NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

Satellite Communication System

Graduation Project
EE- 400

Student: Malik Muhammad Sajid (971299)

Supervisor: Prof. Dr. Fakhreddin Mamedov

Lefkoşa – 2002

TABLE OF CONTENTS

ACKNOWLEDGMENTS

First I want to thank Prof. Dr. Fakhreddin Mamedov to be my supervisor. Under his guidance, I successfully overcome many difficulties and learn a lot about Satellite Communication. In each discussion, he explained my questions patiently, and I felt my quick progress from his advises. He always helps me a lot in my study and all other aspects. I asked him many questions about control and communication and he always answered my questions properly.

Thanks to faculty of engineering for having such a healthy environment.

I thank to my friends in 'NEU': Zahid Qayyum Khokhar, Imran Chatha, Hammad Shah and Tahir Amir. Being with them made my 4 years in 'NEU' full of fun.

I also want to thank my friend Gauher Qayyum Chughtai to give technical assistance in my graduation project.

Finally, I want to thank my family, especially my father Mr. Malik Ashiq Dumra and my mother who always prayed for my success and my younger brother Malik Aamir Dumra who is in 2nd year of Medical. Without their endless support and love. I would never achieve my current position.

ABSTRACT

The Satellite Communication is one of the most important aspects of information theory, upon which many of technological advancements in Satellite Communication. It has evolved into an everyday, common place thing. Most television coverage travels by satellites even reaching directly to the home from space. The bulk of transoceanic telephone and data communication also travels by satellite.

Satellite communication is now part of our environment. Everyday we receive and transmit information by satellite, often without knowing it.

Because of these and more, I prepare to choose my project's subject as "satellite communication".

However, the word 'satellite' used in this project means the spacecraft in outer space providing linking between earth stations.

Satellite communication is very wide field and it cannot be covered even by one book. So we can find lot of books talking about this subject and each book has his own point of view.

One of the mean objective of this project is to give the reader enough of understanding to allow him or her to ask the right question.

As I am doing this project to cover the important subject such a vital field. Whatever, the assumption, one can be assured that satellite will continue to occupy an important place as a mean of communication.

INTRODUCTION

The unique feature of satellite communication is their ability to simultaneously link all users on the earth's surface, thereby providing distance-insensitive point-to-multiunit communications. This capability applies to fixed terminals on earth and to mobile terminals on land, in the air and at sea. Also, with satellites, capacity can be dynamically allocated to users who need it. These features make satellite communications Systems unique in design.

In 1945 Arthur Clark wrote that a satellite with a circular equatorial orbit at a correct altitude of 35, 796 km would make one revolution every 24 hour; that is, it would rotate at the same angular velocity as the earth. An observer looking at such a geo stationary satellite would see it hanging at a fixed spot in the sky. Clark showed that three geostationary satellites powered by solar energy could provide worldwide communication for all possible types of services.

The chapter 1 is about introduction to satellite communication and the identification of its elements. In this chapter we discuss the satellite communication, its advantages, how its work and basic function of satellites. Like frequency allocation for satellite services, which tell us how the frequency of satellites is distributed in the world. Satellite system tells us that how satellite links to earth station. And modulation, in which we studies the process of encoding and electromagnetic carrier wave with massage.

The chapter 2 addresses the orbital mechanics of satellite communication, and earth station together with their construction, especially in relation to a geostationary satellite that appears to an observer on earth to be hanging perfectly still at one spot in the sky. In this chapter we study that any ground based communication facility capable of transmitting, receiving and processing data relayed with orbiting satellites. We also learn about earth station antenna and its types.

In chapter 3 and 4 we study about multiple access schemes. There are two types of multiple access schemes FDMA (frequency division multiple access) and TDMA (time division multiple access).In chapter 3 we study that FDMA, each earth station transmits one or more carriers to the satellites transponder at different center frequencies.

And in the last chapter 4 we learn about the TDMA. TDMA is broadcast system in which each transmitter/receiver operates within its own assigned discrete time slots. Conclusion presents the significant results, contribution of author and future developments.

1. INTRODUCTION TO SATELLITE COMMUNICATION

Communication, the process of transmitting and receiving ideas, information, and messages. The rapid transmission of information over long distances and ready access to information have become conspicuous and important features of human society, especially in the past 150 years, and in the past two decades, increasingly so. Communication between two or more than two people is an outgrowth of methods developed over communication. Communication is essential for the growth of mankind e.g. the use of paper to communicate ideas was and still is, responsible for the growth of Science and Technology. Communication equipment, which is a part of our daily life, are responsible for the acceleration of this process, e.g. Photocopying machine, telephone, radio, television, fax machine, satellite, cellular phone, computers, CD-RW, Internet. Motivation is the electronic communication between the five senses of humans: Ear, Eyes, Nose, Skin, and Tongue. Currently, we are only using two senses to communicate information. Modern living standards demand that we have access to a reliable, economical and efficient means communication, which may be optionally mobile. Almost an endless list of information handling systems developed worldwide.

Typically, signals are transferred over wires, through optical fibers or through space using electromagnetic waves. We live in a world of networks, which avoids dedicated connections, allows the sharing of resources, promotes the exchange of information around the world, etc.

The developments are:

1. Telephone number per person
2. Wireless networks - schools, companies, etc.
3. Integration of services & traffic (data, voice, graphics, and video): Home banking, bills.
4. The electronic communication of "scent", "taste" and "touch". Goals can be counted as:

1. Minimize the time to access information
2. Minimize location constraints to access information

3. Maximize the simultaneous access to information
4. Make use of all five senses

1.1 Satellite Communication

All major satellite operators, INTELSAT, EUTELSAT, INMARSAT, etc. mostly use the geo-stationary orbit (GEO). In this orbit, the satellite appears to be stationary when viewed from the Earth. Thus, the Earth station antennas point in a fixed direction as in figure 1.1.

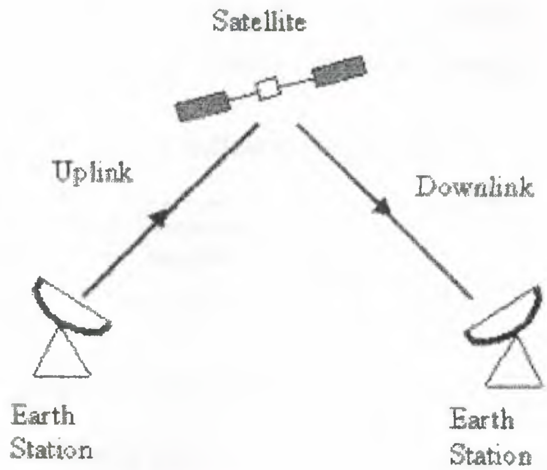


Figure 1.1: Satellite position

In the GEO orbit (as in figure 1.2), the satellite is approx. 22,300 miles above the equator.

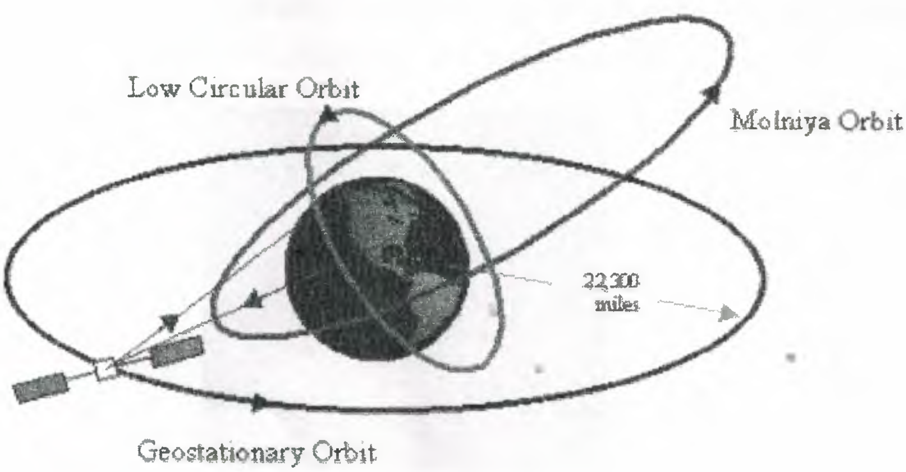


Figure 1.2: An Orbit

Most desired frequency band for satellite communications is 6 GHz on the uplink and 4 GHz on the downlink, referred to as the 6/4 GZ C-band. In this range, cosmic noise is small, and rainfall does not appreciably attenuate the signals. Also, losses due to the ionosphere and atmospheric absorption are small.

Second generation satellites operate using the 14/12 GHz Ku-band. These higher frequencies make it possible to build smaller and less expensive antennas.

Each satellite has a number of transponders (receiver-to-transmitter) aboard to amplify the received signal from the uplink and down-convert the signal for transmission on the downlink. Typically, there are 24 transponders in a satellite. The figure 1.3 below shows the basic components of a single transponder.

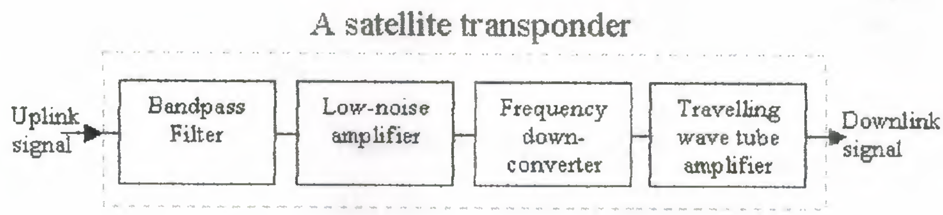


Figure 1.3: Components of a single transponder

For the standard C-band (6/4 GHz) television relay service, each satellite is assigned a total of a 500 MHz bandwidth. A typical satellite has 24 transponders aboard, with each transponder using 36 MHz of the 500 MHz bandwidth assignments. Note that the satellites reuse the same frequency band by having 12 transponders operating with vertically polarized signals and 12 transponders with horizontally polarized signals. The figure 1.4 below shows the sample satellite.

Figure1.4: A sampled satellite

The figure 1.5 below illustrates this for the Galaxy satellites. In particular, the G5 satellite on C-band (because its my favorite). Note that this is analog television in which a single TV channel is frequency modulated onto a 6 GHz carrier. In the near future, such analog systems will be a thing of the past.

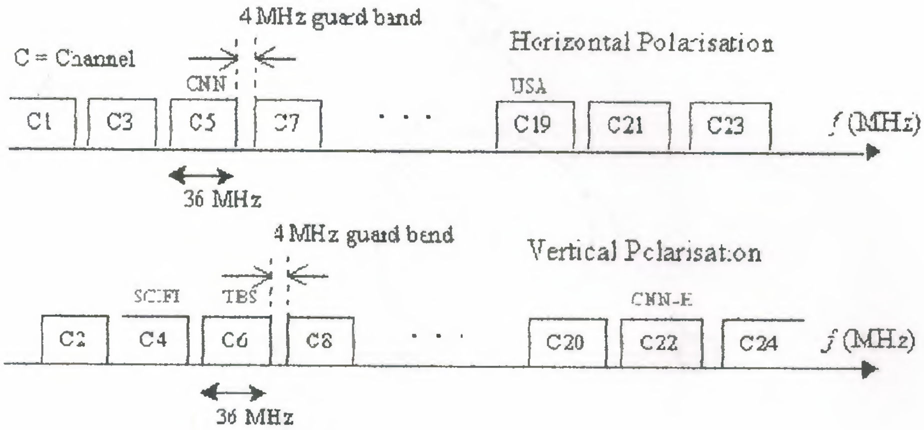


Figure 1.5: Galaxy satellites

High-power satellites, called direct broadcast satellites (DBS), provide TV service directly to the home, which has a small receiving antenna e.g. Direct TV. The base band video signal is sampled, digitized, and compressed by removing redundant samples that occur frame to frame. Satellite communication became a possibility when it was realized that a satellite orbiting at a distance of 36000Km from the Earth would be geo-stationary, i.e. would have an angular orbital velocity equal to the Earth's own orbital velocity. It would thus appear to remain stationary relative to the Earth if placed in an equatorial orbit. This is a consequence of Kepler's law that the period of rotation T of a satellite around the Earth was given by:

$$T = \frac{2\pi r^{3/2}}{\sqrt{(g_s R^2)}}$$

Where r is the orbit radius, R is the Earth's radius and $g_s = 9.81 ms^{-2}$ is the acceleration due to gravity at the Earth's surface. As the orbit increases in radius, the angular velocity reduces, until it is coincident with the Earth's at a radius of 36000Km. In principle, three geostationary satellites correctly placed can provide complete coverage of the Earth's surface as in figure 1.6

For intercontinental communication, satellite radio links become a commercially attractive proposition. Space communication showed phenomenal growth in the 1970s. And it will continue to grow for some years to come. The growth has been so rapid that there is now danger of overcrowding the geostationary orbit.

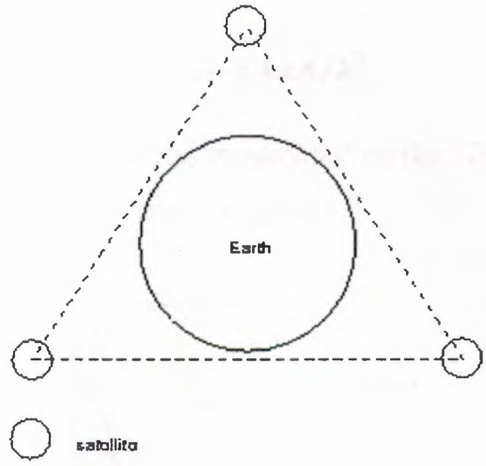


Figure 1.6: Geo-stationary satellites

1.2 Advantages of Satellite Communication

Satellite communication has a number of advantages:

1. The laying and maintenance of intercontinental cable is difficult and expensive.
2. The heavy usage of intercontinental traffic makes the satellite commercially attractive.
3. Satellites can cover large areas of the Earth. This is particularly useful for sparsely populated areas.

Satellite communication is limited by four factors:

1. Technological limitations preventing the deployment of large, high gain antennas on the satellite platform.
2. Over-crowding of available bandwidths due to low antenna gains.
3. The high investment cost and insurance cost associated with significant probability of failure.
4. High atmospheric losses above 30GHz limit carrier frequencies.

1.3 Microwave Antenna

A microwave antenna has two functions. It provides gain (i.e. amplification). It also directs the radiation into confined regions of space: the antenna beam. These properties are largely dependent on the antenna size. For a circular, dish antenna, the gain G is related to the antenna area A by the formula:

$$G = 4\pi A/\lambda^2$$

Where $\lambda$is the wavelength of the transmitted carrier. Thus, large antennas have high gains and narrow beams as shown in figure 1.7.

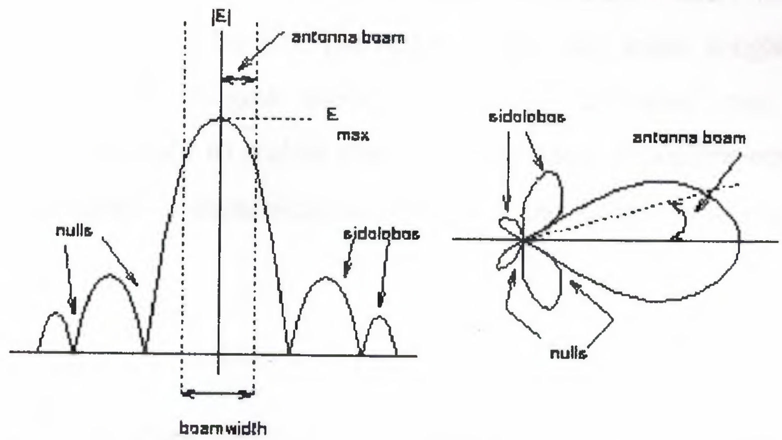


Figure 1.7: A typical antenna beam profile of a dish antenna

The cost of constructing an antenna is a strong function of its size. A rough rule of thumb is the cost is proportional to the diameter cubed. Thus a doubling of the antenna size will result in the satellite cost increasing eight times. As a result, antenna sizes are limited. The limitation in antenna size means that the satellite beam is wide. In order to prevent electromagnetic interference with terrestrial stations, the power radiated by the satellite is limited by international convention. In any event power is severely limited on a satellite platform.

Because the radiated power is low, large receiving antennas are required. The larger the receiver antenna, the larger the antenna gain, and hence the better the receiver SNR. The SNR is a function of the bandwidth, and the atmospheric attenuation. Ground stations close to the poles of the Earth have low elevation look angles, and signals have to pass through a thicker section of atmosphere. The size of receiver antenna is determined by the two requirements; 500MHz receive bandwidth and full capability at ±80°of latitude. A standard INTELSAT receiver is 30m in diameter. An antenna this large has a very narrow beam, typically 0.01°. A geostationary satellite is not truly stationary; it wanders slightly in the sky. The very narrow beam width of the receiver requires automatic tracking of the satellite, and continuous pointing of the receiver antenna.

The use of satellites for regional communication is possible if there is sufficient demand for traffic. By reducing the range of latitudes down to ±60°, and reducing the bandwidth down to 50MHz, large reductions in satellite and ground station receiver costs are possible. One such direct-to-user (DTU) system is the Satellite Business System (SBS) covering a range of business and government's users with a demand for high-speed data links in the US. The region is split into areas, roughly coincident with the satellite antenna gain contours, denoting increased cost of receiver technology. It is important to realize that the economies of satellite communication only make this regional communication possible if the system is heavily used as in figure 1.8.

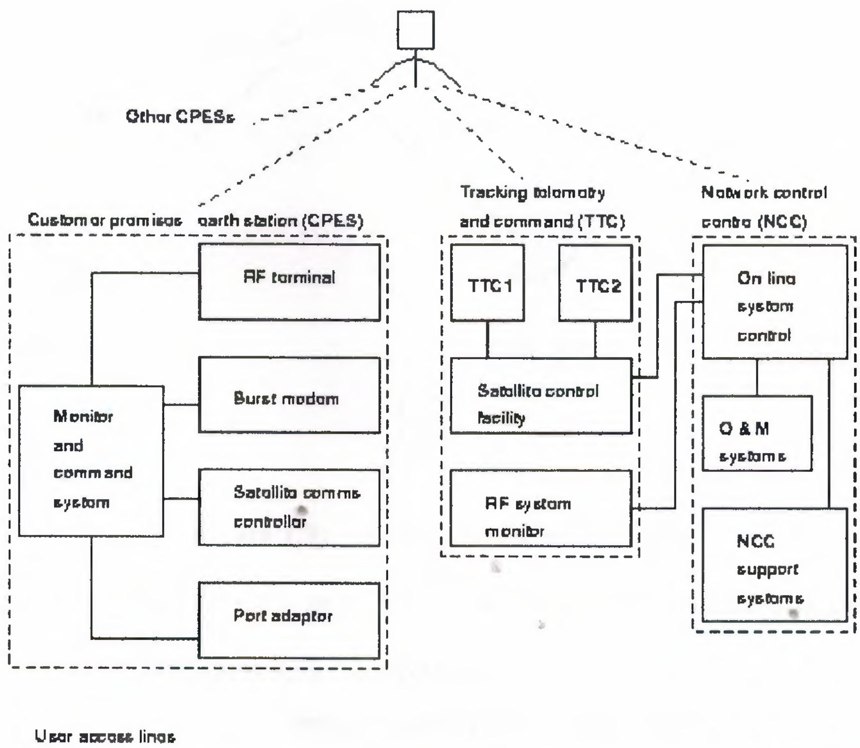


Figure 1.8: The Satellite Business System operational schematic

Improvements in satellite receiver technology have permitted smaller antennas to be used as ground station receivers. However, antennas are reciprocal. They have the same directional characteristics in transmit and receive. The use of low gain, wide beam earth stations for DTU systems have contributed considerably to the bandwidth-overcrowding problem, particularly in the US.

Recently there has been interest in low-earth orbiting (LEO) satellites. Here, a satellite placed in a 1000Km orbit has an orbital time of 1 hour. These satellites can be operated in a store-and-forward mode, picking up data at one part of the globe and physically transferring it to another. Because the data-rates and orbit radius are greatly reduced, small, low-cost satellites and ground stations are possible. However, such satellites have yet to demonstrate any commercial success.

1.4 Carrier to Noise Density Ratio

P_R / P_o is traditionally referred to as the C/N_o Carrier-to-Noise density ratio. The word "density" is used because the bandwidth of the signal is not taken into account as shown in figure 1.9 below.

