SATELLITE COMMUNICATIONS

UNIT-II

SATELLITE SUBSYSTEMS: -

The major subsystems required on the satellite are given below:

- Attitude and Orbit Control System (AOCS)
- Telemetry, Tracking, Command & Monitoring (TTC&M)
- Power System
- Communication Subsystems
- Satellite Antennas.

Attitude & Orbit Control System: -

This subsystem consists of rocket motors that are used to move the satellite back to the correct orbit when external forces cause it to drift off station and gas jets or inertial devices that control the attitude of satellite

Telemetry, Tracking, Command & Monitoring: -

These systems are partly on the satellite & partly at the controlling earth station. The telemetry system sends data derived from many sensors on the satellite which monitor the satellite's health to controlling earth station. The tracking systems is located at earth station & provides information on the range & elevation & azimuth angles of satellite. Repeated measurement of these three parameters permits computation of orbital elements. Based on telemetry data received & orbital data obtained, the control system is used to correct the position & attitude of satellite. It is also used to control antenna pointing and communication system configuration and to operate switches on the satellite.

Power Systems: -

All communications satellites derive their electrical power from solar cells. The power is used by communications systems mainly in transmitters and all other electrical systems of satellites.

Communications Subsystems: -

It is the major component of communication satellite and remaining subsystems are solely to support it. It has one or more antennas, which receive & transmit over wide bandwidths at microwave frequencies. It has a set of receivers & transmitters that amplify & retransmits the incoming signals. The receiver transmitter units are known as Transponders.

Satellite Antennas: -

It is a part of complete communication system which is considered separately from transponders. The antenna systems on GEO Satellites are very complex and produce beams with shapes to match the areas on the Earth's surface served by satellite. Most satellite antennas are designed to operate in single frequency band. A satellite which uses multiple frequency bands has four or more antennas.

ATTITUDE & ORBIT CONTROL SYSTEM

The attitude & orbit of a satellite must be controlled so that the satellite's antennas point toward the earth so that the user knows where to look for satellite. For GEO satellites the earth stations antennas that are used with GEO satellites are fixed and movement of satellite away from its position in the sky will cause a loss of signal. There are several forces acting on satellite that tend to change its attitude & orbit. The most important are gravitational fields of sun & Moon, irregularities in earth's gravitational; field, solar pressure from the sun and variations in earth's magnetic field.

Solar pressure on satellite and earth's magnetic field generates eddy currents in satellite's metallic structure causes rotation in satellite body. The presence of gravitational fields from the sun & moon cause the orbit of satellite to change with time. The orbit control system is able to move the satellite back into the equatorial plane before orbital inclination become excessive. To maintain the accurate station keeping, the satellite must be periodically accelerated in opposite direction to the forces acting on it that can be controlled from earth via TTC&M system.

ATTITUDE CONTROL SYSTEM:-

There are two ways to make a satellite stable in orbit.

- Spinning the satellite (Spinner Satellite)
- Momentum of wheels (Three Axis stabilization)

Spinning the Satellite: -

To create a gyroscopic force, the entire body of satellite can be rotated at a a rate of 30 and 100 RPM that provides stability of spin axis & keeps it pointing in the same direction. These satellites are called Spinners.

Momentum of wheels (Three Axis stabilization):-

The satellite can be stabilized by one or momentum wheels called as three axis stabilized satellite. The momentum wheel is usually a solid metal disk driven by electric motor. There must be one momentum wheel for each of three axes of satellite and rotated to provide rotational force about any of the three axis. According to the principal of angular momentum, increasing the speed of momentum wheel causes the satellite to pre cess in the opposite direction.

Spinner Satellite: -

The spinner design of satellite consist of cylindrical drum covered in solar cells that contains the power systems and rocket motors.The communication system is mounted in top of the drum and is driven by an electric motor in the opposite direction to the rotation of the satellite body to keep antennas pointing towards earth. These satellites are called **despun**.

- There are two types rocket motors used on satellites.
    - Bipropellant Thruster.
    - Arc Jets or ion thrusters.

Bipropellant Thruster:-

The satellite is spun up by operating small radial gas jets mounted on the periphery of the drum, at an appropriate point in the launch space.A variety of liquid propulsion mixes have been used for the gas jets most common being Hydrazine(N_2H_4) Increased power can be obtained from hydrazine gas jets by electrically heating the catalyst and gas. Satellites that use liquid fuel thrusters have standardized on bipropellant fuels called as thruster fuels. The most common bipropellants used for thruster are monomethyl hydrazine & nitrogen tetroxide. They are hypogolic. That is they ignite spontaneously on contact. By adjusting flow of bipropellants, pulses of thrust can be generated at correct time and in correct direction.

Arc jets or ion thrusters:-

These are mainly used for north-south station keeping where the greatest use of fuel is required for station keeping maneuvers and become operational on satellite buses. These lack the total thrust required to move satellites quickly but a small continuous thrust is adequate to maintain N-S & E-W position keeping.

