Ingegneria delle Telecomunicazioni

Satellite Communications

5. How it's Made (Sat Architecture)

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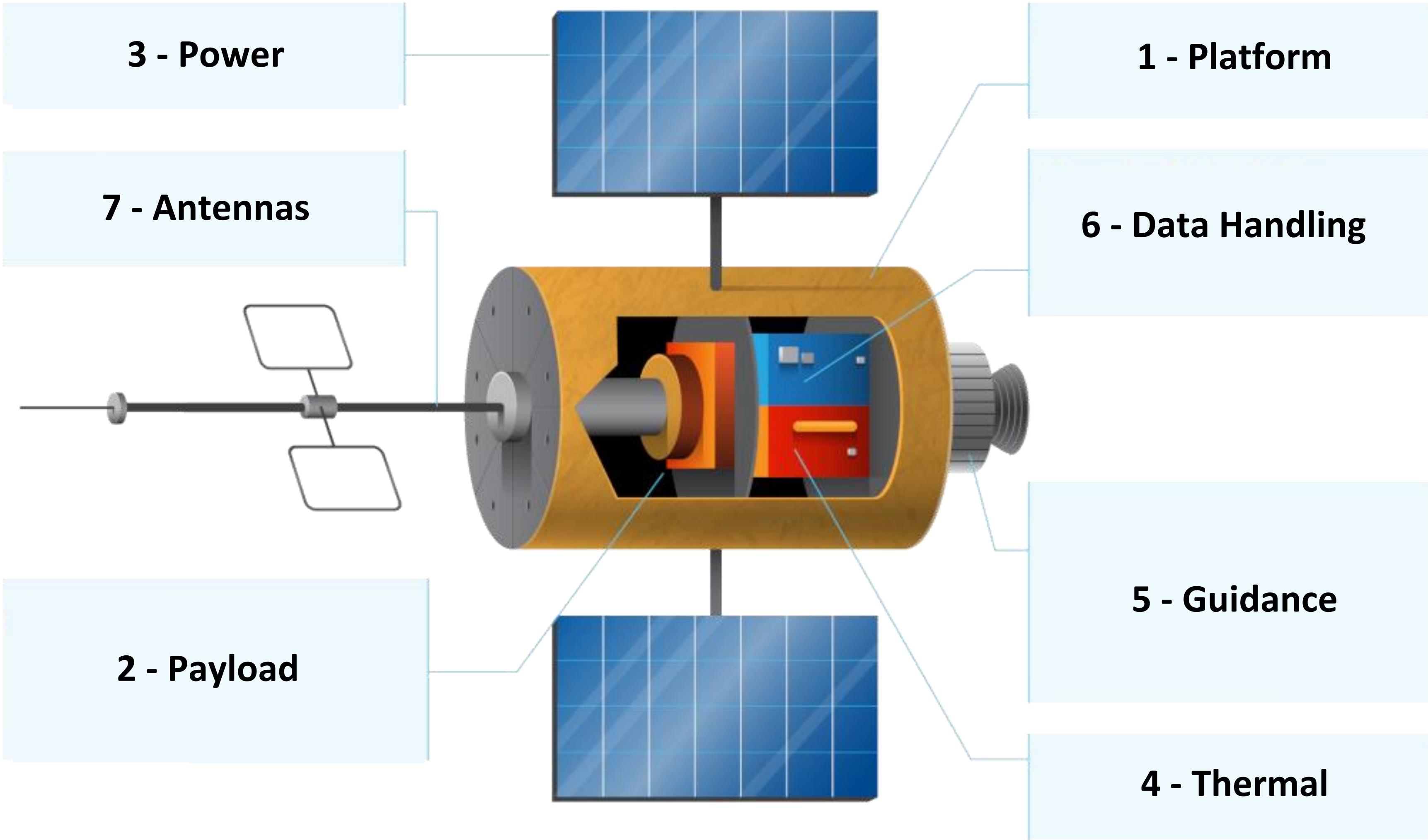
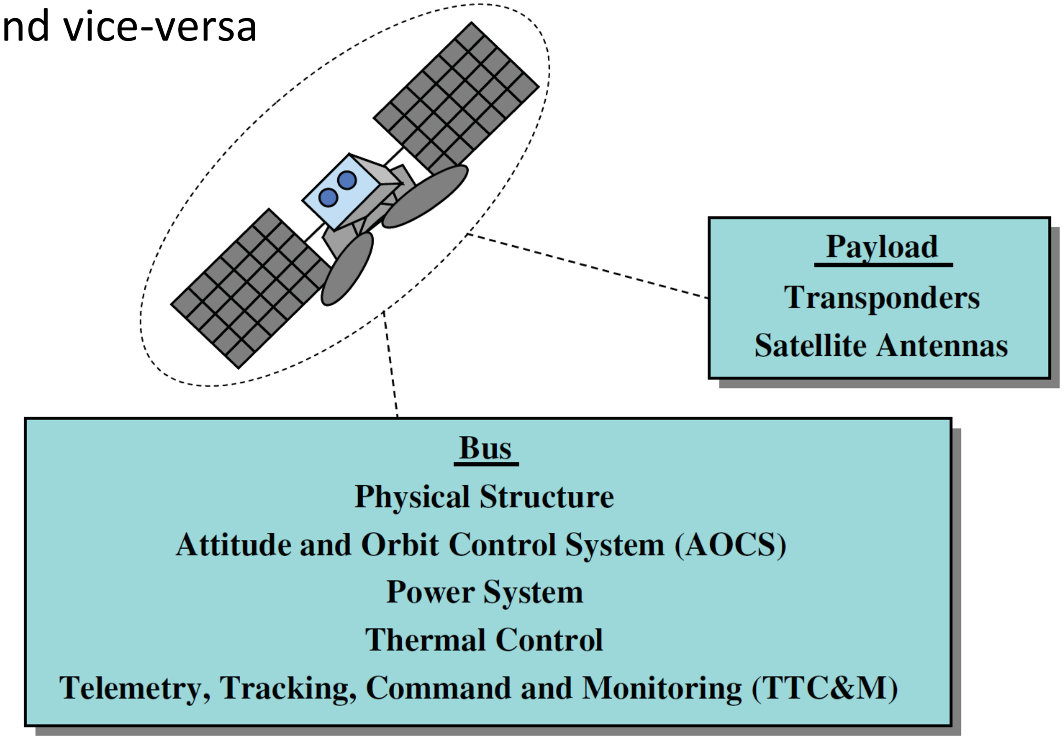
Satellite Anatomy

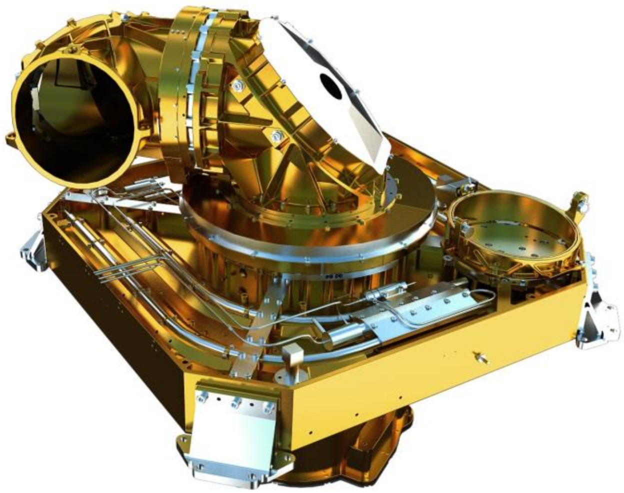


Main Components

- **1 - Platform (aka Bus)**
  - Satellite structure and ancillary subsystems – not directly involved in communication links and possibly shared by different payloads
- **2 - Payload (more later on)**
  - All the equipment that is needed to establish a (digital) link between Earth and space and vice-versa



