Satellite Communication Notes Unit (1 to 3)

Computer Science And Engineering (CMR Technical Campus)

LECTURE NOTES

ON

SATELLITE COMMUNICATIONS

IV B. Tech I semester (CMRIT-R17)

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ELECTRONICS AND COMMUNICATION ENGINEERING

CMR INSTITUTE OF TECHNOLOGY

(UGC - Autonomous)

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SATELLITE COMMUNICATIONS

IV -B.Tech.-I-Sem L T P C **Subject Code: 17EC4103PC 4 1 - 4**

Course Outcomes: Upon completion of this course, the student able to

1. summarize orbital effects on satellitecommunications
2. interpret the subsystems ofsatellite
3. classify various multiple access and spread spectrum techniques
4. illustrate satellite link design and earth stationtechnology
5. outline the satellite navigation and global positioning system

Unit-I

Introduction: Brief history of Satellite systems; Principles, architecture, advantages, disadvantages, applications and frequency bands used for satellite communication.

Orbital Mechanics and Launchers: Orbital Mechanics, Look Angle determination, Orbital perturbations, Orbital determination, Launches and Launch vehicles, Orbital effects in communication systems performance.

Unit–II

Satellite Subsystems: Attitude and Orbit control system, Telemetry, Tracking, Commanding and Monitoring, Power Systems, Communication Subsystems, Satellite antennas, Equipment reliability and Space qualification.

Unit-III

Multiple Access: Frequency Division Multiple Access (FDMA), Intermodulation, calculation of C/N. Time Division Multiple Access (TDMA), Frame structure, Examples.

Satellite Switched TDMA Onboard processing, DAMA, Code Division Multiple Access (CDMA), Spread Spectrum Transmission and Reception.

Unit-IV

Satellite Link Design: Basic transmission theory, system noise temperature and G/T ratio, Design of down links, Uplink design, Design of satellite links for specified C/N, System design examples.

Earth Station Technology: Introduction, Transmitters, Receivers, Antennas, Tracking systems, Terrestrial Interface, Primary Power test methods.

Unit-V

Low Earth Orbit and Geo-Stationary Satellite Systems: Orbit considerations, Coverage and Frequency Consideration, Delay and Throughput considerations, Systems considerations, Operational NGSO Constellation Designs.

Satellite Navigation and Global Positioning System: Radio and Satellite Navigation, GPS Position Location principles, GPS Receivers and Codes, Satellite Signal Acquisition, GPS Navigation Message, GPS Signal Levels, GPS Receiver Operation, GPS C/A code accuracy, Differential GPS.

Textbooks:

1. Satellite Communications- Timothy Pratt, Charles Bostian and Jeremy Allnutt, WSE, Wiley Publications, 2nd Edition,2003.

References:

1. Satellite Communications: Design Principles- M. Richharia, B S publications, 2nd Edition, 2003.
2. Satellite Communication- D.C Agarwal, Khanna Publications, 5th Edition.

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 eventually evolved. 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 Station when 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 been possible 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 Radio Relays 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.

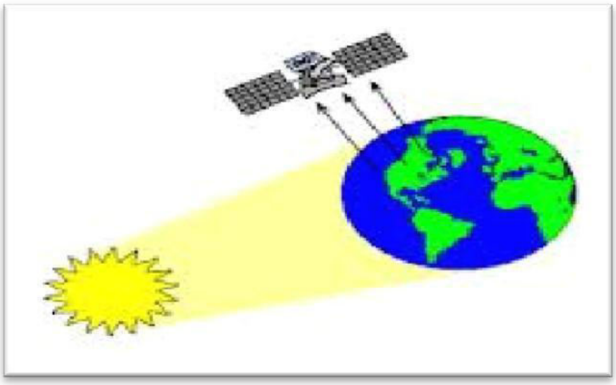
- The commercial satellite communications industry has its beginnings in the mid-1960s, and in less than 50 years has progressed from an alternative exotic technology to a mainstream transmission technology, which is pervasive in all elements of the global telecommunications infrastructure. Today's communications 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.

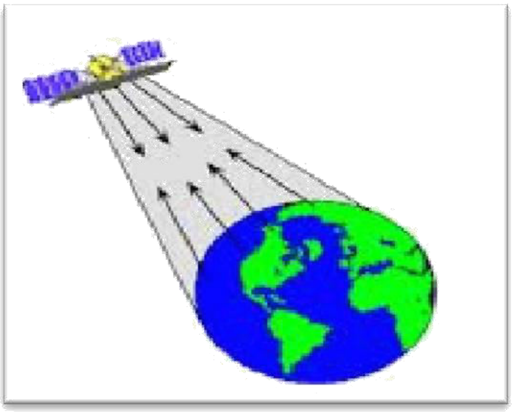


Disadvantages:

- 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.

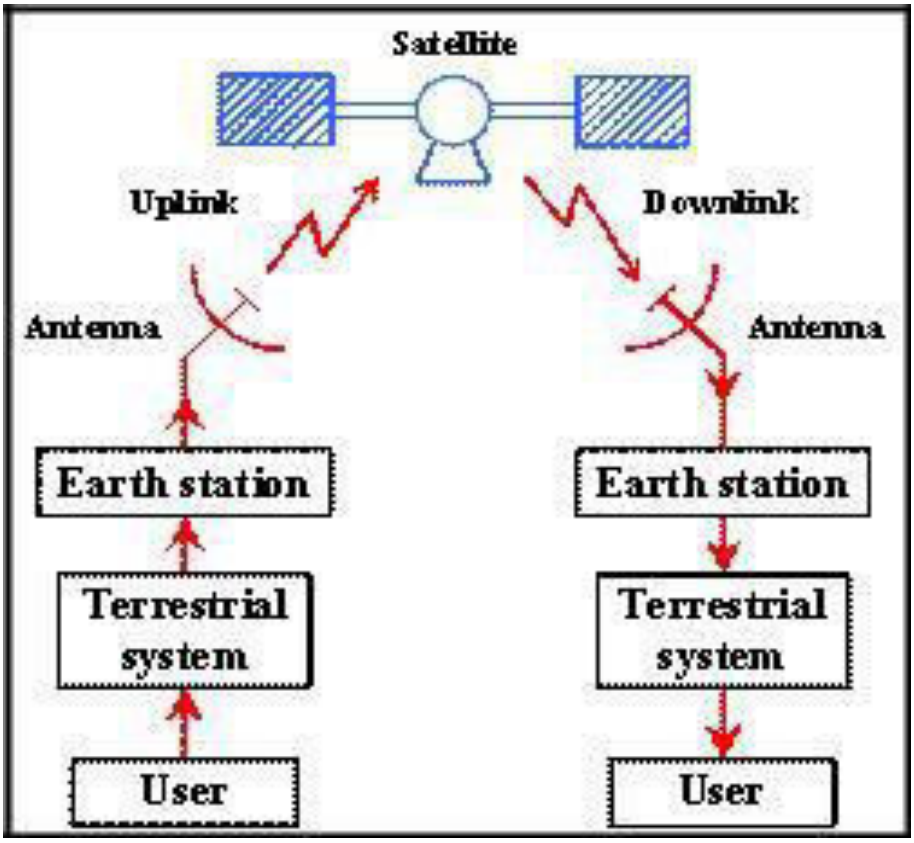


Disadvantages:

- 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.

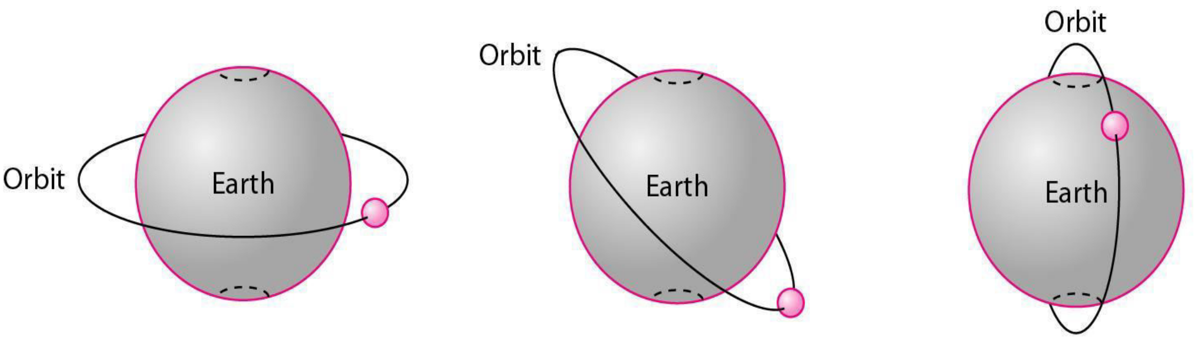
Fixed terminals are designed to access the satellite while fixed in-place on the ground. They may be providing different types of services, but they are defined by the fact that they are not moving while communicating with the satellite. Examples of fixed terminals are small terminals used in private 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., larger antennas 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

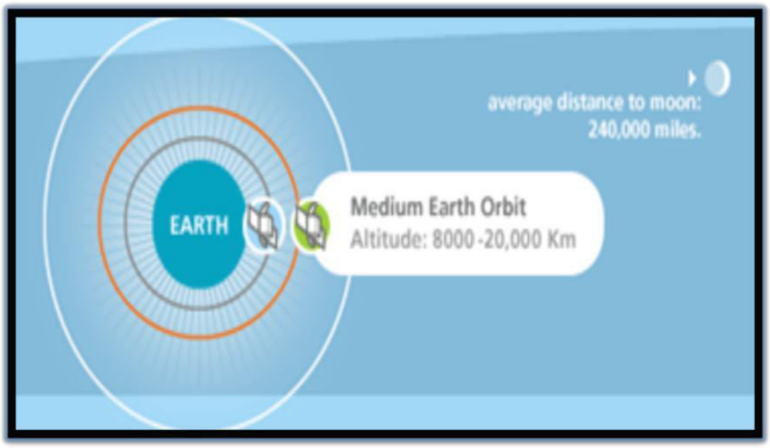
- Minimal Doppler shift
- These factors make it ideal for satellite broadcast and other multipoint applications
- GEO satellites have a 24 hour view of a particular area.
- A GEO satellite's distance from earth gives it a large coverage area, almost a fourth of the earth's surface.

