UNIT III The Space Segment & Earth Segment:

The Power Supply
Attitude Control
Spinning satellite stabilization
Momentum wheel stabilization
Station Keeping
Thermal Control
TT&C Subsystem
Transponders
The wideband receiver
The input demultiplexer
The power amplifier
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.
- 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.

The Power Supply: The primary electrical power for operating the electronic equipment is obtained from solar cells. Individual cells can generate only small amounts of power, and therefore, arrays of cells in series-parallel connection are required.

- At the beginning of life, the panels produce 940 W dc power, which may drop to 760 W at the end of 10 years. During eclipse, power is provided by two nickel-cadmium (Ni-Cd) long-life batteries, which will deliver 830 W. At the end of life, battery recharge time is less than 16 hr.

- Higher powers 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.

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. Attitude control is necessary, for example, to ensure that directional antennas point in the proper directions. 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.
- Usually, the attitude-control process takes place aboard the satellite, but it is also possible for control signals to be transmitted from earth, based on attitude data obtained from the satellite. Also, where a shift in attitude is desired, an attitude maneuver is executed. The control signals needed to achieve this maneuver may be transmitted from an earth station.
- Controlling torques may be generated in a number of ways. Passive attitude control refers to the use of mechanisms which stabilize the satellite without putting a drain on the satellite’s energy supplies; at most, infrequent use is made of these supplies, for example, when thruster jets are impulsed to provide corrective torque. Examples of passive attitude control are spin stabilization and gravity gradient stabilization.

- The other form of attitude control is active control. With active attitude control, there is no overall stabilizing torque present to resist the disturbance torques.
- Methods used to generate active control torques include momentum wheels, electromagnetic coils, and mass expulsion devices, such as gas jets and ion thrusters. The electromagnetic coil works on the principle that the earth's magnetic field exerts a torque on a current-carrying coil and that this torque can be controlled through control of the current.

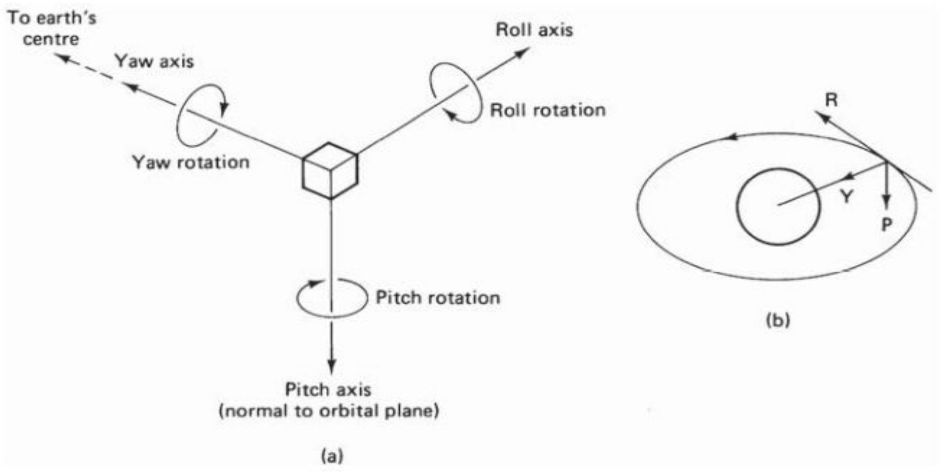

Figure 7.4 (*a*) Roll, pitch, and yaw axes. The yaw axis is directed toward the earth's center, the pitch axis is normal to the orbital plane, and the roll axis is perpendicular to the other two. (*b*) RPY axes for the geostationary orbit. Here, the roll axis is tangential to the orbit and lies along the satellite velocity vector.

The three axes which define a satellite's attitude are its roll, pitch, and yaw (RPY) axes. 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.

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 Fig. 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 as nutation dampers.

