The Global VSAT Forum

Education & Training Working Group

VSAT Installation & Maintenance Training

Level 1

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The Global VSAT Forum (GVF) is a not for profit organization comprised of a large number of satellite communications companies from over 60 countries in every major region of the world. The GVF's mission is to act in an independent manner for the general promotion of the global VSAT Industry, whether this be technology or service based. The Global VSAT Forum represents the best interests of its membership at relevant industry symposia, regulatory and legal consultations and forms a single point of contact for any suppliers to the industry or any users of VSAT equipment or services. The Forum's actions are always consistent with the promotion and growth of the VSAT Industry and its membership.

Second Edition February 2006.

Dear Reader,

Everyone knows that modern communications satellites are at the heart of the high quality telecommunications services satellite service provides to our myriad customers around the world. However we sometimes take for granted just how remarkable these satellites and their associated ground systems have become. Weighing about the same as a full size American car, when these satellites roll of the assembly line their fuel tanks will be filled and then they will be subjected to the full force and fury of a controlled explosion known as a launch vehicle. With several additional pushes from an internal rocket, after two weeks they will finally arrive at the proper orbital slot 22,300 miles above the earth. For the next thirteen to fifteen years, in spite of the continuous push from the "solar wind" and the constant pull of gravitational forces, the satellite must be kept in exactly the same position - again using internal rockets under ground control - so that the customers antennas will not have to search to find it. After the antennas and solar panels are unfolded and a short period of testing is completed, the satellites will be expected to run twenty four hours a day, seven days a week for thirteen to fifteen years with no stops at the dealer for repairs or even routine maintenance. They will also be expected to provide continuous communications services between all points on the earth within the antenna "footprints" carrying huge volumes of video, voice and data for your or your company's customers.

One of the goals of this training manual is to make the development, launch and operation of these "modern miracles"" and the installation of ground segment as earth stations look easy to you as a VSAT Technician and ultimately, to your worldwide customers.

Because satellite technology is a rapidly evolving area of technology it cannot be over-emphasized that training should be a continual activity. It is necessary that both the executive and technical staff keep up-to-date with technological developments in this field. As a minimum, VSAT technicians should have good knowledge of RF transmission, digital technology and some knowledge of mechanical systems. Managers need to understand the importance of continuing education for personnel to enhance knowledge, improve skills and keep up with new technology.

This Training Manual provides the reader with an overview of satellite technology and VSAT technology in particular. In addition, it addresses issues typical to all VSAT installations. It should be noted that the issue of human health and safety from electromagnetic radiation is not included in this manual, as compliance with national and regional standards and limits in this area is insured through each national licensing process.

Please take your time to read through the manuals and make notes where required. If necessary, insert comments, remarks or questions.

The Manual is far from perfect but efforts will be made to keep it updated. In addition this paper is written by a non-native English speaker what occasionally may result in funny grammar.

At any time never hesitate to contact me for remarks, suggestions or critics.

Amsterdam, The Netherlands.

August 2003

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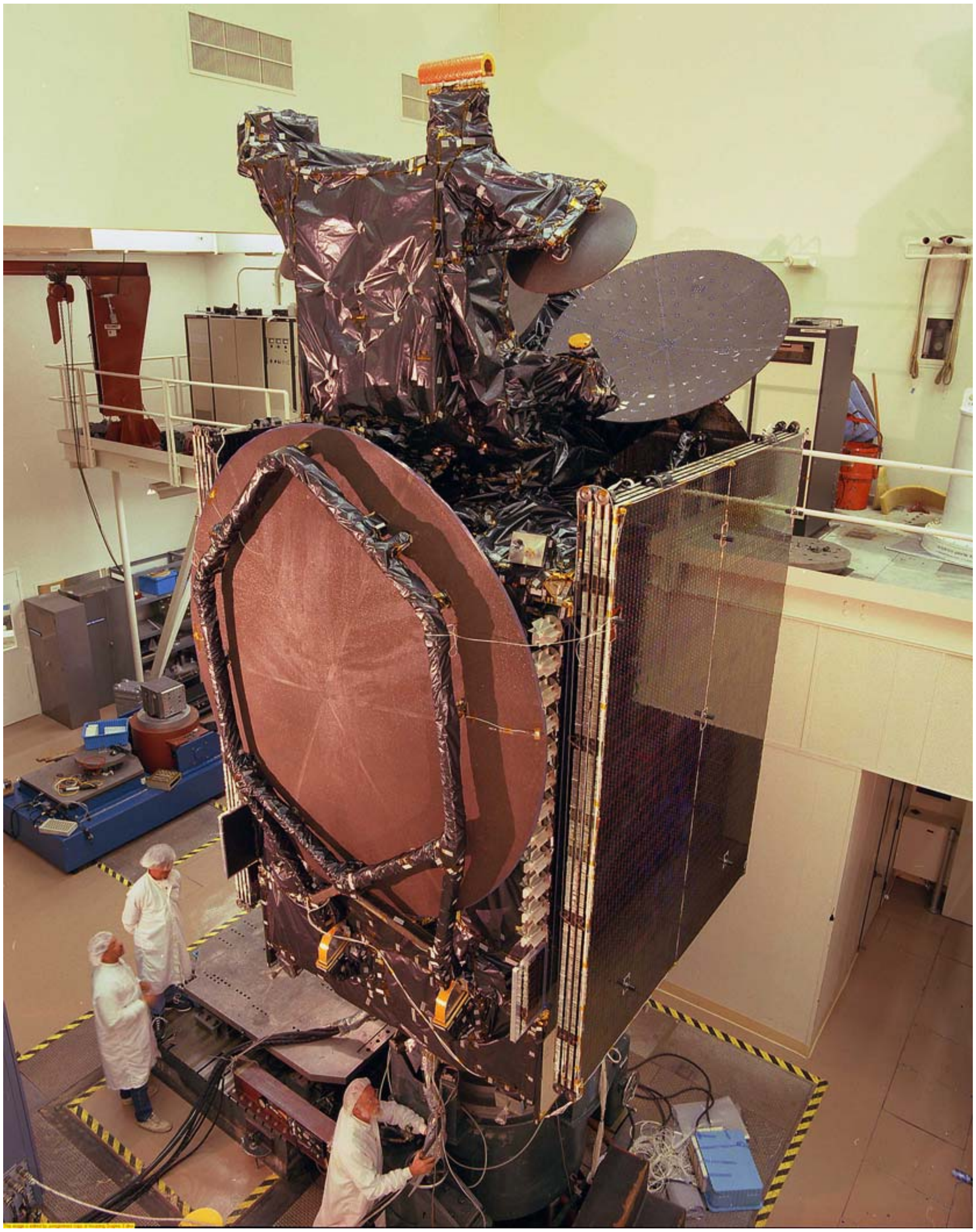
History Edition

Version	Date	Author	Notes
Draft 0.0	30 April 2003	Onno Beemsterboer	Initial set-up
Rev 1.0	22 July 2003	Onno Beemsterboer	Implementation of suggestions
Rev 1.1	10 September 2003	Onno Beemsterboer	Implementation of suggestions
Rev 1.2	18 November 2003	Onno Beemsterboer	Adding copyright clause
Rev 1.3	14 December 2003	Onno Beemsterboer	Update introduction; update charts on page 122 and 125
Rev 2.0	3 February 2006	Onno Beemsterboer	Level split and update


Satellite under construction at Space Systems/Loral

Part 1

Satellite Communications Basics

1. What is a communication satellite and how does it work

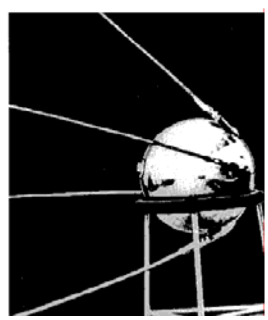
1.1. Introduction

Almost everyone in the industry knows that modern communication satellites are at the heart of the high quality telecommunications services provide to millions of people around the world. However we sometimes take for granted just how remarkable these satellites and their associated ground systems have become. Weighing about the same as a full size American car, when these satellites roll of the assembly line their fuel tanks will be filled and then they will be subjected to the full force and fury of a controlled explosion known as a launch vehicle. With several additional pushes from an internal rocket, after two weeks they will finally arrive at the proper orbital slot 22,247 miles above the earth. For the next thirteen to fifteen years, in spite of the continuous push from the "solar wind" and the constant pull of gravitational forces, the satellite must be kept in exactly the same position - again using internal rockets under ground control - so that the customers antennas will not have to search to find it. After the antennas and solar panels are unfolded and a short period of testing is completed, the satellites will be expected to run twenty four hours a day, seven days a week for thirteen to fifteen years with no stops at the dealer for repairs or even routine maintenance. They will also be expected to provide continuous communications services between all points on the earth within the antenna "footprints" carrying huge volumes of video, voice and data.

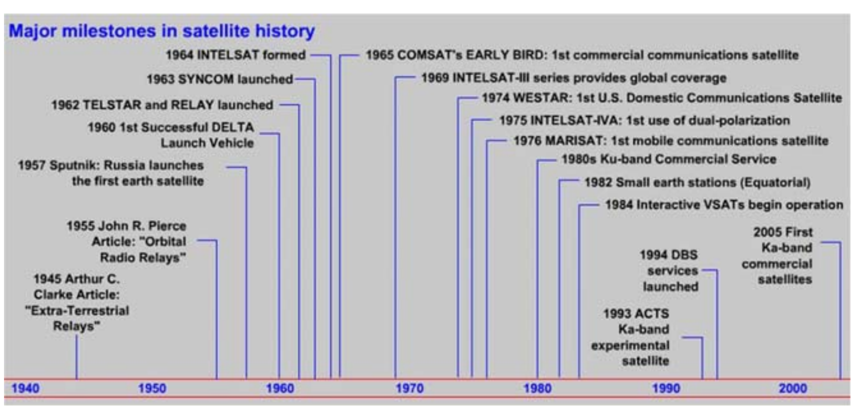
Satellite communications technology evolved from microwave, radar and rocketry technologies developed during the Second World War. In 1945 Arthur C. Clark conceived the idea of geosynchronous satellites located in space to effect long distance communication. In the 1960's, successful experiments demonstrated the transmission of voice, data and video via satellite. In the late 70's and early 80's, microwave components became cheaper and satellite technology found more and more attractive applications in private networks. This trend was accelerated by the use of higher frequency bands such as the Ku- and Ka band.

In 1957 Russia became the first space power with the first satellite Sputnik 01 (also called PS1). Its two radio transmitters send signals during 21 days. It enabled propagation and ionospherical studies. In 1962, the American telecommunications giant AT&T launched the world's first true communications satellite, called Telstar. Since then, countless communications satellites have been placed into earth orbit, and the technology being applied to them is forever growing in sophistication.

Launch date:	4 Oct 1957
Perigee/Apogee:	227/945 km
Inclination:	65°
Period:	96.1 min
Dimension:	58 cm diameter
Mass at launch:	83.6 kg
Frequencies:	20.005 & 40.002 MHz
Decay (End of life):	3 Jan 1958



First Satellite, Sputnik



1.2. What is a satellite

In general a satellite is something that orbits, or goes around a larger something. Some satellites are natural, like the moon, which is a natural satellite of the earth. Other satellites are made by scientists and technologists and go around the earth and do certain jobs.

For our specific situation, the *communications satellite* is a highly complex electronic device that typically requires two years and millions of dollars to build. Today's satellites vary enormously in size. There are some huge monsters out there and even the LEO (low earth orbit) satellites are about as big as a small family car. Smaller, very specialized, satellites do exist but most of the hundreds that now circle the earth are sizeable and hefty chunks of metal. Since 1993 satellites have been classified by weight.

Size	Weight [kg]
Picosat	Less than 1
Nanosat	1 – 10
Microsat	10 – 100
Smallsat	100 – 1000
Standardsat	More than 1000

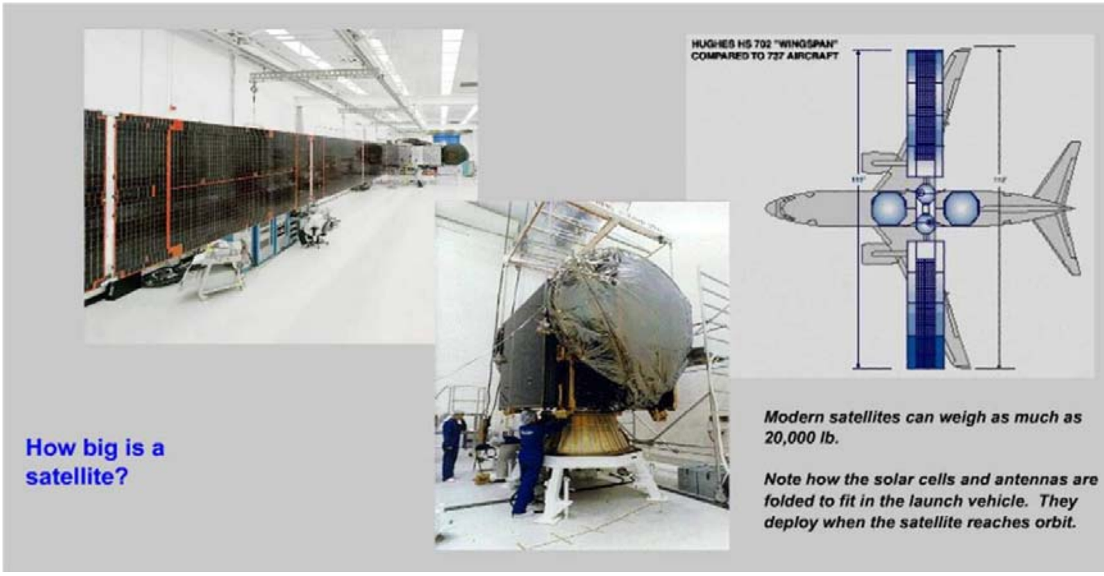
The primary role of a satellite is to reflect electronic signals. In the case of a telecom satellite, the primary task is to receive signals from a ground station and send them down to another ground station located a considerable distance away from the first.



