Introduction to Satellite Communication

Satellites are specifically made for the purpose of telecommunication. They are used for mobile applications such as communication to ships, vehicles, planes, hand-held terminals, TV and Radio broadcasting. They are responsible for providing these services to an assigned region on the earth. The power and bandwidth of these satellites depend upon the size of the footprint, complexity of traffic control protocol schemes and the cost of ground stations.

A satellite works most efficiently when the transmissions are focused with a desired area. When the area is focused, then the emissions don't go outside that designated area and thus minimizing the interference to other systems. This leads to more efficient spectrum usage.

Satellite's antenna patterns play an important role and must be designed to best cover the designated geographical area. Satellites should be designed by keeping in mind its usability for short and long term effects throughout its life time.

The earth station should be in a position to control the satellite if it drifts from its orbit and if subjected to any kind of drag from the external forces. The following are the applications of satellites.

- Weather Forecasting
- Radio and TV Broadcasting
- Military Satellites
- Navigation Satellites
- Global Telephone
- Connecting Remote Area
- Global Mobile Communication

Satellites orbit around the earth. Depending on the application, these orbits can be circular or elliptical. Satellites in circular orbits always keep the same distance to the earth‟s surface following a simple law: The attractive force Fg of the earth due to gravity equals m·g (R/r) 2 The centrifugal force Fc trying to pull the satellite away equals m·r·ω 2 The variables have the following meaning: m is the mass of the satellite; R is the radius of earth with R = 6,370 km; ri s the distance of the satellite to the centre of the earth; g is the acceleration of gravity with g = 9.81 m/s2; ω is the angular velocity with ω = 2·π·f, f is the frequency of the rotation.

To keep the satellite in a stable circular orbit, the following equation must hold: Fg = Fc, i.e., both forces must be equal. Looking at this equation the first thing to notice is that the mass m of a satellite is irrelevant (it appears on both sides of the equation). Solving the equation for the distance r of the satellite to the centre of the earth results in the following equation:

The distance $r = (g \cdot R^2 / (2 \cdot \pi \cdot f)^2)^{1/3}$

From the above equation it can be concluded that the distance of a satellite to the earth‟s surface depends on its rotation frequency. Important parameters in satellite communication are the inclination and elevation angles. The inclination angle δ is defined between the equatorial plane and the plane described by the satellite orbit. An inclination angle of 0 degrees means that the satellite is exactly above the equator. If the satellite does not have a circular orbit, the closest point to the earth is called the perigee.

Applications :

Weather Forecasting :

Certain satellites are specifically designed to monitor the climatic conditions of earth. They continuously monitor the assigned areas of earth and predict the weather conditions of that region. This is done by taking images of earth from the satellite. These images are transferred using assigned radio frequency to the earth station. (Earth Station: it‟s a radio station located on the earth and used for relaying signals from satellites.) These satellites are exceptionally useful in predicting disasters like hurricanes, and 4 monitor the changes in the Earth's vegetation, sea state, ocean color, and ice fields.

Radio and TV Broadcast :

These dedicated satellites are responsible for making 100s of channels across the globe available for everyone. They are also responsible for broadcasting live matches, news, world-wide radio services. These satellites require a 3040 cm sized dish to make these channels available globally.

Military Satellites :

These satellites are often used for gathering intelligence, as a communications satellite used for military purposes, or as a military weapon. A satellite by itself is neither military nor civil. It is the kind of payload it carries that enables one to arrive at a decision regarding its military or civilian character.

Navigation Satellites :

The system allows for precise localization world-wide, and with some additional techniques, the precision is in the range of some meters. Ships and aircraft rely on GPS as an addition to traditional navigation systems. Many vehicles come with installed GPS receivers. This system is also used, e.g., for fleet management of trucks or for vehicle localization in case of theft.

Global Telephone :

One of the first applications of satellites for communication was the establishment of international telephone backbones. Instead of using cables it was sometimes faster to launch a new satellite. But, fiber optic cables are still replacing satellite communication across long distance as in fiber optic cable, light is used instead of radio frequency, hence making the communication much faster (and of course, reducing the delay caused due to the amount of distance a signal needs to travel before reaching the destination.). Using satellites, to typically reach a distance approximately 10,000 kms away, the signal needs to travel almost 72,000 kms, that is, sending data from ground to satellite and (mostly) from satellite to another location on earth. This cause‟s substantial amount of delay and this delay becomes more prominent for users during voice calls.

Connecting Remote Areas :

Due to their geographical location many places all over the world do not have direct wired connection to the telephone network or the internet (e.g., researchers on Antarctica) or because of the current state of the infrastructure of a country. Here the satellite 5 provides a complete coverage and (generally) there is one satellite always present across a horizon.

Global Mobile Communication :

The basic purpose of satellites for mobile communication is to extend the area of coverage. Cellular phone systems, such as AMPS and GSM (and their successors) do not cover all parts of a country. Areas that are not covered usually have low population where it is too expensive to install a base station. With the integration of satellite communication, however, the mobile phone can switch to satellites offering world-wide connectivity to a customer. Satellites cover a certain area on the earth. This area is termed as a „footprint" of that satellite. Within the footprint, communication with that satellite is possible for mobile users. These users communicate using a Mobile-UserLink (MUL). The base-stations communicate with satellites using a Gateway-Link (GWL). Sometimes it becomes necessary for satellite to create a communication link between users belonging to two different footprints. Here the satellites send signals to each other and this is done using Inter-Satellite-Link (ISL).

Kepler's laws

Satellites orbiting the earth follow the same laws that govern the motion of the planets around the sun. Kepler's laws apply quite generally to any two bodies in space which interact through gravitation. The massive of the two bodies is referred to as the *primary* and the other, the *secondary* or *satellite*.

Kepler's First Law

Kepler's first law states that the path followed by a satellite around the primary will be an ellipse. An ellipse has two focal points $F1$ and $F2$ as shown in Figure 1.1. The center of mass of the two-body system, termed the *bary center,* is always center of the foci.

The semi major axis of the ellipse is denoted by '*a'* and the semi minor axis, by '*b'*. The eccentricity '*e'* is given by

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

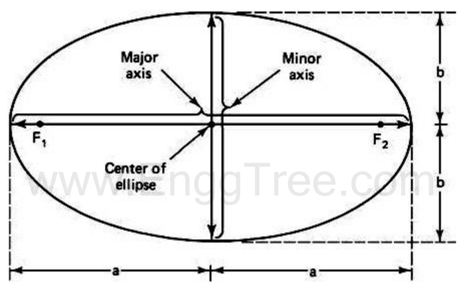

Fig 1.1 Foci $F1$ and $F2$, the semi major axis a, and the semi minor axis b of an ellipse

Kepler's Second Law

Kepler's second law states that for equal time intervals, a satellite will sweep out equal areas in its orbital plane focused at the bary center. Referring to Figure 1.2, assuming the satellite travels distances S_1 and S_2 meters in 1 second, then the areas A_1 and A_2 will be equal. The average velocity in each case is S_1 and S_2 m/s, and because of the equal area law, it follows that the velocity at S_2 is less than that at S_1.

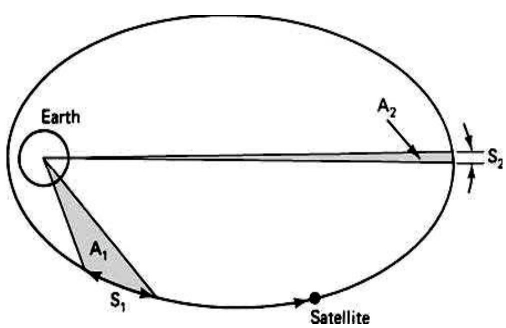

Fig 1.2 The areas $A1$and $A2$ swept out in unit time are equal

Kepler's Third Law

Kepler's third law states that the square of the periodic time of orbit is proportional to the cube of the mean distance between the two bodies. The mean distance is equal to the semi major axis *a*. For the artificial satellites orbiting the earth, Kepler's third law can be written in the form

$$a^3 = \mu/n^2$$

Where 'n' is the mean motion of the satellite in radians per second and the earth's geocentric gravitational constant is given by

$$\mu=3.986005 \times 10^{14} m^3/s^2$$

Newton's laws

Newton's First law

An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force. This law is also called "the law of inertia".

Newton's Second law

Acceleration is produced when a force acts on a mass. The greater the mass (of the object being accelerated) the greater the amount of force needed (to accelerate the object).

Newton's Third law

For every action there is an equal and opposite re-action. This means that for every force there is a reaction force that is equal in size, but opposite in direction. Whenever an object pushes another object it gets pushed back in the opposite direction equally hard.

Orbital Parameters

Apogee: A point for a satellite farthest from the Earth. It is denoted as **ha.** **Perigee:** A point for a satellite closest from the Earth. It is denoted as **hp.**

Line of Apsides: Line joining perigee and apogee through centre of the Earth. It is the major axis of the orbit. One-half of this line‟s length is the semi-major axis equivalents to satellite's mean distance from the Earth.

Ascending Node: The point where the orbit crosses the equatorial plane going from north to south

Descending Node: The point where the orbit crosses the equatorial plane going from south to north

Inclination: The angle between the orbital plane and the Earth's equatorial plane. It's measured at the ascending node from the equator to the orbit, going from East to North. This angle is commonly denoted as **i.**

Line of Nodes: The line joining the ascending and descending nodes through the centre of Earth

Prograde Orbit: An orbit in which satellite moves in the same direction as the Earth's rotation. Its inclination is always between 00 to 900. Many satellites follow this path as earth's velocity makes it easier to lunch these satellites.

Retrograde Orbit: An orbit in which satellite moves in the same direction counter to the earth's rotation.

Argument of Perigee: An angle from the point of perigee measure in the orbital plane at the earth's centre, in the direction of the satellite motion.

Right ascension of ascending node: The definition of an orbit in space, the position of ascending node is specified. But as the Earth spins, the longitude of ascending node changes and cannot be used for reference. Thus for practical determination of an orbit, the longitude and time of crossing the ascending node are used. For absolute measurement, a fixed reference point in space is required. It could also be defined as “right ascension of the ascending node; right ascension is the angular position measured eastward along the celestial equator from the vernal equinox vector to the hour circle of the object”.

Mean anamoly: It gives the average value to the angular position of the satellite with reference to the perigee.

True anamoly: It is the angle from point of perigee to the satellite’s position, measured at the Earth’s centre.

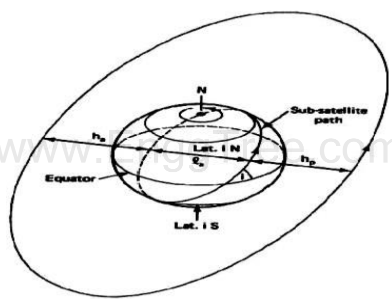

Fig Apogee height *ha*, Perigee height *hp*, and inclination i; *La* is the line of apsides

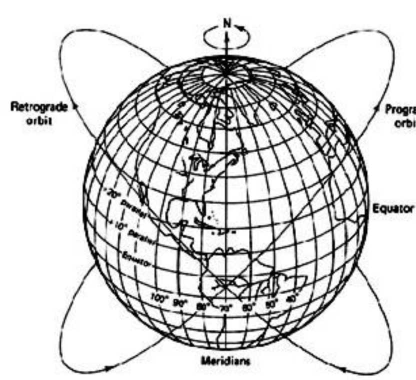

Fig Pro-grade and Retrograde Orbits

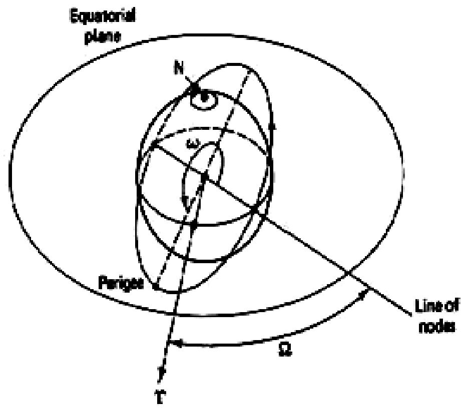

Fig Argument of Perigee 'w' and Right Ascension of the Ascending Node

Orbital Perturbations

An orbit described by Kepler is ideal as Earth, considered to be a perfect sphere and the force acting around the Earth is the centrifugal force. This force is supposed to balance the gravitational pull of the earth. In reality, other forces also play an important role and affect the motion of the satellite. These forces are the gravitational forces of Sun and Moon along with the atmospheric drag. The effect of Sun and Moon is more pronounced on geostationary earth satellites where as the atmospheric drag effect is more pronounced for low earth orbit satellites.

Effects of Non-Spherical Earth

As the shape of Earth is not a perfect sphere, it causes some variations in the path followed by the satellites around the primary. As the Earth is bulging from the equatorial belt, it is the forces resulting from an oblate Earth which act on the satellite produce a change in the orbital parameters. This causes the satellite to drift as a result of regression of the nodes and the latitude of the point of perigee. This leads to rotation of the line of apsides. As the orbit itself is moving with respect to the Earth, the resultant changes are seen in the values of argument of perigee and right ascension of ascending node.

Due to the non-spherical shape of Earth, one more effect called as the "Satellite Graveyard" is observed. The non-spherical shape leads to the small value of eccentricity at the equatorial plane. This causes a gravity gradient on GEO satellite and makes them drift to one of the two stable points which coincide with minor axis of the equatorial ellipse.

Atmospheric Drag

For Low Earth orbiting satellites, the effect of atmospheric drag is more pronouncing. The impact of this drag is maximum at the point of perigee. The drag (pull towards the Earth) has an effect on velocity of Satellite. This causes the satellite not to reach the apogee height successive revolutions. This leads to a change in value of semi-major axis and eccentricity. Satellites in service are maneuvered by the earth station back to their original orbital position.

Station Keeping

In addition to having its attitude controlled, it is important that a geo-stationary satellite be kept in its correct orbital slot. The equatorial ellipticity of the earth causes geostationary satellites to drift slowly along the orbit, to one of two stable points, at 75°E and 105°W. To counter this drift, an oppositely directed velocity component is imparted to the satellite by means of jets, which are pulsed once every 2 or 3 weeks. These maneuvers are called as *east-west station-keeping maneuvers*.

Satellites in the 6/4-GHz band must be kept within 0.1° of the designated longitude and in the 14/12-GHz band, within 0.05°.

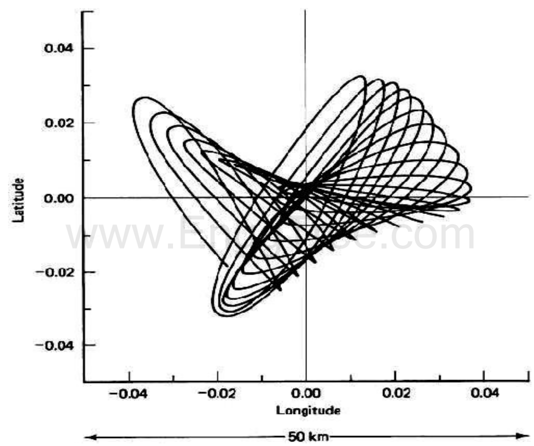

Fig 1.5 Typical Satellite Motion

Geo stationary and Non Geo-stationary orbits

Geo stationary Orbit

A **geostationary** orbit is one in which a satellite orbits the earth at exactly the same speed as the earth turns and at the same latitude, specifically zero, the latitude of the equator. A satellite orbiting in a geostationary orbit appears to be hovering in the same spot in the sky, and is directly over the same patch of ground at all times.

A **geosynchronous** orbit is one in which the satellite is synchronized with the earth's rotation, but the orbit is tilted with respect to the plane of the equator. A satellite in a geosynchronous orbit will wander up and down in latitude, although it will stay over the same line of longitude. A geostationary orbit is a subset of all possible geosynchronous orbits.

The person most widely credited with developing the concept of geostationary orbits is noted science fiction author Arthur C. Clarke (Islands in the Sky, Childhood's End, Rendezvous with Rama, and the movie 2001: a Space Odyssey). Others had earlier pointed out that bodies traveling a certain distance above the earth on the equatorial plane would remain motionless with respect to the earth's surface. But Clarke published an article in 1945's Wireless World that made the leap from the Germans' rocket research to suggest permanent manmade satellites that could serve as communication relays.

Geostationary objects in orbit must be at a certain distance above the earth; any closer and the orbit would decay, and farther out they would escape the earth's gravity altogether. This distance is 35,786 kilometers from the surface. The first geo-synchrous satellite was orbited in 1963, and the first geostationary one the following year. Since the only geostationary orbit is in a plane with the equator at 35,786 kilometers, there is only one circle around the world where these conditions obtain.

This means that geostationary 'real estate' is finite. While satellites are in no danger of bumping in to one another yet, they must be spaced around the circle so that their frequencies do not interfere with the functioning of their nearest neighbors.

Geostationary Satellites

There are 2 kinds of manmade satellites - One kind of satellite ORBITS the earth once or twice a day and the other kind is called a communications satellite and it is PARKED in a STATIONARY position 35,900 km above the equator of the STATIONARY earth. A type of the orbiting satellite includes the space shuttle and the international space station which keep a low earth orbit (LEO) to avoid the Van Allen radiation belts.

The most prominent satellites in medium earth orbit (MEO) are the satellites which comprise the GLOBAL POSITIONING SYSTEM (GPS).

Global Positioning System

The global positioning system was developed by the U.S. military and then opened to civilian use. It is used today to track planes, ships, trains, cars or anything that moves. Anyone can buy a receiver and track their exact location by using a GPS receiver.

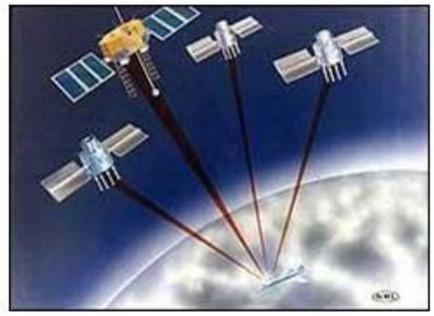

Fig 1.6 GPS satellites orbit at a height of about 19,300 km and orbit the earth once every 12 hours

These satellites are traveling around the earth at speeds of about 7,000 mph. GPS satellites are powered by solar energy. They have backup batteries onboard to keep them running when there's no solar power. Small rocket boosters on each satellite keep them flying in the correct path. The satellites have a lifetime of about 10 years until all their fuel runs out.

At exactly 35,900 km above the equator, the force of gravity is cancelled by the centrifugal force of the rotating universe. This is the ideal spot to park a stationary satellite.

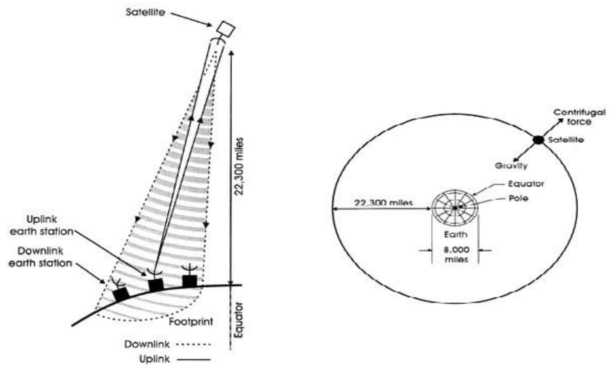

Fig At exactly 35,900 km above the equator, the earth's force of gravity is canceled by the centrifugal force of the rotating universe

Non Geo-Stationary Orbit

For the geo-stationary case, the most important of these are the gravitational fields of the moon and the sun and the non-spherical shape of the earth. Other significant forces are solar radiation pressure and reaction of the satellite to motor movement within the satellite. As a result, station- keeping maneuvers must be carried out to maintain the satellite within limits of its nominal geostationary position.

An exact geostationary orbit is not attainable in practice, and the orbital parameters vary with time. The two-line orbital elements are published at regular intervals. The period for a geostationary satellite is 23 h, 56 min, 4 s, or 86,164 s. The reciprocal of this is 1.00273896 rev/day, which is about the value tabulated for most of the satellites as in Figure 1.7. Thus these satellites are *geo-synchronous,* in that they rotate in synchronism with the rotation of the earth. However, they are not geostationary. The term *geosynchronous satellite* is used in many cases instead of *geostationary* to describe these near-geostationary satellites.

In general a geosynchronous satellite does not have to be near-geostationary, and there are a number of geosynchronous satellites that are in highly elliptical orbits with comparatively large inclinations. The small inclination makes it difficult to locate the position of the ascending node, and the small eccentricity makes it difficult to locate the position of the perigee. However, because of small inclination, the angles *w* and Ω can be assumed to be in the same plane. The longitude of the sub-satellite point is the east early rotation from the Greenwich meridian.

$$\phi_{SS} = \omega + \Omega + v - \mathrm{GST}$$

The *Greenwich sidereal time* (GST) gives the eastward position of the Greenwich meridian relative to the line of Aries, and hence the sub-satellite point is at longitudeand the mean longitude of the satellite is given by

$$\phi_{SSmean} = \omega + \Omega + M - \mathrm{GST}$$

The above equation can be used to calculate the true anomaly and because of the small eccentricity, this can be approximated as v= $M + 2e\sin M$.

Look Angle Determination

The look angles for the ground station antenna are Azimuth and Elevation angles. They are required at the antenna so that it points directly at the satellite. Look angles are calculated by considering the elliptical orbit. These angles change in order to track the satellite. For geostationary orbit, these angle values do not change as the satellites are stationary with respect to earth. Thus large earth stations are used for commercial communications.

For home antennas, antenna beam-width is quite broad and hence no tracking is essential.

This leads to a fixed position for these antennas.

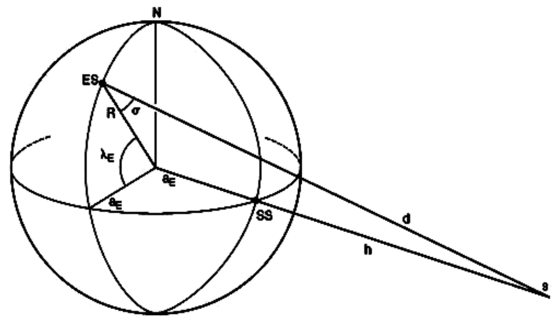

Fig Geometry used in determining the look angles for Geostationary Satellites

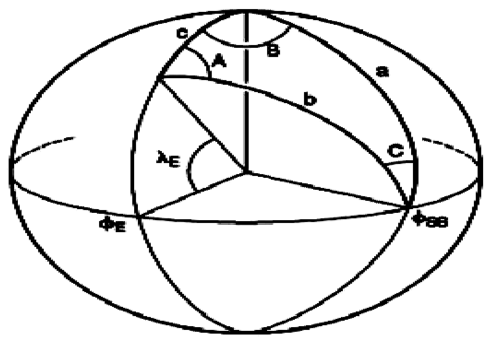

Fig Spherical Geometry related to Figure

With respect to the figure 1.8 and 1.9, the following information is needed to determine the look angles of geostationary orbit.

- Earth Station Latitude: λ_E
- Earth Station Longitude: Φ_E
- Sub-Satellite Point’s Longitude: Φ_{SS}
- ES: Position of Earth Station
- SS: Sub-Satellite Point
- S: Satellite
- d: Range from ES to S
- ζ: angle to be determined

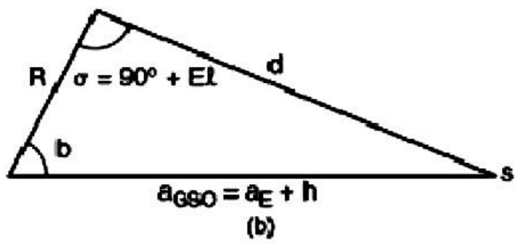

Fig Plane triangle obtained from
Figure

Considering Figure , it's a spherical triangle. All sides are the arcs of a great circle. Three sides
of this triangle are defined by the angles subtended by the centre of the earth.

- Side a: angle between North Pole and radius of the sub-satellite point.
- Side b: angle between radius of Earth and radius of the sub-satellite point.

- Side c: angle between radius of Earth and the North Pole.
- a $=90^0$ and such a spherical triangle is called quadrantal triangle. c = $90^0 - \lambda$
- Angle B is the angle between the plane containing c and the plane containing a.

Thus, B = ΦE-ΦSS

- Angle A is the angle between the plane containing b and the plane containing c.
- Angle C is the angle between the plane containing a and the plane containing b.

Thus, a = 90^0 c =

90^0 - λE B = ΦE-

ΦSS

Thus, b = arcos (cos B cos λE)

And A = arcsin (sin |B| / sin b)

Applying the cosine rule for plane triangle to the triangle of F i g u r e,

$$d = \sqrt{R^2 + a_{GSO}{}^2 - 2Ra_{GSO}\cos b}$$

Applying the sine rule for plane triangles to the triangle of Figure, allows the angle of elevation to be found:

$$El = \arccos\left(\frac{a_{GSO}}{d}\sin b\right)$$

Limits of Visibility

The east and west limits of geostationary are visible from any given Earth station. These limits are set by the geographic coordinates of the Earth station and antenna elevation. The lowest elevation is zero but in practice, to avoid reception of excess noise from Earth. Some finite minimum value of elevation is issued. The earth station can see a satellite over a geostationary arc bounded by **+- (81.30)** about the earth station's longitude.

Eclipse

It occurs when Earth's equatorial plane coincides with the plane the Earth's orbit around the sun. Near the time of spring and autumnal equinoxes, when the sun is crossing the equator, the satellite passes into sun's shadow. This happens for some duration of time every day. These eclipses begin 23 days before the equinox and end 23 days after the equinox. They last for almost 10 minutes at the beginning and end of equinox and increase for a maximum period of 72 minutes at a full eclipse.

The solar cells of the satellite become non-functional during the eclipse period and the satellite is made to operate with the help of power supplied from the batteries. A satellite will have the eclipse duration symmetric around the time t=Satellite Longitude/15 + 12 hours. A satellite at Greenwich longitude 0 will have the eclipse duration symmetric around 0/15 UTC +12hours = 00:00 UTC.

The eclipse will happen at night but for satellites in the east it will happen late evening local time. For satellites in the west eclipse will happen in the early morning hour's local time. An earth caused eclipse will normally not happen during peak viewing hours if the satellite is located near the longitude of the coverage area. Modern satellites are well equipped with batteries for operation during eclipse.

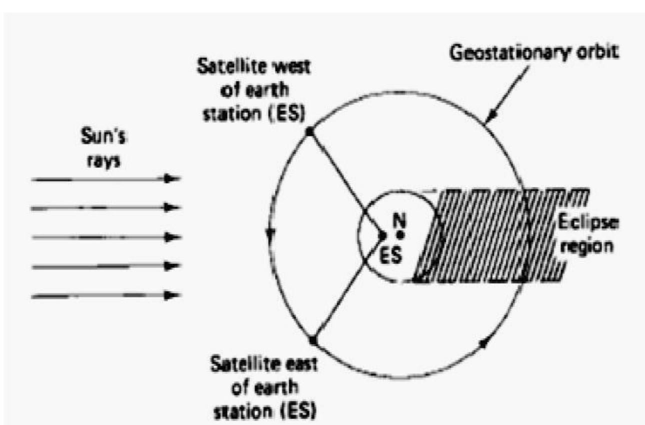

Fig 1.11 A satellite east of the earth station enters eclipse during

daylight busy hours at the earth station. A Satellite west of earth station enters eclipse during night hours

Sub satellite Point

Sub satellite Point is the point at which a line between the satellite and the center of the Earth intersects the Earth's surface. The location of the point is expressed in terms of latitude and longitude. If one is in the US it is common to use -

- Latitude – degrees north from equator
- Longitude – degrees west of the Greenwich meridianas:

$$L_s = \frac{\pi}{2} - \cos^{-1}\left(\frac{z_r}{\sqrt{x_r^2 + y_r^2 + z_r^2}}\right)$$

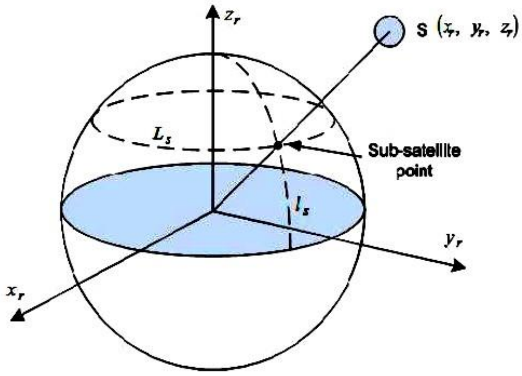

Fig 1.12 Sub satellite Point

Sun Transit Outage

Sun transit outage is an interruption or distortion of geostationary satellite signals caused by interference from solar radiations. Sun appears to be an extremely noisy source which completely blanks out the signal from satellite. This effect lasts for 6 days around the equinoxes. They occur for a maximum period of 10 minutes.

Generally, sun outages occur in February, March, September and October, that is, around the time of the equinoxes. At these times, the apparent path of the sun across the sky takes it directly behind the line of sight between an earth station and a satellite.

As the sun radiates strongly at the microwave frequencies used to communicate with satellites (C-band, Ka band and Ku band) the sun swamps the signal from the satellite. The effects of a sun outage can include partial degradation, that is, an increase in the error rate, or total destruction of the signal.

