SATELLITE COMMUNICATIONS

20A04701c

Lecture Notes

ECE – IVth B.Tech -Ist Semester

Prepared by,

P. IMRAN KHAN M.Tech.,(PhD)

Assistant Professor

ECE Department

Electronics and Communication Engineering

St.Johns College of Engineering & Technology

Yerrakota, Yemmiganur-518360, Kurnool(D), A.P.

JAWAHARLAL NEHRU TECHNOLOGICAL UNIVERSITY ANANTAPUR

B.Tech (ECE)– IV-I Sem

L	T	P	C
3	0	0	3

(20A04701c) SATELLITE COMMUNICATIONS
(Professional Elective Course –III)

Course Objectives:
To introduce various aspects in the design of systems for satellite communication.

Course Outcomes:
- Learn the dynamics of the satellite.
- Understand the communication satellite design.
- Understand how analog and digital technologies are used for satellite communication networks.
- Learn the design of satellite links.
- Study the design of Earth station and tracking of the satellites.

UNIT I
Elements of orbital mechanics. Equations of motion. Tracking and orbit determination. Orbital correction/control. Satellite launch systems. Multistage rocket launchers and their performance

UNIT II
Elements of communication satellite design. Spacecraft subsystems. Reliability considerations. Spacecraft integration.

UNIT III
Multiple access techniques. FDMA,TDMA,CDMA. Random access techniques. Satellite onboard processing.

UNIT IV
Satellite link design: Performance requirements and standards. Design of satellite links – DOMSAT, INSAT, INTELSAT and INMARSAT. Satellite - based personal communication. links.

UNIT V
Earth station design. Configurations. Antenna and tracking systems. Satellite broadcasting.

Textbooks:
D. Roddy, Satellite Communication (4/e), McGraw- Hill, 2009.
T. Pratt & C.W. Bostain, Satellite Communication, Wiley 2000.

References:
B.N. Agrawal, Design of Geosynchrons Spacecraft, Prentice- Hall,1986

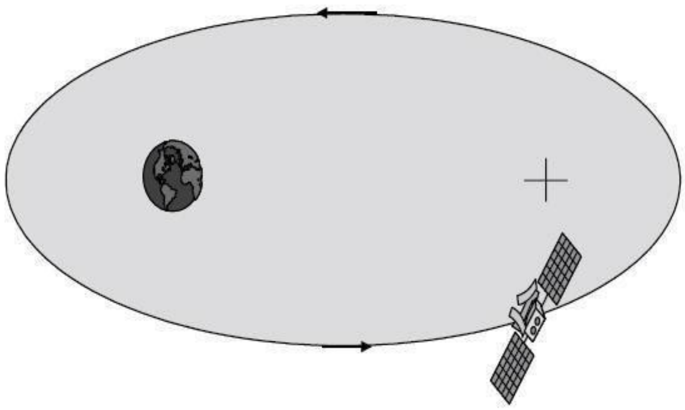
Unit - 01

Kepler's Laws:

Kepler's laws of planetary motion apply to any two bodies in space that interact through gravitation. The laws of motion are described through three fundamental principles.

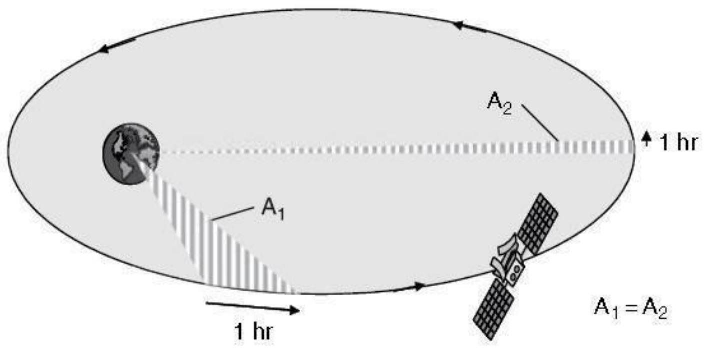
Kepler's First Law, as it applies to artificial satellite orbits, can be simply stated as: 'The path followed by a satellite around the earth will be an ellipse, with the center of mass of earth as one of the two foci of the ellipse.'

This is shown in Figure:



If no other forces are acting on the satellite, either intentionally by orbit control or unintentionally as in gravity forces from other bodies, the satellite will eventually settle in an elliptical orbit, with the earth as one of the foci of the ellipse. The 'size' of the ellipse will depend on satellite mass and its angular velocity.

Kepler's Second Law can likewise be simply stated as: 'for equal time intervals, the satellite sweeps out equal areas in the orbital plane.' Figure 2.3 demonstrates this concept.



The shaded area A1 shows the area swept out in the orbital plane by the orbiting satellite in a one hour time period at a location near the earth. Kepler's second law states that the area swept out by any other one hour time period in the orbit will also sweep out an area equal to A1. For example, the area swept out by the satellite in a one hour period around the point farthest from the earth (the orbit's apogee), labeled A2 on the figure, will be equal to A1, i.e.: A1 =A2.

This result also shows that the satellite orbital velocity is not constant; the satellite is moving much faster at locations near the earth, and slows down as it approaches apogee. This factor will be discussed in more detail later when specific satellite orbit types are introduced.

Kepler's Third Law is as: 'the square of the periodic time of orbit is proportional to the cube of the mean distance between the two bodies.' This is quantified as follows:

$$T^2 = \left[\frac{4\pi^2}{\mu}\right] a^3$$

Where T = orbital period in s;

a = distance between the two bodies, in km;

μ = Kepler's Constant = 3.986004×105 km3/s^2. If the orbit is circular, then a = r, and

$$r = \left[\frac{\mu}{4\pi^2}\right]^{\frac{1}{3}} T^{\frac{2}{3}}$$

This demonstrates an important result: Orbit Radius = [Constant] × (Orbit Period)$^{2/3}$

Under this condition, a specific orbit period is determined only by proper selection of the orbit radius. This allows the satellite designer to select orbit periods that best meet particular application requirements by locating the satellite at the proper orbit altitude. The altitudes required to obtain a specific number of repeatable ground traces with a circular orbit are listed in Table.

Orbit altitudes for specified orbital periods

Revolutions/day	Nominal period (hours)	Nominal altitude (km)
1	24	36000
2	12	20200
3	8	13900
4	6	10400
6	4	6400
8	3	4200

Orbital Elements:

We know that the path of satellite revolving around the earth is known as **Orbit**. This path can be represented with mathematical notations. Orbital mechanics is the study of the motion of the satellites that are present in orbits. So, we can easily understand the space operations with the knowledge of orbital

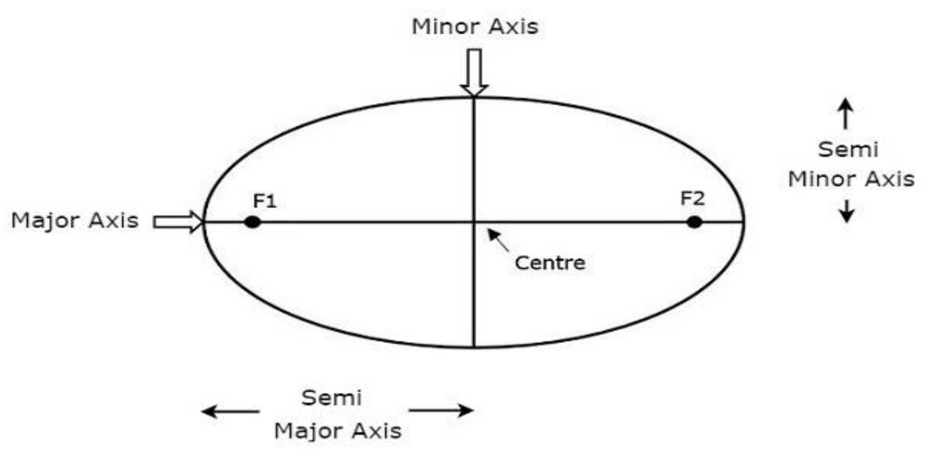
Orbital elements are the parameters, which are helpful for describing the orbital motion of satellites. Following are the **orbital elements**.

- Semi-major axis
- Eccentricity
- Mean anomaly
- Argument of perigee
- Inclination
- Right ascension of Ascending Node

The above six orbital elements define the orbit of earth satellites. Therefore, it is easy to discriminate one satellite from other satellites based on the values of orbital elements.

(i) Semi Major Axis:

The length of **Semi-major axis (a)** defines the size of satellite's orbit. It is half of the major axis. This runs from the center through a focus to the edge of the ellipse. So, it is the radius of an orbit at the orbit's two most distant points.



Both semi major axis and semi minor axis are represented in above figure. Length of **semi major axis (a)** not only determines the size of satellite's orbit, but also the time period of revolution.

If circular orbit is considered as a special case, then the length of semi-major axis will be equal to **radius** of that circular orbit.

(ii) Eccentricity:

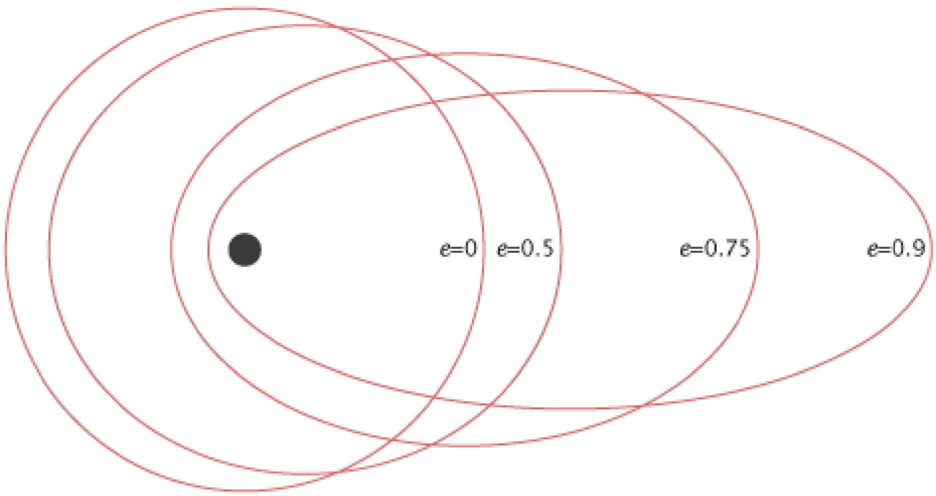
The value of **Eccentricity (e)** fixes the shape of satellite's orbit. This parameter indicates the deviation of the orbit's shape from a perfect circle.

If the lengths of semi major axis and semi minor axis of an elliptical orbit are a & b, then the mathematical expression for **eccentricity (e)** will be

$$e = \sqrt{1 - \frac{b^2}{a^2}}$$

The value of eccentricity of a circular orbit is **zero**, since both a & b are equal. Whereas, the value of eccentricity of an elliptical orbit lies between zero and one.

The following figure shows the various satellite orbits for different eccentricity (e) values



In above figure, the satellite orbit corresponding to eccentricity (e) value of zero is a circular orbit. And, the remaining three satellite orbits are of elliptical corresponding to the eccentricity (e) values 0.5, 0.75 and 0.9.

(iii) Mean Anomaly:

For a satellite, the point which is closest from the Earth is known as Perigee. **Mean anomaly** (M) gives the average value of the angular position of the satellite with reference to perigee.

If the orbit is circular, then Mean anomaly gives the angular position of the satellite in the orbit. But, if the orbit is elliptical, then calculation of exact position is very difficult. At that time, Mean anomaly is used as an intermediate step.

(iv) Argument of Perigee:

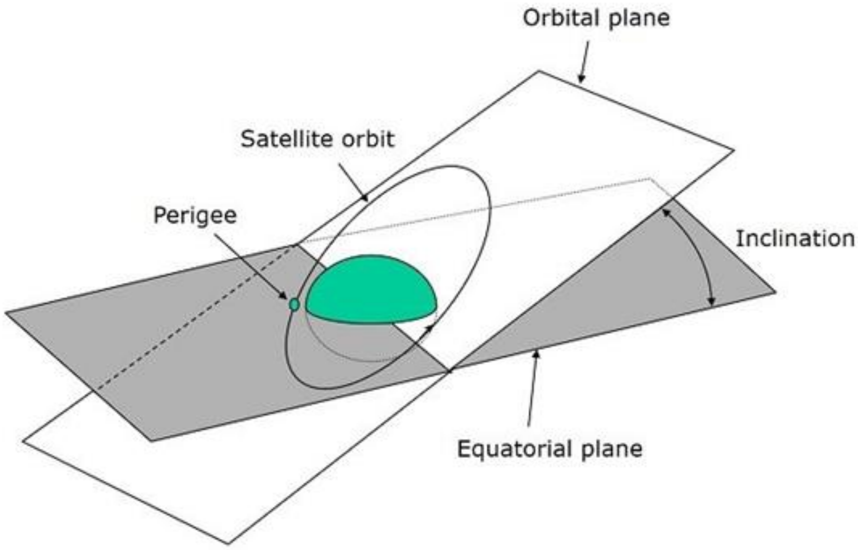
Satellite orbit cuts the equatorial plane at two points. First point is called as **descending node**, where the satellite passes from the northern hemisphere to the southern hemisphere. Second point is called as **ascending node**, where the satellite passes from the southern hemisphere to the northern hemisphere.

Argument of perigee (ω) is the angle between ascending node and perigee. If both perigee and ascending node are existing at same point, then the argument of perigee will be zero degrees

Argument of perigee is measured in the orbital plane at earth's center in the direction of satellite motion.

(v) Inclination:

The angle between orbital plane and earth's equatorial plane is known as **inclination (i)**. It is measured at the ascending node with direction being east to north. So, inclination defines the orientation of the orbit by considering the equator of earth as reference.



There are four types of orbits based on the angle of inclination.

- ✓ **Equatorial orbit**−Angle of inclination is either zero degrees or 180 degrees.
- ✓ **Polar orbit** − Angle of inclination is 90 degrees.
- ✓ **Prograde orbit** − Angle of inclination lies between zero and 90 degrees.
- ✓ **Retrograde orbit**−Angle of inclination lies between 90 and 180 degrees.

(vi) Right Ascension of Ascending Node:

We know that **ascending node** is the point, where the satellite crosses the equatorial plane while going from the southern hemisphere to the northern hemisphere.

Right Ascension of ascending node **(Ω)** is the angle between line of Aries and ascending node towards east direction in equatorial plane. Aries is also called as vernal and equinox.

Satellite's **ground track** is the path on the surface of the Earth, which lies exactly below its orbit. The ground track of a satellite can take a number of different forms depending on the values of the orbital elements.

Orbital Equations:

In this section, let us discuss about the equations which are related to orbital motion.

Forces acting on Satellite:

A satellite, when it revolves around the earth, it undergoes a pulling force from the earth due to earth's gravitational force. This force is known as **Centripetal force** (F_{in}) because this force tends the satellite towards it.

Mathematically, the **Centripetal force**(F_1) acting on satellite due to earth can be written as

$$\mathbf{Fin = m\ (G\ M_E / r^2\ )}$$

Where,

G is universal gravitational constant and it is equal to 6.673×10^{-11} N·m²/kg².

M_E is mass of the earth and it is equal to 5.98×10^{24} Kg.

m is mass of the satellite.

r is the distance from satellite to center of the Earth.

The standard acceleration due to gravity at the earth surface is 981 cm/s. The value decreases with height above the earth's surface. The acceleration, a, due to gravity at adistance r from the centre of the earth is

$$a=\mu/r^2 \text{ km/ s}^2$$

Where the constant μ is the product of the universal gravitational constant G and the mass of the earth M_E.

The product GM_E is called kepler's constant and has the value 3.98 x 10^5 km^3/s^2.

The universal gravitational constant is G = 6.672x 10^{-11} Nm^2/kg^2 .

The mass of the earth M_E =5.97 x 10^{24} kg.

Since fore= mass x acceleration, the centripetal force acting on the satellite, Fin is given by

$$F_{in} = m\ (\mu/r^2)$$
$$= m\ (G M_E / r^2)$$

A satellite, when it revolves around the earth, it undergoes a pulling force from the sun and the moon due to their gravitational forces. This force is known as **Centrifugal force** (F_2) because this force tends the satellite away from earth.

The centrifugal acceleration is given by,

$$a = v^2/r$$

Mathematically, the **Centrifugal force**(F_{out}) acting on satellite can be written as,

$$F_{out} = m * v^2/r$$

Where, **v** is the orbital velocity of satellite.

Orbital Velocity:

Orbital velocity of satellite is the velocity at which, the satellite revolves around earth. Satellite doesn't deviate from its orbit and moves with certain velocity in that orbit, when both Centripetal and Centrifugal forces are **balance** each other.

So, **equate** Centripetal force(F_{in}) and Centrifugal force(F_{out}).

$$F_{in} = F_{out}$$

Therefore, the **orbital velocity** of satellite is $v = (\mu/r)^{1/2}$

So, the orbital velocity mainly **depends** on the distance from satellite to center of the Earth (r).

Tracking and Orbit Determination:

The in-orbit control of a spacecraft requires knowledge of its position in space. For geostationary spacecraft the position is required relative to Earth-centered axis systems, both inertially fixed and rotating with the Earth, the former largely for maneuver design and event prediction, the latter for purposes of Earth station coverage and antenna pointing.

The process by which the spacecraft's position is determined is known as tracking and orbit determination. Tracking is the process of making observations of the spacecraft's position relative to a tracking station or other fixed point (such as a star) whose position is accurately known. Orbit determination is the process wherein the tracking observations are used to determine the spacecraft's orbital characteristics and its position in space.

As far as tracking is concerned, the spacecraft's mission can be divided into the transfer orbit phase and the geosynchronous orbit phase. The tracking characteristics for the two phases are generally quite different.

In the transfer orbit phase the spacecraft is only intermittently visible from any one ground station. Moreover, the command and control workload is rather heavy, and is compressed into a relatively short time span. These considerations require the spacecraft's orbit to be determined to acceptable accuracy quite rapidly. This in turn implies that several ground stations are required to co-operate in the process of tracking and orbit determination. Such a collection of co-operating ground stations is known as a network, and is characterized by commonality of tracking systems and standards. Overall control is exercised by a single element of the network, known as the control centre.

The ground stations within the network respond to tracking measurement requests from the control centre, and pass on tracking measurements to the control centre. At the control centre, the tracking measurements from all the stations are collected, and the orbit determination process is carried out. The tracking system (mainly the choice of frequencies) used in transfer orbit is intimately connected with the telemetry and command system that is employed during this phase. In fact, the telemetry, tracking, and command (TTC) hardware on board the spacecraft is selected for compatibility with the ground station network chosen to support the spacecraft during its transfer orbit phase.

When the spacecraft is operational in geostationary orbit, tracking is generally carried out through the communications payload equipment, and must therefore conform with its frequency band. Since the spacecraft is continuously within view of the ground station used to communicate with it, a network is not required. Furthermore, since the schedule of activities is very much more relaxed than in transfer orbit, tracking is required infrequently and is generally a more long drawn out process, in that observations are collected over a day or two before the orbit is determined. The transfer orbit TTC system acts as the back-up system during the operational phase of the spacecraft.

The most common type of tracking measurement for geostationary spacecraft is ranging.

Ranging is the determination of the spacecraft-to-ground station distance .This is done by bouncing a coded signal off the spacecraft and detecting it at the ground station. The signal could consist of either a transmission at radio frequency, or a laser beam. Only the former is in use for geostationary spacecraft.

The ranging process can be broken down into the discrete steps outlined below.

(1) Transmission of the signal by the ground station;

(2) Propagation of the signal from the ground station to the spacecraft;

(3) Signal turn-around by the spacecraft;

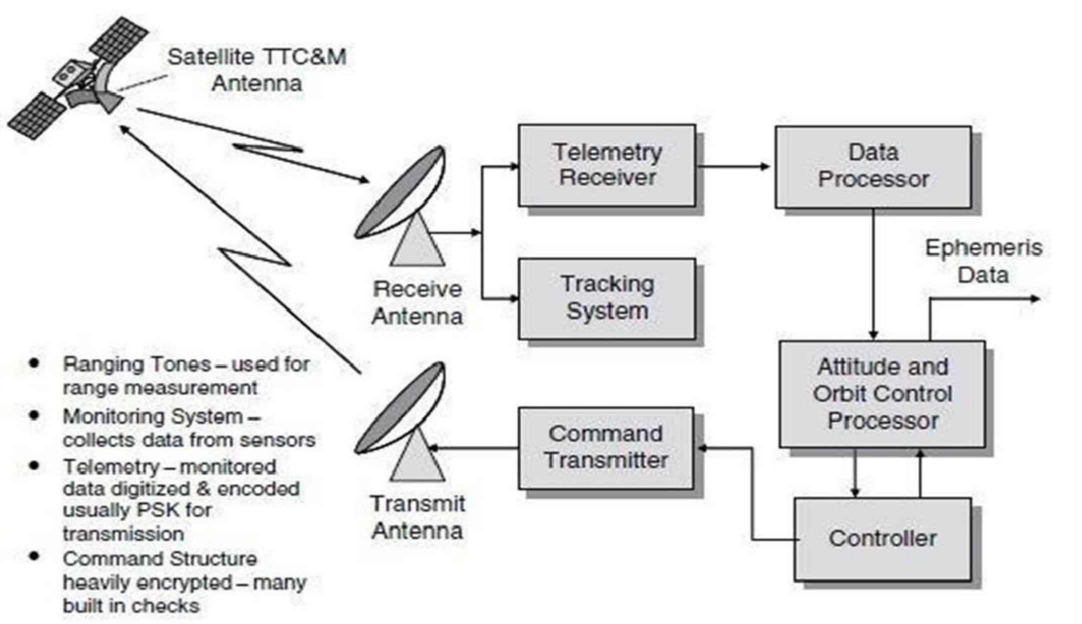
(4) Propagation of the signal from the spacecraft to the ground station;

(5) Reception of the signal by the ground station.

Errors arise at each step of the process, instrumentation errors for steps (I), (3), and (5), and environmental effects for steps (2) and (4).

Orbit determination requires that sufficient measurements be made to determine uniquely the six orbital elements needed to calculate the future of the satellite, and hence calculate the required changes that need to be made to the orbit to keep it within the nominal orbital location. The control earth stations used to measure the angular position of the satellites also carryout range measurements using unique time stamps in the telemetry stream or communication carrier. These earth stations generally referred to as the TTC&M (telemetry tracking command and monitoring) stations of the satellite network.

Telemetry, Tracking, Command & Monitoring (TTC&M):



Telemetry & Monitoring System:

- ❖ It collects data from many sensors within satellite & sends these data to thecontrolling earth station.
- ❖ Several hundred of sensors are located on satellite to monitor pressure in the fuel tanks, voltage & current in power conditioning unit, current drawn by each subsystem, & critical voltages & current in communications electronics.
- ❖ Temperature of many subsystems must be kept within predetermined limits, so many temp. Sensors are fitted.
- ❖ The sensor data, the status of each subsystem are reported back to the earth by telemetry system.
- ❖ Telemetry data are digitized and transmitted as phase shift keying (PSK) of low- power telemetry carrier using time division techniques.
- ❖ At controlling earth station a computer can be used to monitor, store, and decode telemetry data so that status of any system or sensors on the satellite can be determined immediately.
  - ❖ Alarms can also be sounded if any vital parameter goes outside allowable limits.

Tracking:

- ❖ A no. of techniques can be used to determine current orbit of satellite.

- ❖ Velocity & acceleration sensors on satellite can be used to establish the change in orbit from last known position, by integration of data.
- ❖ The earth station controlling satellite can observe the Doppler shift of telemetry carrier to determine rate at which range is changing.
- ❖ Active determination of range can be achieved by transmitting a pulse, or sequence of pulses, to the satellite and observing the time delay before pulse is received again.

Command:

- ❖ The command system is used to make changes in attitude and corrections to the orbit and to control communication system.
- ❖ During launch, it is used to control firing of AKM & to spin up spinner orextend solar sails & antennas of 3- axis stabilized satellite.
- ❖ The command structure must possess safeguards against unauthorized attempts to make changes to satellite's operation.
- ❖ Encryption of commands & responses is used to provide security in command system.
- ❖ After monitoring all the data, commands are generated at the control terminal of computer.
- ❖ The command word is sent in a TDM frame to the satellite.
- ❖ After checking for validity in satellite, command word is sent back to the control station via telemetry link where it is checked again in the computer.
- ❖ If it found correctly, an execute instruction will sent to satellite.
- ❖ The entire process may take 5 0r 10s, but minimizes the risk of erroneous commands causing satellite malfunction.

Orbital Correction / Control:

Attitude and orbit control system is used to control the orbit of the satellite, besides helping to maintain stabilization and its position. The control can be affected by the satellite itself and from the ground. Attitude and Orbit Control System (AOCS) consists of four major parts:

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

Forces Acting on a Satellite

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 :

1. **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.
2. **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.
3. **Pressure due to solar radiation:** It can also change orientation (spin-axis) of the satellite.
4. **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 satellites 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 equitorial 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.

(i) Sensors

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

- ✓ Earth Sensor
- ✓ Sun Sensor

Earth Sensor

It is a passive infrared device, operating in 14-16 μm 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° north and 5° 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**.

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°. 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. Command are generated and sent to the satellite to fire the rocket motor for correcting the axis.

(ii) 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.

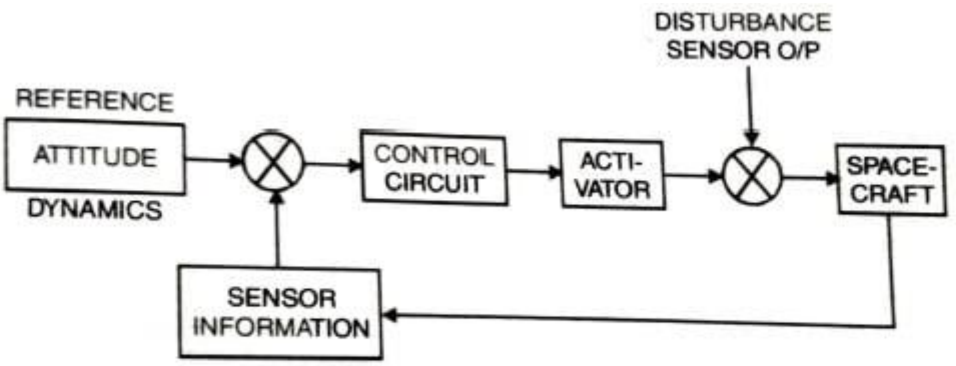
Out of these three propulsion units the low thrust actuators are of much importance for geostationary orbit because it is responsible for keeping the satellite in its orbit with its perfect attitude till its life end. The low thrust actuators can be either **chemical** ones or the **electrical** ones.

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 propellants 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.

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 figure below.



Control scheme

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

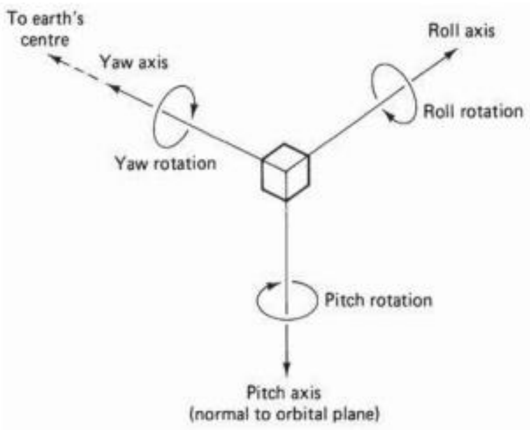
- ✓ Passive
- ✓ Active

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



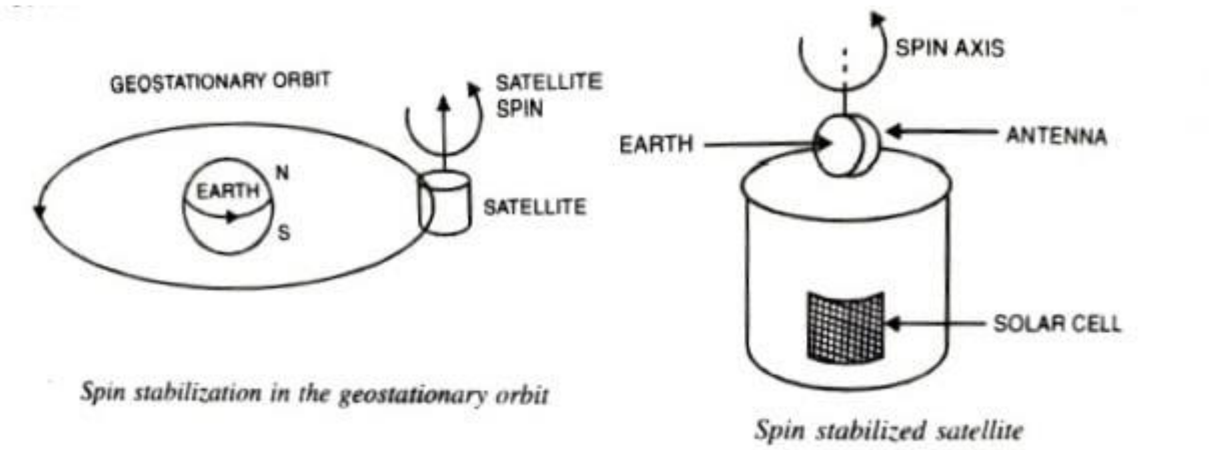
Satellite Stabilization:

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.

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 shows the spin stabilization in the geostationary orbit. Spin stabilized satellites are mainly the communication satellites.

