IV B.TECH II SEMESTER

SATTELITE COMMUNICATIONS

UNIT-1

COMMUNICATION SATELLITE

ORIGIN OF SATELLITE COMMUNICATIONS

The outer space has always fascinated people on the earth and communication through space evolved as an offshoot of ideas for space travel. The earliest idea of using artificial satellites for communications is found in a science fiction **Brick Moon** by Edward Evert Hale, published in 1869-70. While the early fictional accounts of satellite and space communications bear little resemblance to the technology as it exists today, they are of significance since they represent the origins of the idea from which the technology eventuallyevolved. In the area of satellite communications, the technology has been responsive to the imaginative dreams. Hence it is also expected that technological innovations will lead the evolution of satellite communications towards the visions of today.

Concept of Satellite Communications

Scientists from different countries conceived various ideas for communications through space along with the technological breakthroughs in different fields of science. The Russian scientist Konstantin Tsiolkovsky (1857-1935) was the first person to study space travel as a science and in 1879 formulated his Rocket Equation, which is still used in the design of modern rockets. He also wrote the first theoretical description of a man- made satellite and noted the existence of a geosynchronous orbit. But he did not identify any practical applications of geosynchronous orbit. The noted German Scientist and rocket expert, Hermann Oberth, in 1923 proposed that the crews of orbiting rockets could communicate with remote regions on earth by signalling with mirrors. In 1928, Austrian Scientist Hermann Noordung suggested that the geostationary orbit might be a good location for manned space vehicle. Russian Scientists in 1937 suggested that television images could be relayed by bouncing them off the space vehicles. During 1942-1943, a series of articles by George O Smith were published in Astounding Science Fictions concerning an artificial planet, Venus Equilateral, which functioned as relay station between Venus and Earth Stationwhen direct communication was blocked by Sun. However, Arthur C. Clarke, an electronic engineer and the well-known science fiction writer is generally credited with originating the modern concept of Satellite Communications.

In 1945, Clarke, in his article **`Extra Terrestrial Relays: Can Rocket Stations give Worldwide Radio Coverage?'** published in Wireless World outlined the basic technical considerations involved in the concept of satellite communications. Clarke proposed orbiting space stations, which could be provided with receiving and transmitting equipment and could act as a repeater to relay transmission between any two points of the hemisphere beneath. He calculated that at an orbital radius of 42,000 km. the space station's orbit would coincide with the earth's rotation on its axis and the space station would remain fixed as seen from any point on the earth. He also pointed out that three such synchronous stations located 120 degrees apart above the equator could provide worldwide communications coverage. The concept was later considered to be generating a billion dollar business in the area of communications. However, Clarke did not patent the most commercially viable idea of twentieth century as he thought satellites would not be technically and economically viable until the next century.

Realization of concept to reality:

In October 1957, the first artificial satellite **Sputnik -I** was launched by former Soviet Russia in the earth's orbit and in 1963 Clark's idea became a reality when the first geosynchronous satellite **SYNCOM** was successfully launched by NASA.

The realization of the concept of satellite communications from an idea to reality has been possible due to a large number of technological breakthroughs and practical realization of devices and systems, which took place during and after the World War II. The pressures of international military rivalry during cold war period were also able to a great extent to push scientific and technological research and development far faster than it would have beenpossible if applied for peaceful purposes.

The successful launching of communications satellite in earth's orbit was possible because of keen interests shown by specific groups of people along with the developments in diverse areas of science and technology. Some of these factors, which are considered important in the realization of satellite communications, are:

- Development of high power rocket technology and propulsion systems capable of delivering satellites in high altitude orbits
- Scientific and military interests in Space Research
- Development of Transistors and miniaturization of electronic circuitry.
- Development of Solar Cells for providing sustained energy source for the satellite.
- Development of high-speed computers for calculating and tracking orbits.
- Government support in large-scale financial commitment to Space Technology Development for Military, Scientific Experiments and Civilian Applications.
- International military rivalry among super powers.
- The psychological impact of Sputnik Challenge leading to long range program of scientific research and development undertaken by US.

Before the transformation of the concept of communications by satellite to blue print and subsequent development of the hardware took place it was necessary to make the scientific communities convinced about the technical feasibility of such a system. In US J.R. Pierce, of Bell Laboratories initiated this by promoting the idea of transoceanic satellite communications within the scientific and technical communities. In 1955 Pierce in a paper entitled Orbital RadioRelays proposed detailed technical plan for passive communications satellites, disregarding the feasibility of constructing and placing satellites in orbit. He proposed three types of repeaters.

- Spheres at low altitudes
- A plane reflector
- An active repeater in 24 Hr. orbit

Pierce concluded his paper with a request to the scientific community to develop rockets capable of launching communications satellite. Fortunately, scientific and military interest in rocketry after World War II contributed in the development of a number of rockets like Atlas, Jupiter and Thor rockets in US and different multistage rockets in former USSR that ultimately made the launching of satellites in orbit possible.

On Oct. 4, 1957, **Sputnik-1** was launched as part of Russia's program for International Geophysical Year. The launching of Sputnik marks the dawn of the space age and the world's introduction to artificial satellite. Mass of Sputnik was only 184 lbs. in an orbit of 560 miles above the earth. It carried two radio transmitters at 20.005 MHz and 40.002 MHz. However this space craft was far more than a scientific and technical achievement as it had a tremendous psychological and political impact particularly on United States resulting in a technological competition between United States and Russia, long term planning in Space Research and establishment of NASA.

Four months after the launch of Sputnik, US **Explorer-1** was launched in January 1958 by a Jupiter rocket and the space race between Russia and US began.

HISTORICAL BACKGROUND:

Category	Year	Activity	Person/Agency/ Country.
Geostationary concept	1945	Suggestion of Geostationary satellite communication feasibility.	A. Clark (U.K)
Moon Reflection	1946	Detection of Lunar Echo by Radar	J. Mofenson (U.S.A.)
	1954	Passive relaying of voice by moon reflection.	J.H. Trexler (U.S.A.)
	1960	Hawaii-Washington, D.C. Communication by Moon Reflection.	U.S.A. Navy.
Low altitude orbit.	1957	Observation of signals from Sputnik -1 Satellite.	U.S.S.R., Japan and others.
	1958	Tape-recorded voice transmission by Satellite SCORE.	U.S.A. Air Force.
	1960	Meteorological facsimile Trans mission by Satellite Tiros-1.	U.S.A. NASA
	1960	Passive relaying of telephone and television by Satellite Echo-1.	U.S.A. Army.
	1960	Delayed relaying of recorded voice by	U.S.A. Army.

		Satellite Courier-1B.	
	1962	Active transatlantic relaying of communication by Satellite Telstar-1.	U.S.A., U.K., France.
	1962	Communication between manned Satellites Vostok-3 and 4; Space television transmission.	U.S.S.R.
	1963	Scatter communication by tiny needles in Orbit. (West Ford Project 6)	U.S.A. MIT.
	1963	Active transpacific relaying of communication by Satellite Relay 1.	U.S.A. NASA, Japan.
Synchronous Satellite.	1963	USA-Europe-Africa communication by Satellite Syncom 2.	U.S.A. NASA
	1964	Olympic Games television relaying by Satellite Syncom 3	U.S.A., NASA Japan.
	1965	Commercial Communication (Semi-experimental) by Satellite Early Bird.	INTELSAT.

BASIC CONCEPTS OF SATELLITE COMMUNICATIONS

- A communication satellite is an orbiting artificial earth satellite that receives a communications signal from a transmitting ground station, amplifies and possibly processes it, then transmits it back to the earth for reception by one or more receiving ground stations.

- Communications information neither originates nor terminates at the satellite itself. The satellite is an active transmission relay, similar in function to relay towers used in terrestrial microwave communications.

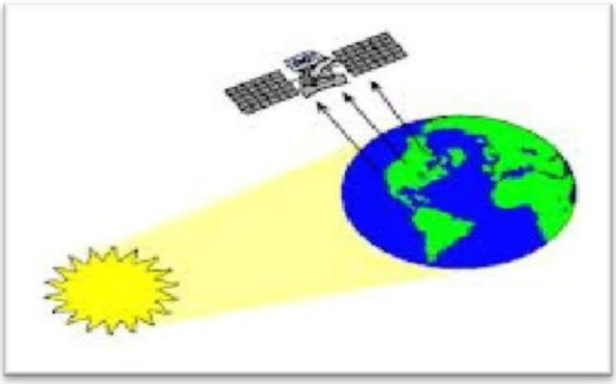
- The commercial satellite communications industry has its beginnings in the mid-1960s, and in less than 50 years has progressed from an alternative exotic technology to a mainstream transmission technology, which is pervasive in allelements of the global telecommunications infrastructure. Today’s communications satellites offer extensive capabilities in applications involving data, voice, and video, with services provided to fixed, broadcast, mobile, personal communications,and private networks users.

Evolution of Satellite Communication:

- During early 1950s, both passive and active satellites were considered for the purpose of communications over a large distance.
- Passive satellites though successfully used in the early years of satellite communications, with the advancement in technology active satellites have completely replaced the passive satellites.

Passive Satellites:

- A satellite that only reflects signals from one Earth station to another or from several Earth stations to several others.
- It reflects the incident electromagnetic radiation without any modification or amplification.
- It can't generate power, they simply reflect the incident power.
- The first artificial passive satellite Echo-I of NASA was launched in August 1960.

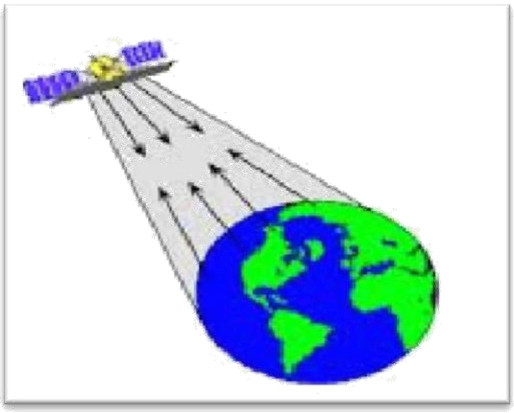


Disadvantages:

- Earth Stations required high power to transmit signals.
- Large Earth Stations with tracking facilities were expensive.
- A global system would have required a large number of passive satellites accessed randomly by different users.
- Control of satellites not possible from ground.
- The large attenuation of the signal while traveling the large distance between the transmitter and the receiver via the satellite was one of the most serious problems.

Active Satellites:

- In active satellites, it amplifies or modifies and retransmits the signal received from the earth.
- Satellites which can transmit power are called active satellite.
- Have several advantages over the passive satellites.
- Require lower power earth station.
- Not open to random use.
- Directly controlled by operators from ground.

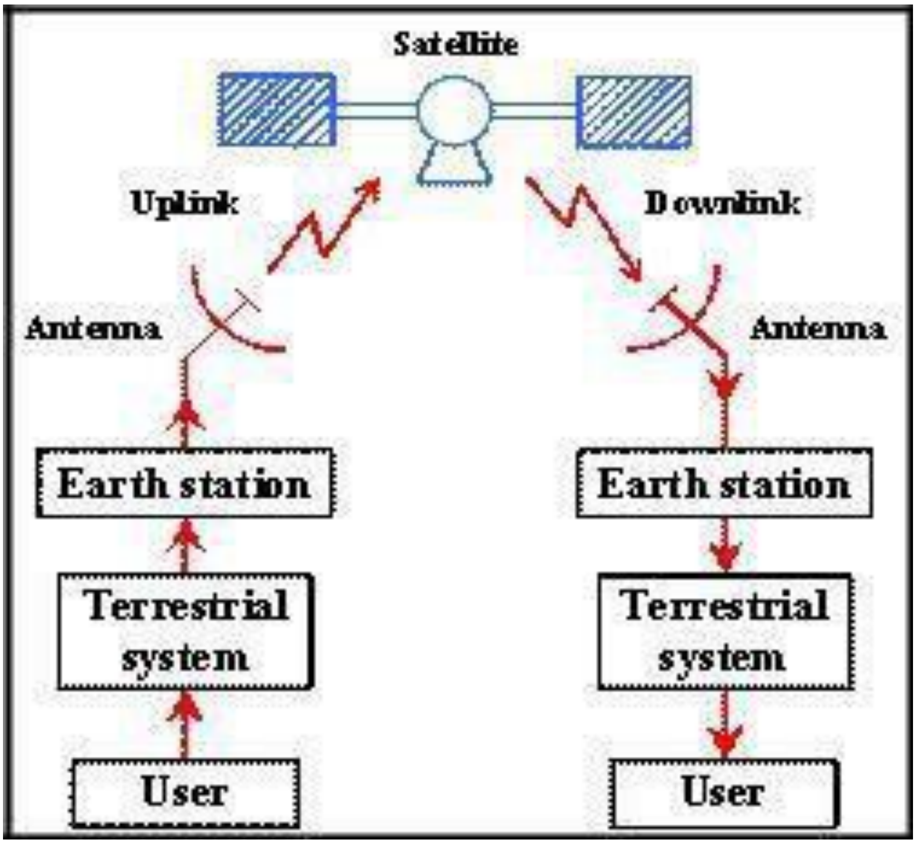


Disadvantages:

- Requirement of larger and powerful rockets to launch heavier satellites in orbit.
- Requirement of on-board power supply.
- Interruption of service due to failure of electronics components

Two major elements of Satellite Communications Systems are:

The satellite communications portion is broken down into two areas or segments: the ***space segment*** and the ***ground (or earth) segment***.



General architecture of Satellite Communication

Space Segment:

The elements of the space segment of a communications satellite system are shown in Figure. The space segment includes the satellite (or satellites) in orbit in the system, and the ground station that provides the operational control of the satellite(s) in orbit. The ground station is variously referred to as the ***Tracking, Telemetry, Command (TT&C)*** or the ***Tracking, Telemetry, Command and Monitoring (TTC&M)*** station. The TTC&M station provides essential spacecraft management and control functions to keep the satellite operating safely in orbit. The TTC&M links between the spacecraft and the ground are usually separate from the user communications links. TTC&M links may operate in the same frequency bands or in other bands. TTC&M is most often accomplished through a separate earth terminal facility specifically designed for the complex operations required to maintain a spacecraft in orbit.

Ground segment:

The ground segment of the communications satellite system consists of the earth surface area based terminals that utilize the communications capabilities of the Space Segment. TTC&M ground stations are ***not*** included in the ground segment. The ground segment terminals consist of three basic types:

- fixed (in-place) terminals;
- transportable terminals;
- mobile terminals.

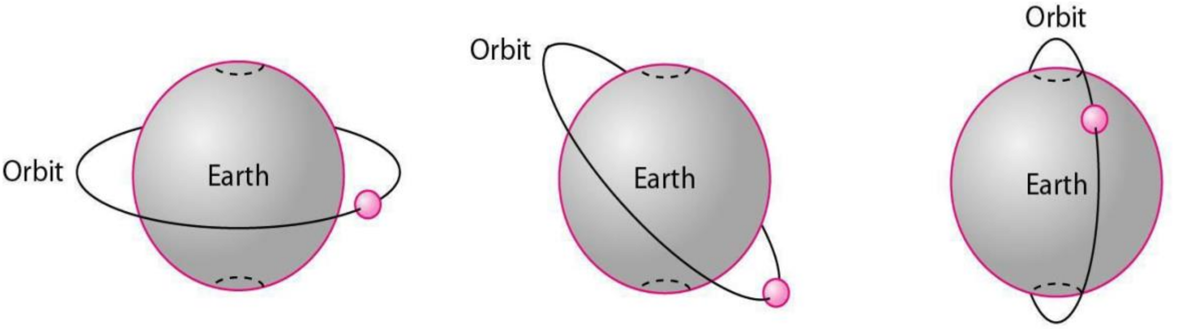
Fixed terminals are designed to access the satellite while fixed in-place on the ground. They may be providing different types of services, but they are defined by the fact that they are not moving while communicating with the satellite. Examples of fixed terminals are small terminals used in private networks (VSATs), or terminals mounted on residence buildings used to receive broadcast satellite signals. Transportable terminals are designed to be movable, but once on location remain fixed during transmissions to the satellite. Examples of the transportable terminal are satellite news gathering (SGN) trucks, which move to locations, stop in place, and then deploy an antenna to establish links to the satellite.

Mobile terminals are designed to communicate with the satellite while in motion. They are further defined as land mobile, aeronautical mobile, or maritime mobile, depending on their locations on or near the earth surface.

Satellite Control Centre function:

- Tracking of the satellite
- Receiving data
- Eclipse management of satellite
- Commanding the Satellite for station keeping.
- Determining Orbital parameters from Tracking and Ranging data
- Switching ON/OFF of different subsystems as per the operational requirements

SATELLITE ORBITS



a. Equatorial-orbit satellite b. Inclined-orbit satellite c. Polar-orbit satellite

Orbit: The path a Satellite follows around a planet is defined as an orbit.

- Satellite Orbits are classified in two broad categories :
  - Non-Geostationary Orbit (NGSO)
  - Geo Stationary Orbit (GSO)

- Early ventures with satellite communications used satellites in Non-geostationary low earth orbits due to the technical limitations of the launch vehicles in placing satellites in higher orbits.

Disadvantages of NGSO

- Complex problem of transferring signal from one satellite to another.
- Less expected life of satellites at NGSO.
- Requires frequent replacement of satellites compared to satellite in GSO

Geo Stationary Orbit (GSO)

- There is only one geostationary orbit possible around the earth
- Lying on the earth's equatorial plane.
- The satellite orbiting at the same speed as the rotational speed of the earth on its axis.

Advantages:

- Simple ground station tracking.
- Nearly constant range
- Very small frequency shift

Disadvantages:

- Transmission delay of the order of 250 msec.
- Large free space loss
- No polar coverage

Note: A geostationary orbit is a type of geosynchronous orbit. A geosynchronous orbit can be any orbit, like with an elliptical path, that has a period equal to the Earth's rotational period, whereas a geostationary orbit has to be a circular orbit and that too placed above the equator.

Satellite orbits in terms of the orbital height:

- According to distance from earth:
  - Geosynchronous Earth Orbit (GEO)
  - Medium Earth Orbit (MEO)
  - Low Earth Orbit (LEO)

Geostationary or geosynchronous earth orbit (GEO)

GEO satellites are synchronous with respect to earth. Looking from a fixed point from Earth, these satellites appear to be stationary. These satellites are placed in the space in such a way that only three satellites are sufficient to provide connection throughout the surface of the Earth (that is; their footprint is covering almost 1/3rd of the Earth). The orbit of these satellites is circular.

There are three conditions which lead to geostationary satellites. Lifetime expectancy of these satellites is 15 years.

1) The satellite should be placed 35,786 kms (approximated to 36,000 kms) above the surface of the earth.

2) These satellites must travel in the rotational speed of earth, and in the direction of motion of earth, that is eastward.

3) The inclination of satellite with respect to earth must be 0^0.

Geostationary satellite in practical is termed as geosynchronous as there are multiple factors which make these satellites shift from the ideal geostationary condition.

1) Gravitational pull of sun and moon makes these satellites deviate from their orbit. Over the period of time, they go through a drag. (Earth's gravitational force has no effect on these satellites due to their distance from the surface of the Earth.)

2) These satellites experience the centrifugal force due to the rotation of Earth, making them deviate from their orbit.

3) The non-circular shape of the earth leads to continuous adjustment of speed of satellite from the earth station.

These satellites are used for TV and radio broadcast, weather forecast and also, these satellites are operating as backbones for the telephone networks.

Disadvantages of GEO: Northern or southern regions of the Earth (poles) have more problems receiving these satellites due to the low elevation above a latitude of 60°, i.e., largerantennas are needed in this case. Shading of the signals is seen in cities due to high buildings and the low elevation further away from the equator limit transmission quality. The transmit power needed is relatively high which causes problems for battery powered devices. These satellites cannot be used for small mobile phones. The biggest problem for voice and also data communication is the high latency as without having any handovers, the signal has to at least travel 72,000 kms. Due to the large footprint, either frequencies cannot be reused or the GEO satellite needs special antennas focusing on a smaller footprint. Transferring a GEO into orbit is very expensive.

