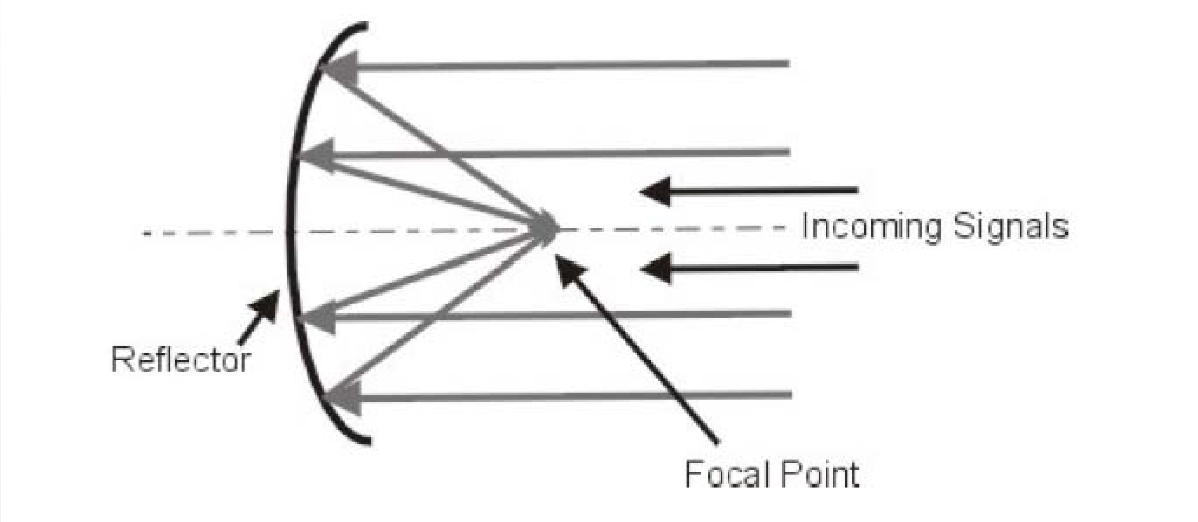
Day 2 course

Earth Station Technology

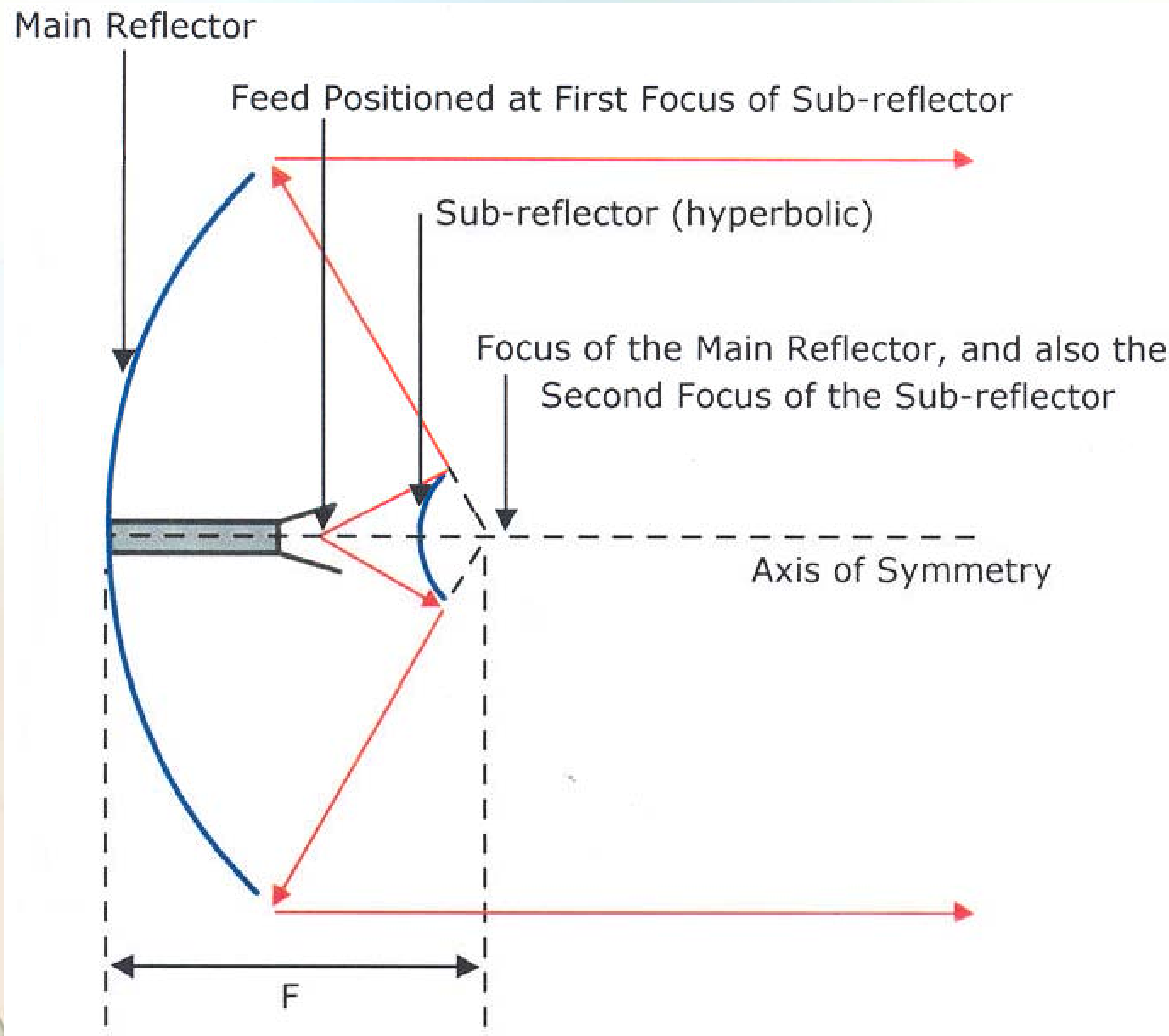
By NIAMEOGO W. Eric

1- Types of antennas

Geostationary satellites are far from earth and require directional antennas in order to communicate. A directional antenna uses a parabolic reflector (commonly referred to as a dish) to focus the radiated energy from the transmitter, and to focus the incoming energy to the receiver. This ability to focus energy is referred to as "antenna gain."