Modern Satellites

Different kinds of satellites are used in different situations, for different purposes but they all have a great deal of equipment packed inside them. No matter what type of structure is chosen for, the structure must provide adequate protection to all on-board equipment at any time. We know to main types of communication satellites, which come in different sizes:

- Spin-stabilized satellite - A spin-stabilized satellite is often called a "tin can" because of its cylindrical shape. The satellite is divided into halves, allowing one half to spin while the other half remains "looking" at earth. The spinning portion contains the solar panels, while the lower half contains the communications payload. Because of their relative simplicity, spin-stabilized spacecraft are less expensive and faster to produce than larger, dual-payload satellites and are also easier to control from the ground. Spin-stabilized satellites rotate around its axis at 60 to 70 revolutions per minute to provide the gyroscopic effect.
- Three-axis or body-stabilized satellite - More modern and more favorite are the three-axis or body-stabilized satellites. This type of spacecraft does not spin but instead appears to be continuously pointed at the same spot on earth. Typically larger than the spin-stabilized satellite, the body-stabilized satellite is box-like in appearance upon launch. When the satellite reaches its final orbital location in space, the spacecraft's solar panels are unfurled to a "wing span" of more than 80 feet. The solar panels are designed to support greater power, thereby permitting dual payloads and more transmission power to the ground. Three-axis-stabilized satellites use internal gyroscopes rotating at 4,000 to 6000 revolutions per minute. Today most of the modern satellites use 3-axis stabilization.



Satellite under construction at Space Systems/Loral

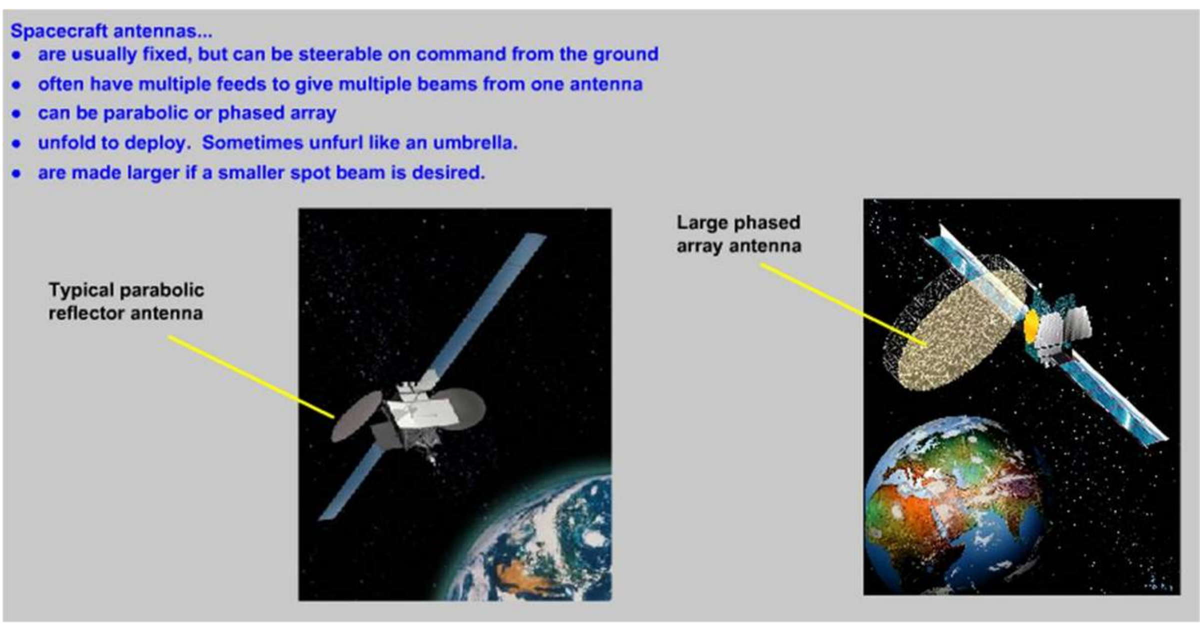
1.3. Major satellite components

Once a satellite has been placed in orbit, it is not practical to carry out direct, on-site maintenance and repair. In order to obtain the maximum operational lifetime from a satellite (about 10-15 years), one must pay great attention to its design and testing. Another major problem in satellite design is staying within the overall mass capability of the launch vehicle. Keeping the mass of the structure to a minimum is very important.

The two most important components of the spacecraft are the service module with all its electronics and mechanics to keep the satellite on going, and the communications or *mission payload*, which carries out the mission requirements, *e.g.*, the communications transponders. As an example Loral Skynet's Telstar-11 mission payload has a mass of 375 kg, and its dimensions are 1.7 x 1.6 x 2.1 meters.

The service module includes:

- The Propulsion Subsystem - The propulsion subsystem includes the rocket motor that brings the spacecraft to its permanent position, as well as small thrusters (motors) that help to keep the satellite in its assigned place in orbit. Satellites drift out of position because of solar wind or gravitational or magnetic forces. When that happens, the thrusters are fired to move the satellite back into the right position in its orbit. Satellites weigh more at the beginning of life in orbit than at the end. This is because they carry rocket fuel for the thruster engines that will keep them in place in their orbits. As the fuel is used up, the satellite gets lighter.
- Antennas - The antennas of a communications satellite are often a limiting element in the complete system. In an ideal spacecraft, there would be one antenna beam for each earth station, completely isolated from all other beams, for transmit and receive. However such a situation is not realistic. Antennas on the spacecraft are usually highly complex. In many larger satellites, the antennas use offset parabolic reflectors with clusters of feeds to provide carefully controlled beam shapes.



- The Power Subsystem (Energy Source and Storage) - To carry out all its functions the satellite requires electrical energy. Early satellites carried primary batteries, which had a very limited life and couldn't be recharged. On most current satellites energy is generated by silicon solar cells. One of the main drawbacks with the solar cell energy sources is that energy is generated only when the sun illuminates the cells. When the Earth is between the satellite and the sun (this is called eclipse) no energy can be generated. In order to allow the mission payload to operate under all conditions some form of energy storage (re-chargeable batteries) must be included in the service module. Satellite solar panel and battery limitations mean that transponder output power is limited. The total power source for a communications satellite is typically in the range of 1.2 to 5 kW. This power has to be shared among all the transponders and the control circuitry.

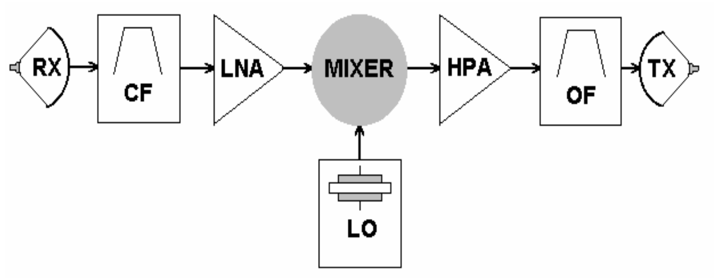
- **Attitude Control** - To do their jobs, the satellite antennas must point always toward the earth. With the very low gain antennas that were used in the early days, stabilizing the orientation of one axis of the satellite with respect to the earth was sufficient. However, satellites using highly directional antennas require more sophisticated techniques. The attitude control subsystem points the spacecraft precisely to maintain the communications "footprints" in the correct location. When the satellite gets out of position, the attitude control system tells the propulsion system to fire a thruster that will move the satellite back where it belongs.
- **Thermal Control** - During each orbit the satellite is subjected to extremes of temperature by the presence or absence of the sun's illumination. Also heat is generated by the electrical components on board the satellite. In order to ensure correct operation, temperatures must be maintained within acceptable limits. The thermal control subsystem keeps the active parts of the satellite cool enough to work properly.
- **Tracking, Telemetry and Telecommand (TT&C)** - In order to ensure that each part of the satellite is functioning as required, one must be able to monitor certain parameters within the satellite. Monitoring is achieved by means of a telemetry sub-system in which the appropriate data is transmitted to earth on the telemetry link. The telemetry and command system provides a way for people at the ground stations to communicate with the satellite and to check its health.

The typical satellite launch from a launch vehicle is a very costly and complex operation. Generally 72 hours are needed from the time of launch vehicle ignition to the deployment of the solar arrays for the spacecraft to get on station or in its assigned orbital slot. Once the satellite is in position, it will provide service typically for 10 to 15 years.

Launch of a Satellite from Sea Launch

1.4. Satellite transponders and satellite capacity

Probably the most important part of a telecom satellite is the transponder. The word “transponder” is compounded from *trans*(mitter) and (res)*ponder.* This piece of electronic equipment inside the satellite acts like a microwave repeater, which receives, amplifies, and re-transmits the incoming signals back to earth into its footprint. A single satellite can have a large number of transponders. Each transponder supports a small portion of the total operational frequency bandwidth (also named space segment) of the satellite. Common transponder bandwidths are 36 MHz and 54 MHz.



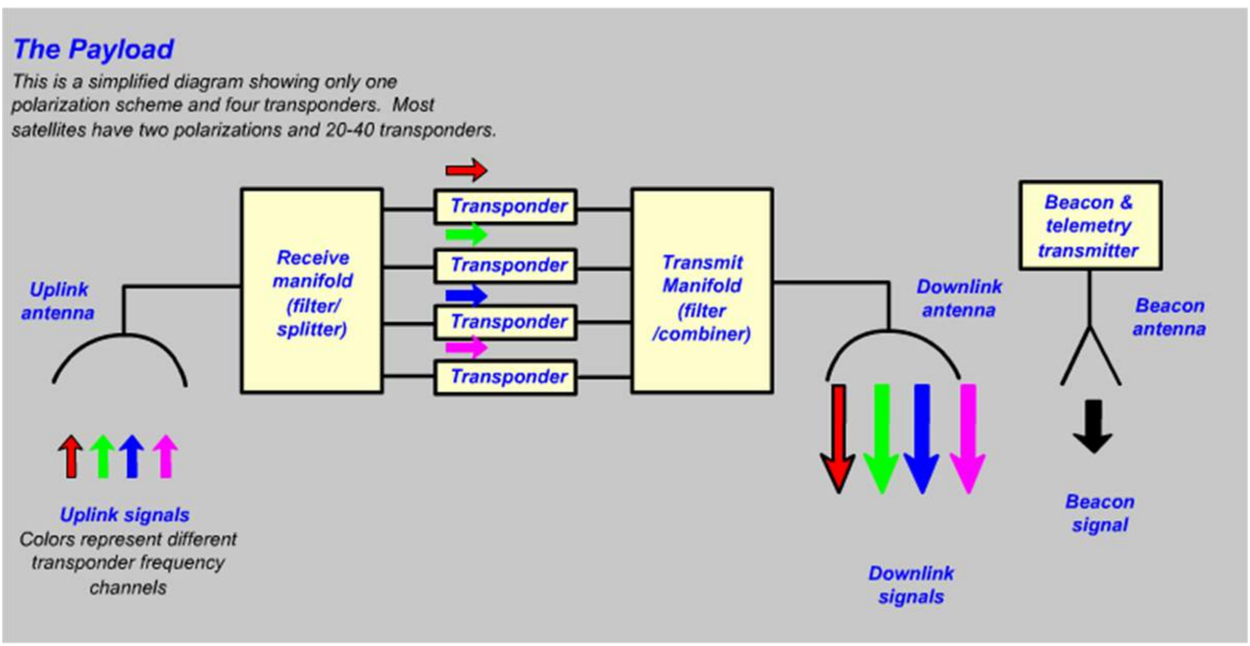
RX:	Receive antenna for the 14 GHz earth uplink station
CF:	Channel or Input Filter
LNA:	Low Noise Amplifier
HPA:	High Power Amplifier
OF:	Output Filter
LO:	Local Oscillator
Mixer:	Device for transforming the uplink station
TX:	TX antenna for the 12 GHz down link

Simplified schematic diagram of a transponder

Space segment on a communication satellite is very expensive (charges are often per kHz per month) and should be planned very carefully. Reusing frequencies can easily enhance satellite capacity. Two techniques are currently available to meet this goal:

1. Space diversity via regional or spot beams
2. Polarization diversity like linear or circular

Another very important bandwidth saver is the transformation from analog signals into digital signals. By choosing the right modulation scheme (e.g. QPSK or 8PSK) and Forward Error Encoding (FEC) an even better efficiency can be obtained.



1.4.1. Total bandwidth available for one transponder

For satellites in geostationary orbit, there are two frequency bands in the Fixed Satellite Service. The standard transponder bandwidth at C band is 36 MHz. This bandwidth became a standard as it is sufficient to accommodate one FM video channel. At Ku band, 27 MHz and 54 MHz are typical bandwidths. The total satellite bandwidth is 500 MHz in each direction (uplink/downlink) in each band. With two linear polarizations, this bandwidth is sufficient for twenty-four 36 MHz transponders at C band and typically twenty-four 27 MHz and four 54 MHz transponders at Ku band. In the Direct Broadcast Service (17/12 GHz), the bandwidth of each transponder is 24 MHz. There are 16 transponders in each of two circular polarizations (32 transponders per orbital slot). For proposed broadband satellites at Ka band (30/20 GHz), the typical satellite bandwidth is also 500 MHz.

This spectrum is typically divided into frequency reuse cells. For example, the Astrolink system (now defunct) would have divided the spectrum into four cells per cluster, each cell with 125 MHz and consisting of a one degree beam.

There are no typical transponder bandwidths for non-geostationary orbit, although the total bandwidths are much smaller than in GEO. An Iridium satellite occupies 5.15 MHz of spectrum using FDMA/TDMA while a Globalstar satellite occupies about 10 MHz of spectrum using channelized CDMA. These systems provide telephone service via satellite. Although both companies went bankrupt, both systems are still operating under reorganization (Sep 2002).

In order to make more efficient use of transmission capacity, digital broadcast signals are reduced in size by digital compression. This has a minimum effect on the received signal quality but allows several compressed TV channels to be transmitted in the space required for one analogue channel.

