INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)

Dundigal, Hyderabad -500 043

ELECTRONICS & COMMUNICATION ENGINEERING

COURSE LECTURE NOTES

Course Name	**SATELLITE COMMUNICATIONS**
Course Code	AEC522
Programme	B.Tech
Semester	VI
Course Coordinator	Dr. V Sivanagaraju, Professor
Course Faculty	Dr. V Sivanagaraju, Professor
Lecture Numbers	1-45
Topic Covered	All

COURSE OBJECTIVES (COs):

The course should enable the students to:	
I	Be Proficient in the concept of Satellite communication and understand placement of communication satellite in GEO.
II	Analyze the Satellite link budget and explain the satellite subsystems like telemetry, tracking and command system.
III	Discuss the different types of multiple access techniques in communication satellites.
IV	Understand the concept of VSAT systems and packet switching in satellites.

COURSE LEARNING OUTCOMES (CLOs):

Students, who complete the course, will have demonstrated the ability to do the following:

AEC522.01	Discuss the different satellite systems like Low earth orbit (LEO), Medium earth orbit (MEO) and Geo synchronous earth orbit (GEO).
AEC522.02	Understand how the satellite is locating with respect to earth and orbital perturbations due to earth's oblateness, moon and sun.
AEC522.03	Understand the satellite sub systems like Telemetry, tracking and command system, power system, satellite antenna equipment, communications subsystem and transponders

AEC522.04	Analyze the design of satellite links for a specified C/N with and without frequency Re-use and link budget.
AEC522.05	Discuss the propagation effects like atmospheric absorption, cloud attenuation, troposphere and ionospeheric scintillation and low angle fading.
AEC522.06	Discuss the effects of rain, rain induced attenuation, rain induced cross polarization and interference.
AEC522.07	Analyze the various multiple access techniques used in communication satellites like FDMA, TDMA and CDMA.
AEC522.08	Analyze the concept of demand assignment multiple access (DAMA), types of demand assignment and characteristics.
AEC522.09	Understand the significance of Spread Spectrum Multiple Access (SSMA), Direct sequence CDMA (DS-CDMA) or DS spread spectrum transmission and reception.
AEC522.10	Understand and analyze the Earth Station technology transmitters, receivers, antennas, tracking systems, terrestrial interface, power test methods and lower orbit considerations.
AEC522.11	Analyze the Very Small Aperture Terminal (VSAT) network architecture, access control and multiple access selection.
AEC522.12	Analyze the constellation design of Non Geostationary Orbit (NGSO) coverage, frequency bands, delay and throughput.
AEC522.13	Understand the message transmission by FDMA using M/G/1 queue and message transmission by TDMA using pure aloha.
AEC522.14	Apply the error control coding for digital satellite links like block codes and convolution codes.
AEC522.15	Evaluate the future satellite communication systems and introduction to satellite laser communication.
AEC522.16	Apply the concept of satellite communication to understand and analyze real time applications.
AEC522.17	Acquire the knowledge and develop capability to succeed national and international level competitive examinations.

SYLLABUS

Module-I	**COMMUNICATIONS SPACECRAFT AND ORBITS**	**Classes: 09**
Overview of present and future trends of satellite communications introduction to satellite systems: Low earth orbit (LEO); Medium earth orbit (MEO); Geo synchronous earth orbit (GEO); Geostationary earth orbit (GEO); Orbital mechanics: Orbital elements; Locating the satellite with respect to the earth; Coverage angle; Slant range; Inclined orbits; Orbital perturbations due to earth's oblateness and moon and sun; Eclipse of GEO satellite; Sun transit outage		
Module-II	**SPACE SEGMENT**	**Classes: 09**
Placement of a communication satellite in GEO satellite sub systems: Telemetry, tracking and command system, power system, satellite antenna equipment, communications subsystem and transponders, TWT amplifier operation, satellite frequency bands and allocations; Satellite link: Basic transmission theory, system noise temperature and G/T ratio, basic link analysis, design of satellite links for a specified C/N with and without frequency Re-use , link budget; Propagation effects: Introduction, atmospheric absorption, cloud attenuation, troposphere and ionospeheric scintillation		

and low angle fading; Effects of rain: Rain induced attenuation, rain induced cross polarization interference.		
Module-III	**COMMUNICATION SATTELLITE ACCESS SYSTEMS**	**Classes: 09**
Multiple Access: Frequency division multiple access (FDMA), Time division multiple access (TDMA), frame structure, burst structure, satellite switched TDMA, on-board processing, demand assignment multiple access (DAMA), types of demand assignment, characteristics. Code Division Multiple Access (CDMA) / Spread Spectrum Multiple Access (SSMA); Direct sequence CDMA (DS-CDMA) or DS spread spectrum transmission and reception, adjacent channel interference, inter modulation, handover, satellite diversity.		
Module-IV	**EARTH STATION AND VSAT SYSTEMS TECHNOLOGY**	**Classes: 09**
Earth Station: Transmitters, receivers, antennas, tracking systems, terrestrial interface, power test methods, lower orbit considerations; VSAT (Very Small Aperture Terminal) Systems: Overview of VSAT systems, VSAT network architecture, access control, and multiple access selection. NGSO constellation design: Orbits, coverage, frequency bands, delay and throughput, non geostationary orbit (NGSO) constellation design and problems.		
Module-V	**SATELLITE PACKET COMMUNICATION**	**Classes: 09**
Message transmission by FDMA: M/G/1 queue, message transmission by TDMA, pure aloha, satellite packet switching, slotted aloha, packet reservation, tree algorithm; Error control for digital satellite links: Error control coding, block codes, convolution codes, implementation of error detection on satellite links. Overview of future satellite communication systems, introduction to satellite laser communication, data relay communication satellites, satellite mobile services, applications.		
Text Books:		
1. Dennis roddy, ―Satellite Communications, 4th Edition, 2004. 2. Pratt. Bostian, Allnutt, ―Satellite Communications, Wiley India, 2nd Edition, 2006. 3. Gérard Maral, ―Satellite Communication Systems, 1993. 4. Tri T. Ha, Digital Satellite Communications 2nd edition, TMH, 1990.		
Reference Books:		
1. Rappaport T.S., ―Wireless communications, 2nd Edition, Pearson Education, 2010. 2. Bruce Elbert, ―Introduction to Satellite Communications, 1987. 3. M Richharia, Satellite Communication Systems 2nd edition, MacMillan, 2005.		

MODULE-I

COMMUNICATIONS SPACECRAFT AND ORBITS

Overview of present and future trends of satellite communications: Satellite communication systems exist because the earth is a sphere. Radio waves travel in straight lines at the microwave frequencies used for wide band communications, so a repeater is needed to convey signals over long distances satellites, because they can link places on the earth that are thousands of miles apart, are a good place to locate a repeater and a GEO satellite is the best place of all. A repeater is simply a receiver linked to a transmitter, always using different radio frequencies that can receive a signal from one earth station amplify it and retransmit it to another earth station. These include: wide area coverage with distance-insensitive cost, communication to remote areas, rapid extension to new locations; highly flexible networking, large capacity; reliable long range service to moving platforms like ships, aircraft, vehicles; and transmission of command and control information in a combat area. Development efforts to realize future satellite systems are directed on technologies in EHF band, more sophisticated on-board signal processing, and the adaptive antennas to make the satellites more adaptable to changing tactical scenarios, to provide flexible coverage, improve resistance to jamming, ability to reconfigure the networking for survivability, more efficient demand assignment techniques and protection against nuclear effects/physical attack. Inter-satellite links (or cross-links) may be used to extend the coverage area of a geostationary system, eliminating the need for intermediate anchor stations or as links between low orbiting and geostationary or super synchronous satellites. Communication could be either by EHF at 60 GHz or optically. Calculations suggest that excessive powers are not required, and the main problems lie in the antenna/aperture acquisition and tracking. The military satellite communication networks of future will be more flexible, more cost-effective and most importantly capable of functioning under any scenario from peace through protracted nuclear war. This goal will be achieved by ensuring inter-operability of links handling communications, mission data, or satellite tracking, telemetry and command for different types of future defense satellite communication systems.

Satellites were once relatively small, while the Earth stations that employed them were correspondingly large. We are now moving into new technologies to further enhance the potential to deliver services that are more useful and economic. Applications like GEO mobile services and two-way multimedia and digital audio broadcasting are pushing the platforms to go beyond what satellites flying in 1998 could deliver. Power levels up to 20 kW and beam pointing down to less than ±0.025 become the norm. In contrast, the requirements of non-GEO systems have pushed spacecraft manufacturers to devise more cost-effective platforms. That is because of the vastly greater number of satellites required coupled with the need for quicker replacement. Launch vehicle agencies have extended their systems to lift the largest class of GEO satellite into transfer orbit. Multiple launch systems were introduced so that non-GEO constellations can be created economically. Competition is the other factor working to the benefit of satellite users, as new rocket systems and launch services companies enter the world market.

The first synchronous orbit communication satellite was SYNCOM II launched in July 1963 and the first commercial communications satellites INTEL SAT-1 was launched in April 1965 - it opened the new era of global communications. The evolution of INTELSAT system from that time until the present has been a succession of increasing satellite capacities and enlarging earth station network. INTELSAT-1 could handle only 240 voice circuits at a time and modem communication satellites have in excess of 30,000 voice circuits. However, one should compare the capability of INTEL SAT -I with TAT- I the first transatlantic telephone cable installed in 1956 having capacity to handle only 48 simultaneous voice calls. INTELSAT-1 required earth stations antenna diameters of 32 meters. The hand-held terminals which will be used for mobile communication world-wide by IRIDIUM/GLOBALSTARI ICO etc in the near future is a sea change from those days.

In the 1970's and early 1980's communication satellites were used mainly to relay terrestrial communications via large trunking terminals. Thousands of voice circuits were multiplexed together and relayed from one office switch to another. Single television channels used entire transponders. There were few individual users with enough traffic to occupy an entire transponder and rich enough to afford 10-m ground terminals.

THE INDIAN SATELLITE COMMUNICATIONS SYSTEM The first major step in the development of satellite communications in India was the construction of an experimental earth station ESCES at Ahmedabad in 1967. This was followed by satellite Instructional Television Experiment (SITE) using A TS-6 satellite. SITE involved transmission of TV signals at 860

MHz to 2400 community direct reception sets in six clusters of rural India for I year from August 1975 to July 1976 APPLE an experimental communication satellite built in India was launched in 1981. Experiments in teleconferencing, distance education, news gathering, networking of banks etc were conducted by APPLE, which was first geostationary communication satellite designed and built by India. Having established the need of having a domestic satellite communication system by these earlier experiments it was decided to have an operational system for India. INSAT-1 was the culmination of various studies carried out in India to fulfill the need for services in telecommunications, broadcasting and meteorology. Four satellites INSAT-1A through INSAT-ID were procured from M/s Ford Aerospace of USA in the period 1982-1990 period. The multipurpose INSAT-1 Satellite had 12 C-band transponders along with 2, S-band transponders, a 400 MHz Data Relay transponder and Very High Resolution Radiometer (VHRR) operating in visible and infra-red bands.

INSAT-2 satellites have taken over the continuation of services provided by INSAT-1 satellite. The 4 indigenously built satellites by ISRO were launched in the period 1992 to 1997 in the series INSAT-2A through INSAT-2D. The fifth and last in the series, INSAT-2E is scheduled to be launched in late 1998. The INSA T system has three major service components, namely telecommunications, television and meteorology.

The overview of Indian satellites:

1. Aryabhata 19.04.1975
First Indian satellite. Provided technological experience in building and operating a satellite system. Launched by Russian launch vehicle Intercosmos.

2. Bhaskara-I 07.06.1979
First experimental remote sensing satellite. Carried TV and microwave cameras. Launched by Russian launch vehicle Intercosmos.

3. Bhaskara-II 20.11.1981
Second experimental remote sensing satellite similar to Bhaskara-1. Provided experience in building and operating a remote sensing satellite system on an end-to-end basis. Launched by Russian launch vehicle Intercosmos.

4.Ariane Passenger Payload Experiment (APPLE) 19.06.1981

First experimental communication satellite. Provided experience in building and operating a three-axis stabilised communication satellite. Launched by the European Ariane.

5. Rohini Technology Payload (RTP) 10.08.1979

Intended for measuring in-flight performance of first experimental flight of SLV-3, the first Indian launch vehicle. Could not be placed in orbit.

6. Rohini (RS-1) 18.07.1980 Used for measuring in-flight performance of second experimental launch of SLV-3.

7. Rohini (RS-D1) 31.05.1981

Used for conducting some remote sensing technology studies using a landmark sensor payload. Launched by the first developmental launch of SLV-3

8. Rohini (RS-D2) 17.04.1983 Identical to RS-D1. Launched by the second developmental launch of SLV-3.

9. Stretched Rohini Satellite Series (SROSS-C) 20.05.1992

Launched by third developmental flight of ASLV. Carried Gamma Ray astronomy and aeronomy payload.

10. Stretched Rohini Satellite Series (SROSS-C2) 04.05.1994

Launched by fourth developmental flight of ASLV. Identical to SROSS-C. Still in service.

Indian National Satellite System (INSAT)

11. INSAT-1A 10.04.1982

First operational multi-purpose communication and meteorology satellite procured from USA. Worked only for six months. Launched by US Delta launch vehicle.

12. INSAT-1B 30.08.1983 Identical to INSAT-1A. Served for more than design life of seven years. Launched by US Space Shuttle.

13. INSAT-1C 21.07.1988 Same as INSAT-1A. Served for only one and a half years. Launched by European Ariane launch vehicle.

14. INSAT-1D 12.06.1990 Identical to INSAT-1A. Launched by US Delta launch vehicle. Still in service.

15. INSAT-2A 10.07.1992 First satellite in the second-generation Indian-built INSAT-2 series. Has enhanced capability than INSAT-1 series. Launched by European Ariane launch vehicle. Still in service.

16. INSAT-2B 23.07.1993
Second satellite in INSAT-2 series. Identical to INSAT- 2A. Launched by European Ariane launch vehicle. Still in service.

17. INSAT-2C 07.12.1995
Has additional capabilities such as mobile satellite service, business communication and television outreach beyond Indian boundaries. Launched by European launch vehicle. In service.

18. INSAT-2D 04.06.1997
Same as INSAT-2C. Launched by European launch vehicle Ariane. Inoperable since Oct 4, 97 due to power bus anomaly.

19. INSAT-2DT January Procured in orbit from ARABSAT 1998

20. INSAT-2E 03.04.1999 Multipurpose communication & meteorological satellite launched by Ariane.

21. INSAT-3B 22.03.2000

Multipurpose communication – business communication, developmental communication and mobile communication purpose.

22. GSAT-1 18.04.2001

Experimental Satellite for the first developmental flight of Geo-synchronous Satellite Launch Vehicle, GSLVD1.

23. INSAT-3C 24.01.2002

To augment the existing INSAT capacity for communication and broadcasting, besides providing continuity of the services of INSAT-2C.

24. KALPANA-1 12.09.2002 METSAT was the first exclusive meteorological satellite built by ISRO named after Kalpana Chawla.

25. INSAT-3A 10.04.2003

Multipurpose Satellite for communication and broadcasting, besides providing meteorological services along with INSAT-2E and KALPANA-1.

26. GSAT-2 08.05.2003

Experimental Satellite for the second developmental test flight of India's Geosynchronous Satellite Launch Vehicle, GSLV

27. INSAT-3E 28.09.2003 Exclusive communication satellite to augment the existing INSAT System.

28. EDUSAT 20.09.2004 India’s first exclusive educational satellite.

29. HAMSAT 05.05.2005

Microsatellite for providing satellite based Amateur Radio Services to the national as well as the international community (HAMs).

30. INSAT-4A 22.12.2005 The most advanced satellite for Direct-to-Home television broadcasting services.

31. INSAT-4C 10.07.2006 State-of-the-art communication satellite - could not be placed in orbit.

32. INSAT-4B 12.03.2007
An identical satellite to INSAT-4A further augment the INSAT capacity for Direct-To-Home (DTH) television services and other communications.

33. INSAT-4CR 02.09.2007
Designed to provide Direct-To-home (DTH) television services, Video Picture Transmission (VPT) and Digital Satellite News Gathering (DSNG), identical to
INSAT- 4C .

Indian Remote Sensing Satellite (IRS)

34. IRS-1A 17.03.1988 First operational remote sensing satellite. Launched by a Russian Vostok.

35. IRS-1B 29.08.1991 Same as IRS-1A. Launched by a Russian Launch vehicle, Vostok. Still in service.

36. IRS-1E 20.09.1993 Carried remote sensing payloads. Could not be placed in orbit.

37. IRS-P2 15.10.1994 Carried remote sensing payload. Launched by second developmental flight of PSLV.

38. IRS-1C 28.12.1995 Carries advanced remote sensing cameras. Launched by Russian Molniya launch vehicle. Still in service.

39. IRS-P3 21.03.1996

Carries remote sensing payload and an X-ray astronomy payload. Launched by third developmental flight of PSLV. Still in service.

40. IRS-1D 29.09.1997 Same as IRS-1C. Launched by India's PSLV service. In
service.

41. IRS-P4 Oceansat 26.05.1999

Carries an Ocean Colour Monitor (OCM) and a Multifrequency Scanning Microwave Radiometer (MSMR), Launched by India’s PSLV-C2,

42. Technology Experiment

Satellite (TES) 22.10.2001 Technology Experiment Satellite Launched by PSLVC3

.

43. IRS-P6 Resourcesat-1 17.10.2003 Launched by PSLV - C5, carries three camera, names,LISS-4, LISS-3 and AwiFS

44. CARTOSAT -1 05.05.2005

Launched by PSLV-C6, carries two panchromatic cameras - PAN (fore) and PAN (aft) - with 2.5 meter resolution. The cam mounted with a tilt of +26 deg and -5 deg along the track to provide stereo images.

45. CARTOSAT - 2 10.01.2007

Launched by PSLV-C7, it is an advanced remote sensing satellite carrying a panchromatic camera capable of providing scene specific spot imageries.

46. SRE - 1 10.01.2007

Launched by PSLV-C7, Space capsule Recovery Experiment (SRE-1), intended to demonstrate the technology of an orbiting platform for performing experiments in microgravity conditions. SRE-1 was recovered successfully after 12 days over Bay of Bengal.

47. CARTOSAT-2A 28.04.2008 Identical to CARTOSAT - 2, launched by PSLV-C9

48. IMS-1 28.04.2008 Launched by PSLV-C9 along with CARTOSAT-2A and
other Eight Nanosatellites

Enhanced Processing On-Board: There will be FH uplink~ from small terminals and having multiple access in FDMA mode. This will be possible as wide bandwidth at EHF will be available. Therefore, protection against jamming for large number of tactical terminals is anticipated. Other features of on-board processing such as the demodulation to baseband and data routing on-board is also envisaged. Antenna technology will be critical to future developments. In addition to downlink antenna developments including the electronically steered multi beam antennas, sophisticated antenna arrays will be required for uplink reception. These may provide jammer rejection together with high gain and perhaps frequency re-use on-board. Adaptive algorithms will discriminate against jamming or interference and wanted signals may need to be distinguished by secure spread-spectrum format. Developments may be anticipated in phased array antennas for spacecraft.

EHF Technology: The bulk of satcom systems presently operate at SHF (7/8 GHz). Major exploitation of EHF band is envisaged in future satcom systems. Satcom frequency band is allocated as uplinks 43.5 to 45.5 GHz and downlinks 20.2 to 21.2 GHz. The 2 GHz uplink bandwidth will give increasing processing gain which may be further enhanced because of on-board de-spreading. For ECCM purpose, EHF will have further advantage as EIRP of small terminals increases with frequency while for the large terminals (jammer) tends to reach practical limits. The wider bandwidth at EHF will also allow higher traffic capacity and relative freedom from constraints on orbital spacing of satellites. Even small tactical antennas will be capable of narrow bearnwidths. The smaller size and weight of hardware will encourage the use of more sophisticated on-board adaptive antennas. The cost of development of the advance technology in EHF is expected to fall as and when few countries start operating EHF satellite communication within next few years.

Optical Communication by Satellite: While optical satcom is particularly appropriate for inter-satellite links (where performance would seem to be comparable to EHF system), there is also scope for space-to-ground communications subject to the obvious problems of cloud and rain. Such a system might operate around 1.3 micron wavelength most likely with Nd: y AG sources and use pulse position modulation. Current technology is largely based on the direct detection methods. Coherent detection systems, where the optical signal is heterodyned down to RF, offer considerable potential. Use of the blue-green lasers may permit communication with submarines below the sea surface. This might involve a one-way broadcast from a low orbiting satellite using modulated scanning spot beam, an optical wavelength appropriate to transmission in sea water, and a very narrow receiver optical filter to reject background noise.

Inter-satellite links: Inter-satellite links (or cross-links) may be used to extend the coverage area of a geostationary system, eliminating the need for intermediate anchor stations or as links between low orbiting and geostationary or super synchronous satellites. Communication could be either by EHF at 60 GHz or optically. Calculations suggest that excessive powers are not required, and the main problems lie in the antenna/aperture acquisition and tracking.

Introduction to satellite systems

There are 4 types of orbits, they are: 1. LEO (Low earth orbit) 2. MEO (medium earth orbit) 3. GEO (Geo-synchronous earth orbit) 4. GEO (Geo-stationary earth orbit).