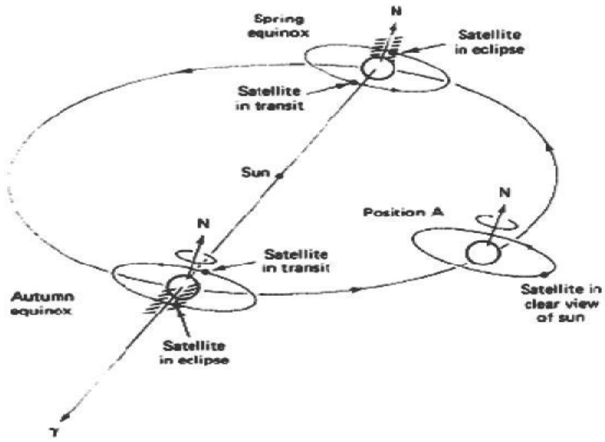

Fig 1.13 Earth Eclipse of a Satellite and Sun transit Outage

Launching Procedures

Introduction

Low Earth Orbiting satellites are directly injected into their orbits. This cannot be done in case of GEOs as they have to be positioned 36,000kms above the Earth's surface. Hence Launch vehicles are 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 will be expensive to inject the satellite in its orbit directly. For this purpose, a satellite must be placed to a transfer orbit between the initial lower orbit and destination orbit. The transfer orbit is commonly known as Hohmann-Transfer Orbit.

Orbit Transfer

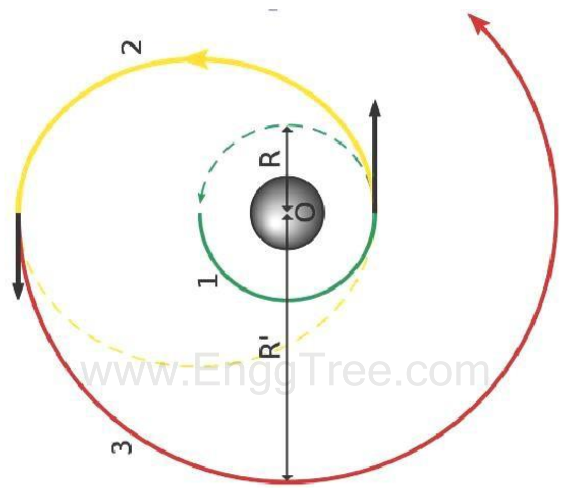

Fig 1.14 Orbit Transfer Positions

Hohmann Transfer Orbit

This manoeuvre is named after the German Civil Engineer Walter Hohmann, who first proposed it. He didn't work in rocketry professionally 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 is a reaction force described 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 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 is 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.

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 less fuel to launch into orbit.

In addition, launching at the equator provides an additional 1,036 mph 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.

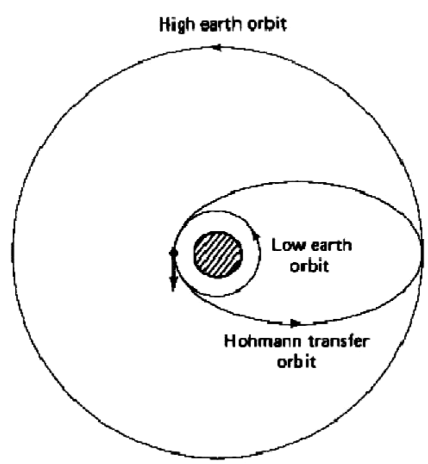

Fig 1.5 Hohmann Transfer Orbit

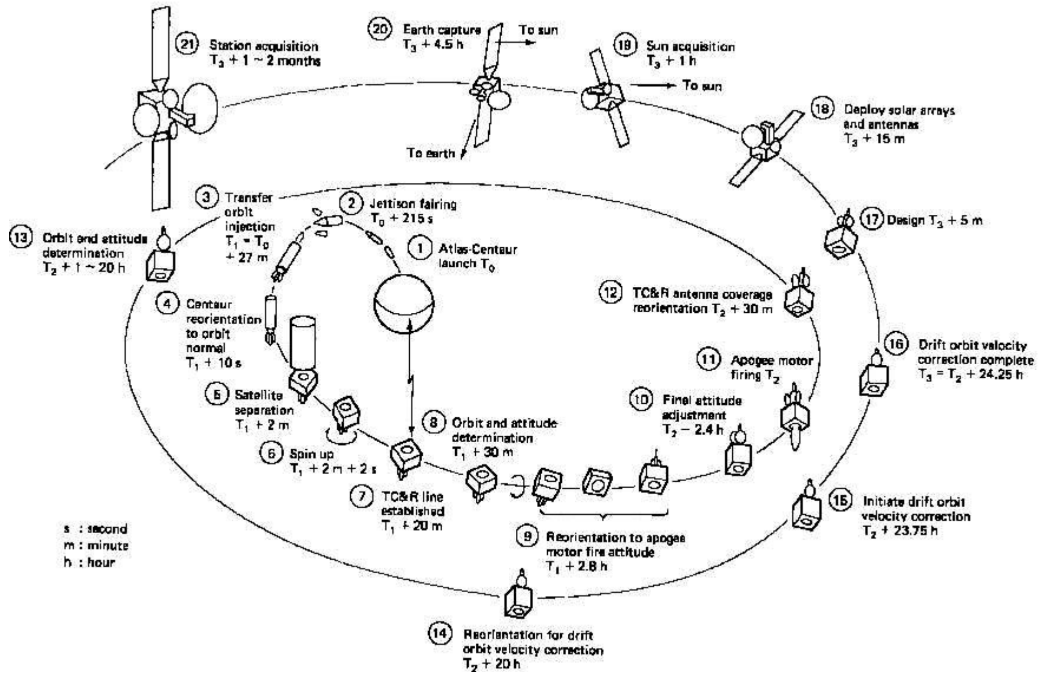

Fig 1.16 Launching stages of a GEO

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 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, daVinci 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, 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.

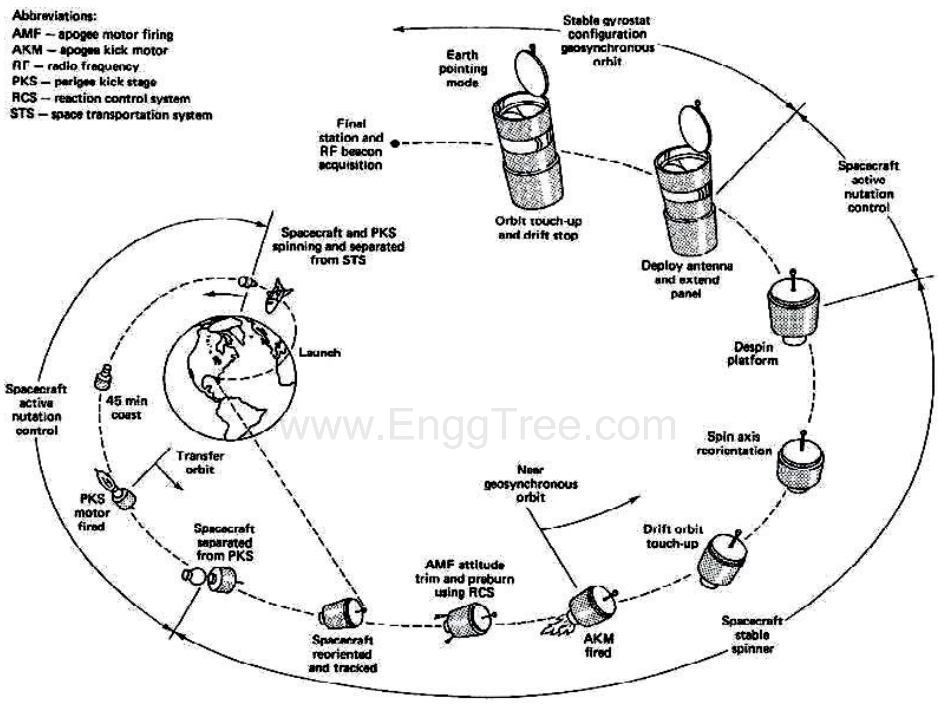

Fig 1.17 STS-7/Anik C2 mission scenario

Spacecraft Technology- Structure

A satellite communications system can be broadly divided into two segments—a ground segment and a space segment.

The space segment will obviously include the satellites, but it also includes the ground facilities needed to keep the satellites operational, these being referred to as the T*racking, Telemetry, and Command* (TT&C) facilities. In many networks it is a common practice to employ a ground station solely for the purpose of TT&C.

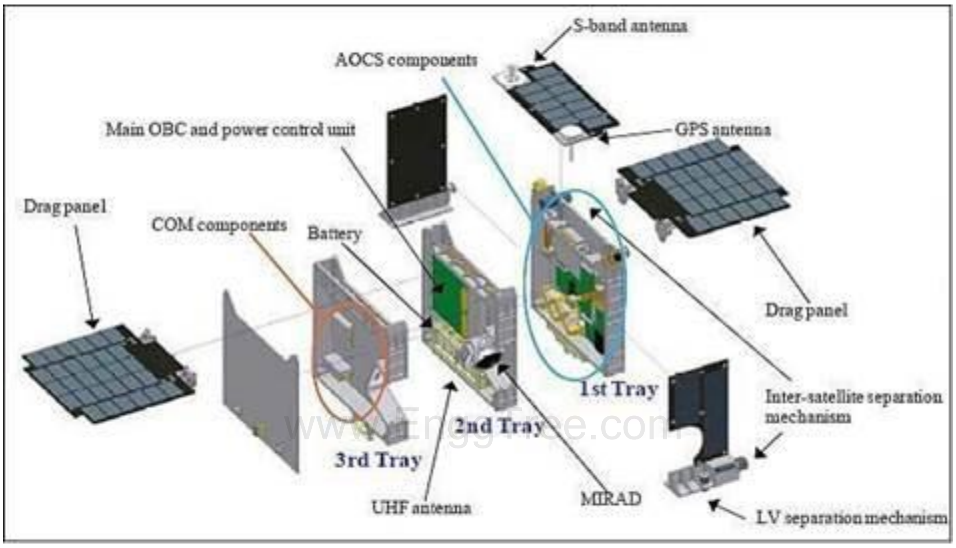

Fig 2.1 Satellite Structure

The equipment carried aboard the satellite also can be classified according to function. The *payload* refers to the equipment used to provide the service for which the satellite has been launched.

In a communications satellite, the equipment which provides the connecting link between the satellite's transmit and receive antennas is referred to as the T*ransponder*. The transponder forms one of the main sections of the payload, the other being the antenna subsystems. In this chapter the main characteristics of certain bus systems and payloads are described.

The Power Supply

The primary electrical power for operating the electronic equipment is obtained from solar cells. Individual cells can generate only small amounts of power and therefore, arrays of cells in series-parallel connection are required. Figure 2.1 shows the solar cell panels for the HS 376 satellite manufactured by Hughes Space and Communications Company.

In geostationary orbit the telescoped panel is fully extended so that both are exposed to sun- light. At the beginning of life, the panels produce 940 W dc power, which may drop to 760 W at the end of 10 years. During eclipse, power is provided by two nickel-cadmium (Ni-Cd) long-life batteries, which will deliver 830 W. At the end of life, battery recharge time is less than 16 h.

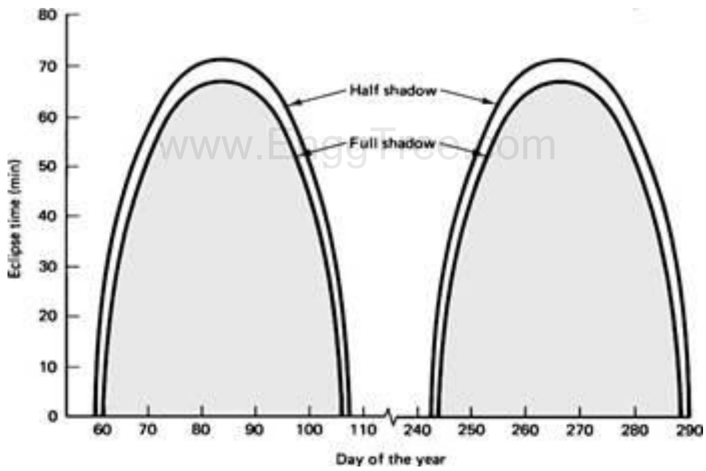

Fig 2.2 Satellite Eclipse time as a function of the current day of the year

In cylindrical and solar-sail satellites, the cross-over point is estimated to be about 2 kW, where the solar-sail type is more economical than the cylindrical type.

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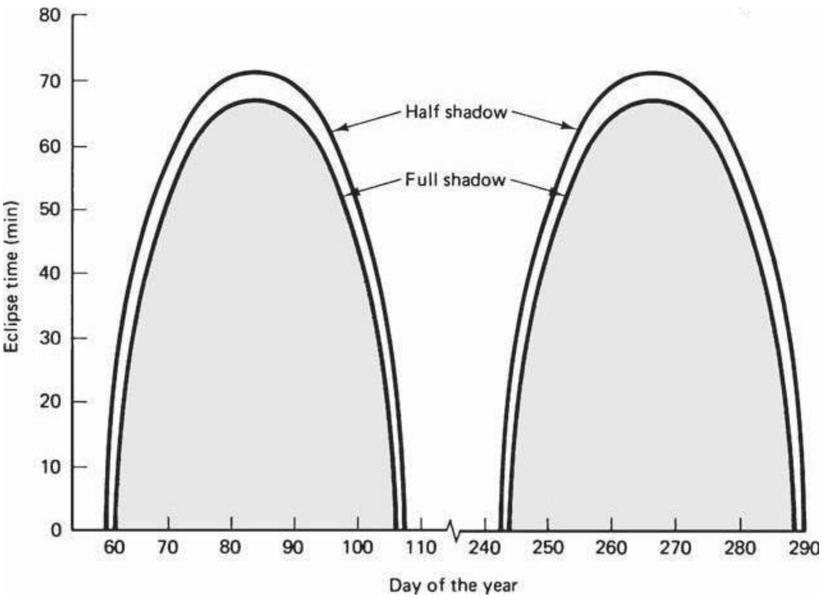


Figure 2.1.(b) Satellite eclipse time as a function of the current day of the year. (*Courtesy of Spilker, 1977. Reprinted by permission of Prentice-*

Hall, Englewood Cliffs, NJ.)

capacity of cylindrical and solar-sail satellites, the cross-over point is esti- mated to be about 2 kW, where the solar-sail type is more economical than the cylindrical type (Hyndman, 1991).

Power Systems

▪ Options for electrical-power production & storage for space missions, current and under development, are shown in the following figure in terms of power vs. mission duration,

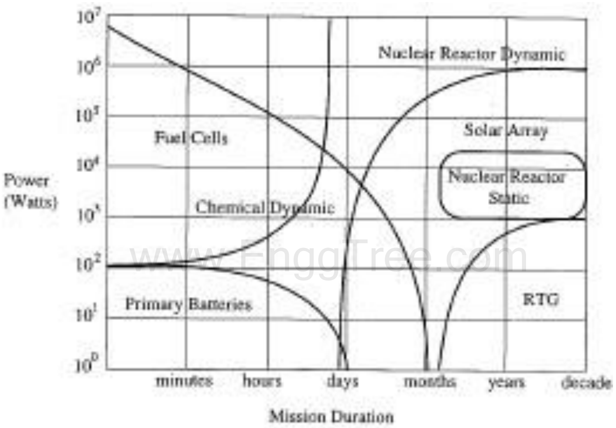


Figure 9.1: Spacecraft power systems (Hyder).

▪ Primary Batteries:

· Produce direct current by electrochemistry

· Currently used: LiCFx (lithium polycarbon monofluoride) electrolyte · Economical for small spacecraft for missions of relatively short duration.

▪ Solar PV – Battery:

· Photovoltaic cell, semi-conductor material, directly converts sunlight to electricity.

· Most widely used energy-conversion device for spacecraft

· Provide relatively high power levels over long duration (up to 10 to 15 years). · Batteries required to provide power during eclipse.

▪ Radioisotope-Thermoelectric Generators (RTGs):

· Compact and continuous source of power

· Used in deep-space missions over several decades

· Considered nuclear fuel but relatively easy to handle safely:

Curium-244 & Plutonium-238

[strontium-90 less expensive but not safe to handle]

· High energy particles heat a thermoelectric material that, in turn, produces an electric potential:

Lead telluride SiGe (silicon germanium) doped w. phosphorous

▪ Fuel cells:

· Produce direct current by chemical reaction of an oxidant and a fuel.

· Currently used: O_2 & H_2.

· Work as long as supply of oxidant & fuel available.

▪ Solar Concentrator – Dynamic:

· Mirrors used to concentrate sunlight to heat a working fluid that powers a turbine:

Steam Liquid metal, e.g. potassium chloride Gas, e.g. helium, xenon

▪ Chemical Dynamic:

· Burn fuel & oxidant, e.g. H_2 & O_2, CH_4 & O_2, to power a turbine.

Power conversion & storage options and status:

Table 9.1: Power system current and estimated performance (Hyder et al.).

System or Component		Parameter	Circa 1985	Estimated 2000
Solar-Battery Systems		Power Output	5 kW	100 kW
		Specific Power	10 W/kg	50 W/kg
		Solar Array-Battery Costs	$3000/W	$1000/W
Solar Cells and Arrays		Cell Power Output	5 kW	100 kW
		Cell Efficiency (in space)	14%	25%
		Array Specific Power	35 W/kg	150W/kg
		Array Design Life (LEO/GEO)	5yr/7yr	10yr/15yr
		Array Specific Cost	$1500/W	$500/W
Batteries				
Primary				
	AgZn	Energy Density	150W-hr/kg	
		Design Life	2 yr	
	$LiSOCl_2$	Energy Density	200W-hr/kg	700 W-hr/kg
		Design Life	3 yr	5 yr
Secondary				
	NiCd (LEO)	Energy Density	10W-hr/kg	
	NiCd(GEO)	Energy Density	15 W-hr/kg	
	NiCd (LEO/GEO)	Design Life	5yr/10yr	
	NiH_2(LEO)	Energy Density	25 W-hr/kg	
	NiH_2 (GEO)	Energy Density	30 W-hr/kg	
Nuclear Power				
Reactors		Power Level	10kW	10kW
		Specific Power	10W/kg	10W/kg
		Efficiency	10%	10%
RTG		Power Level	2 kW	2 kW
		Specific Power	6 W/kg	10W/kg
		Efficiency	8%	12%
Typical Overall System Parameters				
		Power	12 kW	25kW
		Voltage	28 V	50V
		Frequency	DC	DC/AC
		Cost –on–Orbit	~$1000/kW-hr	
		Radiator Specific Mass	20kg/kW	

Table 9.2: Power Limits & Performance.

System	Limit, kW	Eff, %	SP, W/kg	Source
Solar-PV	20	15-30	5-10	experience
RTG	1	7-15	7-15	same
Nuclear-TEC	100	7-15	?	projected

SP is specific power

R&D always seeking improvements:

Example) NASA funding development of solar array design for SP 100 W kg .

- Copper-indium-diselenide thin-film PV cell

- Low-mass structure

▪ Basic Power System

· A general system is shown in the following block diagram,

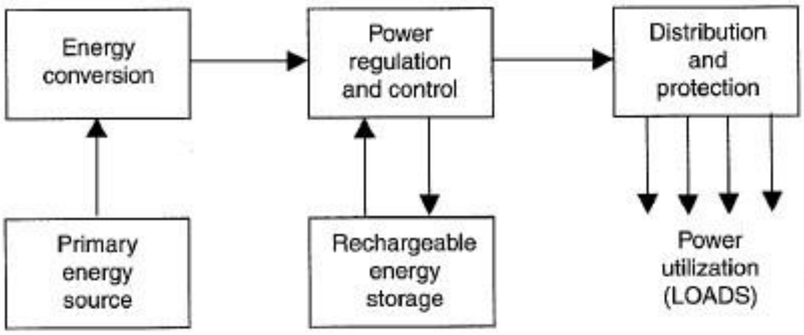


Figure 9.2: Power system block diagram (Patel).

▪ System <u>Voltage</u>

· Initial spacecraft designed for 28 VDC (automotive typically 12 VDC).

· Higher the power requirement → higher the operating voltage to reduce losses, i.e.

$$P = IV \qquad V = IR \qquad I = \text{current, amperes} \qquad R = \text{resistance,ohms}$$

$$P_{loss} = I R^2 \qquad \text{in conductors}$$

For fixed power: Higher the voltage, lower the current, lower the loss.

· <u>Standard</u> distribution ("bus") <u>voltages</u>:

$\boxed{28}$ $\boxed{50}$ $\boxed{70}$ $\boxed{100}$ $\boxed{120}$ $\boxed{160}$ V

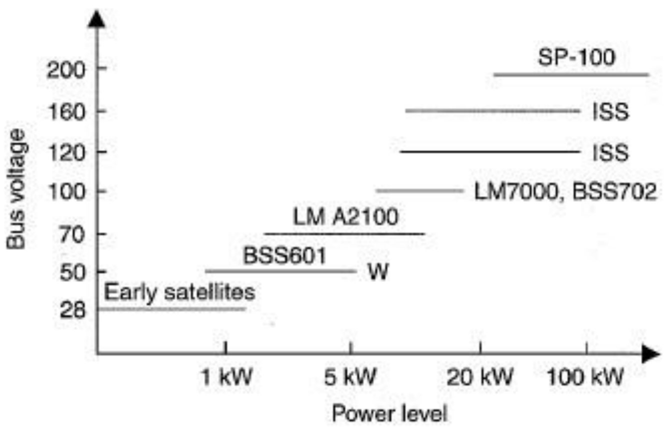


Figure 9.3: Bus voltage versus power level for several spacecraft (Patel).

LM A2100: Communications satellite

LM7000: Communications, Intelsat, 1998

BSS702: Communications, VSAT, 2001
ISS: International Space Station
SP-100: Space Power 100 kW (program canceled)

▪ Rules-of-thumb for bus voltage in LEO orbits:

1. Above ~160 V, solar-array current-leakage to space plasma (negatively charged electron field) starts to increase exponentially, with electric arcing above ~180 to 200 V.
2. At 100 V, for every square meter of exposed conductor area, $\boxed{\text{leakage current} \approx 1\text{ mA}}$.

Leakage current increases with voltage.

3. Above 160 V, conductors require insulation (additional mass).

Voltage Scaling Law:

· Design experience has shown empirically,

$$V_{opt} = 0.025\,P \tag{9.1.1}$$

where V_{opt} = optimum system voltage

P = required system power

▪ Mass Scaling Law:

· An empirical scaling law to estimate mass of a new system, from design experience, is,

$$m_{new} = m_{exist} \times \left(\frac{P_{new}}{P_{exist}}\right)^{0.7} \tag{9.1.2}$$

where m_{new} = mass of a new system

m_{exist} = mass of an existing, similar system

P_{new} = power requirement of the new system

P_{exist} = power of existing system

▪ A more detailed system diagram showing various power subsystems is given below,

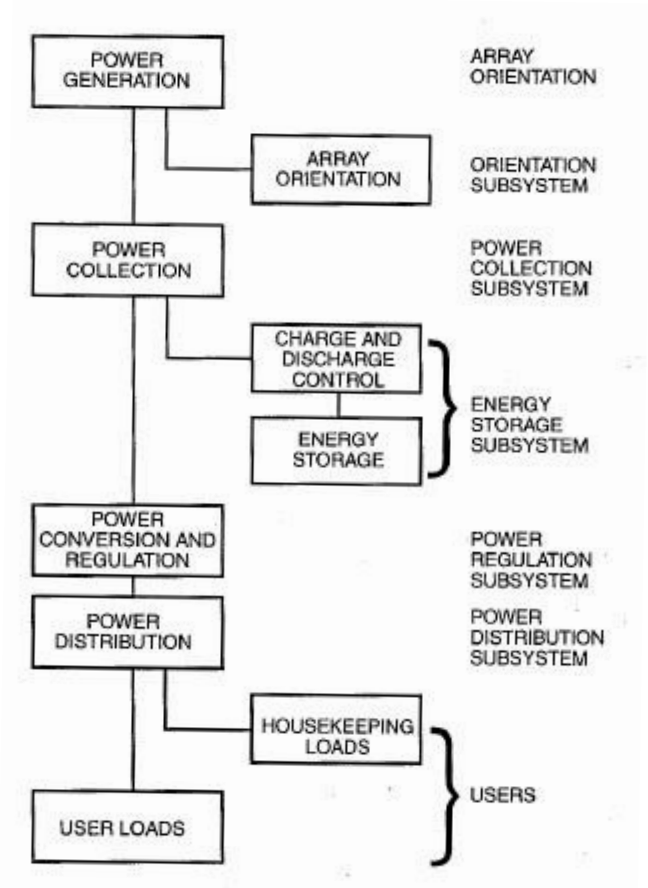


Figure 9.4: Spacecraft power system block diagram (Hyder et al.)

Solar PV – Battery System

- The most common electrical-power-generation system for spacecraft is the combination of solarphotovoltaic arrays and batteries as shown schematically in the following figure,

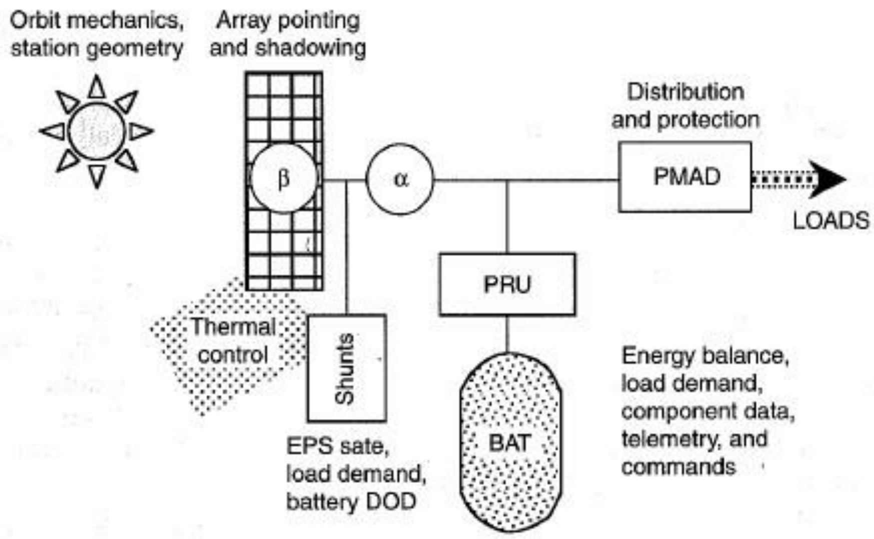


Figure 9.5: Photovoltaic- battery system (Patel).

PMAD = power management and distribution

PRU = power regulation unit

BAT = batteries

EPS = electrical power system

α = $\alpha-$drive,rotates 360° once per orbit

β = $\beta-$gimbals, rotate $\pm\beta°$ to compensate for the solar β angle

The PV Cell

▪ The building block of the solar array is the PV cell:

· Diode-type junction of two crystalline semiconductors

· Generates electricity directly under sunlight

· Photons transferred to electron system of the material, create charge carriers

· Charge carriers produce a potential gradient (voltage), circulate as current in an external circuit

· Concept illustrated in the following simple schematic,

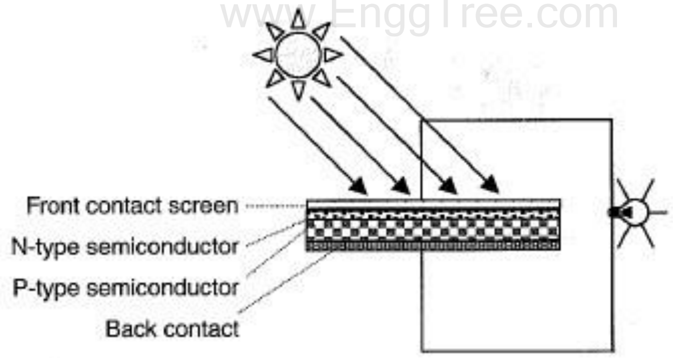


Figure 9.6: Photovoltaic cell cross-section (Patel).

The conversion efficiency of a PV cell is given by,

$$\eta = \frac{\text{electrical power output}}{\text{solar power incident on the cell}} = \frac{IV}{P_{SF}} \quad (9.2.1)$$

▪Conversion efficiency for three common PV cell materials:

Silicon (Si) 12-14%

Gallium arsenide/Germanium

(GaAs/Ge)	18-19%
GaInP2/GaAs/Ge	24-26%

▪ The useful energy absorption of the sunlight spectrum for silicon is illustrated in the following figure,

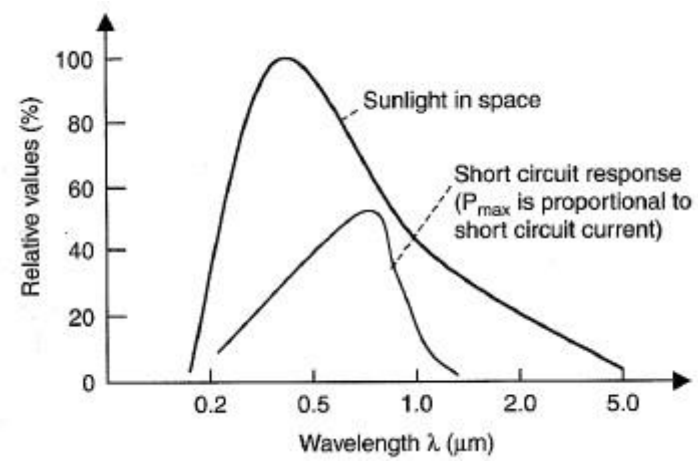


Figure 9.7: Sunlight spectrum and useable photovoltaic spectrum.

・About two-thirds of solar-radiation energy lies between wavelengths, 0.4 1.1 m.

・Silicon has a cut-off wavelength of about, 1.1 m.

・Radiation absorbed and not converted to electrical power is converted to heat in the cell material

Example:A photon of blue light, energy of 3 eV, generates about 0.5 eV of electricity and 2.5 eV of heat.