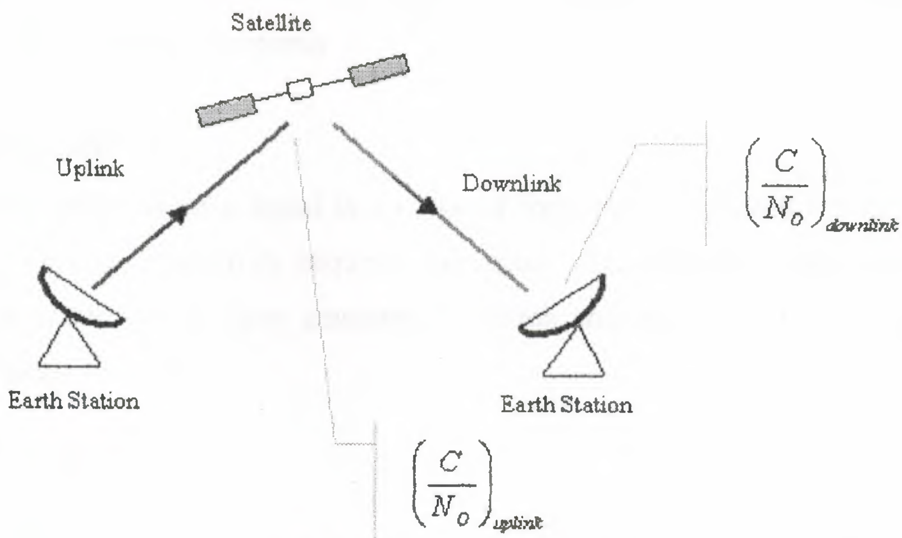


Figure 1.9: Carrier-to-Noise density ratio

Only if the received power is in the form of a digitally modulated signal, can we use $P_R = r_b E_b$. Thus, for most links budgets, the carrier-to-noise density ratio is calculated first. If the satellite communication system simply relays the signal from one Earth station to another, then the overall carrier to noise density ratio is given by

$$\left(\frac{C}{N_o}\right)_{overall} = \left[\left(\frac{C}{N_o}\right)^{-1}_{uplink} + \left(\frac{C}{N_o}\right)^{-1}_{downlink}\right]^{-1}$$

1.5 Channel Capacity Theorem

1.5.1 Fourier

Jean Baptist Fourier showed that the most complex time-varying analog signal could be decomposed into separate frequency components, each one being a simple sinusoid of a different frequency and phase. For example, consider the Fourier spectrum of a periodic signal. A periodic signal, in relation to computers, in information management and on communications networks, a name or label used as an alternative means of referring to someone or something. On networks, where they are commonly encountered, identify both individuals and groups of people with a common interest. Groups are particularly useful because a message addressed to the alias reaches each person in the group, simplifying the task of distributing information to multiple recipients.

1.5.2 Bandwidth

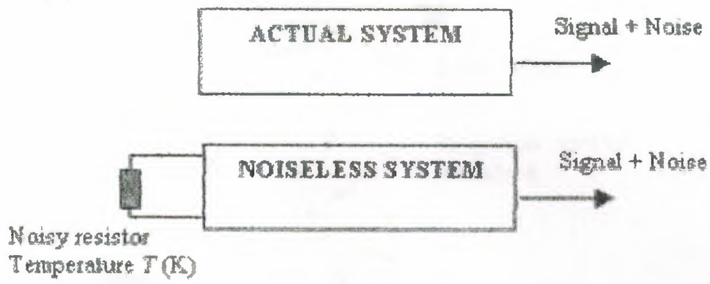
The bandwidth of a signal is a range of frequencies occupied by the signal's Fourier components within its frequency spectrum. This frequency range transmitted is typical chosen to be those components, which encompass most of the original signal energy.

1.5.3 Channel

The bandwidth of a channel is the range of frequencies that is passed by the channel. For example, the bandwidth of a telephone channel is typically the frequency range 300 to 3400 Hz. To determine the bandwidth of channel, a sinusoidal wave of frequency f and amplitude A is transmitted through the channel. The frequency f is varied and plotted versus the received signal amplitude.

1.5.4 Noise Temperature

The equivalent noise temperature T of a system is defined as the temperature at which a noisy resistor has to be maintained such that, by connecting the resistor to the input of a noiseless version of the system, it produces the same available noise power at the output of the system as that produced by all the source of noise in the actual system.



G_R/T ratio is typically provided for the satellite receiving system. The larger its value, the better the system.

1.6 The Anatomy of a Satellite

Satellites have only a few basic parts: a satellite housing, a power system, an antenna system, a command and control system, a station keeping system, and transponders.

1.6.1 Satellite Housing

The configuration of the satellite housing is determined by the system employed to stabilize the attitude of the satellite in its orbital slot. Three-axis-stabilized satellites use internal gyroscopes rotating at 4,000 to 6,000 revolutions per minute (RPM). The housing is rectangular with external features as shown below in figure 1.10.

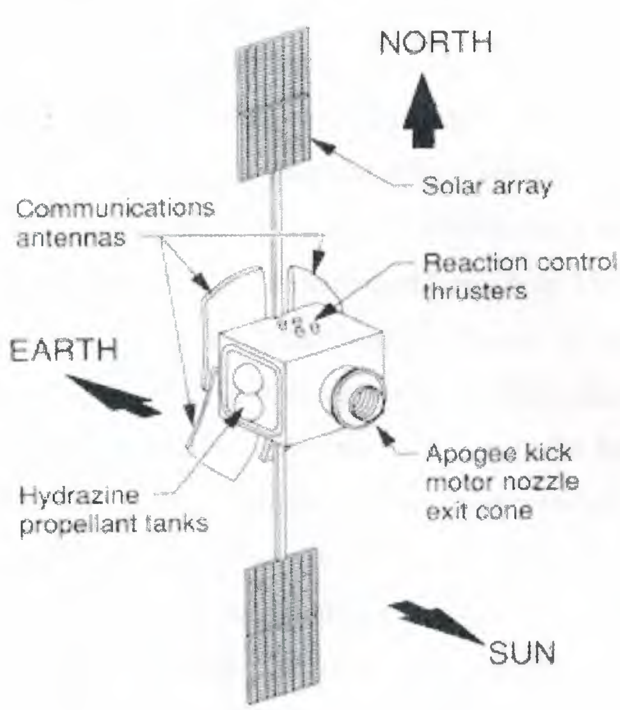


Figure 1.10: Satellite Anatomy

An alternative stabilization system is spin stabilization. As shown below in Figure 1.11, the housing of the INTELSAT spin-stabilized satellite is cylindrical and rotates around its axis at 60 to 70 RPM to provide a gyroscopic effect. To keep the antenna pointed in a fixed direction, it is connected to the body of the satellite by a rotating bearing. In spin-stabilized satellites, the solar cells are mounted on the cylindrical surface of the satellite. The materials used in the construction of satellite housings are typically very expensive. In newer satellites, lightweight and extremely durable epoxy-graphite composite materials are often used.

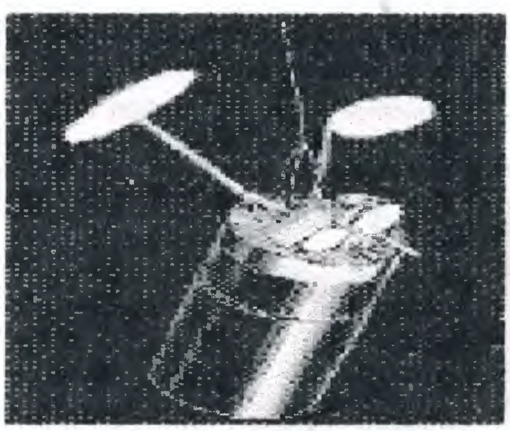


Figure 1.11: The Spin-Stabilized INTELSAT 6

1.6.2 Power System

Satellites must have a continuous source of electrical power--24 hours a day, 365 days a year. The two most common power sources are high performance batteries and solar cells. Solar cells are an excellent power source for satellites. They are lightweight, resilient, and over the years have been steadily improving their efficiency in converting solar energy into electricity. Currently the best gallium arsenide cells have a solar to electrical energy conversion efficiency of 15-20%. There is however, one large problem with using solar energy. Twice a year a satellite in geo-synchronous orbit will go into a series of eclipses where the sun is screened by the earth. If solar energy were the only source of power for the satellite, the satellite would not operate during these periods. To solve this problem, batteries are used as a supplemental on-board energy source. Initially, Nickel-Cadmium batteries were utilized, but more recently Nickel-Hydrogen batteries have proven to provide higher power, greater durability, and the important capability of being charged and discharged many times over the lifetime of a satellite mission.

1.6.3 Antenna System

A satellite's antennas have two basic missions. One is to receive and transmit the telecommunications signals to provide services to its users. The second is to provide Tracking, Telemetry, and Command (TT&C) functions to maintain the operation of the satellite in orbit. Of the two functions, TT&C must be considered the most vital. If telecommunications services are disrupted, users may experience a delay in services until the problem is repaired. However, if the TT&C function is disrupted, there is great danger that the satellite could be permanently lost--drifting out of control with no means of commanding it.

1.6.4 Command and Control System

This control system includes tracking, telemetry & control (TT&C) systems for monitoring all the vital operating parameters of the satellite, telemetry circuits for relaying this information to the earth station, a system for receiving and interpreting commands sent to the satellite, and a command system for controlling the operation of the satellite.

1.6.5 Station Keeping

Although the forces on a satellite in orbit are in balance, there are minor disturbing forces that would cause a satellite to drift out of its orbital slot if left uncompensated. For example, the gravitational effect of the sun and moon exert enough significant force on the satellite to disturb its orbit. As well, the South American land mass tends to pull satellites southward.

Station keeping is the maintenance of a satellite in its assigned orbital slot and in its proper orientation. The physical mechanism for station keeping is the controlled ejection of hydrazine gas from thruster nozzles which portrude from the satellite housing. When a satellite is first deployed, it may have several hundred pounds of compressed hydrazine stored in propellant tanks. Typically, the useful life of a satellite ends when the hydrazine supply is exhausted--usually after ten years.

1.6.6 Transponders

A transponder is an electronic component of a satellite that shifts the frequency of an up-link signal and amplifies it for retransmission to the earth in a down-link. Transponders have a typical output of 5 to 10 watts. Communications satellites typically have between 12 and 24 on-board transponders.

1.7 ELEMENTS OF STATELLITE COMMUNICATIONS

1.7.1 Satellite Frequency Bands

Communications systems employ the electromagnetic frequency spectrum. The frequencies used for satellite communications are allocated in superhigh-frequency (SHF) and extremely high-frequency (EHF) bands, which are broken down into subbands as summarized in Table 1.1. Spectrum management is an important activity that facilitates the orderly use of the electromagnetic frequency spectrum not only for satellite communications but for other telecommunications applications as well.

TABLE 1.1 Satellite frequency spectrum.

Frequency Band	Range (GHz)
L	1-2
S	2-4
C	4-8
X	8-12
Ku	12-18
K	18-27
Ka	27-40
Millimeter	40-300

This is done under the auspices of the international Telecommunication Union (ITU) which is a specialized agency of the United Nations (UN). It predates the UN, having come into existence in 1932 as a result of the merging of the International Telegraph Union (1865-1932) and the Radio Telegraph Union (1903-1932). There are four permanent organs of the ITU: (1) the General Secretariat, headquartered in Geneva and responsible for executive management and technical cooperation; (2) the International Frequency Registration Board (IFRB), responsible for recording frequencies and orbital positions and for advising member countries on operation of the maximum practical number of radio channels in portions of the spectrum where harmful interference may occur; (3) the International Radio Consultative Committee (CCIR), from the initial letters in French), responsible for studying technical and operational questions relating to radio communications which results in reports, recommendations, resolutions, and decisions published as a group in the Green Books every 4 yr. following CCIR plenary assemblies; and (4) the International Telegraph and Telephone Consultative Committee (CCITT), responsible for studying technical, operational, and tariff questions relating to telegraphy and telephony and for adopting reports and recommendations.

1.7.2 Satellite Systems

A satellite system consists basically of a satellite in space, which links many earth stations on the ground, as shown schematically in Fig 1.12. The user generates the base band signal, which is routed to the earth station through the terrestrial network. The terrestrial network can be a telephone switch or a dedicated link to the earth station. At the earth

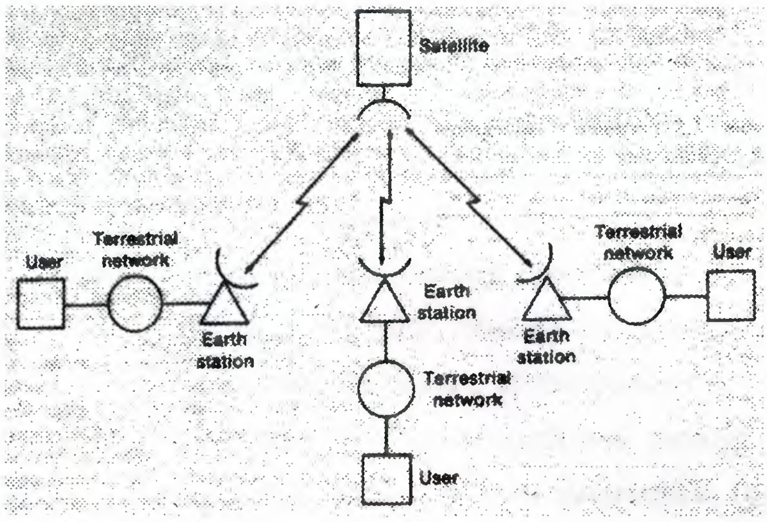


Figure 1.12 A basic Satellite System.

station the base band signal is proceeded and transmitted by a modulated radio frequency (RF) carrier to the satellite. The satellite can be thought of as a large repeater in space. It receives the modulated (RF) carriers in its Up link (earth-to-space) frequency spectrum from all the earth stations in network, amplifies these carriers, and retransmits then back to earth in the down-link (space to earth) frequency spectrum which is different from the up-link frequency spectrum in order to avoid interference. The receiving earth station processes the modulated RF carrier down to the base-band signal, which is sent through the terrestrial network to the user.

Most commercial communications satellites today utilize a 500-MHz bandwidth on the up-link and a 500-MHz bandwidth on the down-link. The most widely used frequency spectrum is the 6/4-GHz band, with an up-link of 5.725 to 7.075 GHz and a down-link of 3.4 to
4.8GHz. The 6/4 GHz band for geo-stationary satellites is becoming overcrowded because it is also used by common carriers for terrestrial microwave links. Satellites are now being operated in the 14/12-GHz band using an up-link of 12.75 to 14.8 GHz and a down-link of either 10.7 to 12.3 GHz or 12.5 to 12.7 GHz. The 14/12-GHz band will be used extensively in the future and is not yet congested, but one problem exists-rain, which attenuates 14/12-GHz signals much more than it does those at 6/4 GHz. The frequency spectrum in the 30/20-GHz band has also been set aside for

commercial satellite communications, with a down-link of 18.1 to 21.2 GHz and an up-link of 27.5 to 31 GHz. Equipment for the 30/20-GHz band is still in the experimental stage and is expensive.

The typical 500-MHz satellite bandwidth at the 6/4 and 14/12 GHz bands can be segmented into many satellite transponder bandwidths. For example, eight transponders can be provided, each with a nominal bandwidth of 54 MHz and a center-to-center frequency spacing of 61 MHz. Modern communications satellites also employ frequency reuse to increase the number of transponders in the 500 MHz allocated to then Frequency reuse can be accomplished through orthogonal polarizations where one transponder operates in one polarization (e.g., vertical polarization) and a cross-polarized transponder operates in the orthogonal polarization (e.g., horizontal polarization). Isolation of the two polarizations can be maintained at 30 dB or more by staggering the center frequencies of the cross-polarized transponders so that only side-band find energy of the RF carriers overlaps, as shown in Fig. 1.13. With orthogonal polarization a satellite can double the number of transponders in the available 500-MH bandwidth, hence double its capacity.

With this brief discussion of a general satellite system we will now take a look at an earth station that transmits information to and receives information from a satellite figure 1.13 shows the functional elements of a digital earth station. Digital information in the form of binary digits from the terrestrial network enters the transmit side of the earth station and is then processed (buffered, multiplexed, formatted, etc.) by the base-band equipment so that these forms of information can be sent to the appropriate destinations. The presence of noise and the nonideal nature of any communication channel introduce errors in the information being sent and thus limit the rate at which it can be transmitted between the source and the destination. Users generally establish an error rate above which the received information is not usable. If the received information does not meet the error rate requirement, error-correction coding performed by the encoder can often be used to reduce the error rate to the acceptable level by inserting extra digits into the digital stream from the output of the base-band equipment. These extra digits carry no information but are used to accentuate the uniqueness of each information message. They are always chosen so as to make it unlikely that the channel disturbance will corrupt enough digits in a message to destroy its uniqueness.

In order to transmit the base-band digital information over a satellite channel that is a bandpass channel, it is necessary to transfer the digital information to a carrier wave at the appropriate bandpass channel frequency. This technique is called digital carrier modulation. The function of the modulator is to accept the symbol stream from the encoder and use it to modulate an intermediate frequency (IF) carrier. In satellite communications, the IF carrier frequency is chosen at 70 MHz for a communication channel using a 36-MHz transponder bandwidth and at 140 MHz for a channel using a transponder bandwidth of 54 or 72 MHz. A carrier wave at an intermediate frequency rather than at the satellite RF up-link frequency is chosen because it is difficult to design a modulator that works at the up-link frequency spectrum (6 or 14 GHz, as discussed previously). For binary modulation schemes, each output digit from the encoder is used to select one of two possible waveforms. For Many modulation schemes, the output of the encoder is segmented into sets of k digits, where $M = 2^k$ and each k-digit set or symbol is used to select one of the M waveforms. For examples, in one particular binary modulation scheme called phase-shift keying (PSK), the digit 1 is represented by the waveform $s_1(t) = A\cos\omega_0 t$ and the digit O is represented by the waveform $s_0(t) = -A\cos\omega_0 t$, where ω_0 is the intermediate frequency.

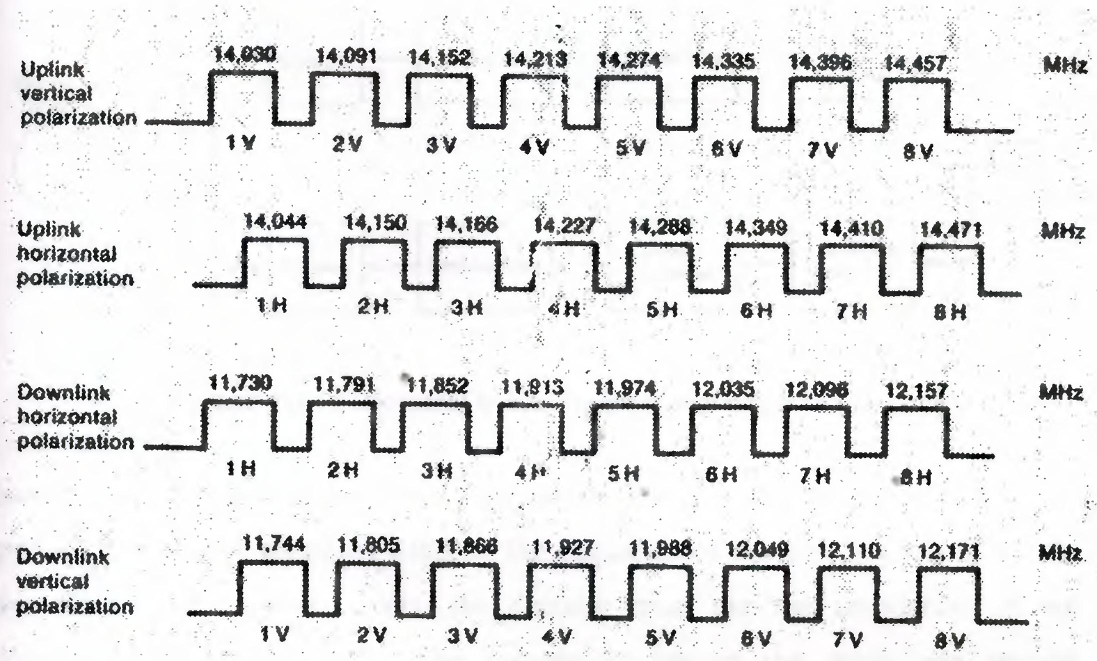


Figure 1.13 Staggering frequency reuses Ku-band transponders.

The modulated IF carrier from the modulator is fed to the up-converter, where its intermediate frequency ω_0 is translated to the up-link RF frequency ω_u in the up-link frequency spectrum of the satellite. The high-power amplifier (H PA) then amplifies this modulated RF carrier to a suitable level for transmission to the satellite by the antenna.

