NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

DIGITAL SATELLITE COMMUNICATION SYSTEM

Graduation Project
EE – 400

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ABSTRACT

We had thought to do our work on the Digital Satellite Communication, and then we searched of the important parts on this subject since the Digital Satellite Communication is one of the most common and important parts in the Communication System.

The last few years, the importance of Digital Satellite Communication has been increased rapidly, although there has been an explanation and revolution in the Digital Satellite Communication System technology over the past years since Digital Satellite was published.

There are several objective of this project, which are as the following in each chapter:

- In the first chapter deals with the details about the Historical of Satellite Communication.
- In the second and the third chapter we are going to see how to fix a satellite in its orbit which is at a constant distance from the earth and to see how we feed the satellite of power.
- Also to cover the concepts of satellite transponder and the multiple access techniques.
- And in the end to study the whole system, Digital Satellite Communication System, as Earth station, Satellite links, the Antenna in the digital satellite communication field and the transponders.

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CHAPTER ONE

HISTORICAL OF SATELLITE COMMUNICATION

1.1 Overview

In 1954, Arthur C. Clarke proposed the idea of using an *earth – orbiting* satellite as a really point for communication between two earth station. In 1957, the Soviet Union launched Sputniks I, which telemetry signals for 21 days. This was followed shortly by launching of Explorer I by the US in 1958, which transmitted telemetry signals for about fine months. A major experimental step in communication satellite technology was taken with the launching of Telstar 1 from Cape Canaveral on July 10,1962.

In 1963 Congress passed the Communications Satellite Act; establishng the Communications Satellite Co-operation (Comsat) and barring the Bell system from further direct participation in satellite communications. While we will not go into the many conflicting reasons why this should or should not have been done (the authors have friends who are involved on all sides of matter), this caused considerable bitterness in the Bell system. Which had invested substation resources in the ECHO and TELSTAR programs. The Bell engineers felt that, once their company proved that communications satellite would work, the opportunity to profit by their investment was taken away and given to someone else. The TELSTAR satellite considerable knowledge from pioneering works by John R. Pierce. The satellite was capable of relaying TV programs across the Atlantic's; this was made possible only through the use of maser receiver and large antennas. In July 1964, INTELSAT, a multinational organization, was formed. The purpose of INTELSAT was to design, develop, construct, establish, and maintain the operation of the space segment of a global commercial communication satellite system. Early Bird (INTELSAT 1), a geostationary communicatons satellite, was launched in April 1965. In a period of seven years, four generations of this historical account of telecommunication swtching is based on Joel (1984). On the other hand, power and antenna requirements were serve; a typical ECHO link from bell laboratories in New Jersey to the Jet Propulsion Laboratory in California used to 10 kW transmitter at ends, an 85 ft dish in California.

1.2 Satellite System Architectures

Supported services satellite systems can complement terrestrial systems, as they are particularly suitable for covering sparsely populated areas. In other areas they can support emerging networks such as the broadband (B)-ISDN or mobile systems. Satellite systems can support a wide set of interactive and distributive services that, according to ITUR (the successor to thhe CCIR), are divided into three categories; conversion, control and management of the satellite transmission resources.

a) **Fixed Satellite Services :** Concerning communication services between earth station at given positions. Video and sound transmissions are included, primarily point-to-point basis, but these services also extended to some broadcasting applications.

b) **Broadcast Satellite Services :** Principally comprising direct reception of video and sound by the general public.

c) **Mobile Satellite Services :** Including communications between a mobile eart station and a fixed station, or between mobile stations.

Each of these services group are defined for a different satellite environment and technology, but they cover the whole range of B-ISDN interctive and distributive services defined in ITU-T (formerly CCITT) recommendation. These satellite services are designed for provision by both geostationary orbit (LEO) satellite systems.

1.3 Satellite Systems

Satellite systems essentially include the following elements:

1.3.1 Ground Segment

Which includes traffic interfaces, gateway function for traffic adaptation, protocol conversion, control and management of the satellite transmission resources a space segment comprising the satellite (s). Two main types of satellites are considered; transparent and future on-board processing (OBP) of the many types of OBP satellite, those that include switching function (e.g. ATM local connection switching functions), will be designated here as switching satellites.

1.3.2 Earth Station

The initially small number of earth station has now increased consderably, with operation on all continents. Typical earth station characteristic is 5 to 10 kW of transmitter power radiation from an antenna having a reflector between 10 and 32 m in diameter. Reception is by the same antenna. The overall receiving system noise temperature is between 50 and 200 K at 5^0 elevation angle. A very suitable characteristic indicative of the quality of receiving system in the merit G/T, that is the ratio of the receiving antenna gain to the system noise temperature in Kelvin's, expreessed in dB/K. A large earth station, having an antenna diameter about 25 m and a system noise temperature of 50 K, operating at 4 GHZ has a G/T figure of about 41 dB/K. In smaller earth station the G/T figure decreases.

1.4 Decicated Satellite

Specific national requirements have promoted several countries to start dedicated satellte for their own domestic systems. Dedicated satellite offers technical advantages whereby it is possible either to increase the transponder traffic capacity or to reduce the cost of the earth segment by simplifying the earth station with the use of smaller antennas.

1.4.1 Inmarsat

An international marine satellite communication system, Inmarsat is also in operation. A. European consortium has proposed the Marots system as the first stage of

Imarsat, interfacing with Marisat. Inmarsat has 53 members' nations future Intelsat and satellite my include maritime communications capability.

1.4.2 Aerosat

Clearly there are other potential mobile users for satellite communications besides ships. US, CANADA and several European countries had planed an aeronautical satellite system. Although the project came to standstill because of economic and institutional obstacles, considerable work has been done on defining the Aerosat system and this may eventually bear fruit.

1.5. International Telecommunication Satellite Organization

INTELSAT was established in 1964, whereby it became possible for all nations to use and share in the development of one satellite system. Its prime objective is to provide on a commercial basis the space segment for International Public Telecommunications Services of high quality and reliability. To be available to all areas of the world where the INTELSAT organization had grown to 114 investor members as of February 1988. Communication is the American signatory of INTELSAT. A part from its global system, INTELSAT is currently leasing satellite transponders to European PTT authorities for their domestic communication.

And now we are going to see on this chapter some information about what are we going to study so as:

1. *Power Supply :*

   All working satellites need power to operate. The sun provides power to most of the satellite orbiting earth. This power system uses solar arrys to make elecricity from sunlight, batteries to store the electricity, and distribution units that send the power to all the satellite's instruments.

2. *Command and Data :*

   The Command and Data Handing system controls all the functions of the spacecraft. It's like the satellite brain. The hert of this is the Flight computer.

There is also an input/output processor that directs all the control data that moves to and from the Flight Computer.

3. ***Communications :***

The communications system has a transmitter, a recevier, and various antennas to relay messages between the satellite and earth. Ground control uses it to send operating insturctions to the satellite's computer. This system also sends pictures and other data captured by the satellite back to engineers on earth.

4. ***Pointing Control :***

The Pointing Control system keeps the satellite steady and pointing in the right direction. The system uses sensors, like eyes, so the satellite can "see" wehere it's pointing. The satellite needs a way to move into its proper position, so the system has a propulsion mechanism or momentum wheel. The type of pointing control a satellite needs depends on its mission. A satellite making scientific observations needs a more precise steering system than a communications satellite does.

5. ***Mission Pyload :***

The Payload is all the equipment a satellite needs to do its job. It's different for every mission. A communications satellite needs large antenna reflectors to send telephone or TV signals. An earth remote sensing satellite needs digital camera and image sensors to take pictures of the earth's surface. A scientific research satellite needs attelescope and image sensors to record views of stars and other planets.

CHAPTER TWO

SATELLITE COMMUNICATIONS

2.1 Overview

A communications satellite is a spacecraft that carries aboard communications equipment, enabling a communications link to be established between distant points. Satellite that orbit the earth do so a result of the balance between centrifugal gravitational forces. Johannes Kepler (1571-1630) discovered the laws that govern satellite motion. Although Kepler was investigating the motion in planets and their moons (so-called heavenly bodies), the same laws apply the artificial satellites launched for communications purposes. Before examining the role of these satellites play in telecommunications, a brief intruding to Kepler's laws will be presented as they apply to such satellites. Kepler's laws apply to any two bodies in space that interact through gravitation. The more massive of the bodies is called the primary end the other secondary or satellite.

2.2 Kepler's Law

2.2.1 Kepler's First Law

Kepler's first law, states that the satellite will follow an elliptical path its orbit around the primary body. An ellipse has two focal points or (foci). Thee center of mass of two-bodies systems, termed the barycentre, is always center on one of the foci. In our specific case, because of the enomous difference between the masses of the earth and satellites, the center of mass always coincides with the center of the earth, which is therefor at one of the foci. This is an important point because the geometric properties of the ellipse are normally made with reference to one of the foci that can be selected to be one centered in the earth.

2.2.2 Kepler's Second Law

Kepler's second law state that for equal time intervals the satellite sweeps out equal areas in the orbital plane, facused at the barycenter. Referring to assuming that the satellite travels distance S1 and S2 meters in 1 s, the areas A1&A2 will be equal. The average velocities are S1 and S2 m/s. Because of the equal area law, it is obivous that distance S1 is greater thaan distance S2, and hence the velocity S1 is greater than velocity S2 generalising. It can be said that the velocity will be greatest at the point of closest approach the earth (termed the perigee) and will be at least the farthest. Point from the earth (termed the pogee).

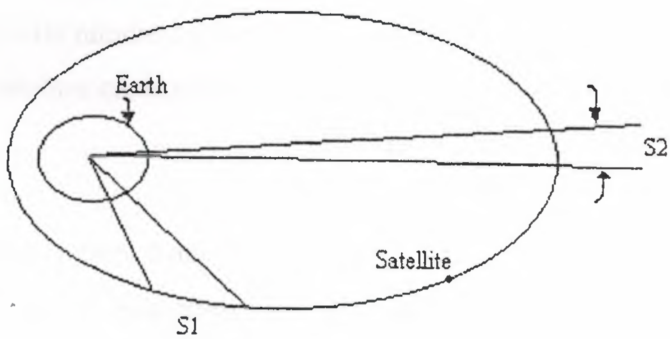


***Figure (2.1)** Kepler's Second Law*

2.2.3 Kepler's Third Law

Kepler's third law states that the square of the periodic time of orbit is promotional to the cube of the mean distnce between the two bodies. The mean distance as used by Kepler can be shown to be equal to the semimajor axis, and the third law can be stated in matheematical frorm as:

$$a = Ap^{\frac{2}{3}} \tag{2.1}$$

Where A is a constant. With a in Km and P in mean solar days, the constant A for earth evaluates to A = 42241.0979

These equatins apply for the ideal cases of a satellite orbiting a peerfectly spherical earth with no disturbing forces.

In reality, the earth's equatorial bulge and external disturbing forces will result deviations in the satellite motion from the idea. Fortunately thee major deviations can be calculated and allowed for satellite that orbit close to the earth (coming within several hundred kilometers) will be affected by atmospheric drag and by the earth's magnetic field. For the more distant satellites, the main disturbing forces are the gravitational fields of the sun and the moon.

2.3 Satellite Orbits

Although an infinite numbers of orbits are possible, only a very limited number of these are of use for satellite communicatons. Some of the terms useed in describing an orbits are

Apogee. The point farthest from the earth.
Perigee. The point of closest approach to the earth.

Ascending node, the point where the orbit crosses the equatorial plane going from south to north and the angle from the earth's equatorial plane to the orbital plane measured counterclockwise at the ascending node.

2.3.1 Geostationary Orbit

A geostationary satellite is one that appears to be stationary relative to the earth. There is only one geostationary orbit, but this occupied by a large number of satellites. It is most widely used orbit by far, for the very pratical reason that the earth station antennas don't needs to track geostationary satellites. The first and obvious requirements for a geostationary satellite is that it must have zero inclination. Any other inclination would carry the satellite over some range of latitudes and hence would not be geostationary.

Thus the geostationary orbit must lie in thi earth equatorial plane. Th second obvious requirements are that geostationary satellites should travel eastward at the same rotational velocity as the earth. Sincere this velocity is constant, then from Kepler's second law.

2.3.2 Geo-synchronous Orbit

Basic Orbital Characteristics

The earth's period of rotation, that is, the time taken for one complete rotation about its center of mass relative to the stellar background, is one sidereal day, approximately 23 hours 6 minutes 4 seconds. If a satellite has a durect, circular orbit and its period of revlution measured as above, it is a geo-synchronous satellite. The radius of its orbit (Rg) will be 422164 km. and its hight abov the earth's surface will be about 35786 km. If this satellite daily Earth track (that is, the locus of the points on the points on the earth's surface that rae vertically below the satellite at any instant) is traced, the maximum extent of the pattern in degrees of latitude, north and south of the eqyator, is equal to the angle of inclination of the orbit. Provided that the orbit is indeed circular, the north-going track crosses-over point of the north-going tracks is no longer located in the equatorial plne and te pattern becomes asymmetrical.

Advantages

The GSO is better for the most communication systems than any other orbit. Thee reasons are:

One satellite can provide continous links between earth stations. An inclined geosynchronous satellite can do this also, although the geo-graphocal area that can be served is more limited if the angle of inclination is large, and the disadvantages of using satellite with an orbital period of less than one siderial day for systems that are required to provide continous connections.

The gain and radiation pattern of satellite antennas can be obtimized so that the geographical area illuminated by the beam, called the footprint that canbe matched accurately to the service area, yielding significant benefits.

The geo-graphical area visible from the satellitee, and therefor potentially accessible for communication, is very large, as showing in the figure (2.1) below the diameter of the area with in which the angle of elevation σ of geo-stationary satellite is greater thaan 5^0 is about 19960 km. If the orbit is accurately geo-stationary, earth station antennas of considerable gain can be used without automatic satellite tracking equipment cost and minimizing the operational attenuation required.

The assignement used in different geo-stationary satellite networks can be coordinated efficiently, the satellite footprints can be matched to the service area, and earth station antennas usually have high again.

Disadvantage

1. A satellite link from earth to station via ageo-stationary satellite is very long.
2. The angle of elevation of the satellite as seen from earth station in high latidues is quite low, leading at times to degraded radio propagation and possible obstruction by hills, buildings, and so on.

2.3.3 Inclined Elliptical Orbits

a. Basic orbital

The shape of an ellipse is characterized by its eccentricity ε, where:

$$\in = (1 - b^2 / a^2)^{\frac{1}{2}} \tag{2.2.a}$$

a and b are the semi-major and semi-minor axes of the ellipse. There are two foci located on the major axis and separated from the orijin ellipse by distance c, where

$$c = \varepsilon a \tag{2.2.b}$$

For an earth satellite with an elliptical of the earth. The points on the orbitwhere the satelliite is most and least distnce from theearth are called the appogee and the periigee respectively. The greaatest and least distances from the surface of the earth, the altitudes of apogee and pergee ha and hpgiven by

$$h_a = a(1+\in) - R_E \tag{2.3}$$

$$h_p = a(1-\in) - R_E \tag{2.4}$$

a, b are semi-major and semi-minor axes of the ellipse. These various terms are illustarted in Figure (2.2)

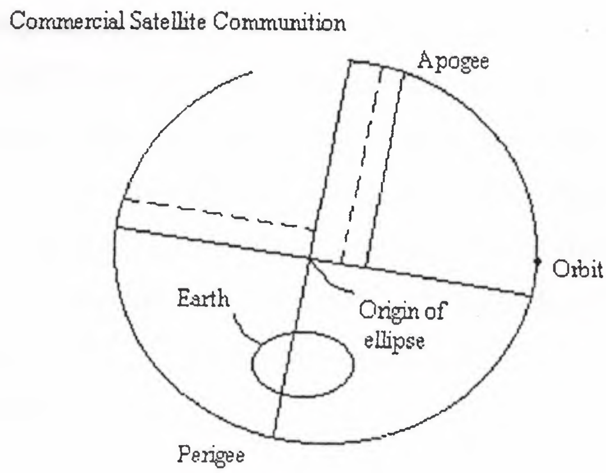


Figure (2.2) *Semi major and semi manor axis of the ellipse*

A satellite is perfectly circular orbit has uniform speed round that orbit, but the speed of motion a satellite in an elliptical orbit varies. As the satellite moves from apogee to perigee its potential energy falls and its kinetic energy, as reealed by its speed, rises. Correspondingly, the potential energy rises and the speed fails as the satellite moves from perigee to apogee. This variation of speed is conventially expressed in the form of Kepler's second law of planetary motion as shown in page(6).

b. The Earth Coverage Of Satellite In elliptical Orbits

Satellite in orbits of substantial eccentricity spend most of each orbital perid at a high altitude, close to the heiht of their apogee, from which they can cover a large footprint. In general they are of little use at low altitude, near to perigee. The systems that might find such orbits of value aree national or regional in coverage rather than global. Thus it is necessary to stabilize the Earth track, to ensure that the point on the earth directly beneath the apogee should be consistently located at an appropriate point in the services area.

c. High Latitude Coverage

A point on the surface of the earth sweeps through right ascension at a constant rate of approximately 3600/24=15° per hour. A satellite in a direct elliptical orbit with period of T (hours) sweeps through right ascension in the same direction as the the earth and at an average rate 360°/T per hour, although the rate will be considerably less than the average near apogee and more than the average near perigee. The Earth track of the Molniya orbit, centered as an example on lonitude 0°, the satellite passes thhrough apogee twice each day, at about the same location in the celestial frme of reference. At each apogee the satellite is seen from the earth surface to be within a few degrees of a central point around latitude 60° N and, for this example at lonritude 0° or 180° for a period of about eight hours.

d. Short Orbital Period

Satellite in circular orbits with heihgt above the earth of 8000 km. have an orbital period of 4.7 hours; 12 satellite in phsed orbits might be needed to provide continous coverage of a service area tahtis coninential in extent. A satellite with an eliptical orbit having a period of two hours might also have a height above the earth's surface at apogee of 8000 km., depending on the eccentricity of its orbits.

e. Medium-Altitude Orbits

Geo-stationary satellite have great advantages for communications applications where polar coverage is not required. In the early days of satellite communication, it was fered that one-way trasmission times exeeding 250 ms might be an unacceptable impediment to telephone conversation. Geo-stationary satellite seems likely to continue to dominate satellite communications with high-capacity links between fixed points. However, there has recently been a revival of interest in using medium-altitude orbits for serving mobile earth stations, because compared with the GSO, the transmission loss is lower.

2.3.4 The Global Star System

Loral Qualcomm Satellite Services company develop the Global-Star at 1944.the first group is suppsed launched in mid 1997, service will begin in mid 1998, and full service will be in 1999. Global-Star use of MMA technology allows users to connect multiple satellite, improves single qulity, eliminates intergerence, and disconnets cross talk and loss of data.

2.3.5 The Orboccomm System

The orbital communication co-operation (Orboccomm) is a law earth orbital (LEO) satellite system intended to provide two way message and data communication servicess and position determination. The first two satellite o (Orboccomm) launched at April 1995. In Feb 1996 the production subscriber communication equipment became available. Orboccomm covers 67 countries and about two-third of the earth's populatio. This is served by launched by the end of 1997. During the interval until the costellation is completed, the licenses will be building their own ground stations and beinning their own service. Offered in europe and most of latin american beginning in 1997. Fullg lobal availability is projected for 1999.

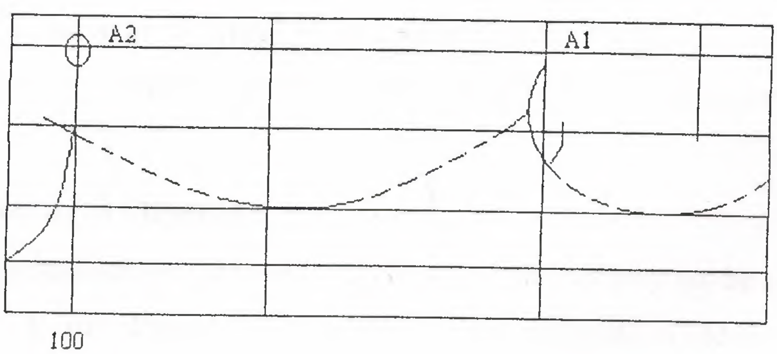
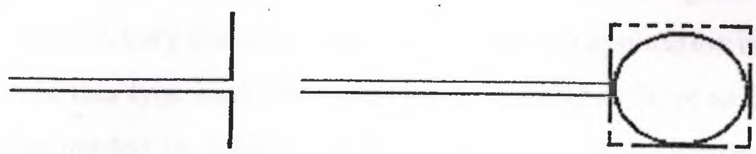


Figure (2.3) Longitude (degrees)

2.4 ANTENNAS

2.4.1 Wire Antennas

Wire antenns are familiar to the layman because they are seen vertically everywhere. In automobiles, building ships aircraft, and so on. There are various shaes of wire antennas such as stright wire (dipole), loop, and helix, which are like the below;



(a) Dipole (b) circular loop

Figure (2.4) Straight wire Dipole

Loop antennas neds not only be circuilar. They may take the form of rectangular, squre, ellipse, or ny other configuration. The circular loop is the most common because of its simplicity in construction.