▪ Photon energy is given by,

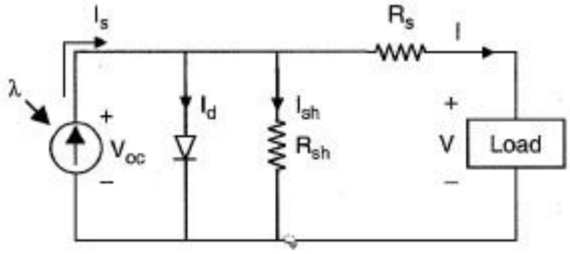
$$e_p = h\nu \qquad (9.2.2)$$

h Planck's constant $= 6.626 \times 10^{-34}$ J-s
ν = frequency, cps

$$= c/\lambda \qquad (9.2.3)$$

c speed of light 2.9979×10^{8} m/s
λ = wave length

- The complex physics of a PV cell can be represented by the electrical circuit in the following diagram,



where
and,
where

Figure 9.8: Photovoltaic-cell equivalent circuit (Patel).

- The cell acts as a constant current source shunted by a perfect diode:

Here, I_s = source or photo current
I_d = the diode current
I_{sh} = the ground shunt current
R_s = internal resistance of the material
R_{sh} = resistance to internal current leakage to ground

In an ideal PV cell, $R_s = 0$ (no series loss)
$R_{sh} = \infty$ (no leakage to ground)
In a typical silicon cell, $R_s = 0.05$ to $0.10\ \Omega$
$R_{sh} = 200$ to $300\ \Omega$

- The current delivered to the external load is,

$$I = I_s - I_d + I_{sh} \qquad (9.2.4)$$

- An important parameter for PV cells is the open-circuit voltage, V_{oc}, and is the case for zero load current, i.e. an open circuit, given by,

$$V_{oc} = V + IR_s \qquad (9.2.5)$$

- The diode current is given by the classical diode-current expression,

$$I_d = I_o\left[e^{qV_{oc}/AkT} - 1\right] \qquad (9.2.6)$$

where I_o = diode-saturation (dark) current
q = electron charge $= 0.1592 \times 10^{-18}$ coulombs
k = Boltzmann's constant $= 1.381 \times 10^{-23}$ J/K
T = absolute temperature, K
A = curve-fit constant

- From (3.4) & (3.6), the load current is,

$$I = I_s - I_o\left[e^{qV_{oc}/AkT} - 1\right] - \frac{V_{oc}}{R_{sh}} \qquad (9.2.7)$$

where V_{oc}/R_{sh} = ground leakage and can be ignored compared to I_s & I_d.

- The diode-saturation current is measured by applying an open-circuit voltage, V_{oc}, to the cell in the dark and measuring the current going to the cell.

- Under sunlight, the diode current, I_d, is small compared to I_s.

The *I-V* and *P-V* curves for a cell in sunlight are shown in the following figures,

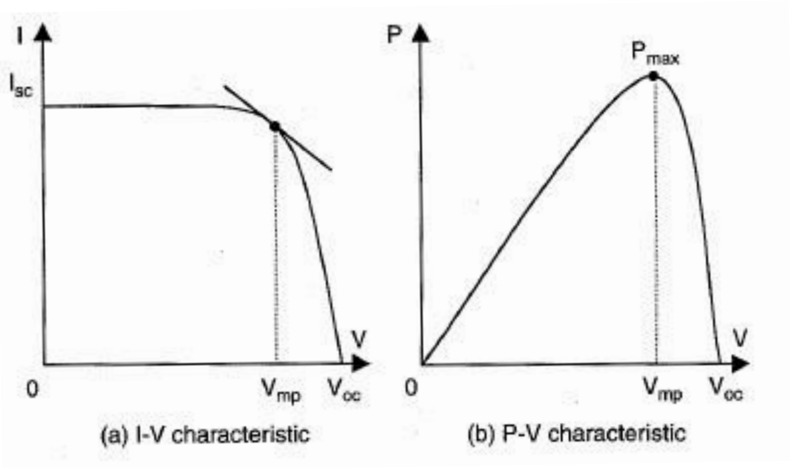


Figure 9.9: Photovoltaic-cell current-voltage and power-voltage characteristics (Patel).

· In figure (a), I_{sc} is the <u>short-circuit current</u> that is determined by shorting the output terminals and measuring the resultant current under <u>full sunlight</u>.

· Ignoring the small diode and ground leakage current in (2.7), the <u>short-circuit current</u> is ~ equal to the load current, where the load current is a <u>maximum</u>.

- This is the maximum current a cell can provide.

· At the bottom right of the curve, at zero current, is the <u>open-circuit voltage</u>, V_{oc}.

Ignoring ground-leakage current, the open-circuit voltage can be obtained from (3.7) for I 0, where,

$$I_s = I_o\left[e^{qV_{oc}/AkT} \quad 1\right]$$

or

$$V_{oc} \quad \frac{AkT}{q}\ln\left(\frac{I_s}{I_o}+1\right) \qquad (9.2.8)$$

· In practical photocells, the photo current I_s □ I_o.

· Under constant illumination, I_s/I_o is a function of cell temperature.

▪ Cell output power is the product of load current and voltage. The functional relationship is shown in (b) in the figure at the top.

• The maximum power of a photo cell occurs at the knee in the *I-V* curve.

- Solar panels are designed to operate at this point.
- Solar panels are modeled in the electrical system as a constant-current source, per (a) above.

• Typical photo-cell characteristics:

Material	Vmp, V	Imp, mA/cm^2	Pmp, mW/cm^2
Silicon	0.50	40	20
GaAs	1.0	30	30

▪ An important effect for solar-array design is PV-cell degradation from radiation of charged particles in space: Protons, electrons, alpha particles.

· Different particles have different damaging effect on I_{sc} & V_{oc}.

· Radiation levels measured in MeV (10^6 electron-volts) for a given period of time.

· Degradation of p/n GaAs solar cells is shown in the next figure for proton fluence,

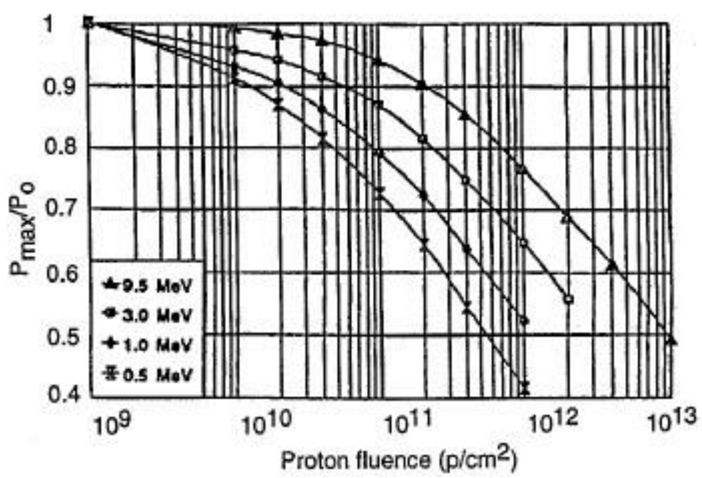


Figure 9.10: Photovoltaic-cell power output as a function of proton fluence (Hyder et al.).

Attitude Control & Orbit Control

The *attitude* of a satellite refers to its orientation in space. Much of the equipment carried aboard a satellite is meant for the purpose of controlling its attitude. Attitude control is necessary, to ensure that directional antennas point in the proper directions. In the case of earth environmental satellites, the earth-sensing instruments must cover the required regions of the earth, which also requires attitude control. A number of forces, referred to as *disturbance torques,* can alter the attitude, some examples being the gravitational fields of the earth and the moon, solar radiation, and meteorite impacts.

Attitude control must not be confused with station keeping, which is used for maintaining a satellite in its correct orbital position, although the two are closely related. To exercise attitude control, there must be available some measure of a satellite's orientation in space and of any tendency for this to shift. In one method, infrared sensors, referred to as *horizon detectors,* are used to detect the rim of the earth against the background of space.

With the use of four such sensors, one for each quadrant, the center of the earth can be readily established as a reference point. The attitude-control process takes place aboard the satellite, but it is also possible for control signals to be transmitted from earth, based on attitude data obtained from the satellite. Whenever a shift in attitude is desired, an *attitude maneuver* is executed. The control signals needed to achieve this maneuver may be transmitted from an earth station.

Controlling torques may be generated in a number of ways. *Passive attitude control* refers to the use of mechanisms which stabilize the satellite without putting a drain on the satellite's energy supplies; at most, infrequent use is made of these supplies, for example, when thruster jets are impulsed to provide corrective torque. Examples of passive attitude control are *spin stabilization* and *gravity gradient stabilization*.

The other form of attitude control is *active control*. With active attitude control, there is no overall stabilizing torque present to resist the disturbance torques. Instead, corrective torques are applied in response to disturbance torques. Methods used to generate active control torques include momentum wheels, electromagnetic coils, and mass expulsion devices, such as gas jets and ion thrusters.

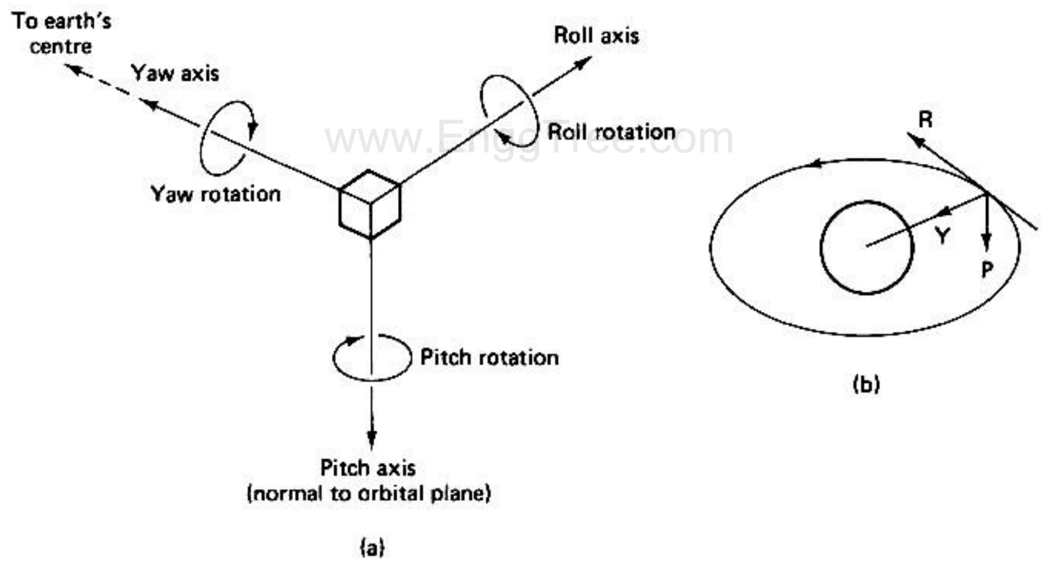


Fig 2.3 Roll, Pitch, and Yaw Axes (*b*) RPY axes for Geostationary Orbit

The three axes which define a satellite's attitude are its *roll*, *pitch*, and *yaw* (RPY) axes. These are shown relative to the earth in Figure 2.3. All three axes pass through the center of gravity of the satellite. For an equatorial orbit, movement of the satellite about the roll axis moves the antenna footprint north and south; movement about the pitch axis moves the footprint east and west; and movement about the yaw axis rotates the antenna footprint.

Spinning Satellite Stabilization

Spin stabilization may be achieved with cylindrical satellites. The satellite is constructed so that it is mechanically balanced about one particular axis and is then set spinning around this axis. For geostationary satellites, the spin axis is adjusted to be parallel to the N-S axis of the earth, as illustrated in Figure 2.4. Spin rate is typically in the range of 50 to 100 rev/minute. Spin is initiated during the launch phase by means of small gas jets.

In the absence of disturbance torques, the spinning satellite would maintain its correct attitude relative to the earth. Disturbance torques are generated in a number of ways, both external and internal to the satellite.

Solar radiation, gravitational gradients, and meteorite impacts are all examples of external forces which can give rise to disturbance torques. Motor-bearing friction and the movement of satellite elements such as the antennas also can give rise to disturbance torques.

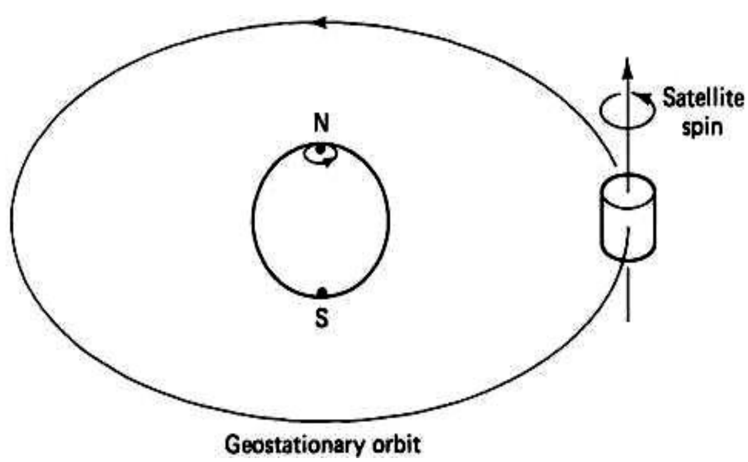


Fig 2.4 Spin stabilization in the geostationary orbit

The overall effect is that the spin rate will decrease, and the direction of the angular spin axis will change. Impulse-type thrusters, or jets, can be used to increase the spin rate again and to shift the axis back to its correct N-S orientation.

Nutation, which is a form of wobbling, can occur as a result of the disturbance torques and/or from misalignment or unbalance of the control jets. This nutation must be damped out by means of energy absorbers known as *nutation dampers*. The antenna feeds can be connected directly to the transponders without the need for radiofrequency rotary joints, while the complete platform is despun. Of course, control signals and power must be transferred to the despun section and a mechanical bearing must be provided. The complete assembly for this is known as the *bearing and power transfer assembly* (BAPTA). Figure 2.5 shows a photograph of the internal structure of the HS 376.

Certain dual-spin spacecraft obtain spin stabilization from a spinning fly- wheel rather than by spinning the satellite itself. These flywheels are termed *momentum wheels*, and their average momentum is referred to as *momentum bias.*

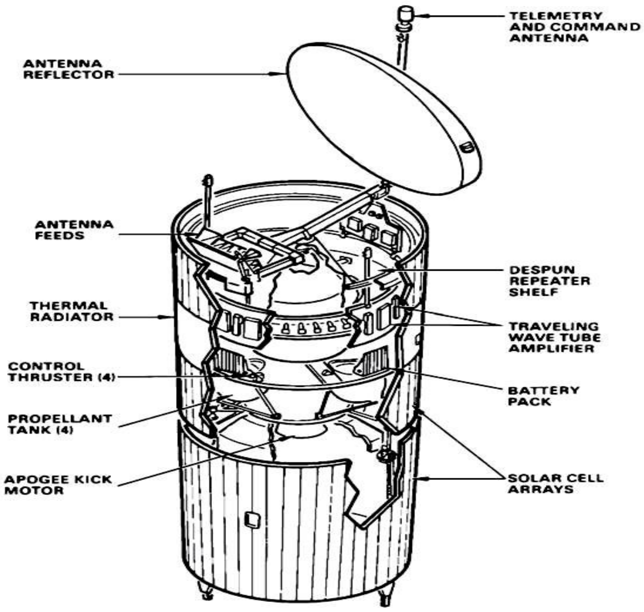


Fig 2.5 HS 376 Spacecraft

Momentum wheel stabilization

In the previous section the gyroscopic effect of a spinning satellite is shown to provide stability for the satellite attitude. Stability also can be achieved by utilizing the gyroscopic effect of a spinning flywheel, and this approach is used in satellites with cube-like bodies and the INTELSAT V type satellites. These are known as *body-stabilized* satellites. The complete unit, termed a momentum wheel, consists of a flywheel, the bearing assembly, the casing, and an electric drive motor with associated electronic control circuitry. The flywheel is attached to the rotor, which consists of a permanent magnet providing the magnetic field for motor action. The stator of the motor is attached to the body of the satellite. Thus the motor provides the coupling between the flywheel and the satellite structure. Speed and torque control of the motor is exercised through the currents fed to the stator.

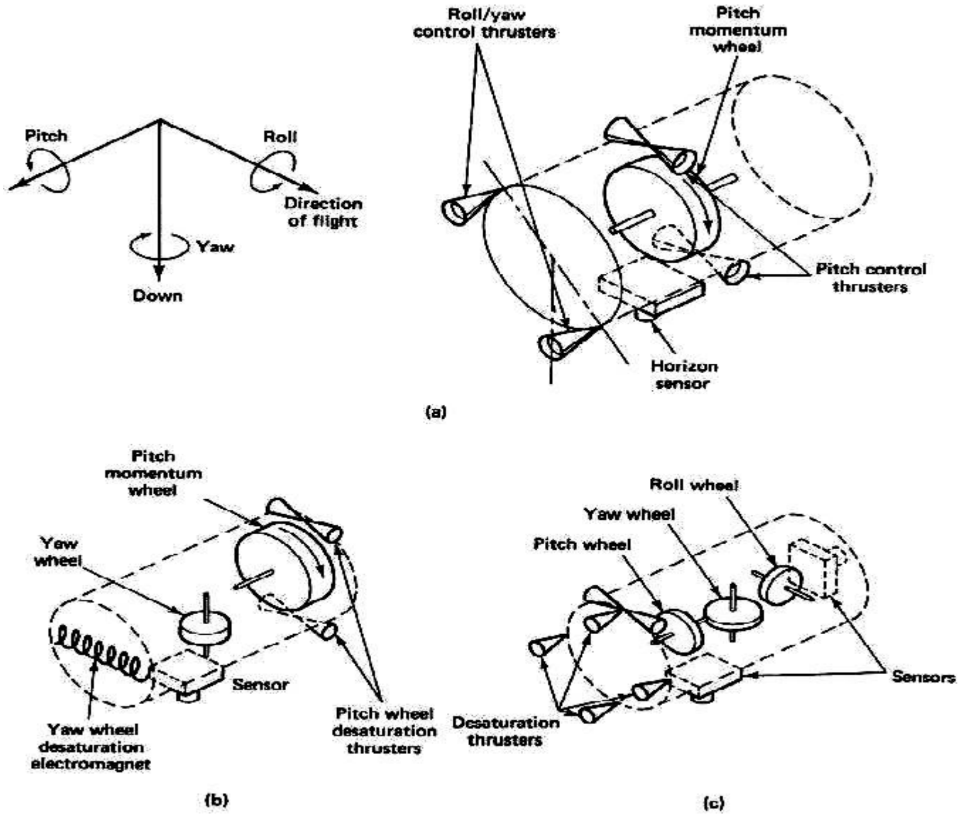


Fig 2.6 Alternative momentum wheel stabilization systems: (*a*) one-wheel, (*b*) two- wheel, (*c*) three- wheel

When a momentum wheel is operated with zero momentum bias, it is generally referred to as a *reaction wheel*. Reaction wheels are used in three- axis stabilized systems. Here each axis is stabilized by a reaction wheel, as shown in Figure 2.6. Reaction wheels can also be combined with a momentum wheel to provide the control needed.

Random and cyclic disturbance torques tends to produce zero momentum on average. However, there will always be some disturbance torques that causes a cumulative increase in wheel momentum, and eventually at some point the wheel *saturates*. In effect, it reaches its maximum allowable angular velocity and can no longer take in any more momentum. Mass expulsion devices are then used to unload the wheel, remove momentum from it. The operation of the mass expulsion devices consumes part of the satellite’s fuel supply.

Thermal Control and Propulsion

Satellites are subject to large thermal gradients, receiving the sun's radiation on one side while the other side faces into space. In addition, thermal radiation from the earth and the earth's *albedo*, which is the fraction of the radiation falling on earth which is reflected, can be significant for low-altitude earth-orbiting satellites, although it is negligible for geostationary satellites.

Equipment in the satellite also generates heat which has to be removed. The most important consideration is that the satellite's equipment should operate as nearly as possible in a stable temperature environment. Thermal blankets and shields may be used to provide insulation. Radiation mirrors are often used to remove heat from the communications payload.

The mirrored thermal radiator for the Hughes HS 376 satellite can be seen in Figure 2.5. These mirrored drums surround the communications equipment shelves in each case and provide good radiation paths for the generated heat to escape into the surrounding space.

One advantage of spinning satellites compared with body-stabilized is that the spinning body provides an averaging of the temperature extremes experienced from solar flux and the cold back-ground of deep space. In order to maintain constant temperature conditions, heaters may be switched on to make up for the heat reduction which occurs when transponders are switched off. The INTELSAT VI satellite heaters are used to maintain propulsion thrusters and line temperatures.

Communication Payload and Supporting Subsystems

The physical principle of establishing communication connections between remote communication devices dates back to the late 1800s when scientists were beginning to understand electromagnetism and discovered that electromagnetic radiation generated by one device can be detected by another located at some distance away.

By controlling certain aspects of the radiation, useful information can be embedded in the EM waves and transmitted from one device to another. The second major module is the communication payload, which is made up of transponders. A transponder is capable of -

- Receiving uplinked radio signals from earth satellite transmission stations (antennas).
- Amplifying received radio signals.
- Sorting the input signals and directing the output signals through input/output signal multiplexers to the proper downlink antennas for retransmission to earth satellite receiving stations (antennas).

Telemetry, Tracking and Command Subsystem (TTC)

The TT&C subsystem performs several routine functions aboard the spacecraft. The telemetry function could be interpreted as *measurement at a distance*. It refers to the overall operation of generating an electrical signal proportional to the quantity being measured and encoding and transmitting this to a distant station, which for the satellite is one of the earth stations.

Data transmitted as telemetry signals include attitude information such as that obtained from sun and earth sensors; environmental information such as the magnetic field intensity and direction, the frequency of meteorite impact etc and spacecraft information such as temperatures, power supply voltages, and stored-fuel pressure.

The telemetry subsystem transmits information about the satellite to the earth station, while the command subsystem receives command signals from the earth station, often in response to telemetered information. The command subsystem demodulates and decodes the command signals and routes these to the appropriate equipment needed to execute the necessary action. Thus attitude changes may be made, communication transponders switched in and out of circuits, antennas redirected, and station-keeping maneuvers carried out on command. It is important to prevent unauthorized commands from being received and decoded, and the command signals are often encrypted.

Encrypt is derived from a Greek word *kryptein,* meaning *to hide,* and represents the process of concealing the command signals in a secure code. This differs from the normal process of encoding which converts characters in the command signal into a code suitable for transmission. Tracking of the satellite is accomplished by having the satellite transmit beacon signals which are received at the TT&C earth stations. Tracking is obviously important during the transfer and drift orbital phases of the satellite launch. Once it is on station, the position of a geo-stationary satellite will tend to be shifted as a result of the various disturbing forces. Therefore, it is necessary to be able to track the satellite's movement and send correction signals as required.

Transponders

A transponder is the series of interconnected units which forms a single communications channel between the receive and transmit antennas in a communications satellite. Some of the units utilized by a transponder in a given channel may be common to a number of transponders. Thus, although reference may be made to a specific transponder, this must be thought of as an equipment *channel* rather than a single item of equipment.

Before describing in detail the various units of a transponder, the overall frequency arrangement of a typical C-band communications satellite will be examined briefly. The bandwidth allocated for C-band service is 500 MHz, and this is divided into sub-bands, one transponder.

A typical transponder bandwidth is 36 MHz, and allowing for a 4-MHz guard-band between transponders, 12 such transponders can be accommodated in the 500-MHz bandwidth.

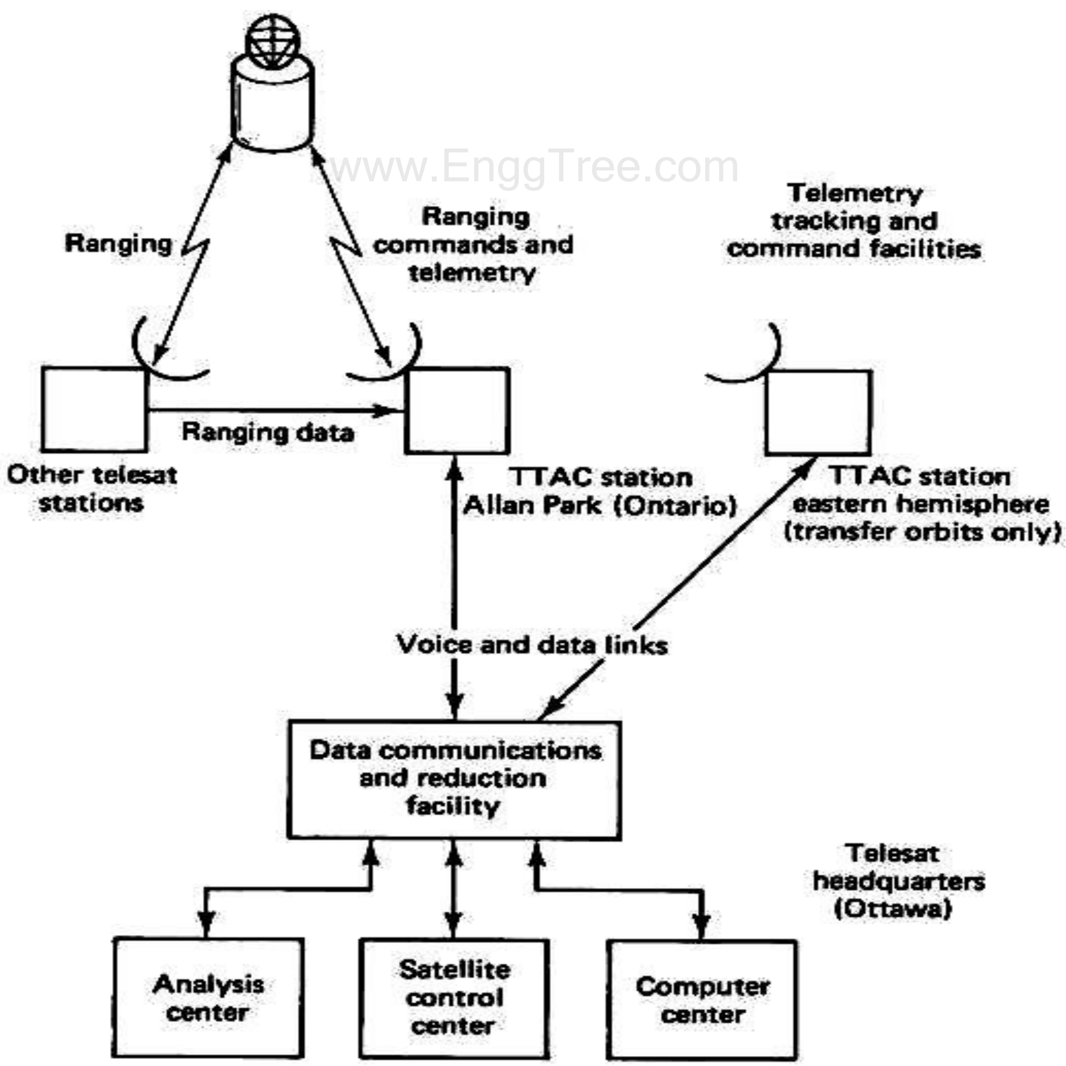
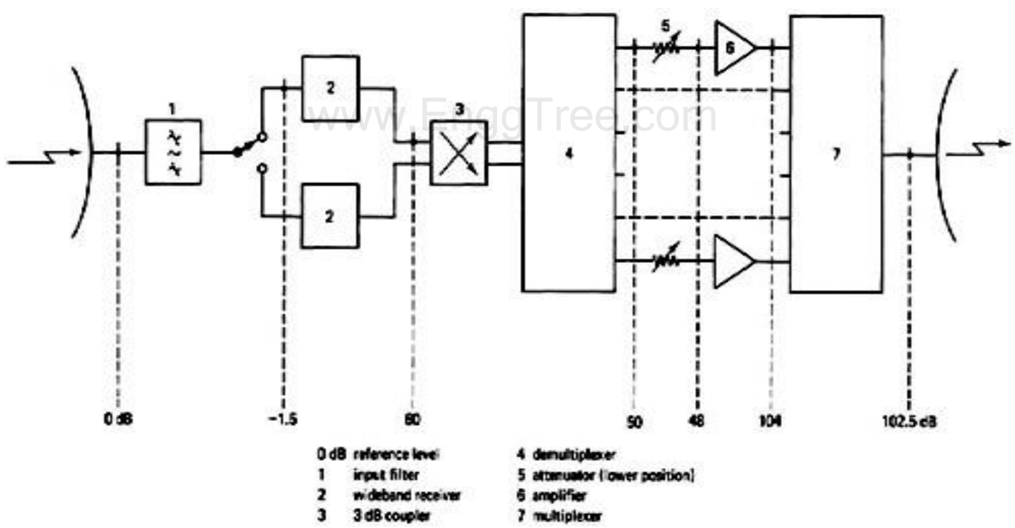


Fig 2.7 Satellite Control System

By making use of *polarization isolation*, this number can be doubled. Polarization isolation refers that carriers, which may be on the same frequency but with opposite senses of polarization, can be isolated from one another by receiving antennas matched to the incoming polarization. With linear polarization, vertically and horizontally polarized carriers can be separated in this way, and with circular polarization, left-hand circular and right-hand circular polarizations can be separated. Because the carriers with opposite senses of polarization may overlap in frequency, this technique is referred to as *frequency reuse*. Figure 2.8 shows part of the frequency and polarization plan for a C-band communications satellite.