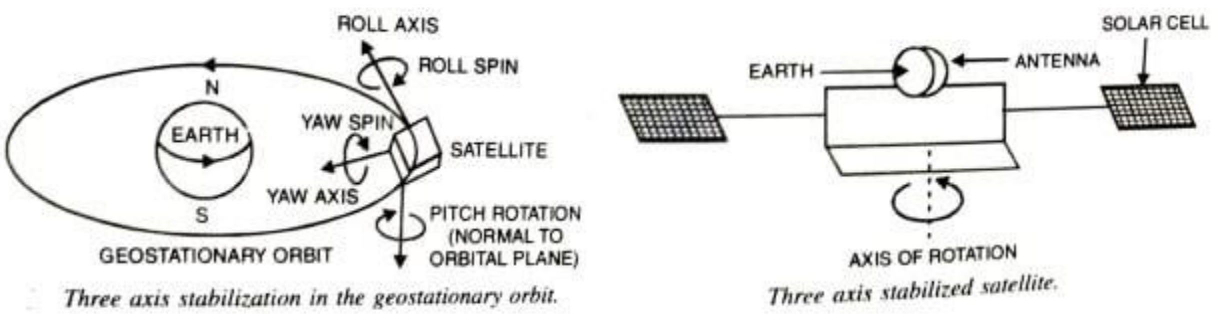


Spin stabilization

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 the figure below.



Three Axis Body Stabilization

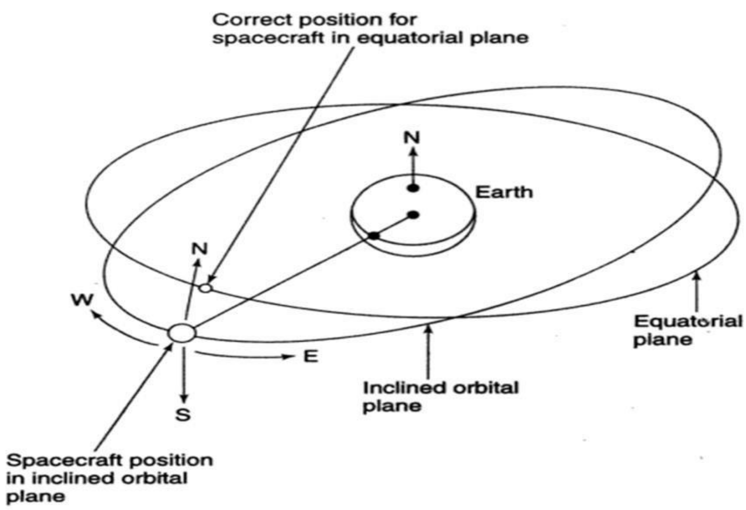
A momentum wheel is a high speed wheel driven by a motor. It is kept in a sealed evaluated chamber. Increase in its speed increases the angular momentum. Change in the attitude are transmitted to the earth station by telemetring the data from the sensors. The data is analyzed and commands are sent to the satellite to increase or decrease the speed of the momentum wheels as per requirement to correct the attitude about its three axis: role 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.

Orbit Control System:

A GEO satellite is subjected to several forces that tend to accelerate it away from its required orbit. It is the function of the orbit control system to return it to its correct orbit.

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 analyzed 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 ±0.1°. 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°. It will be reduced by 0.85° 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.



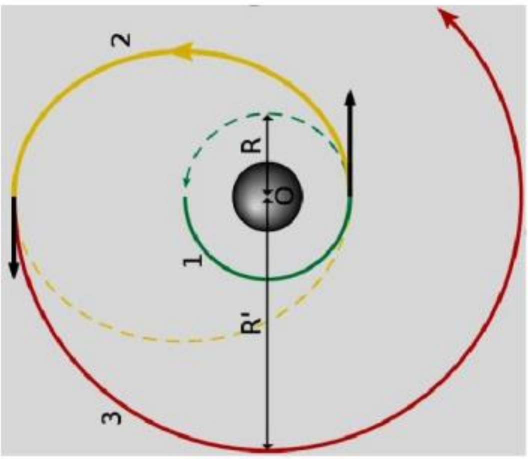
- For the orbit to be truly geostationary, it must lie in equatorial plane, becircular and have correct altitude.
- The various forces acting on the satellite will steadily pull it out of the correct orbit; it is the function of the orbit control system to return it to thecorrect orbit.
- Gas jets that can impart velocity changes along three reference axes of satellite are used.
- Correcting the inclination of a satellite orbit requires more fuel to expanded than for any other orbital correction.
- This places a weight penalty on those satellites that must maintain accurate station keeping & reduces communication payload they can carry.

Satellite Launch Systems:

Launching Procedures:

Low Earth Orbiting satellites are directly injected into their orbits. This cannot be done incase of GEOs as they have to be positioned 36,000kms above the Earth's surface. Launch vehicles are hence used to set these satellites in their orbits. These vehicles are reusable. They are also known as „Space Transportation System"(STS). When the orbital altitude is greater than 1,200 km it becomes expensive to directly inject the satellite in its orbit. For this purpose, a satellite must be placed in to a transfer orbit between the initial lower orbit and destination orbit. The transfer orbit is commonly known as *Hohmann-Transfer Orbit.

Orbit Transfer:



Orbit Transfer positions

*About Hohmann Transfer Orbit: This maneuver is named for the German civil engineer who first proposed it, Walter Hohmann, who was born in 1880. He didn't work in rocketry professionally (and wasn't associated with military rocketry), but was a key member of Germany's pioneering Society for Space Travel that included people such as Willy Ley, Hermann, and Werner von Braun. He published his concept of how to transfer between orbits in his 1925 book, The Attainability of Celestial Bodies.) The transfer orbit is selected to minimize the energy required for the transfer. This orbit forms a tangent to the low attitude orbit at the point of its perigee and tangent to high altitude orbit at the point of its apogee.

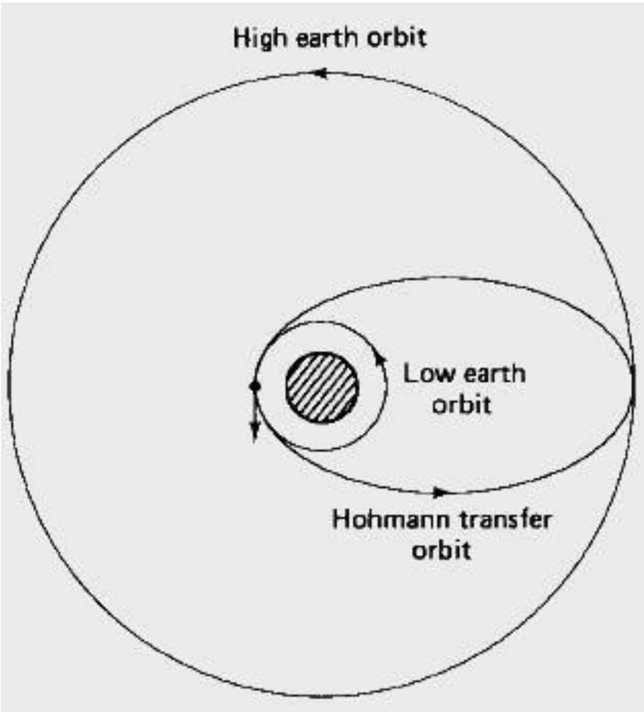
Launch vehicles and propulsion:

The rocket injects the satellite with the required thrust** into the transfer orbit. With the STS, the satellite carries a perigee kick motor*** which imparts the required thrust to inject the satellite in its transfer orbit. Similarly, an apogee kick motor (AKM) is used to inject the satellite in its destination orbit. Generally it takes 1-2 months for the satellite to become fully functional. The Earth Station performs the Telemetry Tracking and Command**** function to control the satellite transits and functionalities. (**Thrust: It is a reaction force described quantitatively by Newton's second and third laws. When a system expels or accelerates mass in one direction the accelerated mass will cause a force of equal magnitude but opposite direction on that system.) Kick Motor refers to a rocket motor that is regularly employed on artificial satellites destined for a geostationary orbit. As the vast majority of geostationary satellite launches are carried out from spaceports at a significant distance away from Earth's equator. The carrier rocket would only be able to launch the satellite into an elliptical orbit of maximum apogee 35,784-kilometres and with a non-zero inclination approximately equal to the latitude of the launch site.

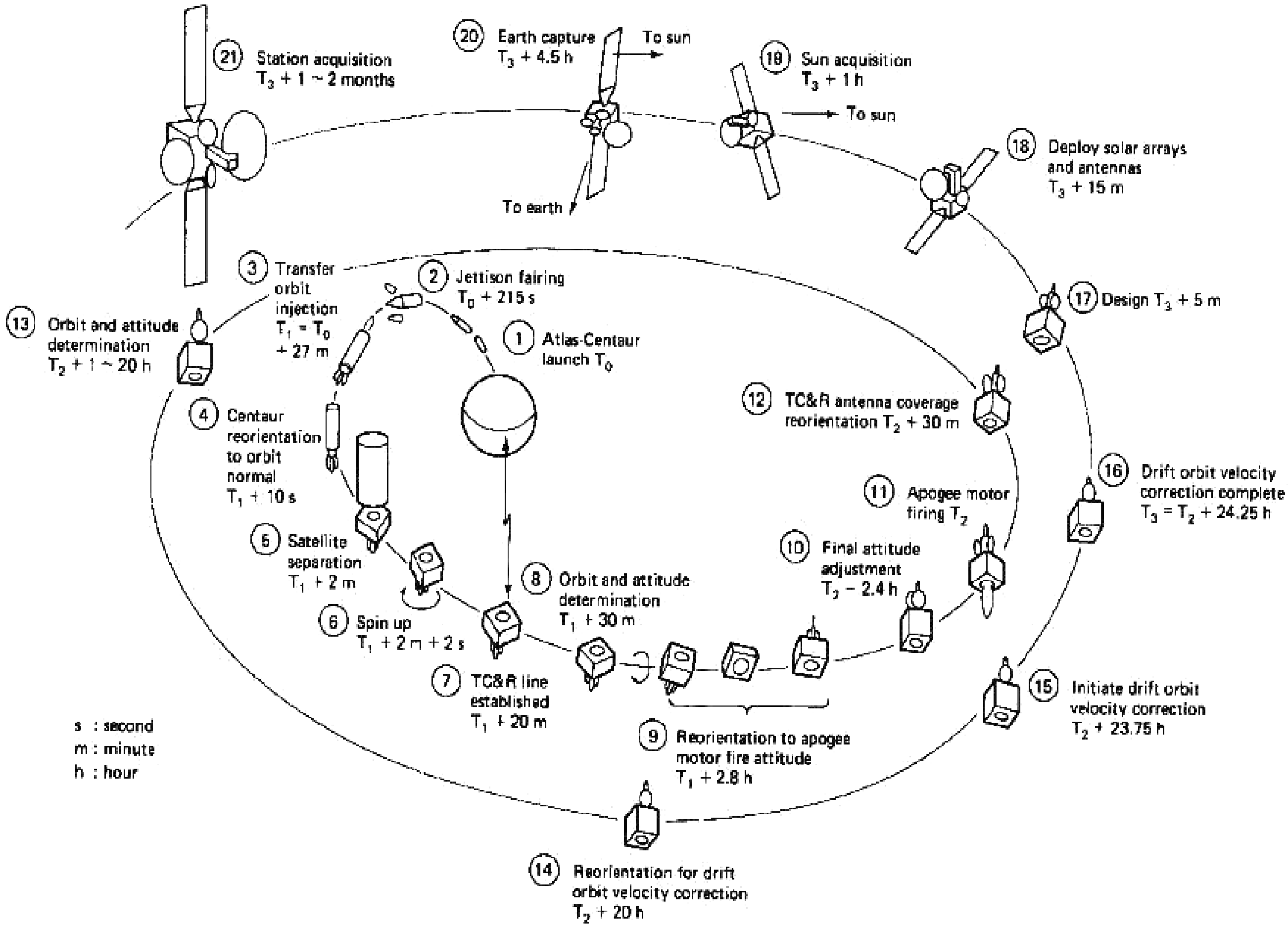
TT&C: it’s a sub-system where the functions performed by the satellite control network to maintain health and status, measure specific mission parameters and processing over time a sequence of these measurement to refine parameter knowledge, and transmit mission commands to the satellite. Detailed study of TT&C in the upcoming units.

Transfer Orbit:

It is better to launch rockets closer to the equator because the Earth rotates at a greater speed here than that at either pole. This extra speed at the equator means a rocket needs less thrust (and therefore less fuel) to launch into orbit. In addition, launching at the equator provides an additional 1,036 mph (1,667 km/h) of speed once the vehicle reaches orbit. This speed bonus means the vehicle needs less fuel, and that freed space can be used to carry more pay load.



Hohmann Transfer Orbit



Launching stages of a GEO (example INTELSAT)

Rocket launch:

A rocket launch is the takeoff phase of the flight of a rocket. Launches for orbital spaceflights, or launches into interplanetary space, are usually from a fixed location on the ground, but may also be from a floating platform (such as the Sea Launch vessel) or, potentially, from a super heavy An-225-class airplane.

Launches of suborbital flights (including missile launches), can also be from:

- a missile silo
- a mobile launcher vehicle
- a submarine

- air launch:
  - ✓ from a plane (e.g. Scaled Composites Space Ship One, Pegasus Rocket, X-15)
  - ✓ from a balloon (Rockoon, da Vinci Project (under development))
  - ✓ a surface ship (Aegis Ballistic Missile Defense System)
  - ✓ an inclined rail (e.g. rocket sled launch)

"Rocket launch technologies" generally refers to the entire set of systems needed to successfully launch a vehicle, not just the vehicle itself, but also the firing control systems, ground control station, launch pad, and tracking stations needed for a successful launch and/or recovery.

Orbital launch vehicles commonly take off vertically, and then begin to progressively lean over, usually following a gravity turn trajectory.

Once above the majority of the atmosphere, the vehicle then angles the rocket jet, pointing it largely horizontally but somewhat downwards, which permits the vehicle to gain and then maintain altitude while increasing horizontal speed. As the speed grows, the vehicle will become more and more horizontal until at orbital speed, the engine will cut off.

Multistage Rockets:

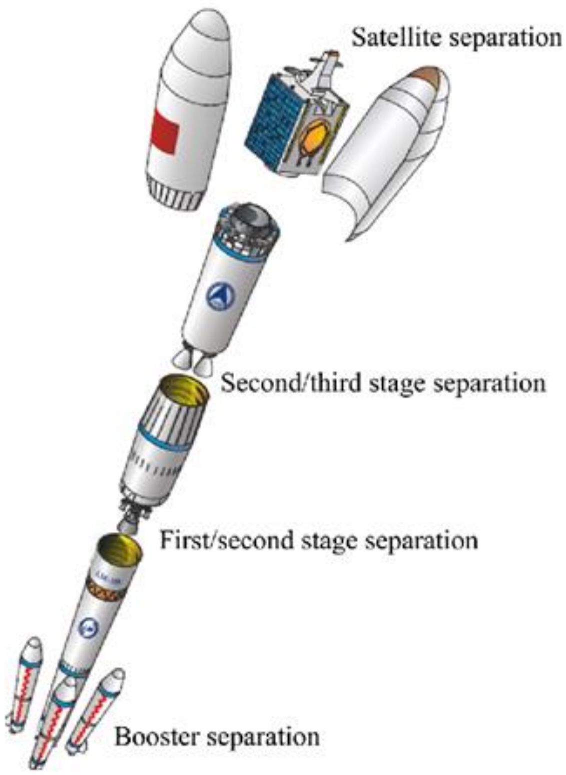
A **multistage rocket** or **step rocket** is a launch vehicle that uses two or more rocket *stages*, each of which contains its own engines and propellant. A *tandem* or *serial* stage is mounted on top of another stage; a *parallel* stage is attached alongside another stage. The result is effectively two or more rockets stacked on top of or attached next to each other. Two-stage rockets are quite common, but rockets with as many as five separate stages have been successfully launched.

By jettisoning stages when they run out of propellant, the mass of the remaining rocket is decreased. Each successive stage can also be optimized for its specific operating conditions, such as decreased atmospheric pressure at higher altitudes. This *staging* allows the thrust of the remaining stages to more easily accelerate the rocket to its final speed and height.

In serial or tandem staging schemes, the **first stage** is at the bottom and is usually the largest, the **second stage** and subsequent **upper stages** are above it, usually decreasing in size. In parallel staging schemes solid or liquid rocket boosters are used to assist with launch. These are sometimes referred to as "stage 0". In the typical case, the first-stage and booster engines fire to propel the entire rocket upwards. When the boosters run out of fuel, they are detached from the rest of the rocket (usually with some kind of small explosive charge or explosive bolts) and fall away. The first stage then burns to completion and falls off. This leaves a smaller rocket, with the second stage on the bottom, which then fires. Known in rocketry circles as **staging**, this process is repeated until the desired final velocity is achieved. In some cases with serial staging, the upper stage ignites *before* the separation—the inter-stage ring is designed with this in mind, and the thrust is used to help positively separate the two vehicles.

A multistage rocket is required to reach orbital speed. Single-stage-to-orbit designs are sought, but have not yet been demonstrated.

Multistage rockets are spacecraft/satellite launch vehicles that consist of two or more rocket stages with each stage containing its engines and propellants which are detached post-launch one after the other till the payload reaches its intended orbit or destination. Multistage rockets are predominantly used as they are much more cost-effective when compared to single-stage rockets and they will help the payload to reach its maximum speed by getting rid of any additional weight. The Saturn V rocket that was used for the Apollo Mission was a three-stage rocket with the payload located at the top.



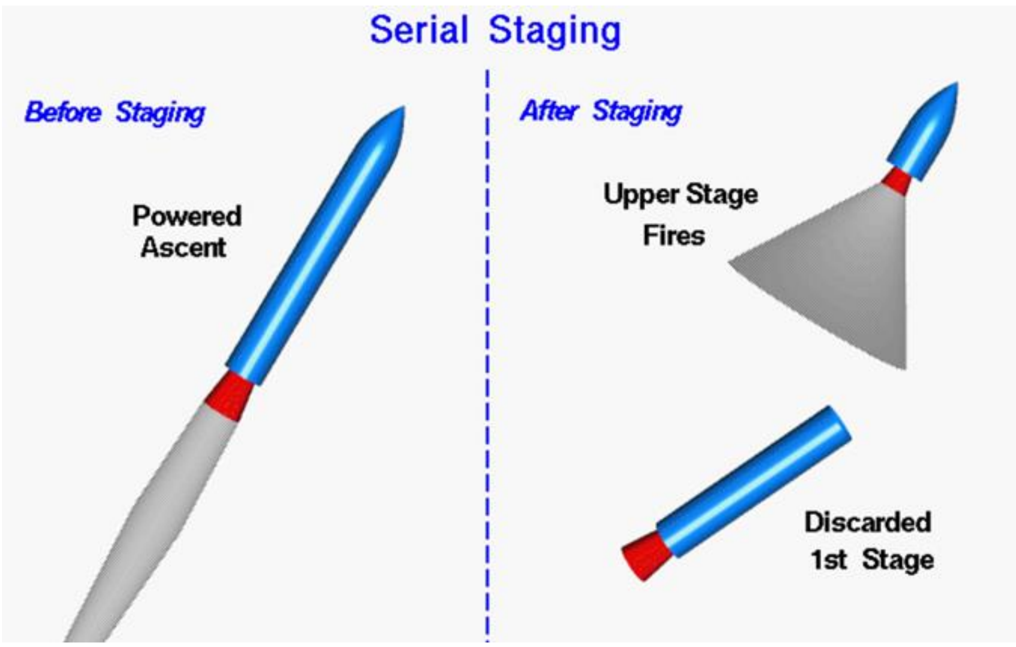
The structure of the launch vehicle consists of two or more rocket stages, with each stage containing its engines and propellants. The fuel required for a launch vehicle is large, hence, the fuel is stored in multiple stages. The payload (satellite or spacecraft) is kept at the top of the launch vehicle. Post-launch, if the fuel of any stage is exhausted, the empty fuel tank (stage) is detached from the launch vehicle body & the fuel in the next stage is ignited. This process is repeated till the payload is deployed or separated. By using the separation process which takes place from bottom to top, the overall weight of the launch vehicle reduces which helps the satellite or the spacecraft to gather more speed. Additionally, the overall fuel consumption is also reduced.

Multistage rockets are separated using explosive bolts. The point of contact that holds the two stages of a multistage rocket consists of holes (refer to figure below) when observed from a cross-sectional perspective. These holes are filled with explosive bolts. There are close to 300 points that can be filled with explosive bolts for each stage. A fire is ignited from the upper stage of a rocket that acts as a catalyst for the explosive bolt which goes off all around the stage and separates the lower stage that has exhausted its fuel and is of no use from the upper stage which separates and keeps burning.

Multistage rockets can be developed in different configurations. The method of deciding the configuration of a multistage rocket is known as staging. The combination of several rocket sections, or stages, that fire in a specific order and then detach, so a payload can penetrate Earth's atmosphere and reach space.

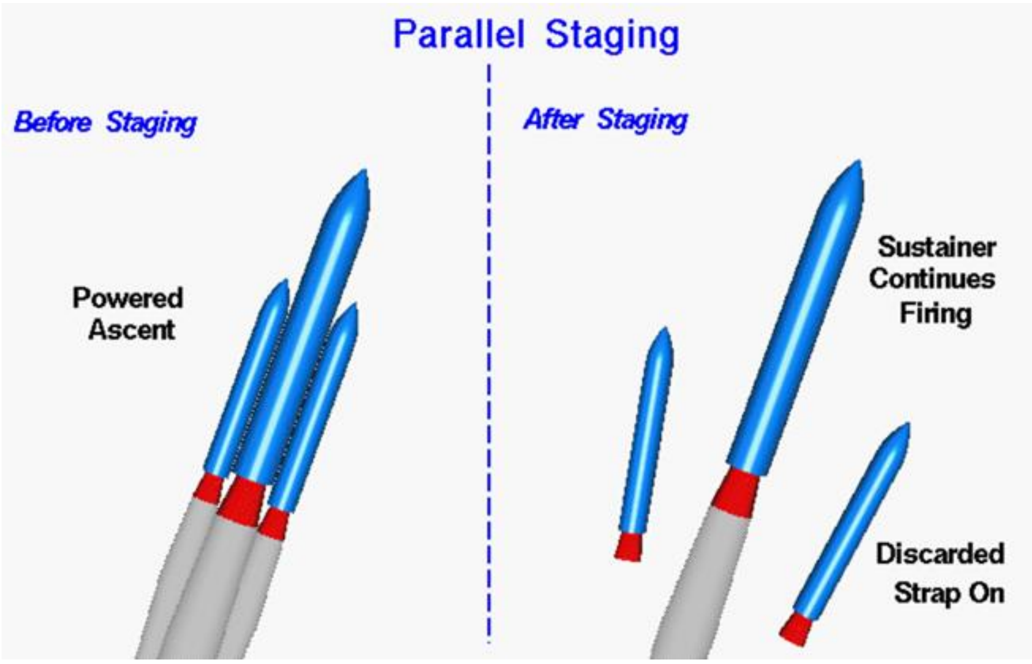
There are three different types of staging that are used for a multistage rocket.

Serial Staging:



In a serial stage configuration, the stages are attached one on top of the other or stacked. The first stage ignites at launch and burns through the fuel until it's completely exhausting. Now the first stage acts as an empty fuel tank and is dead weight, the first stage is detached, and immediately the second stage is ignited. Depending on the rocket & its mission, the second stage may get the payload into orbit or may require a third or fourth stage to deliver the payload into space or its intended destination.

Parallel Staging:



Whereas the serial staging configuration involves stacked stages, parallel staging features multiple boosters staged that are strapped to a central sustainer. The boosters that are attached to the sustainer are also ignited at launch which helps the rocket attain the required thrust that is needed to break free from the Earth’s gravity. When the fuel of the boosters runs out, they are detached from the central sustainer. The central sustainer engine keeps burning and takes the payload to a high altitude near space.

Serial & Parallel Staging:

This configuration includes a sustainer stage attached to boosters, that is detached once they are exhausted. The sustainer takes the payload to a considerable height after which it detaches itself and other stages that are serially stacked are ignited one after the other till the payload reaches its intended orbit. The Titan III rocket uses both serial & parallel staging. It used a two-stage sustainer in a parallel configuration and added two rocket stages in a serial configuration that detached themselves once they were exhausted.

Multistage rockets once discarded from each stage after it has served their purpose are made to crash towards the earth's surface where they will burn up on re-entry. However, only the lower stages can be made to crash towards the earth. Upper rocket stages will still pose a risk to contribute towards space debris. To tackle this problem, the upper rocket stages after detaching conserve some fuel so that they can be redirected towards the graveyard orbit. However, this solution is not optimal, as the fuel conserved might not be enough to take the upper rocket stage to the graveyard orbit. Various space organizations are working on a novel solution to discard the upper rocket stages efficiently to negate the problem of space debris.

Performance:

The reason multi-stage rockets are required is the limitation the laws of physics place on the maximum velocity achievable by a rocket of given fueled-to-dry mass ratio. This relation is given by the classical rocket equation:

$$\Delta v = v_e \ln\left(\frac{m_0}{m_f}\right)$$

where:

Δv is delta-v of the vehicle (change of velocity plus losses due to gravity and atmospheric drag);

m_o is the initial total (wet) mass, equal to final (dry) mass plus propellant;

m_f is the final (dry) mass, after the propellant is expended;

v_e is the effective exhaust velocity (determined by propellant, engine design and throttle condition);

ln is the natural logarithm function.

The delta v required to reach low Earth orbit (or the required velocity of a sufficiently heavy suborbital payload) requires a wet to dry mass ratio larger than can realistically be achieved in a single rocket stage. The multistage rocket overcomes this limit by splitting the delta-v into fractions. As each lower stage drops off and the succeeding stage fires, the rest of the rocket is still traveling near the burnout speed. Each lower stage's dry mass includes the propellant in the upper stages, and each succeeding upper stage has reduced its dry mass by discarding the useless dry mass of the spent lower stages.

A further advantage is that each stage can use a different type of rocket engine, each tuned for its particular operating conditions. Thus the lower-stage engines are designed for use at atmospheric pressure, while the upper stages can use engines suited to near vacuum conditions. Lower stages tend to require more structure than upper as they need to bear their own weight plus that of the stages above them. Optimizing the structure of each stage decreases the weight of the total vehicle and provides further advantage.

The advantage of staging comes at the cost of the lower stages lifting engines which are not yet being used, as well as making the entire rocket more complex and harder to build than a single stage. In addition, each staging event is a possible point of launch failure, due to separation failure, ignition failure, or stage collision. Nevertheless, the savings are so great that every rocket ever used to deliver a payload into orbit has had staging of some sort.

One of the most common measures of rocket efficiency is its specific impulse, which is defined as the thrust per flow rate (per second) of propellant consumption.

$$I_{sp} = \frac{T}{\frac{dm}{dt} g_0}$$

When rearranging the equation such that thrust is calculated as a result of the other factors, we have:

$$T = I_{sp} g_0 \frac{dm}{dt}$$

These equations show that a higher specific impulse means a more efficient rocket engine, capable of burning for longer periods of time. In terms of staging, the initial rocket stages usually have a lower specific impulse rating, trading efficiency for superior thrust in order to quickly push the rocket into higher altitudes. Later stages of the rocket usually have a higher specific impulse rating because the vehicle is further outside the atmosphere and the exhaust gas does not need to expand against as much atmospheric pressure.

When selecting the ideal rocket engine to use as an initial stage for a launch vehicle, a useful performance metric to examine is the thrust-to-weight ratio, and is calculated by the equation:

$$TWR = \frac{T}{m g_0}$$

The common thrust-to-weight ratio of a launch vehicle is within the range of 1.3 to 2.0.[3] Another performance metric to keep in mind when designing each rocket stage in a mission is the burn time, which is the amount of time the rocket engine will last before it has exhausted all of its propellant. For most non-final stages, thrust and specific impulse can be assumed constant, which allows the equation for burn time to be written as:

$$\Delta t = \frac{I_{sp} g_0}{T} \times (m_0 - m_f)$$

Where m_o and m_f are the initial and final masses of the rocket stage respectively. In conjunction with the burnout time, the burnout height and velocity are obtained using the same values, and are found by these two equations:

$$h_{\mathrm{bo}} = \frac{I_{\mathrm{sp}} g_0}{m_{\mathrm{e}}} \times (m_{\mathrm{f}} \ln(m_{\mathrm{f}}/m_0) + m_0 - m_{\mathrm{f}})$$

$$v_{\mathrm{bo}} = I_{\mathrm{sp}} g_0 \ln(\frac{m_0}{m_{\mathrm{f}}}) - g_0 \frac{m_0 - m_{\mathrm{f}}}{\frac{\mathrm{d}m}{\mathrm{d}t}} + v_0$$

When dealing with the problem of calculating the total burnout velocity or time for the entire rocket system, the general procedure for doing so is as follows.

1. Partition the problem calculations into however many stages the rocket system comprises.
2. Calculate the initial and final mass for each individual stage.
3. Calculate the burnout velocity, and sum it with the initial velocity for each individual stage. Assuming each stage occurs immediately after the previous, the burnout velocity becomes the initial velocity for the following stage.
4. Repeat the previous two steps until the burnout time and/or velocity has been calculated for the final stage.

It is important to note that the burnout time does not define the end of the rocket stage's motion, as the vehicle will still have a velocity that will allow it to coast upward for a brief amount of time until the acceleration of the planet's gravity gradually changes it to a downward direction. The velocity and altitude of the rocket after burnout can be easily modeled using the basic physics equations of motion.