2.4.2 Aperture Antennas

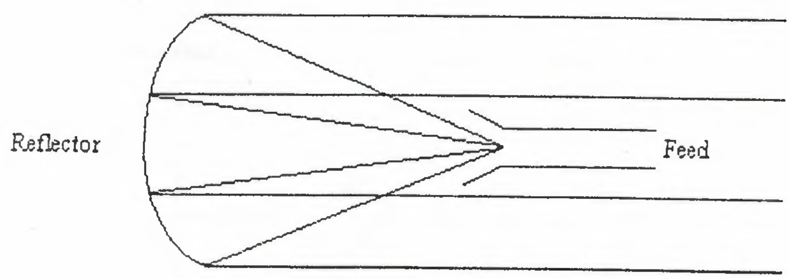
Aperture Antennas may bee more familiar to layman today then in the past because of the increasing demand for most sophesticated forms of antennas and utilization of higher frequencies. Some forms of aperture antennas of this type are very usefull for aircraft or spacecraft applications, because they can be very conveniently flush monted on the skin of aircraft or spacecraft. In addition, they can be covered with a dielectric material to protect them from hazardous conditios of environment.

2.4.3 Array Antennas

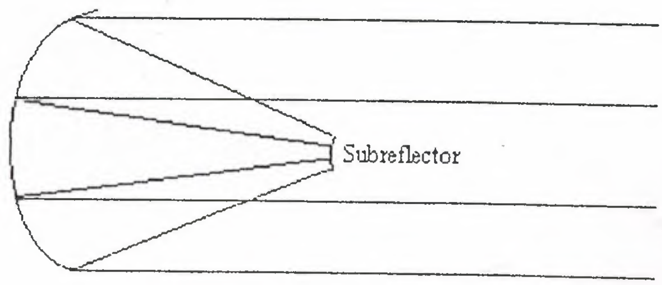
Many applications rewuire radiation characteristic that may not be achievable by a single element. It may, however, be possible that an aggregate of radiating elements in an electrical and geo-metrical arrangement (an arry) will result in the desirde radiation characteristics. The arrangement of the array may be such tht the radiation from the element adds up to give a radiation maximum a particular directions, minimum in others as desired.

2.4.4 Reflector Antennas

The causes in the exploration of outeer space has rulted in advancement of antenna theory, because of the need to communicate over great distance, sophisticated forms of antennas had to be used in order to trasmit and receive signals that had to travel millions of miles. A very common antenna form such in application is a parabolic reflector. Antennas of this type have beev built with diameter as large as 305 m. such large dimensions are needed to achieve the high gain required to transmit or receive after million of miles of travel.



(a) Parabolic reflector with front feed



(b) Parabolic reflector with Cassegrain feed

Figure (2.5) Parabolic Reflector

2.4.5 Lens Antennas

Lenses are primarily used to collimate incident divergent energy to prevent it from spreading in undesired directions. By properly shapingg the geo-metrical configuration and chossing the appropriate material of the lenses, they can transform various forms of divergent energy into plane waves. They can bee used in most of the same applications as become execeedingly large at lower frequencies. Lens antennas re calssified according to the material forms are shown in figure bellows. In summary, an ideal antenna is one that will directions. In practice, however, such ideal performance cannot be achieved but may be closely approached. Various typs of antennas are available and each type can take different forms in order too achieve the desired radiation characteristics for the particular application.

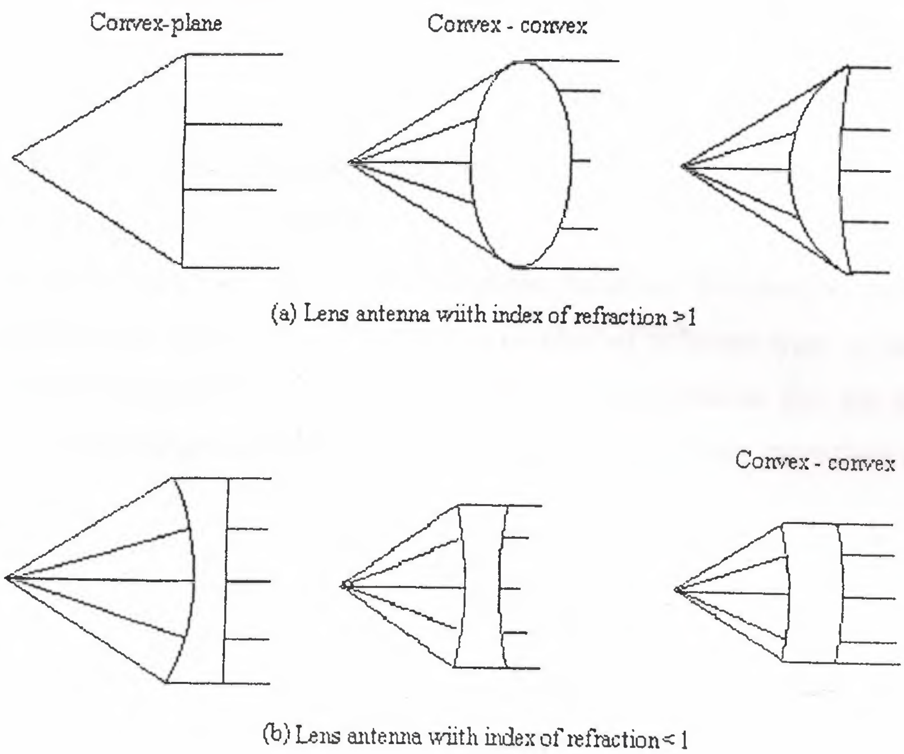


Figure (2.6) Lens antenna with index of refraction

2.5 Launchers And Launching

2.5.1 Itroduction

A satellite may be launched into orbit a multi-stage expendable launch vehicle or a manned or unmanned resuable. The process of launching a satellte is based mainly on launching into equatorial circular orbits, and inparticular the GSO, but broadly satellite into an orbit of the desired altitude, namely by direct ascet or by a Hohmann transfer ellipse. In the direct ascent method. The thrust of the launch vehicle is used to place the satellite in a trajectory, the turning point of which is marginally above the altitude of the direct orbit apogee kick motor (AKM) is often incorprated into the satellite itself, where other thrusters are also installed for adjusting the orbit or the satellite altitude throughout its operatiing liftime in space. The Hohmann transfer ellipse trajectory that quires to be loced in an orbit at the desired altitude using the trajectory that quires the least energy. In practice it is usual for thhe direct ascent method to be used to inject a satellite into a LEO and for the Hohmann transfer ellipse method to be used for higher orbits.

2.5.2 Expandable Launch Vehicle :

a. Descreption And Capabilities :

Launch vehicle and their noise fairing imposee mass and dimensional constrains on the satellite that can be launched. However, a number of different types of launcher are availabke for commericial use and thee satellite designer ensures that the satellite will meet the constraints and capabilities of one of them, or preferably more than one.

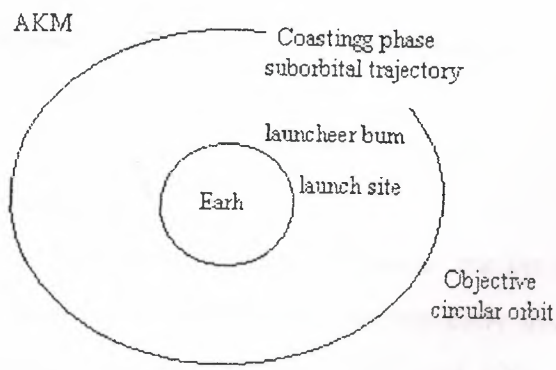


Figure (2.7) Launching Commercial Satellite.

A brief description of the major expendable currently used for launching commercial satellite follows in this section. It should be noted that a few of them have the capability off placing satellite directly into a high circular orbit; with the others; use is made of a Hommann transfer elliptical orbit. When the objective is the GSO, the transfer orbit is called a Geo-synchronous or Geo-staationary transfer orbit (GTO). All of these vehicles consist of several stages, mostly fuelled by bi-properlane liquids, and slid racket boosters strapped on to the firs assist some of them. The dimensional constraint on the launcher payload, consisting of one or more satellite, is determined by the size and shape of the nose fairing which protects the payload while the launcher is within the atmosphere. Several different fairing are available for most launchers, accommodating satellites of different size and shapes after they have been prepared for launching by folding back such structures as solar arrays and large antennas.

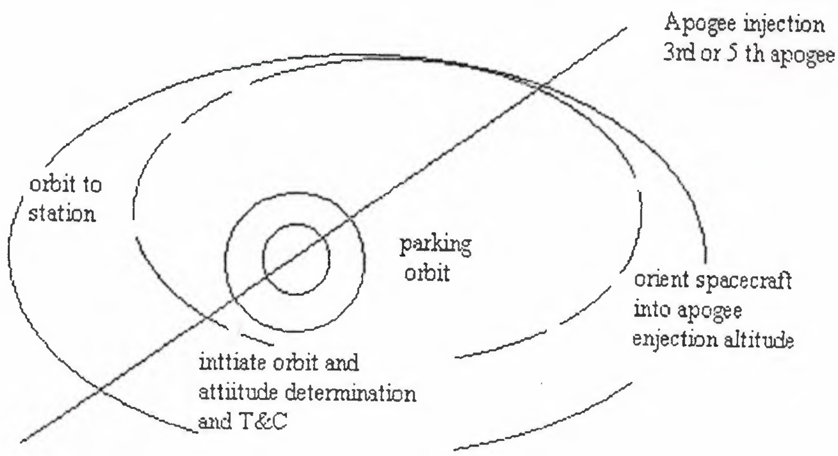


Figure (2.8) Solar Array of Launching Commerical

b. Satellite Launch Industry

According to study of Euro consult entitled services market survey worldwide prospects, 1996-2006, the launch services industry are currently undergoing a radiacl change in size. Structure and operations. Between 1987 and 1996, an average of 36 satellite were launched each year worldwide (excluding the Commonwealth of independent state CIS). At least three times more are schdueld Per year over the next ten years. Similarly the annual average mass launched into various orbits is expected to double from 69000 to 150000 kg whole demaned for both the Geo-stationary satellite orbit(GSO) and medium Earth Orbit (MEO) Low Earth Orbit (LEO) will peak over the next five years, potentially saturating launch capacities. This period will also see the commerical introduction of several new vehicle, therefore enlaring competittion in the diiferent market segments. As areesult of growing competitionand decreasing launch demand, anticipated around 2005, a buyer's market could well develop.

CHAPTER THREE

THE POWER SYSTEMS

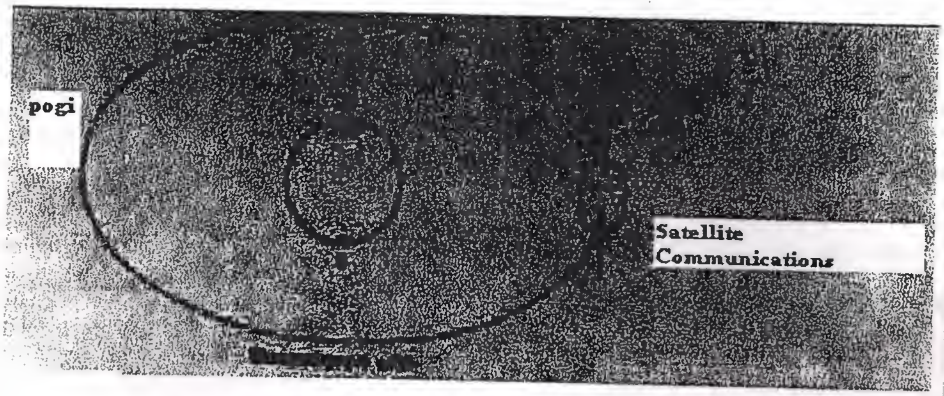
3.1 Overview

A satellite stays in orbit essentially as a result of natural forces and in the absence of external disturbances would orbit the earth indefinitely without having to carry fuel for propulsion. In practice, disturbance torque's and forces exist, as described in the following sections. As a result of these disturbances, satellites must carry fuel on board so that corrective forces can be applied from time to time, usually through thruster jets. The need to carry fuel imposes one of the major limitations on the useful life of a satellite. In addition, the satellite must receive energy to power the electronic equipment on board. This is invariably supplied by solar cells. With cylindrically shaped satellites, these are arranged around the body of the satellite, as shown in Figure.(3.1)

The advantage of the cylindrical arrangement is that the satellite can be set spinning to maintain the sun illuminates its positiion through the gyro acopic effect, but with this arrangement only about one-third of the satellite body at any given time, and so the power available is limited. As an example, the INTELSAT VI satellite employs the cylindrical arrangement that is designed to provide at least 2 kW thoughout the expected 10 year life of the satellite.

An alternative arrangement is to employ solar sails, as shown in Figure(3.2). With this type of construction, spin stabilization cannot be used and other methods are discussed in the next section.

The orientation of the solar cells can be adjusted automtically for maximum solar illumination, so high power outputs can be obtained. For example, the European



Phase satellite in the Geo-stationary Orbit

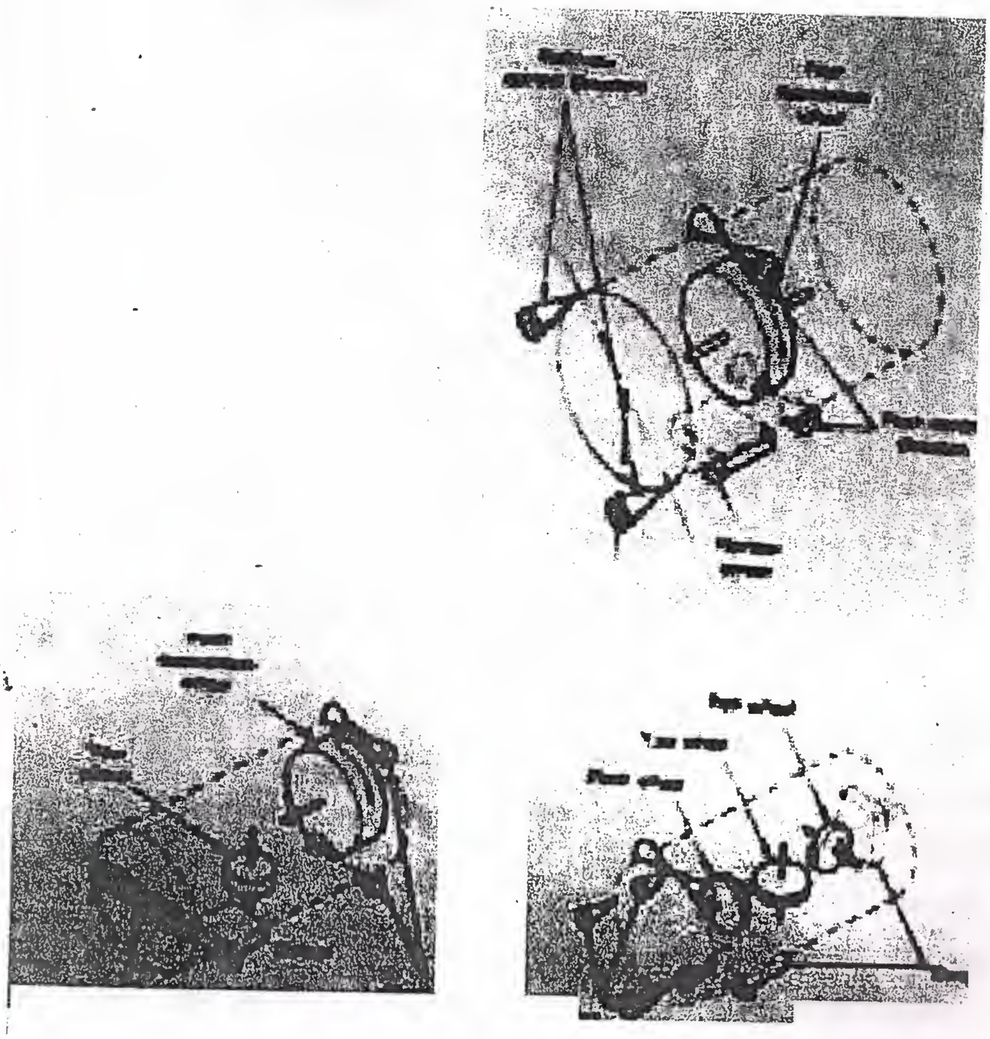


Figure (3.1) *Attitude Satellite 3.3 Antenna*

3.3.1 Antenna Look Angles

To maximize transmission and reception, the direction of maximum again of the earth station antenna, referred to as the antenna bore sight, mus point directly at the satellite. To aling the antenna in this way, two angels must be known. These are the azimuth, are angle measured from the true north, and the elevation, or angle measured up from the local horizontal plane, the conventions used in the calculations are that east longitudes a positive numbers and west longitudes are negative numbers (measured from the Greenwich meridian). Latitudes are positive measured north and negative measured south from the equator. Certain rules know as Kepler's rules, which apply to spherical trigonometry, must be used in these calculations.

3.3.2 Frequency Plans and Polarization

Frequency allocations are mde throjgh the international telecommunication Union (ITU). The most widely used bands at present are the C band and the Ku band. Up-link transmissions in the C baand are nominally at 60Hz and down-link transmissions nominal at 40Hz. The band is sometimes referred to as the 6/40Hz. Band. Up-link transmissions in the Ku band take place in the region of 140Hz. And down-link in the region of 12 0Hz, this being referred to as the 14/120Hz band. (The designation Ku arises from the fact that this frequency is under a microwave band known as the K band and the u is sometimes shoown as a subscriipt.) For each band, the bandwidth available is 500 MHz. For each band mentioned, the higher-frequency range is used for the up-link (very rarely the situation is reversed, the higher frequency being used for the down-link). The reason for using the higher frequency on the up-link is that losses tend to be greater at higher frequencies, and it is much easier to increase the power from an earth station rather than from a satellite to compensate for this. To make the most of the available bandwidth, polarization, for example horizontal and vertical. The 24-transponder channels are first of all formed into two groups of 12, labeled A and B transponders. The down-link signals for group A are horizontally polarized and for group B vertically polarized. Thus, although there is some overlaap in the transponder bandwidths, the different polarization prevents interference from occurring. For example, transponder 2A has a center frequency of 3760 MHz, and its bandwidth (including guard bands) extends from 3740 to 3780 MHz. Transponder 2B has a center frequency of 3780 MHz, and its badwidth extends from 3760 to 3800 MHz. The use of polarization to increase the available frequency banwidth is referred to as frequency reuse. It will also be observed from:

Right-hand circular (RHC) and left-hand circular (ILHC) polarization may also be used in addition to vertical and horizontal polarization, which permiits a further increase in frequency reuse. The Intel sat series of satellites utilize all four types of polarizatin.

3.4 Digital Systems

The first digital microwave PSTN links was installed in the UK in 1982 Harrison. They operated with a bit rate of 140 M bit I s at a carrier frequency of 11 GHZ using QPSK modulation, in more recent systems there has been a move towards 16-and 64-Qa1M. The practical spectral efficiency of a 4 to 5 bit/s/Hz. Which 64-QAM systems offer. Means that the 30 MHz channel can support a 140 114bit/s multiplexed telephone traffic signal. For example, 1021-QAM, to increase the capacity of the radiation 0-59Hz; channel still further.

Microwave radio links at 2 and 18 GHZ are also being applied at low modulation at rates, in place of copper wire connections. In rural communities for implementing the local loop exchange connection.

3.4.1 LOS Link Design

The first-order designs problem for a microwave link, whether analogue digitl, is to ensure adequate clearance over thee underlying terrain path clearances is affected by the following factors.

1. Antenna heights.
2. Terrain's cover.
3. Terrain profile.
4. Earth curvature.
5. Troposphere refraction

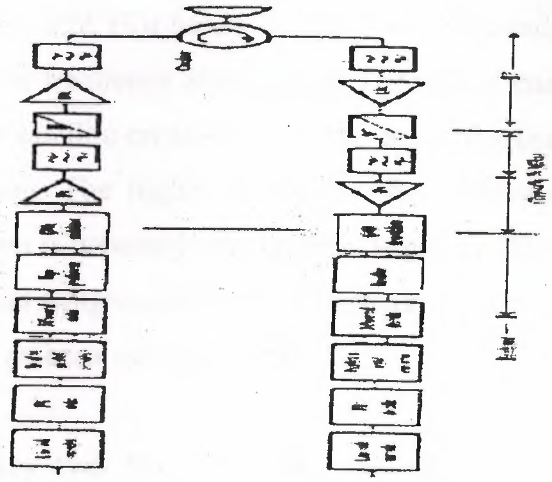


Figure (3.2) Block diagram of a typical microwave digital radio

3.4.2 Fixeed point satelliite communications

The use of satellites is one of the three most important developments in telecommunications over the past 40 years. (The other two are cellular radio and the use of optical fibers). The scientist and science fiction writers Arthur C. Clarke proposed geosttonary satellites, which are essentially mtionless with respect to points on the earth's surface and which first made satellite communications commercially feasible.

The Geo-stationary orbit lies in the equatorial plane of the earth, is circular and has the same sense of rotation as the earth, its orbital radius is 42,164 km. and since earth's mean equatorial radius is 6,378 km. and its altitude is 35,786 km. For simple calculations of satellite range from given earth station, the earth is assumed to be spherical with radius (6.371 km.). There are other classes of satellite orbit, which have advantages over the geo-stationary orbit for certain applications. These include highly.