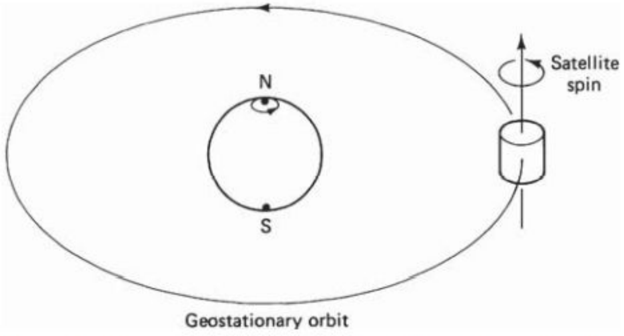

Figure 7.5 Spin stabilization in the geostationary orbit. The spin axis lies along the pitch axis, parallel to the earth's N-S axis.

The antenna subsystem consists of a parabolic reflector and feed horns mounted on the despun shelf, which also carries the communications repeaters (transponders). The antenna feeds can therefore be connected directly to the transponders without the need for radiofrequency (rf) rotary joints, while the complete platform is despun. Of course, control signals and power must be transferred to the despun section, and a mechanical bearing must be provided.

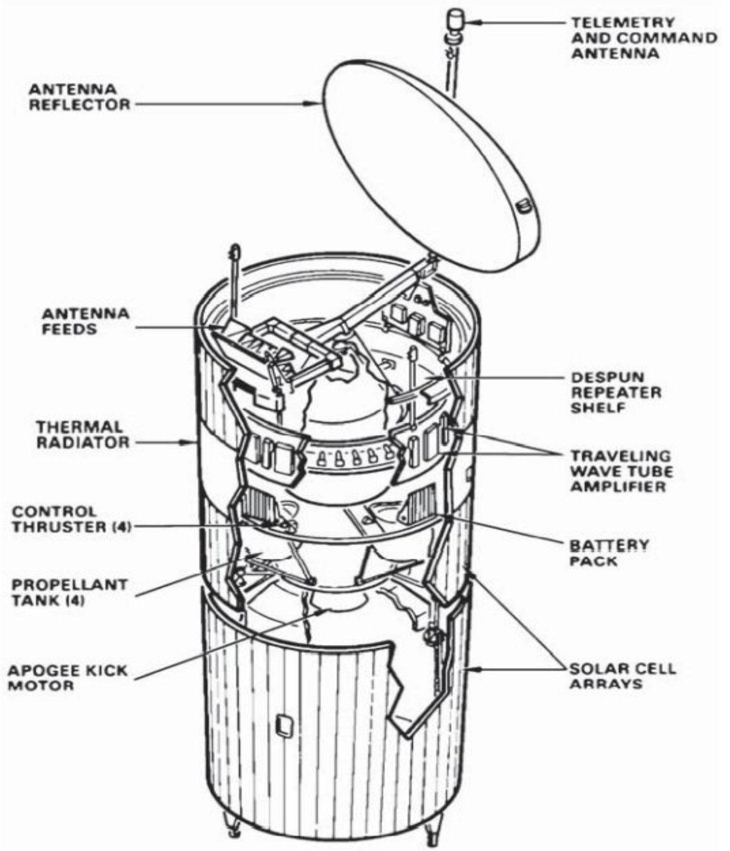

Figure 7.6 HS 376 spacecraft. (*Courtesy of Hughes Aircraft Company Space and Communications Group.*)

- 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, 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.

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.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.
- momentum wheels ranging in size from 20, 26, 35, 50, to 60 cm in diameter that are 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 a 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 Fig.Control about the pitch axis is achieved by changing the speed of the wheel.