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 than a 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

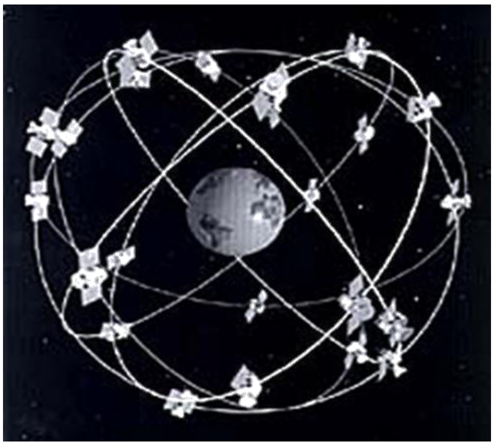
- A MEO satellite's longer duration of visibility and wider footprint means fewer satellites are needed in a MEO network than a LEO network.

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

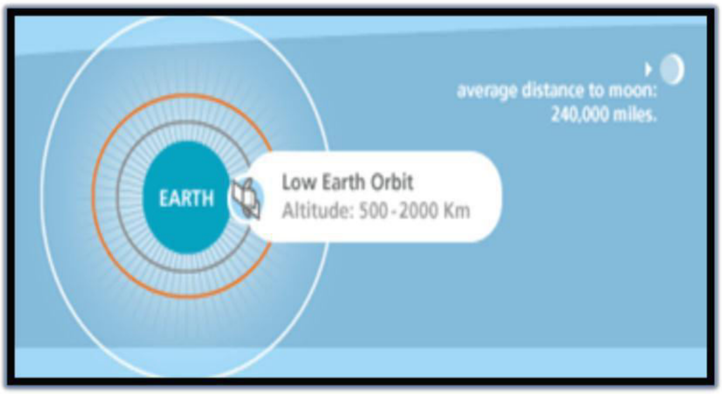
Low Earth Orbit (LEO) satellites:
These satellites are placed 500-1500 kms above the surface of the earth. As LEOs circulate on a lower orbit, hence they exhibit a much shorter period that is 95 to 120 minutes. LEO systems try to ensure a high elevation for every spot on earth to provide a high quality 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 better frequency reuse, similar to the concepts used for cellular networks. LEOs can provide a much higher elevation in Polar Regions and so better global coverage.

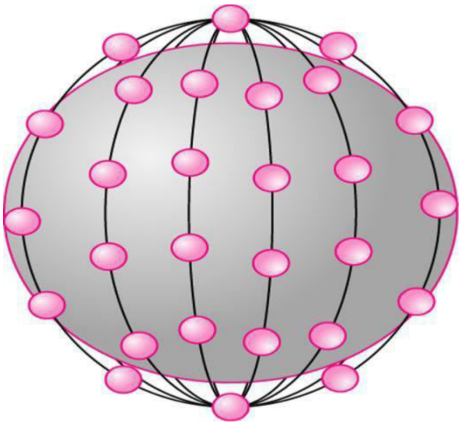
These satellites are mainly used in remote sensing an providing mobile communication services (due to lower latency).

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 service**s: 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

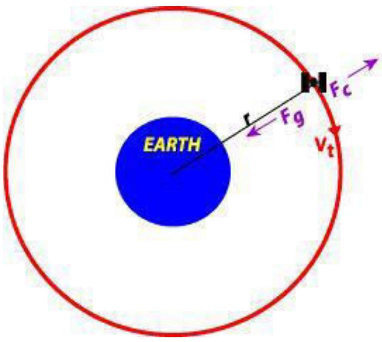
Which are very important in our daily life.

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 $2\prod r$, 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:

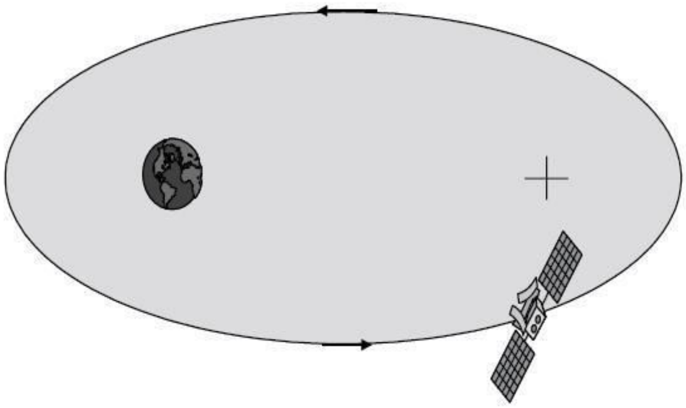


Figure Kepler's First Law

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.

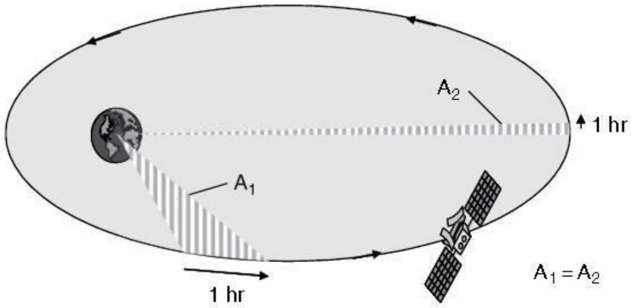


Figure 2.3 Kepler’s Second Law

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.

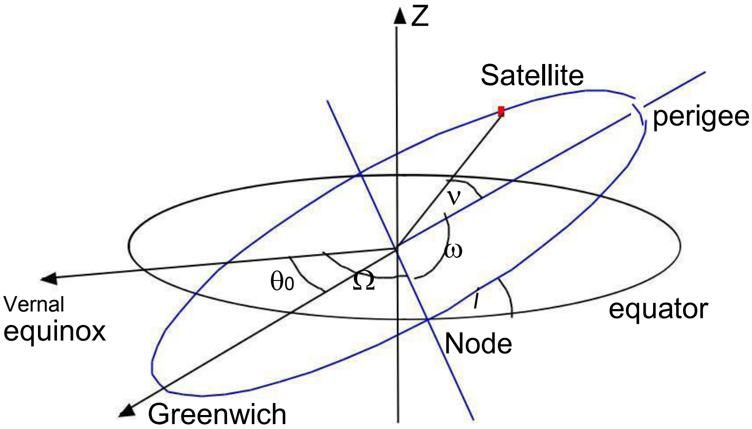
Retrograde Orbit: an orbit in which satellite moves in the same direction counter to the Earth's rotation.

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.

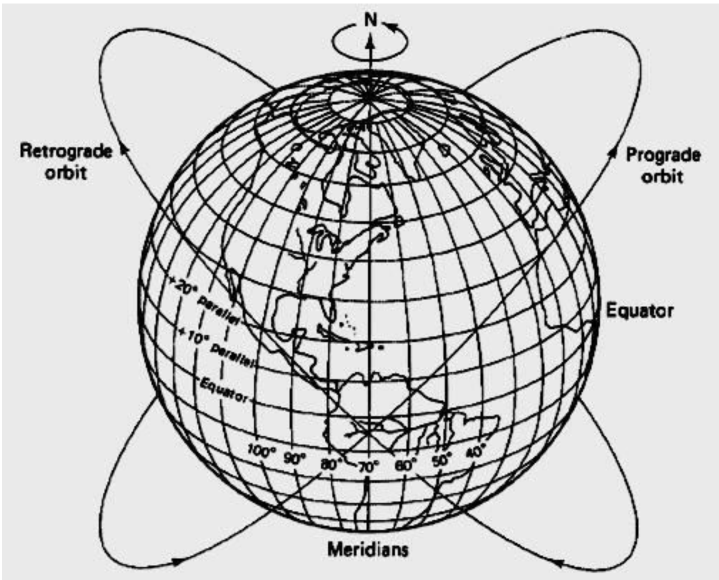
Right ascension of ascending node: The definition of an orbit in space, the position of ascending node is specified. But as the Earth spins, the longitude of ascending node changes and cannot be used for reference. Thus for practical determination of an orbit, the longitude and time of crossing the ascending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

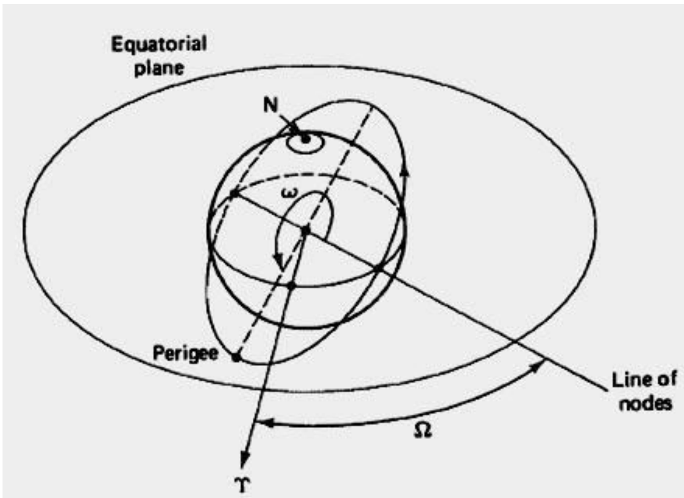
True anamoly: It is the angle from point of perigee to the satellite's position, measure at the Earth's centre.



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.

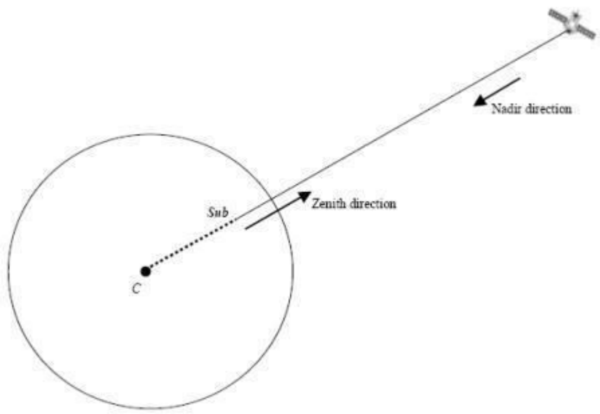
LOOK ANGLE DETERMINATION

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.