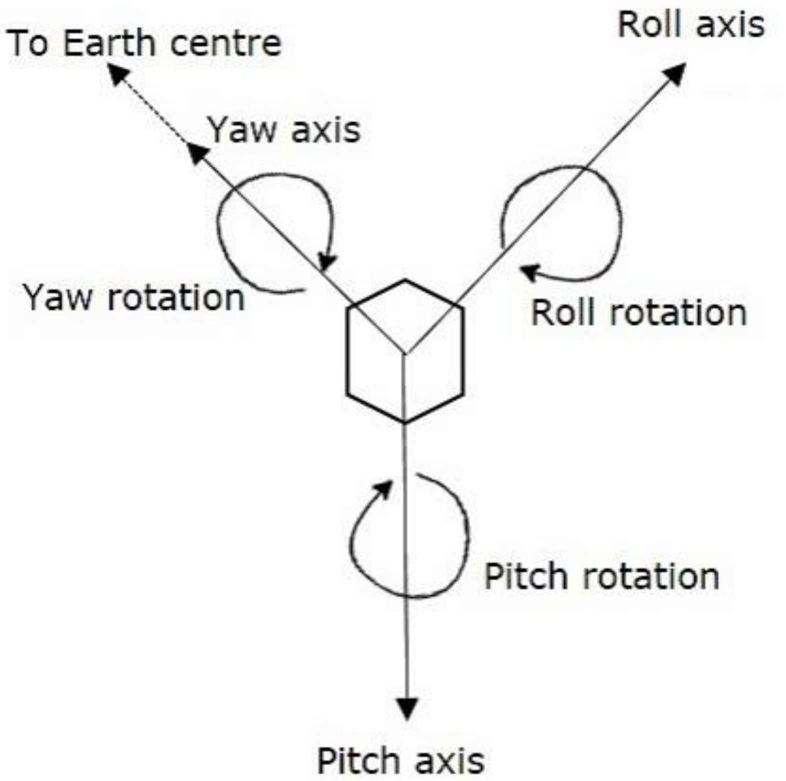
Spin Stabilized Satellite
(Cylindrical Structure)

Three Axis Stabilized Satellite:-

In this method, we can stabilize the satellite by using one or more momentum wheels. This method is called as **three-axis method**. The advantage of this method is that the orientation of the satellite in three axes will be controlled and no need of rotating satellite's main body.

In this method, the following **three axes** are considered.

- **Roll axis** is considered in the direction in which the satellite moves in orbital plane.
- **Yaw axis** is considered in the direction towards earth.
- **Pitch axis** is considered in the direction, which is perpendicular to orbital plane.



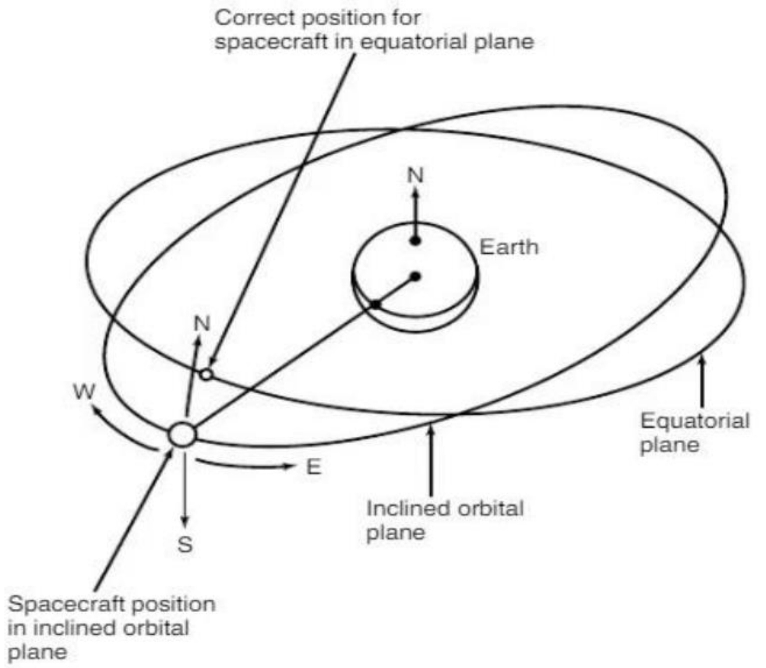
Let X_R, Y_R and Z_R are the roll axis, yaw axis and pitch axis respectively. These three axis are defined by considering the satellite's position as **reference**. These three axes define the altitude of satellite.

Let X, Y and Z are another set of Cartesian axes. This set of three axis provides the information about orientation of the satellite with respect to reference axes. If there is a change in altitude of the satellite, then the angles between the respective axes will be changed.

In this method, each axis contains two gas jets. They will provide the rotation in both directions of the three axes.