3.4.3 Satellite frequency bands and orbital spacing

The principal European frequency bands allocated to fixed-point satellite services. The 6/4 GHZ (G-band) allocations are now fairly congested and new systems are being implemented at 14/11 GHZ (Ku-band). 30/20 GHZ (Ku-band), systems are currently being investigated. The frequency allocation at 12 GHZ is mainly for direct broadcast satellites (DBS). Inter satellite cross-links use the higher frequencies, as here there is no atmospheric attenuation. The higher of the two frequencies allocated for a satellite communications system is invariably the up-link frequency. This is because satellite has limited antenna size and a high antenna noise temperature (typically 290 K). The gain of the satellite-receiving antenna on the up-link.

(The reasons why two frequencies are necessary at all) is that the isolation between the satellite transmits and receive? Antennas are finite. Since the satellite transponder hes enormous gain there would be the possibility of positive feedback and oscillation if a Frequency offset was not introduced. Although the circumference of a circle of radius 42,000 km. is large, the number of satellites, which can be accommodated in the geo-stationary orbit is limited by the need t illuminate only one satellite wheen transmitting signals from a given earth-station, if ıother satellites are illuminated then interference may result. For practical antenna sizes 4° spacing is required between satelliites in the 6/4 GHZ bands. Since narrower beam widths are achievable in the 14/11 GHZ band. 3° spacing is permissible here and in the 30/20 GHZ band spacing can approach 10°.

3.4.4 Slant path propagation considerations

The principal effects, which contribute to changes in signal level on earth-space paths from that expected for free space propagation, are;

1. Background atmospheric absrption.
2. Rain fading.
3. Scintillation.

The principal mechanisms of noise and interference enhancement are:

1. Sun transit
2. Rain enhancement of antenna temperature.
3. Interference caused by precipitation scatter and ducting.
4. Cross-talk caused by cross polarization.

3.4.5 Background gaseous absorption

Gaseous absorption on slant path links can be described BV. $A=yL_{eff}$ but with replaced by effective path length in the atmosphere L_{eff}. L_{eff} is leess than thee physical path length in the atmosphere do to the decreasing density of the atmosphere with heiht, In practice the total-attenuation. A(f) are usually calculated using curves of zenith attenuation, and a simple geometrical dependence on elevation angle ∅?

$$A(F) = A.zenith.(f)/(Sin\varnothing) \qquad (3.1)$$

3.4.6 Rain Fading

The same commits can be made for rain fading on slant path pantyhose, which have already been made for terrestrial paths. The slnt-path geometry. However, means that the calculation of effective path Length depends not only on the horizontal structure of the rain but also on its vertical structure.

3.4.7 Scintillation

Scintillation refers to the relatively small fluctuations (usually less than, or equal to, a few dB peak to peak) have received signal level due to the inhomogeneous and dynamic nature of the atmosphere. Spatial fluctuations of electron density in the ionosphere and fluctuations of temperature and humidity in the troposphere result in non-infirmities in the atmospheric refractive index. As the refractive index structure changes and/or moves across the slant-path (with, for example, the mean wind velocity) these spatial variations are translated to time variations in received signal level. The fluctuations occur typically on a time scale of a few seconds to several minutes. Scintillation, unlike rain fading, can result in signal enhancements as well as fades. The CNR is degraded, however, during the fading part of the scintillating signal and as such has ptential to degrade system performance.

Whilst severe fading is usually dominated by rain and occurs for only small percentages of time the less severe fading due to scintillation occurs for large percentages of time and may be significant in the performance of low-Marion, low availability, systems such as VSATs. At very low elevvation angle multi-path propagation due to reflection from, and/or refraction through, stable atmospheric layers may occur. Distinguishing between severe scintillation and multi-path propagation in this situation may, in practice, be difficult however. Scintillation intensity is sensitively dependent on elevation angle, increasing as elevation angle decreases.

3.4.8 Mechanisms of noise enhancement

Excess thermal noise using from rain, precipitation scatter, ducting and cross-polarization may all affect satellite systems in essentially the same way as terrestrial systems. Rain induced cross-polarization, however, is usually more severe on slant-path links since the system designer is not free to choose the earth stations's polarization. Futrhermore, since the propagation path continues above the rain height, troposphere ice crystals may also contribute to cross-polarization. Earth-space links employing full frequency reuse (i.e. orthogonal polarization's for independent con frequency carriers) may therefore require adaptive cross-plar cancellation devices to maintain satisfactory isolation between carriers.

Sun transit refers to the passage of the sun through the beam of a receiving earth station antenna. The enormous noise temperature of the sun effectively makes the system unavailable for the duration of this effect. Geo stationary satellite systems suffer sun transit for a short period each dy around the spring and vernal equinoxes.

3.4.9 System availability constraints

The propagation effects described above will degrade a system's CNR below its dear sky level for a small, but significant, fraction of time. In order to estimate the constraints which propagation effects put on system availability (i.e. the fraction of time that the CNR exceeds its required minimum value) the clear sky CNR must be modified to account for these propagation effects. In principle, since received signal levels fluctuate due to variations in gaseous absorption and scintillation, these effects must be combined with the statistics of rain fading to produce an overall fading cumulative distribution, in order to estimate the CNR exceeded for a given percentage of time. Gaseous absorption and scintillation give rise to relatively small fade levels compared to rain fading (at least at the large time percentage end of the fading CD) and it is therefore often adequate, for traditional high availability systems. To treat gaseous absorption as constaant and neglect scintilltion altogether. Once the up-link and down-link fade levels for the required percentage of time have been established then the CNRs can be modified as described below.

The up-link CNR exceeded for 100-p% of time (where typically 100-p%=99.99%, i.e. p=0.01%), (CIN) "u100p" is simply the clear sky carrier to noise ratio, ICIN)", reduced by the fade level exceeded for p% of time, F"(p), i.e.:

$$(C/N)\ u100\text{-}p=(C/N)\text{-}Fu(p)(dB) \tag{3.2}$$

The up-link noise is not increased by the fade since the attenuating event is localized to a small fraction other receiving satellite antenna's coverage area. (Even if this was not so the temperature of the earth behind the event is essentially the same as the temperature of the even itself).

If up-link interference arises from outside the fading region then the up-link carrier to interference ratio exceeded for 100-p% of time will also be reduced by

$$(C/I)u100\text{-}p=(C/I)\text{-}Fu(p)(dB) \tag{3.3}$$

In the absence of up-link fading (or the presence of up-link power control of to compensate up-link fades) the down-link CNR exceeded for 100-p% of time is determined by the down-link fade statistics alone.

(C/N) d, however, is reduced not only by down-link carrier fading but also by enhanced antenna noise temperature (caused by thermal radiation from the attenuation medium in the earth stations normally cord antenna beam).

From a system design point of view fade *margins* can be incorporated into the satellite up-link and down-link budgets such that under clear sky conditions the system operates with the correct back-off but with excess up-link and down-link CNR (over those required for adequate overall CNR) of *Fu* (p) and Fd (*p*) respectively. Assuming fading does not occur simultaneously on up-link and down-link this ensures that an adequate overall CNR will be available for 1 00-2p% of time. More accurate estimates of the system performance limits imposed by fading would require joint statistics of up-link and down-link attenuation, consideration of changes in back-of produced by up-link fades (including consequent *improvement* in intermodulation noise), allowance for possible cross-plarization induced cornstalk, hydrometer scatter and other noise and interference enhancement effects. Power limitation and high-power amplifier nonlinearities in on-board satellite communications systems.

This paper discusses the problem of power limitation in on-board satellite communications systems. It considers the nonlinear characteristics of on-board high-power amplifiers and corresponding linearisation techniques. It is shown that, with the recent development of solid-state high-power amplifier designs and linearisation techniques for traveling wave-tube amplifiers, it is now possible to operate on-board amplifiers near to saturation without increasing their nonlinear effects.

3.5 Traveling – Wave – Tube Amplifier

3.5.1 Introduction

As traveling-wave-tube amplifiers (TWTA) satisfy the need for broadband capability, high output power and particularly high power-added efficiency (DC-to-RF conversion efficiency), most satellite transponders today employ a TWTA as their main power amplifier. Because power on-board the satellite is at a premium, it is desirable that the TWTA be operated as efficiently as possible i.e. close to or at saturation. However, for this operating mode, the TWTA introduces two kinds of nonlinearly distortions due to:

(a) A nonlinear relationship between output and input amplitudes, known as the amplitude modulation to amplitude modulation (AM-AM) conversion effect

(b) Dependence of the output phase on the input amplitude, known as amplitude modulation to phase modulation (AM-PM) conversiton.

For an input signal to the TWTA given by R $\cos w_{c}t$, the output signal can be represented as

$$g(R)\cos[\omega_{c}t + \varphi(R)] \tag{3.4}$$

Where, g(R) and ψ(R) represent the AM-AM and AM-PM conversiton effects, respectively.

The phase and amplitude characteristics for a TRW DSCS II satellite TWTA; power levels have been referred to their values at saturation.

When operating in a colse-to-sturation mode it is customary[1] to talk in terms of input back-off (IBO) which is defined as the input power in decibels relative to its value at saturation, and output back-off (OBO), which is the output power in decibels relative to its value at saturation.

TWTA output back-off affects the system performance in two opposing ways. An increase in back-off give less AM-AM and AM-PM conversion effects but also a reduction in output power and hence less tolerance to noise and interference. In contrast, operating close to saturation improves the tolerance to noise and interference but increases AM-AM and AM-PM conversioon effects. The AM-AM and AM-PM conversion effects have the following deteriorate effects on the system performance:

(a) Degradation of the bit error rate (BER) of the system. This is partly due to distorted amplitude and phase of the signaling elements in the transmitted signal constellation and partly due to inter symbol interference, both caused by the AM-AM and AM-PM nonlinearities of the high-power amplifier (LIPA of the BER degradation of a QPSK signal due to the nonlinearities of a TWTA operating at saturation. It is assumed that the up link signal-to-noise ratio is infinite (or very large) and that the overall modulator and demodulator channel filtering has a raised cosine roll-of shaping response with a 40% roll-off factor (α = 0.4) equally split between modulator and demodulator.

(b) Spectral spreading of the transmitted signal, which increases undesirable interference to the adjacent channels. This is also referred to as regeneration of the side-lobes of a band-limited signal at the output of the nonlinear HPA, thee spectral spreading by a TWTA operating at saturation. The channel roll-off is again assumed to be 0.4.

(c) In frequency division multiple access (FDMA) systems the different carrier frequencies mix together generating intermodulation products at all combinations of sum and difference frequencies. The power in these intermodulation products represents a loss of wanted signal power, and in addition there is a serious problem of interference between the various. Channels passing through the HPA, and intereference with other satellites and services.

3.5.2 Solid-state high-power amplifiers

Microwave transistors have been considerably improved in recent years. The silicon bipolar trnsistor and the GaAs MESFET have performed best in high-power amplification applications. The maximum power that these devicescan generate at different frequencies; an amplifier with four devices in a power-combining configuration has been assumed. Power combining is necessary to increase the output power, but if more than four devices are combined the losses in the combining network cause severe efficiency degradation. For mst satellite applcations the GaAs MESFET is the preferred device as it can operate up to at least Ku-band with high power, excellent linearity, and good provided efficiency. More recently, Hereto junction devices have started to offer comparable out powers to the GaAs MESFET, a millimeter-wave operation.

With these recent development in solid-state power amplifiers (SSPAs), it is now possible to replace TWTAs with SSPAs in some applications such as land mobile, aeronautical and very small apeture terminal (VSAI systems. Also, the introduction spot beam antennas for satellite systems has resulted in lower required EIRP (effective isotropic radiated power) and hence a reduction of output power from the on-board HPAs. As a result makes it possible to use SSPA the main HPAs on-board satellite. For example, INTELSAT VII will 30 W linear SSPA in the C-band payload with spot beams.

Although they offer lower power and efficiency than TWTAs, SSPAs have the major advantage of higher reliability, lower mass lower DC voltage supplies. SSPAs also exhibit less AM-AM and AM-PM conversion effects, resulting in a major improve in system performance particularly when non-constant envelope modulations scheme to be used. SSPAs are more linear than TWTAs and the measured AM-AM and AM-PM characteristics of a 20 W L-band SPPA developed for the pyload of an experimental land mobile satellite. The AM-AM characteristic is linear right up to 43 dBm output power, beyond which the amplifier saturtes shrply at an output power of 44.6 dBm (29W). The AM-PM characteristic is very good (0-3 degrees/dB) up to an output power of 44 dBm. As the amplifier goes into saturation, however, the phase changes rapidly (5 degrees/dB). Extensive simulations have been carried out on the power spectral density and bit-error rate of a QPSK signal transmitted through this amplifier and it is found that an *E*/Degradation of only 0.3 dB is achieved at a BER of 10^{-6} when operating at 1.6 dB OBO.

This is a much better result than for the TWTA, but the 1.6-dB OBO results in a highly undesirable drop in power efficiency. Hence, SSPAs in satellite applications may still require the use of linearisation techniques in order to increase the linearity and power efficiency, particularly when high-level modulation schemes such as 1 6-QAM are used.

3.5.3 Linearisation Techniques

One way to operate a high-power amplifier close to saturation with considerably reduced distortion is to employ linearisation (compensation) techniques. These are based on compensation of the AM-AM and AM-PM cornerstone effects so that the overall characteristics of the HPA approach those of a linear amplifier. No actual increase in maximum saturated power is achieved, as this is limited by voltage and thermal breakdown effects, but the amplifier can be operted closer to saturation, thus giving higher power and efficiency without the undesirable signal distortion.

Three distinct techniques, which have been considered for satellite systems, are feed forward, feedback, and predistortion linearisers.

3.5.4 Feed forward linearisers

The block diagram of a feed forward lineareitiesis the input signal is split into two parallel paths, one passing through TWT 1 and the other through a low-level delay line ( ). The delay line delay is equal to the delay introduced by TWT1. An error signal is obtained b (τ1) comparing the outputs from TWT1 and the delay line. This error signal is amplified in TWT2 to bring its level to a proper value relative to the main amplified signal. The output of TWT1 is then delayed by an amount equal to the delay time of TWT2 (τ2). The amplified error signal and the delayed output of TWT 1 is finally combined in an error injection coupler which gives the required compensated signal for transmission. It is imprtant to note that the linearised performance of the TWTA has been shown to be equal to the highly linear characteristics of a GaAs FBT amplifier, so that the linearised TWTA gives all the advantages of high power, efficiency, and linearity. The main disadvantage of the feed forward lineariser is the use of a second TWT and corresponding metched elements, which increase the cost, size, and mass of the HPA considerably. With property-matched elements an increase in output power of 2 to 3 dB is possible, however.

3.5.5 Predistortion techniques

Predistortion techniques can be implemented at RF, IF or base-band; they do not require a compensating TWT and therefore are a less costly approach. The RF or IF Predistortion circuit has characteristics, which approach the inverse of those of the high-power amplifier so that the overall characteristics approach those of an ideal linear amplifier. However, because of the physical limitation on the amplifier output power, at best the characteristics of a soft-limited can be achieved. Systems with these types of characteristics have been found to give a considerable improvement in system performance. The SL-LRZ consists of two main parts: a Predistortion type laniaries and FET limited amplifier. The two FET amplifiers FETA1 and FETA2 have the same characteristics, but are operated at different levels determined by the division ratio of the input directional coupler. The output directional coupler forms the difference of the output signals from the nonlinear and linear paths. By adjusting the relative output levels of the two paths, it is possible to achieve nearly, the inverse characteristic of a TWTA.

For the same operating and link conditions as the INTELSAT VI system, this lineariser/TWTA combination has shown a carrier-to-noise-ratio improvement of 4.5 dB at a BER of 10^{-6} for an output back off of 0.3 dB. The major advantage of the SL-LRZ technique is that the sofitimer action means that there is a constant output power from the TWTA for negative values of input back off. This means that there is no drop in output power when the amplifier is driven hrd into saturation, and this is an important feature in Satellite systems.

A base-bnd lineariser linearises the transfer characteristics of a high-power amplifier by predistorting the signal prior to modulation. An example of a base-band lineariser for QPSK transmission is given in Fig. 10. This lineariser predistorts the in-phse and quadrate components of the base-band sign; in order to compensate for the effects of AM-AM and AM-PM distortions caused by the HPA. It consists of an envelope Predistortion circuit, which attenuates the two base-band components of the signal equally without changing the signal phase and a phase Predistortion circuit, which predistorts the angle formed by the two base-band components of the signal but does not affect the envelope of the signal. This technique works very well and hs the advantage that, with the high level of integration that can be achieved using VLSI technology, it offers advantages of size and cost compared with RF Predistortion-linearisers, as well as considerable flexibility if programmable DSP techniques are used. Recently, a new, simple, low-cost base-band Predistortion circuit for low data rate satellite services has been reported. It employs a simple look-up table technique, which incorporates spectral shaping filters and a base-band Predistortion circuit. It has been shown that this technique substantially improves the ferformance of a digital communication system for practical carrier-to-noise ratios.

3.5.6 Feedback linearisers

In low-frequency amplifiers it is possible to use negative feedback to improve linearity. In microwave amplifiers, however, there is too little gain for this. A solution to thes problem is to sample the transmitted signal and extract a low-frequency component from it for feedback purpses: this could be the signal envelope, or some inter modulation product, or the signal could be demodulated to recover the base-band signal itself. For quadrate modulation schemes such as QPSK the technique is to demodulate the signal and to use the actual trasmitted base-band anaphase (I) and quadrate (Q) values as feedback signals. The demodulated Q and I signal are fed back to the modulator for adaptive Predistortion of the signal constellation. This is known as Cartesian feedback and has been demonstrated successfully using analogue feedback loops. A highly integrated approach using DSP and look-up table techniques. This technique is expected to become very popular becaus it offers such an elegant solution. It has the disadvantage, however, that the modulator must be on-board with the HPA, which satellite systems. An alternative approach, especially for FDMA systems, is to filter the signal harmonics and inter modulation products from the output of the HPA and feed them back in order to cancel them.

3.5.7 Applications

Linearisers have received a gereat deal of attention in the literature and many different circuit techniques have been reported. For satellite payload applications the RF Predistortion lineariser has become the preferred technique, mainly because the lineariser/FIPA can be regarded as a self-contained unit which is more flexible for the operator. One of the first Linearisers to fly was a Ku-band lineariser on-board as sat. NBC have reported a conventional RF predistorter for C-band, which has been developed for the INTELSAT VII spacecraft, the first INTELSAT VII launch is scheduled for late 1993. The NEC/INTELSAT Linearisers are designed for broadband operation, covering four 250 MHz sub-bnds simultaneously. Bach TWTA has a dedicated lineariser that can be switched in or out, and they are particularly intended for multi-carrier services operating close to saturation for high efficiency. In the USA, GB has developed a Ku-band lineariser for use in doestic satellites, and Hughes has also developed linearisers intended for a new series of satellites.

Base-band and feedback linearisers which rely on a knwledge of the modulation format have the disadvantage that they could not easily be adapted the space segment was to be reconfigured. However as on-board processing becomes an accepted practice for satellite payloads these techniques are expected to become very favorable.

3.6 Conclusions

The paper has addressed the problem of power limitation and high-power amplifier nonlinearities on-board satellite communication Systems. The importance of using linearisation techniques for TWTAs has been described and the improvements the system performance has been shown to be very considerable. The impact of solid-state power amplifiers on future satellite systems has been discussed, and further advances in this area are anticipated.

CHAPTER FOUR

SATELLITE TRANSPONDERS

4.1 Introduction

Communication satellite system are designed to have an operating life time of 5 to 10 years. The operator of the system hopes to recover the initial and operating costs well within the expeected life time of the spacecraft, and the designer must provide a satellite that can survive the environment of the outer space for that long. In order to support the communications system, the spacecraft must provide a stable platform on which to mount the antennas, be capable of station keeping, provide the required electrical power for the communications electronics. In this chapter we discuss the sub-systems needed on spacecraft to support its primary mission of communications.

The word transponder is coined from transmitter-responder and it refers to the equipment channel through the satellite that connects the receive antenna with the transmit antenna. The transponder itself is not a single unit of equipment, but consists of some units that are transporder channels and other that can be identified with a particular channel. (4.1) shows in block schematics from typical transponder.