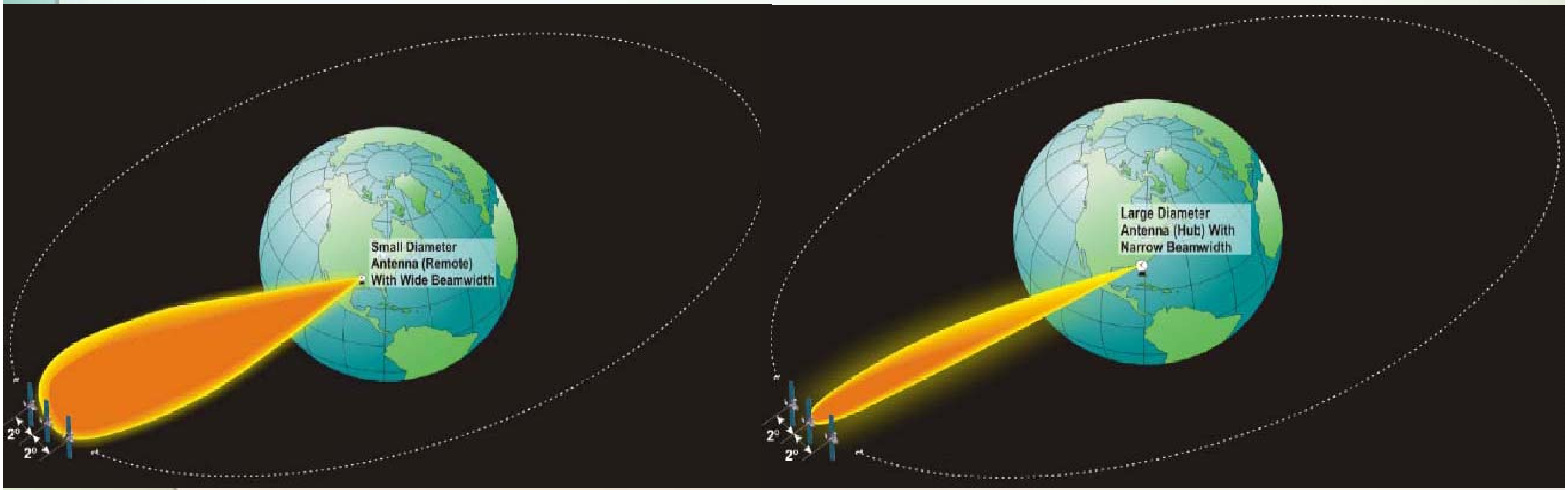


1- Types of antennas



1- Types of antennas

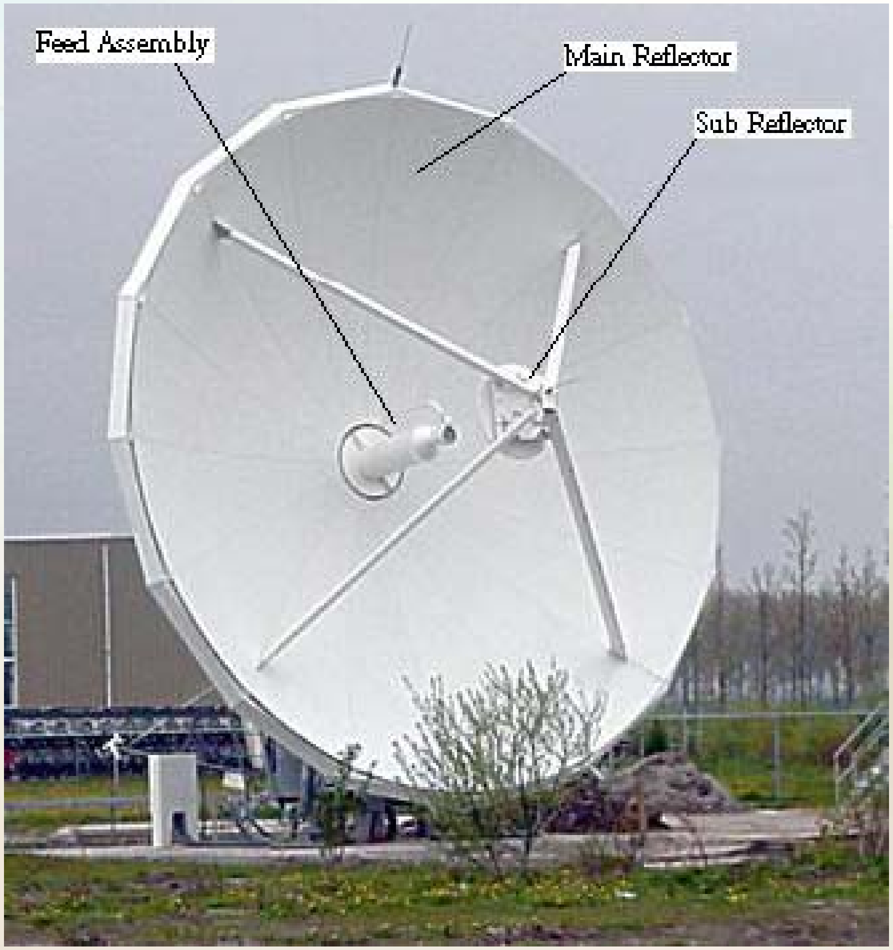
The larger the antenna, the smaller the main lobe (beamwidth). In the case of an Intelsat Standard-A 30m antenna the accuracy must be approximately 0.015 degrees, which requires an automatic tracking device to control the azimuth and elevation adjustment of the antenna.



1- Types of antennas

The antenna system consists of the following parts:

- Mechanical system – comprising main reflector, back structure, pedestal or mount assembly, and for automatic tracking antenna, the driving gear or servo system.
- The primary source – comprising the illumination horn, the associated reflector sub-assemblies, and non-radiating components (couplers, diplexers etc.).



1- Types of antennas

The features of an earth station antenna are common to transmission and reception and must adhere to the following test related standards:

- High gain for transmission and reception

  This requires reflectors which are large in relation to the wavelength and have an accurate reflector contour. C Band antennas are typically larger than KU.

- Low level of interference (for transmission) and of sensitivity to interference (for reception)

  This requires a very directional gain envelope with low levels outside the main lobe (low off axis side lobes)

- Radiation with high polarization purity (xpol)

1- Types of antennas

There is a wide range of satellite earth station antennas. Each one refers to a particular use.

One of the classification could be :

- Television antennas
- Tx/Rx antennas
- Antennas with tracking system

1- Types of antennas

Television Antenna

TVRO stands for Television Receive Only antenna. It is a reception antenna used to receive broadcast emissions.

The antennas diameter size can go from 1,2 meters to more than 33 meters

1- Types of antennas

Television Antenna

DBS stands for Direct Broadcast Satellite. DBS is broadcast by medium and high powered satellites operating in Ku Band.

It's makes possible to pick up the signal with small dishes

The antennas diameter size can go from 0,45 meters to 0,75 meters

1- Types of antennas

Tx/Rx antennas

The Tx/Rx antennas are used to establish a two way communication between the earth station and the satellite.

The antennas diameter size can go from 1,2 meters to more than 33 meters

1- Types of antennas

Tracking antennas

Antenna is moving to be always aligned to the satellite. It’s often used by large antennas to follow satellites that drifts …

Also used to align on inclined orbit satellite.

The antennas diameter size varies from small to large. It’s applies more to large antennas

1- Types of antennas

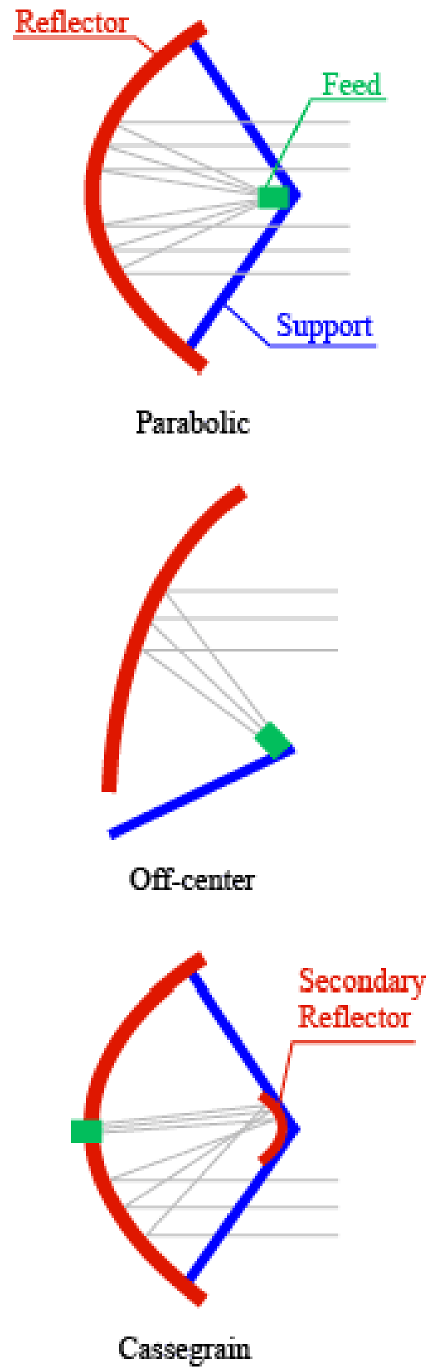
Mobile antennas

Antenna is moving to be always aligned on the satellite. Mobile communications (ships, vehicles,…) need to follow different satellite…

1- Types of antennas

The antennas by their design can also be categorized in the following types :

- Prime focus
- Gregorian
- Off-center
- Cassegrin



1- Types of antennas

Cassegrain and Gregorian antennas make use of a dual reflector system fed by a primary radiator located at the focus of the system. Main earth station antennas are predominantly of the dual reflector axi-symmetric Cassegrain type although there are also Gregorian dual reflector designs.

C Band antennas tend to be larger than KU antennas because antenna gain is a function of frequency. Radiated power, or Effective Isotropic Radiated Power (EIRP) is a function of both antenna gain, HPA power, and losses caused by filters and waveguide runs, so designers can achieve the required EIRP by trading HPA power for antenna gain (or vice versa).