On the receive side the earth station antenna receives the low-level modulated RF carrier in the down-link frequency spectrum of the satellite. A low-noise amplifier (LNA) is used to amplify this low-level RF carrier to keep the carrier-to-noise ratio at a level necessary to meet the error rate requirement. The downconverter accepts the amplified RF carrier from the output of the low-noise amplifier and translates the down-link frequency ω_d to the intermediate frequency ω_0. The reason for downconverting the RF frequency of the received carrier wave to the intermediate frequency is that it is much easier to design the demodulator to work at 70 or 140 MHz than at a down-link frequency of 4 or 12 GHz. The modulated IF carrier is fed to the demodulator, where the information is extracted. The demodulator estimates which of the possible symbols was transmitted based on observation of the received IF carrier. The probability that a symbol will be correctly detected depends on the carrier-to-noise ratio of the modulated carrier, the characteristics of the satellite

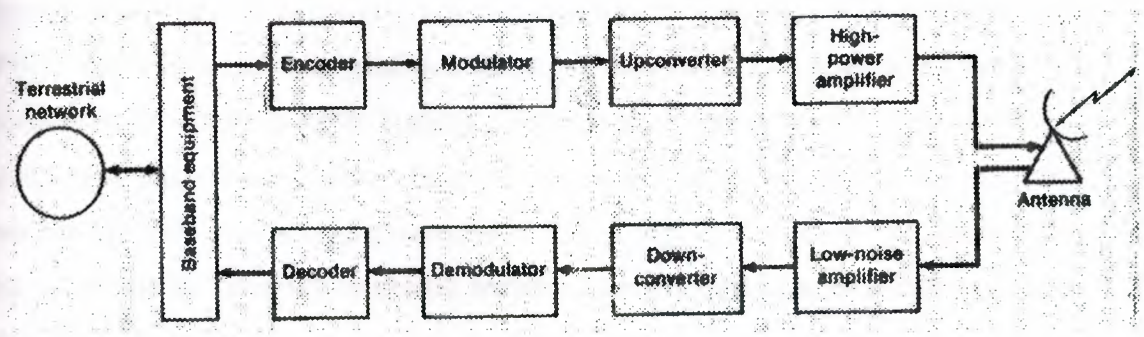


Figure 1.14 Functional block diagram of a digital earth station.

channel, and the detection scheme employed. The decoder performs a function opposite that of the encoder. Because the sequence of symbols recovered by the demodulator may contain errors, the decoder must use the uniqueness of the redundant digits introduced by the encoder to correct the errors and recover information-bearing digits. The information stream is fed to the base-band equipment for processing for delivery to the terrestrial network.

In the United States the Federal Communications Commission (FCC) assigns orbital positions for all communications satellites to avoid interference between adjacent satellite systems operating at the same frequency. Before 1983 the spacing was established at 4^0 of the equatorial arc, and the smallest earth station antenna for a simultaneous transmit-receive operation allowed by the FCC is 5 m in diameter.

In 1983, the FCC ruled that fixed service communications satellites in the geostationary orbit should be spaced every 2^{0} along the equatorial arc instead of 4^0. This closer spacing allows twice as many satellites to occupy the same orbital arc.

The FCC ruling poses a major challenge to antenna engineers to design a directional feed for controlling the amount of energy received off-axis by the antenna feed, thus reducing interference from an adjacent satellite. This challenge is especially great because the trend in earth stations is toward smaller antennas, but smaller antennas have a wider beamwidth and thus look at a wide-angle in the sky.

1.8 Transmission and Multiplexing

In the above section we took a look at a simplified satellite communications system where digital information (a sequence of symbols instead of continuous signals) is carried between terrestrial networks. Historically, analog transmission has dominated satellite communications since its inception. Even today many satellite Systems still transmit telephone and television signals using frequency modulation (FM), and this trend will continue for some time to come because of the large investment in existing earth stations. With the advent of digital electronics and computers, many earth stations have begun to use digital transmission to improve satellite capacity over analog transmission. These digit earth stations can interconnect digital terrestrial networks or analog terrestrial networks with appropriate analog-to-digital (AID) conversion equipment. A clear advantage of digital transmission is that it permits integration of information in various forms. Such analog information as speech and visual signals can be converted to digital form and thereby combined with data for transmission, switching, processing, and retrieval.

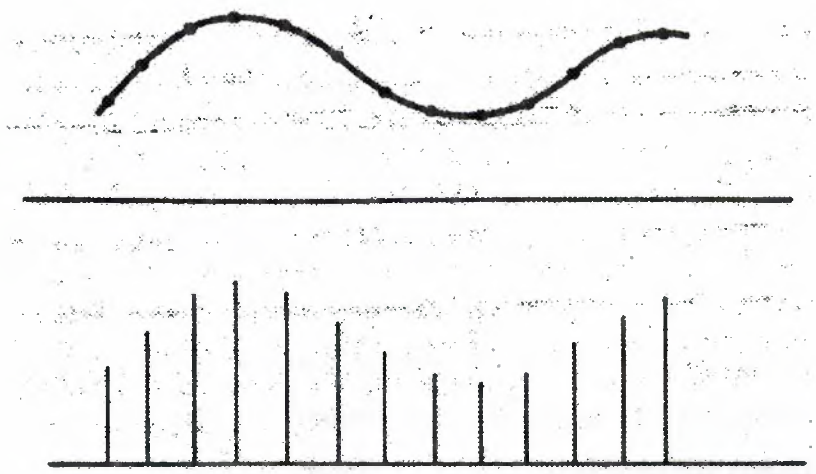


Figure 1.14 Sampling of an analog signal.

1.8.1 Pulse Code Modulation

One commonly used technique for converting an analog signal to digital form is pulse code modulation (PCM) which requires three operations: sampling, quantizing, and coding. Sampling converts the continuous analog signal into a set of periodic pulses, the amplitudes of which represent the instantaneous amplitudes of the analog signal at the sampling instant, as shown in Fig. 1.14. Nyquist proved that, if the analog signal is band-limited to a bandwidth of B hertz, the signal can be completely reconstructed if the sampling rate is at least the Nyquist rate, which is 2B. For example, telephone speech is band-limited to 4 kHz and thus requires 8000 samples per second. Since analog signals have a continuous amplitude range, the samples are also continuous in amplitude. When the continuous amplitude samples are transmitted over a noisy channel, the receiver cannot discern the exact sequences of transmitted values. This effect of noise in the system can be minimized by breaking the sample amplitude into discrete levels and transmitting these levels using a binary scheme. The process of representing the continuous amplitude of the samples by a finite set of levels is called quantizing. If V quantized levels are employed to represent the amplitude range, it will take $\log_2 V$ bits to code each sample. In telephone transmission 2S6 quantized levels are employed, hence each sample is coded using $\log_2 256 = 8$ bits, and thus the digital bit rate is 8000 x 8 = 64,000 bits per second (bps).

1.8.2 Delta Modulation

It has been found that analog signals such as speech and video signals generally have a considerable' amount of redundancy; that is, there is a significant correlation between successive samples when these signals are sampled at a rate slightly higher than the Nyquist rate. For example, the frequency spectrum of the human voice is 300 to 3400 Hz but it is sampled at 8000 samples per second in a PCM system. When these correlated samples are coded as in a PCM system, the resulting digital stream contains redundant information. The redundancy in these analog signals makes it possible to predict a sample value from the preceding sample values and to transmit the difference between the actual sample value and the predicted sample value estimated from past samples. This results in a technique called difference encoding. One of the simplest forms of difference encoding is delta modulation, which provides a staircase approximation of the sampled version of the analog input signal as shown in Fig. 1.15. The difference between the input and the approximation is quantized into two levels, $+\Delta$ and $-\Delta$, corresponding to a positive and a negative difference, respectively. Thus at any sampling instant the approximation is increased by Δ or decreased by Δ depending on whether it is below or above the analog input signal. A digital output of 1 or 0 can be generated according to whether the difference is $+\Delta$ or $-\Delta$. In delta modulation, overloading can occur if the amplitude of the analog input signal changes too fast for the encoding to keep up. Increasing the Step size Δ will result in poor resolution, and increasing

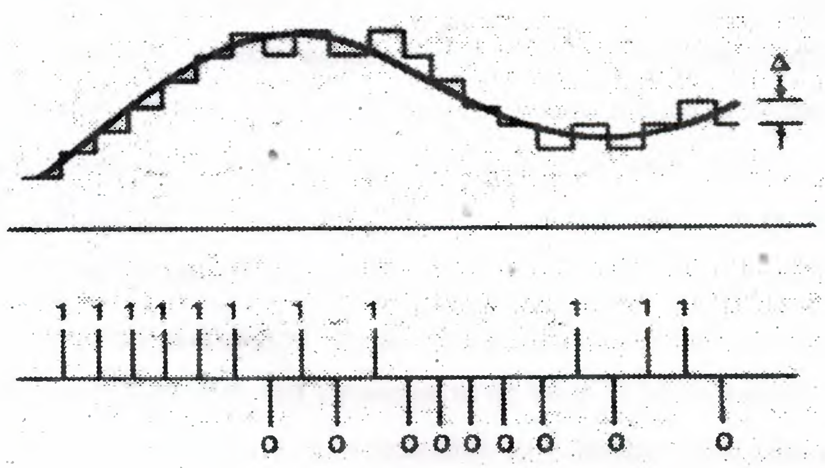


Figure 1.15 Delta Modulation

the sampling rate will lead to a higher digital bit rate. A better scheme for avoiding overloading is to detect the overloading condition and to adjust the step size Δ to a larger value. This is called adaptive delta modulation. Delta modulation has been used to encode speech with good quality at 32,000 bps. Another important approach in digital encoding of analog signals is differential pulse code modulation. This is basically a modification of delta modulation where the difference between the analog input signal and its approximation at the sampling instant is quantized into V levels and the output of the encoder is coded into $\log_2 V$ bits. Differential PCM combines the simplicity of delta modulation and the multilevel quantizing feature of PCM, and in many applications it can provide good reproduction of analog signals comparable to PCM with a considerable reduction in the digital bit rate.

There are other new strategies to encode speech at lower bit rates than the above methods One method is linear predictive coding (LPC). which achieves speech compression by estimating a speech signal as a linear function of past outputs of the speech quantizing system. Near-toll-quality speech vocoders (speech digitizing systems) at 4.8 kbps are now being developed for mobile satellite communications

1.8.3 Time Division Multiplexing-Pulse Code Modulation

Information traffic between a terrestrial network and an earth station involves much more than a PCM channel at 64,000 bps. In order to carry many more channels simultaneously over a single transmission facility such as a wire pair or coaxial cable, multiplexing must be employed. One of the most widely used multiplexing techniques for telephone speech signal is time division multiplexing-pulse code modulation (TDM-PCM) Fig. 1.16. Here 24 speech signals are fed to 24 contacts of a pair of synchronized electronic switches at the transmit and receive ends. The continuous amplitude of the speech signals is repeatedly sampled as the switch rotates. Each of the 24 speech signals is sampled every 125 μs and interleaved to form a time division-multiplexed signal. Each sample of the time division-multiplexed signal is quantized and converted to an 8-bit PCM codeword. The 8-bit PCM codeword forms a time slot corresponding to a sample from one of the 24 speech signals. Twenty-four time slots form a I 25 μs frame which consists of 192 bits and an additional 193rd bit at the end of the frame that is used for establishing and maintaining frame timing. Normally the receiver checks the 193rd bit every frame to make sure that it has not lost synchronization. If synchronization bas been lost, the receiver can scan for the framing pattern and be resynchronized. Since there are 193 bits/1.25 μs the total bit rate is 1.544 Mbps.

In addition to the voice signal, the frame also carries signaling information needed to transmit telephone dial tones as well as on-hook and off-hook signals. Every sixth frame, the least significant bit (the eighth bit) of each voice channel is deleted and a signaling bit is inserted in its place. This type of TDM-PCM bit stream is employed in the Bell System's T1 carrier, which is used in North America.

An international standard also exists for PCM transmission. The CCITT has a recommendation for a PCM carrier at 2.048 Mbps. In this carrier, there are 32 8-bit time slots in each 1 25- μs frame. Thirty of these time slots are used for speech at a bit rates of 64 Kbps, one for synchronization and one for signaling. The 2.048-Mbps P C M carriers are used Outside North America and Japan.

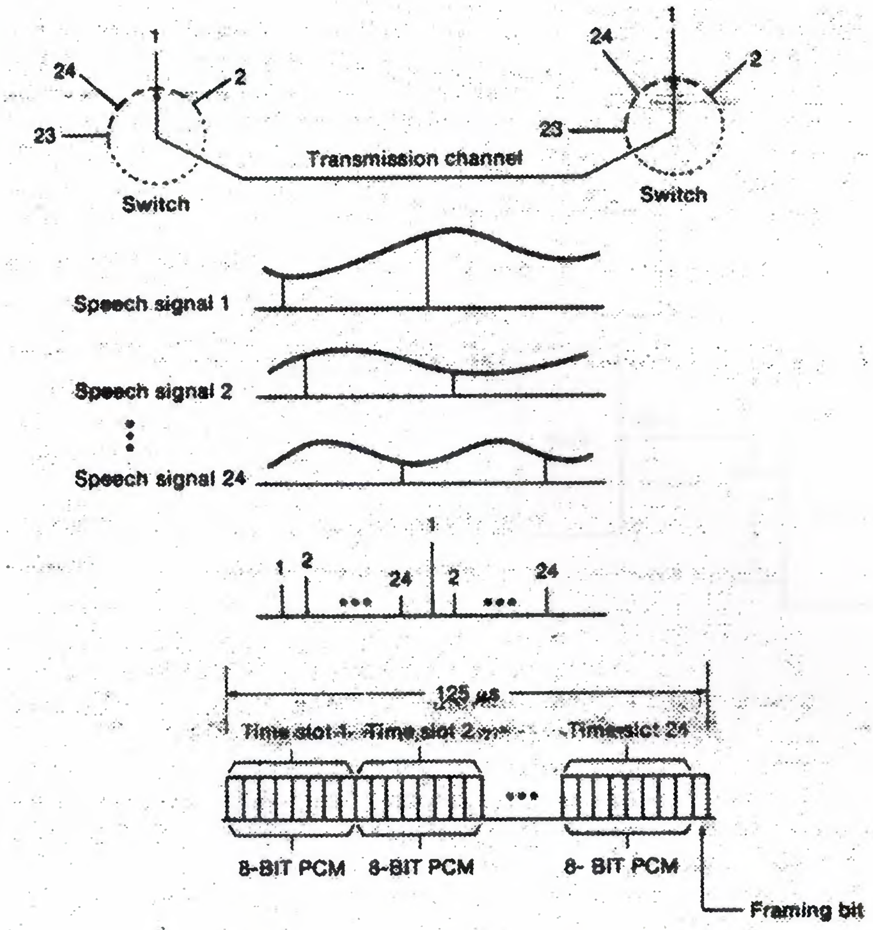


Figure 1.16 Time division multiplexing-Pulse code modulation.

1.8.4 Digital Hierarchy

To transmit digitized analog signals such as telephone speech and visual signals having different bit rates, and data with a diversified bit rate over the same transmission channel, higher-order digital multiplexing or a digital hierarchy must be used. Figure 1.17 illustrates the Bell System digital hierarchy, which consists of four levels. The respective data signals with bit rates of 1.544 Mbps (T1), 6.312 Mbps (T2), 44.736 Mpbs (T3), and 274.176 Mbps (T4) correspond to levels 1, 2, 3, and 4. Level 1 is the output of a D1 channel bank which time division-multiplexes and PCM encodes 24 speech signals, or one of the four outputs of a D3 channel bank which multiplexes and encodes 96 speech channels, or the output of a data multiplexer which multiplexes data with bit rates of 2.4, 4.8, 9.6, and 56 kbps. The DS-l data signal is carried by the T1 carrier system over a wire pair. Level 2 is formed by multiplexing four DS-1 data signals and is carried by a T2 carrier system over a wire pair. Level 3 is formed by multiplexing seven DS-2 data signals and is carried by a T3 carrier system over coaxial cable. Level 4 is formed by multiplexing six DS-3 data signals and is carried by a T4 carrier system over coaxial cable.

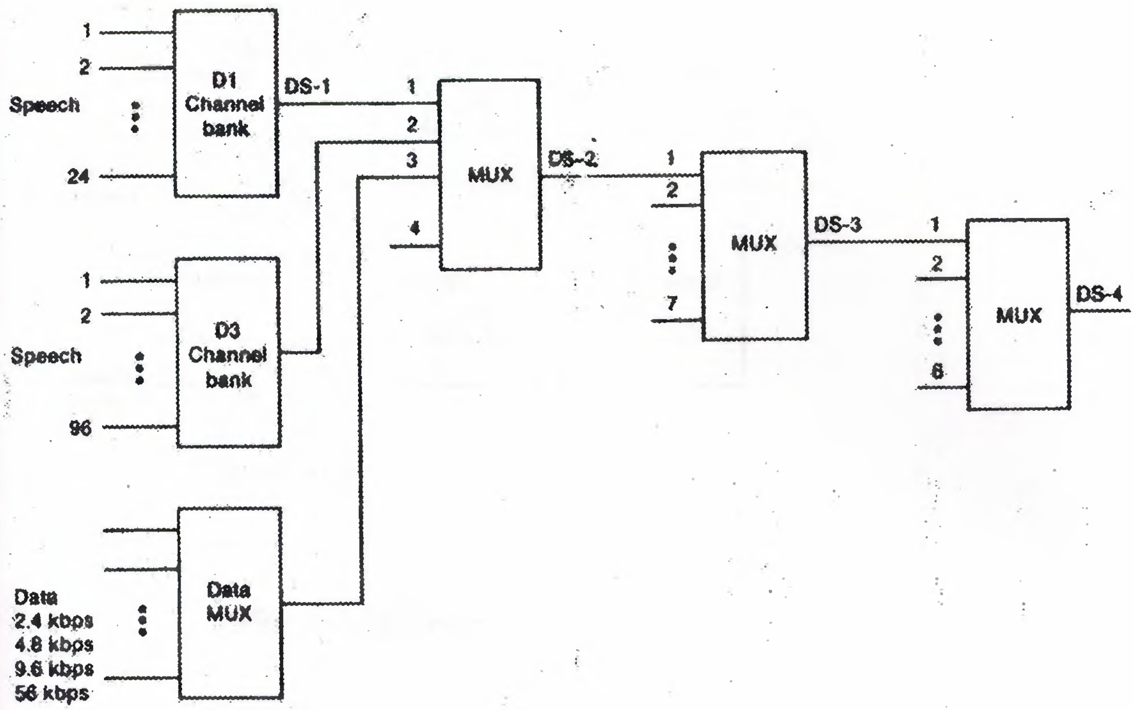


Figure 1.17 Digital Hierarchy.

1.8.5 Frequency Division Multiplexing

Another form of multiplexing that characterizes analog communications is frequency division multiplexing (FDM), as shown in Fig. 1.18. Twelve speech signals, each of which occupies a bandwidth from 300 to 3400 Hz, are used to modulate 12 separate carriers each 4 kHz apart. The output of the modulator, which is the product of the speech signal and the carrier, consists of a lower side-band the carrier frequency. The signals are then passed through 4-kHz bandpass filters that reject the upper side-band and pass only the lower side-band. This technique is called single-side-band suppressed carrier (SSBSC) generation. Twelve lower side-bands are then combined to form a group that occupies the frequency band from 60 to 108 kHz. Five groups can be multiplexed in a similar fashion to form a supergroup of 60 speech signals that occupies the band from 312 to 552kHz, and five supergroups form a master group of 300 speech channels that occupies the band from' 812 to 2044 kHz.

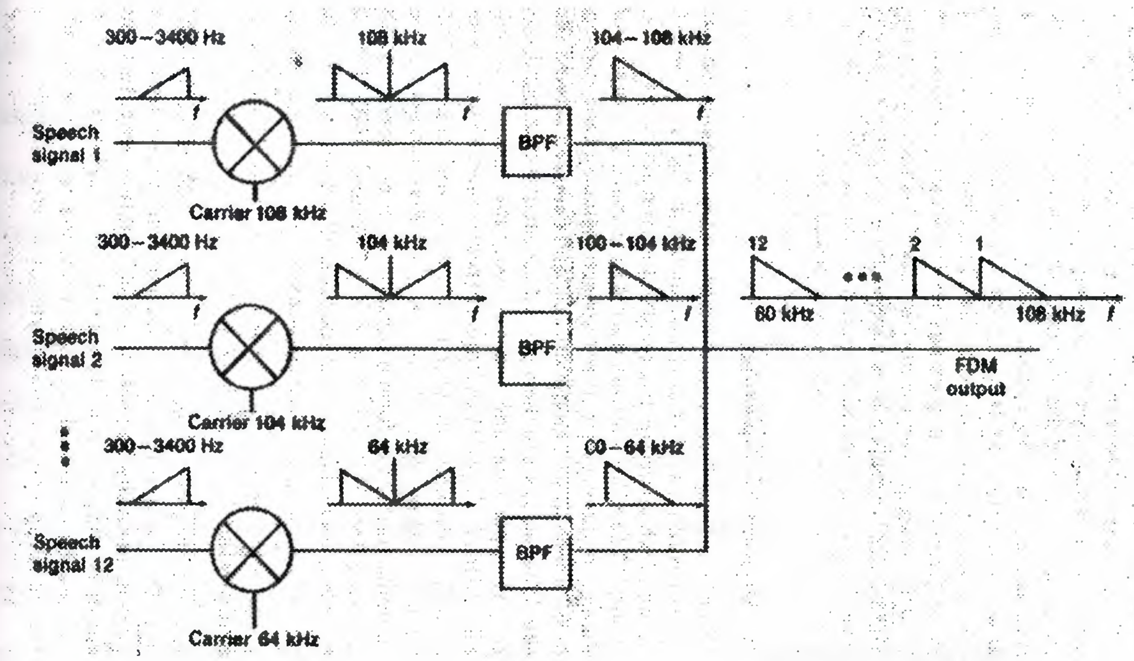


Figure 1.18 Frequency division multiplexing.