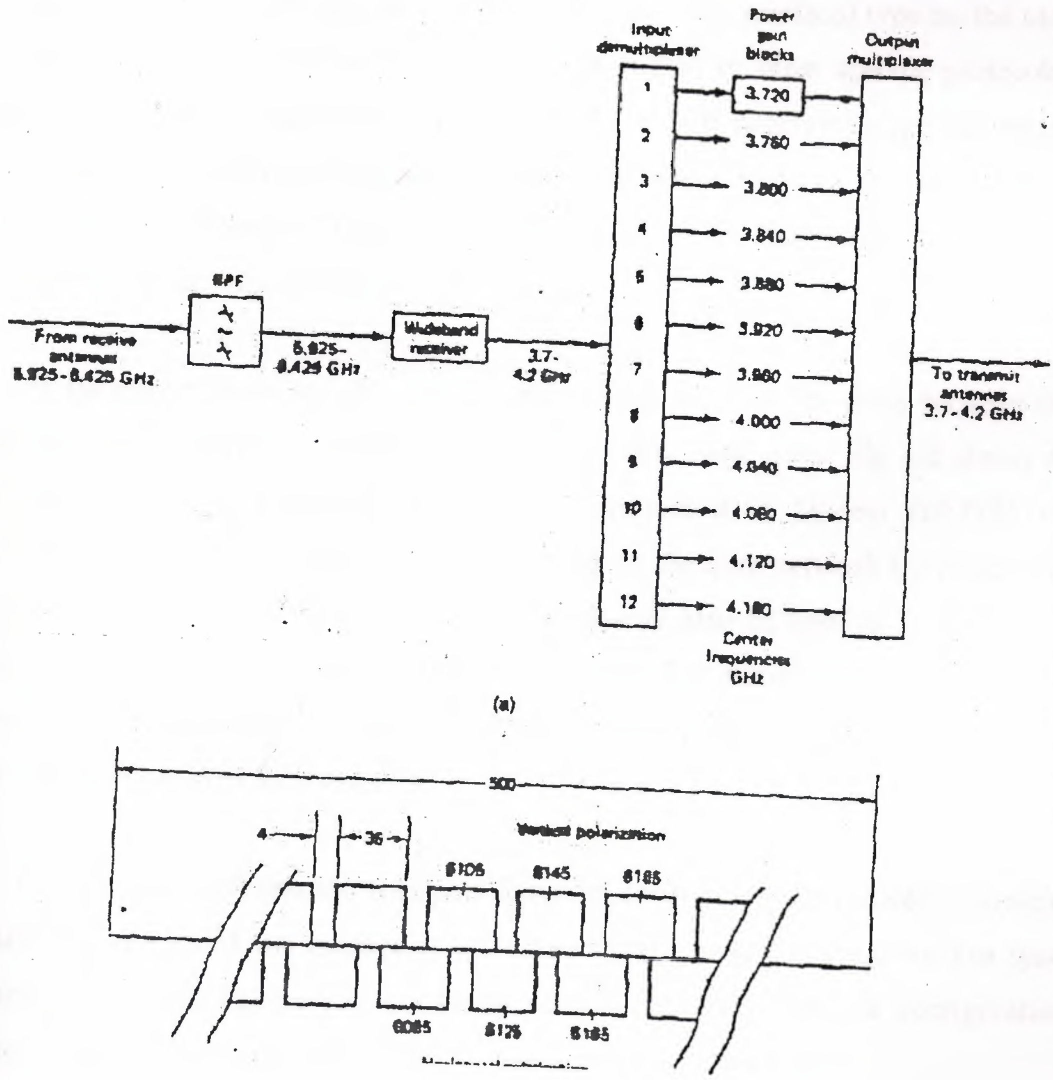


Figure (4.1) Block schematics from typical Transponder.

4.2 Satellite in UMTS and B-ISDN

A satellite system can essentially be applied in two modes: access and transit. In the *IBC* user access mode, the satellite system is located at the border of the B-ISDN, as shown in fig 4.1. The satellite network provides access links to a large number of the users and on the gateway earth station provides concentration/-deemultiplexing function. The interfaces to the satellite system in this mode are of the UNI (usernetwork interface) type on one side and of the NNI (network-node interface) type on the other. Conversation from a customer premises network (CPN) or other specific protocols is performed at the user side of the network. In the RACE program, a special focus is placed on the optimization of this access mode. The main research areas include coding techniques leading to lower costs of the satellite links and the specifcation of new access protocols to shared satellite links.

In the transit mode, satellite system can provide high bit rate links between IBC mode and islands through networked interface on the both sides. Fig 4.2 shows the interconnection of a Universal Mobile Telecommunication System (UMTS) cell switching site (CSS) node and of an IBC island to the core network by means of a transparent satellite. Switching satellite can obviously also be applied in thee transit mode; in this case the satellite would also realize the transit switching functions necessary to switch th traffic between the local exchange, the cell switching site and the rest of the core network as appropriate.

In addition to information transport functions (bearer services). Satellite systems can also realize control and management functions implemented in the ground or space segments, including monitoring and alarm control functions, network configuration, billing statistical information and mobility managemen functions.

To ensure that the future broadband network is capable of satisfying future customer needs it is necessary to have a means of representing all the relevant functions and their interrelationship. This is the achieved by the reference configuration.

The concept of the reference configuration also provides the means for ensuring that the different network elements can be interconnected in an effective manner and that the various technical and evolutionary options can be integrated to form a coherent network. It comprises a set of functional groups, which are separated by means of reference points; at some of these reference points interface (UNI) and the network-node interface (NNI). For the UNI and the NNI define the boundaries of satellite systems applied to IBC. Other reference points and interface within the satellite system could be identified and defined if appropriate.

A generic logical model of the UMTS satellite and terrestrial access that is intended to be valid for all foreseeable environments and network integration scenarios has been produced by the European Telecommunication Standards Institute (ETSI) 'SMG5/WG. Satellite' "group" and is currently being discusseed and refined within the (ETSI) 'SMG5/WG Architecture working group and the RACE Mobile Networks Community. In particular, the generic reference configuration has to be derived by clearly separating the user and control planes that are now still partially combined. It should then be possible to map all the functions identified in the basic functional model for UMTS' into these reference configurations and describe in detail relevant specific cases. The most relevant functional groups that are peculiar to satellite and terrestrial UMTS applications and that are identified in this model are listed below:

Mobile customer premises equipment (MCPE): include all the customer local functions that are necessary for accessing a set of UMTS terrestrial and satellite services within the UMTS services area. It may simultaneously serve one or more users, i.e. include one or more fixed and/or mobile customer premises networks. In the case of dual operation, both terrestrial and satellite UMTS transceiving functions are included. It can also support several simultaneous connections with the network.

Radio access link (RAL): includes the relevant satellite or terrestrial UMTS radio accesses link transceiving functions. In the terrestrial UMTS component the raido access link includes the base station functions.

It therefor includes the network termination-1 (NT-1) function. Satellite Exchange (SAT EX): includes satellite on-board switching connections between the raido accesses links and between radio access links the core network. Call control functions can be realized in the space segment (satellite) as well as in the ground segment. Hybrid solutions are also possible.

Feeder/inter-satellite link (FL/ISL): connects respectively, a satellite with the terrestrial network infrastructure or two satellites directly; these links include the relevant transceiving functions. The capability to handle intersatellite links associated with ATM switching will greatly enhance satellite flexibility.

Cell site switch (CSS): provides a switching connection among the radio access links within a UMTS cell as well as to the core network. It also provides the necessary protocol adaptation function.

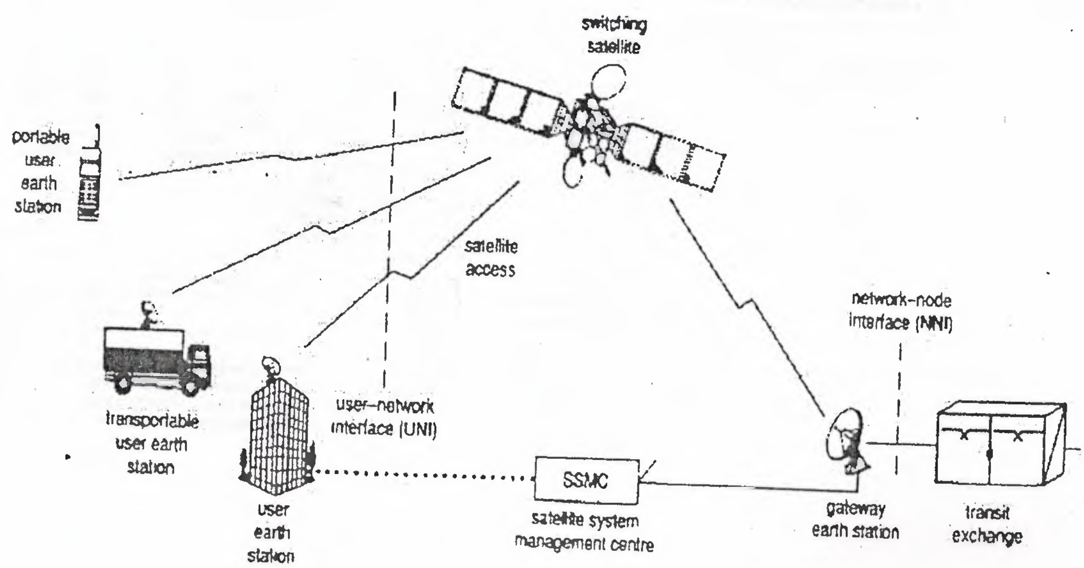


Figure (4.2) Interconnection of a universal Mobile telecommunication System.

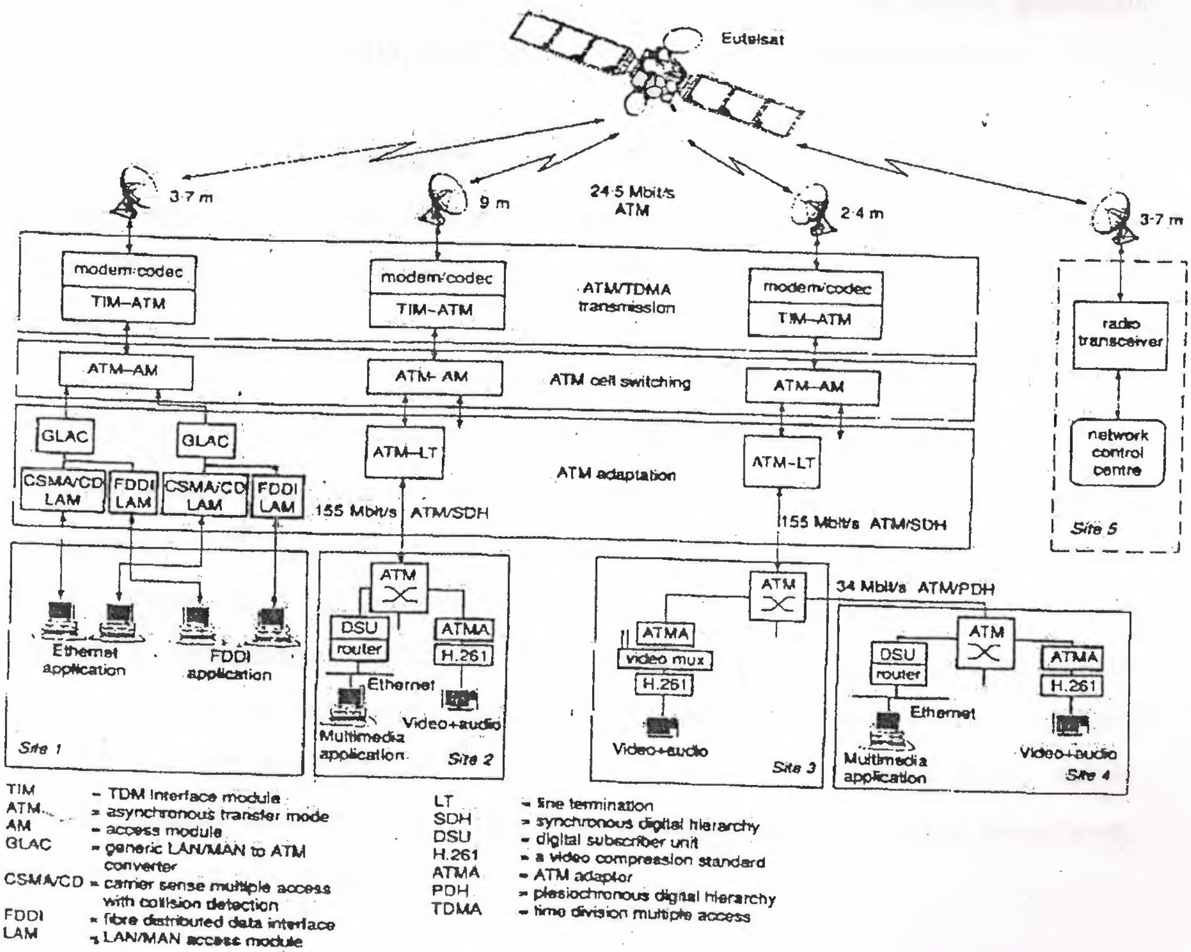


Figure (4.3) Terrestrial UMTS application

4.3 Satellite System Evolution Scenarios

At present, IBC satellite systems are applied mainly in the transit mode, principally to interconnect fixed network nodes. For mobile services other satellite systems address specific categories of user; the existing land mobile networks, however, not yet coordinated with those provide these services.

In the future, satellite systems will continue to offer mobile services to specific users but they are expected to become more integrated with the second generation (GSM) and, more particularly, with third generation (UMTS) mobile systems.

In the short time, transparent satellite will continue to be dominant. In this time frame, satellite systems and land mobile systems will still be completely separated, adopt different standards, have different numbering schemes and provide different services.

In the medium term, both transparent and OBP satellite will be increasingly deployed in the access mode to provide IBC services to users who are not yet connected or cannot be cost effectively connected to the terrestrial networks. In this time frame, limited integration of satellite systems with second generation land mobile systems is expected to be economically feasible. The optimum level of integration to be realized of, for example, services, numbering, signaling and network management is an open issue to be resolved by the main players in this field i.e. operators of the mobile networks (mainly GSM operators owing to its expected penetration in this time-frame) and the operators of satellite systems.

The users will be able to access both systems, probably with a dual terminal and with different subscriptions, but services, numbering, call-handling procedure and network management systems are expected to continue to be at least partially, different adaptation units will ve required and are expected to continue to be deployed mainly in the satellite ground segment and in terrestrial networks.

The long-term in the time-frame is associated with th introduction of the terrestrial UMTS, which is currently planned to start after the year 2000. The process of integration is expected to progress in parallel with UMTS diffusion; the full integration of satellite systems with UMTS and B-ISDN is also expected to be achieved at least in the final part of time-frame. Many relevant expect be being considered already within RACE and ETSI SMG5 and some results can be expected before 1994.

4.3.1 Possible integration scenarios and activities within RACE

Integrtion of satellite systems in to the UMTS and IBC is being considered within the RACE community. In particular the CATELYST project has demonstrated a broadband multipoint satellite system designed for interconnection of Ethernet and fiber-distributed-data interface local area networks (FDDI LANs), distributed-queue-dual-bus metropolitan area networks (DQDB MANs) and ATM networks via a common ATM transport and transport and routing schemes, as shown in Figure 4.4.

The CATALYST system can configure as an access network to geographically dispersed users; it is also designed to provide ATM transit links between network nodes. The system implements an ATM cross connect able to route and allocate point-to-point and point-to-multipoint semipermanent links between several stations which may be located anywhere within the beam coverage of the satellite (e.g. the whole of Europe for Eutelsat). These stations include protocol conversion between LAN/MAN technologies and ATM (generic LAN/MAN to ATM conversion-GLAC). They also realize function at the ATM layer (i.e. cell switching) and at the satellite physical layer (i.e. coding and TDMA mapping), ensuring high quality of service bearer connections. The user data between terminals are flexible and may be adjusted from 100 Kbit/s up to20 Mbit/s within the 24-5 Mbit/s total system capacity.

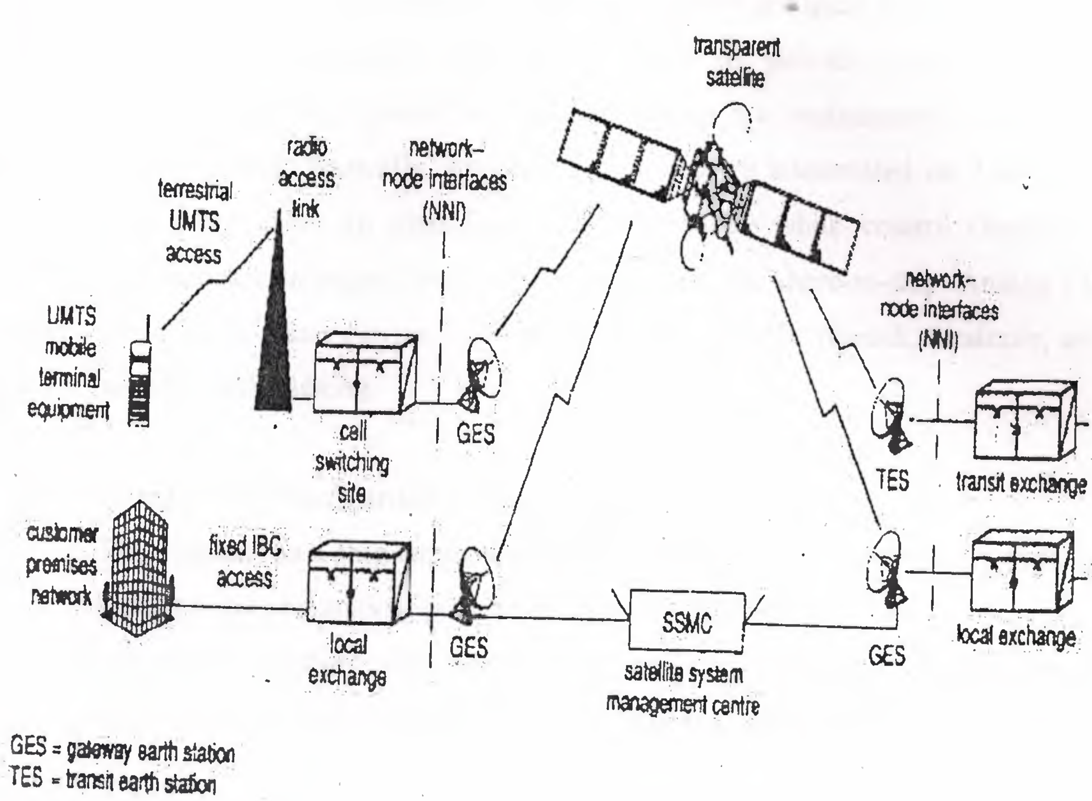


Figure (4.4) ATM network via ATM transport,

4.3.2 The Marisat System

Since 1976, the Marisat system has been using satellites to provide up-to-date telex, telephone, facsimile, and data service to ships and offshore facilities equipped with appropriate terminals. The Marist system provides global commercials services through Atlantic, Pacific, and Indian Ocean region stationary satellite. Each Marisat satellite operates at three different frequencies to serve varying needs: UHF for the American Navy and C band (6/4 GHz) and L bands (1.60/0.4 GHz) for comercial users.

Mobile terminals are installed on merchant ships and offshore equipment to operate with Marisat. The terminals units include an above deck portion enclosed in a fiberglass random consisting of a 1.22-m stabilized antenna locked on the satellite at all time. Comsat General Corporation of the US operates the system.

Coverage of earth by three Marisat satellites is given in Figure (4.5). The DAMA technique is used in junction with SCPC carriers to provide voice and Telex transmission. The signaling control and Telex operation are implemented using TDM and TDMA techniques. Basically, requests for service are transmitted on 1.6/4 GHz from ship-to shore using an open-loop TDMA channel, while control (frequency assignment, broadcast messages, and so on) is provide in the shore-to-ship. Analog FM channels on an SCPC basis carries TDM channel on 1.5/6 GHz. Speech, facsimile, and data, i.e., without multiplexing.

Communication via Marisat is established as follow.

1. The operator on a ship requests a Marisat communications channel by sending a short burst of signaling pulses to shore via a satellite.
2. The signling pulses, which are at the same carrier frequency for all ships, identify the requesting ship and the type of chnnel required.

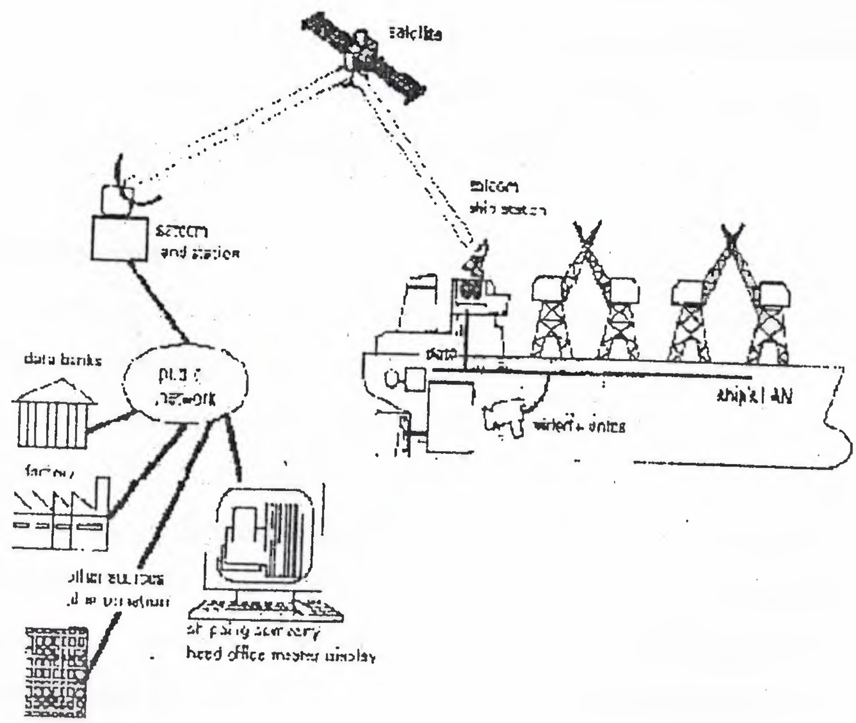


Figure (4.5) Marisat Satellite

When the shore-station receivers the request, it selects a pair of frequencies and assigns them to the requesting ship. When the call is completed, the frequency pair is released and made available for another call. Digital TDM channels, by contrast, carry Teleprinter messages. A bit streams modulte the shore-to-ship carrier at 1.2Kb/s. The ship-to-shore carrier is occupied by pulse bursts transmitted in a predetermined sequence by up to 22 ships. Each burst is modulated at 4.0 Kb/s and contains up to 12 characters of message text. The continuously received carrier from shore synchronizes the ship transmissions. Time intervals are automatically allocated between bursts to allow for propagation-delay differences between terminals at the center and those at the edge of the satellite coverage area.

