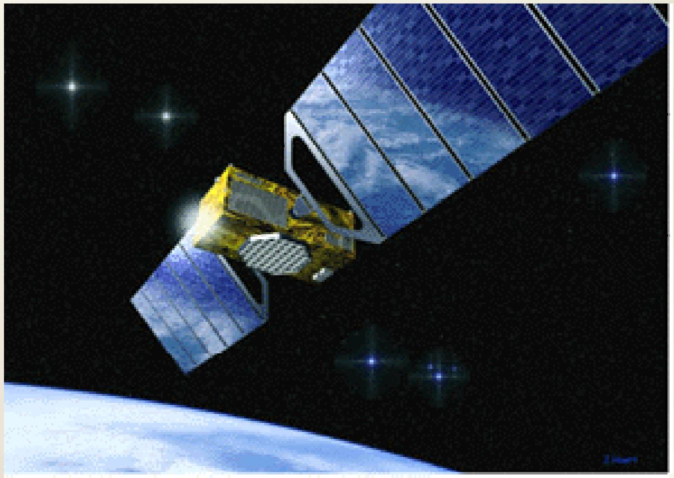
Day 1 course

Satellite Technology: Satellites fundamentals, Orbits, Satellite design, Operation, Life Cycle Management, Tracking Telemetry and Control (TTCM)

By NIAMEOGO W. Eric

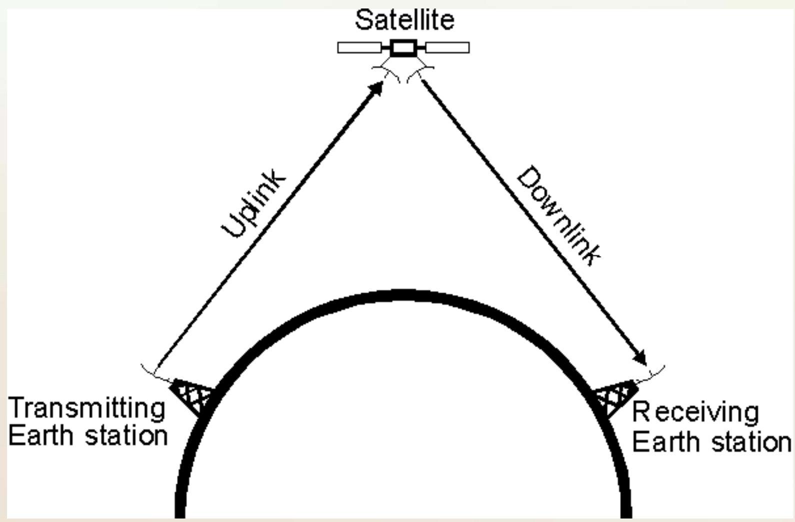
1- Satellite overview

Satellites are able fulfill a number of roles. One of the major roles is for satellite communications. Here the satellite enables communications to be established over large distances - well beyond the line of sight. Communications satellites may be used for many applications including relaying telephone calls, providing communications to remote areas of the Earth, providing satellite communications to ships, aircraft and other mobile vehicles, and there are many more ways in which communications satellites can be used.



1- Satellite overview

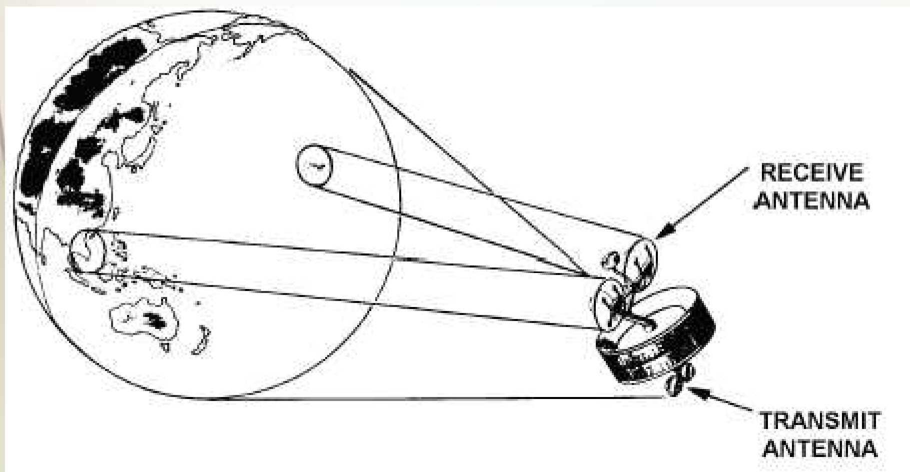
When used for communications, a satellite acts as a repeater. Its height above the Earth means that signals can be transmitted over distances that are very much greater than the line of sight. An earth station transmits the signal up to the satellite. This is called the up-link and is transmitted on one frequency. The satellite receives the signal and retransmits it on what is termed the down link which is on another frequency.



1- Satellite overview

In the context of spaceflight, a **satellite** is an object which has been placed into orbit by human endeavor.

Such objects are sometimes called **artificial satellites** to distinguish them from natural satellites such as the Moon.



1- Satellite overview

TRANSPONDER

The circuitry in the satellite that acts as the receiver, frequency changer, and transmitter is called a transponder.

This basically consists of a low noise amplifier, a frequency changer consisting a mixer and local oscillator, and then a high power amplifier. The filter on the input is used to make sure that any out of band signals such as the transponder output are reduced to acceptable levels so that the amplifier is not overloaded.

Similarly the output from the amplifiers is filtered to make sure that spurious signals are reduced to acceptable levels.

1- Satellite overview

TRANSPONDER

Figures used in here are the same as those mentioned earlier, and are only given as an example.