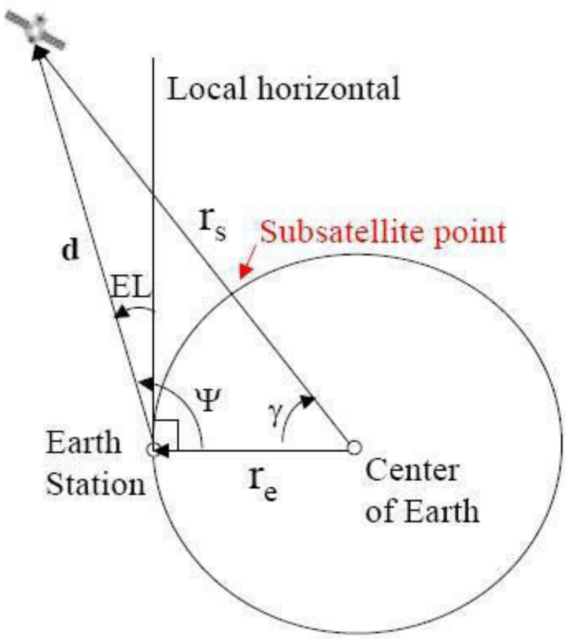


The following information is needed to determine the look angles of geostationary orbit.

- 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 $L_s = 0^o$ 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

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

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

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: $Az = 360^\circ - \alpha$

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

$$\cos(\gamma) = \cos(L_e)\cos(l_s - l_e) = \cos(52)\cos(66) = 0.2504$$

yielding $\gamma = 75.4981^\circ$

$$El = 5.85^{o}$$

Step 3. Find the intermediate angle, α

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

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

$= 70.6668$

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

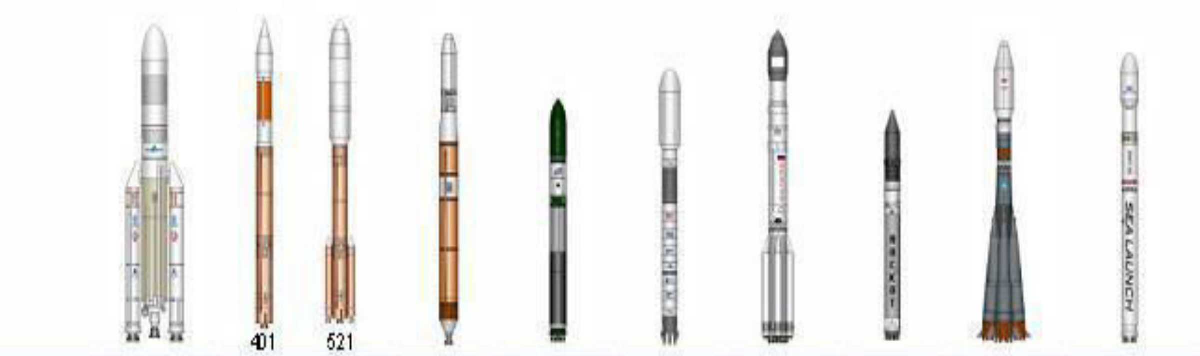
Orbit determination requires that sufficient measurements be made to determine uniquely the six orbital elements needed to calculate the future of the satellite, and hence calculate the required changes that need to be made to the orbit to keep it within the nominal orbital location. The control earth 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. There is little point in orbiting the correct height and not having the appropriate velocity component in 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 inclination of zero degrees an ellipticity of zero, and a velocity of 3074.7m/s tangential to the earth in the plane of the orbit, which is the earths equatorial plane. The further out from the earth the orbit is greater the energy required from the launch vehicle to reach that orbit. In any earth satellite launch, 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.

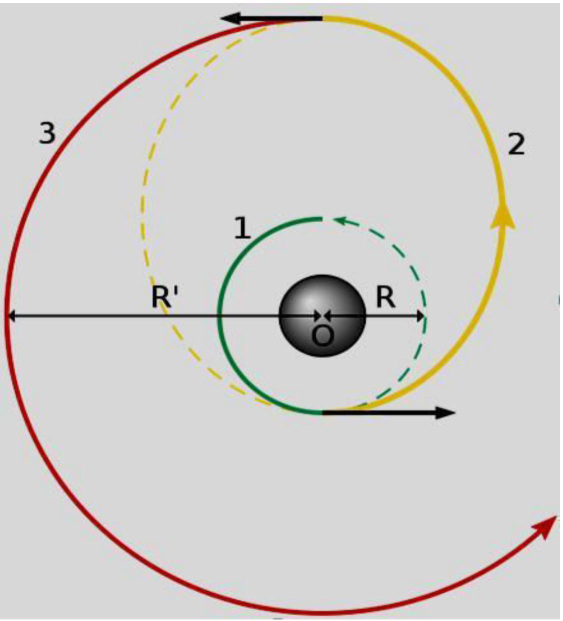


Figure: Orbit Transfer positions

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.

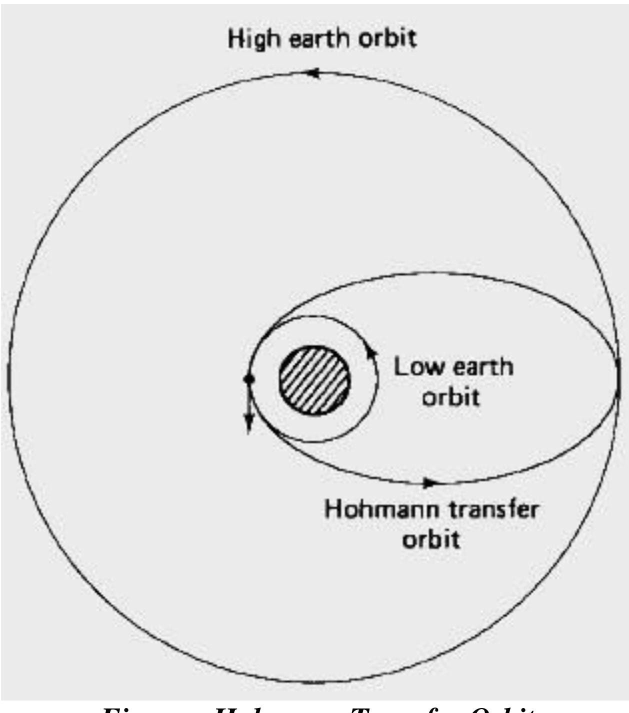


Figure : Hohmann Transfer Orbit

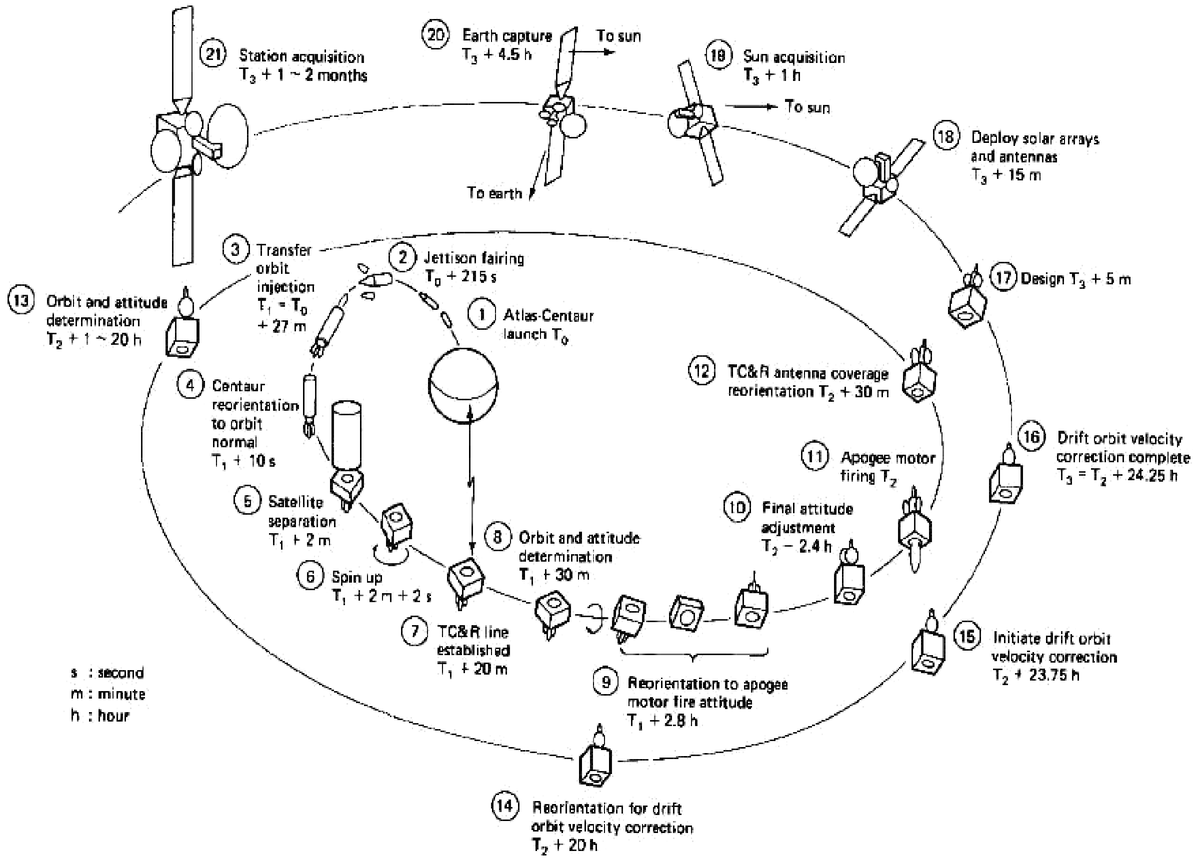


Figure : Launching stages of a GEO (example INTELSAT)

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 shape of 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.

