UNIT II

SPACE SEGMENT

Spacecraft Technology - Structure, Primary Power, Attitude and Orbit Control, Thermal Control and Propulsion, Communication Payload and Supporting Subsystems, Telemetry, Tracking and Command – Transponders - The Antenna Subsystem.

Introduction

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.

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.

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.

SPACE CRAFT CONFIGURATION

- ✓ The spacecraft provides a platform on which the communications equipment can function and maintains this platform in the chosen orbit.
- ✓ The design of the spacecraft is a complicated exercise involving just about every branch of engineering and physics.
- ✓ The interrelations among the requirements for communication performance, the need to provide a begin environment for the communication equipment, and the problems of launching into the desired orbit constitute the subject of space systems engineering.

SPACECRAFT DESING

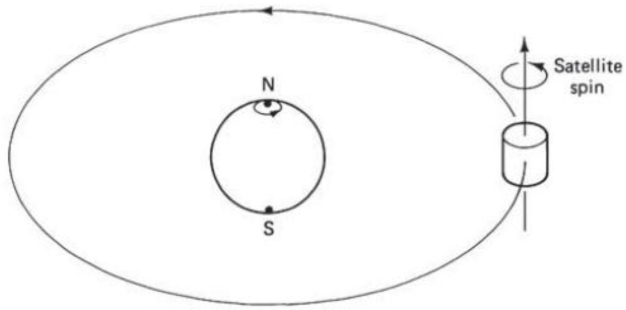
- ✓ **Methods of stabilization:** The principal characteristic of a communication satellite is its method of stabilization.
- ✓ The method adopted depends on both tangible factors, such as the type of orbit and the specification of the payload, and intangibles, such as design philosophy and compatibility with existing satellites within the system.
- ✓ Methods of stabilization may be divided into two categories: ***passive and active.***

Passive methods: Include gravity-gradient stabilization and magnetic damping, which are methods that have been used on some small, low-earth-orbiting spacecraft.

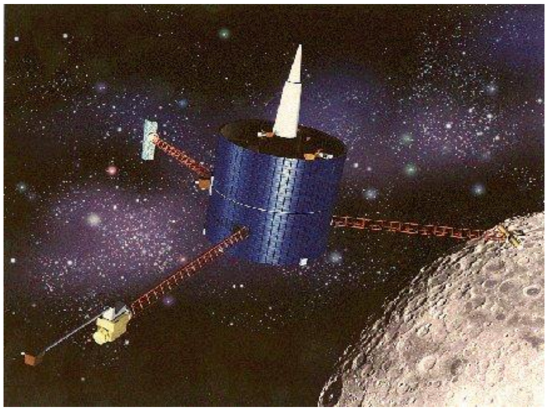
Active methods: Include spin stabilization and three axis stabilization. These are the only two viable alternatives for geostationary satellites.

Spinning satellite stabilization:

- ✓ Spin stabilization may be achieved with cylindrical satellites.
- ✓ The satellite is constructed so that it is mechanically balanced about one particular axis and is then set spinning around this axis.
- ✓ For geostationary satellites, the spin axis is adjusted to be parallel to the N-S axis of the earth, as illustrated in Figure, Spin rate is typically in the range of 50 to 100 rev/min.



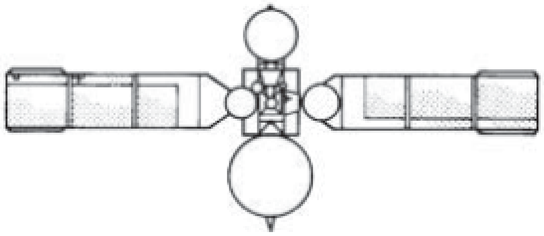
- ✓ Spin is initiated during the launch phase by means of small gas jets.
- ✓ In the absence of disturbance torques, the spinning satellite would maintain its correct attitude relative to the earth.
- ✓ Disturbance torques are generated in a number of ways, both external and internal to the satellite. Solar radiation, gravitational gradients, and meteorite impacts are all examples of external forces which can give rise to disturbance torques.
- ✓ Motor-bearing friction and the movement of satellite elements such as the antennas also can give rise to disturbance torques.
- ✓ The overall effect is that the spin rate will decrease, and the direction of the angular spin axis will change.
- ✓ Impulse-type thrusters, or jets, can be used to increase the spin rate again and to shift the axis back to its correct N-S orientation.
- ✓ ***Nutation,*** which is a form of wobbling, can occur as a result of the disturbance torques and/or from misalignment or unbalance of the control jets. This nutation must be damped out by means of energy absorbers known as ***nutation dampers***.
- ✓ Certain dual-spin spacecraft obtain spin stabilization from a spinning flywheel rather than by spinning the satellite itself.
- ✓ These flywheels are termed ***momentum wheels***, and their average momentum is referred to as ***momentum bias.***
- ✓ Reaction wheels, described in the next section, operate at zero momentum bias.
- ✓ In the Intelsat series of satellites, the INTELSAT-VI series spacecraft are spin-stabilized, all the others being 3-axis stabilized (body stabilized) through the use of momentum wheels.