When comparing one rocket with another, it is impractical to directly compare the rocket's certain trait with the same trait of another because their individual attributes are often not independent of one another. For this reason, dimensionless ratios have been designed to enable a more meaningful comparison between rockets. The first is the initial to final mass ratio, which is the ratio between the rocket stage's full initial mass and the rocket stage's final mass once all of its fuel has been consumed. The equation for this ratio is:

$$\eta = \frac{m_{\mathrm{E}} + m_{\mathrm{p}} + m_{\mathrm{PL}}}{m_{\mathrm{E}} + m_{\mathrm{PL}}}$$

Where m_E is the empty mass of the stage, m_p is the mass of the propellant, and m_{PL} is the mass of the payload. The second dimensionless performance quantity is the structural ratio, which is the ratio between the empty mass of the stage, and the combined empty mass and propellant mass as shown in this equation.

$$\epsilon = \frac{m_{\mathrm{E}}}{m_{\mathrm{E}} + m_{\mathrm{P}}}$$

The last major dimensionless performance quantity is the payload ratio, which is the ratio between the payload mass and the combined mass of the empty rocket stage and the propellant:

$$\lambda = \frac{m_{\mathrm{PL}}}{m_{\mathrm{E}} + m_{\mathrm{P}}}$$

After comparing the three equations for the dimensionless quantities, it is easy to see that they are not independent of each other, and in fact, the initial to final mass ratio can be rewritten in terms of structural ratio and payload ratio.

$$\eta = \frac{1+\lambda}{\epsilon+\lambda}$$

These performance ratios can also be used as references for how efficient a rocket system will be when performing optimizations and comparing varying configurations for a mission.

Unit - 02

Elements of Communication Satellite Design:

The key elements of the satellite payload in the design of Communication Satellite are Transponders and Antenna subsystems.

Transponder:

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.

A typical commercial communications satellite today can have 24 to 48 transponders, operating in the C-band, Ku-band, or Ka-bands. The number oftransponders 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 (horizontal and vertical sense) and circular polarization (right-hand and left-hand sense) 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: the frequency translation transponder and 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. 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 transponders are used for FSS, BSS, and MSS applications, in both GSO and NGSO orbits. The uplinks and downlinks are codependent, meaning that anydegradation 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

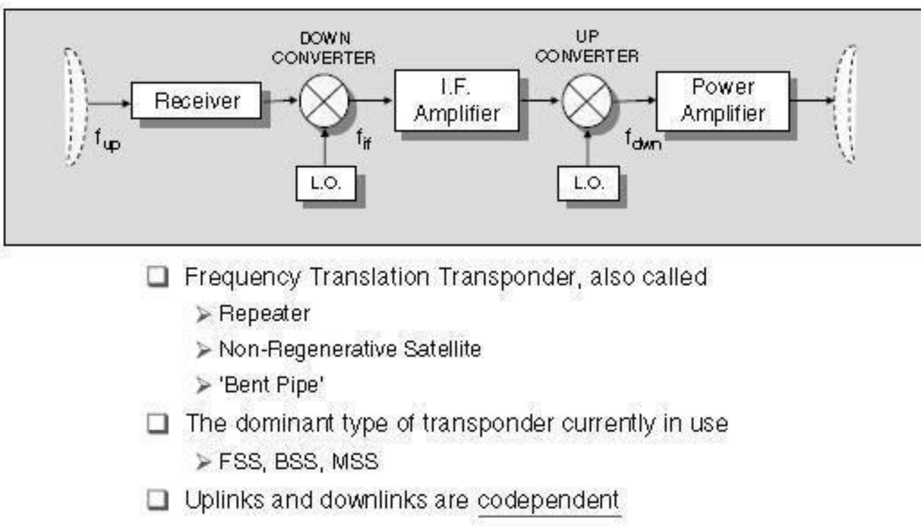
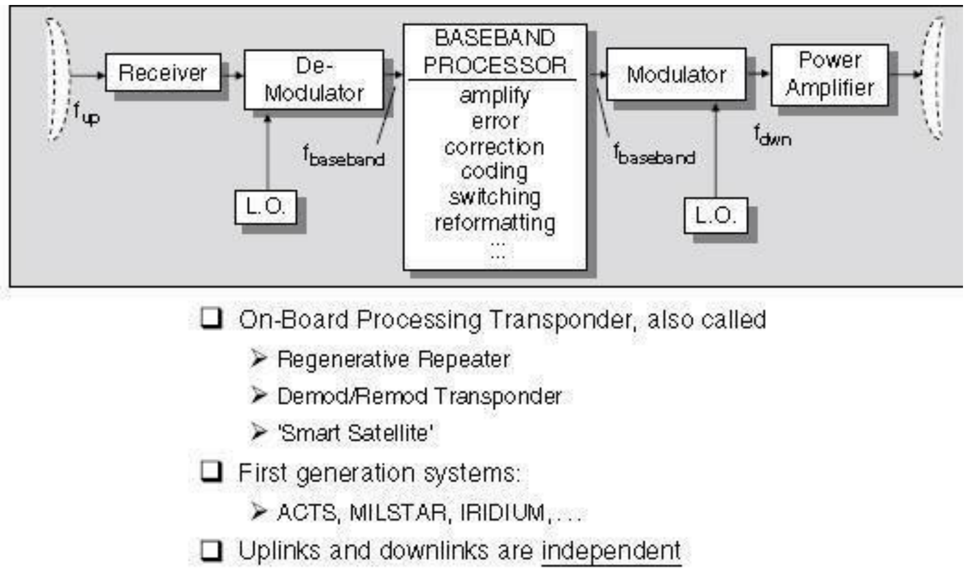


Fig: Frequency Translation Transponder

On-board Processing 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



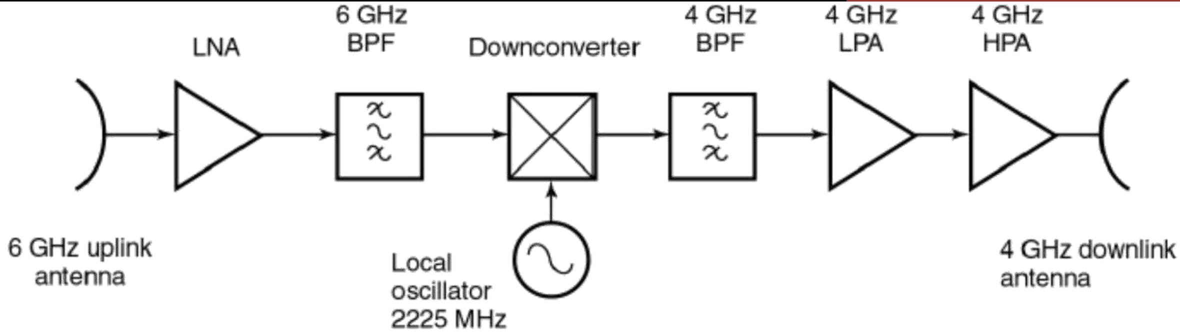
uplink degradations are codependent, as discussed earlier.

Fig: On-board processing Transponder

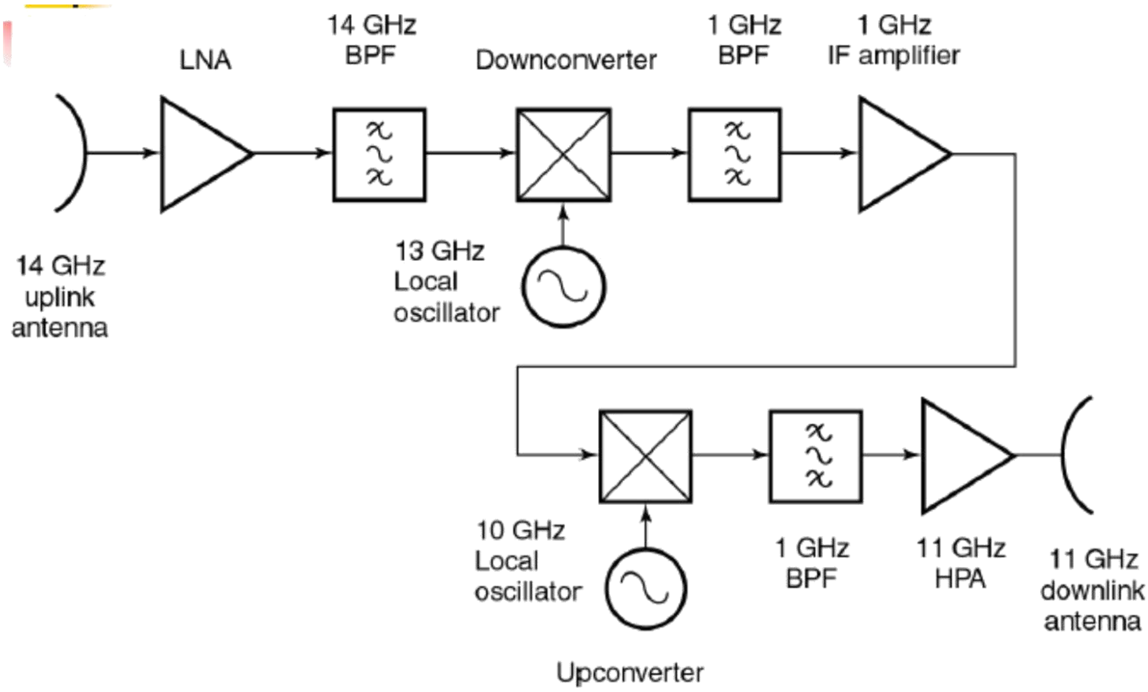
On-board processing satellites tend to be more complex and expensive than frequency translation satellites; however, they offer significant performance advantages, particularly for small terminal users or for large diverse networks.

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. TWTAs for space applications can operate to well above 30 GHz, with output powers of 150 watts or more, and RF bandwidths exceeding 1 GHz. SSPAs are used when power requirements in the 2–20 watt region are required. SSPAs operate with slightly better power efficiency than the TWTA.

Other devices may be included in the basic transponder configurations.



Simplified single conversion transponder (bent pipe) for 6/4 GHz band.



Simplified double conversion transponder (bent pipe) for 14/11 GHz band.

Satellite Antenna:

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.

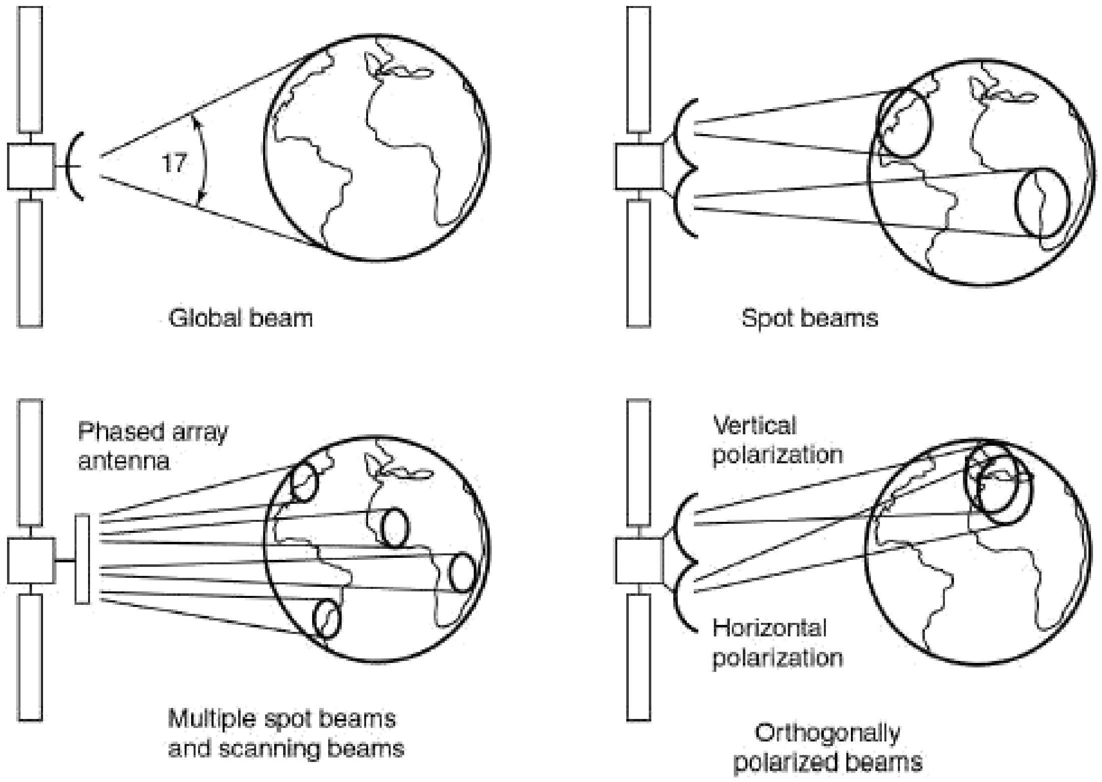
The antenna gain is usually expressed in ***dBi***, decibels above an isotropic antenna, which is an antenna that radiates uniformly in all directions. The beamwidth is usually expressed as the ***half-power beamwidth*** or the ***3-dB beamwidth***, which is a measure of the angle over which maximum 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.

The common types of antennas used in satellite systems are the linear dipole, the horn antenna, the parabolic reflector, and the array antenna. 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 are used at frequencies from about 4 GHz and up, when relatively wide beams are required, such as global coverage from a GSO satellite. A horn is a flared section of waveguide that provides gains of up to about 20 dBi, with beamwidths of 10◦ or higher. Ifhigher gains or narrower bandwidths are required, a reflector or array antenna must be used. The most often used antenna for satellite systems, particularly for those operating above 10 GHz, is the ***parabolic reflector antenna***. Parabolic reflector antennas are usually illuminated by one or more horn antenna feeds at the focus of the paroboloid. Parabolic reflectors offer a much higher gain than that achievable by the horn antenna alone. Gains of 25 dB and higher, with beamwidths of 1◦ or less, are achievable with parabolic reflector antennas operating in the C, Ku, or Ka bands. Narrow beam antennas usually require physical pointing mechanisms (gimbals) on the spacecraft to point the beam in the desired direction. There is increasing interest in the use of ***array antennas*** for satellite communicationsapplications.

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.



Spacecraft Subsystems:

An operating communications satellite system consists of several elements or segments, ranging from an orbital configuration of space components to ground based components and network elements. The particular application of the satellite system, for example fixed satellite service, mobile service, or broadcast service, will determine the specific elements of the system.

A generic satellite system, applicable to most satellite applications, can be described by the elements shown in Figure.

The basic system consists of a satellite (or satellites) in space, relaying information between two or more users through ground terminals and the satellite. The information relayed may be voice, data, video, or a combination of the three. The user information may require transmission via terrestrial means to connect with the ground terminal. The satellite is controlled from the ground through a satellite control facility, often called the master control center (MCC), which provides tracking, telemetry, command, and monitoring functions for the system.

The space segment of the satellite system consists of the orbiting satellite (or satellites) and the ground satellite control facilities necessary to keep the satellites operational.

The ground segment, or earth segment, of the satellite system consists of the transmit and receive earth stations and the associated equipment to interface with the user network. Ground segment elements are unique to the type of communications satellite application, such as fixed service, mobile service, broadcast service, or satellite broadband, and will be covered in later chapters where the specific applications are discussed. The space segment equipment carried aboard the satellite can be classified under two functional areas: the bus and the payload, as shown in Figure.

Bus: The bus refers to the basic satellite structure itself and the subsystems that support the satellite. The bus subsystems are: the physical structure, power subsystem, attitude and orbital control subsystem, thermal control subsystem, and command and telemetry subsystem.

Payload: The payload on a satellite is the equipment that provides the service or services intended for the satellite. A communications satellite payload consists of the communications equipment that provides the relay link between the up- and downlinks from the ground. The communications payload can be further divided into the transponder and the antenna subsystems.

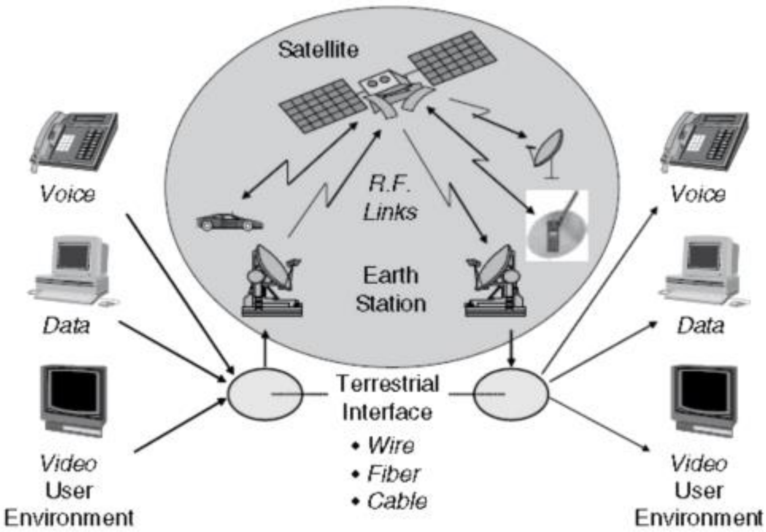


Fig: Communications via Satellite

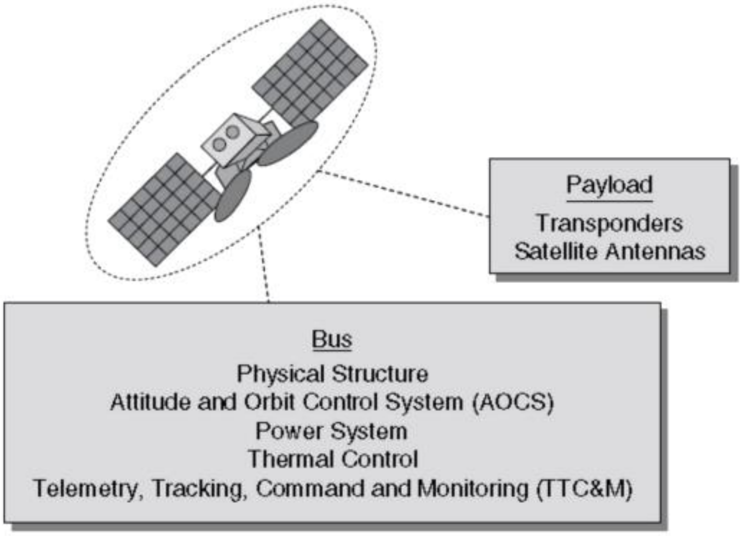


Fig: Communication Satellites Subsystems

Power Systems:

The electrical power for operating equipment on a communications satellite is obtained primarily from solar cells, which convert incident sunlight into electrical energy. The radiation on a satellite from the sun has an intensity averaging about 1.4 kW/m2. Solar cells operate at an efficiency of 20–25% at ***beginning of life*** (BOL), and can degrade to 5–10% at ***end of life*** (EOL), usually considered to be 15 years. Because of this, large numbers of cells, connected in serial-parallel arrays, are required to support the communications satellite electronic systems, which often require more than one to two kilowatts of prime power to function. The spin-stabilized satellite usually has cylindrical panels, which may be extended after deployment to provide additional exposure area. A cylindrical spin-stabilized satellite must carry a larger number of solar cells than an equivalent three-axis stabilized satellite, because only about one-third of the cells are exposed to the sun at any one time.

The three-axis stabilized satellite configuration allows for better utilization of solar cell area, because the cells can be arranged in flat panels, or sails, which can be rotated to maintain normal exposure to the sun – levels up to 10kW are attainable with rotating panels.

All spacecraft must also carry storage batteries to provide power during launch and during eclipse periods when sun blockage occurs. Eclipses occur for a GSO satellite twice a year, around the spring and fall equinoxes, when earth's shadow passes across the spacecraft. Daily eclipses start about 23 days before the equinox, and end the same number of days after.

The daily eclipse duration increases a few minutes each day to about a 70-minute peak on equinox day, then decreases a similar amount each day following the peak. Sealed nickel cadmium (Ni-Cd) batteries are most often used for satellite battery systems. They have good reliability and long life, and do not outgas when in a charging cycle. Nickel-hydrogen (NiH2) batteries, which provide a significant improvement in power-to-weight ratio, are also used. A power conditioning unit is also included in the power subsystem, for the control of battery charging and for power regulation and monitoring.

The power generating and control systems on a communications satellite account for a large part of its weight, often 10 to 20% of total dry weight.

Reliability Considerations:

Reliability is counted by considering the proper working of satellites critical components. Reliability could be improved by making the critical components redundant. Components with a limited lifetime such as travelling wave tube amplifier etc should be made redundant.

Travelling Wave Tube Amplifier (TWTA): travelling wave tube amplifiers have applications in both receiver and transmitter systems, and come in all shapes and sizes, but they all consist of three basic parts-the tube, the tube mount (which includes the beam focussing magnets) and the power supply.

The main attraction of these devices is their very high gain (30-60 dB), linear characteristics and 1-2 octave bandwidth. They are quite widely used professionally, but are still rather scarce in amateur circles. This article describes a little of the theory of twts, and explains how to use them, in the hope that more amateurs may be able to acquire and use these fascinating components.

When used as receiver RF amplifiers they are characterized by high gain, low noise figure and wide bandwidth, and are known as low noise amplifiers (LNAS). These usually come with tube, mount and power supply in one integral unit, with no external adjustments to make-just input socket, output socket and mains supply connections. A typical LNA has an octave bandwidth (eg 2-4 GHz), 30 dB gain, 8 dB noise figure, and a saturated power output of 10 mW, within a volume of 2 in by 2 in by 10 in.

Transmitter TWTAs are naturally somewhat bulkier, and often have the power or supplies as a separate unit. Medium-power tubes have outputs of up to about 10 W, while high-power tubes deliver several hundred watts. Such tubes have gains of the order of 30 or 40 dB, and bandwidths of up to an octave.

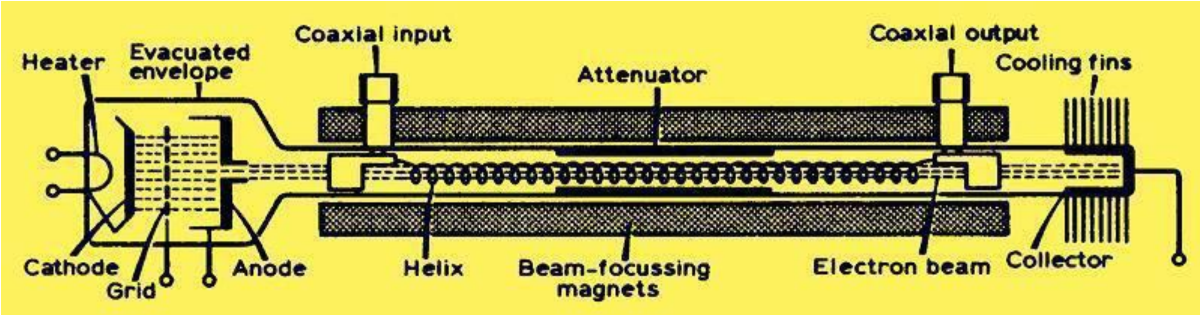


Fig: TWTA

Other critical components are antenna reflectors, beaming assemblers etc.

A reliability model is used to calculate the satellite‟s reliability. It is defined as "the probability that a given component or system performs its functions as desired within a specific time t.

The failure rate for all components is calculated and they are categorized into the following three categories:

- ❖ Early high failure rate region: used for manufacturing faults, defects in material etc.
- ❖ Low failure: used for random component failure.
- ❖ High failure rate: used for components weave-out.

Certainly early failures criteria is eliminated as most of the components are tested before usedin the satellite.

Random failures are more seen. They could be reduced by using reliable engineering techniques.

The life-spam of component could be increased by improving manufacturing techniques and the type of material used to reduce the number of worn out parts and hence reducing the high failure rate criteria.

It is sent that the failure rate is constant over time and is looking at this reliability can be determined.

The system is made of several components, connected in a series, then the overall reliabilityis determined.

By duplicating the less reliable and critical components, the overall reliability of the system could be improved. If any failure occurs in operational unit, then the standby unit takes over to develop a system with redundant components, its redundant elements are considered in parallel.

Parallel redundancy is useful when the reliability of an individual sub-system is high.

Example: consider a system having *i* parallel components in which reliability of each elementis independent of others.

If Q_i is the unreliability of the ith parallel element, then the probability that all units will fail is the product of the individual un-reliabilities:

$$Qs = Q1\ Q2\ Q3 \ldots.\ Qi$$

When the un-reliability of all elements is equal, then Qs = Qi where Q is the un-reliability of each element.

By doing a complete failure analysis, one could find out which failure occurs more than the rest and such analysis help in finding out the manufacturing defects in the product of a given batch of components or probably a design defect.

This analysis is done to reduce the overall reliability to a value less than that predicted by the above analysis.

Co-related failures could also be reduced by using units from different manufacturers. The design defects are generic to all satellite produced in a series. Generally these defects are detected and corrected to minimize their impact. This is done when a complete design change cannot be implemented.

Even through the reliability can be improved by adding redundant devices and components, the weight of the satellite increases which again becomes a problem. Redundant component also increase the cost of the satellite.

The two major cost components are:

- ❖ Cost of equipment together with the switching and failure sensing mechanism used.
- ❖ The associated increase in weight of the satellite resulting in an increased launch cost.

Optimization techniques are performed for cost minimization purpose.

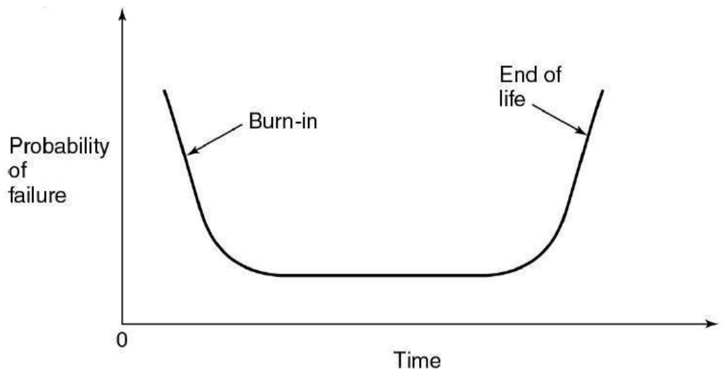


Fig: Bathtub curve for probability of failure

Redundancy:

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 tin=me of 50,000h is approximately 6 years of continuous operation, which is close to the typical design life time os a satellite. To further improve the reliability ofthe transponder, a second redundant transponder may be provided with switching between thetwo systems. Note that 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.

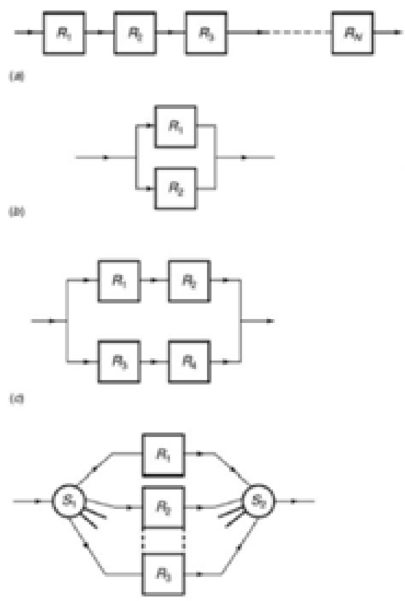
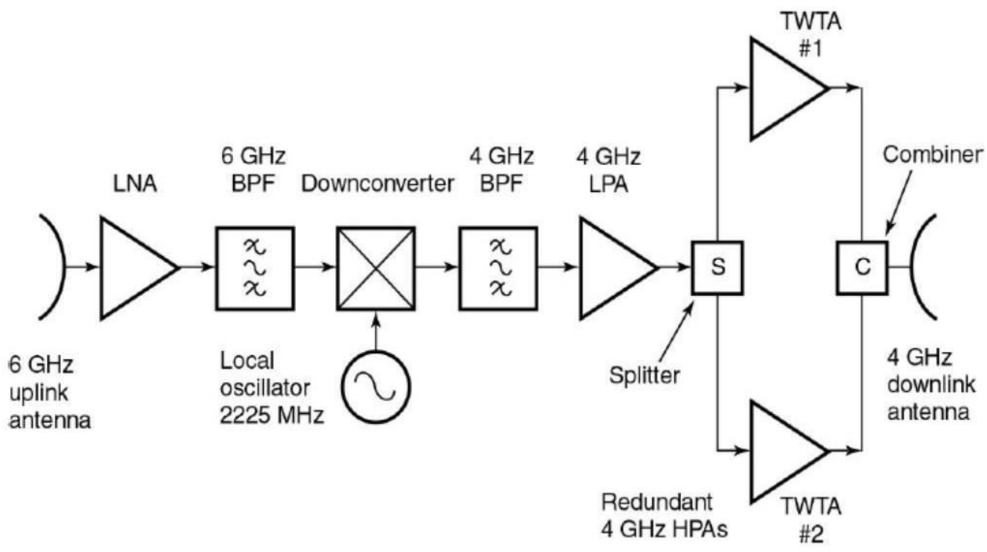


Figure
Redundancy connections. (*a*) Series connection. (*b*) Parallel connection. (*c*) Series/parallel connection. (*d*) Switched connection.



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

Spacecraft Integration:

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 and 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^o to 75^oC. This requires a thermal control system that manages heat flow throughout a GEO satellite as the sun moves around once every 24hr.

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. The thermal model contains all the electronics packages and other components that must be maintained at correct temperature. 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.

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 jeopardize the mission 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.

MULTIPLE ACCESS

With the increase of channel demands and the number of earth stations, efficient use of a satellite transponder in conjunction with many stations has resulted in the development of multiple access techniques. Multiple access is a technique in which the satellite resource (bandwidth or time) is divided into a number of non overlapping segments and each segment is allocated exclusively to each of the large number of earth stations who seek to communicate with each other. There are three known multiple access techniques.