GEO: 35,786 km above the earth

Advantages Of GEO

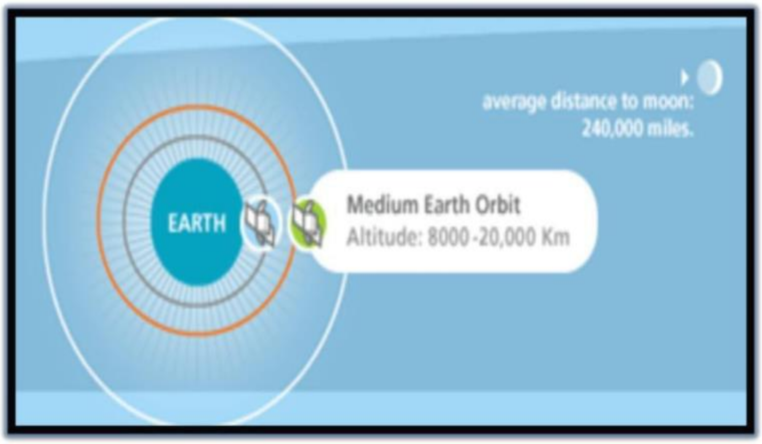
- Minimal Doppler shift
- These factors make it ideal for satellite broadcast and other multipoint applications
- GEO satellites have a 24 hour view of a particular area.
- A GEO satellite's distance from earth gives it a large coverage area, almost a fourth of the earth's surface.

Medium Earth Orbit (MEO) satellites:

MEOs can be positioned somewhere between LEOs and GEOs, both in terms of their orbit and due to their advantages and disadvantages. Using orbits around 20,000 km, the system only requires a dozen satellites which is more than a GEO system, but much less thana LEO system. These satellites move more slowly relative to the earth's rotation allowing a simpler system design (satellite periods are about six hours). Depending on the inclination, a MEO can cover larger populations, so requiring fewer handovers.

Disadvantages: Again, due to the larger distance to the earth, delay increases to about 70–80 ms. the satellites need higher transmit power and special antennas for smaller footprints.

MEO: 8,000-20,000 km above the earth



Advantages Of MEO

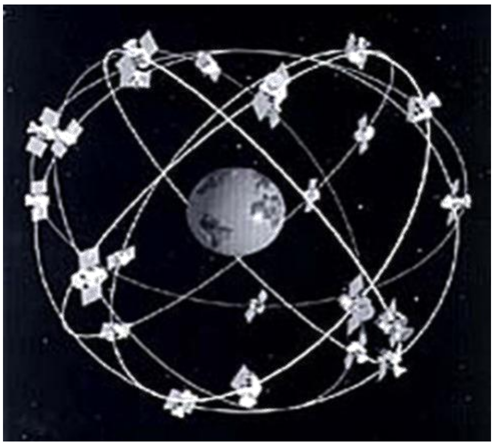
- A MEO satellite's longer duration of visibility and wider footprint means fewer satellites are needed in a MEO network than a LEO network.

Disadvantages Of MEO

- A MEO satellite's distance gives it a longer time delay and weaker signal than a LEO satellite, though not as bad as a GEO satellite.

MEO satellites

The GPS constellation calls for 24 satellites to be distributed equally among six circular orbital planes



GPS Constellation

Low Earth Orbit (LEO) satellites:

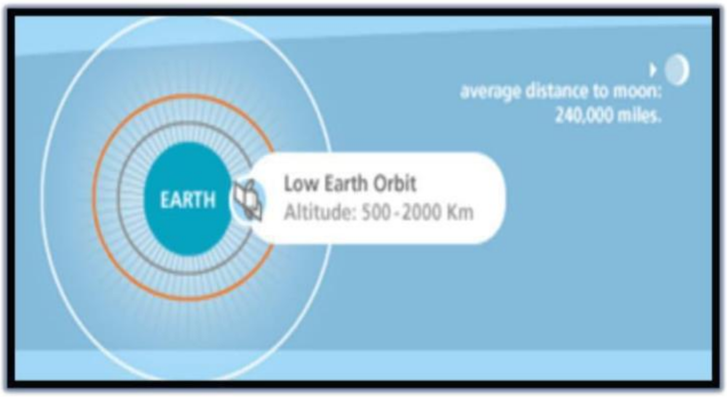
These satellites are placed 500-1500 kms above the surface of the earth. As LEOs circulate on a lower orbit, hence they exhibit a much shorter period that is 95 to 120 minutes. LEO systems try to ensure a high elevation for every spot on earth to provide a high quality communication link. Each LEO satellite will only be visible from the earth for around ten minutes.

Using advanced compression schemes, transmission rates of about 2,400 bit/s can be enough for voice communication. LEOs even provide this bandwidth for mobile terminals with Omni-directional antennas using low transmit power in the range of 1W. The delay for packets delivered via a LEO is relatively low (approx 10 ms). The delay is comparable to long-distance wired connections (about 5–10 ms). Smaller footprints of LEOs allow for betterfrequency reuse, similar to the concepts used for cellular networks. LEOs can provide a muchhigher elevation in Polar Regions and so better global coverage.

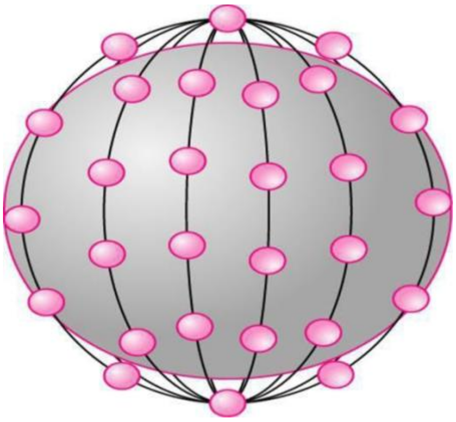
These satellites are mainly used in remote sensing an providing mobile communicationservices (due to lower latency).

Disadvantages: The biggest problem of the LEO concept is the need for many satellites if global coverage is to be reached. Several concepts involve 50–200 or even more satellites in orbit. The short time of visibility with a high elevation requires additional mechanisms for connection handover between different satellites. The high number of satellites combined with the fast movements resulting in a high complexity of the whole satellite system. One general problem of LEOs is the short lifetime of about five to eight years due to atmospheric drag and radiation from the inner Van Allen belt1. Assuming 48 satellites and a lifetime of eight years, a new satellite would be needed every two months. The low latency via a single LEO is only half of the story. Other factors are the need for routing of data packets from satellite to if a user wants to communicate around the world. Due to the large footprint, a GEO typically does not need this type of routing, as senders and receivers are most likely in the same footprint.

LEO: 500-2,000 km above the earth



The Iridium system shown below has 66 satellites in six LEO orbits, each at an altitude of 750 km.



Iridium is designed to provide direct worldwide voice and data communication using handheld terminals, a service similar to cellular telephony but on a global scale.

Advantages Of LEO

- A LEO satellite's proximity to earth compared to a GEO satellite gives it a better signal strength and less of a time delay, which makes it better for point to point communication.
- A LEO satellite's smaller area of coverage is less and waste of bandwidth.

Disadvantages Of LEO

- A network of LEO satellites is needed, which can be costly
- LEO satellites have to compensate for Doppler shifts cause by their relative movement.
- Atmospheric drag effects LEO satellites, causing gradual orbital deterioration.

Advantages Of Satellite Communication

- **Universal:** Satellite communications are available virtually everywhere.
- **Versatile:** Satellites can support all of today's communications needs.
- **Reliable:** Satellite is a proven medium for supporting a company's communications needs.
- **Seamless:** Satellite's inherent strength as a broadcast medium makes it perfect.
- **Fast:** Since satellite networks can be set up quickly, companies can be fast-to-market with new services.
- Flexible
- Expandable
- High Quality
- Quick Provision of Services
- Mobile and Emergency Communication
- Suitable for both Digital and Analog Transmission

FREQUENCY ALLOCATIONS FOR SATELLITE SERVICES

Allocation of frequencies to satellite services s a complicated process which requires international coordination and planning. This is done as per the International Telecommunication Union (ITU). To implement this frequency planning, the world is divided into three regions:

Region1: Europe, Africa and Mongolia
Region 2: North and South America and Greenland
Region 3: Asia (excluding region 1 areas), Australia and south-west Pacific.

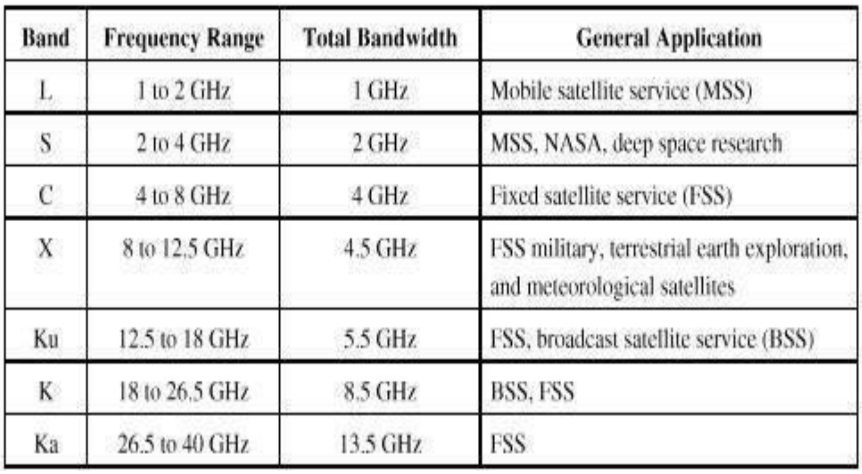
Within these regions, he frequency bands are allocated to various satellite services. Some of them are listed below.

- **Fixed satellite service**: Provides Links for existing Telephone Networks Used for transmitting television signals to cable companies
- **Broadcasting satellite service**: Provides Direct Broadcast to homes. E.g. Live Cricket matches etc
- **Mobile satellite services**: This includes services for: Land Mobile Maritime Mobile Aeronautical mobile
- **Navigational satellite services** : Include Global Positioning systems
- **Meteorological satellite services**: They are often used to perform Search and Rescue service

Below are the frequencies allocated to these satellites:
Frequency Band (GHZ) Designations:
VHF: 01-0.3
UHF: 0.3-1.0
L-band: 1.0-2.0
S-band: 2.0-4.0
C-band: 4.0-8.0
X-band: 8.0-12.0
Ku-band: 12.0-18.0 (Ku is Under K Band)
Ka-band: 18.0-27.0 (Ka is Above K Band)
V-band: 40.0-75.0
W-band: 75-110
Mm-band: 110-300
µm-band: 300-3000
Based on the satellite service, following are the frequencies allocated to the satellites:

Frequency Band (GHZ) Designations:

VHF: 01-0.3 ---Mobile & Navigational Satellite Services
L-band: 1.0-2.0 --- Mobile & Navigational Satellite Services
C-band: 4.0-8.0 --- Fixed Satellite Service
Ku-band: 12.0-18.0 --- Direct Broadcast Satellite Services



Band	Frequency Range	Total Bandwidth	General Application
L	1 to 2 GHz	1 GHz	Mobile satellite service (MSS)
S	2 to 4 GHz	2 GHz	MSS, NASA, deep space research
C	4 to 8 GHz	4 GHz	Fixed satellite service (FSS)
X	8 to 12.5 GHz	4.5 GHz	FSS military, terrestrial earth exploration, and meteorological satellites
Ku	12.5 to 18 GHz	5.5 GHz	FSS, broadcast satellite service (BSS)
K	18 to 26.5 GHz	8.5 GHz	BSS, FSS
Ka	26.5 to 40 GHz	13.5 GHz	FSS

APPLICATIONS OF SATELLITE COMMUNICATION

1) 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 monitor the changes in the Earth's vegetation, sea state, ocean color, and ice fields.

2) 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 30-40 cm sized dish to make these channels available globally.

3) 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.

4) 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.

5) 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.

6) 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 provides a complete coverage and (generally) there is one satellite always present across a horizon.

7) 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-User-Link (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).

FUTURE OF SATELLITE COMMUNICATIONS

Future communication satellites will have

- More onboard processing capabilities,
- More power, and
- Larger-aperture antennas that will enable satellites to handle more bandwidth.
- The demand for more bandwidth will ensure the long-term viability of the commercial satellite industry well into the 21st century.

Conclusion:

By going through the above slides we came to know that satellite is mostly responsible for:

- Telecommunication transmission
- Reception of television signals
- Whether forecasting

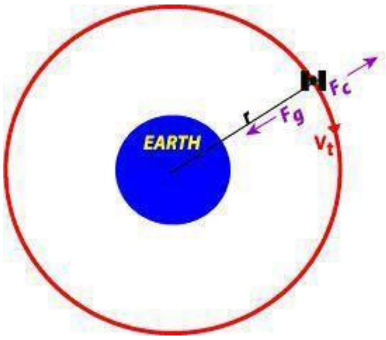
Which are very important in our daily life.

ORBITAL MECHANICS AND LAUNCHERS

ORBITAL MECHANICS

- To achieve a stable orbit around the earth, a spacecraft must first be beyond the bulk of the earth's atmosphere, i.e., in what is popularly called space.
- According to Newton's law of motion F=ma. Where a = acceleration, F= force acting on the object and m= mass of the object. It helps us understand the motion of satellite in a stable orbit.(neglecting any drag or other perturbing forces).
- (F=ma) states that the force acting on a body is equal to the mass of the body multiplied by the resulting acceleration of the body.
- Thus, for a given force, the lighter the mass of the body, the higher the acceleration will be.
- When in a stable orbit, there are two main forces acting on a satellite: a centrifugal force due to the kinetic energy of the satellite, which attempts to fling the satellite into a higher orbit, and a centripetal force due to gravitational attraction of the planet about which the satellite is orbiting, which attempts to pull the satellite towards the planet.
- If these two forces are equal the satellite remains in a stable orbit.

Forces involved in orbital mechanics



There are two relevant forces involved in this problem

1. Gravitational force= attraction between any two objects, given by

2. Centrifugal force=an outward-directed force that normally balances the inward-directed centripetal force

The standard acceleration due to gravity at the earth surface is 981 cm/s^2. The value decreases with height above the earth's surface. The acceleration, a, due to gravity at a distance r from the centre of the earth is

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

Where the constant μ is the product of the universal gravitational constant G and the mass of the earth M_E.
The product GM_E is called kepler's constant and has the value 3.98 x 10^5 km^3/s^2.
The universal gravitational constant is G=6.672x 10^{-11} Nm^2/kg^2.

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

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

$$\mathbf{Fin= m \times (\mu/r^{2})}$$

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

In a similar fashion, the centrifugal acceleration is given by

$$\mathbf{a=v^{2}/r}$$

Which will give the centrifugal force, Fout as

$$\mathbf{Fout=m \times (v^{2} /r)}$$

If the forces of the satellite are balanced **Fin=Fout**

$$\mathbf{m \times (\mu/r^{2})=m \times (v^{2} /r)}$$

Hence the velocity v of the satellite in a circular orbit is given by

$$\mathbf{v=(\mu/r)^{1/2}}$$

If the orbit is circular, the distance traveled by a satellite in one orbit around a planet is 2∏r , where r is the radius of the orbit from the satellite to the center of the planet. Since distance divided by velocity equals time to travel the distance, the period of satellite's orbit, T, will be

$$\mathbf{T= (2\prod r)/v = (2\prod r)/[(\mu/r)^{1/2}]}$$

$$\mathbf{T=(2\prod r^{3/2})/(\mu^{1/2})}$$

Using standard mathematical procedures we can develop an equation for the radius of the satellite's orbit, r, namely

____

Kepler's Laws

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

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

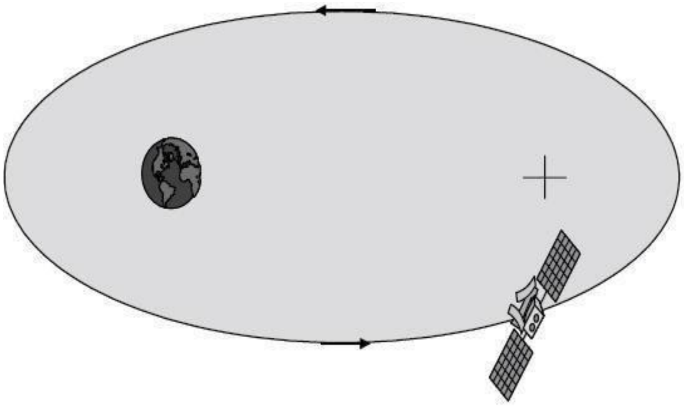


Figure Kepler's First Law

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

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

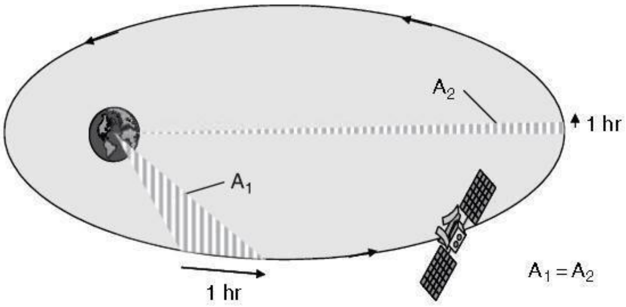


Figure 2.3 Kepler’s Second Law

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

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

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

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

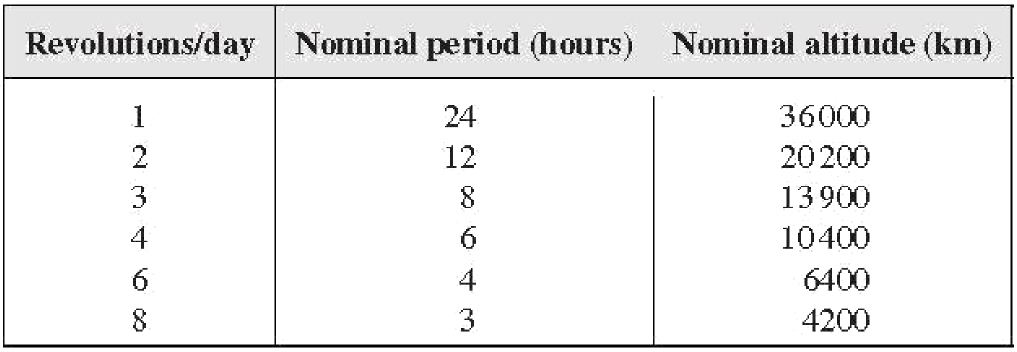
Where T=orbital period in s; a=distance between the two bodies, in km;
μ=Kepler’s Constant =3.986004×105 km3/s2. If the orbit is circular,
then a=r, and

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

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

Under this condition, a specific orbit period is determined only by proper selection of the orbit radius. This allows the satellite designer to select orbit periods that best meet particular application requirements by locating the satellite at the proper orbit altitude. The altitudes required to obtain a specific number of repeatable ground traces with a circular orbit are listed in Table 2.1.

Table 2.1 Orbit altitudes for specified orbital periods



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

Orbital Elements:

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. Its measured at the ascending node from the equator to the orbit, going from East to North. Also,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 0^0 to 90^0. Many satellites follow this path as Earth's velocity makes it easier to lunch these satellites.

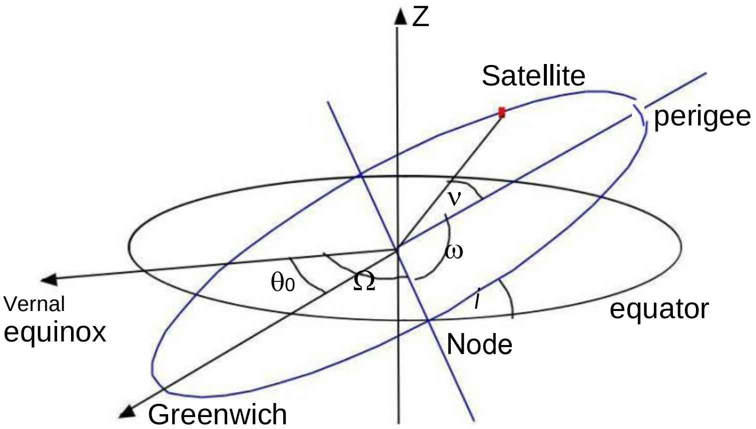
Retrograde Orbit: an orbit in which satellite moves in the same direction counter to the Earth's rotation.

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.