Low earth orbit

LEO satellites operate at a distance of about 500-1500 km. A low Earth orbit (LEO) is an Earth-centered orbit with an altitude of 2,000 km (1,200 mi) or less (approximately one-third of the radius of Earth) or with at least 11.25 periods per day (an orbital period of 128 minutes or less) and an eccentricity less than 0.25. Most of the manmade objects in outer space are in LEO.

The LEO region is defined by some sources as the region in space that LEO orbits occupy. Some highly elliptical orbits may pass through the LEO region near their lowest altitude (or perigee) but are not in an LEO Orbit because their highest altitude (or apogee) exceeds 2,000 km (1,200 mi). Sub-orbital objects can also reach the LEO region but are not in an LEO orbit because they re-enter the atmosphere. The distinction between LEO orbits and the LEO region is especially important for analysis of possible collisions between objects which may not themselves be in LEO but could collide with satellites or debris in LEO orbits.

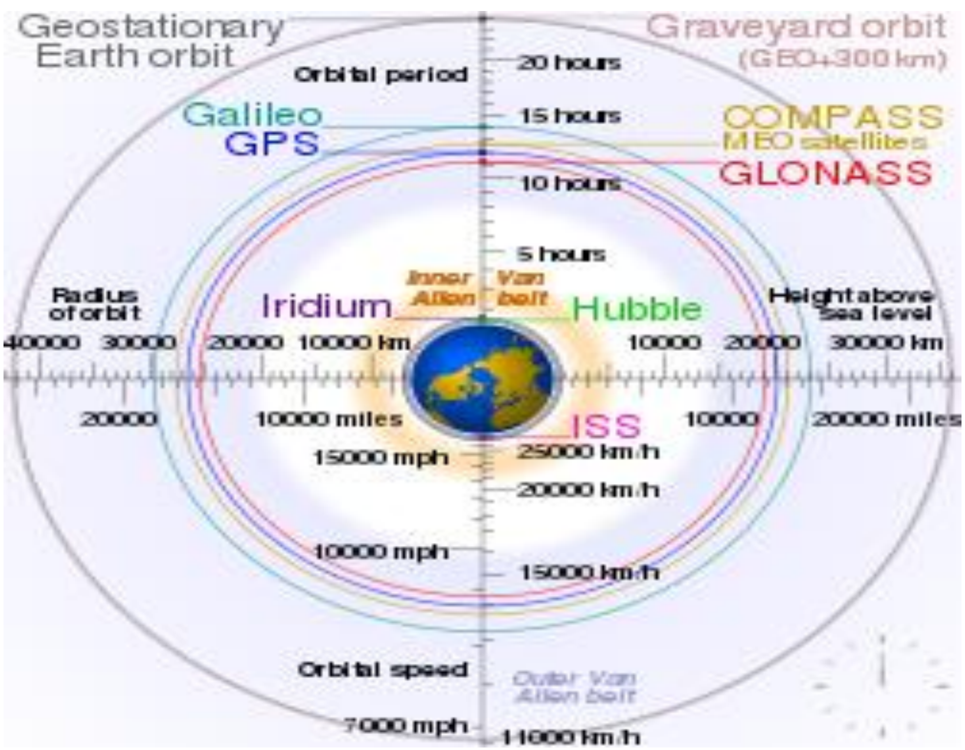
The International Space Station conducts operations in LEO. All crewed space stations to date, as well as the majority of satellites, have been in LEO. The altitude record for human spaceflights in LEO was Gemini 11 with an apogee of 1,374.1 km (853.8 mi). Apollo 8 was the first mission to carry humans beyond LEO on December 21–27, 1968. The Apollo program continued during the four-year period spanning 1968 through 1972 with 24 astronauts who flew lunar flights but since then there have been no human spaceflights beyond LEO.

Advantages of Low Earth Orbit

1. The antennas can have low transmission power of about 1 watt.
2. The delay of packets is relatively low.
3. Useful for smaller foot prints.

Disadvantages of Low Earth Orbit

1. If global coverage is required, it requires at least 50-200 satellites in this orbit.
2. Special handover mechanisms are required.
3. These satellites involve complex design.



A low Earth orbit requires the lowest amount of energy for satellite placement. It provides high bandwidth and low communication latency. Satellites and space stations in LEO are more accessible for crew and servicing.

Since it requires less energy to place a satellite into a LEO, and a satellite there needs less powerful amplifiers for successful transmission, LEO is used for many communication applications, such as the Iridium phone system. Some communication satellites use much higher geostationary orbits, and move at the same angular velocity as the Earth as to appear stationary above one location on the planet.

Medium Earth Orbit

Satellite at different orbits operates at different heights. The MEO satellite operates at about 5000 to 12000 km away from the earth's surface. These orbits have moderate number of satellites. Medium Earth orbit (MEO), sometimes called intermediate circular orbit (ICO), is the region of space around Earth above low Earth orbit (altitude of 2,000 km (1,243 mi) above sea level) and below geosynchronous orbit (altitude of 35,786 km (22,236 mi) above sea level).[1]

The orbit is home to a number of artificial satellites – the most common uses include navigation, communication, and geodetic/space environment science. The most common altitude is approximately 20,200 kilometers (12,552 mi)), which yields an orbital period of 12 hours, as used, for example, by the Global Positioning System (GPS). Other satellites in medium Earth orbit include Glonass (with an altitude of 19,100 kilometers (11,900 mi) and Galileo (with an altitude of 23,222 kilometers (14,429 mi)) constellations. Communications satellites that cover the North and South Pole are also put in MEO.

The orbital periods of MEO satellites range from about 2 to nearly 24 hours. Telstar 1, an experimental satellite launched in 1962, orbited in MEO.

Advantages of Medium Earth Orbit

1. Compared to LEO system, MEO requires only a dozen satellites.

2. Simple in design.
3. Requires very few handovers.

Disadvantages of Medium Earth Orbit

1. Satellites require higher transmission power.
2. Special antennas are required.

Geo-synchronous earth orbit

A geosynchronous orbit is a high Earth orbit that allows satellites to match Earth's rotation. Located at 22,236 miles (35,786 kilometers) above Earth's equator, this position is a valuable spot for monitoring weather, communications and surveillance.

“Because the satellite orbits at the same speed that the Earth is turning, the satellite seems to stay in place over a single longitude, though it may drift north to south,” NASA wrote on its Earth Observatory website.

Satellites are designed to orbit Earth in one of three basic orbits defined by their distance from the planet: low Earth orbit, medium Earth orbit or high Earth orbit. The higher a satellite is above Earth (or any other world for that matter), the slower it moves. This is because of the effect of Earth's gravity; it pulls more strongly at satellites that are closer to its center than satellites that are farther away. An orbit around earth whose orbital period is equal to a sidereal day (23h,56m) irrespective of its inclination.

A satellite in geosynchronous orbit can see one spot of the planet almost all of the time. For Earth observation, this allows the satellite to look at how much a region changes over months or years. The drawback is the satellite is limited to a small parcel of ground; if a natural disaster happens elsewhere, for example, the satellite won't be able to move there due to fuel requirements.

This is a large benefit for the military. If, for example, the United States is concerned about activities in a certain region of the world — or it wants to see how its troops are doing — a geosynchronous orbit allows constant pictures and other surveillance of one particular region. An example of this is the United States' Wideband Global SATCOM 5, which launched in 2013. Joining a "constellation" of four other WGS satellites, it extends the military's communications system to provide blanket coverage over virtually the entire planet. The network serves troops, ships, drones and civilian leaders and is supposed to provide communications for ground personnel.

Communications for civilians also benefit from geosynchronous orbit. There are numerous companies that provide telephone, Internet, television and other services from satellites in that orbital slot. Because the satellite is constantly hovering over one spot on the ground, communications from that location are reliable as long as the satellite is well connected to the location you want to communicate with.

Geo-Stationary Earth Orbit

A geostationary orbit, also referred to as a geosynchronous equatorial orbit[a] (GEO), is a circular geosynchronous orbit 35,786 kilometres (22,236 miles) above Earth's equator and following the direction of Earth's rotation.

An object in such an orbit has an orbital period equal to the Earth's rotational period, one sidereal day, and so to ground observers it appears motionless, in a fixed position in the sky. The concept of a geostationary orbit was popularised by Arthur C. Clarke in the 1940s as a way to revolutionise telecommunications, and the first satellite to be placed in this kind of orbit was launched in 1963.

Communications satellites are often placed in a geostationary orbit so that Earth-based satellite antennas (located on Earth) do not have to rotate to track them, but can be pointed permanently at the position in the sky where the satellites are located. Weather satellites are also placed in this orbit for real time monitoring and data collection, and navigation satellites to provide a known calibration point and enhance GPS accuracy.

Geostationary satellites are launched via a temporary orbit, and placed in a slot above a particular point on the Earth's surface. The orbit requires some stationkeeping to keep its position, and modern retired satellites are placed in a higher graveyard orbit to avoid collisions. These satellites have almost a distance of 36,000 km to the earth.

E.g. All radio and TV, whether satellite etc, are launched in this orbit.

Advantages of Geo-Stationary Earth Orbit

1. It is possible to cover almost all parts of the earth with just 3 geo satellites.
2. Antennas need not be adjusted every now and then but can be fixed permanently.
3. The life-time of a GEO satellite is quite high usually around 15 years.

Disadvantages of Geo-Stationary Earth Orbit

1. Larger antennas are required for northern/southern regions of the earth.
2. High buildings in a city limit the transmission quality.
3. High transmission power is required.
4. These satellites cannot be used for small mobile phones.
5. Fixing a satellite at Geo stationary orbit is very expensive.

Orbital mechanics:

Orbital elements: Orbital elements are the parameters required to uniquely identify a specific orbit. In celestial mechanics these elements are generally considered in classical two-body systems, where a Kepler orbit is used (derived from Newton's laws of motion and Newton's law of universal gravitation). There are many different ways to mathematically describe the same orbit, but certain schemes each consisting of a set of six parameters are commonly used in astronomy and orbital mechanics.

A real orbit (and its elements) changes over time due to gravitational perturbations by other objects and the effects of relativity. A Keplerian orbit is merely a mathematical approximation at a particular time.

The satellite moves in an elliptical path about the origin. The foci of the ellipse are located at points O and F; the Earth is located at focal point O. This constitutes the first of Kepler’s Three Laws of Planetary Motion: the orbit of a smaller body about a larger body is always an ellipse, with the centre of mass of the larger body coinciding with one of the two foci of the ellipse.

When viewed from an inertial frame, two orbiting bodies trace out distinct trajectories.

Each of these trajectories has its focus at the common center of mass. When viewed from the non-inertial frame of one body only the trajectory of the opposite body is apparent; Keplerian elements describe these non-inertial trajectories. An orbit has two sets of Keplerian elements depending on which body used as the point of reference. The reference body is called the primary, the other body is called the secondary. The primary is not necessarily more massive than the secondary, even when the bodies are of equal mass, the orbital elements depend on the choice of the primary.

The main two elements that define the shape and size of the ellipse:

Eccentricity - shape of the ellipse, describing how flattened it is compared with a circle.

Semimajor axis ( ) - the sum of the periapsis and apoapsis distances divided by two. For circular orbits the semimajor axis is the distance between the bodies, not the distance of the bodies to the center of mass.

Two elements define the orientation of the orbital plane in which the ellipse is embedded:
Inclination - vertical tilt of the ellipse with respect to the reference plane, measured at the ascending node (where the orbit passes upward through the reference plane) (green angle i in diagram).

Longitude of the ascending node - horizontally orients the ascending node of the ellipse (where the orbit passes upward through the reference plane) with respect to the reference frame's vernal point (green angle Ω in diagram).
And finally:

Argument of periapsis defines the orientation of the ellipse (in which direction it is flattened compared to a circle) in the orbital plane, as an angle measured from the ascending node to the semimajor axis. (violet angle in diagram)

Mean anomaly at epoch ( ) defines the position of the orbiting body along the ellipse at a specific time (the "epoch").

The mean anomaly is a mathematically convenient "angle" which varies linearly with time, but which does not correspond to a real geometric angle. It can be converted into the true anomaly, which does represent the real geometric angle in the plane of the ellipse, between periapsis (closest approach to the central body) and the position of the orbiting object at any given time. Thus, the true anomaly is shown as the red angle in the diagram, and the mean anomaly is not shown.

The angles of inclination, longitude of the ascending node, and argument of periapsis can also be described as the Euler angles defining the orientation of the orbit relative to the reference coordinate system.

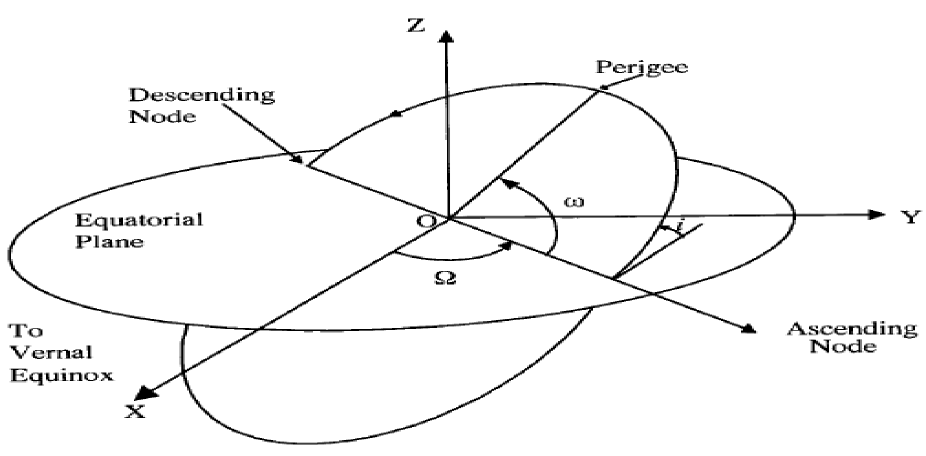
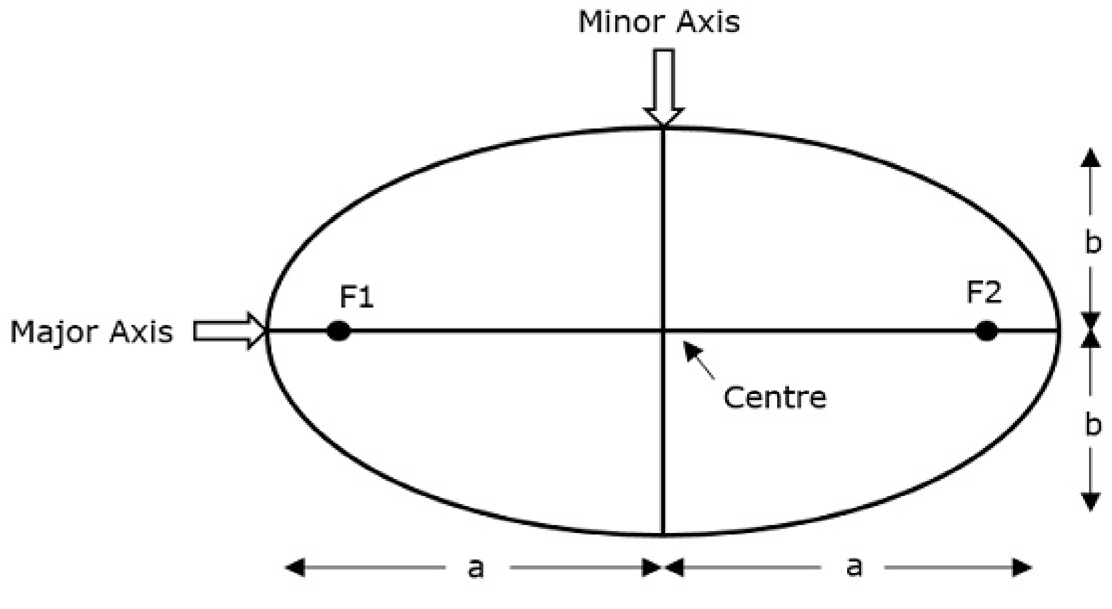


Figure 3.3 Satellite parameters in the geocentric-equatorial co-ordinate system.

Kepler's First Law

Kepler's first law states that the path followed by a satellite around its primary (the earth) will be an ellipse. This ellipse has two focal points (foci) F1 and F2 as shown in the figure below. Center of mass of the earth will always present at one of the two foci of the ellipse.



Kepler's 1st law

If the distance from the center of the object to a point on its elliptical path is considered, then the farthest point of an ellipse from the center is called as **apogee** and the shortest point of an ellipse from the center is called as **perigee**.

Eccentricity "e" of this system can be written as −

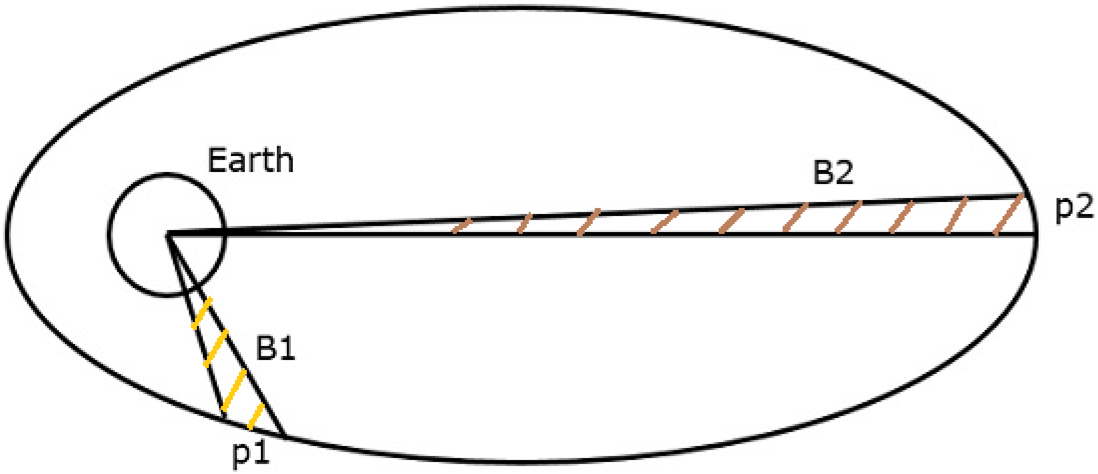
$$e = \frac{\sqrt{a^2 - b^2}}{a}$$

Where, **a** & **b** are the lengths of semi major axis and semi minor axis of the ellipse respectively.

For an **elliptical path**, the value of eccentricity (e) is always lie in between 0 and 1, i.e. 00 < ee < 11, since a is greater than b. Suppose, if the value of eccentricity (e) is zero, then the path will be no more in elliptical shape, rather it will be converted into a circular shape.

Kepler's Second Law

Kepler's second law states that for equal intervals of time, the **area** covered by the satellite will be same with respect to center of mass of the earth. This can be understood by taking a look at the following figure.



Assume, the satellite covers p1 and p2 distances in the same time interval. Then, the areas B1 and B2 covered by the satellite at those two instances are equal.

Kepler's Third Law

Kepler's third law states that, the square of the periodic time of an elliptical orbit is proportional to the cube of its semi major axis length. Mathematically, it can be written as follows −

$$T^2 \propto a^3$$

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

Where, $\frac{4\pi^2}{\mu}$ is the proportionality constant.

μ is Kepler's constant and its value is equal to 3.986005 x $10^{14} m^3 / sec^2$

Locating the satellite with respect to the earth:

A fixed rectangular coordinate system (x_i, y_i, z_i) called the geocentric equatorial coordinate system whose origin is the center of the earth. The rotational axis of earth is the z_i axis, which is through the geographic North Pole. The x_i axis is from the center of the earth toward a fixed location in space called the first point of Aries. This coordinate system moves through space, it translates as the earth moves in its orbit around the sun, but it does not rotate as the earth rotates. The x_i direction is always the same, whatever the earth's position around the sun and is in the direction of the first point of Aries. The (x_i, y_i) plane contains the earth's equator and is called the equatorial plane.

Angular distance measured east ward in the equatorial plane from the x_i axis is called right ascension (RA). The two points at which the orbit penetrates the equatorial plane are called nodes. The satellite moves upward through the equatorial plane at the ascending node and downward through the equatorial at the descending node. The right ascension of the ascending node is called Ω. The angle that the orbital plane makes with the equatorial plane is called the inclination ‘i’. To locate the orbital coordinate system with respect to the equatorial coordinate system we need ‘ω’ the argument of perigee west. This is the angle measured along the orbit from the ascending node to the perigee.

Sidereal time is a time-keeping system astronomers use to keep track of the direction to point their telescopes to view a given star in the night sky. From a given observation point, a star found at one location in the sky will be found at basically the same location at another night when observed at the same sidereal time. This is similar to how the time kept by a sundial can be used to find the location of the Sun. Just as the Sun and Moon appear to rise in the east and set in the west, so do the stars. Both solar time and sidereal time make use of the regularity of the Earth's rotation about its polar axis. The basic difference between the two is that solar time maintains orientation to the Sun while sidereal time maintains orientation to the stars in the night sky. The exact definition of sidereal time fixes it to the vernal equinox. Precession and nutation, though quite small on a daily basis, prevent sidereal time from being a direct measure of the rotation of the Earth relative to inertial space. Common time on a typical clock measures a slightly longer cycle, accounting not only for the Earth's axial rotation but also for the Earth's annual revolution around the Sun of slightly less than 1 degree per day.

