

# SATELLITE SUBSYSTEMS

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### 3.1. INTRODUCTION

Geostationary communication satellites are very complex and, very expensive to purchase and launch. It is very difficult to maintain a communication system 35,800 km out in space. The life of communication satellite is 5 to 10 years. The cost of a satellite is several million dollar and it is because of the need of dedicated earth station for the monitoring and control of the satellite. The revenue of these costs is obtained by selling the communication capacity of the satellite to the users.

It can be done by two ways :

- Way of leasing circuits of transponder.
- Charging for circuit use as in International Telephone Service.

Since its cost is very high, the operator of the system try to recover the initial and operating cost within the expected life time of the spacecraft. The designer must provide a satellite that can survive the hostile environment of outer space for its long life. In this chapter we will discuss the communication subsystems required on a spacecraft in details.

### 3.2. SATELLITE SUBSYSTEMS

A complete satellite consists of several subsystems, but most important of these are :

1. Power supply system
2. Attitude and orbit control system
3. Telemetry, tracking and command system
4. Communication subsystem

Figure 3.1 shows a typical block diagram of a satellite subsystem.

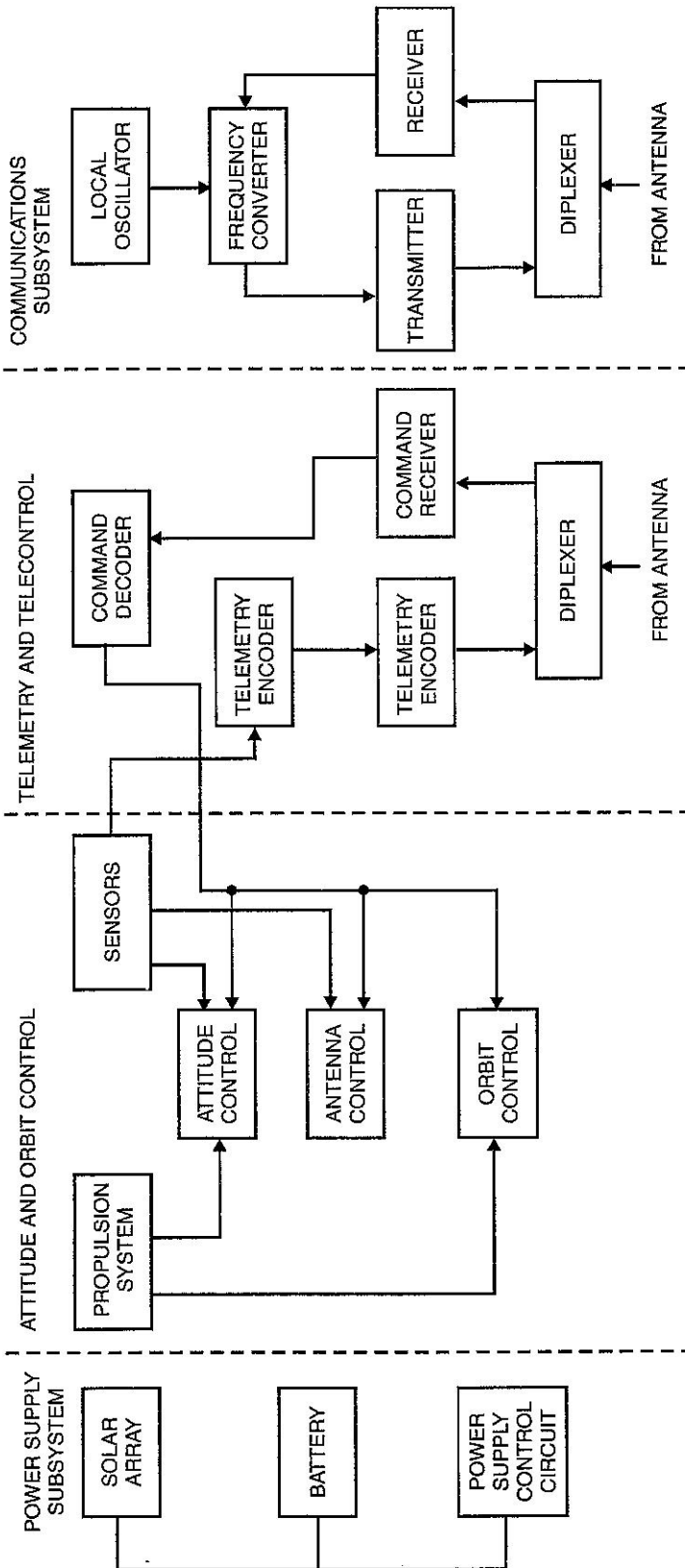


Fig. 3.1. Block diagram of a satellite showing various subsystems.