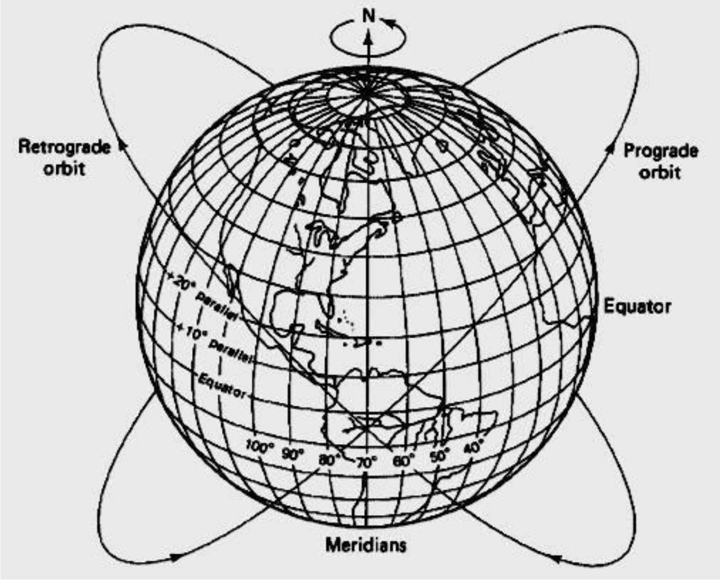
Right ascension of ascending node: The definition of an orbit in space, the position of ascending node is specified. But as the Earth spins, the longitude of ascending node changes and cannot be used for reference. Thus for practical determination of an orbit, the longitude and time of crossing the ascending node is 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.

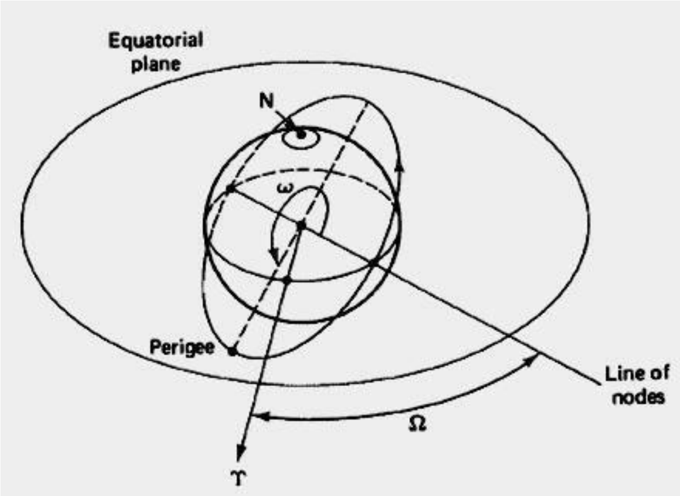
True anamoly: It is the angle from point of perigee to the satellite's position, measure at the Earth's centre.



i Inclination
Ω Right Ascension of ascending node ω Argument of perigee ν True anomaly



Prograde and Retrograde orbits



Argument of Perigee and Right ascension of ascending node

Orbital Elements Following are the 6 elements of the Keplerian Element set commonly known as orbital elements.

- Semi-Major axis (a)
- Eccentricity (e)

They give the shape (of ellipse) to the satellite’s orbit.

3. Mean anomaly (M0)

It denotes the position of a satellite in its orbit at a given reference time.

4. Argument of Perigee

It gives the rotation of the orbit’s perigee point relative to the orbit‟s nodes in the earth‟s equatorial plane.

- Inclination
- Right ascension of ascending node

They relate the orbital plane’s position to the Earth. As the equatorial bulge causes a slow variation in argument of perigee and right ascension of ascending node, and because other perturbing forces may alter the orbital elements slightly, the values are specified for the reference time or epoch.

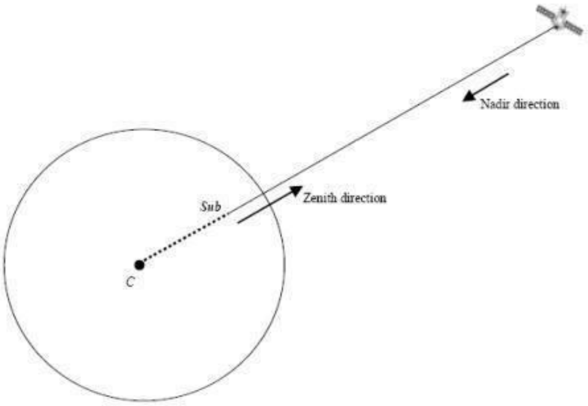
LOOK ANGLE DETERMINATION

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 angels values does not change as the satellites are stationary with respect to earth. Thus large earth stations are used for commercial communications, these antennas beamwidth is very narrow and the tracking mechanism is required to compensate for the movement of the satellite about the nominal geostationary position.

For home antennas, antenna beamwidth is quite broad and hence no tracking is essential. This leads to a fixed position for these antennas.

Sub satellite point: The point, on the earth’s surface of intersection between a line frim the earth’s center to the satellite.



The following information is needed to determine the look angles of geostationary orbit.

☐ Earth Station Latitude

☐ Earth Station Longitude

☐ Sub-Satellite Point’s Longitude

☐ ES: Position of Earth Station

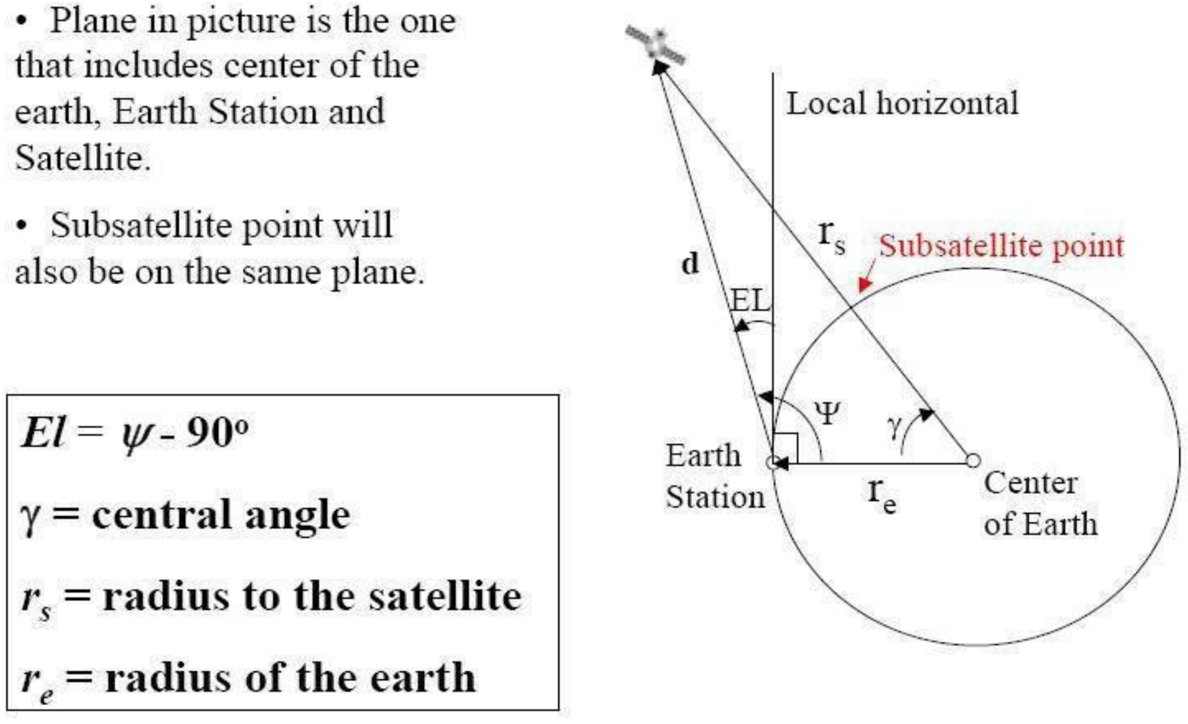
☐ SS: Sub-Satellite Point

☐ S: Satellite

☐ Range from ES to S

☐ Angle to be determined

Geometry of Elevation Angle



- Plane in picture is the one that includes center of the earth, Earth Station and Satellite.
- Subsatellite point will also be on the same plane.

$El = \psi - 90^{o}$

γ = central angle

r_s = radius to the satellite

r_e = radius of the earth

Satellite Coordinates

- SUB-SATELLITE POINT
  Latitude Ls
  Longitude ls
- EARTH STATION LOCATION
  Latitude Le
  Longitude le

Calculate γ, Angle at earth center

Central Angle

γ is defined so that it is non-negative and

$$\cos(\gamma) = \cos(Le)\cos(L_s)\cos(l_s - l_e) + \sin(L_e)\sin(L_s)$$

The magnitude of the vectors joining the center of the earth, the satellite and the earth station are related by the law of cosine:

$$d = r_s\left[1 + \left(\frac{r_e}{r_s}\right)^2 - 2\left(\frac{r_e}{r_s}\right)\cos(\gamma)\right]^{1/2}$$

Elevation Angle Calculation

By the sine law we have

$$\frac{r_s}{\sin(\psi)} = \frac{d}{\sin(\gamma)}$$

Which yields

$$\cos(El) = \frac{\sin(\gamma)}{\left[1 + \left(\frac{r_e}{r_s}\right)^2 - 2\left(\frac{r_e}{r_s}\right)\cos(\gamma)\right]^{1/2}}$$

Azimuth Angle Calculation for GEO Satellites

- SUB-SATELLITE POINT
  - Equatorial plane, Latitude Ls = 0^0
  - Longitude ls
- EARTH STATION LOCATION
  - Latitude Le
  - Longitude le

The original calculation previously shown:

$$\cos(\gamma) = \cos(Le)\cos(L_s)\cos(l_s - l_e) + \sin(L_e)\sin(L_s)$$

Simplifies using $L_s = 0°$ since the satellite is over the equator:

$$\boxed{\cos(\gamma) = \cos(Le)\cos(l_s - l_e)}$$

Step 2. Find the elevation angle *El*

$$\cos(El) = \frac{\sin(\gamma)}{\left[1.0228826 - 0.3025396\cos(\gamma)\right]^{1/2}}$$

To find the azimuth angle, an ***intermediate angle***, *α*, must first be found. The intermediate angle allows the correct quadrant (see Figs. 2.10 & 2.13) to be found since the azimuthal direction can lie anywhere between 0° (true North) and clockwise through 360° (back to true North again). The intermediate angle is found from

$$\alpha = \tan^{-1}\left[\frac{\tan\left|(l_s - l_e)\right|}{\sin(L_e)}\right]$$

Case 1: Earth station in the Northern Hemisphere with
- (a) Satellite to the SE of the earth station: $Az = 180° - \alpha$
- (b) Satellite to the SW of the earth station: $Az = 180° + \alpha$

Case 2: Earth station in the Southern Hemisphere with
- (c) Satellite to the NE of the earth station: $Az = \alpha$
- (d) Satellite to the NW of the earth station: $Az = 360° - \alpha$

Example for Look Angle Calculation of a GEO satellite

FIND the **Elevation** and **Azimuth** Look Angles for the following case:

Earth Station Latitude	52° N	London, England Dockland region
Earth Station Longitude	0°	
Satellite Latitude	0°	Geostationary INTELSAT IOR Primary
Satellite Longitude	66° E	

Step 1. Find the central angle γ

$$\begin{aligned}\cos(\gamma) &= \cos(L_e)\cos(l_s - l_e)\\ &= \cos(52)\cos(66)\\ &= 0.2504\end{aligned}$$

yielding $\gamma = 75.4981°$

$$El = 5.85^{o}$$

Step 3. Find the intermediate angle, α

$$\alpha = \tan^{-1}\left[\frac{\tan\left|(l_s - l_e)\right|}{\sin(L_e)}\right]$$

$$= \tan^{-1}\left[\, (\tan(66 - 0)) / \sin(52) \,\right]$$

$$= 70.6668$$

The earth station is in the Northern hemisphere and the satellite is to the South East of the earth station. This gives

$Az = 180^{o} - \alpha$

$= 180 - 70.6668 = 109.333^{o}$ (clockwise from true North)

ANSWER: The look-angles to the satellite are

Elevation Angle = 5.85^{o}

Azimuth Angle = 109.33^{o}

NOTE

- The earth station can see a satellite over a geostationary arc bounded by **+- (81.30)** about the earth station’s longitude.

ORBITAL PERTURBATIONS

- Theoretically, an orbit described by Kepler is ideal as Earth is 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.
- 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.
- 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, and keeping in mind that an orbit is not a physical entity, and 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 (point closest to the Earth). 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 seen. 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.
- Working satellites are made to drift back to their position but out-of-service satellites are eventually drifted to these points, and making that point a Satellite Graveyard.

Atmospheric Drag

- For Low Earth orbiting satellites, the effect of atmospheric drag is more pronounces. The impact of this drag is maximum at the point of perigee. Drag (pull towards the Earth) has an effect on velocity of Satellite (velocity reduces).
- This causes the satellite to not 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.

ORBIT DETERMINATION

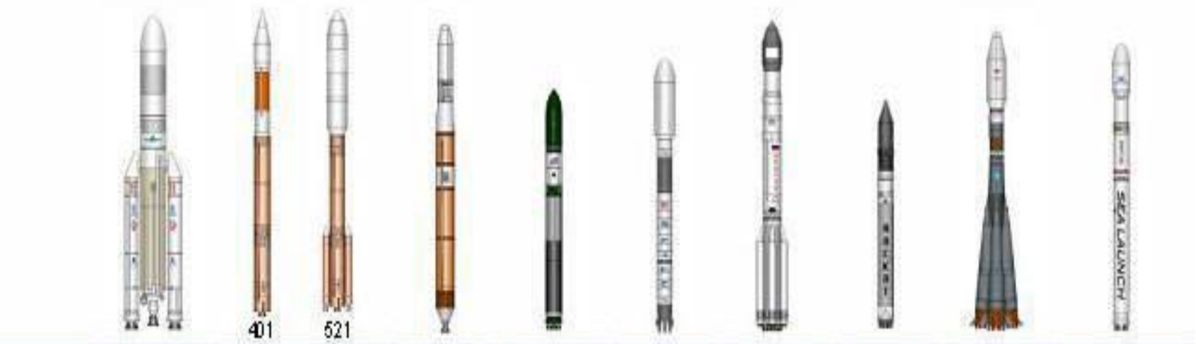
Orbit determination requires that sufficient measurements be made to determine uniquely the six orbital elements needed to calculate the future of the satellite, and hence calculate the required changes that need to be made to the orbit to keep it within the nominal orbital location. The control earth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

LAUNCHES AND LAUNCH VEHICLES

A satellite cannot be placed into a stable orbit unless two parameters that are uniquely coupled together the velocity vector and the orbital height are simultaneously correct. Thereis little point in orbiting the correct height and not having the appropriate velocity componentin the correct direction to achieve the desired orbit. A geostationary satellite for example must be in an orbit at height 35,786.03km above the surface of the earth with an inclinationof zero degrees an ellipticity of zero, and a velocity of 3074.7m/s tangential to the earth in theplane of the orbit, which is the earths equatorial plane. The further out from the earth the orbitis greater the energy required from the launch vehicle to reach that orbit. In any earth satellitelaunch, the largest fraction of the energy expanded by the rocket is used to accelerate the vehicle from rest until it is about 20miles (32 km) above the earth.

To make the most efficient use of the fuel, it is common to shed excess mass from the launcher as it moves upward on launch; this is called staging.

Most launch vehicles have multiple stage and as each stage is completed that portion of the launcher is expended until the final stage places the satellite into the desired trajectory. Hence the term:expandable lauch vehicle(ELV). The space shuttle , called the space transportation system (STS)by NASA, is partially reusable. The solid rocket boosters are recovered and refurbished for future mission and the shuttle vehicle itself is flown back to earth for refurbishment and reuse. Hence the term:reusable launch vehicle(RLV) for such launchers.



Vehicle	Ariane 5	Atlas V	Delta IV Medium	Dnepr M	Falcon 9	Proton M	Rockot	Soyuz 2	Zenit 3SL
Country	Europe	USA	USA	Russia	USA	Russia	Russia	Russia	Multinational
LEO kg (lbs)	17,250 (37,950)	9,800-29,400 (21,600-64,820)	8,120 (17,885)	4,100 (9,030)	10,450 (22,990)	21,000 (46,305)	1,850 (4,075)	7,800 (17,100)	15,246 (33.611)
GTO kg (lbs)	10,500 (23,127)	4,750-13,000 (10,470-28,660)	4,210 (9,273)	--	4,680 (10,296)	5,500 (12,125)	--	1,700 (3,800)	6,100 (13,448)

Launch vehicle selection factor

- Price/cost
- Reliability-Recent launch success/failure history
- Dependable launch schedule- Urgency of the customer
- Performance
- Spacecraft fit
- Safety issues
- Launch site location
- Availability-launch site; vehicle; schedule;
- Market conditions-what the market will bear

LAUNCHING ORBITS

Low Earth Orbiting satellites are directly injected into their orbits. This cannot be done incase of GEOs as they have to be positioned 36,000kms above the Earth‟s surface. Launch vehicles are hence used to set these satellites in their orbits. These vehicles are reusable. They are also known as „Space Transportation System‟ (STS).

When the orbital altitude is greater than 1,200 km it becomes expensive to directly inject the satellite in its orbit. For this purpose, a satellite must be placed in to a transfer orbit between the initial lower orbit and destination orbit. The transfer orbit is commonly known as *Hohmann-Transfer Orbit.

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

The transfer orbit is selected to minimize the energy required for the transfer. This orbit forms a tangent to the low attitude orbit at the point of its perigee and tangent to high altitude orbit at the point of its apogee.

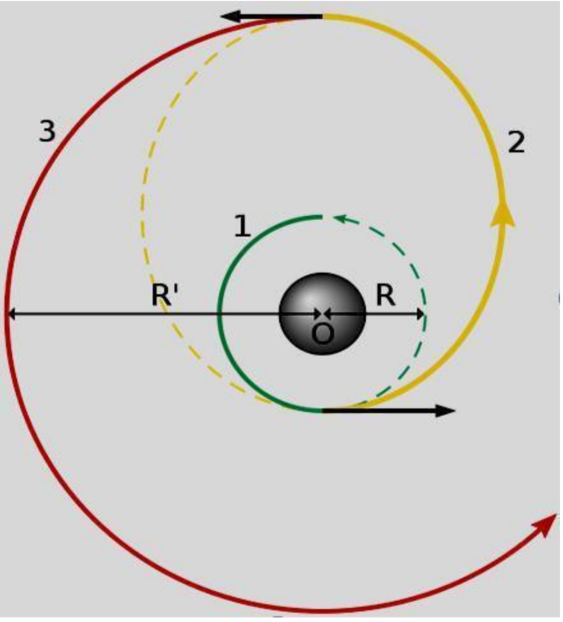


Figure: Orbit Transfer positions

The rocket injects the satellite with the required thrust** into the transfer orbit. With the STS, the satellite carries a perigee kick motor*** which imparts the required thrust to inject the satellite in its transfer orbit. Similarly, an apogee kick motor (AKM) is used to inject the satellite in its destination orbit.

Generally it takes 1-2 months for the satellite to become fully functional. The Earth Station performs the Telemetry Tracking and Command**** function to control the satellite transits and functionalities.

(**Thrust: It is a reaction force described quantitatively by Newton's second and third laws. When a system expels or accelerates mass in one direction the accelerated mass will cause a force of equal magnitude but opposite direction on that system.)
(***Kick Motor refers to a rocket motor that is regularly employed on artificial satellites destined for a geostationary orbit. As the vast majority of geostationary satellite launches are carried out from spaceports at a significant distance away from Earth's equator, the carrier rocket would only be able to launch the satellite into an elliptical orbit of maximum apogee 35,784-kilometres and with a non-zero inclination approximately equal to the latitude of the launch site.) (****TT&C: it"s a sub-system where the functions performed by the satellite control network to maintain health and status, measure specific mission parameters and processing over time a sequence of these measurement to refine parameter knowledge, and transmit mission commands to the satellite. Detailed study of TT&C in the upcoming units.)
It is better to launch rockets closer to the equator because the Earth rotates at a greater speed here than that at either pole. This extra speed at the equator means a rocket needs less thrust (and therefore less fuel) to launch into orbit. In addition, launching at the equator provides an additional 1,036 mph (1,667 km/h) of speed once the vehicle reaches orbit. This speed bonus means the vehicle needs less fuel, and that freed space can be used to carry more pay load.