Spin and Three-Axis Stabilization

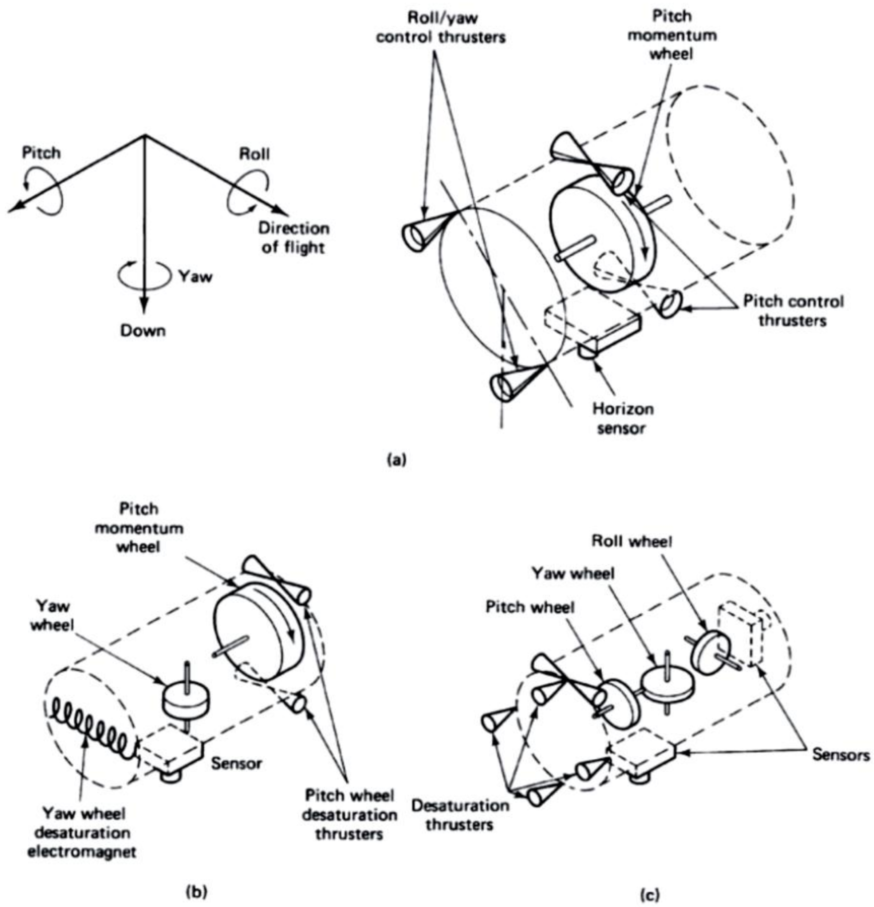
Momentum wheel stabilization

- ✓ In the previous section the gyroscopic effect of a spinning satellite was shown to provide stability for the satellite attitude.
- ✓ Stability also can be achieved by utilizing the gyroscopic effect of a spinning flywheel, and this approach is used in satellites with cube-like bodies (the INTELSAT V type satellites shown in Figure). These are known as ***body-stabilized*** **satellites.**



- ✓ The complete unit, termed a momentum wheel, consists of a flywheel, the bearing assembly, the casing, and an electric drive motor with associated electronic control circuitry.
- ✓ The flywheel is attached to the rotor, which consists of a permanent magnet providing the magnetic field for motor action.
- ✓ The stator of the motor is attached to the body of the satellite. Thus the motor provides the coupling between the flywheel and the satellite structure.
- ✓ Speed and torque control of the motor is exercised through the currents fed to the stator.
- ✓ The housing for the momentum wheel is evacuated to protect the wheel from adverse environmental effects, and the bearings have controlled lubrication that lasts over the lifetime of the satellite.
- ✓ TELDIX manufactures momentum wheels ranging in size from 20, 26, 35, 50 to 60 cm in diameter that is used in a wide variety of satellites.
- ✓ The term momentum wheel is usually reserved for wheels that operate at nonzero momentum.

- ✓ This is termed a momentum bias. Such as wheel provides passive stabilization for the yaw and roll axes when the axis of rotation of the wheel lies along the pitch axis, as shown in Figure (a) , Control about the pitch axis is achieved by changing the speed of the wheel.



Alternative momentum wheel stabilization systems:
(a) one-wheel, (*b*) twowheel, (*c*) three-wheel.

- ✓ When the momentum wheel is operated with zero momentum bias, its generally referred as a *reaction wheel.* Reaction wheels are used in three-axis stabilized systems. Here, as the name suggests, each axis is stabilized by a reaction wheel, as shown in Figure (c).
- ✓ Reaction wheels can also be combined with a momentum wheel to provide the control needed.
- ✓ Random and cyclic disturbance torques tends to produce zero momentum on average.
- ✓ However, there will always be some disturbance torques that causes a cumulative increase in wheel momentum, and eventually at some point the wheel *saturates.* In effect, it reaches its maximum allowable angular velocity and can no longer take in any more momentum.
- ✓ Mass expulsion devices are then used to unload the wheel, that is, remove momentum from it (in the same way brake removes energy from a moving vehicle0. Of course, operation of the mass expulsion devices consumes part of the satellite’s fuel supply.