4.4 Spacecraft Subsystem

The major sub-system for spacecraft as following:

4.4.1 Attitude and Orbit Control System (AOSC)

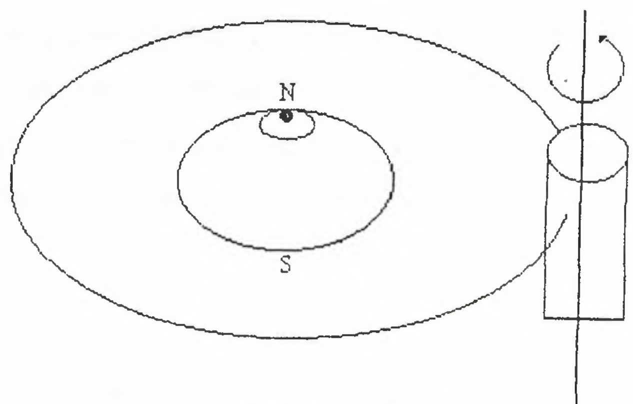
The sub-system consists of rocket motors that are used to move the satellite back to the correct orbit when external forces causes it to drift off station and gas jets or internal devices that control the attitude of the spacecraft.

a. Attitude control

The attitude of satellite refers to its orientation in space. Much of the equipment carried aboard a satellite is necessary, for the purpose of controlling its attitude. Attitude control is necessary, for example, to ensure that directional antennas point in the proper directions. In the case of earth environmental satellite, the earth-sensing instruments must cover the required regions of the earth which, also require attitude control. A number of forces, referred to as disturbance torque's, can alter the attitude, some example being the gravitaational fields of the earth and the moon, solar radiation, and meteorite impacts. Attitude control must not be confused with station keeping, which is the term used for maintaining a satellite in its correct orbital position, although the two are closely related. Controlling torque's may be generated in a number of ways.

b. Spin stabilization

Spin stabilization is used with cylindrical satellite. The satellitee is constructed so that it is mechanically balanced about one particular axis and is then set spinning aroudn this axis. For satellite, the spin axis is adjusted to be parallel to the N-S axis of the earth as illustrated in Figure 4.1. Spin rte is typically in the range of 50 to 100 rev/min. In the absence of disturbance torque's, the spinning satellite would maintain its correct attitude and internal to satellite. Solar radiation gravitational gradients and meteorite impacts are all examples of external forces, which can give, rise to disturbaance torque's.



Geostationary orbit
Spn stabiliizing in the geostationary orbit.
The spin axis lies along the pitch axis, parallel to the earth's N.S

Figure (4.6) *Geo-stationary Orbit*

c. Orbital Control

For communications satellite to accomplish its mission, it must first acquire and then maintain its specified orbit with in close limits. The orbital perturbations which make subsequent corrections of the parameters of the orbit necessary. The final stage of the launching process and all of the in service orbital corrections are carried out by firing thrusts on board the satellite in appropriate directions to obtain the desired incremental velocity vectors. While the satellite is on station and operating, it must also be correctly oriented, so that is antennas and its solar arrays can function as intended; this orientation of the satellite attitude in space also facilities the adjustment of the orbital parameters.

4.4.2 Telemetry, Tracking, and Command (TT&C)

These systems are partly on the satellite and partly at the controlling earth station. The telemetry system sends data derived from many sensors on the spacecraft, which monitor the spacecraft's "health" via telemetry links to the controlling earth station. The tracking system is located at this earth station and provides information on the range and the elevation and azimuth angels of the satellite. Repeating measurement of these three parameters permits computation of orbital elements, from which changes in the orbital of the satellite can be detected. Based on telemetry data received from the satellite and orbital data obtained from the tracking system, the control system is used to correct the position and attitude of the spacecraft. It is also used to control the antenna pointing and communication system configuration to suit current traffic requirements, and to operate switches on the spacecraft. Telemetry, tracking and command (TT&C) systems support the function of spacecraft management. These functions are vital for successful operation of all satellite and are treated seprately from communication management.

The Main Functions of a TT&C System are to

a. Monitor the performance of all satellite sub-system and transmit the monitored data to the satellite control center.
b. Support the determination of orbital parameters.
c. Provide a source to earth stations for tracking.
d. Receive commands from the control center for performing various functions of the satellite.

a. Telemetry Sub-System

The function is to monitor various parameters such as voltage, current, temperature and equipment status and to transmit the measuder values to te satellite control center. The telemeter data are analyzed at the control and used for routine operational and failure diagnostic purpose. For example, the data can be used to provide information about the amount of fuel remaining on the satellite. A need to switch redudant chain or an HPA overloads.

The parameters most commonly monitored are:

a. Voltage, current and temperature of all major subsystem.
b. Switch status of communication transponders.
c. Pressure of propulsion tanks.
d. Output from attitude sensonrs.
e. Reaction whell speed.

The monitored signals are all multiplexed and transmitted as a continuous digital system. Several sensors provide analog signals whereas others give digital signal. Analog signals are digitally encoded and multiplexed with other digital signals. Figure 4.2 shows the main elements of a telemetry sub-system.

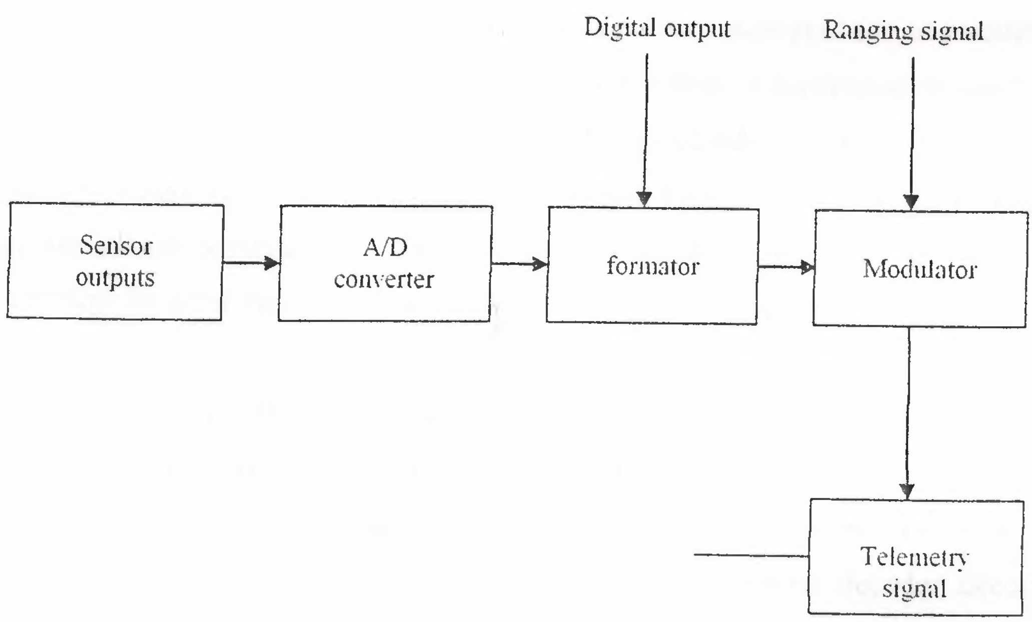


Figure (4.7) Elements of telemetry sub-system

b. Command Sub-System

The command system receies commands transmitted from the satellite control center, verifies reception and executes these commands. For example:

1. Transponder switching
2. Switch matrix configurtion
3. Antenna pointing control
4. Controlling direction speed of solar array drive
5. Battery reconditioning
6. Thruster firing

Typically, over 300 different commands could be used on a communication satellite. From the example listed above, it can be noted that it is vital that commands be decoded and executed correctly. Consider the situation where a command for switching off an active thruster is misinterpreted the thruster remains activated the consequence would be depletion of station keeping fuel and possibly loss of satellite as the satellite drifts away from its nominal position. A fail-safe has to be achieved under low carrier-to-noise conditions (typically 78dB). A commonly used safetly feature demands verification of each command by the satellite control center is execution. To reduce the impact of high bit error rate, coding and repetition of data are employed.

Figure (4.8) shows the block diagram of a typical command system. The antennas used during the orbit-raising phase are near Omni-directional to maintain contact for possible orientations of the sat. During critical maneuvers. The receiver's converts RF signals to base band. Typical bit rate is 100 bps. A command decoder decodes commands. This commands back too the sat. Control center via the telemetry carrier. The command is stored in a memory and is executed only, after verification. The Tele-command receiver also provides the base-band output of ranging tone. This base band is modulated on the telemetry beacon and transmitted back to the satellite control system.

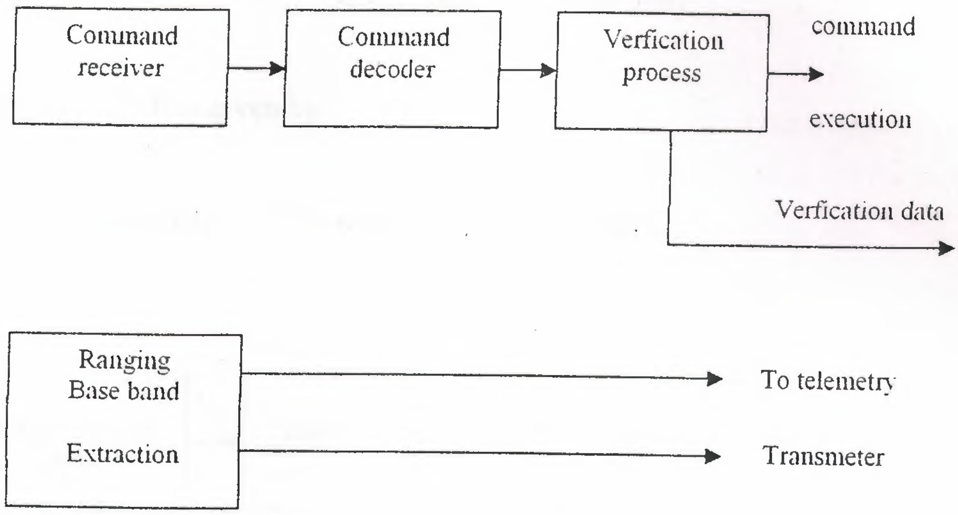


Figure (4.8) Block diagram typial command system

c. Tracking Satellite Position

To maintain a sat, in it's assigned orbital slot and provide look angle information to earth station in the network it is necessary to estimate the orbital parameters of a sat, regularly. These parameters can be obtained by tracking the communication sat, from the ground and measuring the angular position and range of the sat. During orbit raising when the sat is a non-geo-stationary orbit, a network of ground stations distributed through out the global is used for obtaining the orbital parameters. The most commonly used method for angular tracking is the mono-pulse technique. Angular positions measured though a single station taken over a day is adequate for the determination of orbital parameters. The range of a sat can be obtained by measuring the phase difference between the transmitted and received tones shows the main blocks of a multi-tones can be more than 360^{o}, leading to errors in multiple tones of tone time period. Lower frequencies resolve ambiguityand the high tone frequencies provide the desired accuracy. Consider a total phase shift in degrees.

$\Phi > 360^{\circ}$

$\Phi = 360^{\circ} n + \Delta\Phi$ where $\mathbf{n}$ = unknown integer

$\Delta\Phi$ = Measured phase shift

- The range of **R** is given by

$\mathbf{R = \lambda + (\Delta\Phi/360^{o}).\lambda,}$ where λ = wave length

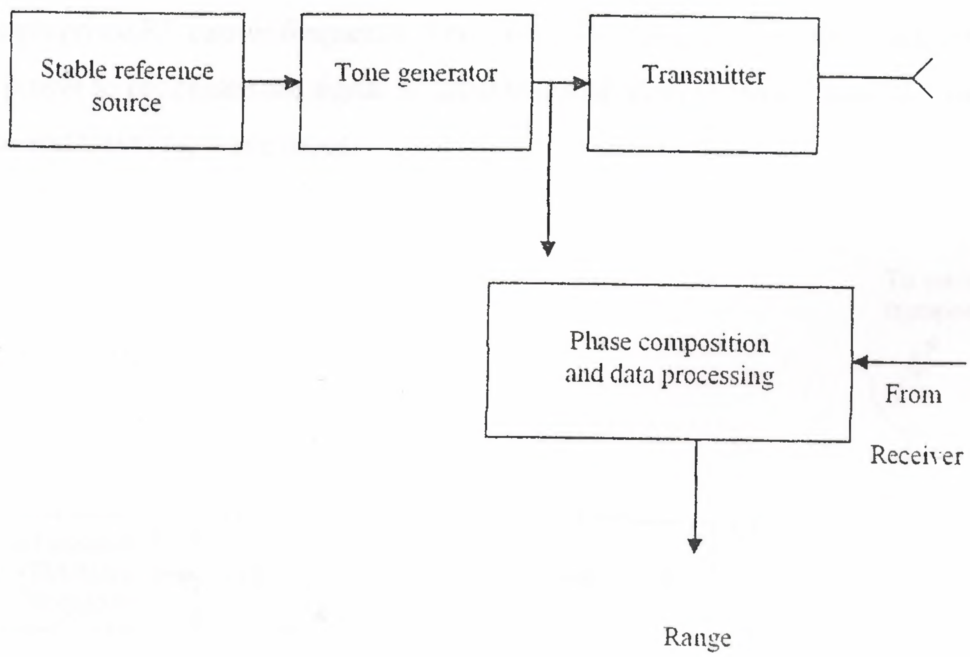


Figure (4.9) *Tracking Satellite Position.*

4.5 Satellite System Link Models

Essentially, a satellite system consists of three basic sections: an up-link, satellite transponder and down-link.

4.5.1 Up-link model

The primary component within the up-link section of a satellite system is the earth station transmitter. A typical earth station transmitter consists of an IF modulator, an IF-to-RF microwave up-converter, a high power amplifier (HPA), and some means of band limiting the final output spectrum (i.e. an output bandpass filter). Figure 4.4 as shown below shows that the block diagram of satellite earth station transmitter. The IF modulator converts the input bseband signals to eithr a FM, PSK, or QAM modulated intermadiate frequeency. The up-converter (mixer and baseband filter) converts the IF to an appropriate RF carrier frequency. The HPA provides adequate input sensitivty and output power to propagate the signal to satellite transponder. HPAs commonly used are klystons and traveling-wave tubes.

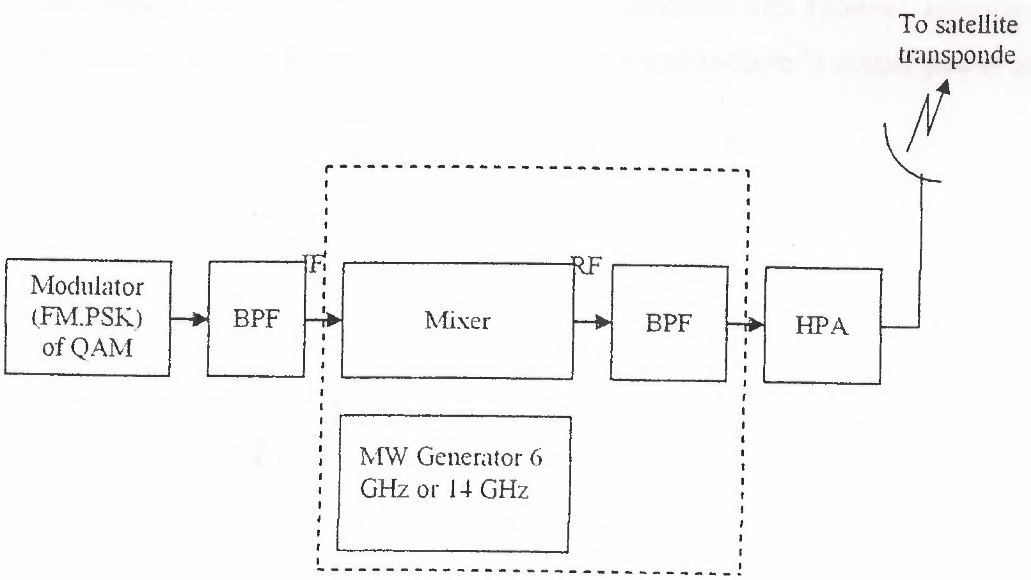


Figure (4.10) Blocak diagram of a satellite earth station

4.5.2 Down-Link model

An earth station receiver includes an input BPF an LNA, and RF-to-IF down converter.

Figure (4.4) shows a block diagram of typical earth station receiver. Again the BPF limits the input noise power to the LNA. The LNA is a highly sensitive, low-noise device such as a tunnel diode amplifier or a parametric amplifier. The RF-to-IF down-converter is a mixer/bandpass filter combination which converts the received RF signally an IF frequency.

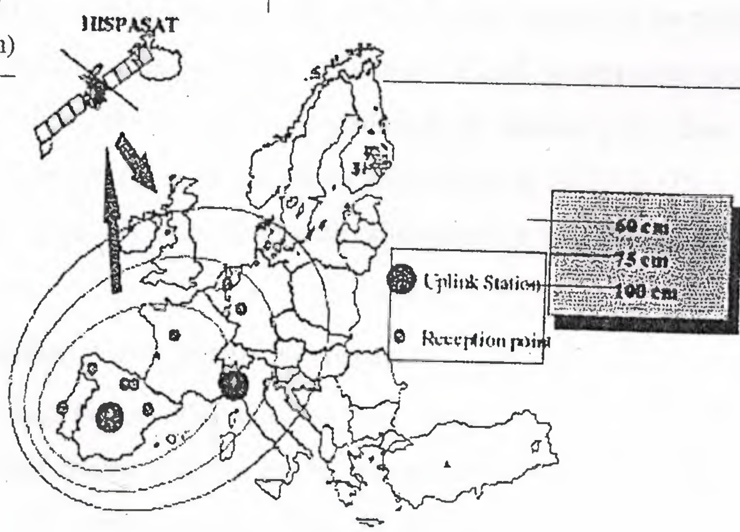
4.5.3 Cross-Links

Occasionally, there is an application where it is necessary to communicate between Satellites. This is done using satellite cross-links (ISLs), as shown in Figure 4.5. A disadvantage of using an ISL is that both transmitter and receiver aerospace-boun. Consequently, both the transmitters are output power receiver's output power and receiver's input sensitivity is limited.

RECEPTION POINTS

HISPASAT (Spain)
HISPASAT Satellite Control Center (Spain)
El Escorial – Summer Course (Spain)
TELEVISIONS ESPANOLA (Spain)
ESTUDIOS TELECINCO (Spain)
CANAL PLUS (Spain)
RETEVISION (Spain)
AGENCIA EFE (Spain)
RAI (Italy)
ETSIT Vigo (Spain)
TORINA Politecnica (Italy)
MULTICANAL TPS (Spain)

- GENERALITATDE CATALUNA (Spain)
- PORTUGAL TELECOM (Portugal)
- FUBA (Germany)
- IKUSI (Spain)
- TELEVES (Spain)
- ROBOTIKER FAGOR (Spain)
- MIER (Spain)
- INTELSIS (Spain)
- SAT (France)
- EC (Belgium)



CHAPTER FIVE

DIGITAL COMMUNICATIONS AND MULTIPLE ACCESS

5.1 Overview

Both the Navistar GPS and GLONASS satellite navigation systems, developed respectively by the United States and the Soviet Univon (now the Commonwealth of Independent States), are now planned to become operational by the year 1994/95. Both systems are capable of providing the civil community with high-precision position-fixes and/or timing references on a continuous, worldwide basis. For many years both systems have had satellites in orbit in order for pre-opertional testing to be conducted. The paper discusses the widely-differing launch histories of both systems developments in the planned use of orbits, the deliberate degadation of accuracy by thee use of selective availability progress in plans to provide a joint Navistar GPS/GLONASS civil satellite navigaton system, possibly integrated with other satellite ranging systems.

5.2 Global Satellite Navigation Systems

The Navistar GPS and GLONASS satellite navigation systems have been under development by the United States and the Soviet Union (now the Commonwealth of Independent States – CI S). Respectively, since the 1970s and are now planned to become fully operational by 1994/95; the number of hours of available operation during each day has increased steadily as the pre-operational build-up continues. They are intended to replce earlier satellite navigation systems (Transit and Cicada), also

* Navistar GPS = navigation system with time and ranging global positioning system GLONASS = global orbiting navigation satellite system operated by the USA and USSR, which provide limited daily coverge and are unable to provide the user with velocity information. These two earlier systems employ similar orbits with a small

number of low-altitude (1100-km) polar-orbiting satellites transmitting information at dual frequencies arounnd 150 and 400 MHz. The user waits for a single satellite (possibly as long as two hours) and then makes a series of measurements of Doppler shifts of the received frequencies during the short period (<16 minutes) when the satellite remains above the horizon. The satellite's position and velocity are included in the naviggation message transmitted by the satellite and these, together with the Doppler measurements are sufficient to allow the user to compute his position.