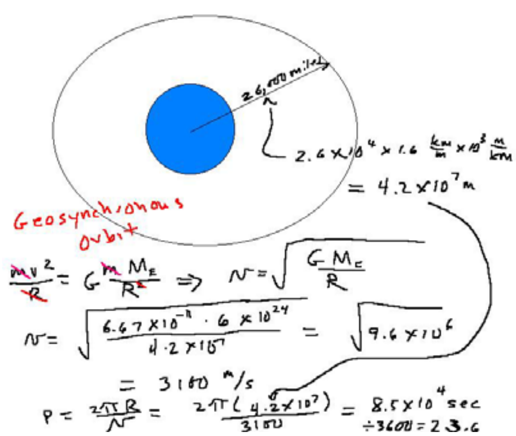
1.5. Orbits

1.5.1. Comparison between LEO, MEO and GEO

	Low Earth Orbit (LEO)	Medium Earth Orbit (MEO)	Geostationary Earth Orbit (GEO)
Altitude (km):	700 to 1400	10,000 to 15,000	36,000
Satellites Needed For Global Coverage:	40 +	10 to 15	3 to 4 (1)
Link Characteristics			
One-way Transmission Delay:	0.05 s	0.10 s	0.25 s
Elevation Angle:	Low	Medium to High	Low to Medium
Operations:	Complex	Medium	Simple
Building Penetration:	Poor	Poor	None
Satellite Characteristics			
Space Segment Cost:	High	Low	Medium
Satellite Lifetime (years):	3 to 7	10 to 15	10 to 15
Telephony Network Characteristics			
Terrestrial Gateway Costs:	High	Medium	Low
Hand Held Terminal Possible:	Yes	Yes	Yes
Hand Held Terminal Costs:	Low	Low	Low
Mobile Terminal Costs:			Medium
Fixed Terminal Costs:	Low	Low	Low to Medium
Data and TV Network Characteristics			
Store and Forward Possible:	Yes	Not Required	Not Required
Point to Point Connections Possible:	No	No	Yes
VSATs Possible:	Yes (2)	Yes (2)	Yes (3)
Broadcast TV Possible:	No	No	Yes

Notes:
(1) Coverage only extends to latitudes of 70° N and 70° S.
(2) Via a regional gateway.
(3) Private and shared hubs possible

Geosynchronous systems have several advantages in terms of long satellite life and wide area coverage by a small number of satellites. They have the disadvantages of round trip latencies that exceed a half a second, poor coverage and inadequate elevation angles (to avoid building radio shadows in urban areas) at the high latitudes. These weaknesses are addressed by the low earth orbit (LEO) systems allowing to provide reduced delays and better coverage and elevation angles. However, LEOs require substantially greater numbers of satellites to provide adequate coverage, and these will need more frequent replacement.

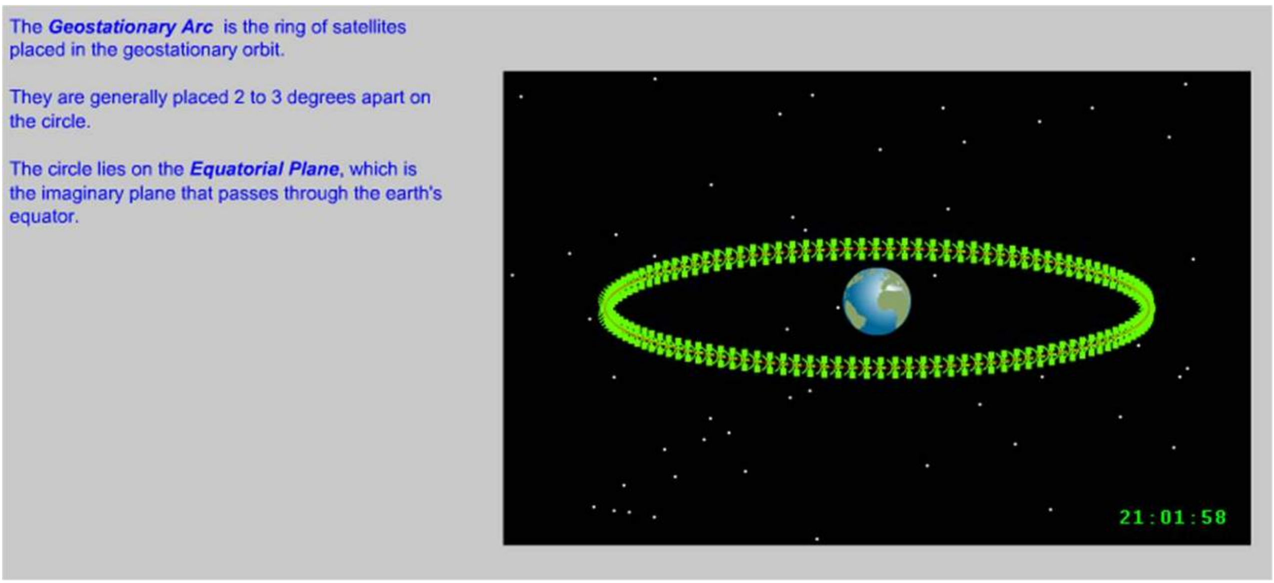


1.5.2. Geostationary orbit

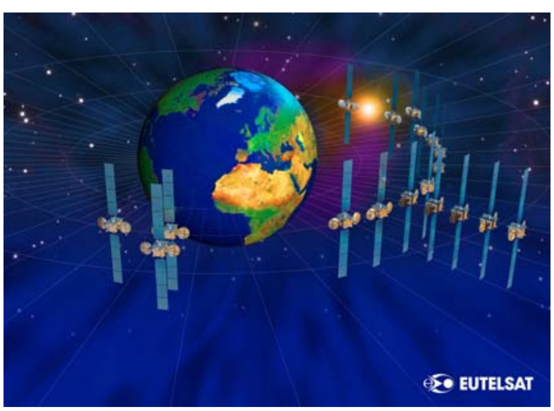
Communication satellites are usually brought into geostationary orbit or Clark Belt, which is located 22.247 miles or 35800 km above the equator. At this altitude, a satellite has an orbital velocity equal to the earth's rotational speed (one revolution per 24 hours), causing the satellite to appear stationary or motionless above the earth. That's why ground antennas can be aimed easily and stay pointed toward the right place. The place of a satellite on the Clarke Belt is referred to as position or slot.

The satellite's position is expressed in degrees and indicates a point east or west of the prime meridian. As an example Astra-1A is located in the 19.2° East slot. So satellites have unique, fixed positions.

> The position of GEO satellites is given in degrees of longitude. *Longitude* indicates a point east or west of the prime meridian. Position of an earth station is given in longitude and latitude. *Latitude* indicates a point north or south of the equator.



Sometimes a group or cluster of satellites is positioned at the same orbital location. When seen from earth it looks as if these satellites are at the same point in the sky, so is said that these satellites are co-located. A good example is the six ASTRA satellites, which are co-located at 19.2° East. In addition, the Eutelsat Hotbird constellation is co-located at 13° east. The main advantage of co-location is that these satellites can be received with only one single dish. Co-location of satellites is only possible if the satellites do not interfere with each other. This implies that the different satellites must operate at different frequency bands.



Eutelsat's satellite constellation including Hotbird 1-5, co-located at 13° East.

With more than 2000 commercial and non-commercial satellites up there in geosynchronous orbit, how do we keep them from running into each other or from attempting to use the same location in space? To tackle that problem, international regulatory bodies like the International Telecommunications Union (ITU) and national government organizations like the Federal Communications Commission (FCC) designate the locations on the (geosynchronous) orbit where (communications) satellites can be located. In response to the huge demand for orbital slots, the FCC and ITU have progressively reduced the required spacing down to only 2 degrees for C band and Ku band satellites.

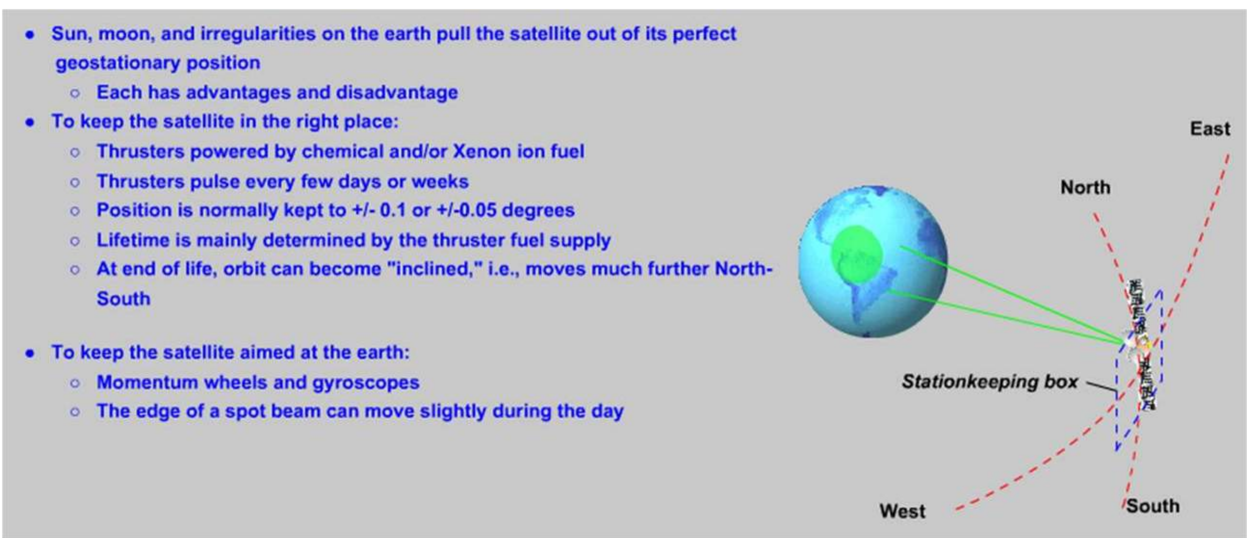
http://www.lyngsat.com provides up-to-date information on communication satellites concerning the availability of channels, transponders, beam configurations, location of satellites, and much, much more.

1.5.3. Station keeping

Station keeping is the maintenance of a satellite in its assigned orbital slot and in its proper orientation. Every satellite's orbit will change with time due to atmospheric drag-- or the pull of gravity--on the spacecraft. Frequent adjustment of the satellite is necessary to keep its solar panels facing the Sun and to align the satellite with its target region. Consequently, all satellites carry scientific and engineering sensors to measure changes in the satellite and its surroundings. Horizon seekers, star trackers, and Sun seekers, are examples of sensors used to help determine the satellite's position. Other instruments detect changes in the power supply, the temperature, and the pressure of the satellite.

All satellites drifts east/west and north/south in a 24 hour cyclus. Most satellites drifts within a box of +/-0.05 degrees. Some within as little as +/-0.01 degrees.

The physical mechanism for station keeping is the controlled ejection of hydrazine gas from thruster nozzles which protrude from the satellite housing. For this reason, the service life of a satellite ends when its hydrazine supply is exhausted--typically in about ten to fifteen years.



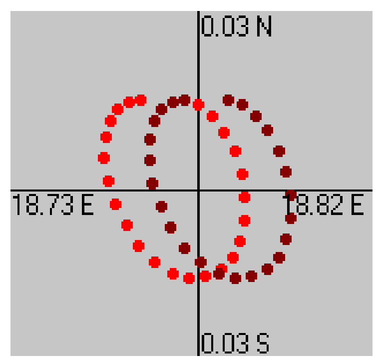
1.5.4. Inclined orbit

The Sun, the Moon, and the Earth's gravitational field all affect the movement of satellites orbiting the Earth. These natural effects impel telecommunications satellites to wander from their assigned orbital positions over the Earth's equator. The amount of movement can be predicted over 24-hour intervals using some complicated mathematical equations. All geo-stationary satellites are launched with enough station-keeping fuel to counteract the effects of these natural forces for a period of several years, and in the case of the very newest satellites, for up to fourteen years. It is the precise expenditure of fuel at periodic intervals over the lifetime of each spacecraft which permits each satellite to remain continuously on station at its assigned geo-stationary orbital position.

The controlling engineers typically cease expending station-keeping fuel once the satellites have expended most of their remaining fuel. Once the north/south station-keeping maneuvers have ceased, the natural forces described above will cause the spacecraft to begin drifting in the north/south direction. This is called an inclined orbit.

During the first few months of inclined orbit operations, the amount of drift in the north/south direction is minimal and is transparent to all but the largest receiving antennas on Earth. Eventually, however, the amount of drift will grow and the satellite's signal will fall outside of each receiving antenna's main beam for portions of each 24-hour orbital inclination period. The amount of inclination will increase at a rate of approximately ±0.85 degrees per year, and as time goes on, the length of the diurnal (twice daily) outages at all receiving stations also will increase.

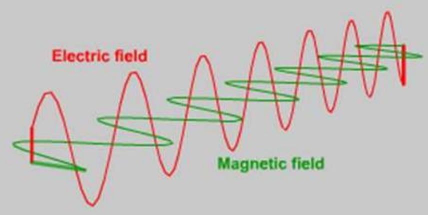
The only way for an earth station system to maintain continuous contact with an inclined orbit satellite is to have a motorized mount and an automatic tracking system to permit periodic adjustments to the antenna's direction setting.



Restrained usage of station-keeping fuel (which results in inclined-orbit operation) adds about 3 years to a satellite's lifetime. During this extended time, the satellite's function in relaying of electromagnetic signals is in a completely normal mode and equals in quality to a brand new satellite. The reason is that the high-power amplifiers and the solar cells which supply their power have a lifetime much longer than the station-keeping fuel. Extension of a satellite's lifetime allows the satellite operator to offer space segment lease prices reduced by about 75%. The end user, however, must make a one-time investment in adding tracking facilities to his earth station. This extra investment is usually paid for by the saving in the first couple of months in space capacity lease charges.

1.6. The electro-magnetic spectrum

- **Electromagnetic waves...**
  - are made of oscillating electric and magnetic fields
  - travel through air and the vacuum of space
  - bounce off metals
  - travel at the speed of light: 300,000 km/sec or 186,000 miles/sec



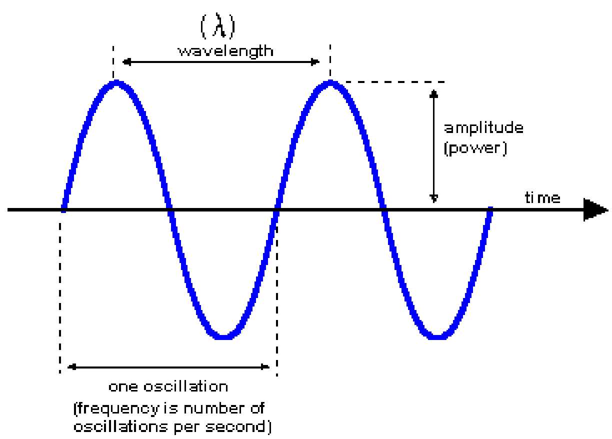
- **These are all electromagnetic waves:**
  - Radio signals
  - Microwaves
  - Infra-red
  - Light
  - X-rays
  - TV signals
- **The only difference is their *wavelength***

1.6.1. Amplitude and frequency review

Waves are defined by their:

1. Frequency: Frequency is the number of oscillations (vibrations) in one second. Frequency is expressed in Hertz [Hz], the name of a German physicist Heinrich Hertz, who lived a century ago. One Hz is one wave (or cycle) per second. For example, the alternating current in a wall outlet in the U.S. and Canada is 60Hz and in Europe 50 Hz. Higher frequencies are measured in kHz (1 kilohertz = 1000 Hz), higher frequencies in MHz (1MegaHertz = 1000 kHz) and even higher frequencies in GHz (1 Gigahertz = 1000 MHz). Therefore, a GHz is 1,000,000,000 Hz (one billion).
2. Amplitude: Amplitude is the strength of the wave at its peak. It's defined by unites such as Volts, Watts and dBW

Related to frequency is wavelength. It is the distance between the peaks. It's expressed in units such as mm or inch. The wavelength determines the nature of the various forms of radiant energy that comprise the electromagnetic spectrum. For electromagnetic waves, the wavelength in meters is computed by the speed of light divided by frequency (300,000,000/Hz). For sound waves, the wavelength is determined by 335/Hz.