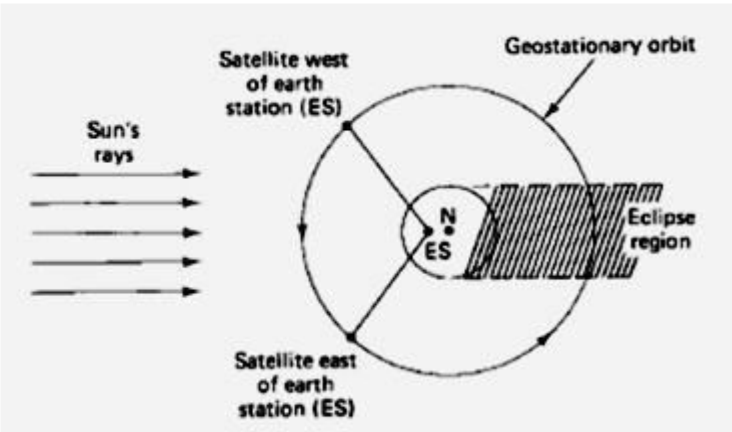


Figure : A satellite east of the earth station enters eclipse during daylight busy) hours at the earth station. A Satellite west of earth station enters eclipse during night and early morning hours (non busy time).

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.

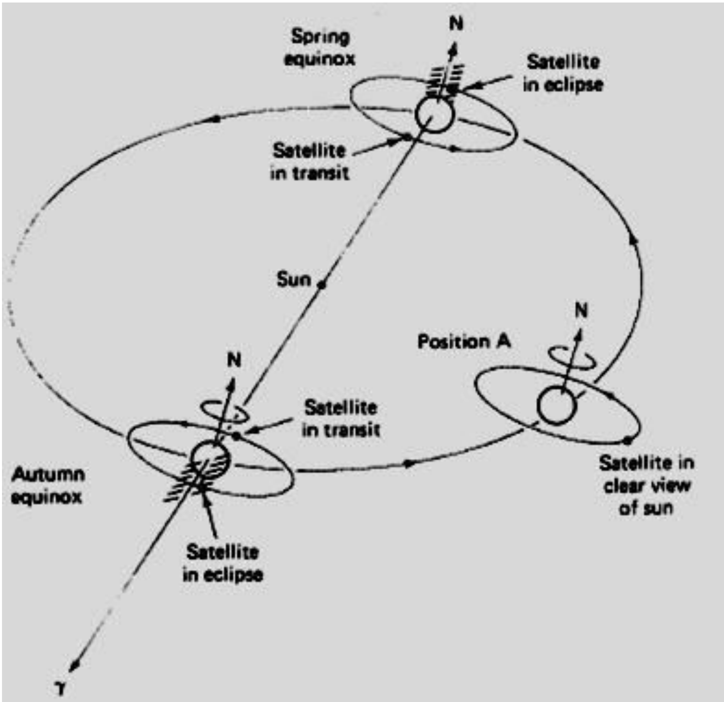


Figure: Earth Eclipse of a Satellite and Sun transit Outage

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Unit–II

Satellite Subsystems: Attitude and Orbit control system, Telemetry, Tracking, Commanding and Monitoring, Power Systems, Communication Subsystems, Satellite antennas, Equipment reliability and Space qualification.

Attitude & Orbit Control System(AOCS):

- This subsystem consists of rocket motors that are used to move the satellite back to the correct orbit when external forces cause it to drift off station.
- Gas jets are used to control the attitude of the satellite.
- The attitude and orbit of a satellite must be controlled so that the satellite's antennas point toward the earth and so that user knows where in the sky to look for the satellite.

Attitude control system

- There are two ways to make a satellite stable in orbit.
- The body of the satellite can be rotated at rate between 30 & 100 rpm that provides stability of the spin axis & keeps it pointing in the same direction, such satellites are known as spinners.
- Alternatively, the satellite can be stabilized by the one or more momentum wheels, called as three- axis stabilized satellite.

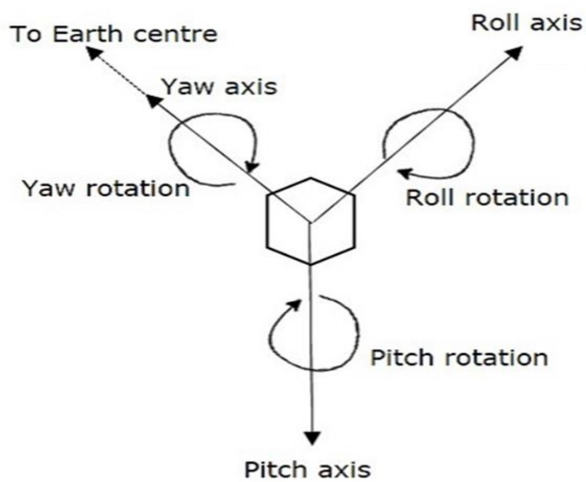
Spinning the satellite

- In this method, the body of the satellite rotates around its spin axis.
- In general, it can be rotated at 30 to 100 rpm in order to produce a force, which is of gyroscopic type.
- Due to this, the spin axis gets stabilized and the satellite will point in the same direction. Satellites are of this type are called as spinners.

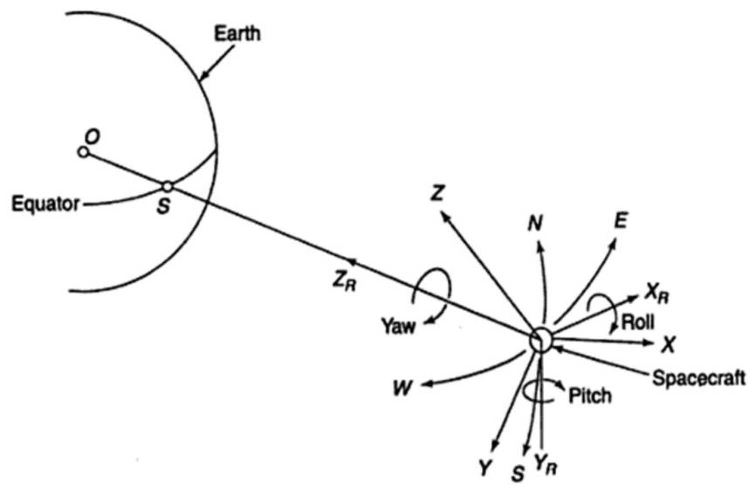
- Spinner contains a drum, which is of cylindrical shape. This drum is covered with solar cells. Power systems and rockets are present in this drum.
- Communication subsystem is placed on top of the drum. An electric motor drives this communication system. The direction of this motor will be opposite to the rotation of satellite body, so that the antennas point towards earth. The satellites, which perform this kind of operation are called as de-spin.
- During launching phase, the satellite spins when the small radial gas jets are operated. After this, the de-spin system operates in order to make the TTCM subsystem antennas point towards earth station.

Three Axis Method

- In this method, we can stabilize the satellite by using one or more momentum wheels. This method is called as three-axis method. The advantage of this method is that the orientation of the satellite in three axes will be controlled and no need of rotating satellite's main body.
- In this method, the following three axes are considered.
- Roll axis is considered in the direction in which the satellite moves in orbital plane.
- Yaw axis is considered in the direction towards earth.
- Pitch axis is considered in the direction, which is perpendicular to orbital plane.



Let XR, YR and ZR are the roll axis, yaw axis and pitch axis respectively. These three axis are defined by considering the satellite's position as reference. These three axes define the altitude of satellite.



(a)

- Let X, Y and Z are another set of Cartesian axes. This set of three axis provides the information about orientation of the satellite with respect to reference axes. If there is a change in altitude of the satellite, then the angles between the respective axes will be changed.
- In this method, each axis contains two gas jets. They will provide the rotation in both directions of the three axes.

- The first gas jet will be operated for some period of time, when there is a requirement of satellite's motion in a particular axis direction.
- The second gas jet will be operated for same period of time, when the satellite reaches to the desired position. So, the second gas jet will stop the motion of satellite in that axis direction.
- Error in attitude is determined by attitude error detection sensors(Infra red earth sensors) attached to the satellite.
- Any object which is above absolute zero degree Kelvin radiates energy & earth at 300 degree kelvin radiates infrared energy more compared to other wavelength bands.

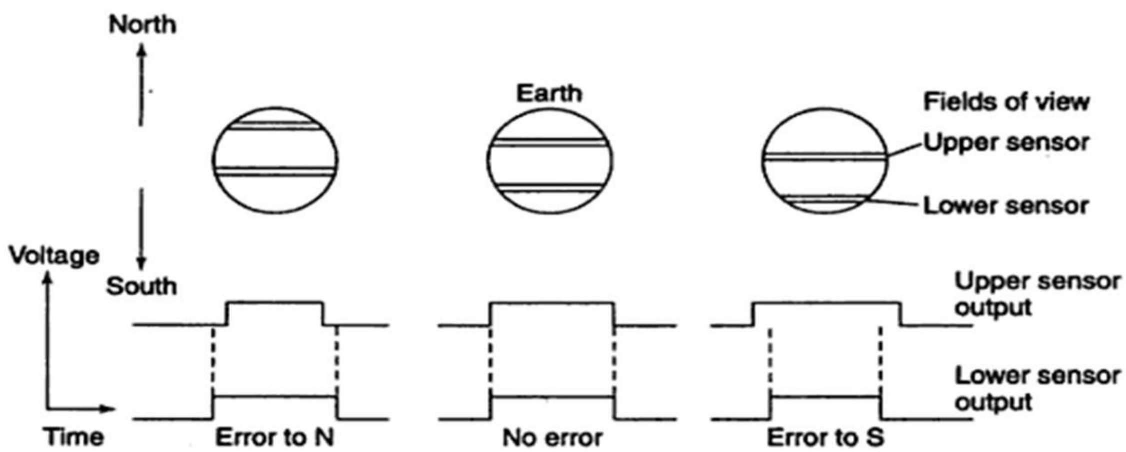
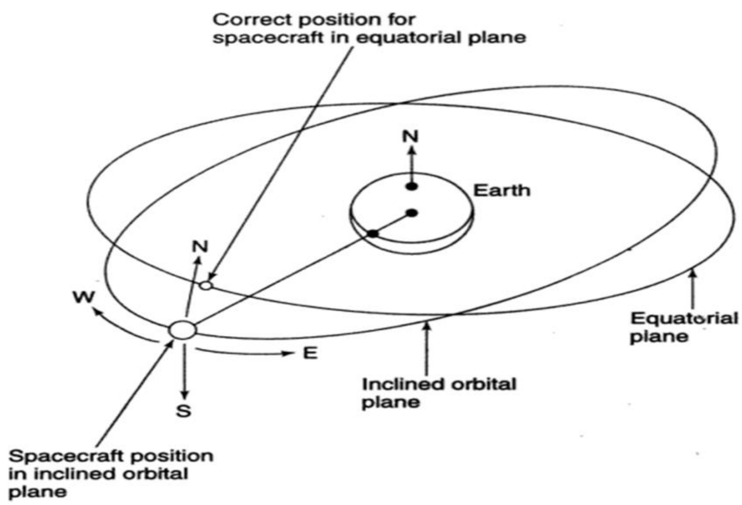


FIGURE 3.5 Principle of N–S control of a spinner satellite using infrared Earth sensors.