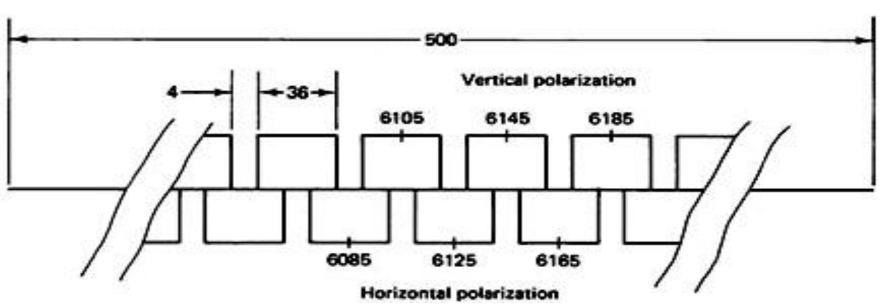


Fig 2.8 Section of an Uplink Frequency and Polarization Plan

Frequency reuse also may be achieved with spot-beam antennas, and these may be combined with polarization reuse to provide an effective bandwidth of 2000 MHz from the actual bandwidth of 500 MHz. For one of the polarization groups, Figure 2.8 shows the channeling scheme for the 12 transponders in more detail. The incoming, or uplink, frequency range is 5.925 to 6.425 GHz. The frequency conversion shifts the carriers to the downlink frequency band, which is also 500 MHz wide, extending from 3.7 to 4.2 GHz. At this point the signals are channelized into frequency bands which represent the individual transponder bandwidths.

The wideband receiver

The wideband receiver is shown in more detail in Fig. 2.10. A duplicate receiver is provided so that if one fails, the other is automatically switched in. The combination is referred to as a *redundant receiver*, meaning that although two are provided, only one is in use at a given time.

The first stage in the receiver is a *low-noise amplifier* (LNA). This amplifier adds little noise to the carrier being amplified, and at the same time it provides sufficient amplification for the carrier to override the higher noise level present in the following mixer stage.

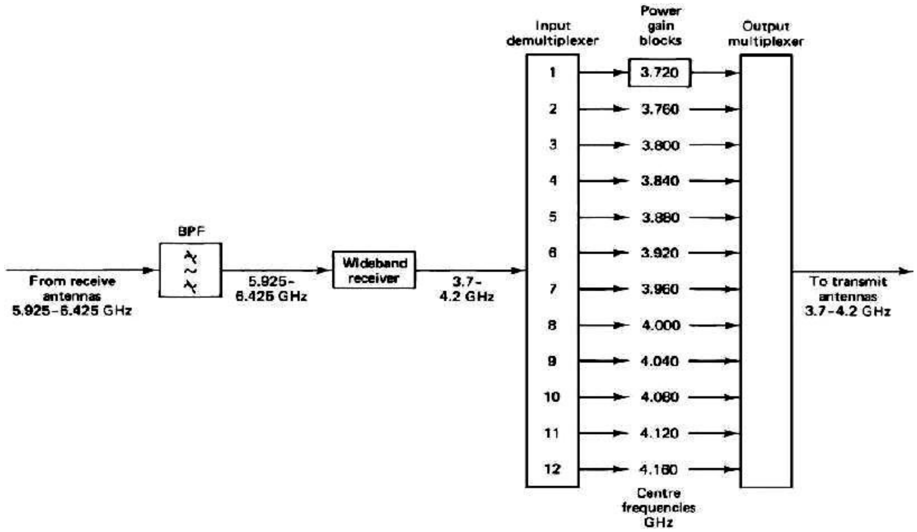


Fig 2.9 Satellite Transponder Channels

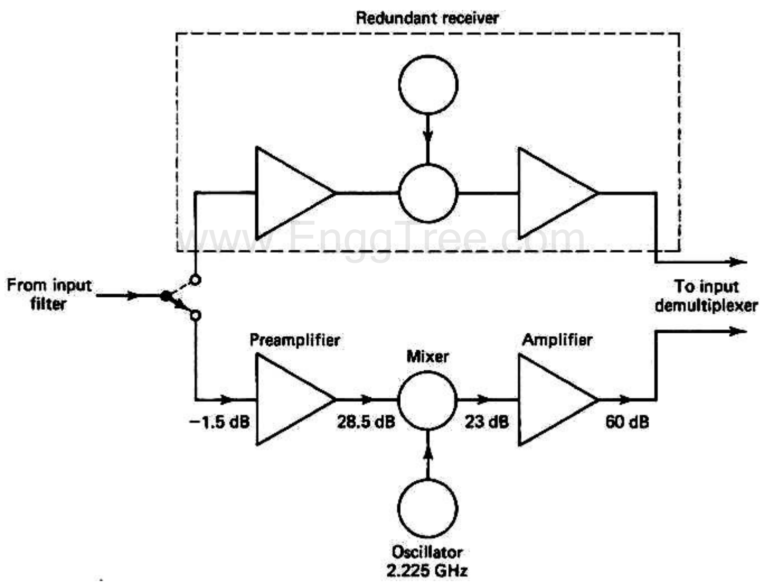


Fig 2.10 Satellite Wideband Receiver

It is more convenient to refer all noise levels to the LNA input, where the total receiver noise may be expressed in terms of an equivalent noise temperature. In a well-designed receiver, the equivalent noise temperature referred to the LNA input is basically that of the LNA alone. The overall noise temperature must take into account the noise added from the antenna. The equivalent noise temperature of a satellite receiver may be on the order of a few hundred kelvins.

The LNA feeds into a mixer stage, which also requires a *local oscillator* (LO) signal for the frequency-conversion process. With advances in *field-effect transistor* (FET) technology, FET amplifiers, which offer equal or better performance, are now available for both bands. Diode mixer stages are used. The amplifier following the mixer may utilize *bipolar junction transistors* (BJTs) at 4 GHz and FETs at 12 GHz, or FETs may in fact be used in both bands.

The input de-multiplexer

The input de-multiplexer separates the broadband input, covering the frequency range 3.7 to 4.2 GHz, into the transponder frequency channels. This provides greater frequency separation between adjacent channels in a group, which reduces adjacent channel interference. The output from the receiver is fed to a power splitter, which in turn feeds the two separate chains of circulators.

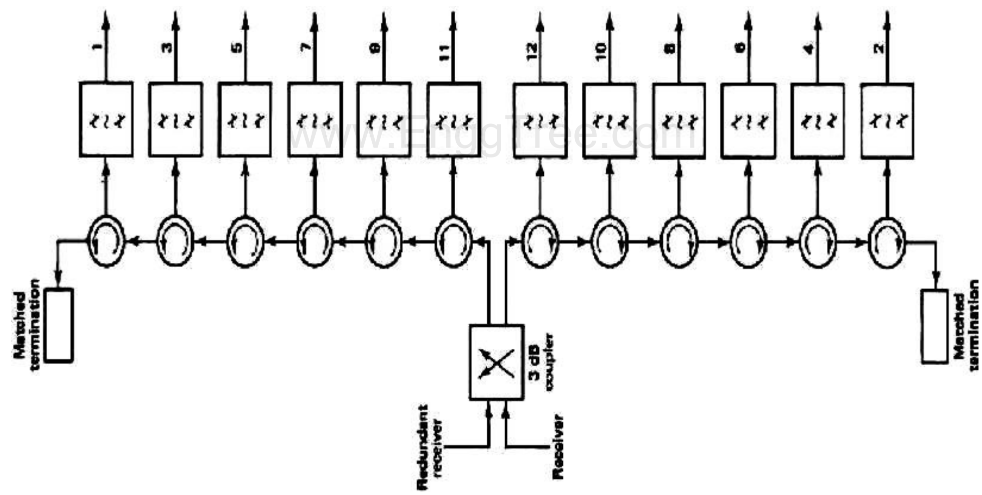


Fig 2.11 Satellite Input Multiplexer

The full broadband signal is transmitted along each chain, and the channelizing is achieved by means of channel filters connected to each circulator. Each filter has a bandwidth of 36 MHz and is tuned to the appropriate center frequency, as shown in Fig. 2.11. Although there are considerable losses in the demultiplexer, these are easily made up in the overall gain for the transponder channels.

The power amplifier

The fixed attenuation is needed to balance out variations in the input attenuation so that each transponder channel has the same nominal attenuation, the necessary adjustments being made during assembly. The variable attenuation is needed to set the level as required for different types of service. Because this variable attenuator adjustment is an operational requirement, it must be under the control of the ground TT&C station.

Traveling-wave tube amplifiers (TWTAs) are widely used in transponders to provide the final output power required to the transmit antenna. Figure 2.12 shows the schematic of a *traveling wave tube* (TWT) and its power supplies. In the TWT, an electron-beam gun assembly consisting of a heater, a cathode, and focusing electrodes is used to form an electron beam. A magnetic field is required to confine the beam to travel along the inside of a wire helix.

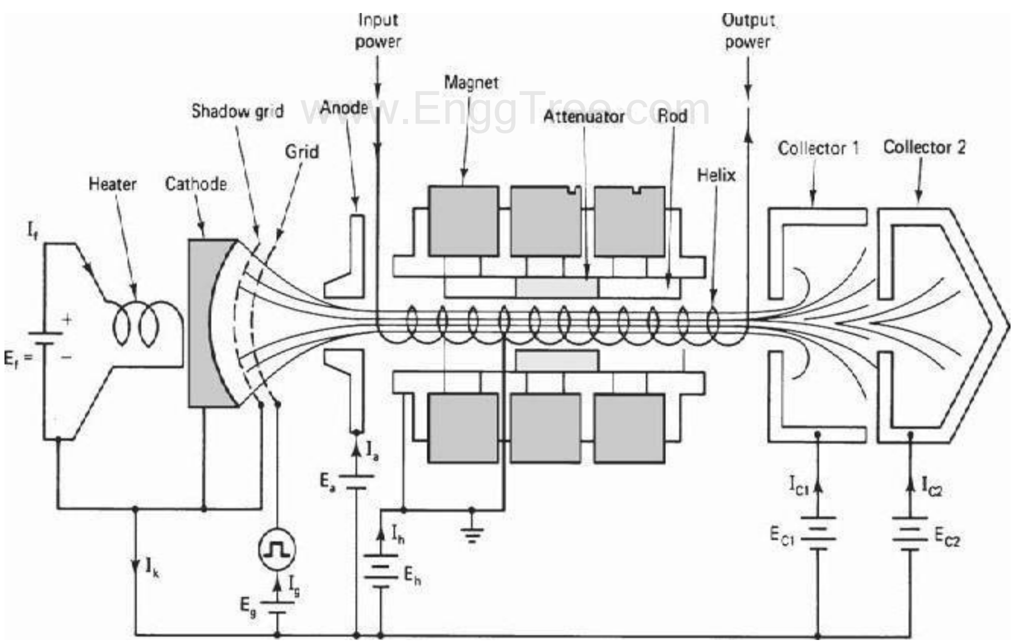


Fig 2.12 Satellite TWTA

The magnetic field can be provided by means of a solenoid and dc power supply. The comparatively large size and high power consumption of solenoids make them unsuitable for use aboard satellites and lower-power TWTs are used which employ permanent-magnet focusing. The wave will travel around the helical path at close to the speed of light, but it is the axial component of wave velocity which interacts with the electron beam.

This component is less than the velocity of light approximately in the ratio of helix pitch to circumference. Because of this effective reduction in phase velocity, the helix is referred to as a *slow wave structure*. The advantage of the TWT over other types of tube amplifiers is that it can provide amplification over a very wide bandwidth. Input levels to the TWT must be carefully controlled, however to minimize the effects of certain forms of distortion. The results from the nonlinear transfer characteristic of the TWT are illustrated in Figure 2.13.

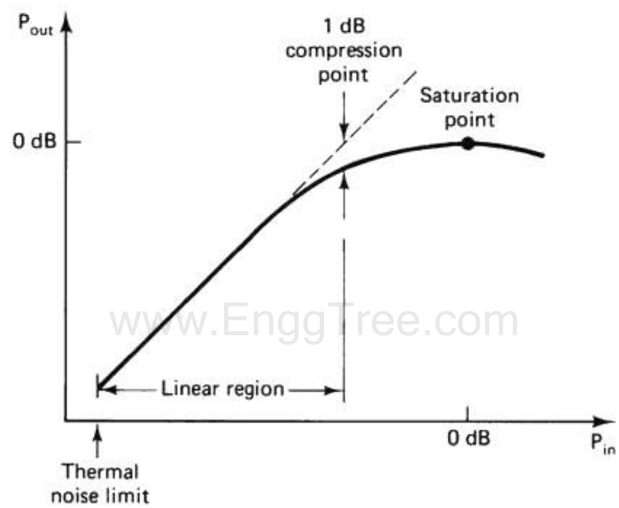


Fig 2.13 Power Transfer Characteristics of a TWT

At low-input powers, the output-input power relationship is linear. At higher power inputs, the output power saturates, the point of maximum power output being known as the *saturation point.* The saturation point is a very convenient reference point and input and output quantities are usually referred to it. The linear region of the TWT is defined as the region bound by the thermal noise limit at the low end and by what is termed the *1-dB compression point* at the upper end. This is the point where the actual transfer curve drops.

Satellite Uplink and Downlink Analysis and Design

Introduction

The link-power budget calculations basically relate two quantities, the transmit power and the receive power, and show in detail how the difference between these two powers is accounted for. Link-budget calculations are usually made using decibel or decilog quantities. Where no ambiguity arises regarding the units, the abbreviation dB is used. For example, Boltzmann's constant is given as 228.6 dB, although, strictly speaking, this should be given as 228.6 deci logs relative to 1 J/K.

Equivalent Isotropic Radiated Power

A key parameter in link-budget calculations is the *equivalent isotropic radiated power,* conventionally denoted EIRP. The maximum power flux density at some distance '*r*' for transmitting antenna of gain '*G* i'

$$\mathrm{Pr} = \frac{GP}{4\pi^2}$$

An isotropic radiator with an input power equal to GP*S* would produce the same flux density. Hence, this product is referred to as the EIRP, or EIRP is often expressed in decibels relative to 1 W, or dBW. Let *PS* be in watts; then [EIRP] = [*PS*] x [*G*] dB , where [*PS*] is also in dBW and [*G*] is in dB.

Transmission Losses

The [EIRP] may be thought of as the power input to one end of the transmission link, and the problem is to find the power received at the other end. Losses will occur along the way, some of which are constant. Other losses can only be estimated from statistical data, and some of these are dependent on weather conditions, especially on rainfall.

The first step in the calculations is to determine the losses for *clear- weather* or *clear-sky conditions*. These calculations take into account the losses, including those calculated on a statistical basis which does not vary with time. Losses which are weather-related, and other losses which fluctuate with time, are then allowed for by introducing appropriate *fade margins* into the transmission equation.

Free-space transmission:

As a first step in the loss calculations, the power loss resulting from the spreading of the signal in space must be determined.

Feeder losses:

Losses will occur in the connection between the receive antenna and the receiver proper. Such losses will occur in the connecting waveguides, filters, and couplers. These will be denoted by RFL, or [RFL] dB, for *receiver feeder losses*.

Antenna misalignment losses:

When a satellite link is established, the ideal situation is to have the earth station and satellite antennas aligned for maximum gain, as shown in Figure 2.14. There are two possible sources of off-axis loss, one at the satellite and one at the earth station. The off-axis loss at the satellite is taken into account by designing the link for operation on the actual satellite antenna contour; this is described in more detail in later sections. The off-axis loss at the earth station is referred to as the *antenna pointing loss*. Antenna pointing losses are usually only a few tenths of a decibel. In addition to pointing losses, losses may result at the antenna from misalignment of the polarization direction. The polarization misalignment losses are usually small, and it will be assumed that the antenna misalignment losses, denoted by [AML], include both pointing and polarization losses resulting from antenna misalignment.

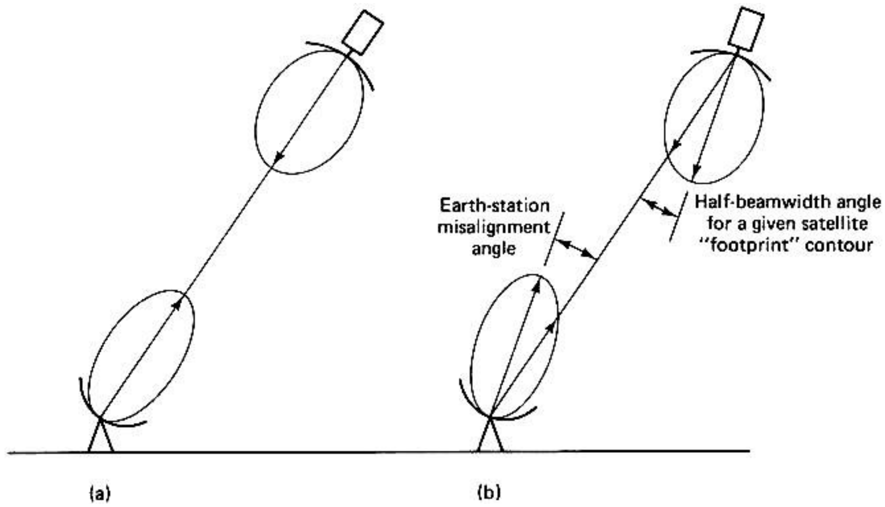


Fig 2.14 (*a*) Satellite and earth-station antennas aligned for maximum gain; (*b*) earth station situated on a
given satellite "footprint," and earth-station antenna misaligned.

The Link-Power Budget Equation

The losses for the link have been identified, the power at the receiver, which is the power output of the link, may be calculated simply as [EIRP] [LOSSES] [*GR*], where the last quantity is the receiver antenna gain. The major source of loss in any ground-satellite link is the free-space spreading loss [FSL], the basic link-power budget equation taking into account this loss only. However, the other losses also must be taken into account, and these are simply added to [FSL].

The losses for clear-sky conditions are

[LOSSES] = [FSL] +[RFL] +[AML]+[AA] -[PL] equation for the

received power is then [PR] = [EIRP] X [GR] -[LOSSES]

Whe
re

[PR] - the received power, dBW

[EIRP] - equivalent isotropic radiated power, dBW [FSL] free-

space spreading loss, dB [RFL] - receiver feeder loss, dB

[AML] -antenna misalignment loss, dB

[AA] - atmospheric absorption loss, dB [PL] polarization mismatchloss, dB

2.8.1 Amplifier Noise Temperature

Consider first the noise representation of the antenna and the *low noise amplifier* (LNA) shown in Fig. 2.15. The available power gain of the amplifier is denoted as G, and the noise power output, as P_{no}.

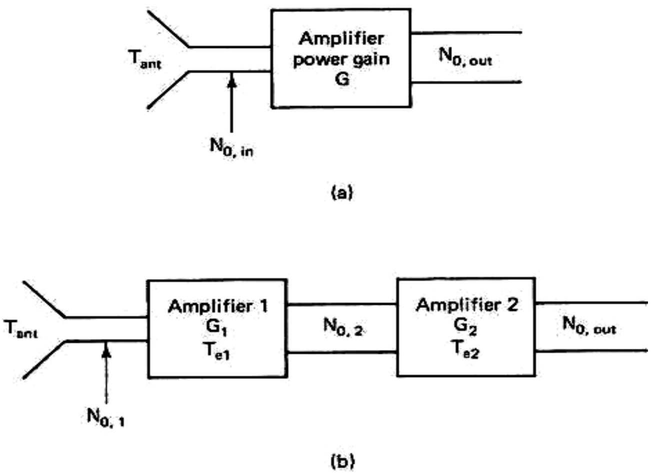


Fig 2.15 LNA Amplifier Gain

For the moment, the noise power per unit bandwidth, which is simply noise energy in joules as shown by the following Equation. The input noise energy coming from the antenna is

$$N_{0,\text{ant}} = kT_{\text{ant}}$$

The Uplink

The uplink of a satellite circuit is the one in which the earth station is transmitting the signal and he satellite is receiving it t specifically that the uplink is being considered.

$$\frac{C}{N} = [EIRP] - [LOSSES] + [k]$$

In the above equation, the values to be used are the earth station EIRP, the satellite receiver feeder losses, and satellite receiver G/T. The free-space loss and other losses which are frequency-dependent are calculated for the uplink frequency.

Input back-off

Since the number of carriers are present simultaneously in a TWTA, the operating point must be backed off to a linear portion of the transfer characteristic to reduce the effects of inter modulation distortion. Such multiple carrier operation occurs with *frequency- division multiple access* (FDMA). The point to be made here is that *backoff* (BO) must be allowed for in the link- budget calculations. Suppose that the saturation flux density for single-carrier operation is known. Input BO will be specified for multiple-carrier operation, referred to the single- carrier saturation level.

The earth-station EIRP will have to be reduced by the specified BO,

resulting in an uplink value of $[\mathrm{EIRP}]_U = [\mathrm{EIRP}_S]_U + [\mathrm{BO}]_i$

The earth station HPA

The earth station HPA has to supply the radiated power plus the transmit feeder losses, denoted here by TFL, or [TFL] dB. These include waveguide, filter, and coupler losses between the HPA output and the transmit antenna. The earth station may have to transmit multiple carriers and its output also will require back off, denoted by $[\mathrm{BO}]_{\mathrm{HPA}}$. The earth station HPA must be rated for a saturation power output given by

$$[P_{\mathrm{HPA,sat}}] = [P_{\mathrm{HPA}}] + [\mathrm{BO}]_{\mathrm{HPA}}$$

Downlink

The downlink of a satellite circuit is the one in which the satellite is transmitting the signal and the earth station is receiving it. Equation can be applied to the downlink, but subscript D will be used to denote specifically that the downlink is being considered.

$$\frac{C}{N} = [EIRP] - [LOSSES] + [k]$$

In the above equation, the values to be used are the satellite EIRP, the earth- station receiver feeder losses, and the earth-station receiver *G*/*T*. The free space and other losses are calculated for the downlink frequency. The resulting carrier-to-noise density ratio appears at the detector of the earth station receiver.

Output back-off

Where input BO is employed as described in a corresponding output BO must be allowed for in the satellite EIRP. As the curve of Figure 2.16 shows that output BO is not linearly related to input BO. A rule of thumb, frequently used, is to take the output BO as the point on the curve which is 5 dB below the extrapolated linear portion. Since the linear portion gives a 1:1 change in decibels, the relationship between input and output BO is $[BO]_0$ $[BO]_i$ 5 dB. For example, with an input BO of $[BO]_i$ 11 dB, the corresponding output BO is $[BO]_0$

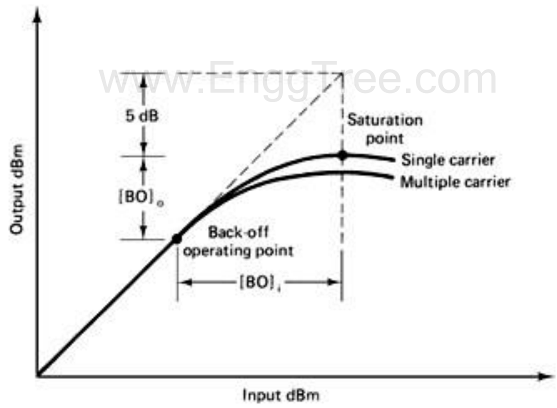


Fig 2.16 Input and output back- off relationship for the satellite traveling-wave-tube amplifier

Effects of Rain

In the C band and, more especially, the Ku band, rainfall is the most significant cause of signal fading. Rainfall results in attenuation of radio waves by scattering and by absorption of energy from the wave. Rain attenuation increases with increasing frequency and is worse in the Ku band compared with the C band. This produces a depolarization of the wave; in effect, the wave becomes elliptically polarized. This is true for both linear and circular polarizations, and the effect seems to be much worse for circular polarization. The C/N_0 ratio for the downlink alone, not counting the P_{NU} contribution, is P_R/P_{ND}, and the combined C/N_0 ratio at the ground receiver is

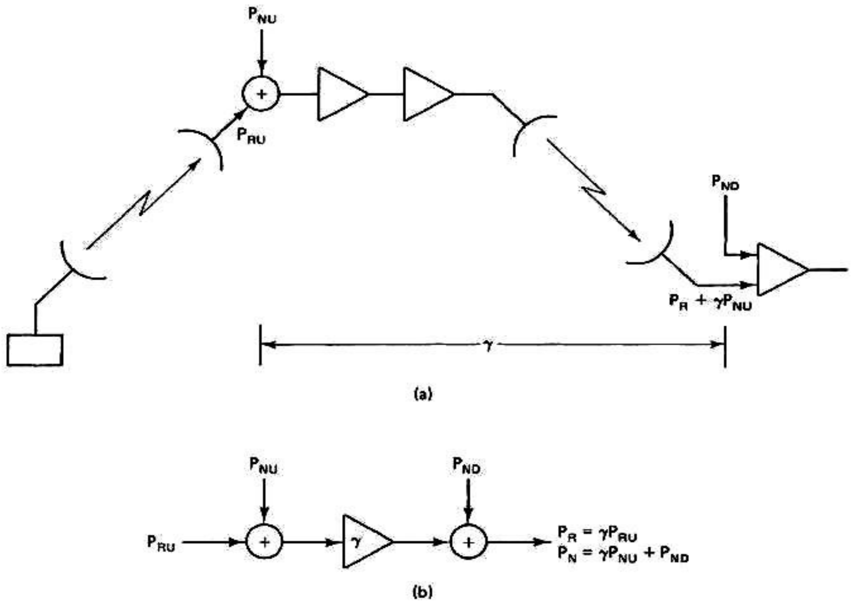


Fig 2.17 (*a*) Combined uplink and downlink (*b*) power flow diagram

The reason for this reciprocal of the sum of the reciprocals method is that a single signal power is being transferred through the system, while the various noise powers, which are present are additive. Similar reasoning applies to the carrier-to-noise ratio, C/N.

Inter-modulation and Interference

Inter-modulation interference is the undesired combining of several signals in a nonlinear device, producing new, unwanted frequencies which can cause interference in adjacent receivers located at repeater sites. Not all interference is a result of inter-modulation distortion. It can come from co-channel interference, atmospheric conditions as well as man-made noise generated by medical, welding and heating equipment.

Most inter-modulation occurs in a transmitter's nonlinear power amplifier (PA). The next most common mixing point is in the front end of a receiver. Usually it occurs in the unprotected first mixer of older model radios or in some cases an overdriven RF front-end amp.

Inter-modulation can also be produced in rusty or corroded tower joints, guy wires, turnbuckles and anchor rods or any nearby metallic object, which can act as a nonlinear "mixer/rectifier" device.

3.1 Satellite Uplink and Downlink Analysis and Design

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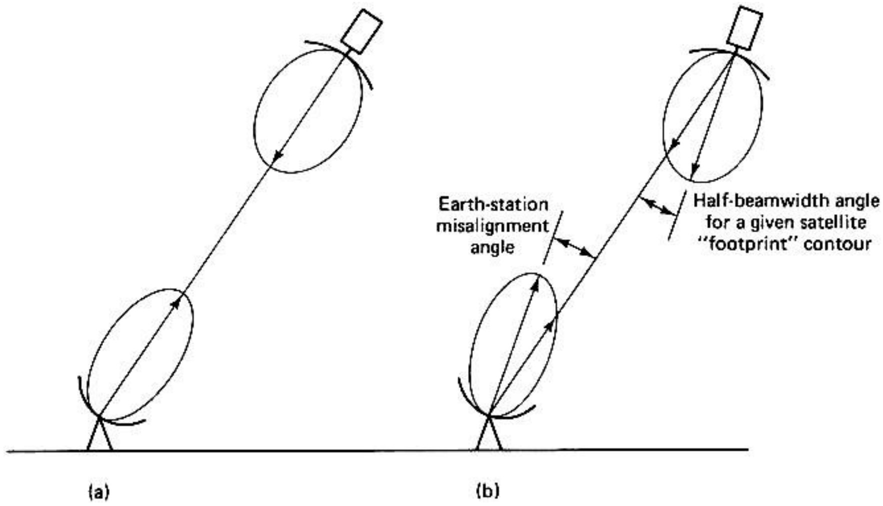

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received power is then [P_R] = [EIRP] X [G_R] -[LOSSES]

Where

[PR] - the received power, dBW

[EIRP] - equivalent isotropic radiated power, dBW [FSL] free-space

spreading loss, dB [RFL] - receiver feeder loss, dB

[AML] -antenna misalignment loss, Db [AA] - atmospheric absorption loss, dB [PL] polarization mismatchloss, dB

Ionospheric scintillation

Ionospheric scintillation is a rapid fluctuation of radio-frequency signal phase and/or amplitude, generated as a signal passes through the ionosphere. Scintillation occurs when a radio frequency signal in the form of a plane wave traverses a region of small scale irregularities in electron density. The irregularities cause small-scale fluctuations in refractive index and subsequent differential diffraction (scattering) of the plane wave producing phase variations along the phase front of the signal. As the signal propagation continues after passing through the region of irregularities, phase and amplitude scintillation develops through interference of multiple scattered signals.

Ionospheric scintillation is a well-known phenomenon that has been studied extensively in the past yet it remains a difficult phenomenon to predict or model on a large scale. Scintillation is caused by small-scale fluctuations in the refractive index of the ionospheric medium which in turn are the result of inhomogeneities. Inhomogeneities in the ionospheric medium are produced by a wide range of phenomena (eg plasma bubbles), and those responsible for scintillation occur predominantly in the F-layer of the ionosphere at altitudes between 200 and 1000km. The primary disturbance region, however, is typically in the F-region between 250 and 400km. E-layer irregularities such as sporadic-E and auroral E can also produce scintillation but their effect on L-band GPS signals is minimal.