### 3.3. POWER SUPPLY SYSTEM

In communication satellite the electric power supply system provides electrical energy required to run the spacecraft, when the satellite is in stationary orbit. This sub-system is further divided into three parts :

- (a) Solar array
- (b) Battery
- (c) Power supply control circuit

Solar cells are photovoltaic cells that converts solar radiation into electricity and then it is converted to the required voltage level in a power supply. The conversion efficiency of solar cell is around 12% to 15% and typical satellite solar cells generate 1 to 2 KW of power. Thousands of minute solar cells are placed on the surface of the satellite. If its surface area is inadequate, then separate projections are used. These so-called **solar panels** convert sun energy into electrical energy. Under the effect of radiation the efficiency is decreases by about 30-35% in seven years. During the time of ejection of satellite into transfer orbit, the electro mechanical accumulators provide the electric power supply. The power is mainly used by the communication system, especially in its transmitter and also by all other systems on the spacecraft. Later use term is house keeping, since these subsystems supports the communication system.

### 3.4. ATTITUDE AND ORBIT CONTROL SYSTEM (AOCS)

Attitude and orbit control is used to control the orbit of the satellite, besides helping to maintain stabilization and its position. The control can be effected from the satellite itself and from ground. This subsystem consists of four major parts :

1. Sensors
2. Propulsion system
3. Attitude control
4. Orbit control

There are a number of forces working on a satellite which tend to change attitude and orbit of a satellite beyond the permissible limit. These forces are :

(a) **Asymmetry of the earth's gravitational field** : Earth is not a true sphere. It is bulging at the equator by about 65 km at the longitudes of 165°E and 15°W. This causes an acceleration and hence for accurate positioning, the satellite must be accelerated in the opposite direction by firing the rocket motors called **thrusters** at appropriate intervals. Earth is flattered at the poles by about 20 km but this has little effect on a geostationary satellite.

(b) **Gravitation due to sun, planets and moon** : They set up rotational moments if the satellite is not perfectly balanced. Moon being the nearest heavy mass, has maximum effect.

(c) **Pressure due to solar radiation** : It can also change orientation (spin-axis) of the satellite.

(d) **Magnetic field of the earth** : It can exert forces on the satellite if a net magnetic moment is present, thus affecting its velocity and orientation.

## Need of Attitude and Orbit Control

Change in the spin axis of the satellite will cause pointing error between the satellite's antenna and the earth station's antenna. This will reduce the signal at the receiving side and will degrade C/N ratio. Hence the need of maintenance of correct attitude. As the extra forces can change velocity of the satellite and therefore angle of inclination of the orbital plane with respect to the equatorial plane, the satellite will become non-geostationary. This will require steering of the earth station antenna to get the best signal from the satellite. Thus correct attitude and correct orbit are essential requirements for the optimized performance of the satellite links.

### 3.4.1. Sensors

For attitude control, two types of sensors are used in the satellite :

1. Earth sensor
2. Sun sensor

#### 3.4.1.1. Earth Sensor

It is a passive infrared device, operating in 14-16  $\mu\text{m}$  wavelength. It senses the infrared rays coming from around the horizon. There is a sharp temperature difference between the space and the earth's horizon, as space is cool and earth is warm. Two earth sensors are used, positioned  $5^\circ$  north and  $5^\circ$  south of the spin axis. When the spin axis of the satellite is correctly maintained the output of north and south sensors are in phase, otherwise they are out of phase. The phase difference pulses are sent to the earth station and they measure **earth aspect angle**.

#### 3.4.1.2. Sun Sensors

It has a fan shaped field of view. It operates in the visible spectrum and uses a photocell for detecting solar radiations. There are two solar sensors, one parallel to the spin axis and the other canted  $35^\circ$ . Pulses from the sun sensors are sent to the earth station to determine **solar aspect angle**.