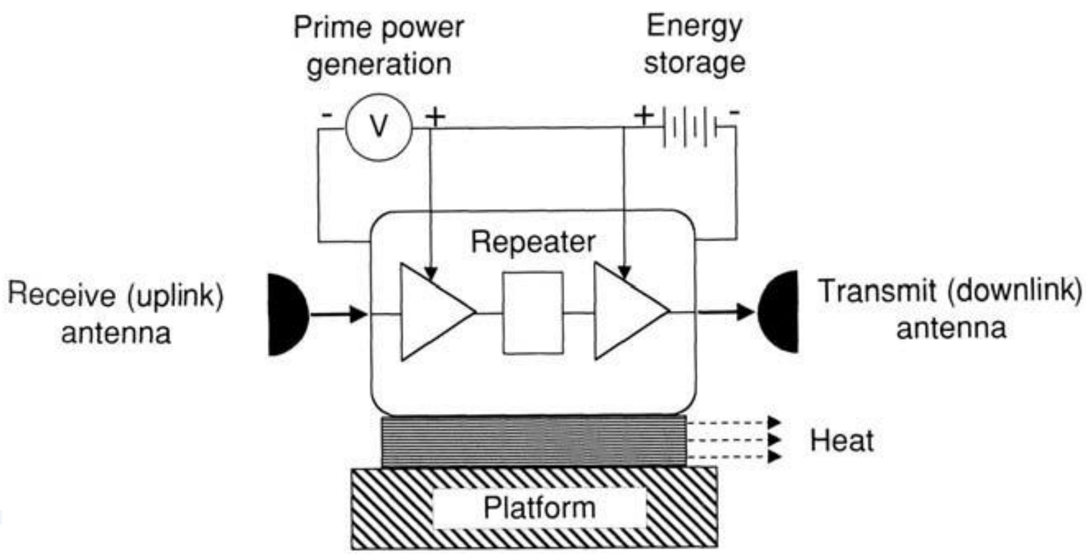
Payloads of AlphaSat



- An **advanced laser communications terminal** to link from geostationary to low-Earth orbit, contributed by German space agency DLR with Tesat-Spacecom
- A **Q-V band communications experiment** to assess the feasibility of these unexploited bands for future commercial applications, overseen by Space Engineering S.p.A.
- An **advanced star tracker** with Active Pixel Sensor technology, offering enhanced radiation tolerance and dynamic range, developed by Galileo (Leonardo)
- An **environmental effects facility** to monitor the geostationary radiation environment and its effects on electronic components and sensors. This Alphasat Environment and Effects Facility (AEEF) is the work of a consortium led by RUAG Space Switzerland (formerly Oerlikon Space).

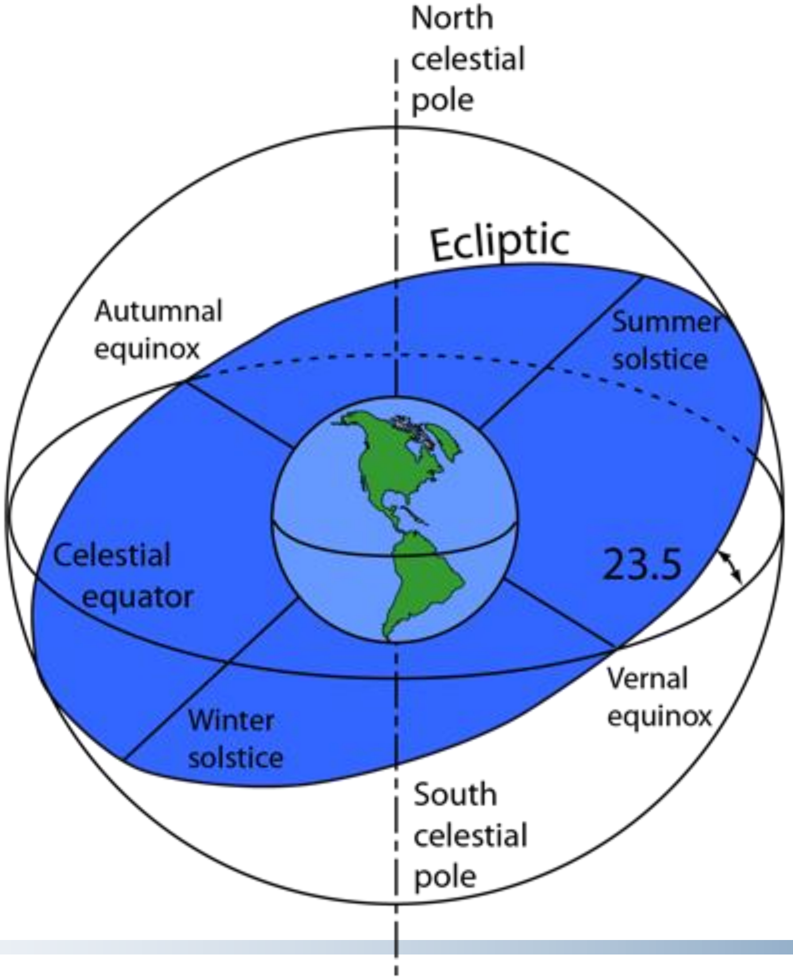
3 - Power Subsystem

- The electrical power for operating equipment on a communications satellite is obtained primarily from **solar cells**, which convert incident sunlight into electrical energy. The radiation on a satellite from the sun has an intensity averaging about 1.4 kW/m2.
- Solar cells operate at an efficiency of 20–25% at ***beginning of life*** (BOL), and can degrade to 5–10% at ***end of life*** (EOL), usually considered as 15 years
- All spacecraft must also carry storage **batteries** to provide power during launch and during **eclipse periods** when sun blockage occurs.

