions for which the radiation is very weak are called nulls.

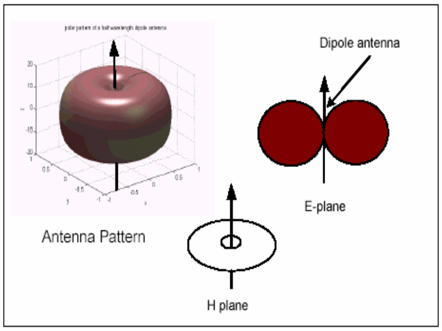




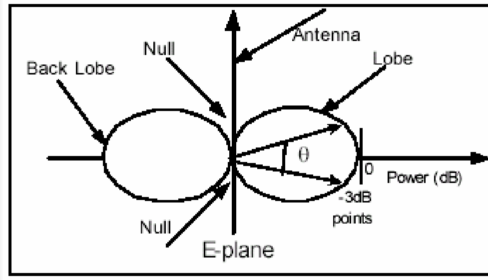
Antenna Beamwidth.

- Antenna beamwidth is defined as the angle θ between half power points on the main beam. In case that we have a power pattern in [dB] units, it means that we measure the angle between two 3dB points.

Measuring E and H field of antenna



E field cut of dipole antenna



Half-power beam width

- **It is the angular beam width at *3 dB*. It can be approximated as,**

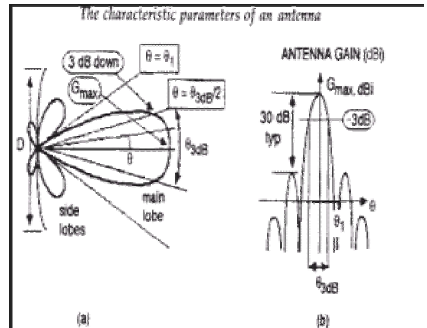
$$\theta_{hp} = \frac{N\lambda}{D}$$

$N = 58^\circ$ for uniform distribution
$N = 70^\circ$ for typical tapered distr.

- **D is the antenna's diameter.**
- **λ is the operational wavelength.**

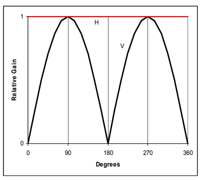
Half-power beam width

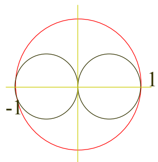
The characteristic parameters of an antenna



Antenna radiation pattern. (a) Polar representation. (b) Cartesian representation

Short Dipole in Free Space FF

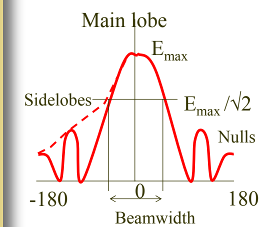




Horizontal plane: $G_{Vi}/G_{Vimax} = 1$

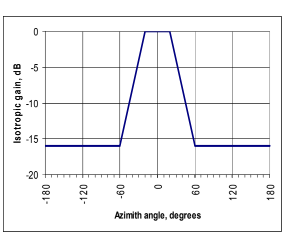
Vertical plane: $G_{Hi}/G_{Himax} = |\sin\theta|$

Elements of Radiation Pattern



- **Gain**
- **Beam width**
- **Nulls (positions)**
- **Side-lobe levels (envelope)**
- **Front-to-back ratio**

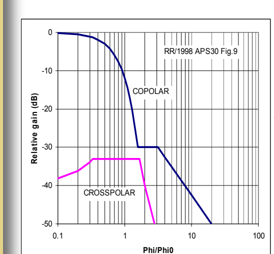
Antenna Mask (Example 1)

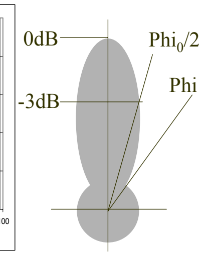


- **Typical relative directivity-mask of receiving antenna (Yagi ant., TV dcm waves)**

[CCIR doc. 11/645, 17-Oct 1989)

Antenna Mask (Example 2)





Reference pattern for co-polar and cross-polar components for satellite transmitting antennas in Regions 1 and 3 (Broadcasting ~12 GHz)

Types of Ground Antennas Used in Satellite Missions

- Different satellite missions have different allotted frequency slots by ITU, each slot behaves differently between ground and earth segment in terms of dispersion, attenuation and noise accumulation
- Generally at frequencies below 1GHz, TTT&C are running, the antenna may then be arrays of dipoles, helices and yagi-uda arrays, such type of antenna systems have wider beamwidth and medium gain. Deploying them in an array pattern results in increased gain and fanned and shaped beams thus enabling them for comparatively easy tracking
- At frequencies above 1GHz the electromagnetic waves become highly directional but more susceptible to attenuation, fading and dispersion, therefore, horn and parabolic antennas are most commonly used. The most popular and widely used are the aperture antennas given bellow;

Types of Ground Antennas Used in Satellite Missions

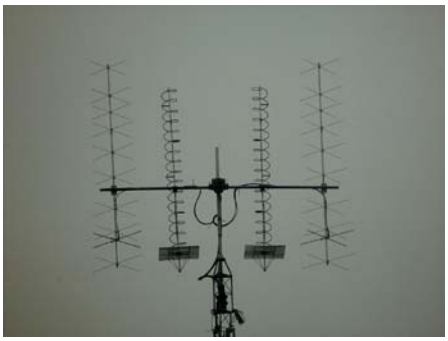
- **Axially Symmetric Fed Antenna**
  - This is the most common type of antennas found on roof tops or back yards of homes. They come in different configurations. Axis symmetric point focus feed. Front feed and Vortex feed
- **Cassegrain Feed Antenna**
  - The second common configuration used particularly in large antennas is the Cassegrain antenna. Here the feed is located at the vertex of the parabolid and illuminates a hyperbolic shaped sub-reflector located at the focal area. The benefit here is that the electronics is located at a more accessible part of the antenna but with some sacrifice in sidelobe level because of the blockage.

