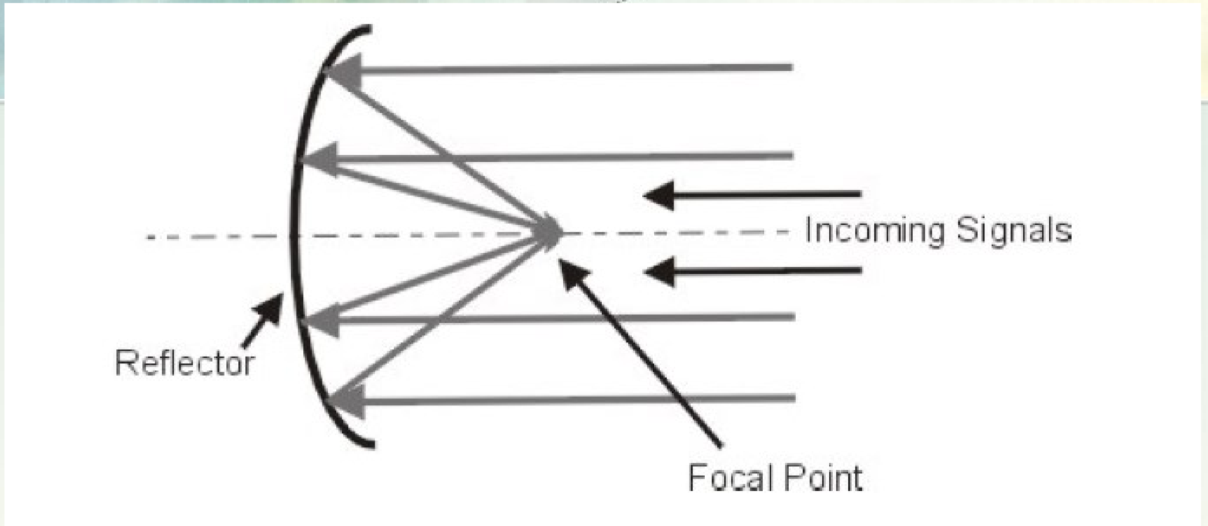
# Day 1 Session 2

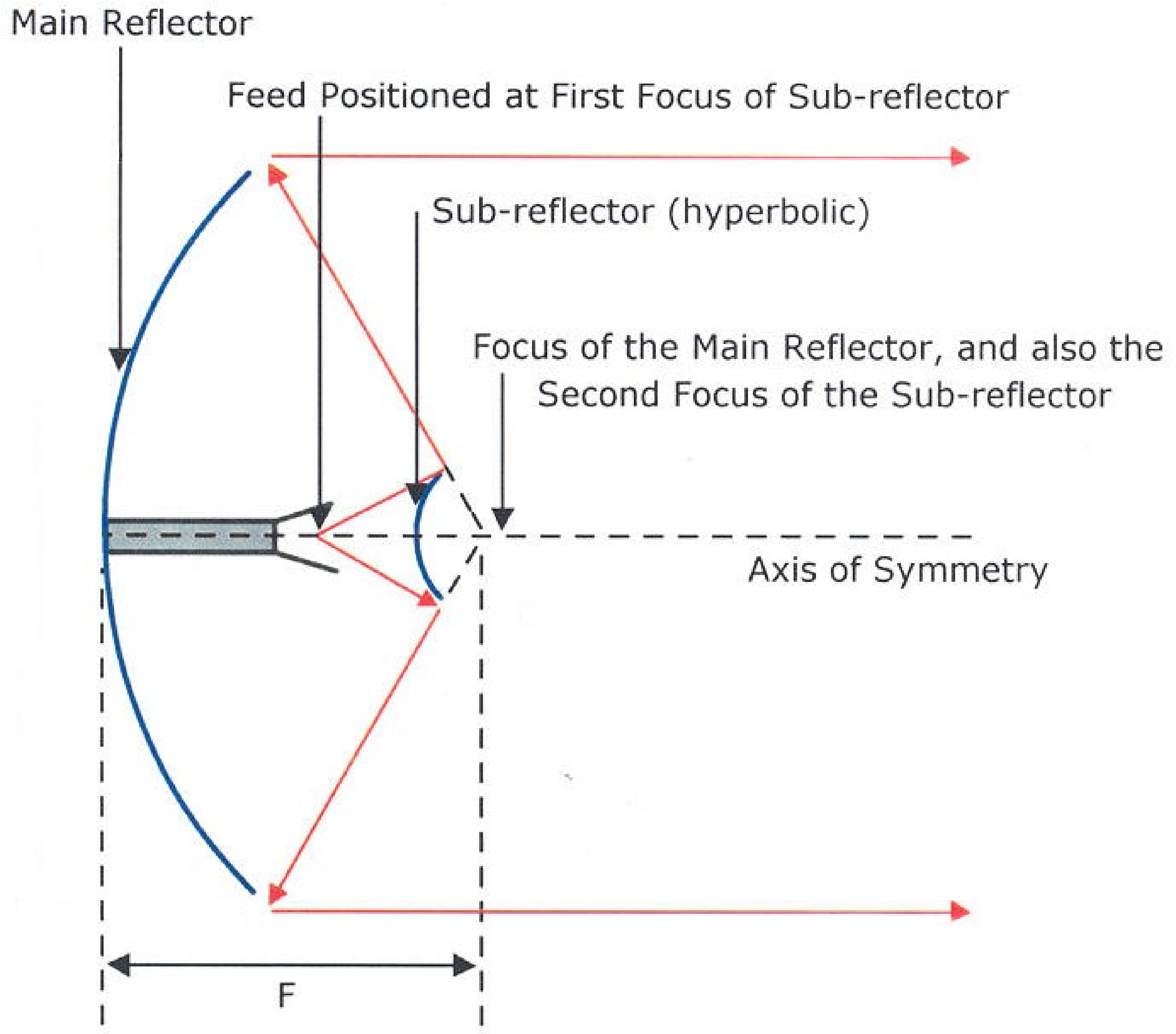
Earth Station Technology

# 1- Types of antennas

Satellites being far from earth require directional antennas in order to communicate. A directional antenna normally 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."

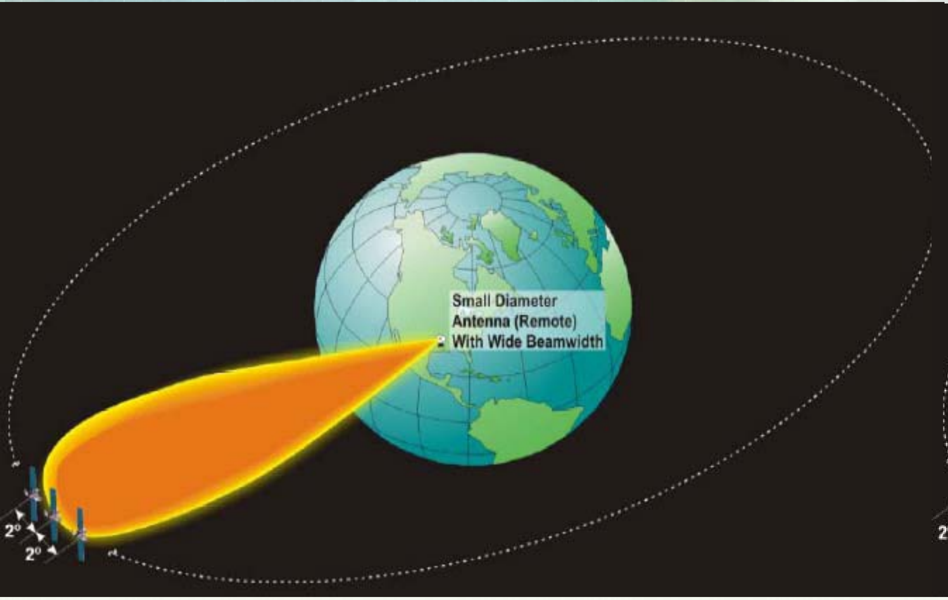


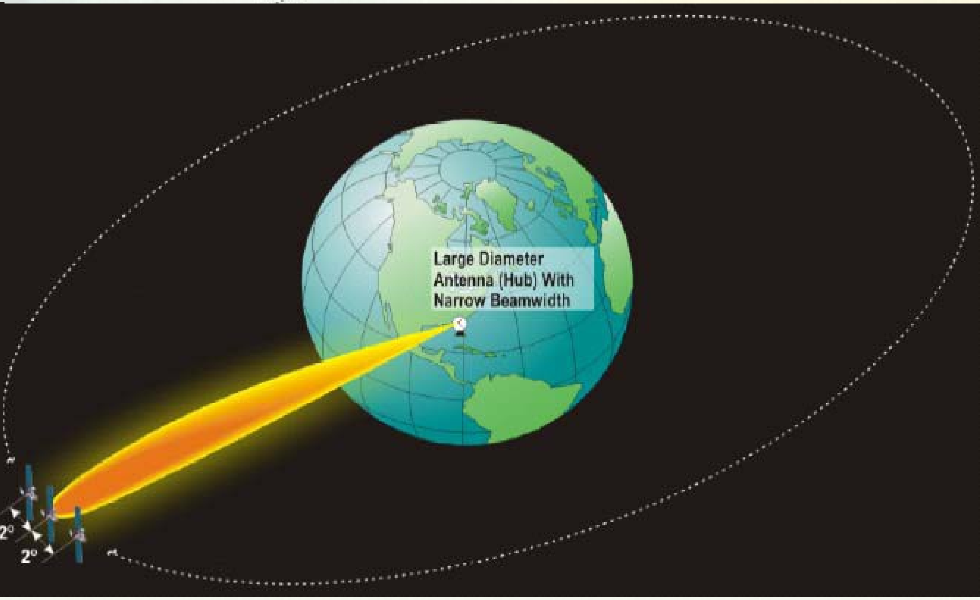
# 1- Types of antennas



# 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.

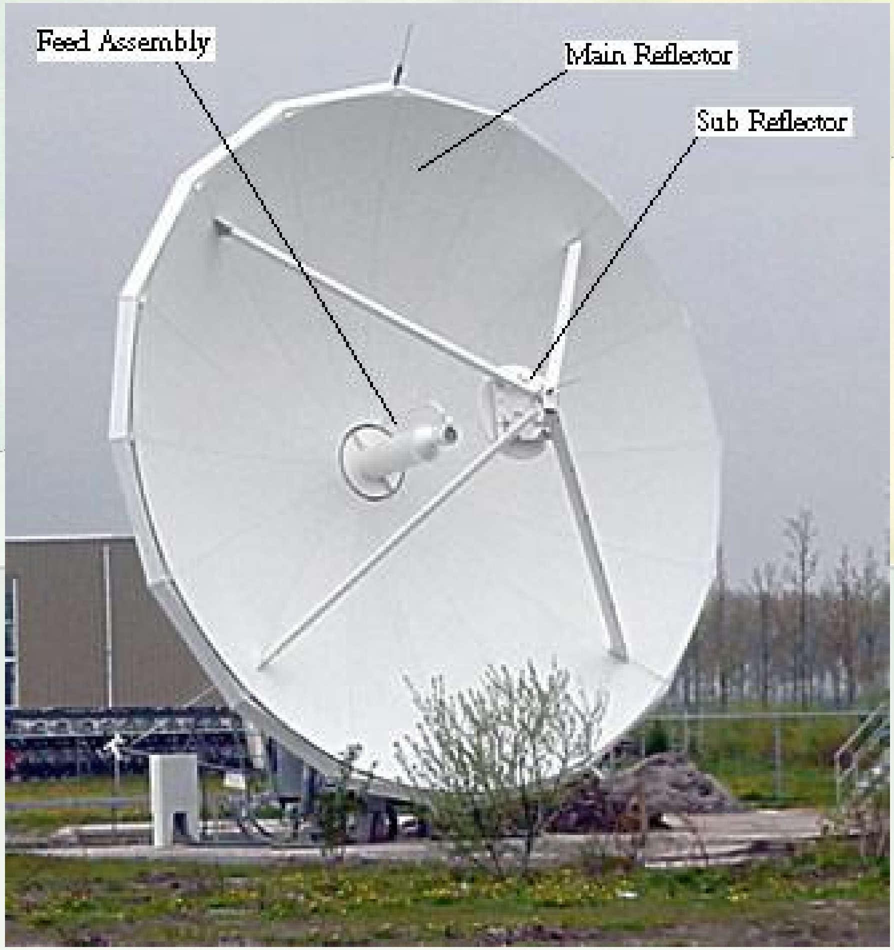


# 1- Types of antennas

The antenna system consists of the following parts:

- Mechanical system – comprising main reflector, back structure, pedestal or mount assembly, and for an 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 :

- Receive only antennas (e.g. DTH or DBS)
- Tx/Rx fixed antennas
- Antennas with tracking system

# 1- Types of antennas

Television Antenna

TVRO stands for Television Receive Only antenna

The antennas can range from 1.2 meters to more than 32 meters dependent on the application (e.g. SMATV or Turnaround)

# 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 typically range from 0.45 meters to 0.9 meters

DTH= Direct To Home

# 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 range from 0.9 meters to more than 33 meters

# 1- Types of antennas

## Tracking antennas

- Antenna is constantly re-peaking so as to be always precisely aligned towards the satellite.
- Also used with inclined orbit satellites.