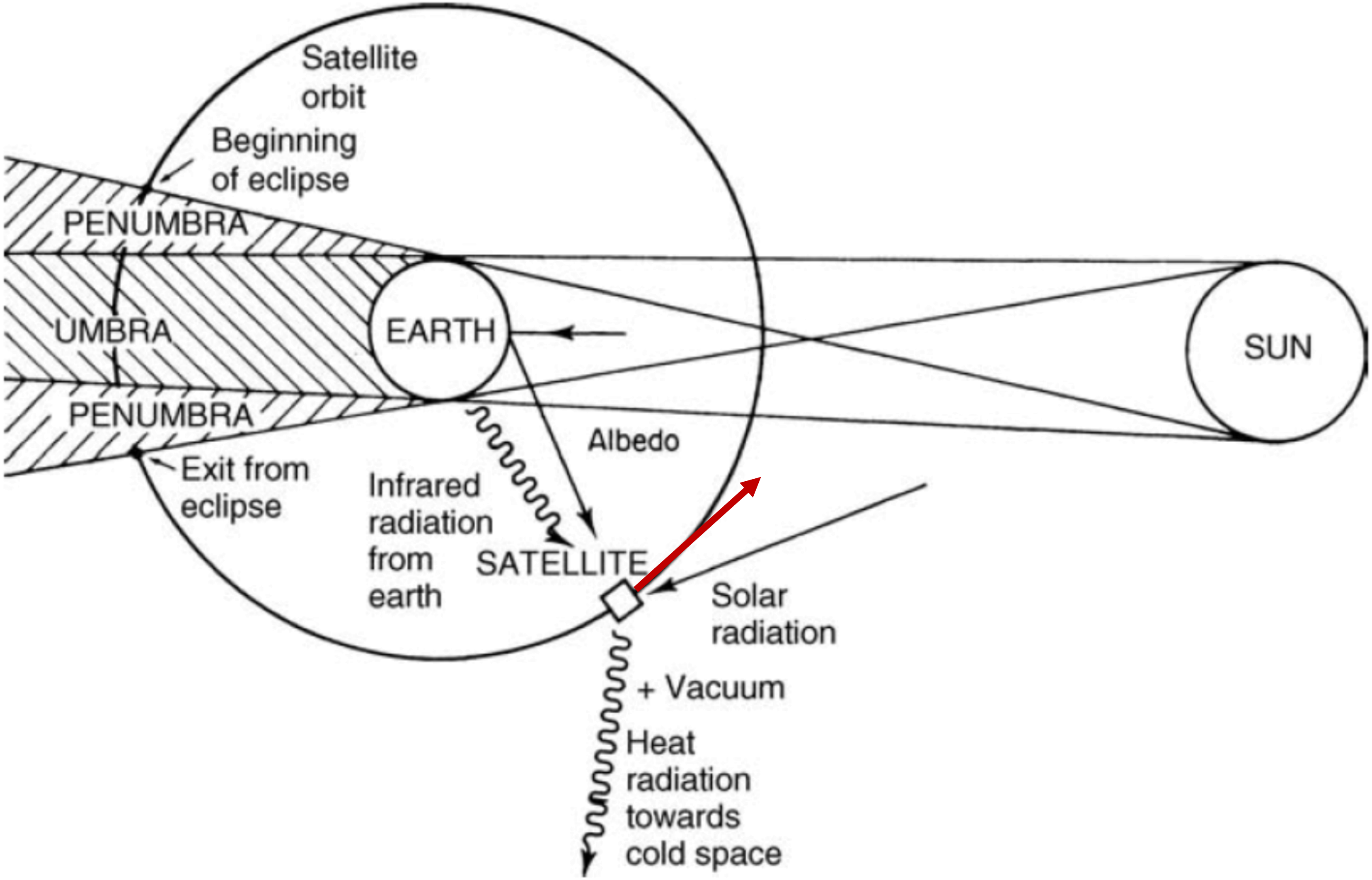


Eclipses 1/4

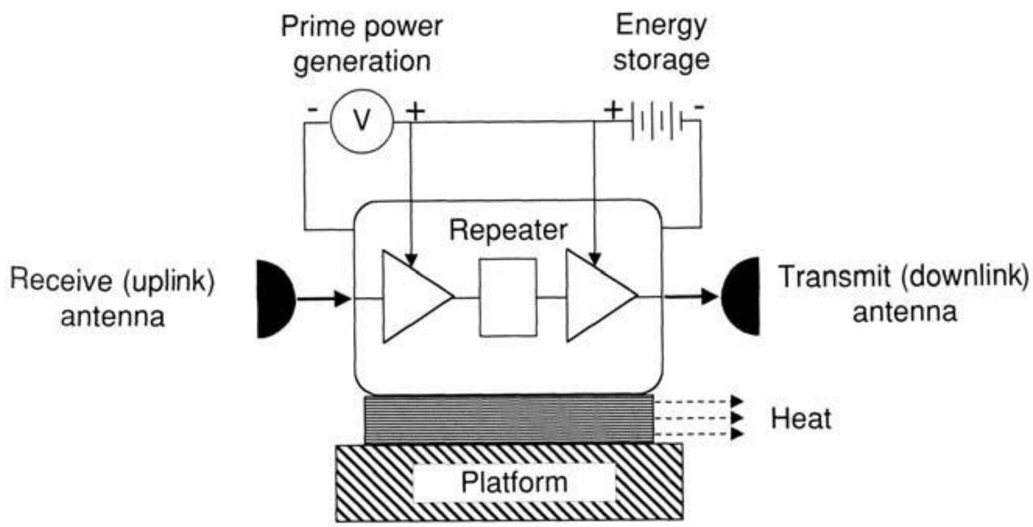
- **The Earth equatorial plane (i.e., the orbital plane of the satellite) is slant wrt the orbital plane of the Earth (the *ecliptic* plane) by 23.5 degrees**



Eclipses 2/4

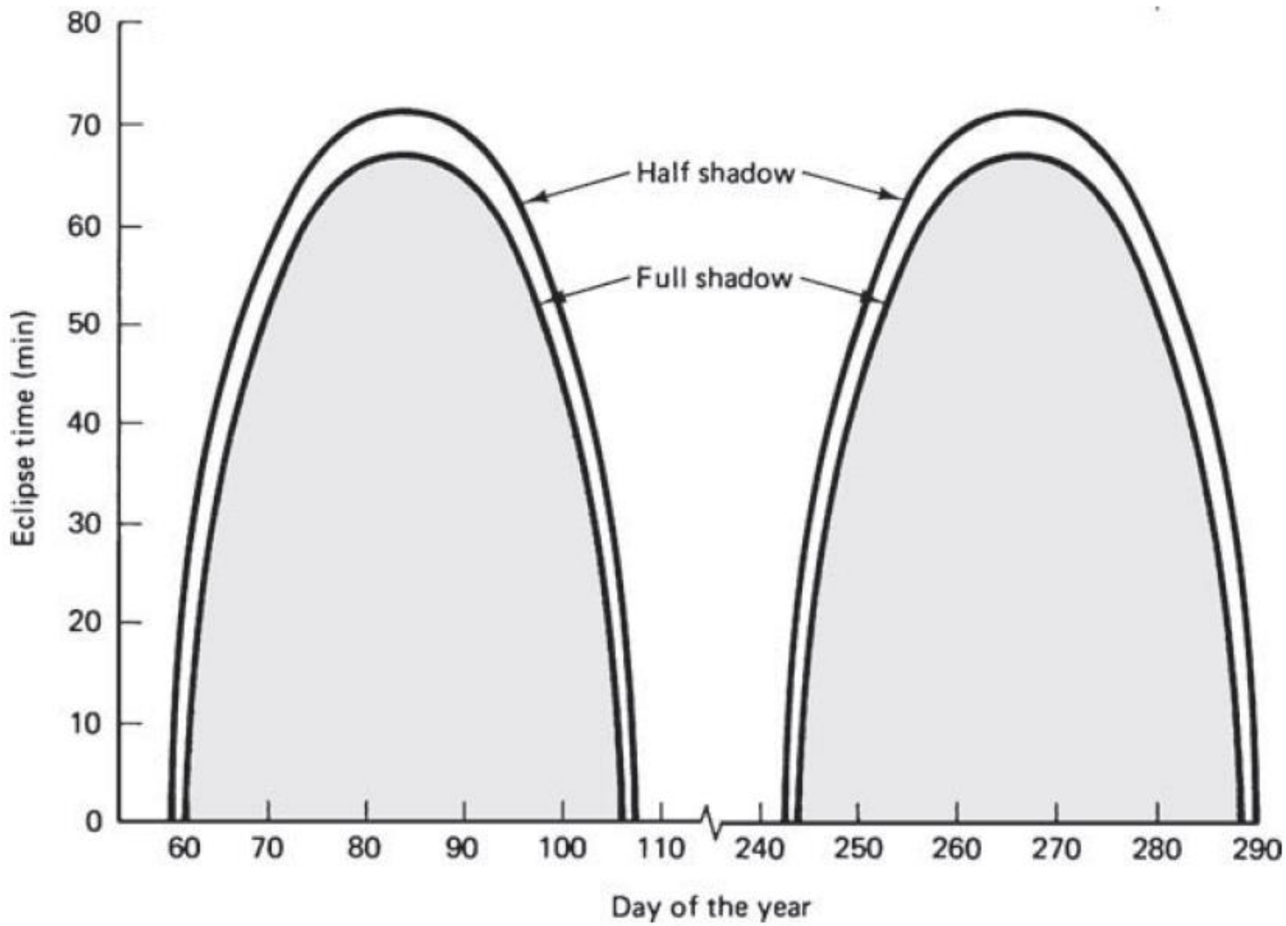

Satellite
orbit
Beginning
of eclipse
PENUMBRA
UMBRA
PENUMBRA
EARTH
SUN
Albedo
Exit from
eclipse
Infrared
radiation
from
earth
SATELLITE
Solar
radiation
+ Vacuum
Heat
radiation
towards
cold space

Eclipses 3/4



- Eclipses occur for a GEO satellite twice a year, around the *spring and fall equinoxes* (28 February to 11 April and 2 September to 14 October). They start about 23 days before the equinox, and end the same number of days after. The daily eclipse duration increases a few minutes each day to about a **70-minute peak on equinox day**, then decreases a similar amount each day following the peak
- The power generating and control systems on a communications satellite account for a large part of its weight, often 10 to 20% of total dry weight.