Data from the earth and sun sensors is analyzed and orientation of the satellite is accurately determined by the computers at the earth's station. Commands are generated and sent to the satellite to fire the rocket motor for correcting the axis.

### 3.4.2. Propulsion System

It is the reaction control system carried by the satellite in the geostationary orbit so as to generate forces on it whenever required. The reaction control system has a supply of fuel and it helps the satellite to move, to its assigned position in orbit, to maintain it in that position and to maintain the direction of spin axis attitude control in the case of forces that perturb it. Usually a propulsion system consists of 3 units :

1. **Low thrust actuators** : Devoted to attitude and orbit corrections that provide an annual velocity increment of the order of 50 m/s.
2. **High thrust motor** : Which provides the velocity increment required for the geostationary orbit injection at the transfer orbit apogee.
3. **With space shuttle launched satellites** : It provides the velocity increment required to inject the satellite into the transfer orbit.

Out of these three propulsion units the low thrust actuators are of much importance for geostationary orbit because it is responsible for keeping the

satellite in its orbit with its perfect attitude till its life end. The low thrust actuators can be either **chemical** ones or the **electrical** ones.

**The chemical thrusters** have a thrust level of between 0.5 N and few 10000 N. In chemical thrusters gases are generated at high temperatures by chemical reaction of propellents which may be either solid or liquid. The gases are then accelerated by a nozzle.

**The electric thrusters** produce a thrust only in between 2 and 10 mN. They provide thrust by accelerating ionized mass in an electromagnetic or electrostatic field. In communication satellites chemical thrusters are used.

### 3.4.3. Attitude Control System

The attitude control of a spacecraft is necessary so the antennas must be pointed correctly at the earth. Gravitational forces from the sun, moon and planets will setup rotational moments when the spacecraft is not perfectly balanced. These are carried out by control loops based on error detection and decision systems as shown in Fig. 3.2.

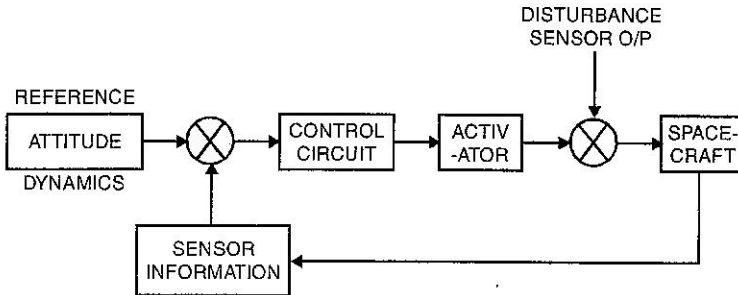


Fig. 3.2. Control scheme.

They use the telemetry, tracking and command (TT&C) subsystems for information exchange between satellite and earth. The attitude control may be :

- Passive
- Active

In **passive attitude control** the required attitude corresponds to a position of a satellite, while for **active attitude control** the satellite is unstable or sufficiently stable within the desired attitude configurations. Mainly four operations are required for this :

1. Detection of the satellite attitude
2. Comparison with the reference axis
3. Determination of the corrective torque.
4. Correction of the altitude by actuators mounted on the satellite.

Any spacecraft is governed using three axis :

- Yaw
- Roll
- Pitch.

In order to control the attitude in space, the satellite has to be properly oriented using momentum wheels and thruster motors in these three axis. The two major methods used are :

- Spin stabilization.
- Three axis body stabilization.

**3.4.3.1. Spin Stabilization**

It is the most commonly employed method where the entire spacecraft is rotated at 30 to 100 rotations per minute. This spin provides a powerful gyroscopic action to maintain the spin axis in the correct direction. Such satellites consist of cylindrical drum covered by solar cells and the rocket motors. The transponder is mounted on the top of the drum. It is driven by an electric motor in the appropriate direction to that of the drum, so that the antennas remain pointing towards the earth. This opposite motion is called **despun**. The despun section is kept stationary by counter rotation provided is by small gas jets mounted on the periphery of the drum. Figure 3.3 shows the spin stabilization in the geostationary orbit. Spin stabilized satellites are mainly the communication satellites.