# 1- Types of antennas

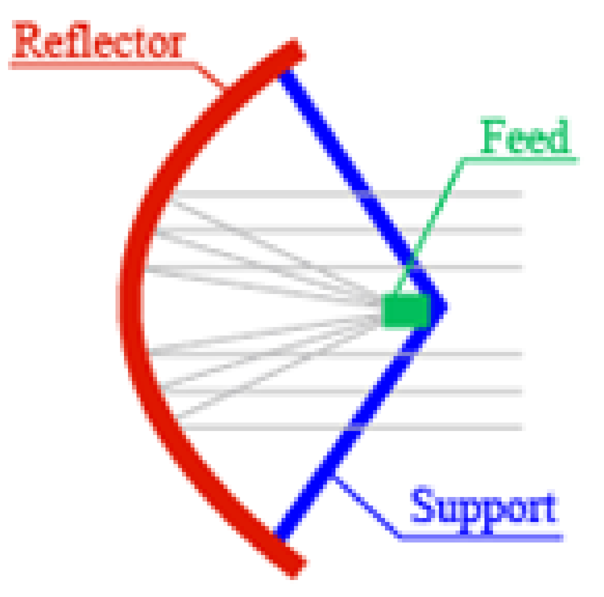
## Mobile antennas

On a moving vehicle (Ship, Train, Truck etc.) the antenna is constantly moving to be always aligned on the satellite.

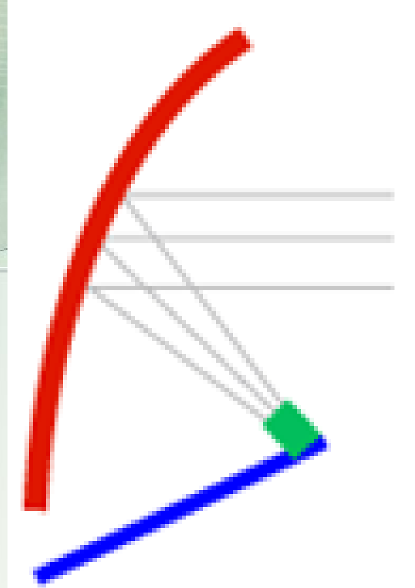
# 1- Types of antennas

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

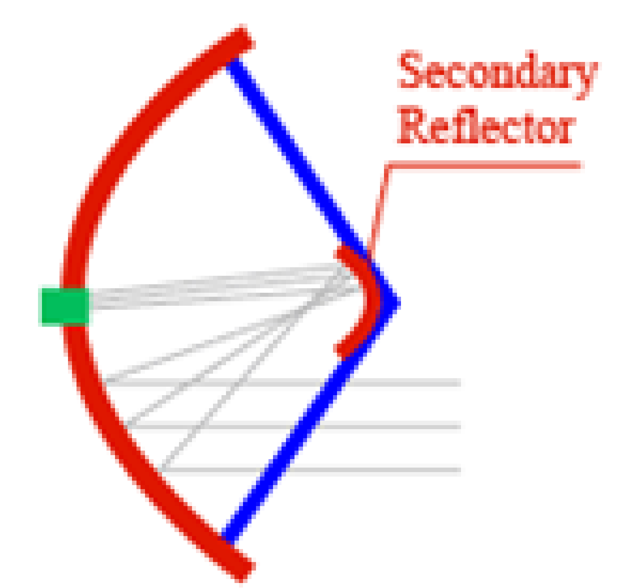
**Centre fed** | **Offset** | **Dual reflector**




Parabolic



Off-center




Cassegrain

# 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 of this design.

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

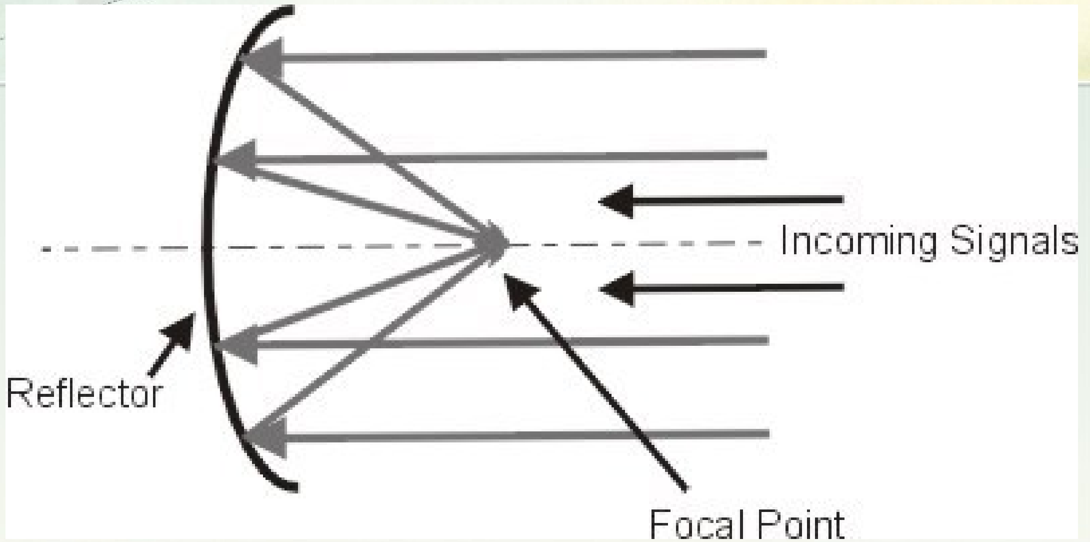
Earth stations that operate in the 6/4 GHz and 14/12 GHz bands are often classified according to the size of the antenna.

- 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. 0.7 to 3 meters

# 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.

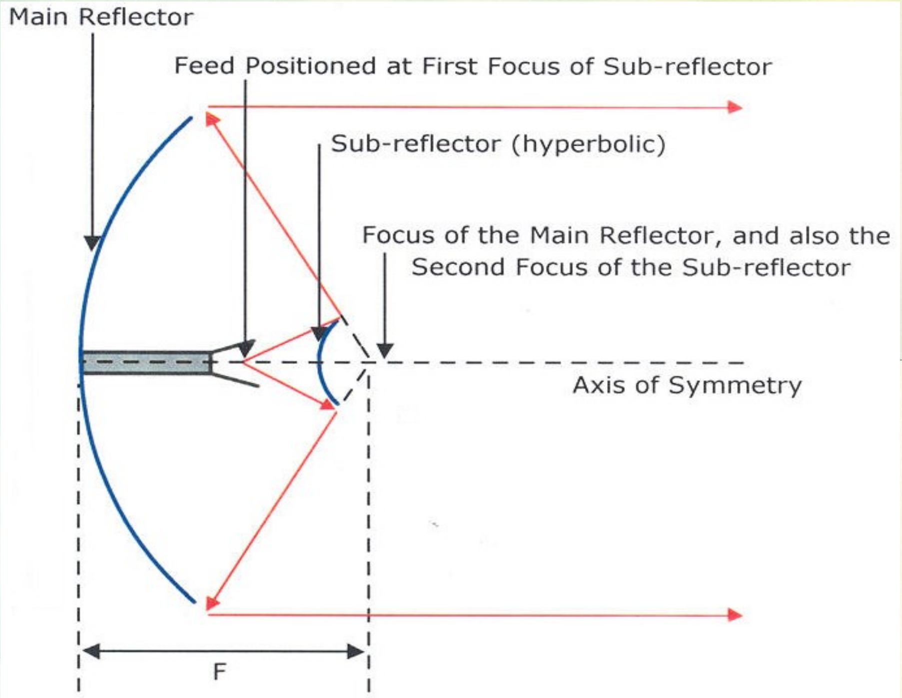


## 1- Types of antennas

### Prime Focus Antenna

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.

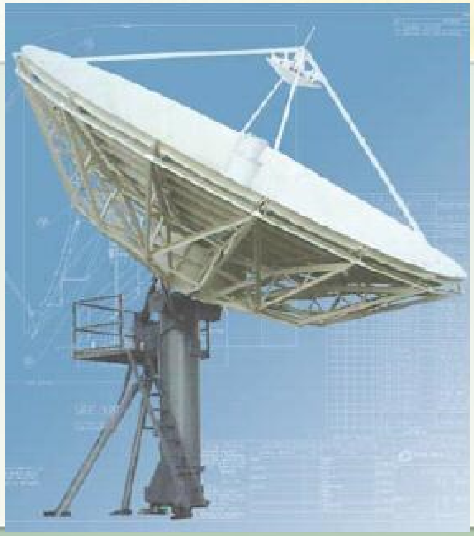
# 1- Types of antennas




## 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:

- 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

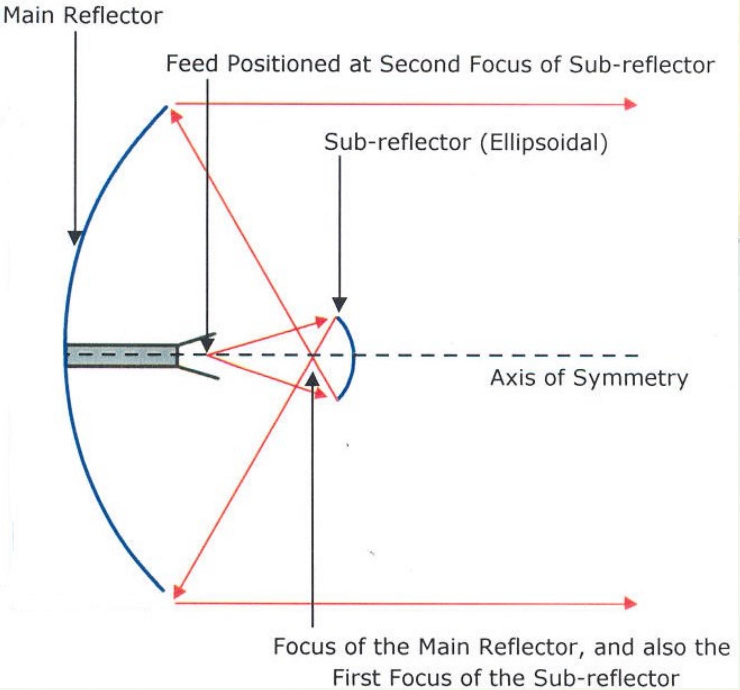
For the reasons stated above, it is very difficult to provide an efficient Cassegrain antenna smaller than 3 meters in diameter.