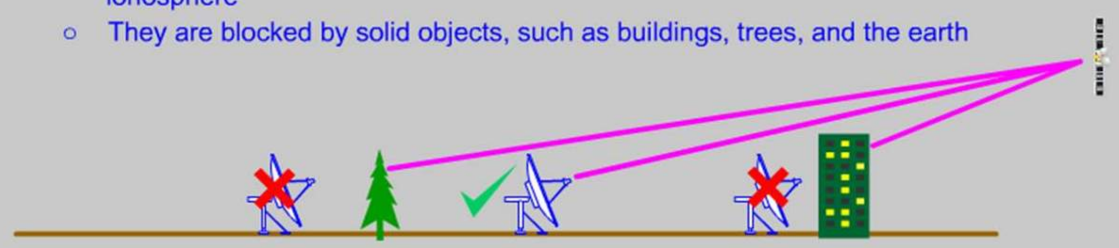


Each sub-set or band of frequencies within the electromagnetic spectrum has unique properties that are the result of changes in wavelength. For example:

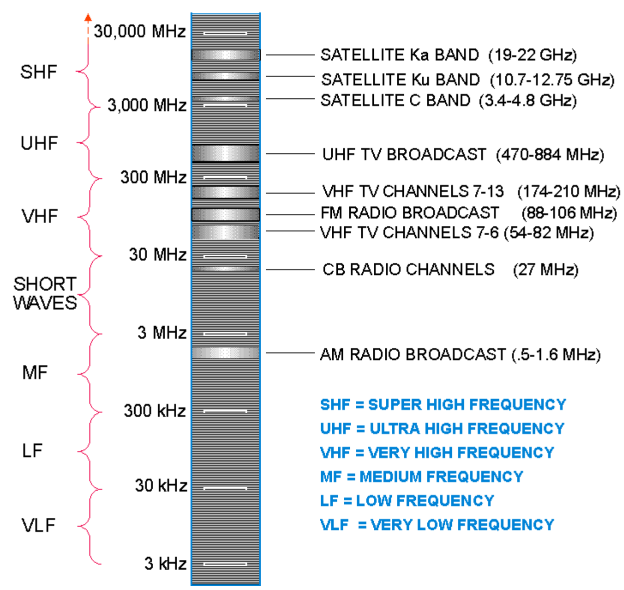
- **Medium Wave** signals (500 kHz to about 3 MHz) radiate along the Earth's surface over hundreds of miles, perfect for relaying AM radio stations throughout a region.
- International radio stations use the **Short Wave** bands (3 to 30 MHz) to span distances of thousands of miles; the ionosphere, upper layers of the Earth's atmosphere that are electrically charged by the sun, reflects these short waves back down to Earth, much as a mirror or any other shiny metal object can reflect beams of light.
- TV and FM radio broadcasters use the **Very High Frequency** (VHF) and **Ultra High Frequency** (UHF) bands located from 30 to 300 MHz and 300 to 900 MHz because these signals only cover short distances; they cannot travel very far along the Earth's surface or skip off the ionosphere. The advantage to using these frequency bands for local communications is that dozens of TV and FM radio stations can use identical frequencies within any one country or region without causing interference
- Satellite transmissions use the space in the **Super High Frequency** (SHF) bands located between 2.5 and 22 GHz. At these frequencies, the wavelength of each cycle is so short that the signals are called microwaves. These microwaves have many characteristics of visible light: they travel directly along the line of sight from any satellite to its primary coverage area and are not impeded by the Earth's ionosphere.

Blockage

- The frequencies used for satellite communications are in the range called ***microwaves***
  - Frequencies are between 3 GHz and 30 GHz.
  - Wavelengths vary from 100 mm down to 10 mm (very short!).
- Microwaves have many of the characteristics of visible light:
  - They travel in a straight line (the ***line of sight***)
  - They pass through transparent things, e.g., the earth's atmosphere and ionosphere
  - They are blocked by solid objects, such as buildings, trees, and the earth



THE ELECTRO-MAGNETIC SPECTRUM



1.6.2. Satellite transmission delay (latency)

To transmit and receive a signal entails a delay of approximately half a second while the electromagnetic wave travels to and from the satellite. Most industry experts concur that the delay does not affect the accuracy of satellite data transmissions, nor does it hinder users of most services. Although engineers have developed new technologies that alleviate satellite delay, some problems still exist. The most irritating aspect of the delay is during voice or two-way video conferencing communications, where it becomes apparent to the user. The geostationary satellite system one-way transmission delay [ms] is given in the table on the next page:

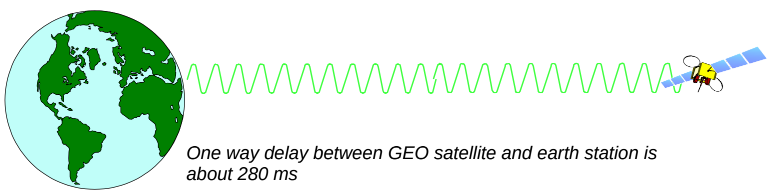
	One-way transmission delay [ms]		
	Minimum	Maximum*	Mean
Between earth stations:	240	280	260
Terrestrial extensions:	10	50	30
Total:	250	330	290

* Maximum delay is based on 5º elevation angle

IMPORTANT! Round-trip delay, is double of what is shown above

Other delay considerations that should be accounted for may include:

- Front end multiplexers and/or switches
- Transmission equipment (error coding, overhead processing, scramblers, Doppler buffers)
- Host/server (application processing)



One way delay between GEO satellite and earth station is about 280 ms

TCP/IP and delay: The delay becomes a more important factor in satellite-delivered Internet services because of the effect of Internet transmission protocols. Notably, the Transmission Control Protocol (TCP) requires each data packet to be acknowledged as received intact before sending further packets. While designed to operate efficiently in terrestrial networks with delays of typically less than 100 milliseconds, TCP does not perform as well over satellites where the round trip delay is about 500 milliseconds. This limitation of TCP can be overcome in a number of ways by using techniques such as acknowledgments compression and protocol emulation to reduce the amount of acknowledgment traffic. Other techniques simply replace TCP with a more efficient protocol for use with the unique characteristics of satellite networks. In reality, many users will not even notice the satellite delay and the impact of TCP/IP.

- **Voice**
  - Most people consider the 0.25 second delay tolerable but not ideal.
  - Modern echo cancelers help reduce the perceived delay.
- **Data - TCP/IP**
  - TCP is used form most Web communications
  - TCP is an end-to-end protocol and requires confirmation of IP packet delivery
  - TCP does not understand delay: it assumes that all delay is caused by congestion in the network, so it **slows down (!!!)** to prevent the Internet from collapsing
  - This effect limits the throughput speed of a simple TCP connection over satellite to 64-256 kbps
  - The problem can be solved in two ways:
    1. Adjusting the settings of the PC and server at each end
    2. Accelerators and proxies (hardware or software that intercepts the TCP packets and "spoof" the end computers)

1.7. Satellite uplink and downlink transmission frequencies

Transmission from the earth station to the satellite is called uplink, and the system from the satellite to the earth station is called downlink. To avoid mutual interferences, the uplink and downlink frequencies are separated. The downlink frequency is usually lower than the uplink frequency as it suffers smaller propagation losses from the satellite to earth, thus requiring less of the satellites limited power resource.

For satellite communications important and often-used frequency ranges are listed in the table below:

Name	Receive Range
L band	1 - 2 GHz
S band	2 - 4 GHz
C band	4 - 6 GHz
X band	8 - 12 GHz
Ku band	10.7-18 GHz
Ka band	18 - 40 GHz

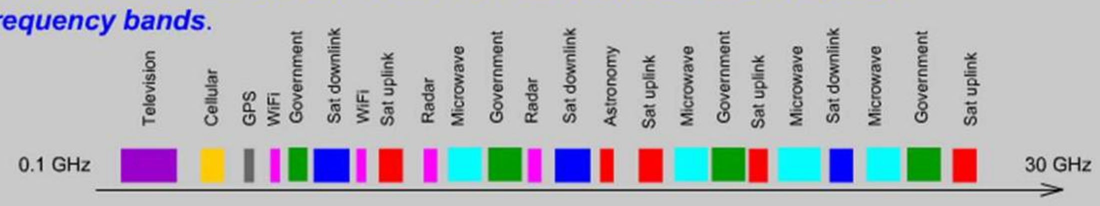
Frequencies available for satellite communications are allocated on an international basis by the ITU (International Telecom Union). The ITU is an international organization within which governments and the private sector co-ordinate global telecom networks and services. Through the ITU nations cooperate in the use and management of telecom resources and also adopt policies to minimize interference, to provide common standards and to promote the development of efficient technical facilities. More information about the ITU and its publications on http://www.itu.org

The frequencies allocated to commercial satellite communications are mainly in the so-called C band, Ku band, and Ka band. The geostationary orbit using C band is almost fully populated. The Ku band is rapidly filling. This is forcing communication satellite services to the higher frequencies. The Ka band should start to fill in the next 10 years. Parallel to the development of Ka band satellite systems that will provide high data rate, interactive multimedia services to consumers with small antennas, Ku band is becoming available in more and more areas of the world, including Asia, South America and the Middle East.

Frequency Band	Uplink Frequency* [GHz]	Downlink Frequency* [GHz]
C band	5.925 – 6.425	3.700 – 4.200
Ku band	13.75 – 14.50 / 17.30 – 17.80	10.70 – 12.75
Ka band	29.50 – 30.00	19.70 – 20.20

- C band: C band is the first band used by commercial satellite systems. A disadvantage is, that its available bandwidth of 500 MHz is simultaneously used by satellite and terrestrial microwave users what may result in serious interference problems. C band technology is well proven and propagation affects such as rain and depolarization do not significantly affect signal transmission.
- Ku band: The Ku band is not shared by terrestrial microwave systems. This significantly reduces the need for frequency co-ordination and terrestrial interference analyses. However Ku band transmissions incur signal strength reduction, depolarization and distortion due to rain (At the Ku band wavelength an average raindrop is a perfect 1/4 wave attenuator).
- Ka band: The Ka band has an available bandwidth of 2500 MHz. Higher-powered satellites will use this band for low cost 2-way communications. Due to their small antenna sizes (compared to C band and Ku band), Ka band terminals can be compact, even portable and easier to install in built-up metropolitan areas. As a disadvantage Ka band signals are more difficult to handle and they are much more susceptible to moisture in the atmosphere - whether it is clouds, snow or rain. Particularly in tropical regions this could be, like for Ku band a problem.

- The frequency spectrum is divided up into sections called ***bands***.
  - Bands are allocated by the International Telecommunications Union (ITU)
  - Individual governments agree to them by treaty
  - In the U.S., the government agency that enforces them is the FCC
- Why do we need bands? ***To prevent interference***.
  - Uplink signals are much to strong to separate from downlink signals in a satellite antenna if they were on the same frequency. Solution: put ***satellite uplinks*** and ***satellite downlinks*** in ***separate frequency bands***.
  - Local land-based microwave, TV, and cellular transmitters are very strong compared to satellite signals. Solution: put ***different services*** in ***separate frequency bands***.



1.7.1. Why uplink and downlink frequencies are different

The uplink and downlink frequencies are different to avoid interference between the two signals on the satellite and at the earth station. To further isolate the signals, one polarization is usually used for the uplink and the other for the downlink. (The principal reason for polarization, however, is for frequency reuse, so that two channels can use the same frequency band.) The uplink frequency is higher because it reduces the complexity of the satellite by:

1. Permitting a smaller receive antenna and
2. Reducing the size of the traveling wave tubes in the power amplifiers.

The gain of the antenna is proportional to the square of the frequency, so by using the higher frequency the receive antenna can be smaller. Also, the TWTA size is proportional to the wavelength, which decreases as the frequency increases.

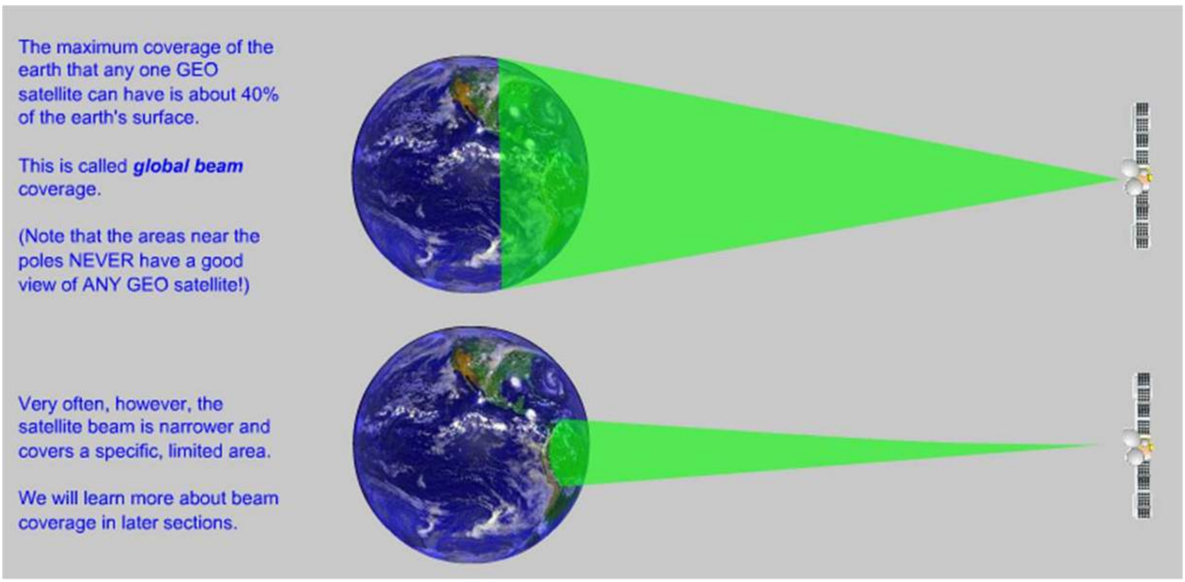
Thus the practice has been to use the higher frequency for the uplink and the lower frequency for the downlink, for example, 6/4 GHz at C band or 14/12 GHz at Ku band, and "put the burden on the ground." It is easier to increase the size and power of the earth station antenna.