1- Types of antennas

Classification of Earth Station Antennas

Earth stations that operate in the 6/4 GHz and 14/12 GHz bands are often classified according to the size of the antenna.

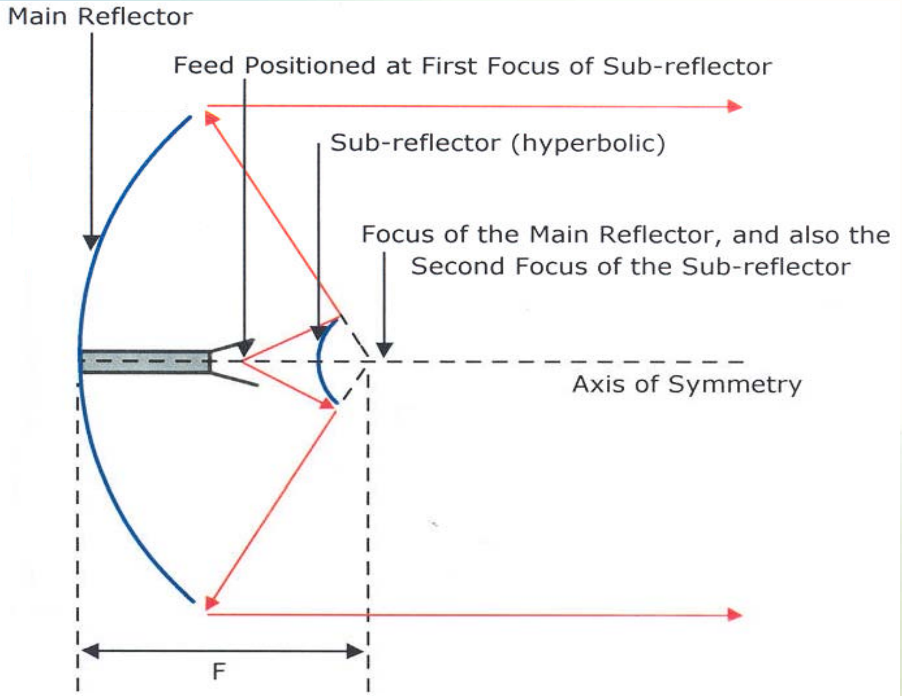
- Large earth stations – antenna approx. 15 to 33 meters
- Medium earth stations – antenna approx. 7 to 15 meters
- Small earth stations – antenna approx. 3 to 7 meters
- Very Small Aperture Terminals (VSAT) – antenna approx. 0.6 to 3 meters

1- Types of antennas

Cassegrain Antenna

The Cassegrain antenna is a “rear-fed” antenna which provides a convenient location for the complete feed system.

The reflector system consists of a main reflector (which is normally a “parabolic”) and a secondary reflector called a “sub-reflector”. A Cassegrain antenna has a hyperbolic sub-reflector.



1- Types of antennas

Cassegrain Antenna advantages

Parabolic antennas that are circularly symmetric about the “z-axis” are termed axis-symmetric antennas. They may consist of a single reflector or, as in the case of the Cassegrain antenna, multiple reflectors.

The ability to modify the sub-reflector gives two advantages:

- Reduction in “spillover”
- Uniform distribution of energy on the reflector resulting in an improvement in antenna efficiency

Cassegrain antennas exhibit lower noise temperatures than front-fed antennas due to the fact that the “spill-over” radiation from the primary feed is directed towards the sky, whereas with front-fed antennas spill-over is directed to / collected from the ground.

1- Types of antennas

Cassegrain Antenna disadvantages

Cassegrain antennas suffer from a number of disadvantages:

- Partial blockage of the main reflector caused by the sub-reflector
- Direct radiation of the primary feed outside the sub-reflector diameter (spillover radiation) increases the side lobes of the antenna pattern
- Sub reflector struts are normally placed in the radiation area of the main reflector, causing a scattered radiation (increased side lobes)
- Blockage by the sub-reflector causes shadowing of the antenna reflector and so decreases antenna gain for transmit and receive

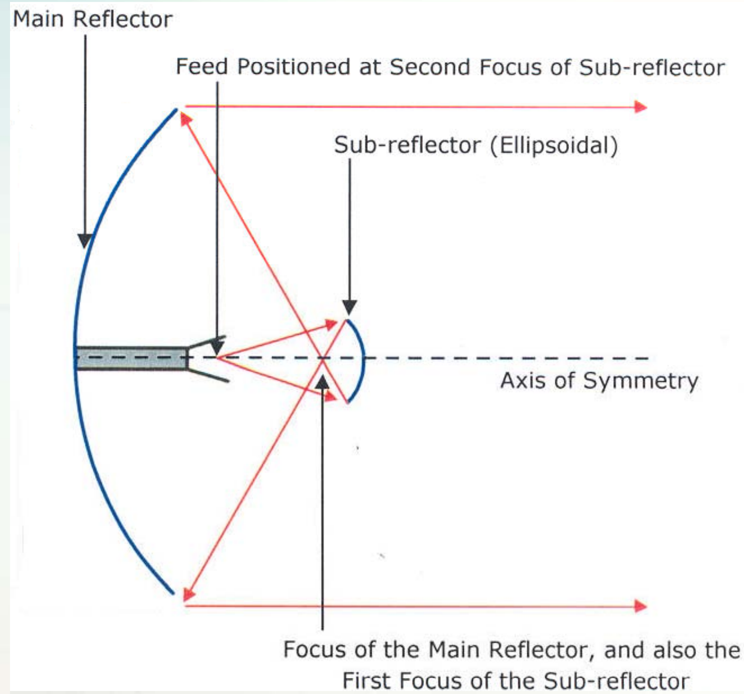
For the reasons stated above, it is very difficult to provide an efficient Cassegrain antenna smaller than 3 meters in diameter.

1- Types of antennas

Gregorian antennas use an ellipsoidal sub-reflector as opposed to the hyperbolic sub-reflector of a Cassegrain antenna.

The radiation from the feed hitting the sub-reflector intersects after reflection, but before hitting the main reflector surface. As a result of this design, the structure of the Gregorian antenna cannot be as compact as that of the Cassegrain type.

An advantage of using the ellipsoidal sub-reflector is that the feed and sub-reflector edges are subject to less radiation and consequently less interference is caused. This method of illumination, along with Cassegrain, is commonly found on medium and large earth stations antennas.

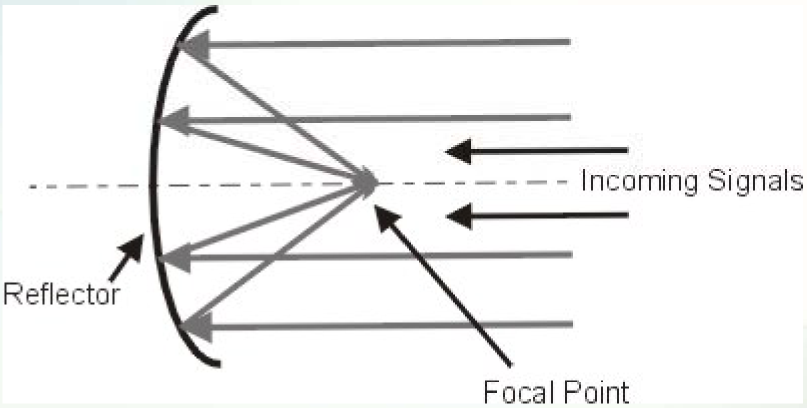


1- Types of antennas

Prime Focus Antenna

Most antenna systems, either parabolic with front feed or Cassegrain / Gregorian types are axisymmetrical. A prime focus antenna (below) gathers the reflected RF in a feedhorn, which is located directly at the focal point.

For axisymmetric antennas, blockage by the feed and associated components, including the feed support structure, causes shadowing of the antenna reflector and so decreases antenna gain.