1.9 Modulation

Modulation must be employed to transmit base-band information over a bandpass channel. In analog modulation such as frequency modulation, which is extremely popular in satellite communications, the signal-to-noise ratio at the output of the FM demodulator is an intuitive measure of how well the FM demodulator can recover the analog information signal from the received modulated carrier in the presence of additive white Gaussian noise (AWGN). The output signal-to-noise ratio is defined as the ratio of the average power of the analog information signal to the average power of the noise at the output of the demodulator. In digital modulation, the performance of the demodulator is measured in terms of the average probability of bit error, or the bit error rate as it is often called. The binary information, which consists of sequences of 1 and 0 digits, can be used to modulate the phase, frequency, or amplitude of a carrier. Consider the carrier $A\cos(\omega_c t+\phi)$, where A is the carrier amplitude, ω_c is the carrier frequency, and ϕ is the carrier phase. To transmit the binary digit or bit 1, ϕ is set to 0 rad, and to transmit the bit 0, ϕ is set to π radians. Thus 1 is represented by the waveform $A\cos\omega_c t$, and 0 is represented by the waveform $A\cos(\omega_c t+\pi)=-A\cos\omega_c t$. This type of discrete phase modulation is called phase shift keying (PSK). Similarly 1 can be transmitted by using the waveform $A\cos\omega_1 t$ and 0 transmitted by using the wave form $A\cos\omega_2 t$, Where $\omega_1 \neq \omega_2$ This type of digital modulation is called frequency-shift keying (FSK), where two waveforms at different carrier frequencies ω_1 and ω_2 are used to convey the binary information. The problem with digital modulation is that sometimes the binary digit 1 is transmitted but the demodulator decodes it as a 0, or vice versa, because of perturbation of the carrier by noise; this results in bit errors in the demodulation of the binary information. The average probability of bit error P_b is a convenient measure of the performance of the demodulator and is a function of the ratio of the energy per bit to the noise density, E_b/N_0, where the energy per bit E_b is the energy of the carrier during a signaling interval or bit duration T_b and $N_o/2$ is the noise power spectral density. When the base-band information is transmitted at a rate of R bits per second, the bit duration is simply T_b=1/R seconds, and this is also the signaling interval of the waveform that represents a particular bit. For example, in PSK modulation,

$$s_1(t)=A\cos\omega_c t \qquad 0\le t\le T_b$$

$$s_2(t)=-A\cos\omega_c t \qquad 0\le t\le T_b$$

where $s_1(t)$ represents 1 and $s_2(t)$ represents 0. By definition we have

$$E_b=\int_0^{T_b} s_1^2(t)dt=\int_0^{T_b} s_2^2(t)dt=\int_0^{T_b} A^2\cos^2\omega_c t dt \tag{1.1}$$

Note that $E_b \approx A^2T_b/2$ when $\omega > 2\pi/T_b$. The quantity E_b/N_0 can be related to the average carrier power C, and the noise power N measured within the receiver noise bandwidth B. By definition, the average carrier power is

$$C=\frac{1}{T_b}\int_0^{T_b} E[s^2(t)]dt \tag{1.2}$$

Where s(t) is the carrier waveform during the signaling interval T_b and E $[\cdot]$is the expected value. If all the carrier waveforms have identical energy E_b during any signaling interval, then

$$C=\frac{E_b}{T_b} \tag{1.3}$$

Recall that the power spectral density of noise is $N_0/2$ and that the noise bandwidth is

B. Hence the noise power measured within the noise bandwidth for both positive and negative frequencies is

$$N = N_o B \tag{1.4}$$

Therefore it is seen that the ratio of energy per bit to the noise density can be expressed as

$$\frac{E_b}{N_o} = \frac{CT_b}{N/B} = T_b B\left(\frac{C}{N}\right) \tag{1.5}$$

where C/N is the average carrier-to-noise ratio. In satellite communications, it is the quantity C/N that is directly evaluated, as we will discuss in Chap. 4. Once the C/N is known and the bandwidth of the receiver is selected, E_b / N_o can be calculated, as well as the average probability of bit error P_b, which is a function of E_b / N_o.

1.10 Advent of Satellite Communication

The future trend in satellite communications is toward digital techniques. Frequency division multiplexing-frequency modulation-frequency division multiple access (FDM-FM-FDMA) has been the most popular technique used in commercial satellite Systems because it has been field-proven and makes it easy to provide quality satellite links at a low cost. As the number of earth stations increases, the transponder capacity decreases markedly in a FDM-FM-FDMA system. In addition, FDM-FM-FDMA is inflexible in responding to traffic changes. On the other hand, a digital satellite system such as quaternary phase shift keying-time division multiple access (QPSK-TDMA) can accommodate a large number of earth stations with only a small loss in transponder capacity. Furthermore, it can quickly respond to traffic variations. Also associated with digital satellite communications are techniques such as demand assignment and digital speech interpolation to further increase the efficiency. With advanced satellite systems with on-board switching and processing, multiple spot beams, and beam hopping, a digital system can serve a mixture of large, medium, and small earth stations with high efficiency. Unlike an analog satellite system, a digital satellite system can employ error-correction coding to trade bandwidth for power. Finally, the use of code-division multiple access (CDMA) (Chap. 11) for low data rate applications enables users to employ micro earth stations (0.5-m antenna) at an extremely low cost ($3000) to obtain premium quality services. The flexibility of digital satellite systems will make them even more promising when integrated digital networks become fully implemented.

2. SATELLITE ORBIT AND EARTH STATION

2.1 Satellite Orbits

As shown in Fig 2.1, there are three basic types of satellite orbits: Geo stationary Earth Orbits (GEO), Medium Earth Orbits (MEO), and Low Earth Orbits (LEO).

2.1.1 Geostationary Earth Orbit (GEO)

Most of the current satellites in operation fall into this category. This orbit is approximately 35,786 km above the earth. The terms geosynchronous and geostationary are often used inter-changeably, but there is an important difference between them.

Geosynchronous satellites have an orbit whose period is one sidereal day or 24 hours. However, due to the earth's revolution around the sun, the actual period is slightly shorter: 23 hour, 56 min, and 4.ls. Obviously, the satellite must also be in a direct orbit, that is, the satellite must move in the same direction as the rotation of the earth. The inclination of a geosynchronous satellite's orbit may be at any angle with respect to the earth's equatorial plane.

A truly geostationary satellite also has the same period and the same direction of rotation as the earth. However, it must have an orbit that is close to the equatorial plane of the earth, that is, it must have a zero inclination. An observer looking at such a geostationary satellite would see it hanging a perfectly fixed spot in the sky. But this is all relative. An observer in space sees a geostationary satellite orbiting the earth at a speed of 11 .068.8 km/h. The round-trip propagation delay for GEO link is about 260 ms.

The geostationary orbit is now employed for most commercial satellites because of the following advantages:

- The satellite remains stationary with respectect to one point on earth; therefore the earth station antenna is not required to track the satellite periodically. This reduces the station's cost considerably;
- With a 5 minimum elevation angle of the earth station antenna, the geostationary satellite can cover almost 38% of the surface of the earth. Three geostationary satellites (1200 apart) can cover the entire surface (except for the Polar Regions above latitudes 760 N and 760 S).
- The Doppler shift caused by a satellite drifting in orbit (because of the gravitational

attraction of the moon and the sun) is small for all the earth stations within the geostationary satellite coverage. This is desirable for many synchronous digital systems.

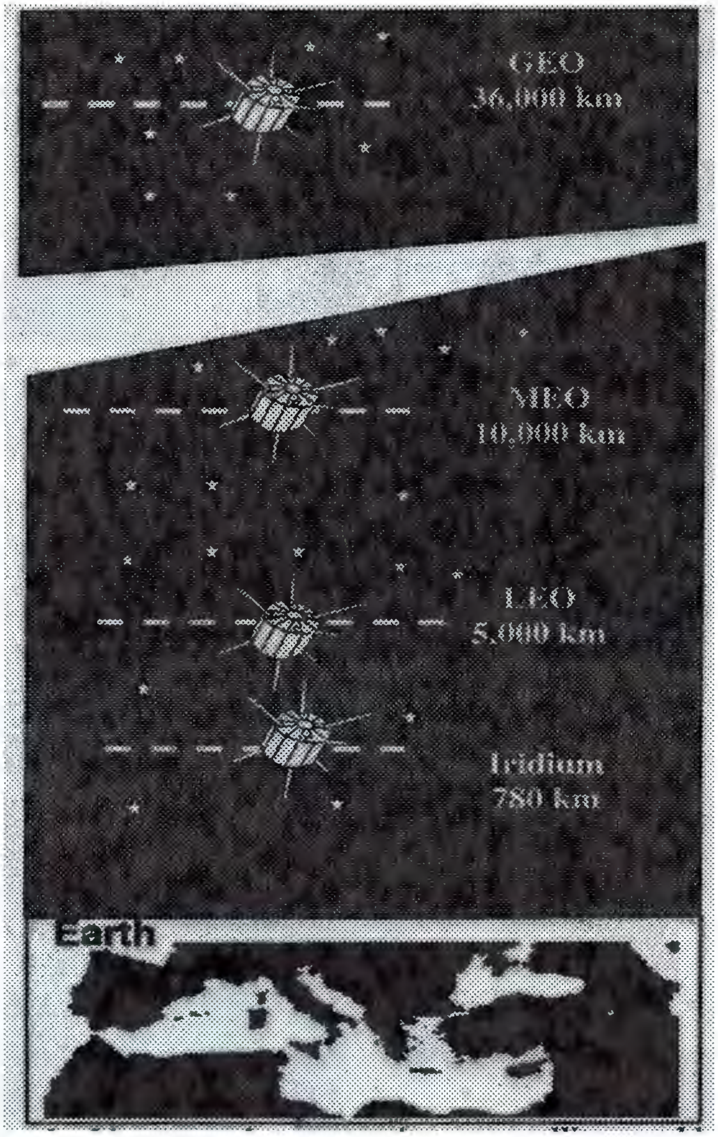


Figure 2.1 Three basic types of Satellite Orbits.

2.1.2 Medium Earth Orbit (MEO) Satellites

The medium earth orbits is approximately at about 10,000 km above the earth. Their space earth transmission loss is much less than for geostationary satellites, and the roundtrip transmission is reduced to 100-150 ms. Circular MEO orbits have periods in the range 8-12 h. As a result of the lower orbit, they do not travel at the same speed relative to the earth. This introduces the need for several MEO satellites in order to provide continuous coverage.

Although geostationary satellites seem likely to dominate satellite communications with high-speed link between fixed points, lower transmission loss of MEO satellites make them particularly attractive for mobile-satellite systems because hand-held terminals with much lower power and simple omnidirectional antennas can be used.

An example of a MEO system is the proposed ICO system of ICO Global Communications

2.1.3 Low Earth Orbit (LEO) Satellites

A low earth orbit would provide a further reduction in space-earth transmission loss relative to the geostationary orbit and transmission times of 20-25 ms. This allows the use even low power, handheld terminals in MSS.

Altitudes between 780 and 1400 km are favored, corresponding with orbital periods between 100 and 113 min. Thus, LEO systems require slightly more satellites than MEO systems to provide continuous coverage. For example, 66 satellites are used in the Iridium system.

Examples of LEO systems are Iridium Inc.'s "Iridium", Loral-Oualcomm's "Globalstar"

Frequency Bands

Spectrum in several bands has been allocated internationally for Fixed Satellite Service (FSS) and MSS systems:

- Below 1 GHz for "Little LEO" MSS systems;
- Around 1.6 GHz and 2.4 GHz for "Big LEO" MSS systems;
- Around 2 6Hz for future personal communications services (PCS) MSS Systems; Around 4 and 18 GHz for FSS systems.

2.2 The iridium- 66 Constellation

In June 1990, experts at Motorola Inc. unveiled their blue-sky vision for a futuristic new constellation of mobile communication satellites. Their initial architectural approach called for seven slender rings of satellites marching in single file up over the North and South Poles with 11 satellites in each circular ring in fig 2.2.

Motorola engineers decided to name their mobile communication system “Iridium" because their 77-satellite constellation was in direct analogy with the 77 electrons circling around Iridiums nucleus. (Iridium is one of the platinum metals, a precious silver-white substance harder than iron, nearly as brittle as flint glass, and denser than copper or brass. Iridium alloys are sold as jewelry) Unfortunately, when they later decided to increase the number of spot-beams and the transmitter power of each satellite, they also decided to reduce the number of satellites to only 66.

With a full load of fuel, an Iridium satellite weighs about 690 kg.

In space, a pair of wings with gallium arsenide photovoltaic solar cells deploys, and attitude stabilized by a three-axis momentum-wheel control system. Gallium arsenide has been replacing traditional silicon in photovoltaic cells in space because of its superior efficiency yielding about one-third more power for comparable cell areas.

A trio of phased-array antennas extends and points earthward to establish direct links over the 1.610-1.625-0Hz band to Iridium subscribers. The Iridium constellation, with a company-projected price tag of $3.4 billion, is one of the most costly concepts ever devised for providing mobile communication services. Each satellite in the Iridium constellation will send out 48 pencil-thin spot-beams each of which can handle 230 simultaneous duplex conversations. Iridium satellites are distributed among six evenly spaced, near-polar orbits (86.4 degrees inclination) 780 km above the earth, sixty of the satellites provide overlapping global coverage, and Polar Regions included. The other six are in-orbit spares. Iridium subscriber equipment offers voice, data, paging, and facsimile services see Fig 2.2.

A call placed by Iridium subscriber to another subscriber is transmitted directly by satellite to its destination worldwide, it is the only worldwide system to do this. If the call is to a party with a conventional fixed or mobile phone, it will be upconverted and transmitted by a feeder link from the satellite to a gateway. From there it is routed through the public switched telephone network to its destination. When an Iridium communicator is activated, the nearest satellite (working in concert with the ground-based Iridium network) ascertains the validity of that subscriber's account, then determines the location of the user. The system automatically checks to see if an inexpensive terrestrial link is available to handle the call. If not, the call is relayed through the nearest satellite and, if necessary, from satellite to satellite to its destination. If an Iridium subscriber is at a remote location, the call will be transmitted directly to the intended recipient. If the subscriber is in the vicinity of a land-based telecommunication system, conventional terrestrial communication channels will be used instead.

The satellite-to-satellite cross links, the satellite-to-Iridium gateway stations and downlinks connecting the Iridium satellites with their their ground-based system control stations are provided using Ka-band at 20 0Hz. The transmission links connecting the hand-held communicators, the paging units, and the remote area telephones will all be handled with the L-band frequencies between 1.5 and 1.6 0Hz. Iridium employs CDMA modulations and TDMA architecture. This approach will require that a dedicated portion of the frequency spectrum be allocated to Iridium to provide interference-free operation. Iridium's transmission rates have been set at 4800 bps for voice, and both 4800 and 2400 bps for digital data transmissions.

Characteristic of iridium

1. Eleven orbital planes of six satellites each with an l, 414-km circular orbits inclined at 86.40.
2. Each satellite mass, approximately 690 kg;
3. Orbital period - 100 minute;
4. Electrical power; 2 sun collected solar arrays with sun tracking solar panel;
5. Antennas: satellite antenna provides 48 spot beams each can handle 230 duplex conversation
6. Frequency bands
   - Ka-band (20 GHz) -satellite-to-satellite; satellite-to-gateway and satellite-to-control stations;

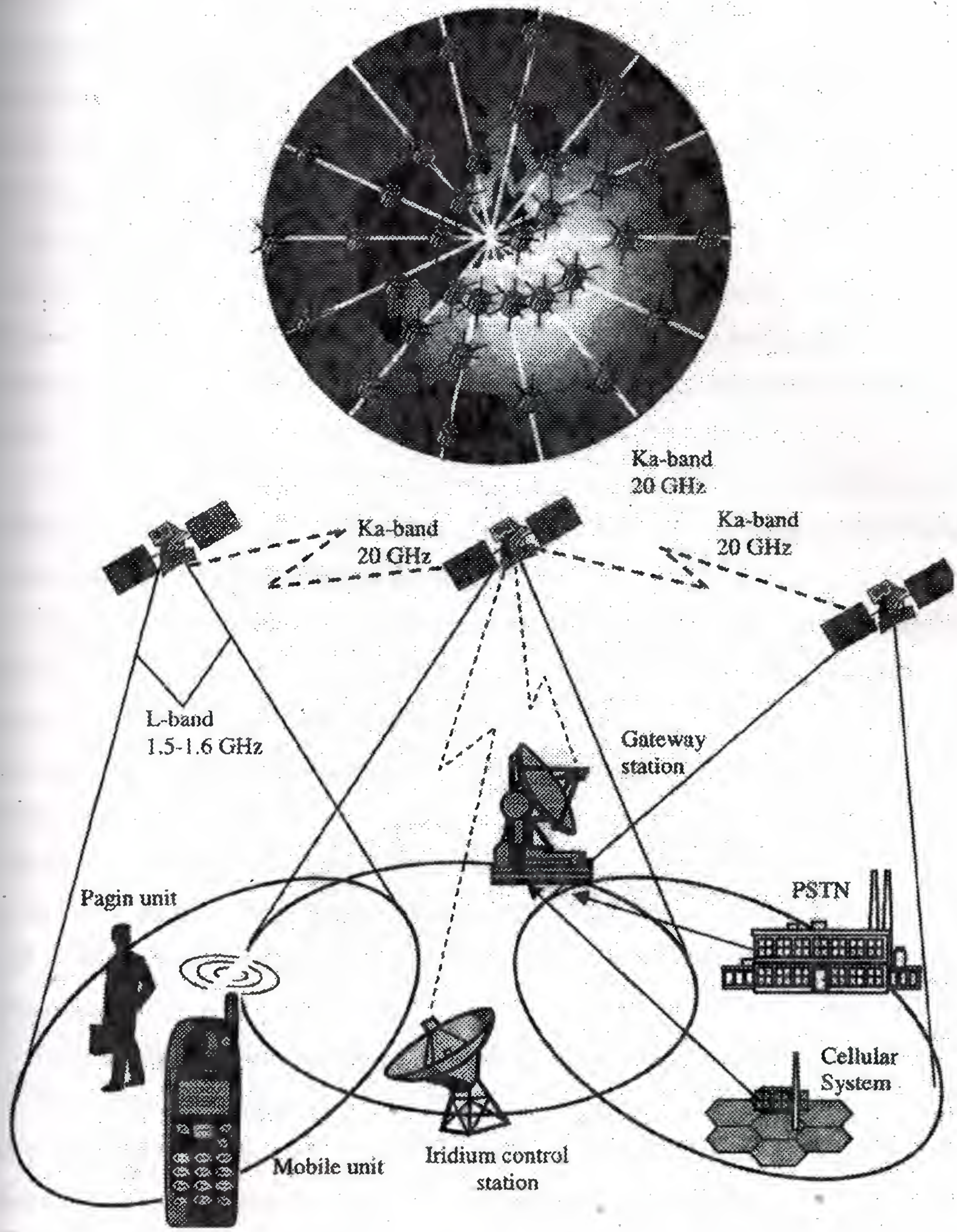


Figure 2.2 Seven-selender rings of Satellites and overlapping global coverage.

- L-band (1.5-1.6) GHz-direct, with subscribers;

The Iridium constellation, when fully implemented, will provide more than 1,100 simultaneous voice and data channels each with a 4800 bps data rate.

The Globalstar- 48 Constellation

Communication engineers at Loral Cellular Systems purposely avoided the use of cross-linking between the Globalstar satellites and on-board switching techniques because they are convinced that these approaches are needless technological frills driven by engineering considerations rather than any real user needs.

In contrast to Iridium, Globalstar designers preferred a simpler, less risky and hence cheaper spacecraft. It has neither onboard processing nor intersatellite communication links. Instead, as many functions as possible, including call processing and switching operations are located on the ground where they are accessible for maintenance and future upgrades.

Thus Globalstar is a potential competitor for Iridium, but it uses much simpler constellation architecture with gateway stations tied into the existing ground-based infrastructure to be used for message switching.

The Global star constellation is being planned with 48 satellites (8 orbit, 6 satellite in ach) boosted into eight orbit planes inclined 52 degrees with respect to the equator. The nominal altitude of the satellites is 1414 km. Each 450-kg global star satellite will employ six spot-beams with CDMA modulations for highly effective use of the available frequency spectrum.

The Globalstar constellation, when fully implemented, will provide 28,000 simultaneous voice and data channels each with a 4800 bps data rate. The antenna patterns will be formed on board each satellite by flat arrays constructed from both active and passive antenna elements.

Each satellite is powered by two deployable solar arrays, generating 1.1 kW

There they are processed and routed through the terrestrial infrastructure. But if the called party is another Globalstar subscriber the call will be uplinked from the same or another gateway to a satellite for transmission to the destination

Globalstar has set up franchises with more than a hundred local service providers covering about 88 percent of the world's population. By the close of 1997 it had secured approvals for operation. In 19 countries, among them being the United States, Russia, China, and Brazil.

To overcome limits on the frequencies available to users, Globalstar reuses the 16 MHz of bandwidth in each beam.

Aboard the satellite is a well-established repeater design that acts as a "'bent pipe" transponder relaying signals directly to the ground with minimal processing. This type of repeater is replaced b) more complicated designs on satellites with a larger number of beams and where there is digital processing.