- **first gas jet** will be operated for some period of time, when there is a requirement of satellite's motion in a particular axis direction.
- The **second gas jet** will be operated for same period of time, when the satellite reaches to the desired position. So, the second gas jet will stop the motion of satellite in that axis direction.

ORBIT CONTROL SYSTEM



A geostationary satellite is subjected to several forces that tend to accelerate it away from its required orbit. The most important, for the geostationary satellite, are the gravitation forces of the moon and the sun, which cause inclination of the orbital plane, and the non spherical shape of the earth around the equator, which causes drift of the subsatellite point. There are many other smaller forces that act on the satellite causing the orbit to change.

Accurate prediction of the satellite position a week or 2 weeks ahead requires a computer program with up to 20 force parameters. Inclined orbital plane close to the geostationary orbit. For the orbit to be truly geostationary, it must lie in the equatorial plane, be circular, and have the correct altitude.

The various forces acting on the satellite will steadily pull satellite out of the correct orbit; it is the function of the orbit control system to return it to the correct orbit. This cannot be done with momentum wheels since linear accelerations are required. Gas jets that can impart velocity changes along the three references axes of the satellite are required.

If the orbit is not circular, a velocity increase or decrease will have to be made along the orbit, in the X -axis direction. On a spinning satellite, this is achieved by pulsing the radial jets when they point along the X axis On a three-axis stabilized satellite, there will usually be two pairs of X -axis jets acting in opposite directions, one pair of which will be operated for a predetermined length of time to provide the required velocity change.

The orbit of a geostationary satellite remains approximately circular for long periods of time and does not need frequent velocity corrections to maintain circularity. Altitude corrections are made by operating the Z-axis gas jets. The inclination of the orbit of a satellite that starts out in a geostationary orbit increases at an average rate of about 0.85°per year, with an initial rate of change of Inclination for a satellite in an equatorial orbit between 0.75°to 0.94°per year.

Correcting the inclination of a satellite orbit requires more fuel to be expended than for any other orbital correction. East–west station keeping is effected by use of the X-axis jets of the satellite. For a satellite located away from the stable points at 75°E and 252°E,a slow drift toward these points will occur. Typically, the X-axis jets are pulsed every 2 or 3 weeks to counter the drift and add a small velocity increment in the opposite direction.

The satellite then drifts through its nominal position, stops at a point a fraction of a degree beyond it, and then drifts back again. East–west station keeping requires only a modest amount of fuel and is necessary on all geostationary communications satellites to maintain the spacing between adjacent satellites.

Low earth orbit (LEO) and medium earth orbit (MEO) satellites also need AOC systems to maintain the correct orbit and attitude for continuous communication. Because of the much stronger gravitational force of the earth in LEO orbit, attitude stabilization is often accomplished with a rigid gravity gradient boom. This is a long pole that points toward the center of the earth, providing damping of oscillations about the satellite's z axis by virtue of the difference in gravitational field at the top of the pole and at the bottom.

TELEMETRY, TRACKING, COMMAND & MONITORING SYSTEM

The TTC&M system is essential to the successful operation of communication satellite. It involves an earth station, usually dedicated to that task, and a group of personnel.

The main functions of satellite management are

- To control the orbit and attitude of the satellite
- To monitor the status of all sensors and subsystems on the satellite.
- To switch on or off sections of the communication system.
- On large geostationary satellites, some repointing of individual antennas may be possible, under the command of the TTC&M system. • Tracking is performed primarily by the earth station

On large geostationary satellites, some repointing of individual antennas may be possible, under the command of the TTC&M system. Tracking is performed primarily by the earth station.

Telemetry and Monitoring System:-

The monitoring system collects data from many sensors within the satellite and sends these data to the controlling earth station. Hundreds of sensors located on the satellite to monitor pressure in the fuel tanks, Voltage and current in the power conditioning unit, Current drawn by each subsystem, Critical voltages and currents in the communications electronics.

Many temperature sensors are fitted – to sense temperature within the limits. The sensor data, the status of each subsystem, and the positions of switches in the communication system are reported back to the earth by the telemetry system.The sighting devices used to maintain attitude are also monitored via the telemetry link: not to cause the satellite to point in the wrong direction.

The faulty unit must then be disconnected and a spare brought in, via the command system, or some other means of controlling attitude devised. Telemetry data are usually digitized and transmitted as phase shift keying (PSK) of a low-power telemetry carrier using time division techniques. A low data rate is normally used to allow the receiver at the earth station to have a narrow bandwidth and thus maintain a high carrier to noise ratio.

The entire TDM frame may contain thousands of bits of data and take several seconds to transmit. At the controlling earth station a computer can be used to monitor, store, and decode the telemetry data so that the status of any system or sensor on the satellite can be determined immediately by the controller on the earth. Alarms can also be sounded if any vital parameter goes outside allowable limits.