# 1- Types of antennas

## Gregorian Antenna

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.



## 1- Types of antennas

### Gregorian Antenna

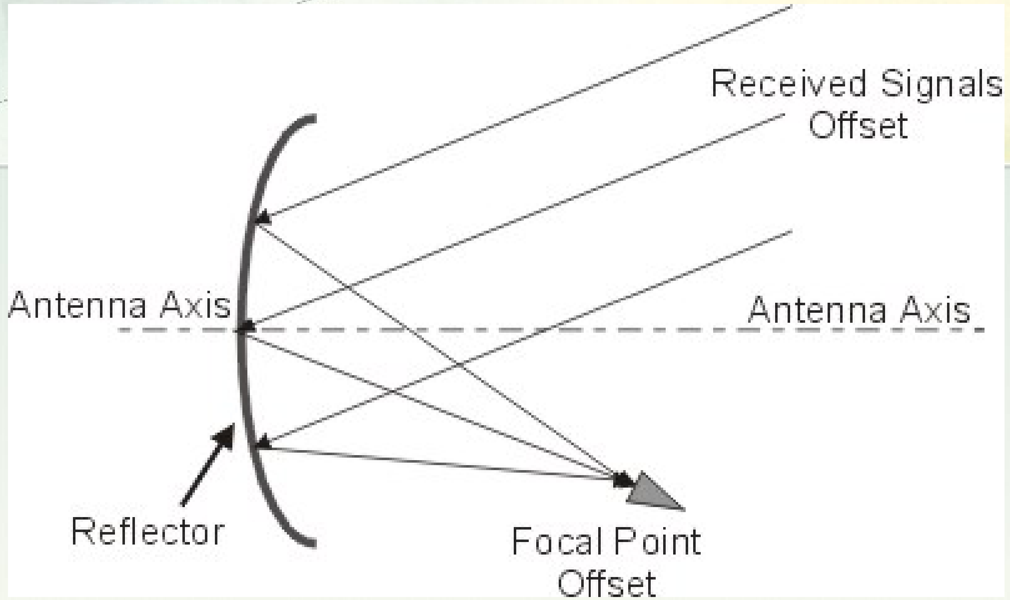
An advantage of using the ellipsoidal sub-reflector is that the feed and sub-reflector edges are subject to less radiation and consequently less interference is caused.

# 1- Types of antennas

## Offset Antenna

Offset antennas are typically used for VSATs. An offset antenna is a section of a prime focus antenna.

This type of antenna has significant advantages.



## 1- Types of antennas

**Offset Antenna**

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- Antenna performance

## 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 radiates equally in all directions. It is expressed in dB or dBi.

G= 10*log(Pout/Pin)

Examples at 12.75 GHz (4.2 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- Antenna performance

## Gain

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

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

## 2- Antenna performance

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.

$EIRP = G \cdot P_{in}$

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

The measurement is expressed in dBW EIRP

## 2- Antenna performance

EIRP

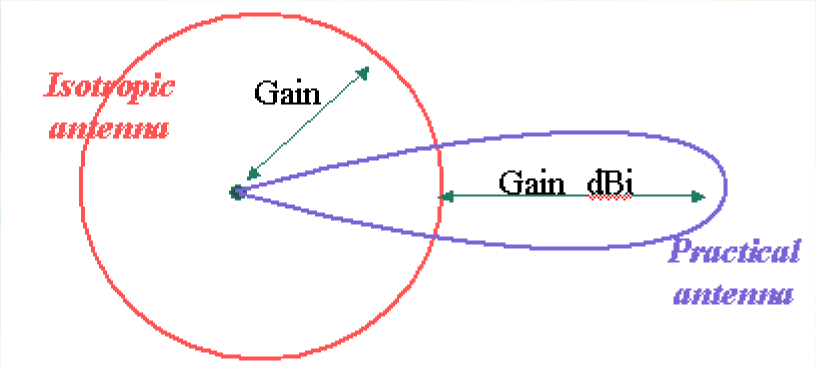
Ex : Power output = 10 dBm

Cable attenuation = 2 dB

Antenna Gain = 19 dBi

EIRP = 27 dBm

EIRP = 501 mW



## 2- Antenna performance

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.