They are:

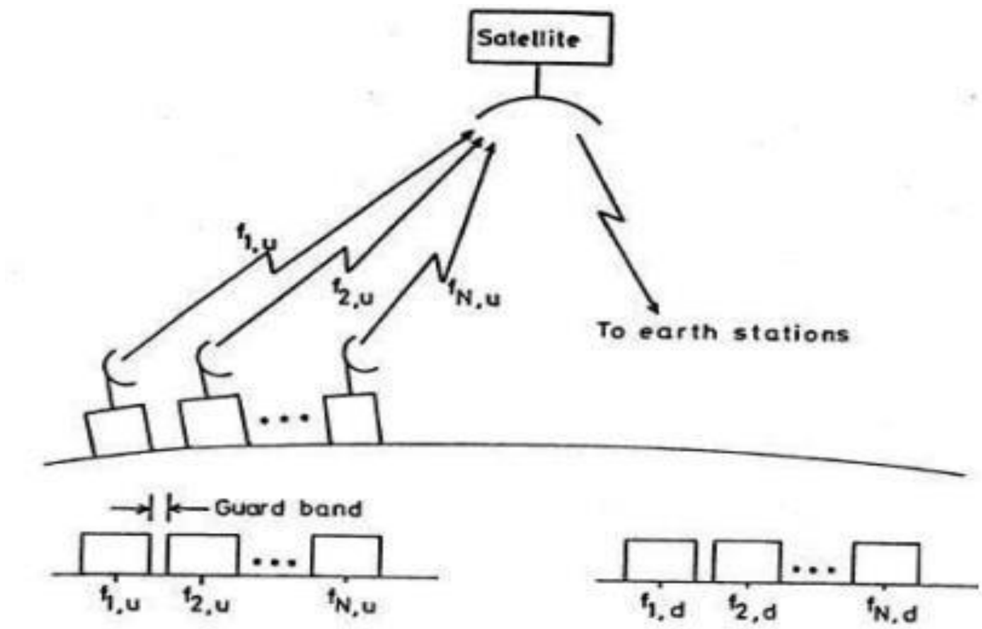
(1) Frequency Division Multiple Access (FDMA)

(2) Time Division Multiple Access (TDMA)

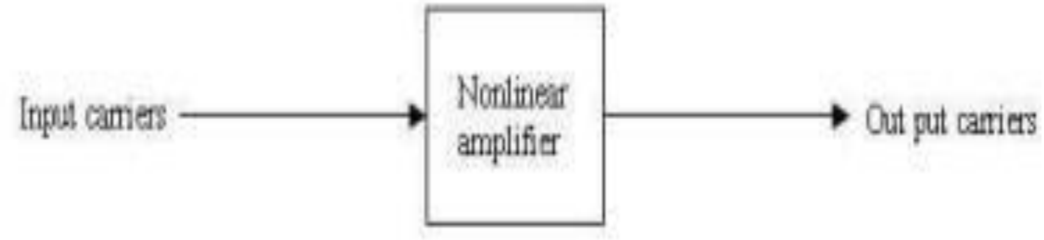
(3) Code Division Multiple Access (CDMA)

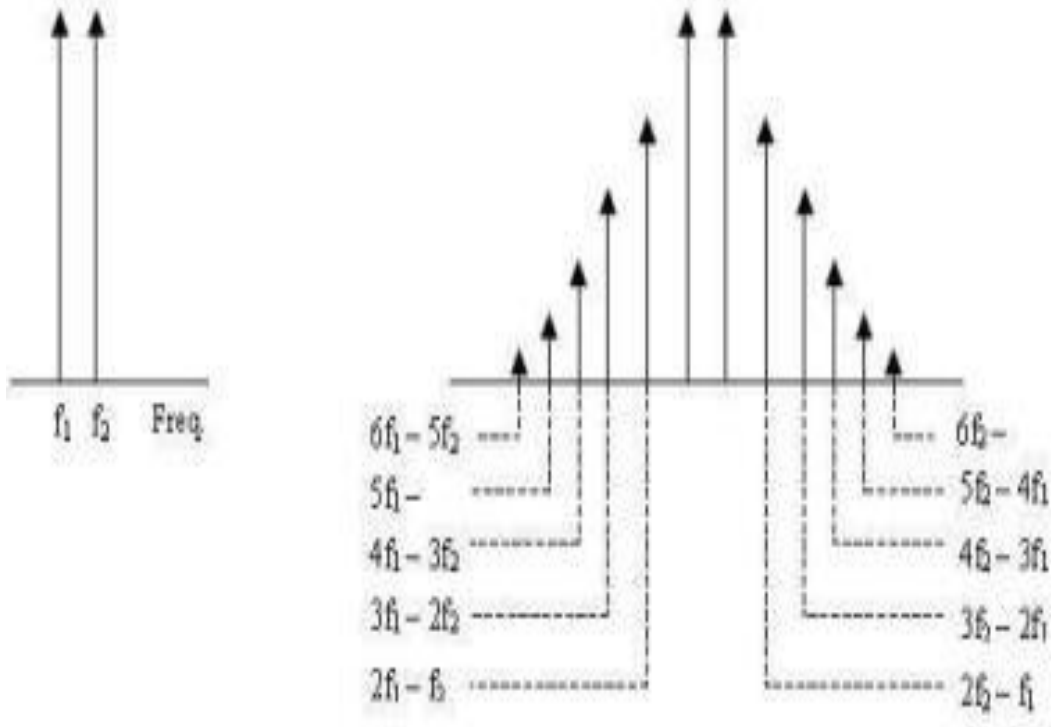
FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)

The most widely used of the multiple access techniques is FDMA. In FDMA, the available satellite bandwidth is divided into portions of non-overlapping frequency slots which are assigned exclusively to individual earth stations. A basic diagram of an FDMA satellite system is shown in Fig.



Examples of this technique are FDM/FM/FDMA used in INTELSAT II & III and SCPC satellite systems. Also, SPACE (signal-channel-per-carrier PCM multiple access demand assignment equipment) used in INTELSAT IV in which channels are assigned on demand to earth stations is considered as a FDMA system. In FDMA systems, multiple signals from the same or different earth stations with different carrier frequencies are simultaneously passed through a satellite transponder. Because of the nonlinear mode of the transponder, FDMA signals interact with each other causing inter modulation products (inter modulation noise) which are signals at all combinations of sum and difference frequencies as shown in the example given in Fig





The power of these inter modulation products represents a loss in the desired signal power. In addition, if these inter modulation products appear within the bandwidth of the other signals, they act as interference for these signals and as a result the BER performances will be degraded. The other major disadvantage of the FDMA system is the need for accurate uplink power control among network stations in order to mitigate the weak signal suppression effect caused by disproportionate power sharing of the transponder power.

Intermodulation

Intermodulation products are generated whenever more than one signal is carried by nonlinear device. Sometimes filtering can be used to remove the IM products, but if they are within the bandwidth of the transponder they cannot be filtered out. The saturation characteristic of a transponder can be modeled by a cubic curve to illustrate the generation of third –order intermodulation. Third -order IM is important because third –order products often have frequencies close to the signals that generate the intermodulation, and are therefore likely to be within the transponder bandwidth. To illustrate the generation of third – order intermodulation products, we will model the nonlinear characteristic of the transponder HPA with a cubic voltage relationship and apply two unmodulated carriers at frequencies f1 and f2 at the input of the amplifier

$$V_{out} = AV_{in} + b(V_{in})^3 \quad \ldots\ldots.(1)$$

where $A >> b$.

The amplifier input signal is

$$V_1 \cos\omega_1 t + V_2 \cos\omega_2 t \quad \ldots. (2)$$

The amplifier output signal is

$$V_{out} = AV_{in} + b(V_{in})^3$$
$$= \underbrace{AV_1 \cos\omega_1 t + AV_2 \cos\omega_2 t}_{\text{linear term}} + \underbrace{b(V_1 \cos\omega_1 t + V_2 \cos\omega_2 t)^3}_{\text{cubic term}} \tag{6.3}$$

The linear term simply amplifies the input signal by a voltage gain A. The cubic term, which will be denoted as V_{3out}, can be expanded as

$$V_{3out} = (V_1 \cos\omega_1 t + V_2 \cos\omega_2 t)^3$$
$$= b[V_1^3 \cos^3\omega_1 t + V_2^3 \cos^3\omega_2 t +$$
$$2V_2^2 \cos^2\omega_2 t \times V_2 \cos\omega_2 t + 2V_2^2 \cos^2\omega_2 t \times V_1 \cos\omega_1 t] \tag{6.4}$$

The first two terms contain frequencies f_1, f_2, $3f_1$, and $3f_2$. The triple frequency components can be removed from the amplifier output with band-pass filters. The second two terms generate the third-order IM frequency components.

We can expand the cosine squared terms using the trig identity $\cos^2 x = \frac{1}{2}[\cos 2x + 1]$. Hence the IM terms of interest become

$$V_{IM} = bV_1^2 \times V_2[\cos\omega_2 t \times (\cos 2\omega_1 t + 1)] +$$
$$bV_2^2 \times V_1[\cos\omega_1 t \times (\cos 2\omega_2 t + 1)]$$
$$= bV_1^2 \times V_2[\cos\omega_2 t \cos 2\omega_1 t + \cos\omega_2 t] +$$
$$bV_2^2 \times V_1[\cos\omega_1 t \cos 2\omega_2 t + \cos\omega_1 t] \tag{6.5}$$

The terms at frequencies f_1 and f_2 add to the wanted output of the amplifier, so the third-order intermodulation products are generated by the $f_1 \times 2f_2$ and $f_2 \times 2f_1$ terms.

Using another trig identity

$$\cos x \cos y = \cos(x + y) + \cos(x - y)$$

The output of the amplifier contains IM frequency components given by

$$V'_{IM} = bV_1^2 \times V_2[\cos(2\omega_1 t + \omega_2 t) + \cos(2\omega_1 t - \omega_2 t)]$$
$$+ bV_2^2 \times V_1[\cos(2\omega_2 t + \omega_1 t) + \cos(2\omega_2 t - \omega_1 t)] \tag{6.6}$$

We can filter out the sum terms in Eq. (6.6), but the difference terms, with frequencies $2f_1 - f_2$ and $2f_2 - f_1$ may fall within the transponder bandwidth. These two terms are known as the third-order intermodulation products of the high-power amplifier, because they are the only ones likely to be present at the output of a transponder which incorporates a narrow bandpass filter at its output. Thus the third-order intermodulation products that are of concern are given by V_{3IM} where

$$V_{3IM} = bV_1^2 V_2 \cos(2\omega_1 t - \omega_2 t) + bV_2^2 V_1 \cos(2\omega_2 t - \omega_1 t) \tag{6.7}$$

The magnitude of the IM products depends on the parameter b, which describes the nonlinearity of the transponder, and the magnitude of the signals. The wanted signals at the transponder output, at frequencies f_1 and f_2, have magnitudes AV_1 and AV_2. The wanted output from the amplifier is

$$V_{out} = AV_1 \cos\omega_1 t + AV_2 \cos\omega_2 t$$

The total power of the wanted output from the HPA, referenced to a 1 ohm load, is therefore

$$P_{out} = \tfrac{1}{2}A^2V_1^2 + \tfrac{1}{2}A^2V_2^2 = A^2(P_1 + P_2)\ \text{W} \tag{6.8}$$

where P_1 and P_2 are the power levels of the wanted signals. The power of the IM products at the output of the HPA is

$$P_{IM} = 2 \times (\tfrac{1}{2}b^2V_1^6 + \tfrac{1}{2}b^2V_2^6) = b^2(P_1^3 + P_2^3)\ \text{W} \tag{6.9}$$

It can be seen that IM products increase in proportion to the cubes of the signal powers with power levels that depend on the ratio $(b/A)2$. The greater the nonlinearity of the amplifier (larger b/A ratio), the larger the IM products.

Intermodulation Example

Consider the case of a 36 -MHz bandwidth C -band transponder which has an output spectrum for downlink signals in the frequency range 3705-3741 MHz. The transponder carries two unmodulated carriers at 3718 and 3728 MHz with equal magnitudes at the input to the HPA. Using Eq. (6.7), the output of the HPA will contain additional frequency components at frequencies

f31= (2 x 3718 — 3728) = 3708 MHz

f32= (2 X 3728 — 3718) = 3738 MHz

Both of the IM frequencies are within the transponder bandwidth and will there be present in an earth station receiver that is set to the frequency of this transponder. magnitude of the IM products will depend on the ratio b/A, a measure of the nonlinearity of the HPA, and on the actual level of the two signals in the transponder.

Now consider the case where the two signals carry modulation which spreads signal energy into a bandwidth of 8 MHz around each carrier. Carrier 1 has frequencies 3714 to 3722 MHz and carrier 2 has frequencies 3726 to 3734 MHz. Denoting the band of frequencies occupied by the signals as fnlo to fnhi, the intermodulation products cover the frequency bands (2f1lo-f2hi) to (2f1hi-2f2lo) and (2f2lo-f1hi) to (2f2hi-f1lo)

The IM products are spread over bandwidths (2B1+ B2) and (2B2+ B1). Hence the third -order IM products for this example cover these frequencies: 3706 —3730 MHz and 3716 — 3740 MHz with bandwidths of 24 MHz.

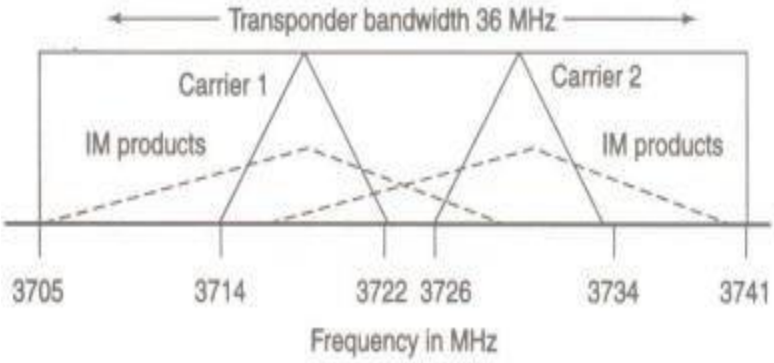


FIGURE 6.4Intermodulation between two C -band carriers in a transponder with third -order nonlinearity.

The location of the 8 MHz wide signals and 24 MHz wide IM products is illustrated in Figure 6.4. The intermodulation products now interfere with both signals, and also cover the empty frequency space in the transponder. Third -order IM products grow rapidly as the output of the transponder increases Toward saturation. Equation (6.9) shows that IM power increases as the cube of signal power in decibel units, every 10 dB increase in signal power causes a 30 dB increase in IM product-power. Consequently, the easiest way to reduce IM problems is to reduce the level of it the signals in the HPA. The output power of an operating transponder is related to its saturated output power by output backoff. Backoff is measured in decibel units, so a transponder with a 50W rated (saturated) output power operating with an output power of 25 W has output backoff of 17 dBW —14 dBW = 3 dB. Intermodulation products are reduced by 9 dB when 3 dB backoff is applied, so any nonlinear transponder carrying more than one signal will usually have some backoff applied. Since a transponder is an amplifier, the output power level is controlled by the input power, and there is a saturated input power level corresponding to the saturated output level. When the transponder is operated with output backoff, the power level at its input is reduced by the input backoff because the transponder characteristics are not linear, input backoff is always larger than output backoff. Figure 6.5 illustrates the operating point and input and output backoff for a transponder with a nonlinear TWTA. The nonlinearity of the transponder causes the input and output backoff values to be unequal. In the example shown in Figure 6.5, the transponder saturates at an input power of —100 dBW. The transponder is operated at an input power of —102.2 dBW, giving an input backoff of —2.2 dB. The corresponding output backoff is 1.0

dB, giving an output power of 16 dBW (40W), 10W below the saturated output power of 50W (17 dBW).

Calculation of C/N with Intermodulation:

Intermodulation between carriers in a nonlinear transponder adds unwanted products into the transponder bandwidth that are treated as though the interference were Gaussian noise For wideband carriers, the behavior of the IM products will be noiselike; with narrow band carriers, the assumption may not be accurate, but is applied because of the difficulty of determining the exact nature of the IM products.

The output backoff of a transponder reduces the output power level of all carriers, which therefore reduces the (C/N) ratio in the transponder. The transponder C/N ratio appears as $(C/N)_{up}$ in the calculation of the overall $(C/N)_0$ ratio in the earth station receiver 1M noise in the transponder is defined by another C/N ratio, (C/N), Which enters the overall $(C/N)_0$ ratio through the reciprocal formula (using linear C/N power ratios)

$(C/N)_0 = 1/[1/(C/N)_{up} + 1/(C/N)_{dn} + 1/(C/N)_{IM}$

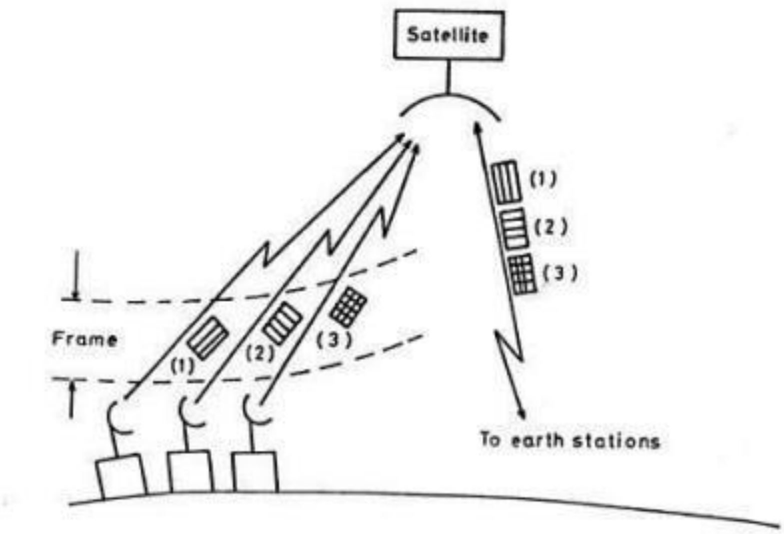
Techniques for the calculation of $(C/N)_{IM}$ are beyond the scope of this text. Full knowledge of the transponder nonlinearity and the signals carried by the transponder is required to permit $(C/N)_{IM}$ to be calculated. There is an optimum output backoff for any nonlinear transponder operating in FDMA mode. Figure 6.6 illustrates the effect of the HPA operating point on each C/N ratio in Eq. (6.10) when the operating point is set by the power transmitted by the uplink earth station. The uplink $(C/N)_{up}$ ratio increases linearly as the transponder input power is increased, leading to a corresponding nonlinear increase in transponder output power as the nonlinear region of the transponder is reached, the downlink $(C/N)_{dn}$ ratio increases less rapidly than $(C/N)_{up}$ because the nonlinear transponder is going into saturation Intermodulation products start to appear as the nonlinear region is approached, increasing rapidly as saturation is reached. With a third -order model for nonlinearity, the intermodulation products increase in power at three times the rate at which the input power to the transponder is increases, causing $(C/N)_{IM}$ to decrease rapidly as saturation is approached.

When all three C/N ratios are combined through Eq. (6.10), the overall $(C/N)_0$ ratio in the receiving earth station receiver has a maximum value at an input power level of —104 dBW in the example in Figure 6.6. This is the optimum operating point for the transponder. The optimum operating point may be many decibels below the saturated output level of the transponder under some conditions.

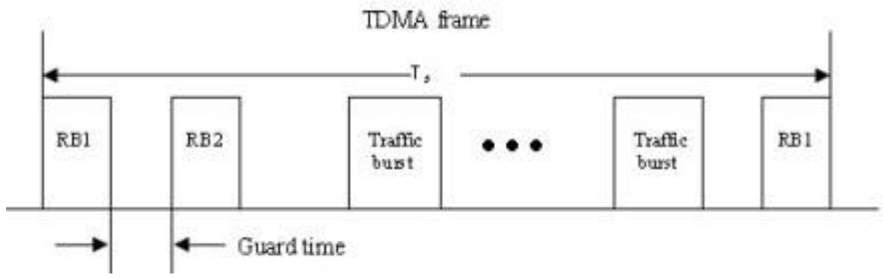
VSAT networks and mobile satellite telephones often use single channel per carrier (SCPC) FDMA to share transponder bandwidth. Because the carriers are narrowband, in the 10 to 128 kHz range typically, a 36 or 54 MHz transponder may carry many hundreds of carriers simultaneously. The balance between the power levels of the carriers may not be maintained, especially in a system with mobile transmitters that can be subject to fading. The transponder must operate in a linear mode for such systems to be feasible, either by the use of a linear transponder or by applying large output backoff to force operation of the transponder into its linear region.

TIME DIVISION MULTIPLE ACCESS (TDMA)

In search of an alternative multiple access technique; attention was focused on the possibilities afforded by TDMA. In TDMA, the sharing of the communication resource by several earth stations is performed by assigning a short time (time slot) to each earth station in which they have exclusive use of the entire transponder bandwidth and communicate with each other by means of non-overlapping burst of signals. A basic TDMA system is shown in Fig.



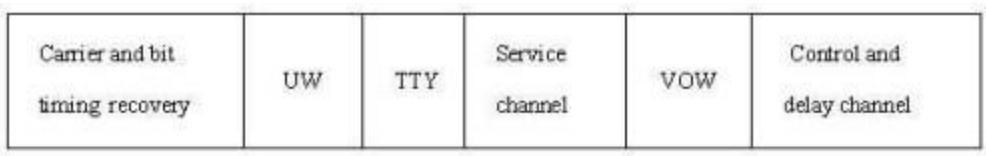
In TDMA, the transmit timing of the bursts is accurately synchronized so that the transponder receives one burst at a time. Each earth station receives an entire burst stream and extracts the bursts intended for it. A frame consists of a number of bursts originating from a community of earth stations in a network. A TDMA frame structure is shown in Fig.



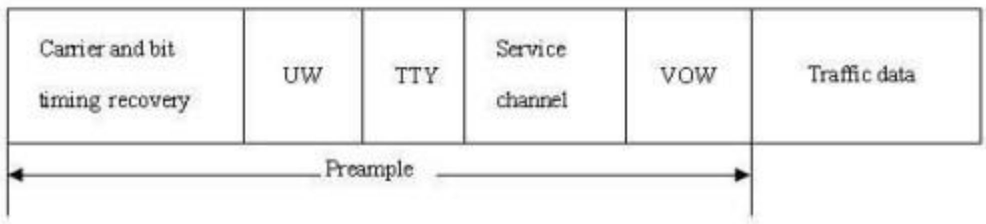
It consists of two reference bursts RB1and RB2, traffic bursts and the guard time between bursts. As can be seen, each TDMA frame has two reference bursts RB1 and RB2. The primary reference burst (PRB), which can be either RB1 or RB2, is transmitted by one of the earth stations in the network designated as the primary reference earth station. For reliability, a second reference burst (SRB) is transmitted by a secondary reference earth station. To ensure undisrupted service for the TDMA network, automatic switchover between these two reference stations is provided. The reference bursts carry no traffic information and are used to provide synchronization for all earth stations in the network.
The traffic bursts carry information from the traffic earth station. Each earth station accessing a transponder may transmit one or two traffic bursts per TDMA frame and may posit ion them anywhere in the frame according to a burst time plan that coordinates traffic between earth stations in the network.

The Guard time between bursts ensures that the bursts never overlap at the input to the transponder.

The TDMA bursts structure of the reference and traffic burst are given in Fig



Reference burst



Traffic burst

In the traffic burst, traffic data (information bits) is preceded by a pattern of bits referred to as a preamble which contains the information for synchronization, management and control. Various sequences in the reference burst and traffic burst are as follows:

Carrier and bit timing recovery (CBTR)

The CBTR pattern provides information for carrier and timing recovery circuits of the earth station demodulator. The length of the CBTR sequence depends on the carrier-to-noise ratio at the input of the demodulator and the acquisition range. For example, the 120 Mb/s TDMA system of INTELSAT V has a 48 symbol pattern for carrier recovery and a 128 symbol pattern for bit timing recovery.

Unique word (UW)

The unique word sequence in the reference burst provides the receive frame timing that allows an earth station to locate the position of a traffic burst in the frame. The UW in the traffic burst marks the beginning of the traffic burst and provides information to an earth station so that it selects only those traffic bursts intended for it. The UW is a sequence of ones and zeros selected to exhibit good correlation properties to enhance detection. The UW of the INTELSAT V TDMA system has a length of 24 symbols.

Teletype (TTY) and voice order wire (VOW)

Teletype and voice order wire patterns carry instructions to and from earth stations. The number of symbols for each of the patterns is 8 symbols for the INTELSAT V TDMA.

Service channel (SC)

The service channel of the reference burst carriers management instructions such as burst time plan which gives the coordination of traffic between earth stations, i.e. position, length, and source and destination earth stations corresponding to traffic bursts in the TDMA frame. The channel also carries monitoring and control information to the traffic stations. The SC of the traffic burst carries the traffic station’s status to the reference station (value of transmit delay used and reference station from which the delay is obtained). It also contains other information such as the high bit error rate and UW loss alarms to other traffic stations. The INTELSAT V TDMA has an 8-symbol SC for each of the bursts.

Control and delay channel (CDC)

The control and delay channel pattern carries acquisition and synchronization information to the traffic earth stations to enable them to adjust their transmit delays so that bursts arrive at the satellite transponder within the correct time slots in the frame. It also carries the reference station status code which enables them to identify the primary and secondary reference bursts. Eight symbols are allocated for this channel in the INTELSAT V TDMA.

Traffic data

This portion contains the information from a source traffic station to a destination traffic station. The informants can be voice, data, video or facsimile signals. The traffic data pattern is divided into blocks of data (referred to as subburst). The size of each data block is given by: Subburst size (symbols) = symbol rate (symbols/sec) X frame length (sec). The INTELSAT TDMA with a frame length of $T_f = 2$ msec for PCM voice data has a subburst size of 64 symbols long.

In the traffic burst, traffic data (information bits) is preceded by a pattern of bits referred to as a preamble which contains the information for synchronization, management and control. Various sequences in the reference burst and traffic burst are as follows:

Carrier and bit timing recovery (CBTR)

The CBTR pattern provides information for carrier and timing recovery circuits of the earth station demodulator. The length of the CBTR sequence depends on the carrier-to-noise ratio at the input of the demodulator and the acquisition range. For example, the 120 Mb/s TDMA system of INTELSAT V has a 48 symbol pattern for carrier recovery and a 128 symbol pattern for bit timing recovery.

Unique word (UW)

The unique word sequence in the reference burst provides the receive frame timing that allows an earth station to locate the position of a traffic burst in the frame. The UW in the traffic burst marks the beginning of the traffic burst and provides information to an earth station so that it selects only those traffic bursts intended for it. The UW is a sequence of ones and zeros selected to exhibit good correlation properties to enhance detection. The UW of the INTELSAT V TDMA system has a length of 24 symbols.

Teletype (TTY) and voice order wire (VOW)

Teletype and voice order wire patterns carry instructions to and from earth stations. The number of symbols for each of the patterns is 8 symbols for the INTELSAT V TDMA.

Service channel (SC)

The service channel of the reference burst carriers management instructions such as burst time plan which gives the coordination of traffic between earth stations, i.e. position, length, and source and destination earth stations corresponding to traffic bursts in the TDMA frame. The channel also carries monitoring and control information to the traffic stations. The SC of the traffic burst carries the traffic station's status to the reference station (value of transmit delay used and reference station from which the delay is obtained). It also contains other information such as the high bit error rate and UW loss alarms to other traffic stations. The INTELSAT V TDMA has an 8-symbol SC for each of the bursts.

Control and delay channel (CDC)

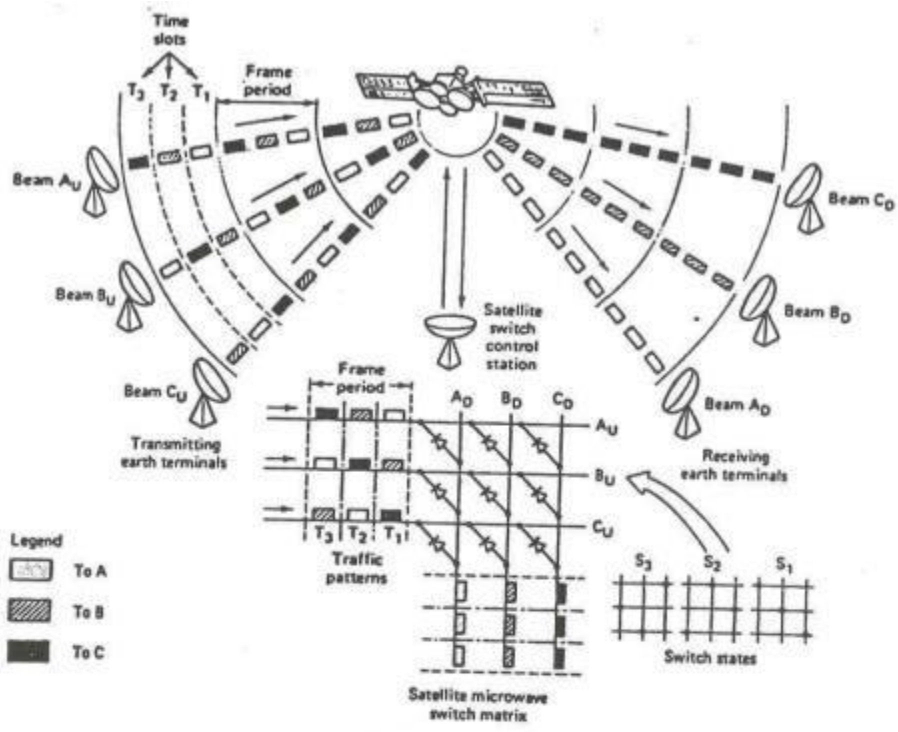
The control and delay channel pattern carries acquisition and synchronization information to the traffic earth stations to enable them to adjust their transmit delays so that bursts arrive at the satellite transponder within the correct time slots in the frame. It also carries the reference station status code which enables them to identify the primary and secondary reference bursts. Eight symbols are allocated for this channel in the INTELSAT V TDMA.

Traffic data

This portion contains the information from a source traffic station to a destination traffic station. The informants can be voice, data, video or facsimile signals. The traffic data pattern is divided into blocks of data (referred to as subburst). The size of each data block is given by: Subburst size (symbols) = symbol rate (symbols/sec) X frame length (sec). The INTELSAT TDMA with a frame length of $T f = 2$ msec for PCM voice data has a subburst size of 64 symbols long.