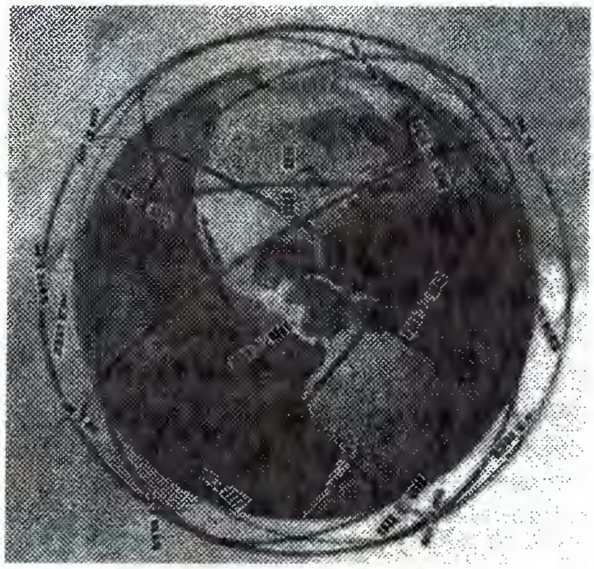


Figure 2.3 The Globalstar Constellation.

Characteristic of Global star

1. Eight orbital planes of six satellites each with a 1414-km circular orbit inclined at 520.
2. Orbit period 113 minute;
3. Each satellite mass, approximately 450 kg;
4. Electrical power; 2 sun collected solar arrays with sun tracking solar panel;
5. Antennas: satellite antenna provides 16 spot beam covering several thousand km; User antenna omnidirectional; gateway antenna tracking
6. Frequency bands

(a) User links:

- L-band (1610-1626.5) MHz –user-to-satellite;
- S-band (2483.5-2500) MHz –satellite-to-user;
- C-band (6875-7055) MHz –satellite-to-gateway;

a) Fiber links;

- C-band (5091-5250) MHZ-gateway-to-satellite.

2.4 Orbital Period and Velocity

The motion of a satellite orbiting the earth can be described by Newton's laws of motion and the law of gravitation. Consider the earth as having a mass of m_1 and the satellite a mass of m_2 at distances r_1 and r_2 from some inertial origin as shown in Fig. 2.4. From Newton's second law of motion, which says that force acting on a body is equal to the product of its mass and its acceleration, the forces F_1 on the earth and F_2 on the satellite are given by

$$F_1 = m_1 \frac{d^2\mathbf{r}_1}{dt^2}$$

$$F_{2\ 1} = m_2 \frac{d^2\mathbf{r}_2}{dt^2}$$

Also according to Newton's law of gravitation, the attractive force between any two bodies is directly. Proportional to the product of their masses and inversely proportional to the square of the distance between them. Thus

$$F_1 = -F_2 = g\frac{m_1 m_2}{r^2}\left(\frac{\mathbf{r}}{r}\right)$$

Where g is the universal gravitational constant. From the above three equations we deduce that

$$\frac{d^2\mathbf{r}_1}{dt^2} = g\frac{m_2}{r^2}\left(\frac{\mathbf{r}}{r}\right)$$

$$\frac{d^2\mathbf{r}_2}{dt^2} = -g\frac{m_1}{r^2}\left(\frac{\mathbf{r}}{r}\right)$$

Substituting $\mathrm{r} = \mathbf{r}_2 - \mathbf{r}_1$

$$\frac{d^2\mathbf{r}}{dt^2} = g(m_1 + m_2)\left(\frac{\mathbf{r}}{r^3}\right)$$

$$= -\mu\frac{\mathrm{r}}{r^3} \qquad (2.1)$$

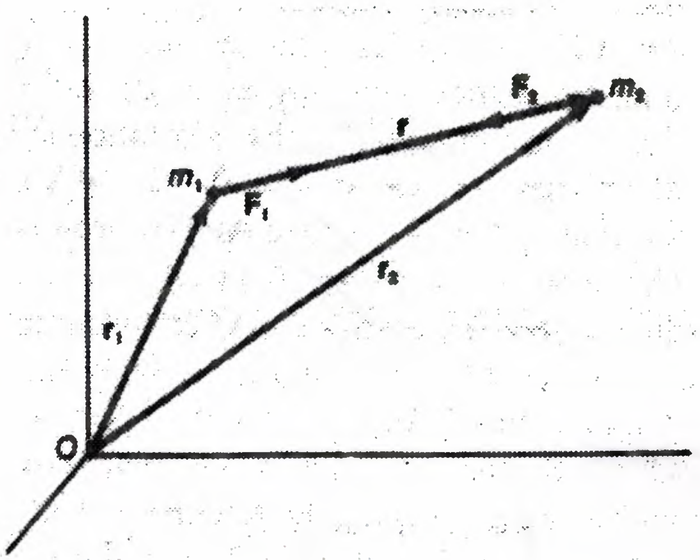


Figure 2.4 Satellite earth coordinates.

Where $\mu = g\,(m_1 + m_2) \approx gm_1$, since the mass of the satellite is negligible compared to that of the earth. The value gm_1 is given in as $\mu \approx gm_1 = 3.986013 \times 10^5\ km^3/s^2$. Equation (2.1) is known as the two-body equation of motion in relative form. It describes the motion of a satellite orbiting the earth.

A satellite orbit is either elliptical or circular, as shown in Fig. 2.5, and its characteristics are governed by Kepler's laws:

First law. The orbit of a satellite is an ellipse with the center of the earth at one focus.

Second law. The line joining the center of the earth and the satellite sweeps over equal areas in equal time intervals.

Third law. The squares of the orbital periods of two satellites have the same ratio as the cubes of their mean distances from the center of the earth.

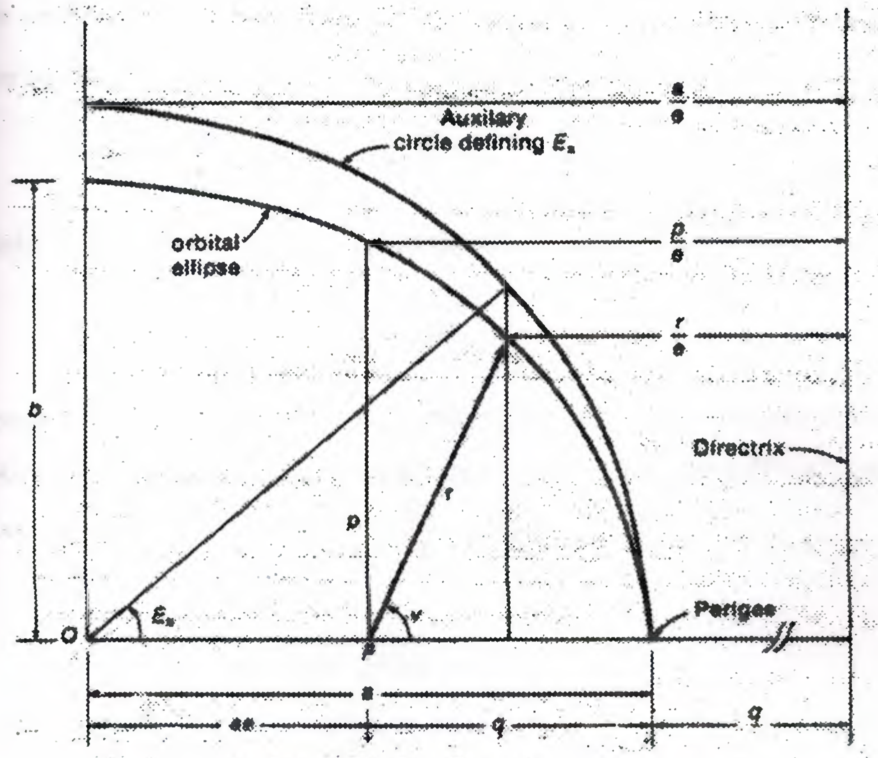


Figure 2.5 Satellite Orbit.

In Fig. 2.3 the following notation is used:

r = distance of satellite from primary focus F which is the center of the earth

v = true anomaly, measured from primary focus F in the direction of motion from the perigee to the satellite position vector r

a = semimajor axis of ellipse

b = semiminor axis of ellipse

e = eccentricity

E_a = eccentric anomaly defined by an auxiliary circle of radius a having the center *0* of the ellipse as origin

p = semiparameter

q = perigee distance, the point on the orbit closest to focus F

Q = apogee distance, the point on the orbit farthest from the focus F (not shown in Fig. 2.4).

The first law is stated as the polar equation of the ellipse with the origin at the primary focus. By using $p/e = r/e + r \cos v$, we have

$$p = r(1 + e \cos v) \tag{2.2}$$

The second law, tile law of areas, can be derived by finding the cross-product of the position vector **r** and the acceleration vector $d^2\mathbf{r}/dt^2$ given by Newton's laws in (2.1):

$$\mathrm{r}\times\frac{d^2\mathbf{r}}{dt^2}=\mathbf{r}\times\left(-\mu\frac{\mathbf{r}}{r^3}\right) \qquad (2.3)$$

With the help of the first law the integral of the above cross-product yields

$$\left|\mathbf{r}\times\frac{d^2\mathbf{r}}{dt^2}\right|=r^2\frac{dv}{dt}=\sqrt{\mu p} \qquad (2.4)$$

Which means that the area swept out by the radial vector **r** in an infinitesimal time is constant. Rewriting the above equation and using the fact that p = a (1 - e^2), as seen in Fig. 2.6, we have

$$r^2dv=\sqrt{\mu p}dt$$

$$=\sqrt{\mu a(1-e^2)}dt \qquad (2.5)$$

By using relations

$$\cos v=\frac{\cos E_a-e}{1-e\cos E_a} \qquad (2.6a)$$

And

$$\sin v=\frac{\sqrt{1-e^2}\sin E_a}{1-e\cos E_a} \qquad (2.6b)$$

We obtain, by differentiating (2.6a)

$$-\sin v dv=\frac{dE_a}{(1-e\cos E_a)^2}\left[-\sin E_a(1-e\cos E_a)-e\sin E_a(\cos E_a-e)\right]$$

And, with the substitution of (2.6b),

$$\frac{\sqrt{1-e^2}\sin E_a dv}{1-e\cos E_a}=\frac{dE_a}{(1-e\cos E_a)^2}(1-e^2)\sin E_a$$

$$dv=\frac{\sqrt{1-e^2}}{1-e\cos E_a}dE_a$$

By using the relation $r=a(1-e\cos E_a)$ and dv in the expression of r^2dv in *(2.5),* we obtain

$$a^2(1-e\cos E_a)\sqrt{1-e^2}dE_a=\sqrt{\mu a(1-e^2}dt$$

Or

$$(1-e\cos E_a)dE_a = \frac{\sqrt{\mu}}{a^{3/2}}dt$$

The integral of this equation is called Kepler's equation:

$$M = E_a - e\sin E_a = \frac{\sqrt{\mu}}{a^{3/2}}(t-t_0) \qquad (2.7)$$

M is called the mean anomaly and increases at a steady rate n, known as the mean angular motion:

$$n = \frac{\sqrt{\mu}}{a^{3/2}} \qquad (2.8)$$

To obtain the third law, the orbital period law, $E_a = 2\pi$ and $T = t - t_0$ to for the satellite period:

$$2\pi = \frac{\sqrt{\mu}}{a^{3/2}}T$$

Or

$$T = 2\pi\frac{a^{3/2}}{\sqrt{\mu}} \qquad (2.9)$$

Note that the circular orbit is just a special case of the elliptical orbit where a = b = r.

To derive the orbital velocity of the satellite, we find the scalar product of the acceleration $d^2\mathbf{r}/dt^2$ in (2.1) and $d\mathbf{r}/dt$, obtaining

$$\frac{d\mathbf{r}}{dt}\bullet\frac{d^2\mathbf{r}}{dt^2} = -\frac{\mu}{r^3}\left(\frac{d\mathbf{r}}{dt}\bullet\mathbf{r}\right) = -\frac{\mu}{r^2}\left(\frac{dr}{dt}\right)$$

The integral of this equation is

$$\frac{1}{2}\left(\frac{d\mathbf{r}}{dt}\bullet\frac{d\mathbf{r}}{dt}\right) = \frac{1}{2}V^2 = \frac{\mu}{r} + C = \frac{1}{2}\left[\left(\frac{dr}{dt}\right)^2 + \left(r\frac{dv}{dt}\right)^2\right]$$

Where V is the velocity. At the perigee dr/dt = 0 and r = q, hence from (2.4)

$$r\frac{dv}{dt} = \frac{\sqrt{\mu p}}{r} = \frac{\sqrt{\mu p}}{q}$$

And

$$\frac{\mu}{q} + C = \frac{\mu p}{2q^2}$$

$$C = \frac{\mu}{q}\left(\frac{p}{2q} - 1\right) = -\frac{\mu}{2a}$$

Hence the orbital velocity is given by

$$V = \sqrt{\mu\left(\frac{2}{r} - \frac{1}{a}\right)} \tag{2.10}$$

As derived before, the orbital period of the satellite is expressed in terms of mean solar time; it is not as accessible to measurement as another kind of time which is determined from the culminations of stars-sidereal time. A sidereal day is defined as the time required for the earth to rotate once on its axis relative to the stars. Observations of other stars can be made more precisely than observations of the sun because of their greater distance from the earth. Stars appear as point sources in telescopes, and their culminations can be accurately timed. A sidereal day is measured as 23 h, 56 min, and 4.09 s of mean solar time. A satellite with a circular orbital period of one sidereal day is called a synchronous satellite and has an orbit radius of

$$a = \left(\frac{T\sqrt{\mu}}{2\pi}\right)^{2/3} = 42{,}164.2 \text{ km}$$

If the synchronous orbit is over the equator and the satellite travels in the same direction as the earth's surface, the satellite will appear to be stationary over one point on earth. This type of orbit is called a geostationary orbit. By taking the mean equatorial radius of the earth to be 6378.155 km, the distance from the satellite to the subsatellite point is found to be $42{,}164.2 - 6378.155 = 35{,}786.045$ km for a geostationary orbit. (The subsatellite point is the point where the equator meets the line joining the center of the earth and the satellite.)

The geostationary orbit is now employed for most commercial satellites because of the following advantages:

1. The satellite remains stationary with respect to one point on earth; therefore the earth station antenna is not required to track the satellite periodically. Instead, the earth station antenna beam can be accurately aimed toward the satellite by using the elevation angle and the azimuth angle. This reduces the station's cost considerably.
2. With a 5^0 minimum elevation angle of the earth station antenna, the geostationary satellite can cover almost 38% of the surface of the earth.
3. Three geostationary satellites (1200 apart) can cover the entire surface of the earth with some overlapping, except for the Polar Regions above latitudes 76^0N and 76^0S

assuming a 5^0 minimum elevation angle.

4. The Doppler shift caused by a satellite drifting in orbit (because of the gravitational attraction of the moon and the sun) is small for all the earth stations within the geostationary satellite coverage. This is desirable for many synchronous digital systems.

To cover the Polar Regions and to provide higher elevation angles for earth stations at high northern and southern latitudes inclined orbits such as the one in Fig. 2.7 can be used. The disadvantages of an inclined orbit are that the earth station antenna must acquire and track the satellite and the necessity for switching from a setting satellite to a rising satellite. This handover problem can be minimized by designing the orbit so that the satellite is over a certain region for a relatively long part of its period. The Russian Molniya satellite has a highly inclined elliptical orbit with a 63^0 inclination angle and an orbital period of 12 h. The apogee is above the Northern Hemisphere. Communications are established when the satellite is in the apogee region where the orbital period is small and antenna tracking is slow. The satellite visibility for a station above 600 latitude with an antenna elevation greater than 20^0 is between 4.5 and 10.5 h.

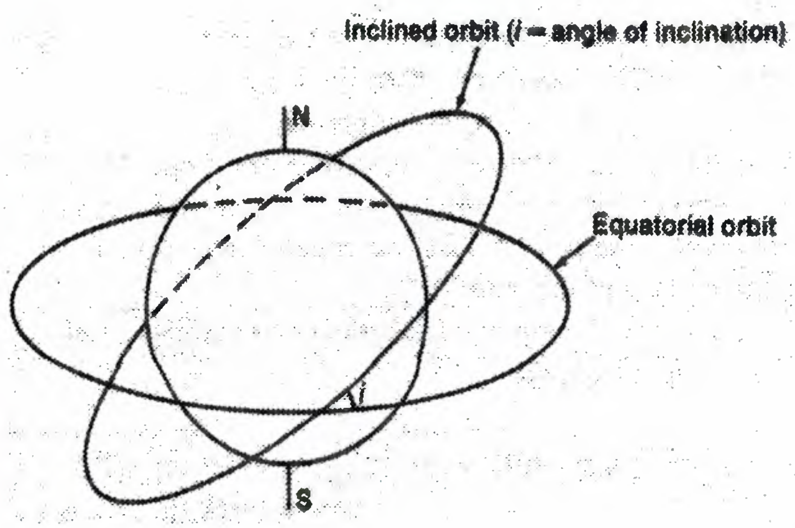


Figure 2.6 Inclined Orbit.

Although a geostationary satellite appears to be stationary in its orbit, the gravitational attraction of the moon and to a lesser extent that of the sun cause it to drift from its stationary position and the satellite orbit tends to become inclined at a rate of about 1°/year. Also, the nonuniformity of the earth's gravitational field and the radiation pressure of the sun cause the satellite to drift in longitude. But this drift is several orders of magnitude smaller than that resulting from the attraction of the moon and the sun. Station keeping is therefore required to maintain the position of a satellite accurately so that satellites in a geostationry orbit do not drift close together and cause adjacent satellite interference. North south stationkeeping is required to prevent a drift in latitude, and east-west station-keeping is needed to prevent a drift in longitude.

2.5 Effects Of Orbital Inclination

The maximum drift in both latitude and longitude due to orbit inclination can be determined by considering Fig. 2.8. Let R be the satellite's instantaneous projection on the earth's surface (the intersection of the earth's surface and the line joining the satellite and the earth's center) and let λ and ψ denote the instantaneous latitude and relative longitude (with respect to the ascending node P) of R. Considering the spherical triangle PRQ and a nonrotating earth we obtain

$$\sin\psi = \frac{\tan\lambda}{\tan i}$$

The arc PR is the trace of the orbit and subtends an angle u given by

$$\sin u = \frac{\tan\lambda}{\tan i}$$

Now consider a rotating earth. Let t_p be the time at which the satellite passes the ascending node P; then, when the satellite reaches the latitude λ in time t, the earth has rotated eastward through an angle u. Therefore, if the relative longitude of the satellite projection R is ψ it becomes $\psi - u$ Thus the relative longitude of the satellite for any given latitude λ is equal to

$$\psi = \sin^{-1}\left(\frac{\tan\lambda}{\tan i}\right) - \sin^{-1}\left(\frac{\sin\lambda}{\sin i}\right) \tag{2.11}$$

The trace of a synchronous satellite (the orbital period is the same as the sidereal period of the earth) with inclination i is plotted in Fig. 2.9. It is seen that this inclination in effect gives the satellite an apparent movement. The maximum latitude deviation from the equator is given by

$$\lambda_{\max} = i \tag{2.12}$$

And the maximum longitude deviation from the ascending node $\psi_{\max}$ and the corresponding latitude λ when i is small (i <5^0) can be numerically approximated from (2.11) by

$$\psi_{\max} = \frac{i^2}{228} \tag{2.13a}$$

$$\lambda = 0.707i \tag{2.13b}$$

Where i is in degrees. From (2.12) and (2.13) it is seen that the displacement in latitude is more pronounced than the displacement in longitude for a synchronous satellite with a Small inclination. In this case the displacement D_λ (corresponding to $\lambda_{\max}$) and D_ψ (corresponding to $\psi_{\max}$ can be calculated as follows:

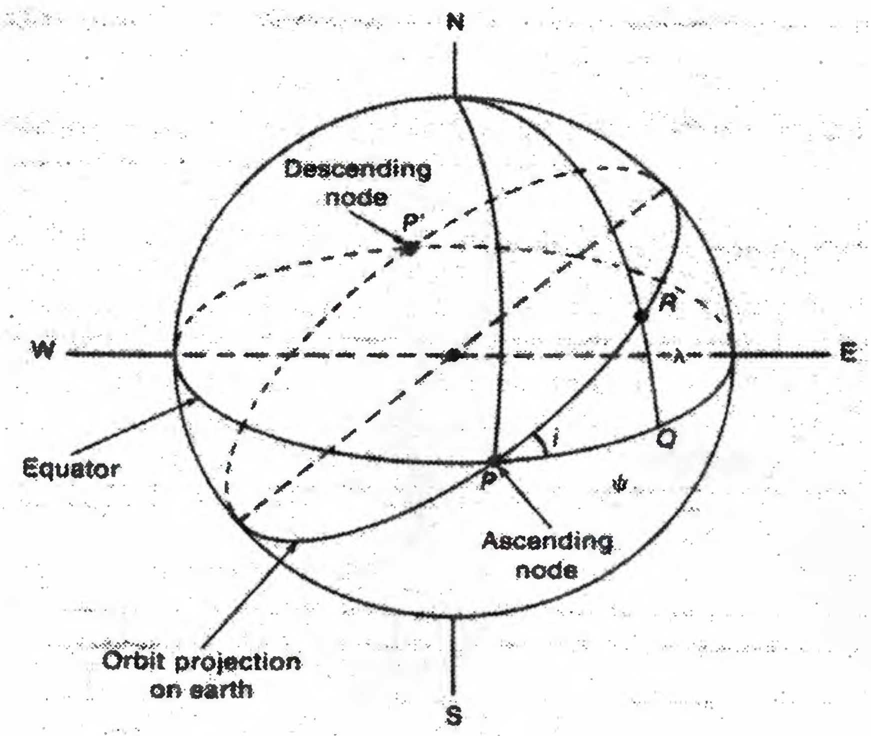


Figure 2.7 Longitude and latitude of a Satellite in an inclined and synchronous orbit.

$$\frac{D_\lambda}{R_e \lambda_{\max}} = \frac{a}{R_e}$$

$$\frac{D_\psi}{D_\lambda} = \frac{\psi_{\max}}{\lambda_{\max}} = \frac{i}{228}$$

Where a is the orbital radius (a = 42,164.2 km) and R_e is the earth's radius; Therefore,

$$D_\lambda = a\lambda_{\max} = \frac{42{,}164.2i}{360/2\pi} = 735.9i \text{ (km)} \tag{2.14}$$

$$D_\psi = \frac{iD_\lambda}{228} = 3.23i^2 \text{ (km)} \tag{2.15}$$

where i in (2.14) and (2.15) is in degrees. As an example, consider the case when $i = 1^0$; then D_λ = 735.9 km and D_ψ3.25 km.