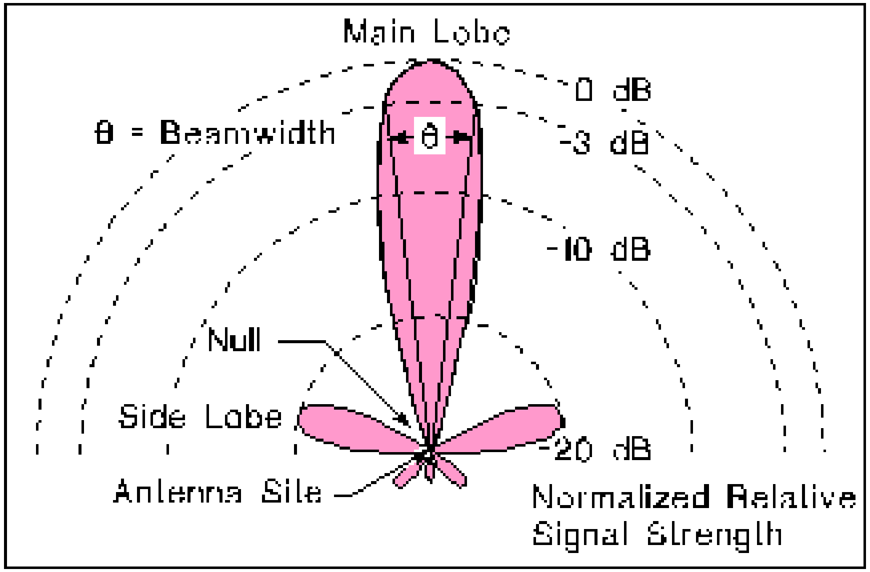
G is the gain of the receiver

T is the system temperature a measure of the total noise

# 2- Antenna performance

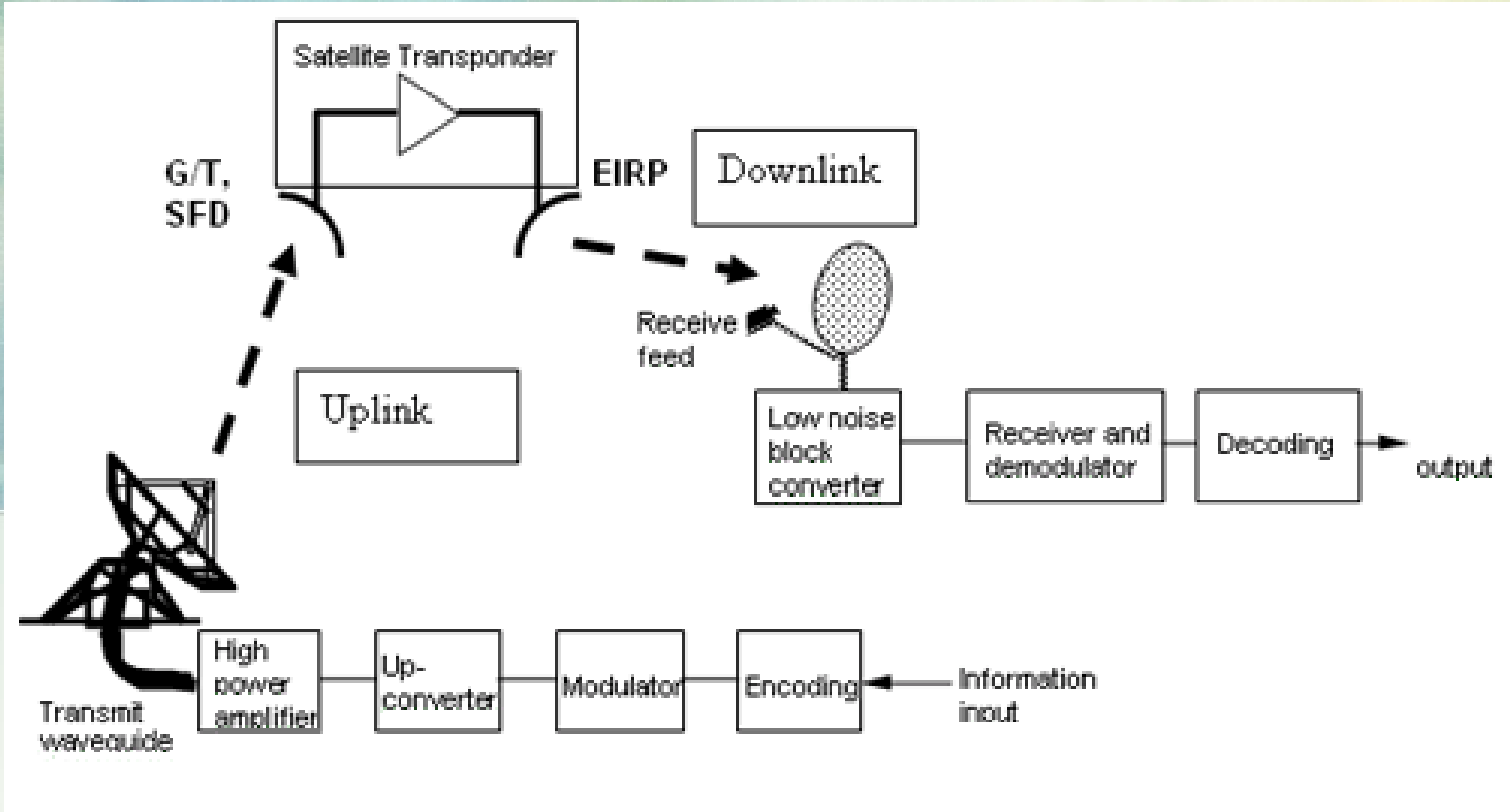
Radiation pattern

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



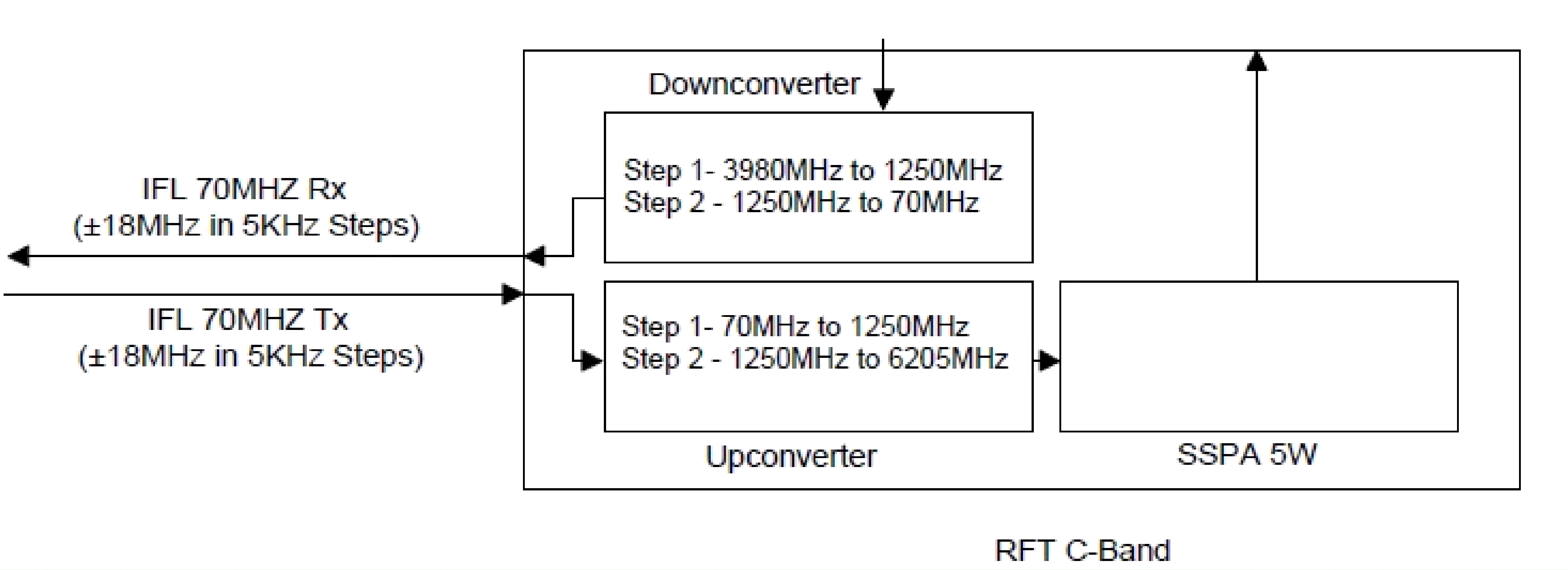

side lobe

# 3- RF Equipment



# 3- RF Equipment

## General frequency conversion scheme



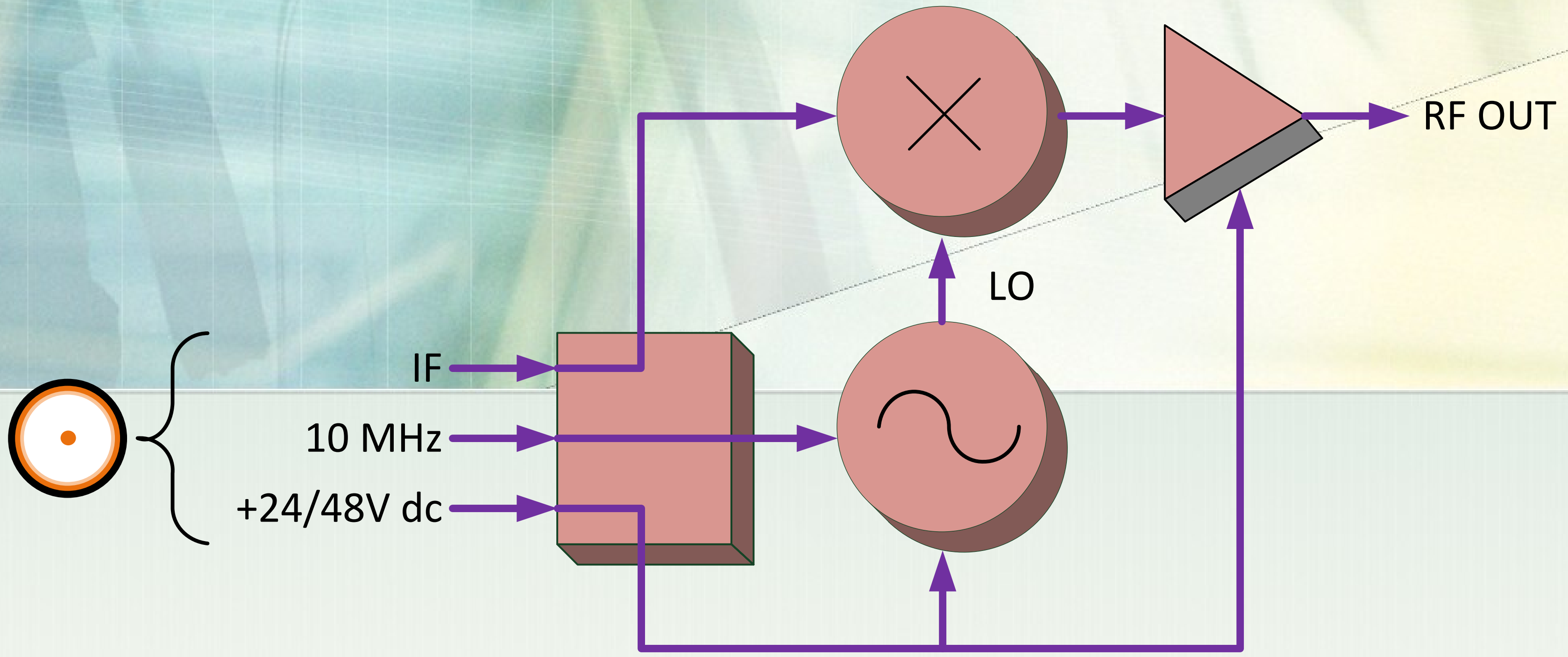
# 3- RF equipment

## 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 C, X, Ku or Ka band using a fixed frequency local oscillator

# 3- RF equipment

BUC



# 3- RF equipment

BUC

| IF (GHz) | LO (GHz) | RF Out (GHz) |
|---|---|---|
| 0.95-1.825 | 4.900 | 5.85-6.725 |
| 1.525-0.95 | 7.375 | 5.85-6.425 |
| 1.1-1.4 | 5.625 | 6.725-7.025 |
| 0.975-1.275 | 5.750 | 6.725-7.025 |
| 1.275-0.975 | 8.000 | 6.725-7.025 |
| 0.95-1.45 | 13.05 | 14.0-14.5 |
| 0.95-1.45 | 12.80 | 13.0-13.25 |
| 0.95-1.45 | 11.80 | 12.75-13.25 |

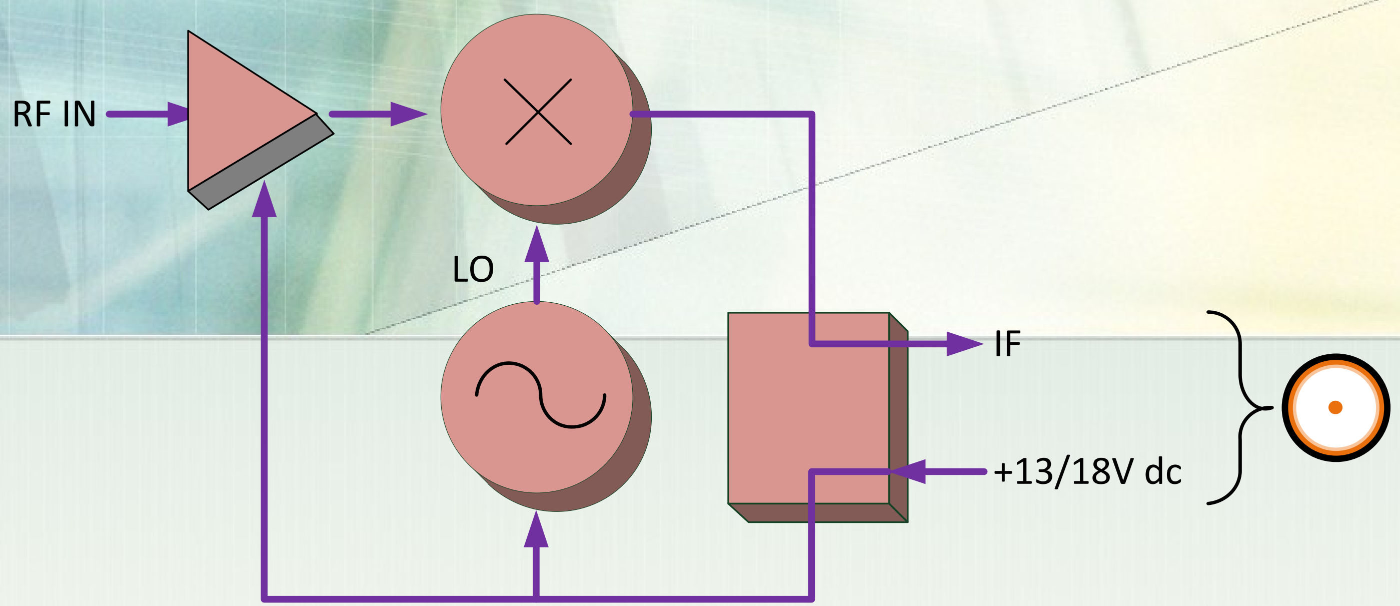
## 3- RF equipment

LNB

The LNB (Low Noise Block) converts the signals from the receive band (C, X, Ku or K-band) to L-band.

# 3- RF equipment

LNB



# 3- RF equipment

## Feed horn

This feedhorn is essentially the front-end of a waveguide that gathers the signals at or near the focal point of the reflector and 'conducts' them to a LNA, LNB or LNC. In the transmit path the feed horn carries the signal from the high power amplifier.

# 3- RF equipment

## Polarization

There are two types of polarization (circular and linear).

Circular polarization is defined as Left Hand Circular (LHCP) or Right Hand Circular (RHCP).

Circular polarization is predominantly used in C, X, K and Ka Band although some broadcast satellites in the American region also use it at Ku Band.

## 3- RF equipment

Polarization

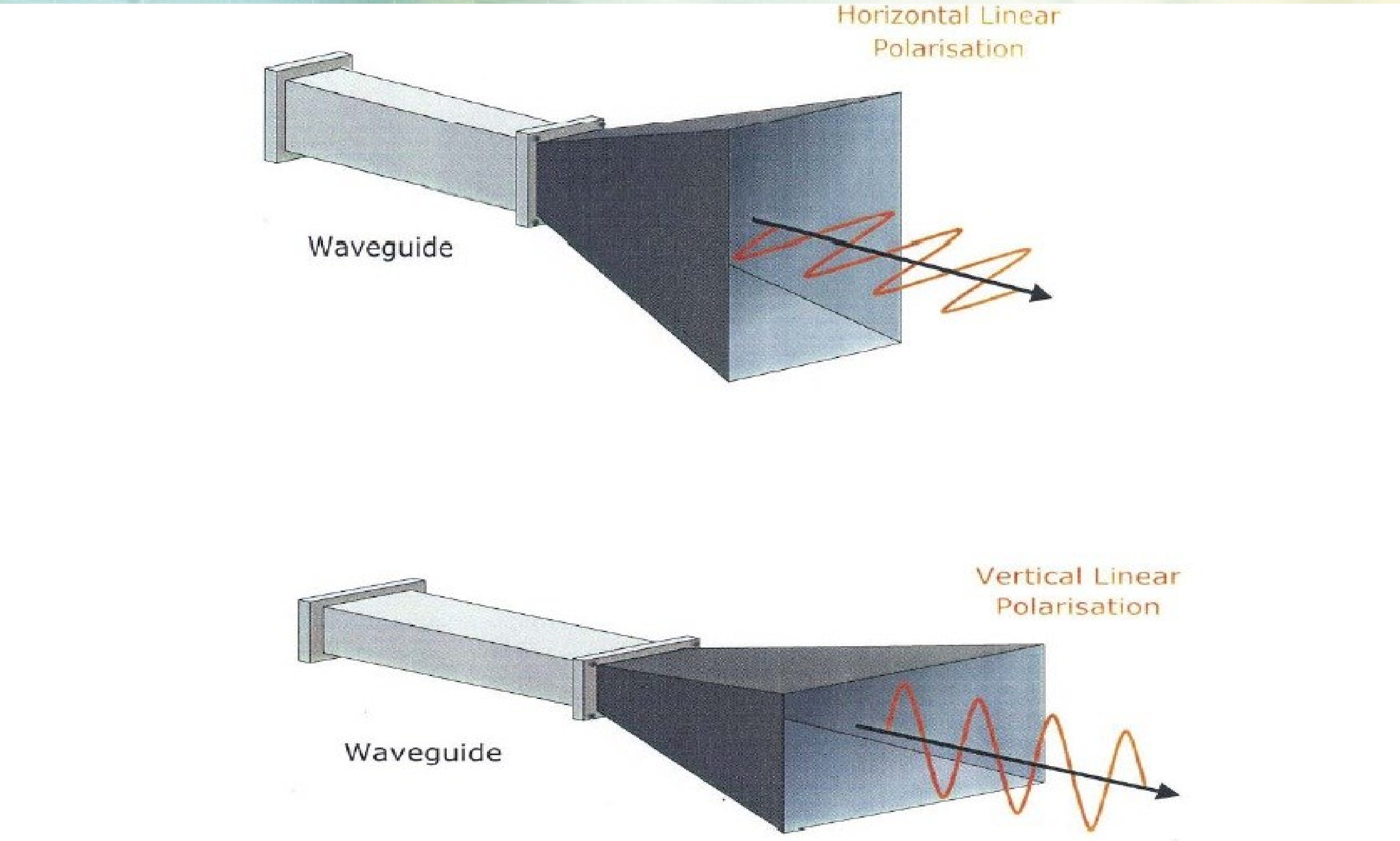
Linear polarization is predominantly used on Ku and K band but occasionally on C-Band antennas.