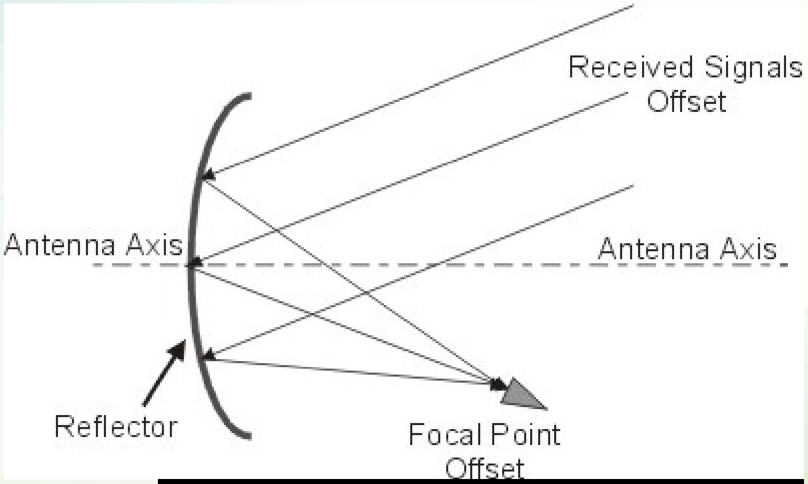
1- Types of antennas

Offset Antenna

Offset antenna are typically used for low power, small and micro station antenna. An offset antenna is a section of a prime focus antenna normally taken 22.5 degrees above the centre line. This type of antenna has significant advantages.

The feed is located at the focus of the main parabola but is tilted towards the centre of the main reflector, and is not in the line of sight between the parabolic reflector and the satellite. Therefore there is no blockage of the signal.

The offset antenna feed angle also provides better shielding from the hot earth (noise).



2- Antennas performance measure

Gain

The gain is the measure of how much of the input power is concentrated in a particular direction. It is expressed with respect to a hypothetical isotropic antenna which radiate equally in all directions. It is expressed in dB or dbi.

G= 10*log(Pout/Pin)

TV parabolic antennas dish gain examples : 12,75 Ghz (2,4 Ghz)

- 60 cm : 36,8 dB (20,5 dB)
- 80 cm : 38,5 dB (22,5 dB)
- 90 cm : 39,5 dB (23,5 dB)
- 120 cm : 42 dB (26,5 dB)

2- Antennas performance measure

Gain

An antenna with the effective radiated power of twice the input power would therefore have a gain of 10*log(2/1) = 3dBD

As can be seen, "gain" is also "loss". The higher the gain of an antenna the smaller the effective angle of use.

2- Antennas performance measure

EIRP

The equivalent isotropic radiated power (EIRP) is the power radiated equally in all directions that would produce a power flux density equivalent to the power flux density of the actual antenna.

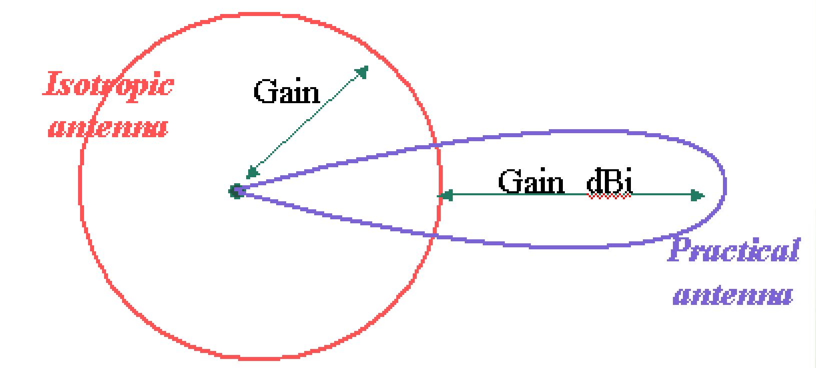
EIRP= G X P_{in}

EIRP = Poutpout of Tx – Loss Tx to Antenna + Gain Antenna

The measure is expressed in dBm or mW

2- Antennas performance measure

EIRP



Ex : Power output = 10 dBm

Cable attenuation = 2 dB

Antenna Gain = 19 dBi

EIRP = 27 dBm

EIRP = 501 mW

2- Antennas performance measure

G/T

An antenna property also known as the Figure of Merit. This is a ratio of the amount of power amplification in an antenna to the amount of signal noise. It is measured in dB/K and, since signal noise is a detrimental property, larger ratios are preferred. Earth Station performance is typically indicated in terms of the value of the receive system G/T. The larger this value is, the more sensitive is the receive system and higher link performance is achieved.