A **sidereal day** is approximately 23 hours, 56 minutes, 4.091 seconds (23.93447 hours or 0.99726957 mean solar days), corresponding to the time it takes for the Earth to complete one rotation relative to the vernal equinox. The vernal equinox itself precesses very slowly in a westward direction relative to the fixed stars, completing one revolution every 26,000 years approximately. As a consequence, the misnamed sidereal day, as "sidereal" is derived from the Latin sidus meaning "star", is some 0.008 seconds shorter than the Earth's period of rotation relative to the fixed stars.

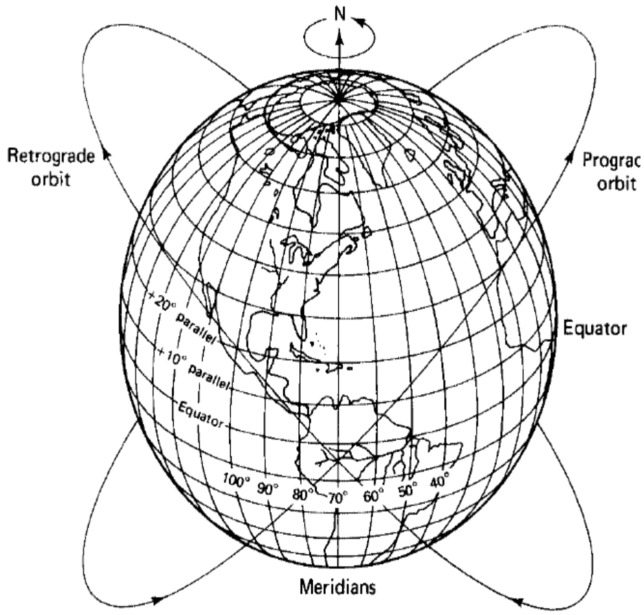


Figure 2.4 Prograde and retrograde orbits.

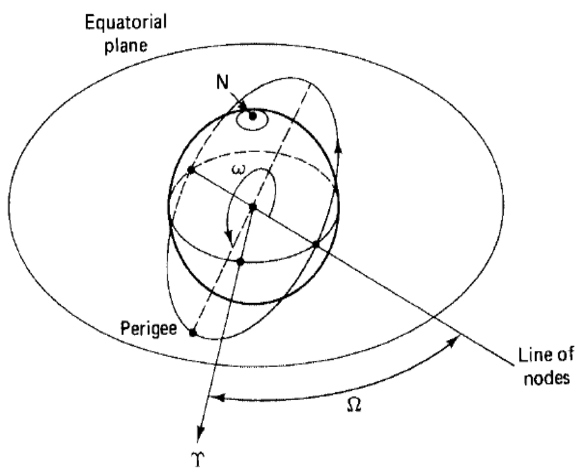


Figure 2.5 The argument of perigee ω and the right ascension of the ascending node Ω.

Coverage angle & Slant range:

Communication with a satellite is possible if the earth station is in the footprint of the satellite. In other words, the earth-satellite link is established only when the earth station falls in the beam width of the satellite antenna. This would be a function of time and the satellite is to be tracked in case of a non-geostationary satellite. But for a geostationary satellite once the link is established, the link is available throughout the lifetime of the satellite without any tracking. To have the communication between the earth station-satellite-earth stations, both the antennas of the transmitting and receiving earth station are to be pointed towards the antenna of the spacecraft. With the help of look angle determination, this can be established. To locate the earth station in the footprint of the satellite, the information of slant range and coverage area/angle is required.

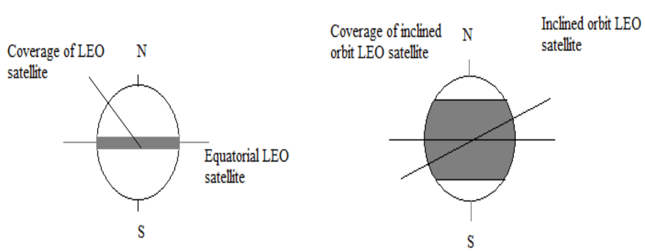
The position of the satellite within its orbit considered from the ground station point of view is defined by Azimuth (Az) and Elevation ($\varepsilon 0$) angles. The azimuth is the angle of the direction of the satellite, measured in the horizon plane from geographical north in clockwise direction. The range of azimuth is 0º to 360º. The elevation is the angle between a satellite and the observer's (ground station's) horizon plane. The range of elevation is 0º to 90º. The coverage area of a single satellite is a circular area on the Earth surface in which the satellite can be seen under an elevation angle equal or greater than the minimum elevation angle determined by the link budget requirements of the system. The largest coverage area is achieved under elevation of 0º, but in order to avoid obstacles caused by natural barriers at too low elevation, usually for the link budget calculations it is determined the minimal elevation angle which ranges on (2-10)º. For simulation purposes of coverage it is considered the elevations up to 10 º. The satellite's coverage area on the Earth depends on orbital parameters. Ground stations (GS) can communicate with LEO (Low Earth Orbiting) satellites only when the ground station is under coverage area (satellite footprint)

Inclined orbits:

Satellites that can no longer be maintained in a fully geostationary orbit, but are still used for communications services, are referred to as inclined orbit satellites, there are advantages and disadvantages to inclined orbits, depending on the mission goals and the data recovery requirements. The greater the inclination of the orbit is, the larger the surface area of the earth that the satellite will pass over at some time in its flight.

The inclined orbit will take the space craft at one time or another, over the earth's entire surface that lies approximately between the latitudes given by ± the orbital inclination. The superior coverage of the earth with an inclined orbit satellite is counter balanced by the disadvantage that the master control station (MCS) will not be able to communicate directly with the satellite on every orbit as with an equatorial orbit satellite.

A LEO satellite orbits the earth with a period of 90 to 100 min and for an inclined orbit satellite; the earth will have rotated the master control station out of the path of the satellite on the next pass over the same side of the earth.



Orbital perturbations due to earth's oblateness:

Perturbations:

Introduction:

Most of the studies for identifying potential relative motion orbits for flying formations have assumed a spherical Earth. The relative motion orbits identified from this assumption result primarily from small changes in the eccentricity and the inclination. This is satisfactory for identifying the potential relative motion orbits, but unsatisfactory for determining long term motion, fuel budgets and the best formations. Assuming that all satellites in the formation are nearly identical, the primary perturbation is the differential gravitational perturbation due to the Earth's oblateness. Since the differential gravity perturbations are a function of (a,e,i) the small changes in these elements result in different drift rates for each satellite and the negation of these drifts result in different fuel requirements for each satellite. Since some satellites running out of fuel before others will degrade the system performance it would be advantageous to have the satellites have equal fuel consumption. Satellites do not describe perfect elliptical orbits around its central body (this case is Earth).

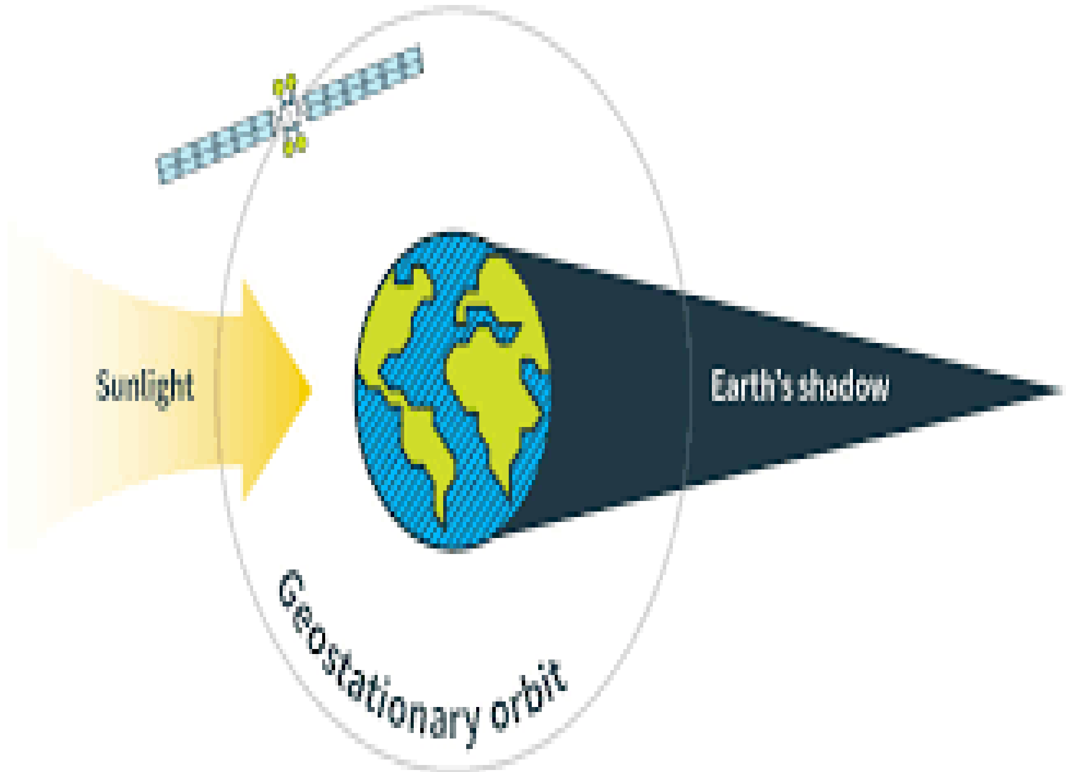
Since the earth is not a perfect sphere with a symmetric distribution of mass, its gravitational potential does not have a simple (1/r) dependence assumed by the equations of previous sections. The earth's gravitational potential is represented more accurately by an expression in Legendre polynomials J n in ascending powers of earth's radius/orbital radius. The effect of the dominant J 2 coefficient term is to cause an unconstrained geosynchronous satellite to drift towards and circulate around the nearer of two stable points. These correspond to sub-satellite longitudes of 105 º W and 75 º E, locations called graveyards because they collect old satellites whose station keeping fuel is exhausted.

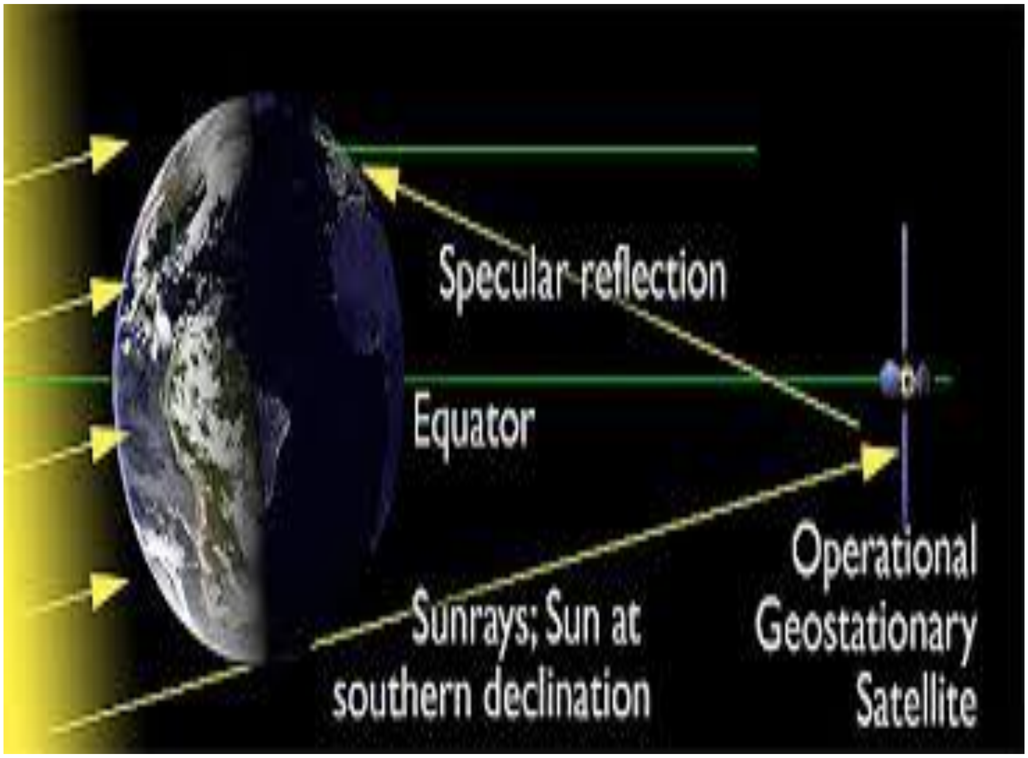
Effects of sun and moon:

Gravitational attractions by the sun and moon cause the orbital inclination of a geostationary satellite to change with time. If not countered by north-south station keeping, these forces would increase the orbital inclination from an initial 0° to 14.67° 26.6 years later. Since, no satellite has such a long lifetime, the problem is not acute.

Eclipse of GEO satellite:

A geostationary satellite utilizes solar energy to generate the required DC power to operate all the subsystems of the spacecraft. Solar energy is not available for a geostationary satellite when eclipse occurs. This occurs when the earth comes in between the sun and satellite in line and blocks the solar energy from reaching the solar panels of the satellite. This is a periodic feature and estimation of maximum duration of the eclipse period is very much required so as to determine the maximum capacity of the standby battery, which supplies the energy required for the subsystems during eclipse period. In total, the satellite will be in eclipse for a period of 44.26 days around each equinox of the year. The period of equinox starts from zero per day from the starting day of the eclipse period i.e., 22.13 days before the equinox, gradually increases to 1.16 h per day on the day of equinox and then gradually reduces and becomes zero at the end of the eclipse period after 22.13 days after equinox. This process of eclipse occurs twice in a year.





Sun transit outage:

The overall receiver noise will rise significantly to effect the communications when the sun passes through the beam of an earth station antenna. This effect is predictable and can cause outage for as much as 10 min a day for several days and for about 0.02% an average year. The receiving earth station has to wait until the sun moves out of the main lobe of the antenna. This occurs during the daytime, where the traffic is at its peak and forces the operator to hire some other alternative channels for uninterrupted communication link.

MODULE – II
SPACE SEGMENT

Placement of satellite into geostationary orbit:

The placement of a satellite in a stationary orbit involves many complex sequences. This type of satellite launching is known as Hofmann Transfer. First, the launch vehicle places the satellite in an elliptical transfer orbit whose apogee distance is equal to the radius of the geostationary orbit (42,164.2 km). The perigee distance of the elliptical transfer orbit is approximately 6678.2 km, about 300 km above the earth's surface. The satellite spin is stabilized in the transfer orbit so that ground control can communicate with the telemetry system. When the orbit and attitude of the satellite have been determined exactly and when the satellite is at the apogee of the transfer orbit, the apogee kick motor is fired to circularize the orbit. This circular orbit, with a radius of 42,164.2 km is a geostationary orbit if the launch is carried at 0° latitude, the equator. If the satellite is launched from any other latitude, the orbit would be geosynchronous with inclination i greater than or equal to the latitude θi when the injection at the perigee is horizontal.

Satellite sub systems:

Although the main purpose of communication satellites is to provide communication services, meaning that the communication sub-system is the most important sub-system of a communication satellite, for communication satellites to function properly, they must include many important subsystems other than the communication sub-system. The following is a description of the main sub-subsystems of a communication satellite.

1) Attitude and Orbit Control Sub-system:

   The attitude of a satellite is the direction at which the satellite points to with respect to Earth. Communication satellites, and most other types of satellites, must point to Earth or point in some other specific direction.

2) Telemetry, Tracking, Command, and Monitoring (TTC & M) Sub-system:

   Telemetry and Monitoring: is the process of measuring different parameters of the satellite and determining the condition of a satellite and its health, which include 100s of parameters, obtained from sensors onboard the satellite and sending them back to the Earth station to take actions. Some of these parameters include: Pressure in fuel tank indicating amount of fuel remaining, Power provided by solar cells, Power consumed by different communication parts, Temperature of different parts of the satellite, Position of switches that control different devices on the satellite, Attitude information

Tracking: is the process of determining exactly where the satellite is located, where it is heading, its speed, and its acceleration

Command: is the process of ordering the satellite to perform some operation.

Command Channel: to avoid having any un-authorized tampering with the satellite, secure channels (encryption of commands and responses) are used for sending commands to the satellite and receiving responses.

3) Power Sub-system

Batteries: Because satellites sometimes pass through the shadow of Earth and to remain operational, satellites are equipped with batteries to store excess energy from the solar cells during the period in which the solar cells are illuminated by the Sun and provide the satellite with energy when satellite is in the dark:

Solar Cells: Solar cells are the element that provides the whole communication satellites with power to perform all of its tasks (other than orbit control). The sun provides an amount of energy equal to approximately 1.361 kW of power per square meter at Earth's distance from the sun. Although Earth's atmosphere absorbs a significant amount of this power (mostly around the ultra violet region of the spectrum), since satellites are in space, this is the amount of energy that they can theoretically get from the sun per square meter.

4) Communication Sub-system

Clearly, the communication sub-system is the most important system of a communication satellite. All other sub-systems are there to serve this sub-system. The basic building block of the communication sub-system is called transponder, which is basically a block that receives a signal from an Earth station, changes its frequency and amplifies it, and then transmits it to another Satellite or back to Earth.

Telemetry, tracking and command system:

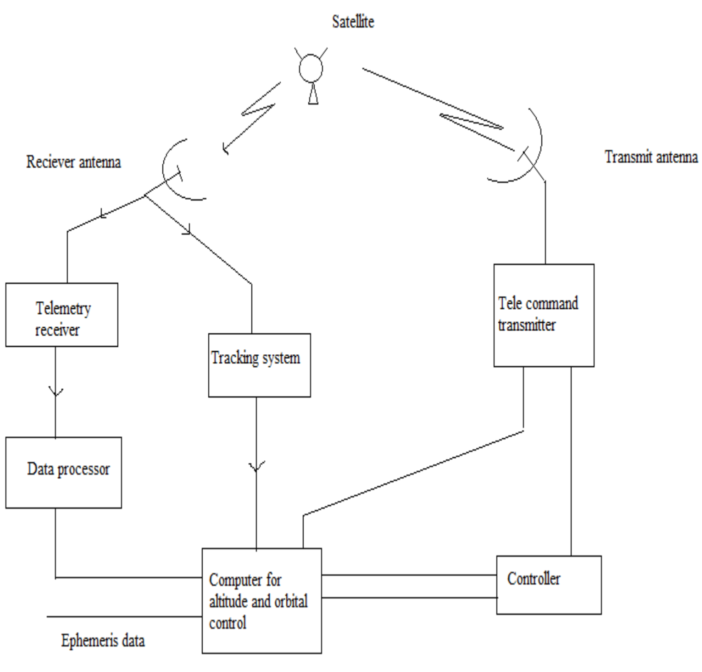


Figure: 2.1

Telemetry & monitoring system:

The monitoring system collects data from many sensors within the satellite and sends these data to the controlling earth station. There may be several hundred sensors located on the satellite to monitor pressure in the fuel tanks, voltage and current in the power conditioning unit, current drawn by each sub system and critical voltages. The sensor data, the status of each sub system and the positions of switches in the communication system are reported back to the earth by the telemetry system.

At the controlling earth station a computer can be used to monitor, store and decode the telemetry data so that the status of any system or sensor on the satellite can be determined immediately by the controller on the earth.

Tracking:

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

If a sufficient number of earth stations with an adequate separation are observing the satellite, its position can be established by triangulation from the earth station by simultaneous range measurements.

Command:

A secure and effective command structure is vital to successful launch and operation of any communications satellite. The command system is used to make changes attitude and corrections to the orbit and to the control the communication system. During launch it is used to control the firing of the apogee kick motor and to spin up a spinner or extend the solar sails and antennas of a 3- axis stabilized satellite.

The control code is converted into a command word, which is sent in a TDM frame to the satellite. After checking for validity in the satellite, the word is sent back to the control station via the telemetry link where it is checked again in the computer. If it is found to have been received correctly, an execute instruction will be sent to the satellite so that the command is executed. The entire process may take 5 or 10 sec.

Transponders:

The subsystem, which provides the connecting link between transmitting and receiving antennas of a satellite, is known as **Transponder**. It is one of the most important subsystems of space segment subsystems. Transponder performs the functions of both transmitter and receiver (Responder) in a satellite. Hence, the word ‘Transponder’ is obtained by the combining few letters of two words, Transmitter **(Trans)** and Responder **(ponder)**.

Transponder performs mainly **two functions**. That is amplifying the received input signal and translates the frequency of it. In general, different frequency values are chosen for both uplink and down link in order to avoid the interference between the transmitted and received signals.