Tracking: -

To determine the current orbit of a satellite. Velocity and acceleration sensors on the satellite are used to establish the change in orbit from the last known position, by integration of the data. The earth station controlling the satellite can observe the Doppler shift of the telemetry carrier or beacon transmitter carrier to determine the rate at which range is changing.

Together with accurate angular measurements from the earth station antenna, range is used to determine the orbital elements. Active determination of range can be achieved by transmitting a pulse, or sequence of pulses, to the satellite and observing the time delay before the pulse is received again.

Command: -

A secure and effective command structure is vital to the successful launch and operation of any communications satellite. The command system is used to make changes in attitude and corrections to the orbit and to control the communication system.

During launch, it is used to control the firing of the apogee kick motor and to spin up a spinner or extend the solar sails and antennas of a three axis stabilized satellite. The command structure must possess safeguards against unauthorized attempts to make changes to the satellite's operation, and also against inadvertent operation of a control due to error in a received command.

Encryption of commands and responses is used to provide security in the command system. Originate commands at the control terminal of the computer. The control code is converted into a command word, which is sent in a TDM frame to the satellite. After checking for validity in the satellite, the word is sent back to the control station via the telemetry link where it is checked again in the computer.

If it is found to have been received correctly, an execute instruction will be sent to the satellite so that the command is executed. The entire process may take 5 or 10 s, but minimizes the risk of erroneous commands causing a satellite malfunction. The command and telemetry links are usually separate from the communication system, although they may operate in the same frequency band (6 and 4 GHz).

Two levels of command system are used in the Intelsat satellite: the main system operates in the 6-GHz band, in a gap between the communication channel frequencies; the main telemetry system uses a similar gap in the 4-GHz band. These are earth coverage horns, so the main system can be used only after correct attitude of the satellite is achieved. During the launch phase and injection into geostationary orbit, the main TTC & M system may be inoperable because the satellite does not have the correct attitude or has not extended its solar sails.

A backup system is used at this time, which controls only the most important sections of the satellite. A great deal of redundancy is built into this system, since its failure will jeopardize the entire mission. Near omnidirectional antennas are used at either UHF or S band

(2–4 GHz), and sufficient margin is allowed in the signal-to-noise ratio (S/N) at the satellite receiver to guarantee control under the most adverse conditions.

The backup system provides control of the apogee kick motor, the attitude control system and orbit control thrusters, the solar sail deployment mechanism (if fitted), and the power conditioning unit. With these controls, the satellite can be injected into geostationary orbit, turned to face the earth, and switched to full electrical power so that hand over to the main TTC&M system is possible. In the event of failure of the main TTC & M system, the backup system can be used to keep the satellite on station.

It is also used to eject the satellite from geostationary orbit and to switch off all transmitters when the satellite eventually reaches the end of its useful life.

POWER SYSTEMS

All communications satellites obtain their electrical power from solar cells which convert incident sunlight into electrical energy. At geostationary altitude, the radiation falling on a satellite has an intensity of $1.39 {}^{KW}/_{m^2}$.

Solar cells do not convert all this incident energy into electrical power since their efficiency is about 20 to 25% at beginning of life and falls with time because of aging of cells. Since sufficient power must be available at the End of Life of the satellite to supply all the systems on board, 15% extra area of cells is usually provided as allowance for aging.

A spin stabilized satellite usually has a cylindrical body covered in solar cells. The solar cells are on a cylindrical surface, half of the cells are not illuminated at all. The cells that are not illuminated by sunlight experience cold space which causes them to cool down. So the solar cells on a spinner satellite have low temperate than those of solar sails which increases their efficiency.

A three axis stabilized satellite can make better use of its solar cell area, since the cells can be arranged on flat panels that can be rotated to maintain normal incidence of sunlight. One-third of solar cells are required compared to spinner satellite which saves weight. The main advantage is that by unfurling a folded soar array when the satellite reaches geostationary orbit, an excess power of 10KW can be generated with large arrays. The satellite must carry batteries to power the subsystems during launch and during eclipses.

To avoid the need of large battery, a part or all of communications systems load may be shut down during eclipse. Batteries are usually of nickel-hydrogen type which do not gas when charging and have good reliability and long life. A power conditioning unit controls the charging current and dumps excess current from solar cells into heaters on the cold side of satellite.

Sensors on the battery, power regulator & solar cells monitor temperature, voltage & current and supply these data to the onboard control system and controlling earth station via telemetry link.

COMMUNICATION SUBSYSTEMS

A communications satellite exists to provide a platform in geostationary orbit for the relaying of voice, video & data communications. All other subsytems on the satellite exists to support the communication subsystem although it is a small part of the volume, weight & cost of satellite. These are designed to provide large traffic capacity that earns revenue for system operator.