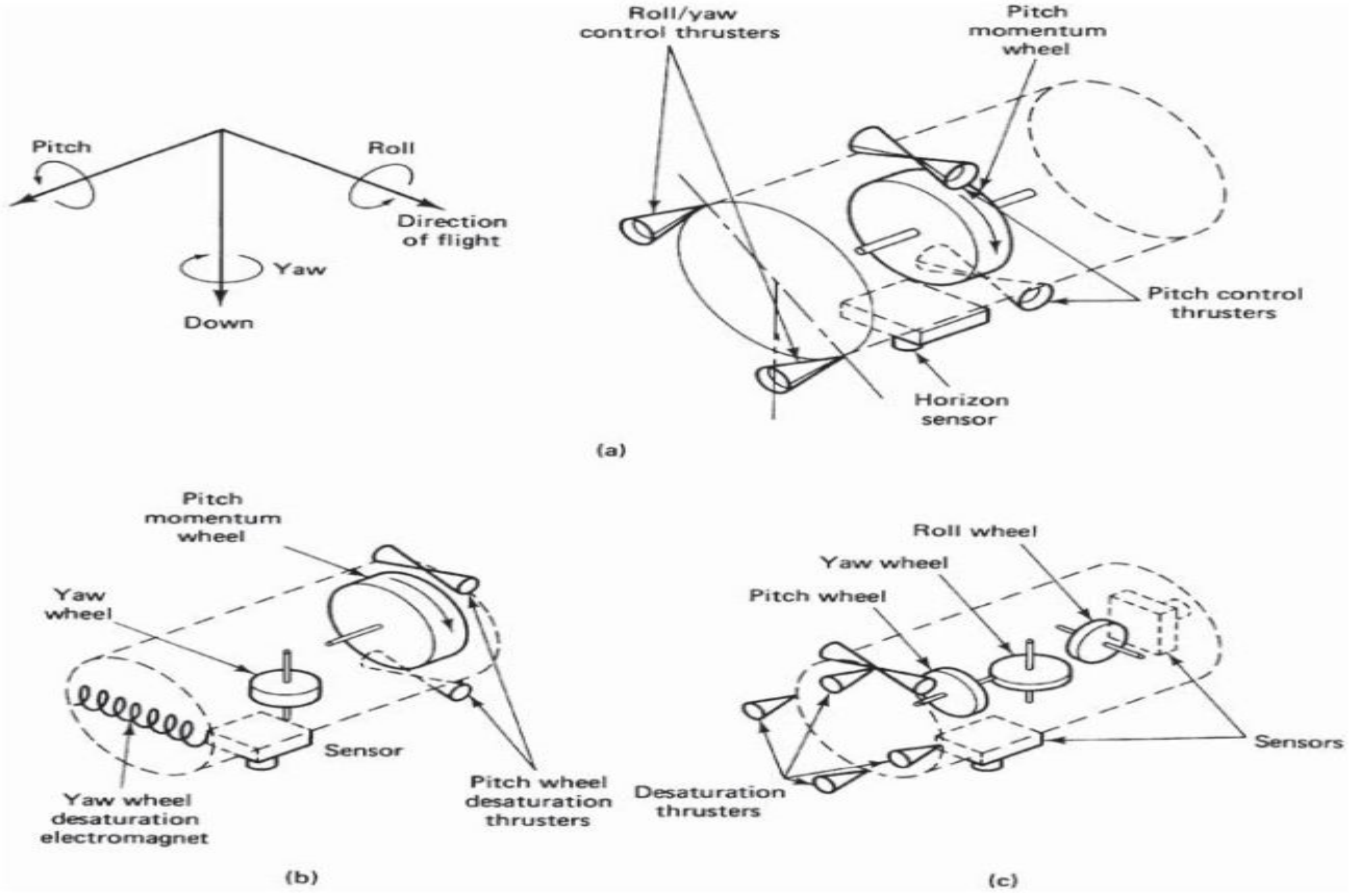

Figure 7.8 Alternative momentum wheel stabilization systems: (*a*) one-wheel, (*b*) two-wheel, (*c*) three-wheel. (*Reprinted with permission from Spacecraft Attitude Determination*

When a momentum wheel is operated with zero momentum bias, it is generally referred to as a reaction wheel. Reaction wheels are used in three-axis stabilized systems.