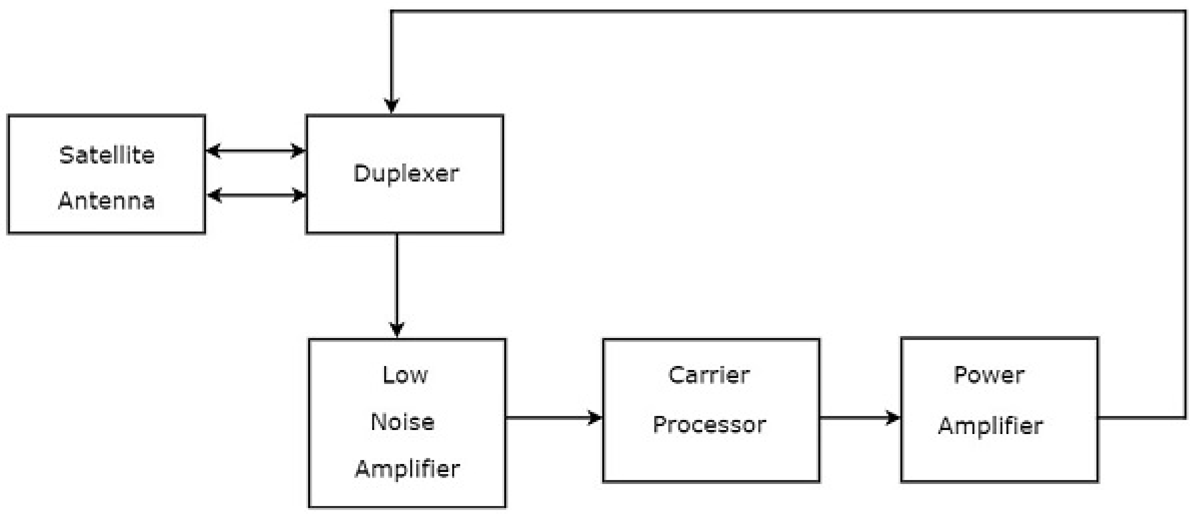


Figure: 2.2

- **Duplexer** is a two-way microwave gate. It receives uplink signal from the satellite antenna and transmits downlink signal to the satellite antenna.
- **Low Noise Amplifier** (LNA) amplifies the weak received signal.
- **Carrier Processor** performs the frequency down conversion of received signal (uplink). This block determines the type of transponder.
- **Power Amplifier** amplifies the power of frequency down converted signal (down link) to the required level.

Types of Transponders:

Basically, there are two types of transponders. Those are Bent pipe transponders and Regenerative transponders.

Bent Pipe Transponders: Bent pipe transponder receives microwave frequency signal. It converts the frequency of input signal to RF frequency and then amplifies it. Bent pipe transponder is also called as repeater and conventional transponder. It is suitable for both analog and digital signals.

Regenerative Transponders: Regenerative transponder performs the functions of Bent pipe transponder. i.e., frequency translation and amplification. In addition to these two functions, Regenerative transponder also performs the demodulation of RF carrier to baseband, regeneration of signals and modulation.

Regenerative transponder is also called as processing transponder. It is suitable only for digital signals. The main advantages of Regenerative transponders are improvement in Signal to Noise Ratio (SNR) and have more flexibility in implementation.

TWT amplifier operation:

Traveling Wave Tube Amplifiers (TWTA) are commonly used in satellite communication links, earth observation payloads, scientific missions or probes, inter-spacecraft communications links etc. The TWTA consists of Electronic Power Conditioner (EPC) and Traveling Wave Tube (TWT). The TWT is a complex multidisciplinary technology involving controlled interaction of microwave with electron beam under ultra high vacuum. The criticality of TWT realization can be gauged by the fact that every single TWT involves defect free realization of over 300 small precise piece parts and more than 260 leak proof joints. This also involves handling of the DC voltages of the order of 6 KV. TWTA is one of the integral parts of all communication payloads. Hence, their dimensions, mass and efficiency are major contributors to the satellite's power budget and require special attention.

A TWT performs as a wideband microwave amplifier. This wideband amplification feature is obtained by the use of an interaction circuit which is essentially a transmission line and does not usually contain any resonant. The principle of operation of a TWT is strikingly simple. As illustrated here, an electron beam is emitted from the cathode and accelerated toward the collector at the opposite end of the device. The electrons of the beam are surrounded by a radio frequency wave with a strong field component in the direction of the beam travel. If the velocities of the beam and the wave are nearly the same, interaction takes place. The delay line slows the radio frequency wave down to the velocity of practical beams. This line is constructed so that the field components are primarily longitudinal in the vicinity of the beam. If a helix is used as the delay line, the radio frequency wave actually travels along the path of the helix, but the beam sees only the much longer and slower wave components in the longitudinal direction; that is in traveling around one turn of the helix, the wave proceeds forward only by one pitch. The resultant velocity is a fraction of the original wave velocity.

The gain of a TWT amplifier depends on beam current, the maximum gain that can be obtained from a given TWT is limited by the stability limit, that is, the beam current value at which the TWT begins to oscillate; the safe emission limit of the cathode; and the maximum current which can be focused through the helix without causing excessive current to be intercepted by the helix or other TWT elements and thereby producing overheating. For high power operation, the TWT must employ elements which can dissipate the heat created by the radio frequency wave and intercepted beam current. In high power TWT amplifiers, therefore, a maximum value is often specified for helix and collector power dissipation.

Satellite frequency bands and allocations:

Frequency Band	Frequency Range(GHz)	Bandwidth(GHz)	Applications
L band	1-2	1	MSS
S band	2-4	2	MSS
C band	4-8	4	FSS
X band	8-12.5	4.5	meteorological satellite and FSS military
Ku band	12.5-18	5.5	FSS,BSS
K band	18-26.5	8.5	FSS,BSS
Ka band	26.5-40	13.5	FSS

Satellite applications include FSS, BSS and MSS. FSS stands for Fixed Service Satellite, BSS stands for Broadcast Service Satellite and MSS stands for Mobile Service Satellite.

Satellite link:

Designing a satellite system therefore requires knowledge of the requires performance of the uplink and down link, the propagation characteristics and rain attenuation for the frequency band being used at the earth station locations, and the parameters of the satellite and the earth stations.

In a satellite link there are two signal paths: an uplink from the earth station to the satellite and a downlink from the satellite to the earth station. The overall C/N at the earth station receiver depends on both links and both. Path attenuation in the earth's atmosphere may become excessive in heavy rain, causing the C/N ratio to fall below the minimum permitted value, especially when the 30/20 GHz band is used, leading to a link outage.

The baseband channel BER or S/N ratio is determined by the carrier- to- noise ratio(C/N) at the input to the demodulator in the receiver. In the most satellite communications applications, the C/N ratio at the demodulator must be greater than 6dB for analog links and below 10dB for digital links.

Basic transmission theory:

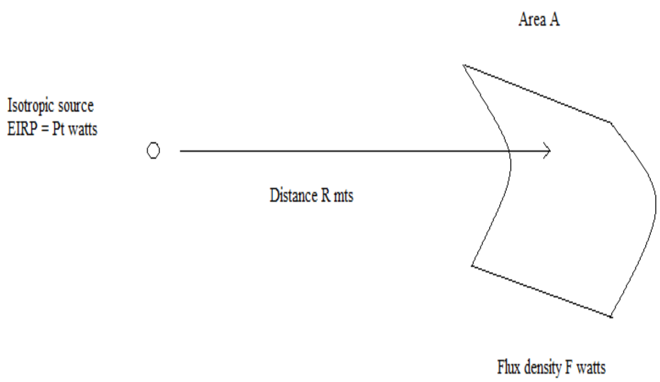


Figure: 2.3

Consider a transmitting source, in free space radiating a total power P_t watt uniformly in all directions, such a source is called isotropic. At a distance R meters from the hypothetical isotropic source transmitting RF power P_t watts, the flux density crossing the surface of a sphere with radius R is given by

$$F = \frac{P_t}{4\pi R^2} \;\; W/_{m^2}$$

Any real antenna has a gain G(θ), defined as the ratio of power per unit solid angle radiated in a direction θ to the average power radiated per unit solid angle

$$G(\theta) = \frac{P(\theta)}{P_0/_{4\pi}}$$

Where P (θ) is the power radiated per unit solid angle by the antenna.

P_0 is the total power radiated by the antenna.

G (θ) is the gain of the antenna at an angle θ.

For a transmitter with output P_t watts driving a loss less antenna with gainG_t , the flux density in the direction of the antenna bore sight at distance R meters is

$$F = \frac{P_t G_t}{4\pi R^2} \quad W/_{m^2}$$

The product $P_t G_t$ is often called the effective isotropically radiated power or EIRP.

An ideal receiving antenna with an aperture area of A m^2, the collected power P_r

$$P_r = F * A \text{ Watts}$$

A practical antenna with a physical aperture area of A_r m^2 , therefore the effective aperture A_e is

$$A_e = \eta_A A_r$$

Where η_A is the aperture efficiency.

The power received by a real antenna with a physical receiving area A_r and effective aperture area A_e m^2 is

$$P_r = \frac{P_t G_t G_r}{4\pi R^2} \text{ W}$$

Substituting for A_e in above equation is

$$P_r = \frac{P_t G_t G_r}{\left(4\pi R/_{\lambda}\right)^2} \text{ W}$$

The above expression is known as the link equation.

System noise temperature and G/T ratio:

Noise temperature is a useful concept in communication receivers, since it provides a way of determining how much thermal noise generated by active and passive devices in the receiving system. The noise power is given by

$P_n = k\, T_p\, B_n$

K = Boltzmann’s constant

($1.38X10^{-23}$ J/K = -228.6dBW/K/Hz)

T_p = Physical temperature of source in Kelvin degree

B_n = Noise bandwidth in which the noise power is measured in hertz

P_n = available noise power

The system noise temperature (T_S) is the noise temperature of a noise source, located at the input of a noise less receiver, which gives the same noise power as the original receiver, measured at the output of the receiver and usually includes noise from the antenna.

If the overall end to end gain of the receiver is G_{rx} and narrowest bandwidth is B_n Hz, the noise power at the demodulator input is

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

Where

G_{rx} = gain of the receiver from RF input to the demodulator input

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

$$P_n = KT_sB_n$$

Let the antenna deliver a signal power P_r watts to the receiver RF input. The signal power at the demodulator input is $P_r G_{rx}$. Hence, the carrier to noise ratio at the demodulator is given by

$$\frac{C}{N} = \frac{P_r G_{rx}}{kT_sB_nG_{rx}} = \frac{P_r}{kT_sB_n}$$

The noisy devices in the receiver are replaced by equivalent noiseless blocks with the same gain and noise generators at the input to each block such that the block produces the same noise at its output as the device it replaces. The total noise power at the output of IF amplifier of the receiver.

$P_n = G_{IF}\ k\ T_{IF}\ B_n + G_{IF}G_mkT_mB_n + G_{IF}G_mG_{RF}kB_n(T_{RF}+T_{in})$

Where G_{RF} is gain of the amplifier,

G_m is the gain of the mixer,

G_{IF} is the gain of the IF amplifier,

T_{RF} is the equivalent noise temperature,

T_{IF} is the noise temperature of IF amplifier,

T_m is the noise temperature of mixer,

T_{in} is the temperature of the antenna.

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

= $G_{IF}G_mG_{RF}$ k B_n [T_{RF}+T_{in} +T_m /G_{RF}+ T_{IF} /($G_{RF}G_m$)]

In terms of T_S , the same noise power P_n at the output of IF amplifier

$P_n = G_{IF}G_mG_{RF}$ k T_s B_n

System noise temperatureT_S , where

T_s = [T_{RF}+T_{in} +T_m /G_{RF}+ T_{IF} /($G_{RF}G_m$)]

G/T ratio for earth stations:

The link equation can be rewritten as:

$$\frac{C}{N} = \left[\frac{P_t G_t G_r}{K T_s B_n}\right]\left[\frac{\lambda}{4\pi R}\right]^2$$

$$= \left[\frac{P_t G_t}{K B_n}\right]\left[\frac{\lambda}{4\pi R}\right]^2\left[\frac{G_r}{T_s}\right]$$

Thus$\frac{C}{N} \propto \frac{G_r}{T_s}$, this$\frac{G_r}{T_s}$ ratio is widely known as $\frac{G}{T}$ ratio and is the figure of merit.

Basic link analysis:

Link analysis determines properties of satellite equipment (antennas, amplifiers, data rate, etc,). In satellite communication there are two types of links are exist, one is uplink and other is downlink.

Elements of a satellite link:

1. Transmit power
2. Transmitter antenna gain
3. Path losses
   i) Free space
   ii) Transmitter/receiver antenna losses

iii) Environmental losses

4. Receiver antenna gain
5. Receiver properties
   i) Noise temperature
   ii) Sensitivity (S/N & ROC)
6. Design margins required to guarantee certain reliability.

Design of satellite links for a specified C/N

The transmitted signal [carrier] undergoes a path attenuation and absorption before reaching the antenna, both at the satellite and receiving earth station. In addition to that the noise is introduced both at the antenna and the receiving system. The net result is that the performance of the communication link not only depends upon the modulated carrier power but also the amount of noise introduced in the before the signal is detected. It is a common practice to represent the system performance by a factor called carrier to noise ratio.

When more than one C/N ratio is present in the link, we can add the individual C/N ratios reciprocally to obtain an overall C/N ratio, which will denote here as $\left({C}/{N}\right)_O$. The overall $\left({C}/{N}\right)_O$ ratio is what would be measured in the earth station at the output of the IF amplifier

$$\left({C}/{N}\right)_O = \frac{1}{\left[\frac{1}{({C}/{N})_1}+\frac{1}{({C}/{N})_2}+\frac{1}{({C}/{N})_3}+ \ldots\ldots\right]}$$

This is sometimes referred to as the reciprocal C/N formula. All the C values are the same in above equation expanding the formula by cross multiplying gives the overall $\left({C}/{N}\right)_O$ as a power ratio, not in decibels

$$\left({C}/{N}\right)_O = \frac{1}{\left[\frac{N_1}{C}+\frac{N_2}{C}+\frac{N_3}{C}+ \ldots\right]} = \frac{C}{[N_1+N_2+N_3+ \ldots\ldots]}$$

The satellite always transmits noise as well as signal, so a C/N ratio measurement at the receiver will always yield$\left({C}/{N}\right)_O$, the combination of transponder and earth station (C/N) ratios.

To calculate the performance of satellite link we must therefore determine the uplink $\left({C}/{N}\right)_{up}$ ratio the transponder and the downlink $\left({C}/{N}\right)_{dn}$ in the earth station receiver. We must also consider whether there is any interference present, either in the satellite receiver or the earth station receiver.

Link budget:

A link budget is a tabular method for evaluating the received power and noise power in a radio link. Link budgets invariably use decibel units for all quantities so that signal and noise powers can be calculated by addition and subtraction.

The link budget must be calculated for an individual transponder and must be repeated for each of the individual links. In a two-way satellite communication link there will be 4 separate links, each requiring a calculation of C/N ratio.

Link budgets are usually calculated for a worst case, the one in which the link will have the lowest C/N ratio. When an earth station located at the edge of the satellite coverage zone, it receives 3dB lower signal than in the center of the zone because of the satellite antenna pattern, maximum path length from the satellite to the earth station, a low elevation angle at the earth station giving the highest atmospheric path attenuation in clear air and maximum rain attenuation on the link causing loss of received signal power and an increase in receiving system noise temperature. The calculation of carrier to noise ratio in a satellite link is based on the two equations for received signal power and receiver noise power.

$$P_r = EIRP + G_r - L_P - L_a - L_r - L_t \; dBW$$

A receiving terminal with a system noise temperature KT_S and a noise bandwidth B_n Hz has a noise power P_n referred to the output terminals of the antenna.

$$P_n = KT_S B_n \;\; \text{W}$$

Propagation effects:

Introduction: There are many phenomena that lead to signal loss on transmission through the earth’s atmosphere. These include: Atmospheric absorption (gaseous effects), Cloud attenuation, Tropospheric scintillation (refractive effects), Ionospheric scintillation, Rain attenuation.

Atmospheric absorption:

At microwave frequencies, electromagnetic waves interact with molecules in the atmosphere to cause signal attenuation. At certain frequencies, resonant absorption occurs and severe attenuation can result. Resonant absorption peaks on a zenith path from a sea level location right through the neutral atmosphere. Neutral means that no ionization is present.

The first absorption band is due to water vapor at 22.2 GHz. The K- band sets of frequencies are on both sides of this absorption band, which has led to the terminology of Ku band (under the absorption band) and Ka band (above the absorption band). It is common to specify a satellite frequency band by the uplink frequency.

Cloud attenuation:

Clouds have become an important factor for some Ka- band paths and all V- band (50/40GHz) systems. The difficulty with modeling cloud attenuation is that clouds are of many types and can exist at many levels, each type having a different probability of occurrence. The water droplet concentrations in each cloud will also vary, and clouds made up of ice crystals cause little attenuation. Typical values of cloud attenuation for water filled clouds are between 1 & 2 dB at frequencies around 30GHz on paths at elevation angles of close to 30 degrees in temperate latitudes. In warmer climates, where clouds are generally thicker in extent and have greater probability of occurrence than temperate latitudes, cloud attenuation is expected to be higher.

Troposphere scintillation & low angle fading:

When a signal encounters a turbulent atmosphere, the rapid variation in refractive index along the path will lead to fluctuations in the received signal level. These fluctuations are generally about a fairly constant mean signal level and are called scintillations. Because the bulk of the fluctuations are caused within 4 kilometers of the earth surface, they are referred to as tropospheric scintillations.

The magnitude of scintillations become generally larger as the frequency increases, the path elevation angle reduces and the climate becomes warmer and more humid. When the elevation angle falls below 10 degrees, propagation is effected by low angle fading. Low angle fading is the same phenomenon as multi path fading on terrestrial paths. A signal transmitted from a satellite arrives at the earth station receiving antenna via different paths with different phase shifts. On combination, the resultant waveform may be enhanced or attenuated from the normal clear sky level.

Signal enhancement is observed an exceed 8dB on 3.3 degrees path at 11.198GHz, while cancellation can cause complete link drop out. Low angle fading is only significant in very still air on very low elevation angle paths.

Ionospeheric scintillation:

Energy from the sun causes the ionosphere to grow during the day, increasing the total electron content (TEC) by to orders of magnitude or more. The TEC is the total number of electrons that would exist in vertical column of 1 square meter area from the surface of the earth all the way through the earth's atmosphere. Typical values of TEC range from $\sim 10^{18}$ during the day to $\sim 10^{16}$ during the night. It is the rapid change in TEC from the day time value to the night time value that gives rise to irregularities in the ionosphere.

The irregularities cause the signal to vary rapidly in amplitude and phase, which leads to rapid signal fluctuations that are called ionospheric scintillations.

Effects of rain:

The importance of communication link and the over bearing effect of rain on the link at frequencies above 10GHz. Basically, communication links operating at these frequencies are severely affected by the presence of rain over the link path, more so, in the tropical regions because of the high intensity of rain. Raindrops absorb and scatter radio waves, leading to signal attenuation and reduction of the system availability and reliability. The severity of rain impairment increases with frequency and varies with regional locations. It is therefore very important to make accurate prediction for the rain induced attenuation when planning for both microwave and terrestrial line-of-sight link.

Rain attenuation is by far the most important of these losses for frequencies above 10GHz, because it can cause the largest attenuation, the limiting factor in Ku and Ka band satellite link design. Rain drops absorb and scatter electromagnetic waves. In Ku and Ka bands rain attenuation is almost entirely caused by absorption.

Rain induced attenuation:

At frequencies above 10GHz, rain is the dominant propagation phenomenon satellite links. Basically, communication links operating at these frequencies are severely affected by the presence of rain over the link path, more so, in the tropical region because of high intensity of rain. The severity of rain impairment increases with frequency and varies with regional locations. It is therefore very important to make accurate prediction for the rain induced attenuation when planning for both micro wave and terrestrial line of sight link.

Rain attenuation and depolarization occur because individual raindrops absorb energy from radio waves. The drops absorb some of the instant energy and same is scattered the size and shape of rain drops have been measured. The most common mathematical description of the distribution of rain drop sizes is exponential and of the form

$$N(D) = N_0 e^{\left(-D/D_m\right)} mm^{-1}m^{-3}$$

Where D_m is the medium drop diameter.

Rain induced cross polarization interference:

The isolation between the two orthogonal polarizations employed in frequency reuse systems would be effected by rain. The rain degrades the isolation between the orthogonal polarizations due to depolarization effect of satellite on the earth station antennas due to propagation of the signal in the rain.

These effects because a portion of the signal energy transmitted in one polarization to be transferred to the signal in the orthogonal polarization causing cross polarization interference between to satellite channels. Rain drops falling through the atmosphere take an oblate shape due to effects of air resistance.

A linearly polarized wave polarized parallel to an axis of symmetry of a rain drop has its amplitude attenuated and its phase changed but retains polarization state. When the same linearly polarized wave is incident at an angle, each symmetry axis of the rain drop produces different amplitude attenuation and a different phase change. The differential attenuation and phase shift alter the polarization state of the wave.

MODULE – III
COMMUNICATION SATTELLITE ACCESS SYSYTEMS

Multiple Accesses:

Applications employ multiple-access systems to allow two or more Earth stations to simultaneously share the resources of the same transponder or frequency channel. These include the three familiar methods: FDMA, TDMA, and CDMA. Another multiple access system called space division multiple access (SDMA) has been suggested in the past. In practice, SDMA is not really a multiple access method but rather a technique to reuse frequency spectrum through multiple spot beams on the satellite. Because every satellite provides some form of frequency reuse (crosspolarization being included), SDMA is an inherent feature in all applications. TDMA and FDMA require a degree of coordination among users: FDMA users cannot transmit on the same frequency and TDMA users can transmit on the same frequency but not at the same time. Capacity in either case can be calculated based on the total bandwidth and power available within the transponder or slice of a transponder. CDMA is unique in that multiple users transmit on the same frequency at the same time (and in the same beam or polarization). As will be discussed, this is allowed because the transmissions use a different code either in terms of high-speed spreading sequence or frequency hopping sequence.