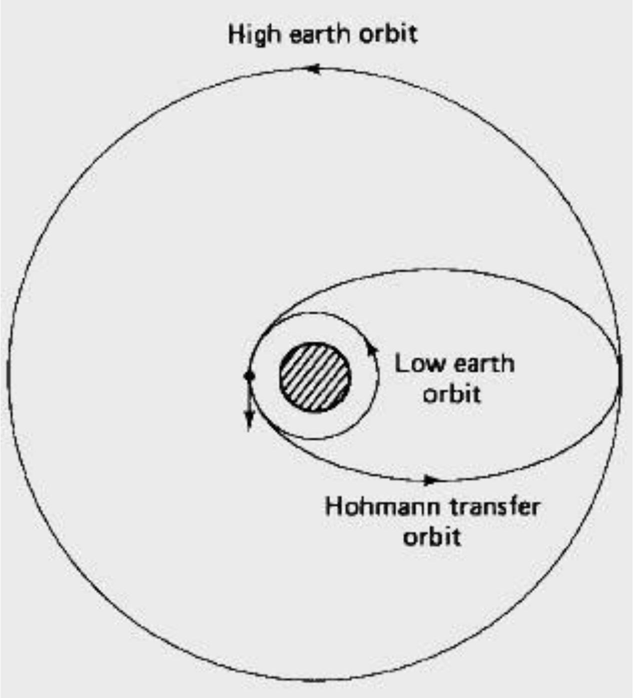


Figure : Hohmann Transfer Orbit

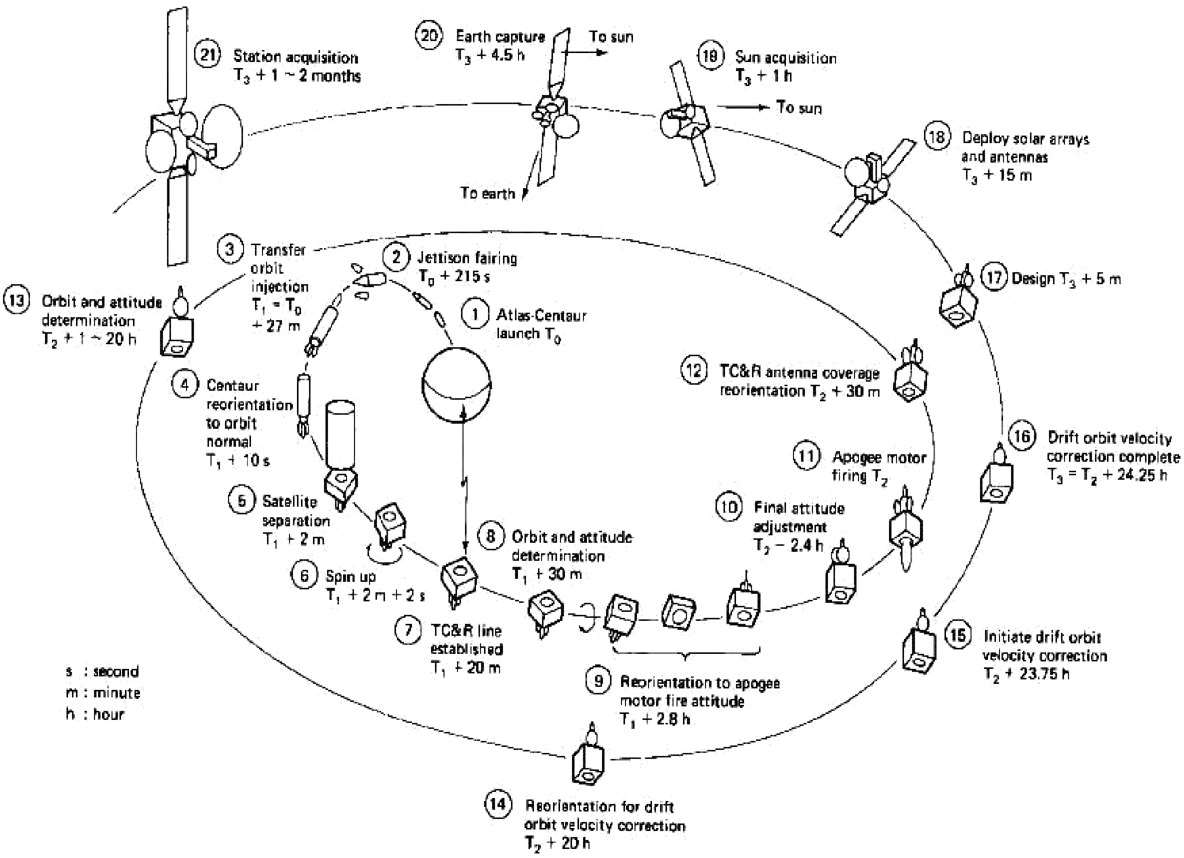


Figure : Launching stages of a GEO (example INTELSAT)

ORBITAL EFFECTS IN COMMUNICATION SYSTEMS PERFORMANCE

There are a number of perbuting forces that cause an orbit to depart from ideal Keplerian orbit. The most effecting ones are gravitational fields of sun and moon, non-spherical shapeof the Earth, reaction of the satellite itself to motor movements within the satellites.

Thus the earth station keeps manoeuvring the satellite to maintain its position. Within a set of nominal geostationary coordinates. Thus the exact GEO is not attainable in practice and the orbital parameters vary with time. Hence these satellites are called “Geosynchronous” satellites or “Near-Geostationary satellites”.

Doppler Effect

To a stationary observer, the frequency of a moving radio transmitter varies with the transmitter’s velocity relative to the observer. If the true transmitter frequency (i.e., the frequency that the transmitter would send when at rest) is f_T, the received frequency f_R is higher than f_T when the transmitter is moving toward the receiver and lower than f_T when the transmitter is moving away from the receiver.

Range variations

Even with the best station keeping systems available for geostationary satellites, the position of a satellite with respect to earth exhibits a cyclic daily variation. The variation in position will lead to a variation in range between the satellite and user terminals. If time division multiple access(TDMA) is being used, careful attention must be paid to the timing of the frames within the TDMA bursts so that the individual user frames arrive at the satellite in the correct sequence and at the correct time.

Earth Eclipse of A Satellite

It occurs when Earth"s equatorial plane coincides with the plane f he 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.

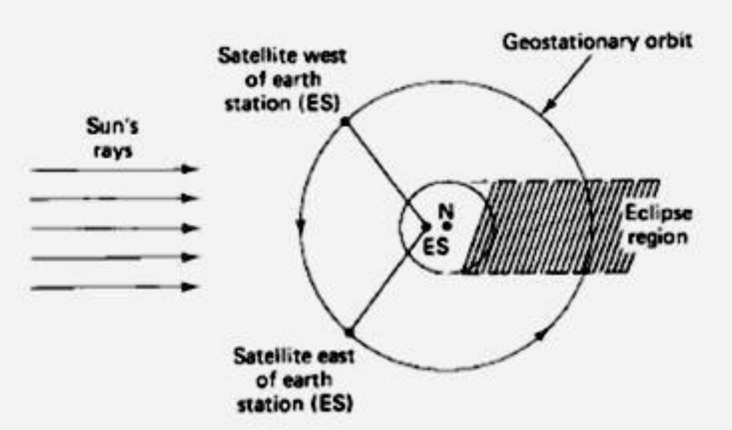


Figure : A satellite east of the earth station enters eclipse during daylight busy) hours at the earth station. A Satellite west of earth station enters eclipse during night and early morning hours (non busy time).

Sun Transit Outage

Sun transit outage is an interruption in or distortion of geostationary satellite signals caused by interference from solar radiation. 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.

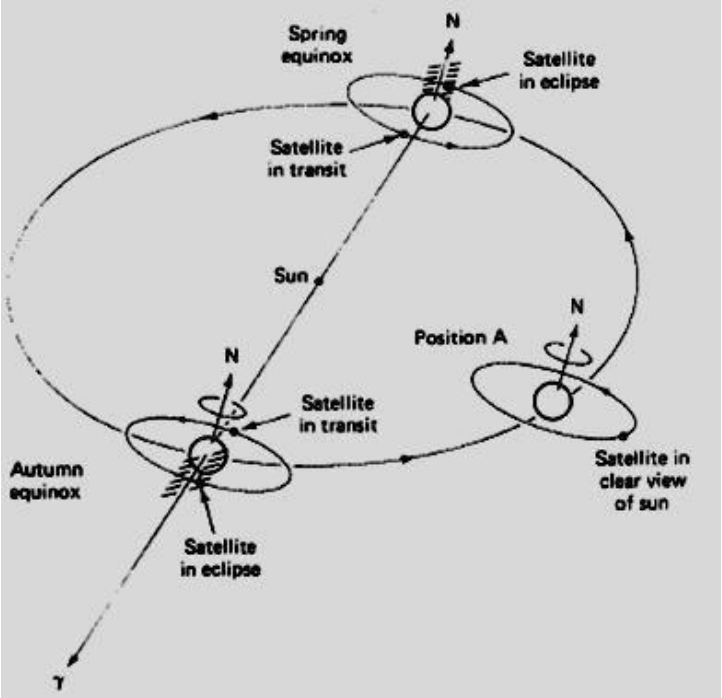


Figure: Earth Eclipse of a Satellite and Sun transit Outage

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UNIT II
SATELLITE SUBSYSTEMS

An operating communications satellite system consists of several elements or segments, ranging from an orbital configuration of space components to ground based components and network elements. The particular application of the satellite system, for example fixed satellite service, mobile service, or broadcast service, will determine the specific elements of the system. A generic satellite system, applicable to most satellite applications, can bedescribed by the elements shown in Figure 3.1.

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

The ***space segment*** of the satellite system consists of the orbiting satellite (or satellites) and the ground satellite control facilities necessary to keep the satellites operational. The ***ground segment***, or earth segment, of the satellite system consists of the transmit and receive earth stations and the associated equipment to interface with the user network.

Ground segment elements are unique to the type of communications satellite application, such as fixed service, mobile service, broadcast service, or satellite broadband, and will be covered in later chapters where the specific applications are discussed. The space segment equipment carried aboard the satellite can be classified under two functional areas: the ***bus*** and the ***payload***, as shown in Figure 3.2.

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

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

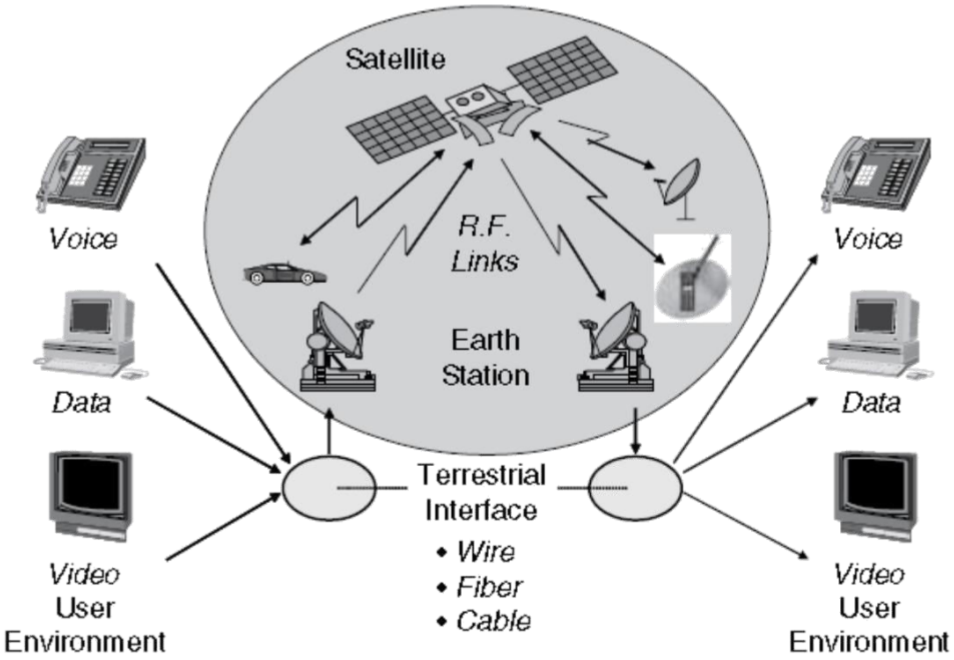


Figure 3.1 Communications via satellite

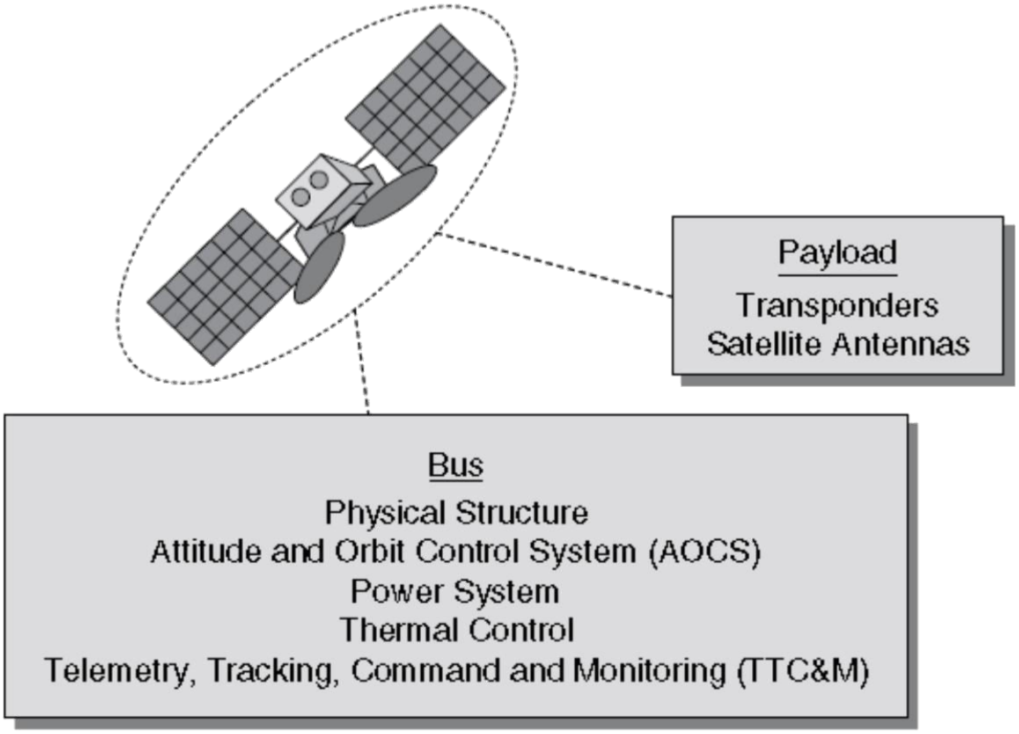


Figure 3.2 Communications satellite subsystems

A satellite may have more than one payload. The early Tracking and Data Relay Satellites (TDRS), for example, had an ‘Advanced Westar’ communications payload in addition to the tracking and data payload, which was the major mission of the satellite.

ATTITUDE AND ORBIT CONTROL SYSTEM

Satellite Bus

The basic characteristics of each of the bus subsystems are described in the following subsections.

Physical Structure

The physical structure of the satellite provides a ‘home’ for all the components of thesatellite. The basic shape of the structure depends of the method of stabilization employed to keep the satellite stable and pointing in the desired direction, usually to keep the antennas properly oriented toward earth. Two methods are commonly employed: ***spin stabilization*** and ***three axis*** or ***body stabilization***. Both methods are used for GSO and NGSO satellites.

Figure 3.3 highlights the basic configurations of each, along with an example of a satellite of each type.

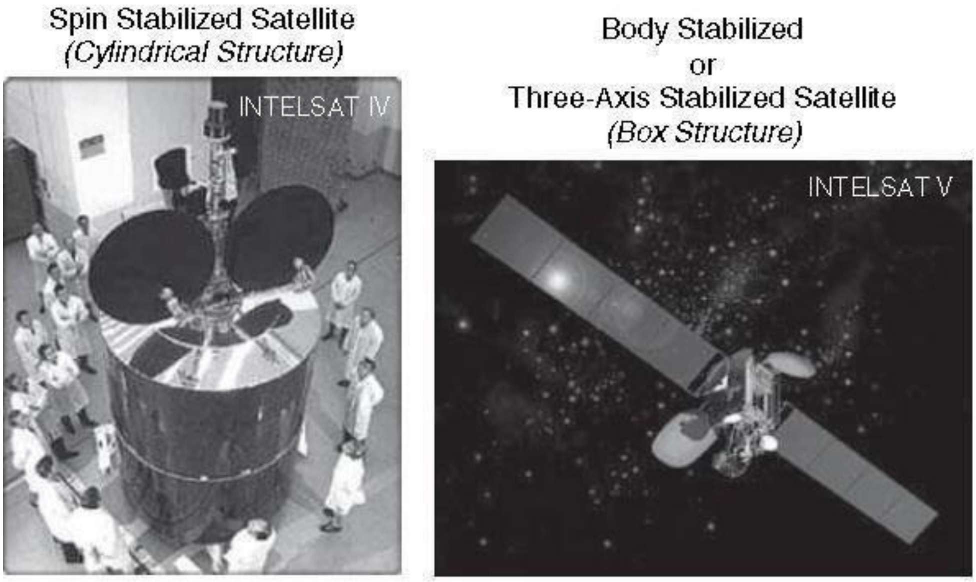


Figure 3.3 Physical structure

Spin Stabilization

A spin stabilized satellite is usually cylindrical in shape, because the satellite is required to be mechanically balanced about an axis, so that it can be maintained in orbit by spinning on its axis. For GSO satellites, the spin axis is maintained parallel to the spin axis of the earth, with spin rates in the range of 30 to 100 revolutions per minute.

The spinning satellite will maintain its correct attitude without additional effort, unless disturbance torques are introduced. External forces such as solar radiation, gravitational gradients, and meteorite impacts can generate undesired torques. Internal effects such as motor bearing friction and antenna subsystem movement can also produce unwanted torquein the system. Impulse type thrusters, or jets, are used to maintain spin rate and correct any wobbling or nutation to the satellite spin axis.

The entire spacecraft rotates for spin-stabilized satellites that employ omnidirectional antennas. When directional antennas are used, which is the prevalent case, the antenna subsystem must be ***despun***, so that the antenna is kept properly pointed towards earth. Figure 3.4 shows a typical implementation of a despun platform on a spin-stabilized satellite. The antenna subsystem is mounted on a platform or shelf, which may also contain some of the transponder equipment. The satellite is spun-up by small radial gas jets on the surface of the drum. The rotation, ranging from 30 to 100 rpm, provides gyroscopic force stability for the satellite.

The propellants used include heated hydrazine or a bipropellant mix of hydrazine and nitrogen tetroxide. The despun platform is driven by an electric motor in the opposite direction of the satellite spin, on the same spin axis and at the same spin rate as the satellite body, to maintain a fixed orientation for the antennas, relative to earth.

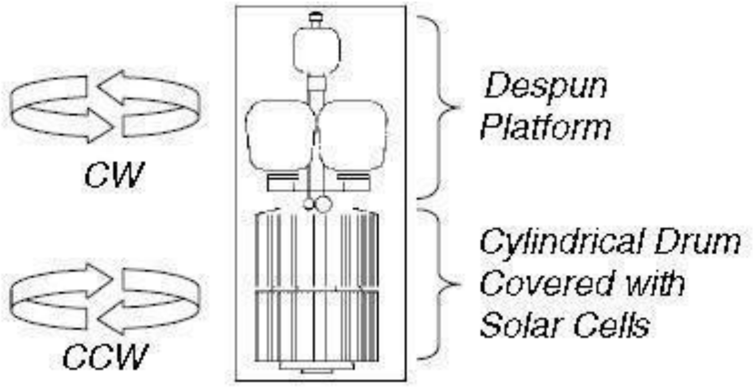


Figure 3.4 Despun platform on spin-stabilized satellite

Three-axis Stabilization

A three-axis stabilized satellite is maintained in space with stabilizing elements for each of the three axes, referred to as roll, pitch, and yaw, in conformance with the definitions first used in the aircraft industry. The entire body of the spacecraft remains fixed in space, relativeto the earth, which is why the three-axis stabilized satellite is also referred to as a body- stabilized satellite.

Active attitude control is required with three-axis stabilization. Control jets or reaction wheels are used, either separately or in combination, to provide correction and control for ach of the three axes. A reaction wheel is basically a flywheel that absorbs the undesired torques that would shift spacecraft orientation. Fuel is expended for both the control jets and for the reaction wheels, which must periodically be ‘unloaded’ of momentum energy that builds upin the wheel.

The three-axis stabilized satellite does not need to be symmetric or cylindrical, and most tend be box-like, with numerous appendages attached. Typical appendages include antenna systems and solar cell panels, which are often unfurled after placement at the on-orbitlocation.

Attitude Control

The ***attitude*** of a satellite refers to its orientation in space with respect to earth. Attitude control is necessary so that the antennas, which usually have narrow directional beams, are pointed correctly towards earth. Several forces can interact to affect the attitude of the spacecraft, including gravitational forces from the sun, moon, and planets; solar pressures acting on the spacecraft body, antennas or solar panels; and earth's magnetic field.