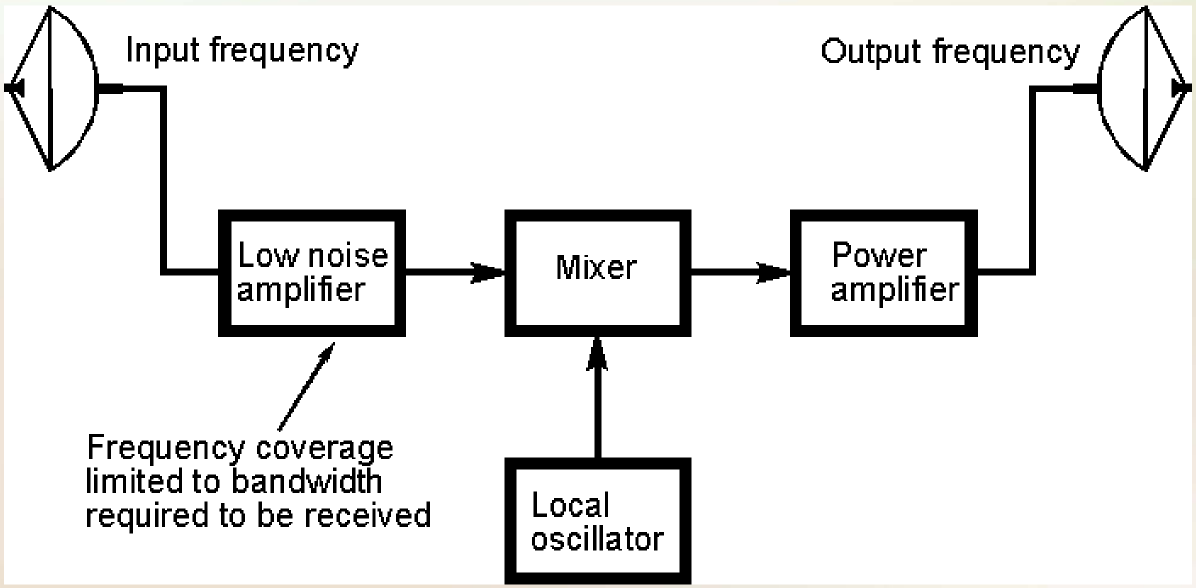
The signal is received and amplified to a suitable level. It is then applied to the mixer to change the frequency in the same way that occurs in a superheterodyne radio receiver.

As a result the communications satellite receives in one band of frequencies and transmits in another.

1- Satellite overview

TRANSPONDER

In view of the fact that the receiver and transmitter are operating at the same time and in close proximity, care has to be taken in the design of the satellite that the transmitter does not interfere with the receiver. This might result from spurious signals arising from the transmitter, or the receiver may become de-sensitised by the strong signal being received from the transmitter. The filters already mentioned are used to reduce these effects.



1- Satellite overview

There are many actors in the satellite communications :

- Satellite Service Providers (Intelsat, Gilat, Astrasat,…)
- VSAT Installers (Libercom, skytel,…)
- Regulators (FCC, ARCE,…)

1- Satellite overview

Among the regulations agencies you have :

- International regulators (ITU)
- Continental regulators associations (CITEL, APT, ATRN)
- Regional regulators (Regulatel, Comtelca, ARTAO, TRASA …)
- National regulators (FCC, NTIA,…)
- International Organizations (INTELSAT, ITSO, GVF,…)

ITU is an international organization within the UnitedNations system. As well as responsibility for Telecommunications matters, they are also responsible for global regulations for all radio uses• The ITU is based in Geneva, Switzerland.

1- Satellite overview

Continental and Regional Regulators associations

The ITU Radio Regulations form a framework for Radio Regulations, but are not sufficient for complete Regulation•

Almost all countries / territories fall within a Regional Regulatory group

– *IRG for Europe*

– *CITEL across the Americas*

– *APT across Asia Pacific Region*

– *Arab States*

These groups often provide more detailed regulation, specific to the needs of the Region.

1- Satellite overview

Continental and Regional Regulators associations

The continental and regional associations have different degree of maturity and competencies.

They can rarely impose their decisions to their members, despite a consensual decision making, some of them can advance or even facilitate the adoption of common positions including during regional international meetings of the International Union of Telecommunications (ITU) or the World Trade Organization (WTO)