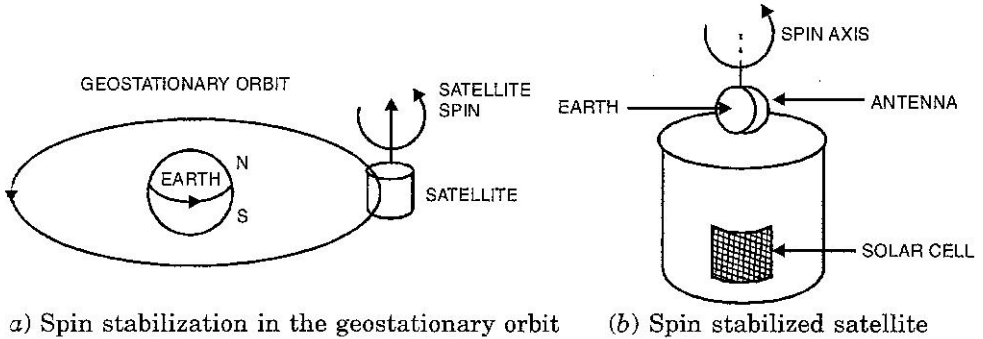


Fig. 3.3.

**3.4.3.2. Three Axis Body Stabilization**

On the other hand, a satellite can rotate about the three axis termed as yaw, roll and pitch axis. When a satellite is stabilized about these axis, it is called three axis body stabilization.

In this method stability is achieved by mounting three momentum wheels on three mutually perpendicular axis as shown in Fig. 3.4.

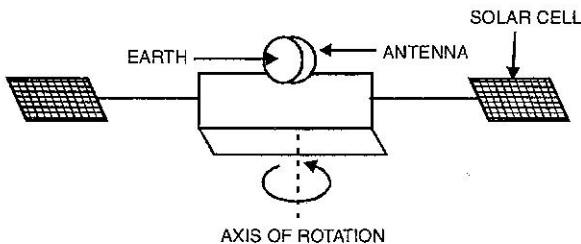
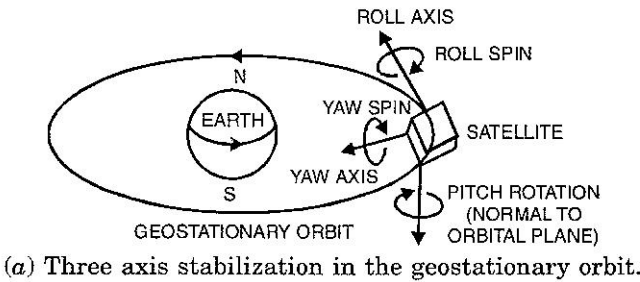


Fig. 3.4.

A momentum wheel is a high speed wheel driven by a motor. It is kept in a sealed evaluated chamber. Increase in its speed increases the angular momentum. Change in the attitude are transmitted to the earth station by telemetering the data from the sensors. The data is analysed and commands are sent to the satellite to increase or decrease the speed of the momentum wheels as per requirement to correct the attitude about its three axes : roll axis (the orbital plane), pitch axis (normal to the orbital plane) and yaw axis (the local vertical plane facing the earth station). Antennas are mounted on the satellites surface facing the earth.

#### **3.4.4. Orbit Control System**

For orbit control, sensors are used in the satellite to measure linear acceleration (momentum wheels cannot be used for this control because they cause rotational torques), changes in velocity, sensed by the velocity sensors, are transmitted to the earth's controlling station. These changes are analysed and, appropriate commands are generated and sent to the satellite for correcting the velocity.

To correct change in the inclination angle ( $i$ ), change of velocity at right angles to the orbital plane is needed. This correction requires more fuel than for any other correction. A typical satellite weighing 1000 kg may need 30 kg of fuel to maintain inclination within  $\pm 0.1^\circ$ . This puts a penalty by reduction in the communication payload and therefore reduction in satellite's capacity. Hence in most of the satellite systems, inclination control is not used. Instead, the satellite is launched with an initial inclination of about  $3^\circ$ . It will be reduced by  $0.85^\circ$  per year due to forces working on the satellite. Thus after three or four years, the orbit would be in the equatorial plane. With earth stations having steerable antennas, drift in inclination can be managed by proper tracking and saving in fuel can be used to carry more transponders.

### **3.5. TELEMETRY, TRACKING AND COMMAND (TT&C)**

Data received from the satellite about status of attitude, orbit and other parameters, is processed at the ground station. Telemetry, tracking and command subsystem is a part of satellite management task and it involves an earth station. The main functions of the TT&C subsystems are :

1. Measurement of angle and range for the localization of the satellite.
2. Transmission of housekeeping information.
3. Status of satellite to the ground control station.
4. Receiving command signals for station keeping operations of the onboard equipments.