Transmissions on two frequencies are used to allow an ionosphere group delay correction to be applied. The two systems have two major drawbacks: the system in not available 24 hours a day and the user velocity must be known.

Navstar GPS and GLONASS are designed to overcome the difficulties associated with the earlier systems and to provide on a global basis (on the earth's surface, on land and at sea, in the air and in space itself) precise, continuous position-fixing capabilities with velocity and time information by using navigatioon satellites transmitting dual-frequency spread-spectrum signals in L-band (1.2 and 1.6 GHz). Both systems comprise a number of satellites placed in orbits such that observers anywhere on the surface of the earth always have at last four satellites in view. In constrast to the earlier VHF systems, the pflmar/7 navigation mode is based on range measurement rather than integrated Doppler.

Under the control of highlystable, onboard frequency references (atomic clocks), the satellites simultaneously, transmit timing signals (epochs) and data. The transmitted data includes a precise ephemeris for each satellite, i.e. an almanac of the satellite's position from which the position and velocity of the satellite at a given time can be computed. In addition, each satellite provides information on the behavior of its own on-board clock. The observer measures the time-of-arrival of signals from three satellites and at the same time uses the received data to compute the position of the satellites.

Given a synchronized ground time reference the observer can determine the signal propagation times from each satellite and hence, knowing the velocity of propagation, the range Lo each satellite. In principle he an then solve three range equation's for the three unkknown: ordinates of his position. In practice, the observer will not normally, have a synchronized time reference and will therefore choose to determine the pseudorange to four satellites instead of three, and use the fourth measurement to compute the instantaneous time error of the local clock. The question of which satellites to access (there can be as many as 8 or 9 to choose from) is important in that the position estimate is related to 'pseudo-range' through a factor called PDOP (position dilution of position), whose value is dependent on the geometry of the chosen satellite configuration. The primer, justification for the provision of a global, continuous and precise satellite navigation system is military. National governments only allocate the enormous financial resources required to implement such a system on the grounds of defense and national security. However, as in the case of Transit and Cicada, a role for civil use of the systems available has also been deemed acceptable. Both Navstar GPS and GLONASS therefore also offer a navigation facility to both the military and civil user.

5.2.1 Overview of Navstar GPS and GLONASS

The Navstar system will consist of 24 primary, satellites in near-circular orbits at an altitude of approximately 20000-km. Four unequally spaced satellites will be placed in each of 6 orbital planes (A-F) which have the same inclination of 55° to the equatorial plane. The 6 planes are separated by 60°, i.e. their intersections with the equatorial plane are separated by 60° of longitude (this is referred to as 60° separation between the ascending nodes of the orbits the points where the satellites make a north going crossing of the equeator). The orbital period is 11 hours 57.94 minutes so that all satellites have a ground track repeat of two orbits with the result tht theey appear at the same position each day 4.07 minutes earlier than the previous day. In the early stages of the programmer, the orbital inclination was defined to be 630 but this figure was then amended to 55° to allow launch by the *Space Shuttle*. The satellites share a common time system known as GPS time and transmit a precise time references as a spread-spectrum signal at two frequencies in L band: 1575.42 MHz *(L_1)* and 1227.6 MHz *(L_2)*.

Two spread-spectrum codes are used: a civil 'clear acquisition' (C/A) and a 'military' 'precise' (P) code. The C/A code is a 1023-bit Gold code clocked at 1 023 Mbit/s, repeating every 1 ms. The P code is clocked at 10.23 Mbit/s and repeats after approximately 38 weeks. The same 50 baud data is modulo-2 added to each code before final BPSK (binary phase shift keying) modulation at the carrier frequency. The signal at L_2 only contains the P code, although the capability exists to include the C/A code; the signal at L_1 contains both a P and a C/A code modulated onto quadrate carriers.

Received signal power using an isotropic antenna is of the order of −160 dB for the C/A code and 3 dB less for the P code. The resultant received signal is some 22 dB down on the Ambient noises power within the signal bandwidth so that code acquistion and signal dispersing is necessary before carrier recovery can be accomplished.

GLONSS offers many features in common with Navstar GPS. Its orbital plan also foresees 24 satellites forming the space segment (21 operational satellites with 3 in-orbit spares) but will use only 3 orbital planes separated by 1200 of longitude and with equal spacing between satellites of 45° within the plane. The orbits are near circular with a period of around 11 25 hours at a height of 19 100 km and an inclination of 64.8°. As GPS, GLONASS also transmits two spread-spectrum signals in L-band at around the same power levels (-160 dBW at L_1, -163 dBWatL_2), however GLONASS satellites are distinguished by radio frequency channel rather than spreadspectrum code. In GLONASS a single code of length 5 11 bits repeating every 1 ms is used. Information is differentially encoded in an RZ (return to zero) format with a final data rate of 50 baud.

Technical details of both systems have been made available to international organizations for the purposes of future planning requiring navigation satellites. Both systems are expected to reach full operational capability by 1994/5, however the satellites already in orbit can now be used extensively in all parts of the globe.

5.2.2 Development Phase

The US Navstar GPS system saw its first launch in 1978; the USSR's GLONASS system was inaugurated 4 years later. GLONASS satellites are launched three at a time from the Tyuratam space center. Successful launches are followed by an announcement within a day or two in *Pravda* giving basic details of the mission. There have been 20 launches since the first one in late 1982, all of theem successful expcept the ones in April 1987 and February' 1988 where the satellites failed to reach final orbit because of a malfunciton of the fourth stage of the Proton launch vehicle. Table 2 presents the international identifiers, and the Cosms and GLONASS numbers of all know launches since the first one in 1982; all triple launches have taken place into one of two of the three. Orbital planes (referred to in the Table as planes 1 and 3) separated by 1200. No satellite has as yet been launcheed into the remaining plane 2. Each launch aims to produce a final, stable, near circular inclined (orbit at a distance from the earth center of about four earth radii. (The first seven launches only two the three launched satellites achieved the said stable orbit; the third satellite remained in an orbit without ground-track repeat and was not observed to transmit.

Since then launches 8-13 (with the exception of failed launches 9 and 11) resulted in a stable orbit for all three satellites, which have also transmitted full navigation messages and can therefore be regarded as fully-Hedged member of the pre-operational system. Exceptionally launches 14 and 15 placed two GLONSS satellites into stable orbit (the third member of the group was a passive laser-ranging satellite called Etalon). Launches 16-20 reverted to the practice of launches 8-13.

The GLONASS system has suffered from poor satellite reliability since program started. Of the 45 satellites successfully placed in orbit only 12 are presently operational, 7 in plane 1 (GGLONASS 55, 40, 53, 47, 49, 48 and 54) and 6 enplane 3 (GLONASS 44, 57, 45, 58, 51 and 56), In cotrast with GLONASS launches, which plce three satellites at once into orbit, launches of Navstar GPS place only one satellite into orbit at a time. There are to be three phases in th development of the Navstar GPS space segment. The first, proportional phase incorporated Block I satellites and terminted at the end of 1988. The operational be launched in 1989 and currently 17 of these satellites are operating. The Block II phase will continue until full operation in 1994. Following the full implementation of GPS, a further series of replenishment satellites (know as Block IIRs) will be launched; these satellites will have the capability of interstellite rnging, thus making the system operation less dependent on ground control.

Commitment to Space Shuttle launches of the first Block II satellites led to difficulties following the Challenger accident early in 1986. In fact the lack of alternative Means of launching Navstar GPS led to a delay of more than three years between the launch of the last of the Block I satellites and the first of the Block II satellites (by Delta II launcher) early in 1989. As already explained, there are six Navstar GPS launch planes, known as I-F, separated by 600. All Block I satellites werelaunched with a nominal inclination of 630 into either launch plane A or C; Block II satellites all have a nominal inclination of 55°. A summary of Navstar GPS launches is included in Table 3. Currently 4 Block I and 17 Block II satellites are fully operational. The design lifetime of the Block I satellites was 5 years; as is now obvious, several of those satellites have exceeded their lifetimes by many years. Should some still be operational as the full Block II sequence of 24 satellites approaches, it is not clear whether the remaining Block I satellites are to be counted as part of the complete configuration or not.

5.3 Orbital Considerations

For a given number of satellites in the final operational system the choice of orbital planes and phases within the plane is constrained to ensure visibility of four well-located satellites on a continuous global basis. An approach common to GPS and GLONASS is to adopt a small number (3 or 6) of equally-separated inclined orbital planes with a number of satellites distributed in phase around each plane and with an offset in phase between planes. It is intended to augment this approach with a number of satellites in the geostationary arc (Inmarsat-3 satellites).

5.3.1 Orbital Plans and Current Occupation

For an explanation of orbit terminology see the panel 'Satellite-earth geometry in earth-centered, earth-fixed (ECEF) inertial frame.

1) Navistar : An important change has taken place with regard to the original plans for Navstar GPS orbits. The initial intention to employ three orbital planes separated by 120° and with eight satellites in each plane has been changed to a six-plane orbit with up to four satellites in each plne. As explained earlie, Block II GPS satellites occupy one of six planes A-F separateed by 60°, whereas Block I satellites occupied one of three planes A-C separated by 120°. There is no correspondence in the positions of Block I and Block II satellites with the same letter.

2) GLONASS : The GLONNAS satellite navigation system foresees an operational configuration of 24 satellites with eight satellites in each of three orbital planes separated by 120° in right ascension of the ascending node (RAAN – essentially the equaator-crossing longitude expressed in a star-fixed reference frame). There is a separation in argument of latitude (or orbital phase) within the plane of 45°, There is also a displacement of +30° and-30° for satellites in planes 2 and 3, respectively, with reference to plane 1. This nomenclature follows that assumed by the GLONASS almanac format. Relative positions of satellites remain very stble over long periods because they have very much the same, small rates of change of RAAN, amounting to about –0.03° per day for near-circular GLONASS orbits.

All satellites hve the same nominal orbit period of 675.73 minutes with longitude change of 16.41° W each orbit. This orbit produces a ground-track repeat every 17 orbits lasting 8 whole days less 32.56 minutes. The diurnal offset of $\Delta T = 4.07$ minutes from a full 24-hour day coincides with that of Navstar G-S and is very nearly the difference between a solar and sidereal day (3.93 minutes). This implies that each complete day less AT minutes a satellite performs 1 7/8 orbits, or 2 whole revolutions plus an additional 1/8 revolution, equivalent to 45° It follows that two satellites in thee same plane but separated by 45° in orbital phase appear at precisely the same position on successive days less ΔT minutes. During that interval, the earth hs rotated very nearly 360° with the result that the ground-based observer sees the two stellites at the same pointing azimuth and elevation but on successive days. Over a ground track repeat interval of 8 days then, all stellites in the same plane with separation of 45° appear in turn at the same position at intervals of 1 day less AT minutes. After 8 days, the whole cycles naturally repeats.

By examining the phases of satellites in the planes 2 and 3, it becomes apparent that these satellites will also appear at the same position as the reference satellite in plane 1 within the same 8-day period. This arises because the time taken by the earth to rotate through the angle 120° separating planes 1 and 2 is the same time taken by a satellite in that plane with phase +255° to travel round to the same position as the reference satellite. The ear rotates through 120° in 478.69 minutes, very nearly 8 hours, which corresponds almost exactly to 17/24 of a GLONASS orbit or +255°. The same argument holds for plane 3 at 240° separation for satellite at phase +150° (or twice +255° less 360°). The angular separation of 45° within the plan together with the angular phase differences of 30° between planes assures that, in an 8-day period, 24 satellites will pass through the position with the reference subsatellite location.

5.3.2 Communications from GLONASS/Navstar GPS

For the purposes of allowing the user to compute his own position navigation satellits transmit details of their own positions and time reference. In systems such GLONASS and Navstar GPS whose purpose is primarily military, the user is expected to play a passive role as any transmissions to a satellite might identify,' his position to an adversary'. Similarly, the navigation message is protected against deliberate jamming by the use of spread-spectrum codes, which increase the bandwidth occupied by the signal and hence (that of the intending jammed. It should be clear, however, that, even were the system design to exclusively for civil purposes, it likely that spread spectrum would still be used for tqo reasons:

a) As to minimizes interference to others and

b) To providee sufficient bandwidth and hence definition the epoch timing edge. An 'epoch (is simply a time marker within transmitted signal, usually at the transition from one second (or submultiple of a second) of time the next. In the following discussion the structure of the navigation message from global navigation satellites to the user be considered.

5.4 Radio – Frequency Transmissions

The transmission carrier frequencies chosen for the new satellite navigation systems lie L-band. Dual-frequency navigation meessages at L_1 and L_2 allow the user to correct for ionospheric propagation effects and are incorporated into both Navstar and GLONASS. A High-precision spread spectrum code is modulated onto both carriers whereas the lower-precision civil code only appears at L_1. Spread-spectrum techniques are primarily involved to reduce the effects of deliberate of accidental jamming of signals.

Radio-frequency carriers used by GLONASS occupy channels within the bands 1240-1260 MHz and 1597-1617 MHz, thee channel spacing being 7/16 (or 0-4375) MHz at the lower frequencies and 9/16 (or 0-5625) MHz at the higher frequencies. The carrier frequencies themselves are also multiples of channeling spacing and the number of planned channels is 24. GLONSS L *[transmit* carrier frequencies *(FREQ,* in megahertz) and channel numbes *(CHN)* are related by the expression:

$$FREQ = 1602 + 0.5625\ CHN \tag{5.1}$$

Corresponding frequenciees at L_2 are in the ratio 7/9.

In stark cntrast to the FDMA (frequency division multiple access) system chosen by GLONASS to distinguish satellites, Navstar GPS uses the same frequency for all satellites and differentiates one satellite from another by individual Gold codes, a from of CDM (code division multiplex). This difference between thee two systems is of major significance in designin receivers capable of joint operation. It is worth pointing out that the regime chosen for the European Space Agency's putative Navsat system is TDM (time division multiplex).

5.4.1 Information transmission, bandwidth and code rates

Each satellite sends dta at low speed from which it's own position at any reference time may be calculated. This data commonly sent at a 50 baud rate, is superimposed on a pseudorandm noise (PRN) code that is, in fact, periodic and very much longer than a single data bit. The GLONASS low-precision code has a length of 511 bits as compared to Navistar's 1023 bits for its equivalent code. A code sequence lasts only 1 ms so that each data bit occupies 20 entire code sequences, the code itself of its inverse being sent depending on whether the data bit is a '0' or a '1'. In this manner, the information spectrum is spreead across a wide range since bandwidth is determined by the most rapid change of state in the message. On the assumption that, in transmission, the signal will be corrupted by Gaussian noise whose power level is proportional to bandwidth, the signal will become immersed in the noise at the receiver's terminal aand recoverable only by reversing the coding operation applied at the transmitter. This implies knowledge of the PRN codes on the part of the receiver.

The code rate can bee seen from the figures already given to be 511 kbit/s aand 1023 kbit/s for the civil GLONASS and Navstar codes, respectively. Military codes are at ten times these rates and, of course, the sequence lengths are very much longer. To transmit the encoded data, a binary phase-shift keyed (BPSK) modulation technique is employed, the first nulls in the transmitteed spectrum being at plus/minus the bit rate. Hence bandwidths for the GLONASS transmission can be taken as 1 MHz and 10 MHz for the civil and military codes, respectively. These figures compare with 2 MHz and 20 Mhz for Navistar's equivalent bandwidths.

At the L_2 frequency only the high-rate code is carried but at L_1 both codes are transmitted on the same carrier, one in-phase and the other in quadrate. This results in a signal spectrum, which superimposes the two individual spectra, whose bandwidths differ by a factor of ten. Since both transmissions carry the same power, a spectrum analyzer display will show the narrower-band code at 10 times the strength of the wide-band code, giver equal powers.

5.4.2 Data Message

The data carried on transmissions from satellites is low bit-rate at 50 baud and essentially provides accurate positions for the transmitting satellite as well as information on its on-board frequency standard. In addition, data is given in the form of low-precision almanacs of all the other satellites currently available so as to allow the user to pln usage and to assist with signal acquisition. Data is sent is lines, subframes and frames, with preambles at the start and parity checks at the end of each line. The reader is referred elsewhere for details.

5.5 Multiple Access And Modulation Techniques

To achieve as high a degree of flexibility of interconnection between the earth stations as may be desired, multiple aaccess is an operational requirement of utmost importance. *Multiple access* refers to techniques, which allow more that two earth stations to enter a single satellite transponder, providing real-time interconnection for simultaneous two way communications between any two stations.

There are three basic multiple-access techniques: frequency-division (FDMA), time division (TDMA), and code-division (CDMA). They differ in there- utilization of the satellite power, time, and frequency (bandwidth). All can be used for any of the three forms of operation, namely, preassignment, time-assignment, or demand-assignment operation.

In *frequency-division multiple* access (FDMA), the satellite frequency domain (bandwidth) is divided into n discrete frequency channels. Each earth station can use one or more channels. Each frequency channels. Each frequency channel has full use of satellite time but shares the satellite frequency and power with all other frequency channels.

In *time-division multiple access* (TDMA), each interval of *T* seconds *(called a frame period)* of the satellite time domain is divided into n discrete time slots. Each earth station can use one or more time slots. All time slots share satellite time, frequency, and power.

In *code-division multiple access* (CDMA), neither the satellite frequency nor the time domain is divided among the earth stations. Instead, each earth station has common usage of the full satellite bandwidth and time slots by employing a special coding-decoding technique. Each station uses a code different from the others. The satellite power, however, is shared by all earth stations.

The three basic multiple-aaccess techniques can bee combined to generate several hybrids. Most noweworthy are FD/TDMA, FD/CDMA, TD/CDMA, and FD/TD/CDMA.

CHAPTER SIX

DIGITAL SATELLITE COMMUNICATION SYSTEM

6.1 Introduction

The first commercial communication satellite, INTELSAT I (known as 'Early Bird'), was launched in April 1965. Since then, satellite communications have become a major means for international as well as domestic communications over logn or moderate distances. Although the initial task of satellite communications was the transmission of telephone and television signals, it's mission has been extended to cover other applications. It's applications include:

- Fixed satellite communication systems
- Broadcast satellite communications systems
- Land mobile communications systems
- Maritime satellite communications systems
- Aeronautical saatellite communications systems
- Radio determination satellite systems
- Satellite personal communications systems
- Satellite interset access systems

The servisces offered by the satellite can be divideed into the following categories:

Voice services

- Telephony
- Audio broadcsting – DAB
- Voice conferencing

Video and image services

- Facsimile
- Graphics
- Freeze-frame video
- Full-motion video
- Broadcast quality video
- Teletext/videotext
- HDTV

Data services

- Electronic mail
- Database access
- File transfer
- Remote data monitoring
- Short message transmission
- Paging
- Electronic funds transfer

6.2 Satellite Earth Orbits

There are three common types of satellite earth orbits: Geostationary Earth Orbits(GEO), Low Earth Orbiits (LEO) and Medium Earth Orbits (MEO).

The GEO is a circular orbits in the equfatorial plan. The angular velocity of the satellite is the same as that of the earth. Therefore, the satellite seems to be remained stationary in the sky.

The LEO and MEO orbits are lower altitude orbits. There particularly suitable for the satellite personal communicaitons systems due to their low path losses and low propagation delays. A comprison of the LEO, MEO and GEO orbits is given in Table 1.

Table 1

	LEO	MEO	GEO
Altitude	700-1,000 km.	10,354 km.	35,786
Orbital Period	100 minutes	6 hours	Stationary
No. of Satellitee for full global coverage	48-66	10-12	3
Space Segment Cost	Highest	Lowest	Medium
Satellite	5-7.5	10-15	10-15
Lifetime (Years)	Imperceptible	Imperceptible	Long
Propagation Delay	Frequent	Infrequent	None
Call Handover			

The objective of this section is to give the readers a general knowledge of digital satellite communication systems in order to have better understanding of the problems involved in the analysis and design of modern satellite communication systems.

6.3 Digital Satellite System Configuration

The block diagrams of a two-link satellite communication system is shown in Fig. 6.1 The transmitted path form an earth station to the satellite is referred to as 'uplink' and the transmitted path from the satellite to an earth station as 'downlink'. The on-bord repeater may contain one or more transporders (a transponder is a single on-board RF channel).