Linear polarization can be Horizontal and Vertical.

An Orthogonal Mode Transducer (OMT) is used to seperate the 2 polarites.

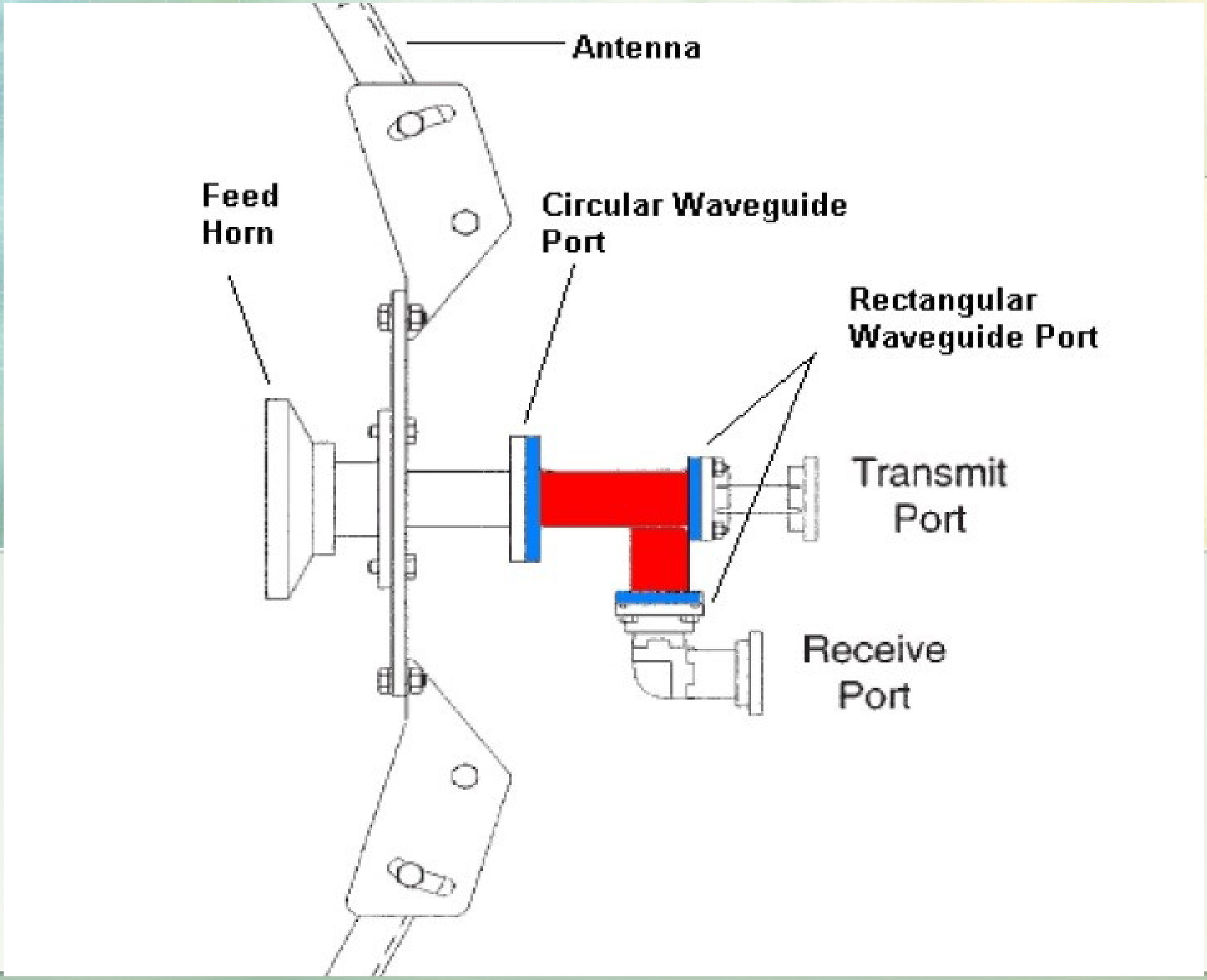
# 3- RF equipment

## Polarization



# 3- RF equipment

## Polarization



# 3- RF equipment

## Polarization

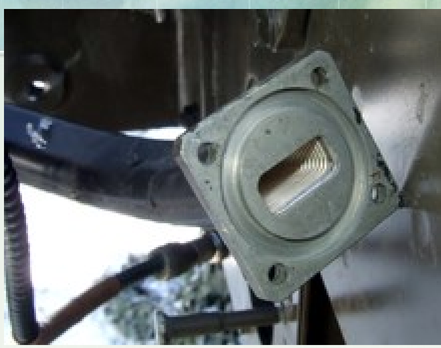
Ku Band Satellites receive signals between 12.75 and 14.75 GHz (although the most commonly used band is 13.75-14.5 GHz).

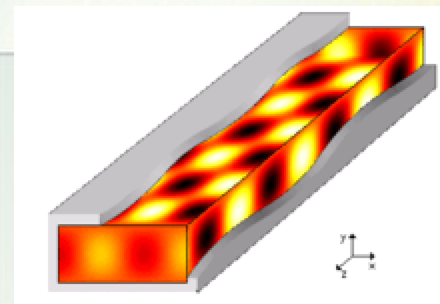
The satellite translates the uplink to a lower frequency and then retransmits it to earth. This translation is different depending on which part of the world one is located in and may range from 10.7 to 12.75 GHz.

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 polarizations. 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

Modem

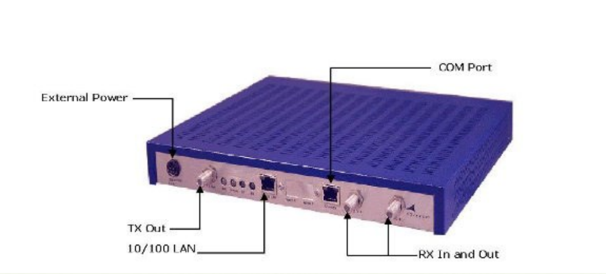
Modem (MODulator/ DEModulator) is a full duplex device that modulates a RF carrier with encoded data.

Satellite modems incorporate Forward Error Correction (FEC) and PSK modulation.

Modern Satellite modems often incorporate an IP router and/or a TDM multiplexer.

Modems having an RF interface at L-Ba a

BUC ar



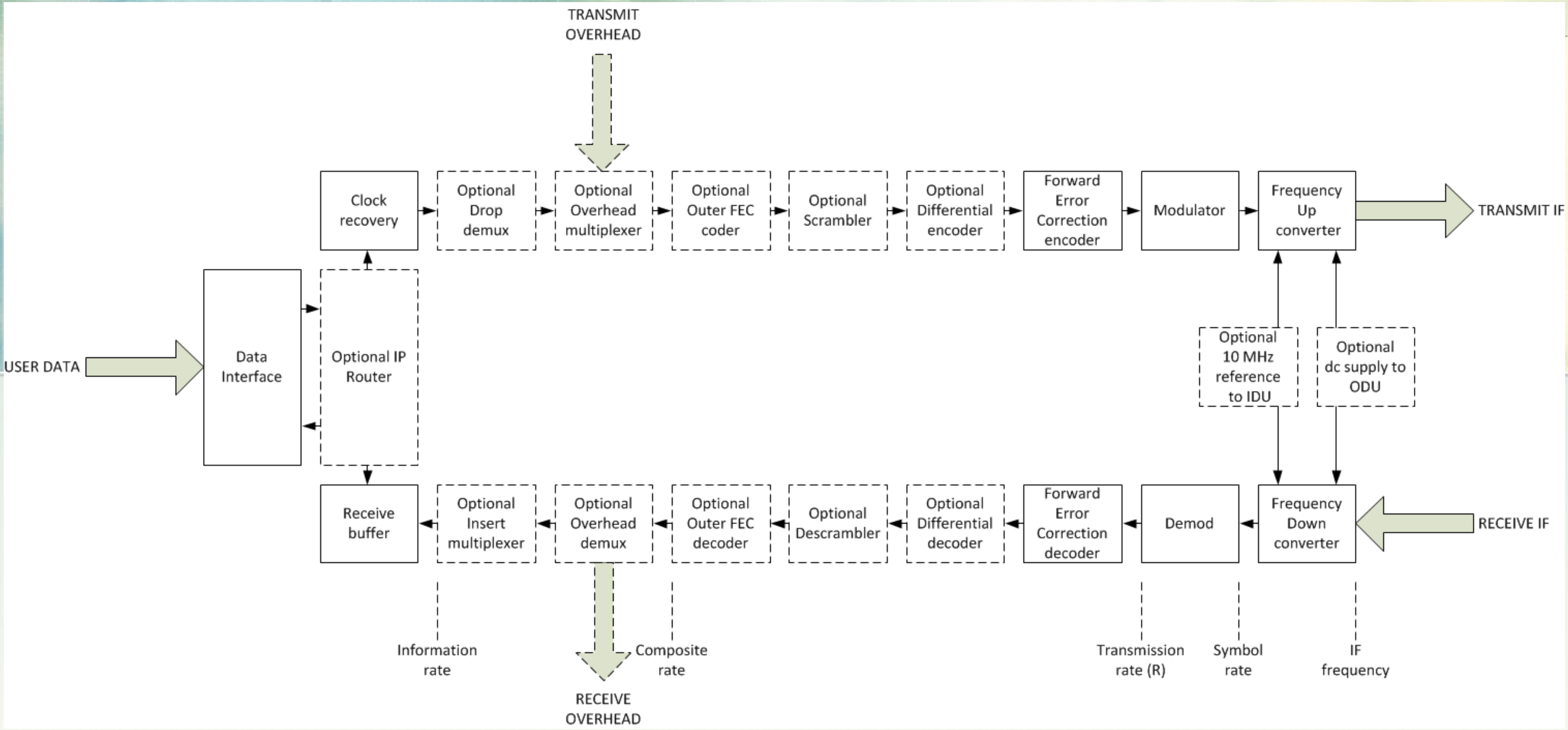

# 3- RF equipment

Modem

There are some devices that include only a demodulator (and no modulator, thus only allowing data to be received from the satellite) they are also referred to as “receivers“ or “IRDs” (Integrated Receiver Decoder). These devices can be used in satellite Internet access.