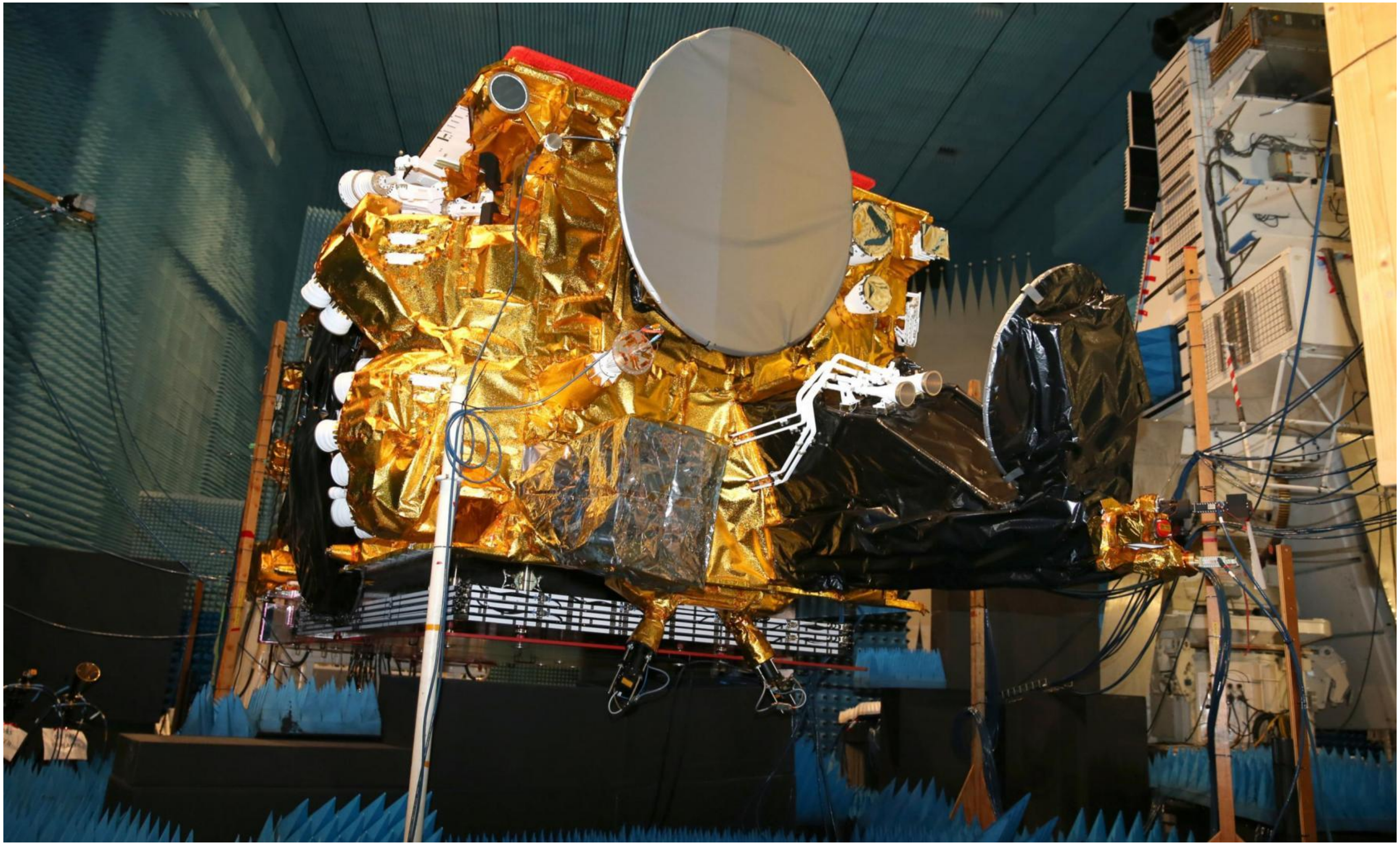
Eclipses 4/4


80
70
60
50
40
30
20
10
0
Eclipse time (min)
Half shadow
Full shadow
60
70
80
90
100
110
240
250
260
270
280
290
Day of the year

4 - Thermal Control 1/2

- Thermal radiation from the sun heats one side of the spacecraft, whereas the side facing outer space is exposed to the extremely low temperatures of space
- Equipment in the satellite generates heat, which must be controlled
- Low orbiting satellites can also be affected by thermal radiation reflected from the Earth itself.
- Control is carried out by means of:
  - Thermal blankets
  - Thermal Shields
  - Radiation mirrors
  - Heat pumps
- It may happen during eclipses that you need to heat up some components (thrusters) with:
  - Heaters

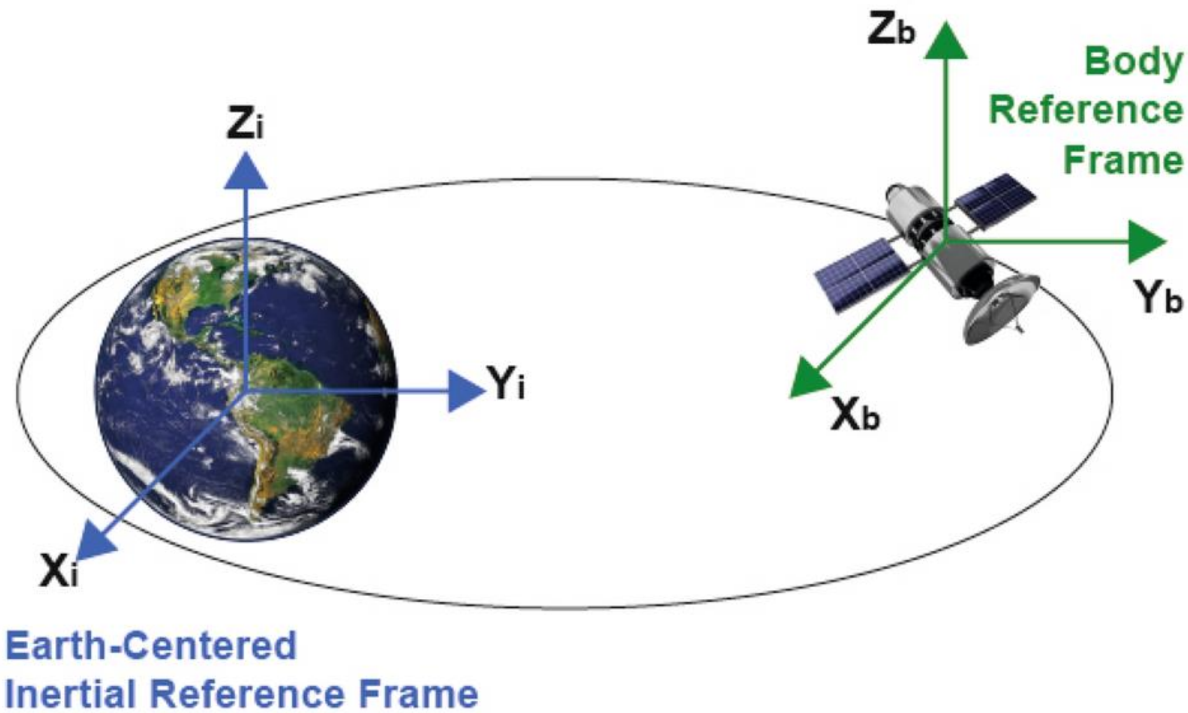
4 - Thermal Control 2/2



SES-14 Satellite (Astra)

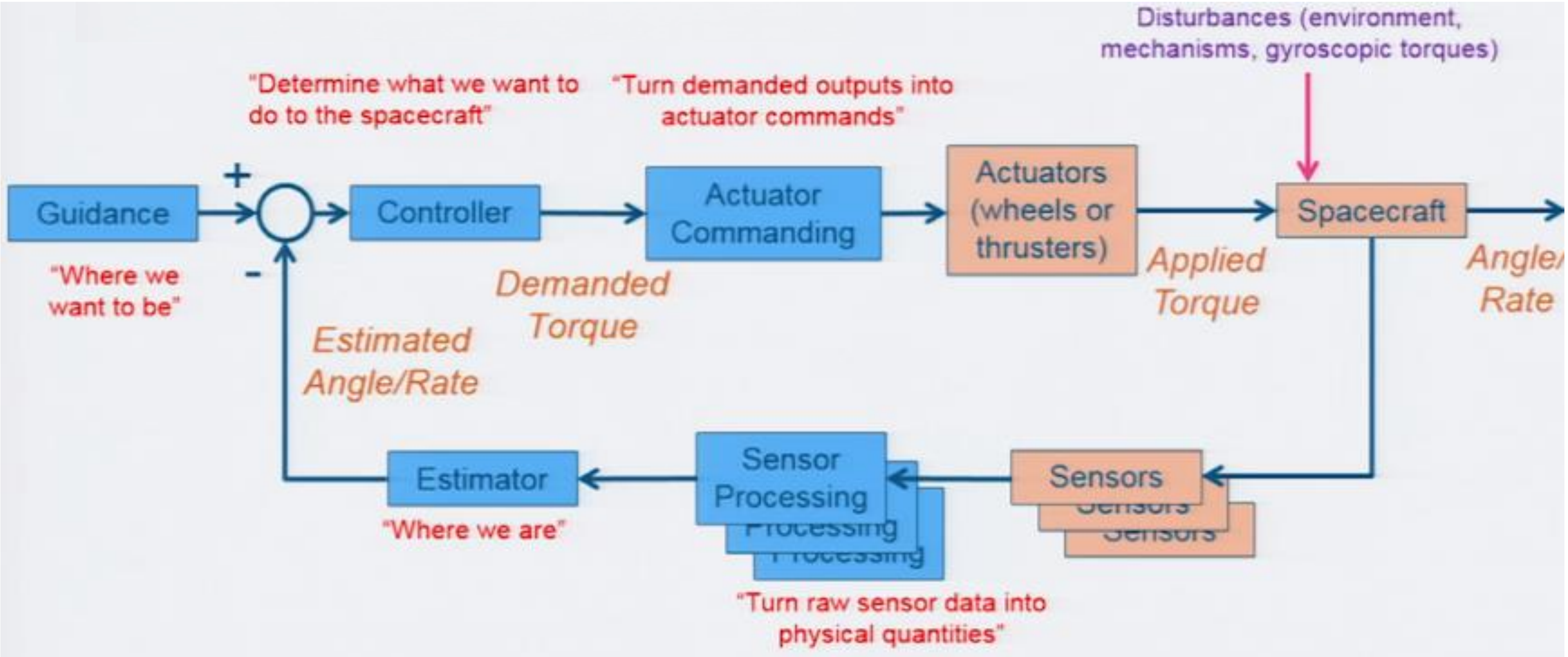
5 - Attitude Control 1/2

- The ***attitude*** of a satellite refers to its orientation in space with respect to Earth.
- Attitude control is necessary so that the antennas, which usually have narrow directional beams, are pointed correctly towards earth.