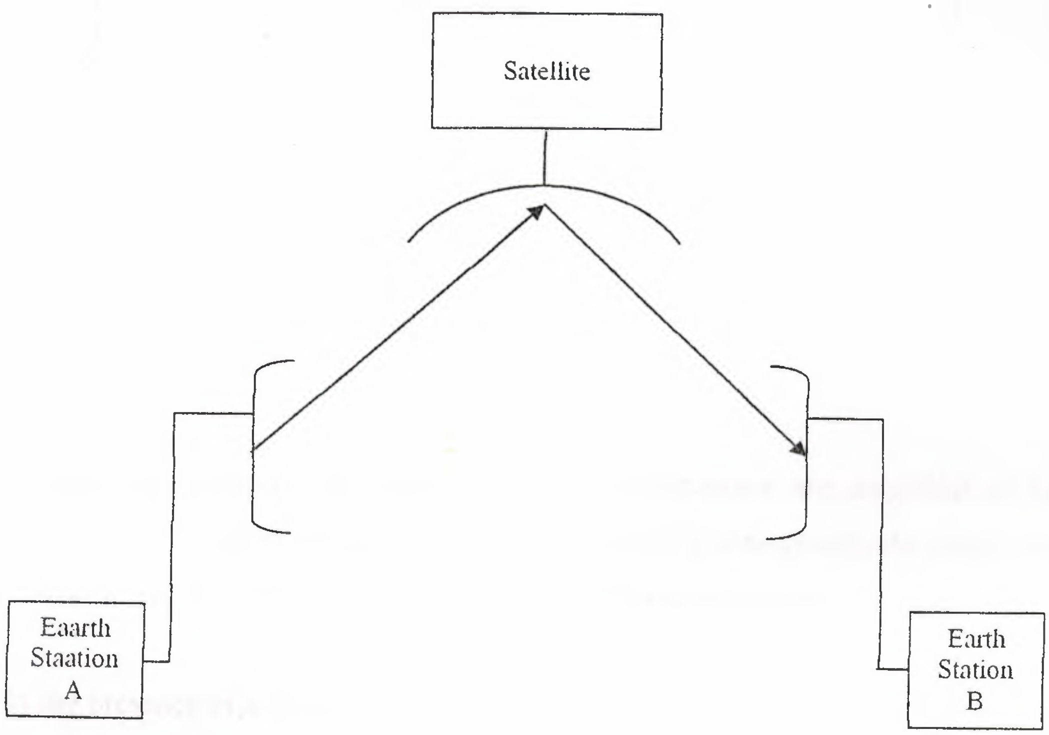


Figure 6.1

There are two types of transponders: transparent (amplifyingg) and regenerative types.

6.3.1 Transparent transponders

A simplified block diagram of a conventional transparent (amplifying) transponder is shown in Fig. 6.2. It consists of three main components – low – noise amplifier (LNA), frequency converter and high power amplifier (HPA) with relevant filtering.

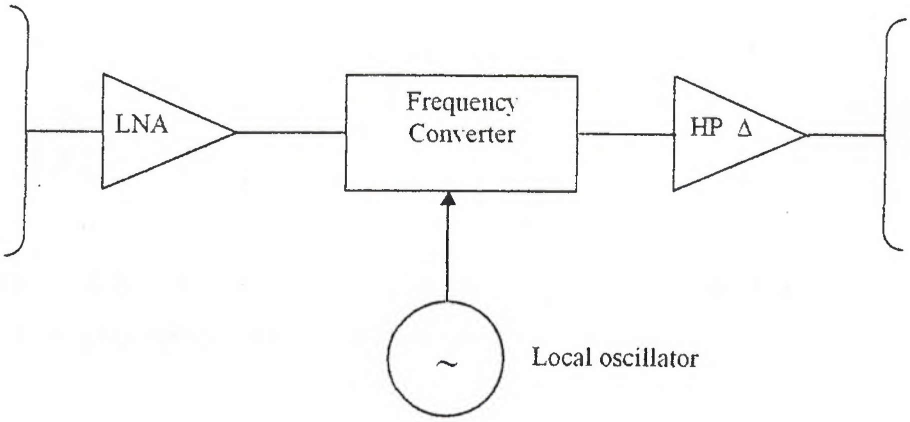


Figure 6.2

In these transponders, the uplink noise and interference are amplified at the transponders and transmitted to the receiving earth station. Consequently, the uplink and downlink noise and interference are added at the earth station receiver.

In the presence of additive white Gaussian noise only, the overall carrier-to-noise ratio (CNR) at thee receiving earth station is:

$$\frac{C}{N} = \frac{1}{\frac{1}{\left(\frac{C}{N}\right)_u} + \frac{1}{\left(\frac{C}{N}\right)_d}} \tag{6.1}$$

Where $\left(\frac{C}{N}\right)_u$ and $\left(\frac{C}{N}\right)_d$ are the up-and-down-link CNR's, respectively

Similarly, the overall bit energy-to-noise power spectral density at the input to the earth station receiver is given by:

$$\frac{E_b}{N_o} = \frac{1}{\frac{1}{\left(\frac{E_b}{N_o}\right)_u} + \frac{1}{\left(\frac{E_b}{N_o}\right)_d}} \tag{6.2}$$

(As an exercise derive the above equations). In the case when a QPSK modulation is used, the overall bit-error probability is given by:

$$P_e = \frac{1}{2} erfc\sqrt{\frac{E_b}{N_o}} \tag{6.3}$$

Where $\frac{E_b}{N_o}$ is btained from Equation (6.2).

6.3.2 Regenerative transponders

A regenerative transponder is a complete transreceiver including a demodulator and modulator as shown in Fig. 6.3.

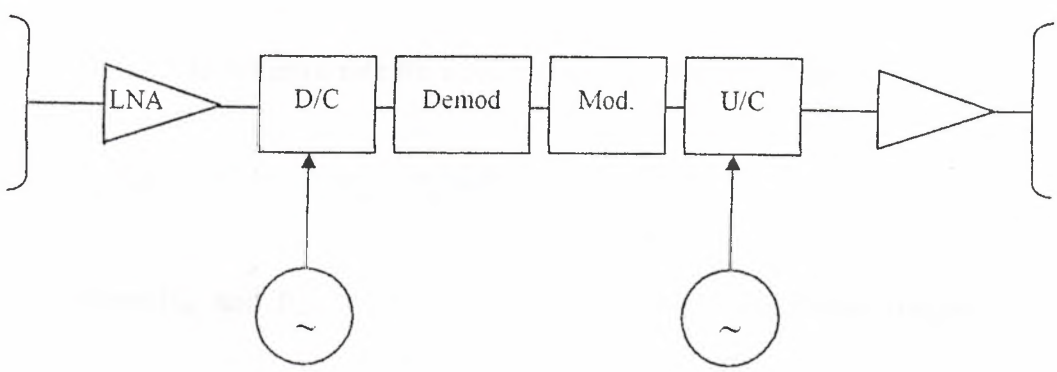


Figure 6.3

The uplink signal is down-converted to IF and then demodulted to baseband. The individual pulses are deetected and reshaped. These pulses are then remodulated into a downlink carrier, up-converted and amplified before retransmission to the receiving earth station.

In a regenerative satellite the up-and down-links are decoupled and hence the noise and interference of two links do not add. As a result, each link can be optimised separately.

Satellite systems employing regenerative transponders have the following advantages:

a) Different modulation and coding formts my be used in each link.
b) On-board processing may be used on-board.
c) Possibility of using baseband switching on-board.
d) Improved error rate.
e) Cheaper earth terminals.

The disadvantages of such systems are:

a) Decreasing reliability due to increase in complexity
b) Extra weight
c) Power dissipation.
d) Cost.

The overall bit error rate for a regenerative transporder is given by:

$$P_e = P_{eu} + P_{ed} - 2P_{eu}P_{ed} \cong P_{eu} + P_{ed} \tag{6.4}$$

Where P_{eu} and P_{ed} are the uplink and downlink bit error rates, respeectively.

(As an exercise prove the above).

In the case when QPSK signalling is used for both links, the overall bit error rate can be obtained as:

$$P_e = \frac{1}{2} erfc\sqrt{\frac{E_b}{N_o}} + \frac{1}{2} erfc\sqrt{\left(\frac{E_b}{N_o}\right)_d} \tag{6.5}$$

Figure 6.4 shows the up-and down-link $\frac{E_b}{N_o}$ combinations required to obtain a specific bit error rate for QPSK transparent and regenertive transponders.

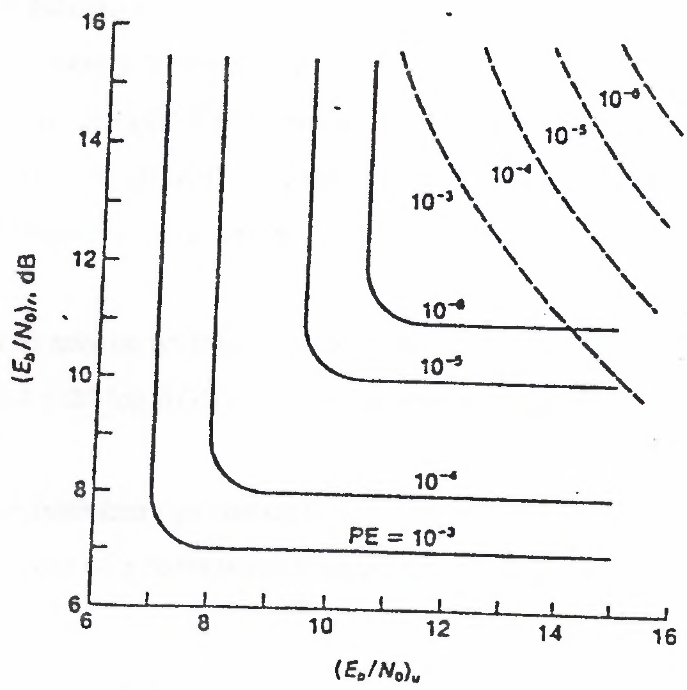


Figure 6.4

6.4 Link Budget Calculation

A link budget shows the losses, gains and noise in the uplink and downlink of a satellite radio system. To calculate the link budget for a particulaar satellite system, the link designer may use the following system parameters.

1. Antenna gain

Present day satellite communication systems employ parabolic (dish) antennas for transmitting and receiving signals. A useful approximated gain expression for parabolic antennas is given by:

$$G = \eta\left(\frac{\pi D}{\lambda}\right)^2 \tag{6.6}$$

Where η = antenna efficiency (typically 55 percent)

D = antenna diameter

λ = wavelength of radio wave = c/f

c = velocity of light = 3x108 m/s

f = radio wave frequency.

Equation (6.6) may be written in decibels as:

$$G\,(dB) = 20.4 + 20 \log f(GHz) + 20 \log D\,(m) + 10 \log \eta \tag{6.7}$$

2. Free-space path loss (spreading loss)

The loss of power pf a radio wave is given by:

$$L_p = \left(\frac{4\pi d}{\lambda}\right)^2 = \left(\frac{4\pi f d}{c}\right)^2 \tag{6.8}$$

Where d is the distance travelled in free-space (path length).

Equation (6.8) may be expressed in decibels as:

$$L_p\,(dB) = 92.4 + 20 \log d\,(km) + 20 \log f\,(GHz) \tag{6.9}$$

3. Receiver input noise power and system noise temperature

The total noise power at the input of a receiver is given by:

$$N = K\, T_s\, B_n \tag{6.10}$$

Where K is Boltzmann's constant = 1.38×10^{-23} Joules / K, T_s is the system noise temperature and B_n is the receiver equivalent noise bandwidth. The system temperature can be obtained as:

$$T_s = T_{ae} + (LF - 1)\, T_o \tag{6.11}$$

Where T_{ae} is the equivalent antenna noise temperature, L represents thee total loss due to the antenna feed, diplexer, connectors, etc. (any lossy components at the receiver input), F is the receiver noise figure and T_o = 290K.

The value of T_{ae} depends on the specific characteristic of the nois background observed by the receiving antenna. A satellite antenna, looking towards earth has an equivalent temperature of 300K. On the other hand, T_{ae} for an earth-station antenna, looking towards sky is a combination of galactic and re-radiated atmospheric noise temperatures as shown in Fig. 6.5[8].

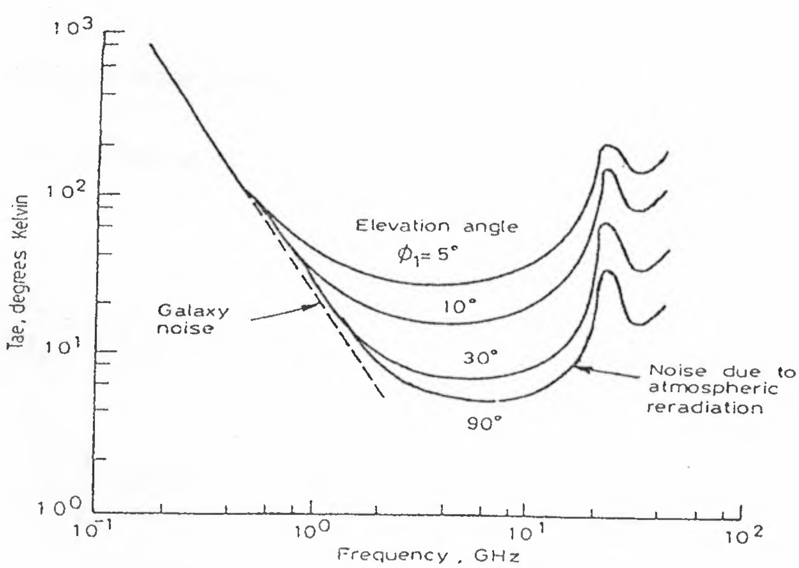


Figure 6.5

4. Effective isotropic radiated power (EIRP)

EIRP of an earth-station or of a transponder can be expressed as:

$$\text{EIRP (dBW)} = P_t\ \text{(dBW)} + G_t\ \text{(dB)} \tag{6.12}$$

Where P_t = transmitted power including back-off and any losses at the output of the HPA (e.g. combining losses) and G_t = transmitter antenna gain.

5. Figure of merit, (G/T)

The sensitivity of a satellite or of an earth station receiver is frequently expressed in terms of the ratio between the receiver antenna gain and system noise teemperature expressed as:

$$G/T\,(dB\,K^{-1}) = G_r\,(dB) - 10\log T_s\,(K) \tag{6.13}$$

6. Received carrier power-to-system noise temperature ratio, C/T

C/T is the ratio between the received carrier power and the system noise temperature at the transponder or earth-station receiver input and expressed as:

$$C/T\,(dBW\,K^{-1}) = C(dBW) - 10\log T_s(K) \tag{6.14}$$

7. Bit energy-to-noise power spectral density ratio, E_b/N_o

$\frac{E_b}{N_o}$ can be expressed as:

$$\frac{E_b}{N_o} = \frac{CT_b}{KT_s} = \frac{C}{KT_s f_b} \tag{6.15}$$

where $T_b = \frac{1}{f_b}$ is the biit duration and f_b is the bit rate of the signal. Equation (6.15) may be written in decibels as:

$$\frac{E_b}{N_o}(dB) = \frac{C}{T}(dBW\,K^{-1}) - 10\log K\,(dBW\,K^{-1}Hz^{-1}) - 10\log f_b(dB\,Hz) \qquad (6.16)$$

As an example, the link budget of the 14/11 GHz European communications Satellite (ECS) system is given in Table 6.2[9].

Table 6.2

Uplink		
1. Transmitter output power at saturation. 2 KW	33	dBW
2. Backoff and combining losses	7	dB
3. Transmit antenna gain (15 m, 14 GHz)	64	dB
4. EIRP	90	dBW
5. Free space loss (14 GHz)		207.5 dB
6. Atmospheric loss (14 GHz, clear weather)	0.6	dB
7. Satellite G/T	-5.3	dBK^{-1}
8. C/T at repeater input	-23.4	$dBWK^{-1}$
9. Boltzmnn's constant	-228.6	$dBWK^{-1}$
10. Bit rate, 120 Mb/s	80.8	dBHz
11. E_b / N_o at repeater input		24.4 dB
Dowlink		
1. EIRP at beam edge (unmodulated carrier. saturation)	40.8	dBW
2. Modulation backoff and bandlimiting losses	0.6	dB
3. Free space loss (11.7 GHz)	205.6	dB
4. Atmosphheric loss (11.7 GHz, clear weather)	0.4	dB
5. Power at receiive antenna	-165.8	dBW
6. Receive antenna gain (15 m, 11.7 GHz)	62	dB
7. Receive system noise temperature (clear weather) 270 K	24.3	dBK
8. Earth station G/T	37.7	dBk^{-1}
9. C/T at receiver input	-128.1	$dBWK^{-1}$
10. Boltzmann's constant	-228.6	$dBWK^{-1}$
11. Bit rate 120 Mb/s	80.8	Hz^{-1}
12. E_b/N_o at receiver input	18.4	dBHz
		dB

• *This systeem will provide 17,000 two-waay digital telephone circuits by 1990. Individual satellite transponders will carry 120 Mb/s of traffic.*

6.5 Multiple Access Techniques

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

1) Frequency Division Multiple Access (FDMA)
2) Time Division Multiple Access (TDMA)
3) Code Division Multiple Access (CDMA)

6.5.1 Frequency Division Multiple Access (FDMA)

The most widely used of the multiple access techniques is FDMA. In FDMA, the available satellite bandwidth is divided into portions of non-overlapping frequency slots which are assigned exclusvely to individual earth stations. A basic diagram of an FDMA satellite system is shown in Fig. 6.6

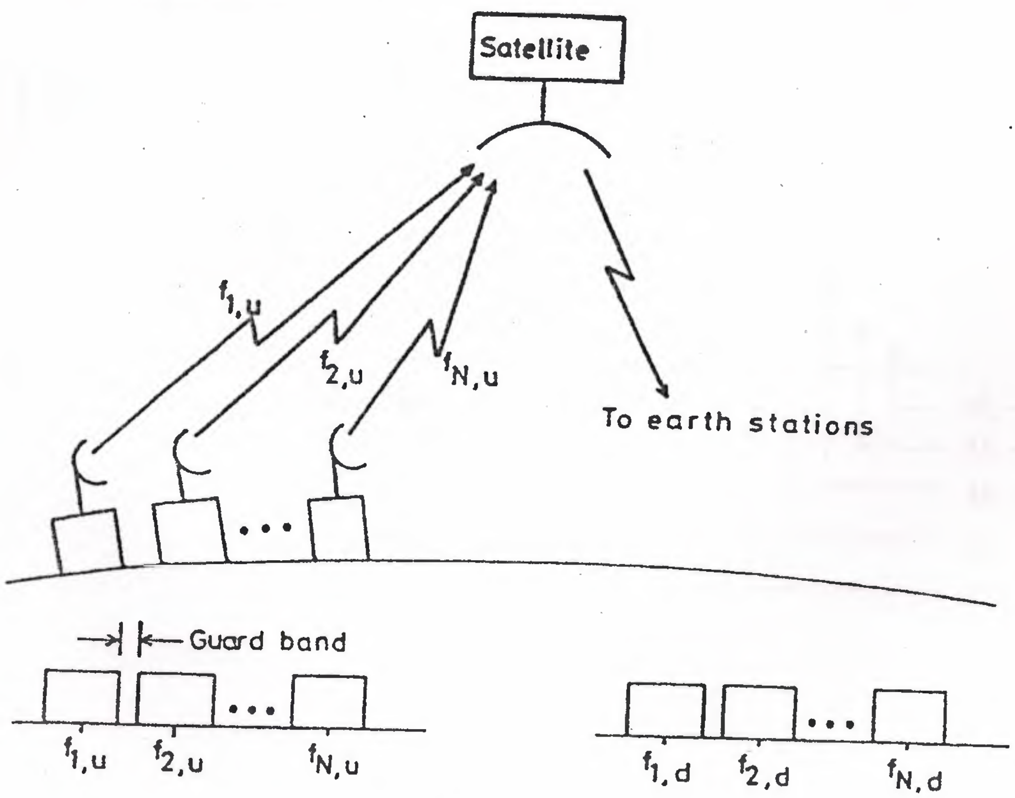


Figure 6.6

Examples of this technique are FDM/FM/FDMA used in INTELSAT II & III and SCPC satellite systems. Also, SPACE (signal-channel-per-carrier PCM multiple access demand assignment equipment) used in INTELSAT IV in which channels are assigned on demand to earth stations is considered as a FDMA system.

In FDMA systems, multiple signals from the same or different earth stations with different carrier frequencies are simultaneously passed through a satellite transponder. Because of the nonlinear mode of the transponder, FDMA signals interact with each other causing intermodulation products (intermodulation noise) which are signals at all combinations of sum and difference frequencies as shown in the example given in Fig.6.23.