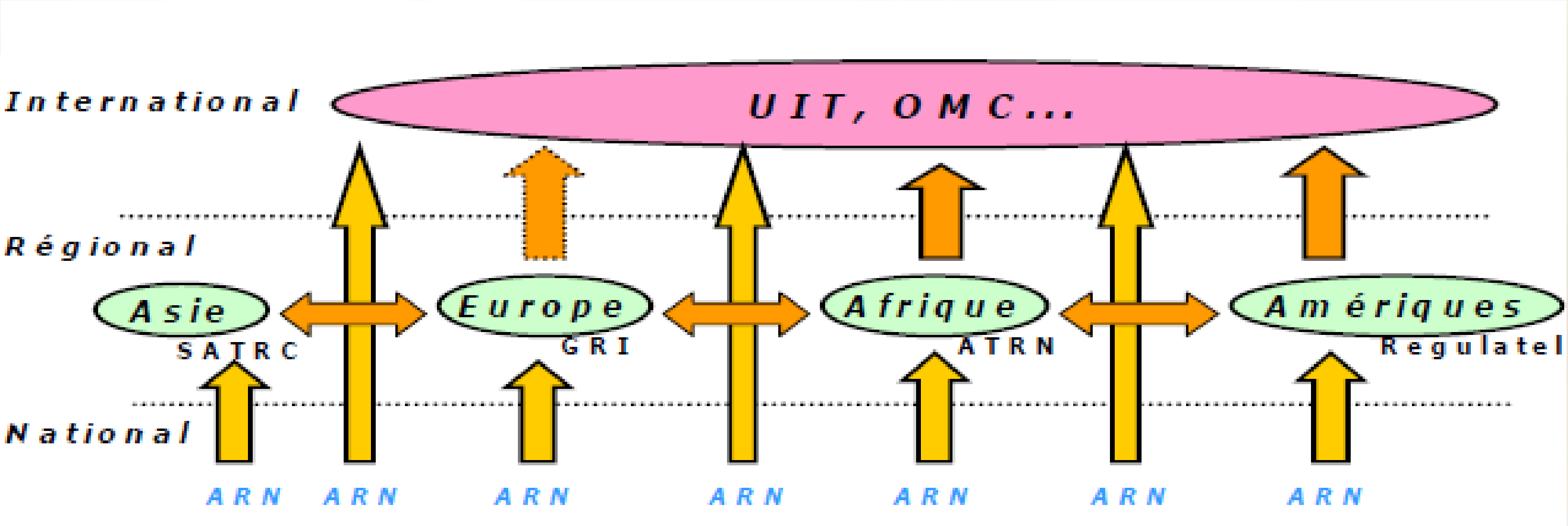
1- Satellite overview

National Regulation

Ultimately the responsibility for licensing falls to a National Regulatory Authority (a Government department), e.g.

– *Ofcom in the United Kingdom*

– *FCC & NTIA in the USA*



1- Satellite overview

ITSO

ITSO is the continuation of INTELSAT, the intergovernmental organization established by treaty in 1073.On July 18, 2001, the satellite fleet, customer contracts and other operational assets were transferred to Intelsat Ltd, a new private company now registered in Luxembourg and various amendments to the ITSO Agreement took effect.

Under the ITSO Agreement, as amended , ITSO's primary role was that of supervising and monitoring Intelsat's provision of public telecommunications satellite services as specified in the Public Services Agreement(PSA) entered into between ITSO and Intelsat. In addition, the Director General , on behalf of the Organization, must consider all issues related to the Common Heritage. ITSO currently has 150 Member State."

1- Satellite overview

ITSO

The **International Telecommunications Satellite Organization** is an intergovernmental organization charged with overseeing the public service obligations of Intelsat.

GVF

Global VSAT Forum is an association of key companies involved in the business of delivering advanced digital fixed satellite systems and services.

1- Satellite overview

International Organization

Intelsat, Ltd. is a communications satellite services provider. Originally formed as **International Telecommunications Satellite Organization** (**INTELSAT**), it was an intergovernmental consortium owning and managing a constellation of communications satellites providing international broadcast services. As of 2007, Intelsat owns and operates a fleet of 51 communications satellites.

Eutelsat S.A. is a French-based satellite provider. Providing coverage over the entire European continent, as well as the Middle East, Africa, India and significant parts of Asia and the Americas, it is one of the world's three leading satellite operators in terms of revenues.

1- Satellite overview

International Organization

The **International Mobile Satellite Organization (IMSO)** is the intergovernmental organization that oversees certain public satellite safety and security communication services provided via the Inmarsat satellites. These public services include:

services for maritime safety within the Global Maritime Distress and Safety System (GMDSS) established by the International Maritime Organization (IMO)

- distress alerting
- search and rescue co-ordinating communications
- maritime safety information (MSI) broadcasts
- general communications

1- Satellite overview

International Organization

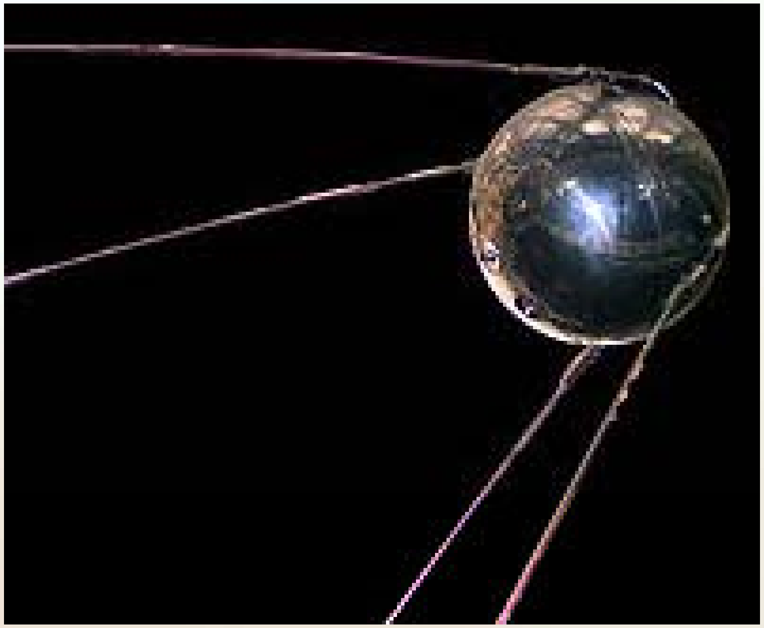
The **International Mobile Satellite Organization (IMSO)**

- aeronautical safety AMS(R)S services through compliance with the Standards and Recommended Practices (SARPs) established by the International Civil Aviation Organization (ICAO)

IMSO also acts as the International LRIT Coordinator, appointed by IMO to coordinate the establishment and operation of the international system for the Long Range Identification and Tracking of Ships (LRIT) worldwide.

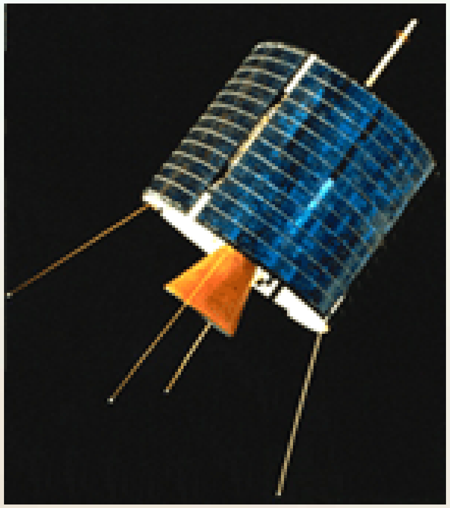
1- Satellite overview

First satellite was launched in 1957 by Russia. It was sputnik 1.