Figure 3.5 shows a typical arrangement of a telemetry, tracking and command system.

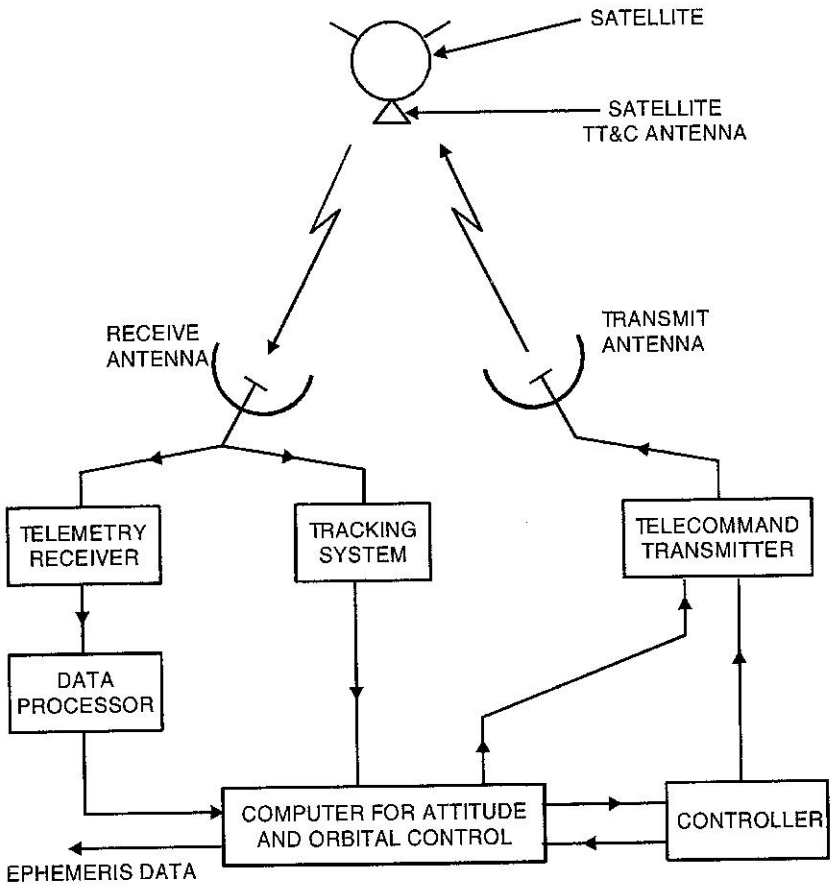


Fig. 3.5. General diagram of telemetry, tracking and command system.

### 3.5.1. Telemetry

Telemetry system collects the data from many sensors and sends this data to the controlling earth station. The sensors are mounted on the satellite and they monitor :

- The pressure in fuel tank.
- Voltage and currents in the power conditioning unit.
- Current drawn by each subsystem.
- Critical voltage and currents in the communication electronics.
- Temperature of other subsystems.
- Position of switches and attitude.

Typically 100 sensors are required to monitor these data. When the satellite is in transfer orbit, the telemetry transmitter is connected to a TWTA in the satellite repeater. The telemetry data is digitized in nature and transmitted as frequency or phase shift keying (FSK or PSK) of a low power telemetry carrier using time division techniques.

Figure 3.6 shows the block diagram of telemetry system.

To maintain a high carrier to noise ratio and narrow bandwidth, a low data rate is used to allow the receiver at the earth station. The entire TDM frame can take several seconds to transmit thousands of bits of data. The

controlling earth station uses a computer to monitor, store and decode the telemetry data so that the status of any system or sensor on the spacecraft can be determined. Alarms can also be used if any parameter goes outside the allowable limits.