5 - Attitude Control 2/2

- Orientation is monitored on the spacecraft by infrared ***horizon detectors***, which detect the rim of earth against the background of space.
- Four detectors are used to establish a reference point, usually the center of the Earth, and any shift in orientation is detected by one or more of the sensors.



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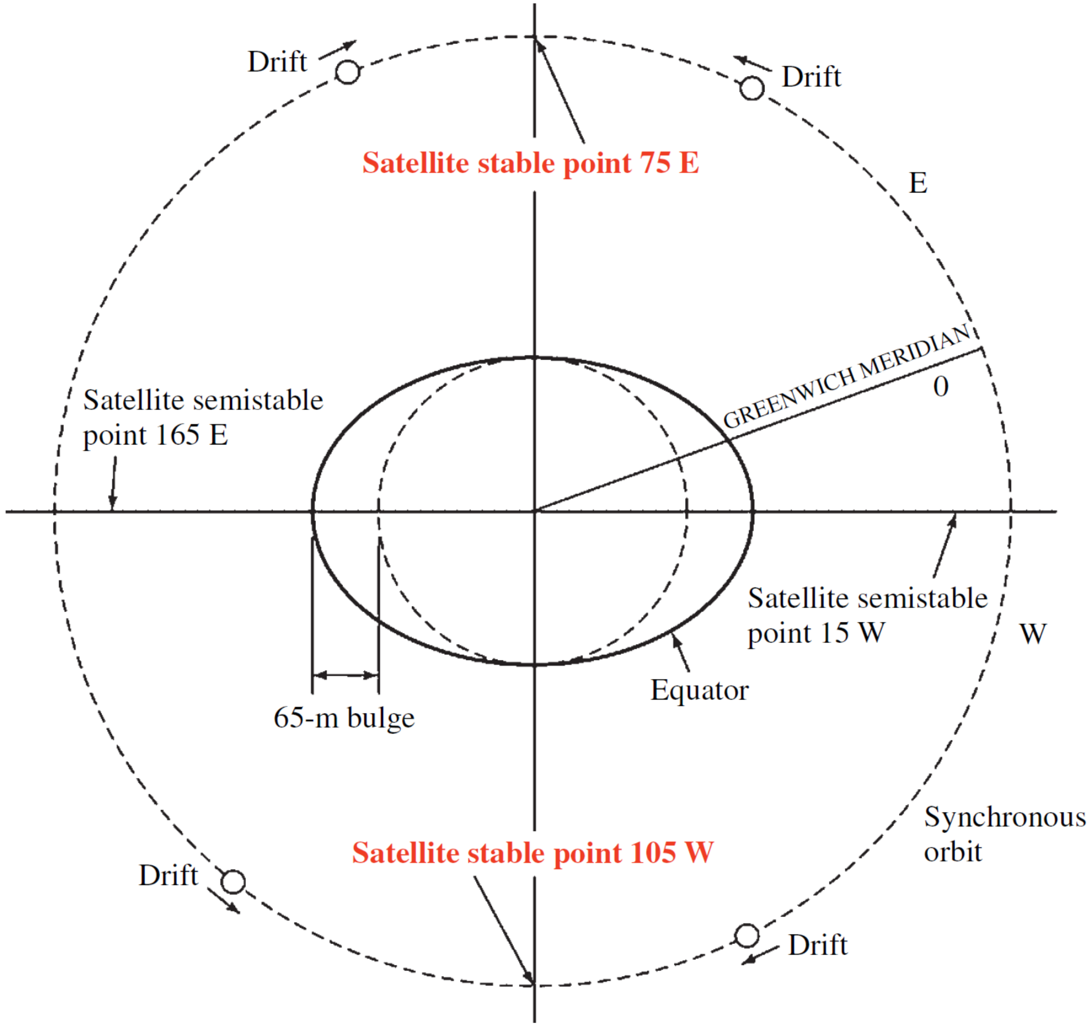
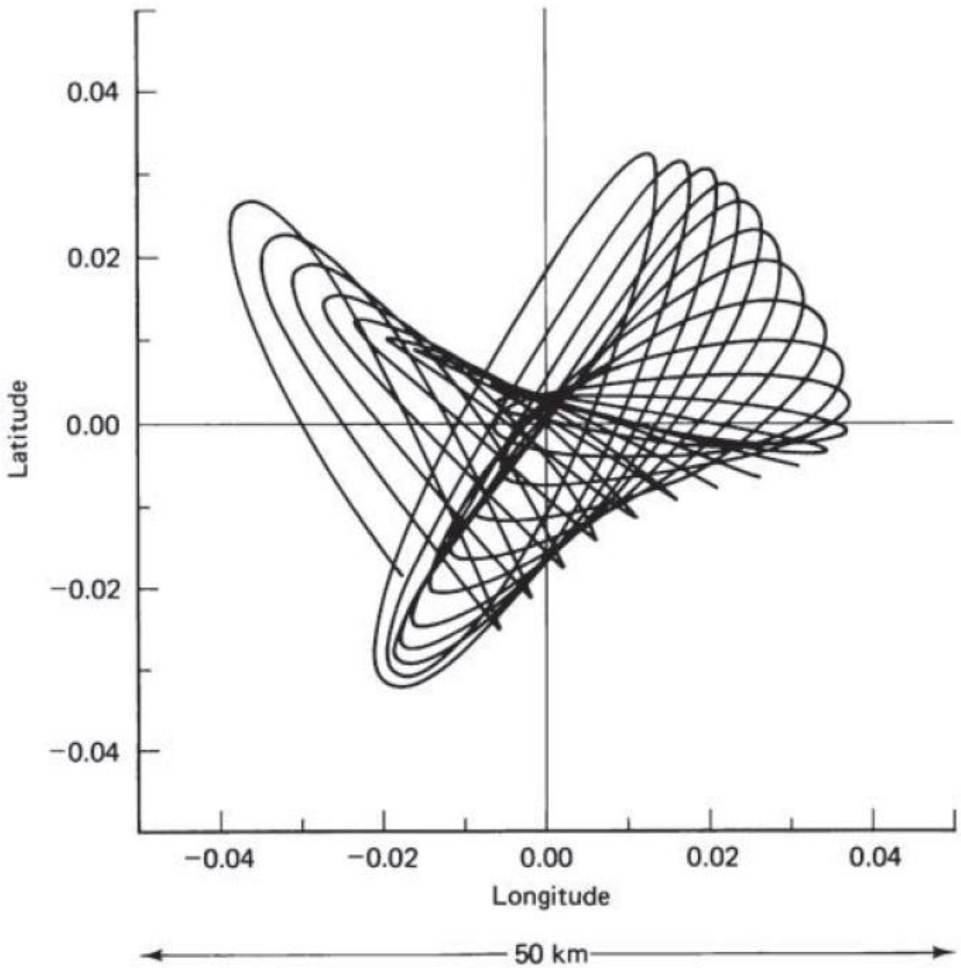
5 - Orbital Control 1/2

- Orbital control, often called ***station keeping***, is the process required to maintain a satellite in its proper orbit location.
- It is similar to, although clearly not the same, as attitude control
- Accuracy down to a tenth of a degree
- Not all points on the GEO orbit are actually stable since the Earth is ***not*** spherical !



GEO Satellite motion

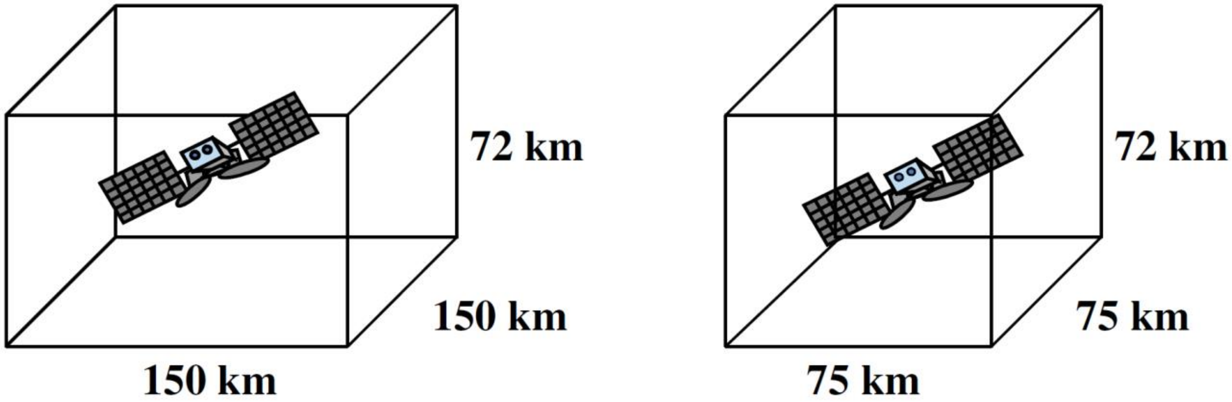


5 - Orbital Control 2/2

Most expensive to maintain (Inclination Angle)