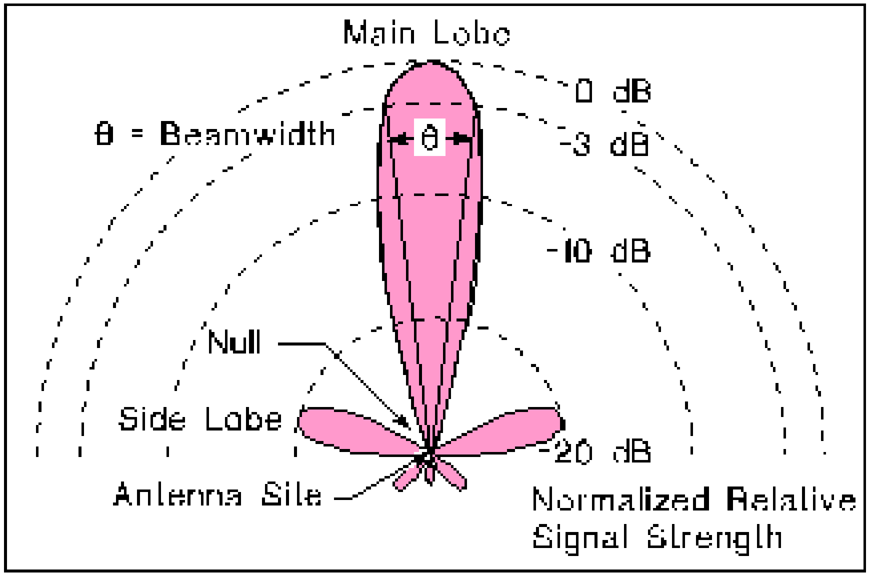
G is the gain of the receiver

T is the system temperature a measure of the total noise

2- Antennas performance measure

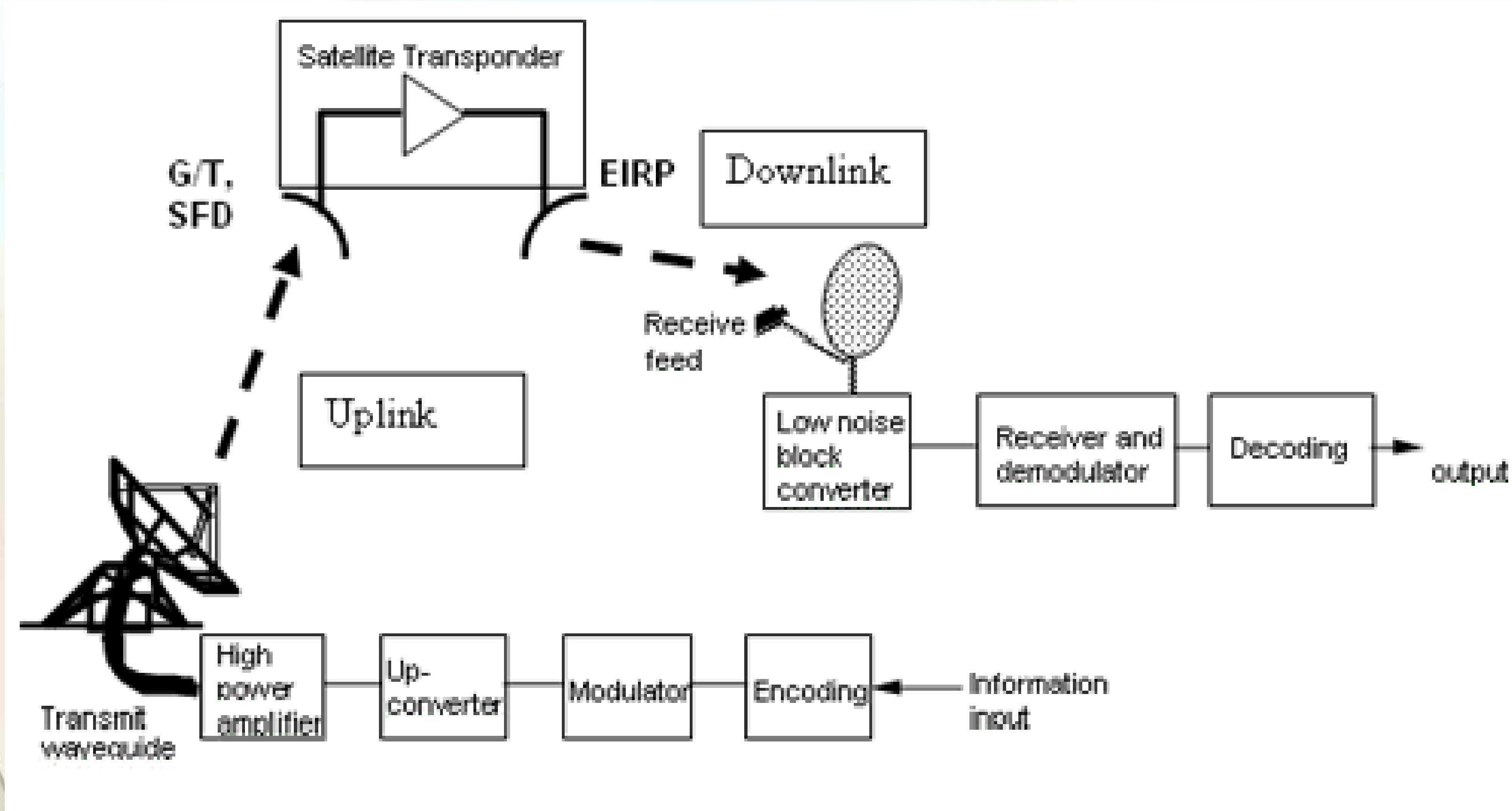
Side lobe

In a directional antenna radiation pattern , a lobe in any direction other than that of the main lobe



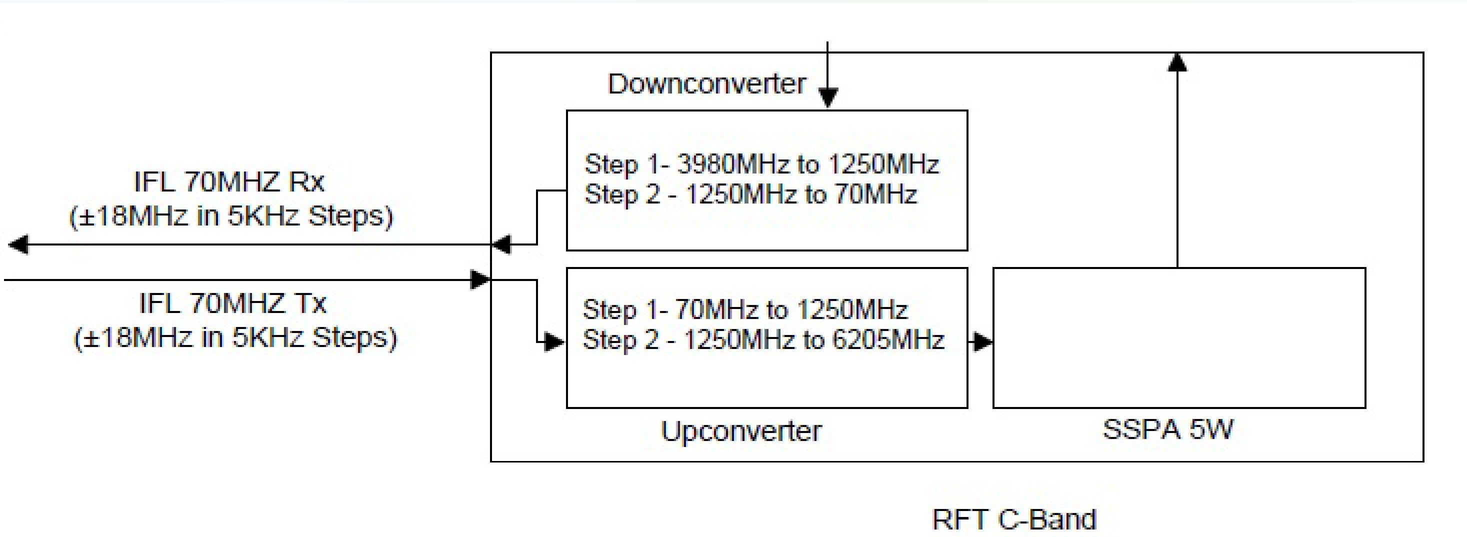
side lobe

3- RF Equipment



3- RF equipment

General frequency conversion scheme



3- RF equipment

BUC

A **block up converter** (BUC) is used in the transmission (uplink) of satellite signals. It converts a band (or "block") of frequencies from a lower frequency to a higher frequency. Modern BUCs convert from the L band to K_u band, C band and K_a band.

BUC stands for “Block up Converter ". It is used as the transmit part in a V-sat system. A BUC has a fixed local oscillator (typical 13.05 GHz) and the frequency is being determinated in the satellite modem. BUC's have an L-band (1 GHz) input frequency.

3- RF equipment

LNB

The LNB (Low Noise Block) converts the signals from electromagnetic or radio waves to electrical signals and shifts the signals from the downlinked C-band and/or K_u-band to the L-band range.

3- RF equipment

Feedhorn

This feedhorn is essentially the front-end of a waveguide that gathers the signals at or near the focal point and 'conducts' them to a low-noise block down converter or LNB.

3- RF equipment

Polarization

There are two major types of polarization: Cross-pol and Co-pol. We are going to concentrate on cross polarization as that is primarily what we will be working with the most.

There are two types of cross polarization that we are familiar with but probably only deal with one. The two type are circular and linear. Within the circular realm there is the Left Hand Circular, or LHCP, or Right Hand Circular, or RHCP. This type of polarization is used in C-Band and in X-Band. One will be hard pressed to find circular polarization on Ku- or Ka-Band frequencies.