To correct the orbital inclination it is necessary to apply a velocity impulse perpendicular to the orbital plane when the satellite passes through the nodes (see Fig. 2.8), as indicated in Fig. 2.10. For a given i, the impulse amplitude is given by

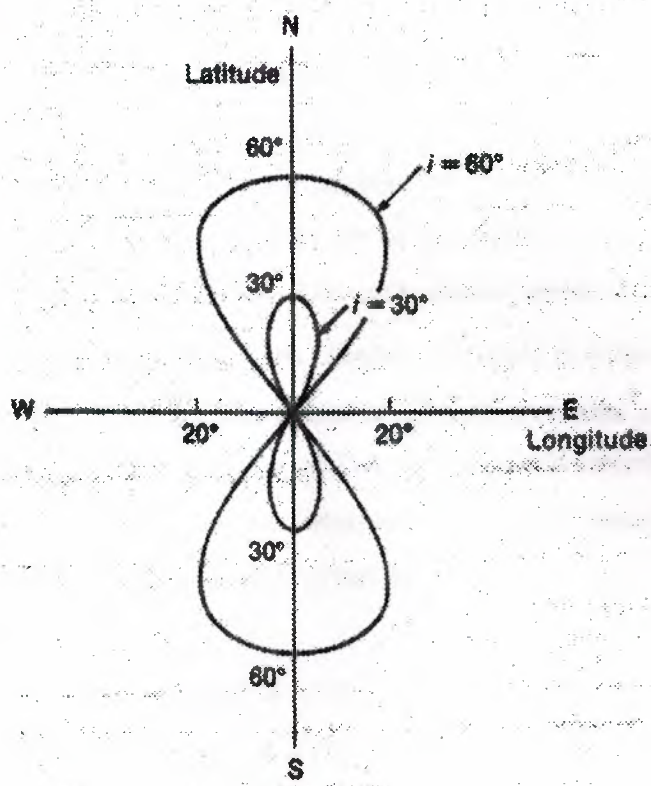


Figure 2.8 Apparent movement of a satellite in an inclined and synchronous orbit with respect to the ascending node.

$$\Delta V = V \tan i = \sqrt{\frac{\mu}{a}} \tan i \qquad (2.16)$$

Where $V = \sqrt{\mu / a} = 3074.7$ m/s and is the orbital velocity. For $i = 1^0$, $\Delta V = 3074.7$ $\tan 1^0 = 53.7$ m/s.

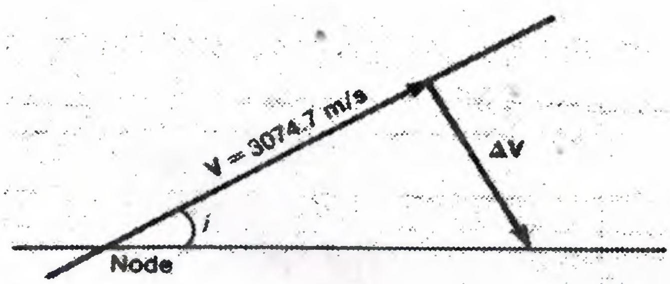


Figure 2.9 Correction of the inclination of a synchronous orbit.

2.6 Azimuth and Elevation

As previously mentioned, a satellite in a geostationary orbit appears to be stationary with respect to a point on the earth. Therefore, if an earth station is within the coverage of the satellite, it can communicate with the satellite by simply pointing its antenna toward it. Such a positioning of the earth station antenna can be accomplished using the azimuth angle A and the elevation angle E based on knowledge of the earth station latitude θ_l and longitude θ_L and the satellite longitude θ_S as shown in fig 2.10a. The azimuth angle is defined as the angle measured clockwise from the true north to the intersection of the local horizontal plane. TMP and the plane TSO (passing through the earth station, the satellite, and the earth's center). The azimuth angle A is between 0 and 360^0. Depending on the location of the earth station with respect to the subsatellite point, the azimuth angle A is given by:

1. Northern Hemisphere

   Earth station west of satellite: $A = 180^0 - A'$

   Earth station east of satellite: $A = 180^0 + A'$

2. Southern hemisphere

   Earth station west of satellite: $A = A'$

   Earth station east of satellite: $A = 360^0 - A'$

Where A' is the positive angle defined in Fig. 2.10a. The elevation angle E is defined as the angel produced by the intersection of the local horizontal plane TMP and the plane TSO with the line of sight between the earth station and the satellite. Of course we assume that the earth is a perfect sphere with radius R_e. From Fig. 2.10a we have

$$A' = \tan^{-1}\left(\frac{MP}{MT}\right)$$

$$= \tan^{-1}\left(\frac{MO\tan|\theta_S - \theta_L|}{R_e \tan\theta_l}\right)$$

$$= \tan^{-1}\left[\frac{(R_e/\cos\theta_l)\tan|\theta_S - \theta_L|}{R_e \tan\theta_l}\right]$$

$$A' = \tan^{-1}\left(\frac{\tan|\theta_S - \theta_L|}{\sin\theta_l}\right) \tag{2.17}$$

To calculate the elevation angle E, consider the triangle TSO shown in fig2.10a and redrawn in Fig. 2.10b.

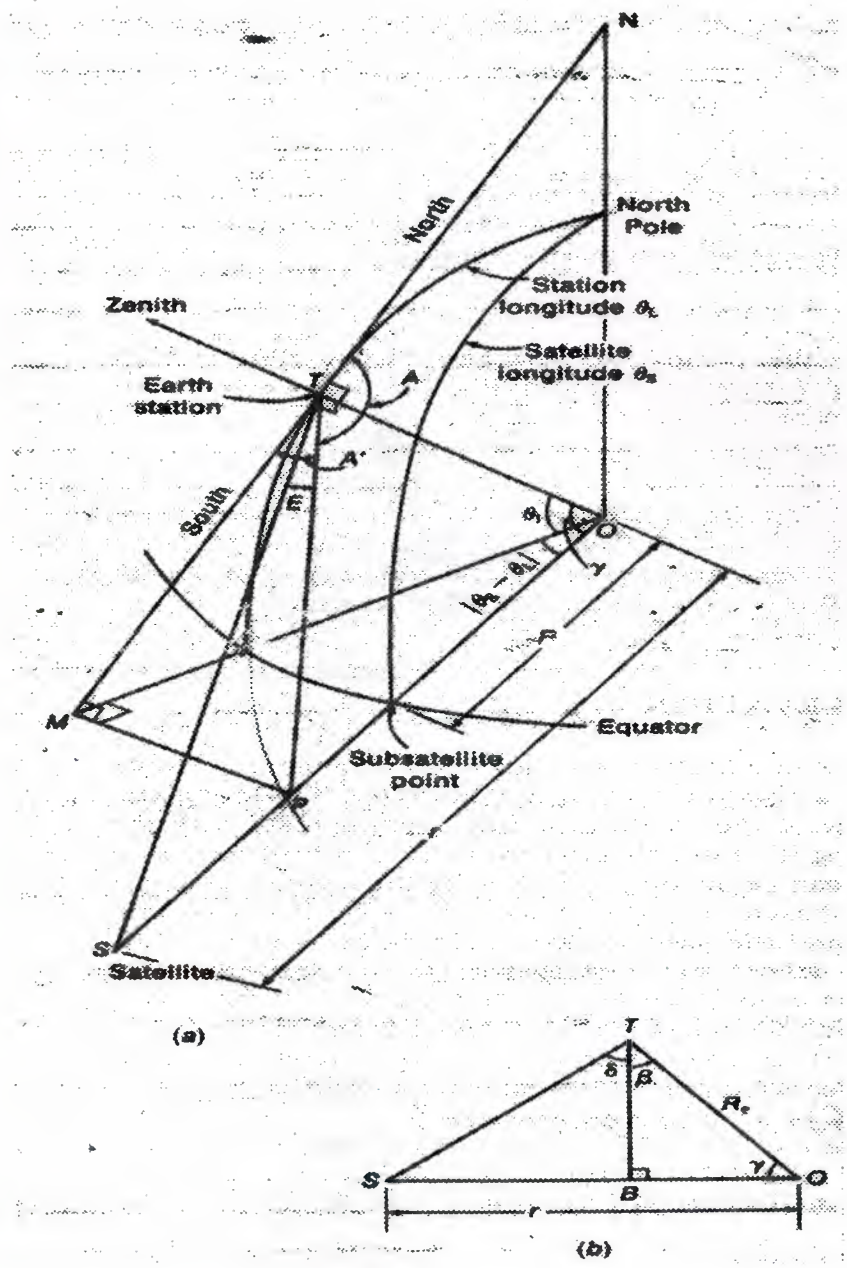


Figure 2.10 (a) Azimuth and Elevation. (b) Triangle to calculate elevation.

$$E = \beta + \delta - 90^0$$
$$= (90^0 - \gamma) + \delta - 90^0$$
$$= \delta - \gamma$$

The angle γ can be evaluated from the triangle TPO as follows:

$$\gamma = \cos^{-1}\left(\frac{R_e}{OP}\right)$$

Since $OP = MO / \cos|\theta_S - \theta_L| = R_e / \cos\theta_1 \cos|\theta_S - \theta_L|$ as seen from the triangles MPO and TMO, we have

$$\gamma = \cos^{-1}(\cos\theta_1 \cos|\theta_S - \theta_L|$$

To evaluate the angle δ in Fig. 2.8b, we note that

$$\delta = \tan^{-1}\left(\frac{SB}{TB}\right)$$

$$= \tan^{-1}\left(\frac{r - R_e \cos\gamma}{R_e \sin\gamma}\right)$$

$$\delta = \tan^{-1}\left(\frac{r - R_e \cos\theta_1 \cos|\theta_s - \theta_l|}{R_e \sin\left[\cos^{-1}(\cos\theta_1 \cos|\theta_s - \theta_l|)\right]}\right)$$

Thus the elevation angle **E** can be expressed by

$$E = \tan^{-1}\left(\frac{r - R_e \cos\theta_1 \cos|\theta_S - \theta_L|}{R_e \sin\left[\cos^{-1}\left(\cos\theta_1 \cos|\theta_S - \theta_L|\right)\right]}\right) - \cos^{-1}(\cos\theta_1 |\theta_S - \theta_L|) \qquad (2.18)$$

2.7 Eclipse

For a geostationary satellite that utilizes solar energy, the duration and periodicity of solar eclipses are important because no solar energy is available during eclipses. The earth's equatorial plane is inclined at an angle $i_e(t)$ respect to the direction of the sun. This annual sinusoidal variation is given in degrees.

$$i_e(t) = 23.4 \sin \frac{2\pi t}{T} \qquad (2.19)$$

Where the annual period T = 365 days and the maximum inclination is $I_{e,max}$=23.4^0 The time t_A and t_S when the inclination angle i_e is zero are called the autumn equinox and the spring equinox and occur about September 21 and March 21, respectively. The times t_W and t_{SU} when the inclination angle i_e at its maximum are called the winter solstice and the summer soltice and occur about December 21 and June 21; respectively.

To find the eclipse duration consider Fig. 2.11 where the finite diameter of the sun is ignored (the sun is assumed to be at infinity with respect to the earth), hence the earth's shadow is considered to be a cylinder of constant diameter. The maximum shadow angle occurs at the equinoxes and is given by

$$\phi_{max} = 180^0 - 2\cos^{-1}\left(\frac{R_e}{a}\right)$$

$$= 180^0 - 2\cos^{-1}\left(\frac{6378.155}{42{,}164.2}\right)$$

$$= 17.4^0 \tag{2.20}$$

Because a geostationary satellite period is 24 h, this maximum shadow angle is equivalent to maximum daily eclipse duration

$$\tau_{max} = \frac{17.4^0}{360^0} \times 24 = 1.16h \tag{2.21}$$

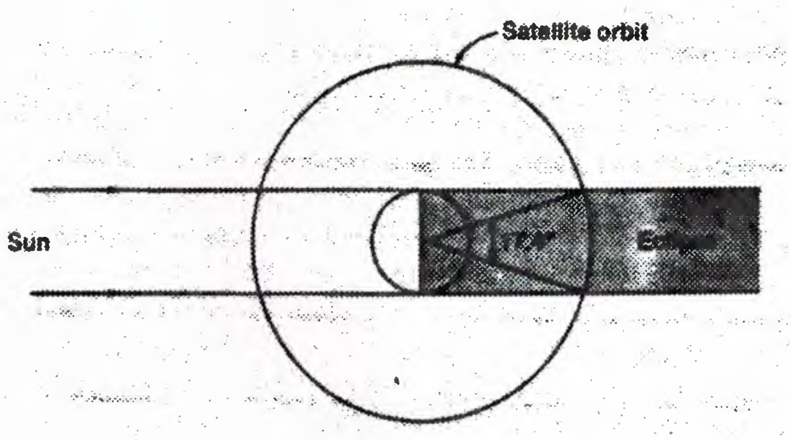


Figure 2.11 Eclipse when the sun is at equinox.

The first day of eclipse before an equinox and the last day of eclipse after an equinox correspond to the relative position of the sun such that the sun rays tangent to the earth pass through the satellite orbit. Thus the inclination angle of the equatorial plane with respect to the direction of the sun in these cases (Fig. 2.12) is

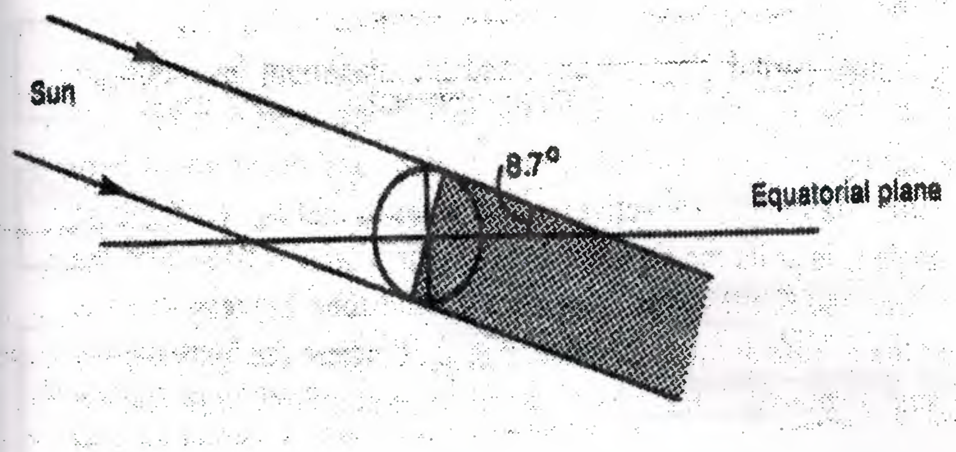


Figure 2.12 Earth inclination at first day of eclipse before equinox.

$$i_e = \frac{1}{2}\phi_{max} = 8.7^0 \quad (2.22)$$

Substituting $i_e = 8.7^0$ into (2.19) yields the time from the first day of eclipse to the equinox and also the time from the equinox to the last day of eclipse:

$$t = t = \frac{365}{2\pi}\sin^{-1}\left(\frac{8.7}{23.4}\right) = 22.13 days \quad (2.23)$$

Where the angle is in radians.

2.8 Communications Subsystems

The communications subsystems provides the receive and transmit coverage for the satellite consists of a communications antenna and a communications repeater. The communications antenna serves an interface between the earth stations on the ground and various satellite subsystems during operation. The main function of the antenna is to provide shaped downlink and uplink beams for transmission and reception of communications signals in the operating frequency bands In addition the antenna may be used to provide a signal link for the satellite telemetry, command, and ranging subsystem which in conjunction with the altitude control subsystem provides beacon tracking signals for precise pointing of the antenna toward the earth coverage areas. Communication Satellite subsystem is given in Fig 2.13.

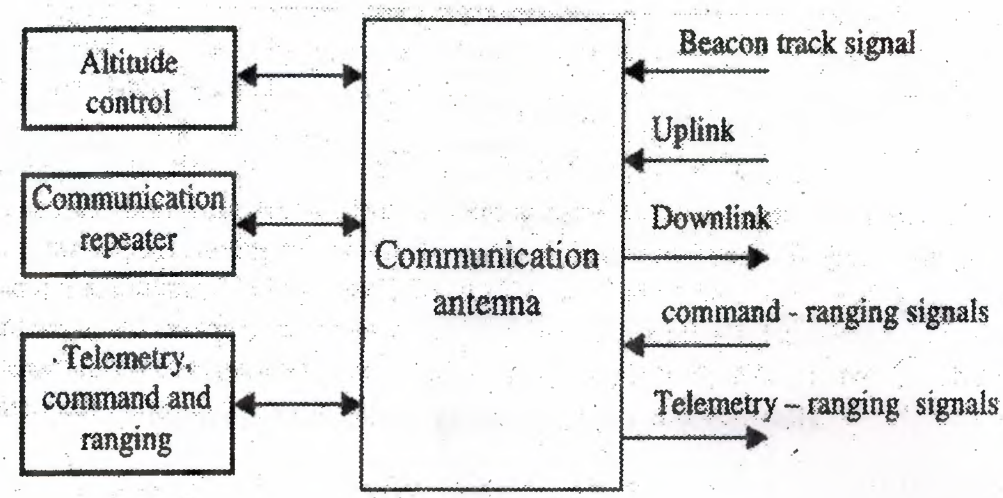


Figure 2.13 Communication Satellite subsystem.

The communications repeater generally consists of the following modules, as shown schematically in Fig2.14.

1. A wideband communications receiver/downconverter
2. An input multiplexer
3. Channelized traveling 'wave tube amplifiers (TWTA)
4. An output multiplexer

The wideband communications receiver/downconverter is designed to operate within the typical 500-MHz bandwidth allocated for C-band (5.9 to 6.4 GHz) and Ku-band (14 to 14.5 GHz) uplink signals and is shown schematically in Fig2.13 for a Ku-band uplink The uplink signals are first filtered by a waveguide bandpass filter with about a 600-MHz bandwidth and then amplified by a parametric or a solid-state gallium arsenate field effect transistor (GaAs FET) low-noise amplifier with a typical noise figure of 2 to 4 dB.

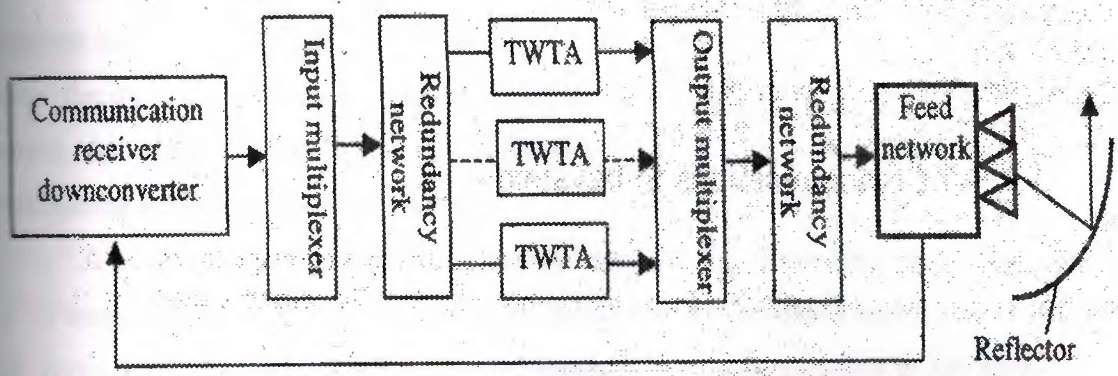


Figure 2.14 Communication repeaters schematically.