1- Satellite overview

Intelsat I (nicknamed **Early Bird** for the proverb "The early bird catches the worm") was the first (commercial) communications satellite to be placed in geosynchronous orbit, on April 6, 1965.



2- Interest of satellites

Satellites Provides Capabilities Not Available with Terrestrial Communication Systems

- Adaptable to the needs of different customers
- Variable Information Rates
- Mobility
- Cost advantage over building land lines for a limited population
- No geographical obstructions that prohibit landlines
- Quick implementation – e.g. News Gathering
- Alternate routing or redundancy as required
- Cost is independent of distance
- Cost effective for short term requirements e.g. Sporting Events

2- Interest of satellites

Satellites are complementary to cable for the following reasons:

- 1) Submarine cables (and landline fibre) are subject to cuts. Satellites provide an excellent means of back-up and should always be considered in any national plan as a means of resilience and network security
- 2) Although a lot of countries are getting access to fibre, they have a problems distributing that large bandwidth to centers far away from the cable landing. Microwave or landline fibre may not be cost effective in the short run or may take a long time to reach upcountry locations. The interim solution is to have a VSAT network utilizing satellites for cellular backhaul and internet trunking until terrestrial capacity on microwave or fibre can reach
- 3) There are certain satellite systems utilizing MEO which are about to be launched which will have both capacity (1.2Gb per beam) and quality (low latency of 120 ms round trip) and cost ($750 per Mb per month) factors that approach that of submarine cable.

3- Types of satellites

- **Communications satellites:** A communications satellite is a radio relay station in orbit above the earth that receives, amplifies, and redirects analog and digital signals carried on a specific radio frequency.

In addition to communications satellites, there are other types of satellites:

- **Weather satellites:** These satellites provide meteorologists with scientific data to predict weather conditions and are equipped with advanced instruments

3- Types of satellites

- **Earth observation satellites:** These satellites allow scientists to gather valuable data about the earth's ecosystem
- **Navigation satellites:** Using GPS technology these satellites are able to provide a person's exact location on Earth to within a few meters
- **Broadcast satellites**: broadcast television signals from one point to another (similar to communications satellites).
- **Scientific satellites :** perform a variety of scientific missions. The Hubble Space Telescope is the most famous scientific satellite, but there are many others looking at everything from sun spots to gamma rays.

3- Types of satellites

- **Military satellites:** are up there, but much of the actual application information remains secret. Intelligence-gathering possibilities using high-tech electronic and sophisticated photographic-equipment reconnaissance are endless. Applications may include:

- Relaying encrypted communications
- Nuclear monitoring
- Observing enemy movements
- Early warning of missile launches
- Eavesdropping on terrestrial radio links
- Radar imaging
- Photography (using what are essentially large telescopes that take pictures of militarily interesting areas)

4- Satellite orbits

Geosynchronous Orbit (GEO): 35,786 km above the earth

Orbiting at the height of 22,282 miles above the equator (35,786 km), the satellite travels in the same direction and at the same speed as the Earth's rotation on its axis, taking 24 hours to complete a full trip around the globe. Thus, as long as a satellite is positioned over the equator in an assigned orbital location, it will appear to be "stationary" with respect to a specific location on the Earth.

4- Satellite orbits

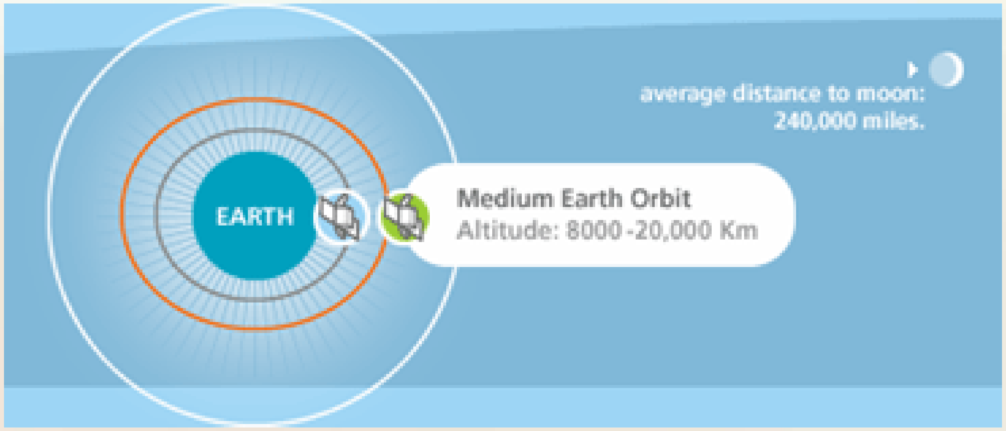
Geosynchronous Orbit (GEO): 35,786 km above the earth

A single geostationary satellite can view approximately one third of the Earth's surface. If three satellites are placed at the proper longitude, the height of this orbit allows almost all of the Earth's surface to be covered by the satellites.