By processing the pulse width generated by sensors, it is possible to measure the attitude error about Roll & Pitch axes.

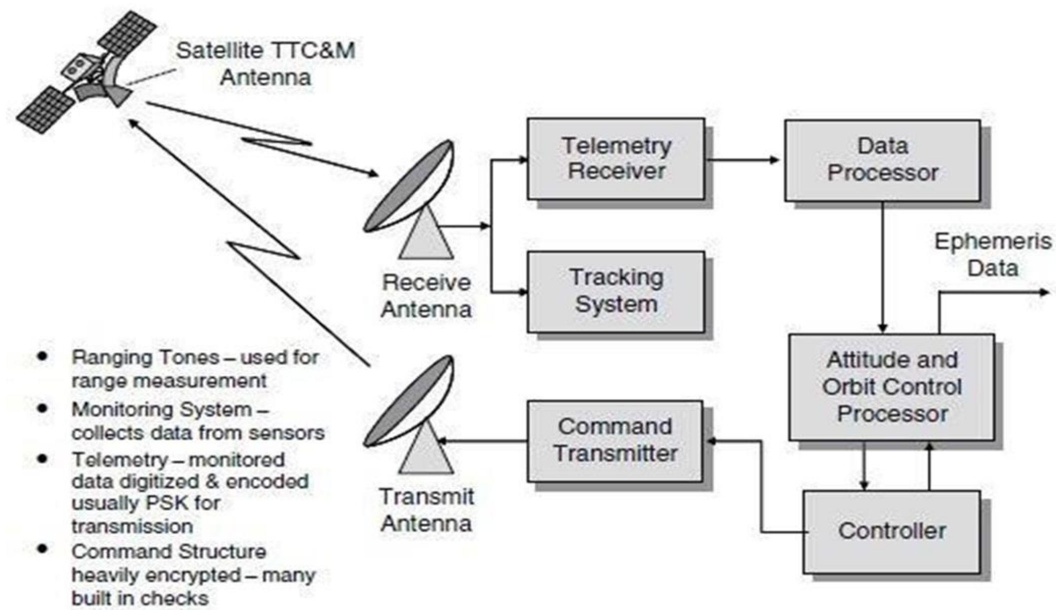
Orbit control:

- The gravitation forces of moon & the sun cause inclination of orbital plane.
- There are many other smaller forces that act on satellite causing the orbit to change.
- For the orbit to be truly geostationary, it must lie in equatorial plane, be circular and have correct altitude.



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

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



Telemetry & Monitoring System:

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

- Alarms can also be sounded if any vital parameter goes outside allowable limits.

Tracking:

- A no. of techniques can be used to determine current orbit of satellite.
- Velocity & acceleration sensors on satellite can be used to establish the change in orbit from last known position, by integration of data.
- The earth station controlling satellite can observe the Doppler shift of telemetry carrier to determine rate at which range is changing.
- Active determination of range can be achieved by transmitting a pulse, or sequence of pulses, to the satellite and observing the time delay before pulse is received again.

Command:

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

Power System

- All communication satellites obtain their electrical power from solar cells, which converts incident sunlight into electrical energy. Some deep space planetary research satellites have used thermonuclear generators.
- Communication satellites have not used nuclear generators. Sun is a powerful source of energy.
- At geostationary altitude, the radiation falling on a satellite has an intensity of 1.39kW/$m2$.
- Solar cells do not convert all incident energy into electrical power; their efficiency is typically 20 to 25% at beginning of life (BOL) but falls with the time because of aging of the cells.
- Since sufficient power must be available at the end of life (EOL) of satellite to supply all the systems on board, about 15% extra area of solar cells is usually provided as an allowance for aging.
- A spin stabilized satellite usually has a cylindrical body covered in solar cells. Because solar cells are on cylindrical surface, half of the cells are not illuminated at all, which results little electrical power being generated.
- The cells that are not illuminated by sunlight face cold space, which cause them to cool down.
- More recently, large communication satellites for direct broadcast operation generate up to 6kW from solar power.

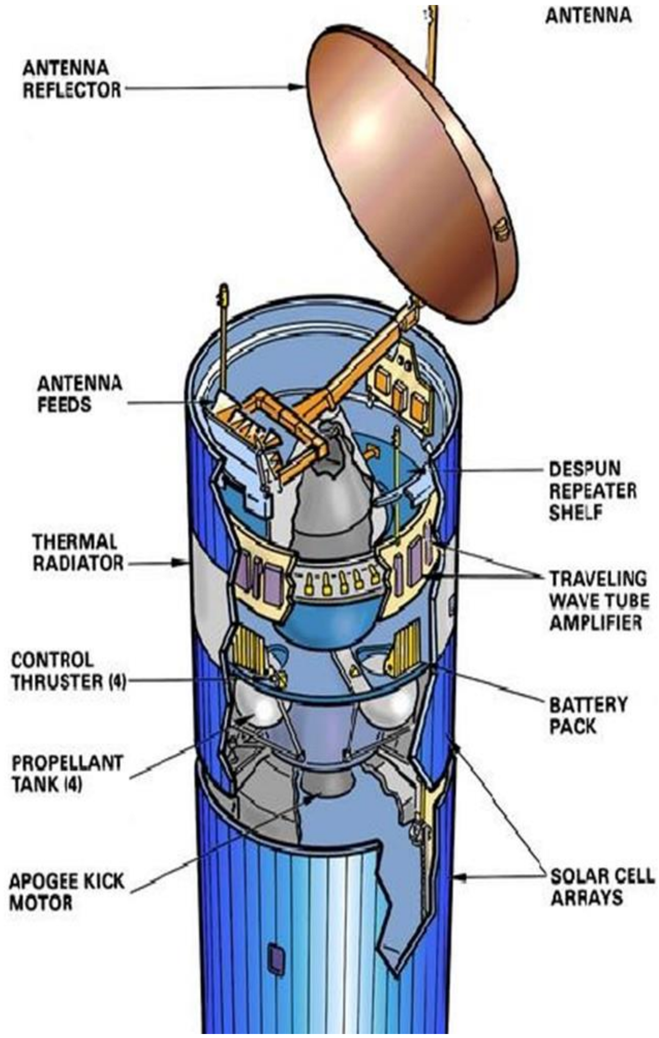


Fig : Satellite Structure

- A three- axis stabilized satellite can make better use of its solar cell area, since the cells can be arranged on flat panels that can be rotated to maintain normal incidence of the sunlight.
- A primary advantage is that by unfurling a folded solar array when the satellite reaches geostationary orbit, power in excess of 10kW can be generated with large array.
- To obtain 10kW from a spinner requires a very large body as compared to three-axis stabilized body.

Communication Subsystems:

Transponders-

- A transponder consists of BPF to select the particular channel's band of frequency, a down converter & an output amplifier.

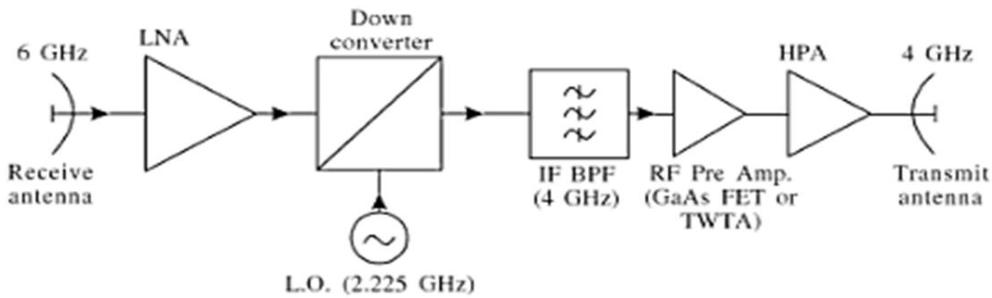


Fig. shows a typical single conversion bent pipe transponder used on many satellites for 6/4 GHz band.

- The local oscillator is at 2225 MHz to provide the appropriate shift in frequency from 6 GHz to 4 GHz.

- Band pass filter after the mixer removes unwanted frequencies.

- The output power amplifier is usually a solid state power amplifier (SSPA) unless a very high output power is required.
- Redundancy is provided for high-power amplifiers in each transponder by including a spare TWTA (travelling Wave tube amplifier) or solid-state amplifier (SSPA) that can be switched if primary power amplifiers fail.

- The lifetime of high power amplifier's is limited and they represent least reliable component in most transponders.

- Providing a spare HPA in each transponder increases the probability that the satellite will reach the end of its working life with all its transponders working.