# 3- RF equipment

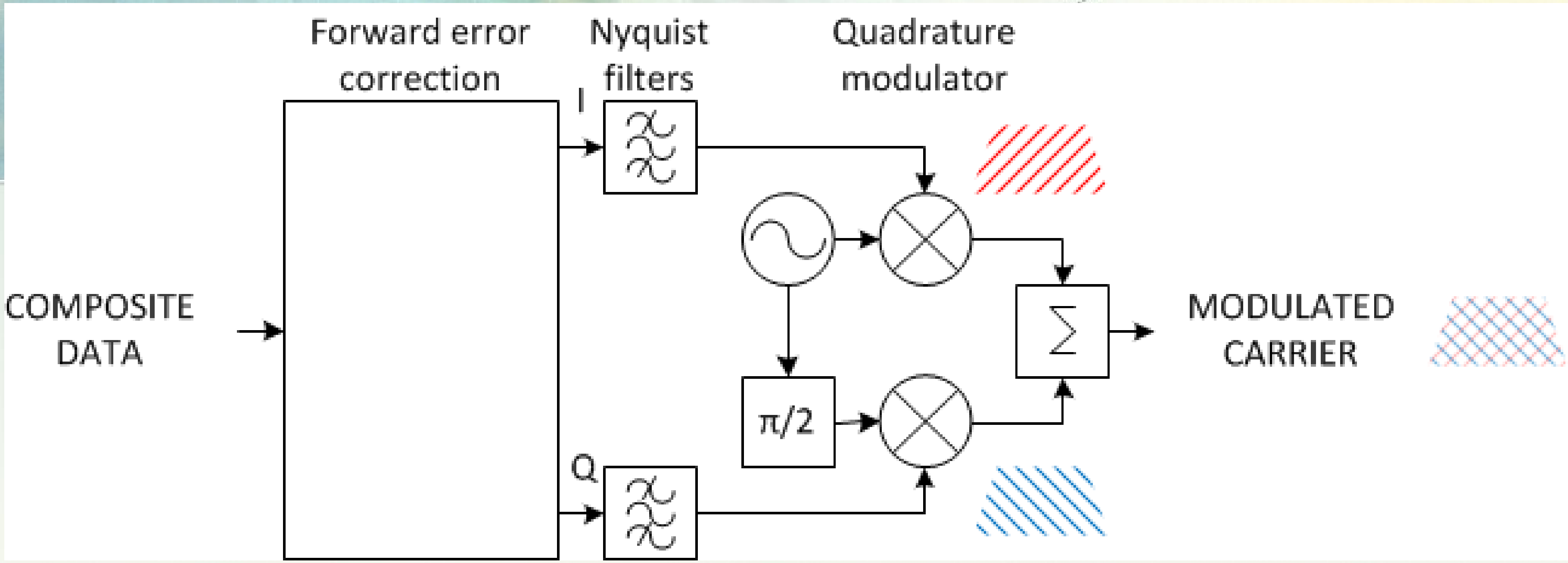
## Modem



# 3- RF equipment

## Modem – Transmit

After the addition of FEC bits and digital-to-analog conversion, the signal passes through a Nyquist filter is modulated and frequency converted to the IF frequency.



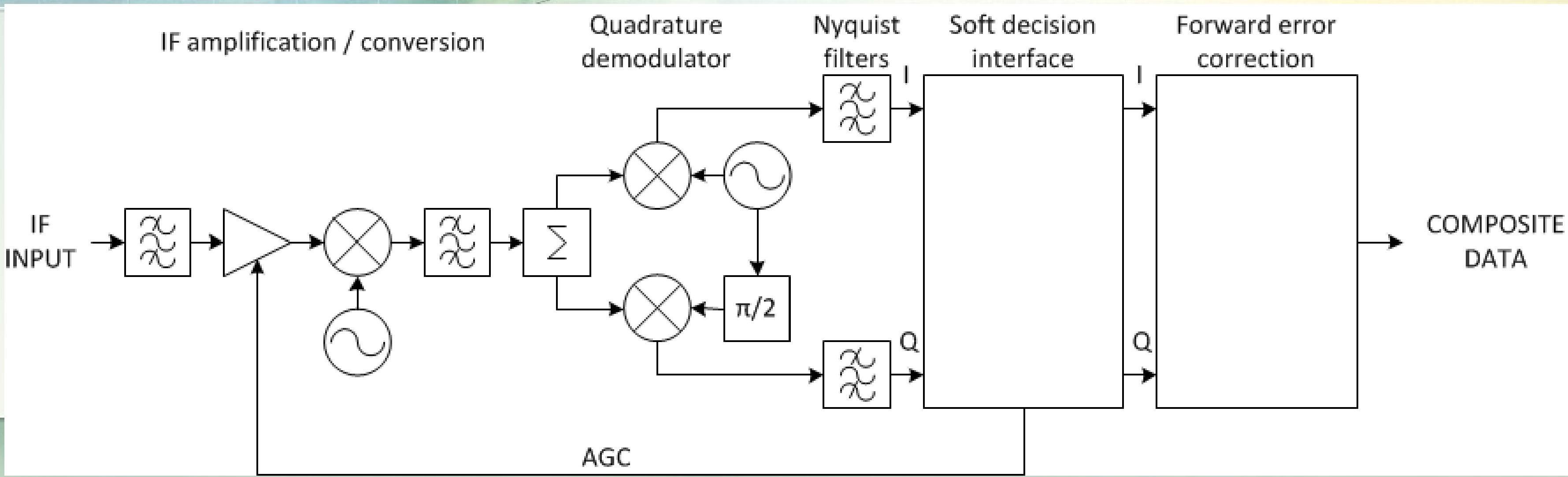
# 3- RF equipment

## Modem – Receive

The IF strip in the receiver converts the incoming signal to baseband and adjusts the level via an automatic gain control circuit.

Then the signal is either sampled or processed by the four-quadrant multiplier which produces the complex envelope components (*I*,*Q*)

The signal passes through an anti-aliasing filter and is sampled and decoded.



## 3- RF equipment

### Modem – FEC Coding

Error correction techniques are essential for satellite communications, because, due to the 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.

# 3- RF equipment

## VSAT Modem – Differential Coding

There are several modulation types (such as PSK and QAM) that have a phase ambiguity. Differential coding is one method 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

### 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

## 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 the several streams which it may consist of.

A satellite modem may use a “D&I multiplexer” which drop timeslots from a T1 or E1 terrestrial fame.

# 4- Modulation

In telecommunications, **modulation** is the process of conveying a message signal, for example a digital bit stream or an analog audio signal, inside another signal that can be physically transmitted. Modulation of a sine waveform is used to transform a baseband message signal to a passband signal, for example a radio-frequency signal (RF signal). In radio communications, cable TV systems or the public switched telephone network for instance, electrical signals can only be transferred over a limited passband frequency spectrum, with specific (non-zero) lower and upper cutoff frequencies.

# 4- Modulation

The three basic types of modulation are :

- Amplitude Shift Keying (ASK)
- Frequency Shift Keying (FSK)
- Phase Shift Keying (PSK)

All of these techniques varies a parameter of a sinusoid to represent the information which we wish to send. A sinusoid has 3 different parameters that can be varied. These are amplitude, phase and frequency

# 4- Modulation

## Amplitude Modulation (AM)

Varying the voltage of a carrier or a direct current in order to transmit analog or digital data. Amplitude modulation (AM) is the oldest method of transmitting human voice electronically. In an analog telephone conversation, the voice waves on both sides are modulating the voltage of the direct current loop connected to them by the telephone company.

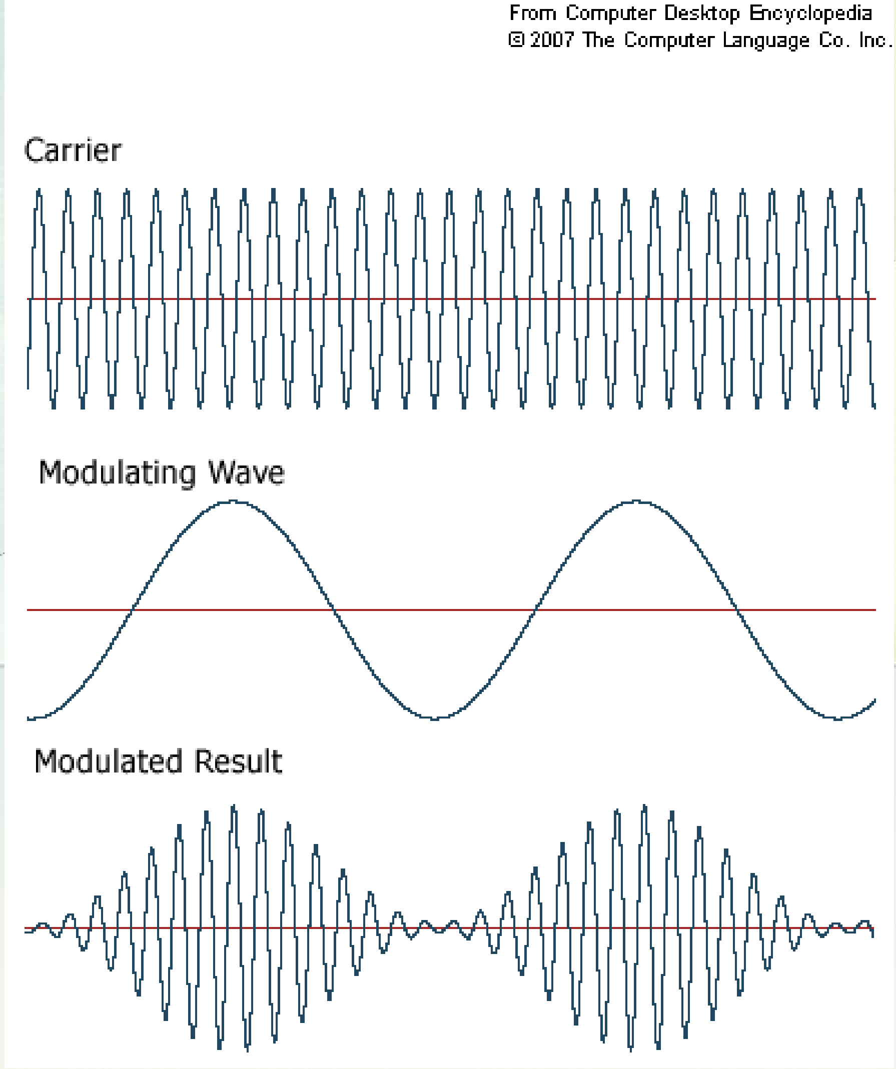
AM is also used for digital data. In quadrature amplitude modulation (QAM), both amplitude and phase modulation are used to create different binary states for transmission