4- Satellite orbits

Medium Earth Orbit (MEO): 8,000-20,000 km above the earth

- These orbits are primarily reserved for communications satellites that cover the North and South Pole
- Unlike the circular orbit of the geostationary satellites, MEO's are placed in an elliptical (oval-shaped) orbit

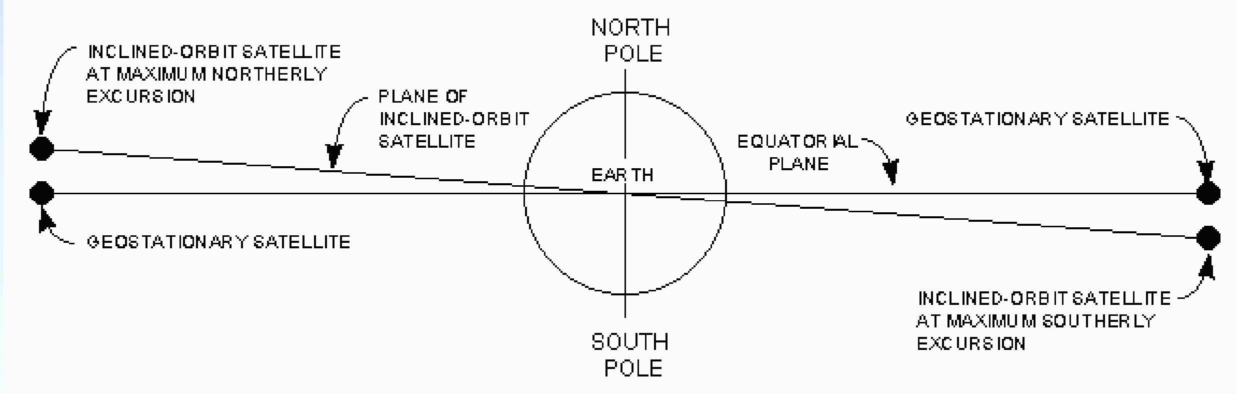


4- Satellite orbits

Low Earth Orbit (LEO): 500-2,000 km above the earth

- These orbits are much closer to the Earth, requiring satellites to travel at a very high speed in order to avoid being pulled out of orbit by Earth's gravity
- At LEO, a satellite can circle the Earth in approximately one and a half hours

4- Satellite orbits



Inclined orbits

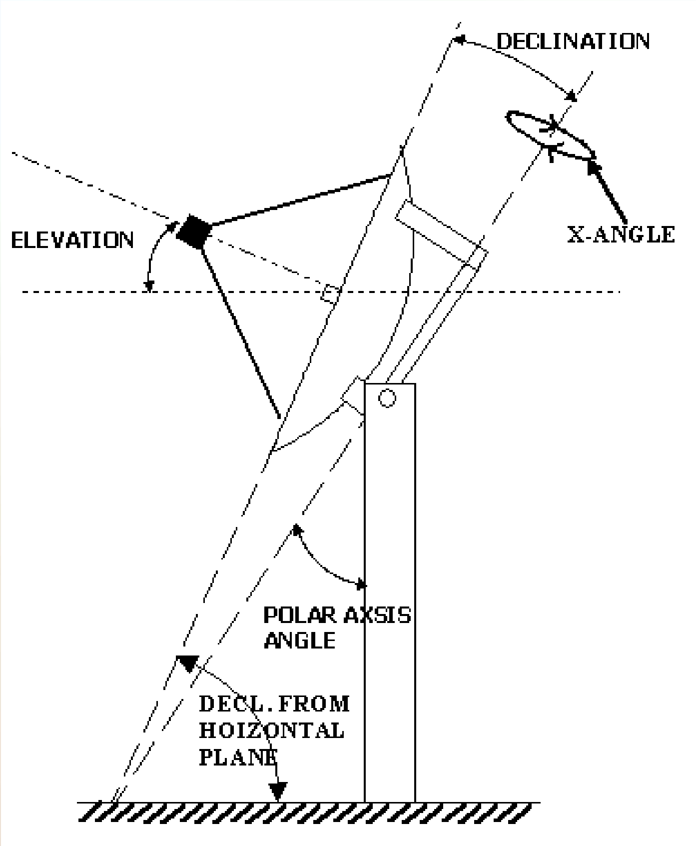
Once a satellite has been placed accurately into its geostationary orbit position it gradually starts to drift north-south on a daily basis due to the influence of the sun and moon. There is a gradual increase in the inclination of the orbit. If left alone, a satellite that has initial zero inclination will have its inclination increase at the rate of 0.8 deg per year.

With some old satellites the lifetime can be prolonged by saving fuel for orbital north/south maneuvers which result the satellite drifting in the Latitude. In the extreme some satellites is 15 degrees inclined which means they moves inside a +/-15 degree box not a +/-0.03 degree box like in the Astra 1B example.

4- Satellite orbits

Inclined orbits (Implications for earth station inclination tracking)

During the inclined orbit years earth stations must must have tracking systems so that their pointing is adjusted to aim at the satellite all during the day.



4- Satellite orbits

Inclined orbits (Implications for earth station inclination tracking)

To avoid loss of service, the earth stations need to track the satellite following the daily sinusoidal movements. If you are located on the same longitude as the satellite the north-south daily movement will be up and down. If you are on the equator then all the satellites are in a straight line across the sky from east to west, via directly overhead. North-south movement of all these satellites will be a sideways movement. Anywhere else and you have daily diagonal movements to content with, which means using two motors for an azimuth-elevation mount or a declination only motor on a polar mount dish.

Due to the problems with tracking and the uncertainty of operation of old satellites that have exceeded their regular life, the prices charged for satellite transponder capacity are lower.

4- Satellite orbits

GEO vs. MEO vs. LEO

- Most communications satellites in use today for commercial purposes are placed in the geostationary orbit, because of the following advantages:
- One satellite can cover almost 1/3 of Earth's surface, offering a reach far more extensive than what any terrestrial network can achieve
- Communications require the use of fixed antennas. Since geosynchronous satellites remain stationary over the same orbital location, users can point their satellite dishes in the right direction, without costly tracking activities, making communications reliable and secure
- GEO satellites are proven, reliable and secure - with a lifespan of 10-15 years

5- Satellite design

The equipment carried aboard the satellite also can be classified according to function.

The *payload* refers to the equipment used to provide the service for which the satellite has been launched.

The *bus* refers not only to the vehicle which carries the payload but also to the various subsystems which provide the power, attitude control, orbital control, thermal control, and command and telemetry functions required to service the payload.