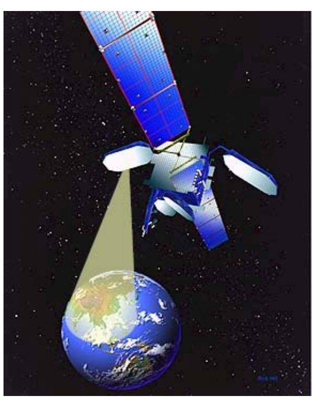
However, spectrum is now becoming scarce. Therefore, more sophisticated methods of modulation and coding are being developed that better utilize the existing spectrum. In addition, the concept of using "reverse band" frequencies for the uplink and downlink is being considered. Thus at some time in the future, it is likely that, in addition to the current frequency plan, the lower frequency will be used for the uplink and the higher frequency for the downlink for satellites that can be placed in between the existing satellites, that is, with one degree spacing, thereby doubling the available geostationary slots and the corresponding spectrum capacity. This technique will become practical because satellites are now very powerful and some of the more conservative approaches of the past are no longer necessary.

1.8. Footprints

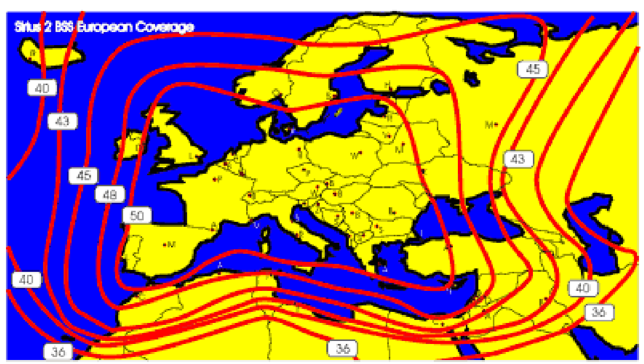
The footprint is the geographic area towards which a satellite downlink antenna directs its signal or conversely the area from which the satellite is visible from the surface of the earth. Satellites that do not support maritime activities have most of their downlink power focused on population centers. The measure of signal strength of this footprint is the Effective Isotropic Radiated Power (EIRP). This the product of the power supplied to the antenna and the antenna gain, in a given direction. EIRP is expressed in dBW.

It is important to note that there is an inverse relationship between EIRP and antenna diameter. The higher the EIRP the smaller the required dish (under the condition that the bandwidth and encoding of the modulated signal remains the same).





Footprint as seen from the satellite



Eirp (dBW):	Ant. diam. (m):
51	0,60
50	0,67
49	0,75
48	0,85
47	0,95
46	1,07
45	1,20
44	1,34
43	1,50
42	1,69
41	1,90
40	2,13
39	2,39
38	2,68
37	3,00
36	3,38

Example of a satellite footprint (Sirius 2, 4.8° East)

A station which is located near the center of the footprint will have an advantage in the received signal compared to another located at the edge of the same beam of the satellite. The satellite antenna pattern has a defined beam edge to which the values of the satellite EIRP are referenced, therefore a footprint as shown in the figure above has lines of contours representing a 1 dB incremental toward the beam center. Footprints and EIRP details of every satellite and its transponders can usually be found on the satellite operator's website or http://www.lyngsat.com

2. What can we do with communication satellites

Satellite systems hold forth the promise of true "anywhere, anytime" access to communications, even in the most rural and remote areas of the globe. Most satellites are known for their video transmissions and many of these transmissions can be received with simple, readily obtainable equipment. On a global basis, the principal application supported by satellites is indeed video transmission, including TV broadcasts to cable networks, to re-transmitters or to individual homes and the transmission of backhaul video feeds between studios and camera crews in the field.

This relay action can be two-way, as in the case of a long distance phone call. Another use of the satellite is when, as is the case with television broadcasts, the ground station's uplink is then down linked over a wide region, so that it may be received by many different customers possessing compatible equipment. Still another use for satellites is observation, wherein the satellite is equipped with cameras or various sensors, and it merely downlinks any information it picks up from its vantage point.

However, satellites also carry large amounts of non-video products that range from telephony to high-speed data systems. Observation of the sun and the earth, navigation, and meteorology are just a few examples. The relaying of medium- and long-distance telephony is common sense over satellite, and a number of world-wide satellite telephone systems have been proposed, and several are already in operation.

The share of data communications is also continuing to increase as Internet access generates more traffic. As a result satellite links are being increasingly used for Internet traffic. With the introduction of digital technology and the explosive growth of the Internet, the need for broadband data delivery system to bring web pages, e-mail, data, audio and video to users is increasing dramatically. Users -- both consumer and corporate -- want more information to be brought to their computers quickly, cost-effectively, accurately and securely.

Broadband is a term often used to describe a high-capacity network that can carry several data services over a single communications medium, such as data, voice, and video. There is no real consensus about a uniform definition and the meaning of the concept is continually changing.

2.1. Analog satellite TV

Analog satellite TV is not much different from analog terrestrial TV except of the fact that analog transmissions are FM (Frequency Modulation) and terrestrial transmissions in general still AM (Amplitude Modulation). An analog FM TV satellite transmission usually requires 27 MHz or 36 MHz channel bandwidth while the same channel in terrestrial AM occupies max. 8 MHz.

More about analog TV can be found on the following Internet web pages:

Conventional analog television - An Introduction:	http://www.ee.washington.edu/conselec/CE/kuhn/ntsc/95x4.htm
TV broadcasting systems:	http://www.ee.surrey.ac.uk/Contrib/WorldTV/broadcast.html
TV frequencies of the world:	http://personal.bna.bellsouth.net/bna/w/9/w9wi/articles/system.htm
Worldwide TV standards:	http://www.ee.surrey.ac.uk/Contrib/WorldTV/
Why do different TV standards exist?	http://www.ee.surrey.ac.uk/Contrib/WorldTV/why.html
HDTV - High Definition TV:	http://www.ee.washington.edu/conselec/CE/kuhn/hdtv/95x5.htm

2.2. Digital satellite TV

Across the globe, the satellite industry continues to dominate the emerging digital television market. The most immediate benefit of digital compression is that it allows many channels to be transmitted in the bandwidth required for one analogue channel. Between about five and 10 television channels and many more audio channels can be compressed and multiplexed onto one transponder.

Besides this is a significant cost saver on satellite space segment, it really is a quantum leap in the number of channels available and therefore greater variety, choice and convenience for the viewer/ user. Digital technology also supports encryption and conditional access keys for truly anti-piracy protection.

Digital broadcasting provides significantly enhanced technical features for the consumer including:

- More channels and better images
- Mobile reception
- Crystal clear reception
- Smaller dishes

The digitization of TV signals has been used for some years for studio applications (serial digital signal distribution) at a total bit ratio of 270 Mbps (= 135 MHz transmission bandwidth using simple Pulse Code Modulation technique). To use digitized TV signals for broadcast applications, a way had to be found to significantly reduce the total amount of data to be transmitted over the 36 MHz or 54 MHz wide satellite transponders. This was found in data compression. In almost all cases the signals received from the satellite are compressed using the DVB or MPEG-2 standard.

2.3. Internet over satellite

With the explosive growth of the Internet, the need for broadband data delivery system to bring Web pages, e-mail, data, audio and video to users is increasing dramatically. Users -- both consumer and corporate -- want more information to be brought to their computers quickly, cost-effectively, accurately and securely. Current Internet transmission systems include telephone lines, cable, fiber and satellite.

For the most part, satellite companies are developing services centered around one or more of the four types of Internet/ Intranet related products:

- Internet backbone services carrying multiplexed traffic between network access points (the information is then delivered to consumers over the PSTN)
- Private networks for corporate Intranet/ Extranet applications.
- Point-to-multipoint data distribution, or multicasting, to consumers or companies.
- Internet access to consumers using telephone lines for user requests and direct satellite delivery of web page information to a home dish.

Satellite (VSAT) systems are used for providing high capacity links for Internet service and to access providers by supplying high capacity links to supplement or even replace lower capacity telephone lines. The data rate, or speed, at which each of these services is provided, is affected by several factors, including the user's requirements, the amount of satellite capacity available, and the protocols used for each service. In general, satellite services provide 35 to 45 Mbps capability for Internet/ Intranet backbone connectivity (although they can go as high as 155 Mbps, 2 to 3 Mbps for multicasting, and 400 kbps for delivery of Internet information to consumers.

2.4. IP multicast over satellite

A key advantage of multicast is that it can be used to distribute electronic information to a large group of geographically dispersed users from a central point.

With conditional access capabilities such a platform lends itself to a variety of multicast applications such as software upgrades, corporate training, selective file transfer, etc. As an example with bit rates of more than 30 Mbps per transponder, a CD-ROM could be transmitted to a whole continent in less than 3 minutes.

2.5. Media streaming

Streaming is a method of transferring digital media across a network (usually the internet) so that the audio or video is played immediately instead of waiting for the entire file to be downloaded. The data is sent in small packets so that the user can access the content as it is received.

Streaming can be done in real time (live-event ‘webcasting’) or on demand (archived). In many cases, the data packets are not stored on the local machine, although one technique frequently used for on-demand archives is progressive downloading (sometimes referred to as pseudo-streaming), which transfers as much of the media as possible to a local hard-drive buffer before playback can begin. Given the fact that most corporate networks already have high-speed connections, webcasting of corporate events is a natural application of streaming.

3. Advantages of satellite communications

Once in orbit and operational the quality of service provided by satellites is exceptionally high and far more reliable than terrestrial links. A solid satellite transponder can support up to 68 Mbps and is available every minute of the year, except for very brief times during the two equinoxes. There are no concerns about dug up cables, power outages in the terrestrial network, or failures of intermediate repeaters. Because of the usage of concatenated (Reed-Solomon and Viterbi) encoding satellite bit-error ratios equal to or are better than terrestrial networks.

If you want to offer, for example, a pan-European service, the satellite has an advantage. VSAT may even be the best alternative for access to Eastern Europe and Africa, with its developing infrastructure and questionable quality of landlines to Western Europe. If the customer is almost your neighbor, a terrestrial link will probably fit better in the budget than one over satellite but if you regularly exchange bulk information over a leased line between two different countries, A and B, you must buy half of the circuit from PTT A and the other half from PTT B. This solution could be very cost ineffective and less reliable than a link over satellite.

Certain types of satellite systems - especially VSATs - are moving into the cost benefit calculations of organizations wanting to bypass telecom monopolies or the fragmented (European) Telecom market. For example a large volume of graphical data (= large bandwidth) is easier to transport via satellite than a common terrestrial lines. When using 'receive only terminals', an infinite number of sites under the footprint(s) can be connected with one source and it is no problem to transmit 25 Mbps of data in less than thirty seconds to all these sites.

The main distinction between the satellite solution and its terrestrial counterparts is the inherent broadcast capability satellite provides. The large footprints of today's satellites allow multicasting to be provided securely and cost-effectively. Another satellite advantage is the speed at which data can be transferred. By bypassing today's relatively low-speed modems, data can be delivered via satellite at higher speeds than most users can receive over telephone lines (up to 3 Mbps versus 56.6 kbps). Moreover, these data rates will increase as new generations of spacecrafts are launched.

Satellite systems make an excellent choice for communications between widely separated points on the earth. They require no user investment in terrestrial "infrastructure" except at the termination points. This reduced entry cost makes them particularly attractive for applications in (rural) areas with poor or no service at all, especially when the terrain is problematic and projected traffic volumes may not support a terrestrial network.

Satellite transmission is a very frequency spectrum-efficient and environmentally friendly way of broadcasting. One range of frequencies in the BSS (Business Satellite Services) and FSS (Fixed Satellite Services) frequency band and 100 Watts (the energy it takes to power a light bulb) transponders are capable of covering an area as big as Europe. The use of satellite transmission spectrum is so efficient because the same range of frequencies can be used from a satellite located three degrees away from another and cover the same geographic region.

The Satellite Communication Advantage Résumé

- High Reliability
- Costs are independent of distance or number of locations
- Satellite transmissions are frequency spectrum efficient
- Services can be provided directly to users facility
- Wide area of coverage is readily available
- Rapid access to undeveloped areas.
- Wideband capability is greater than immediate needs
- Compatible with new technologies and provides capabilities for new concepts and opportunities
- Customer may choose the network topology it prefers.
- Flexible network configurations as e.g. Point to point, Point to multipoint, Meshed or star topology, Broadcast

4. Disadvantages of satellite communications

Disadvantages of satellite communications are the unfamiliarity with the technology and the fact that spectrum space and power are limited, so the cost per bit per hour can be higher than terrestrial solutions. Earth station prices are declining significantly, but are still more expensive than terrestrial terminal equipment. However, these disadvantages are being intensively addressed in the industry. And more dramatically, the increasing use of sophisticated multiple access techniques allows more users to share the same spectrum space, reducing the cost per minute of a circuit.

An executive for a major operator once remarked: "A general problem we have as service providers is that companies view satellite services as something out of 'Star Wars'. Customers are afraid of the satellite falling out of the sky. They are afraid that they cannot communicate if it rains. They are basically nervous about a communications network 36,000 km in the sky".

4.1. Technical disadvantages

Satellites carry their own risks and are extremely capital intensive. Satellite launch providers and satellite operators work in a high-risk business with high stakes. Major technical risks included:

- Losses breakdown: Each launch ends either in success or failure. There is no middle ground.
- In orbit failure*:* After a successful launch or years of successful operations it is possible to loose contact (TT&C), or to face mechanical / electrical problems seriously affecting the lifetime or functioning of the satellite.
- Meteor showers: The Leonid meteor shower occurs annually in mid-November when the Earth crosses the orbital path of the comet 55P, better known as comet Temple-Tuttle. The meteor shower is generated from debris (mostly ice and dust particles dispersed along the comet's path) burning up during entry into the earth atmosphere. The meteoroids are tiny in size but travel at high speed and can potentially cause damage to the in-orbit satellites.