COMMUNICATION PAYLOAD AND SUPPORTING SUBSYSTEMS

- ✓ The typical satellite consists of the communications payload and the network of supporting subsystems, or bus. The supporting subsystems include
  - Structure
  - Primary power
  - Thermal control
  - Telemetry, tracking and command
  - Attitude control
  - Propulsion

- ✓ Table is a simple chart listing these systems, their purposes and the principal parameters that characterize them quantitatively.

System	***Function***	***Principal Quantitative Characteristics***
Communication Transponders Antennas	Receive, amplify, process and retransmit signals; capture and radiate signals	Transmitter power, bandwidth, G/T, beamwidth, orientation, gain, signal-carrier saturated flux density.
Structure	Support spacecraft under launch and orbital environment	Resonant frequencies, structural strengths
Primary power	Supply electrical power to spacecraft	Beginning of life (BOL) power, end of life (EOL) power; solstice and equinox powers, eclipse operation
Thermal control	Maintain suitable temperature ranges for all subsystems during life, operating and non-operating, in and out of eclipse	Spacecraft mean temperature range and temperature ranges for all critical components
Telemetry, tracking, and command (TT & C)	Monitor spacecraft status, orbital parameters, and control spacecraft operation	Position and velocity measuring accuracy, number of telemetered points, number of commands
Attitude control	Keeps antennas pointed at correct earth locations and solar cells pointed at the sun	Role, pitch, and yaw tolerances.
Propulsion	Maintain orbital position, major attitude control corrections, orbital changes, and initial orbit deployment	Specific impulse, thrust, propellant mass
Complete spacecraft	Provide satisfactory communications operations in desired orbit	Mass, primary power, design lifetime, reliability, communications performance; number of channels and types of signals

STRUCTURE

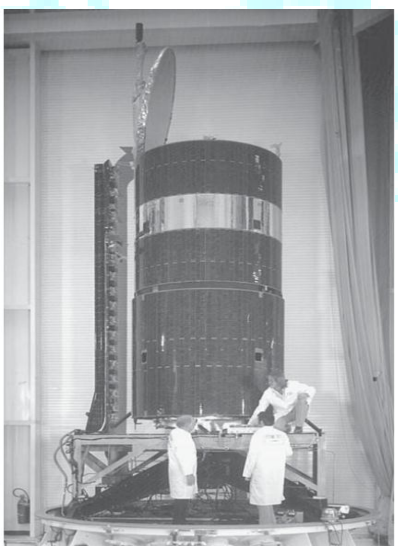
- ✓ The structure to hold the spacecraft together must be designed to withstand a variety of loads.
- ✓ During launch and transfer, there are accelerations, vibration and aerodynamic loads, centrifugal stresses, operating thrusts, and separation shocks.
- ✓ A wide variety of materials and techniques has been used for spacecraft structures. Mostly derivative from aeronautical practice, and Table lists some common structural materials

Table - Common Structural Materials

Aluminium
Magnesium
Stainless steel
Invar
Titanium
Graphite-reinforced phenolic (GFRP)
Fiber-glass epoxy
Beryllium

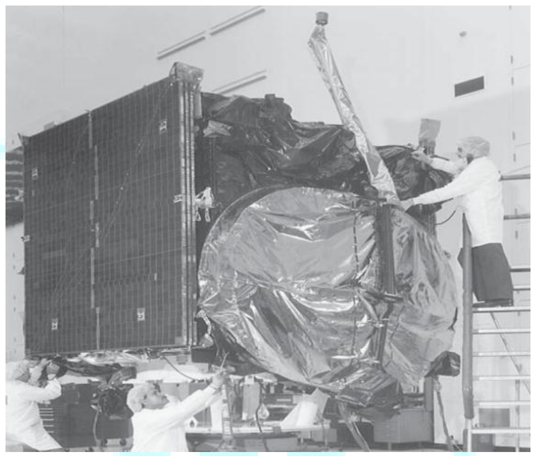
THE POWER SUPPLY

- ✓ The primary electrical power for operating the electronic equipment is obtained form solar cells.
- ✓ Individual cells can generate only small amounts of power, and there force, arrays of cells in series-parallel connection are required.
- ✓ Figure shows the solar cell panels for the HS 376

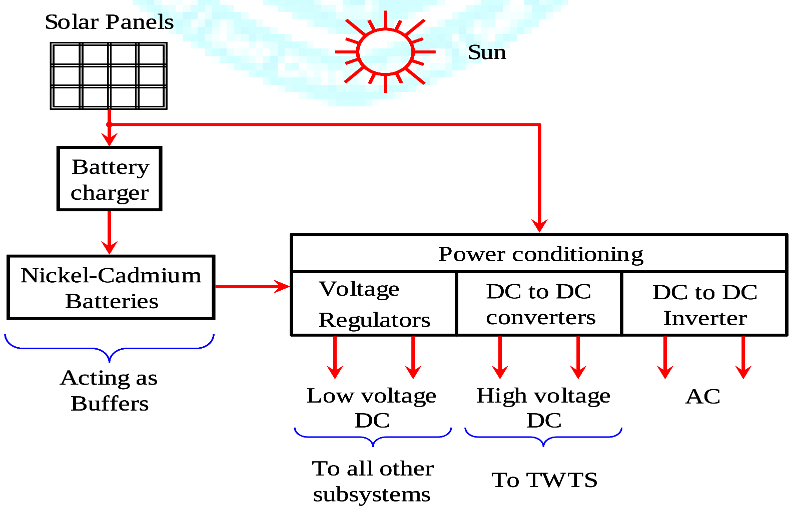


- ✓ During the launch sequence, the outer cylinder is telescoped over the inner one, to reduce the overall length.
- ✓ Only the outer panel generates electrical power during this phase.