Ionospheric scintillation is primarily an equatorial and high-latitude ionospheric phenomenon, although it can (and does) occur at lower intensity at all latitudes.

In terms of geographic (geomagnetic) distribution, ionospheric scintillation generally peaks in the sub-equatorial anomaly regions, located on average ~15° either side of the geomagnetic equator, as can be seen in Figure 1, below.

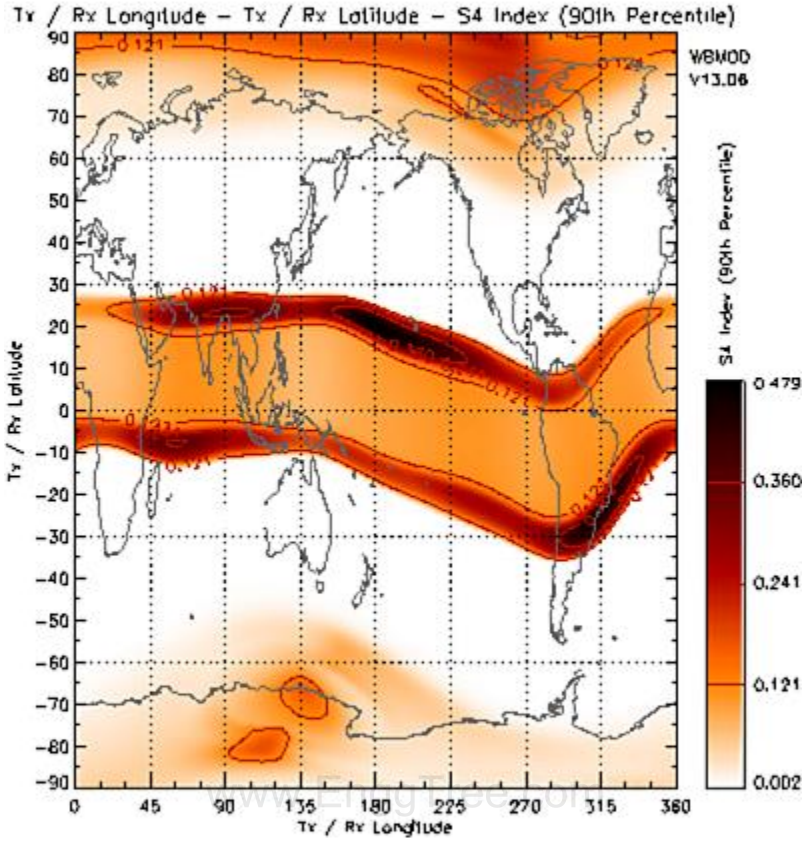


Figure 1: S4 Scintillation index at GPS L1 (1575.42MHz) assuming constant local time (2300) at all longitudes.

The figure shows "WBMOD" model predictions of the 90th percentile S_4 index at 2300 Local Time (everywhere) at the S.Hem autumnal equinox (DOY 091) for GPS L1 (1575.42MHz), low magnetic activity (Kp=10) and high solar activity (SSN=150). Apart from the two strong scintillation bands following ~15° geomagnetic latitude contours, also obvious is the enhanced scintillation between the two bands of maxima and in the polar regions. The mid- latitude regions are relatively free of scintillation, especially at GHz frequencies, however at lower frequencies, closer to 100MHz there can at times be significant scintillation activity.

In terms of diurnal distribution, equatorial ionospheric scintillation generally peaks several hours after dusk, as can be seen in Figure 2, below.

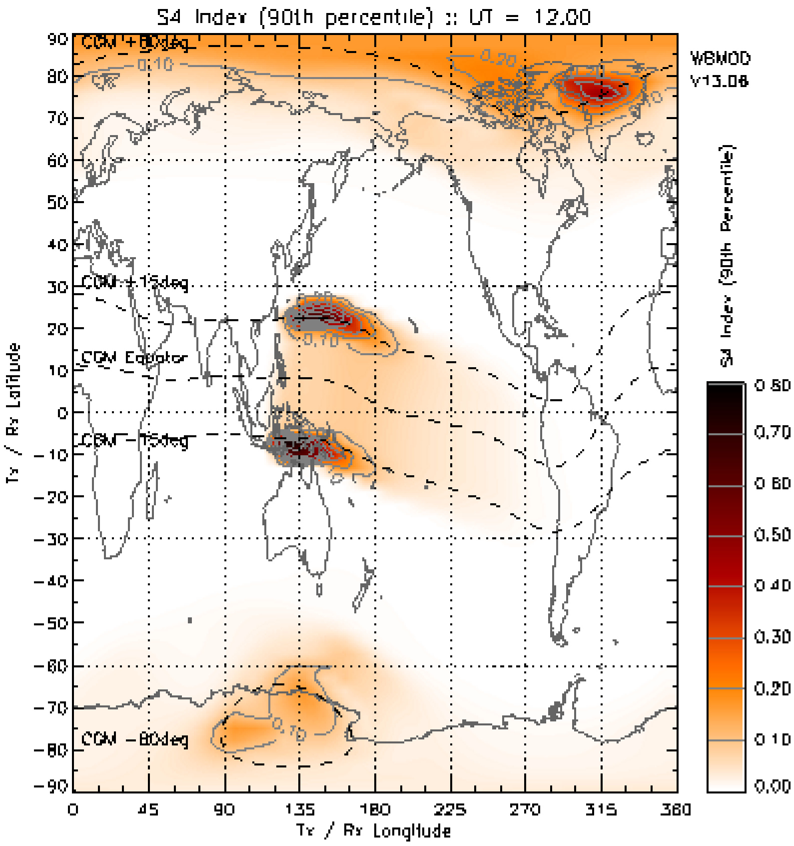


Figure 2: S_4 Scintillation index at GPS L1 (1575.42MHz) assuming constant Universal time (1200). The dashed lines represent lines of constant geomagnetic latitude (as marked).

The figure shows "WBMOD" model predictions under the same conditions as Figure 1 but for 1200UT, rather than at constant local time. The choice of 1200UT during equinox means the left and right hand borders of the plot are at midday local time, the vertical centre line of the plot (longitude 180°) corresponds to local midnight, and dusk is at longitude 90°. Each division on the X axis (15°) corresponds to 1 hour. Again, two strong scintillation bands can be seen roughly corresponding to ±15° geomagnetic latitude (as indicated by the dashed lines). The equatorial scintillation is present at decreasing intensity levels throughout most of the nightside. The scintillation peak in the equatorial regions occurs between 2100 and 2200 local time.

In general, GPS receivers located at mid-latitude sites in Australia (-40° < latitude < -20°) will not be significantly affected by ionospheric scintillation. GPS receivers located at latitudes north of -20° in Australia may experience some degree of ionospheric scintillation, primarily when tracking satellites at low elevation angles to the north, and during active geomagnetic conditions. Locations as far north as Darwin and the Cape York Peninsula are likely to experience ionospheric scintillation more regularly on satellites tracking to the north of the station since the Line Of Sight (LOS) to these satellites will generally pass through the equatorial anomaly regions. GPS receivers located at latitudes southwards of -40° will commonly see ionospheric scintillation activity associated with geomagnetic storm activity, on satellites tracking to the south of the receiver, with the most significant scintillation occurring under the auroral zones.

Ionospheric scintillation affects trans-ionospheric radio signals up to a few GHz in frequency and as such can have detrimental impacts on satellite-based communication and navigation systems (such as GPS-based systems) and also on scientific instruments requiring observations of trans-ionospheric radio signals (eg radio-astronomy).

Amplitude scintillation directly affects the signal to noise ratio (C/No) of signals in a GPS receiver, as well as the noise levels in code and phase measurements. Amplitude scintillation can be sufficiently severe that the received GPS signal intensity from a given satellite drops below the receivers tracking threshold, causing loss of lock on that satellite, and hence the need to re-acquire the GPS signal(s). This results in reduced accuracy navigation solutions, data loss and cycle slips. The nominal C/No for the L1 signal is about 45dB-Hz, and tracking may be lost when the signal drops below ~25dB-Hz, dependent on the receiver-specific tracking loop.

Since the signal power on the GPS L2 frequency is significantly less than that of L1 (~6dB lower), and civil dual frequency receivers use non-optimal codeless or semicodeless techniques for tracking L2 which results in lower C/No values, ionospheric scintillation is much more likely to impact the GPS L2 signal.

Phase scintillation, if sufficiently severe, may stress phase-lock loops in GPS receivers resulting in a loss of phase lock. Phase scintillation also has a significant impact on phase-sensitive systems such as space-based radars (eg image defocussing in synthetic aperture radars (van de

Kamp et al, 2007)) and some ground-based radio-astronomy facilities (eg SKA/LOFAR prototypes (van Bemmel et al, 2007)).

Measuring Ionospheric Scintillation

There are numerous measures of ionospheric scintillation. Perhaps the most common of these is the amplitude scintillation index S_4, and the phase scintillation index P_{rms}. Ionospheric scintillation models produce statistical measures of the specified scintillation index. To produce maps it is necessary to either specify thresholds of this index or to specify a percentage of time an index is exceeded.

Amplitude scintillation - S_4

Amplitude scintillation is quantified by the S_4 parameter which is defined as the square-root of the normalised variance of signal intensity over a given interval of time:

$$\boldsymbol{S}_4 = \sqrt{\left(\langle \boldsymbol{I}^2 \rangle - \langle \boldsymbol{I} \rangle^2\right) / \langle \boldsymbol{I} \rangle^2}$$

where **I** is the signal intensity.

S_4 is a dimensionless number with a theoretical upper limit of 1.0, commonly estimated over an interval of 60 seconds. There are two defined regimes of amplitude scintillation: weak and strong, which roughly correspond to the type of scattering associated with each. Strong scintillation is generally considered to occur when S_4 is greater than ~0.6 and is associated with strong scattering of the signal in the ionosphere. Below this is weak scintillation. An S_4 level below 0.3 is unlikely to have a significant impact on GPS.

Phase scintillation - Φ_{rms}

Phase scintillation is quantified by the P_{rms} (or Φ_{rms}) index which is defined as the standard deviation of the signal phase over a given time interval. This index is measured either in radians or degrees. A

P_{rms} greater than ~ 1° is considered to be strong scintillation. At mid-latitudes, P_{rms} rarely exceeds 1° for more than 1% of the time.

Other scintillation parameters

CkL - Log of the height-integrated irregularity strength (calculated on L.O.S paths from the ground to an overhead satellite). A measure of the total "power" in the electron-density irregularities along a vertical path passing through the entire ionosphere.

Scintillation Intensity (SI) index - Derived from scintillation data recorded on paper chart. Scintillation Intensity index (SI) is defined as:

$$SI = \frac{P_{\max} - P_{\min}}{P_{\max} + P_{\min}}$$

where $\mathbf{P_{max}}$ is the power of the 3rd peak down from the maximum excursion shown during a scintillation occurrence, and $\mathbf{P_{min}}$ is the power of the 3rd peak up from the minimum excursion. These values can be readily and rapidly scaled from a calibrated chart. The SI index is expressed in decibels (dB). An SI value of 15dB corresponds to an S_4 of about 0.6.

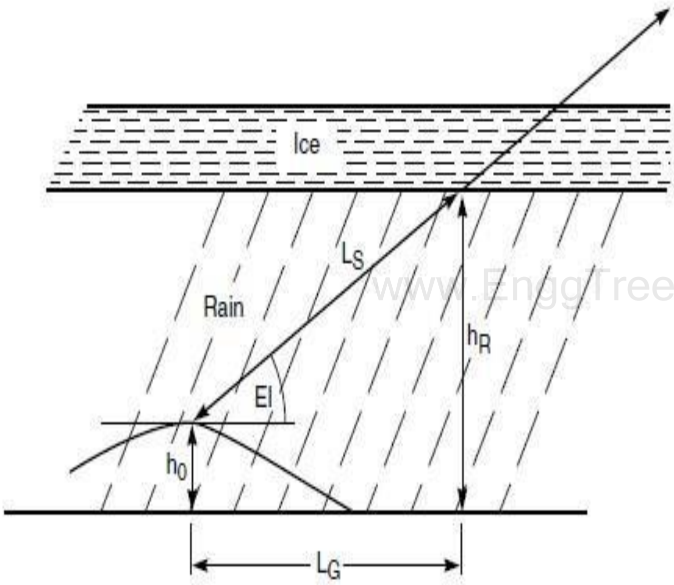
Ionospheric Scintillation Monitor (ISM)

An Ionospheric Scintillation Monitor (ISM) is a single- or dual-frequency GPS receiver specifically designed to monitor ionospheric scintillation levels in real time. The ISM has wide-bandwidth tracking loops to maintain lock longer during intervals of strong ionospheric scintillation, and samples at a rate of 50 Hz to calculate the scintillation statistics S_4 and P_{rms}. The wide-bandwidth tracking improves tracking through strong scintillation however loss of lock on single or multiple satellites can still occur during extreme events, requiring re-acquisition of the GPS signal(s).

SWS Radio and Space Services uses GPS Silicon Valley's GPS Ionospheric Scintillation and TEC Monitor (GISTM) system Model GSV4004B to monitor Ionospheric Scintillation in real time. The GSV4004B consists of an L1/L2 GPS Antenna, a dual-frequency GPS receiver (NovAtel's Euro-3M with modified firmware), and a low phase noise oven-controlled crystal oscillator (OCXO), housed in NovAtel's EuroPak-3M enclosure. The OCXO is required for monitoring phase scintillation.

The primary purpose of the ISM system is to collect ionospheric scintillation statistics (S_4 and P_{rms}) for all visible GPS satellites (up to eleven satellites) and store these (ISMR) binary data logs on the receiver controller hard disk for post processing. The ISM control software can be programmed to collect the ISMR data logs that are generated every 1 minute. Alternatively, raw phase and amplitude data at 0.02 second temporal resolution (50Hz) and code/carrier divergence at 1s (1Hz) can be recorded from the ISM. These data can be used to reconstruct the statistical scintillation indices, such as S_4 recorded in the ISMR data log, from raw data. This allows the user to modify the parameters used in the derivation of scintillation indices, such as de-trending and filter cut-off parameters

3.3 Rain Induced Attenuation: Rain attenuation is a function of *rain rate.* The rain rate is measured in millimeters per hour. The total attenuation is given as $A=\alpha L$ Db *α-Specfic attenuation L-Effective path length* of the signal through the rain The geometric, or slant, path length is shown as L_S. This depends on the antenna angle of elevation and the *rain height* h_R, which is the height at which freezing occurs.



$$L_S = \frac{h_R - h_O}{\sin El}$$

- The effective path length is given in terms of the slant length by $L = L_S r_p$ where r_p is a *reduction factor* which is a function of the percentage time p and L_G, the horizontal projection of L_S. $L_G = L_S \cos El$ With all these factors together into one equation, the rain attenuation in decibels is given by,

$$A_p = aR_p{}^b L_S r_p \text{ dB}$$

Link budget calculations

Equivalent Isotropic Radiated Power:

A key parameter in link budget calculations is the equivalent isotropic radiated power (EIRP). An isotropic radiator with an input power equal to GP_S would produce the same flux density. Hence this product is referred to as the equivalent isotropic radiated power. EIRP = GP_S,

G= Gain and P_S = Power Supplied.

Free Space Loss

In the loss calculations, the power loss resulting from the spreading of the signal in space must be determined. The power flux density at the receiving antenna is given as

$$\Psi_M = \frac{\text{EIRP}}{4\pi r^2}$$

The power delivered to a matched receiver is this power flux d ty multiplied by the effective aperture of the receiving antenna, g by Eq. The received power is therefore

$$\begin{aligned} P_R &= \Psi_M A_{\text{eff}} \\ &= \frac{\text{EIRP}}{4\pi r^2} \, \frac{\lambda^2 G_R}{} \\ &= (\text{EIRP})\,(G_R)\left(\frac{\lambda}{4\pi r}\right)^2 \end{aligned}$$

$$[P_R] = [\text{EIRP}] + [G_R] - 10 \log \left(\frac{4\pi r}{\lambda}\right)^2$$

$$[\text{FSL}] = 10 \log \left(\frac{4\pi r}{\lambda}\right)^2$$

$$[P_R] = [\text{EIRP}] + [G_R] - [\text{FSL}]$$

3.8 Interference

- With many telecommunications services using radio transmissions, interference between services can arise in a number of ways.

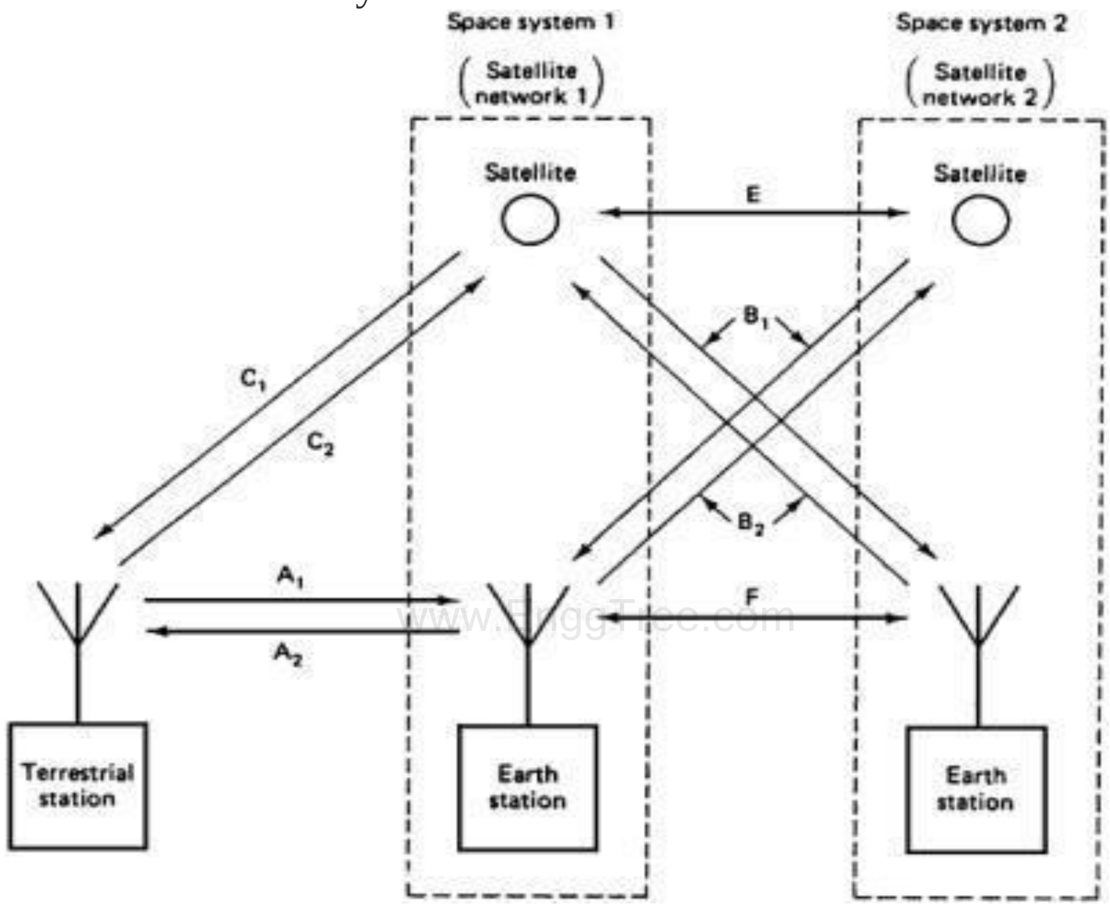


Fig (a)

Possible interference modes between satellite circuits and a terrestrial station Fig. (a) are classified by the International Telecommunications Union (ITU, 1985) as follows: A1: terrestrial station transmissions, possibly causing interference to reception by an earth station A2: earth station transmissions, possibly causing interference to reception by a terrestrial station B1: space station transmission of one space system, possibly causing interference to reception by an earth station of another space system B2: earth station transmissions of one space system, possibly causing interference to reception by a space station of another space system C1: space station transmission, possibly causing interference to reception by a terrestrial station C2: terrestrial station transmission, possibly causing interference to reception by a space station E: space station transmission of one space system, possibly causing interference to reception by a space station of another space system F: earth station transmission of one space system, possibly causing interference to reception by an earth

Combined [C/I] due to interference on both uplink and downlink

Interference may be considered as a form of noise, and assuming that the interference sources are statistically independent, the interference powers may be added directly to give the total interference at receiver B. The uplink and the downlink ratios are combined in exactly the same manner described for noise, resulting in Here, power ratios must be used, not decibels, and the subscript “ant” denotes the combined ratio at the output of station B receiving antenna station of another space system

System Noise Temperature

Consider first the noise representation of the antenna and the *low noise amplifier* (LNA) shown in Fig. 2.15. The available power gain of the amplifier is denoted as *G*, and the noise power output, as P_{no}.

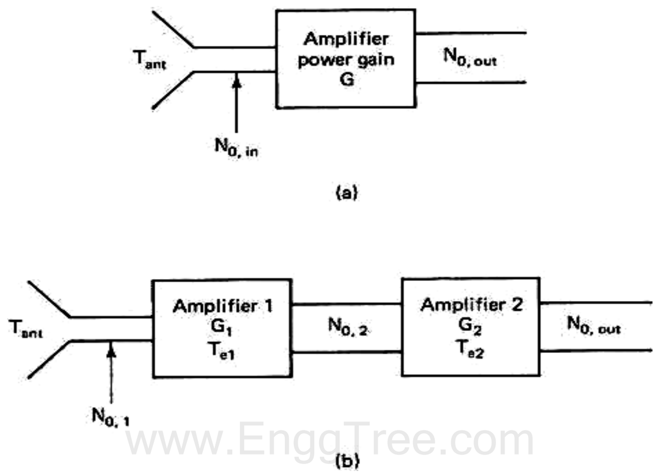


Fig 2.15 LNA Amplifier Gain

For the moment, the noise power per unit bandwidth, which is simply noise energy in joules as shown by the following Equation. The input noise energy coming from the antenna is

$$N_{0,ant} = kT_{ant}$$

2.8.1 The Uplink

The uplink of a satellite circuit is the one in which the earth station is transmitting the signal and he satellite is receiving it t specifically that the uplink is being considered.

$$\frac{C}{N} = [EIRP] - [LOSSES] + [k]$$

In the above equation, the values to be used are the earth station EIRP, the satellite receiver feeder losses, and satellite receiver *G*/*T*. The free-space loss and other losses which are frequency-dependent are calculated for the uplink frequency.

2.8.2 Input back-off

Since the number of carriers are present simultaneously in a TWTA, the operating point must be backed off to a linear portion of the transfer characteristic to reduce the effects of inter modulation distortion. Such multiple carrier operation occurs with *frequency- division multiple access* (FDMA). The point to be made here is that *backoff* (BO) must be allowed for in the link-budget calculations. Suppose that the saturation flux density for single-carrier operation is known. Input BO will be specified for multiple-carrier operation, referred to the single- carrier saturation level.

The earth-station EIRP will have to be reduced by the specified

BO, resulting in an uplink value of [EIRP] U =

[EIRPS] U + [BO]i

2.8.3 The earth station HPA

The earth station HPA has to supply the radiated power plus the transmit feeder losses, denoted here by TFL, or [TFL] dB. These include waveguide, filter, and coupler losses between the HPA output and the transmit antenna. The earth station may have to transmit multiple carriers and its output also will require back off, denoted by [BO]HPA. The earth station HPA must be rated for a saturation power output given by

$$[P_{HPA,sat}] = [P_{HPA}] + [BO]_{HPA}$$

2.8.4 Downlink

The downlink of a satellite circuit is the one in which the satellite is transmitting the signal and the earth station is receiving it. Equation can be applied to the downlink, but subscript *D* will be used to denote specifically that the downlink is being considered.

$$\frac{C}{N} = [EIRP] - [LOSSES] + [k]$$

In the above equation, the values to be used are the satellite EIRP, the earth- station receiver feeder losses, and the earth-station receiver *G*/*T*. The free space and other losses are calculated for the downlink frequency. The resulting carrier-to-noise density ratio appears at the detector of the earth station receiver.

2.8.5 Output back-off

Where input BO is employed as described in a corresponding output BO must be allowed for in the satellite EIRP. As the curve of Figure 2.16 shows that output BO is not linearly related to input BO. A rule of thumb, frequently used, is to take the output BO as the point on the curve which is 5 dB below the extrapolated linear portion. Since the linear portion gives a 1:1 change in decibels, the relationship between input and output BO is $[BO]_0$ $[BO]_i$ 5 dB. For example, with an input BO of $[BO]_i$ 11 dB, the corresponding output BO is $[BO]_0$

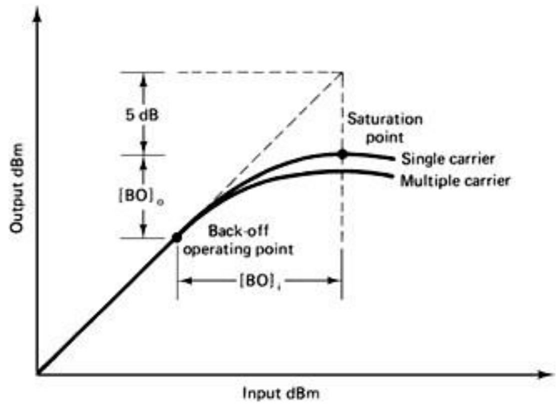
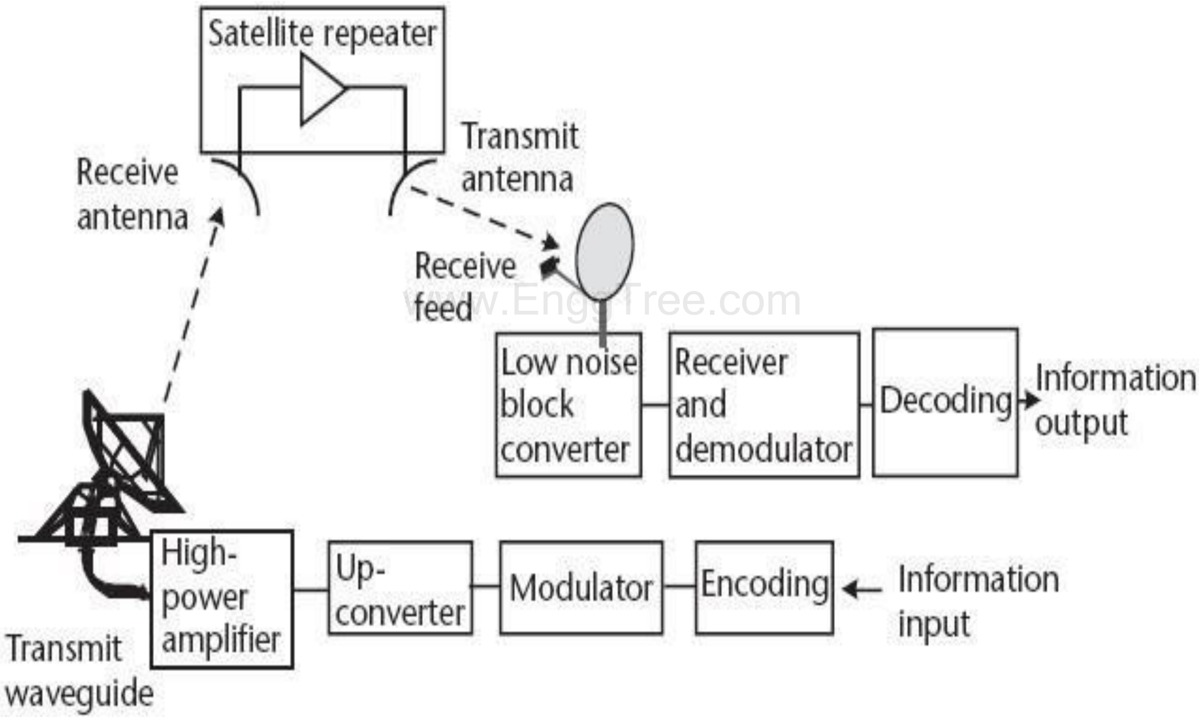


Fig 2.16 Input and output back- off relationship for the satellite traveling-wave-tube amplifier

CEC352-SATELLITE COMMUNICATION

3.5 Link Design with and without frequency reuse

- Intra –orbital links :connect consecutive satellites on the same orbits
- Inter –orbital links :connect two satellites on the different orbits



Design of the Satellite System

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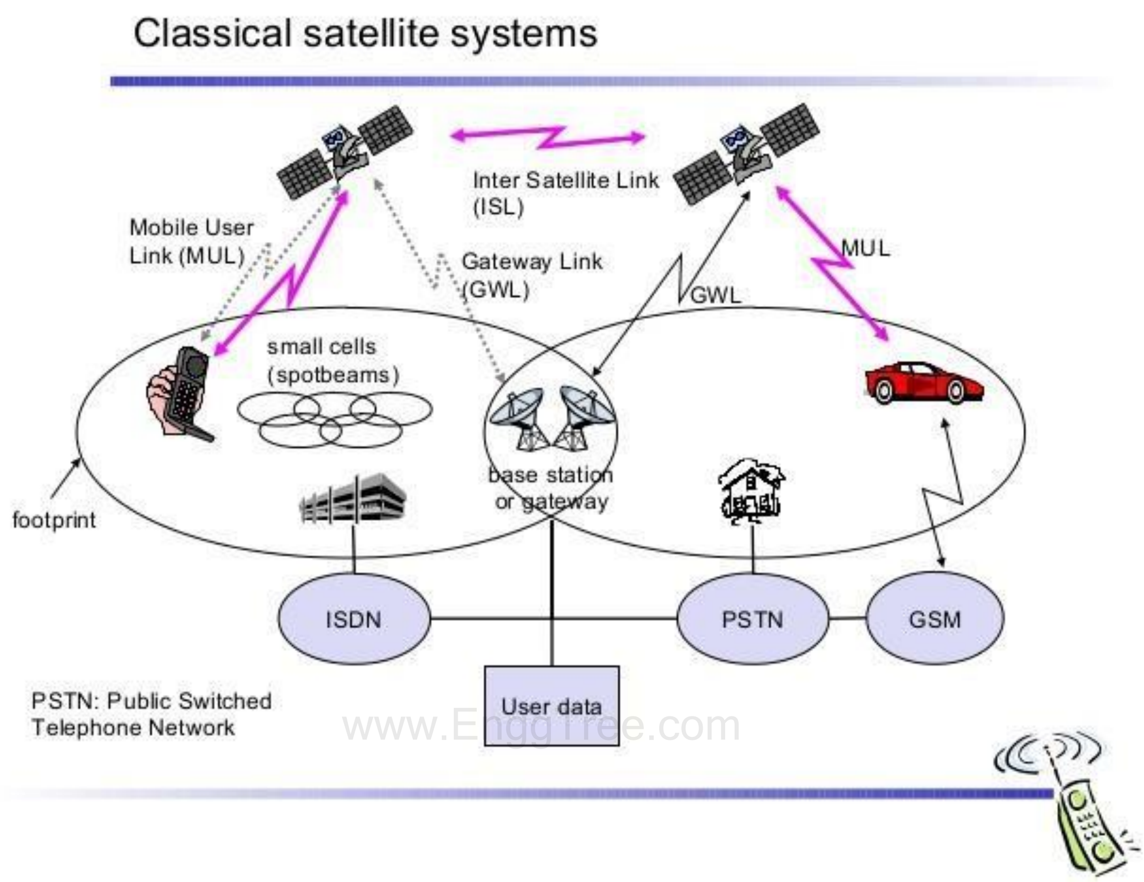

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LNB (LOW NOISE BLOCK DOWN CONVERTER)

- A device mounted in the dish, designed to amplify the satellite signals and convert them from a high frequency to a lower frequency. LNB can be controlled to receive signals with different polarization. The television signa can then be carried by a double-shielded aerial cable to the satellite receive while retaining their high quality. A universal LNB is the present standard version, which can handle the entire frequency range from 10.7 to 12.75 G and receive signals with both vertical and horizontal polarization.