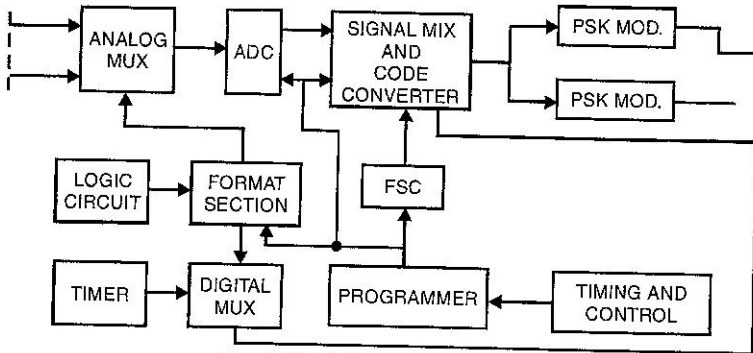


Fig. 3.6. Telemetry system.

### 3.5.2. Tracking or Ranging

It determines the slant range for accurate determination of satellite orbit. It can be done in two ways :

1. By transmitting a command carrier modulated by multiple tones from the earth station to the satellite. The carrier is received by the command receiver in the satellite, demodulated and then goes to the telemetry or beacon transmitter for retransmission to the earth, where the phase difference of the received signal is measured with respect to the transmitted signal.
2. Velocity and acceleration sensors can be used in the satellite to sense the change in the orbit. This data can be sent to the earth station through telemetry, where commands are generated and sent to the satellite for orbit correction.

### 3.5.3. Command Subsystem

For common operation the satellite contains a receiver which works only for command signal transmitted from TTC earth stations. By this command subsystem controls the satellite operation by receiving and decoding command from the TTC earth station. The communication antenna is used for command and ranging when the satellite is in synchronous orbit and, during the satellites position in transfer orbit the omnidirectional antenna is used for command and ranging.

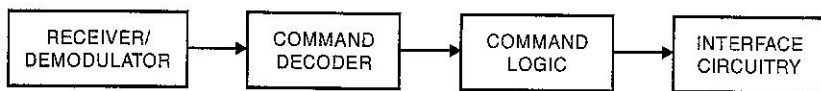
During the enjection of satellite into geostationary orbit a back up system is used which provides :

- The control of apogee boost motors.
- Attitude control systems.
- Orbit control thrusters.

This back up system works with omnidirectional antenna at either UHF or S-band (2-4 GHz) and sufficient margin is required in the signal to noise ratio (S/N) at the satellite receiver. In case of failure of main TT&C system, the back up system can be used to keep the satellite on station. It is also used

to eject the spacecraft from geostationary orbit and to switch off all transmitters, when it reaches the end of its useful life.

The block diagram of spacecraft command system is shown in Fig. 3.7.



**Fig. 3.7. Block diagram of spacecraft command system.**

- Decoder reproduce command messages and produce lock/enable and clock signals.
- Command logic validates the command.
  1. Default is to reject if any uncertainty of validity
  2. Drives appropriate interface circuitry.
- Command decoder detects PCM encoding and outputs binary stream in non-return to zero format. It activates downstream command subsystem components.
- The function of Interface circuitry are latching relays with teletales, pulse commands, level commands and, serial and parallel data commands.

### **3.5.4. TT&C Interface**

The different subsystems and their requirements are listed in Table 3.1 :

**Table 3.1.**

S. No.	Subsystem	Requirements
1.	Attitude determination and control	<ul style="list-style-type: none"> <li>● Antenna pointing</li> </ul>
2.	Command and data handling	<ul style="list-style-type: none"> <li>● Command telemetry data rates</li> <li>● Clock, bit sync, timing requirements</li> <li>● Two way communication requirements</li> <li>● Autonomous fault detection and recovery</li> <li>● Command and telemetry electrical interface</li> </ul>
3.	Electrical power subsystems	<ul style="list-style-type: none"> <li>● Distribution requirements</li> </ul>
4.	Thermal/structural	<ul style="list-style-type: none"> <li>● Heat sinks for TWTAs</li> <li>● Heat dissipation for all active boxes</li> <li>● Location of TT&amp;C subsystem</li> <li>● Ceal field of view and movements for all antennas</li> </ul>
5.	Payload	<ul style="list-style-type: none"> <li>● Storing mission data</li> <li>● RF interface requirements</li> <li>● Special requirements for modulation and coding</li> </ul>

## **3.6. COMMUNICATION SUBSYSTEM**

The communication subsystem is the major part of the operation of a spacecraft. The communication system provides the only link between an operational vehicle and the ground control station. Examples of communicated data can include scientific research, telemetry, payload results, or relayed information from other spacecraft. This subsystem plays a crucial