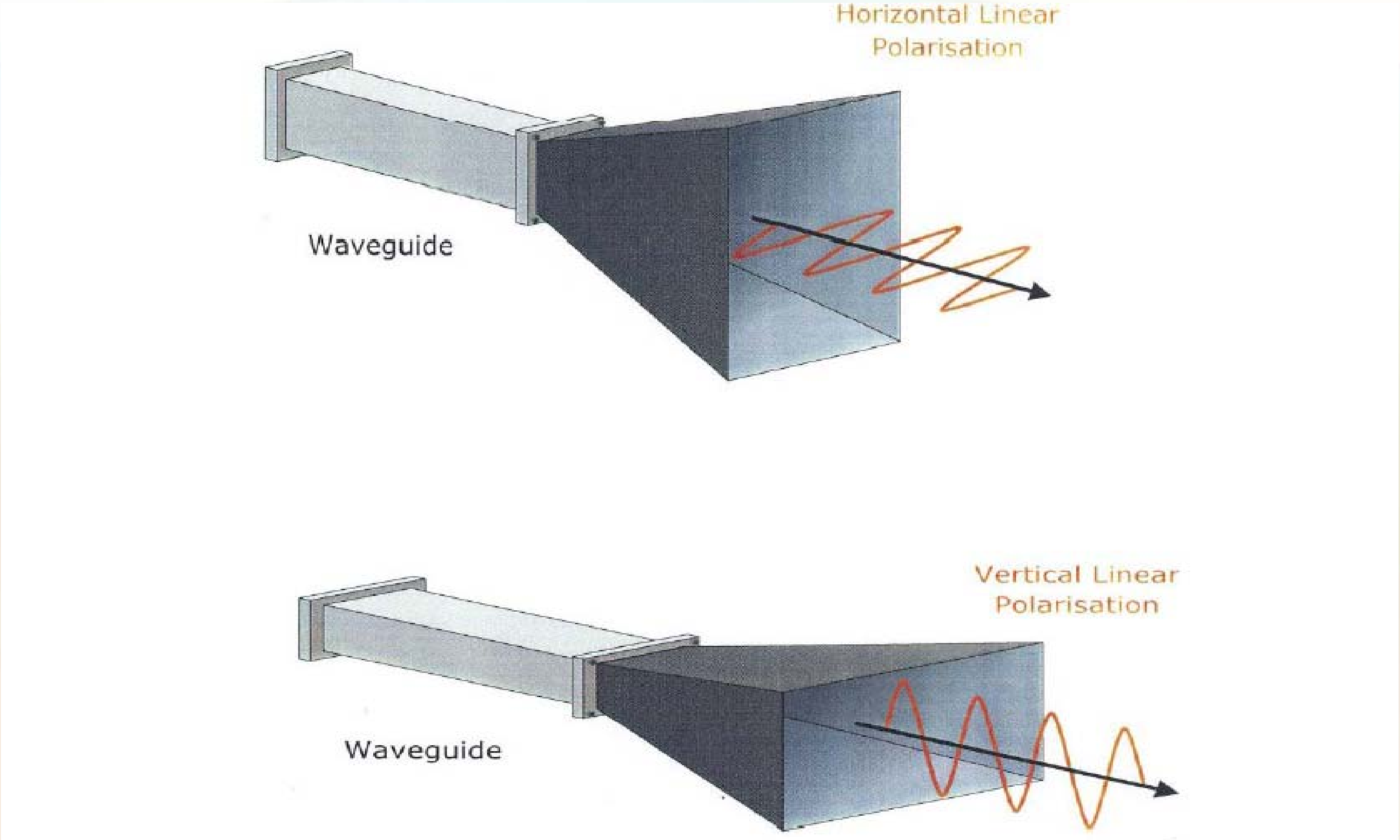
3- RF equipment

Polarization

Linear polarization on the other hand will be seen all the time on Ku- and Ka-Band antennas. With linear, there are two types: Horizontal and Vertical. What exactly is happening in the linear world that we need to know about? Before understanding how linear is used, one must understand the device being used on the satellite dish to let one signal pass while blocking the other signal. This is called the Orthogonal Mode Transducer, or OMT for short.

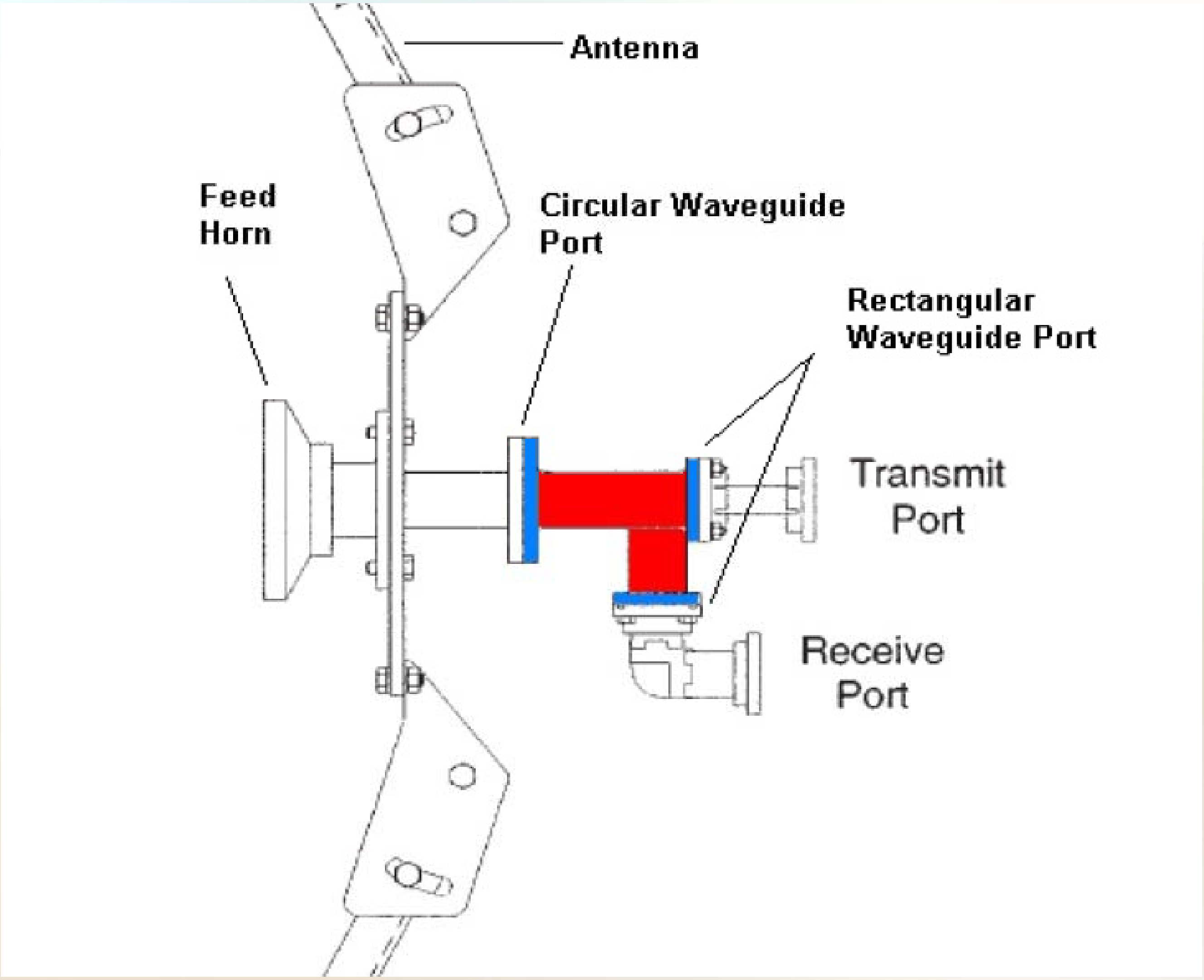
3- RF equipment

Polarization



3- RF equipment

Polarization



3- RF equipment

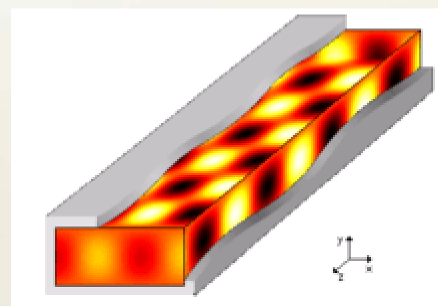
Polarization

Satellites have a series of transmit frequencies that start at 14,000 MHz and end at 14,500 MHz. These are used for sending a signal from the earth station to the satellite. Once there, they are translated to a lower frequency and then returned to earth. This translation is different depending on which part of the world one is located in. For the U.S., the translated frequencies are 11,700 MHz to 12,200 MHz. In Europe and the Middle East, the frequencies are translated to 10,900 MHz to 11,700 MHz. In Australia and New Zealand, the frequencies are translated to 12,200 MHz to 12,700 MHz.

With that in mind, we also have to understand that all these frequencies are reused. In other words, the frequency is used twice, but they are on separate polarization. One frequency is send down in the horizontal plane and the other, the vertical plane.

3- RF equipment

A **waveguide** is a structure which guides waves, such as electromagnetic waves or sound waves. There are different types of waveguide for each type of wave. The original and most common meaning is a hollow conductive metal pipe used to carry high frequency radio waves, particularly microwaves.



3- RF equipment

VSAT Modem

A **satellite modem** or **sat modem** is a modem used to establish data transfers using a communications satellite as a relay.

There is a wide range of satellite modems from cheap devices for home internet access to expensive multifunctional equipment for enterprise use.

A "modem" stands for "modulator-demodulator". A satellite modem's main function is to transform an input bitstream to a radio signal and vice versa.