4.2. Non technical disadvantages

What can be an advantage can also be a disadvantage. Communications via satellite is a technology, which jumps over national boundaries and makes the natural monopoly argument for local infrastructures harder to maintain. Some national governments cannot accept this and start protecting themselves by difficult regulations and / or an extreme high license fee. Obtaining licenses to provide satellite earth station networks or services requires the applicant to deal with national regulators in every country. For a pan-European or pan-Asian system this is a challenging task.

The European Union (EU) alone covers 25 countries (2004), and the wider-ranging Conference of European Posts and Telecommunications Administrations (CEPT) covers 43 countries, from Lisbon to Moscow. DBS operators already face issues of content regulation, as they deliver programming that some countries or localities might challenge for various reasons. These issues might become more significant for VSAT (and related Internet services). Each separate state is allowed to make its own rules with its own local restrictions as for example on installing antennas (particularly in historic areas). For VSAT, service licensing alone, chaos is already there and fees vary wildly among EU member states and other European countries. There are still (EU) countries, which have not yet developed licensing structures for satellite services, and their national operators hold a monopoly over such services. The criteria on which fees are based can be:

- Frequencies (Sweden)
- Power level (Austria)
- Data speed (Belgium)
- Bandwidth (The Netherlands)
- To open the processing file (France & Germany)

Fees can be very straightforward, as in the Scandinavian countries, or extremely detailed, as in Switzerland. Outside the EU, the chaos in some European countries can turn into a nightmare. In one Mediterranean monopoly, an operator is required to pay a large fee and donate the earth stations to the local PTT. Then they must also pay for hypothetical "lost revenues" that the PTT will incur from the service provided by the earth station it would not have owned otherwise.

4.3. Satellite landing rights

Given the vast geographic area covered by a single geostationary earth orbit (GEO) satellite (or, in the case of a constellation of non-geostationary earth orbit (NGSO) satellites, the geographic area covered by the footprint of the constellation) a satellite operator seeking to maximize the size of its market may wish to provide services in every country falling within the footprint of its satellites. This footprint typically spans numerous countries. In order to provide satellite service legally in a country other than the licensing administration, the satellite operator must obtain a "satellite landing right" from that country. From a technical perspective, of course, the satellite service can be provided in any country where an earth station capable of communicating with the satellite is operational.

Unfortunately, the administration of satellite landing rights in the various countries around the globe is not uniform. As a member of the World Trade Organization (WTO), the United States developed a framework in 1997 for other WTO-member countries to gain access to the United States market more easily. Not every WTO-member country has adopted procedures similar to those adopted by the U.S. for granting market access to foreign-licensed satellites. Moreover, numerous countries around the world (many of which represent potentially large markets for the provision of satellite services) are not members of the WTO, and each such country has developed its own regulatory regime for granting access to its markets by satellite (which simply may be a flat denial to all requests for market access by foreign-licensed satellites). In short, satellite landing rights are administered on a case-by-case basis worldwide and, accordingly, they represent one of the major regulatory hurdles facing any satellite operator seeking to provide a global or even a cross-border satellite service.

"Satellite landing right" refers to the legal authority of a satellite operator to provide satellite services in a foreign market without risk of legal sanctions.

International and Satellite Operator Regulations for VSAT networks

- **International treaties and satellite operator requirements**
  - International Telecommunications Union (ITU) Radio Regulations are adopted and adapted by most countries' regulatory administrations
  - Rules are designed to prevent interference
- **Satellite operator requirements**
  - Demand that ground equipment meet specifications for interference control, esp. antenna patterns
  - May require each and every antenna and VSAT to be tested, unless a prior agreement is reached to accept the use of that type of equipment
- **Type approvals by satellite operators**
  - Implicit ("we accept the antenna from experience, but will watch for interference"), or
  - Explicit ("antenna must be on our approved list")
  - Explicit Type Approvals are increasingly made using the GVF MRA process
    - Uniform standard for performance testing and quality control of VSATs

5. The ground or earth station

This is the earth segment. The ground station's job is two-fold. In the case of an uplink, or transmitting station, terrestrial data in the form of base-band signals, is passed through a base-band processor, an up converter, a high powered amplifier, and through a parabolic dish antenna up to an orbiting satellite. In the case of a downlink, or receiving station, works in the reverse fashion as the uplink, ultimately converting signals received through the parabolic antenna to base band signal.

5.1. Earth station standards

Earth stations come in different sizes and are classified according to the globally accepted INTELSAT standard. Depending on the earth station's antenna size, its service, and its technical parameters an earth station will be qualified according to the following table:

E/S Standard	Antenna Size (m)	Frequency Band (GHz)
A	15-18	6/4
B	11-13	6/4
C	11-14	14/11
D1	4.5-6	6/4
D2	11	6/4 & 14/12
E1	3.5-4.5	14/11 & 14/12
E2	5.5-7	14/11 & 14/12
E3	8-10	14/11 & 14/12
F1	4.5-7	6/4
F2	7-8	6/4
F3	9-10	6/4
G1	All sizes	6/4, 14/11 & 14/12
Gx	<4.5 for C band <3.7 for Ku band	6/4, 14/11 & 14/12

5.2. Teleports

Teleports are the "intermodal hubs" of the broadband and broadcast world — gateways that connect satellite circuits with terrestrial fiber optic and microwave circuits. Bridging the gap between land and sky, they allow broadcasters, cable-casters, and public and private network operators to outsource a non-core function that is critical to their businesses. Teleports deliver time-sensitive television and radio programming to audiences around the globe. They provide remote and underdeveloped regions with high-quality Internet and enterprise network connections.

More detailed information about teleports around the globe can be found on the following Internet web pages: http://www.uplinkstation.com and http://www.worldteleport.org

Loral Skynet Mt. Jackson (VA) Teleport

SES-Astra earth station in Luxemburg

T-systems Raisting Teleport (Germany) – 32m antenna

Loral Skynet Hawley Teleport

Loral Skynet Amsterdam Teleport

5.3. VSAT

Another type of ground station or better ground station system is VSAT. VSAT is the abbreviation for **V**ery **S**mall **A**perture **T**erminal and is an earth station characterized by its reduced dimensions and capable of transmitting / receiving a limited volume of traffic. VSATs are usually considered to be those designed to operate with antennas that are equivalent of 3.8 meters diameter or less. The size of a VSAT primarily depends on the data to be transmitted and its location. A VSAT satellite communications system typically serves home and business users.

VSAT in general provide point-to-point or point-to-multipoint connectivity between points across the globe and offers a number of advantages over terrestrial alternatives. For private applications, companies can have total control of their own communication system without dependence on other companies. Unlike traditional landline services, VSAT services are unaffected by physical barriers, multiple service suppliers and problems associated with the "last mile" connection. New sites can be added and existing connections reconfigured usually within a matter of days.

The advantages of a VSAT network are:

- Single network for voice, data, video, e-mail and fax
- Unaffected by geographic barriers or natural disasters
- Quick installation (for a 2.4 meter antenna in general not more than 3 days)
- Customized bandwidth
- High network availability (99.5% - 99.9%)
- Add new sites cost-effectively so it reduces international expansion and operating costs

VSATs are ideal for international businesses requiring worldwide connectivity for mission critical applications, disaster recovery, local access extensions, trunk redundancy, and host-to-host communications. The network's resiliency is crucial in applications that require high availability and reliability. Business and home users also get higher speed reception than if using ordinary telephone service or ISDN.

The data rate, or speed, at which each of these services is provided, is affected by several factors, including the user’s requirements, the amount of satellite capacity available, and the protocols used for each service. In general, satellite services provide 35 to 45 Mbps capability for Internet/ Intranet backbone connectivity (although they can go as high as 155 Mbps, 2 to 3 Mbps for multicasting, and 400 kbps for delivery of Internet information to consumers. For private networks it’s up to the customer and can be from 9.6 kbps to whatever.

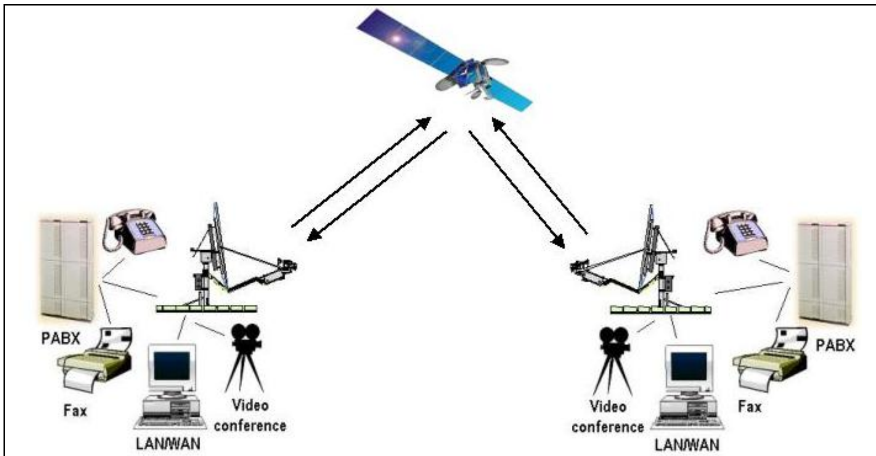
A VSAT end user needs a box that interfaces between the user's computer and an outside antenna with transceiver. VSAT can handle data, voice, and video signals.

Cost factors in VSAT networks

- **Capital costs**
  - VSAT terminal hardware
    - *Prices have steadily reduced over the past 10 years*
  - Hub major antenna and RF hardware
  - Hub electronics hardware (may need to grow as VSATs are added)
- **Recurring costs**
  - Transponder cost:
    - ***This is the dominant factor in most networks, unless average traffic is very light!***
    - ***Can easily exceed VSAT equipment cost in less than a year.***
    - ***Depends on traffic load, DAMA efficiency, and modulation/coding efficiency.***
  - Shared hub service cost:
    - When adding VSATs to an existing network, the service provider may charge a recurring fee for use of the hub and management of the network

5.3.1. VSAT – SCPC

SCPC (Single Channel per Carrier) is satellite transmission system that employs a separate carrier for each channel, as opposed to frequency division multiplexing that combines many channels on a single carrier.



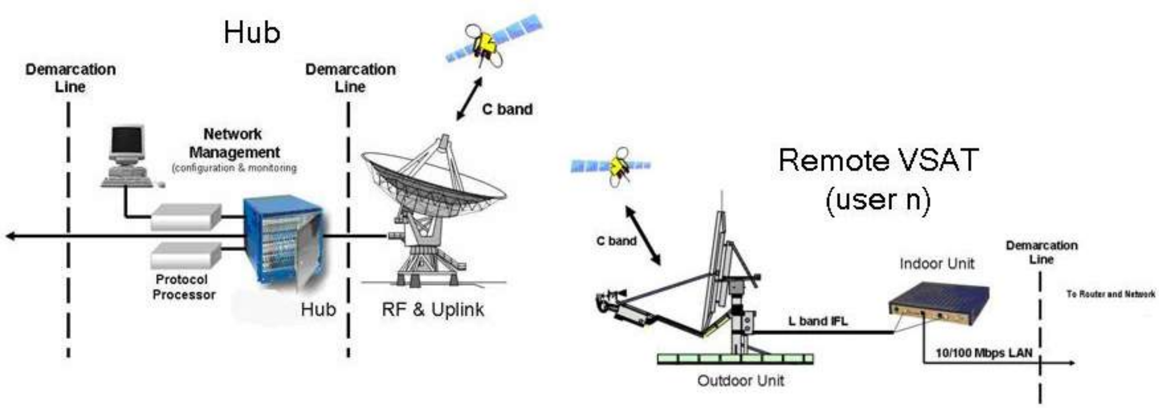
Typical VSAT (SCPC) configuration

SCPC Earth Station Hardware

- Components come from a mix of suppliers. Selected and configured by integration engineer (at a service firm, or sometimes the end user's firm)
- Large stations typically have:
  - Large antenna with multi-polarized feeds
  - RF electronics with redundancy and multiple polarization support
  - High power amplifiers indoors or in the antenna
  - Frequency converters and modems in rack cabinets
- Small stations typically have:
  - Antenna with feed system
  - RF electronics at the antenna including LNB or LNC (for receive), and BUC (with integrated or separate SSPA) or a transceiver (also known as radio)
  - Modem indoors.

5.3.2. Networked VSAT

Networked VSAT is satellite transmission system that employs one carrier from the Hub to all the remote sites (TDM). The remote sites typically use TDMA for the return channel



Networked VSAT Hardware

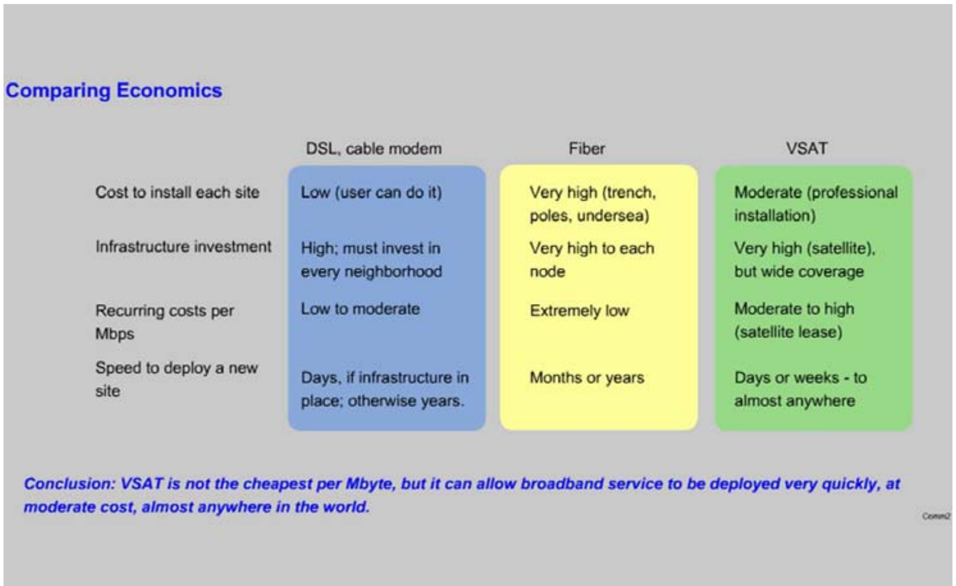
- Pre-engineered by the VSAT system manufacturer
- Major components include:
  - Antenna with feed and combiner
  - LNB (low noise block downconverter)
  - BUC (block upconverter with power amplifier)
  - Sometimes LNB, BUC and/or combiner functions are integrated into one unit
  - IFL (inter-facility link) cables (typically low-cost coaxial cable)
  - Indoor unit (typically a modem/router only)
- Components usually may not be changed without permission from the manufacturer