The capacity of a CDMA network is not unlimited, however, because at some point the channel becomes overloaded by self-interference from the multiple users who occupy it. Furthermore, power level control is critical because a given CDMA carrier that is elevated in power will raise the noise level for all others carriers by a like amount. Multiple access is always required in networks that involve two-way communications among multiple Earth stations. The selection of the particular method depends heavily on the specific communication requirements, the types of Earth stations employed, and the experience base of the provider of the technology. All three methods are now used for digital communications because this is the basis of a majority of satellite networks. The digital form of a signal is easier to transmit and is less susceptible to the degrading effects of the noise, distortion from amplifiers and filters, and interference. Once in digital form, the information can be compressed to reduce the bit rate, and FEC is usually provided to reduce the required carrier power even further. The specific details of multiple access, modulation, and coding are often preselected as part of the application system and the equipment available on a commercial off-the-shelf (COTS) basis. The only significant analog application at this time is the transmission of cable TV and broadcast TV. These networks are undergoing a slow conversion to digital

The two most commonly used methods of multiple access are frequency division multiple access (FDMA) and time-division multiple access (TDMA). These are analogous to frequency-division multiplexing (FDM) and time-division multiplexing (TDM) A third category of multiple access is code-division multiple access (CDMA). In this method each signal is associated with a particular code that is used to spread the signal in frequency and/or time. All such signals will be received simultaneously at an earth station, but by using the key to the code, the station can recover the desired signal by means of correlation.

Multiple access also may be classified by the way in which circuits are assigned to users (circuits in this context implies one communication channel through the multiple-access transponder). Circuits may be preassigned, which means they are allocated on a fixed or partially fixed basis to certain users. These circuits are therefore not available for general use. Preassignment is simple to implement but is efficient only for circuits with continuous heavy traffic. An alternative to preassignment is demand-assigned multiple access (DAMA). In this method, all circuits are available to all users and are assigned according to the demand. DAMA results in more efficient overall use of the circuits but is more costly and complicated to implement. Both FDMA and TDMA can be operated as preassigned or demand assigned systems. CDMA is a random-access system.

Frequency division multiple access (FDMA):

Frequency slots may be preassigned to analog and digital signals, and to illustrate the method, analog signals in the FDM/FM/FDMA format will be considered first. As the acronyms indicate, the signals are frequency division multiplexed, frequency modulated (FM), with FDMA to the satellite. The voice-frequency (telephone) signals are first SSBSC amplitude modulated onto voice carriers in order to generate the single sidebands needed for the FDM. For the purpose of illustration, each earth station will be assumed to transmit a 60-channel super group. Each 60-channel super group is then frequency modulated onto a carrier which is then up converted to a frequency in the satellite uplink band. Typically, a 60-channel FDM/FM carrier occupies 5 MHz of transponder bandwidth, including guard bands. A total frequency allowance of 15 MHz is therefore required for the three stations, and each station receives all the traffic. The remainder of the transponder bandwidth may be unused, or it may be occupied by other carriers.

Nearly every terrestrial or satellite radio communications system employs some form of FDMA to divide up the available spectrum. The areas where it has the strongest hold are in single channel per carrier (SCPC), intermediate data rate (IDR) links, voice telephone systems, VSAT data networks, and some video networking schemes. Any of these networks can operate alongside other networks within the same transponder. Users need only acquire the amount of bandwidth and power that they require to provide the needed connectivity and throughput. Also, equipment operation is simplified since no coordination is needed other than assuring that each Earth station remains on its assigned frequency and that power levels are properly regulated. However, intermodulation distortion (IMD) present with multiple carriers in the same amplifier must be assessed and managed as well. The satellite operator divides up the power and bandwidth of the transponder and sells off the capacity in attractively priced segments. Users pay for only the amount that they need. If the requirements increase, additional FDMA channels can be purchased. The IMD that FDMA produces within a transponder must be accounted for in the link budget; otherwise, service quality and capacity will degrade rapidly as users attempt to compensate by increasing uplink power further. The big advantage, however, is that each Earth station has its own independent frequency on which to operate. A bandwidth segment can be assigned to a particular network of users, who subdivide the spectrum further based on individual needs.

FDMA/FDD in AMPS

The first U.S. analog cellular system, AMPS (Advanced Mobile Phone System) is based on FDMA/FDD. A single user occupies a single channel while the call is in progress, and the single channel is actually two simplex channels which are frequency duplexed with a 45 MHz split. When a call is completed or when a handoff occurs the channel is vacated so that another mobile subscriber may use it. Multiple or simultaneous users are accommodated in AMPS by giving each user a unique signal. Voice signals are sent on the forward channel from the base station to the mobile unit, and on the reverse channel from the mobile unit to the base station. In AMPS, analog narrowband frequency modulation (NBFM) is used to modulate the carrier.

FDMA/TDD in CT2

Using FDMA, CT2 system splits the available bandwidth into radio channels in the assigned frequency domain. In the initial call setup, the handset scans the available channels and locks on to an unoccupied channel for the duration of the call. Using TDD (Time Division Duplexing), the call is split into time blocks that alternate between transmitting and receiving.

FDMA and Near-Far Problem

The near-far problem is one of detecting or filtering out a weaker signal amongst stronger signals. The near-far problem is particularly difficult in CDMA systems where transmitters share transmission frequencies and transmission time. In contrast, FDMA and TDMA systems are less vulnerable. FDMA systems offer different kinds of solutions to near-far challenge. Here, the worst case to consider is recovery of a weak signal in a frequency slot next to strong signal. Since both signals are present simultaneously as a composite at the input of a gain stage, the gain is set according to the level of the stronger signal; the weak signal could be lost in the noise floor.

FDMA downlink analysis:

To see the effects of output backoff which results with FDMA operation, consider the overall carrier-to-noise ratio. In terms of noise power rather than noise power density,

$$\left(\frac{N}{C}\right) = \left(\frac{N}{C}\right)_U + \left(\frac{N}{C}\right)_D + \left(\frac{N}{C}\right)_{IM} \text{……………….(1)}$$

A certain value of carrier-to-noise ratio will be needed, as specified in the system design, and this will be denoted by the subscript REQ. The overall C/N must be at least as great as the required value, a condition which can therefore be stated as

$$\left(\frac{N}{C}\right)_{REQ} \geq \left(\frac{N}{C}\right) \text{…………..(2)}$$

Note that because the noise-to-carrier ratio rather than the carrier to-noise ratio is involved, the actual value is equal to or less than the required value. Using Eq. (1), the condition can be rewritten as

$$\left(\frac{N}{C}\right)_{REQ} \geq \left(\frac{N}{C}\right)_{U} + \left(\frac{N}{C}\right)_{D} + \left(\frac{N}{C}\right)_{IM} \quad \ldots\ldots\ldots\ldots\ldots\ldots..(3)$$

The right-hand side of Eq. (3) is usually dominated by the downlink ratio. With FDMA, back off is utilized to reduce the inter modulation noise to an acceptable level, and the uplink noise contribution is usually negligible.

TDMA:

TDMA is a truly digital technology, requiring that all information be converted into bit streams or data packets before transmission to the satellite. (An analog form of TDMA is technically feasible but never reached the market due to the rapid acceptance of the digital form.) Contrary to most other communication technologies, TDMA started out as a high-speed system for large Earth stations. Systems that provided a total throughput of 60 to 250 Mbps were developed and fielded over the past 25 years. However, it is the low-rate TDMA systems, operating at less than 10 Mbps, which provide the foundation of most VSAT networks. As the cost and size of digital electronics came down, it became practical to build a TDMA Earth station into a compact package. Lower speed means that less power and bandwidth need to be acquired (e.g., a fraction of a transponder will suffice) with the following benefits:

- The full cost of a transponder can be avoided.
- The uplink power from small terminals is reduced, saving on the cost of transmitters.
- The network capacity and quantity of equipment can grow incrementally, as demand grows.

TDMA signals are restricted to assigned time slots and therefore must be transmitted in bursts. This is illustrated in for a hypothetical TDMA time frame of 45 ms. The time frame is periodic, allowing stations to transfer a continuous stream of information on average. Reference timing for start-of-frame is needed to synchronize the network and provide control and coordination information. This can be provided either as an initial burst transmitted by a reference Earth station, or on a continuous basis from a central hub. The Earth station equipment takes one or more continuous streams of data, stores them in a buffer memory, and then transfers the output toward the satellite in a burst at a higher compression speed. At the receiving Earth station, bursts from Earth stations are received in sequence, selected for recovery if addressed for this station, and then spread back out in time in an output expansion buffer. It is vital that all bursts be synchronized to prevent overlap at the satellite; this is accomplished either with the synchronization burst (as shown) or externally using a separate carrier. Individual time slots may be preassigned to particular stations or provided as a reservation, with both actions under control by a master station. For traffic that requires consistent or constant timing (e.g., voice and TV), the time slots repeat at a constant rate.

With TDMA, only one carrier uses the transponder at any one time, and therefore, inter modulation products, which result from the nonlinear amplification of multiple carriers, are absent. This leads to one of the most significant advantages of TDMA, which is that the TWT can be operated at maximum power output or saturation level. Because the signal information is transmitted in bursts, TDMA is only suited to digital signals. Digital data can be assembled into burst format for transmission and reassembled from the received bursts through the use of digital buffer memories.

The basic TDMA concept, in which the stations transmit, bursts in sequence. Burst synchronization is required, and in the system one station is assigned solely for the purpose of transmitting reference bursts to which the others can be synchronized. The time interval from the start of one reference burst to the next is termed a frame. A frame contains the reference burst R and the bursts from the other earth stations the basic principles of burst transmission for a single channel. Overall, the transmission appears continuous because the input and output bit rates are continuous and equal. However, within the transmission channel, input bits are temporarily stored and transmitted in bursts. Since the time interval between bursts is the frame time TF, the required buffer capacity is

$$M = R_b T_F$$

The buffer memory fills up at the input bit rate R_b during the frame time interval. These M bits are transmitted as a burst in the next frame without any break in continuity of the input.

The M bits are transmitted in the burst time T_B, and the transmission rate, which is equal to the burst bit rate, is

$$R_{TDMA} = \frac{M}{T_B}$$

$$= R_b \frac{T_F}{T_B}$$

This is also referred to as the burst rate, but note that this means the instantaneous bit rate within a burst.

TDMA Frame Structure:

Each earth station transmits periodically one or more bursts to the satellite in a TDMA network. The input to the satellite transponder consists of different traffic bursts originated from different earth stations. This set of bursts is referred to as TDMA frame and consists of two reference bursts RB1and RB2, traffic bursts and the guard time between bursts. The TDMA frame is the period between RB1 reference bursts.

There are two reference bursts in each frame of TDMA for reliability. The earth station designated as primary reference station transmits either RB1 or RB2 as primary reference burst; a secondary reference burst is transmitted from either RB2or RB1 by the secondary reference station. The traffic bursts transmitted from the traffic stations carry the digital information. Each station accessing the transponder may transmit one or more traffic bursts per TDMA frame and may position the bursts in the frame anywhere in the frame according to the burst time plan that coordinates traffic between the stations.

Burst structure:

Preamble is the group of bits that precede the information bits in the traffic burst. This synchronizes the burst and carries the management and control information. The reference burst contains only the preamble of the TDMA frame and no information is carried by this burst. The preamble mainly consists of three segments: the carrier and clock recovery, the unique word and the signaling channel.

Satellite-Switched TDMA:

More efficient utilization of satellites in the geostationary orbit can be achieved through the use of antenna spot beams. The use of spot beams is also referred to as space-division multiplexing. Further improvements can be realized by switching the antenna interconnections in synchronism with the TDMA frame rate, this being known as satellite-switched TDMA (SS/TDMA).

In simplified form the SS/TDMA concept, three antenna beams are used, each beam serving two earth stations. A 3*3 satellite switch matrix is used. This is the key component that permits the antenna interconnections to be made on a switched basis. A switch mode is a connectivity arrangement. With three beams, six modes would be required for full interconnectivity.

On-board processing:

The uses of bent pipe transponder, which simply amplifies a signal from earth and retransmits it back to earth at a different frequency. The transponder can be used for any combination of signals that will fit within its bandwidth. The disadvantage of the bent pipe transponder is that it is not well suited to uplinks from small earth stations, especially uplinks operating in Ka band.

Onboard processing or a baseband processing transponder can overcome the uplink attenuation problem by separating the uplink and downlink signals and their C/N ratios. The baseband processing transponder can also have different modulation schemes on the uplink and downlink to improve spectral efficiency and can dynamically apply forward error control to only those links affected by rain attenuation. All LEO satellites providing mobile telephone service use onboard processing and Ka band satellites providing internet access to individual users also use onboard processing.

DAMA:

Demand Assignment Multiple Access (DAMA) is a class of multiple-access techniques that permit a population of users to share satellite resources on a demand basis. The need for flexible local and long-haul communications by mobile military users is increasing rapidly.

DAMA does not require continuous connection from user terminals to a network control system. Typically, an assigned channel consists of a pair of frequencies--one for transmission and another for reception. After DAMA assigns a pair of frequencies to a user terminal, other network terminal users may not be assigned to those frequencies until the session is completed. Then, the frequencies are returned to a list, or central pool, of frequencies available to other terminal users. The number of transient clients that use DAMA network terminals increases according to efficient user sequencing at specific frequencies and different timeslots. Thus, DAMA is used for infrequently-used networks, versus Permanently Assigned Multiple Access (PAMA) technology. Both technologies are related only by channel or frequency resource allocation and should not be confused with multiple access/multiplexing, which divides a single communication channel into multiple channels. Typical VSAT systems use DAMA for point of sale (POS) transactions, such as credit card, polling or radio frequency identification; remote location Internet access and mobile maritime communications. DAMA is also used by the military for satellite communications (SATCOM).

Types:

1. Variable-capacity demand assignment is used for TDMA networks where each station has a large range of slowly varying traffic intensity and relatively few destinations. DAMA gain is reasonable.
2. Per-call variable capacity demand assignment is used for TDMA networks where each station serves many destinations with low, rapidly varying traffic intensity. DAMA gain is close to maximum.
3. Per-call demand assignment is used for TDMA networks where each station serves many destinations with low traffic intensity. DAMA gain is reasonable.
4. Fully variable demand assignment is used for both FDMA & TDMA networks where each station serves many destinations with rapidly varying traffic intensity and total traffic at each station is low.

Code Division Multiple Access (CDMA) / Spread Spectrum Multiple Access (SSMA):

CDMA, also called spread spectrum communication, differs from FDMA and TDMA because it allows users to literally transmit on top of each other. This feature has allowed CDMA to gain attention in commercial satellite communication. It was originally developed for use in military satellite communication where its inherent antijam and security features are highly desirable. CDMA was adopted in cellular mobile telephone as an interference-tolerant communication technology that increases capacity above analog systems. Some of these claims are well founded.

Spread Spectrum Multiple Access

Spread spectrum multiple access (SSMA) uses signals which have a transmission bandwidth whose magnitude is greater than the minimum required RF bandwidth. A pseudo noise (PN) sequence converts a narrowband signal to a wideband noise like signal before transmission. SSMA is not very bandwidth efficient when used by a single user. However since many users can share the same spread spectrum bandwidth without interfering with one another, spread spectrum systems become bandwidth efficient in a multiple user environment.

There are two main types of spread spectrum multiple access techniques:
Frequency hopped multiple access (FHMA)
Direct sequence multiple access (DSMA) or Code division multiple access (CDMA).

Frequency Hopped Multiple Access (FHMA)

This is a digital multiple access system in which the carrier frequencies of the individual users are varied in a pseudo random fashion within a wideband channel. The digital data is broken into uniform a sized burst which is then transmitted on different carrier frequencies.

Direct sequence CDMA (DS-CDMA):

This is the most commonly used technology for CDMA. In DS-SS, the message signal is multiplied by a Pseudo Random Noise Code. Each user is given his own codeword which is orthogonal to the codes of other users and in order to detect the user, the receiver must know the codeword used by the transmitter. There are, however, two problems in such systems which are discussed in the sequel.

Code Division Multiple Access

In CDMA, the same bandwidth is occupied by all the users, however they are all assigned separate codes, which differentiates them from each other (shown in Figure 3.1). CDMA utilize a spread spectrum technique in which a spreading signal (which is uncorrelated to the signal and has a large bandwidth) is used to spread the narrow band message signal.

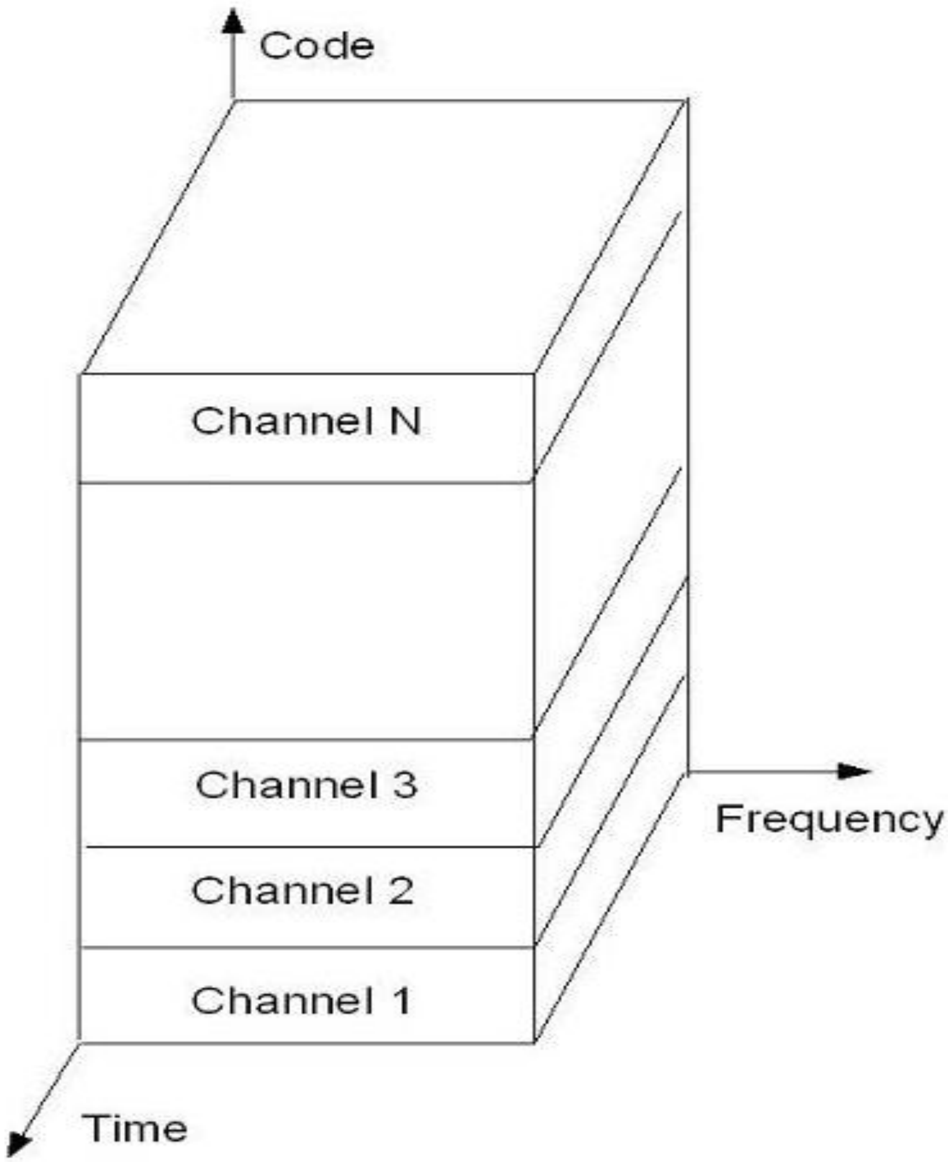


Figure: 3.1

Adjacent channel interference:

It appears when unwanted signals having frequency components that exist within or near the receiver pass band. The interference multi-operator, referred to as “Adjacent channel interference”, is the interference between two CDMA operators whose frequency carrier assignments are especially in situations where their cell towers are not collocated.

This results from signals that are adjacent in the frequency to the desired signal. This results from imperfect receiver filters that allow nearby frequencies to leak in, please remember your handset prices go down because the hardware put in there is cheaper and the filters that we put in there also do not have two stringent requirements. That is, the sharp cut off do not exist. Clearly if you have cheap filters, you will let in more adjacent channel interference. But we really cannot do much with the cost of the handsets. They must keep going down. So what is typically done is to use expensive, very well designed filters at the base station. In fact, the cost of the base station is being shared by so many numbers of users. So adjacent channel interference is actually handled more at the base stations but also at the handsets level. The problem can be severe if the interferer is very close to the subscriber’s receiver. So if my friend and I are going in the same car and by whatever coincidence we both are assigned adjacent channels, then we will have crosstalk or if the interference is in a channel which is used for control, then one of the calls might get dropped or some other problems might occur.

Another effect of adjacent channel interference is called the near far effect. What is the near far effect? When an interferer close to the base station radiates in the adjacent channel while the subscriber is actually far away from the base station. Please remember the path loss exponent is close to four. The signal strength goes down very fast to the power of four of the distance. So if my interfering handset is close to the base station, where as I am, as a subscriber far away from the base station, my signal will get a lot of interference at the base station. Let us look at it from an example. Let us first put a base station and the subscriber. So the subscriber is mobile and he is located at a certain distance from the base station. But there are lot of uses and let us have an interfering handset sitting inside a car which happens to be closer to the base station. As bad luck would have it, the interferer is radiating in an adjacent frequency band. So even though the subscriber is trying to communicate with the base station, by the time the signal reaches the base station, it is fairly weak. The path loss exponent is pretty high. so what is being received at the base station is a low signal level but still it can be handled. It is within the threshold. On the other hand, for the interferer which happens to be located much closer to the base station, it is radiating in the adjacent band and because of the imperfect filters, a lot of energy is leaking in. But it's a lot high energy.