5- Satellite design

In a communications satellite, the equipment which provides the connecting link between the satellite's transmit and receive antennas is referred to as the *transponder.*

The transponder forms one of the main sections of the payload, the other being the antenna subsystems.

5- Satellite design

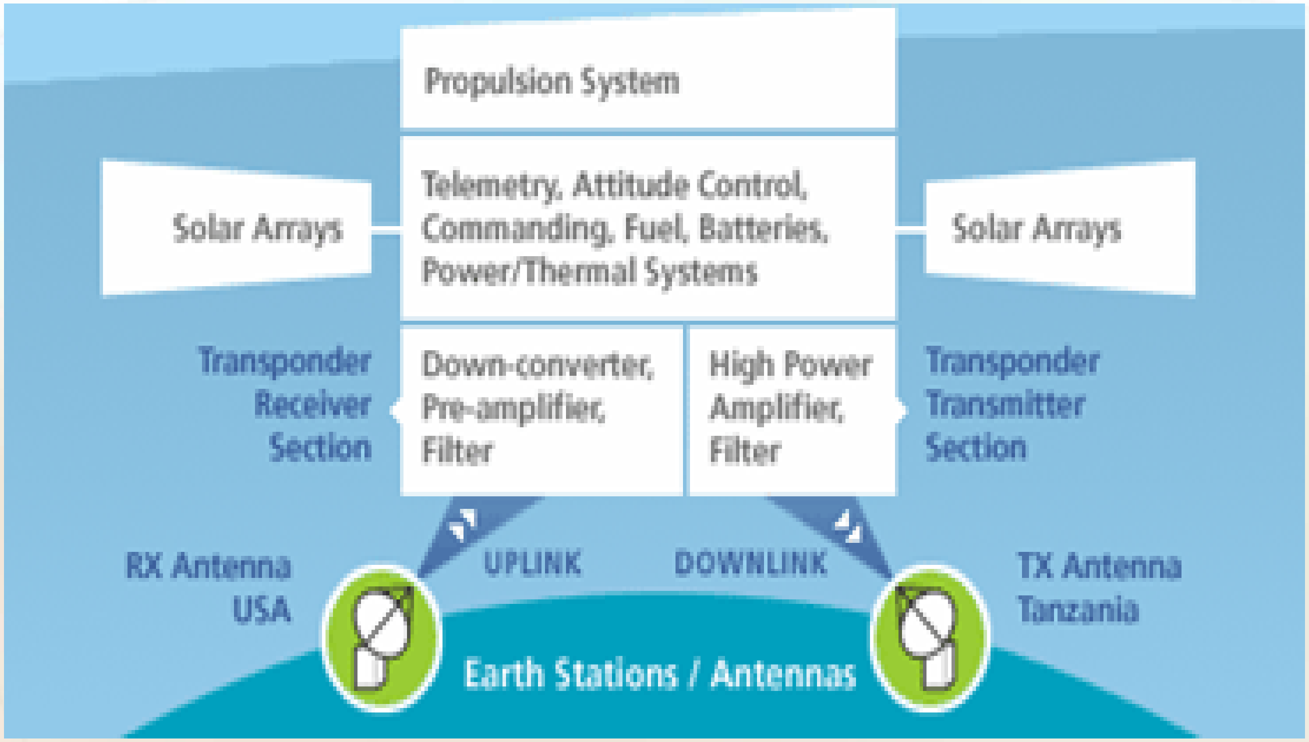
Communications data passes through a satellite using a signal path known as a transponder.

Typically satellites have between 24 and 72 transponders. A single transponder is capable of handling up to 155 million bits of information per second.

With this immense capacity, today's communication satellites are an ideal medium for transmitting and receiving almost any kind of content - from simple voice or data to the most complex and bandwidth-intensive video, audio and Internet content.

5- Satellite design

Diagrammatic Representation of a Satellite



5- Satellite design (electrical power)

Early communications satellites were severely limited by the lack of suitable power sources. This severely limited the output power of the satellite transmitter.

The only source of power available within early weight restrictions was a very inefficient panel of solar cells without battery backup.

A major disadvantage of this type of power source is that the satellite has no power when it is in ECLIPSE (not in view of the sun). For continuous communications, this outage is unacceptable.

5- Satellite design (electrical power)

A combination of solar cells and storage batteries is a better prime power source. This is a practical choice, even though the result is far from an ideal power source.

About ten percent of the energy of the sunlight that strikes the solar cells is converted to electrical power. This low rate is sometimes decreased even further.

You find this when the solar cells are bombarded by high-energy particles that are sometimes found in space.

5- Satellite design (electrical power)

Early satellites had over 8,500 solar cells mounted on the surface of the satellite, which supplied about 42 watts of power. No battery backup was provided in these satellites.

Newer communications satellites have about 32,000 solar cells mounted on the surface of the satellite, and they supply about 520 watts. A nickel cadmium battery is used for backup power during eclipses.

Nuclear power sources have been used in space for special purposes, but their use stops there. Technology has not progressed sufficiently for nuclear power sources to be used as a power source.

5- Satellite design (electrical power)

5- Satellite design (Attitude control)

The *attitude* of a satellite refers to its orientation in space. Much of the equipment carried aboard a satellite is there for the purpose of controlling its attitude.

Altitude control is necessary, for example, to ensure that directional antennas point in the proper directions. In the case of earth environmental satellites, the earth-sensing instruments must cover the required regions of the earth, which also requires attitude control.

A number of forces, referred to as *disturbance torques,* can alter the attitude, some examples being the gravitational fields of the earth and the moon, solar radiation, and meteorite impacts.

5- Satellite design (Attitude control)

Attitude control must not be confused with *station keeping,* which is the term used for maintaining a satellite in its correct orbital position, although the two are closely related.