- ✓ In geostationary orbit the telescoped panel is fully extended so that both are exposed to sunlight. At the beginning of life, the panels produce 940 W dc powers, which may drop to 760 W at the end of 10 years. During eclipse, power is provided by tow **nickel-cadmium (Ni-Cd)** long-life batteries, which will deliver 830 W. At the end of life, battery recharge time is less than 16h.
- ✓ Higher power can be achieved with solar panels arranged in the form of rectangular ***solar sails.*** Solar sails must be folded during the launch phase and extended when in geostationary orbit. Figure shows the HS 601. As shown, the solar sails are folded up on each side, and when fully extended, they stretch to 67 ft (20.42m) from tip to tip.



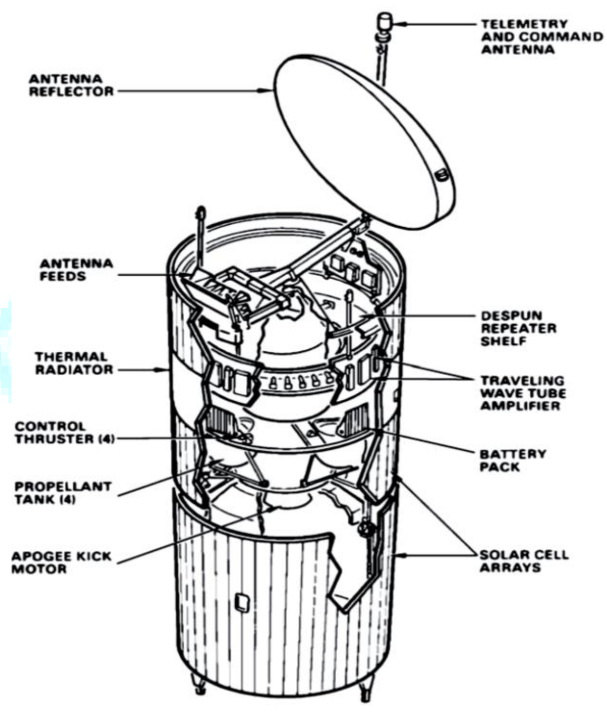
- ✓ The full complement of solar cells is exposed to the sunlight, and the sails are arranged to rotate to track the sun, so they are capable of greater power output than cylindrical arrays having a comparable number of cells.
- ✓ The HS 601 can be designed to provide dc power from 2 to 6 kW.
- ✓ In comparing the power capacity of cylindrical and solar-sail satellites, the cross-over point is estimated to be about 2 kW, where the solar-sail type is more economical than the cylindrical type.



Basic satellite primary power system

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 import consideration is that the satellite's equipment should operate as nearly as possible in a stable temperature environment. Various steps are taken to achieve this.
- ✓ Thermal blankets and shields may be used to provide insulation.
- ✓ Radiation mirrors are often used to remove heat from the communications payload.
- ✓ The mirrored thermal radiator for the HS376 satellite can be seen in Figure. These mirrored drums surround the communications equipment shelves in each case and provide good radiation paths for the generated heat to escape into the surrounding space.