ALTITUDE :

± 1%		(~ 72 Km for GSO)
NORTH-SOUTH / EAST-WEST		
± 0.1 degrees	for C-band	(~ 150 km for GSO)
± 0.05 degrees	for K_u-band	(~ 75 km for GSO)

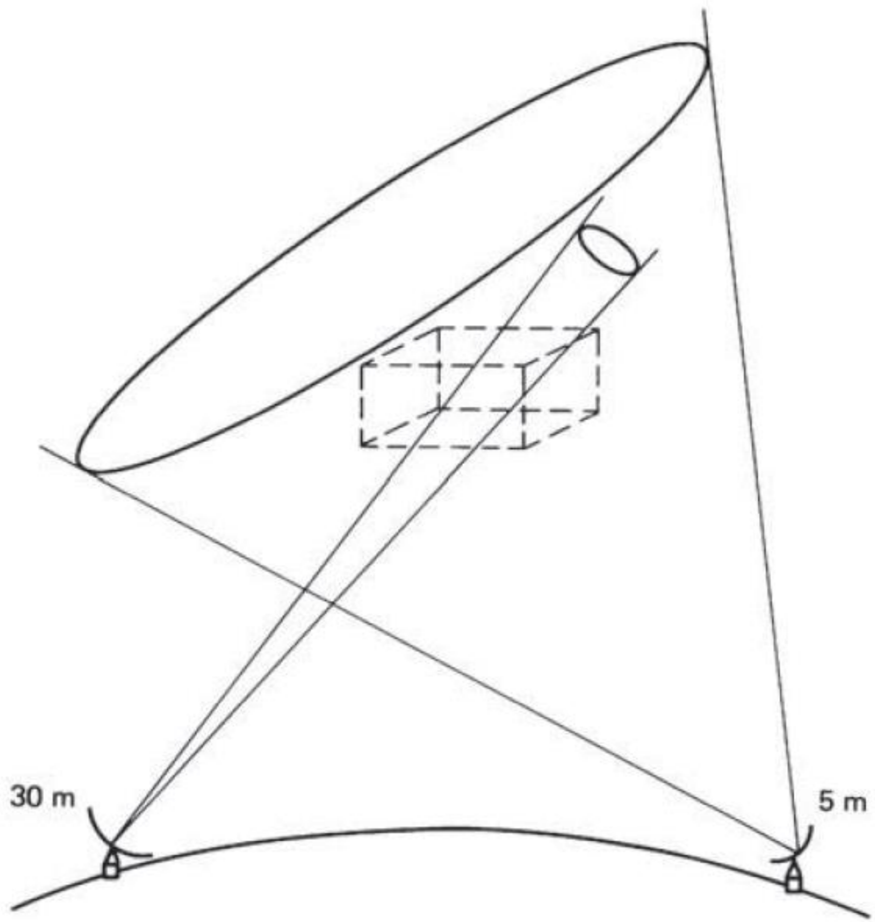


C-band Box

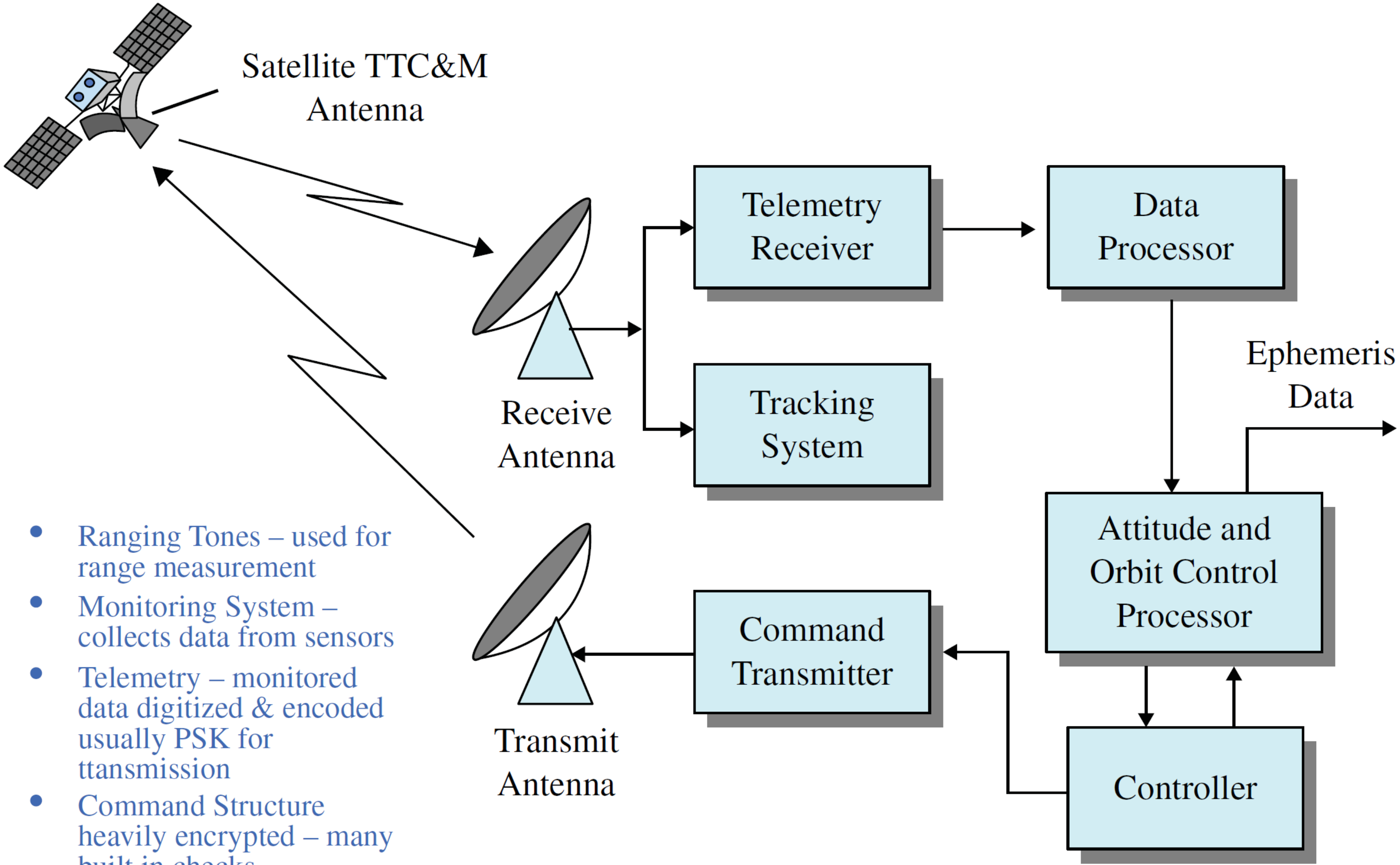
Ku-band Box

The specs of orbital control can be translated into “boxes” around the nominal orbital point, into which the satellite must be confined

Why are “Boxes” important?



6 - TTC&Monitoring



- Ranging Tones – used for range measurement
- Monitoring System – collects data from sensors
- Telemetry – monitored data digitized & encoded usually PSK for ttansmission
- Command Structure heavily encrypted – many built in checks

6 - Tracking

- ***Tracking*** refers to the determination of the current orbit, position, and movement of the spacecraft.
- The tracking function is accomplished by a number of techniques
  - Doppler shift of telemetry carrier is monitored to determine the rate at which the range is changing (the range rate)
  - The range can be determined by observing the time delay of a pulse or sequence of pulses transmitted from the satellite
  - Angular measurements from one or more earth terminals can be used to determine spacecraft location.
  - Acceleration and velocity sensors on the satellite can be used to monitor “local” changes in orbital location.