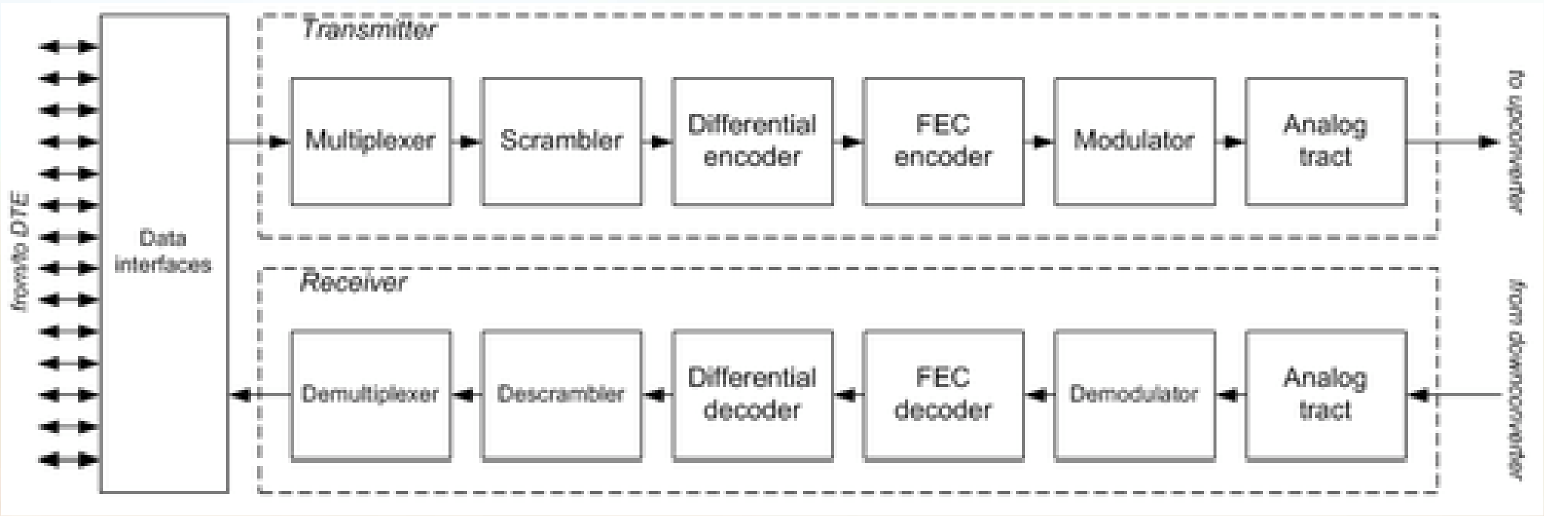
3- RF equipment

VSAT Modem

There are some devices that include only a demodulator (and no modulator, thus only allowing data to be downloaded by satellite) that are also referred to as "satellite modems". These devices are used in satellite Internet access (in this case uploaded data is transferred through a conventional PSTN modem or an ADSL modem).

3- RF equipment

VSAT Modem



3- RF equipment

VSAT Modem – Analog tract

After a digital-to-analog conversion in the transmitter the signal passes through a reconstruction filter. Then its frequency is converted if needed.

The purpose of the analog tract in the receiver is to convert signal's frequency, to adjust its power via an automatic gain control circuit and to get its complex envelope components.

The input signal for the analog tract is at the intermediate frequency or in the L-band, in the second case it must be firstly converted to IF. Then the signal is either sampled or processed by the four-quadrant multiplier which produces the complex envelope components (*I*,*Q*) through multiplying it by the heterodyne frequency.

At last the signal passes through an anti-aliasing filter and **sampled** (**digitized**).

3- RF equipment

VSAT Modem – Modulator and Demodulator

A **modem** (*modulator-demodulator*) is a device that modulates an analog carrier signal to encode digital information, and also demodulates such a carrier signal to decode the transmitted information. The goal is to produce a signal that can be transmitted easily and decoded to reproduce the original digital data. Modems can be used over any means of transmitting analog signals, from driven diodes to radio.

3- RF equipment

VSAT Modem – FEC Coding

Error correction techniques are essential for satellite communications, because, due to satellite's limited power a signal to noise ratio at the receiver is usually rather poor. Error correction works by adding an artificial redundancy to a data stream at the transmitting side, and using this redundancy to correct errors caused by noise and interference.

A *FEC encoder* applies an error correction code to the digital stream, adding redundancy.

3- RF equipment

VSAT Modem – Differential Coding

There are several modulation types (such as PSK and QAM) that have a phase ambiguity, that is, a carrier can be restored in different ways. Differential coding is used to resolve this ambiguity.

When differential coding is used, the data are deliberately made to depend not only on the current *symbol*, but also on the previous one.

3- RF equipment

VSAT Modem – Scrambling

Scrambling is a technique used to randomize a data stream to eliminate long '0'-only and '1'-only sequences and to assure energy dispersal. Long '0'-only and '1'-only sequences create difficulties for timing recovery circuit. Scramblers and descramblers are usually based on linear feedback shift registers.

A scrambler randomizes the data stream to be transmitted. A descrambler restores the original stream from the scrambled one.

Scrambling shouldn't be confused with encryption, since it doesn't protect information from intruders.

3- RF equipment

VSAT Modem – Multiplexing

A multiplexer transforms several digital streams into one stream. This is often referred to as 'Muxing.'

Generally, a demultiplexer is a device which transforms one multiplexed data stream to several streams which it consists of. Satellite modem doesn't have so many outputs, so a *demultiplexer* here performs a drop operation, allowing to choose channels that will be transferred to output.

4- Earth Station Measurements

Spectrum Analyzer

A **spectrum analyzer** or **spectral analyzer** is a device used to examine the spectral composition of some electrical, acoustic, or optical waveform. It may also measure the power spectrum.

4- Earth Station Measurements

Spectrum Analyzer typical functionalities

Frequency: Allows one to fix the window of frequencies to visualize

Marker/peak search: Controls the position and function of markers and indicates the value of power.

Bandwidth/average: Is a filter of resolution. The spectrum analyzer captures the measure on having displaced a filter of small bandwidth along the window of frequencies.

Amplitude: The maximum value of a signal at a point is called amplitude. A spectrum analyzer that implements amplitude analysis is called a Pulse height analyzer.

View/trace: Manages parameters of measurement. It stores the maximum values in each frequency and a solved measurement to compare it.

4- Earth Station Measurements

Sat Finder

A **Sat finder** is a satellite signal meter used to accurately point satellite dishes at communications satellites in geostationary orbit.

In some sat finder there is a pre-registered list of satellites and some other satellites characteristics can be added.

To find the satellite you just need to connect it to your LNB and start tracking the satellite.

5- EIRP

Effective Isotropic Radiated Power (EIRP)

EIRP is the measure of power available from an earth station. It is the product of antenna gain and the input power at the antenna flange. It is expressed as a ratio relative to 1 Watt (dBW).

The output power of the amplifier used in a particular system is dictated (primarily) by the EIRP requirement as identified in the link budget calculation.

The following equation is used to calculate the maximum EIRP of an earth station:

(10 log PA) + GA – FL – OL

1) GA – the gain of the antenna in dBi
2) PA – the HPA output power in Watts
3) FL – typical feed losses in dB
4) OL – other losses in dB

5- EIRP

Antenna Gain GA

The gain of the antenna can be calculated as a function of the number of wavelengths captured by the area of the reflector. Using the following formula : **$10 \log (9.9 * (D/\lambda)^2) * eff$**

where:

λ = the wavelength in metres

D = the diameter of the antenna in metres

Eff = the efficiency of the antenna system

Fortunately this is done for us by the antenna manufacturer. A typical 2.4m KU Band antenna has a transmit gain of 49 dBi.

The larger the antenna, the greater the gain, therefore gain is directly proportional to the diameter of the antenna.

5- EIRP

10 Log PA

The amplifier power is readily available from manufacturers specifications.

It is important to note that many tube amplifiers use a passive device called a circulator, which is fitted to the final output stage and attenuates the active device output power by up to 20%. A 650 watt TWTA, for example, may only provide 520 watts at the output flange.

Smaller devices such as SSPAs and BUCs are easier to qualify. For example, the following sizes in KU Band are available.

1, 2, 4, 8, 16, 20, and 40 watts

Watts	1	2	4	8	16	20	40
10 log PA	0	3	6	9	12	13	16

5- EIRP

FL

The RF power must be transported from the amplifier to the antenna feed horn through a waveguide system. Losses will occur in the waveguide and will be dependent on the type of waveguide used (rigid, flex etc.).

Typically on small to medium earth station antenna this is estimated at 0.5 dB, since the RF is often installed close to the feed and in some cases, directly to it.

On larger earth stations there may be longer waveguide runs as well as combiner and redundant switching networks through which the RF must pass. This can result in losses as high as 2 or 3 dB.

5- EIRP

OL

Other losses are related to the mechanical state of the antenna and its mount. VSAT and small earth stations may suffer from mis-pointing errors, therefore a typical figure of 0.5dB is given as OL.