Satellite-switched TDMA (SS-TDMA)

A satellite-switched TDMA system is an efficient TDMA system with multiple spot beam operation for the uplink and downlink transmissions. The interconnection between the uplink and downlink beams is performed by a high-speed switch matrix located at the heart of the satellite. An SS-TDMA scheme provides a full interconnection of TDMA signals among various coverage regions by means of interconnecting the corresponding uplink and downlink beams at a switching time. Figure shows a three-beam (beams A, B and C) example of a SSTDMA system.



Satellite-switched TDMA (SS/TDMA).

The switch matrix is configured in a crossbar design in which only a single row is connected to a single column at a time. In this figure, three different traffic patterns during time slot

intervals T1, T2 and T3, with three different switch states s1, s2 and s3 are also shown. The switching sequence is programmed via a ground control so that states can be changed from time to time. The advantages of SS-TDMA systems over TDMA systems are:
(1) The possibility of frequency re-use by spot-beam spatial discrimination, i.e. the same frequency band can be spatially re-used many times. Hence, a considerable increase in satellite capacity can be made.
(2) The use of a narrow antenna beam which provides a high gain for the coverage region. Hence, a power saving can be obtained in both the uplink and downlink. An SS-TDMA scheme has been planned for INTELSAT VI and Olympus satellites.

Satellite Switched TDMA

One advantage that TDMA has when used with a baseband processing transponder is satellite switched TDMA. Instead of using a single antenna beam to maintain continuous communication with its entire coverage zone, the satellite has a number of narrow antenna beams that -can be used sequentially to cover the zone. A narrow antenna beam has a high gain than a broad beam, which increases the satellite EIRP and therefore increases the capacity of the downlink. Uplink signals received by the satellite are demodulated to recover the bit streams, which are structured as a sequence of packets addressed to different receiving earth stations. The satellite creates TDMA frames of data that contain packets addressed to specific earth stations, and switches its transmit beam to the direction of the receiving earth station as the packets are transmitted. Note that control of the TDMA network timing could now be on board the satellite, rather than at a master earth station.

ONBOARD PROCESSING

The discussion of multiple access so far has assumed the use of a bent pipe transponder. which simply amplifies a signal received from earth and retransmits it back to earth at a different frequency. The advantage of a bent pipe transponder is flexibility. The transponder can be used for any combination of signals that will fit within its bandwidth. The disadvantage of the bent pipe transponder is that it is not well suited to uplinks from small earth stations, especially uplinks operating in Ka band. Consider a link between a same transmitting earth station and a large hub station via a bent pipe GEO satellite transponder. There will usually be a small rain fade margin on the uplink from the transmitting station because of its low EIRP. When rain affects the uplink, the C/N ratio in the transponder will

fall. The overall C/N ratio in the hub station receiver cannot be greater than the C/N ratio in the transponder, so the bit error rate at the hub station will increase quickly as rain affects the uplink. The only available solution is to use forward error correction coding on the link, which lowers the data throughput but is actually needed for less than 5% of the time. The problem of uplink attenuation in rain is most severe for 30/20 GHz uplinks with small margins. Outages are likely to be frequent unless a large rain fade margin is included- in the uplink power budget. Onboard processing or a baseband processing transponder can overcome this problem by separating the uplink and downlink signals and their C/N ratios. The baseband processing transponder can also have different modulation schemes on the uplink and downlink to improve spectral efficiency, and can dynamically apply forward error control to only those links affected by rain attenuation.
All LEO satellites providing mobile telephone service use onboard processing, and Ka-band satellites providing Internet access to individual users also use onboard processing.

DEMAND ACCESS MULTIPLE ACCESS (DAMA)

Demand access can be used in any satellite communication link where traffic from an earth station is intermittent. An example is an LEO satellite system providing links to mobile telephones. Telephone voice users communicate at random times, for periods ranging from less than a minute to several minutes. As a percentage of total time, the use of an individual telephone may be as little as 1%. If each user were allocated a fixed channel, the utilization of the entire system might be as low as 1%, especially at night when demand for telephone channels is small. Demand access allows a satellite channel to be allocated to a user on demand, rather than continuously, which greatly increases the number of simultaneous users who can be served by the system. The two-way telephone channel may be a pair of frequency slots in a DA-SCPC system, a pair of time slots in a TDM or TDMA system, or any combination or FDMA, TDM, and TDMA. Most SCPC-FDMA systems use demand access to ensure that the available bandwidth in a transponder is used as fully as possible.
In the early days of satellite communication, the equipment required to allocate channels on demand, either in frequency or time, was large and expensive. The growth of cellular telephone systems has led to the development of low cost, highly integrated controllers and frequency synthesizers that make demand access feasible. Cellular telephone

systems use demand access and techniques similar to those used by satellite systems in the allocation of channels to users. The major difference between a cellular system and a satellite system is that in a cellular system the controller is at the base station to which the user is connected by a single hop radio link. In a satellite communication system, there is always a two hop link via the satellite to a controller at the hub earth station. Controllers are not placed on the satellites largely because of the difficulties in determining which links are in use, and who will be charged for the connection.
As a result, all connections pass through a controlling earth station that can determine whether to permit the requested connection to be made, and who should be charged. In international satellite communication systems issues such as landing rights require the owner of the system to ensure that communication can take place only between users in preauthorized countries anti zones. The presence of the signals from all destinations at a central earth station also allows security agencies the option of monitoring any traffic deemed to be contrary to the national interest.

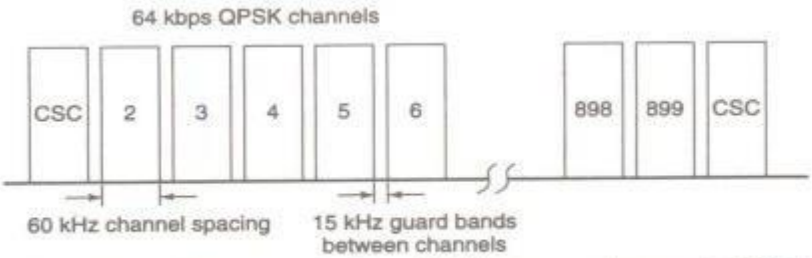


FIGURE Frequency plan for a 54-MHz transponder carrying 900 demand access channels. Each channel has an occupied RF bandwidth of 45 kHz and carries one 64-kbps signal. Channel 1 and channel 900 are common signaling channels (CSC) used by the demand assignment system to set up access to the other 898 channels.

Demand access systems require two different types of channel: a common signalling channel (CSC) and a communication channel. A user wishing to enter the communication network first calls the controlling earth station using the CSC, and the controller then allocates a pair of channels to that user. The CSC is usually operated in random access mode because the demand for use of the CSC is relatively low messages are short, and the CSC is therefore lightly loaded, a requirement for any DA link. Packet transmission techniques are widely used in demand access systems became of the need for addresses to determine the source and destination of signals. Section 6: discusses the design of packets for use in satellite communication systems. Bent pipe transponders are often used in demand access

mode, allowing any configuration of FDMA channels to be adopted. There seem to be few standards for demand access systems in the satellite communication industry, with each network using a different proprietary configuration. Figure shows a typical 54 MHz bandwidth Ku bank transponder frequency plan for the inbound channels of a VSAT network using frequents division multiple access with single channel per carrier and demand access (FDMA-SCPC-DA) on the inbound link.
The individual outbound RF channels are 45 kHz wide, to accommodate the occupied bandwidth of 64-kbps bit streams transmitted using QPSK and RRC filters with a = 0.4. A guard band of 15 kHz is allowed between each RF channel. so one RF channel requires a total bandwidth of 60 kHz. A 54 MHz bandwidth transponder can accommodate 900 of these 60 kHz channels, but it is unlikely that all are used at the same time. Many VSAT systems are power limited, preventing the full use of the transponder bandwidth, and the statistics of .demand access systems ensure that tie likelihood of all the channels being used at one time is small. Considerable backoff is required in a bent pipe transponder with large numbers of FDMA channels.

CODE DIVISION MULTIPLE ACCESS (CDMA)

In CDMA satellite systems, each uplink earth station is identified by an address code imposed on its carrier. Each uplink earth station uses the entire bandwidth transmits through the satellite whenever desired. No bandwidth or time sharing is required in CDMA satellite systems. Signal identification is achieved at a receiving earth station by recognising the corresponding address code.
There are three CDMA techniques as follows:

1. Direct sequence CDMA (DS-CDMA)

In this technique, an addressed pseudo-noise (PN) sequence generated by the PN code generator of an uplink earth station together with the information data are modulated directly on the carrier as shown in Fig. 9.28a. The same PN sequence is used synchronously at the receiving earth station to despread the received signal in order to receive the original data information (Fig. 9.28b).

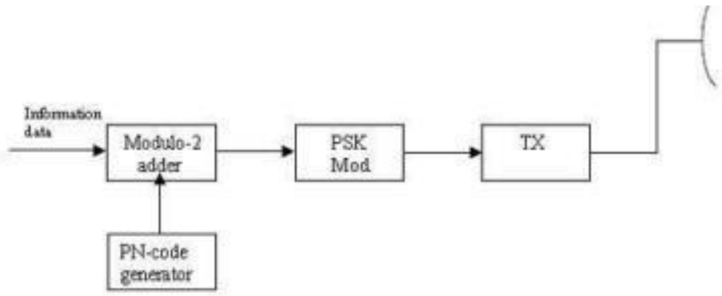
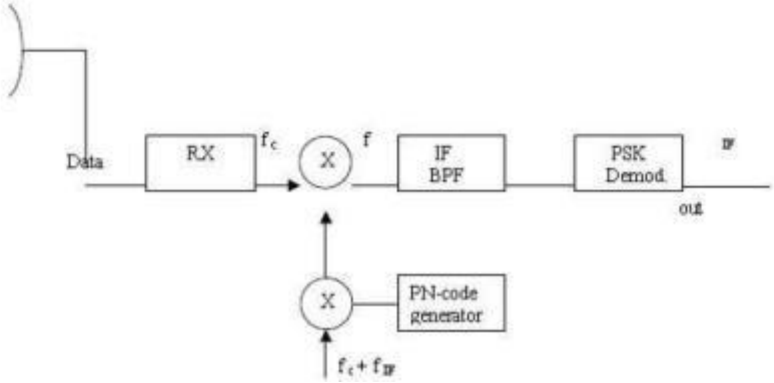


Fig 9.28a

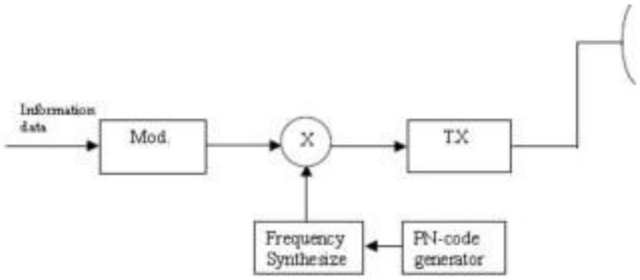


The bits of the PN sequence are referred to as chips. The ratio between the chip rate and information rate is called the spreading factor. Phase-shift-keying modulation schemes are commonly used for these systems. The most widely used binary PN sequence is the maximum length linear feedback shift register sequence (m-sequence) which is generated by an m-stage shift register. The m-sequence has a period of $2^m - 1$. Table 2.3 gives the properties of the sequence sets which exhibit small peak cross-correlation values suitable for DSCDMA.

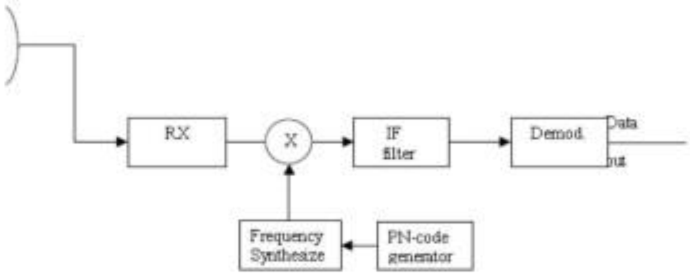
There are two types of DS-CDMA techniques: synchronous and asynchronous. In a synchronous system, the entire system is synchronized in such a way that the PN sequence period (code period) or bit duration of all the uplink carriers in the system are in time alignment at the satellite. This requires that all stations have the same PN sequence period and the same number of chips per PN sequence length. Hence, a synchronous DS-CDMA must have the type of network synchronization used in a TDMA system but in a much simpler form. However, in an asynchronous DS-CDMA satellite no time alignment of the PN sequence period at the satellite is required and each uplink carrier operates independently with no overall network synchronization. Therefore, the system complexity is much simpler than a synchronous system.

2. Frequency hopping CDMA (FH-CDMA)

The block diagram of an FH-CDMA transmitter/receiver is shown in Fig.



Transmitter



Receiver

Here, the addressed PN sequence is used to continually change the frequency of the carrier at the uplink earth station (hopping). At the receiver, the local PN code generator produces a synchronized replica of the transmitted PN code which changes the synthesizer frequency in order to remove the frequency hops on the received signal, leaving the original modulated signal untouched. Non-coherent M-ary FSK modulation schemes are commonly used for these systems.

3. Hybrid CDMA

A hybrid CDMA system employs a combination of DS-CDMA and FHCDMA techniques. In all these techniques, a larger bandwidth is produced than that which will be generate by the modulation alone. Because of this spreading of the signal spectrum, CDMA systems are also referred to as spread spectrum multiple access (SSMA) systems. Spreading the spectrum of the transmitted signal has important applications in military satellite systems since it produces inherent anti jam advantages. In addition to anti jamming protection, another important feature of these systems is their low probability of interception (LPI) and hence, reduces the probability of reception by unauthorized users.

Spread Spectrum Transmission and Reception

This discussion of CDMA for satellite communications will be restricted to direct sequence systems, since that is the only form of spread spectrum that has been used by commercial satellite systems to date. The spreading codes used in DS -SS CDMA systems are designed to have good autocorrelation properties and low cross -correlation. Various codes have been developed specifically for this purpose, such as Gold and Kasarni codes. The DS -SS codes will all be treated as Pseudonoise (PN) sequences in this discussion. Pseudonoise refers to the spectrum of code, which appears to be a random sequence of bits (or chips) with a flat, noise like spectrum. The generation of .a DS -SS signal is illustrated in Figure 1. We will begin by assuming that the system uses baseband signals Most DS -SS systems generate spread spectrum signals using BPSK modulated versions of the data stream, but it is easier to see how a DS -SS system operates if the signals are first considered at baseband. In Figure 1, a bit stream containing traffic data at a rate Rb, converted to have levels of +1 and —1 V corresponding to the logical states 1 and 0, is multiplied by a PN sequence, also with levels +1 and — 1 V, at a rate M X Rb Chips per second. Each data bit results in the transmission of a complete PN sequence of length M chips.

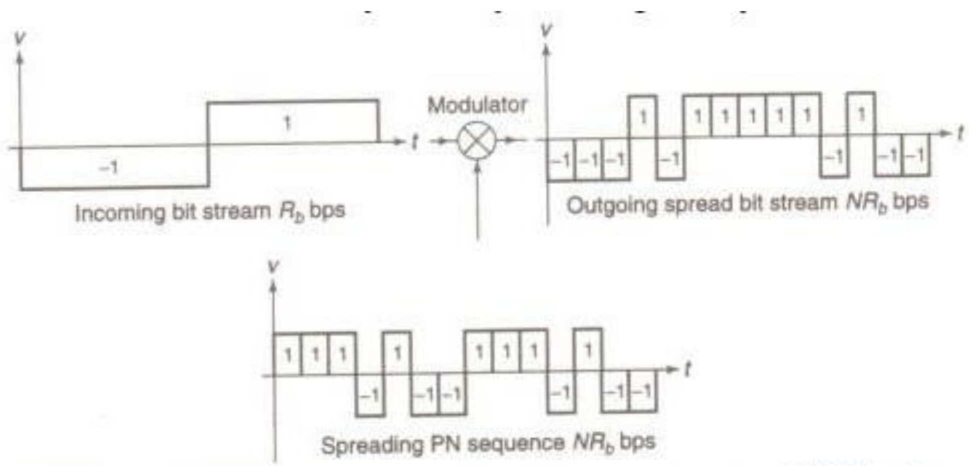


FIGURE 1 The basic principle of a direct sequence spread spectrum (CDMA) system. Each incoming message data bit is multiplied by the same PN sequence. In this example the message sequence is −1 +1 and the PN sequence is +1 +1 +1 −1 +1 −1 −1.

In the example shown in Figure 6.16, the seven chip spreading code sequence is 1110100, which is converted to +1 +1 +1 —1 +1 —1 —1. The spreading sequence multiplies the data sequence 0 1, represented as —1 +1, leading to the transmitted sequence —1 —1 —1 +1 —1

+1 +1 +1 +1 +1 —1+1—1 —1 shown at the right in Figure1. Recovery of the original data stream of bits from the DS-SS signal is achieved by multiplying the received signal by the same PN code that was used to generate it. The process is illustrated in Figures 2 and 3.

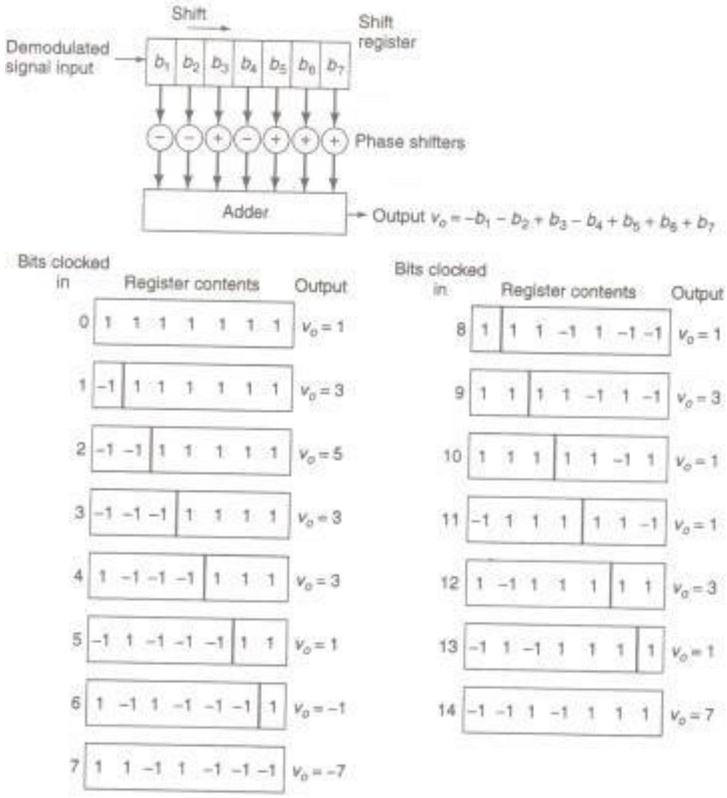


Figure 2: Data bit recovery using an IF correlator (matched filter). In this example the PN sequence is seven bits long for illustration. The CDMA chips from the receiver are clocked into the shift register serially and the shift register contents passed through phase shifters and added. The phase shifters convert —1 chips to +1 when the correct code is in the shift register such that all the voltages add to a maximum when the received sequence is correct. This figure shows the shift register contents and adder output for the chip sequence in Figure 1. Note that a high spurious output of 5 occurs at the third clock step, indicating that the seven bit sequence used here for illustration has poor autocorrelation properties.

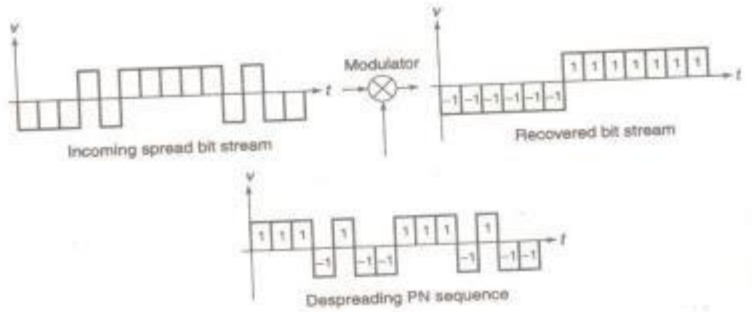


Figure 3: A baseband correlator for dispreading CDMA signals. The original bit stream is recovered by multiplying the received signal by a synchronized copy of the PN sequence that was used in the transmitter.

Satellite Link Design

BASIC TRANSMISSION THEORY:

The RF (or free space)segment of the satellite communications link is a critical element that impacts the design and performance of communications over the satellite. The basic communications link, shown in Figure 4.1, identifies the basic parameters of the link.

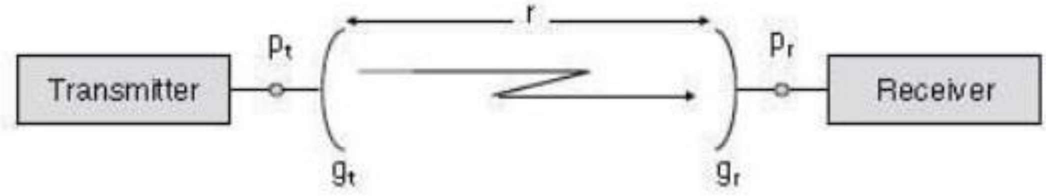


Figure 4.1 Basic communications link

The parameters of the link are defined as:

pt=transmitted power(watts); pr

= received power (watts);

gt=transmit antenna gain;

gr = receive antenna gain;

r =path distance(meters).

An electromagnetic wave, referred to as a ***radio wave*** at radio frequencies, is nominally definedintherangeof~100MHzto100+GHz.Theradiowaveischaracterizedbyvariationsof its electric and magnetic fields. The oscillating motion of the field intensities vibrating at a particular point in space at a frequency f excites similar vibrations at neighboring points ,and the radio wave is said to travel or to ***propagate***. The wavelength ,λ, of the radio wave is the spatial separation of two successive oscillations, which is the distance the wave travels during one cycle of oscillation (Figure 4.2).

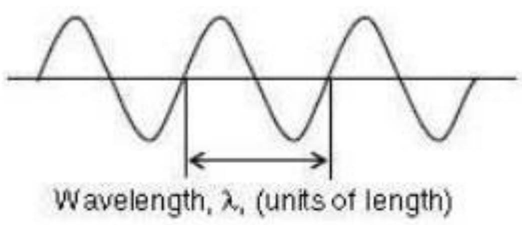


Figure 4.2 Definition of wavelength

The frequency and wavelength in free space are related by

$$\lambda = \frac{c}{f}$$

Where c is the phase velocity of light in a vacuum. With c = 3×10^{8}m/s, the free space wavelength for the frequency in GHz can be expressed as

$$\lambda(\mathrm{cm}) = \frac{30}{f(\mathrm{GHz})} \quad \text{or} \quad \lambda(\mathrm{m}) = \frac{0.3}{f(\mathrm{GHz})}$$

Consider a radio wave propagating in free space from a point source P of power pt watts. The wave is isotropic in space, i.e., spherically radiating from the point source P, as shown in Figure 4.3

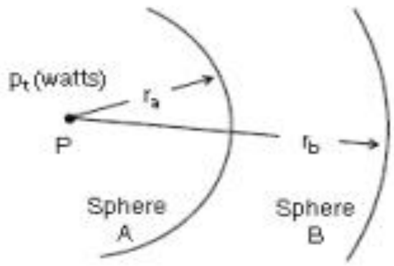


Figure 4.3 Inverse square law of radiation

The power flux density (or power density), over the surface of a sphere of radius ra from the point P, is given by

$$(\mathrm{pfd})_A = \frac{P_t}{4\pi r_a^2}, \ \mathrm{watts/m^2}$$

Similarly, at the surface B, the density over a sphere of radius rb is given by

$$(\mathrm{pfd})_B = \frac{P_t}{4\pi r_b^2}, \ \mathrm{watts/m^2}$$

The ratio of power densities is given by

$$\frac{(\mathrm{pfd})_A}{(\mathrm{pfd})_B} = \frac{r_b^2}{r_a^2}$$

Where (pfd)B < (pfd)A. This relationship demonstrates the well-known *inverse square law of radiation*: the power density of a radio wave propagating from a source is inversely proportional to the square of the distance from the source.

Effective Isotropic Radiated Power An important parameter in the evaluation of the RF link is the *effective isotropic radiated power,* eirp. The eirp, using the parameters introduced in Figure4.1,is defined as

eirp≡pt.gtor,

in db,EIRP=Pt+Gt

The eirp serves as a single parameter‘ figure of merit’ for the transmit portion of the communications link.

Power Flux Density:

The power density, usually expressed in watts/m2, at the distance r from the transmit antenna with a gain gt, is defined as the *power flux density* (pfd)r (see Figure 4.4).

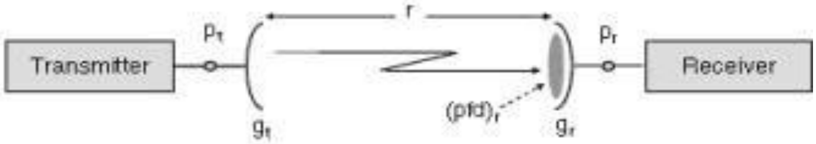


Figure 4.4 Power flux density

The (pfd)r is therefore

$$(pfd)_r = \frac{p_t\, g_t}{4\pi r^2}\ \mathrm{w/m^2}$$

Or, in terms of the eirp,

$$(pfd)_r = \frac{\mathrm{eirp}}{4\pi r^2}\ \mathrm{w/m^2}$$

The power flux density expressed in dB, will be

$$(PFD)_r = 10\log\left(\frac{p_t\, g_t}{4\pi r^2}\right)$$

$$= 10\log(p_t) + 10\log(g_t) - 20\ \log(r) - 10\log(4\pi)$$

With r in meters,

$$(PFD)r = Pt + Gt - 20\ \log(r) - 10.99$$

Or

$$(PFD)r = EIRP - 20\ \log(r) - 10.99$$

Where Pt, Gt , and EIRP are the transmit power, transmit antenna gain, and effective radiated power, all expressed in dB.

The (pfd) is an important parameter in the evaluation of power requirements and interference levels for satellite communications networks.

Antenna Gain

Isotropic power radiation is usually not effective for satellite communications links, because the power density levels will below for most applications (there are some exceptions, such as for mobile satellite networks, some directivity (gain) is desirable for both the transmit and receive antennas.

Also, physical antennas are not perfect receptors/emitters, and this must be taken into account in defining the antenna gain.

Consider first a lossless (ideal) antenna with a physical aperture area of A(m2). The gain of the ideal antenna with a physical aperture area A is defined as

$$g_{ideal} \equiv \frac{4\pi A}{\lambda^2}$$

Where λ is the wavelength of the radio wave.

Physical antennas are not ideal – some energy is reflected away by the structure, some energy is absorbed by lossy components (feeds, struts, sub reflectors). To account for this, an *effective aperture*, Ae, is defined in terms of an *aperture efficiency*, ȘA, such that

$$A_e = \eta_A A$$

Then, defining the 'real' or physical antenna gain as g,

$$g_{real} = g = \frac{4\pi A_e}{\lambda^2}$$

Or,

$$g = \eta_A \frac{4\pi A}{\lambda^2}$$

Antenna gain in dB for satellite applications is usually expressed as the dB value above the gain of an isotropic radiator, written as 'dBi'. Therefore,

$$G = 10 \log\left[\eta_A \frac{4\pi A}{\lambda^2}\right], \text{dBi}$$

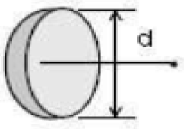
Note also that the effective aperture can be expressed as

$$A_e = \frac{g\lambda^2}{4\pi}$$

The aperture efficiency for a circular parabolic antenna typically runs about 0.55 (55 %), while values of 70% and higher are available for high performance antenna systems.

Circular Parabolic Reflector Antenna

The circular parabolic reflector is the most common type of antenna used for satellite earth station and spacecraft antennas. It is easy to construct ,and has good gain and beam width characteristics for a large range of applications. The physical area of the aperture of a circular parabolic aperture is given by



$$A = \frac{\pi d^2}{4}$$

where d is the physical diameter of the antenna.
From the antenna gain Equation

$$g = \eta_A \frac{4\pi A}{\lambda^2} = \eta_A \frac{4\pi}{\lambda^2}\left(\frac{\pi d^2}{4}\right)$$

or

$$g = \eta_A \left(\frac{\pi d}{\lambda}\right)^2$$

Expressed in dB form,

$$G = 10 \log\left[\eta_A \left(\frac{\pi d}{\lambda}\right)^2\right] \quad \text{dBi}$$

For the antenna diameter d given in meters, and the frequency f in GHz,

$$g = \eta_A\,(10.472\ f\ d)^2$$

$$g = 109.66\, f^2\, d^2\, \eta_A$$

Or, in dBi

$$G = 10\ \log(109.66\, f^2\, d^2\, \eta_A)$$

Free-Space Path Loss

Consider now a receiver with an antenna of gain gr located a distance r from a transmitter of pt watts and antenna gain gt, as shown in Figure 4.4. The power pr intercepted by the receiving antenna will be

$$p_r = (pfd)_r A_e = \frac{p_t g_t}{4\pi r^2} A_e, \text{ watts}$$

Where (pfd)r is the power flux density at the receiver and Ae is the effective area of the receiver antenna, in square meters. Replacing Ae with the representation

$$p_r = \frac{p_t g_t}{4\pi d^2}\,\frac{g_r \lambda^2}{4\pi}$$

Are arranging of terms describes the inter relationship of several parameters used in link analysis:

$$p_r = \underbrace{\left[\frac{p_t g_t}{4\pi r^2}\right]}_{\substack{\text{Power Flux Density} \\ \text{(pfd)} \\ \text{in } w/m^2}} g_r \underbrace{\left[\frac{\lambda^2}{4\pi}\right]}_{\substack{\text{Spreading Loss} \\ s \\ \text{in } m^2}}$$

Basic Link Equation for Received Power:

We now have all the elements necessary to define the basic link equation for determining the receivedpowerattthereceiverantennaterminalsforasatellitecommunicationslink.Werefer again to the basic communications link (Figure 4.1, repeated here as Figure 4.6).