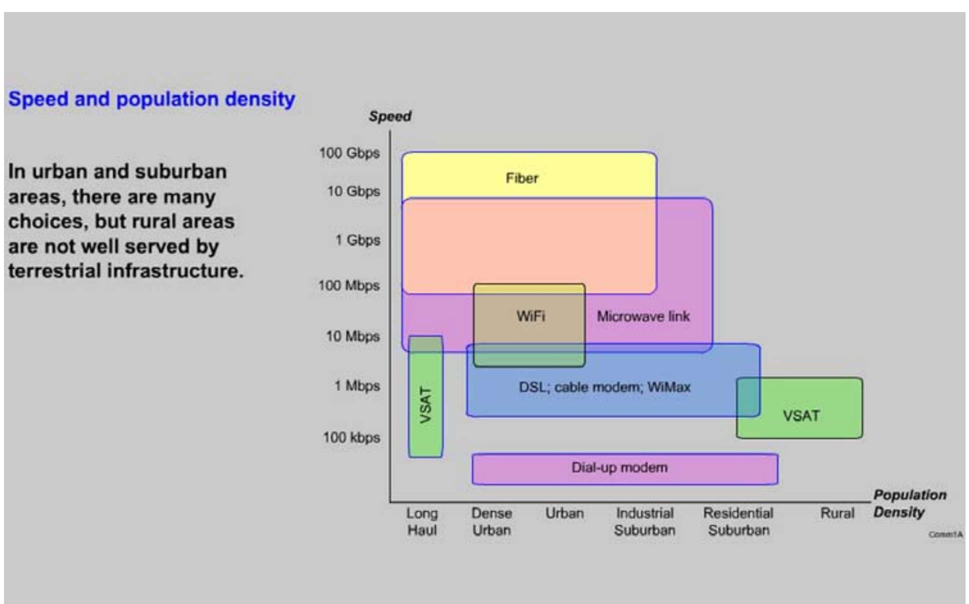

Examples of a typical VSAT Outdoor Unit

5.4. The hybrid solution

While cost is an important point for comparing satellite versus terrestrial systems, the question of whether they compete directly or indirectly depends always on the application involved. Consumers tend to look for the be-all and end-all solution however it's not always easy to understand where what is and what is not available. Satellite has no competition about broadcasting while interactive systems like cable and DSL compete on price and/or quality. A total network solution is often a synergy with cable, satellite and fixed wireless.



All solutions offer high reliability for the most critical connections and they frequently work well together as a hybrid solution. The tendency is usually very application-specific and every case is different in terms of terrain, line of sight, location, license, etc. Organizations should find a solution that provides the needed bandwidth for a justifiable cost. Cost includes installation, on-going charges, upkeep, losses due to downtime and so on. Organizations lose big money when the network connection is too slow, but far more when the link is down completely. Automatic backup is an absolute must. Always plan for the worst-case scenario and seriously consider an alternate backup plan.



	(PSTN) Copper Wire
Good	• Efficient and inexpensive for small data transfers • Almost everybody has it • Well proven technology
Bad	• Low data rate
Ugly	• Local PTT's (Telco's) often have a monopoly
	DSL
Good	• Cheap and easy where you can get it
Bad	• Distance limitation on twisted pair technology is about 6 km from the central office
Ugly	• Too many kinds of DSL (VDSL, IDSL, ADSL) • Physical plant is very expensive
	Cable
Good	• No real distance limitation. • Relatively inexpensive. • Easy to install and use
Bad	• Bandwidth limitation because bandwidth is shared among many cable subs
Ugly	• At peak usage time, a 256 kbps connection can easily act more like a 14.4 kbps connection. • Cable plant is expensive to build and many places require serious upgrades to accept cable modems
	Fixed Wireless (MMDS,LMDS)
Good	• Technology can fill the gaps left by cable and DSL • Minimal Infrastructure required
Bad	• It's line-of-sight, so it's not good in certain geographical situations. • Wireless range is limited. Depending upon whose gear you install, the range might be from 30m to 30 km.
Ugly	• Some providers are using equipment not necessarily optimized for the type of application. Some of it is indoor gear being used
	Satellite
Good	• Quick to install and easy to get to the market. • Infrastructure is already there in the sky. Enormous coverage area (footprint) • Excellent for broadcast and multicast applications • Mountains, rivers, and oceans none of that makes much difference to satellite communications
Bad	• When none of the other alternatives are viable, satellites come into the picture. Main reason is that satellite bandwidth is the most expensive
Ugly	• Satellite bandwidth at the present time is a rapidly dwindling supply. Costs remain high

6. Satellite transmission systems

Satellite networks can be used for broadcast, point-to-point, point-to-multipoint, multipoint-to-multipoint, and multipoint-to-point transmissions, with the earth stations sized to allow location on or very close to the users' premises.

The nature of satellite broadcast offers better possibilities for one-to-many transmissions than may be available by conventional means. Point-to-point satellite carriage is under attack, and it could even be doomed. Satellite data transmission often can't compete on price with terrestrial systems for individual point-to-point connections, and few say that will change in the foreseeable future. There is a cable-laying boom underway around the world. By 2003, the activation of new cables will lead to an exponential increase in point-to-point capacity. There will be over 9000 Gbps of submarine cable capacity available in the Asian region, 7000 Gbps between the United States and Europe, and 6500 Gbps between the United States and Asia. Thus the outlook is grim for point-to-point satellite traffic.

6.1. Access Methods

There are three fundamental access methods:

1. Frequency Division
   - Each VSAT is tuned to a different frequency channel (FDMA).
   - Channels are assigned of an as-needed basis (DAMA)
2. Time Division (TDM or TDMA)
   - VSATs are tuned to the same frequency channel
   - VSATs take turns using the channel (TDMA)
   - Or a broadcast stream of data contains packets addressed to different VSATs (TDM)
3. Code Division
   - VSATs transmit on the same frequency channel, at the same time, but…
   - They scramble the data with different codes, which spreads out the spectrum
   - The receiver seperates the data based on the scrambling codes

As a rough rule of thumb, we can rate the efficiency of each access method based on the type of network and traffic.

	Broadband internet access	Wide area, low-rate enterprise networks	Internet backbone extension to WiFi hot spots	Private network with internal voice and data	Independent network with less than 5 sites	Rural telephone access
TDM/TDMA	✓✓	✓✓✓	✓	✗	✗✗	✓
Mesh TDMA	✗	✗	✓✓	✓✓✓	✓✓	✗
SCPC	✗	✗	✓✓	✓	✓✓✓	✗✗
SCPC/DAMA	✗✗	✗✗	✗✗	✗	✗	✓✓

Legend:

✓ *= a good fit for this application*

✗ *= a poor fit for this application*

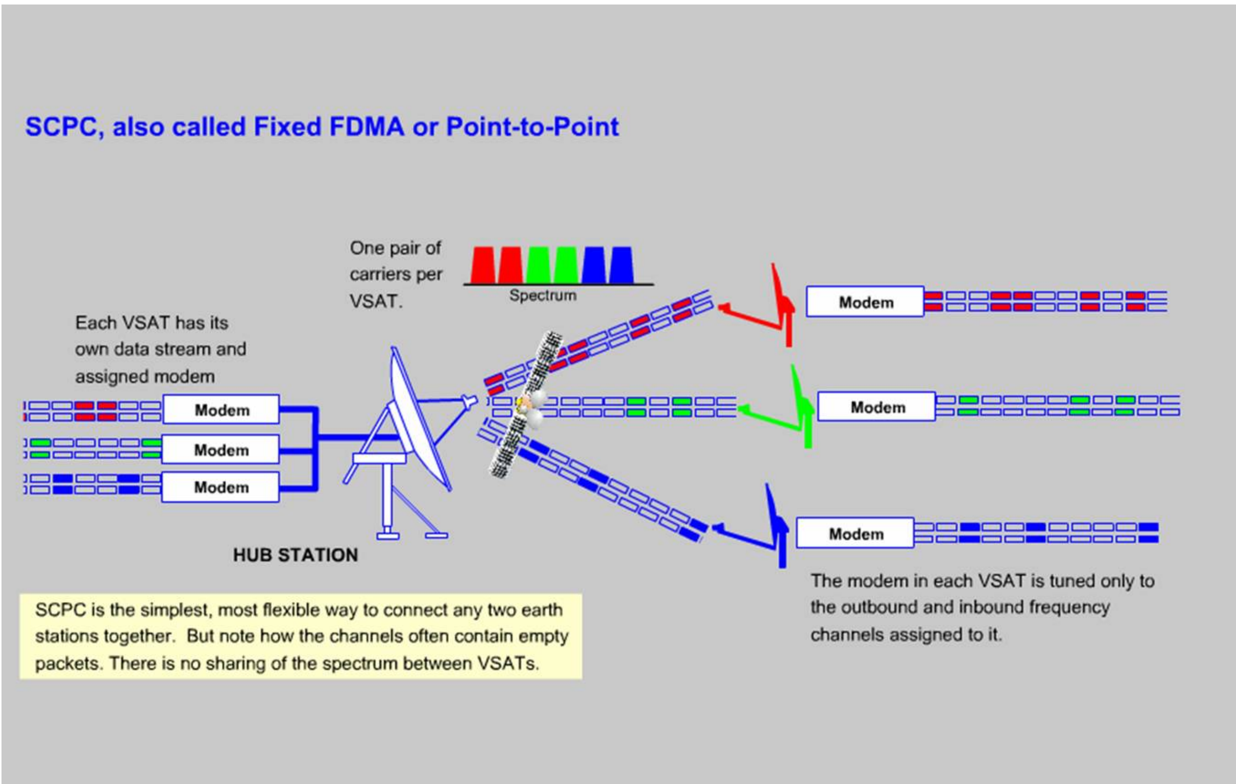
WARNING! This table shows general trends and is not absolute. There are many versatile and advanced combinations of these techniques available in today's VSAT equipment. Be sure to research supplier's equipment features in detail before making critical selection decisions.

6.1.1. SCPC

SCPC (Single Channel per Carrier) is satellite transmission system that employs a separate carrier for each channel, as opposed to frequency division multiplexing that combines many channels on a single carrier.

The primary advantage of SCPC is that the architecture allows full connectivity between any sites in the network. Additionally, SCPC allows incremental usage of the satellite transponder and therefore allows a flexible expansion of the network.

There are, however, several disadvantages in SCPC when compared with the other techniques. In SCPC system, each channel requires a separate satellite modem at each earth station. This results in an incremental cost in ground equipment and has to be considered based on the number of circuits required at each site.

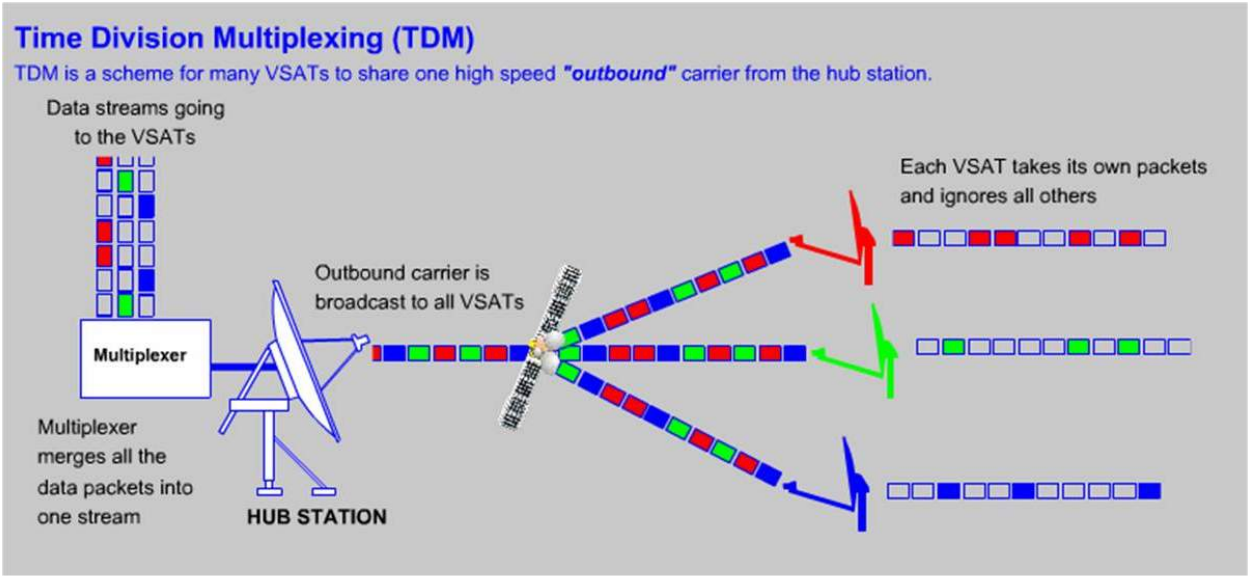


6.1.2. TDM and TDMA

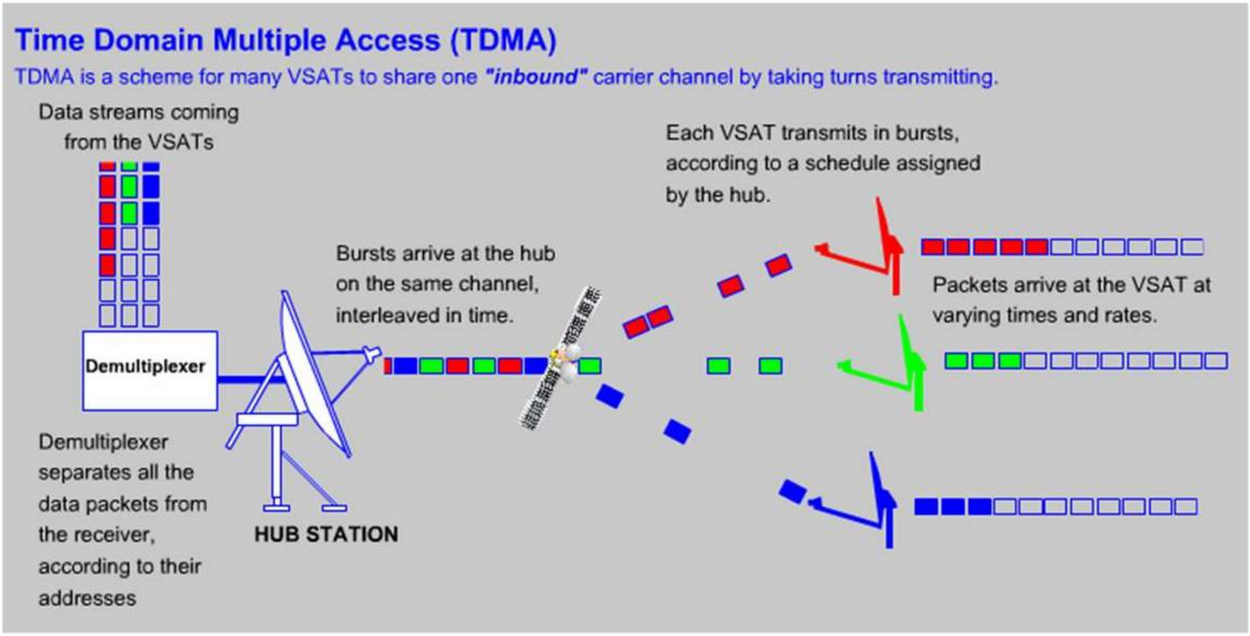
TDM/TDMA is used in almost all large VSAT networks.