Orientation is monitored on the spacecraft by infrared ***horizon detectors***, which detect the rim of earth against the background of space. Four detectors are used to establish a reference point, usually the center of the earth, and any shift in orientation is detected by one or moreof the sensors.Acontrol signal is generated that activates attitude control devices to restore proper orientation. Gas jets, ion thrusters, or momentum wheels are used to provide active attitude control on communications satellites.

Since the earth is not a perfect sphere, the satellite will be accelerated towards one of two 'stable' points in the equatorial plane. The locations are 105◦W and 75◦ E. Figure 3.5 shows the geometry of the stable points and the resulting drift patterns. If no orbit control (station keeping) is provided, the satellite will drift to and eventually settle at one of the stable points. This could take several years and several passes through the stable point before the satellite finally comes to rest at a stable point. The stable points are sometimes referred to as the 'satellite graveyard', for obvious reasons.

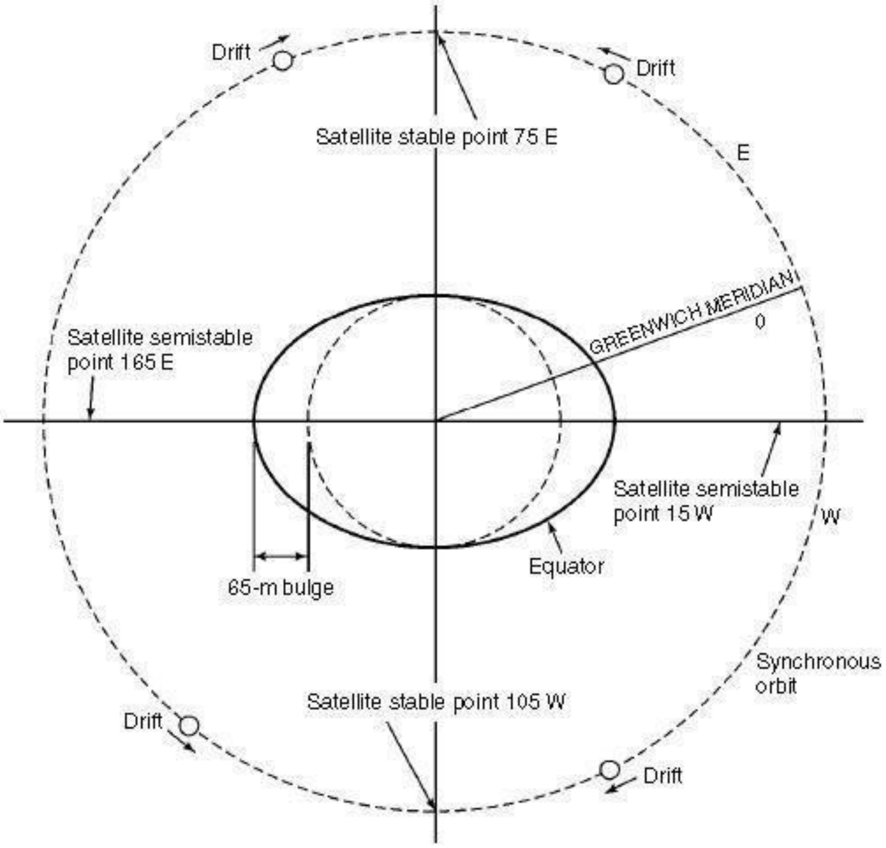


Figure 3.5 GSO satellite stable points *(source: Pratt* et al. *[2]; reproduced by permission of © 2003 John Wiley & Sons, Inc.)*

Orbital Control

Orbital control, often called ***station keeping***, is the process required to maintain a satellite in its proper orbit location. It is similar to, although not functionally the same as, attitude control, discussed in the previous section. GSO satellites will undergo forces that wouldcause the satellite to drift in the east-west (longitude) and north-south (latitude) directions, as well as in altitude, if not compensated for with active orbital control jets. Orbital control is usually maintained with the same thruster system as is attitude control.

The non-spherical (oblate) properties of the earth, primarily exhibited as an equatorial bulge, cause the satellite to drift slowly in longitude along the equatorial plane. Control jets are pulsed to impart an opposite velocity component to the satellite, which causes the satellite to drift back to its nominal position. These corrections are referred to as ***east-west station keeping*** maneuvers, which are accomplished periodically every two to three weeks. Typical C-band satellites must be maintained within •}0.1◦, and Ku-band satellites within •}0.05◦, of nominal longitude, to keep the satellites within the beamwidths of the ground terminalantennas. For a nominal geostationary radius of 42 000 km, the total longitude variationwould be about 150 km for C-band and about 75 km for Ku-band. Latitude drift will be induced primarily by gravitational forces from the sun and the moon.

These forces cause the satellite inclination to change about 0.075◦ per month if left uncorrected. Periodic pulsing to compensate for these forces, called ***north-south station keeping*** maneuvers, must also be accomplished periodically to maintain the nominal satellite orbit location. North south station-keeping tolerance requirements are similar to those for east-west station keeping, 0.1◦ for C-band, and •}0.05◦ for Ku-band.

Satellite altitude will vary about •}0.1 %, which is about 72 km for a nominal 36 000-km geostationary altitude.AC-band satellite, therefore, must be maintained in a 'box' with longitudinal and latitudinal sides of about 150 km and an altitude side of 72 km. TheKu-band satellite requires a box with approximately equal sides of 75 km. Figure 3.6 summarizes the orbital control limits and indicates the typical 'orbital box' that a GSO satellite can be maintained in for the C-band and Ku-band cases.

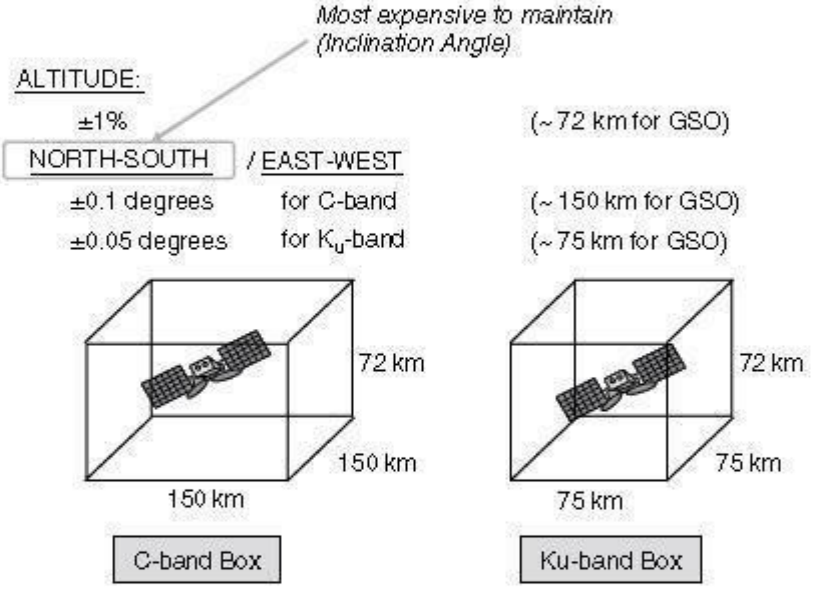


Figure 3.6 Orbital control parameters for GSO satellites

North-south station keeping requires much more fuel than east-west station keeping, and often satellites are maintained with little or no north-south station keeping to extend on-orbit life.

The satellite is allowed to drift with a higher inclination, with the drift compensated for onthe ground with tracking and/or smaller aperture antennas. The expendable fuel that must be carried on-board the satellite to provide orbital and attitude control is usually the determining factor in the on-orbit lifetime of a communications satellite.

As much as one-half of the satellite launch weight is station-keeping fuel. The lifetimes of most of the critical electronic and mechanical components usually exceed the allowable time for active orbit control, which is limited by the weight of fuel that can be carried to orbit with current conventional launch vehicles. It is not unusual for a communications satellite to 'run out of fuel' with most of its electronic communications subsystems still functioning.

Thermal Control

Orbiting satellites will experience large temperature variations, which must be controlled in the harsh environment of outer space. Thermal radiation from the sun heats one side of the spacecraft, while the side facing outer space is exposed to the extremely low temperatures of space. Much of the equipment in the satellite itself generates heat, which must be controlled. Low orbiting satellites can also be affected by thermal radiation reflected from the earth itself.

The satellite thermal control system is designed to control the large thermal gradients generated in the satellite by removing or relocating the heat to provide an as stable as possibletemperature environment for the satellite. Several techniques are employed to provide thermalcontrol in a satellite. ***Thermal blankets*** and ***thermal shields*** are placed at critical locations to provide insulation. ***Radiation mirrors*** are placed around electronic subsystems, particularly for spin-stabilized satellites, to protect critical equipment. ***Heat pumps*** are used to relocate heat from power devices such as traveling wave power amplifiers to outer walls or heat sinks to provide a more effective thermal path for heat to escape. Thermal ***heaters*** may also be usedto maintain adequate temperature conditions for some components, such as propulsion linesor thrusters, where low temperatures would cause severe problems.

The satellite antenna structure is one of the critical components that can be affected by thermal radiation from the sun. Large aperture antennas can be twisted or contorted as the sunmoves around the satellite, heating and cooling various portions of the structure. This 'potato chip' effect is most critical for apertures exceeding about 15m designed to operate at high frequencies, i.e., Ku-band, Ka-band, and above, because the small wavelengths react more severely resulting in antenna beam point distortions and possible gain degradation.

TELEMETRY, TRACKING, COMMAND AND MONITORING

The tracking, telemetry, command, and monitoring (TTC&M) subsystem provides essential spacecraft management and control functions to keep the satellite operating safely in orbit. The TTC&M links between the spacecraft and the ground are usually separate from the communications system links. TTC&M links may operate in the same frequency bands or in other bands.

TTC&M is most often accomplished through a separate earth terminal facility specifically designed for the complex operations required to maintain a spacecraft in orbit. One TTC&M facility may maintain several spacecraft simultaneously in orbit through TTC&M links to each vehicle. Figure 3.7 shows the typical TTC&M functional elements for the satellite and ground facility for a communications satellite application.

The satellite TTC&M subsystems comprise the antenna, command receiver, tracking and telemetry transmitter, and possibly tracking sensors. Telemetry data are received from the other subsystems of the spacecraft, such as the payload, power, attitude control, and thermal control. Command data are relayed from the command receiver to other subsystems tocontrol such parameters as antenna pointing, transponder modes of operation, battery and solar cell changes, etc.

The elements on the ground include the TTC&M antenna, telemetry receiver, command transmitter, tracking subsystem, and associated processing and analysis functions. Satellite control and monitoring is accomplished through monitors and keyboard interface. Major operations of TTC&M may be automated, with minimal human interface required.

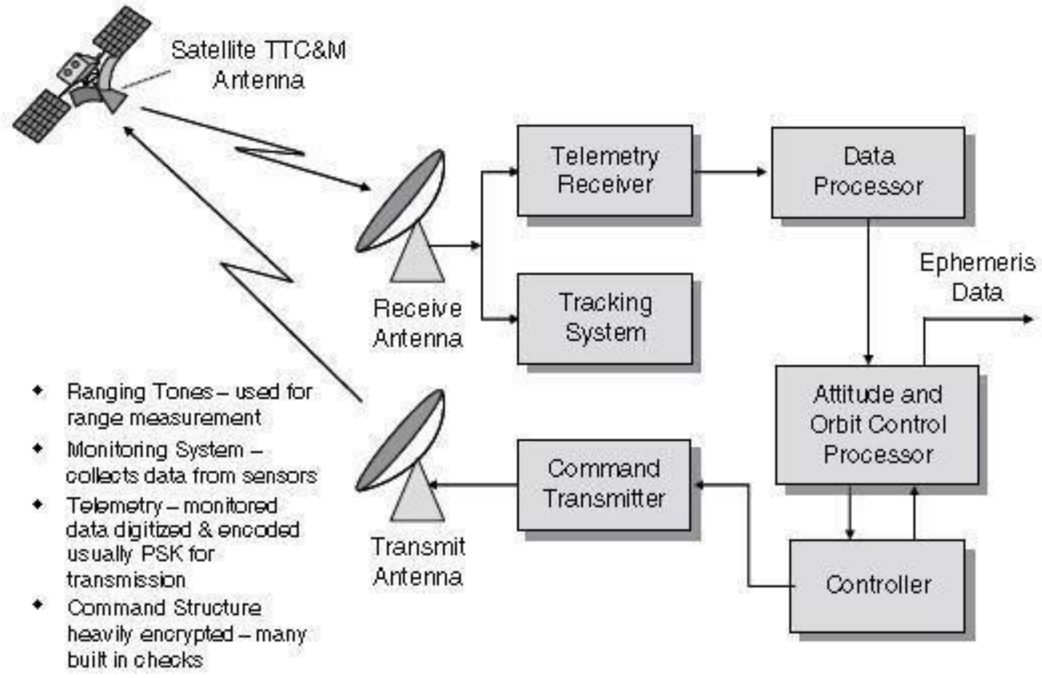


Figure 3.7 Tracking, telemetry, command, and monitoring (TTC&M)

Tracking refers to the determination of the current orbit, position, and movement of the spacecraft. The tracking function is accomplished by a number of techniques, usually involving satellite beacon signals, which are received at the satellite TTC&M earth station. The Doppler shift of the beacon (or the telemetry carrier) is monitored to determine the rateat which the range is changing (the range rate). Angular measurements from one or more earth terminals can be used to determine spacecraft location. The range can be determined by observing the time delay of a pulse or sequence of pulses transmitted from the satellite. Acceleration and velocity sensors on the satellite can be used to monitor orbital location and changes in orbital location.

The ***telemetry*** function involves the collection of data from sensors on-board the spacecraft and the relay of this information to the ground. The telemetered data include such parameters as voltage and current conditions in the power subsystem, temperature of critical subsystems, status of switches and relays in the communications and antenna subsystems, fuel tank pressures, and attitude control sensor status. A typical communications satellite telemetry link could involve over 100 channels of sensor information, usually in digital form, but occasionally in analog form for diagnostic evaluations. The telemetry carrier modulation is typically frequency or phase shift keying (FSK or PSK), with the telemetry channels transmitted in a time division multiplex (TDM) format. Telemetry channel data rates are low, usually only a few kbps.

Command is the complementary function to telemetry. The command system relays specific control and operations information from the ground to the spacecraft, often in response to telemetry information received from the spacecraft. Parameters involved in typical command links include changes and corrections in attitude control and orbital control;

- antenna pointing and control;
- transponder mode of operation;
- battery voltage control.

The command system is used during launch to control the firing of the boost motor, deploy appendages such as solar panels and antenna reflectors, and ‘spin-up’ a spin-stabilized spacecraft body. Security is an important factor in the command system for a communications satellite. The structure of the command system must contain safeguards against intentional or unintentional signals corrupting the command link, or unauthorized commands from being transmitted and accepted by the spacecraft. Command links are nearly always encrypted with a secure code format to maintain the health and safety of the satellite. The command procedure also involves multiple transmissions to the spacecraft, to assure the validity and correct reception of the command, before the execute instruction is transmitted. Telemetryand command during the launch and transfer orbit phases usually requires a backup TTC&M system, since the main TTC&M system may be inoperable because the antenna is notdeployed, or the spacecraft attitude is not proper for transmission to earth. The backup systemusually operates with an omnidirectional antenna, at UHF or S-band, with sufficient marginto allow operation in the most adverse conditions. The backup system could also be used ifthe main TTC&M system fails on orbit.

POWER SYSTEMS

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

The three-axis stabilized satellite configuration allows for better utilization of solar cell area, because the cells can be arranged in flat panels, or sails, which can be rotated to maintain normal exposure to the sun – levels up to 10kW are attainable with rotating panels. All spacecraft must also carry storage batteries to provide power during launch and during eclipseperiods when sun blockage occurs. Eclipses occur for a GSO satellite twice a year, around thespring and fall equinoxes, when earth's shadow passes across the spacecraft. Daily eclipses start about 23 days before the equinox, and end the same number of days after. The daily eclipse duration increases a few minutes each day to about a 70-minute peak on equinox day, then decreases a similar amount each day following the peak. Sealed nickel cadmium (Ni-Cd)batteries are most often used for satellite battery systems. They have good reliability and longlife, and do not outgas when in a charging cycle. Nickel-hydrogen (NiH2) batteries, which provide a significant improvement in power-to-weight ratio, are also used. A power conditioning unit is also included in the power subsystem, for the control of battery charging and for power regulation and monitoring.

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

COMMUNICATION SUBSYSTEM

Satellite Payload

The next two sections discuss the key elements of the payload portion of the space segment, specifically for communications satellite systems: the transponder and antenna subsystems.

Transponder

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

Each transponder generally operates in a different frequency band, with the allocated frequency spectrum band divided into slots, with a specified center frequency and operating bandwidth. The C-band FSS service allocation, for example, is 500MHz wide. A typical design would accommodate 12 transponders, each with a bandwidth of 36 MHz, with guard bands of 4MHz between each.Atypical commercial communications satellite today can have 24 to 48 transponders, operating in the C-band, Ku-band, or Ka-bands. The number oftransponders can be doubled by the use of ***polarization frequency reuse***, where two carriers at the same frequency, but with orthogonal polarization, are used. Both linear polarization (horizontal and vertical sense) and circular polarization (right-hand and left-hand sense) have been used. Additional frequency reuse may be achieved through spatial separation of the signals, in the form of narrow spot beams, which allow the reuse of the same frequency carrier for physically separate locations on the earth. Polarization reuse and spot beams can be combined to provide four times, six times, eight times, or even higher frequency reuse factors in advanced satellite systems.

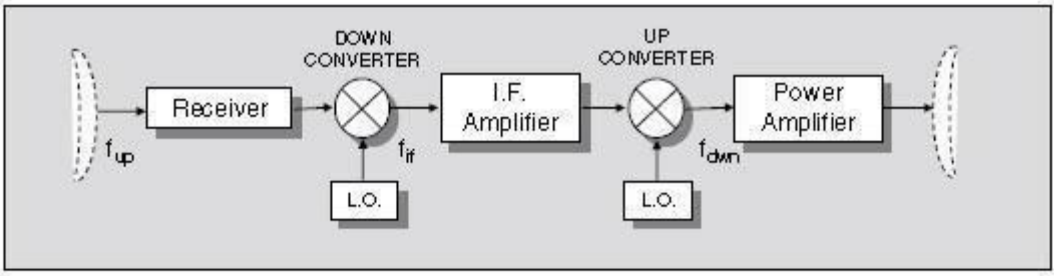
The communications satellite transponder is implemented in one of two general types of configurations: the frequency translation transponder and the on-board processing transponder.

Frequency Translation Transponder

The first type, which has been the dominant configuration since the inception of satellite communications, is the ***frequency translation*** transponder. The frequency translation transponder, also referred to as a ***non-regenerative repeater***, or ***bent pipe***, receives the uplink signal and, after amplification, retransmits it with only a translation in carrier frequency. Figure 3.8 shows the typical implementation of a dual conversion frequency translation transponder, where the uplink radio frequency, fup, is converted to an intermediate lower frequency, fif , amplified, and then converted back up to the downlink RF frequency, fdwn, for transmission to earth.

Frequency translation transponders are used for FSS, BSS, and MSS applications, in both GSO and NGSO orbits. The uplinks and downlinks are codependent, meaning that any degradation introduced on the uplink will be transferred to the downlink, affecting the total communications link.

This has significant impact on the performance of the end-to-end link

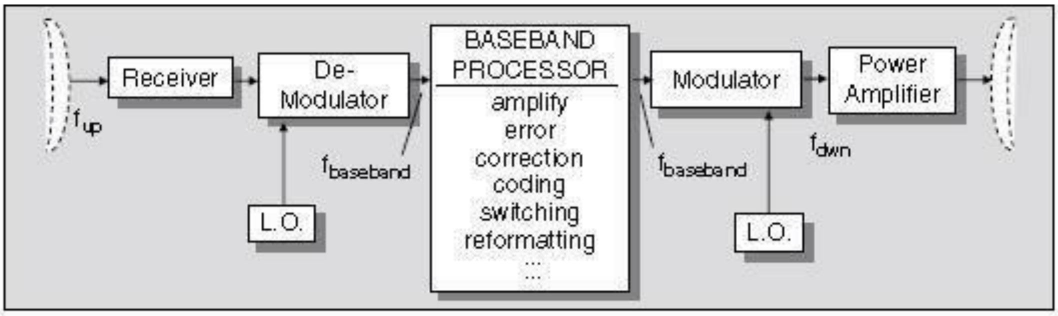


- ❑ Frequency Translation Transponder, also called
  - ➢ Repeater
  - ➢ Non-Regenerative Satellite
  - ➢ 'Bent Pipe'
- ❑ The dominant type of transponder currently in use
  - ➢ FSS, BSS, MSS
- ❑ Uplinks and downlinks are codependent

Figure 3.8 Frequency translation transponder

On-board Processing Transponder

Figure 3.9 shows the second type of satellite transponder, the ***on-board processing*** transponder, also called a ***regenerative repeater demod/remod transponder***, or ***smart satellite***. The uplink signal at fup is demodulated to baseband, fbaseband . The baseband signal is available for processing on-board, including reformatting and error-correction. The baseband information is then remodulated to the downlink carrier at fdwn, possibly in a different modulation format to the uplink and, after final amplification, transmitted to the ground. The demodulation/remodulation process removes uplink noise and interference from the downlink, while allowing additional on-board processing to be accomplished. Thus the uplinks and downlinks are independent with respect to evaluation of overall link performance, unlike the frequency translation transponder where uplink degradations are codependent, as discussed earlier.