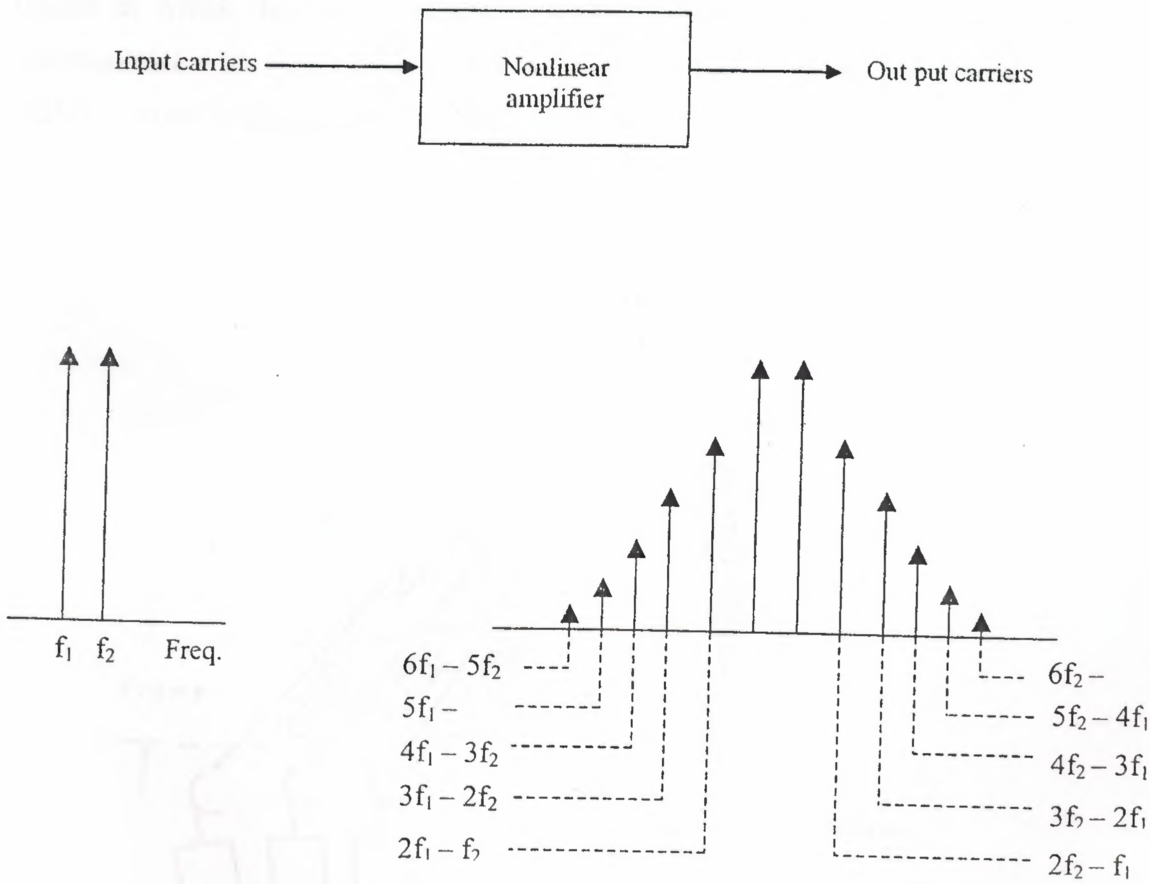


Figure 6.7

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

6.5.2 Time Division Multiple Access (TDMA)

In search of an alternative multiple access technique; attention was focused on the possibilities afforded by TDMA. In TDMA, the sharing of the communication resource by several earth stations in performed by assigning a short time (time slot) to each earth station in which they have exclusive use of the entire transponder bandwidth and communicate with eaach other by means of non-overlapping burst of signals. A basic TDMA system is shown in Fig. 6.24.

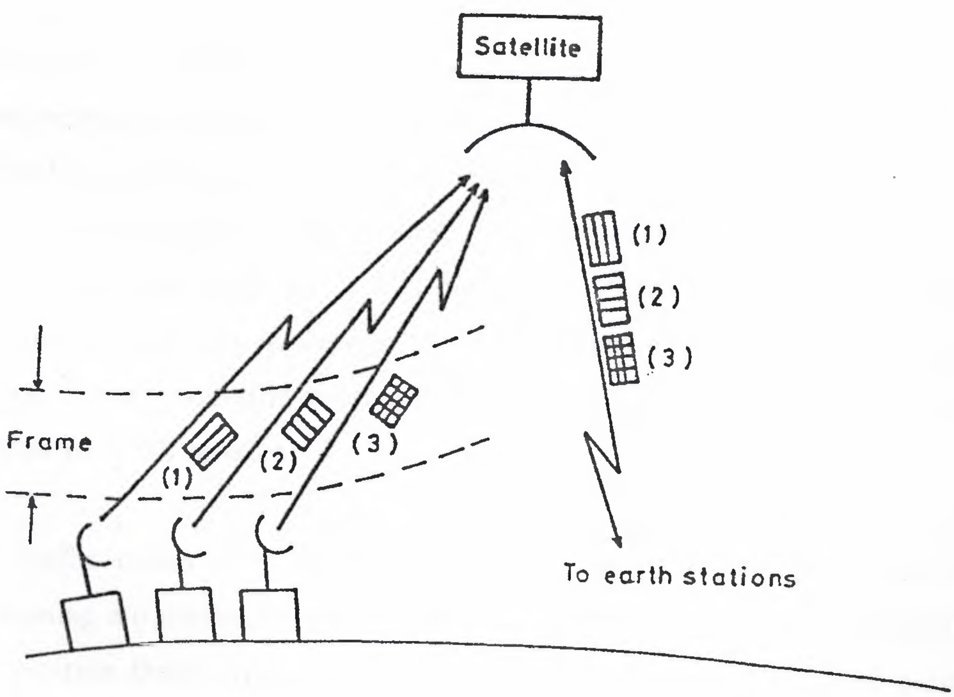


Figure 6.8

In TDMA, the transmit timing of the bursts is accurately synchronized so that the transponder receives one burst at a tme. Each earth station receives an entire burst stream and extracts the bursts intended for it.

A frame consists of a number of bursts originationg from a community of earth stations in a network. A TDMA frame structure is shown in Fig. 6.25.

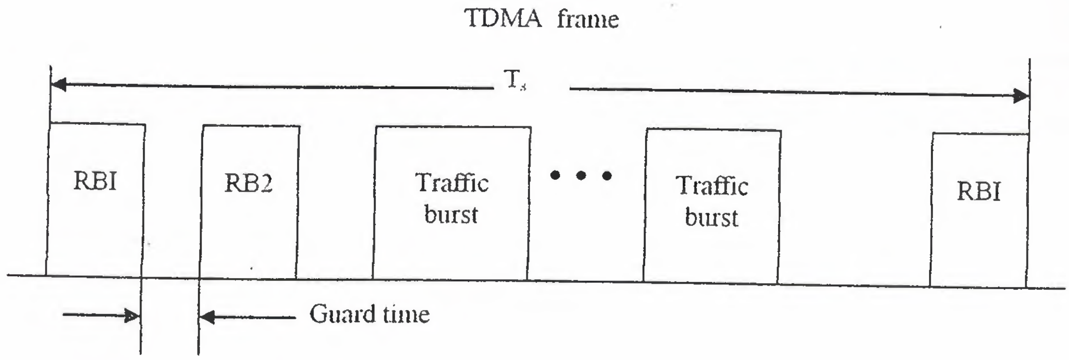


Figure 6.9

It consists of two reference bursts Rb1 and RB2, traffic bursts and the guard time between bursts[10]. As can be seen, each TDMA frame has two reference bursts RB1 and RB2. The primary reference burst (PRB), which can be either RB1 or RB2, is transmitted by one of the earth stations in the network designated as the primary reference earth station. For reliability, a second reference burst (SRB) is transmitteed by a secondary reference earth station. To ensure undisprupted service for the TDMA network, automatic switchover between these two reference stations is provided. The reference bursts carry no traffic information and are used to provide synchronization for all earth stations in the network.

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

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

The TDMA bursts structure of the reference and traffic burst are given in Fig. 6.26.

Carrier and bit timing recovery	UW	TTY	Service channel	VOW	Control and delay channel

Reference burst

Carrier and bit timing recovery	UW	TTY	Service channel	VOW	Traffic data

Preample

Traffic burst

Figure 6.10

In the traffic burst, traffic data (information bits) is preceded by a pattern of bits referred to as a preample which contains the information for synchronization, management and control.

Various sewuences in the reference burst and traffic burst are as follows:

Carrier and bit timing recovery (CBTR)

The CBTR pattern provides information for carrier and timing recorvery circuits of the earth station demodulator. The length of the CBTR sequence depends on the carrier-to-noise ratio at the input of the demodulator and the acquisition range. For example, the 120 Mb/s TDMA system of INTELSAT V has a 48 symbl pattern for carrier recovery and a 128 symbol pattern for bit timing recovery[11].

Unique word (UW)

The unique word sequence in the reference burst provides the receive frame timing that allows an earth station to locate the position of a traffic burst in the frame.

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

Teletype (TTY) and voice order wire (VOW)

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

Service channel (SC)

The service channel of the reference burst carriers management instructions such as burst time paln which gives the coordination of traffic between earth stations, i.e. position, length, and source and destination earth stations corresponding to traffic bursts in the TDMA frame. The channel also carries monitoring and control information to the traffic stations.

The SC of the traffic burst carries the traffic station's sttus to the reference station (value of trnsmit delay used and reference station from which the delay is obtained). It also contains other information such as the high bit error rate and UW loss alarms to other traffic stations. The INTELST V TDMA has an 8-symbol SC for each of the bursts.

Control and delay channel (CDC)

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

Traffic data

This portion contains the information from a source traffic station to a destination traffic station. The informants can be voice, data, video or facsimile signals. The traffic data pattern is divided into blocks of data (referred to as sub-burst). The size of each data block is given by:

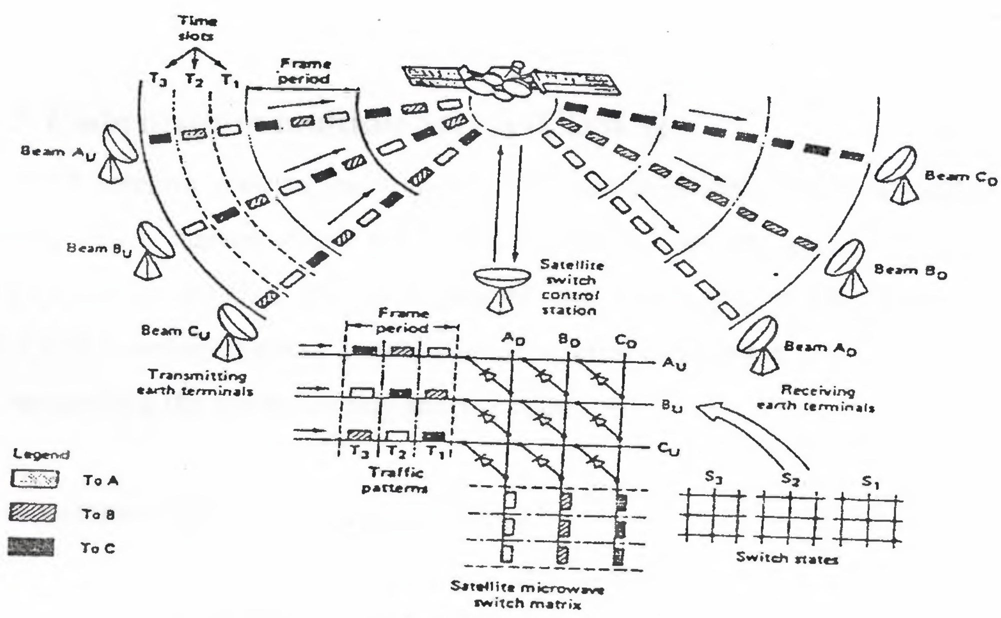
Subburst size (symbols) = symbol rate (symbols/sec) X frame length (sec).

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

6.5.2.1 Satellite – switched TDMA (SS-TDMA)

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

Figure 6.27 shows a three-beam (beams A, B and C) example of a SS-TDMA system[12].



Satellite-switched TDMA (SS/TDMA).

Figure 6.11

The switch matrix is configured in a crossbar design in which only a single row is connected to a single column at a time. In this figure, three different traffic patterns during time slot inteervals T1, T2 and T3, with three different switch states s1, s and s3 are also shown. The switching sequence is programmed via ground control so that states can be changed from time to time.

The advantages of SS-TDMA systems over TDMA systems are:

1) The possibility of frequency re-use by spot-beam spatial discrmination, i.e. the same frequency bnd can be spatially re-used many times. Hence, a considerable increase in satellite capacity can be made.
2) The use of a narrow antenna beam which provides a hihg gain for the coverage region. Hence, a power saving can be obtained in both the uplink and downlink.

An SS-TDMA scheme has been planned for INTELSAT VI and Olympus satellites.

6.5.3 Code division multiple access (CDMA)

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

There are three CDMA techniques as follows:

1. Direct sequence CDMA (DS-CDMA)

In this technique, an addressed pseudo-noise (PN) sequence generated by the PN code generator of an uplink earth station together with the informtion data are modulated directly on the carrier as shown in Fig. 6.28a. The same PN sequence is used synchronously at the receiving earth station to despread the received signal in order to receive thee original data information (Fig. 6.28b).

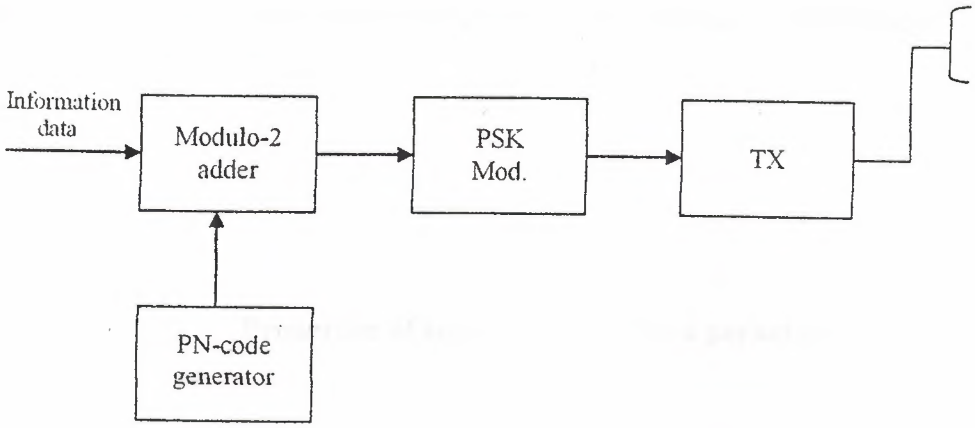


Figure 6.12a

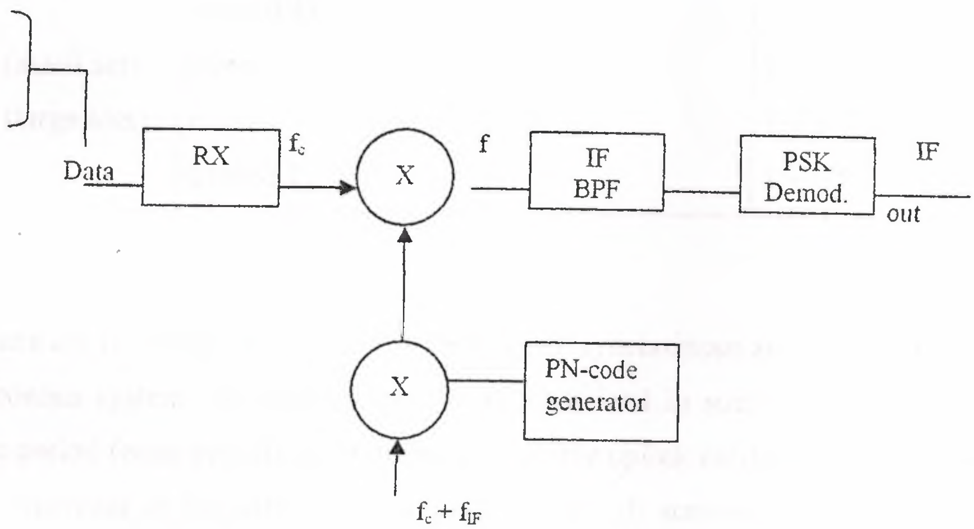


Figure 6.12b

The bits of the PN sequence are referred to as chips. The ratio between the chip rate and information rate is called the spreading factor. Phse-shift-keying modulation schemes are commonly used for these systems.

The most widely used binary PN sequence is the maximum length linear feedback shift register sequence (m-sequence) which is generated by an m-stage shift register.

The m-sequence has a period of $2^m - 1$. Table 2.3 gives the properties of the sequence sets which exhibit small peak cross-correlation values suitable for DS-CDMA[10].

Table 3

Properties of sequence sets with a period of

2^m-1

Family	m	Sez sizee	$\lvert R_{ur,max} \rvert$
Gold	Odd	$2^m + 1$	$1 + 2^{(m+1)/2}$
Gold	2 (mod 4)	$2^m + 1$	$1 + 2^{(m+2)/2}$
Kasami (small set)	Even	$2^{m/2}$	$1 + 2^{m/2}$
Kasami (large seet)	Even	$2^{m/2}(2^m+1)$	$1 + 2^{(m+2)/2}$
Bent	0 (mod 4)	$2^{m/2}$	$1 + 2^{m/2}$

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

2. Frequency hopping CDMA (FH-CDMA)

The block diagram of an FH-CDMA transmitter/receiver is shown in Fig. 6.13

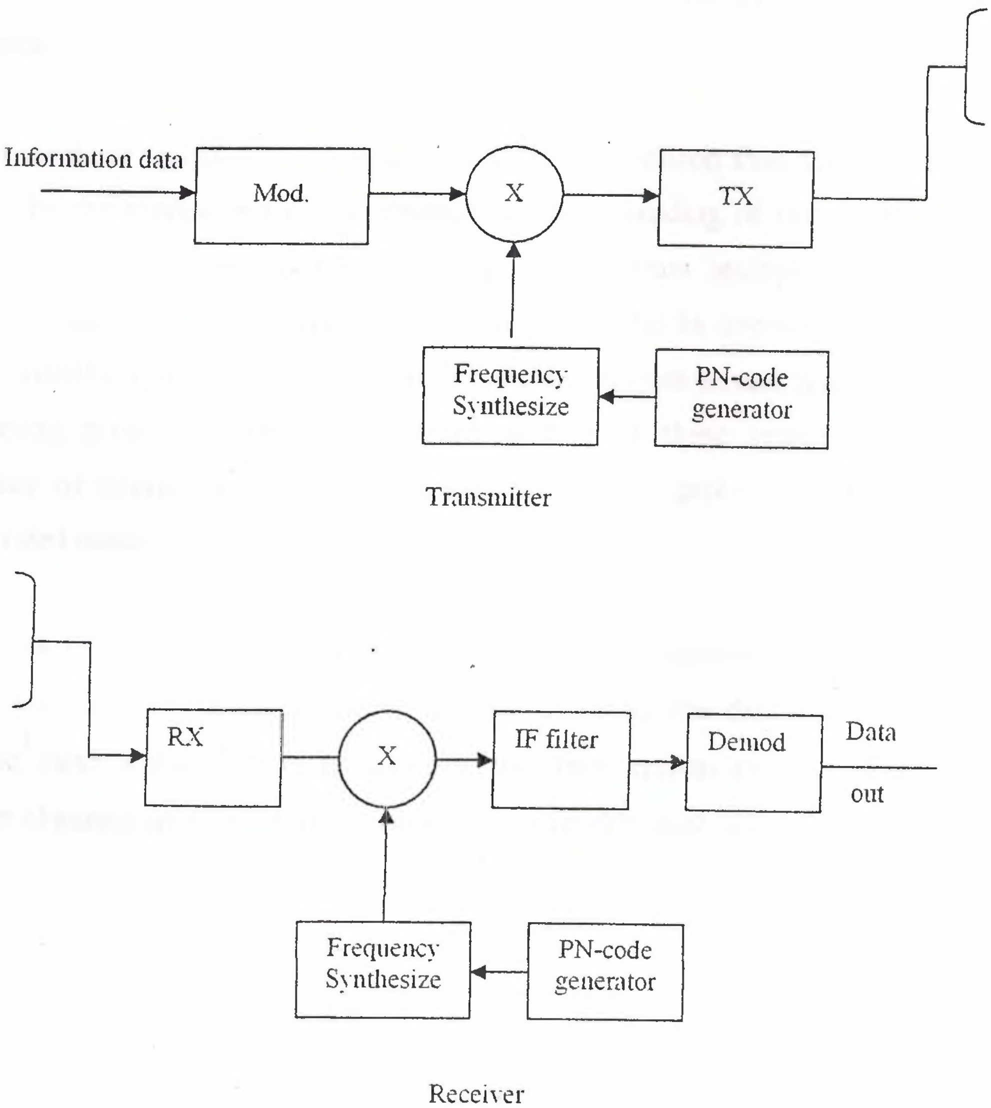


Figure 6.13

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

3. Hybrid CDMA

A hybrid CDMA system employs a combination of DS-CDMA and FH-CDMA techniques.

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

Recently, DS-CDMA; due to its simplicity and low implementation cost has been found suitable for commercial satellite communications for low data rate with small and economic earth stations[13]. It is assumed that thee system consists of 28 spread spectrum channels in a 36 MHz transponder bandwidth; each allows 16 simultaneous accesses.

Table 6.4

Antenna diameter = 1.2 m.
Antenna noise temperature = 70 K
Low noise amplifier temperature = 90 K
High power amplifier = 5 W or 7 dBW
E.I.R.P. to saturate transpnder = 80 dBW
Transponder saturation e.i.r.p. = 36 dBW
Satellite G/T = -3 dB/K
Modulation = PSK
Information bit rate = 2400 b/s
PN code period = $2^8 - 1 = 255$ chips (small Kasami set)
DS-CDMA chip rte = 612 Kb/s
Filtering = square root 100 peer cent cosine roll-off
Spread bandwidth = 1224 kHz

The link budget is given as follows :

Up-Link (6 GHz)

Earth-station e.i.r.p./carrier = 42 dBW
Free space loss = 199.7 dB
Atmospheric attenuation and antenna pointing loss = 0.5 dB
Satellite G/T = -3 dB/K
Boltzmann's constant = -228.6 dB/K-Hz
$(C/N_o)_d$ = 47.6 dB-Hz

Down-Link (4 GHz)

Satellite e.i.r.p.carrier = 6 dBW
Free space loss = 196 dB
Atmospheeric attentuation and antenna pointing loss = 0.3 dB

Earth-station G/T = 9.3 dB/K
Boltzmann's constant = -228.6 dB/K-Hz
$(C/N_o)_d$ = 47.dB-Hz
Link C/N_o = 47.6 dB-Hz

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