Demodulator

A satellite receiver circuit which extracts or "demodulates" the "wanted "signals from the received carrier.

Decoder

- A box which, normally together with a viewing card, makes it possible to view encrypted transmissions. If the transmissions are digital, the decoder usually integrated in the receiver.
- recorded video information to be played back using a television receiver tuned to VHF channel 3 or 4.

- **Modulation**

  The process of manipulating the frequency or amplitude of a carrier in relation to an incoming video, voice or data signal.
- **Modulator**

  A device which modulates a carrier. Modulators are found as components in broadcasting transmitters and in satellite transponders. Modulators are also used by CATV companies to place a baseband video television signal onto a desired VHF or UHF

Atmospheric Layers

A signal traveling between an earth station and a satellite must pass through the earth's atmosphere, including the ionosphere, as shown

Atmospheric Losses

- Losses occur in the earth's atmosphere as a result of energy absorption by the atmospheric gases.

The weather-related losses are referred to as *atmospheric attenuation* and the absorption losses by gases are known as *absorption*. **Atmospheric scintillation:**

This is a fading phenomenon, the fading period being several tens of seconds.

It is caused by differences in the atmospheric refractive index, which in turn results in focusing and defocusing of the radio waves, which follow different ray paths through the atmosphere.

- Fade margin in the link power-budget calculations are used for Atmospheric Scintillation.

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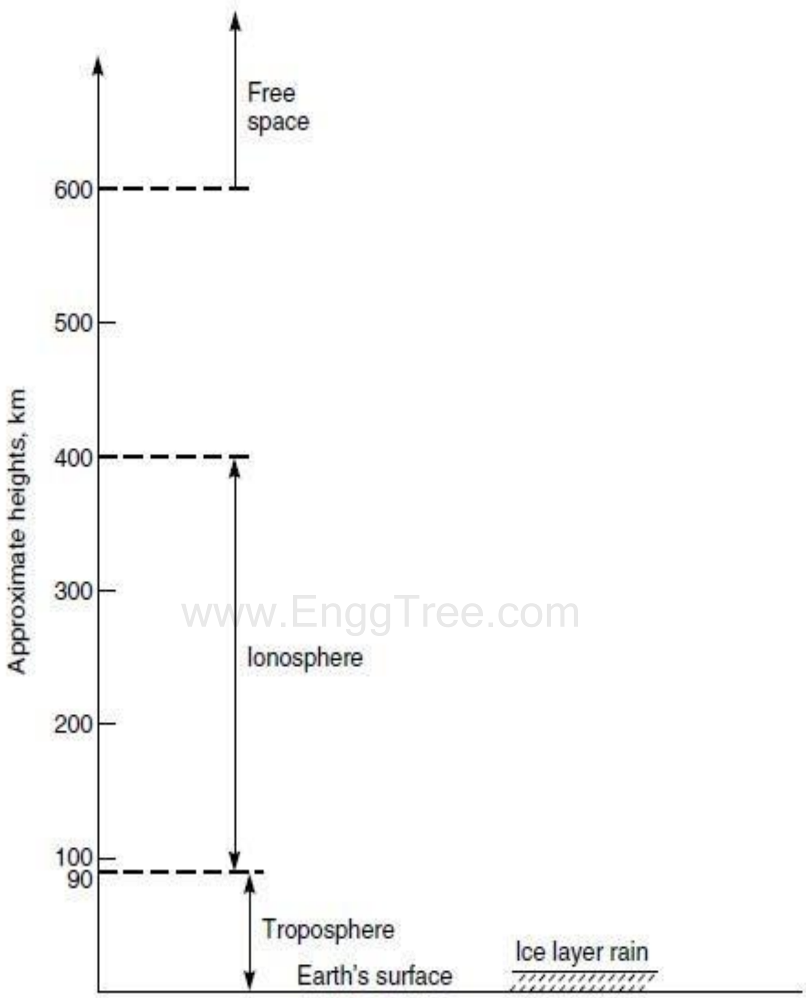

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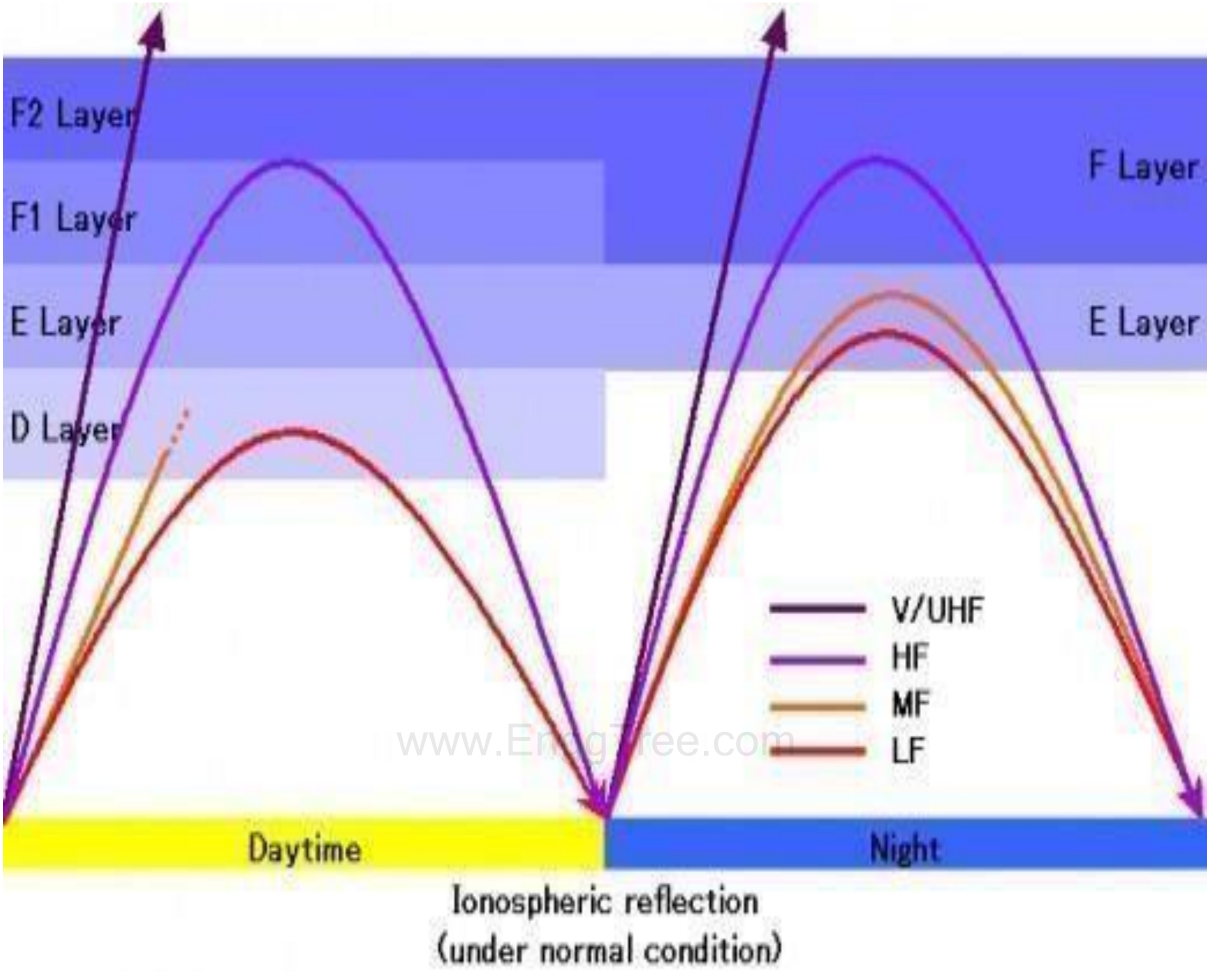

3.6 Ionospheric Effects

- Radio waves traveling between satellites and earth stations must pass through the ionosphere.

- The ionosphere is the upper region of the earth's atmosphere, which has been ionized, mainly by solar radiation. • The free electrons in the ionosphere are not uniformly distributed but form in layers, which effect the signal.

Ionospheric Layers

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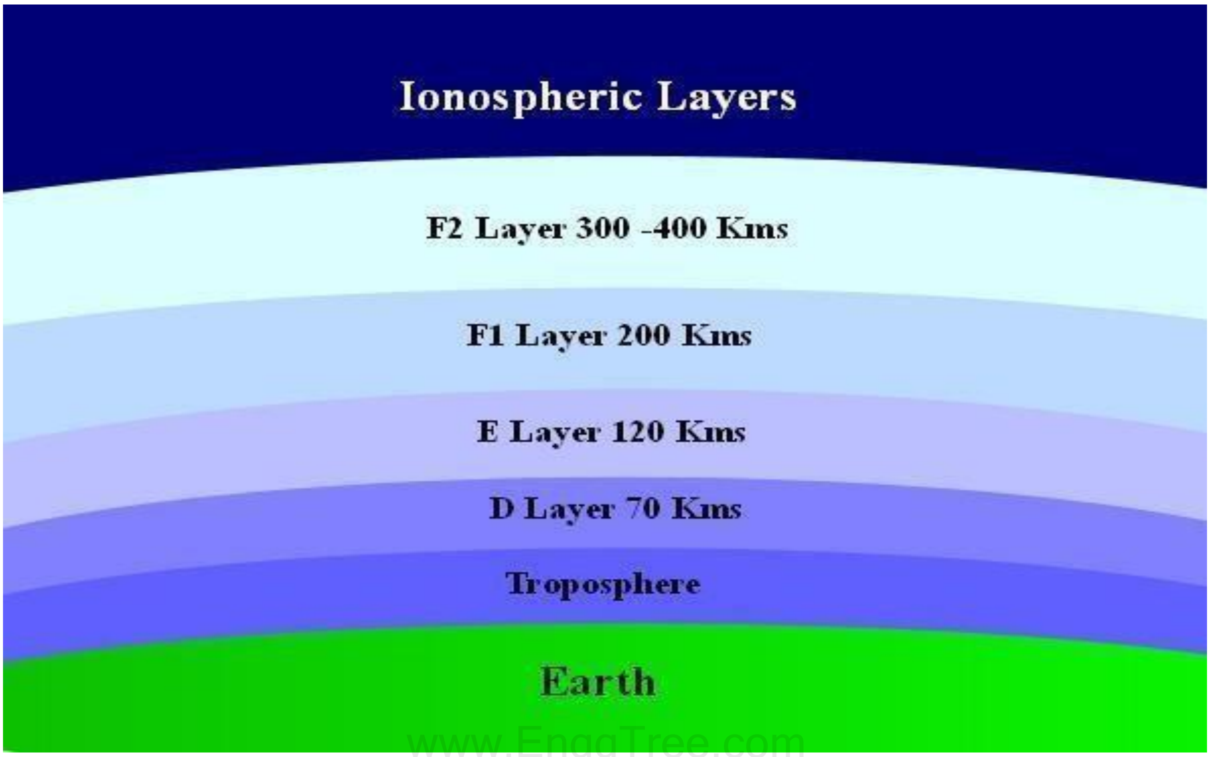

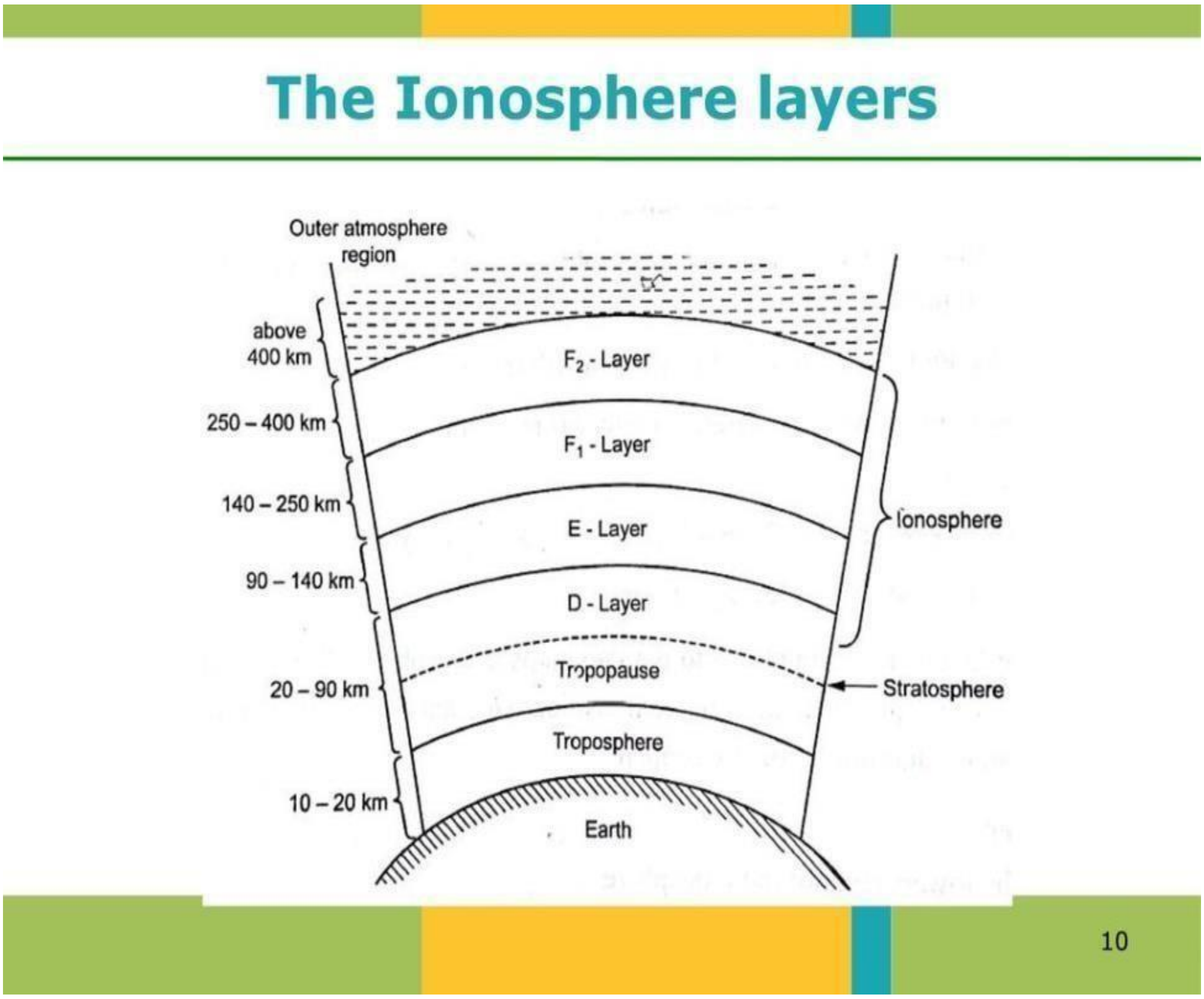

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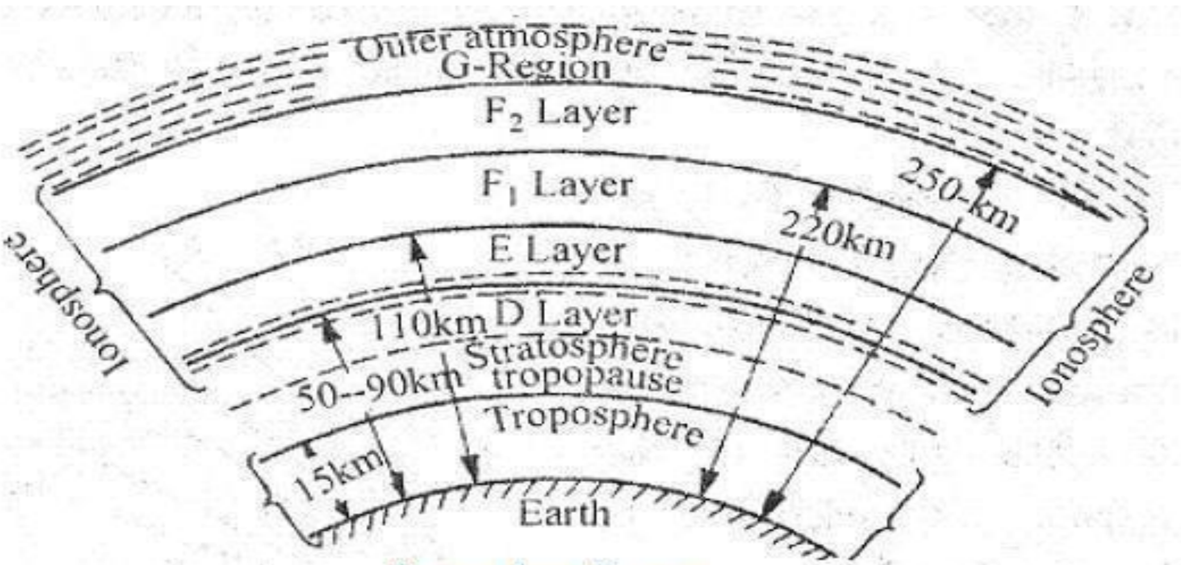
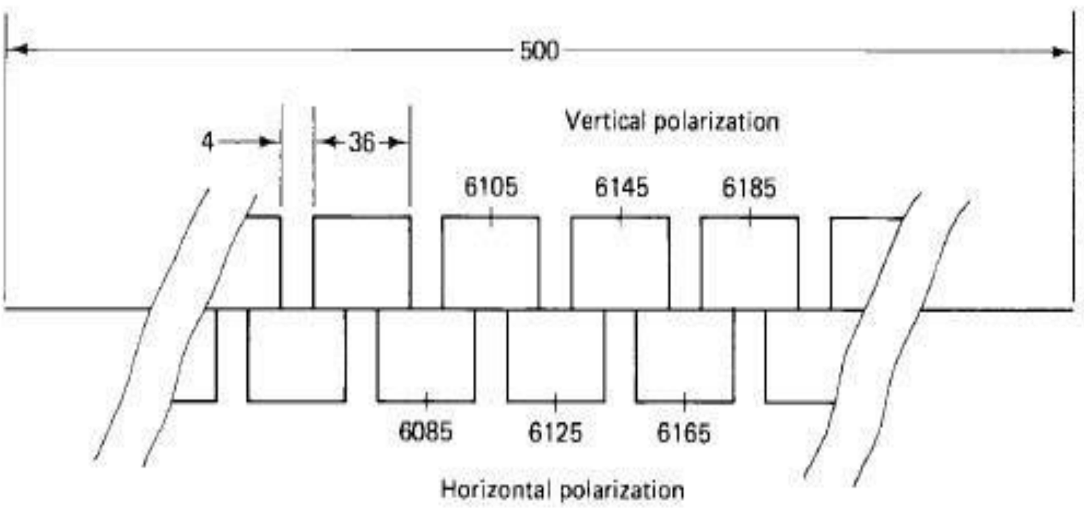


Ionosphere Layers

Link Design With and without Frequency Reuse



- Frequency reuse is employed to reduce the crosspolarization caused by ionosphere, ice crystals in the upper atmosphere and

- rain, when the wave being transmitted from satellite to earth station.
- Frequency reuse achieved with spot-beam antennas, and these may be combined with polarization reuse to provide an effective bandwidth.

- The bandwidth allocated for C band service is 500 MHz, and this is divided into sub bands, one for each transponder. A typical transponder bandwidth is 36 MHz, and allowing for a 4-MHz guard band between transponders, 12 such transponders can be

- accommodated in the 500-MHz bandwidth. this number can be doubled. Polarization isolation refers to the fact that carriers, which may be on the same frequency but with opposite senses of polarization, can be isolated from one another by receiving

- With antennas linear match polarized carriers can be separated in this way, and with circular polarization, left-hand circular and right-hand circular polarizations can be separated. Because the carriers with opposite senses of polarization may overlap in frequency, this technique is referred to as *frequency reuse*

CEC352-SATELLITE COMMUNICATION

RHCP

	1	3	5	. . .	31
Uplink MHz	17324.00	17353.16	17382.32		17761.40
Downlink MHz	12224.00	12253.16	12282.32		12661.40

LHCP

	2	4	6	. . .	32
Uplink MHz	17338.58	17367.74	17411.46		17775.98
Downlink MHz	12238.58	12267.74	12296.50		12675.98

UNIT IV SATELLITE ACCESS

4.1 Modulation and Multiplexing: Voice, Data, Video

Communications satellites are used to carry telephone, video, and data signals, and can use both analog and digital modulation techniques.

Modulation:

Modification of a carrier's parameters (amplitude, frequency, phase or a combination of them) in dependence on the symbol to be sent.

Modulation is the process of transforming a carrier signal so that it can carry the information of a message signal. It superimposes the contents of the message signal over a high-frequency carrier signal, which is then transmitted over communication channels.

Modulation can be of two types −

- Analog Modulation
- Digital Modulation

Analog Modulation

Here, the analog information signal is transformed to the analog carrier signal so that it can travel large distances without substantial loss.

Analog modulation can be of three types −

- Amplitude Modulation
- Frequency Modulation
- Phase Modulation

Digital Modulation

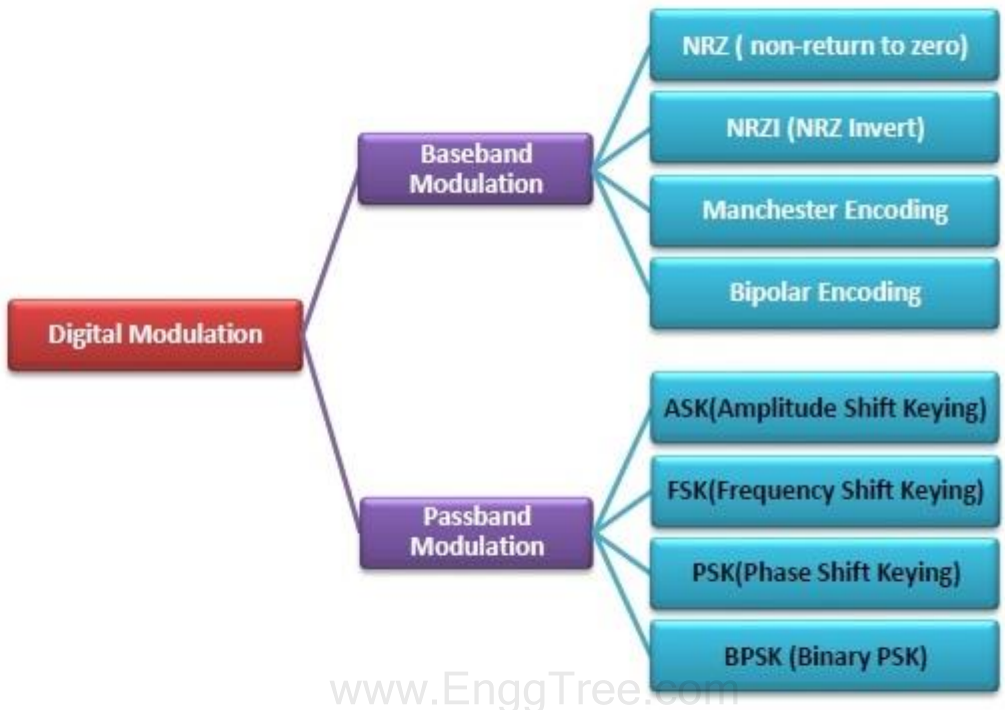
Digital modulation is the process of converting a digital bit stream into an analog carrier wave for transmission via a communication channel.

Digital modulation is broadly divided into two categories −

- **Bandpass Modulation as in baseband transmission:**

Here, the bits are converted directly into signals.

- **Passband Modulation as in passband transmission:**
  Here, the amplitude, phase or frequency of the carrier signal is regulated to transmit the bits.

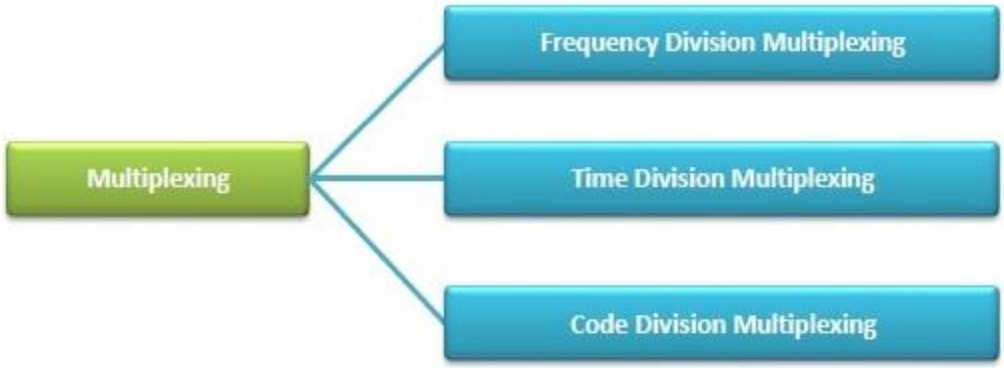


Multiplexing:

Task of multiplexing is to assign space, time, frequency, and code to each communication channel with a minimum of interference and a maximum of medium utilization Communication channel refers to an association of sender(s) and receiver(s) that want to exchange data One of several constellations of a carrier's parameters defined by the used modulation scheme.

Multiplexing is a method of combining more than one signal over a shared medium. Multiplexing divides the capacity of a communication channel into several logical channels, each for a data stream. The method of extracting the original data streams from the multiplexed signal is called demultiplexing.

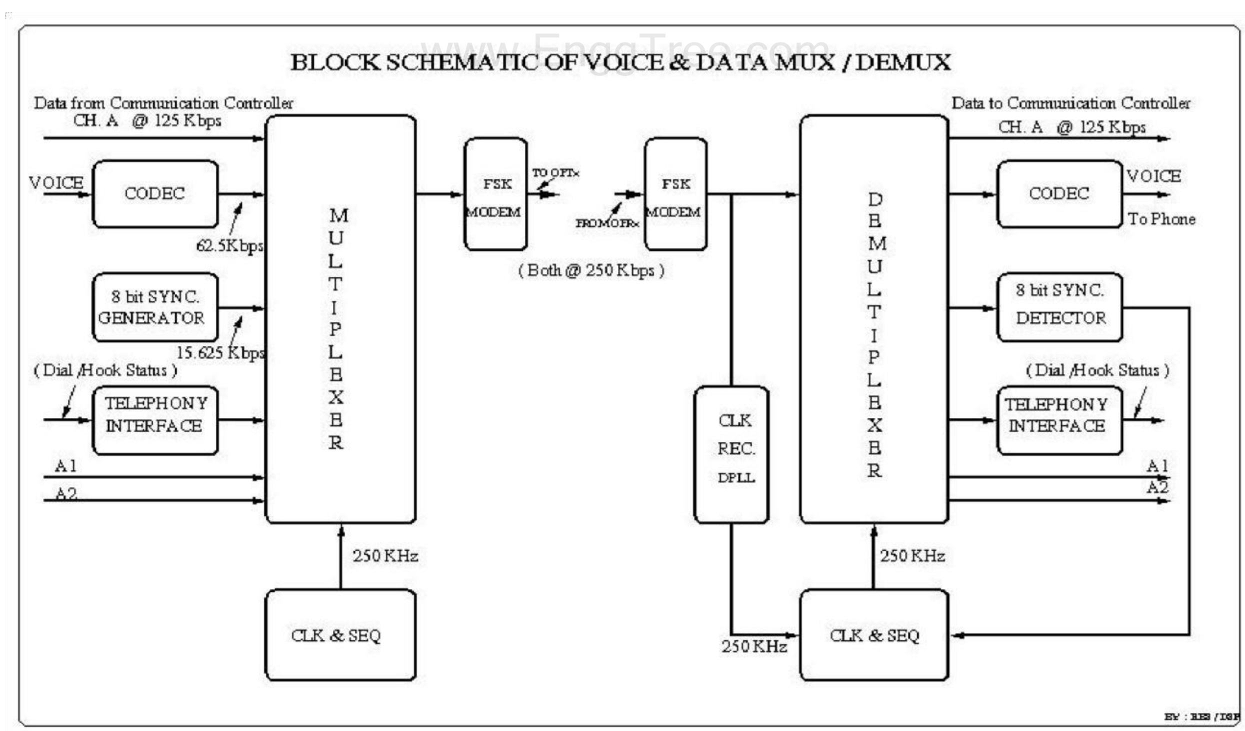
The methods of multiplexing are as follows –



Voice, Data, Video :

The modulation and multiplexing techniques that were used at this time were analog, adapted from the technology developed for the change to digital voice signals made it easier for long-distance.