Types of Ground Antennas Used in Satellite Missions

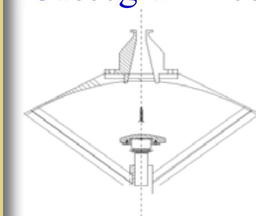
- **Gregorian Feed Antenna**
  - In Gregorian configuration the feed is at the focal point of an ellipse and the elliptical sub-reflector at its other focus. With this configuration there is an improvement in the far-outside lobe level
- **Offset Aperture Antennas**
  - These configurations indicate that the feed are on axis . The same generic types may also be used with offset feeds. The removal of feed from a collimated beam improves the side lobe level and has better effect of reducing mutual interference from adjacent satellites.

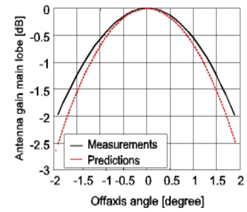
Reflector antennas

Crossed Yagi antennas for circular polarisation
and
right-handed and left-handed helical antennas



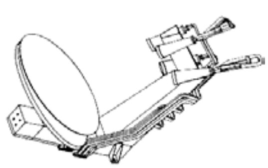
Cassegrain Feed Antenna





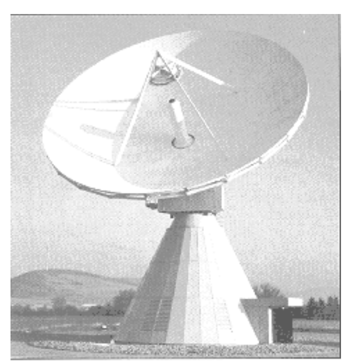
Comparison between the measured antenna gain pattern and the predicted one for small offaxis angles

Front Fed Antenna

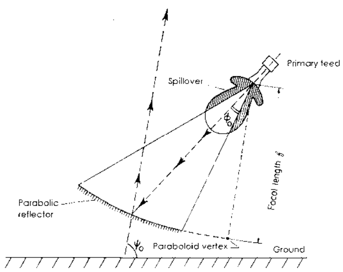


A Front-Fed Offset Reflector Antenna with Multiple-Feed Horns (Courtesy Alenia Spazio)

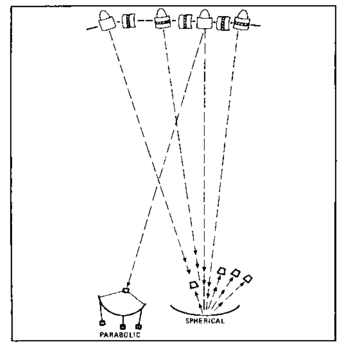
Gregorian Feed Antenna



Offset Parabolic Reflector



Offset Parabolic Antennae



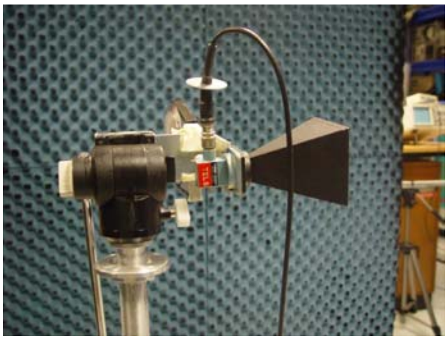
Satellite Antennas

- The physical dimensions of the spacecraft and the availability of limited power restrict use of large antennas.
- Medium gain antennas are used instead which include modified parabolic antennas for large area coverage
- In LEO missions, the satellite may be two axis stabilized, the rotation being on the axis with largest inertia, the antenna gain pattern may not remain uniform when received at the ground station. Therefore, a rotating antenna whose rotation is in the opposite direction of the satellite rotation is used, such type of antenna is called “Despun antenna”
- Circular polarization may employed for TT&C purposes or image transmission like weather satellite
- Helical antennas are used for circularly polarized EM wave pattern, these antennas has larger beamwidth, therefore, tracking by the ground station becomes easier

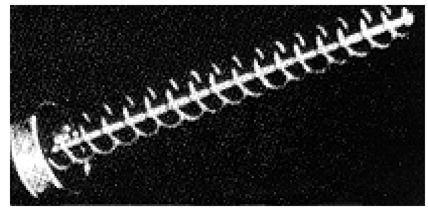
Satellite Antennas

- In GEO satellites, DVB and VSAT applications are dominant
- In broadcast services satellite has to cover larger area , linearly polarized array antennas are used. For broadcast services the transmitting antennas may consist of array of Horn Antennas, Helical Antennas or Disk-on-Rod Antennas. Power beam form the antennas can be steered to cover specific area on the earth’s surface by switching on or off different antennas from the array on the satellite.

18 dBi X-band pyramidal horn antenna



Helical Antenna



- *Question ?*