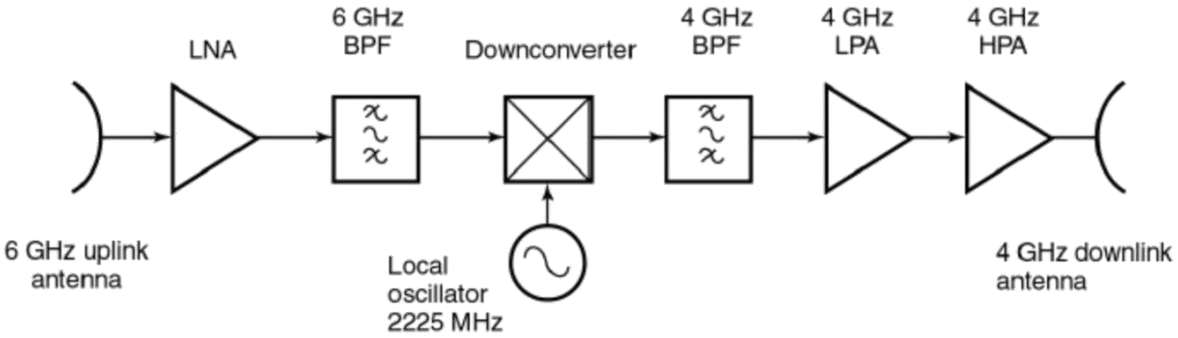
- On-Board Processing Transponder, also called
  - Regenerative Repeater
  - Demod/Remod Transponder
  - 'Smart Satellite'
- First generation systems:
  - ACTS, MILSTAR, IRIDIUM, . . .
- Uplinks and downlinks are independent

Figure 3.9 On-board processing transponder

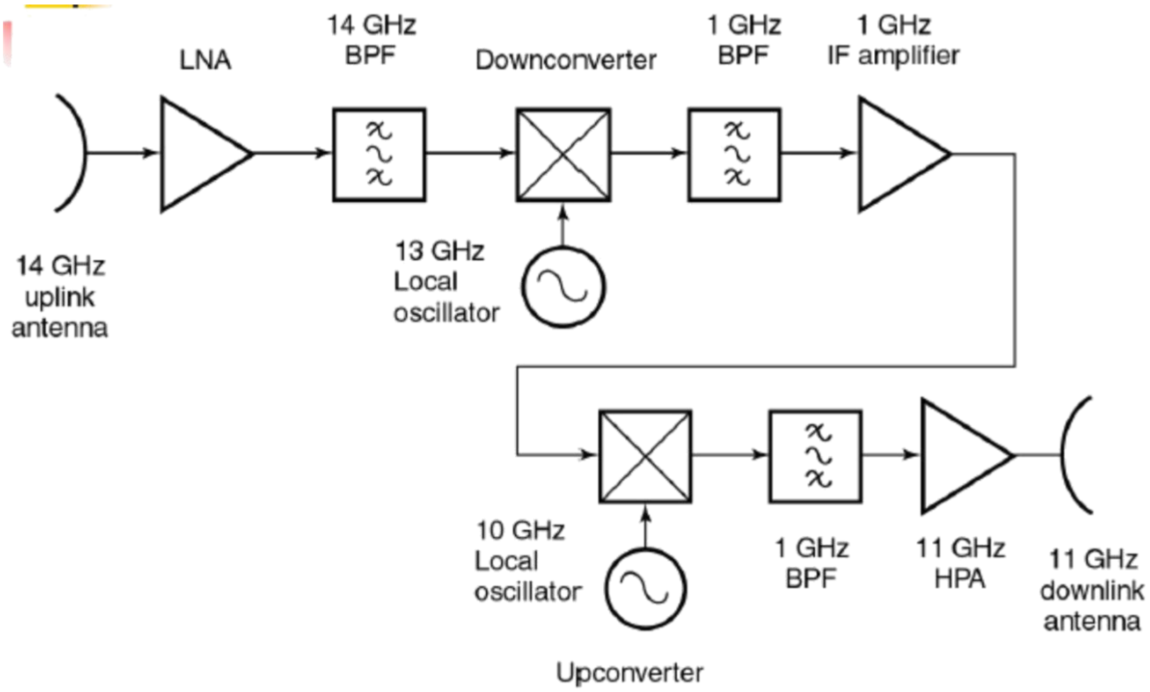
On-board processing satellites tend to be more complex and expensive than frequency translation satellites; however, they offer significant performance advantages, particularly for small terminal users or for large diverse networks. The performance of the on-board processing satellite's composite link is discussed further in Chapter 9.

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

Other devices may be included in the basic transponder configurations of Figures 3.8 and 3.9, including band pass filters, switches, input multiplexers, switch matrices, and output multiplexers. Each device must be considered when evaluating the signal losses and system performance of the space segment of the satellite network.



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



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

SATELLITE ANTENNA

Antennas

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

The most important parameters that define the performance of an antenna are antenna ***gain***, antenna ***beamwidth***, and antenna ***sidelobes***. The gain defines the increase in strength achieved in concentrating the radio wave energy, either in transmission or reception, by the antenna system.

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

Most satellite communications applications require an antenna to be highly directional (high gain, narrow beamwidth) with negligibly small sidelobes.

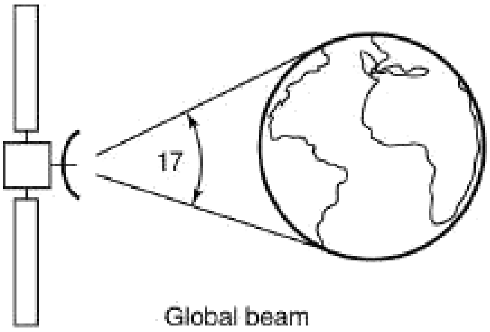
The common types of antennas used in satellite systems are the linear dipole, the horn antenna, the parabolic reflector, and the array antenna. The ***linear dipole antenna*** is an isotropic radiator that radiates uniformly in all directions. Four or more dipole antennas are placed on the spacecraft to obtain a nearly omni-directional pattern. Dipole antennas are used primarily at VHF and UHF for tracking, telemetry, and command links. Dipole antennas are also important during launch operations, where the spacecraft attitude has not yet beenestablished, and for satellites that operate without attitude control or body stabilization (particularly for LEO systems).

Horn antennas are used at frequencies from about 4 GHz and up, when relatively wide beams are required, such as global coverage from a GSO satellite. A horn is a flared section of waveguide that provides gains of up to about 20 dBi, with beamwidths of 10◦ or higher. If higher gains or narrower bandwidths are required, a reflector or array antenna must be used.

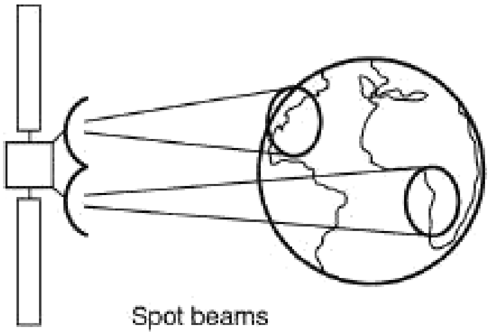
The most often used antenna for satellite systems, particularly for those operating above 10 GHz, is the ***parabolic reflector antenna***. Parabolic reflector antennas are usually illuminated by one or more horn antenna feeds at the focus of the paroboloid. Parabolic reflectors offer a much higher gain than that achievable by the horn antenna alone. Gains of 25 dB and higher, with beamwidths of 1◦ or less, are achievable with parabolic reflector antennas operating in the C, Ku, or Ka bands. Narrow beam antennas usually require physical pointing mechanisms (gimbals) on the spacecraft to point the beam in the desired direction.

There is increasing interest in the use of ***array antennas*** for satellite communications applications.

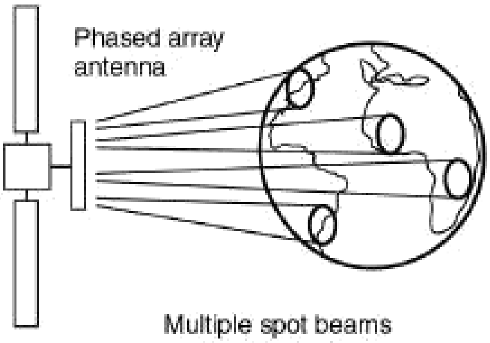
A steerable, focused beam can be formed by combining the radiation from several small elements made up of dipoles, helices, or horns. Beam forming can be achieved by electronically phase shifting the signal at each element. Proper selection of the phase characteristics between the elements allows the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



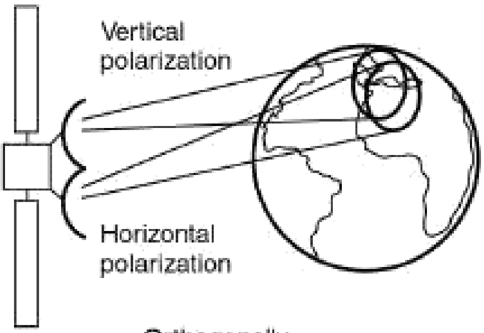
Global beam



Spot beams



Multiple spot beams
and scanning beams



Orthogonally
polarized beams

EQUIPMENT RELIABILITY AND SPACE QUALIFICATION

Communication satellites built already have provided operational lifetimes of up to 15years. Once a satellite is in geo stationary orbit, there is little possibility of repairing components that fail or adding more fuel for station keeping. The components that make up the satellite must therefore have very high reliability in the hostile environment of outer space, and a strategy must be devised that allows some components to fail without causing the entire communication capacity of the satellite to be lost. Two separate approaches are used: space qualification of every part of the satellite to ensure that it has a long life expectancy in orbit and redundancy of the most critical components to provide continued operation when one component fails.

Space Qualification:

Outer space, at geostationary orbit distances is a harsh environment. There is a total vacuum and the sun irradiates the satellite with 1.4kw of heat and light on each square meter of exposed surface. Electronic equipment cannot operate at such extremes of temperature and must be housed within the satellite and heated or cooled so that its temperature stays within the range 0^{0}C to 75^{0}C. This requires a thermal control system that manages heat flow throughout a GEO satellite as the sun moves around once every 24hr.

When a satellite is designed, three prototype models are often built and tested. The mechanical model contains all the structural and mechanical parts that will be included in the satellite and is tested to ensure that all moving parts operate correctly in a vacuum, over a wide temperature range. The thermal model contains all the electronics packages and other components that must be maintained at correct temperature. The electrical model contains all electronic parts of the satellite and is tested for correct electrical performance under total vacuum and a wide range of temperatures.

Many of the electronic and mechanical components that are used in satellite are known to have limited life times, or a finite probability of failure. If failure of one of these components will jeopardize the mission or reduce the communication capacity of the satellite, a backup, or redundant, unit will provided. The design of the system must be such that when one unit fails, the backup can automatically take over or be switched into operation by a command from the ground.

Reliability

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

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

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

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

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

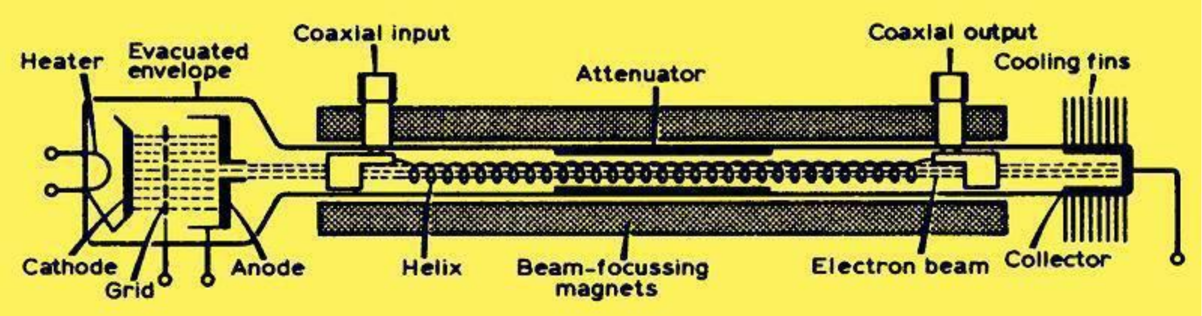


Figure TWTA

Other critical components are antenna reflectors, beaming assemblers etc.

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

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

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

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

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

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

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

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

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

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

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

If Qi is the unreliability of the **ith** parallel element, then the probability that all units will fail is the product of the individual un-reliabilities:
$Qs = Q1\ Q2\ Q3 \ldots.\ Qi$
When the un-reliability of all elements is equal, then $Qs = Qi$ where Q is the un-reliability of each element.

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

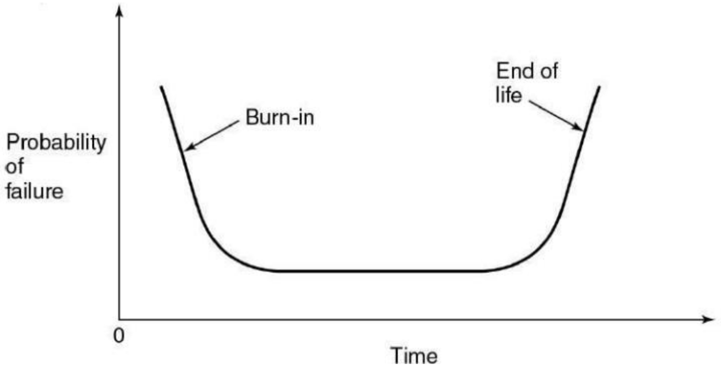
This analysis is done to reduce the overall reliability to a value less than that predicted by the above analysis.

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

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

The two major cost components are:
o Cost of equipment together with the switching and failure sensing mechanism used.
o The associated increase in weight of the satellite resulting in an increased launch cost.

Optimization techniques are performed for cost minimization purpose.



Bathtub curve for probability of failure

Redundancy:

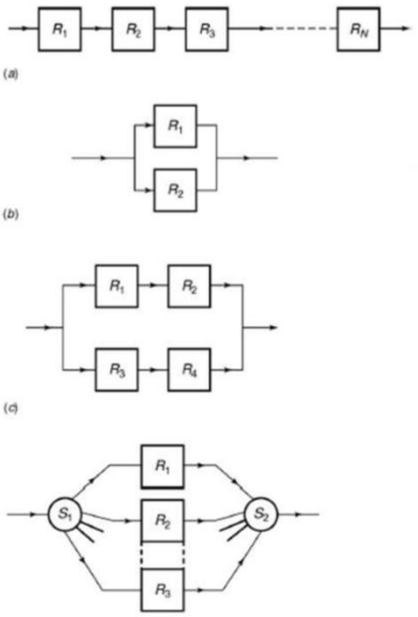
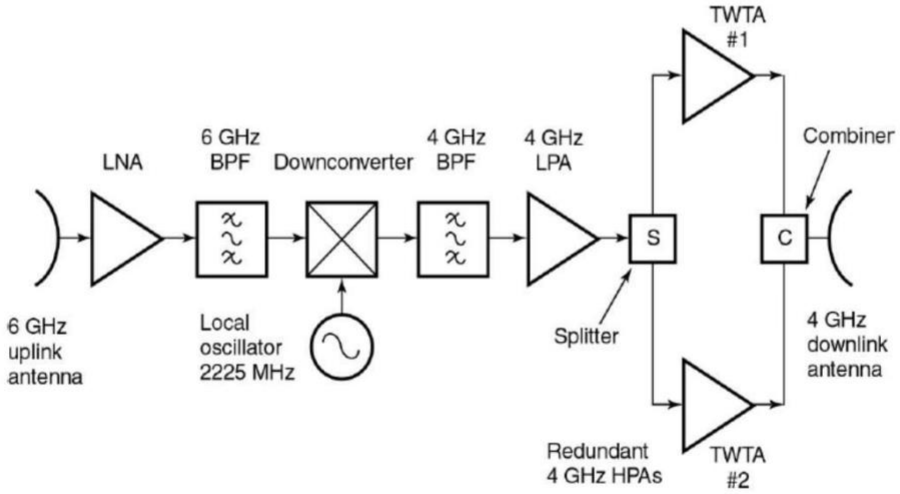


Figure
Redundancy connections. (*a*) Series connection. (*b*) Parallel connection. (*c*) Series/parallel connection. (*d*) Switched connection.



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

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

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SATELLITE LINK

BASIC TRANSMISSION THEORY

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

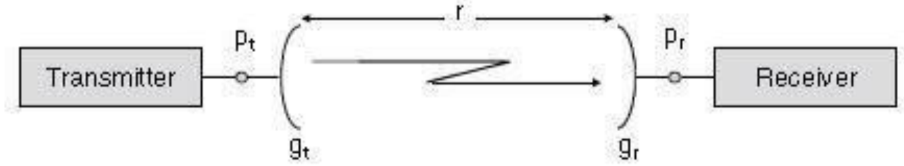


Figure 4.1 Basic communications link

The parameters of the link are defined as: pt = transmitted power (watts); pr = received power (watts); gt = transmit antenna gain; gr = receive antenna gain; and r = path distance (meters).

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

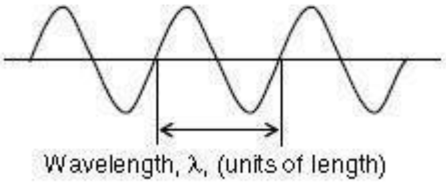


Figure 4.2 Definition of wavelength

The frequency and wavelength in free space are related by

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

Where c is the phase velocity of light in a vacuum.
With c = 3×108 m/s, the free space wavelength for the frequency in GHz can be expressed as

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

Consider a radiowave propagating in free space from a point source P of power pt watts. The wave is isotropic in space, i.e., spherically radiating from the point source P, as shown in Figure4.3

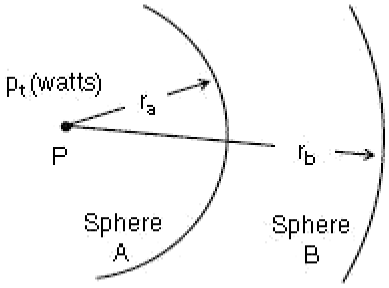


Figure 4.3 Inverse square law of radiation

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

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

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

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

The ratio of power densities is given by

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

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

Effective Isotropic Radiated Power

An important parameter in the evaluation of the RF link is the ***effective isotropic radiated power***, eirp. The eirp, using the parameters introduced in Figure 4.1, is defined as

eirp ≡ pt gt

or, in db, EIRP = Pt + Gt

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

Power Flux Density

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

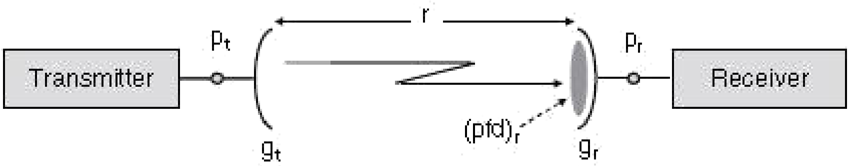


Figure 4.4 Power flux density

The (pfd)r is therefore

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

Or, in terms of the eirp,

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

The power flux density expressed in dB, will be

$$(\mathrm{PFD})_r = 10\log\left(\frac{p_t\, g_t}{4\pi r^2}\right)$$
$$= 10\log(p_t) + 10\log(g_t) - 20\ \log(r) - 10\log(4\pi)$$

With r in meters,

$$(\mathrm{PFD})_r = P_t + G_t - 20\log(r) - 10.99$$

Or

$$(\mathrm{PFD})_r = \mathrm{EIRP} - 20\log(r) - 10.99$$

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

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

Antenna Gain

Isotropic power radiation is usually not effective for satellite communications links, because the power density levels will be low for most applications (there are some exceptions, such as for mobile satellite networks, some directivity (gain) is desirable for both the transmit and receive antennas. Also, physical antennas are not perfect receptors/emitters, and this must be taken into account in defining the antenna gain.