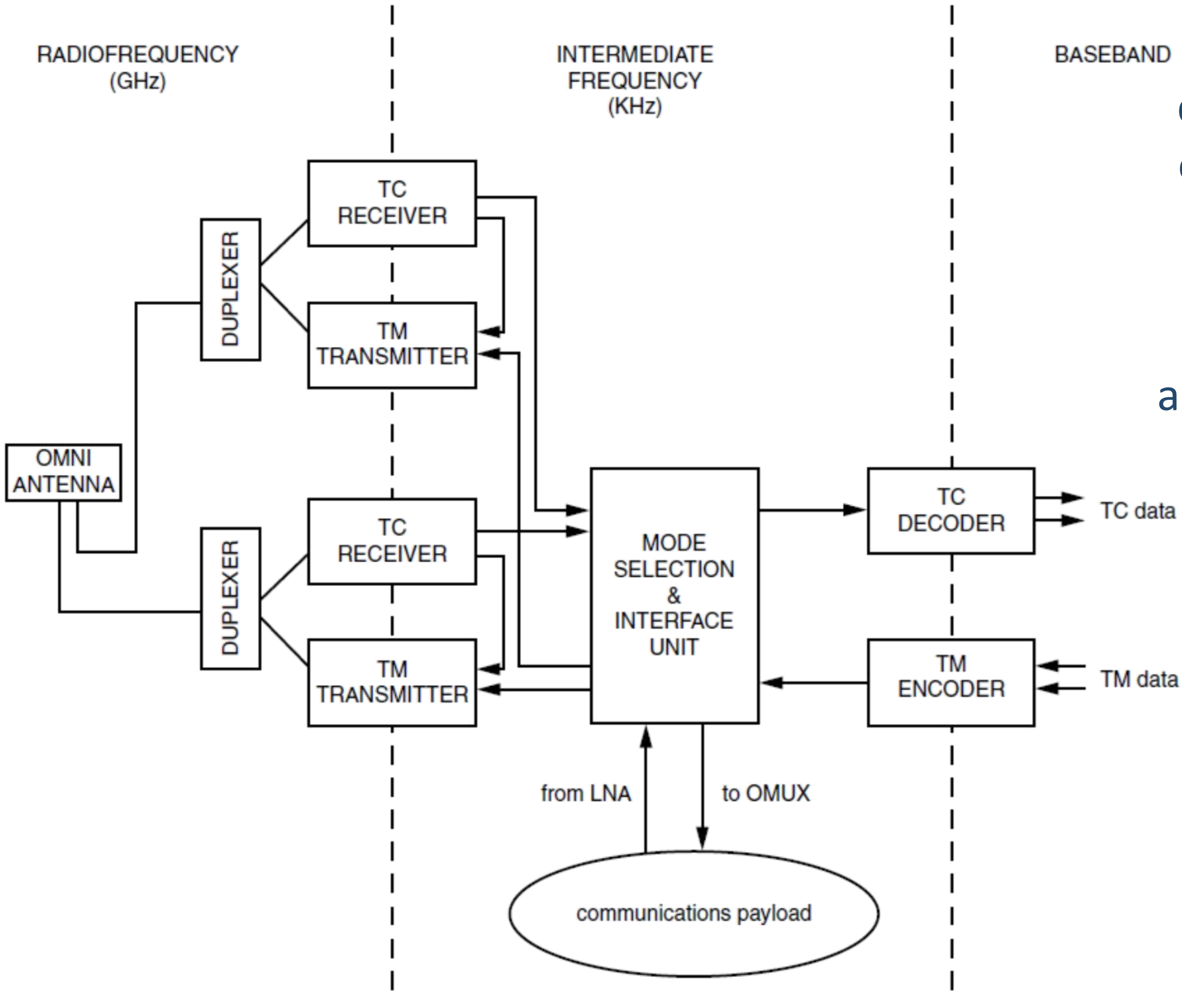
6 - Telemetry

- ***Telemetry*** involves the collection of data from sensors on-board the spacecraft and the relay of this information to the ground.
- The telemetered data include parameters as:
  - voltage and current conditions in the power subsystem
  - temperature of critical subsystems
  - status of switches and relays in the communications and antenna subsystems
  - fuel tank pressure
  - attitude control sensor status
  - IN SUMMARY more than 100 channels of sensor information, for diagnostic evaluations.
- Telemetry channel data rates are low, usually *only a few kbps*.
- Telemetry links has nothing to do with the diverse digital links of a communications satellite

6 - Command

- ***Command*** is the complementary function to telemetry. The command system relays specific control and operations information from the ground to the spacecraft, often in response to telemetry information received from the spacecraft
- Parameters involved in typical command links include:
  - changes and corrections in attitude control and orbital control;
  - antenna pointing and control;
  - transponder mode of operation;
  - battery voltage control.
- The command system is used during launch to control the firing of the boost motor, deploy appendages such as solar panels and antenna reflectors, and 'spin-up' a spin-stabilized spacecraft body.
- The format of the command system must contain safeguards against intentional or unintentional signals corrupting the command link, or unauthorized commands from being transmitted and accepted by the spacecraft. Command links are nearly always encrypted with a secure code format to maintain the health and safety of the satellite.

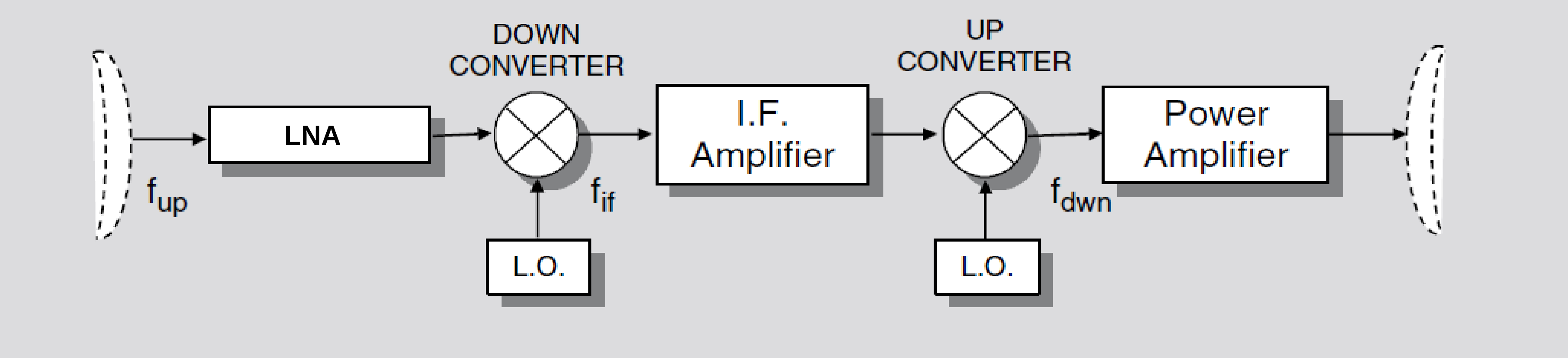
6 - Redundant Systems



Telemetry and command during the launch and transfer orbit phases usually requires a backup TTC&M system, since the main TTC&M system may be inoperable because the antenna is not deployed, or the spacecraft attitude is not proper for transmission to earth. The backup system usually operates with an omnidirectional antenna, at UHF or S-band, with sufficient margin to allow operation in the most adverse conditions.

More on 2 - The Core (or if you wish the Heart)…

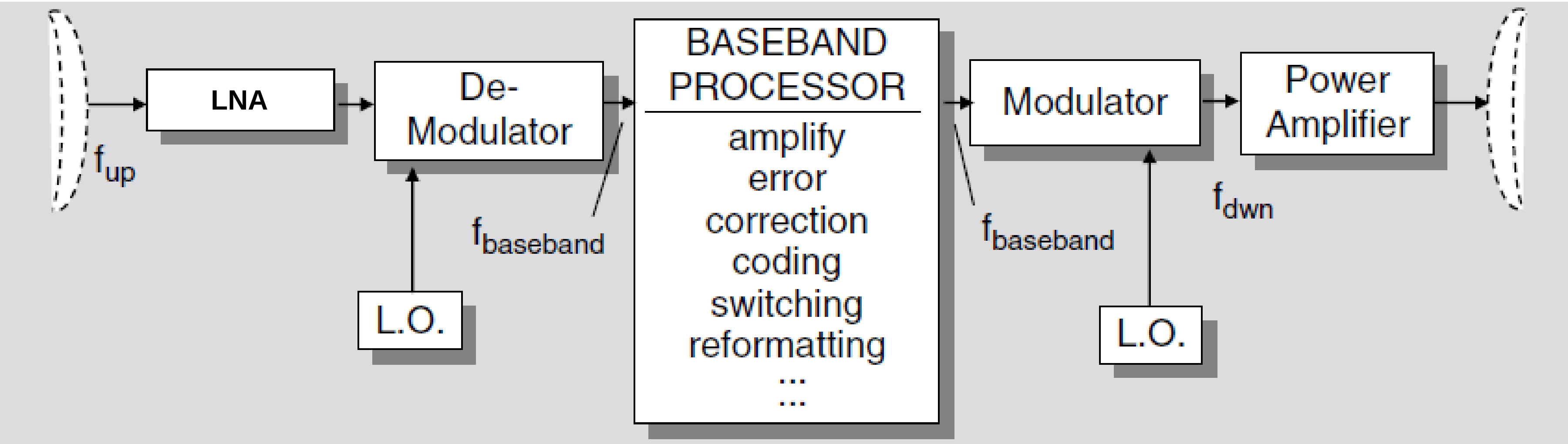
The Nonregenerative TRANSPONDER (bent-pipe, transparent, repeater)



- Just changes the carrier frequency of the incoming signals according to a certain *turnaround ratio*, and sends it down to the Earth
- No signal-processing functions, elementary routing to different antennas/beams
- Very simple and robust, as well as energy-efficient