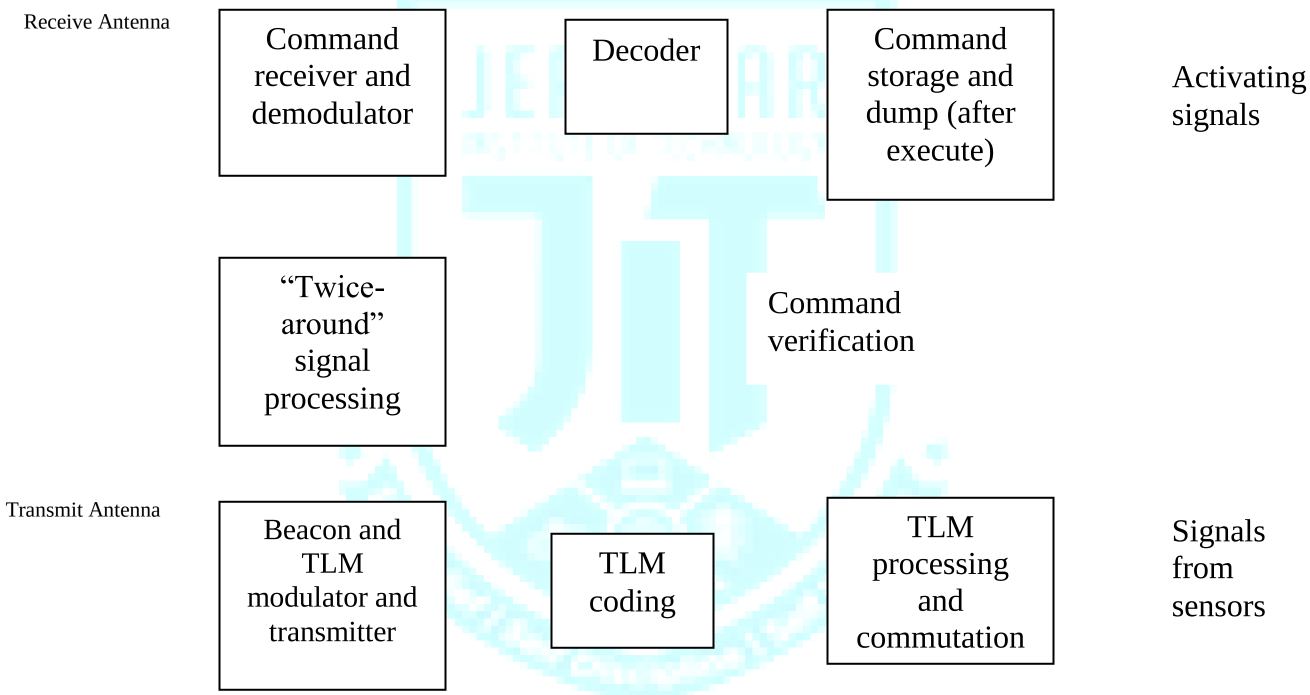


- ✓ One advantage of spinning satellites compared with body-stabilized is that the spinning body provides an averaging of the temperature extremes experienced from solar flux and the cold back, ground of deep space.
- ✓ In order to maintain constant temperature conditions, heaters may be switched on (usually on command from ground) to make up from the heat reduction which occurs when transponders are switched off.

TELEMETRY, TRACKING AND COMMAND (TT & C)

- ✓ The three related functions, telemetry, tracking (including range measurements) and command, are usually grouped into one subsystem called telemetry, tracking and command (TT&C) or alternatively *telemetry, tracking, command and ranging (TTC & R)*. All three are essentially communications functions.
- ✓ Thus the computations of link performance. Signal-to-noise rations, error rats and other communications parameters are identical in principle to those for telephone, TV and data.
- ✓ VHF and S-band links, in common use for all three services. A simplified block diagram of a spacecraft TT&C system is shown in Figure.

Generalized spacecraft TT&C system



Telemetry

- ✓ The satellite condition must be known on the ground at all times. Its usual to choose some hundreds of points around the spacecraft and measure such quantities as
  - Voltage
  - Currents
  - Temperatures
  - Pressures
  - The status of switches and solenoids
- ✓ Sensors for these quantities are provided together with analog-to-digital (A-D) converters and their outputs are sampled in a commutation system. PCM, TDM and PSK are usual telemetry transmission modes. FM analog telemetry is still used occasionally

Tracking

- ✓ Beacon transmitters are usually provided on the spacecraft for tracking during launch and operations.
- ✓ This transmitter can also carry telemetry signals and range signal turnaround and command verifications.
- ✓ Angular measurements are done by conventional terrestrial methods using large antennas and monopulse or conical scanning systems developed years ago for radar.
- ✓ Ranging is done by one of two methods. A standard technique is to phase modulate the uplink or command carrier with pairs of low –frequency tones, detect these signals on board, and remodulate the telemetry carrier on the downlink.
- ✓ The earth station compares the transmitted and received phases to calculate the range.
- ✓ By using the tones in pairs. It's possible to resolve the range ambiguities otherwise present.
- ✓ Another method is to transmit pulsed signals on the uplink and retransmit them on the downlink, measuring the range by time difference in the usual radar manner. \

Command

- ✓ A wide variety of such systems has been developed and the choice depends on the number of commands, the rest of the TT&C, and the security required.
- ✓ Digital systems and low-frequency tones are both used.
- ✓ Most command systems take a similar sequence of operations to protect against unauthorized or take commands and errors the sequence is :
    - An enabling signal is transmitted to permit command system operation.
    - The specific command is sent and stored.
    - The command is verified by transmitting to the earth the telemetry link
    - An execute signal is transmitted and the command is carried out.

- ✓ Commands are necessary for many functions during manual operation, specifically,
    - Transponder switching,
    - Station keeping
    - Attitude changes
    - Gain control
    - Redundancy control

During launch there may be others, for example,

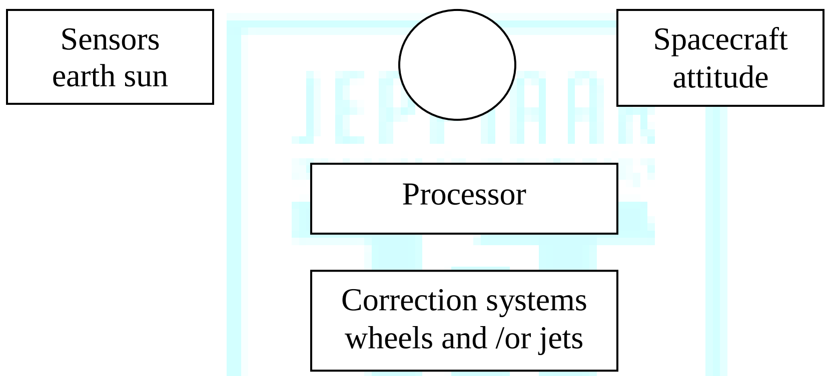
- Separation commands
- Antenna and solar panel deployment
- Apogee motor firing

ATTITUDE CONTROL

- ✓ The attitude control subsystem must accomplish two things
- ✓ First, it must keep the antennas pointed in the proper direction (that is, toward the region to be communicated with) on the surface of the earth or perhaps another satellite,
- ✓ Second, it must keep the solar array pointed toward the sun.