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

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

where λ is the wavelength of the radiowave.

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

$$A_e = \eta_A A$$

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

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

Or,

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

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

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

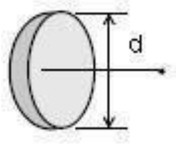
Note also that the effective aperture can be expressed as

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

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

Circular Parabolic Reflector Antenna

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



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

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

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

or

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

Expressed in dB form,

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

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

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

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

Or, in dBi

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

Beamwidth

Figure 4.5 shows a typical directional antenna pattern for a circular parabolic reflectorantenna, along with several parameters used to define the antenna performance. The ***boresight*** direction refers to the direction of maximum gain, for which the value g is determined from the above equations. The 1/2 ***power beamwidth*** (sometimes referred to asthe ‘3 dB beamwidth’) is the contained conical angle θ for which the gain has dropped to 1/2 the value at boresight, i.e., the power is 3 dB down from the boresight gain value.

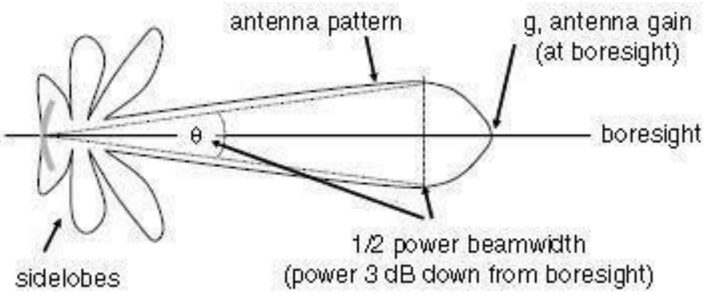


Figure 4.5 Antenna beamwidth

The antenna pattern shows the gain as a function of the distance from the boresight direction. Most antennas have ***sidelobes***, or regions where the gain may increase due to physicalstructure elements or the characteristics of the antenna design. It is also possible that some energy may be present behind the physical antenna reflector. Sidelobes are a concern as a possible source for noise and interference, particularly for satellite ground antennas located near to other antennas or sources of power in the same frequency band as the satellite link.

The antenna beamwidth for a parabolic reflector antenna can be approximately determined from the following simple relationship,

$$\theta \cong 75 \frac{\lambda}{d} = \frac{22.5}{d \, f}$$

Where θ is the 1/2 power beamwidth in degrees, d is the antenna diameter in meters, and f is the frequency in GHz. Antenna beamwidths for satellite links tend to be very small, in most cases much less than 1◦, requiring careful antenna pointing and control to maintain the link.

Free-Space Path Loss

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

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

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

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

A rearranging of terms describes the interrelationship of several parameters used in link analysis:

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

Basic Link Equation for Received Power

We now have all the elements necessary to define the basic link equation for determining the received power at the receiver antenna terminals for a satellite communications link. We refer again to the basic communications link (Figure 4.1, repeated here as Figure 4.6).

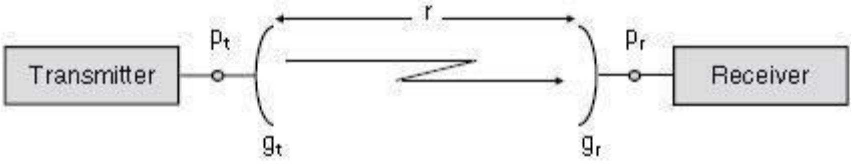


Figure 4.6 Basic communications link

The parameters of the link are defined as: pt = transmitted power (watts); pr = received power (watts); gt = transmit antenna gain; gr = receive antenna gain; and r = path distance (meters or km).

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

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

Or, expressed in dB,

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

This result gives the basic link equation, sometimes referred to as the ***Link Power Budget***

Equation, for a satellite communications link, and is the design equation from which satellite design and performance evaluations proceed.

SYSTEM NOISE TEMPERATURE AND G/T RATIO

Noise temperature:

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

$$P_n = k\, T_p B_n$$

Where

k=Boltzmann's constant=1.39×10^{-23} J/K=-228.6dBW/K/Hz
Tp=Physical temperature of source in kelvin degrees
Bn=noise bandwidth in which the noise power is measured, in hertz

Pn is the available noise power (in watts) and will be delivered only to a load that is impedance matched to the noise source. The term kTp is a noise power spectral density, in watts per hertz. We need a way to describe the noise produced by the components of a low noise receiver. This can conveniently be done by equating the components to a black body radiator with an equivalent noise temperature, Tn kelvins.

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

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

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

$$P_{no} = k T_s B_n G_{rx} \text{ watts}$$

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

The noise power referred to the input of the receiver is Pn where

$$P_{no} = k T_s B_n \text{watts}$$

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

The gain of the receiver cancels out in above equation . So we can calculate C/N ratios for our receiving terminals at the antenna output port. This is convenient, because a link budget will find Pr at this point. Using a single parameter to encompass all of the sources of noise in receiving terminals is very useful because it replaces several sources of noise in the receiver by a single system noise temperature, Ts.

Calculation of system Noise Temperature

The above figure shows a simplified communication receiver with an RF amplifier and single frequency conversion, from its RF input to the IF output. This is the form used for all radio receivers with few exceptions, known as the superhet. The superhet receiver has three main subsystems: a front end (RF amplifier, mixer and local oscillator) an IF amplifier (IF amplifiers and filters), and a demodulator and baseband section.

The RF amplifier in a satellite communications receiver must generate as little noise as possible, so it is called a low noise amplifier or LNA. The mixer and local oscillator from a frequency conversion stage that downconverts the RF signal to a fixed intermediate frequency(IF), where the signal can be amplified and filtered accurately.

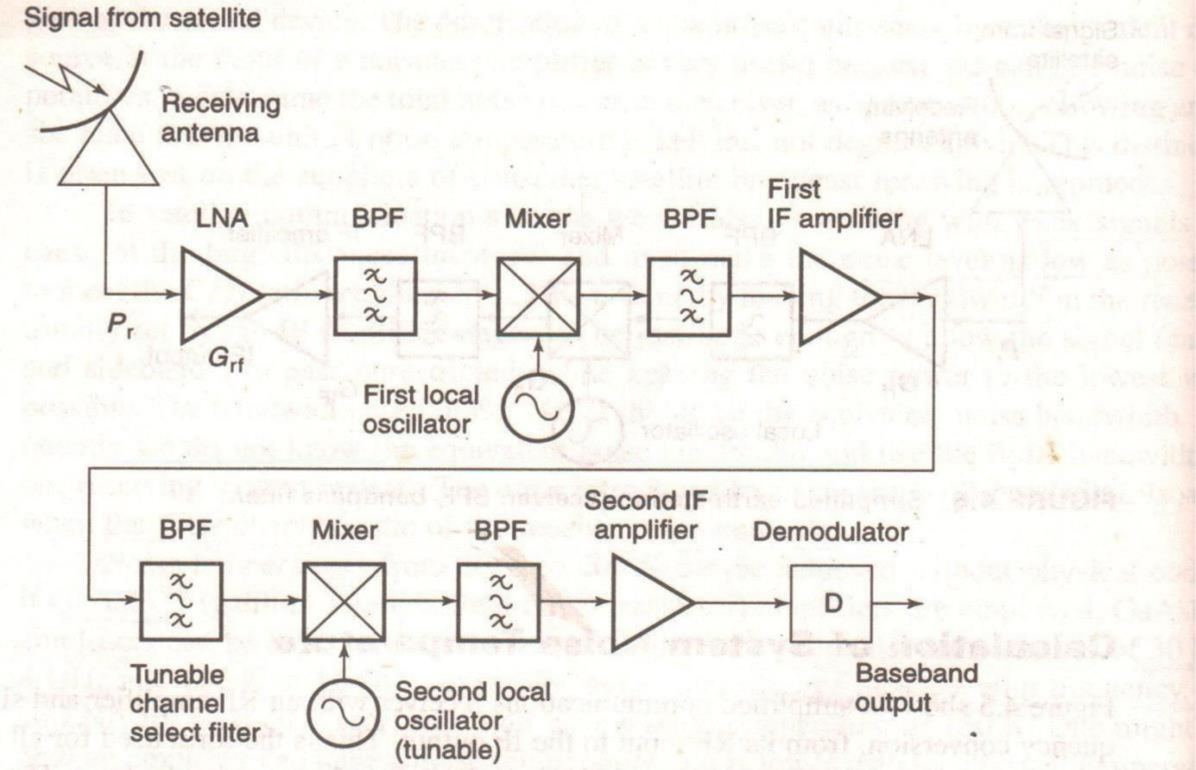
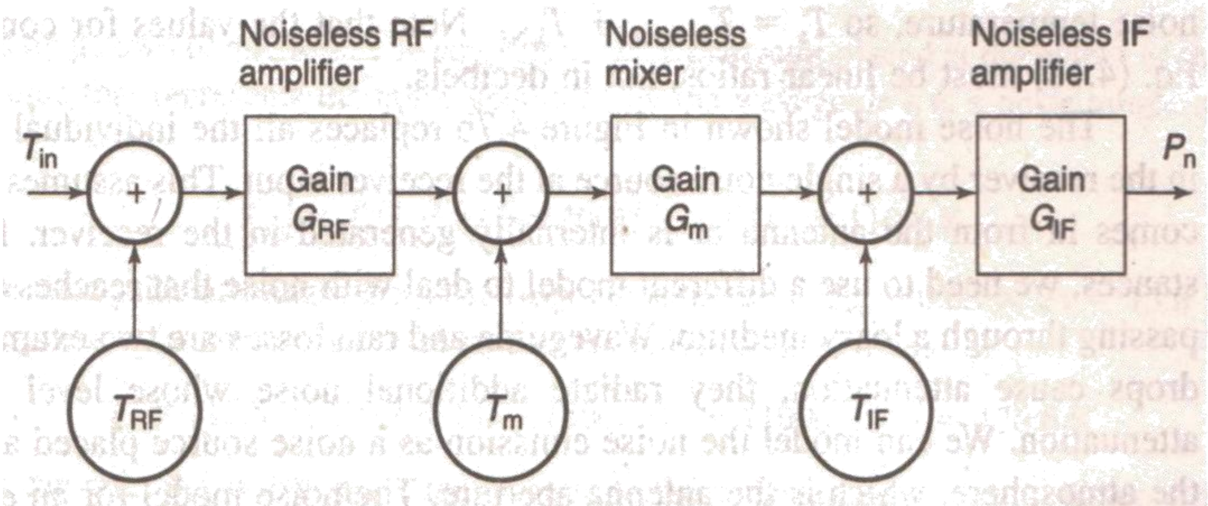


FIGURE 4.6 Double conversion earth station receiver. The first downconversion shifts signals in a 500-MHz band to the first IF range 900–1400 MHz. The second downconverter has a tunable local oscillator and channel selection filter to select the wanted transponder signal in the second IF centered at 70 MHz.



(a) Equivalent noise sources

$$P_n = G_{IF} k T_{IF} B_n + G_{IF} G_m k T_m B_n + G_{IF} G_m G_{RF} k B_n (T_{RF} + T_{in})$$

Where G_{RF}, G_m and G_{IF} are the gains of the RF amplifier, mixer and IF amplifier, and T_{RF},T_m and T_{IF} are their equivalent noise temperatures. Tin is the noise temperature of the antenna, measured at its output port.

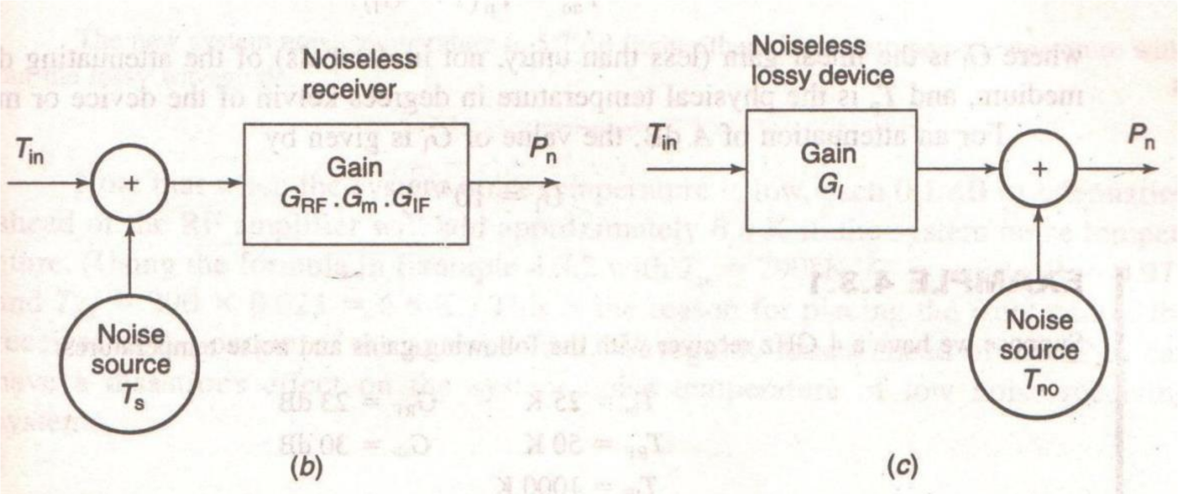


FIGURE 4.7 (*a*) Noise model of receiver. The noisy amplifiers and downconverter have been replaced by noiseless units, with equivalent noise generators at their inputs. (*b*) Noise model of receiver. All noisy units have been replaced by one noiseless amplifier, with a single noise source T_s as its input. (*c*) Noise model for a lossy device. The lossy device has been replaced by a lossless device, with a single noise source T_{no} at its output.

Above equation can be rewritten as

$$P_n = G_{IF}G_mG_{RF}\,[(kT_{IF}B_n)/(G_{RF}G_m) + (kT_mB_n)/G_{RF} + (T_{RF}+T_{in})]$$

$$\bullet\; G_{IF}G_mG_{RF}kB_n[T_{RF} + T_{in} + T_m/G_{RF} + T_{IF}/(G_{RF}G_m)]$$

The single source of noise shown in figure(b) with noise temperature T_s generates the same noise power P_n at its output if

$$P_n = G_{IF}G_mG_{RF}\,kT_sB_n$$

The noise power at the output of the noise model in figure b will be the same as the noise power at the output of the noise model in fig (a) if

$$kT_sB_n = kB_n\,[(T_{in}+T_{RF}+T_m/G_{RF}+T_{IF}/G_mG_{RF})]$$

Hence the equivalent noised source in figure (b) has a system noise temperature T_s

$$\text{where } T_s=[T_{in}+T_{RF}+T_m/G_{RF}+T_{IF}/(G_mG_{RF})]$$

Succeeding gates of the receiver contribute less and less noise to the total system noise temperature. Frequently, when the RF amplifier in the receiver front end has high gain, the noise contributed by the IF amplifier and later stages can be ignored and the system noise temperature is simply the sum of the antenna noise and the LNA noise temperature, so

$$T_s = T_{antenna} + T_{LNA}.$$

Noise figure and noise source

Noise figure is frequently used to specify the noise generated within a device. The operational noise figure (N/F) is defined by the following formula:

$$\frac{(\;)}{(\;)}$$

Because noise temperature is more useful in satellite communication system, it is best to convert noise figure to noise temperature, Td. The relationship is

$$T = T0(NF-1)$$

Where *To* is the reference temperature used to calculate the standard noise figure usually 290k.

G/T Ratio for Earth Stations

The link equation can be rewritten in terms of (C/N)at the earth station

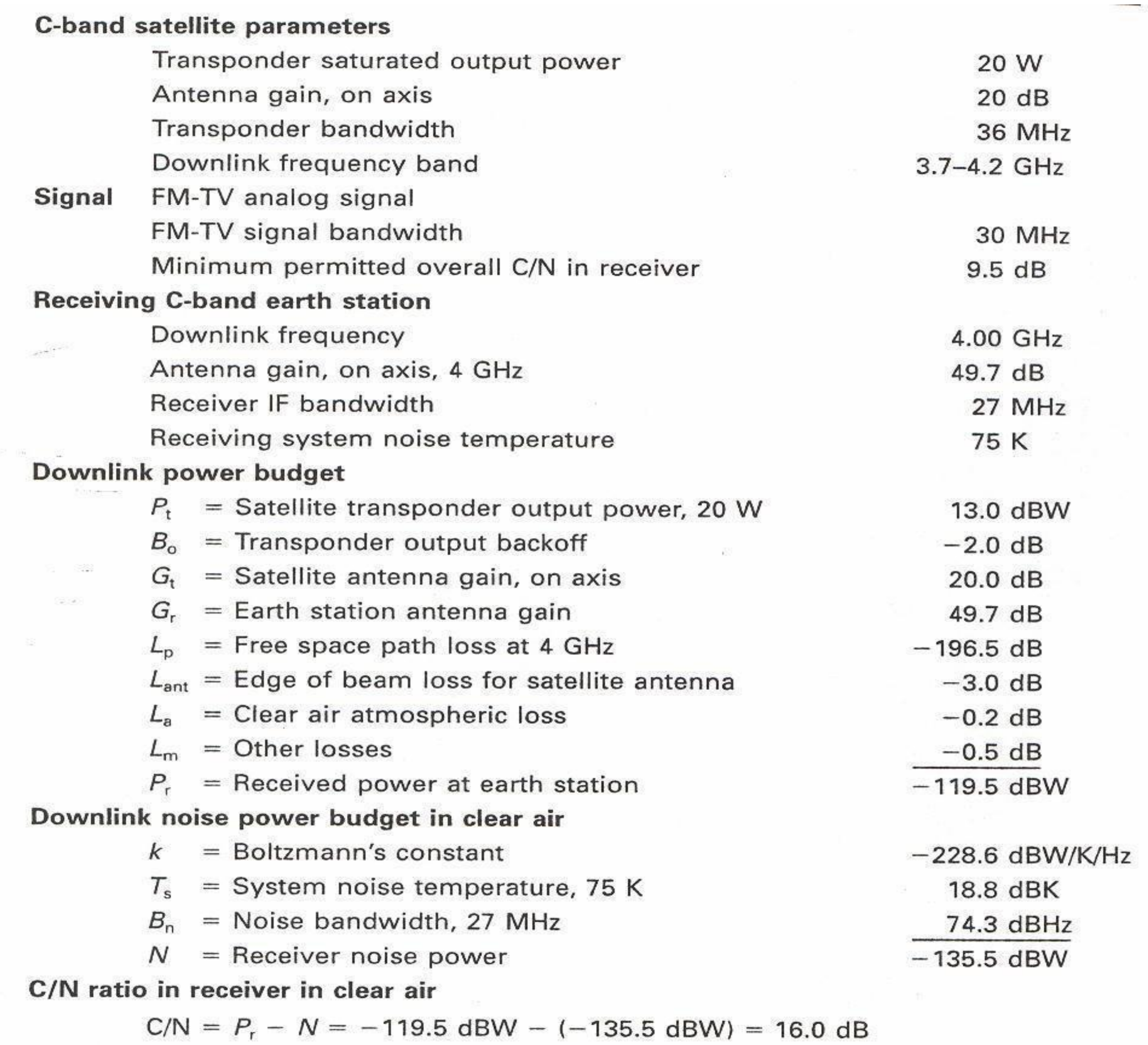
$$[\quad][\quad] = [\quad][\quad][\;]$$

Thus C/N α Gr/Ts and the terms in the square brackets are all constants for a given satellite system. The ratio Gr/Ts, which is usually quoted as simply G/T in decibels, with units db/k, can be used to specify the quality of a receiving earth station or a satellite receiving system, since increasing Gr/Ts increases C/N ratio.

DESIGN OF DOWNLINKS

The downlink of a satellite circuit is where the space craft is transmitting the data to the earth station and the earth station is receiving it.