More on 2 - The Core (or if you wish the Heart)…

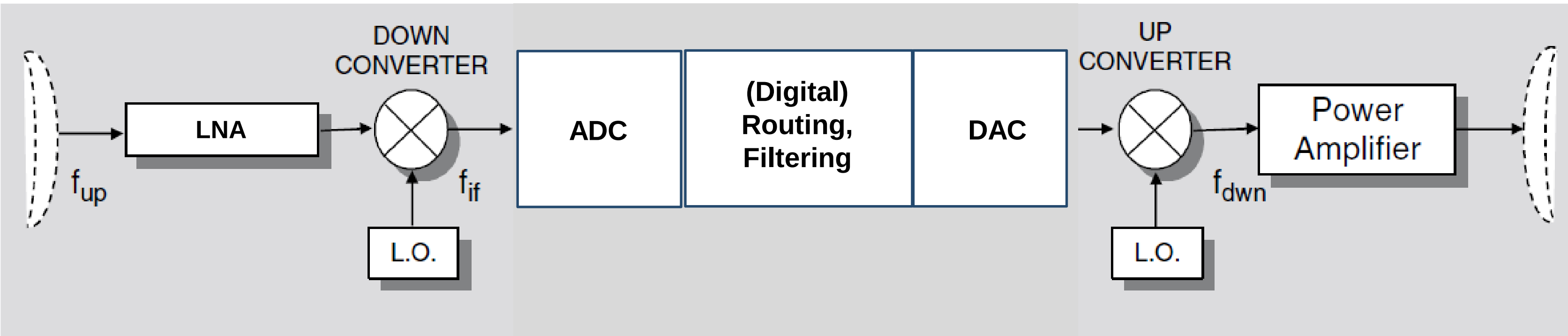
- Performs advanced transmultiplexing & routing functions
- (More) complicated & power-hungry
- Virtually cancels uplink noise like any regenerator



The Regenerative TRANSPONDER (on-board processing)

More on 2 - The Core (or if you wish the Heart)…

The Digital Transparent TRANSPONDER (in-between)



- Performs basically the same functions as the bent-pipe transponder BUT
- Everything is in the digital domain
- Very accurate processing, no need to synchronize/demodulate data wrt regenerative

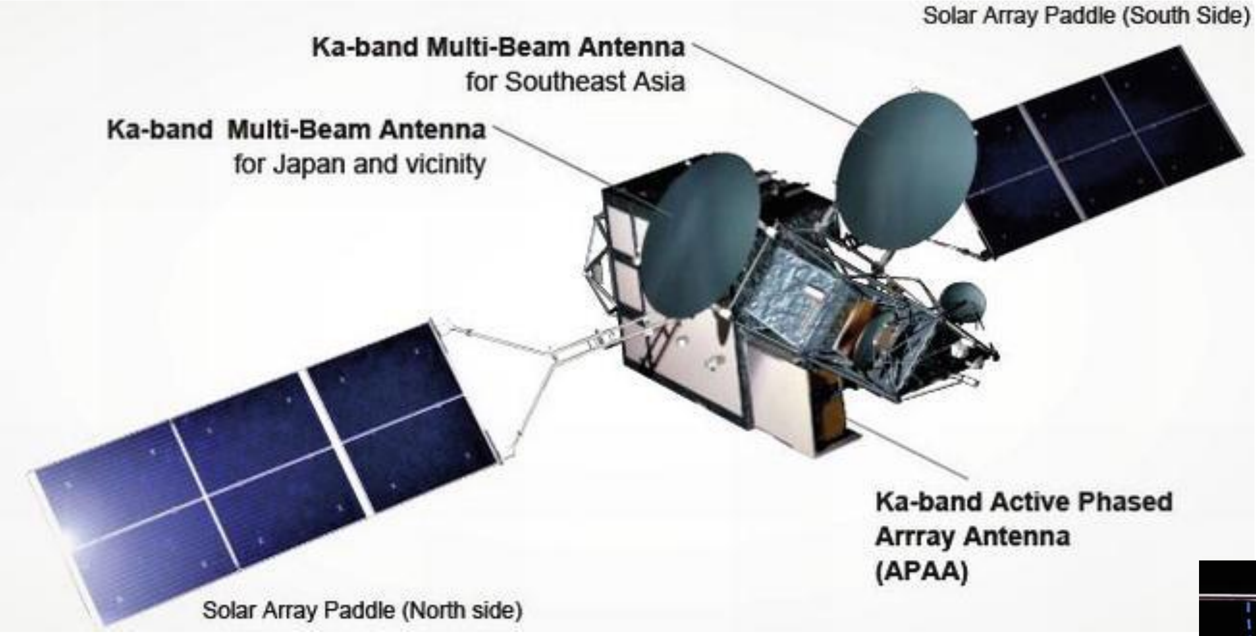
What the Transponder Does

1. Capture the carriers transmitted, in a given frequency band and with a given polarisation, by the earth stations of the network within a certain coverage area;
2. Capture as little interference as possible (the interference is a carrier originating from a different region or not having the specified values of frequency or polarisation);
3. Amplify the received carriers while limiting noise and distortion as much as possible;
4. Change the frequency of the carriers received on the uplinks to that on the downlinks (for example, from 14 to 11 GHz);
5. Provide the power required in a given frequency band at the interface with the transmitting antenna;
6. Radiate the carriers in a given frequency band and with a given polarization on the surface of the Earth.

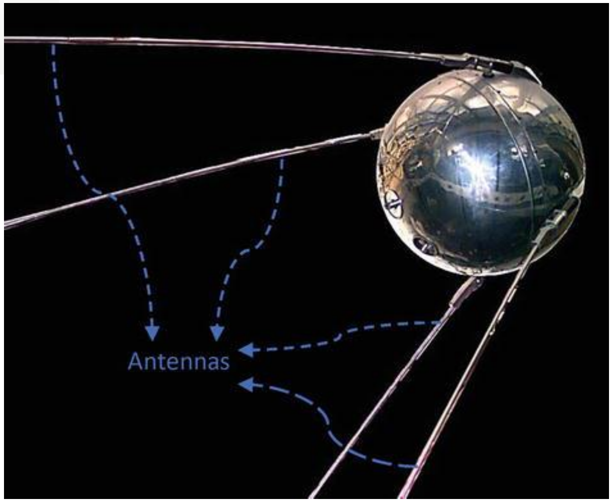
Specifications of the Transponder

1. the transmitting and receiving frequency band and polarization for the various repeater channels;
2. the transmit and receive coverage;
3. the power flux density required at the satellite receiving antenna in order to produce the performance specified at the repeater channel output;
4. the effective isotropic radiated power (*EIRP*) or the power flux density achieved in a given region (satellite transmit coverage);
5. the figure of merit (*G/T*) of the receiving system in a given region (satellite receive coverage);
6. the non-linear characteristics;
7. the reliability after *N* years for a specified number (or percentage) of channels in working order

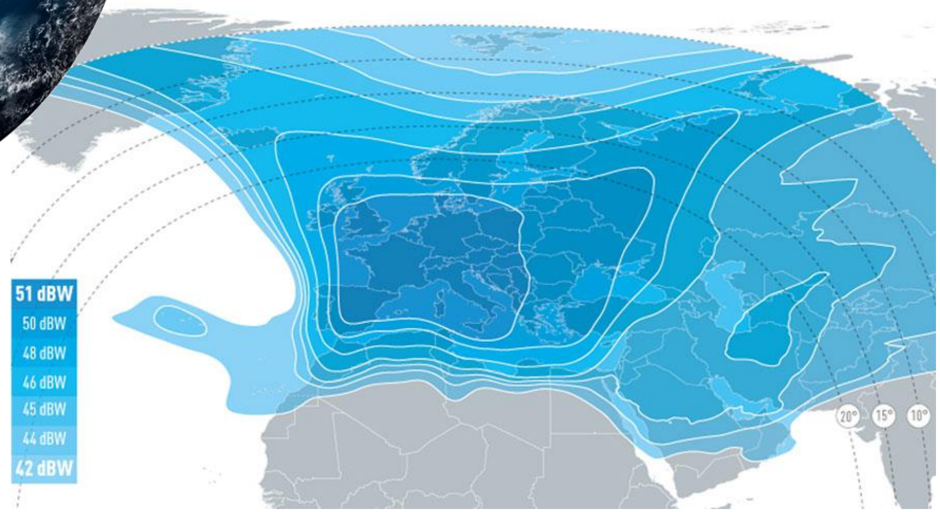
7 - Last but not least...



- Dipole
- Horn
- Reflector
- Phased-Array



7 - Single-Beam Footprint



7 - Multi-Beam Footprint