Inter modulation:

The intermodulation products are generated both in transmitter (Tx) or receiver (Rx) paths, in the case that two or more frequencies are mixed and amplified in a nonlinear device. Intermodulation products of order x are the sums and differences in x terms of the original frequencies. Notice that if one of the terms of the product is weaker than the rest, the intermodulation product power would also decrease significantly. The nonlinear characteristics of the devices, whether Tx or Rx leads to these unwanted frequencies which may get transmitted if generated in the transmitter or receiver, will result in a co-channel type of interference at the victim receiver.

Handover:

Movement of MEO or LEO satellites, which hand over coverage of ground terminals to other satellites or between multiple neighboring spot beams, means that the path taken by traffic between terminals will change over time. When there is a change in path, we can expect changes in path delay.

The path taken will be altered for any packets already in transit whenever terminal handover occurs at the packets' destination. These 'in flight' packets will travel a slightly different path to reach their destination than previous or subsequent packets. This can lead to packet reordering for high rate traffic, where a number of packets are in flight as handover occurs, resulting in spikes in path delay as handover occurs. The larger distances and propagation delays in the constellation network increase the chances of this affecting in-flight traffic, making the effect greater than in terrestrial wireless networks.

Although low-rate traffic is less likely to experience these transient effects during handover, applications sending high-rate and extremely jitter sensitive traffic can be affected, and the impact of handover on network traffic must be carefully considered in the system design.

If the satellites along the path knew that a handover was about to take place at the destination terminal, it might be possible for them to buffer packets destined to the terminal along the path to prevent those packets from reaching the last hop before downlink until after handover has been completed. However, that would impose a lot of per-flow state on the satellite network, and is not practical for the high-rate traffic that is most likely to experience these transients. Handovers cannot always be easily predicted, particularly for mobile terminals experiencing shadowing.

Satellite diversity:

Satellite diversity can provide benefits in terms of reduced blockage probability, soft and softer-handoff capability, slow fading counteraction, and under certain conditions even increased system capacity. In a typical suburban environment the probability of blockage varies with the minimum elevation angle and the number of satellites in view. Reduced blockage translates immediately into improved quality of service. Note that the multiple satellites can be exploited very efficiently in a CDMA system adopting rake receivers to realize soft satellite-handoff and softer spot beam-handoff. CDMA also allows flexible allocation of diversity to different classes of terminals supported by IMT-2000. In fact, fixed or transportable terminals enjoying low blockage probability can be operated without satellite diversity in the forward link thus optimizing network resources exploitation. It should be noted that for packet services directed to nomadic users a selection diversity scheme may be preferable.

Satellite diversity exploitation in the forward link has a few differences with respect to the return link that are worth recalling. In the forward link satellite diversity must be forced by the system operator by sending the same signal to different satellites through highly directive antennas. Note that the forward link transmitted multiplex can adopt synchronous CDMA with orthogonal spreading sequences. Differently from the terrestrial case, the non-selective satellite fading channel preserves the multiplex orthogonality, thus minimizing intra-beam interference. It should be noted that forwarding the signal through different non co-located satellites somewhat increases the amount of inter-beam interference, thus causing an apparent capacity loss. The amount of forward link capacity loss due to satellite diversity exploitation depends on many system parameters.

In general we can say that by proper system design the loss can be kept within acceptable boundaries. Assuming transparent transponders, exploitation of satellite diversity in the return link is practically unavoidable due to the MT quasi Omni-directional antenna. Universal frequency reuse allows for satellite antenna arraying (similar to Deep Space probes ground reception techniques) whereby the different replicas of the same user terminal signal transponded by the different satellites are independently demodulated, time aligned and coherently combined at the gateway station. This detection technique, requiring a rake receiver, results in a drastic reduction in the user terminal EIRP even under LOS conditions

MODULE – IV
EARTH STATION AND VSAT SYSTEMS TECHNOLOGY

Earth Station:

The base band signal from the terrestrial network enters the earth station at the transmitter after having processed (buffered, multiplexed, formatted, etc.,) by the base band equipment. After the encoder and modulator have acted upon the base band signal, it is converted to the uplink frequency. Then it is amplified and directed to the appropriate polarization port of the antenna feed.

The signal received from the satellite is amplified in an LNA first and is then down converted from the down link frequency. It is then demodulated and decoded and then the original base band signal is obtained. Critical components will often be installed redundantly with automatic switch over in the event of failure so that uninterrupted operation is maintained. The isolation of low noise receiver from the high power transmitter is of much concern in the design considerations of earth station

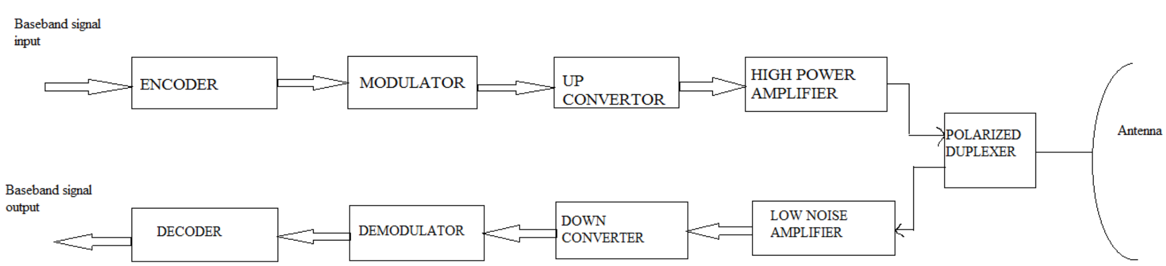


Figure 4.1

Transmitters:

Here the signal to be transmitted is converted to the uplink frequency, with proper encoding and modulation. It is then amplified and directed to the appropriate polarization port of the antenna feed. In a large earth station there will be many transmitters as well as receivers multiplexed together into one antenna to provide channelize communication through satellite transponders. Transmitters are very much expensive part of the earth station because of the tight specifications on out of band emission, frequency stability and power control that are necessary to avoid interference with other channels and satellites. Further as transmitters are not manufactured in large scale so there cost is high. The cost increases with the increase in transmitted power which may vary from tens to thousands of watts.

Since earth stations require the transmission of microwave power, they use high power amplifiers (HPAs) such as travelling tubes and multi cavity klystrons. In fact compared to klystrons, TWTAs allow high power over a wide bandwidth. These tubes require quite a good amount of cooling that is provided by water circulation using a close refrigeration system.

Here modulation is performed at 70MHz IF which is then up converted. The configurations (arrangements) for HPAs to be employed depend on the number of carriers to be transmitted and whether these are FDM or TDM signals. The most common configuration employs one HPA for each transponder to be used. It must be remembered that reliability is of at most importance in satellite communication and therefore the equipments in transmitters always employ some sort of redundancy configuration with automatic switch over in the event of some failure.

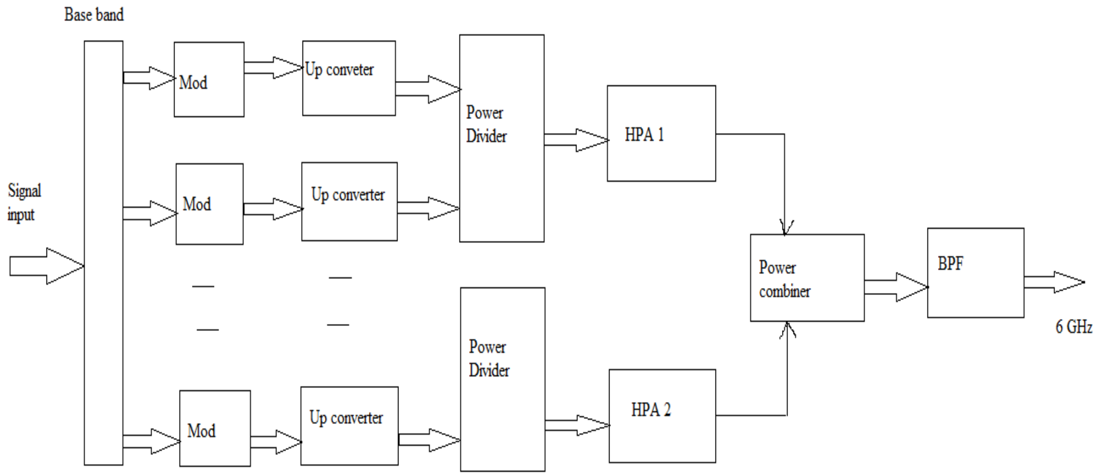


Figure: 4.2

Receiver:

Receiver of an earth station employs mainly low noise amplifier (LNA), down converter, demodulator, decoder and base band signal treatment equipments. In fact in the receive chain of the earth station the weak signals from the satellite are accepted by the same feed that carries the transmitter output. These two signals which differ in power by several orders of magnitude or kept separate in the frequency domain as they are assigned to the uplink and down link bands, and in addition by means of orthogonal polarization, diplexers are used to enhance the separation in the frequency domain.

It is very essential that the receiver should have first stages with very low noise and sufficiently high gain. In particular the large earth stations require such very low noise amplifiers. Therefore there cryogenically cooled parametric amplifiers are widely used, with liquid helium cooling at $4^o K$ above absolute zero to achieve noise temperatures of 20 to 40K at 4GHz. Medium and small earth stations use GaAs FET amplifiers with no cooling or electron thermal (peltier) cooling. These achieve noise temperatures in the range 50 to 120K at 4GHz and 120 to 300 K at 11GHz. LNAs used in earth stations usually cover the 500 MHz fixed service band at 4GHz and 750

MHz at 11 GHz. In receiver too some sort of redundancy configuration is used particularly for LNA.

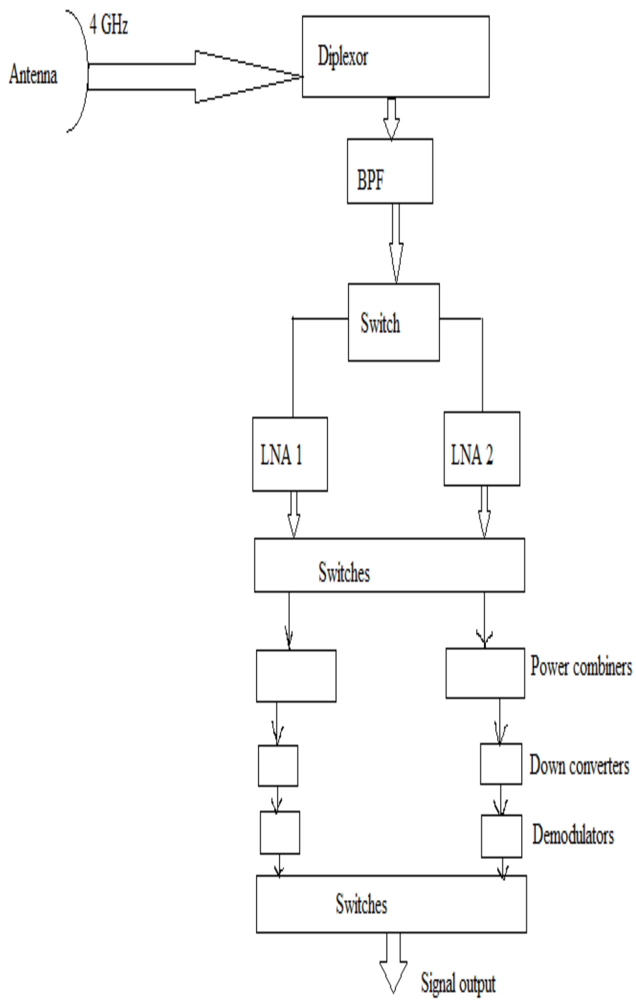


Figure: 4.3

Antennas:

The antenna systems consist of 1.Feed System 2.Antenna Reflector 3.Mount 4.Antenna tracking System.

Feed System: The feed along with the reflector is the radiating/receiving element of electromagnetic waves. The reciprocity property of the feed element makes the earth station antenna system suitable for transmission and reception of electromagnetic waves. The way the waves coming in and going out is called feed configuration Earth Station feed systems most commonly used in satellite communication are:

i)Axi-Symmetric Configuration

ii)Asymmetric Configuration

i) Axi-Symmetric Configuration In an axi-symmetric configuration the antenna axes are symmetrical with respect to the reflector ,which results in a relatively simple mechanical structure and antenna mount.

Primary Feed: In primary, feed is located at the focal point of the parabolic reflector. Many dishes use only a single bounce, with incoming waves reflecting off the dish surface to the focus in front of the dish, where the antenna is located. When the dish is used to transmit, the transmitting antenna at the focus beams waves towards the dish, bouncing them off to space. This is the simplest arrangement.

Cassegrain: Many dishes have the waves make more than one bounce .This is generally called as folded systems. The advantage is that the whole dish and feed system is more compact. There are several folded configurations, but all have at least one secondary reflector also called a sub reflector, located out in front of the dish to redirect the waves. A common dual reflector antenna called Cassegrain has a convex sub reflector positioned in front of the main dish, closer to the dish than the focus. This sub reflector bounces back the waves back toward a feed located on the main dish's center, sometimes behind a hole at the center of the main dish. Sometimes there are even more sub reflectors behind the dish to direct the waves to the fed for convenience or compactness.

Gregorian: This system has a concave secondary reflector located just beyond the primary focus. This also bounces the waves back toward the dish.

ii) Asymmetric Configuration

Offset or Off-axis feed: The performance of the axi-symmetric configuration is affected by the blockage of the aperture by the feed and the sub reflector assembly. The result is a reduction in the antenna efficiency and an increase in the side lobe levels. The asymmetric configuration can remove this limitation..This is achieved by off- setting the mounting arrangement of the feed so that it does not obstruct the main beam. As a result, the efficiency and side lobe level performance are improved.

Antenna Reflector:

Mostly parabolic reflectors are used as the main antenna for the earth stations because of the high gain available from the reflector and the ability of focusing a parallel beam into a point at the focus where the feed, i.e., the receiving/radiating element is located .For large antenna system more than one reflector surfaces may be used in as in the cassegrain antenna system. Earth stations are also classified on the basis of services for example:

1. Two way TV, Telephony and data

2. Two way TV

3. TV receive only and two way telephony and data

4. Two way data

From the classifications it is obvious that the technology of earth station will vary considerably on the performance and the service requirements of earth station

For mechanical design of parabolic reflector the following parameters are required to be considered:

Size of the reflector

Focal Length /diameter ratio

RMS error of main and sub reflector

Pointing and tracking accuracies

Speed and acceleration

Type of mount

Coverage Requirement

Wind Speed: The size of the reflector depends on transmit and receive gain requirement and beam width of the antenna. Gain is directly proportional to the antenna diameter whereas the beam width is inversely proportional to the antenna diameter .for high inclination angle of the satellite; the tracking of the earth station becomes necessary when the beam width is too narrow.

The gain of the antenna is given by

Gain= (η4ΠAeff)/ λ^2

Where Aeff is the aperture

λ is wave length

η is efficiency of antenna system

For a parabolic antenna with circular aperture diameter D, the gain of the antenna is:

Gain= (η4Π/λ^2) (ΠD^2/4) = η $\left(\pi D/\lambda\right)^2$

The overall efficiency of the antenna is the net product of various factors such as 1. Cross Polarization 2. Spill over 3. Diffraction 4. Blockage 5.Surface accuracy 6.Phase error 7. Illumination.

In the design of feed, the ratio of focal length F to the diameter of the reflector D of the antenna system control the maximum angle subtended by the reflector surface on the focal point. Larger the F/D ratio larger is the aperture illumination efficiency and lower the cross polarization.

Antenna tracking system:

Tracking is essential when the satellite drift, as seen by an earth station antenna is a significant fraction of an earth station's antenna beam width. An earth station's tracking system is required to perform some of the functions such as i)Satellite acquisition ii)Automatic tracking iii)Manual tracking iv)Program tracking.

Recent Tracking Techniques: There have been some interesting recent developments in auto-track techniques which can potentially provide high accuracies at a low cost. In one proposed technique the sequential lobbing technique has been implemented by using rapid electronic switching of as single beam which effectively approximates simultaneous lobbing.

Terrestrial interface:

Earth station is a vital element in any satellite communication network. The function of an earth station is to receive information from or transmit information to, the satellite network in the most cost-effective and reliable manner while retaining the desired signal quality. The design of earth station configuration depends upon many factors and its location. But it is fundamentally governed by its Location which are listed below,

• In land • on a ship at sea • Onboard aircraft

The factors are 1. Type of services 2.Frequency bands 3.Function of the transmitter 4. Function of the receiver 5.Antenna characteristics.

Power test methods:

Noise power ratio (NPR):

Noise power ratio (NPR), the traditional measure of intermodulation noise for FDM systems in the communication field. The principle of NPR measurement involves loading the entire base band spectrum, save for the one voice- frequency channel slot, with noise, simulating in total the loading of the system by actual voice traffic in all but that channel. Noise appearing in the unloaded slot is manifestation of intermodulation. The ratio of that noise power to the per-channel loading noise power is the NPR. NPR is measured by a setup as shown in figure . The system can be between any two points of interest the noise generator band is limited by filters to the base band, and the noise generator level is set to simulate full load according to the CCIR formulas

$P = -15 + 10 \log N$ dBmO, $N \geq 240$

$P = -1 + 4 \log N$ dBmO, $N < 240$

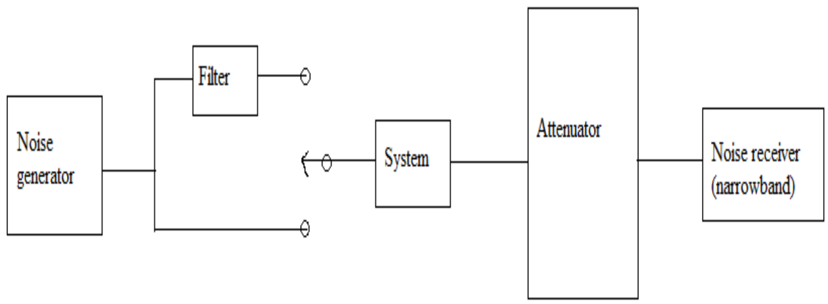


Figure: 4.4

The filter has stop band corresponding to the selected voice channel. The receive pass band corresponds to that same channel the difference between the noise receiver readings with the filter in and out is the NPR. Measurement is typically made at low, center and highest telephone channels. If they are carried out at different levels (and deviations for FM), they have a shape indicative of the system nonlinearities and frequency response. NPR is usually converted to an equivalent per channel signal to noise ratio.

BWR = 10 log $\frac{base\ band\ total\ bandwidth}{signal\ channel\ bandwidth}$

NLR = 10 log $\frac{base\ band\ noise\ test\ power}{test-tone\ power\ per\ channel}$

= dBmO of loading calculation.

The equivalent base band signal - to – noise ratio due to intermodulation is then

S/N = NPR + BWR – NLR.

The measurement of G/T:

System temperature T_S can be determined by conventional laboratory noise generator measurement of receiver noise figure and radio metric measurements of antenna temperature. The basic system parameter $G/_{T_S}$ also requires a knowledge of antenna gain, and as the antennas get larger, this characteristic is not so easy to get. The gain of smaller antennas, say less than 7 or 8m, can be found from pattern measurements on a range or by comparison to gain standard, but these measures are cumbersome and may be impartial for larger antennas.

Large earth stations, with antenna sizes up from 10m, can sometimes use a carefully calibrated satellite signal to measure $G/_{T_S}$. In effect, $G/_{T_S}$ is calculated from the link equation, knowing the other variables. This method is often used with intermediate sized antennas (from 5 to 15m).

An engineer's method has been developed for the measurement of $G/_{T_S}$ for large antennas using the known radio noise characteristics of stellar sources, usually called radio stars. These characteristics, particularly S, the flux density of the source in $W/_{m^2}$ .Hz, have been accurately measured by radio astronomers.

Lower orbit considerations:

In order that a satellite can be used for communications purposes the ground station must be able to follow it in order to receive its signal, and transmit back to it. Communications will naturally only be possible when it is visible, and dependent upon the orbit it may only be visible for a short period of time. To ensure that communication is possible for the maximum amount of time there are a number of options that can be employed:

- The first is to use an elliptical orbit where the apogee is above the planned Earth station so that the satellite remains visible for the maximum amount of time.

- Another option is to launch a number of satellites with the same orbit so that when one disappears from view, and communications are lost, another one appears. Generally three satellites are required to maintain almost uninterrupted communication. However the handover from one satellite to the next introduces additional complexity into the system, as well as having a requirement for at least three satellites.

VSAT (Very Small Aperture Terminal) Systems:

VSAT (Very Small Aperture Terminal) describes a small terminal that can be used for two-way communications via satellite. VSAT networks offer value-added satellite-based services capable of supporting the Internet, data, video, LAN, voice/fax communications, and can provide powerful private and public network communication solutions. They are becoming increasingly popular, as VSATs are a single, flexible communications platform that can be installed quickly and cost efficiently to provide telecoms solutions for consumers, governments and corporations.