The amplified signals are then downconverted to the 11.7 to 12.2-GHz downlink Ku band (3.7 to 4.2 GHz for a downllink C band) by a microwave integrated circuit downconverter. After downconversion, the signals are again amplified by an 11.7 to 12.2 GHz GaAs FET amplifier and passed through a ferrite isolator to the input multiplexer. The input multiplexer is employed to separate the 500-MHz bandwidth into individual transponder channels whose bandwidth depends on the satellite's mission. For example, a 500-MHz bandwidth can be divided into 8 transponder channels with a center-to-center separation of 61 MHz. With frequency reuse, there are altogether 16 transponder channels in the satellite.

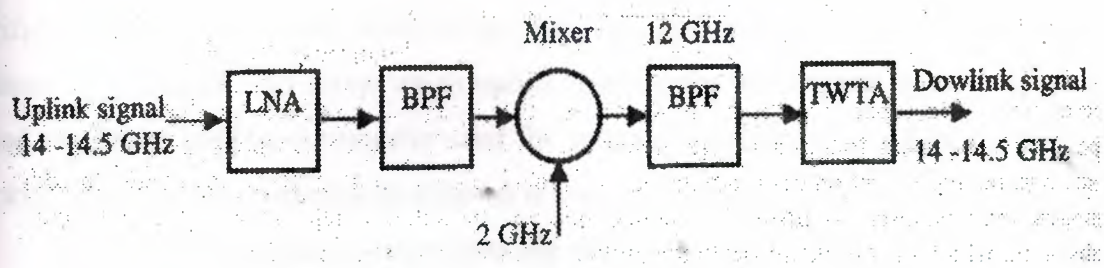


Figure 2.15 Kuband uplink.

The channelized TWTAs amplify the low-level downlink signals to a high level for transmission back to earth. Driver amplifiers are normally employed in front of the high-power TWTAs to allow the communications receiver to be operated in the linear mode. The size of the TWTA depends on the mission and is about 15 to 30 W for a 61-MHz Ku-band transponder. The TWTA establishes the transponder output power and normally operates near saturation to achieve the desired output power. Thus it is the dominant non-linear device in a transponder and can affect the link signal performance considerably. The output downlink signals from the channelized TWTA are combined by the output multiplexer for retransmissions to earth.

A complete communications subsystems employing frequency reuse and consisting of 16 transponders (8 transponders use the horizontal polarization and 8 transponders use the vertical polarization). The number of odd and even transponders in the east and west beams can be selected by using the variable power dividers.

2.9 Telemetry, Command, and Ranging Subsystem

The telemetry subsystem monitors all satellite subsystems and continuously transmits to the earth sufficient information for determination of the satellite altitude, status, and performance as required for satellite and subsystem control. The telemetry transmitter also serves as the downlink transmitter for the ranging tones. The primary telemetry data mode is normally pulse code modulation. In normal on-station operation, telemetry data is transmitted via the communications antenna. In the transfer orbit, the telemetry transmitter is connected to a TWTA in the communications repeater selected to provide adequate power for telemetry coverage via the omni antenna.

The command subsystem controls the satellite operation through a phase of the mission by receiving and decoding commands from the ground station. It also generates a verification signal and upon receipt of an execute signal carries out the commands. The command subsystem also serves as an uplink receiver for the ranging signals. Again, the omni antenna is used in the transfer orbit for command and ranging and as an on-station backup, while the communications antenna is used on-station for command and ranging.

The ranging subsystem determines the slant range from the ground control station to the satellite for precise transfer and geostationary orbit determination. The slant range is determined by transmitting to the satellite multiple tones modulated onto the command carrier which is received by the command receiver, demodulated, and retransmitted by the telemetry transmitter to the ground control station where the phase difference is accurately measured. During on-station operation ranging is performed via the communications antenna; antenna coverage for ranging during the transfer orbit is provided by the omni antenna

2.10 Electrical Power Subsystem

The satellite generates power by using a solar array of silicon cells. In a spin-stabilized satellite the solar array consists of two concentric cylindrical panels of silicon cells. The forward panel is attached to the main structure and is divided into two arrays separated by a thermal radiator band. The aft panel is retracted over the forward panel during a transfer orbit and extended into its operating position in a geostationary orbit. In a transfer orbit, the aft panel provides solar power only. The disadvantage of a spin-stabilized satellite is that only one-third of the solar array is exposed to the sun at any time, resulting in power limitations. For a higher power level a larger satellite is required to provide space for body-mounted solar cells. The three-axis body-stabilized configuration can provide much more power by using deployed solar panels of wings. The array consists of many panels hinged together in two sets. In a transfer orbit, the panels are folded and stowed by restraint bands against the north- and south-facing sides of the satellite. The outermost panel is partially illuminated by the sun and furnishes a small amount of solar power. When the satellite reaches the geostationary orbit, the array is deployed and full power becomes available.

2.11 EARTH STATION

Fig 2.16 shows the functional elements of a digital earth station. Digital information in the form of binary digits from the terrestrial network TN enters the transmitter side of the earth station and is then processed (buffered, multiplexed, formatted, etc.) by the Baseband Equipment (BE) so that these forms of information can be sent to the appropriate destinations. The presence of noise and the non-ideal nature of any communication channel introduce errors in the information being sent and thus limit the rate at which it can be transmitted between the source and the destination. Users generally establish an error rate above which the received information is not useable.

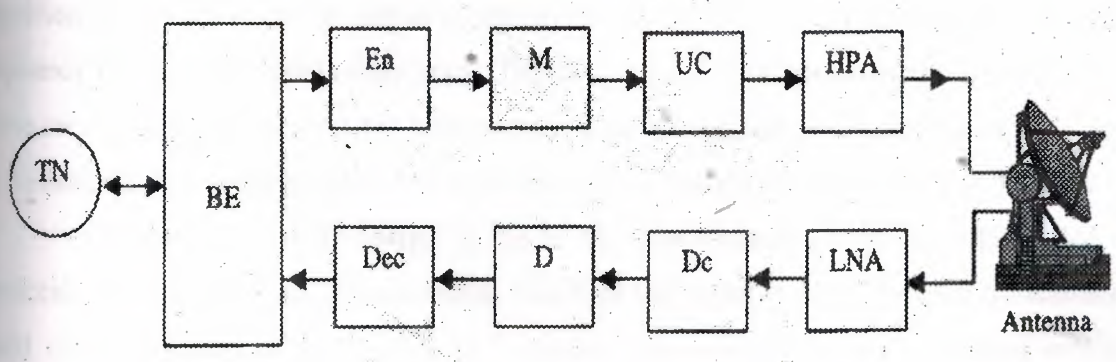


Figure 2.16 Functional elements of a digital earth station.

If the received information does not meet the error rate requirement, error-correction coding performed by the encoder (En) can often be used to reduce the error rate to the acceptable level. Th order to transmit the digital information over a satellite channel that is a bandpass channel, it is necessary to transfer the digital. Information to a carrier wave at the appropriate bandpass channel frequency. This procedure is performed by modulation. The function of the modulator (M) is to accept the symbol stream from the encoder (En) and use it to modulate an intermediate frequency (IF) carrier. In satellite communications, the IF carrier frequency is chosen at 70 MHz for a communication channel using a 36-MHz transponder bandwidth and at 140 MHz for a channel using a transponder bandwidth of 54 or 72 MHz. A carrier wave at an intermediate frequency rather than at the satellite RF uplink frequency is chosen because it is difficult to design a modulator M that works at the uplink frequency spectrum (6 or 14 GHz, as discussed previously). For binary modulation schemes, each output digit from the encoder is used to select one of two possible waveforms. For M-ary modulation schemes, the output of the encoder is segmented into sets of k digits, where $M = 2^K$ and each k-digit set or symbol is used to select one of the M waveforms. The modulated IF carrier from the modulator is fed to the Upconverter (Uc), where its intermediate frequency is translated to the uplink RF frequency. The high-Power Amplifier (HPA) then amplifies this modulated RF carrier by the antenna. The earth station antenna provides the transmitting modulated RF carrier to the satellite within the uplink frequency spectrum and receiving the RF carrier from the satellite within the downlink frequency spectrum.

On the receiver side the earth station antenna receives the low-level modulated RF carrier in the downlink frequency spectrum of the satellite. A Low-Noise Amplifier (LNA) is used to amplify this low-level RF carrier to keep the carrier-to-noise ratio at a level necessary to meet the error rate requirement. The Downconverter (Dc) accepts the amplified RF carrier from the output of the low-noise amplifier and translates the downlink frequency to the intermediate frequency. The reason for downconverting the RF frequency of the received carrier wave to the intermediate frequency is that it is much easier to design the demodulator to work at 70 or 140 MHz than at a downlink frequency of 4 or 12 GHz.

The demodulated IF carrier is fed to the demodulator, where the information is extracted. The demodulator (D) estimates, which of the possible symbols were transmitted, based on observation of the received I F carrier. The probability that a symbol will be correctly detected depends on the carrier-to-noise ratio of the modulated carrier, the characteristics of the satellite channel, and the detection scheme employed. The decoder performs a function opposite that of the encoder. Because the sequence of the symbols recovered by the demodulator may contain errors, the decoder must use the uniqueness of the redundant digits introduced by the encoder to correct the errors and recover information- bearing digits. The information stream is fed to the baseband equipment for processing for delivery to the terrestrial network.

In the United States the Federal Communications Commission (FCC) assigns orbital positions for all communications satellites to avoid interference between adjacent satellite systems. Before 1983 the spacing was established at 4^0 of the equatorial arc, and the smallest earth station antenna for a simultaneous transmit-receive operation allowed by the FCC is 5 m in diameter.

In 1983, the FCC ruled that fixed service communications satellites in the geostationary orbit should be spaced every 2^0 along the equatorial arc instead of 4^0 This closer spacing allows twice as many satellites to occupy the same orbital arc.

2.11.1 Antennas

The earth station antenna is one of the important subsystems of the RF terminal because it provides a means of transmitting the modulated RF carrier to the satellite within the uplink frequency spectrum and receiving the RF carrier from the satellite within the downlink frequency spectrum. The earth station antenna must meet three basic requirements:

The antenna must have a highly directive gain; that is, it must focus its radiated energy into a narrow beam that illuminate the satellite antenna in both the transmit and receive modes, and hence provide the required uplink and downlink carrier power. Also, the antenna radiation pattern must have a low sidelobe level to reduce interference into other satellites and terrestrial systems.

The antenna must have a low noise temperature so that the effective noise temperature of the receive side of the earth station, which is proportional to the antenna temperature, can be kept low I reduce the noise power within the downlink carrier bandwidth.

The antenna must be easily steered so that a tracking system (if required) can be employed to point the antenna beam accurately toward the satellite taking into account the satellite's drift position. This is essential for minimizing antenna-pointing loss.

2.11.2 Antenna Types

The two most popular earth station antennas that meet the above requirements are the paraboloid antenna with a focal point feed and the Cassegrain antenna.

A paraboloid antenna with a focal point feed is shown in Fig 2.17. This type of antenna consists of a reflector, which is a section of a surface formed by rotating a parabola about its axis, and feed whose phase center is located at the focal point of the paraboloid reflector. The size of the antenna is represented by the diameter D of the reflector. The feed is connected to a high power amplifier and low noise amplifier through an orthogonal mode transducer (OMT) which is three port networks.

This type of antenna is easily steered and offers reasonable gain efficiency in the range of 50 to 60%. The disadvantage occurs when the antenna points to the satellite at a high elevation angle. In this case, the feed radiation which spills over the edge of the reflector illuminates the ground whose noise temperature can be as high as 290^0 K and results in a high antenna noise contribution.

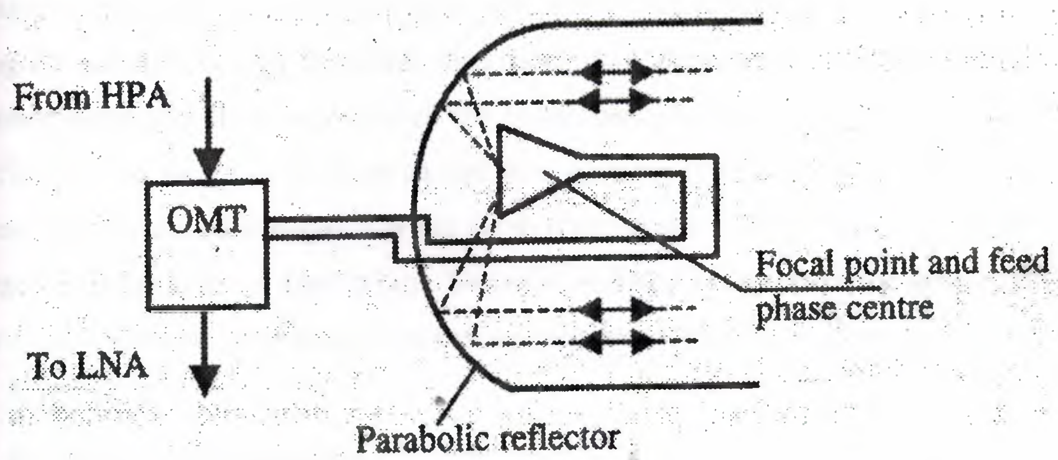


Figure 2.17 A paraboloid antenna with a focal point feed.

A Cassegrain antenna is a dual-reflector antenna, which consists of a paraboloid main reflector, whose focal point is coincident with the virtual focal point of a hyperboloid subreflector Fig 2.18. On the transmit side, the signal energy from the output of the high-power amplifier radiated at the real focal point by the feed and illuminates the convex surface of the subreflector which reflects the signal energy back as if it were incident from a feed whose phase center is located at t common focal point of the main reflector and subreflector. The reflected energy is reflected again the main reflector to form the antenna beam.

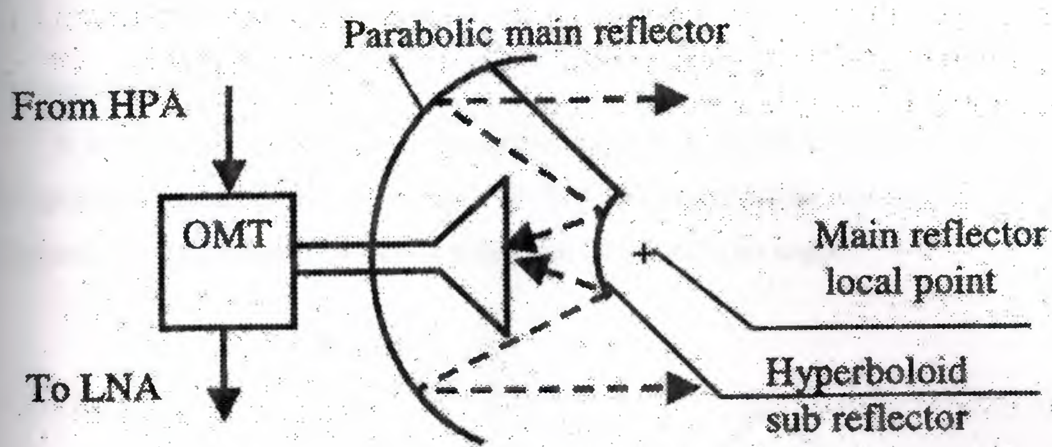


Figure 2.18 A cassegrain antenna.

On the receive side, the signal energy captured by the main reflector is directed toward its focal point. However the sub reflector reflects the signal energy back to its real focal point where the phase center of the feed is located. The feed therefore receives the incoming energy and routes it to the input of the low-noise amplifier through the OMT. A Cassegrain antenna is more expensive than paraboloid antenna because of the addition of the subreflector and the integration of the three antennas. element - the main reflector, subreflector, and feed - to produce an optimum antenna system however, the Cassegrain antenna offers many advantages over the paraboloid antenna: low no temperature, pointing accuracy, and flexibility in feed design. Since the spillover energy from the feed is directed toward the sky whose noise temperature is typically less than 30K.

2.12 Parameters of antenna

2.12.1 Antenna Gain

Gain is perhaps the key performance parameter of an earth station antenna because it directly after the uplink and downlink carrier power. The gain is given by

$$G = \eta \left[\frac{\pi f D}{c} \right]^2$$

Where D - antenna diameter (m).

f - radiation frequency (Hz)

c - speed of light = 2.997925 10 in/5

η - antenna aperture efficiency (=0.95)

2.12.2 Antenna Pointing Loss

A loss in gain can occur if the antenna-pointing vector is not in line with the satellite position vector as shown in Fig 2.19. The antenna pointing loss can be evaluated from the antenna gain pattern, Which is a function of the off-axis angle.

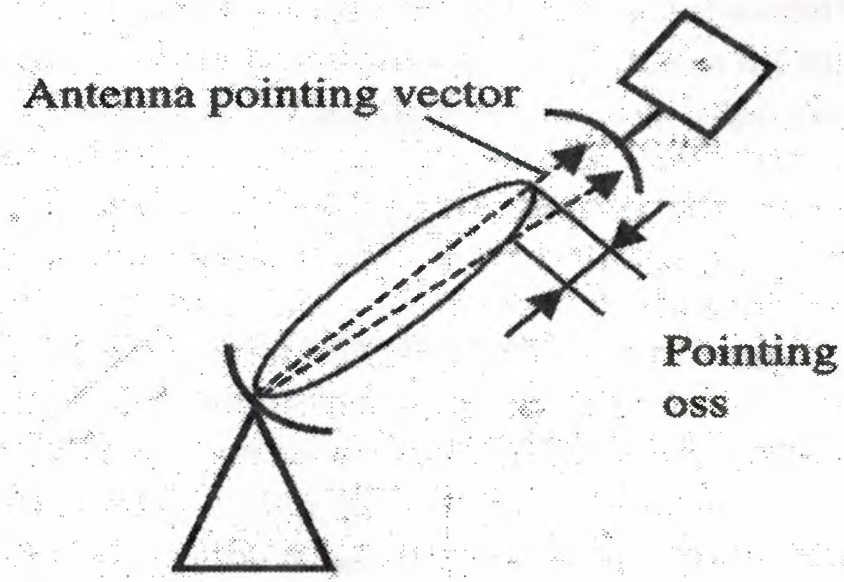


Figure 2.19 Antenna pointing loss.

Because the earth station antenna is subjected to a wind loading effect and the satellite drifts in orbit, an antenna tracking system is necessary for a large diameter antenna to minimize the pointing error. The antenna tracking system is a closed-loop pointing system; that is, the antenna-pointing vector, which is function of the azimuth and elevation angles, is derived from the received signal. One of the commonly used antenna tracking systems for earth stations is a step track which derives the antenna pointing vector from the signal strength of a satellite beacon.

2.12.3 Effective Isotropic Radiated Power

To express the transmitted power of an earth station or a satellite, the effective isotropic radiated power (EIRP) is normally employed. The earth station EIRP is simply the power generated by the high–power (amplifier times the gain of the earth station antenna, taking into account the loss in the transmission line (wave guide) that connects the output of the high power amplifier to the feed of the earth static antenna. If we let P(t) denote the input power at the feed of the antenna and 0(t) the transmit antenna gain, the earth station EIRP is simply

EIRP=P(t).G(t)

For example, consider a 2-kW high-power amplifier and a 20-m Cassegrain antenna whose transmitted gain is 66.82 dB at 14.25GHz..If it is assumed that the loss of the waveguide that conned the high power amplifier to the feed is I dB, then the earth station EIRP in decibel watts is (noting that P (t) decibel-watts is equivalent to 10 log P (t) watts).

EIRP=33+66.82-1 =98.82dBW

2.12.4 Antenna Gain-to-Noise Temperature Ratio

The antenna gain-to-noise temperature ratio G/T is a figure of merit commonly used to indicate the performance of the earth station antenna and the low-noise amplifier in relation to sensitivity ii receiving the downlink.carrier from the satellite. If a piece of waveguide with a 0.53-dB loss is used to (connect the input of the low noise amplifier to the output port of the feed system, the receive antenna gain referred to the input of the low noise amplifier is simply 65 dB. The parameter T is defined as the earth station system noise temperature referred also to the input of the low-noise amplifier. We have discussed the antenna gain previously, therefore in this section we will concentrate on determination of the earth station system noise temperature.

2.13 The high Power Amplifier

One of the most widely used high power amplifiers in earth stations to the traveling wave tube amplifier (TWTA). The traveling wave tube employs the principle of velocity modulation in the form of traveling waves. The RF signal to be amplified travels down a periodic structure called a helix. Electrons emitted from the cathode of the tube are focused into a beam along the axis of the helix by cylendrical megnets and removed at the end by the collecter after delievring their energy to the RF field. The helix slows down the propagation velocity of the RF signal (the velocity of light) to that of the electron beam, which is controlled by the dc voltage at the cathode. Those resultsm in an interaction between the electrical field include by the RF signal and the electrons, which resultd in the transfer of energy from the electron beam to the RF signal causing it to be amplified.

Another type of high-power amplifier used in earth stations is the klystron amplifier, which can provide higher gain and better efficiency than the travelling wave tube amplifier but at a much smaller bandwidth. For low-power amplification are used GaAs FET amplifiers. These are solid state amplifiers and offer much better efficiency than the above two types of amplifiers.

2.14 Upconverter

The upconverter accept the modulated IF carrier and translate its frequency ω_0 to the uplink frequency ω_u by mixing ω_0 with a local oscilator frequency ω_1.