- Service provider operates a large hub station
- VSATs are placed at the customer's remote sites
- Large hub station means VSATs can have small antennas and low power (cheap!)
- But VSAT antennas are too small for them to talk directly to each other meaning that TDM/TDMA networks are always "star" topology

TDM is used for the "outbound" traffic. Hunderds or thousands of VSATs listen to the same outbound carrier signal:



TDMA is used for the "inbound" traffic. VSATs take turns transmitting on a common frequency channel.



7. DVB – Digital Video Broadcasting

The DVB system combines the MPEG-2 standards with technologies enabling digital data to be broadcast via satellite (DVB-S) and cable (DVB-C). DVB-S is DVB's baseline specification for digital television, sound and data services in the satellite frequency range for a range of transponder bandwidths (26 MHz to 72 MHz) for example.

DVB has three strengths indicated by its name:

1. Digital: DVB is all-digital. Digital communications systems do not distinguish between the different types of information they convey. So DVB can deliver any information that can be digitized, whether it is high definition TV, multiple-channel standard definition TV or broadband data and interactive services.
2. Video: At the outset, DVB principally was concerned with television, which is a broadband service. Moreover, DVB is intended to work at the higher satellite communications frequencies, which further enhance its broadband capability.
3. Broadcasting: DVB is designed as a broadcasting service for many users. So, though based on VSAT concepts, the satcom version, DVB-S, with the Return Channel via Satellite (RCS) is scalable to networks far larger than those supported by conventional VSAT systems

The channel encoding specifications for interoperable digital systems were developed by the European Digital Video Broadcasting project (DVB) and were then submitted to the different European standardization bodies that have issued the respective standards. These DVB standards are used to implement digital TV transmission in Europe and in many other countries. DVB is an open standard and therefore a global technical solution for digital broadcasting via all kinds of media including interactivity and data services. DVB transmission standards do not distinguish between audio, video, and data. More detailed information can be found on the Internet: www.dvb.org

DVB Advantages:

- Smaller VSAT antenna (~1 m), no zoning delays
- Easy to install the low cost remotely managed unattended receivers
- Simple receiver interface (Ethernet, 100BT or PCI bus), does not require costly router to support high multicast rates (no HSSI)
- Support for multiple service types including video, audio, and data
- Secure transmission with entitlement control
- Multiple services simultaneously
  - Packing of up to 3 IP/TCP or 4 IP/UDP packets per MPEG transport packet
  - Simultaneous reception of four separate DVB Services at 4 Mbps per receiver
- Higher data rates, up to 63.3 Mbps depending on modulation scheme
  - Common 58Mbs throughput on 54MHz satellite transponders in saturated mode
  - Routing of up to 64 multicast and 512 unicast IP networks per transponder
  - Multiplexing of up to 8192 streams

The video/audio encoder performs the compression of an input video and audio signal and outputs an MPEG-2 compatible digital bit stream. The output bit rate can be varied between around 1.5 and 15 Mbps (or more for data and less for audio) depending on the type of the source material and on the particular quality requirements.

The entire digital (video) spectrum will look much different from an analog spectrum. For example video, rather than a picture carrier and a sound carrier, there's a single flat spectrum extending over most of the channel. Digital video technology is relatively homogeneous until the physical layer, where many different technologies are used depending on the type of system and location within the network. In addition satellite systems use QPSK, cable systems use QAM, and terrestrial networks use COFDM or VSB modulation methods. The symbol rates used on satellite systems are 22 Mega Symbols/s (abbreviated MS/s) in a 26 MHz transponder and 27.5 MS/s in a 33 MHz transponder respectively. As with QPSK modulation one symbol represents 2 bits, 22 MS/s correspond to a gross transponder capacity of 44 Mbps whereas 27.5 MS/s correspond to 55 Mbps. Because of the parity bits used for the error correction the actual useful data capacity is less than 44 or 55 Mbps.

Digital Video Broadcast for Satellite - DVB-S

- **DVB-S is a specific version of TDM**
  - Defined by an ETSI (European) specification
  - Now used globally for digital TV via satellite
  - Originally intended for placing multiple digital TV channels on a single broadcast carrier, using MPEG-2 video compression
  - But it is quite versatile, and is now commonly used for VSAT data carriers
  - Many low-cost, high performance receiver chips and cards support DVB-S
- **Related standards**
  - DVB-S2: A new version with more efficient modulation and forward error error correction.
  - DVB-RCS: Return Channel System using TDMA (enables two-way VSATs)
  - DVB-T: digital terrestrial broadcast television (mainly in Europe)
  - DVB-C: digital cable television

7.1. IP over Digital Video Broadcasting

The basic "unit" of the DVB (Digital Video Broadcasting) system is the DVB multiplex - a very high speed data stream containing data packets from a number of individual smaller data streams. In a DVB TV service, these data streams are the MPEG-2 compressed video and audio (together with control data), which make up the TV channel or radio station. However, DVB today also has the ability to carry TCP / IP - and hence any other standard using TCP / IP - at a very high speed. DVB has been developed to include encapsulation techniques which allow the MPEG-2 data packets to carry TCP / IP traffic at the same multi-Megabit/sec speed as digital television. This allows both digital TV and Internet traffic to co-exist on the same system and be received by either DVB PC Cards or DVB set-top-boxes.

DVB is under development to include a number of capabilities of interest to the interactive community: standard return path protocols via satellite and cable, open platforms, MHEG and compatibility with HTTP IPV6 and other Internet protocols.

DVB uses fixed length data packets to carry compressed video and audio for each of the TV or radio channels being transmitted. DVB-Data uses the same structure for data formats as IP. The data gateway - or encapsulator - acts as a bridge between the IP world and the DVB world. IP packets are encapsulated in DVB format then into MPEG2 packets, which are multiplexed with video and audio into MPEG transport streams and uplinked for transmission by satellite. Conditional access is possible. The recipient's PC card demodulates and reassembles into IP packets and identifies those addressed to the PC, disregarding the others. The recreated original IP packets are viewed - via browser, media player, etc - just as any other IP stream: except a great deal faster!

The ability to transmit the Internet Protocol (IP) over satellite using the DVB standard for digital TV offers a wide range of potential services from a single technology platform. These include:

- Pull services, such as high speed web browsing, where a single user requests a specific item,
- Push or multicast services, where a file or stream is transmitted to many users at the same time, for example, real-time financial information or streamed radio.

Since the whole system is based on the DVB standard - with millions of receivers already in use world-wide, the consumer equipment is both already available and consumer-priced.

7.2. DVB-RCS

DVB Return Channel via Satellite (DVB-RCS), recently published as an ETSI standard, forms the specification for the provision of the interaction channel for GEO satellite interactive networks with fixed return channel satellite terminals (RCST).

The standard, developed under the auspices of the DVB Forum, was created through the cooperation of satellite operators and satellite equipment manufactures, including system providers, hub manufacturers and terminal manufacturers. Companies from Europe, North America and the Middle East have been involved in this activity. DVB-RCS may well become a global satellite standard that allows equipment manufacturers to focus on the same technical solution, thus providing a healthy and open competitive environment, providing enormous benefits to industry and users alike.

In recent years, the multimedia revolution has created a huge demand for high-speed connections to the network. Satellite systems have been designed to respond to such demand. In particular, Regenerative (Ka band) Satellite Systems will constitute the next generation of telecommunication satellites. They will provide very high speed Internet connections to corporate and consumer users equipped with small (60-120cm diameter) antenna terminals. This is achieved by employing high frequency bands, multi-spot coverage areas and high-speed digital signal processing on board the satellite. DVB-RCS also works with the standard non-regenerative Ku band satellites. Typical antenna sizes are 90-180 cm diameter. Typical radio output power is in the range of 0.5W-4W.

In this system, the DVB-RCS return channel standard is applied by all users to access through a standard uplink to the satellite. On board, the regenerative payload is in charge of multiplexing that information from diverse sources into one or more DVB-S data streams capable of being received by any standard IRD equipment. The on board repeater is not only capable of multiplexing signals coming from the same uplink, but also cross-connecting and/or broadcasting channels coming from separate uplink coverage areas to different downlink coverage areas.

A Management Station (Hub) is needed to perform management functions for the integrated system. It also can directly transmit to the satellite the signaling and timing information for network operation by using the same DVB-RCS standard and receiving the different return channels via DVB-S signal.

From the Customers' perspective, this suite of 2-way, hybrid (terrestrial, satellite) Services would allow them to move voice, video, and data traffic between locations using a hub-based architecture. Even locations that are remote and not easily accessible via terrestrial means can communicate with other corporate sites, or, the public Internet. In addition, the premise equipment used to support the Service is non-proprietary, allowing customers to benefit from lower equipment costs and a choice of suppliers.

DVB-RCS systems are scalable. A simple, single-gateway DVB-RCS system might serve up to thousands of users, whilst a distributed gateway architecture DVB-RCS system might provide integrated services to several hundred thousand users.

7.2.1. DVB-RCS: The network

The DVB-RCS network is a star network where each user terminal inter-connects with a hub station to gain access to a wide variety of multimedia services via satellite. The communication between the hub station and the user terminal is done solely through satellite links:

- The link supporting communication between the Satellite Interactive Terminals (SITs) and the hub is called the Return Link (RL) and uses Multi-Frequency Time Division Multiple Access (MF-TDMA). It allows typical data rates from 144 to 2048 kbps
- The link supporting communication between the hub and the SITs is called the Forward Link (FL) and uses a standard Digital Video Broadcasting (DVB) format. Thus the DVB-S (EN 300 421) specification applies. It allows data rates up to 45 Mbps and over.

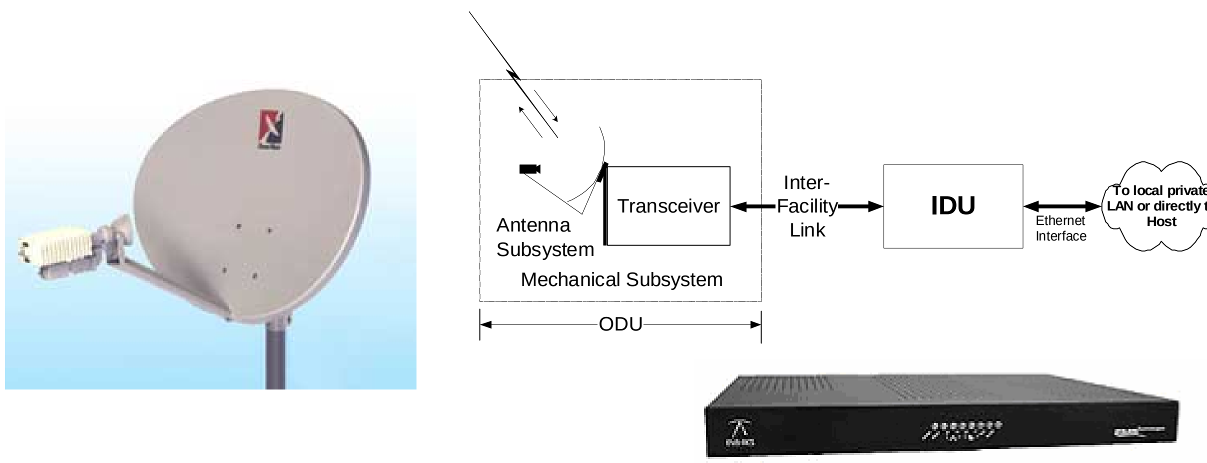
The Satellite Interactive Network, within which a large number of Satellite Interactive Terminals (SIT) will operate, are comprised of the following:

- Hub or Gateway – The hub is primarily responsible for carrying Internet Protocol (IP) traffic between the external networks and the SITs. In addition the hub provides monitoring & control functions. It generates control and timing signals for the operation of the Satellite Interactive Network to be transmitted by one or several Feeder Stations. The hub also includes auxiliary equipment such as the IP Router/ATM Switch and the time/frequency reference subsystem.
- Traffic Gateway - Receives the SIT's return signals, provides accounting functions, interactive services and/or connections to external public, proprietary and private service providers (databases, pay-per-view TV or video sources, software download, tele-shopping, tele-banking, financial services, stock market access, interactive games etc.) and networks (Intranet, ISDN, PSTN etc.).
- Feeder - The Feeder transmits the forward link signal, which is a standard satellite digital video broadcast (DVB-S) uplink, onto which are multiplexed the user data and/or the control and timing signals needed for the operation of the Satellite Interactive Network.

The Forward Path carries user traffic and signaling from the Gateway (hub) to the SITs. The signaling from the Gateway to the SITs that is necessary to operate the Return Path system is called "Forward Path signaling". The Return Path carries user traffic and signaling from SITs to the Gateway. The signaling from the SITs to the Gateway that is necessary to operate the Return Path system is called "Return Path signaling".

7.2.2. DVB RCS: The satellite interactive terminal (SIT)

The DVB-RCS Satellite Interactive Terminal (SIT) is much the same as those units used in a standard satellite TV system with the significant difference being that, unlike TV broadcasting systems, the DVB-RCS SIT is bi-directional. The Satellite Interactive Terminal (SIT) is composed of the Outdoor Unit (ODU), which includes the antenna and RF Transceiver, and the Indoor Unit (IDU). SIT Installation can be done in just a few hours.



Example of a Satellite Interactive Terminal Hardware Set-up

DVB Bitrates calculator on line

Please visit: http://jensts.home.online.no/Satellite/bitrates.htm (link active in Aug03). More calculators on Online Satellite Calculations (http://home.online.no/~jensts/satellite.html)