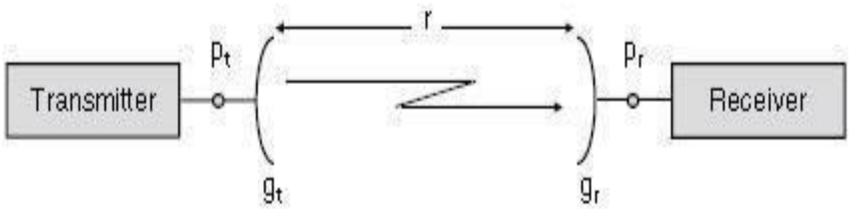


Figure 4.6 Basic communications link

The parameters of the link are defined as:

pt=transmitted power(watts); pr

= received power(watts);

gt=transmit antenna gain;

gr = receive antenna gain;

and r=path distance(meters or km).

The receiver power at the receive antenna terminals ,pr ,Is given as

$$p_r = p_t\, g_t \left(\frac{1}{l_{FS}}\right) g_r$$
$$= \text{eirp} \left(\frac{1}{l_{FS}}\right) g_r$$

Or, expressed in dB,

$$P_r(\text{dB}) = \text{EIRP} + G_r - L_{FS}$$

This result gives the basic link equation, sometimes referred to as the *Link Power Budget Equation*, for a satellite communications link, and is the design equation from which satellite design and performance evaluations proceed.

The link equation expressed in equation.

Power received=EIRP x Receive antenna gain/Path loss [Watts] Using decibel notations

$$P_r = EIRP + G_r - L_p \quad [dBW]$$

where

$$EIRP = 10\log(P_t G_t) \quad [dBW]$$

$$Gr = 10\log\left(4\pi A_e / \lambda^2\right) [dB]$$

$$L_p = 20\log(4\pi R/\lambda) \quad [dB]$$

The path loss component of equation is the algebraic sum of various loss components such as: losses in the atmosphere due to attenuation by air, water vapor and rain, losses at the antenna at each side of the link and possible reduction in antenna gain due to antenna is alignment (due to poor operation of the AOC satellite subsystem). This needs to be incorporated into the link equation to ensure that the system margin allowed is adequate.

$$P_r = EIRP + G_r - \left(l_{ta} + l_{ra} + l_{atm} + l_{rain} + l_{pol} + l_{pt} + \ldots\right)$$

where

l_{ta}–Attenuation due to transmit antenna, l_{ra}–Attenuation due to receive antenna, l_{atm}–Atmospheric attenuation, l_{rain}–Attenuation due to precipitation, l_{pol}–Attanuation due to polarization, l_{pt}–Antenna pointing misalignment related attenuation

Example A:

A satellite downlink at 12 GHz operates with a transmit power of 20 W and an antenna gain of 45 dB. Calculate the EIRP in dBW.

Solution: $EIRP = 10\log 20 + 45 = 58\ dBW$

Example B:

A satellite at a distance of 39,000 km from the EIE departmental building radiates a power of 20 W from an antenna with a gain of 22 dB in the direction of a VSAT at the EIE building with an effective aperture area of 10 m².

Find:

a. The flux density at the departmental building

b. The power received by the VSAT antenna *c. If the satellite operates at a frequency of 11 GHz and the Earth Station (ES) antenna has a gain of 52.3 dB. Determine the received power.*

Solution

Data and conversion:

Satellite antenna gain = 22 dB = $10^{22/10}$ = 158.5 W;

Satellite signal wavelength

$$\lambda = \frac{c}{f} = \frac{3 \times 10^8}{11 \times 10^9} = 0.0273 \ m$$

where c – speed of light;

Earth station to satellite distance, R=39,000 km = 3.9×10^7 m

a) Substituting the given values into (1), we have:

$$\varphi = \frac{20 \times 158.5}{4 \times \pi \times (3.9 \times 10^7)^2} = 1.66 \times 10^{-13} W/m^2$$

Using the decibel notation:

$$\varphi = 10\log(P_t G_t) - (20\log R + 10\log(4\pi))$$
$$= 10\log(20 \times 158.5) - (20\log 3.9 \times 10^7 + 10\log 12.57)$$
$$= 35.01 - 151.82 - 10.99$$
$$= -127.8 \ dBW/m^2$$

Note that

$$= 10\log(1.66 \times 10^{-13}) = -127.8 \ dBW/m^2$$

b) The power received with an effective collecting antenna of 10 m^2 aperture is:

$$P_r = \varphi \times A_e = 1.66 \times 10^{-13} \times 10 \ = 1.66 \times 10^{-12} W$$

In decibels:

$$P_r = [\varphi] + [A] = -127.8 + 10 = -117.8 \ dBW$$

Note that

$$-117.8 \ dBW = 10^{-11.78} W = 1.66 \times 10^{-12} W$$

c) Working in decibels using equation (9) we have:

$$L_P = 20\log(4\pi R/\lambda)$$
$$= 20\log(4 \times \pi \times 3.9 \times 10^7 / 0.0273)$$
$$= 205.08 \ dB$$

$\therefore$

$$P_r = EIRP + G_r - L_p$$
$$= 35.01 + 52.3 - 205.08$$
$$= -117.77 \ dBW.$$

SYSTEMNOISETEMPERATUREANDG/TRATIO

Noise temperature:

Noise temperature is useful concept in communication receivers, since it provides a way of determining how much thermal noise is generated by active and passive devices in the receiving system. At microwave frequencies ,a black body with a physical temperature, Tp degrees kelvin, generates electrical noise over a wide bandwidth. The noise power is given by

$$Pn=k.\mathit{T}n.Bn$$

Where

k=Boltzmann's constant=1.39x10-23J/K=-228.6dBW/K/Hz

Tn=Physical temperature of source in kelvin degrees

Bn=noise bandwidth in which the noise power is measured, in hertz

Pn is the available noise power(in watts) and will be delivered only to a load that is impedance matched to the noise source.

The term kTn is a noise power spectral density, in watts per hertz.

We need a way to describe the noise produced by the components of a low noise receiver. This can conveniently be done by equating the components to a black body radiator with an equivalent noise temperature, Tn kelvins.

To determine the performance of a receiving system we need to be able to find the total thermal noise power against which the signal must be demodulated.

We do this by determining the system noise temperature, Ts.

Ts is the noise temperature of a noise source, located at the input of a noiseless receiver, which gives the same noise power as the original receiver, measured at the output of the receiver and usually includes noise from the antenna.

If the overall lend-to-end gain of the receiver is Grx and its narrowest bandwidth is Bn Hz, the noise power at the demodulator input is

$$\mathbf{Pno= k.\mathit{T}s.Bn.Grx\ watts}$$

Where Grx is the gain of the receiver from RF input to demodulator input.

The noise power referred to the input of the receiver is Pn where Pno=k*T*sBn wa*tt*s

Let the antenna deliver a signal power Pr watts to the receiver RF input. The signal power at the demodulator input is PrGrx watts, representing the power contained in the carrier and sidebands after amplification and frequency conversion within the receiver. Hence, the carrier-to-noise ratio at the demodulator is given by

$$C/N = P_rG_{rx}/KT_nB_nG_{rx}$$
$$= P_r/KT_nB_n$$

Carrier to Noise Ratio (C/N or CNR)

Determining the performance of a satellite communication system is not the signal(or carrier) power but the carrier power to the noise power ratio (C/N) of the received signal, because this ratio is what determines the quality of the transmitted in formation and whether it can be retrieved properly or not.

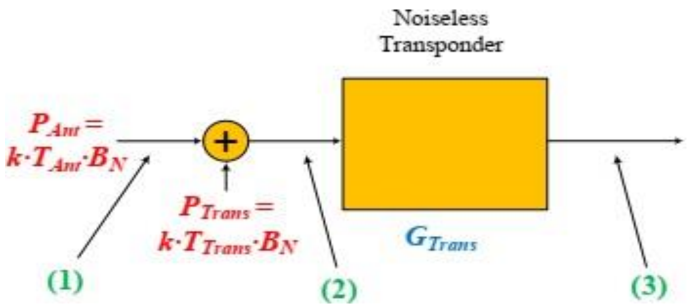
There is a difference between the term Carrier to Noise Ratio (C/N) and the Signal to Noise Ratio (S/N).

Let us determine the relation between the carrier to noise ratio of the different satellite links (uplink and downlink) and the carrier to noise ratio of the whole communication system

C/N Before and After a Block

What happens to the carrier to noise ratio before and after a specific block?

To get the answer, let us use consider a noisy transponder block shown below, where the noise has been transferred to its input. Let us compute the C/N ratio at different points in this system indicated by (1), (2), and (3) as indicated in the figure:



At (1): $$\left(\frac{C}{N}\right)_{(1)} = \frac{C}{k \cdot T_{Ant} \cdot B_N}$$

At (2): $$\left(\frac{C}{N}\right)_{(2)} = \frac{C}{k \cdot (T_{Ant} + T_{Trans}) \cdot B_N}$$

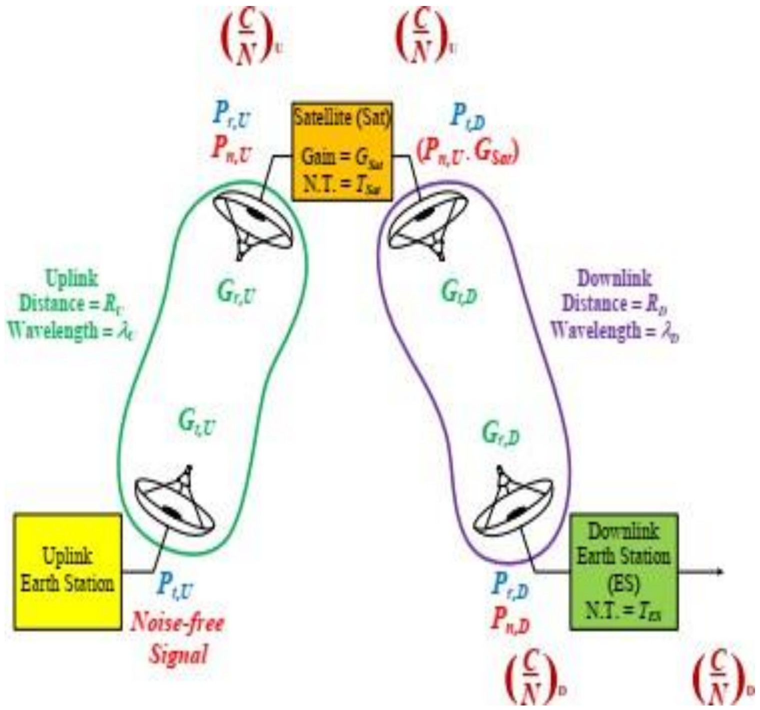
At (1): $$\boxed{\left(\frac{C}{N}\right)_{(3)} = \frac{C \cdot G_{Trans}}{k \cdot (T_{Ant} + T_{Trans}) \cdot B_N \cdot G_{Trans}} = \frac{C}{k \cdot (T_{Ant} + T_{Trans}) \cdot B_N} = \left(\frac{C}{N}\right)_{(2)}}$$

The conclusion, the C/N ratio before and after a noiseless device are the same. So, once the noise of a system is moved to its input, it is enough to compute the C/N ratio before the remaining noiseless device or after because they are basically the same.

C/N for a Complete Satellite System

Let us try to find the C/N ratio for the complete satellite system shown below that involves an uplink and a downlink. We will assume at first that the Uplink Earth station that transmits to the satellite is transmitting a noise-free signal towards the satellite.

We will consider the complete system's C/N ratio and try to relate it to the C/N ratios of the uplink and downlink separately. This will allow us to study the uplink and downlink of a satellite separately and then combine them to get the overall C/N ratio. Note that since we are bringing the noise of the satellite and the Downlink Earth Station (ES) to their inputs, we see that the C/N ratio before and after each of these blocks is the same.



Uplink C/N Ratio

Considering first that the uplink Earth Station is transmitting noise-free signal, the received signal at the Satellite is

$$P_{r,U} = \frac{P_{t,U} \cdot G_{t,U} \cdot G_{r,U}}{\left(\frac{4\pi R_U}{\lambda_U}\right)^2}$$

The uplink noise at the input of the Satellite (resulting from the satellite receiving antenna and satellite transponder noise)is given as below. Note that the bandwidth of all carrier signals and noise signals are equal to *Bn*.

$$P_{n,U} = k \cdot T_{Sat} \cdot B_n$$

So, the Uplink C/N ratio is:

$$\left(\frac{C}{N}\right)_U = \frac{\frac{P_{t,U} \cdot G_{t,U} \cdot G_{r,U}}{\left(\frac{4\pi R_U}{\lambda_U}\right)^2}}{k \cdot T_{Sat} \cdot B_n} = \frac{P_{t,U} \cdot G_{t,U} \cdot G_{r,U}}{\left(\frac{4\pi R_U}{\lambda_U}\right)^2 k \cdot T_{Sat} \cdot B_n}$$

Downlink C/N Ratio

Considering now that the satellite transmits in the downlink a noise-free signal, the received signal at the downlink Earth station is

$$P_{r,D} = \frac{P_{t,D} \cdot G_{t,D} \cdot G_{r,D}}{\left(\frac{4\pi R_D}{\lambda_D}\right)^2}$$

The downlink noise at the input of the Earth Station(ES) (resulting from the ES receiving antenna and ES receiver blocks noise) is given as below. Again, the band width of all carrier signals and noise signals are equal to *Bn*.

$$P_{n,D} = k \cdot T_{ES} \cdot B_n$$

So, the Downlink C/N ratio is:

$$\left(\frac{C}{N}\right)_U = \frac{\frac{P_{t,D} \cdot G_{t,D} \cdot G_{r,D}}{\left(\frac{4\pi R_D}{\lambda_D}\right)^2}}{k \cdot T_{ES} \cdot B_n} = \frac{P_{t,D} \cdot G_{t,D} \cdot G_{r,D}}{\left(\frac{4\pi R_D}{\lambda_D}\right)^2 k \cdot T_{ES} \cdot B_n}$$

Overall C/N Ratio

Now, let us try to evaluate the C/N ratio of the overall system and try to relate it to the C/N ratio of the uplink and C/N of the downlink. Let us again assume that transmitted signal by the uplink ES is noise-free. The received signal at the Satellite is

$$P_{r,U} = \frac{P_{t,U} \cdot G_{t,U} \cdot G_{r,U}}{\left(\frac{4\pi R_U}{\lambda_U}\right)^2}$$

This signal gets amplified by the satellite that has a gain of G_{Sat}such that the transmitted signal by the satellite becomes

$$P_{t,D} = G_{Sat} \cdot P_{r,U} = \frac{G_{Sat} \cdot P_{t,U} \cdot G_{t,U} \cdot G_{r,U}}{\left(\frac{4\pi R_U}{\lambda_U}\right)^2}$$

This results in the received signal at the downlink earth station (ES) becoming:

$$\begin{aligned} P_{r,D} &= \frac{P_{t,D} \cdot G_{t,D} \cdot G_{r,D}}{\left(\frac{4\pi R_D}{\lambda_D}\right)^2} \\ &= \frac{G_{Sat} \cdot P_{r,U} \cdot G_{t,D} \cdot G_{r,D}}{\left(\frac{4\pi R_D}{\lambda_D}\right)^2} \\ &= \frac{\frac{G_{Sat} \cdot P_{t,U} \cdot G_{t,U} \cdot G_{r,U}}{\left(\frac{4\pi R_U}{\lambda_U}\right)^2} \cdot G_{t,D} \cdot G_{r,D}}{\left(\frac{4\pi R_D}{\lambda_D}\right)^2} \end{aligned}$$

For the noise, the signal transmitted from the uplink earth station is assumed to be noise free, so the noise at the satellite is noise that is generated by the satellite and is equal to what we found previously:

$$P_{n,U} = k \cdot T_{Sat} \cdot B_n$$

This noise passes through the satellite, and therefore gets amplified by the gain of the satellite to produce an amount equal to

$$G_{Sat} \cdot P_{n,U} = G_{Sat} \cdot k \cdot T_{Sat} \cdot B_n$$

This noise is transmitted to the downlink ES and experiences the same behavior that the information signal experiences. So, the noise power at the ES becomes two components:

(1) The component that was generated by the satellite and got amplified and transmitted to the ES, and

(2) the noise generated by the ES itself. So, the total noise at the receiver because of the two components becomes:

$$P_{n,D} = \frac{G_{Sat} \cdot P_{n,U} \cdot G_{t,D} \cdot G_{r,D}}{\left(\dfrac{4\pi R_D}{\lambda_D}\right)^2} + k \cdot T_{ES} \cdot B_n$$

$$= \underbrace{\frac{G_{Sat} \cdot k \cdot T_{Sat} \cdot B_n \cdot G_{t,D} \cdot G_{r,D}}{\left(\dfrac{4\pi R_D}{\lambda_D}\right)^2}}_{\text{Component (1)}} + \underbrace{k \cdot T_{ES} \cdot B_n}_{\text{Component (2)}}$$

Given the above carrier and noise powers, the overall C/N ratio becomes:

$$\left(\frac{C}{N}\right)_{Overall} = \frac{\dfrac{\dfrac{G_{Sat} \cdot P_{t,U} \cdot G_{t,U} \cdot G_{r,U}}{\left(\dfrac{4\pi R_U}{\lambda_U}\right)^2} \cdot G_{t,D} \cdot G_{r,D}}{\left(\dfrac{4\pi R_D}{\lambda_D}\right)^2}}{\dfrac{G_{Sat} \cdot k \cdot T_{Sat} \cdot B_n \cdot G_{t,D} \cdot G_{r,D}}{\left(\dfrac{4\pi R_D}{\lambda_D}\right)^2} + k \cdot T_{ES} \cdot B_n}$$

This can be written as follows:

$$\left(\frac{C}{N}\right)_{Overall}=\frac{\dfrac{G_{Sat}\cdot P_{t,U}\cdot G_{t,U}\cdot G_{r,U}}{\left(\dfrac{4\pi R_U}{\lambda_U}\right)^2}\cdot G_{t,D}\cdot G_{r,D}}{G_{Sat}\cdot k\cdot T_{Sat}\cdot B_n\cdot G_{t,D}\cdot G_{r,D}+\left(\dfrac{4\pi R_D}{\lambda_D}\right)^2 k\cdot T_{ES}\cdot B_n}$$

Multiplying both the numerator and denominator by the inverse of the numerator gives:

$$\left(\frac{C}{N}\right)_{Overall}=\frac{1}{\dfrac{\left(\dfrac{4\pi R_U}{\lambda_U}\right)^2 G_{Sat}\cdot k\cdot T_{Sat}\cdot B_n\cdot G_{t,D}\cdot G_{r,D}+\left(\dfrac{4\pi R_U}{\lambda_U}\right)^2\left(\dfrac{4\pi R_D}{\lambda_D}\right)^2 k\cdot T_{ES}\cdot B_n}{G_{Sat}\cdot P_{t,U}\cdot G_{t,U}\cdot G_{r,U}\cdot G_{t,D}\cdot G_{r,D}}}$$

Dividingthedenominatorintotwopartsandcancellingsomequantitiesproduces:

$$\left(\frac{C}{N}\right)_{Overall}=\frac{1}{\dfrac{\left(\dfrac{4\pi R_U}{\lambda_U}\right)^2 \cancel{G}_{Sat}\cdot k\cdot T_{Sat}\cdot B_n\cdot \cancel{G}_{t,D}\cdot \cancel{G}_{r,D}}{\cancel{G}_{Sat}\cdot P_{t,U}\cdot G_{t,U}\cdot G_{r,U}\cdot \cancel{G}_{t,D}\cdot \cancel{G}_{r,D}}+\underbrace{\left[\dfrac{\left(\dfrac{4\pi R_U}{\lambda_U}\right)^2}{G_{Sat}\cdot P_{t,U}\cdot G_{t,U}\cdot G_{r,U}}\right]}_{\frac{1}{P_{t,D}}}\cdot\dfrac{\left(\dfrac{4\pi R_D}{\lambda_D}\right)^2 k\cdot T_{ES}\cdot B_n}{G_{t,D}\cdot G_{r,D}}}$$

$$=\frac{1}{\underbrace{\dfrac{\left(\dfrac{4\pi R_U}{\lambda_U}\right)^2 k\cdot T_{Sat}\cdot B_n}{P_{t,U}\cdot G_{t,U}\cdot G_{r,U}}}_{\frac{1}{\left(\frac{C}{N}\right)_U}}+\underbrace{\dfrac{\left(\dfrac{4\pi R_D}{\lambda_D}\right)^2 k\cdot T_{ES}\cdot B_n}{P_{t,D}\cdot G_{t,D}\cdot G_{r,D}}}_{\frac{1}{\left(\frac{C}{N}\right)_D}}}$$

This gives us

$$\boxed{\left(\frac{C}{N}\right)_{Overall}=\frac{1}{\dfrac{1}{\left(\frac{C}{N}\right)_U}+\dfrac{1}{\left(\frac{C}{N}\right)_D}}}$$

The above is an important conclusion that states that knowing the uplink C/N ratio and the downlink (C/N) ratio (as it is the case when the two links are designed separately) allows us to compute the overall C/N of the system from them.

This relationship is similar to the equivalent resistance that is obtained when connecting two resistors in parallel. Recall that the equivalent resistance of two resistors connected in parallel is smaller than any of the two resistors. The same thing holds here.

The overall C/N ratio is smaller than the either of the C/N ratios of the uplink or downlink. If any of these C/N ratios is much smaller than the other, then it is the one that dominates the overall C/N ratio resulting in an overall C/N ratio is slightly smaller than small C/N ratio.

The above relation can be extended for cases where multiple uplinks and multiple downlinks are used. A general formula for the case where a signal is transmitted over *m* uplinks and *m* downlinks would be:

$$\left(\frac{C}{N}\right)_{Overall} = \frac{1}{\frac{1}{\left(\frac{C}{N}\right)_{U1}} + \frac{1}{\left(\frac{C}{N}\right)_{D1}} + \frac{1}{\left(\frac{C}{N}\right)_{U2}} + \frac{1}{\left(\frac{C}{N}\right)_{D2}} + \cdots + \frac{1}{\left(\frac{C}{N}\right)_{Um}} + \frac{1}{\left(\frac{C}{N}\right)_{Dm}}}$$

In many cases, in addition to the noise that a link suffers from, the link would suffer from interference from other transmitting earth stations or satellites at the same frequency.

For an uplink-downlink case where there is interference in the uplink and interference in the downlink, the above formula can be modified to be become

$$\left(\frac{C}{N+I}\right)_{Overall}$$

which is given by:

$$\left(\frac{C}{N+I}\right)_{Overall} = \frac{1}{\frac{1}{\left(\frac{C}{N}\right)_{U}} + \frac{1}{\left(\frac{C}{I}\right)_{U}} + \frac{1}{\left(\frac{C}{N}\right)_{D}} + \frac{1}{\left(\frac{C}{I}\right)_{D}}}$$

SATELLITE APPLICATIONS

INTELSAT Series:

INTELSAT stands for *International Telecommunications Satellite.* The organization was created in 1964 and currently has over 140 member countries and more than 40 investing entities (see http://www.intelsat.com/ for more details).

In July 2001 INTELSAT became a private company and in May 2002 the company began providing end-to-end solutions through a network of teleports, leased fiber, and *points of presence* (PoPs) around the globe.

Starting with the Early Bird satellite in 1965, a succes- sion of satellites has been launched at intervals of a few years. Figure 1.1 illustrates the evolution of some of the INTELSAT satellites. As the figure shows, the capacity, in terms of number of voice channels, increased dramatically with each succeeding launch, as well as the design lifetime.

These satellites are in *geostationary orbit,* meaning that they appear to be stationary in relation to the earth. At this point it may be noted that geosta- tionary satellites orbit in the earth's equatorial plane and their position is specified by their longitude.

For international traffic, INTELSAT covers three main regions—the *Atlantic Ocean Region* (AOR), the *Indian Ocean Region* (IOR), and the *Pacific Ocean Region* (POR) and what is termed *Intelsat America's Region*.

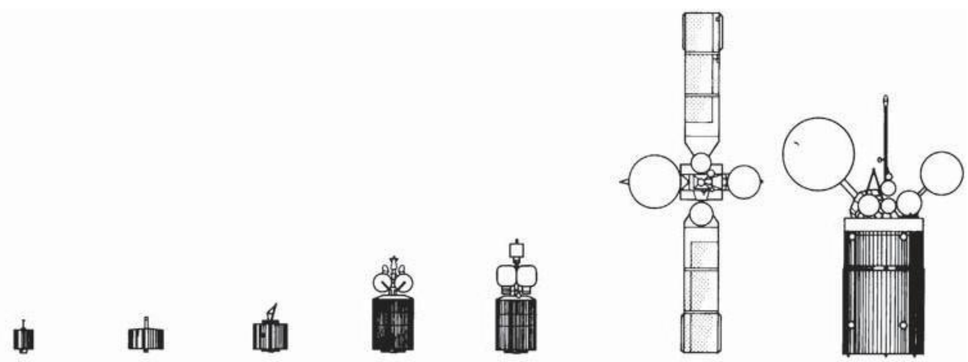
For the ocean regions the satellites are positioned in geostationary orbit above the particular ocean, where they provide a transoceanic telecommunications route. For example, INTELSAT satellite 905 is positioned at 335.5° east longitude.

The INTELSAT VII-VII/A series was launched over a period from October 1993 to June 1996. The construction is similar to that for the V and VA/VB series, shown in Fig. in that the VII series has solar sails rather than a cylindrical body.

The VII series was planned for service in the POR and also for some of the less demanding services in the AOR. The antenna beam coverage is appropriate for that of the POR. Figure 1.3 shows the antenna beam footprints for the C-band hemispheric cover- age and zone coverage, as well as the spot beam coverage possible with the Ku-band antennas (Lilly, 1990; Sachdev et al., 1990). When used in the AOR, the VII series satellite is inverted north for south (Lilly, 1990), minor adjustments then being needed only to optimize the antenna pat- terns for this region. The lifetime of these satellites ranges from 10 to 15 years depending on the launch vehicle.

Recent figures from the INTELSAT Web site give the capacity for the INTELSAT VII as 18,000 two-way telephone circuits and three TV channels; up to 90,000 two-way telephone circuits can be achieved with the use of “digital circuit multiplication.”

The INTELSAT VII/A has a capacity of 22,500 two-way telephone circuits and three TV channels; up to 112,500 two-way telephone circuits can be achieved with the use of digital circuit multiplication. As of May 1999, four satellites were in service over the AOR, one in the IOR, and two in the POR.



Designation: Intelsat	I	II	III	IV	IV A	V	V A/V B	VI
Year of first launch	1965	1966	1968	1971	1975	1980	1984/85	1986/87
Prime contractor	Hughes	Hughes	TRW	Hughes	Hughes	Ford Aerospace	Ford Aerospace	Hughes
Width (m)	0.7	1.4	1.4	2.4	2.4	2.0	2.0	3.6
Height (m)	0.6	0.7	1.0	5.3	6.8	6.4	6.4	6.4
Launch vehicles		Thor Delta		Atlas-Centaur		Atlas-Centaur and Ariane	Atlas-Centaur and Ariane	STS and Ariane
Spacecraft mass in transfer orbit (kg)	68	182	293	1385	1489	1946	2140	12,100/3720
Communications payload mass (kg)	13	36	56	185	190	235	280	800
End-of-life (EOL) power of equinox (W)	40	75	134	480	800	1270	1270	2200
Design lifetime (years)	1.5	3	5	7	7	7	7	10
Capacity (number of voice channels)	480	480	2400	8000	12,000	25,000	30,000	80,000
Bandwidth (MHz)	50	130	300	500	800	2137	2480	3520

Figure INTELSAT Series

The INTELSAT VIII-VII/A series of satellites was launched over the period February 1997 to June 1998. Satellites in this series have similar capacity as the VII/A series, and the lifetime is 14 to 17 years.

It is standard practice to have a spare satellite in orbit on high-reliability routes (which can carry preemptible traffic) and to have a ground spare in case of launch failure.

Thus the cost for large international schemes can be high; for example, series IX, described later, represents a total investment of approximately $1 billion.

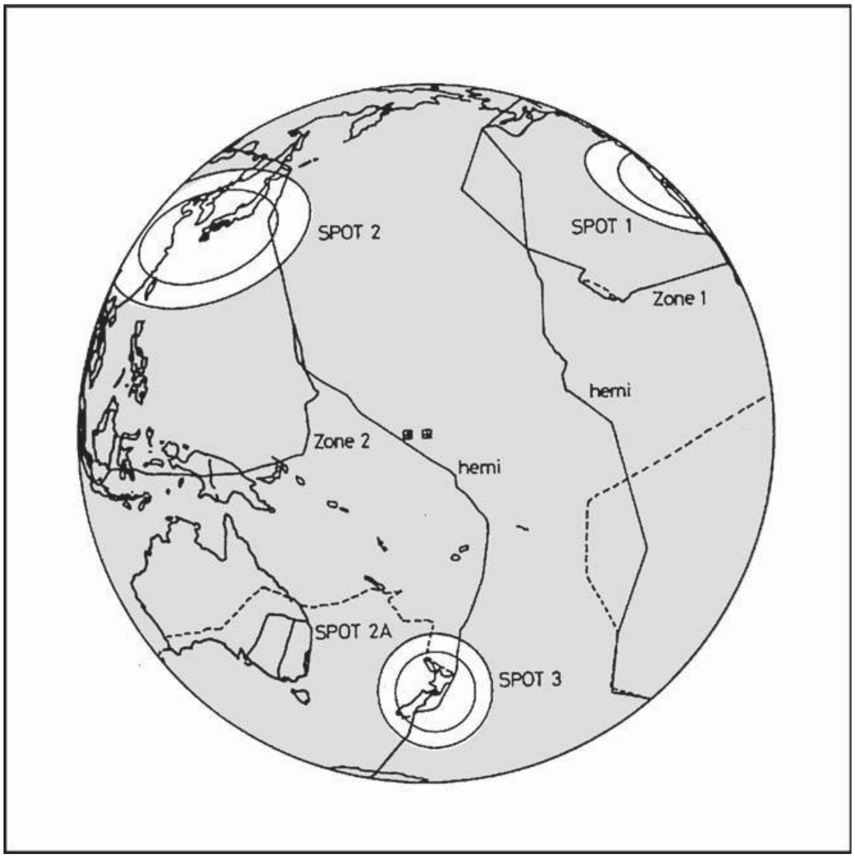


Figure Region of glob

INSAT:

INSAT or the ***Indian National Satellite System*** is a series of multipurpose geo-stationary satellites launched by ISRO to satisfy the telecommunications, broadcasting, meteorology, and search and rescue operations.