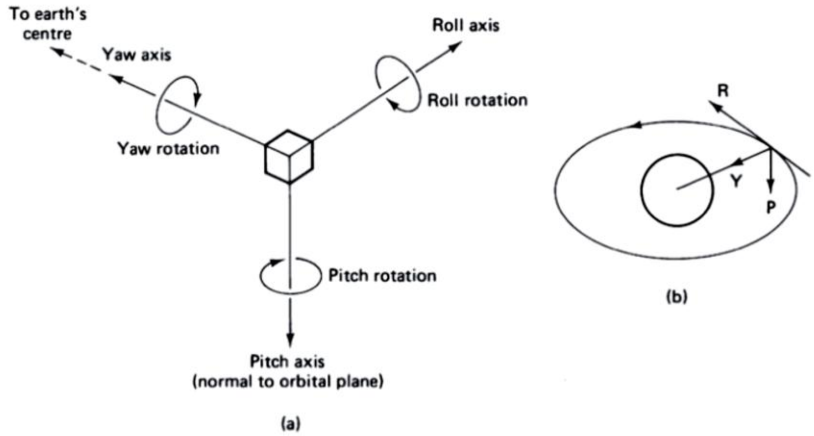
Note that both functions require a double action on the part of the attitude-control system.

- ✓ It must pitch the satellite 15^0 per hour to maintain earth pointing.
- ✓ At the same time, it must correct for attitude changes resulting from orbital disturbances and from upsetting torques generated when making station keeping maneuvers.



Basic attitude-control subsystem.

- ✓ It's important to emphasize that all attitude-control systems function in accordance with the block diagram of figure. Any perturbation in the attitude or position or the satellite is detected by sensors and compared to a reference, and an error signal is derived that is used to command corrections.
- ✓ The correction s are achieved either by varying the speeds of spinning momentum wheels or by thrusters, or by some combination.
- ✓ All attitude control systems require sensors. It is the resolution of these sensors that limits the ultimate pointing accuracy of the spacecraft. Sensors can be optical (either in the visible or infrared regions of the spectrum), or they can be radio-frequency sensors to work in conjunction with ground-based transmitter.
- ✓ All active attitude control systems, whether they use single inertial wheels multiple wheels, or despun platforms, require thrusters to correct large errors.
- ✓ This is sometimes referred to as *dumping momentum* since the use of a jet to expel propellant changes the total angular momentum of the spacecraft itself. (a) Spin-stabilized controls (b) Three axis active control, (c) momentum bias control and (d) Dual spin control are the four principal kinds of active attitude control systems.



(*a*) **Roll, pitch, and yaw axes.** The yaw axis is directed toward the earth's center, the pitch axis is normal to the orbital plane, and the roll axis is perpendicular to the other two.

(*b*) RPY axes for the geostationary orbit. Here, the roll axis is tangential to the orbit and lies along the satellite velocity vector.

The three axes which define a satellite's attitude are its *roll*, *pitch*, and *yaw* (RPY) axes. These are shown relative to the earth in Figure. All three axes pass through the center of gravity of the satellite. For an equatorial orbit, movement of the satellite about the roll axis moves the antenna footprint north and south; movement about the pitch axis moves the footprint east and west; and movement about the yaw axis rotates the antenna footprint.

Earth Station Technology:

The earth segment of a satellite communications system consists of the transmit and receive earth stations. The simplest of these are the home *TV receive-only* (TVRO) systems, and the most complex are the terminal stations used for international communications networks. Also included in the earth segment are those stations which are on ships at sea, and commercial and military land and aeronautical mobile stations.

As mentioned in earth stations that are used for logistic sup- port of satellites, such as providing the *telemetry, tracking, and command* (TT&C) functions, are considered as part of the space segment.

Terrestrial Interface:

Earth station is a vital element in any satellite communication network. The function of an earth station is to receive information from or transmit information to, the satellite network in the most cost-effective and reliable manner while retaining the desired signal quality. The design of earth station configuration depends upon many factors and its location. But it is fundamentally governed by its Location which are listed below,

- In land
- On a ship at sea
- Onboard aircraft

The factors are

- Type of services
- Frequency bands used
- Function of the transmitter
- Function of the receiver
- Antenna characteristics

Transmitter and Receiver

Any earth station consists of four major subsystems

- Transmitter
- Receiver
- Antenna
- Tracking equipment

Two other important subsystems are

- Terrestrial interface equipment
- Power supply

The earth station depends on the following parameters

- Transmitter power
- Choice of frequency
- Gain of antenna
- Antenna efficiency
- Antenna pointing accuracy
- Noise temperature

The functional elements of a basic digital earth station are shown in the below figure