Successive satellites have become larger, heavier & more costly but the rate at which traffic capacity has increased is much greater resulting in lower cost per telephone circuit & transmitted bit width. Communications sub-systems mainly have Transponders & Antenna Subsystems.

Transponders: -

The transponder in a communications satellite is the series of components that provides the communications channel, or link, between the uplink signal received at the uplink antenna, and the downlink signal transmitted by the downlink antenna. A typical communications satellite will contain several transponders, and some of the equipment may be common to more than one transponder.

Each transponder generally operates in a different frequency band, with the allocated frequency spectrum band divided into slots, with a specified center frequency and operating bandwidth. The C-band FSS service allocation, for example, is 500MHz wide. A typical design would accommodate 12 transponders, each with a bandwidth of 36 MHz, with guard bands of 4MHz between each.

Typical commercial communications satellite today can have 24 to 48 transponders, operating in the C-band, Ku-band, or Ka-bands. The number of transponders can be doubled by the use of polarization frequency reuse, where two carriers at the same frequency, but with orthogonal polarization, are used. Both linear polarization and circular polarization have been used. Additional frequency reuse may be achieved through spatial separation of the signals, in the form of narrow spot beams, which allow the reuse of the same frequency carrier for physically separate locations on the earth.

Polarization reuse and spot beams can be combined to provide four times, six times, eight times, or even higher frequency reuse factors in advanced satellite systems.

The communications satellite transponder is implemented in one of two general types of configurations:

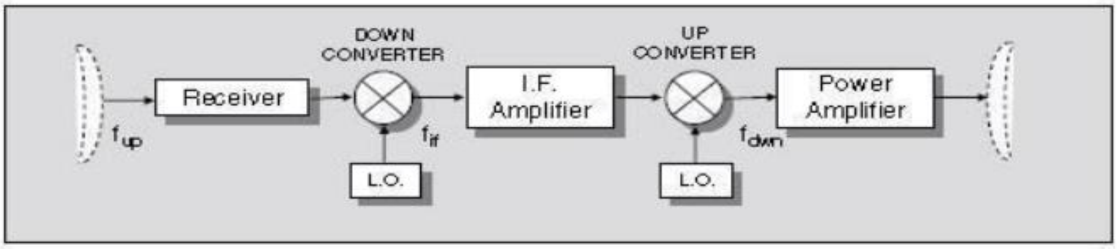
i) The frequency translation transponder

ii) The on-board processing transponder

Frequency Translation Transponder:-

The first type, which has been the dominant configuration since the inception of satellite communications, is the frequency translation transponder. The frequency translation transponder, also referred to as a non-regenerative repeater, or bent pipe, receives the uplink signal and after amplification, retransmits it with only a translation in carrier frequency.

The below Figure shows the typical implementation of a dual conversion frequency translation transponder, where the uplink radio frequency, f_{up}, is converted to an intermediate lower frequency, f_{if} , amplified, and then converted back up to the downlink RF frequency, f_{dwn}, for transmission to earth.



- Frequency Translation Transponder, also called
  - Repeater
  - Non-Regenerative Satellite
  - 'Bent Pipe'
- The dominant type of transponder currently in use
  - FSS, BSS, MSS
- Uplinks and downlinks are codependent

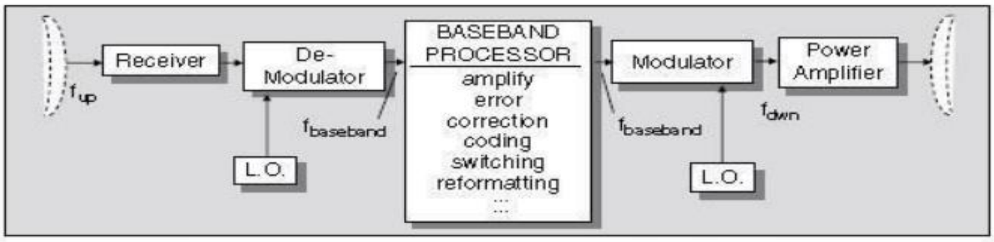
Frequency translation transponders are used for FSS, BSS, and MSS applications, in both GSO and NGSO orbits. The uplinks and downlinks are codependent which means that any degradation introduced on the uplink will be transferred to the downlink, affecting the total communications link. This has significant impact on the performance of the end-to-end link.

On-board Processing Transponder: -

The below Figure shows the second type of satellite transponder, the on-board processing transponder, also called a regenerative repeater demod/remod transponder, or smart satellite. The uplink signal at f_{up} is demodulated to baseband, $f_{baseband}$.

The baseband signal is available for processing on-board, including reformatting and error-correction. The baseband information is then remodulated to the downlink carrier at f_{dwn}, possibly in a different modulation format to the uplink and, after final amplification, transmitted to the ground.

The demodulation/remodulation process removes uplink noise and interference from the downlink, while allowing additional on-board processing to be accomplished. Thus the uplinks and downlinks are independent with respect to evaluation of overall link performance, unlike the frequency translation transponder where uplink degradations are codependent, as discussed earlier.