Commissioned in 1983, INSAT is the largest domestic communication system in the Asia Pacific Region. It is a joint venture of the Department of Space, Department of Telecommunications, India Meteorological Department, All India Radio and Doordarshan. The overall coordination and management of INSAT system rests with the Secretary-level INSAT Coordination Committee.

INSAT satellites provide transponders in various bands (C, S, Extended C and Ku) to serve the television and communication needs of India. Some of the satellites also have the Very High Resolution Radiometer (VHRR), CCD cameras for metrological imaging.

The satellites also incorporate transponder(s) for receiving distress alert signals for search and rescue missions in the South Asian and Indian Ocean Region, as ISRO is a member of the Cospas-Sarsat programme.

INSAT System:.

The Indian National Satellite (INSAT) System Was Commissioned With The Launch Of INSAT-1B In August 1983 (INSAT-1A, The First Satellite Was Launched In April 1982 But Could Not Fulfil The Mission).

INSAT System Ushered In A Revolution In India's Television And Radio Broadcasting, Telecommunications And Meteorological Sectors. It Enabled The Rapid Expansion Of TV And Modern Telecommunication Facilities To Even The Remote Areas And Off-Shore Islands.

Satellites In Service:

Of The 24 Satellites Launched In The Course Of The INSAT Program, 10 Are Still In Operation.INSAT-2E

It Is The Last Of The Five Satellites In INSAT-2 Series{Prateek }. It Carries Seventeen C-Band And Lower Extended C-Band Transponders Providing Zonal And Global Coverage With An Effective Isotropic Radiated Power (EIRP) Of 36 Dbw.

It Also Carries A Very High Resolution Radiometer (VHRR) With Imaging Capacity In The Visible (0.55-0.75 μm), Thermal Infrared (10.5-12.5 μm) And Water Vapour (5.7-7.1 μm) Channels And Provides 2x2 Km, 8x8 Km And 8x8 Km Ground Resolution Respectively.

INSAT-3A

The Multipurpose Satellite, INSAT-3A, Was Launched By Ariane In April 2003. It Is Located At 93.5 Degree East Longitude. The Payloads On INSAT-3A Are As Follows:

12 Normal C-Band Transponders (9 Channels Provide Expanded Coverage From Middle East To South East Asia With An EIRP Of 38 Dbw, 3 Channels Provide India Coverage With An EIRP Of 36 Dbw And 6 Extended C-Band Transponders Provide India Coverage With An EIRP Of 36 Dbw).

A CCD Camera Provides 1x1 Km Ground Resolution, In The Visible (0.63-0.69 µm), Near Infrared (0.77-0.86 µm) And Shortwave Infrared (1.55-1.70 µm) Bands.

INSAT-3D

Launched In July 2013, INSAT-3D Is Positioned At 82 Degree East Longitude. INSAT-3D Payloads Include Imager, Sounder, Data Relay Transponder And Search & Rescue Transponder. All The Transponders Provide Coverage Over Large Part Of The Indian Ocean Region Covering India, Bangladesh, Bhutan,Maldives, Nepal, Seychelles, Sri Lanka And Tanzania For Rendering Distress Alert Services

INSAT-3E

Launched In September 2003, INSAT-3E Is Positioned At 55 Degree East Longitude And Carries 24 Normal C-Band Transponders Provide An Edge Of Coverage EIRP Of 37 Dbw Over India And 12 Extended C-Band Transponders Provide An Edge Of Coverage EIRP Of 38 Dbw Over India.

KALPANA-1

KALPANA-1 Is An Exclusive Meteorological Satellite Launched By PSLV In September 2002. It Carries Very High Resolution Radiometer And DRT Payloads To Provide Meteorological Services. It Is Located At 74 Degree East Longitude. Its First Name Was METSAT. It Was Later Renamed As KALPANA-1 To Commemorate Kalpana Chawla.

Edusat

Configured For Audio-Visual Medium Employing Digital Interactive Classroom Lessons And Multimedia Content, EDUSAT Was Launched By GSLV In September 2004. Its Transponders And Their Ground Coverage Are Specially Configured To Cater To The Educational Requirements.

GSAT-2

Launched By The Second Flight Of GSLV In May 2003, GSAT-2 Is Located At 48 Degree East Longitude And Carries Four Normal C-Band Transponders To Provide 36 Dbw EIRP With India Coverage, Two K_u Band Transponders With 42 Dbw EIRP Over India And An MSS Payload Similar To Those On INSAT-3B And INSAT-3C.

INSAT-4 Series:

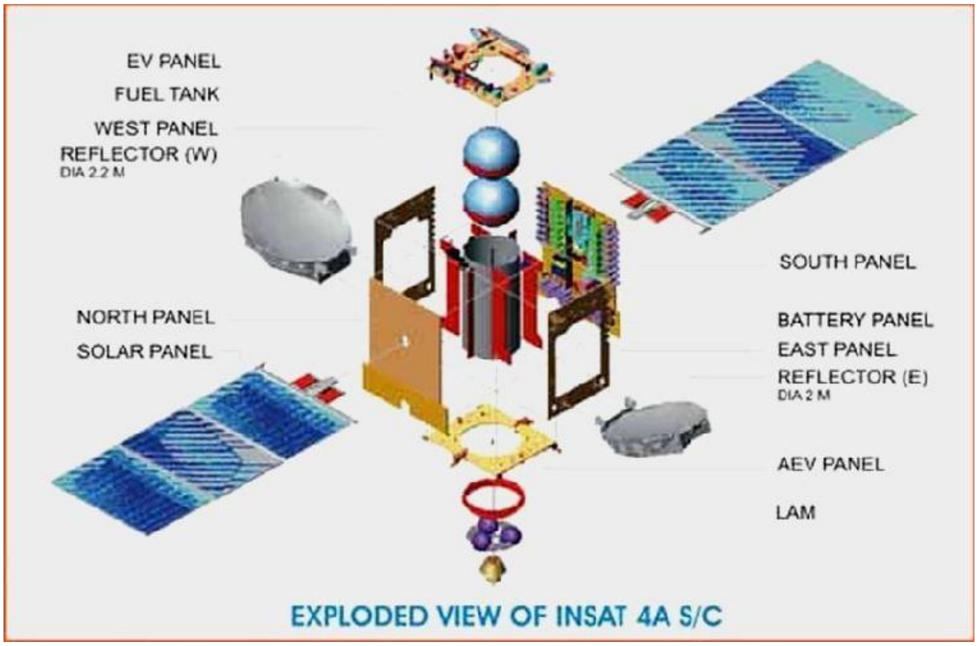


Figure INSAT 4A

INSAT-4A is positioned at 83 degree East longitude along with INSAT-2E and INSAT-3B. It carries 12 Ku band 36 MHz bandwidth transponders employing 140 W TWTAs to provide an EIRP of 52 dBW at the edge of coverage polygon with footprint covering Indian main land and 12 C-band 36 MHz bandwidth transponders provide an EIRP of 39 dBW at the edge of coverage with expanded radiation patterns encompassing Indian geographical boundary, area beyond India in southeast and northwest regions.[8] Tata Sky, a joint venture between the TATA Group and STAR uses INSAT-4A for distributing their DTH service.

- ✓ INSAT-4A
- ✓ INSAT-4B
- ✓ Glitch In INSAT 4B
- ✓ China-Stuxnet Connection
- ✓ INSAT-4CR
- ✓ GSAT-8 / INSAT-4G
- ✓ GSAT-12 /GSAT-10

INMARSAT:

Inmarsat-Indian Maritime SATellite is still the sole IMO-mandated provider of satellite communications for the GMDSS.

- Availability for GMDSS is a minimum of 99.9%

Inmarsat has constantly and consistently exceeded this figure & Independently audited by IMSO and reported on to IMO.

Now Inmarsat commercial services use the same satellites and network &Inmarsat A closes at midnight on 31 December 2007 Agreed by IMO – MSC/Circ.1076. Successful closure programme almost concluded Overseen throughout by IMSO.

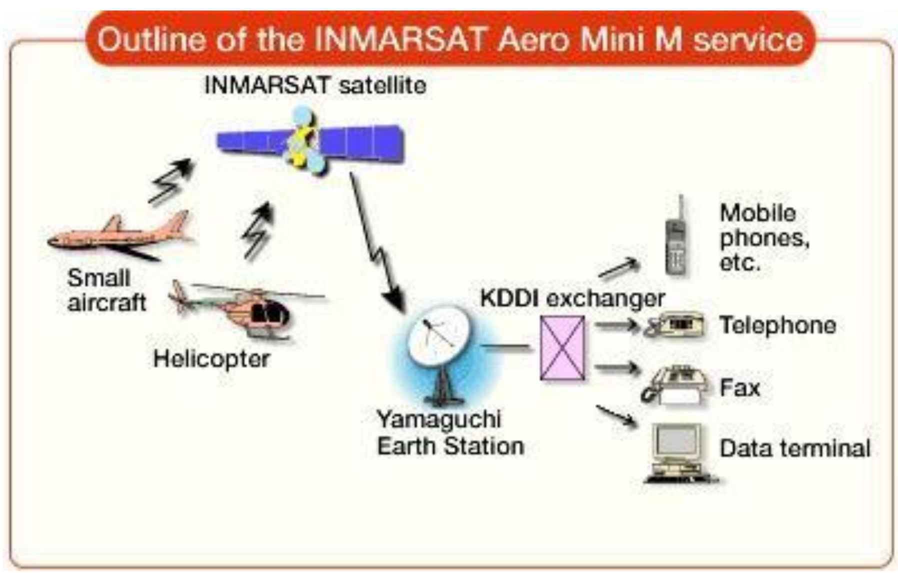


Figure INMARSAT Satellite Service

GMDSS services continue to be provided by:

- Inmarsat B, Inmarsat C/mini-C and Inmarsat Fleet F77
- Potential for GMDSS on FleetBroadband being assessed

- The IMO Criteria for the Provision of Mobile Satellite Communications Systems in the Global Maritime Distress and Safety System (GMDSS)

- Amendments were proposed; potentially to make it simpler for other satellite systems to be approved

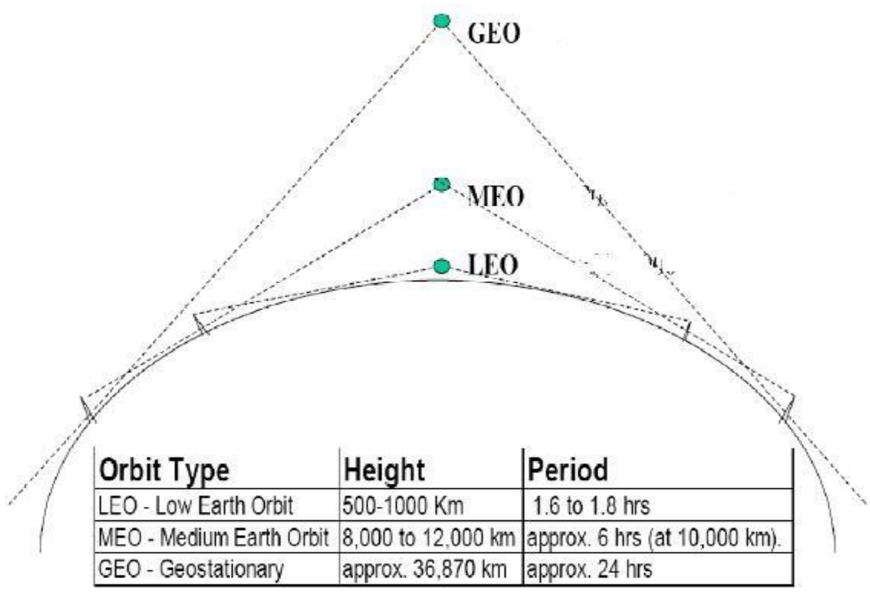
- The original requirements remain and were approved by MSC 83
    - No dilution of standards

- Minor amendments only; replacement Resolution expected to be approved by the IMO 25th Assembly

- Inmarsat remains the sole, approved satcom provider for the GMDSS

LEO: Low Earth Orbit satellites have a small area of coverage. They arepositioned in an orbit approximately 3000km from the surface of the earth

- ✓ They complete one orbit every 90 minutes
- ✓ The large majority of satellites are in low earth orbit
- ✓ The Iridium system utilizes LEO satellites (780km high)
- ✓ The satellite in LEO orbit is visible to a point on the earth for a very short time



Orbit Type	Height	Period
LEO - Low Earth Orbit	500-1000 Km	1.6 to 1.8 hrs
MEO - Medium Earth Orbit	8,000 to 12,000 km	approx. 6 hrs (at 10,000 km).
GEO - Geostationary	approx. 36,870 km	approx. 24 hrs

Figure LEO, MEO & GEO range

MEO: *Medium Earth Orbit* satellites have orbital altitudes between 3,000 and30,000 km.

- ❖ They are commonly used used in navigation systems such as GPS

GEO: *Geosynchronous (Geostationary) Earth Orbit* satellites are positionedover the equator. The orbital altitude is around 30,000-40,000 km

- There is only one geostationary orbit possible around the earth
    - Lying on the earth's equatorial plane.
    - The satellite orbiting at the same speed as the rotational speed of the earth on its axis.
    - They complete one orbit every 24 hours. This causes the satellite to appear stationary with respect to a point on the earth, allowing one satellite to provide continual coverage to a given area on the earth's surface
    - One GEO satellite can cover approximately 1/3 of the world's surface

They are commonly used in communication systems

- Advantages:
    - Simple ground station tracking.
    - Nearly constant range
    - Very small frequency shift
- Disadvantages:
    - Transmission delay of the order of 250 msec.
    - Large free space loss.
    - No polar coverage

- Satellite orbits in terms of the orbital height:
- According to distance from earth:
    - Geosynchronous Earth Orbit (GEO) ,
    - Medium Earth Orbit (MEO),
    - Low Earth Orbit (LEO)

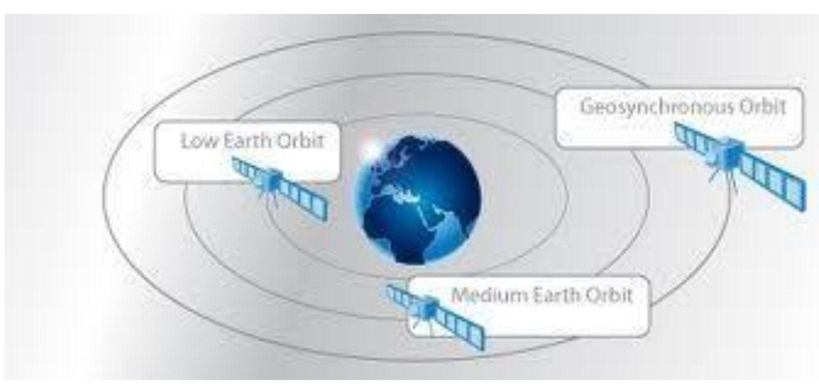


Figure LEO, MEO & GEO Orbits

LEO / MEO / GEO / HEO (cont.)

	Name	Number	Panel	No./Panel	altitude	deg.
LEO	STARSYS	24	6	4	1300km	60
	ORBCOMM	24	4	6	785km	45
	GLOBALSTAR	48	8	6	1400km	52
	IRIDIUM	66	6	11	765km	86
MEO	INMARSAT P	10	2	5	10300km	45
	ODYSEEY	12	3	4	10370km	55
	GPS	24	6	4	20200km	55
	GLONASS	24	3	8	19132km	64.8
HEO	ELLIPSO	24	4	6	A:7800km P:520km	63.4
	MOLNIYA	4	1	4	A:39863km P:504km	63.4
	ARCHIMEDES	4	4	1	A:39447km P:926km	63.4

9

Figure Diff b/w LEO, MEO & GEO Orbits

GEO: 35,786 km above the earth, MEO: 8,000-20,000 km above the earth & LEO: 500-2,000 km above the earth.

Satellite Navigational System:

Benefits:

- ✓ Enhanced Safety
- ✓ Increased Capacity
- ✓ Reduced Delays

Advantage:

- ✓ Increased Flight Efficiencies
- ✓ Increased Schedule Predictability
- ✓ Environmentally Beneficial Procedures

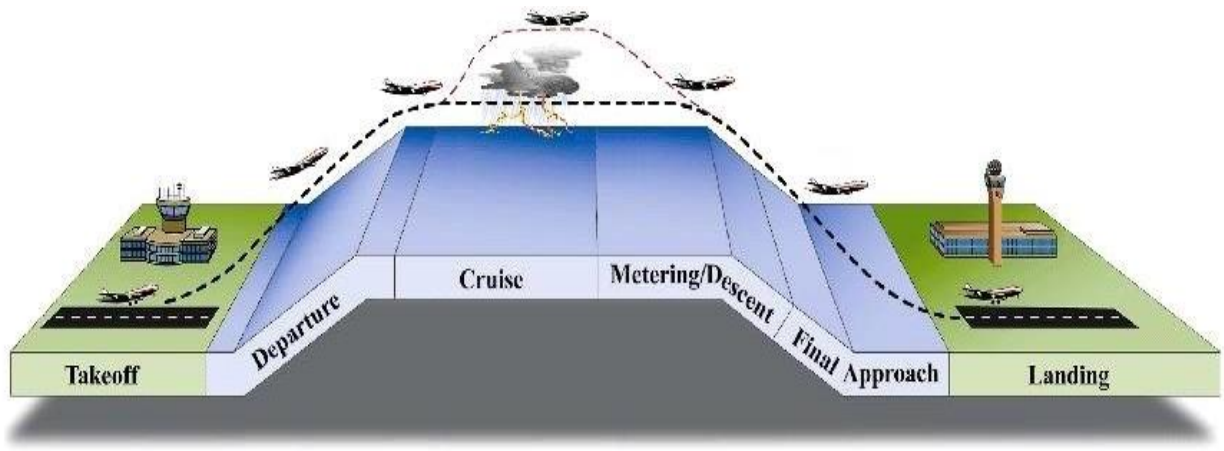


Figure LEO, MEO & GEO Orbits

- Using ICAO GNSS Implementation Strategy and ICAO Standards and Recommended Practices
- GPS Aviation Use Approved for Over a Decade
  - Aircraft Based Augmentation Systems (ABAS) – (e.g. RAIM)
- Space Based Augmentation System (SBAS) since 2003
  - Wide Area Augmentation System (WAAS) augmenting GPS
- Development of GNSS Ground Based Augmentation System (GBAS) Continues
  - Local Area Augmentation System (LAAS)
- GNSS is Cornerstone for National Airspace System

GRAMSAT:

ISRO has come up with the concept of dedicated GRAMSAT satellites, keeping in mind the urgent need to eradicate illiteracy in the rural belt which is necessary for the all round development of the nation.

This Gramsat satellite is carrying six to eight high powered C-band transponders, which together with video compression techniques can disseminate regional and cultural specific audio-visual programmes of relevance in each of the regional languages through rebroadcast mode on an ordinary TV set.

The high power in C-band has enabled even remote area viewers outside the reach of the TV transmitters to receive programmers of their choice in a direct reception mode with a simple .dish antenna.

The salient features of GRAMSAT projects are:

i. Its communications networks are at the state level connecting the state capital to districts, blocks and enabling a reach to villages.

ii. It is also providing computer connectivity data broadcasting, TV-broadcasting facilities having applications like e- governance, development information, teleconferencing, helping disaster management.

iii. Providing rural-education broadcasting.

However, the Gramsat projects have an appropriate combination of following activities.

(i) Interactive training at district and block levels employing suitable configuration

(ii) Broadcasting services for rural development

(iii) Computer interconnectivity and data exchange services

(iv) Tele-health and tele-medicine services.

Direct Broadcast satellites (DBS):

Satellites provide *broadcast* transmissions in the fullest sense of the word, because antenna footprints can be made to cover large areas of the earth.

The idea of using satellites to provide direct transmissions into the home has been around for many years, and the services pro- vided are known generally as *direct broadcast satellite* (DBS) services.

Broadcast services include audio, television, and Internet services.

Power Rating and Number of Transponders:

From Table 1.4 it will be seen that satellites primarily intended for DBS have a higher [EIRP] than for the other categories, being in the range 51 to 60 dBW. At a *Regional Administrative Radio Council* (RARC) meeting in 1983, the value established for DBS was 57 dBW (Mead,2000). Transponders are rated by the power output of their high-power amplifiers.

Typically, a satellite may carry 32 transponders. If all 32 are in use, each will operate at the lower power rating of 120 W.

The available bandwidth (uplink and downlink) is seen to be 500 MHz. A total number of 32 transponder channels, each of bandwidth 24 MHz, can be accommodated.

The bandwidth is sometimes specified as 27 MHz, but this includes a 3-MHz guardband allowance. Therefore, when calculating bit-rate capacity, the 24 MHz value is used.

The total of 32 transponders requires the use of both *right- hand circular polarization* (RHCP) and *left-hand circular polarization* (LHCP) in order to permit frequency reuse, and guard bands are inserted between channels of a given polarization.

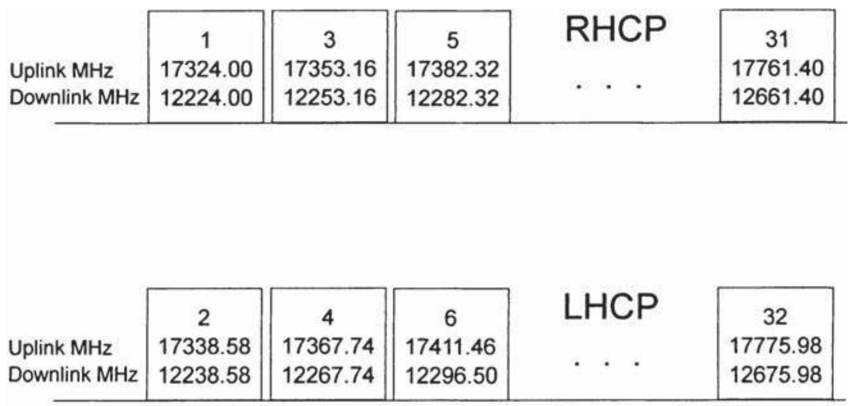


Figure DBS Service

Bit Rates for Digital Television:

The bit rate for digital television depends very much on the picture format. One way of estimating the uncompressed bit rate is to multiply the number of pixels in a frame by the number of frames per second, and multiply this by the number of bits used to encode each pixel.

MPEG Compression Standards:

MPEG is a group within the *International Standards Organization and the International Electrochemical Commission* (ISO/IEC) that undertook the job of defining standards for the transmission and storage of moving pictures and sound.

The MPEG standards currently available are MPEG-1, MPEG-2, MPEG-4, and MPEG-7.

Direct to home Broadcast (DTH):

DTH stands for Direct-To-Home television. DTH is defined as the reception of satellite programmes with a personal dish in an individual home.

- ✓ DTH Broadcasting to home TV receivers take place in the ku band(12 GHz). This service is known as Direct To Home service.
- ✓ DTH services were first proposed in India in 1996.
- ✓ Finally in 2000, DTH was allowed.
- ✓ The new policy requires all operators to set up earth stations in India within 12 months of getting a license. DTH licenses in India will cost $2.14 million and will be valid for 10 years.

Working principal of DTH is the satellite communication. Broadcaster modulates the received signal and transmit it to the satellite in KU Band and from satellite one can receive signal by dish and set top box.

DTH Block Diagram:

- ✓ A DTH network consists of a broadcasting centre, satellites, encoders, multiplexers, modulators and DTH receivers
- ✓ The encoder converts the audio, video and data signals into the digital format and the multiplexer mixes these signals.

It is used to provide the DTH service in high populated area A Multi Switch is basically a box that contains signal splitters and A/B switches. A outputs of group of DTH LNBs are connected to the A and B inputs of the Multi Switch.

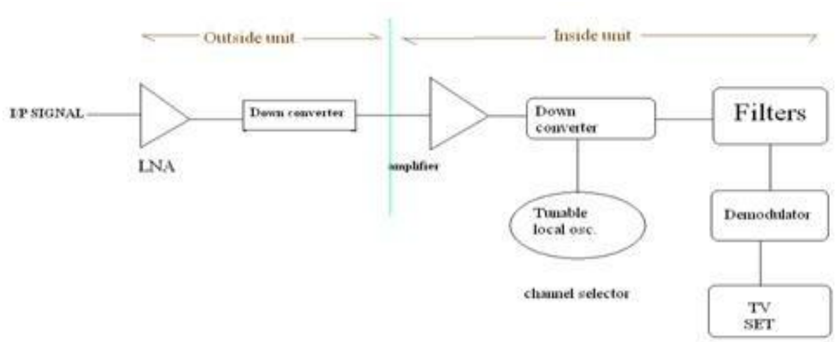


Figure DTH Service

Advantage:

- ✓ DTH also offers digital quality signals which do not degrade the picture or sound quality.
- ✓ It also offers interactive channels and program guides with customers having the choice to block out programming which they consider undesirable
- ✓ One of the great advantages of the cable industry has been the ability to provide local channels, but this handicap has been overcome by many

  DTH providers using other local channels or local feeds.
- ✓ The other advantage of DTH is the availability of satellite broadcast in rural and semi-urban areas where cable is difficult to install.

Digital audio broadcast (DAB):

DAB Project is an industry-led consortium of over 300 companies

- ✓ The DAB Project was launched on 10th September, 1993
- ✓ In 1995 it was basically finished and became operational
- ✓ There are several sub-standards of the DAB standard
  - DAB-S (Satellite) – using QPSK – 40 Mb/s
  - DAB-T (Terrestrial) – using QAM – 50 Mb/s
  - DAB-C (Cable) – using OFDM – 24 Mb/s

- ✓ These three sub-standards basically differ only in the specifications to the physical representation, modulation, transmission and reception of the signal.
- ✓ The DAB stream consists of a series of fixed length packets which make up a Transport Stream (TS). The packets support 'streams' or 'data sections'.
- ✓ Streams carry higher layer packets derived from an MPEG stream & Data sections are blocks of data carrying signaling and control data.
- ✓ DAB is actually a support mechanism for MPEG.& One MPEG stream needing higher instantaneous data can 'steal' capacity from another with spare capacity.

Worldspace services:

WorldSpace (Nasdaq: WRSP) is the world's only global media and entertainment company positioned to offer a satellite radio experience to consumers in more than 130 countries with five billion people, driving 300 million cars. WorldSpace delivers the latest tunes, trends and information from around the world and around the corner.

WorldSpace subscribers benefit from a unique combination of local programming, original WorldSpace content and content from leading brands

around the globe, including the BBC, CNN, Virgin Radio, NDTV and RFI. WorldSpace's satellites cover two-thirds of the globe with six beams.

Each beam is capable of delivering up to 80 channels of high quality digital audio and multimedia programming directly to WorldSpace Satellite Radios anytime and virtually anywhere in its coverage area. WorldSpace is a pioneer of satellite-based digital radio services (DARS) and was instrumental in the development of the technology infrastructure used today by XM Satellite Radio. For more information, visit http://www.worldspace.com.

Business Television (BTV) - Adaptations for Education:

Business television (BTV) is the production and distribution, via satellite, of video programs for closed user group audiences. It often has two-way audio interaction component made through a simple telephone line. It is being used by many industries including brokerage firms, pizza houses, car dealers and delivery services.

BTV is an increasingly popular method of information delivery for corporations and institutions. Private networks, account for about 70 percent of all BTV networks. It is estimated that by the mid-1990s BTV has the potential to grow to a $1.6 billion market in North America with more and more Fortune 1,000 companies getting involved. The increase in use of BTV has been dramatic.

Institution updates, news, training, meetings and other events can be broadcast live to multiple locations. The expertise of the best instructors can be delivered to thousands of people without requiring trainers to go to the site. Information can be disseminated to all employees at once, not just a few at a time. Delivery to the workplace at low cost provides the access to training that has been denied lower level employees. It may be the key to re-training America's work force.

Television has been used to deliver training and information within businesses for more than 40 years. Its recent growth began with the introduction of the video cassette in the early 1970s. Even though most programming is produced for video cassette distribution, business is using BTV to provide efficient delivery of specialized programs via satellite.

The advent of smaller receiving stations - called very small aperture terminals (VSATs) has made private communication networks much more economical to operate. BTV has a number of tangible benefits, such as reducing travel, immediate delivery of time-critical messages, and eliminating cassette duplication and distribution hassles.

The programming on BTV networks is extremely cost-effective compared to seminar fees and downtime for travel. It is an excellent way to get solid and current information very fast. Some people prefer to attend seminars and conferences where they can read, see, hear and ask questions in person. BTV provides yet another piece of the education menu and is another way to provide professional development.

A key advantage is that its format allows viewers to interact with presenters by telephone, enabling viewers to become a part of the program. The satellite effectively places people in the same room, so that sales personnel in the field can learn about new products at the same time.