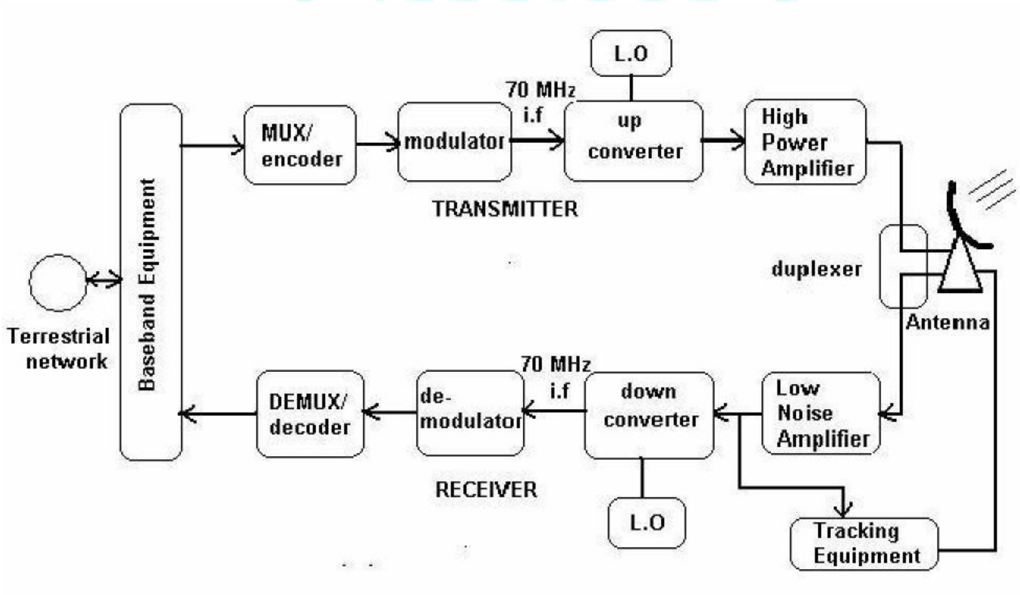


Figure Transmitter- Receiver

Digital information in the form of binary digits from terrestrial networks enters earth station and is then processed (filtered, multiplexed, formatted etc.) by the base band equipment.

The encoder performs error correction coding to reduce the error rate, by introducing extra digits into digital stream generated by the base band equipment. The extra digits carry information.

In satellite communication, I.F carrier frequency is chosen at 70 MHz for communication using a 36 MHz transponder bandwidth and at 140 MHz for a transponder bandwidth of 54 or 72 MHz.

On the receive side, the earth station antenna receives the low-level modulated R.F carrier in the downlink frequency spectrum.

The low noise amplifier (LNA) is used to amplify the weak received signals and improve the signal to Noise ratio (SNR). The error rate requirements can be met more easily.

R.F is to be reconverted to I.F at 70 or 140 MHz because it is easier design a demodulation to work at these frequencies than 4 or 12 GHz.

The demodulator estimate which of the possible symbols was transmitted based on observation of the received if carrier.

The decoder performs a function opposite that of the encoder. Because the sequence of symbols recovered by the demodulator may contain errors, the decoder must use the uniqueness of the redundant digits introduced by the encoder to correct the errors and recover information-bearing digits.

The information stream is fed to the base-band equipment for processing for delivery to the terrestrial network.

The tracking equipment tracks the satellite and align the beam towards it to facilitate communication.

Earth Station Tracking System:

Tracking is essential when the satellite drift, as seen by an earth station antenna is a significant fraction of an earth station's antenna beam width.

An earth station's tracking system is required to perform some of the functions such as

1. Satellite acquisition
2. Automatic tracking
3. Manual tracking
4. Program tracking.

Antenna Systems:

The antenna system consist of

- Feed System
- Antenna Reflector
- Mount
- Antenna tracking System

FEED SYSTEM

The feed along with the reflector is the radiating/receiving element of electromagnetic waves. The reciprocity property of the feed element makes the earth station antenna system suitable for transmission and reception of electromagnetic waves.

The way the waves coming in and going out is called feed configuration Earth Station feed systems most commonly used in satellite communication are:

- Axi-Symmetric Configuration
- Asymmetric Configuration
- Axi-Symmetric Configuration

In an axi-symmetric configuration the antenna axes are symmetrical with respect to the reflector, which results in a relatively simple mechanical structure and antenna mount.

Primary Feed:

In primary, feed is located at the focal point of the parabolic reflector. Many dishes use only a single bounce, with incoming waves reflecting off the dish surface to the focus in front of the dish, where the antenna is located. when the dish is used to transmit ,the transmitting antenna at the focus beams waves toward the dish, bouncing them off to space. This is the simplest arrangement.

Cassegrain :

Many dishes have the waves make more than one bounce .This is generally called as folded systems. The advantage is that the whole dish and feed system is more compact. There are several folded configurations, but all have at least one secondary reflector also called a sub reflector, located out in front of the dish to redirect the waves.

A common dual reflector antenna called Cassegrain has a convex sub reflector positioned in front of the main dish, closer to the dish than the focus. This sub reflector bounces back the waves back toward a feed located on the main dish's center, sometimes behind a hole at the center of the main dish. Sometimes there are even more sub reflectors behind the dish to direct the waves to the fed for convenience or compactness.