Station Keeping:

- Station keeping, which is the term used for maintaining a satellite in its correct orbital position.
- 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.
- These maneuvers are termed east-west station-keeping maneuvers. Satellites in the 6/4-GHz band must be kept within 0.1° of the designated longitude, and in the 14/12-GHz band, within 0.05°
- A satellite which is nominally geostationary also will drift in latitude, the main perturbing forces being the gravitational pull of the sun and the moon. These forces cause the inclination to change at a rate of about 0.85°/year.
- If left uncorrected, the drift would result in a cyclic change in the inclination, going from 0° to 14.67° in 26.6 years and back to zero, at which the cycle is repeated.

- To prevent the shift in inclination from exceeding specified limits, jets may be pulsed at the appropriate time to return the inclination to zero. Counteracting jets must be pulsed when the inclination is at zero to halt the change in inclination. These maneuvers are termed north-south station-keeping maneuvers, and they are much more expensive in fuel than are east-west station-keeping maneuvers. The north-south station-keeping tolerances are the same as those for east-west station keeping, 0.1° in the C band and 0.05° in the Ku band.
- Orbital correction is carried out by command from the TT&C earth station, which monitors the satellite position. East-west and northsouth station-keeping maneuvers are usually carried out using the same thrusters as are used for attitude control.

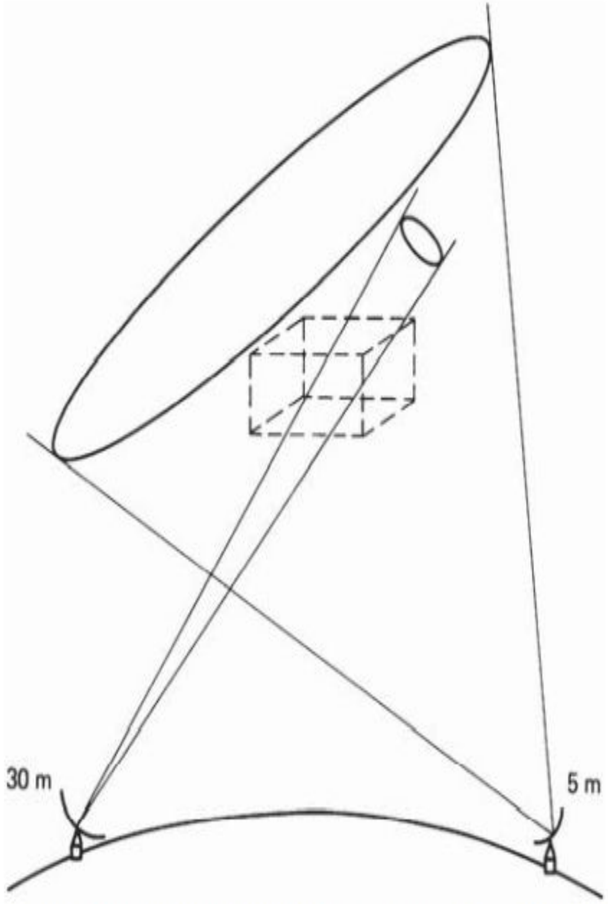

Figure 7.10 The rectangular box shows the positional limits for a satellite in geostationary orbit in relation to beams from a 30-m and a 5-m antenna.

The diameter of the 5-m antenna beam at the satellite will be about 464 km, and this does encompass the box, so tracking is not required. The positional uncertainty of the satellite also introduces an uncertainty in propagation time, which can be a significant factor in certain types of communications networks.

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. Thermal blankets and shields may be used to provide insulation. Radiation mirrors are often used to remove heat from the communications payload. 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.
- In order to maintain constant temperature conditions, heaters may be switched on to make up for the heat reduction which occurs when transponders are switched off. The INTELSAT VI satellite used heaters to maintain propulsion thrusters and line temperatures.