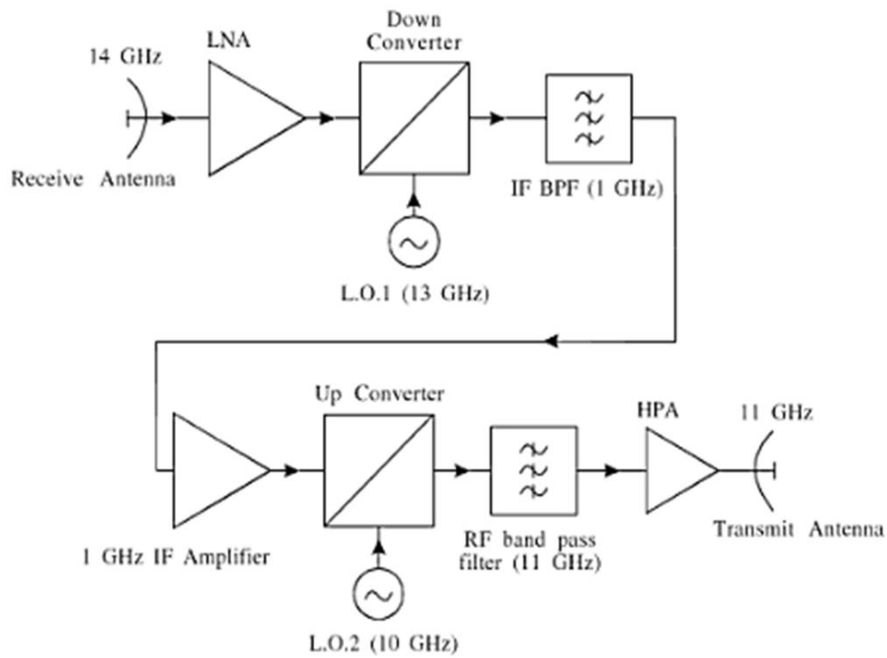


Fig : Transponder Structure

- Transponders for use in the 14/11-GHz bands normally employ a double frequency conversion scheme.

- Incoming 14-GHz carrier is translated to an IF around 1GHz.

- The amplification & filtering are performed at 1 GHz & a relatively high-level carrier is translated back to 11 GHz for amplification by HPA.

Satellite Antennas:

It is classified into four types:

- Wire Antennas: Monopole & Dipole
- Horn Antennas
- Reflector Antennas
- Array Antennas.

Wire Antennas:

- These are used primarily at VHF & UHF to provide communications for the TTC&M systems.
- They are positioned with great care on the body of the satellite in an attempt to provide omnidirectional coverage.
- An antenna pattern is a plot of the field strength in far field on antenna.
- It is usually measured in decibels (dB).

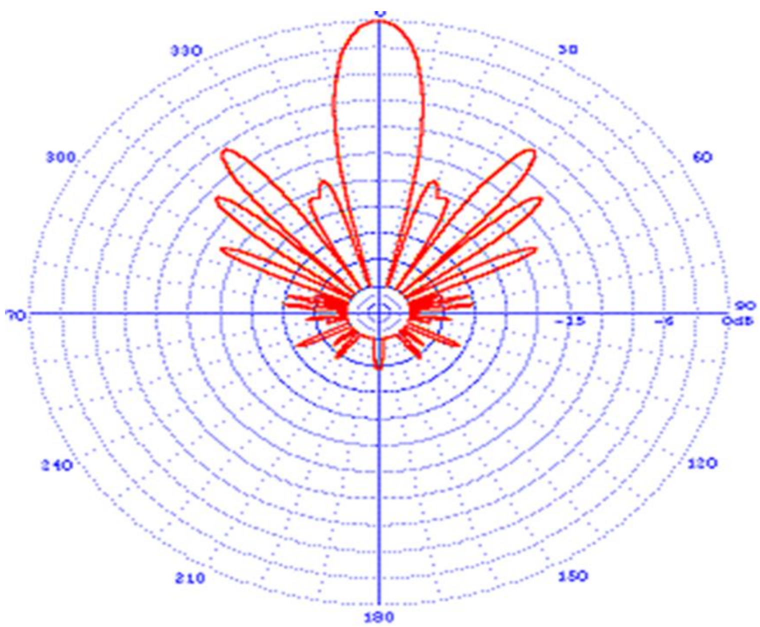


Fig : Antenna Pattern

Horn Antennas:

- These are used at microwave frequencies when relatively wide beams are required, as for global coverage.
- A horn is a flared section of waveguide that provides an aperture several wavelengths wide and a good match between the waveguide impedance and free space.
- Horns are also used as feeds for reflectors.

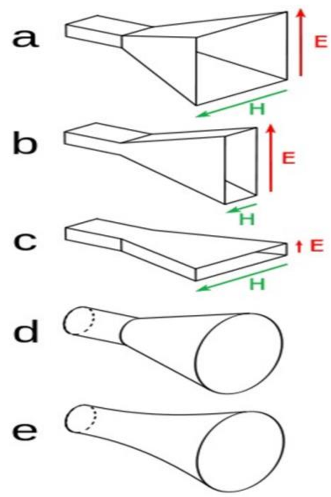


Fig : Types of horn

Reflector Antennas:

- The most often used antenna for satellite systems, particularly for those operating above 10 GHz, is the parabolic reflector antenna.
- These are usually illuminated by one or more horns and provide a lager aperture compared to horn antenna.
- Parabolic reflectors offer a much higher gain than that achievable by the horn antenna alone.

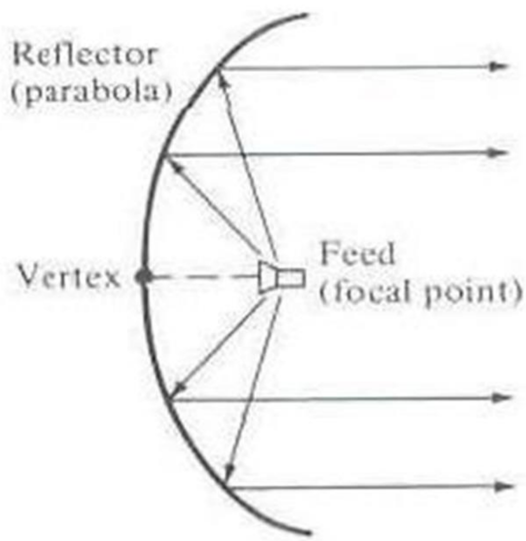


Fig : Reflector Parabola

Array Antennas:

- Array antennas are also used on satellites to create multiple beams from a single aperture.
- Multiple beams are formed by combining the radiation from several small elements made up of dipoles, horns etc.
- Iridium and Global star used these kind of antennas to generate up to 16 beams from a single aperture for their LEO mobile telephone systems.

Equipment Reliability & Space qualification:

- Once satellite is in geostationary orbit, there is little possibility of repairing components that fail or adding more fuel for station keeping.
- The component that makes up the satellite must therefore have very high reliability.
- Two approaches are used: Space qualification of every part of the satellite to ensure that it has a long life expectancy in orbit & redundancy of most critical components to provide continued operation when one component fails.

Space Qualification:

- Outer space,at geostationary orbit distances, is a harsh environment.
- The sun irradiates the satellite with 1.4 kW of heat and light on each square meter of exposed surface.
- When surfaces are in shadow, surface temperature will fall toward absolute zero.
- Electronic equipment can't operate at such extremes of temperature & heated or cooled so that it's temp. Stays within the range 0˚ to 75 ˚C. This requires a thermal control system.
- The first stage in ensuring high reliability in a satellite is by selection and screening of every component used.

- Past operational & test experience of components indicates which components can be expected to have good reliability.
- Each component is tested individually to ensure that it meets its specification. This process is known as quality control or quality assurance & is vital in building any equipment that is to be reliable.
- Once individual components and subsystems have been space qualified, the complete satellite must be tested as a system to ensure that its many systems are reliable.
- When a satellite is designed, three prototype models are often build and tested.

1. Mechanical model- It contains all the structural & mechanical parts that will be included in the satellite & is tested to ensure that all moving parts operate correctly in vacuum, over a wide temperature range. It also subjected to vibration & shock testing.

2. Thermal model- It contains all electronics packages and other components that must be maintained at the correct temperature.

3. Electrical model- contains all the electronic parts of the satellite and is tested for correct electrical performance under total vacuum and a wide range of temperatures.

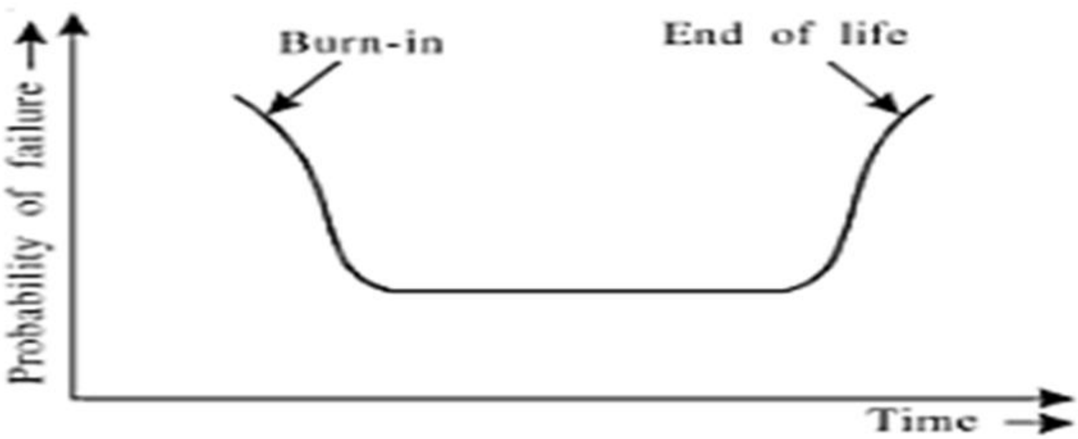
  - Testing carried out on models is designed to overstress the system and induce failure in any weak components.

  - Temperature cycling will be carried out to 10% beyond expected extremes; structural loads 50% above those expected may be applied.

  - Electrical equipment will be subjected to excess voltage and current drain to test for food electronic and thermal reliability.

Reliability:

- We need to be able to calculate reliability for two reasons: We want to know what the probability is that subsystem will still be working after a given time period & we need to provide redundant components or subsystems where probability of failure is too great to be accepted.
- Reliability is a mathematical technique which gives an idea about the probability of failure.



- The reliability of a component can be expressed in terms of probability of failure after time t.
- For most electronic equipment, probability of failure is higher at beginning of life- the burn – in period.
- As the component ages, failure becomes more likely.
- Mathematically reliability of device or sub-system is defined as,

$$R_t = \frac{N_s(t)}{N_o} = \frac{(number\ of\ surviving\ components\ at\ time\ t)}{(number\ of\ components\ at\ start\ of\ test\ procedure)}$$

- The other improvement parameter in reliability study is the meantime before failure (MTBF) and is given by

$$\text{MTBF} = m = \frac{\sum t_i}{N_o}$$

Where ti = time after which ith device fails.