# 4- Modulation

## Amplitude Modulation (AM)

### Vary the Amplitude

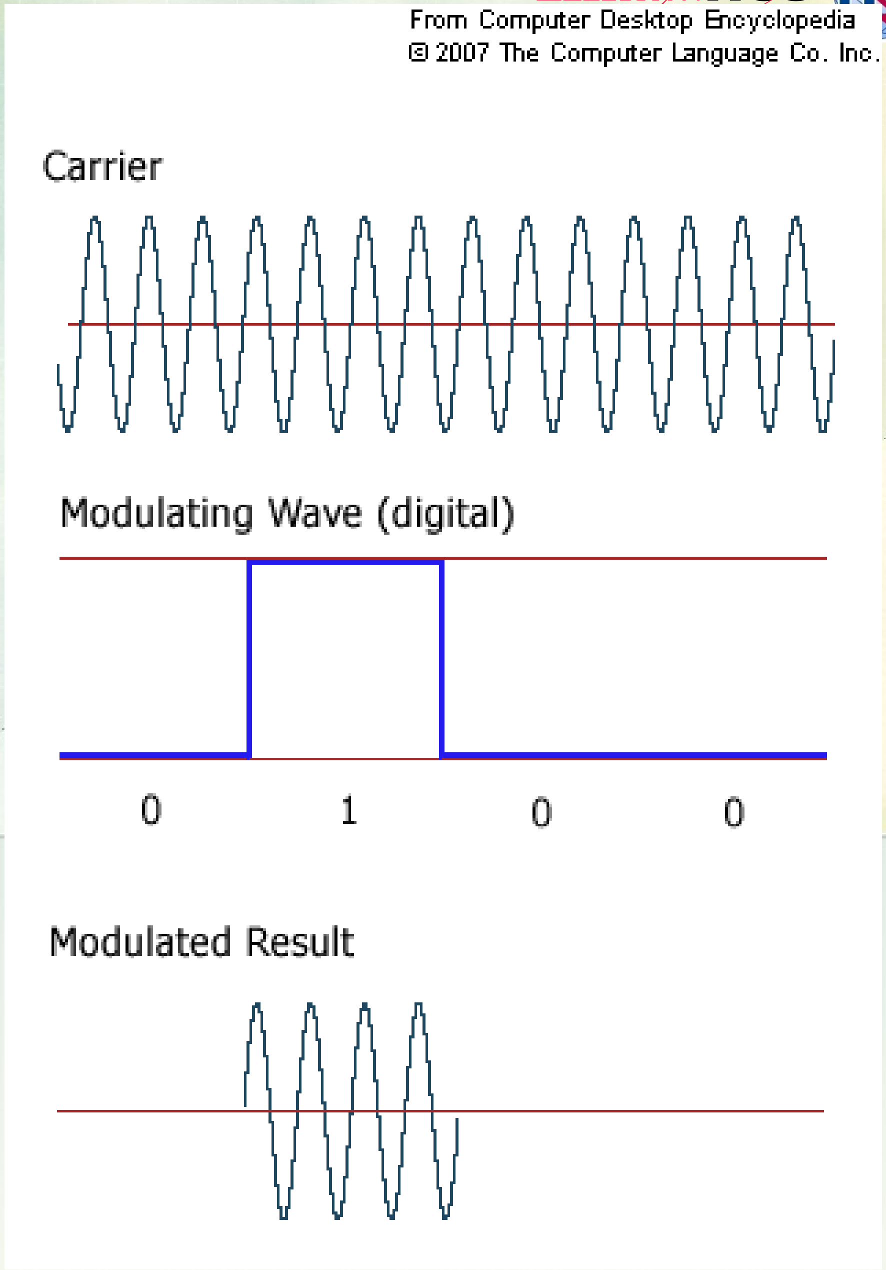
In AM modulation, the voltage (amplitude) of the carrier is varied by the incoming signal. In this example, the modulating wave implies an analog signal.



# 4- Modulation

## Digital Amplitude Shift Keying (ASK)

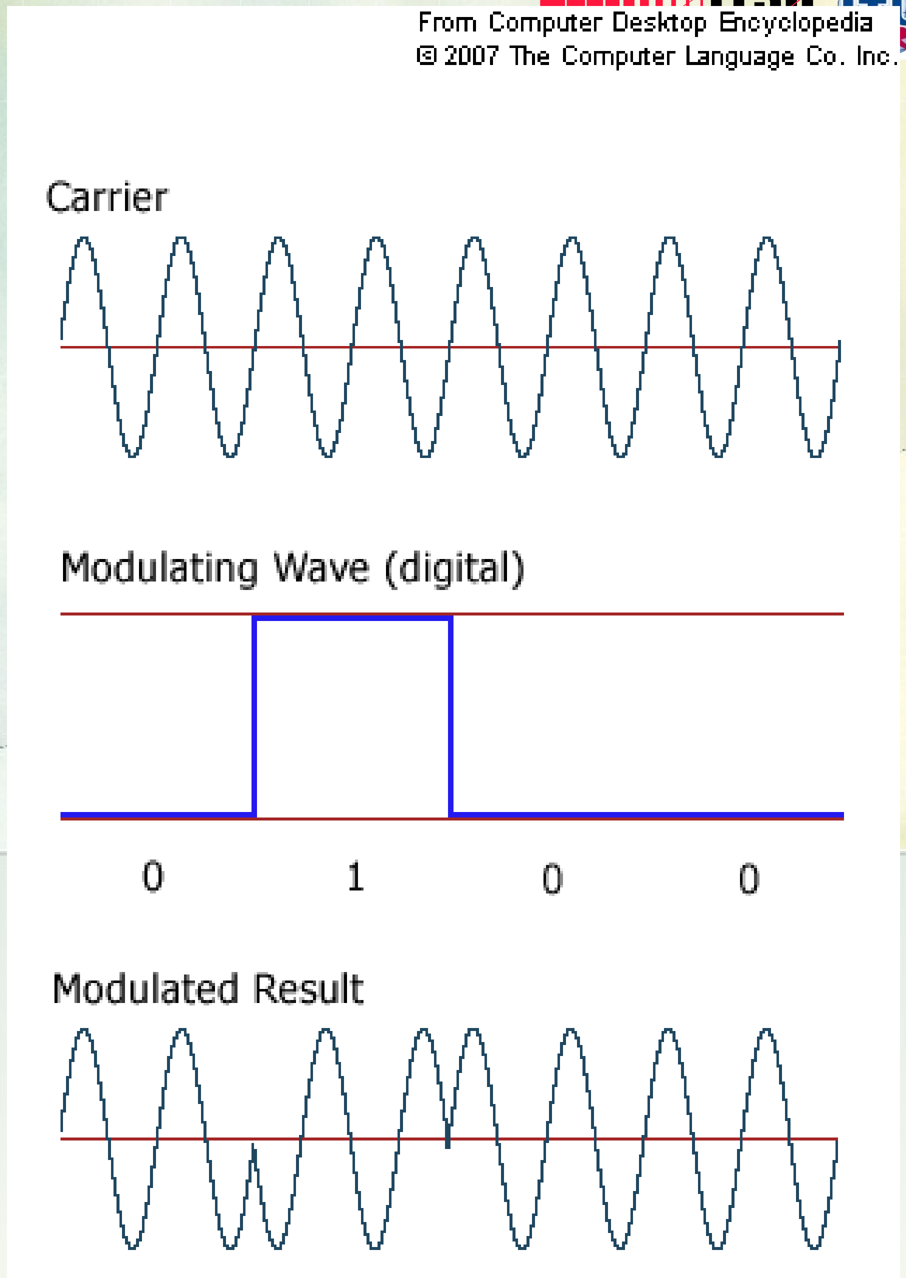
For digital signals, amplitude shift keying (ASK) uses two voltage levels for 0 and 1 as in this example.



# 4- Modulation

## Phase Shift Keying (PSK)

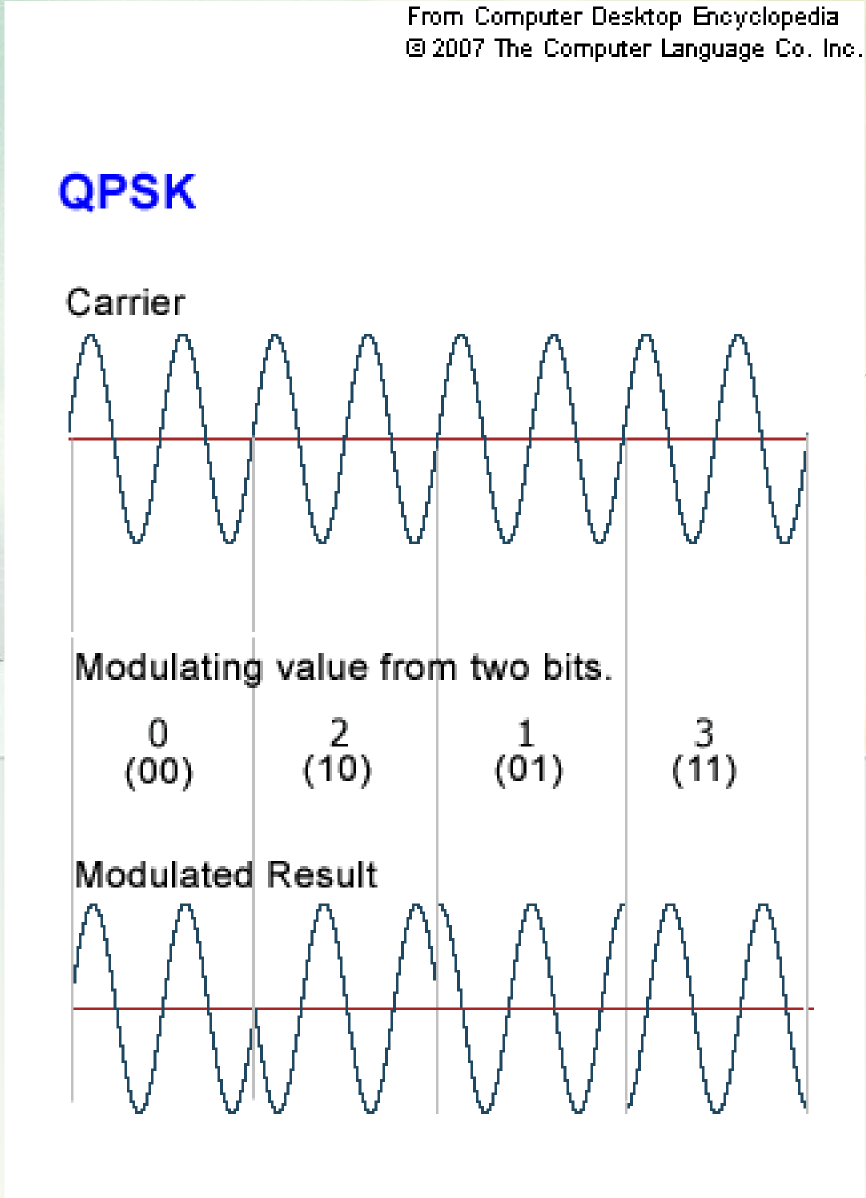
For digital signals, phase shift keying (PSK) uses two phases for 0 and 1 as in this example.



# 4- Modulation

**Quadrature Phase Shift Keying (QPSK)**

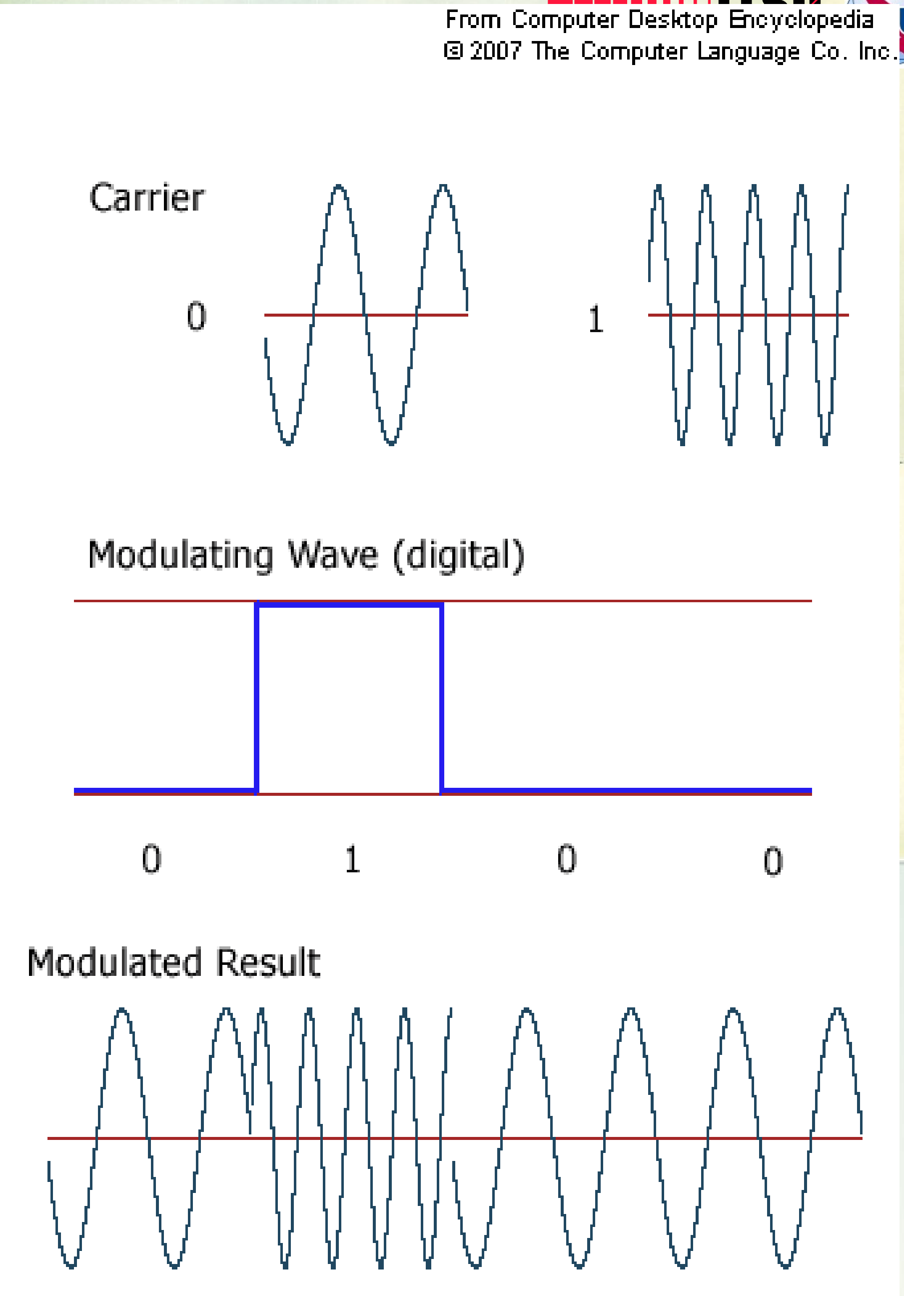
QPSK uses four phase angles to represent each two bits of input; however, the amplitude remains constant.