Infrared sensors, referred to as *horizon detectors,* are used to detect the rim of the earth against the background of space. With the use of four such sensors, one for each quadrant, the center of the earth can be readily established as a reference point.

Any shift in orientation is detected by one or other of the sensors, and a corresponding control signal is generated which activates a restoring torque.

5- Satellite design (Orbital control)

In addition to having its attitude controlled, it is important that a geostationary satellite be kept in its correct orbital slot.

The equatorial ellipticity of the earth causes geostationary satellites to drift slowly along the orbit, to one of two stable points, at 75°E and 105°W.

To counter this drift, an oppositely directed velocity component is imparted to the satellite by means of jets, which are pulsed once every 2 or 3 weeks.

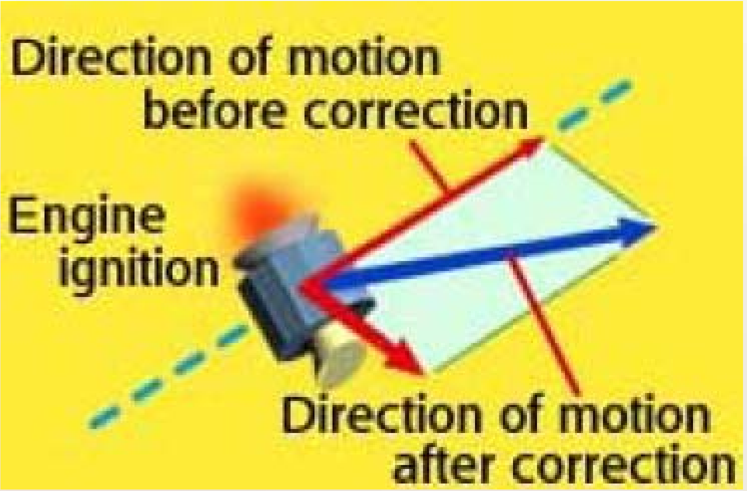
This results in the satellite drifting back through its nominal station position, coming to a stop, and recommencing the drift along the orbit until the jets are pulsed once again.

5- Satellite design (Orbital control)

Orbital correction is carried out by command from the TT&C earth station, which monitors the satellite position. East-west and north south station-keeping maneuvers are usually carried out using the same thrusters as are used for attitude control.

5- Satellite design (Orbital control)

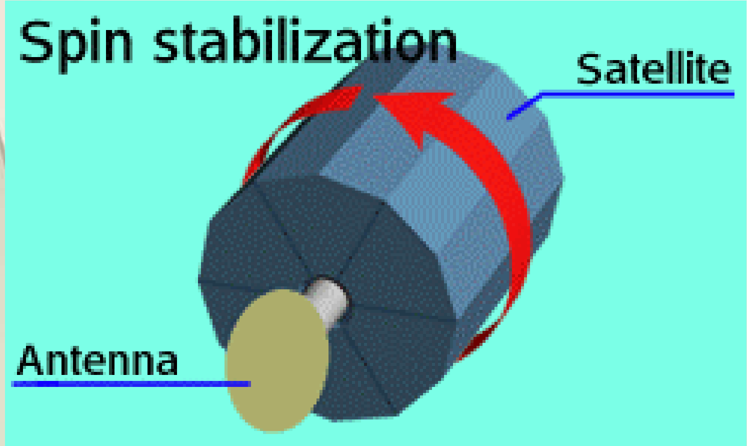
In order for a geostationary communications satellite to continue to function, it must remain stationary with respect to all the earth station antennas that are pointed at it. To correct for the orbital fluctuations that all satellites are subject to, each satellite carries a thrust subsystem to give it an occasional nudge to keep it "On Station."

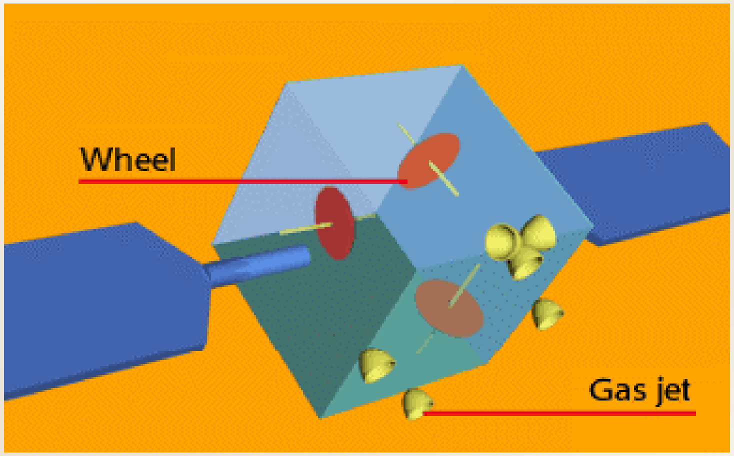


5- Satellite design (Orbital control)

Remaining on-station is only half the battle. Additionally, the satellite's antennas must always be aimed at the same spot on the surface. This requires gyroscopic stabilization of the satellite body. This is accomplished with gyroscopes in one of two configurations:

- Spin stabilization, in which the entire satellite body is spun (antennas are de-spun), or
- Internal gyroscopes





5- Satellite design (Thermal control)

Satellites are subject to large thermal gradients, receiving the sun's radiation on one side while the other side faces into space.

In addition, thermal radiation from the earth and the earth's albedo, which is the fraction of the radiation falling on earth which is reflected, can be significant for low-altitude earth-orbiting satellites, although it is negligible for geostationary satellites.

Equipment in the satellite also generates heat which has to be removed. The most important consideration is that the satellite's equipment should operate as nearly as possible in a stable temperature environment.

5- Satellite design (Thermal control)

In order to maintain constant temperature conditions, heaters may be switched on (usually on command from ground) to make up for the heat reduction which occurs when transponders are switched off.