- On-Board Processing Transponder, also called
  - Regenerative Repeater
  - Demod/Remod Transponder
  - 'Smart Satellite'
- First generation systems:
  - ACTS, MILSTAR, IRIDIUM, . . .
- Uplinks and downlinks are independent

On-board processing satellites tend to be more complex and expensive than frequency translation satellites but they offer significant performance advantages, particularly for small terminal users or for large diverse networks.

Traveling wave tube amplifiers (TWTAs) or solid-state amplifiers (SSPAs) are used to provide the final output power required for each transponder channel. The TWTA is a slow wave structure device, which operates in a vacuum envelope, and requires permanent magnet focusing and high voltage DC power supply support systems. The major advantage of the TWTA is its wide bandwidth capability at microwave frequencies. TWTA's for space applications can operate to well above 30 GHz, with output powers of 150 watts or more, and RF bandwidths exceeding 1 GHz. SSPA's are used when power requirements in the 2–20 watt region are required. SSPA's operate with slightly better power efficiency than the TWTA.

ANTENNA SUBSYSTEMS

The antenna systems on the spacecraft are used for transmitting and receiving the RF signals that comprise the space links of the communications channels. The antenna system is a critical part of the satellite communications system, because it is the essential element in increasing the strength of the transmitted or received signal to allow amplification, processing, and eventual retransmission.

The most important parameters that define the performance of an antenna are antenna gain, antenna beamwidth, and antenna sidelobes.

- The gain defines the increase in strength achieved in concentrating the radio wave energy, either in transmission or reception, by the antenna system. The antenna gain is usually expressed in dBi, decibels above an isotropic antenna, which is an antenna that radiates uniformly in all directions.
- The beamwidth is usually expressed as the half-power beamwidth or the 3-dB beamwidth, which is a measure of the angle over which maximum gain occurs.
- The sidelobes define the amount of gain in the off-axis directions. Most satellite communications applications require an antenna to be highly directional (high gain, narrow beamwidth) with negligibly small sidelobes.

Four main types of antennas are used on satellites. They are

- Wire Antennas (Monopoles & Dipoles)
- Horn Antennas.
- Reflector Antennas.
- Array Antennas.

Wire Antennas:-

These are primarily used VHF & UHF to provide communications for TTC&M Systems. These are positioned on satellite to provide omnidirectional coverage. The linear dipole antenna is an isotropic radiator that radiates uniformly in all directions. Four or more dipole antennas are placed on the spacecraft to obtain a nearly omni-directional pattern. Dipole antennas are used primarily at VHF and UHF for tracking, telemetry, and command links.

Dipole antennas are also important during launch operations, where the spacecraft attitude has not yet been established, and for satellites that operate without attitude control or body stabilization (particularly for LEO systems).

Horn Antennas: -

These are used at microwave frequencies where relatively wide beams are required for global coverage. A Horn is a flared section of waveguide that provides an aperture several wavelengths wide & and provide impedance matching. Horns are used as feed for reflectors. These are aperture antennas that transmit a wave into free space from a waveguide. From Horn antennas it is difficult to provide a gain above 23dB & beamwidth less than 10^0.

Reflector Antennas: -

For higher gains & narrow beam widths reflector antenna or array are used. These are illuminated by one or more horns & provide a larger aperture than achieved by horn antenna. For maximum gain, a plane wave in the aperture of reflector is generated.

This is done by choosing a reflector that has equal path lengths from feed to the aperture such that all the energy radiated by the feed and reflected by reflector reaches the aperture with equal phase angle that creates uniform phase front. This is achieved by paraboloid reflector where the feed is placed at its focus. This is commonly used reflector antenna for earth stations.

Narrow beam antennas usually require physical pointing mechanisms on the spacecraft to point the beam in the desired direction.