- MTBF is related to average failure by

$$\lambda = \frac{1}{MTBF}$$

- The failure rate λ is often given as average failure rate per 109 hours. In terms of reliability of subsystem or device it is given by

$$R = e^{-\lambda t}$$

<u>Redundancy:</u>

- By using redundant components, reliability of subsystem can be increased.
- The redundant device can incorporate with the existing operating devices/ components either in series or in parallel or may be mixed.

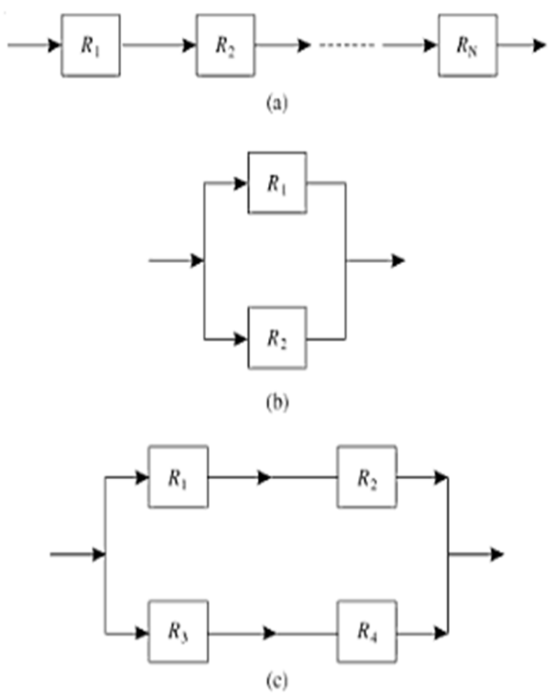


Fig : Redundant block Structure

Unit-III (Part 1)

Multiple Access: Frequency Division Multiple Access (FDMA), Intermodulation, calculation of C/N. Time Division Multiple Access (TDMA), Frame structure, Examples.

MULTIPLE ACCESS

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

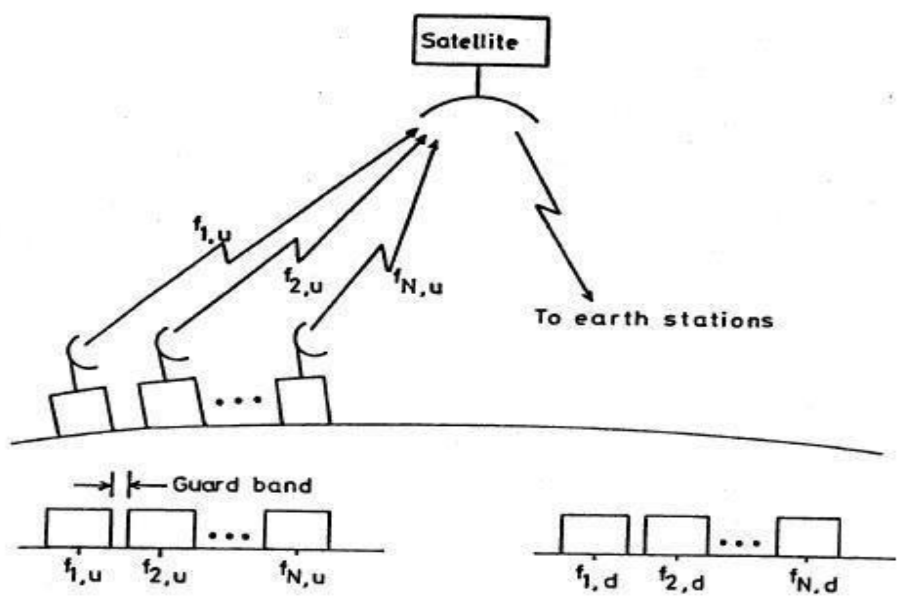
(1) Frequency Division Multiple Access (FDMA)

(2) Time Division Multiple Access (TDMA)

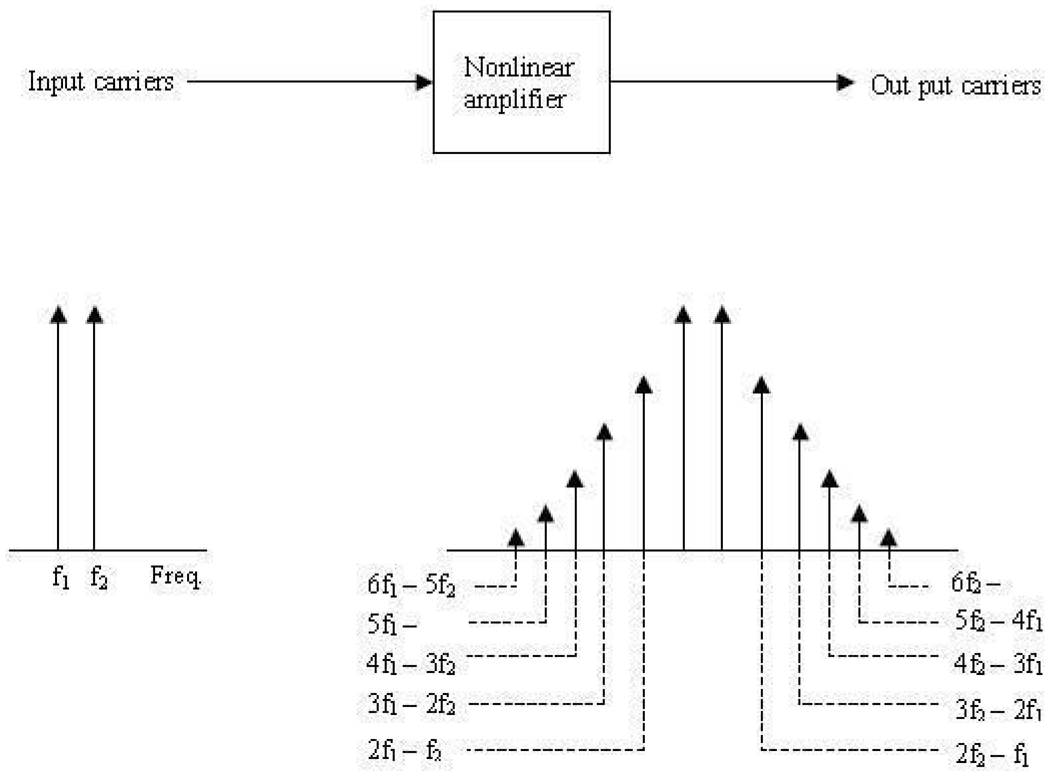
(3) Code Division Multiple Access (CDMA)

FREQUENCY DIVISION MULTIPLE ACCESS (FDMA)

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



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



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

Intermodulation Distortion:

Intermodulation Distortion :-

→ Intermodulation distortion is a serious form of distortion that occurs due to nonlinear transfer characteristics of an TWT (Travelling wave tube).

→ The non linear transfer characteristics may be expressed as Taylor series expansion that relates input and output voltages.

$$e_o = a e_i + b e_i^2 + c e_i^3 + \cdots$$

→ where a, b, c and so on are coefficients that depend on transfer characteristics, e_o is the output voltage, e_i is the input voltage.

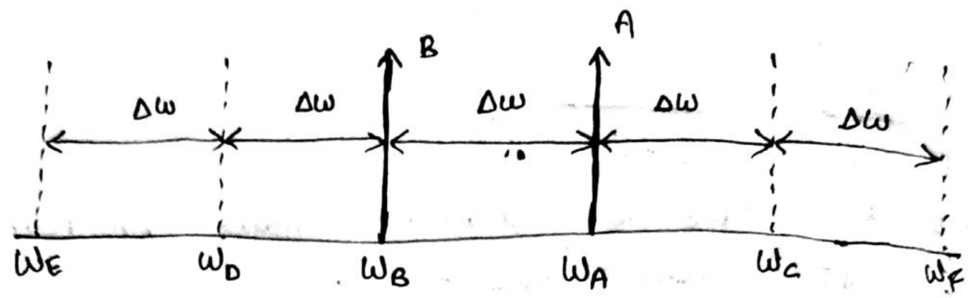
→ Here input voltage consist of sum of the individual carriers.

→ Here third order term gives rise to the intermodulation products.

→ For illustrating this, let the input be two unmodulated carriers.

$$e_i = A \cos \omega_A t + B \cos \omega_B t$$

→ Let the carrier spacing be $\Delta\omega$ as shown in right hand side of fig ①, the terms on the transfer characteristic equation can be interpreted as follows:-



→ First term, ae_i :- This gives the desired linear relationship between e_o & e_i.

→ Second term, be_i^2 :- With e_i as shown, this term can be expanded into following components,

1. a dc component
2. a component at frequency ΔW,
3. Second harmonic components of carriers : Second harmonic $+ \Delta W$ component.

⇒ All these components can be removed by filtering and need not be considered further.

⇒ Third term :- ce_i^3 :- It can be expanded as :-

$$C(A \cos W_A t + B \cos W_B t)^3$$

$$\Rightarrow C(A^3 \cos^3 W_A t + B^3 \cos^3 W_B t + 3A^2 B \cos^2 W_A t \cos W_B t + 3AB^2 \cos W_A t \cos^2 W_B t)$$

⇒ The cubed terms in this can be expanded as

$$\boxed{\cos^3 wt \Rightarrow \frac{1}{4}(3\cos wt + \cos 3wt)}$$

→ The above equation is a fundamental component plus a third harmonic component. The third harmonics can be removed by filtering.

→ The intermodulation products are contained in cross-product terms $3A^2B\cos^2\omega_A t \cos\omega_B t$ and $3AB^2\cos\omega_A t \cos^2\omega_B t$.

→ On further expansion, the first of these will be seen to contain a $\cos(2\omega_A - \omega_B)t$.

→ With the carriers spaced equally by amount $\Delta\omega$, the $2\omega_A - \omega_B$ frequency is equal to $\omega_A + (\omega_A - \omega_B)$ $= \omega_A + \Delta\omega$.

→ This falls exactly on the adjacent carrier frequency at ω_C.