## 4- Modulation

**Frequency Shift Keying (FSK)**

FSK is a simple technique that uses two frequencies to represent 0 and 1.

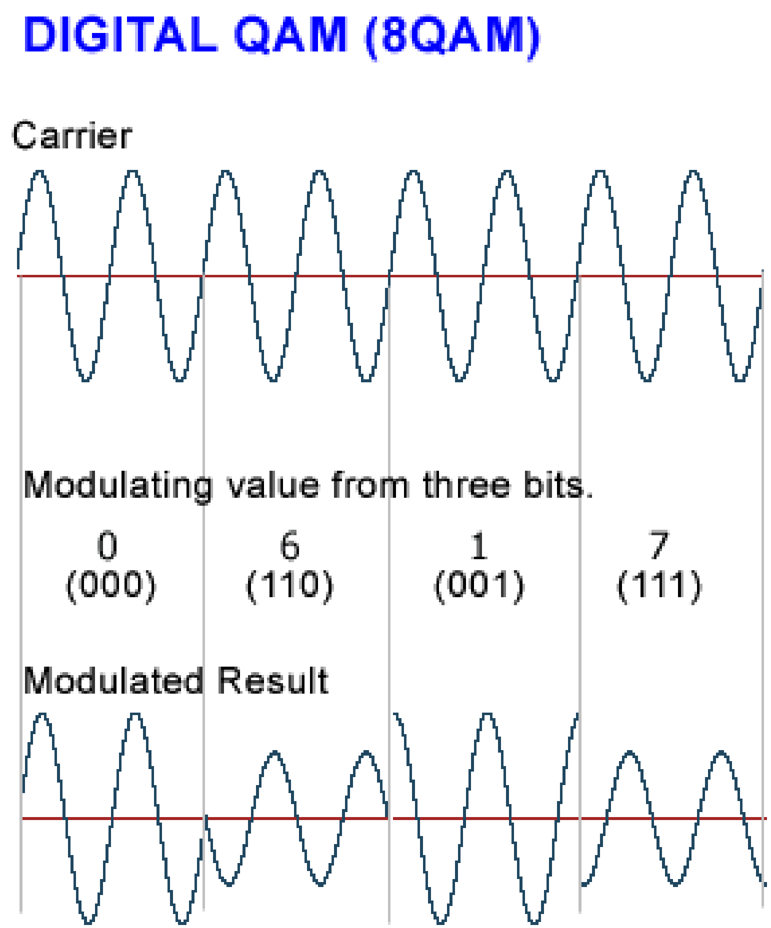


# 4- Modulation

## Digital 8QAM

In this 8QAM example, three bits of input generate eight different modulation states (0-7) using four phase angles on 90 degree boundaries and two amplitudes: one at 50% modulation; the other at 100% (4 phases X 2 amplitudes = 8 modulation states). QAM examples with more modulation states become extremely difficult to visualize.






Note: Only four (0, 6, 1 and 7) out of the eight possible modulation states (0-7) are shown in this illustration.

# 5- Earth Station Measurements

## Spectrum Analyzer

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

## 6- Earth Station Measurements

Spectrum Analyzer typical functionalities

**Frequency:** Tunes to the input frequency to be displayed

**Marker:** Indicates the signal amplitude at a spot frequency

**Bandwidth/average:** The spectrum analyzer displays the signal after filtering at the Resolution bandwidth The displayed trace can be improved through the use of the video bandwidth filter and trace averaging.

**Amplitude:** The amplitude of the input is displayed against frequency

# 6- Earth Station Measurements

## Sat Finder

A **Sat finder** is a satellite signal meter used to point an antenna.

In professional sat finders there is a pre-registered list of satellites with their symbol rate and transponder frequencies and the unit locks to the carrier providing positive identification and precise peaking.

## 6- 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.

## 6- EIRP

**Effective Isotropic Radiated Power (EIRP)**

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

## 6- 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:

$\lambda$ = 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.

## 6- EIRP

10 Log PA

The amplifier power is readily available from manufacturers specifications.

It is important to note that many tube amplifiers use an outout arm that 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 |

## 6- 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.

## 6- 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.

## 6- 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

## 6- EIRP

### Satellite EIRP

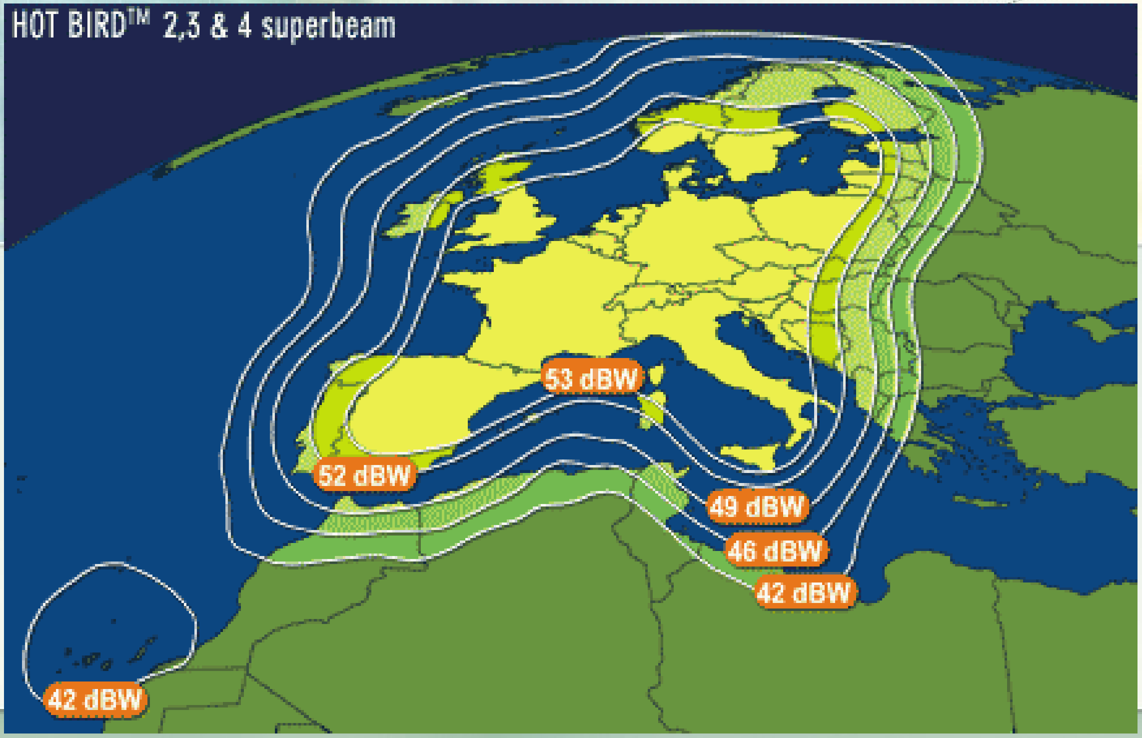
The satellite downlink beam coverage maps show contour lines where each line refers to a particular power level from the satellite. The lines are marked with EIRP values e.g. 45dBW, 44dBW, 43dBW, 42dBW etc. in descending order from the maximum.

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.

# 6- 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).



# 6- 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 dB as follows:

Power (dBW) = 10 log ( Pwatts) = 10 log ( 8 ) = 9.0

## 6- 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.

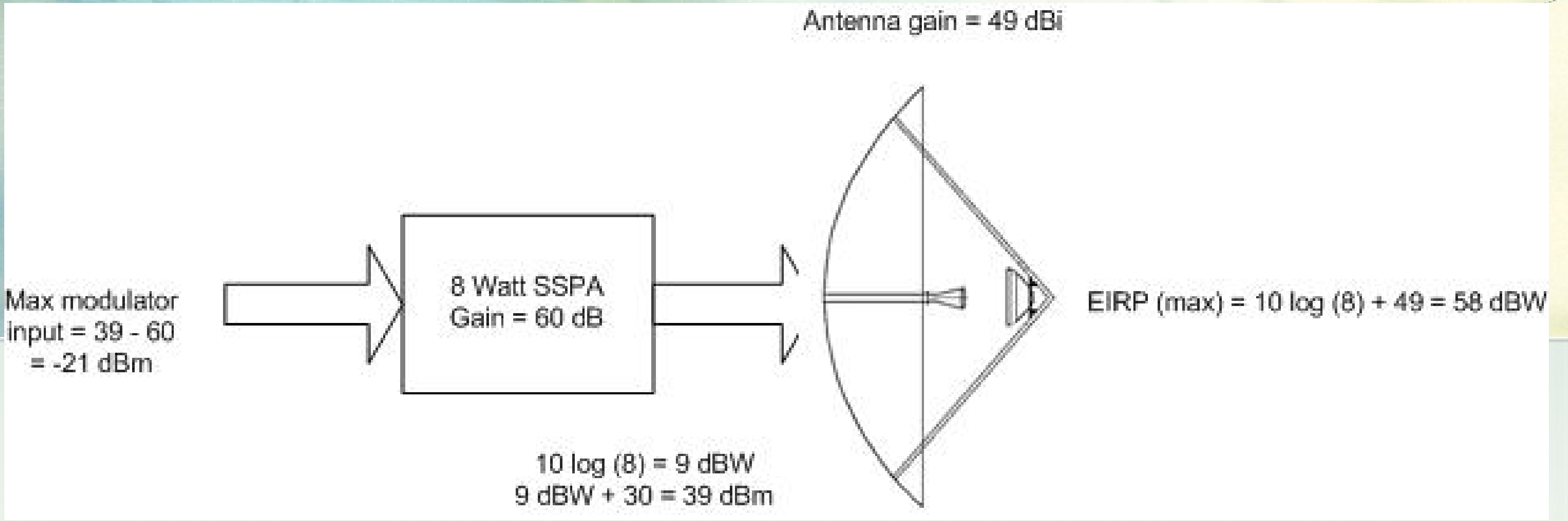
In this example we will use a gain of 60 dB. Therefore the maximum input to the SSPA will be

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

# 6- 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