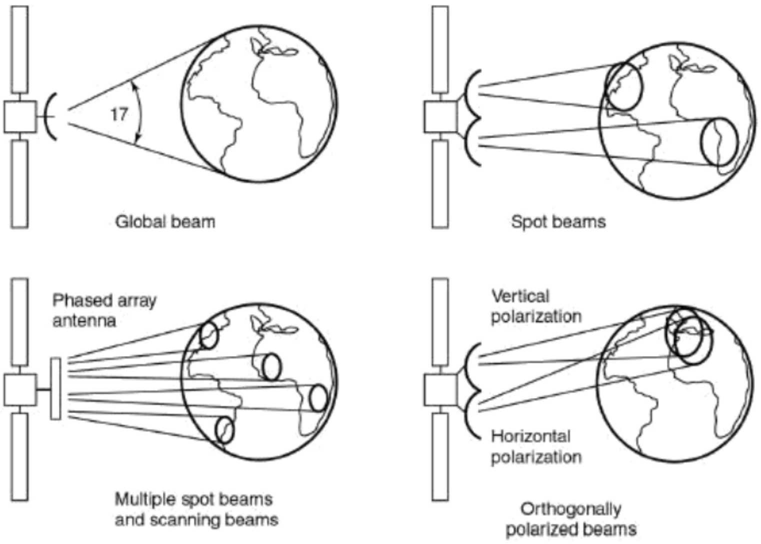
Array Antennas: -

A steerable, focused beam can be formed by combining the radiation from several small elements made up of dipoles, helices, or horns. Beam forming can be achieved by electronically phase shifting the signal at each element. Proper selection of the phase characteristics between the elements allows the direction and beamwidth to be controlled, without physical movement of the antenna system. The array antenna gain increases with the square of the number of elements. Gains and beamwidths comparable to those available from parabolic reflector antennas can be achieved with array antennas.

Phased array antennas are used on satellites to create multiple beams from single aperture especially for LEO satellites.

An aperture antenna has again G given by

$$G = \eta_A \, 4\pi A/\lambda^2$$



EQUIPMENT RELIABILITY & SPACE QUALIFICATION

Communication satellites built already have provided operational lifetimes of up to 15years. Once a satellite is in geo stationary orbit, there is little possibility of repairing components that fail or adding more fuel for station keeping.

The components that make up the satellite must therefore have very high reliability in the hostile environment of outer space, and a strategy must be devised that allows some components to fail without causing the entire communication capacity of the satellite to be lost.

Two separate approaches are used:

- Space qualification of every part of the satellite to ensure that it has a long life expectancy in orbit.
- Redundancy of the most critical components to provide continued operation when one component fails.

Space Qualification: -

Outer space, at geostationary orbit distances is a harsh environment. There is a total vacuum and the sun irradiates the satellite with 1.4kw of heat and light on each square meter of exposed surface. Electronic equipment cannot operate at such extremes of temperature and must be housed within the satellite and heated or cooled so that its temperature stays within the range 0^0 to 75^0C.

This requires a thermal control system that manages heat flow throughout a GEO satellite as the sun moves around once every 24hr. The first stage in ensuring high reliability in a satellite is by selection and screening of each component used.

Past operations & test experience of components indicates which components can be expected to have good reliability. Only components that have good reliability under outer space conditions are selected and tested individually to ensure that it meets its specification. This is called **Quality Control or Quality Assurance.**

When a satellite is designed, three prototype models are often built and tested.

The mechanical model contains all the structural and mechanical parts that will be included in the satellite and is tested to ensure that all moving parts operate correctly in a vacuum, over a wide temperature range. It is also subjected to vibration & shock testing to simulate vibration levels & Gravitational Forces during launch.

The thermal model contains all the electronics packages and other components that must be maintained at correct temperature. The thermal, Vibration & vacuum tests of entire satellite will be combined in thermal vacuum chamber called as ***Shake & Bake Test.***

The electrical model contains all electronic parts of the satellite and is tested for correct electrical performance under total vacuum and a wide range of temperatures. Space qualification is an expensive process which makes GEO Satellites more expensive. Many of the electronic and mechanical components that are used in satellite are known to have limited life times, or a finite probability of failure.

If failure of one of these components will cause the mission to failure or reduce the communication capacity of the satellite, a backup, or redundant, unit will provided. The design of the system must be such that when one unit fails, the backup can automatically take over or be switched into operation by a command from the ground.

Reliability: -

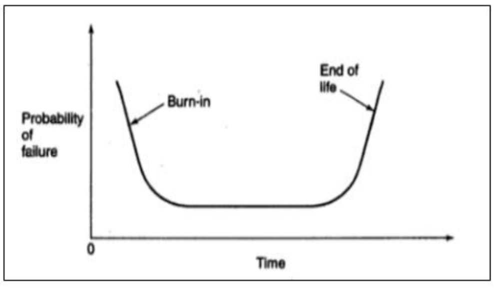
Satellites designed for specific mission lasting 1 or 2 years have frequently operated successfully for up to 25 years. Sufficient reliability was designed into the satellite to guarantee the mission life time such that actual life time has been much greater.

The reliability of satellite subsystem is calculated for two reasons.

- To know the probability that the system will still be working after a given time period.
- To provide redundant components or subsystems where the probability of failure is too great to be accepted.

The manufacturers of satellites provide with predictions of reliability of the satellite & subsystems using reliability theory. Reliability theory is a mathematical attempt to predict the future & is therefore less certain than other mathematical techniques that operate in absolute terms. The application of reliability theory has enabled satellite engineers to build satellites that perform as expected at acceptable construction costs.