Speed of transmission may well be the competitive edge which some firms need as they introduce new products and services. BTV enables employees in many locations to focus on common problems or issues that might develop into crises without quick communication and resolution.

BTV networks transmit information every business day on a broad range of topics, and provide instructional courses on various products, market trends, selling and motivation. Networks give subscribers the tools to apply the information they have to real world situations.

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

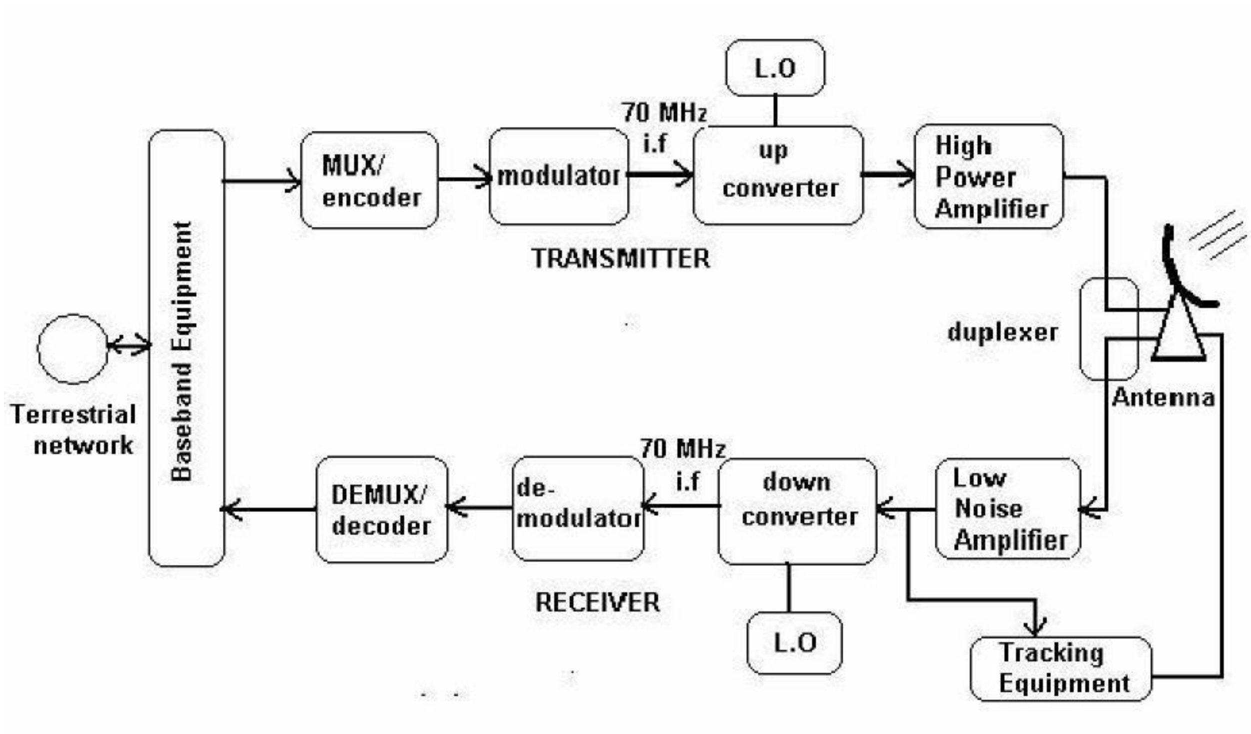


Figure Transmitter- Receiver

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, byintroducing 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 processingfor delivery to the terrestrial network.

❖ The tracking equipments track the satellite and align the beam towardsit 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

i) Satellite acquisition
ii)Automatic tracking
iii)Manual tracking
iv)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:

i) Axi-Symmetric Configuration
ii)Asymmetric Configuration
i)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.

ii) 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:

1.Two way TV ,Telephony and data
2. Two way TV
3. TV receive only and two way telephony and data
4.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 Speeed

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= $(\eta 4\Pi Aeff)/ \lambda 2$

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= $(\eta 4\Pi/ \lambda 2)(\Pi D2/4)$

$= \eta\ (\Pi D/ \lambda)2$

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.

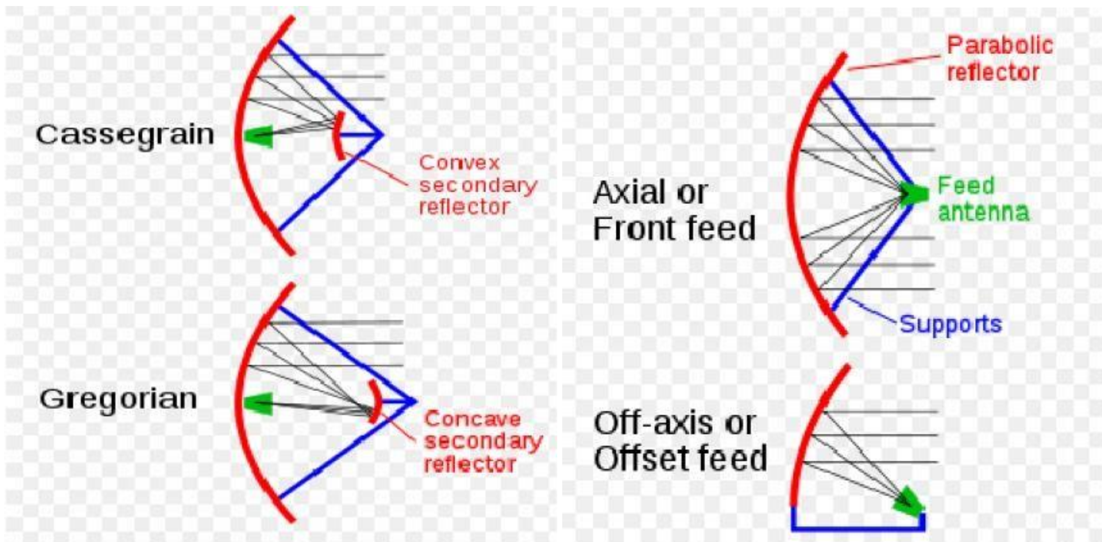


Figure Antenna sub systems

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:

i) 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.

ii) 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

i)Satellite acquisition
ii)Automatic tracking
iii)Manual tracking
iv)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.

Receive-Only Home TV Systems:

Planned broadcasting directly to home TV receivers takes place in the Ku (12-GHz) band. This service is known as *direct broadcast satellite* (DBS) service.

There is some variation in the frequency bands assigned to different geographic regions. In the Americas, for example, the down- link band is 12.2 to 12.7 GHz.

The comparatively large satellite receiving dishes [ranging in diame- ter from about 1.83 m (6 ft) to about 3-m (10 ft) in some locations], which may be seen in some "backyards" are used to receive downlink TV signals at C band (4 GHz).

Originally such downlink signals were never intended for home reception but for network relay to commercial TV outlets (VHF and UHF TV broadcast stations and cable TV "head-end" studios).

The Indoor unit:

Equipment is now marketed for home reception of C-band signals, and some manufacturers provide dual C-band/Ku-band equipment. A single mesh type reflector may be used which focuses the signals into a dual feed- horn, which has two separate outputs, one for the C-band signals and onefor the Ku-band signals.

Much of television programming originates as *first generation signals*, also known as *master broadcast quality signals*.

These are transmitted via satellite in the C band to the network head- end stations, where they are retransmitted as compressed digital signals to cable and direct broadcast satellite providers.

- Another of the advantages, claimed for home C-band systems, is the larger number of satellites available for reception compared to what is available for direct broadcast satellite sys- terms.

- Although many of the C-band transmissions are scrambled, there are free channels that can be received, and what are termed “wild feeds.”

- These are also free, but unannounced programs, of which details can be found in advance from various publications and Internet sources.

- C-band users can also subscribe to pay TV channels, and another advantage claimed is that subscription services are cheaper than DBS or cable because of the multiple-source programming available.

- The most widely advertised receiving system for C-band system appears tobe 4DTV manufactured by Motorola.

This enables reception of:

- ✓ Free, analog signals and “wild feeds”
- ✓ VideoCipher ll plus subscription services
- ✓ Free DigiCipher 2 services
- ✓ Subscription DigiCipher 2 services

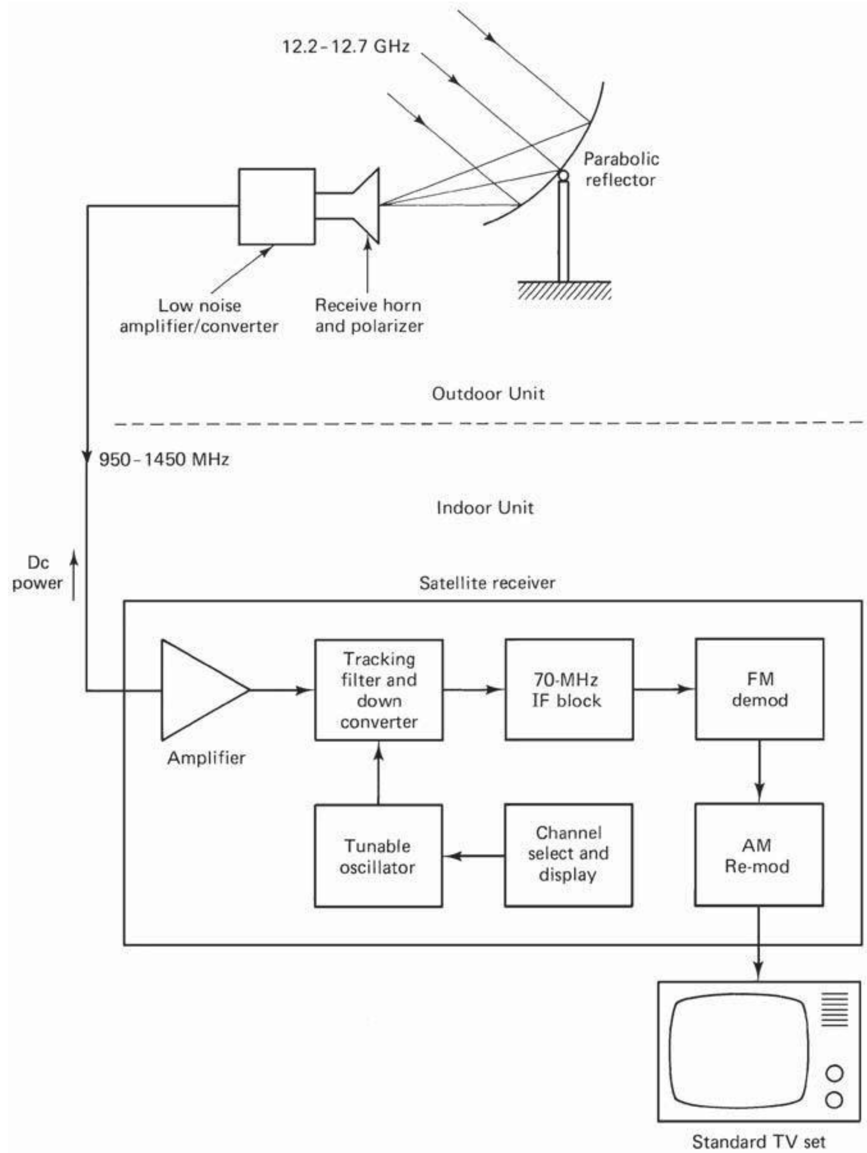


Figure TVRO System block diagrams

.

The outdoor unit:

This consists of a receiving antenna feeding directly into a low-noise amplifier/converter combination. A parabolic reflector is generally used, with the receiving horn mounted at the focus. A common design is to have the focus directly in front of the reflector, but for better interference rejection, an offset feed may be used as shown.

Comparing the gain of a 3-m dish at 4 GHz with a 1-m dish at 12 GHz, the ratio D/λ equals 40 in each case, so the gains will be about equal. Although the free-space losses are much higher at 12 GHz compared with 4 GHz.

The downlink frequency band of 12.2 to 12.7 GHz spans a range of 500 MHz, which accommodates 32 TV/FM channels, each of which is 24-MHz wide. Obviously, some overlap occurs between channels, but these are alternately polarized *left-hand circular* (LHC) and *right-hand circular* (RHC) or vertical/horizontal, to reduce interference to accept- able levels. This is referred to as *polarization interleaving*. A polarizer that may be switched to the desired polarization from the indoor con- trol unit is required at the receiving horn.

The receiving horn feeds into a *low-noise converter* (LNC) or possibly a combination unit consisting of a *low-noise amplifier* (LNA) followed by a converter.

The combination is referred to as an LNB, for *low-noise block*. The LNB provides gain for the broadband 12-GHz signal and then converts the signal to a lower frequency range so that a low-cost coaxial cable can be used as feeder to the indoor unit.

The signal fed to the indoor unit is normally a wideband signal cov- ering the range 950 to 1450 MHz. This is amplified and passed to a tracking filter which selects the desired channel, as shown in Fig.

As previously mentioned, polarization interleaving is used, and only half the 32 channels will be present at the input of the indoor unit for any one setting of the antenna polarizer. This eases the job of the tracking filter, since alternate channels are well separated in frequency.

The selected channel is again down converted, this time from the 950- to 1450-MHz range to a fixed intermediate frequency, usually 70 MHz although other values in the *very high frequency* (VHF) range are also used.

The 70-MHz amplifier amplifies the signal up to the levels required for demodulation. A major difference between DBS TV and conventional TV is that with DBS, frequency modulation is used, whereas with conventional TV, amplitude modulation in the form of *vestigial single side- band* (VSSB) is used.

The 70-MHz, FM *intermediate frequency* (IF) carrier therefore must be demodulated, and the baseband information used to generate a VSSB signal which is fed into one of the VHF/UHF channels of a standard TV set.

Master Antenna TV System:

A *master antenna TV* (MATV) system is used to provide reception of DBS TV/FM channels to a small group of users, for example, to the tenants in an apartment building. It consists of a single outdoor unit (antenna and LNA/C) feeding a number of indoor units, as shown in Fig.

It is basically similar to the home system already described, but with each user having access to all the channels independently of the other users. The advantage is that only one outdoor unit is required, but as shown, separate LNA/Cs and feeder cables are required for each sense of polarization.

Compared with the single- user system, a larger antenna is also required (2- to 3-m diameter) in order to maintain a good signal-to-noise ratio at all the indoor units.

Where more than a few subscribers are involved, the distribution system used is similar to the *community antenna* (CATV) system described in the following section.

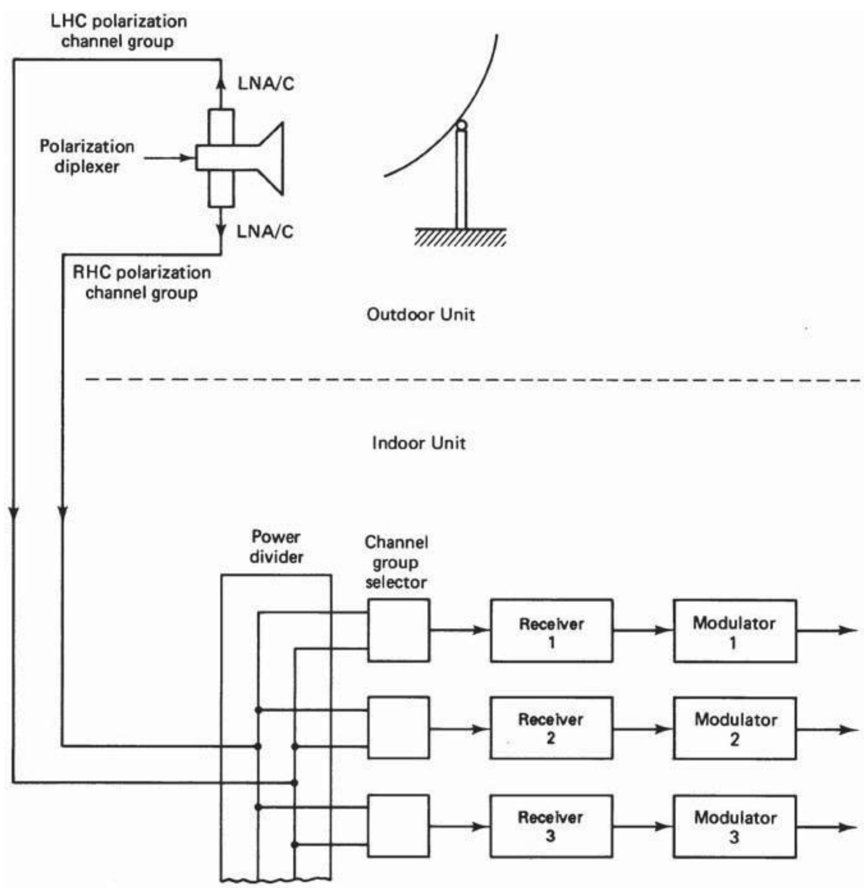


Figure CATV System block diagrams

Community Antenna TV System:

The CATV system employs a single outdoor unit, with separate feeds available for each sense of polarization, like the MATV system, so that all channels are made available simultaneously at the indoor receiver.

Instead of having a separate receiver for each user, all the carriers are demodulated in a common receiver-filter system, as shown in Fig. The channels are then combined into a standard multiplexed signal for transmission over cable to the subscribers.

In remote areas where a cable distribution system may not be installed, the signal can be rebroadcast from a low-power VHF TV transmitter.

Figure shows a remote TV station which employs an 8-m (26.2-ft) antenna for reception of the satellite TV signal in the C band.

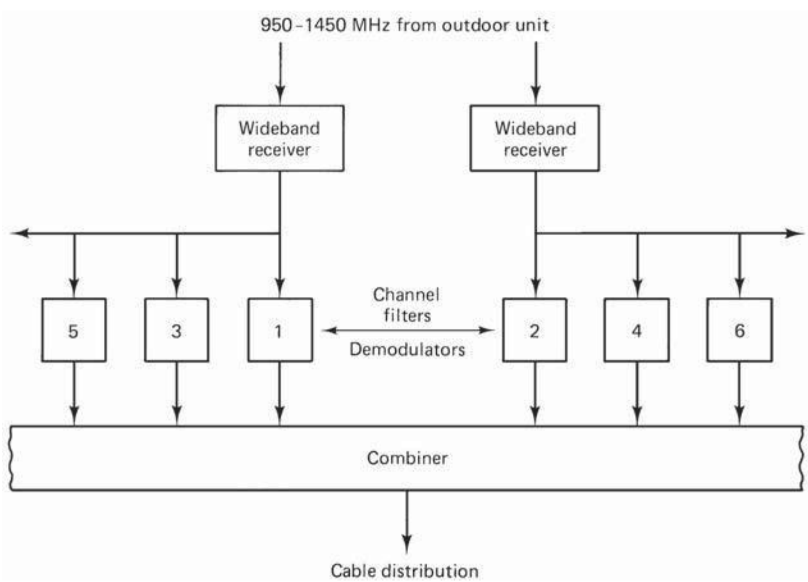


Figure One possible arrangement for the indoor unit of a community antenna TV (CATV) system.

With the CATV system, local programming material also may be distributed to subscribers, an option which is not permitted in the MATV system.

Test Equipment Measurements on G/T, C/No, EIRP:

Measurement of G/T of small antennas is easily and simply measured using the spectrum analyser method. For antennas with a diameter of less than meters it is not normally necessary to point off from the satellite.

A step in frequency would be required into one of the satellite transponder guard bands.

However antennas with a G/T sufficiently large to enable the station to see the transponder noise floor either a step in frequency into one of the satellite transponder guard bands and/or in azimuth movement would be required.

The test signal can be provided from an SES WORLD SKIES beacon.

Procedure :

(a) Set up the test equipment as shown below. Allow half an hour to warm up,
and then calibrate in accordance with the manufacturer's procedures.

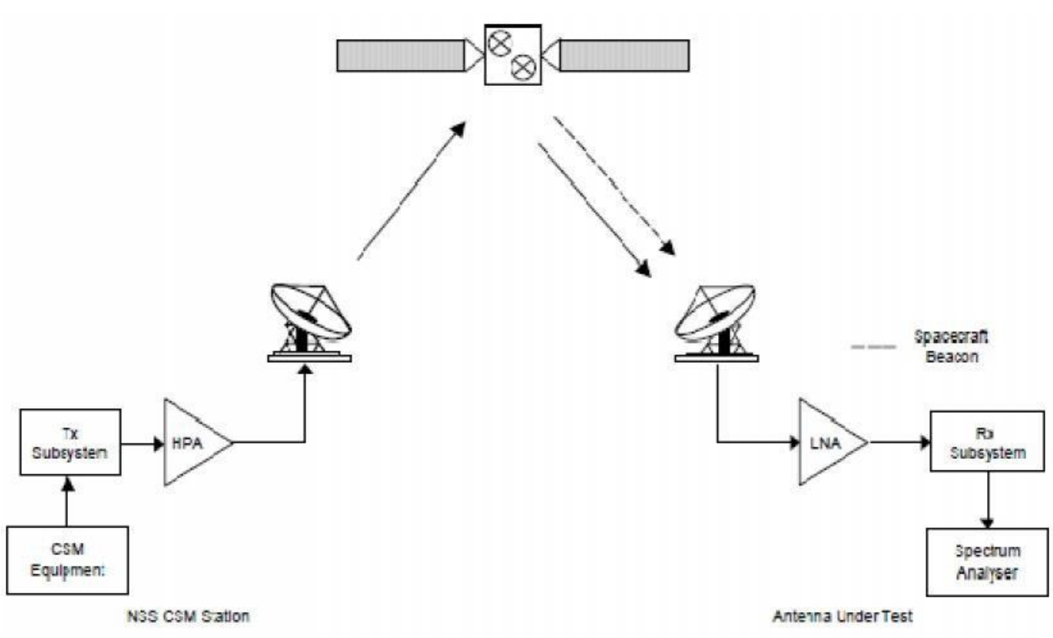


Figure One possible arrangement for Measurement of G/T

(b) Adjust the centre frequency of your spectrum analyzer to receive the SES WORLD SKIES beacon (data to be provided on the satellite used for testing)

(c) Carefully peak the antenna pointing and adjust the polarizer by nulling the
cross polarized signal. You cannot adjust polarization when using the circularly polarized SES WORLD SKIES beacon.

(d) Configure the spectrum analyser as follows:

Centre Frequency: Adjust for beacon or test signal frequency (to be advised).

Use marker to peak and marker to centre functions.

- ✓ Frequency Span: 100 KHz
- ✓ Resolution Bandwidth: 1 KHz
- ✓ Video Bandwidth: 10 Hz (or sufficiently small to limit noise variance)
- ✓ Scale: 5 dB/div
- ✓ Sweep Time: Automatic
- ✓ Attenuator Adjust to ensure linear operation. Adjust to provide the "Noise floor delta" described in steps 7 and 8.

(e) To insure the best measurement accuracy during the following steps, adjust the spectrum analyser amplitude (reference level) so that the measured signal, carrier or noise, is approximately one division below the top line of the spectrum analyser display.

(f) Record the frequency and frequency offset of the test signal from the nominal frequency:

For example, assume the nominal test frequency is 11750 MHz but the spectrum analyser shows the peak at 11749 MHz. The frequency offset in this case is -1 MHz.

(g) Change the spectrum analyser centre frequency as specified by SES WORLD SKIES so that the measurement is performed in a transponder guard band so that only system noise power of the earth station and no satellite signals are received. Set the spectrum analyser frequency as follows:
Centre Frequency = Noise slot frequency provided by the PMOC

(h) Disconnect the input cable to the spectrum analyser and confirm that the noise floor drops by at least 15 dB but no more than 25dB. This confirms that the spectrum analyser's noise contribution has an insignificant effect on the measurement. An input attenuation value allowing a "Noise floor Delta" in excess of 25 dB may cause overloading of the spectrum analyser input. (i) Reconnect the input cable to the spectrum analyser.

(j) Activate the display line on the spectrum analyser.

(k) Carefully adjust the display line to the noise level shown on the spectrum analyser. Record the display line level.

(l) Adjust the spectrum analyser centre frequency to the test carrier frequency
recorded in step (e).

(m) Carefully adjust the display line to the peak level of the test carrier on the
spectrum analyser. Record the display line level.

(n) Determine the difference in reference levels between steps (l) and (j)
which is the (C+N)/N.

(o) Change the (C+N)/N to C/N by the following conversion:

This step is not necessary if the (C+N)/N ratio is more than 20 dB because the resulting correction is less than 0.1 dB.

$$\left(\frac{C}{N}\right) = 10\log_{10}\left(10^{\frac{\left(\frac{C+N}{N}\right)}{10}} - 1\right) \quad \text{dB}$$

(p) Calculate the carrier to noise power density ratio (C/No) using:

$$\left(\frac{C}{No}\right) = \left(\frac{C}{N}\right) - 2.5 + 10\log_{10}(\text{RBW} \;\; \text{x} \;\; \text{SA}_{\text{corr}}) \quad \text{dB}$$

The 2.5 dB figure corrects the noise power value measured by the log converters in the spectrum analyser to a true RMS power level, and the SA_{corr}

factor takes into account the actual resolution filter bandwidth.

(q) Calculate the G/T using the following:

$$\left(\frac{G}{T}\right) = \left(\frac{C}{No}\right) - (EIRP_{SC} - A_{corr}) + (FSL + L_a) - 228.6 \qquad dB/K$$

where,

$EIRP_{SC}$ – Downlink EIRP measured by the PMOC (dBW)

A_{corr} – Aspect correction supplied by the PMOC (dB)

FSL – Free Space Loss to the AUT supplied by the PMOC (dB)

L_a – Atmospheric attenuation supplied by the PMOC (dB)

(r) Repeat the measurement several times to check consistency of the result.

Antenna Gain:

Antenna gain is usually **defined** as the ratio of the power produced by the **antenna** from a far-field source on the **antenna's** beam axis to the power produced by a hypothetical lossless isotropic **antenna**, which is equally sensitive to signals from all directions.

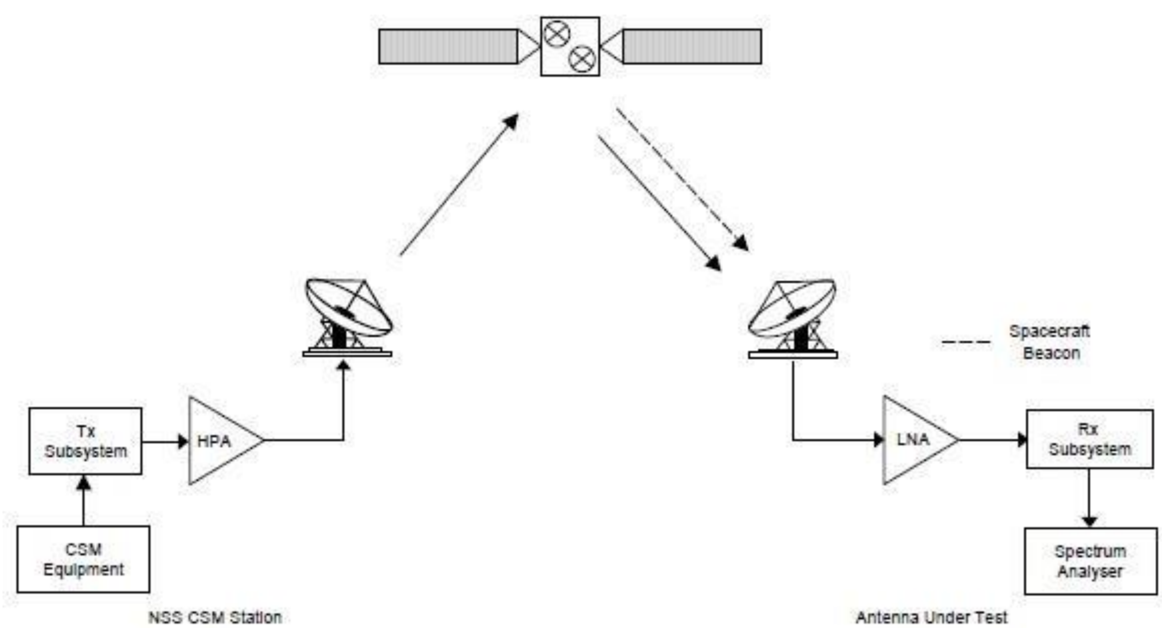


Figure One possible arrangement for Measurement of Antenna Gain

Two direct methods of measuring the Rx gain can be used; integration of the Rx sidelobe pattern or by determination of the 3dB and 10dB beamwidths.

The use of pattern integration will produce the more accurate results but would require the AUT to have a tracking system. In both cases the test configurations for measuring Rx gain are identical, and are illustrated in Figure.

In order to measure the Rx gain using pattern integration the AUT measures the elevation and azimuth narrowband (±5° corrected) sidelobe patterns.

The AUT then calculates the directive gain of the antenna through integration of the sidelobe patterns. The Rx gain is then determined by reducing the directive gain by the antenna inefficiencies.

In order to measure the Rx gain using the beamwidth method, the AUT measures the corrected azimuth and elevation 3dB/10dB beamwidths. From these results the Rx gain of the antenna can be directly calculated using the formula below.

$$G = 10\mathrm{Log}_{10}\left[\frac{1}{2}\left(\frac{31000}{(Az_3)(El_3)} + \frac{91000}{(Az_{10})(El_{10})}\right)\right] - F_{Loss} - R_{Loss}$$

where:

G is the effective antenna gain (dBi)

Az_3 is the corrected azimuth 3dB beamwidth (°)

El_3 is the elevation 3dB beamwidth (°)

Az_{10} is the corrected azimuth 10dB beamwidth (°)

El_{10} is the elevation 10dB beamwidth (°)

F_{Loss} is the insertion loss of the feed (dB)

R_{Loss} is the reduction in antenna gain due to reflector inaccuracies, and is given by:

$$R_{Loss} = 4.922998677(S_{dev}\, f)^2 \text{ dB}$$

where: S_{dev} is the standard deviation of the actual reflector surface (inches)
f is the frequency (GHz)