Design of downlink: Link Budgets

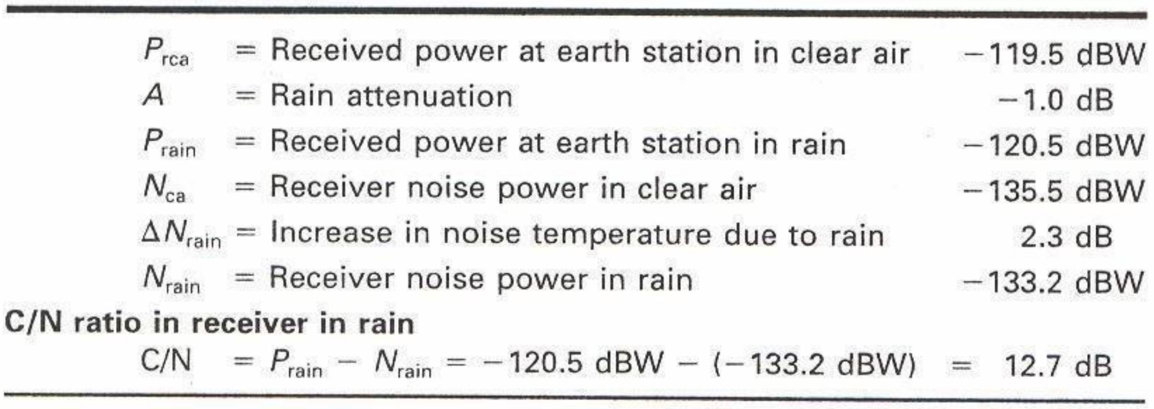


C-band satellite parameters		
	Transponder saturated output power	20 W
	Antenna gain, on axis	20 dB
	Transponder bandwidth	36 MHz
	Downlink frequency band	3.7–4.2 GHz
Signal	FM-TV analog signal	
	FM-TV signal bandwidth	30 MHz
	Minimum permitted overall C/N in receiver	9.5 dB
Receiving C-band earth station		
	Downlink frequency	4.00 GHz
	Antenna gain, on axis, 4 GHz	49.7 dB
	Receiver IF bandwidth	27 MHz
	Receiving system noise temperature	75 K
Downlink power budget		
	P_t = Satellite transponder output power, 20 W	13.0 dBW
	B_o = Transponder output backoff	−2.0 dB
	G_t = Satellite antenna gain, on axis	20.0 dB
	G_r = Earth station antenna gain	49.7 dB
	L_p = Free space path loss at 4 GHz	−196.5 dB
	L_{ant} = Edge of beam loss for satellite antenna	−3.0 dB
	L_a = Clear air atmospheric loss	−0.2 dB
	L_m = Other losses	−0.5 dB
	P_r = Received power at earth station	−119.5 dBW
Downlink noise power budget in clear air		
	k = Boltzmann's constant	−228.6 dBW/K/Hz
	T_s = System noise temperature, 75 K	18.8 dBK
	B_n = Noise bandwidth, 27 MHz	74.3 dBHz
	N = Receiver noise power	−135.5 dBW

C/N ratio in receiver in clear air

$$C/N = P_r - N = -119.5\text{ dBW} - (-135.5\text{ dBW}) = 16.0\text{ dB}$$

C-band GEO Satellite link budget in rain



P_{rca}	= Received power at earth station in clear air	−119.5 dBW
A	= Rain attenuation	−1.0 dB
P_{rain}	= Received power at earth station in rain	−120.5 dBW
N_{ca}	= Receiver noise power in clear air	−135.5 dBW
ΔN_{rain}	= Increase in noise temperature due to rain	2.3 dB
N_{rain}	= Receiver noise power in rain	−133.2 dBW

C/N ratio in receiver in rain

$$C/N = P_{rain} - N_{rain} = -120.5\text{ dBW} - (-133.2\text{ dBW}) = 12.7\text{ dB}$$

Satellite Link Design –Downlink Received Power

The calculation of carrier to noise ratio in a satellite link is based on equations for received signal power *P*r and receiver noise power:

$Pr=EIRP+Gr-Lp-La-Lta-Lra$ dBW

Where:

$EIRP = 10\log 10(PtGt)$ dBW

$Gr = 10\log 10\,(4\prod A_e/\lambda^2)$ dB

Path Loss $Lp = 10\log 10[(4\prod R/\lambda)^2]=20\log 10(4\prod R/\lambda)$ dB

La= Attenuation in atmosphere

Lta= Losses associated with transmitting antenna

Lra= Losses associated with receiving antenna

Satellite Link Design: Down link Noise Power

A receiving terminal with a system noise temperature TsK and a noise bandwidth Bn HZ has a noise power Pn referred to the output terminals of the antenna where

$$P_n=k\,TsB_n$$

The receiving system noise power is usually written in decibel units as

$$N=k+Ts+Bn \text{ dBW}$$

Where

k=Boltzmann's constant=$1.39\text{x}10^{-23}$ J/K= -
228.6dBW/K/Hz Ts= the system noise temperature in dBK
Bn=noise bandwidth in which the noise power is measured, in hertz

UPLINK DESIGN

The uplink of a satellite circuit is where the earth station is transmitting the data to the space craft and the space craft is receiving it.

- Uplink design is easier than the down link in many cases
- Earth station could use higher power transmitters
- Earth station transmitter power is set by the power level required at the input of the transponder.
- Analysis of the uplink requires calculation of the power level at the input to the transponder so that uplink C/N ratio can be found
- With small-diameter earth stations, a higher power earth station transmitter is required to achieve a similar satellite EIRP.
- Uplink power control can be used to against uplink rain attenuation.

The noise power referred to the transponder input is N_{xp} w

$$N_{xp}= k + T_{xp} + B_n \text{ dBw}$$

The power received at the input of the transponder is P_{rxp}

$$P_{rxp}=P_t + G_t + G_r - L_p - L_{up} \text{ dBw}$$

The value of $(C/N)_{up}$ at the LNA input of the satellite receiver is given

$$\text{by } C/N = 10\log_{10}[p_r/(kT_sB_n)] = P_{rxp} - N_{xp} \text{ dB}$$

The received power at the transponder input is also given by

$$P_{rxp} = N + C/N \text{ dBw}$$

DESIGN OF SATELLITE LINKS FOR SPECIFIED C/N

- The BER or S/N ratio in the baseband channel of earth station receiver is determined by the ratio of the carrier power to the noise power in the IF amplifier at the input to the demodulator.
- When more than one C/N ratio is present in the link, we can add the individual C/N ratios reciprocally to obtain overall C/N ratio, which we will denote here as $(C/N)_0$. The overall $(C/N)_0$ ratio is what would be measured in the earth station at the output of the IF amplifier

$$(C/N)_0=1/[1/ (C/N)_1+ 1/ (C/N)_2+ 1/ (C/N)_3+\ldots]$$

Overall $(C/N)_0$ with Uplink and Downlink Attenuation

- The effect of change in (C/N) ratio has a different impact on overall $(C/N)_0$ depending on the operating mode and gain of the transponder.
- There are three different transponder types or operating modes:

Linear transponder: $P_{out}= P_{in} + G_{xp}$ dBW

Nonlinear transponder: $P_{out}= P_{in} + G_{xp} - \Delta G$ dBW

Regenerative transponder: $P_{out}=$ Constant

Where P_{in} is the power delivered by the satellite's receiving antenna to the input of the transponder, P_{out} is the power delivered by the transponder HPA to the input of the satellite's transmitting antenna, G_{xp} is the gain of the transponder.

SYSTEM DESIGN EXAMPLE FOR KU-BAND COMMUNICATION LINK

System and Satellite Specification

Ku -band satellite parameters

Geostationary at 73^{o} W longitude. 28 Ku -band transponders

Total RF output power	2.24 kW
Antenna gain, on axis (transmit and receive)	31 dB
Receive system noise temperature	500 K
Transponder saturated output power: Ku band	80 W
Transponder bandwidth: Ku band	54 MHz

Signal: Compressed digital video signals with transmitted symbol rate of 43.2 Msps

Minimum permitted overall (C/N), in receiver	9.5 dB

Transmitting Ku-band earth station

Antenna diameter	5 m
Aperture efficiency	68%
Uplink frequency	14.15 GHz
Required C.,'N in Ku -band transponder	30 K
Transponder HPA output backoff	1 dB
Miscellaneous uplink losses	0.3 de

Location: -2 dB contour of satellite receiving antenna

Receiving Ku -band earth station

Downlink frequency	11.45 GHz
Receiver IF noise bandwidth	43.2 MHz
Antenna noise temperature	30 K
LNA noise temperature	110 K
Required overall (C/N): in clear air	17 dB
Miscellaneous downlink losses	0.2 dB

Location: -3 dB contour of satellite transmitting antenna

Rain attenuation and propagation factors

Ku -band clear air attenuation

Uplink	14.15 GHr	0.7 dB
Downlink	11.45 GH1	0.5 dB

Rain attenuation

Uplink	0.01% of year	6.0 dB
Downlink	0.01% of year	5.0 dB

Ku -Band Uplink Design

We must Find the uplink transmitter power required to achieve (C/N)up = 30 dB in clear air atmospheric conditions. We will first find the noise power in thc transponder for 43.2 MHz bandwidth, and then add 30 dB to find the transponder input power level.

Uplink Noise Power Budget

K=Boltzmann's constant	-228.6 dBW/K/Hz
Ts= 500K	27.0 dBK
B = 43.2 MHz	76.4 dBHz
N=transponder noise power	-125.2 dBW

The received power level at the transponder input must be 30 dB greater than the noise power.

Pr= power at transponder input = - 95.2 dBW

The uplink antenna has a diameter of 5 m and an aperture efficiency of 68%. At 14.15 GHz the wavelength is 2.120 cm = 0.0212 m. The antenna gain is

Gt =10 log[0.68 x (∏D/λ)2] = 55.7 dB

The free space path loss is Lp = 10 log [(4∏R/ λ)2] = 207.2 dB

Uplink Power Budget

Pt=Earth station transmitter power	Pt dBW
Gt=Earth station antenna gain	55.7 dB
Gr=Satellite antenna gain	31.0 dB
Lp= Free space path loss	-207.2 dB
Lant= E/S on 2 dB contour	-2.0 dB
Lm = Other losses	-1.0 dB
Pr=Received power at transponder	Pt - 123.5 dB

The required power at the transponder input to meet the (C/N)up = 30 dB objective is -95.2dBW. Hence

$$Pt - 123.5\ dB = -95.2\ dBW$$
$$Pt = 28.3\ dBW \text{ or } 675W$$

This is a relatively high transmit power so we would probably want to increase the transmitting antenna diameter to increase its gain, allowing a reduction in transmitter power.

Ku -Band Downlink Design

The first step is to calculate the downlink (C/N)dn that will provide (C/N)o=17dB Where (C/N)up= 30 dB.

$$1/(C/N)dn=1/(C/N)0-1/(C/N)up \text{ (not in dB)}$$

Thus

$$1/(C/N)dn = 1/50 - 1/1000 = 0.019$$
$$(C/N)dn = 52.6=17.2\ dB$$

We must find the required receiver input power to give (C/N)dn = 17.2 dB and then find the receiving antenna gain, Gr.

Downlink Noise Power Budget

K = Boltzmann's constant	-228.6 dB W/K/Hz
Ts = 30 +110 K = 140K	21.5 dBK
Bn= 43.2 MHz	76.4 dBHz
N= transponder noise power	-130.7 dBW

The power level at the earth station receiver input must be 17.2 dB greater than the noise power in clear air.

Pr =power at earth station receiver input =-130.7 dBW +17.2 dB = -113.5dBW

We need to calculate the path loss at 11.45 GHz. At 14.15 GHz path loss was 207.2dB. At 11.45 GHz path loss is

$$Lp= 207.2 - 20 \log_{10} (14.15/11.45) = 205.4\ dB$$

The transponder is operated with 1 dB output backoff, so the output power is 1 dB below 80W (80W=19.0 dBW).

$$Pt = 19\ dBW - 1\ dB = 18\ dBW.$$

Downlink Power Budget

Pt = Satellite transponder output power	18.0 dBW
Gt = Satellite antenna gain	31.0 dB
Gr = Earth station antenna gain	Gr dB
Lp = Free space path loss	-205.4 dB
La= E/S on -3 dB contour of satellite antenna	-3.0 dB
Lm= Other losses	-0.8 dB
Pr= Received power at transponder	Gr - 160.2 dB

The required power into the earth station receiver to meet the (C/N)dn = 17.2 dB objective is Pr = - 120.1 dBW. Hence the receiving antenna must have a gain Gr,where

$$Gr - 160.2 \text{ dB} = -113.5 \text{ dBW}$$

$$Gr = 46.7 \text{ dB or } 46{,}774 \text{ as a ratio}$$

The earth station antenna diameter, D, is calculated from the formula for antenna gain. G, with a circular aperture

$$Gr=0.65X(\prod D/\lambda)^2 =46{,}744$$

At 11.45GHz, the wavelength is 2.62cm=0.0262 m.Evaluating the above equation to find D gives the required receiving antenna diameter as D=2.14m.

UNIT III
Propagation Effects

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. **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.

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.

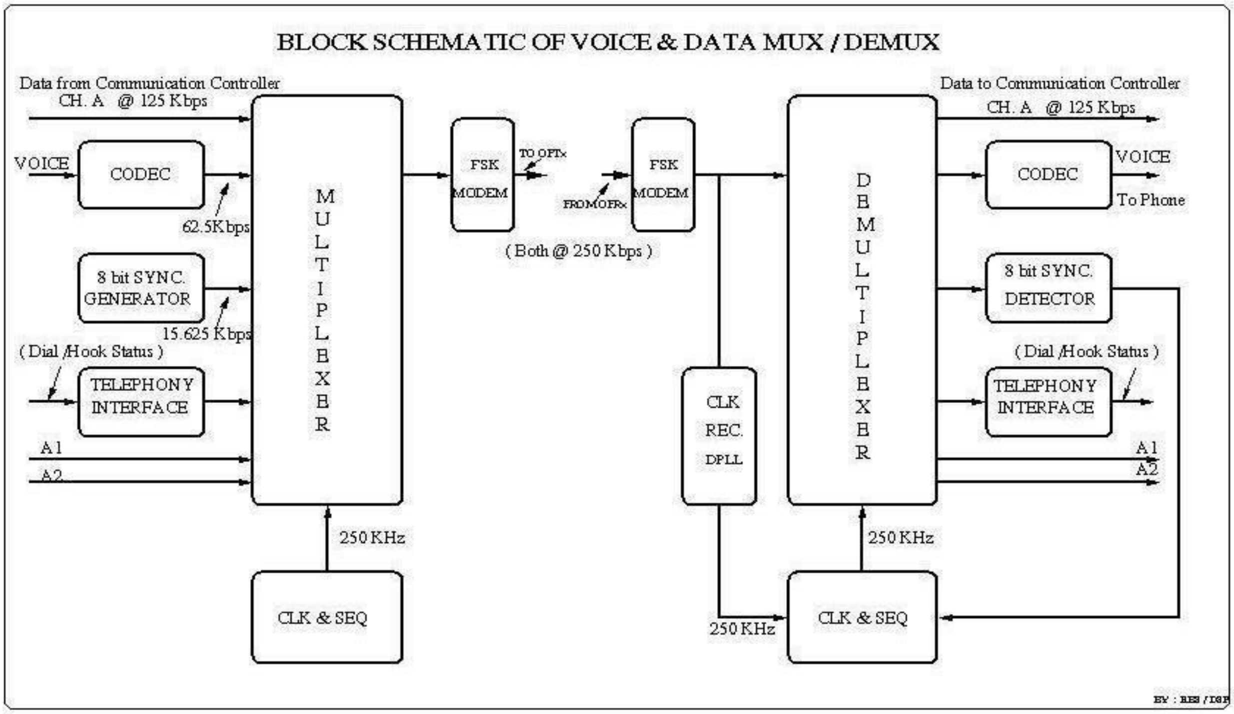


Figure 3.1 Modulation and Multiplexing: Voice/Data/Video

Communication carriers to mix digital data and telephone Fiber-optic Cable Transmission Standards System Bit rate (Mbps) 64- kbps Voice channel capacity 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 overall 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 baseband 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 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 â€" 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.

Analog – digital transmission system :

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.

Also Transmission—transmit without regard to signal content vs. being concerned with signal content. Difference in how attenuation is handled, but not focus onthis.Seeing a shift towards digital transmission despite large analog base. Why?

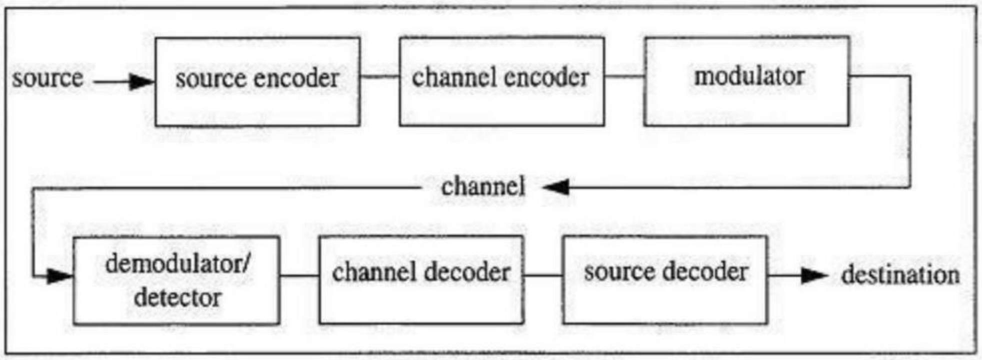


Figure 3.2 basic communication systems

- 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. Can integrate voice, video and digital data.

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.

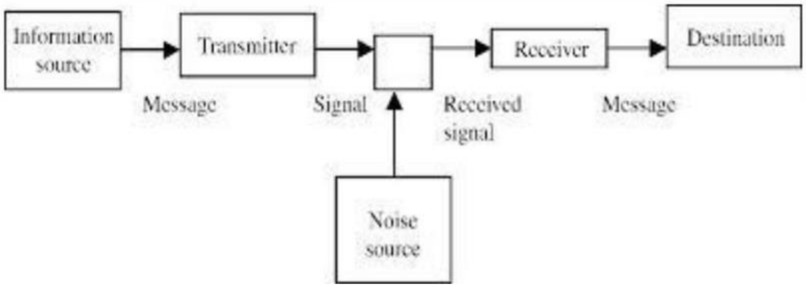


Figure 3.3 Digital /Analog Transmitter & receiver

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 timeslice, 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.

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 article aims at describing what DVB is all about and at introducing some of the technical background of a technology that makes possible the broadcasting.

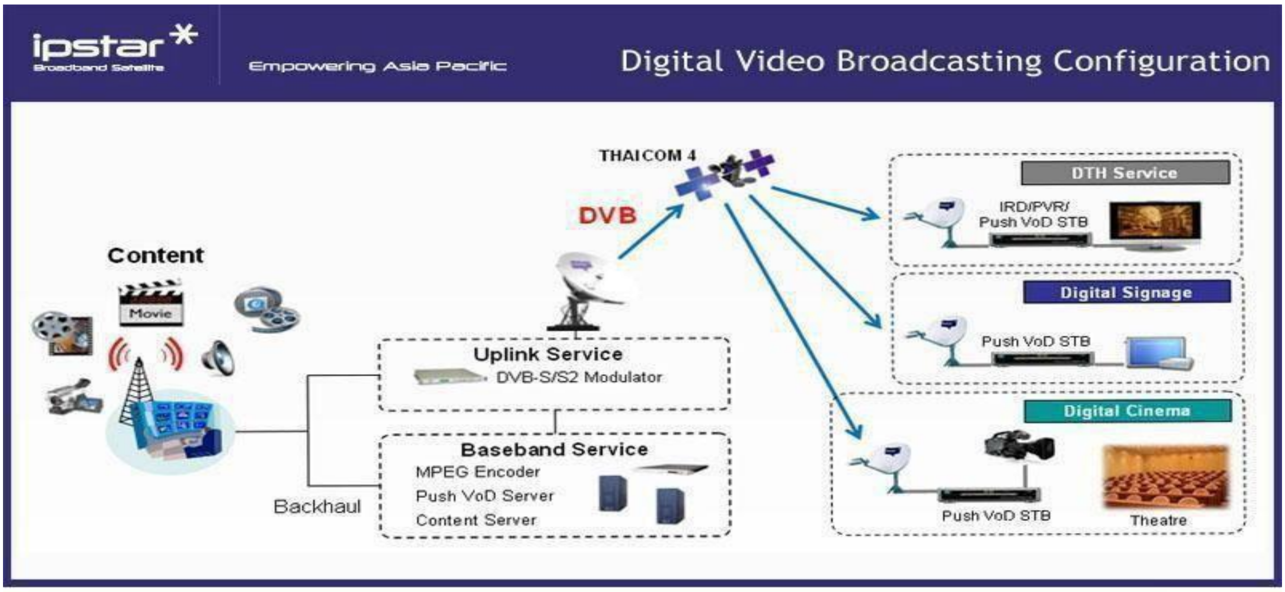


Figure 3.4 Digital Video Broadcasting systems