The reliability of component is expressed in terms of probability of failure after time t, $P_f(t)$. For most electronic component, probability of failure is higher at the beginning of life – burn-in period_ than at some later time. As the component ages, failure becomes more likely , leading to Bath Tub Curve as shown below:



Components for satellites are selected only after extensive testing. The aim of testing is to determine reliability, causes of failure & expected lifetime. Testing is carried out under rigorous conditions representing the worst operating conditions that are encountered in space and may be designed to accelerate failure in order to shorten the testing duration needed to determine the reliability.

The reliability of a device or subsystem is defined as

$$R(t) = \frac{N_s(t)}{N_0} = \frac{Number\ of\ surviving\ components\ at\ time\ t}{Number\ of\ components\ at\ start\ of\ test\ period}$$

The numbers of components that failed in time t is $N_f(t) = N_0 - N_s(t)$

The probability of any one of the components failing is related to ***mean time before failure(MTBF).*** MTBF = m = $\frac{1}{N_0}\sum_{i=1}^{N_0} t_i$

The average failure rate λ is reciprocal of m.

$$\lambda = \frac{Number\ of\ failures\ in\ given\ time}{Number\ of\ surviving\ components} = \frac{1}{N_s}\frac{\Delta N_f}{\Delta t} = \frac{1}{N_s}\frac{dN_f}{dt} = {}^{1}/_{MTBF}$$

The rate of failure $\frac{dN_f}{dt}$ is the negative of rate of survival $\frac{dN_s}{dt}$.

So $\lambda = -\frac{1}{N_s}\frac{dN_s}{dt}$

The reliability $R = \frac{N_s}{N_0}$. So $\lambda = -\frac{1}{N_0 R}\frac{d(N_0 R)}{dt} = -\frac{1}{R}\frac{dR}{dt}$

The solution is $R = e^{-\lambda t}$.

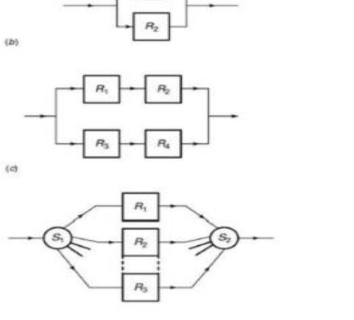
The reliability of device decreases exponentially with time , with zero reliability after infinite time, that is certain failure. The usual life of component is t_l, at which R falls to $0.37({}^{1}/_{e})$ $when\ t_l = {}^{1}/_{\lambda} = m$

Redundancy: -

In a satellite many devices are used each with different $mtbf$ and failure one device causes failure of entire subsystem. If we incorporate redundant devices, the subsystem will continue to function correctly.

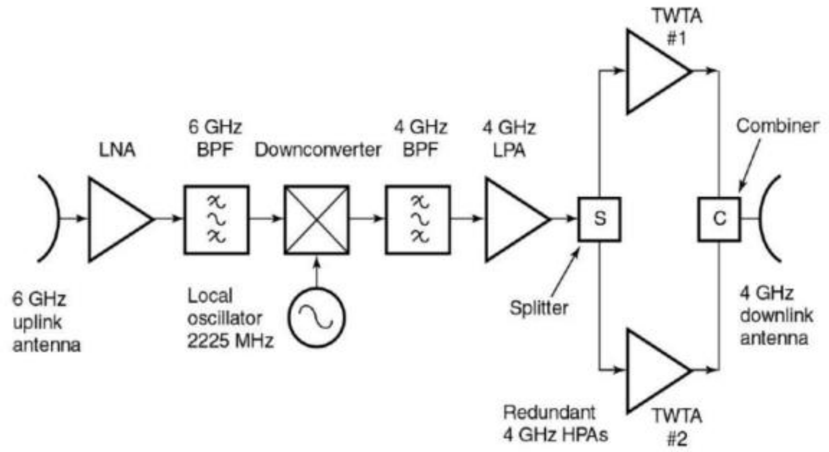
The redundant devices are placed in different situations as shown below.

Figure
Redundancy connections. (*a*) Series connection. (*b*) Parallel connection. (*c*) Series/parallel connection. (*d*) Switched connection.



- Series Connection- Used in Solar Cells
- Parallel Connection- Used to provide redundancy of high power amplifiers in satellite transponders.
- Switched Connection-Used to provide parallel paths with multiple transponders.
- A switched connection is also referred as ring redundancy since any component can be switched in for any other.

For parallel redundancy, a bent pipe transponder is shown below.



Redundant W/TA configuration in HPA of a 6/4 GHz bent pipe transponder.

The parallel connection of two TWTs as shown above raises the reliability of the amplifier stage to 0.60 at the mean time before failure (MTBF) period, assuming zero probability of a short circuit. A life time of 50,000h is approximately 6 years of continuous operation, which is close to the typical design life time of a satellite. To further improve the reliability of the transponder, a second redundant transponder may be provided with switching between the two systems. A combination of parallel and switched redundancy is used to combat failures that are catastrophic to one transponder channel and to the complete communication system.