VSAT networks arose in the mid- to late 1980s as a result of electronic and software innovations that permitted all of the necessary features to be contained into an affordable package about the size of a personal computer. By affordable, we mean that the user pays a total network cost that is competitive with many terrestrial data network alternatives. This includes the cost of ownership of the VSATs and possibly the hub, along with the rental of adequate space segment capacity. The price of a Ku-band VSAT itself started around $15,000 in the mid-1980s, dropping over the years to a level of around $6,000 in 1995, settling at approximately $1,500 at the time of this writing (C-band VSATs may cost slightly higher due to a larger dish needed to receive from a satellite with lower EIRP than at Ku-band, and a somewhat more expensive SSPA due to the higher cost of this class of device). This represents a 90% discount; however, the specific price of a VSAT depends on its configuration and feature set, along with the size of RF amplifier and dish. In recent years, greater integration and large-scale production have brought to price to the same level as a high-end PC and thus makes more applications justifiable from a financial perspective. This permits large-scale application of two-way VSAT technology, including small businesses and SOHO use.

Overview of VSAT systems:

Very Small Aperture Terminal (VSAT) refers to an earth station linked to satellite using RF link and usually will have different diameter antennas. VSATs provide the important communication link to set up a satellite based communication network. VSATs can be used for voice, data, or video transmission and reception. The VSAT comprises of two modules viz. an outdoor unit and an indoor unit. Outdoor unit mainly houses Antenna; feed horn, RF Transceiver, LNA, Power amplifier. The antenna size is typically 1.8 or 2.4 meter in diameter, although smaller antennas are also in use. The indoor unit functions as mux-demux, modem and interfaces with the end user equipments like PCs, LANs, Telephones or an EPABX. Typical schematic consisting various VSAT subsystems.

The VSAT antenna is typically in the range of 1.2m to 2.8m; the size depends on the satellite coverage performance (*G*/*T* and EIRP), the capacity requirements, and the frequency band. The following discussion will address the most popular case: Ku band VSATs with antennas between 1m and 1.8m. As reviewed previously, their rapid rise in the United States was based on Ku-band because Ku-band is not shared with terrestrial microwave. Hence, VSATs can be placed where needed to provide service. No frequency coordination is needed, and licenses can be granted on a network basis—this is termed *blanket licensing* because the national regulator (the FCC in the United States) authorizes the network based on equipment characteristics rather than antenna location (critical at C-band). Ku-band FSS satellites usually have higher EIRP than C-band (50 versus 36 dBW) to allow the smallest antennas on the ground and to overcome the increased rain attenuation at this higher frequency. Adjacent satellite interference is less for the same Earth station antenna size because main-lobe gain increases while side lobe gain does not (for the same satellite spacing). This is taken advantage of by recognizing that a smaller Ku-band antenna has about the same interference potential as the larger antenna used at C-band. A smaller Ku-band antenna can be placed in an inconspicuous place such as on the roof of the building or behind a low screen wall. The transmit power level, being below 4W into the antenna, would not be a hazard to humans for these types of installations (provided that one does not stand close to the antenna and directly in the RF path).

C-band VSATs are required in areas without adequate Ku-band satellite capacity; therefore, the user must usually carry out the necessary frequency coordination prior to use in order to protect existing terrestrial microwave stations.

Because potential customers are really users of telecommunications rather than technology managers, VSAT marketers must make a complete service offering that includes equipment, installation, maintenance, and on occasion, hub, satellite capacity, and network operations. This requires that entrants in this market be prepared to become more vertically integrated than previously required for satellite or teleport operations and equipment sales. Going into this business requires both a significant investment and a commitment to a specific technology platform in terms of VSAT supplier, satellite transponder bandwidth (which must be taken for an extend term), and skilled human resources.

VSAT outdoor unit:

The Outdoor unit is usually mounted near the antenna systems outside hence the name. It consists of RF frequency converters (Up/down converter), Power Amplifier, Low Noise Amplifier (LNA), OMT and Antenna system. The Up/Down converters convert frequencies IF to RF frequencies and vice versa. For example, up converter converts 70MHz to 6175 MHz and down converter converts 3950MHz to 70MHz for C band application. Power Amplifier will amplify the signal before transmitting to the feed horn of the Antenna system. LNAs are designed to amplify the noise added received signal received from the satellite. It is designed such that it will amplify the signal and not the noise. Noise temperature defines LNA performance. Antenna system houses reflector, feed horn, mount and cables. VSAT antenna usually varies from 1.8 meters to 2.4 or 3.8 meters. Feed horn is mounted at focal point of the antenna. The feed horn guides transmitted power towards the antenna dish and will go to the medium consecutively. It also collects the received power from dish and will enter into the LNA. Feed horn is made of array of microwave passive components. The outdoor unit is connected through coaxial cable to the indoor unit, which is situated inside the room/building. Length of the cable is usually about 300 foot (approx. 90 meter).

VSAT indoor unit:

The IDU consists of MUX/DEMUX, EDU (Encryption Decryption Unit), modem (modulator-demodulator). MUX will interface with end user equipments viz. telephone, computers and sometime with EPABX and LAN or router, if it has to carry more information. MUX will multiplex all the channels connected with it using TDM. On receiver side DEMUX is used to de-multiplex the channels and passed on to respective end user equipments. EDU is basically the Encryption-Decryption unit which provides security by modifying the information to be transmitted. On receiver side encryption technique will be conveyed so that the information can be retrieved back again. MODEM is basically performs modulator-demodulator functionality on transmit and receive side respectively. Modulator inserts information on intermediate frequency (IF), usually called carrier. This is done based on modulation scheme set. Usually QPSK scheme is used in satellite communication and Forward Error Correction is also employed in modem which enhances the BER for the same transmitter power usually used in non-FEC systems. In order to communicate between VSAT 1 and VSAT 2, modulator frequency of VSAT 1 and demodulator frequency of VSAT 2 need to be same and vice versa to complete full duplex communication channel. Based on frequency assignments as per FDMA various modem and RF frequency converters are set.

Remote VSAT

The primary function is that of a communications network access device for the local PCs on a LAN, legacy data terminals, and phones (analog, ISDN, and VoIP). In the most common configuration, the VSAT offers an RJ-45 connection to the LAN, for which there are three possibilities:

• A direct LAN connection (making the VSAT appear to the LAN as either a switch or router);

• Connection through a PC that has been loaded with custom software for the particular VSAT network architecture (e.g., proprietary software that is either downloaded through the Internet or from a CD-ROM);

• A router that provides the interface to the LAN (the router also allows local connection to the Internet for alternate routing of traffic).

The baseband equipment performs the necessary protocol conversion or adaptation, an important part of which is to fool the end computer systems into thinking that it is passing data to the distant computer over a minimum delay connection. Various approaches to this have been tried in the past and some have remained effective in allowing the delay of a GEO satellite link to be accommodated.

VSAT network Architectures:

Any telecommunication services there are three basic implementations services: one-way, split-two-way (referred to as split-IP sometimes, when referring to internet traffic) and two-way implementation. Further division of two-way implementation is star and mesh network architectures.

There are two Architectures:

Star: In Star network architecture, all traffic is routed via the main hub station. If a VSAT want to communicate with another VSAT, they have to go through the hub station. This makes double hop link via the satellite. Star is the most common VSAT configuration of the TDM/TDMA. These have a high bit rate outbound carrier (Time Division Multiplexed) from the hub to the remote earth stations, and one or more low or medium bit rate (Time Division Multiple Access) inbound carriers. In a typical VSAT network, remote users have a number of personal computers or dumb terminals that are connected to the VSAT terminal that in turn is connected to a centralized host computer either at individual sites or at a data processing centre. Data sent to the VSAT terminal from the data terminal equipment (DTEs) is buffered and transmitted to the hub in packets.

Mesh: Meshed VSAT networks provide a way to set up a switched point to point data network that can have the capability for high data rates of up to 2Mb/s. Links are set up directly between remote terminals usually on a call by call basis. These networks are usually configured to operate without a large central earth station and carry a mix of data traffic and telephony traffic or only data traffic. These networks generally will have a network control station, which controls the allocation of resources across the network. This control centre is only involved in the signaling for the call setup/teardown and in monitoring the operation of the network.

Access control: In general, multiple access schemes suitable for use in VSAT networks are packet-oriented. Loosely speaking, they may be classified into two broad categories; namely, contention or random access schemes and reservation schemes. The main contention schemes, suitable for use in VSAT systems, are based on the ALOHA concept, of which there are three variations; namely, pure ALOHA, slotted ALOHA and reservation ALOHA

Multiple access selection:

One satellite can simultaneously support thousands of Pico terminal accesses. This means that the number of users in a Pico terminal network can be a multiple of this, resulting in a communication network with an enormous size. To control such a number of terminals, the multiple access schemes for Pico terminals may be a combination of frequency division multiple access (FDMA) and code division multiple access (CDMA). The CDMA spread-spectrum technique normally used for satellite communications is direct sequence spread spectrum.

The use of spread spectrum techniques in Pico terminal networks has several advantages.

- It is advantageous as multiple access schemes, because (asynchronous) SSMA does not need network control and synchronization.
- A second advantage is the inherent interference protection of the system. This is important for Pico terminals which will be more or less sensitive to interference from unwanted directions due to their small antennas.
- A third advantage is that Pico terminals can transmit with low power densities giving less interference problems.
- Finally SSMA gives some kind of message privacy through the encryption with a code word.

NGSO constellation design: Orbits

NGSOs are classified in the following three types as per the inclinations of the orbital plane

- Polar Orbit
- Equatorial Orbit
- Inclined Orbit

In polar orbit the satellite moves from pole to pole and the inclination is equal to 90 degrees. In equatorial orbit the orbital plane lies in the equatorial plane of the earth and the inclination is zero or very small. All orbits other than polar orbit and equatorial orbit are called inclined orbit. A satellite orbit with inclination of less than 90 degrees is called a pro grade orbit. The satellite in pro grade orbit moves in the same direction as the rotation of the earth on its axis. Satellite orbit with inclination of more than 90 degrees is called retrograde orbit when the satellite moves in a direction opposite to the rotational motion of the earth. Orbits of almost all communication satellites are pro grade orbits, as it takes less propellant to achieve the final velocity of the satellite in pro grade orbit by taking advantage of the earth's rotational speed.

Coverage:

The designer of a satellite system has few degrees of freedom in designing a pay load to provide optimum coverage. This occurs in some missions where a shared space craft has to accommodate a no. of payloads. A GEO can be selected or a constellation of NGSO satellites can be designed to provide the necessary coverage overlap between successive satellites. The determination of coverage area, while initially an exercise in simple geometry, is eventually heavily influenced by the available technology both on the ground and in space, and other aspects such as the radiation environment. First consider the geometrical aspects of determining an optimum coverage.

A spacecraft orbits at a distance r_s from the center of the earth, C. Assume that the space craft is a communications satellite and that it needs to be in contact with an earth station located at E. The elevation angle to the satellite is θ. using the sine rule:

$[r_s / sin(90 + \theta)] = [d / sin(\gamma)]$

This yield to $cos(\theta) = [r_s sin(\gamma)]/d$

The angle γ will yield the coverage area on the surface of the earth assuming the satellite has a symmetrical coverage about nadir. The distance d will determine the free space path loss along the propagation path, and will be a factor in the link budget design.

Frequency bands:

Low earth orbit satellite systems providing data and voice service to mobile users tend to use the lowest available RF frequency. The EIRP required by the satellite transponder to establish a given C/N ratio in the mobile receiver is proportional to the square of the RF frequency of the downlink. The power that must be transmitted by a mobile transmitter is also proportional to RF frequency squared when the mobile uses an Omni directional antenna. Since the cost of satellites increases as the EIRP of the transponders increases, a lower RF frequency yields a lower cost system. This is one reason why L-band is allocated for mobile satellite services.

Delay and throughput:

Delay in a communications link is not normally a problem unless the interactions between the users are very rapid – a few milli seconds apart in response time. Long delays, such as those associated with manned missions to the moon. For most commercial satellite links that are over long distances, particularly those with satellites in geostationary orbit, the main problem was not delay, but echo. A mismatched transmission line will always have a reflected signal. If the mismatch is large, a strong echo will return. Over a GEO satellite link, the echo arrives back in the telephone head set about half a second after the speaker has spoken, and usually while the speaker is still speaking. This will interrupt the speaker and the conversation becomes fragmented. The development of echo suppress and even better, echo cancellers, solved the problem.

The time delay for a signal passing between LEO user one and LEO user to in the same instantaneous coverage is 5.4 ms (2.7 ms up & 2.7 ms down) and the go and return (round-trip) delay between the two users is twice this at 10.8 ms. A transoceanic link delay using inter satellite links averaged 253 ms – almost the same as for a GEO satellite link. Delay can also have an adverse effect and the throughput of the signal. Customer acceptance of a service has been found to be driven by three prime factors: access ability (i.e, can the required connection be obtained immediately on request ?), availability (i,e. Once connected, will the call be dropped ?), and performance (i.e, is the error rate low and the throughput high ?).

Non geostationary orbit (NGSO) constellation design:

Constellation design:

- Basic formation
- Station keeping
- Collision avoidance

Constellation: set of satellites distributed over space intended to work together to achieve a common objective. Satellites that are in close proximity are called clusters or formations.

Constellation architectures have been fuelled by recent development of small, low cost satellites.

Principal factors to be defined during constellation design		
Factor	Effect	Selection criteria
No. of satellites	Principal cost & coverage driver	Minimize number consistent with meeting other criteria.
Constellation pattern	Determines coverage Vs latitude	Select for best coverage
Minimum elevation angle	Principal determinant of single satellite coverage	Minimum value consistent with constellation pattern

Altitude	Coverage, environment launch and transfer cost	System level trade of cost Vs performance
No. of orbit planes	Determines coverage plateaus, growth and degradation	Minimize consistent with coverage needs.
Collision avoidance parameters	Key to preventing constellation destruction	Maximize the inter satellite distances at plane crossings

MODULE – V

SATELLITE PACKET COMMUNICATION

Message transmission by FDMA: With Frequency Division Multiple Access (FDMA) the entire available frequency channel is divided into bands and each band serves a single station. Every station is therefore equipped with a transmitter for a given frequency band, and a receiver for each band.

To evaluate the performance of the FDMA protocol, we assume that the entire channel can sustain a rate of R bits/sec which is equally divided among M stations i.e. R/M bits/sec for each. The individual bands do not overlap as such there is no interference among transmitting stations. This allows for viewing the system as M mutually independent queues. Each of these queues has an individual input process governing the packet generation process for that user. If the packet length is a random variable P, then the service time afforded to every packet is the random variable$T = {}^{MP}/_{R}$. To evaluate the throughput of the individual station we note that every bit transmitted is a "good" bit and thus the individual throughput is the fraction of time the individual server is busy. The total throughput is M times the individual throughput while the average packet delay can be obtained by applying little's result to the individual queue.

M/G/1 queue:

Consider a queuing system, in which arrivals occur according to a Poisson process with parameter and in which x is the service rendered to the customers, is distributed according to a distribution B (t). In such a queuing system, an outside observer sees the number of customers in the system as equal to that seen by an arriving customer, which equals that seen by a departing customer.

The following holds for an M/G/1 queuing system:

$$D = x + W = x + \frac{\lambda x^2}{2(1-p)}$$

Where: D= Average delay time; p = λx= Load factor; W= Queuing time.

Therefore, for an FDMA system, considering a typical user that generates packets according to a Poisson process with rate λ packets/sec and its buffering capabilities are not limited, the time required for the transmission of a packet. Each node can therefore be viewed as an M/G/1 queue since each packet size is not constant. Thus, using the known system delay time formula for M/G/1 queuing systems we get that the expected delay of a packet is:

$$D= T + \frac{\lambda T^2}{2(1-\lambda T)}$$

And the delay distribution is given by,

$$D^* = X^*(s)\frac{s(1-p)}{s-\lambda+\lambda X^*(S)}$$

Where X^*(S) is the Laplace transform of the transmission time

Message transmission by TDMA:

In the time division multiple access (TDMA) scheme the entire time frame is divided into time slots, pre-assigned to the different stations. Every station is allowed to transmit freely during the slot assigned to it, that is, during the assigned slot the entire system resources are devoted to that station. Techniques based on contention are suitable for traffic that is bursty in nature. Centralized control is absent in a contention-based system, as such when a node needs to transmit data, it contends for control of the transmission medium. The major advantage of contention techniques is simplicity, as they are easily implementable in individual nodes. The contention techniques are efficient under light to moderate network load, but performance rapidly degrades with increase in load level. Message transmission by TDMA can be done using the ALOHA protocol, packet reservation and tree algorithm. The ALOHA scheme was invented at the University of Hawaii for the purpose of interconnecting remote stations and data terminals to a central server over a packet radio network. The ALOHA model vis-a-vis satellite communications uses satellite connections between earth stations. The model consists of three top-level modules: an earth station (earth segment), a central satellite station (space segment) that serves as the communications link between the earth stations and a statistics module. Towards achieving the objective of a simple design, some functions such as satellite round-trip delay, collision detection, and transmission delay are implemented on the satellite. Any collision detected during the receipt of a packet by the satellite is tagged before onward broadcast to receiving earth stations. A continuous retransmit process is initiated by the transmitting earth station until it receives the original packet back without the collision flag. At which point the packet is discarded, and the transmission of the next packet in queue commences. Suffice to note here that all packets are equal in size and both pure and slotted ALOHA operations are supported by the earth station module.

Pure aloha satellite packet switching:

Stations are allowed random access of the satellite through a common radio frequency band and the satellite broadcasts all received signals on a different frequency band. This enables the stations to perform their duty of monitoring for the presence of packet collisions. The stations implement the simplest protocol; whenever it has a packet to send, it simply does so. In this setup, packets will suffer collision and colliding packets are destroyed. A station determines whether any of its sent packets has suffered a collision or not by monitoring the signal sent by the satellite, after the maximum round-trip propagation time. If all packets have a fixed duration of T, then a given packet will suffer collision if another station starts to transmit at any time from T before to until T after the start of the packet. This gives a vulnerable period of 2T. The channel utilization can be calculated based on this assumption. The channel utilization, measured as the channel throughput S, in terms of the available channel capacity G is given by

$S = Ge^{-2G}$.

S is maximum and equals 1/2e at G = 1/2, which is approximately 0.18. This value is referred to as the capacity of the pure Aloha channel i.e. 18%.

Slotted aloha:

The Pure Aloha implemented with a slotted channel variation is known as the slotted Aloha protocol. For the slotted Aloha variant, all packets are of equal length and time is slotted. The packet transmission time a full slot. Packets are only transmitted in the next subsequent slot to their arrival slot. It also assumes that there is no buffering, i.e. a station never has more than one packet to transmit in a single time slot, in which case, the station would have needed to buffer one or more packets for subsequent transmission. To accommodate the “no buffering” assumption, it assumes that there is an infinite number of stations, with each new arrival from a new 'source' station. Inevitable collision occurs if more than one station venture to transmit packets in one and the same time slot, and consequently the receivers cannot receive the packets correctly. Successful transmission happens only when there is exactly one packet transmitted in a slot. If no packet is transmitted in a slot, the slot is called idle. If there is a collision, the colliding packets are retransmitted at a later slot after a randomly chosen back-off period. Such packets are also called backlogged packets. Slotted ALOHA was developed as an improvement on the efficiency of pure ALOHA. In this protocol, the channel is divided into slots equal to T (duration of packet transmission). Packet transmission is initiated only at the beginning of a slot. This reduces the vulnerable period in half from 2T to T and improves efficiency significantly by reducing the probability of collision. Channel utilization, measured as throughput S, in terms of the available channel capacity G is given by

$$S = Ge^{-G}.$$

This gives a maximum throughput of 37% at G = 1 i.e. 100% of offered (available) channel capacity.

Throughput:

It can be proved that the average number of successful transmissions for slotted ALOHA is $S = G * e^{-G}$. The maximum throughput Smax is 0.368, when G = 1. In other words, if a frame is generated during one frame transmission time, then 36.8 percent of these frames reach their destination successfully. This result can be expected because the vulnerable time is equal to the frame transmission time. Therefore, if a station generates only one frame in this vulnerable time (and no other station generates a frame during this time), the frame will reach its destination successfully.

Packet reservation:

Dynamic channel allocation protocols are designed to overcome the drawback faced by static conflict-free protocols, which involves (inefficient) under utilization of the shared channel, especially when the system is lightly loaded or when the loads of different users are asymmetric. The static and fixed assignment in these protocols, cause the channel (or part of it) to be idle even though some users have data to transmit. With dynamic allocation strategies, the channel allocation changes with time and is based on current (and possibly changing) demands of the various users. The more responsive and better usage of the channel achieved with dynamic protocols does not come for free: it requires control overhead that is unnecessary with static protocols and consumes a portion of the channel. An example of a protocol that belongs to the family of dynamic conflict-free protocols is the Mini Slotted Alternating Priority (MSAP) protocol. It is designed for a slotted system, i.e., one in which the time axis is divided into slots of equal duration and where a user's transmission is limited to within the slot (this represents a TDMA system). The MSAP protocol guarantees conflict-free transmission by way of reservation. All these protocols have a sequence of bits precede serving to reserve or announce upcoming transmissions (this is known as the reservation preamble).