In INTELSAT VI, heaters are used to maintain propulsion thrusters and line temperatures.

6- Satellite operation

Satellite operations (SatOps) are conducted to:

- Verify and maintain satellite health
- Reconfigure and command the spacecraft
- Detect, identify and resolve anomalies
- Perform launch and early orbit operations.

7- Satellite lifecycle management

In principle, geostationary satellites occupy a fixed position in space and consequently the ground-based antennas do not need to be constantly redirected to follow the satellite's movements.

The fact that the orientation of ground-based antennas is fixed is a major advantage of the geostationary satellite orbit used by satellite broadcasters.

In practice however, the satellite wanders slightly around its nominal orbital position under the gravitational influence of bodies such as the Sun and the Moon, as well as other influences such as Sun radiation pressure and Earth asymmetry.

7- Satellite lifecycle management

It is therefore necessary to take corrective actions in order to keep the satellite within acceptable margins from its ideal position. This is achieved by activating the so-called ‘thrusters’ that are mounted on the body of the satellite as part of its propulsion system.

As long as the satellite has enough fuel left to operate its thrusters, it can be kept in the correct position. Typically this is 10 – 15 years. As soon as the satellite is out of fuel, it will drift out of control and into space, which brings an end to its operational life.

7- Satellite lifecycle management

The satellite service operator can decide to save on fuel (and by consequence extend the lifetime expectancy of a satellite) by allowing the satellite to drift a little bit.

This is known as an inclined orbit. Although this may bring down the costs for the communication via this satellite, there is a consequence on the Earth station side. These stations have to be equipped for tracking (following the drift of) the satellite.

8- Tracking Telemetry and Control (TT&C)

A satellite communications system can be broadly divided into two segments :

- a ground segment
- and a space segment.

The space segment will obviously include the satellites, but it also includes the ground facilities needed to keep the satellites operational, these being referred to as the *tracking, telemetry, and command* (TT&C) facilities. In many networks it is common practice to employ a ground station solely for the purpose of TT&C.

8- Tracking Telemetry and Control (TT&C)

An acronym for the satellite subsystem Telemetry, Tracking, and Control. TT&C refers to the brain of a satellite and its operating system.

TT&C is the satellite's method for storing and analyzing the data it collects, and controlling its various systems.

It also logs every activity of the satellite, receives information from the ground station, and takes care of any general upkeep, or "housekeeping", the satellite needs to do.

8- Tracking Telemetry and Control (TT&C)

Telemetry system

The telemetry, tracking, and command (TT&C) subsystem performs several routine functions abroad a spacecraft.

The telemetry or "telemetering" function could be interpreted as "measurement at a distance".

Specifically, it refers to the over all operation of generating an electrical signal proportional to the quantity being measured, and encoding and transmitting this to a distant station, which for the satellite is one of the earth stations.

8- Tracking Telemetry and Control (TT&C)

Telemetry system

Data that are transmitted as telemetry signals include attribute information such as obtained from sun earth sensors; environmental information such as magnetic field intensity and direction; the frequency of meteorite impact and so on ;and spacecraft information such as temperatures and power supply voltages, and stored fuel pressure.

8- Tracking Telemetry and Control (TT&C)

Command systems

Command system receives instructions from ground system of satellite and decodes the instruction and sends commends to other systems as per the instruction.

8- Tracking Telemetry and Control (TT&C)

Tracking

Tracking of the satellite is accomplished by having the satellite transmit beacon signals which are received at the TT&C earth stations.

Tracking is obviously important during the transmitter and drift orbital phases of the satellite launch.

When on-station, a geo-stationary satellite will tend to shifted as a result of the various distributing forces, as described previously .Therefore it is necessary to be able to track the satellites movements and send correction signals as required.

8- Tracking Telemetry and Control (TT&C)

TT&C Earth Station

9- Satellite footprint

The geographic area of the Earth's surface over which a satellite can transmit to, or receive from, is called the satellite's "footprint." The footprint can be tailored to include beams with different frequencies and power levels.

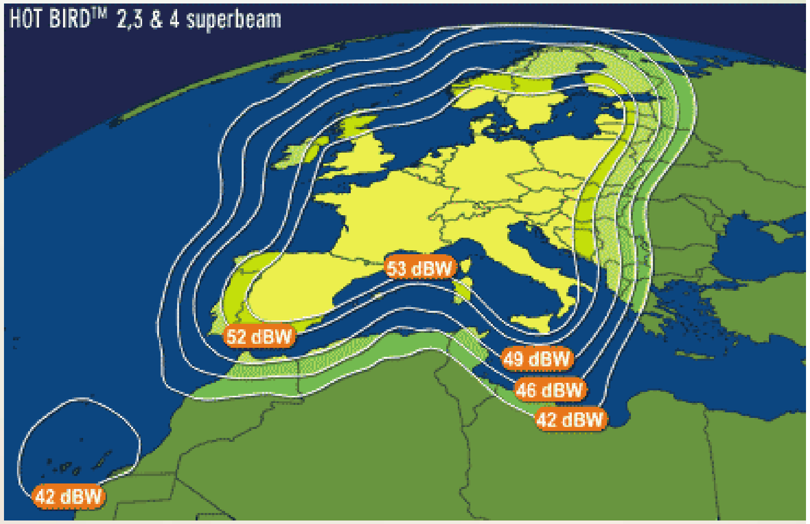
Regional Coverage Eutelsat W1

Spotbeam Coverage Eutelsat W1

10- Satellite beams

Modern satellites are designed to focus on different ranges of frequency bands and different power levels at particular geographic areas. These focus areas are called beams. Intelsat offers four beam types:

- Global: covering almost 1/3 of Earth's surface
- Hemi: covering almost 1/6 of Earth's surface
- Zone: covering a large landmass area
- Spot: covering a specific geographic area



End of Day 1 course

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