→ Samelike, the expansion of second cross product terms contains a $\cos(2\omega_B - \omega_A)t$ that yields an intermodulation product at frequency $\omega_B - \Delta\omega$, it falls exactly on carrier frequency at ω_D.

Calculation of [C/N]:

Calculation of [C/N] :-

→ It is measure of the performance of a satellite link.

→ It is the ratio of carrier power to noise power at receiver input.

→ It is used for link budget calculations.

→ A ratio is denoted by [C/N] or [CNR] that is equivalent to (P_R/P_N).

→ It is measured in terms of decibels.

$$\left[\frac{C}{N}\right] = [P_R] - [P_N] \quad \text{—} (1)$$

where P_R = Received power at earth station

P_N = Noise power at earth station

substituting $[P_R]$ and $[P_N]$ in Equation (1)

$$\left[\frac{C}{N}\right] = [EIRP] + [G_R] - [LOSSES] - [k] - [T_s] - [B_N] \quad \text{—} (2)$$

where EIRP = Effective isotropic radiated power

G_R = Earth station antenna gain

K = Boltzman constant

T_S = System noise temperature

B_N = Noise Bandwidth.

→ The $[G/T]$ ratio is a key parameter in specifying the receiving system performance. The antenna gain G_R and system noise temperature $[T_S]$ can be combine in above equation

$$[G/T] = [G_R] - [T_S] \ dBK^{-1} \quad — ③$$

∴ the link equation Eq ② becomes

$$\left[\frac{C}{N}\right] = [EIRP] + \left[\frac{G}{T}\right] - [LOSSES] - [K] - [B_N] \quad — ④$$

→ The ratio of carrier power to noise power density (P_R/N_0) may be the quantity actually required

since $P_N = k T_N B_N \Rightarrow N_0 B_N$, then

$$\left[\frac{C}{N}\right] = \left[\frac{C}{N_0 B_N}\right]$$

$$\Rightarrow \left[\frac{C}{N_0}\right] - [B_N]$$

therefore

$$\left[\frac{C}{N_0}\right] = \left[\frac{C}{N}\right] + [B_N] \quad — ⑤$$

⇒ $\left[\frac{C}{N}\right]$ is a true power ratio in units of decibels, $[B_N]$ is in decibels relative to 1 Hz or dB Hz.

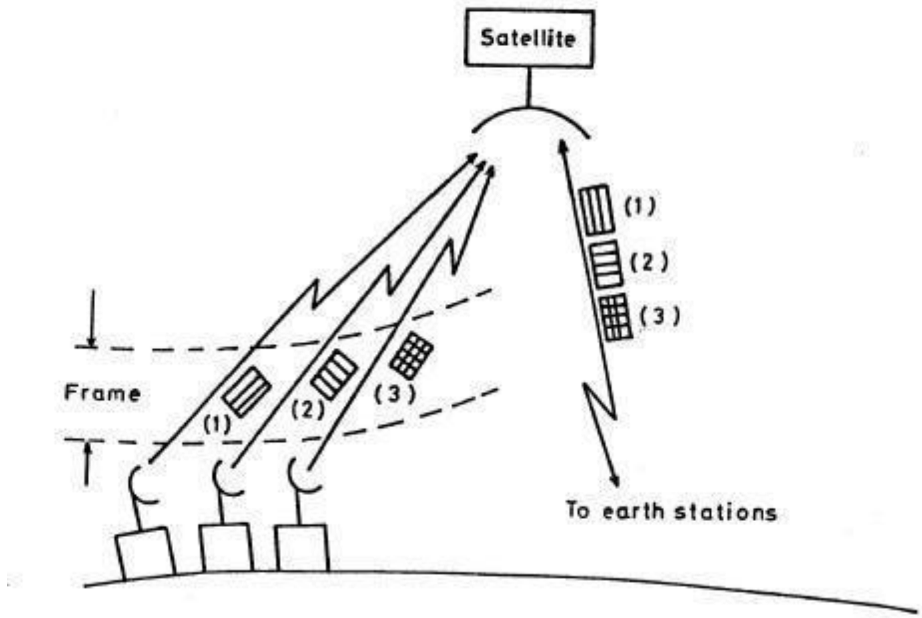
Thus, the units for $[C/N_0]$ are dB Hz.

Substituting Eq [5] for $[C/N]$ gives

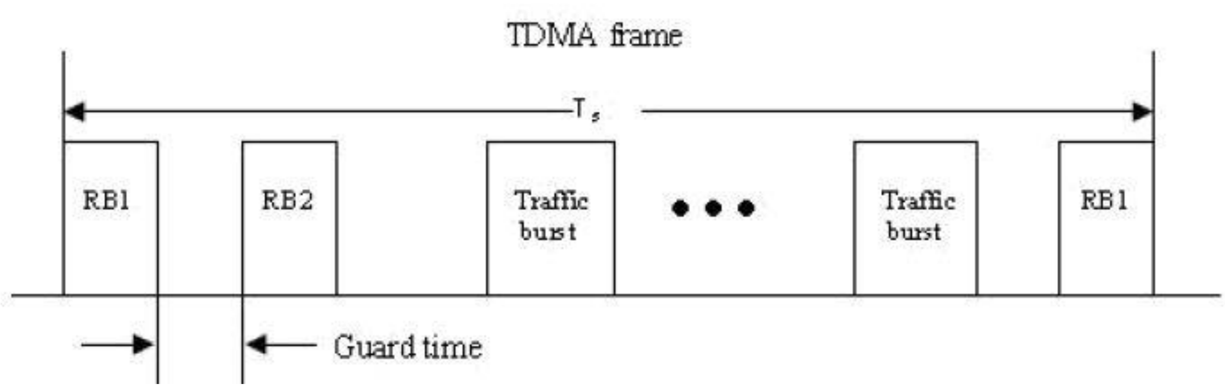
$$\left[\frac{C}{N_0}\right] = [EIRP] + \left[\frac{G}{T}\right] - [LOSSES] - [K] \quad — ⑥$$

TIME DIVISION MULTIPLE ACCESS (TDMA)

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



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

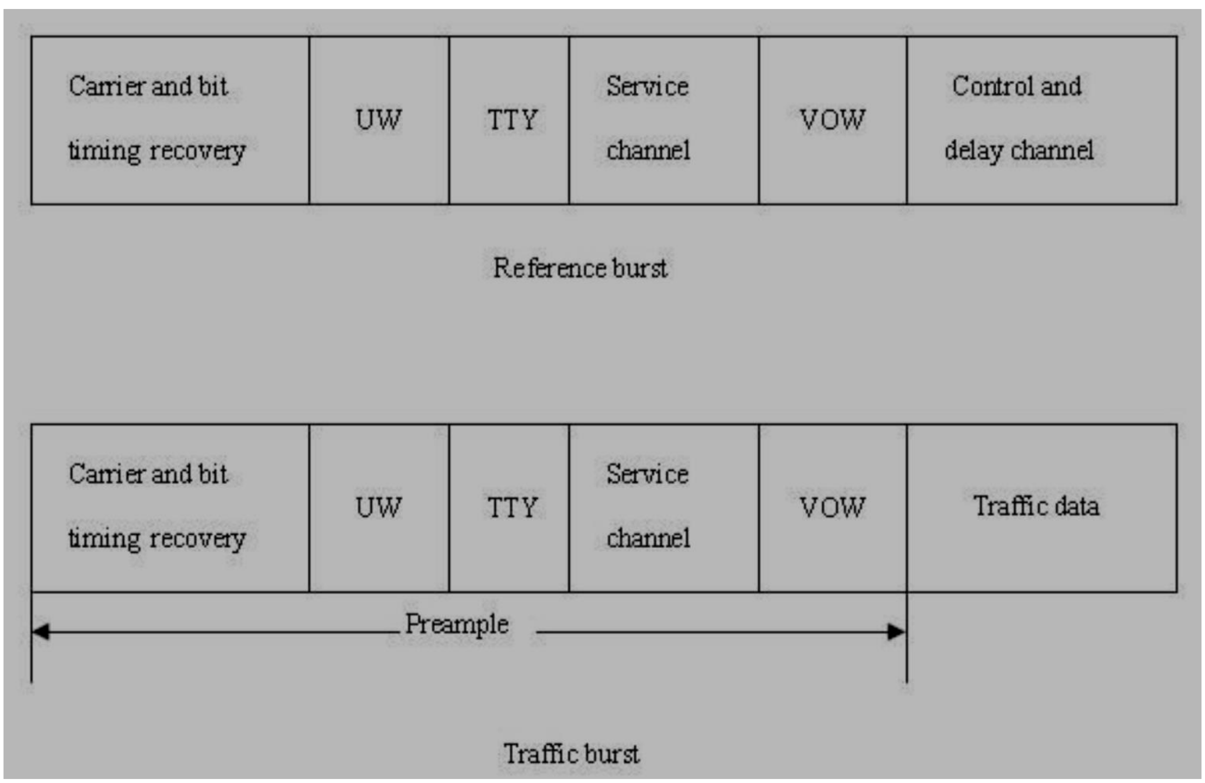


It consists of two reference bursts RB1and RB2, traffic bursts and the guard time between bursts. As can be seen, each TDMA frame has two reference bursts RB1 and RB2. The primary reference burst (PRB), which can be either RB1 or RB2, is transmitted by one of the earth stations in the network designated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

The traffic bursts carry information from the traffic earth station. Each earth station accessing a transponder may transmit one or two traffic bursts per TDMA frame and may position them anywhere in the frame according to a burst time plan that coordinates traffic between earth stations in the network.

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

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



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

Carrier and bit timing recovery (CBTR)

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

Unique word (UW)

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

Teletype (TTY) and voice order wire (VOW)

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

Service channel (SC)

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

Control and delay channel (CDC)

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

Traffic data:

This portion contains the information from a source traffic station to a destination traffic station. The informants can be voice, data, video or facsimile signals. The traffic data pattern is divided into blocks of data (referred to as subburst).

The size of each data block is given by:

Subburst size (symbols) = symbol rate (symbols/sec) X frame length (sec).

The INTELSAT TDMA with a frame length of T f = 2 msec for PCM voice data has a subburst size of 64 symbols long.