TT&C Subsystem:

- The telemetry, or telemetering, function could be interpreted as measurement at a distance.
- Data which are transmitted as telemetry signals include attitude information such as that obtained from sun and earth sensors; environmental information such as the magnetic field intensity and direction, the frequency of meteorite impact and spacecraft information such as temperatures, power supply voltages, and stored-fuel pressure.
- Once the satellite is on station, one of the normal communications transponders may be used along with its directional antenna.
- The telemetry subsystem transmits information about the satellite to the earth station, while the command subsystem receives command signals from the earth station, often in response to telemetered information.
- The command subsystem demodulates and, if necessary, decodes the command signals and routes these to the appropriate equipment needed to execute the necessary action.
- Thus attitude changes may be made, communication transponders switched in and out of circuits, antennas redirected, and station-keeping maneuvers carried out on command.
- 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 transfer and drift orbital phases of the satellite launch. Once it is on station, the position of a geostationary satellite will tend to be shifted as a result of the various disturbing forces.

- To track the satellite's movement and send correction signals as required. Tracking beacons may be transmitted in the telemetry channel, or by pilot carriers at frequencies in one of the main communications channels, or by special tracking antennas. Satellite range from the ground station is also required from time to time. This can be determined by measurement of the propagation delay of signals especially transmitted for ranging purposes.

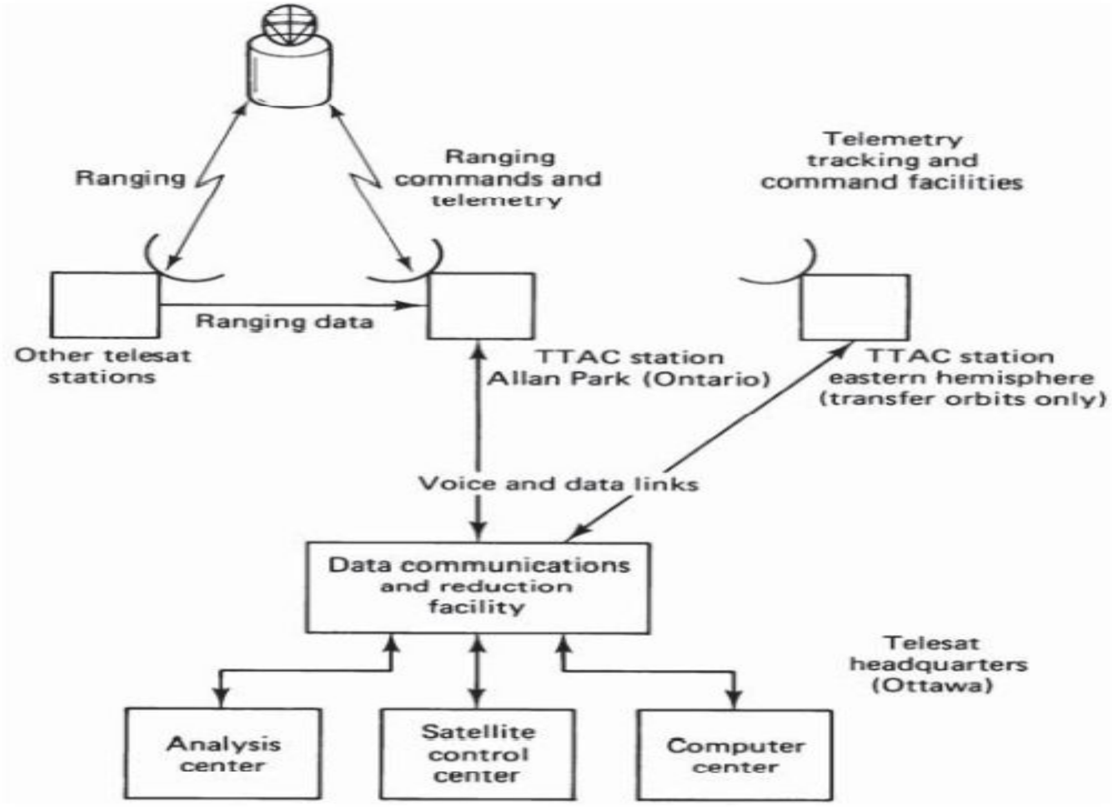

Figure 7.11 Satellite control system. (*Courtesy of Telesat Canada, 1983.*)