Gregorian

This system has a concave secondary reflector located just beyond the primary focus. This also bounces the waves back toward the dish.

Asymmetric Configuration

Offset or Off-axis feed

The performance of tan axi- symmetric configuration is affected by the blockage of the aperture by the feed and the sub reflector assembly. The result is a reduction in the antenna efficiency and an increase in the side lobe levels. The asymmetric configuration can remove this limitation.. This is achieved by off-setting the mounting arrangement of the feed so that it does not obstruct the main beam.As a result ,the efficiency and side lobe level performance are improved

ANTENNA REFLECTOR:

Mostly parabolic reflectors are used as the main antenna for the earth stations because of the high gain available from the reflector and the ability of focusing a parallel beam into a point at the focus where the feed, i.e., the receiving/radiating element is located. For large antenna system more than one reflector surfaces may be used in as in the cassegrain antenna system.

Earth stations are also classified on the basis of services for example:

- Two way TV ,Telephony and data
- Two way TV
- TV receive only and two way telephony and data
- Two way data

From the classifications it is obvious that the technology of earth station will vary considerably on the performance and the service requirements of earth station for mechanical design of parabolic reflector the following parameters are required to be considered:

- Size of the reflector
- Focal Length /diameter ratio
- RMS error of main and sub reflector
- Pointing and tracking accuracies
- Speed and acceleration
- Type of mount
- Coverage Requirement

Wind Speed

The size of the reflector depends on transmit and receive gain requirement and beamwidth of the antenna. Gain is directly proportional to the antenna diameter whereas the beamwidth is inversely proportional to the antenna diameter .for high inclination angle of the satellite, the tracking of the earth station becomes necessary when the beamwidth is too narrow.

The gain of the antenna is given by Gain= (η4ΠAeff)/ λ2
Where Aeff is the aperture Λ is wave length
H is efficiency of antenna system

For a parabolic antenna with circular aperture diameter D, the gain of the antenna is :

Gain= (η4Π/ λ2) (ΠD2/4) = η (ΠD/ λ)2

The overall efficiency of the antenna is the net product of various factors such as

1. Cross Polarization
2. Spill over
3. Diffraction
4. Blockage
5. Surface accuracy
6. Phase error
7. Illumination

In the design of feed ,the ratio of focal length F to the diameter of the reflector D of the antenna system control the maximum angle subtended by the reflector surface on the focal point. Larger the F/D ratio larger is the aperture illumination efficiency and lower the cross polarization.

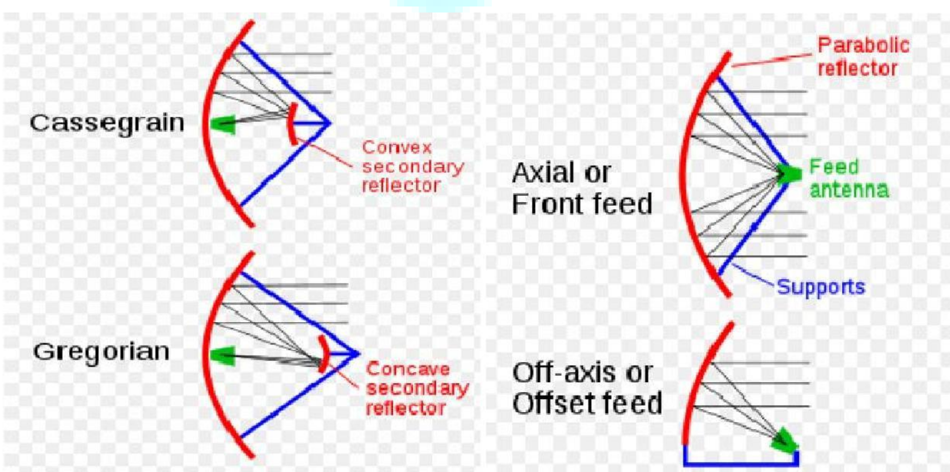


Figure Antenna sub systems

ANTENNA MOUNT:

Type of antenna mount is determined mainly by the coverage requirement and tracking requirements of the antenna systems. Different types of mounts used for earth station antenna are:

The Azimuth –elevation mount:

This mount consists of a primary vertical axis. Rotation around this axis controls the azimuth angle. The horizontal axis is mounted over the primary axis, providing the elevation angle control.

The X-Y mount:

It consists of a horizontal primary axis (X- axis) and a secondary axis (Y-axis) and at right angles to it. Movement around these axes provides necessary steering.

ANTENNA TRACKING SYSTEM:

Tracking is essential when the satellite drift, as seen by an earth station antenna is a significant fraction of an earth station's antenna beam width.

An earth station's tracking system is required to perform some of the functions such as

- Satellite acquisition
- Automatic tracking
- Manual tracking
- Program tracking.

Recent Tracking Techniques:

There have been some interesting recent developments in auto-track techniques which can potentially provide high accuracies at a low cost.

In one proposed technique the sequential lobing technique has been I implemented by using rapid electronic switching of a s single beam which effectively approximates simultaneous lobbing