A satellite voice and data connection can also be configured to carry video, internet, or other data services.



Stuffing bits and words are added to the satellite data stream as needed to fill empty bit and word spaces. Primarily for video provided that a satellite link's over all carrier-to-noise but in to older receiving equipment at System and Satellite Specification Ku band satellite parameters.

Modulation And Multiplexing:

In analog television (TV) transmission by satellite, the base band video signal and one or two audio subcarriers constitute a composite video signal.

Digital modulation is obviously the modulation of choice for transmitting digital data. Voice are digitized analog signals may conveniently share a channel with digital data, allowing a link to carry a varying mix of voice and data traffic.

Digital signals from different channels are interleaved for transmission through time division multiplexing. TDM carry any type of traffic on the bent pipe transponder that can carry voice, video, or data as the marketplace demands.

Hybrid multiple access schemes can use time division multiplexing of baseband channels which are then modulate.

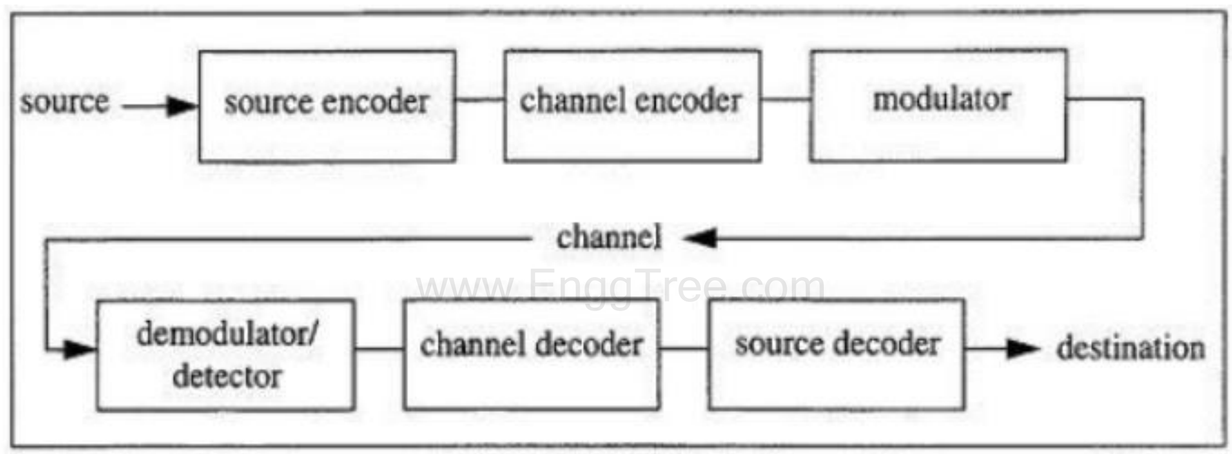
4.2 Analog - Digital Transmission System

1. Analog vs. Digital Transmission:

Compare at two levels:

1. Data—continuous (audio) vs. discrete (text)

2. Signaling—continuously varying electromagnetic wave vs. sequence of voltage pulses.



Basic communication systems

• Improving digital technology

• Data integrity. Repeaters take out cumulative problems in transmission.

• Can thus transmit longer distances.

• Easier to multiplex large channel capacities with digital

• Easy to apply encryption to digital data

• Better integration if all signals are in one form. It is difficult to integrate voice, video and digital data.

Analog Transmission

- An analog wave form (or signal) is characterized by being continuously variable along amplitude and frequency.
- Analog facilities have limited bandwidth, which means they cannot support high-speed data.
- Another characteristic of analog transmission is that noise is accumulated as the signal traverses the network. As the signal moves across the distance, it loses power and becomes impaired by factors such as moisture.
- By the time the signal arrives at the amplifier, it is not only attenuated, it is also impaired and noisy ending up with very high error rates.

Digital Transmission

- Digital transmission is quite different from analog transmission.

- For one thing, the signal is much simpler.
- Rather than being a continuously variable wave form, it is a series of discrete pulses, representing one bits and zero bits.
- Digital networks use regenerative repeaters.
- The repeater regenerates the weak and impaired signal to pass on to the next point in the network, in the essence eliminating noise and thus vastly improving the error rate.

Digital Transmission of Analog Signals

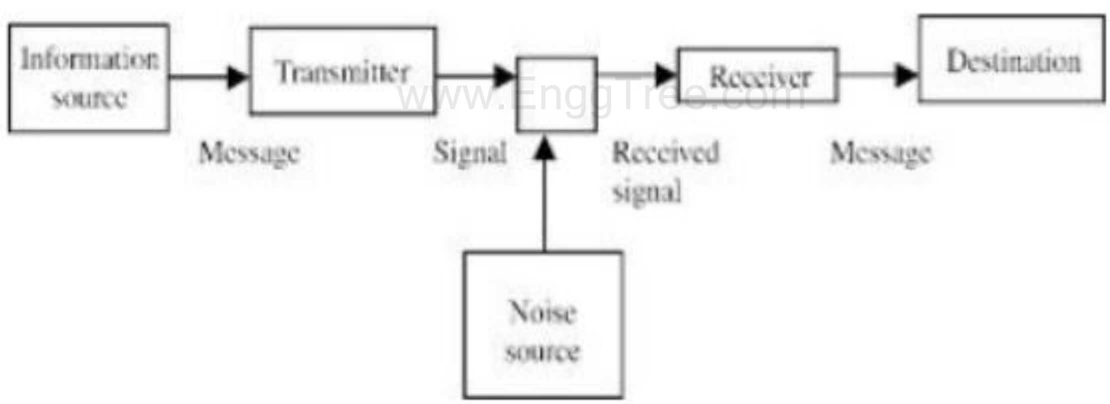
- To transmit analog message signals, such as voice and video signals, by digital means, the signal has to be converted to a digital signal.

- This process is known as the analog-to-digital conversion, or sometimes referred as digital pulse modulation.
- Two important techniques of analog-to-digital conversion are Pulse Code Modulation (PCM) and Delta Modulation (DM).

2. Digital Data/Analog Signals:

Must convert digital data to analog signal such device is a modem to translate between bit-serial and modulated carrier signals?

To send digital data using analog technology, the sender generates a carrier signal at some continuous tone (e.g. 1-2 kHz in phone circuits) that looks like a sine wave. The following techniques are used to encode digital data into analog signals.



Digital /Analog Transmitter & receiver

Resulting bandwidth is centered on the carrier frequency.

• **Amplitude-shift modulation (keying):** vary the amplitude (e.g. voltage) of the signal. Used to transmit digital data over optical fiber.

• **Frequency-shift modulation:** two (or more tones) are used, which are near the carrier frequency. Used in a full-duplex modem (signals in both directions).

- **Phase-shift modulation:** systematically shift the carrier wave at uniformly spaced intervals. For instance, the wave could be shifted by 45, 135, 225, 315 degree at each timing mark. In this case, each timing interval carries 2 bits of information. Why not shift by 0, 90, 180, 270? Shifting zero degrees means no shift, and an extended set of no shifts leads to clock synchronization difficulties.

Frequency division multiplexing (FDM): Divide the frequency spectrum into smaller subchannels, giving each user exclusive use of a subchannel (e.g., radio and TV). One problem with FDM is that a user is given all of the frequency to use, and if the user has no data to send, bandwidth is wasted — it cannot be used by another user.

Time division multiplexing (TDM): Use time slicing to give each user the full bandwidth, but for only a fraction of a second at a time (analogous to time sharing in operating systems). Again, if the user doesn't have data to sent during his time slice, the bandwidth is not used (e.g., wasted).

Statistical multiplexing: Allocate bandwidth to arriving packets on demand. This leads to the most efficient use of channel bandwidth because it only carries useful data. That is, channel bandwidth is allocated to packets that are waiting for transmission, and a user generating no packets doesn't use any of the channel resources.

4.3 Digital Video Broadcasting (DVB)

- Digital Video Broadcasting (DVB) has become the synonym for digital television and for data broadcasting world-wide.
- DVB services have recently been introduced in Europe, in North- and South America, in Asia, Africa and Australia.
- This topic aims at describing what DVB is all about and at introducing some of the technical background of a technology that makes possible the broadcasting.
- Digital Video Broadcasting is a common standard for digital television and video used in many parts of the world.

- There are different DVB standards, such as:
- DVB-T, DVB-T2 for digital terrestrial television
- DVB-C and DVB-C2 for cable television
- DVB-S and DVB-S2 for satellite television
- DVB-SH for microwave
- DVB was born in Europe in the early 1990s when a group of broadcasters, consumer equipment manufacturers, and regulatory bodies formed the European Launching Group (ELG) to discuss the introduction of digital television throughout Europe.
- The ELG later became the DVB Project, which now has more than 220 organizations in more than 29 countries worldwide.

- DVB also refers to an industry-led collaboration of the world's leading digital TV and technology companies.
- Manufacturers, software developers, network operators, broadcasters, and regulators all partner to design open technical standards for the delivery of digital TV and other broadcast services.

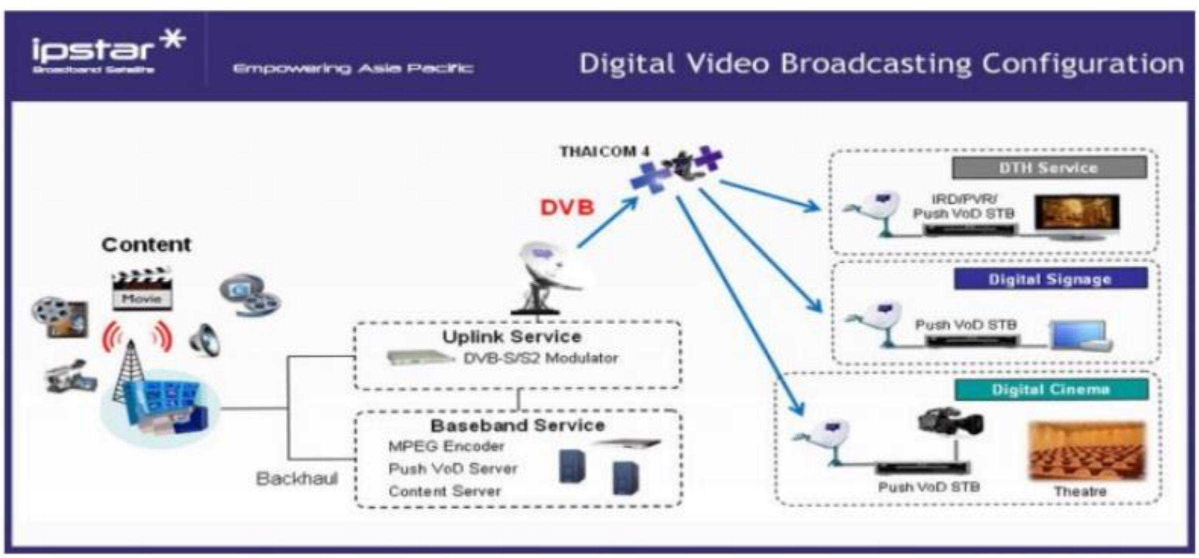
How Digital Video Broadcasting works

- Unlike analog television, digital televisions transform data into "packets" of compressed data.
- The data is subject to encoding and decoding, which ensures high-quality multimedia without the lag faced by analog television broadcasting.
- DVB networks rely on their interactivity solutions, a limited set of return channels and relevant specifications for the multipoint distribution of data.
- A fundamental decision of the DVB Project was the selection of MPEG-2, one of a series of MPEG standards for compression of audio and video signals.
- MPEG-2 reduces a single signal bandwidth from 166 Mbps to 5 Mbps, allowing broadcasters to transmit digital signals using an existing cable, satellite and terrestrial systems.
- MPEG-2 uses the lossy compression method, which means the digital signal sent to the television is compressed and some data is lost.

- This lost data does not affect how the human eye perceives the picture.

Increased Security with Digital Video Broadcasting

- DVB uses conditional access (CA) systems to prevent external piracy.
- There are numerous CA systems available to content providers, allowing them to choose the CA system they feel is adequate for the services they provide.
- Each CA system provides a security module that scrambles and encrypts data.
- DVB allows content providers to offer their services anywhere regardless of geographic location.
- It expands its services easily and inexpensively, and ensures restricted access to subscribers, thus reducing lost revenue due to unauthorized viewing.



Digital Video Broadcasting systems

4.4 Multiple Access Techniques

- The transmission from the BS in the downlink can be heard by each and every mobile user in the cell, and is referred as *broadcasting*. Transmission from the mobile users in the uplink to the BS is many-to-one, and is referred to as multiple access.

- Multiple access schemes to allow many users to share simultaneously a finite amount of radio spectrum resources.

  - Should not result in severe degradation in the performance of the system as compared to a single user scenario.
  - Approaches can be broadly grouped into two categories: narrowband and wideband.

- Multiple Accessing Techniques : with possible conflict and conflict - free

- Random access
- Frequency division multiple access (FDMA)
- Time division multiple access (TDMA)
- Spread spectrum multiple access (SSMA) : an example is Code division multiple access (CDMA)
- Space division multiple access (SDMA)

Duplexing

For voice or data communications, must assure two way communication (duplexing, it is possible to talk and listen simultaneously). Duplexing may be done using frequency or time domain techniques.

- ❖ Forward (downlink) band provides traffic from the BS to the mobile
- ❖ Reverse (uplink) band provides traffic from the mobile to the BS.

4.4.1 Frequency division duplexing (FDD)

Provides two distinct bands of frequencies for every user, one for downlink and one for uplink.

A large interval between these frequency bands must be allowed so that interference is minimized.

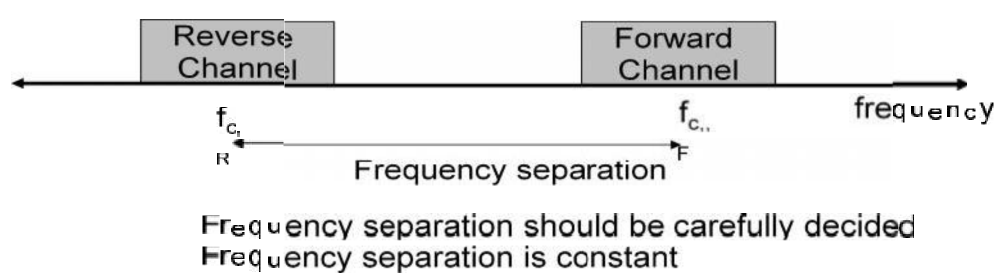


Figure 4.5 Frequency Separation

4.4.2. Time division duplexing (TDD)

- ❖ In TDD communications, both directions of transmission use one contiguous frequency allocation, but two separate time slots to provide both a forward and reverse link.

- Because transmission from mobile to BS and from BS to mobile alternates in time, this scheme is also known as ping pong.
- As a consequence of the use of the same frequency band, the communication quality in both directions is the same. This is different from FDD.

Figure 4.6 Time Slot

4.4.3 FDMA

- In FDMA, each user is allocated a unique frequency band or channel. During the period of the call, no other user can share the same frequency band.

Figure 4.7 FDMA Channels

- All channels in a cell are available to all the mobiles Channel assignment is carried out on a first-come first-served basis.

- The number of channels, given a frequency spectrum BT, depends on the modulation technique (hence Bw or Bc) and the guard bands between the channels 2Bguard.

- These guard bands allow for imperfect filters and oscillators and can be used to minimize adjacent channel interference
- FDMA is usually implemented in narrowband systems.

Figure 4.8 FDMA/FDD/TDD

Nonlinear effects in FDMA

- In a FDMA system, many channels share the same antenna at the B power amplifiers or the power combiners, when opera saturation are nonlinear.
- The nonlinearities generate inter-modulation frequencies.
- Undesirable harmonics generated outside the mobile band ra interference to adjacent services.
- Undesirable harmonics present inside the band cause interfe users in the mobile system.

4.4.4 TDMA

- TDMA systems divide the channel time into frames. Each frame is further partitioned into time slots. In each slot only one user is allowed to either transmit or receive.
- Unlike FDMA, only digital data and digital modulation must be used.
- Each user occupies a cyclically repeating time slot, so a channel may be thought of as a particular time slot of every frame, where N time slots comprise a frame.

Figure 4.9 TDMA Channels

Features

- Multiple channels per carrier or RF channels.
- Burst transmission since channels are used on a time sharing basis.
  - Transmitter can be turned off during idle periods.
- Narrow or wide bandwidth depends on factors such as modulation scheme, number of voice channels per carrier channel.
- High ISI Higher transmission symbol rate, hence resulting in high ISI.
  - Adaptive equalizer required.

Figure 3.10 TDMA Channels time slot

- A guard time between the two time slots must be allowed in order to avoid
  - interference, especially in the uplink direction.
- All mobiles should synchronize with BS to minimize interference.
- Efficient power utilization: FDMA systems require a 3- to 6-dB power back
  - off in order to compensate for inter-modulation effects.

- Efficient handoff: TDMA systems can take advantage of the fact that the transmitter is switched off during idle time slots to improve the handoff procedure. An enhanced link control, such as that provided by mobile assisted handoff (MAHO) can be carried out by a subscriber by listening to
  - neighboring base station during the idle slot of the TDMA frame.
- Efficiency of TDMA
- Efficiency of TDMA is a measure of the percentage of bits per frame which contain transmitted data. The transmitted data include source and channel coding bits.

- bOH includes all overhead bits such as preamble, guard bits, etc.

4.4.5 Code Division Multiple Access (CDMA)

- Spreading signal (code) consists of chips
    - Has Chip period and and hence, chip rate
    - Spreading signal use a pseudo-noise (PN) sequence (a pseudo-random sequence)
    - PN sequence is called a codeword
    - Each user has its own cordword
    - Codewords are orthogonal. (low autocorrelation)
    - Chip rate is order of magnitude larger than the symbol rate.
- The receiver correlator distinguishes the senders signal by examining the wideband signal with the same time-synchronized spreading code
- The sent signal is recovered by despreading process at the receiver.

CDMA Advantages:

- Low power spectral density.
    - Signal is spread over a larger frequency band
    - Other systems suffer less from the transmitter
- Interference limited operation
    - All frequency spectrum is used
- Privacy
    - The codeword is known only between the sender and receiver. Hence other users can not decode the messages that are in transit
- Reduction of multipath affects by using a larger spectrum

CDMA data

Figure 4.11 CDMA Channels transmission

DSSS Transmitter:

Figure 4.12 CDMA Transmitter

DSSS Receiver

Figure 4.13 CDMA Receiver

ðv FDMA / CDMA

ð§ Avaliable wideband spectrum is frequency divided into number narrow band radio channels. CDMA is employed inside each channel.

ðv DS/FHMA

ð§ The signals are spread using spreading codes (direct sequence signals

ð§ are obtained), but these signal are not transmitted over a constant

ð§ carrier frequency; they are transmitted over a frequency hopping carrier frequency.

ðv Time Division CDMA (TCDMA)

ðq Each cell is using a different spreading code (CDMA employed between cells) that is conveyed to the mobiles in its range.

ðq Inside each cell (inside a CDMA channel), TDMA is employed to multiple x multiple users.

- Time Division Frequency Hopping
  - At each time slot, the user is hopped to a new frequency according to a pseudo-random hopping sequence.
  - Employed in severe co-interference and multi-path environments.

Bluetooth and GSM are using this technique

- A large number of independently steered high-gain beams can be formed without any resulting degradation in SNR ratio.
- Beams can be assigned to individual users, thereby assuring that all links operate with maximum gain.
- Adaptive beam forming can be easily implemented to improve the system capacity by suppressing co channel interference.

Advantage of CDMA

- It is recognized that CDMA's capacity gains over TDMA
- FDMA are entirely due to its tighter, dynamic control over the use of the power domain.

- Choosing a new non-orthogonal PN sequence a CDMA system does not encounter the difficulties of choosing a spare carrier frequency or time slot to carry a Traffic Channel
- Ensure that interference will not be too great if it begins to transmit - that there is still enough space left in the power domain.

Disadvantages of CDMA

- Satellite transponders are channelized too narrowly for roadband CDMA, which is the most attractive form of CDMA.
- Power control cannot be as tight as it is in a terrestrial system because of long round-trip delay.

4.5. Channel allocation schemes

In radio resource management for wireless and cellular network, channel allocation schemes are required to allocate bandwidth and communication channels to base stations, access points and terminal equipment.

The objective is to achieve maximum system spectral efficiency in bit/s/Hz/site by means of frequency reuse, but still assure a certain grade of service by avoiding co-channel interference and adjacent channel interference among nearby cells or networks that share the bandwidth. There are two types of strategies that are followed:-

- Fixed: FCA, fixed channel allocation: Manually assigned by the network operator
- Dynamic:
  - DCA, dynamic channel allocation,
  - DFS, dynamic frequency selection
  - Spread spectrum

4.5.1 FCA

In Fixed Channel Allocation or Fixed Channel Assignment (FCA) each cell is given a predetermined set of frequency channels.

FCA requires manual frequency planning, which is an arduous task in TDMA and FDMA based systems, since such systems are highly sensitive to co-channel interference from nearby cells that are reusing the same channel.

This results in traffic congestion and some calls being lost when traffic gets heavy in some cells, and idle capacity in other cells.

4.5.2. DCA and DFS

Dynamic Frequency Selection (DFS) may be applied in wireless networks with several adjacent non-centrally controlled access points.

A more efficient way of channel allocation would be Dynamic Channel Allocation or Dynamic Channel Assignment (DCA) in which voice channel are not allocated to cell permanently, instead for every call request base station request channel from MSC.

4.6 Spread spectrum

Spread spectrum can be considered as an alternative to complex DCA algorithms. Spread spectrum avoids cochannel interference between adjacent

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.

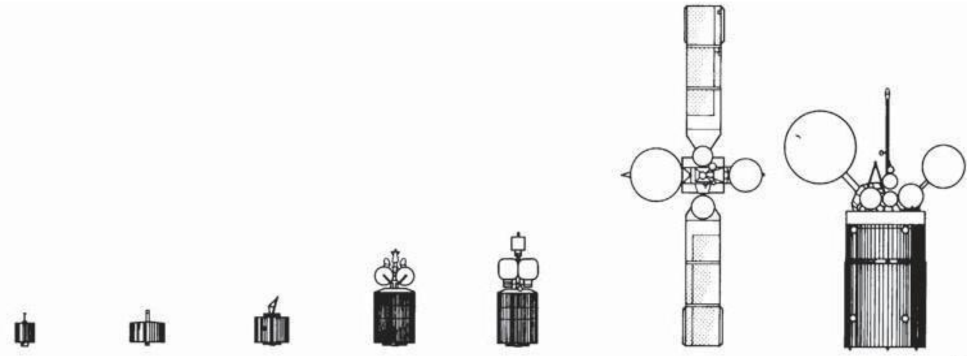
These satellites are in *geostationary orbit*, meaning that they appear to be stationary in relation to the earth. At this point it may be noted that geosta- tionary satellites orbit in the earth's equatorial plane and their position is specified by their longitude.

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 5.1 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.

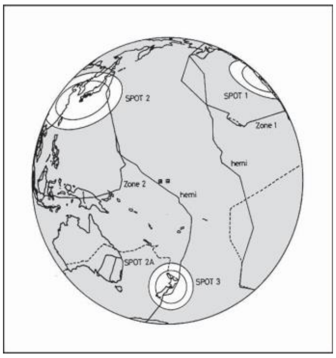


Figure 5.2 Region of globe

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 boun dary, 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

VSAT

VSAT stands for *very small aperture terminal* system. This is the dis- tinguishing feature of a VSAT system, the earth-station antennas being typically less than 2.4 m in diameter (Rana et al., 1990). The trend is toward even smaller dishes, not more than 1.5 m in diameter (Hughes et al., 1993).

In this sense, the small TVRO terminals for direct broadcast satellites could be labeled as VSATs, but the appellation is usually reserved for private networks, mostly providing two-way communications facilities.

Typical user groups include bank- ing and financial institutions, airline and hotel booking agencies, and large retail stores with geographically dispersed outlets.

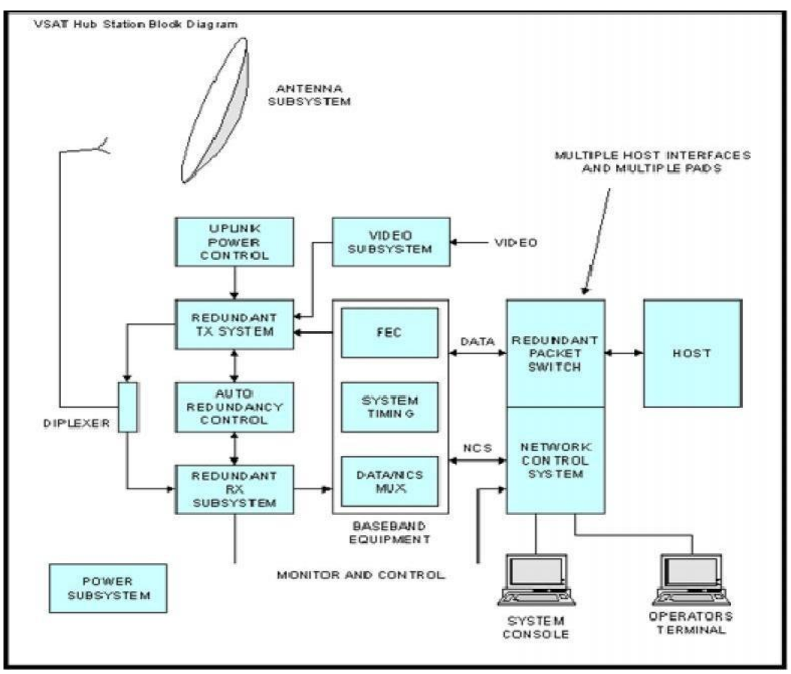


Figure 5.4 VSAT Block Diagrams

VSAT network

The basic structure of a VSAT network consists of a hub station which provides a broadcast facility to all the VSATs in the network and the VSATs themselves which access the satellite in some form of multiple- access mode.

The hub station is operated by the service provider, and it may be shared among a number of users, but of course, each user organ- ization has exclusive access to its own VSAT network.

Time division mul- tiplex is the normal downlink mode of transmission from hub to the VSATs, and the transmission can be broadcast for reception by all the VSATs in a network, or address coding can be used to direct messages to selected VSATs.

A form of *demand assigned multiple access* (DAMA) is employed in some systems in which channel capacity is assigned in response to the fluctuating demands of the VSATs in the network.

Most VSAT systems operate in the Ku band, although there are some C- band systems in existence (Rana et al., 1990).

Applications

- ✓ Supermarket shops (tills, ATM machines, stock sale updates and stock ordering).
- ✓ Chemist shops - Shoppers Drug Mart - Pharmaprix. Broadband direct to the home. e.g. Downloading MP3 audio to audio players.
- ✓ Broadband direct small business, office etc, sharing local use with many PCs.
- ✓ Internet access from on board ship Cruise ships with internet cafes, commercial shipping communications.

GSM

Services and Architecture

If your work involves (or is likely to involve) some form of wireless public communications, you are likely to encounter the GSM standards. Initially developed to support a standardized approach to digital cellular communications in Europe, the "Global System for Mobile Communications" (GSM) protocols are rapidly being adopted to the next generation of wireless telecommunications systems.

In the US, its main competition appears to be the cellular TDMA systems based on the IS-54 standards. Since the GSM systems consist of a wide range of components, standards, and protocols.

The GSM and its companion standard DCS1800 (for the UK, where the 900 MHz frequencies are not available for GSM) have been developed over the last decade to allow cellular communications systems to move beyond the limitations posed by the older analog systems.

Analog system capacities are being stressed with more users that can be effectively supported by the available frequency allocations. Compatibility between types of systems had been limited, if non-existent.

By using digital encoding techniques, more users can share the same frequencies than had been available in the analog systems. As compared to the digital cellular systems in the US (CDMA [IS -95] and TDMA [IS-54]), the GSM market has had impressive success. Estimates of the numbers of telephones run from 7.5 million GSM phones to .5 million IS54 phones to .3 million for IS95.