Some satellite provider link budgets include an EIRP degradation loss figure if the station is declared as “non-tracking”, in consideration of the effects of satellite movement. On a 3.7m antenna this is usually taken as 1 dB.

5- EIRP

Example of Calculation of VSAT EIRP

With our benchmark 2.4m antenna, let us calculate the maximum EIRP when fitted with a 1 watt SSPA.

(10 log PA) + GA – FL – OL

Maximum EIRP = 0 + 49.0 – 0.5 – 0.5 = 48 dBW

With a 2 watt PA the maximum EIRP would be 51 dBW

With a 4 watt PA the maximum EIRP would be 54 dBW

5- EIRP

Satellite EIRP

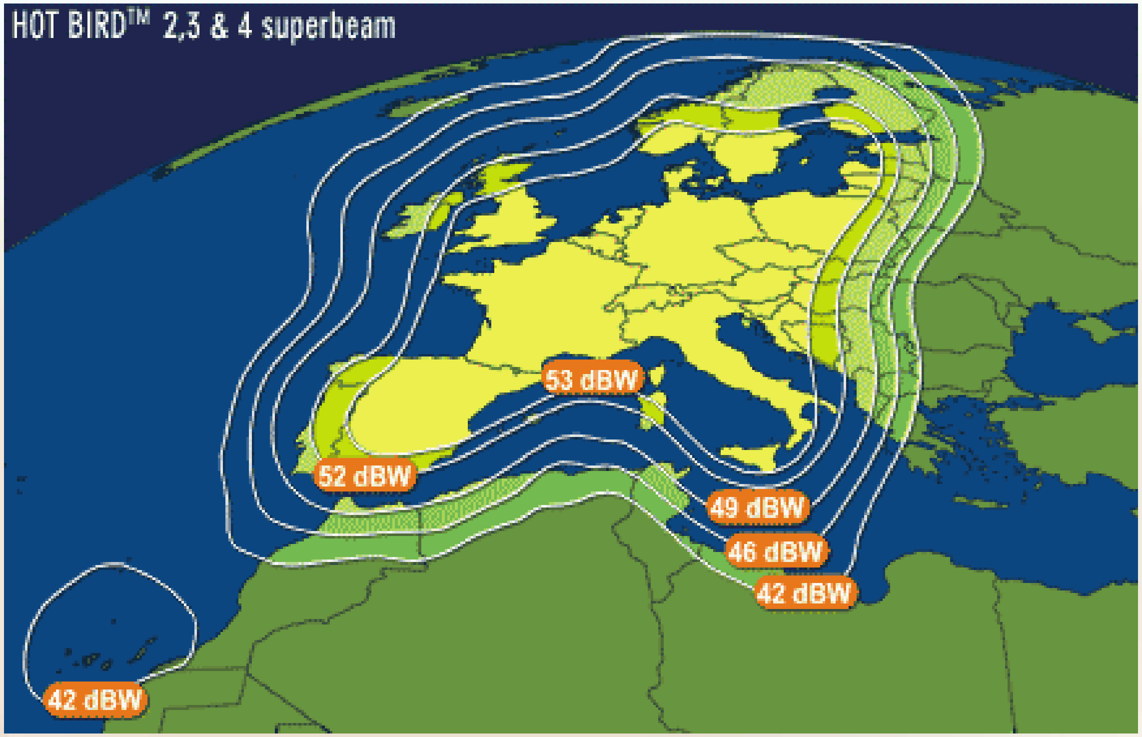
The satellite downlink beam coverage maps show contour lines where each line refers to a particular power level from the satellite. The lines are marked with EIRP values like 45dBW, 44dBW, 43dBW, 42dBW etc. in descending order from the maximum.

The highest number towards the middle of the coverage map shows where the downlink beam is strongest and most easy to receive. In the centre of the beam a smaller receive dish on the ground is required. As you move further away from the beam peak, the beam becomes less powerful and a larger dish is required.

5- EIRP

Satellite EIRP

In practice, an EIRP contour of 53 dBW could be produced by a satellite using a 200 watt transmitter (200W = 10log(200) = 23dBW) plus a satellite transmit antenna with a gain of 30 dBi (maximum).



5- EIRP

EIRP calculation example

Based on what we have discussed, the following is an example of the calculation of

- maximum input power to the BUC from the modulator
- EIRP

We will assume that we are using the following

- 8 watt SSPA
- 2.4m KU antenna with gain spec of 49 dBi

Step One: First we must convert the SSPA rated power to dBm as follows: Power (dBW) = 10 log (Pwatts) = 10 log (8) = 9.0

5- EIRP

EIRP calculation example

Step Two: Next we must convert the power in dBW to dBm as follows:

Power (dBm) = P(dBW) + 30 = 39 dBm

Step Three: We must obtain from the SSPA manufacturer the gain of the SSPA.

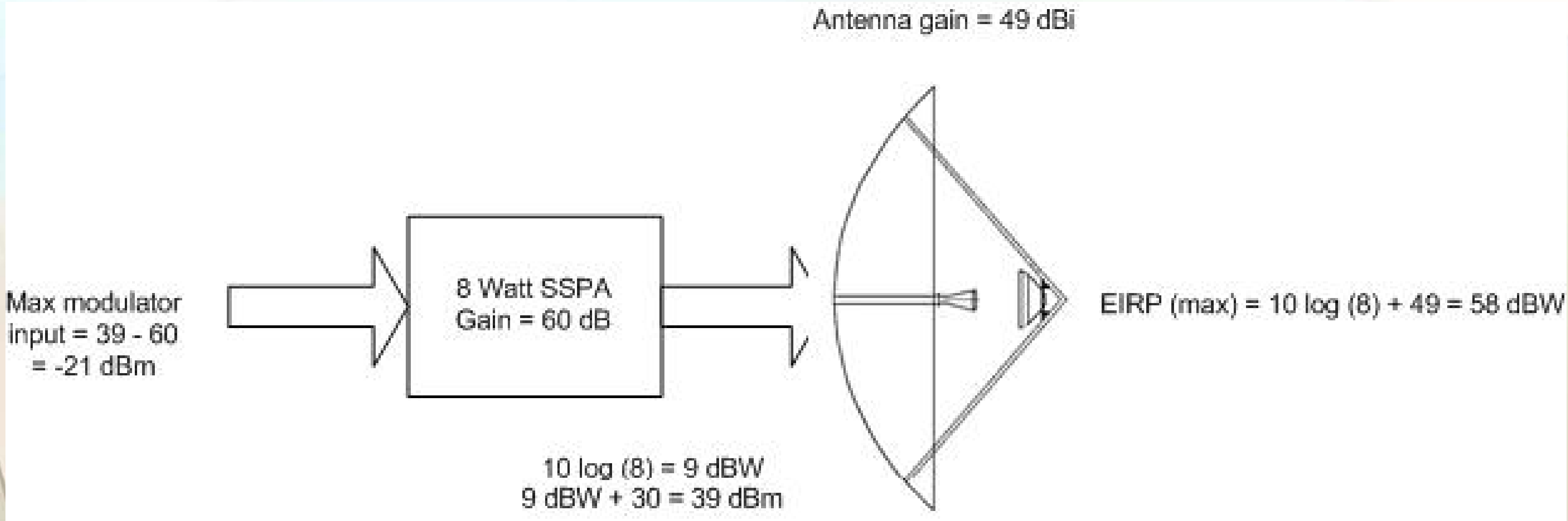
In this example we will use a gain of 60 dB. Therefore the maximum input to the SSPA will be

Maximum SSPA input = SSPA Power dBm - Gain SSPA = 39 – 60 = -21 dBm

Step Four: Simple EIRP without feed or associated losses can be calculated as

10 Log (Pwatts) + Antenna_Gain = 10 Log (8) + 49 = 58 dBW

5- EIRP



Antenna gain = 49 dBi
Max modulator
input = 39 - 60
= -21 dBm
8 Watt SSPA
Gain = 60 dB
EIRP (max) = 10 log (8) + 49 = 58 dBW
10 log (8) = 9 dBW
9 dBW + 30 = 39 dBm

End of Day 2 course

Earth Station Technology