To ensure freedom of transmission conflicts it is necessary to reach an agreement among the stations on who transmits in a given slot. This agreement involves collecting information as to which are the ready stations, i.e., those who request channel allocation, and an arbitration algorithm by which one of these stations is selected for transmission. This latter mechanism is nothing but imposing a priority structure on the set of earth stations each of which constitutes a separate priority class. The MSAP protocol handles properly various such structures. The priority enforcement is based on the observation that if in the most recent slot the channel was allocated to station i then it must have been the one with the highest priority. Defining the priority structure is thus the determination of the transmission order after the transmission of a station. There are three types of priority structures: a) Fixed, b) Round-Robin and c) Alternating priority structures.

Tree algorithm:

This is a collision resolution protocol (CRP). As opposed to the instability of the ALOHA protocol, the efforts of CRP are concentrated on resolving collisions as soon as they occur. Here, the fixed-length packets involved in collision participate in a systematic partitioning procedure for collision resolution, during which time new messages are not allowed to access the channel. The stability of the system is ensured provided that the arrival rate of new packets to the system is lower than its collision resolution rate. The tree-type protocols have excellent channel capacity capabilities, but are vulnerable to deadlocks due to incorrect channel observation [3]. The basic form of the Collision Resolution Protocol is the Binary-Tree Algorithm. According to this protocol when a collision occurs in a slot r, all stations that are not involved in the collision wait until the collision is resolved. The stations involved in the collision split randomly into two subsets. The stations in the first subset retransmit in slot r + 1, while those in the second subset wait until all those in the first finish transmitting their packets successfully. If slot r + 1 is either idle or contains a successful transmission, the stations of the second subset retransmit in slot r + 2. If slot r + 1 contain a fresh collision, the procedure is repeated. A collision is resolved when the all the transmitting stations know that all packets involved in the collision have been transmitted successfully. The time interval starting with the original collision (if any) and ending when this collision is resolved is called Collision resolution interval (CRI). The Operation of a binary-tree protocol can also be described by the Stack Algorithm.

The performance of the binary-tree protocol can be improved in two ways. The first is to speed up the collision resolution process by avoiding certain, avoidable, collisions. The second is based on the observation that collisions among a small number of packets are resolved more efficiently than collisions among a large number of packets. Therefore, if most CRIs start with a small number of packets, the performance of the protocol is expected to improve. Examples of improved binary-tree protocols are

1. The Modified binary-tree protocol: Its operation requires ternary feedback, i.e., the users have to be able to distinguish between idle and successful slots.

2. The Epoch Mechanism: Its operation models the system in such a way that the CRI starts with the transmission of exactly one packet (yields a throughput of 1) by determining when packets are transmitted for the first time.

3. The Clipped binary-tree protocol: This improved on the Epoch mechanism by adopting the rule that whenever a collision is followed by two successive successful transmissions, the packets that arrived in.

Error control for digital satellite links:

Error control coding:

The primary function of an error control encoder-decoder pair (also known as a codec) is to enhance the reliability of message during transmission of information carrying symbols through a communication channel. An error control code can also ease the design process of a digital transmission system in multiple ways such as the following: a) the transmission power requirement of a digital transmission scheme can be reduced by the use of an error control codec. This aspect is exploited in the design of most of the modern wireless digital communication systems such as a cellular mobile communication system. b) Even the size of a transmitting or receiving antenna can be reduced by the use of an error control codec while maintaining the same level of end-to-end performance [example: VSAT (Very Small Aperture Terminal) network terminals]. c) Access of more users to same radio frequency in a multi-access communication system can be ensured by the use of error control technique [example: cellular CDMA]. d) Jamming margin in a spread spectrum communication system can be effectively increased by using suitable error control technique. Increased jamming margin allows signal transmission to a desired receiver in battlefield and elsewhere even if the enemy tries to drown the signal by transmitting high power in-band noise. The major categories of activities on error control coding can broadly be identified as the following: a) to find codes with good structural properties and good asymptotic error performance, b) to devise efficient encoding and decoding strategies for the codes and c) to explore the applicability of good coding schemes in various digital transmission and storage systems and to evaluate their performance.

Forward Error Correction (FEC):

Complete process of decoding is applied on the received sequence to detect error positions in the sequence and correct the erroneous symbols. However, the process of error correction is not fool-proof and occasionally the decoder may either fail to detect presence of errors in a received sequence or, may detect errors at wrong locations, resulting in a few more erroneous symbols. This happens if, for example, too much noise gets added to the signal during transmission through a wireless channel.

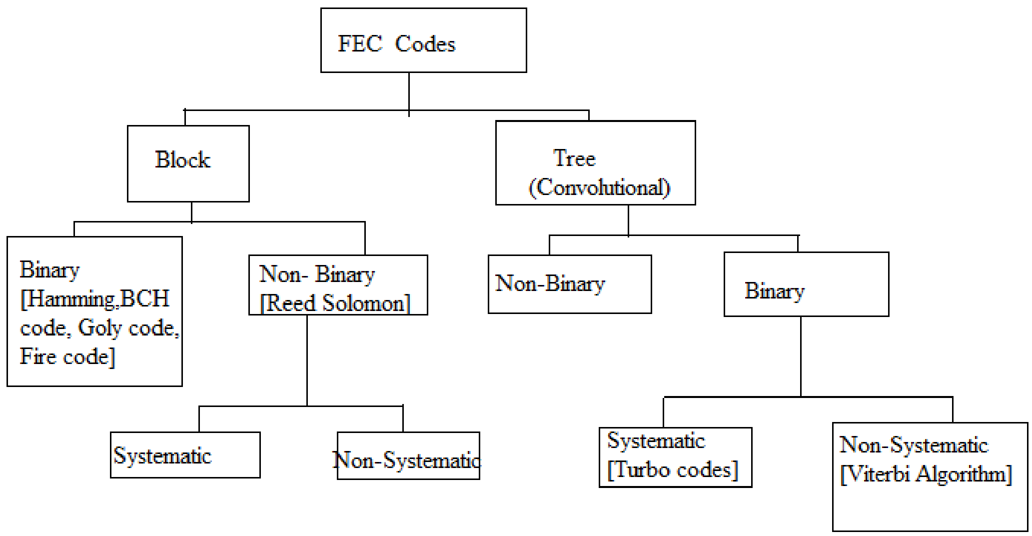


Figure: 5.1

Block Codes:

The encoder of a block code operates on a group of bits at a time. A group or 'block' of 'k' information bits (or symbols) are coded using some procedure to generate a larger block of 'n' bits (or symbols). Such a block code is referred as an (n, k) code.

Encoding of block code:

The encoder takes k information bits and computes (n-k) parity bits from these bits using a specific code generator matrix. A codeword of 'n' bits (or symbols) is generated in the process. This operation may be 'systematic' or 'nonsystematic'. In a systematic encode the first (or last) bits in a codeword are the information bits and the rest (n-k) bits are the parity check bits.

For a nonsystematic code, the information symbols do not occupy such fixed positions in a codeword. In fact, they may not be identified by a simple mean.

Following matrix notation, the encoding operation can be described as a matrix multiplication: C = D.G where, D: information matrix and G: generator matrix. For a systematic block code, the generator matrix can be expressed as G = [P/I] k, where 'I' is a (k * k) identity matrix and 'P' is a (k x [n-k]) parity check matrix.

Following an equivalent polynomial notation, the encoder starts with a 'message polynomial' defined as below.

$$m(x) = m_0 + m_1x + m_2x + \cdots + m_{k-1}x_{k-1} = \sum_{i=0}^{k=1} m_i x_i$$

Here m_i 's are the information bits (or symbols) and 'x' is an indeterminate representing unit delay. The exponents of 'x' indicate number of unit delays.

Convolution codes:

Convolutional codes, which are used in a variety of systems including today's popular wireless standards (such as 802.11) and in satellite communications. Convolutional codes are beautiful because they are intuitive, one can understand them in many different ways, and there is a way to decode them so as to recover the mathematically most likely message from among the set of all possible transmitted messages.

Convolutional codes are a bit like the block codes in that they involve the transmission of parity bits that are computed from message bits. Unlike block codes in systematic form, however, the sender does not send the message bits followed by (or interspersed with) the parity bits; in a convolutional code, the sender sends only the parity bits. The encoder uses a sliding window to calculate r > 1 parity bits by combining various subsets of bits in the window. The combining is a simple addition in F2, as in the previous lectures (i.e., modulo 2 addition, or equivalently, an exclusive-or operation). Unlike a block code, the windows overlap and slide by 1. The size of the window, in bits, is called the code's constraint length. The longer the constraint length, the larger the number of parity bits that are influenced by any given message bit. Because the parity bits are the only bits sent over the channel, a larger constraint length generally implies a greater resilience to bit errors. The trade-off, though, is that it will take considerably longer to decode codes of long constraint length, so one can't increase the constraint length arbitrarily and expect fast decoding.

The encoder looks at K bits at a time and produces r parity bits according to carefully chosen functions that operate over various subsets of the K bits, with K = 3 and r = 2 (the rate of this code, 1/r = 1/2). The encoder spits out r bits, which are sent sequentially, slides the window by 1 to the right, and then repeats the process

Implementation of error detection on satellite links:

Invariably the error detection is a user defined service, which forms a part operating protocol of any type of communication system. Implementation of error correction by use of error detection and retransmission requires the use of protocols. The protocols are the set of actions, which helps in an accurate and ordered data transmission through the link. The usual technique is ARQ, but ARQ system works well on terrestrial data links with relatively low data rates and short time delays but their implementation on satellite link is more difficult due to the long transmission delay and thus forward error correction is preferred for satellite links.

The following three basic techniques can be used, which are based on the type of the link used for retransmission request:

1. In a one way simplex link, the ACK and NAK signal must travel on the same path as the data, so the transmitter must stop transmission after each block and wait for the receiver to send back a NAK or ACK before it retransmits the last data block or sends the next one. Here the data rate is very slow and thus useful for links in which data are generated slowly.
2. In a stop and wait system, the transmitting end sends a block data and waits for the acknowledgement to arrive on the return channel. Though the implementation is simple but the amount of delay is the same as the simplex case.
3. In a continuous transmission system using the go- back – N technique, data are sent in the form of a block continuously and held in a buffer at the receiver of the end of the link. When the data block arrives, it is checked for error and the appropriate ACK or NAK is send back to the transmitting end with block number specified. When a NAK (N) is received, the transmit end goes back to block N and retransmits all subsequent

blocks. The whole process requires a total hold time of 480ms of data on a satellite link. In the method after the receive signal, the delay results only due to transmission and thus the throughput is much greater than with the stop and wait system.

Overview of future satellite communication systems: Introduction to satellite laser communication

A crosslink, or communication between two satellites, may be needed to solve certain requirements of satellite communication architecture. Laser communications offers the user number of unique advantages over radio frequency (RF) systems, including size, weight, power and integration ease on the spacecraft. Integration ease issues include compactness of terminals, elimination of complex frequency planning and authorization, and RF interference issues. Laser cross links will be enable the transfer of data between satellites at rates compatible with ground fiber networks. This is an exciting era for space laser communications. Not only is information transfer driving the requirements to higher data rates, but laser crosslink technology explosions, global development activity, and increased hardware/design maturity are all contributing to interest in space laser communication Laser communication links also hold the promise of high data rate. Satellite-ground links would, however, be complicated by propagation loss and sporadic availability. The optical communication systems become more and more attractive as the interest in high-capacity and long-distance space links grows. Advancer in laser communication system architectures and optical components technology make such high capacity links feasible. The laser communication equation (LCE) is a basic resort of LICS's (Laser Inter-satellite Communication System) analysis. Based on the background and receiver noise and the type of signal modulation which is to be detected, a required signal is generated. The ratio of received signal to required signal is the system link margin. Identifying these gains and losses requires intimate knowledge of the system design, including both the internal constraints and design choices and knowledge of the external factors, including range, data rate, and required signal criteria.

The laser communication equation, this equation is used for analysis and optimization. The equation starting with the transmit source power, the designer identifies all sources of link degradation (losses) and improvements (gains) and determines the received signal level. The laser communication equation (LCE) is very analogous to the link equation for any RF communication link.

The link equation can be written as

$$P_r = P_t G_t G_r L_t L_R L_r$$

where: P_r …the receive signal power (dB), P_t …the transmitted signal power (dB), G_t…the effective transmit antenna gain (dB), L_t…the efficiency transmitter loss (dB), L_R…the free space range loss (dB), G_r…the receive antenna gain (dB), L_r…the efficiency loss associated with the receiver (dB).

Data relay communication satellites:

Data Relay Satellite System (DRSS) is primarily meant for providing continuous/real time communication of Low-Earth-Orbit (LEO) satellites/human space mission to the ground station. A data relay satellite in the Geo-stationary Orbit (GEO) can see a low altitude spacecraft for approximately half an orbit. Two such relay satellites, spaced 180^0 apart in GEO, could theoretically provide continuous contact for any spacecraft in LEO. The data rates of Earth Observation (EO) satellites are steadily increasing and will exceed 1 Gbps in near future with high resolution multispectral & hyper spectral imaging systems and memory sizes of onboard designed for beyond 10s of Terra bytes. Thus, data transfer from earth observing LEO satellite to Ground Station (GS) is becoming a real challenge because of the limited visibility of the LEO spacecraft from GS, allowing only short time for data download. Further, continuous visibility is an indispensable requirement for manned missions as human lives are involved. Study shows that nearly 41 ground stations provide about 70% visibility of low earth missions. The above challenges can be met through the use of relay satellites especially in Geostationary Orbit wherein, EO satellites orbiting in LEO transmit data to GEO satellite which then relays the data to ground as it is always visible to the ground station.

Architecture of a Generic DRSS satellite:

DRSS architecture is categorized into three segments, namely Space Segment, Ground Segment and User Segment.

a) DRSS Space Segment

The DRSS space segment primarily consists of high altitude satellite system of GEO or Molniya class, defined in a modular way providing several payloads satisfying the data relay service requirements at different orbital positions with on-board state-of-the-art technologies.

b) DRSS Ground Segment

The Ground Segment consists of mission and satellite control centre, which includes the TTC, satellite control and mission control elements. Its task would be to control and operate the DRSS GEO Space Segment. DRSS Network Control Centre, whose task will include managing and operating the end to end data relay links and to provide data relay customer interface for mission request, mission planning, scheduling and mission execution.

c) DRSS User Segment

The users of DRSS services can be broadly categorized as Institutional users (e.g. Space agency), Commercial users (e.g. Other Launcher/Satellite Agencies) and Human Space Missions.

Satellite mobile services:

Mobile satellite service (MSS) is the term used to describe telecommunication services delivered to or from the mobile users by using the satellites. MSS can be used in remote areas lacking wired networks. Limitations of MSS are availability of line of sight requirement and emerging technologies.

The basic Mobile satellite service (MSS) System comprises of these three segments:

- **Space segment:** Space segment is equipped with satellite pay-load equipment. The Pay load is used to enable the ability of the satellite for users in space communication.
- **User segment:** The user segment consists of equipment that transmits and receives the signals from the satellite.
- **Control segment:** The control segment controls the satellite and operations of all internet connections to maintain the bandwidth and adjust power supply and antennas.

The mobile satellite services are classified into the following five types:

1. Maritime mobile satellite service (MMSS):

This service consists of different types of earth stations such as mobile earth station (MES); ship earth station (SES); and communication earth station (CES).This service is mainly used in shipyards and military ships. In this type of service, the mobile earth station located on ships provide commercial and safety communication. MMSS service enables mobile satellite link between the communication earth station and the ship earth station or between two associated ships and other satellite communication stations in all positions in sea or in ports.

A maritime terminal is a portable or fixed on the board ship, whereas the communication earth station is a maritime earth station located at a specified fixed point on the coast to provide a feeder link for MMSS. The ship earth station is a maritime earth station fixed on board ships or other floating objects that provide the communication links with the subscribers onshore via a communication earth station and a communication space craft.

2. Land mobile satellite service (LMSS):

The Land mobile satellite service has a mobile earth station located on different types of trains and other transportation systems. This service consists of a personal location beacon terminal that acts as an earth station. This service can be used in different applications such as military applications remote and rural environments. LMSS enables a mobile link between the communication earth system and the vehicle's earth system or two or more vehicles' earth stations or two MSC stations. The communication earth station is used as an earth station to be located in a specified fixed point on the coast to provide a feeder link for LMSS.

The VES is a land mobile earth station fixed on the board or rail line to provide a communication link between the terrestrial subscribers through VES and communication spacecraft. The land vehicle or person alerts the service for distrain or safety in the LMSS system.

3. Aeronautical mobile satellite service (AMSS):

A mobile satellite service in which earth stations are located onboard aircraft, survival aircraft, airplanes and helicopters is known as aeronautical mobile satellite service (AES).This service is also used in business and private communication and traffic control. This service consists of various earth stations like a mobile earth station, an aircraft earth station and a ground earth station. A special emergency locator terminal which is either fixed or portable onboard is used as earth station and enables the link between the ground earth station and the aircraft earth station. The AES is an aeronautical earth station that is fixed on board to provide a communication link with the subscribers on land via GES and space craft.

This is mostly used in the aircraft applications as it provides safety through the radio communication to control flight locations and the movements of light and the positions of aircraft on land as well.

4. Personal mobiles satellite service (PMSS):

This is a communication service provided by the satellite for supporting mobile, fixed and broadband communication systems. The satellites can be geo-stationary or non geo-stationary satellites. This service consists of two earth stations: base earth station and personal earth station. It also consists of a PLB terminal which is used in this service for the coordination of the mobile system. This type of service enables a link between a base earth station and personal earth station, or between a personal earth station, or between an earth base station and two satellites using the same satellite providers. It is a handheld terminal carried by an individual or fixed on board. It provides two communication links for subscribers by satellites through gateways or personal earth station.

5. Broadcast mobile satellite service (BCMSS):

A broadcast satellite system service is a one-way radio communication solution that transmits signals by earth stations, and retransmits the signals by space stations. The present broadcast mobile satellite service operates at a frequency of 12 GHz. The broadcast satellite service system transmits data in three types of broadcasting forms:

- Audio broadcasting
- Video broadcasting
- Data broadcasting

This service is equipped with very small terminals used for transmitting signals from small antennas. This service can be used in applications like ships, airlines and TV broadcasting systems.

Applications of satellites:

Satellites that are launched in to the orbit by using the rockets are called man-made satellites or artificial satellites. Artificial satellites revolve around the earth because of the gravitational force of attraction between the earth and satellites. Unlike the natural satellites (moon), artificial satellites are used in various applications. The various applications of artificial satellites include:

1. Weather Forecasting
2. Navigation
3. Astronomy
4. Satellite phone
5. Satellite television
6. Military satellite
7. Satellite Internet
8. Satellite Radio.

1. Weather forecasting

Weather forecasting is the prediction of the future of weather. The satellites that are used to predict the future of weather are called weather satellites. Weather satellites continuously monitor the climate and weather conditions of earth. They use sensors called radiometers for measuring the heat energy released from the earth surface. Weather satellites also predict the most dangerous storms such as hurricanes.

2. Navigation

Generally, navigation refers to determining the geographical location of an object. The satellites that are used to determine the geographic location of aircrafts, ships, cars, trains, or any other object are called navigation satellites. GPS (Global Positioning System) is an example of navigation system. It allows the user to determine their exact location at anywhere in the world.

3. Astronomy

Astronomy is the study of celestial objects such as stars, planets, galaxies, natural satellites, comets, etc. The satellites that are used to study or observe the distant stars, galaxies, planets, etc. are called astronomical satellites. They are mainly used to find the new stars, planets, and galaxies. Hubble space telescope is an example of astronomical satellite. It captures the high-resolution images of the distant stars, galaxies, planets etc.

4. Satellite phone

Satellite phone is a type of mobile phone that uses satellites instead of cell towers for transmitting the signal or information over long distances.

Mobile phones that use cell towers will work only within the coverage area of a cell tower. If we go beyond the coverage area of a cell tower or if we reach the remote areas, it becomes difficult to make a voice call or send text messages with the mobile phones. Unlike the mobile mobiles, satellite phones have global coverage. Satellites phones uses geostationary satellites and low earth orbit (LEO) satellites for transmitting the information.

5. Satellite television

Satellite television or satellite TV is a wireless system that uses communication satellites to deliver the television programs or television signals to the users or viewers.

TV or television mostly uses geostationary satellites because they look stationary from the earth. Hence, the signal is easily transmitted. When the television signal is send to the satellite, it receives the signal, amplifies it, and re transmits it back to the earth. The first satellite television signal was send from Europe to North America by using the Telstar satellite.

6. Military satellite

Military satellite is an artificial satellite used by the army for various purposes such as spying on enemy countries, military communication, and navigation. Military satellites obtain the secret information from the enemy countries. These satellites also detect the missiles launched by the other countries in the space. Military satellites are used by armed forces to communicate with each other. These satellites also used to determine the exact location of an object.

7. Satellite internet

Satellite internet is a wireless system that uses satellites to deliver the internet signals to users. High-speed internet is the main advantage of satellite internet. Satellite internet does not use cable systems, but instead it uses satellites to transmit the information or signal.

8. Satellite radio

Satellite radio is a wireless transmission service that uses orbiting satellites to deliver the information or radio signals to the consumers. It is primarily used in the cars. When the ground station transmit signal to the satellite that is revolving around the earth, the satellite receives the signal, amplifies it, and redirects the signal back to the earth (radio receivers in the cars).