GSM has gained in acceptance from its initial beginnings in Europe to other parts of the world including Australia, New Zealand, countries in the Middle East and the far east. Beyond its use in cellular frequencies (900 M Hz for GSM, 1800 MHz for DCS1800), portions of the GSM signaling protocols are finding their way into the newly developing PCS and LEO Satellite communications systems.

While the frequencies and link characteristics of these systems differ from the standard GSM air interface, all of these systems must deal with users roaming from one cell (or satellite beam) to another, and bridge services to public communication networks including the Public Switched Telephone Network (PSTN), and public data networks (PDN).

The GSM architecture includes several subsystems

The Mobile Station (MS) -- These digital telephones include vehicle, portable and hand-held terminals. A device called the Subscriber Identity Module (SIM) that is basically a smart -card provides custom information about users such as the services they've subscribed to and their identification in the network

The Base Station Sub-System (BSS) -- The BSS is the collection of devices that support the switching networks radio interface. Major components of the BSS include the Base Transceiver Station (BTS) that consists of the radio modems and antenna equipment.

In OSI terms, the BTS provides the physical interface to the MS where the BSC is responsible for the link layer services to the MS. Logically the transcoding equipment is in the BTS, however, an additional component.

The Network and Switching Sub-System (NSS) -- The NSS provides the switching between the GSM subsystem and external networks along with the databases used for additional subscriber and mobility management.

Major components in the NSS include the Mobile Servi ces Switching Center (MSC), Home and Visiting Location Registers (HLR, VLR). The HLR and VLR databases are interconnected through the telecomm standard Signaling System 7 (SS7) control network.

The Operation Sub-System (OSS) -- The OSS provides the support functions responsible for the management of network maintenance and services. Components of the OSS are responsible for network operation and maintenance, mobile equipment management, and subscription management and charging.

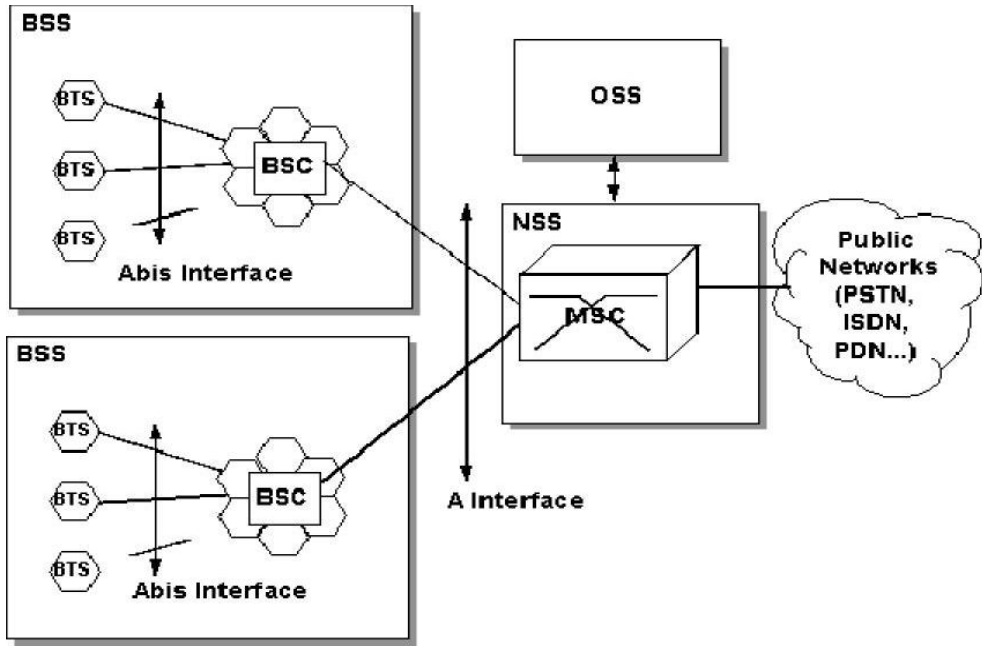


Figure: GSM Block Diagrams

Several channels are used in the air interface

- ✓ **FCCH** - the frequency correction channel - provides frequency synchronization information in a burst
- ✓ **SCH** - Synchronization Channel - shortly following the FCCH burst (8 bits later), provides a reference to all slots on a given frequency
- ✓ **PAGCH** - Paging and Access Grant Channel used for the transmission of paging information requesting the setup of a call to a MS.
- ✓ **RACH** - Random Access Channel - an inbound channel used by the MS to request connections from the ground network. Since this is used for the first access attempt by users of the network, a random access scheme is used to aid in avoiding collisions.
- ✓ **CBCH -** Cell Broadcast Channel - used for infrequent transmission of broadcasts by the ground network.
- ✓ **BCCH** - Broadcast Control Channel - provides access status information to the MS. The information provided on this channel is used by the MS to determine whether or not to request a transition to a new cell
- ✓ **FACCH -** Fast Associated Control Channel for the control of handovers
- ✓ **TCH/F** - Traffic Channel, Full Rate for speech at 13 kbps or data at 12, 6, or 3.6 kbps
- ✓ **TCH/H** - Traffic Channel, Half Rate for speech at 7 kbps, or data at 6 or 3.6 kbps

Mobility Management

One of the major features used in all classes of GSM networks (cellular, PCS and Satellite) is the ability to support roaming users. Through the control signaling network, the MSCs interact to locate and connect to users throughout the network.

"Location Registers" are included in the MSC databases to assist in the role of determining how, and whether connections are to be made to roaming users. Each user of a GSM MS is assigned a Home Location Register (HLR) that is used to contain the user's location and subscribed services.

Difficulties facing the operators can include

a. Remote/Rural Areas. To service remote areas, it is often economically unfeasible to provide backhaul facilities (BTS to BSC) via terrestrial lines (fiber/microwave).

b. Time to deploy. Terrestrial build-outs can take years to plan and implement.

c. Areas of 'minor' interest. These can include small isolated centers such as tourist resorts, islands, mines, oil exploration sites, hydro-electric facilities.

d. Temporary Coverage. Special events, even in urban areas, can overload the existing infrastructure.

GSM service security

GSM was designed with a moderate level of service security. GSM uses several cryptographic algorithms for security. The A5/1, A5/2, and A5/3 stream ciphers are used for ensuring over-the-air voice privacy.

GSM uses General Packet Radio Service (GPRS) for data transmissions like browsing the web. The most commonly deployed GPRS ciphers were publicly broken in 2011The researchers revealed flaws in the commonly used GEA/1.

5.4 GPS Position Location Principles, Differential GPS

Definition and History of GPS positioning

GPS Definition

Global Positioning System GPS (Global Position System) is a space rendezvous and fixed-point navigation system that can be used for timing and ranging, providing continuous, real-time, high-precision three-dimensional position, three-dimensional speed, and time information to users worldwide.

The generation and development of GPS, from TRANSIT to GPS

(1) In October 1957, the first artificial earth satellite in the sky, space-based electronic navigation was born.

(2) The United States built the Meridian Satellite Navigation and Positioning System (TRANSIT) in 1964.

(3) The United States began to build the Global Positioning System (GPS) in 1973, and it was fully completed and put into operation in 1994.

The initial development of GPS positioning was mainly used for military purposes. Such as the army, navy, and air force to provide real-time, all-weather, and global navigation services, intelligence collection, nuclear explosion monitoring, emergency communications, and demolition positioning.

As the GPS system enters the experimental and practical stage, the high degree of automation of its positioning technology and the high accuracy and great potential it achieves have attracted the general attention of governments and the great interest of surveyors.

Especially in recent years, GPS positioning technology has made rapid development in the research of application basis, the development of new application fields, and the development of software and hardware.

The composition of the GPS system

The space satellite part consists of 21 working satellites and 3 backup satellites.

The ground control part consists of 1 main control station, 5 monitoring stations, and 3 injection stations.

The basic types of user receivers are navigation type and terrestrial type. The earth type receiver is divided into single frequency type (L1) and dual-frequency type (L1, L2).

The GPS positioning method classification

The GPS positioning method can be divided into static positioning and dynamic positioning according to the state of the user receiver antenna in the measurement, and absolute positioning and relative positioning according to the positioning result.

Static positioning, that is, in the positioning process, the location of the receiver antenna (observatory) relative to the surrounding ground points, in a static state; while dynamic positioning is the opposite, that is, in the positioning process, the receiver antenna is in motion, the positioning results are continuously changing.

Absolute positioning, also known as single-point positioning, is the independent determination of the absolute position of the user receiver antenna (station) in the WGS-84 coordinate system using GPS.

Relative positioning is to determine the relative position between the receiver antenna (observatory) and a ground reference point in the WGS-84 coordinate system, or the relative position between the two observatories.

Various positioning methods can also have different combinations, such as static absolute positioning, static relative positioning, dynamic absolute positioning, dynamic relative positioning, etc. At present, in the field of engineering and mapping, the most widely used are static relative positioning and dynamic relative positioning.

According to the data solution of relative positioning, whether it is real-time or not, it can be divided into post-processing positioning and real-time dynamic positioning (RTK), among which, post-processing positioning can be further divided into static (relative) positioning and dynamic (relative) positioning.

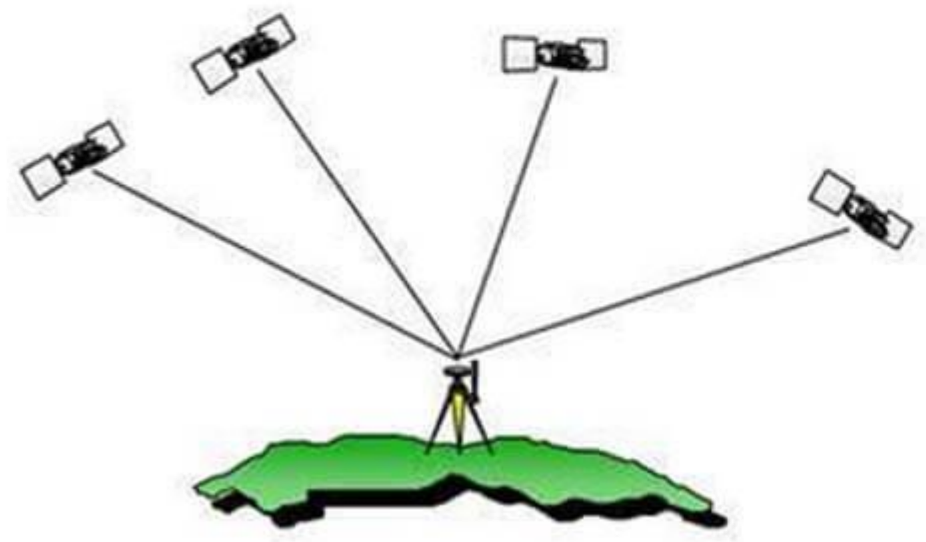
GPS Positioning Principle

Absolute GPS Positioning Principle

The basic principle of absolute positioning by GPS is based on the observed geometric distance between the GPS satellite and the user receiver antenna, and the instantaneous coordinates of the satellite (XS, YS, ZS) to determine the location of the point corresponding to the user receiver antenna, i.e. the location of the observatory.

Let the phase center coordinates of the receiver antenna be (X, Y, Z).

The instantaneous coordinates of the satellite (XS, YS, ZS) can be obtained according to the navigation message, so there are only three unknown quantities X, Y, Z in the equation, and the coordinates of the station (X, Y, Z) can be solved as long as three GPS satellites are received at the same time. It can be seen that the essence of GPS single-point positioning is the backward rendezvous of spatial distance.



Absolute GPS positioning map

Relative GPS Positioning Principle

The relative GPS positioning also called differential GPS positioning, is the most accurate positioning method in GPS positioning at present.

The basic positioning principle is to use two GPS user receivers placed at the two ends of the baseline and observe the same GPS satellites synchronously to determine the relative position or baseline vector of the baseline endpoints (measurement sites) in the WGS-84 coordinate system.

GPS post-processing positioning methods

At present, the relative positioning mode is widely used in engineering. The post-processing positioning methods are static GPS positioning and dynamic GPS positioning.

Static relative GPS positioning

(1) Method

Several GPS receivers are placed on the endpoints of the baseline, kept stationary, and more than 4 satellites are observed simultaneously. Several periods of time can be observed, with each period lasting from ten minutes to about one hour. Finally, the observation data are input into the computer and the coordinates of each point are calculated by the software.

(2) It is the most accurate operation mode. It is mainly used for geodesy, control measurement, deformation measurement, and engineering measurement.

(3) Accuracy can reach (5mm + 1ppm)

Dynamic relative GPS positioning

(1) Method

First, establish a reference station, and place a receiver on it to continuously observe the visible satellite, another receiver in the first point of static observation for a few minutes, and then in the other points in turn to observe a few seconds. Finally, the observation data are input into the computer and the coordinates of each point are calculated by the software. The operating range of dynamic relative positioning generally cannot exceed 15km.

(2) It is suitable for fractional measurement with low accuracy requirements.

(3) Accuracy can be achieved (10-20mm + 1ppm)

GPS real-time dynamic positioning (RTK) method

1. RTK working principle and method

Compared with the dynamic relative positioning method, the positioning mode is the same, only a set of data chains is added between the reference station and the mobile station to realize the real-time calculation and real-time output of the coordinates of each point.

2. RTK is suitable for the construction sampling and fragmentation measurement which does not require high accuracy.
3. The operating range is about 10km.
4. Accuracy can be achieved (10-20mm + 1ppm)

Differential GPS

Differential GPS(DGPS) is a system in which differences between observed and computed co-ordinates ranges (known as differential corrections) at a particular known point are transmitted to users(GPS receivers at other points) to upgrade the accuracy of the users receivers position.

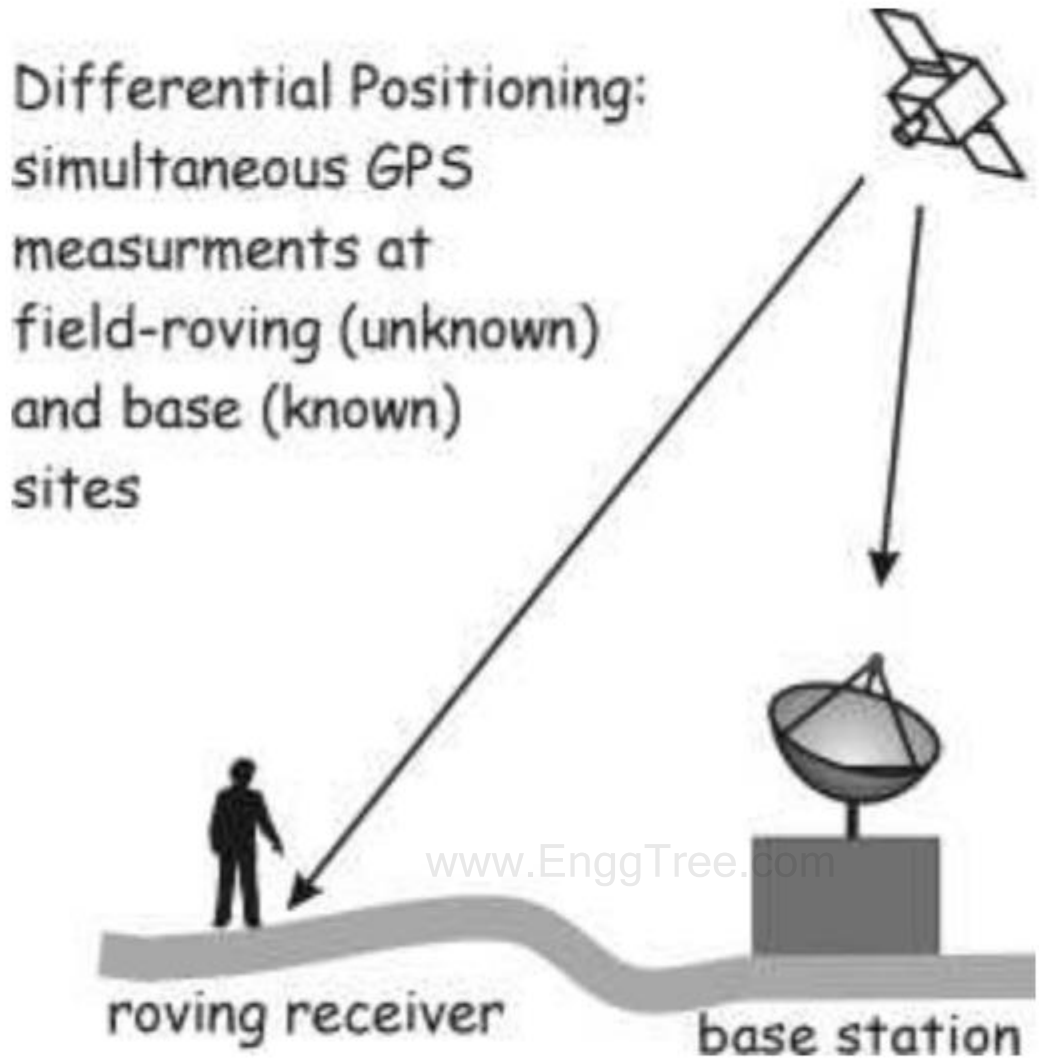
Differential GPS Positioning

Differential positioning user finds the point position derived from the satellite signals and applies correction to that position. These corrections, difference of the determined position and the known position are generated by a Reference Receiver, whose position is known and is fed to the instrument and are used by the second Receiver to correct its internally generated position. This is known as Differential GPS positioning.

Differential Correction

Differential correction is a technique that greatly increases the accuracy of the

collected DGPS data.



It involves using a receiver at a known location - the "base station"- and comparing that data with DGPS positions collected from unknown locations with "roving receivers."

5.5 Direct Broadcast Satellites (DBS/DTH)

Introduction

Satellites provide broadcast transmissions in the fullest sense of the word, since 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 provided are known generally as direct broadcast satellite (DBS) services. Broadcast services include audio, television, and Internet services.

A type of satellite service that allows direct transmission of signals from the satellites present in the geostationary orbit to the personal dish antennas present in homes audiences is known as Direct Broadcast Satellite. It is abbreviated as DBS.

More simply, DBS is regarded as a technique of transmitting messages or signals directly to the general public (existing as an individual or a community) using artificial satellites orbiting the earth. The frequency band in which the DBS operates change according to the region in which the operation is taking place.

DBS

Direct Broadcast Television is nothing but digital TV. The use of satellites for the purpose of providing services directly to homes using satellites has evolved several years ago, more specifically, DBS-TV was introduced in the year 1986. The various broadcasting services offered by the DBS are audio, video and internet services.

The frequency band of operation for the direct broadcast television service changes according to the region of operation. Generally, Ku-band (14/12 GHz) is specified for DBS services as it is less prone to problems such as interference. The reason is that at such high-frequency bands the chances of congestion are quite low, along with that, ku-band is not utilized in terrestrial microwave communication. When the frequency is high then the receiving antenna required will also be of small length and due to smaller antenna size higher value of EIRP is obtained from the satellite. This resultantly reduces the overall cost of the equipment.

For DBS, it is said that the satellites used for providing the service offers broadcast transmission in a way that the antenna footprints are made wide so that it can cover a sufficiently large region. Thus, the satellite in motion in space when receives a signal from one earth station then that respective signal can be received by various home TV dish antennas that are present within the footprint region. Thus, DBS allows direct reception of signal that is coming from the satellite.

It is to be noted here that at the receiving end, it can be a single user that is willing to receive or it can be a group of users among which the received signal is distributed.

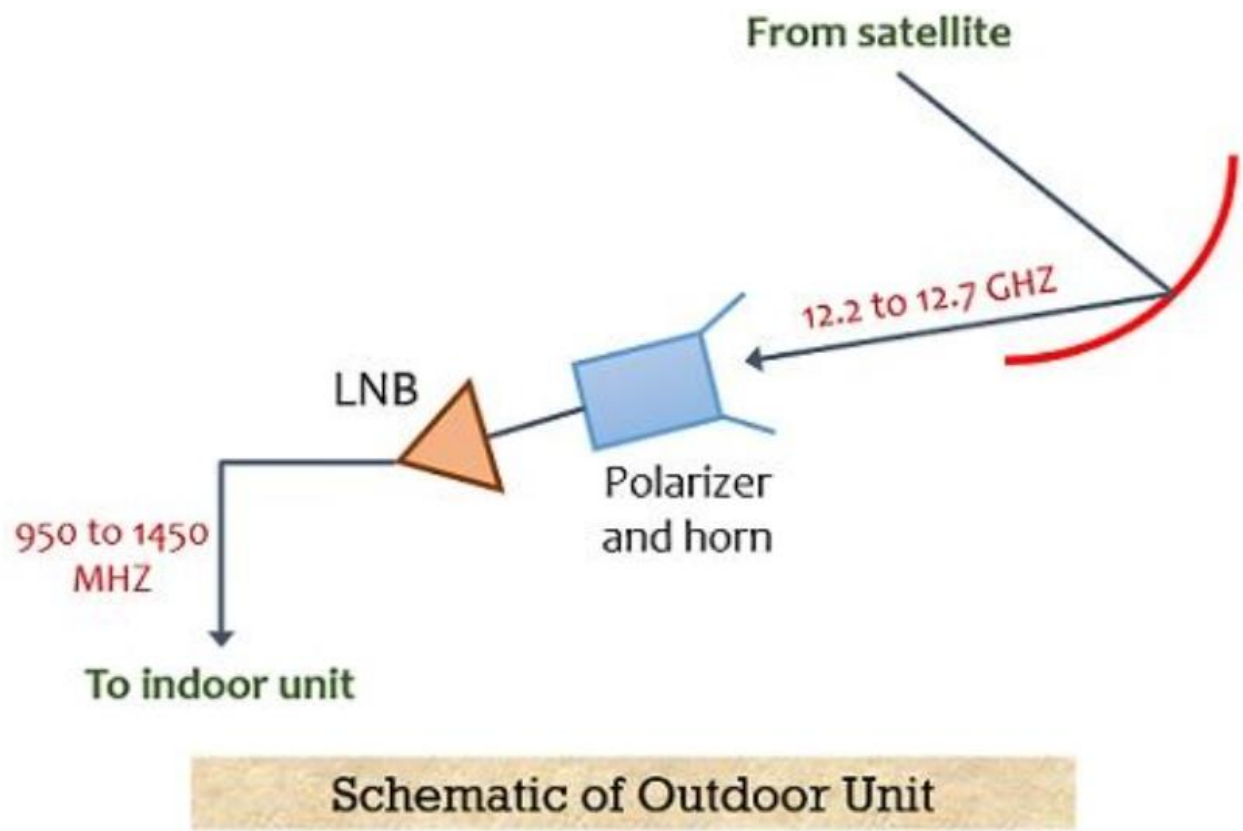
DBS is known to be an active field of satellite development and can help in providing innovations in other fields as well such as HDTV.

DBS – Home Receiver

The home receiver system of a Direct Broadcast System mainly has 2 units namely, an outdoor unit and an indoor unit. Let us first see:

The Outdoor Unit

The figure below represents the schematic of the Outdoor Unit for the DBS Home Receiver:



Block diagram of outdoor unit of DBS

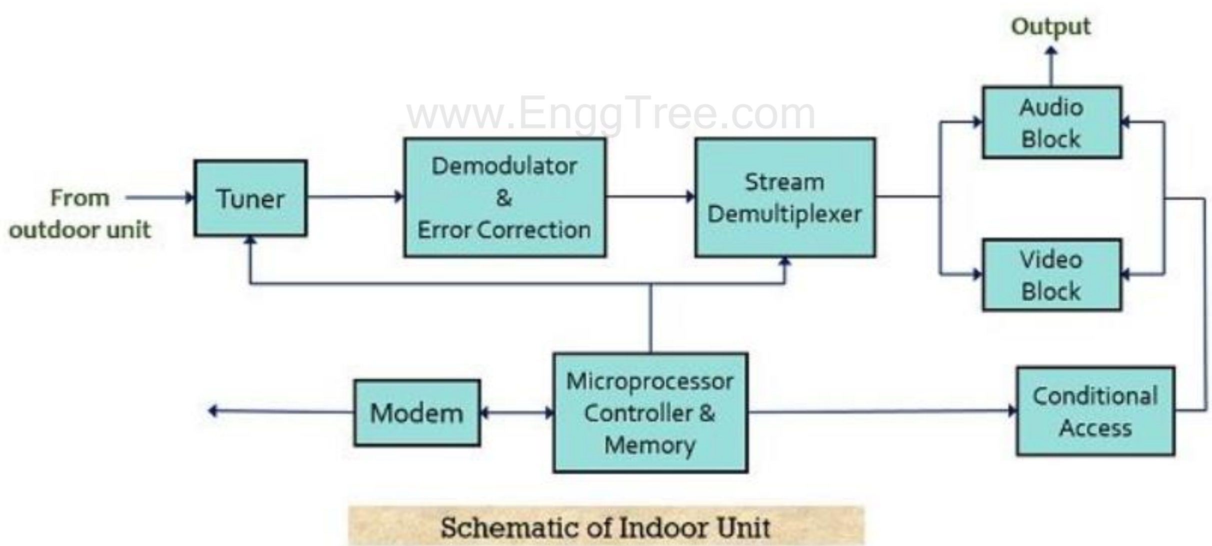
It is clearly shown in the above figure that the dish antenna at the receiver first receives the downlink signal from the satellite which is in the range from 12.2 GHz to 12.7 GHz. The received signal is then focussed towards the receive horn. The receive horn directs the signal towards the polarizer that helps to pass the left-hand circular or right-hand circular polarized signals by performing adequate switching.

There is a low noise block that contains a combination of a Low Noise Amplifier (LNA) and a downconverter. The LNA is the unit that is responsible for the amplification of low strength signals. These are the signals that are hardly recognized by the antenna and necessary amplification must be performed without the addition of noise. Now, the downconverter comes into action and down-conversion of the signal in the range from 12.2 to 12.7 GHz is performed which is converted into the range 950 to 1450 MHz. The reason for this down conversion is that for the transmission of a signal from the connecting cable to the indoor unit, these down-converted frequencies are suited properly.

It is to be noted here that in order to gather most of the signal the arrangement of the receiving antenna must be such that it should exhibit an obstruction-free view from the satellite cluster in space. And as there is a cluster of satellites thus, the beamwidth of the antenna should be sufficiently wide so that it can receive from all the satellites present in the cluster.

The Indoor Unit

The figure below shows the block diagram representation of the indoor unit:



Block diagram of indoor unit of DBS

The tuner is the foremost block of the indoor unit which is used for selecting the transponder. As we know that the down-converted frequency is in the range from 950 to 1450 MHz but the guard band of 24 MHz is maintained by the transponder in the selected bandwidth. Thus, out of the 32 transponders, any of them must be received by the indoor unit.

It is to be noted here that for a single polarization only a signal from 16 transponders must be available. The modulation of the carrier at the centre frequency performed here is QPSK. Further, demodulation of the quadrature phase-shift keying modulated signal is performed and it is converted into the equivalent bitstream. Once this is done then an error correction scheme is implemented to eliminate the errors from the received sequence.

Here demultiplexing of the received sequence is performed where individual programs get separated and then get separated in the buffer memories so that further processing may take place. At this stage, further processing may correspond to the conditional accessibility, usage history view, modem connection, etc.

Applications of DBS

The approach of transmitting the signals directly from the satellite to the home receivers helps in providing broadcast services of audio and video along with other interactive data services. A properly installed DBS system helps in providing information when any rapid disaster (such as forest fire) occurs in any remote area. DBS also finds applications in fields where on-demand information is required such as weather forecasting. One of the basic applications includes providing distance learning programs.

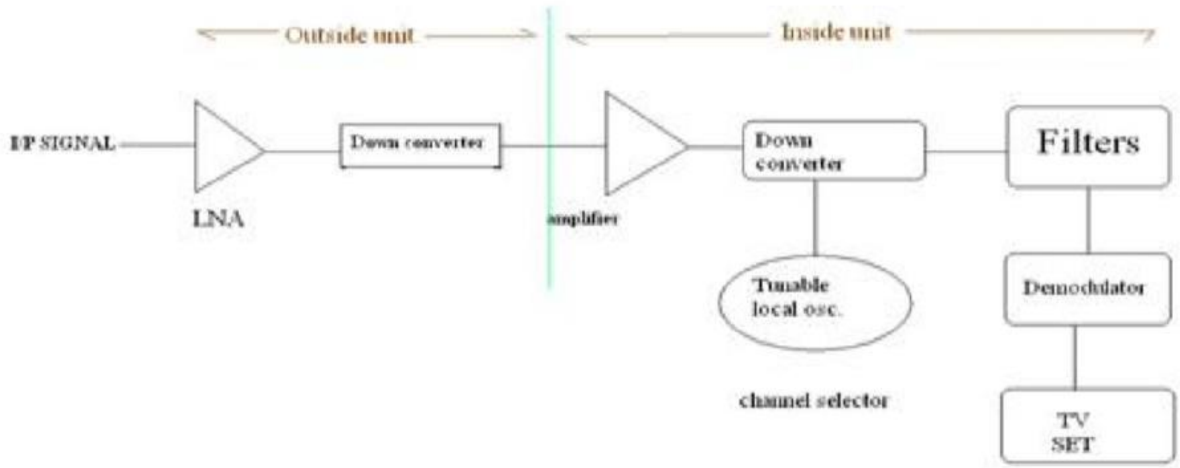
Direct to home Broadcast (DTH):

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.
- The outputs of group of DTH LNBs are connected to the A and B inputs of the Multi Switch.



Block Diagram of DTH Service

Advantages of DTH:

- 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.

What is the difference between DTH and DBS?

Direct to home technology is the satellite television broadcasting process which is actually intended for home reception. This technology is originally referred to direct broadcast satellite (DBS) technology.