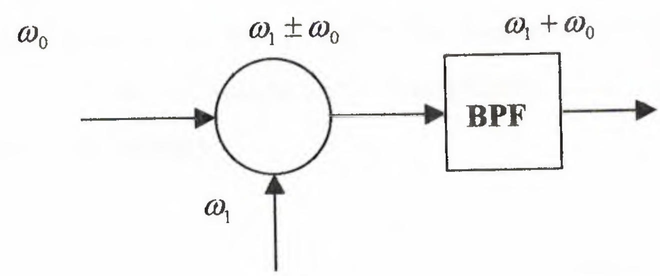


Figure 2.20 upconverter.

The upconversion may be accomplished with the single or double conversion processes.

2.15 Downconverter

The downconverter (DC) recieves the modulated RF carrier from the loe-noise amplifier and translate its radio frequency ω_d in the downlink frequency spectrum of the satellite to the intermediate frequency ω_0. Like upconversion downconversion may be achieved with a single conversion process or with a dual conversion process using mixer.

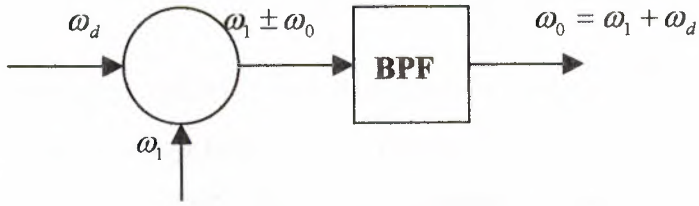


Figure 2.21 downconverter.

2.16 Redundancy configrations

As we have senn in previous sections, except for the antenna all earth stations systems namely, the high-power amplfier, the upconverter, and the downconverter must employ some sort of redundancy to maintain high reliability which is of utmost importance. When the online equipmentin the redundancy configration fails the standby equipment is automatically switched over and becomes the online equipment. The process of detecting critical failure modes and resolving all these failure modes by automatic switchover from the fail to the redundant system is called monitoring and control. Reliabilty is of utmost importance in satellite communications. When a single high-power amplifier is used, transmission will stop upon its failure. Therefore the high-power amplifier in earth stations always employs some part of redundancy configration. The most basic redundancy configration is the 1:1 redundancy.

3. FREQUENCY DIVISION MULTIPLEXING

Frequency division multiplexing (FDM) is the simultaneous transmission of multiple separate signals through a shared medium (such as a wire, optical fiber or light beam) by modulating, at the transmitter, the separate signals into separable frequency bands, and adding those results linearly either before transmission or within the medium. While thus combined, all the signals may be amplified, conducted, translated in frequency and routed toward a destination as a single signal, resulting in economies, which are the motivation for multiplexing. Apparatus at the receiver separates the multiplexed signals by means of frequency passing or rejecting filters, and demodulates the results individually, each in the manner appropriate for the modulation scheme used for that band or group.

Bands are joined to form groups, and groups may then be joined into larger groups; this process may be considered recursively, but such technique is common only in large and sophisticated systems and is not a necessary part of FDM.

The FDMA class of signals includes many variations in the number and bandwidth of carriers transmitted by a given earth station. For example, we might transmit only one carrier per earth station, where the data to all receive terminals is multiplexed on that single carrier. Alternatively, each terminal might transmit separate carriers for each receive earth terminal being addressed. This latter approach has the advantage that it requires the receive earth terminal to demodulate only the data intended for it, but this technique may not have any power or efficiency advantage. Finally, one can provide a separate carrier for each voice channel. This single-channel per carrier (SCPC) system has the advantage that it can be used in a demand-assigned mode and can thereby improve the system efficiency. These SCPC carriers can also be voice- activated such that carrier power is turned on only during time intervals when the voice envelope exceeds a threshold level.

Neither the transmitters nor the receivers need be close to each other; ordinary radio, television, and cable service are examples of FDM. It was once the mainstay of the long distance telephone system. The more recently developed time division multiplexing in its several forms lends itself to the handling of digital data, but the low cost and high quality of available FDM equipment, especially that intended for television signals, make it a reasonable choice for many purposes.

3.1 Frequency Division Multiple Access

With FDMA the bandwidth of the channel is divided among the population of stations. For example, with six stations the frequency range of the channel is divided by six and each station gets its own private frequency. In this way there is no interference between users. Frequency division multiplexing is show below in figure 3.1.

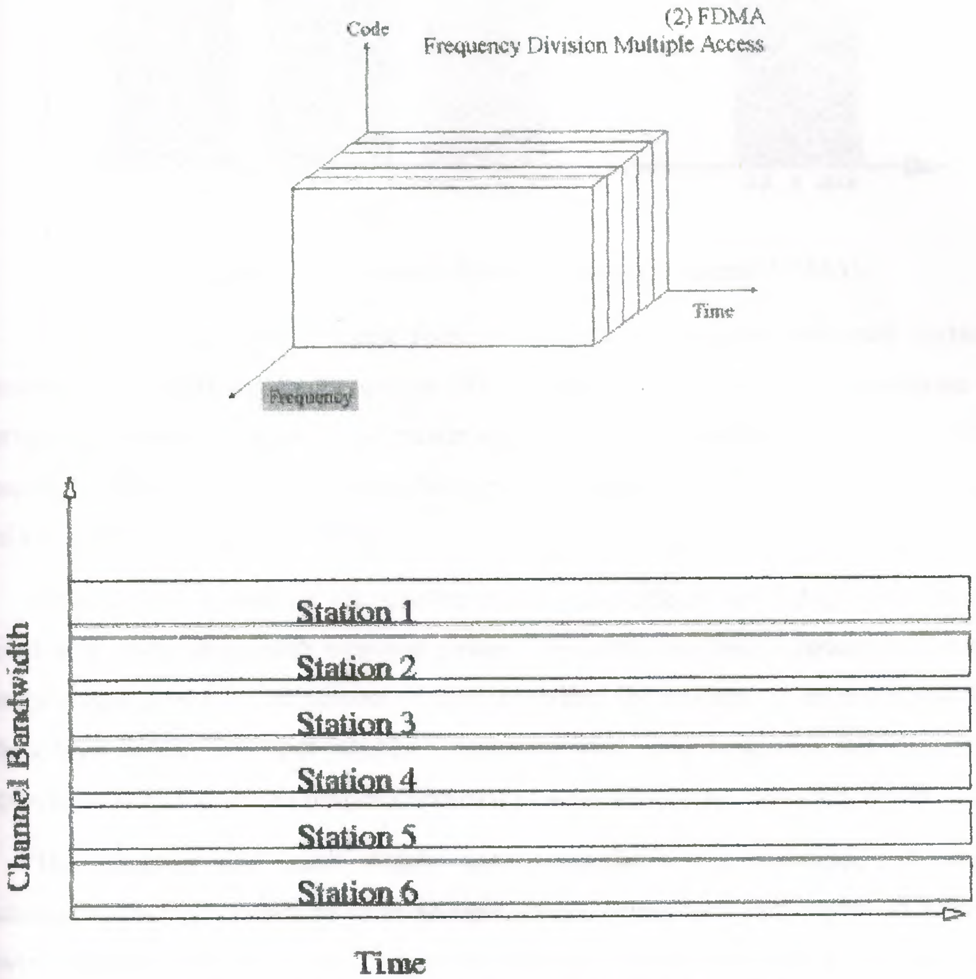


Figure 3.1: Frequency Division Multiple Access

In the receiving station the composite signal is available at the output of the receiver demodulator, which is then fed to band pass filters that are tuned to the center frequencies of the sub carrier oscillators. The outputs from the filters are the demodulated and the original transducer signals are recovered. An other kind of frequency division multiplexing is show below in figure 3.2.

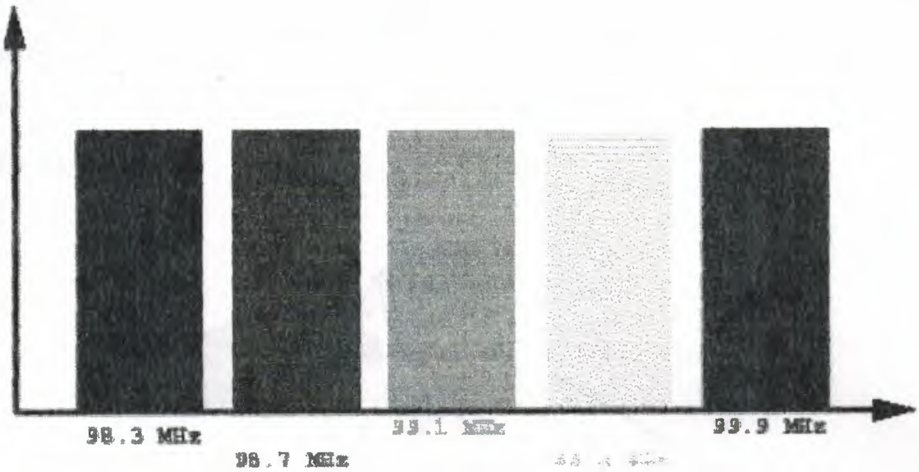


Figure 3.2: Frequency Division Multiple Access (FDMA).

Here we address the simplest form of multiple accesses wherein each carrier is transmitted at a different frequency. In FDMA, each signal is assigned a separate non overlapping frequency channel, and power amplifier inter modulation products are either accepted or minimized by appropriate frequency selection and/or reduction of Input power levels to permit quasi-linear operation.

Attention is focused on the satellite transponder effects since this power is more critical and costly than earth terminal power. Typically, one might reduce the satellite average output power by 50 percent or more to reduce IM products to an acceptable level with a high density of input signals. Oscillators with good long-term stabilization are employed to keep the signals properly centered in non-overlapping frequency bands.

The simplest and most widely used multiple access technique of satellite communications is frequency division multiple access, where each earth station in a satellite network transmits one or more carriers at, different center frequencies to the satellite transponder. Each carrier is assigned a frequency band (Be) with a small guard band (BG) to avoid overlapping between adjacent carriers.

The satellite transponder receives all the carriers in its bandwidth, amplifies them, and retransmits them back to earth. A frequency division multiple access system is shown schematically in figure shown below. In this type of system each carrier can employ either analog modulation, such as frequency modulation, or digital modulation, such as phase-shift keying. A major problem in the operation of FDMA satellite systems is the presence of inter-modulation products in the carrier bandwidth generated by the amplification of multiple carriers by a common TWTA in the satellite transponder that exhibits both amplitude non linearity and phase non linearity. As the number of carriers increases, it becomes necessary to operate the TWTA close to saturation in order to supply the required power per carrier to reduce the effect of downlink thermal noise. Frequency distribution is show below in figure 3.3.

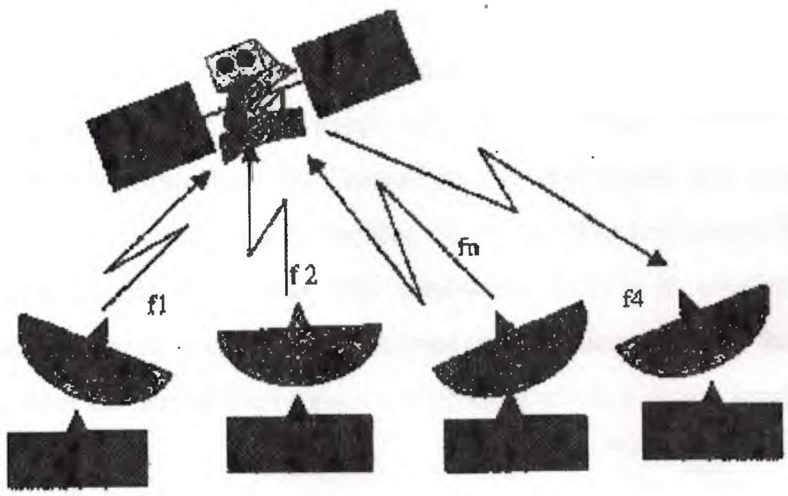


Figure 3.3: Frequency distribution.

But near saturation the input/output amplitude transfer characteristic of the TWTA is highly nonlinear, and consequently the level of inter modulation products is increased and affects the overall performance.

Inter-modulation noise distributed over the entire frequency band. This inter-modulation noise must be included in assessing FDMA performance. In order to do this, however, it is first necessary to derive a somewhat rigorous no linearity model that will analytically account for the inter-modulation terms.

3.2 FDMA Channelization

In wave motion of all kinds, the frequency of the wave is usually given in terms of the number of wave crests that pass a given point in a second. The velocity of the wave and its frequency and wavelength are interrelated. The wavelength (the distance between successive wave crests) is inversely proportional to frequency and directly proportional to velocity. In mathematical terms, this relationship is expressed by the equation V = ë f, where V is velocity, f is frequency, and ë (the Greek letter *lambda*) is wavelength. From this equation any one of the three quantities can be found if the other two are known.

We have found that when dealing with an FDMA system using nonlinear satellite amplifiers, the available satellite power in the downlink must be divided among all carriers. Furthermore, strong carriers tend to suppress weak carriers in the downlink. This means that, when a mixture of both strong and weak carriers are to use the satellite simultaneously, we must ensure that the weaker carriers can maintain a communication link, especially if the mixture is to be transmitted to a relatively small (small g/T) receiving station. One way in which weak carrier suppression can be reduced in FDMA formats is by the use of satellite Channelization. In Channelization, the strong and weak carriers are assigned frequencies so that they can be received in the satellite in separate RF bandwidths. That is. The total available satellite RF bandwidth (BRF) is divided into smaller bandwidths, and the uplink carriers are assigned frequencies so as to he grouped in a bandwidth with other carriers of the (approximate) same satellite power level.

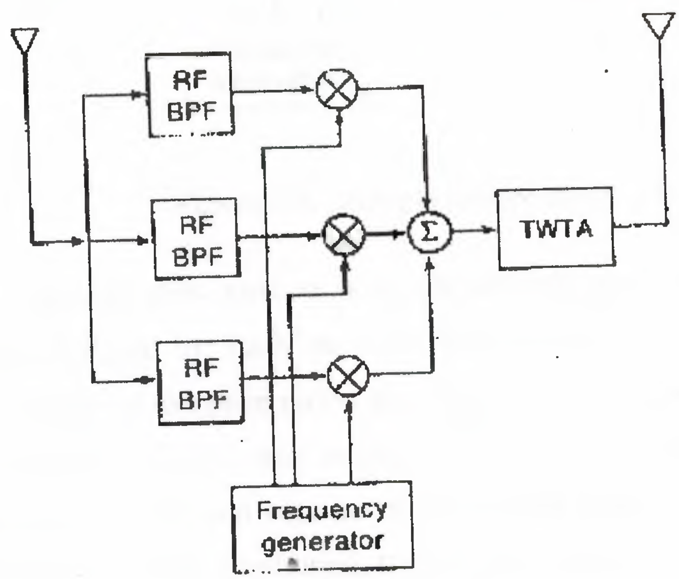


Figure 3.4: Single TWTA

These individual RF bandwidths are called satellite channels, and they can be used in two basic ways. One is to permit each channel to have a separate RF filter and amplifier, but to use only a single power amplifier. The outputs of all channel amplifiers are summed prior to limiting and power amplification. The advantage of the Channelization is that the amplifier gains in each channel can be individually adjusted so that all carriers will have roughly the same power levels when they appear at the amplifier input.

This prevents suppression effects due to strong uplink carriers, although the total number of carriers and the total amount of noise remains the same. In essence, uplink power control is obtained at the satellite instead of at the earth stations.

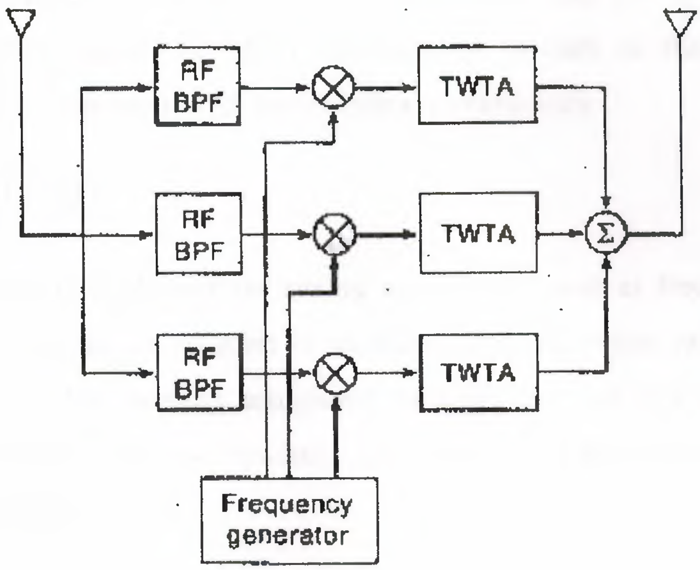


Figure 3.5: Multiple transponders

The second Channelization method is to use separate power amplifiers for each channel (as shown in figure b). Each satellite channel then becomes an independent transponder. Only carriers of the same power are used in the same channel. The power of each amplifier is therefore divided only among the carriers in its own bandwidth. The uplink noise per channel is reduced because of the smaller bandwidths, thus leading to improved CNR for the downlink. In addition, the inter-modulation and power suppression effects are reduced since there are fewer carriers in each transponder. The limit, of course, is when each uplink carrier is assigned its own transponder channel, which is the so-called SCPC (single channel per carrier) format and all nonlinear effects are removed. The advantages of Channelization are achieved, of course, at the expense of a more complex satellite, since the weight of not only the additional power amplifiers and filters must be included but also that of the supporting auxiliary primary power. The advantages in performance of the increased number of independent transponders must be carefully weighed against the additional satellite cost.

The use of increasing numbers of satellite transponders is an obvious trend in modern satellite design. Above figure shows the processing block diagram for the 12- transponder Intelsat satellite. The uplink and downlink RF bandwidth is divided, as shown in above figure b. Each individual transponder has a 36-MHz bandwidth, with each channel center frequency separated by 40 MHz. The 12 transponders therefore utilize the entire 500-MHz RF bandwidth. Satellites may employ additional channels by making use of antenna beam separation or antenna polarization separation in the uplink and the downlink. Recall that this allows frequency reuse, in which two separate carriers as the same uplink and downlink frequencies can use the RF bandwidth simultaneously.

3.3 FDM-FM-FDMA

Since the inception of satellites analog modulation, such as frequency modulation, has been used for carrier modulation in satellite communications using FDMA; it will probably be employed in existing equipment for years to come despite advances in the development of digital satellite systems. There are two main FDMA techniques in operation today as in figure 3.6.

Multi channel -per-carrier transmission, where the transmitting earth station frequency division-multiplexes several single sideband suppressed carrier telephone channels into one carrier base band assembly, which frequency-modulates a RF carrier and is transmitted to a FDMA satellite transponder, This type of operation is referred to as FDM-FM-FDMA. Single-channel-per-carrier transmission, where each telephone channels independently modulates a separate RF carrier and is transmitted to a FDMA satellite transponder. The modulation can be analog, such as FM, or digital, such as PSK.

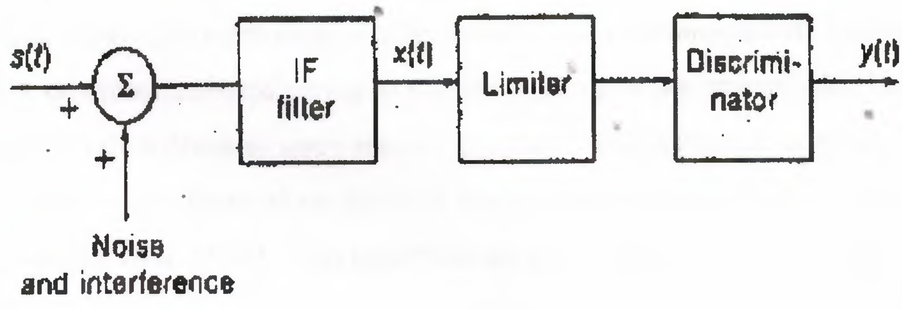


Figure 3.6: FDMA block Diagram

3.4 Single Channel Per Carrier

Unlike FDM-FM-FDMA systems, which serve large-capacity links, single-channel-per-carrier systems are more suitable for applications that require only a few channels per link. In these systems each telephone channel independently modulates a separate RF carrier and is transmitted to the satellite transponder on a FDMA basis. A 36-MHz transponder can carry as many as 800 voice channels or more. If the carrier modulation is digital, the performance is measured in terms of the average probability of bit error.

For analog carrier modulation, FM is employed.

1. FM-SCPC systems are the most commonly used systems because of their attractiveness in terms of cost and simplicity.
2. The design of a FM-SCPC link can be expressed in terms of the signal-to-noise ratio at the FM demodulator output, as in FDM-FM-FDMA.

3.5 FM-FDMA Television

Television broadcasting via satellite in the United States is among the most highly developed in the world. TV programming is distributed on the fixed satellite service portion of the C and Ku bands. In 1983 the Federal Communications Commission approved a frequency band for domestic direct broadcast satellite services (DBS) to provide direct-to-home television: an uplink frequency of 173 to 17.8 GHz and a downlink frequency of 12.2 to 12.7 GHz.

The DBS downlink portion of the Ku band is adjacent to the 11.7-to 12.2-GHz downlink frequency of the FSS portion of the Ku band. High-power direct broadcast satellites have many characteristics similar to those of communications satellites except that the DBS downlink radiated power is about 10 dB more per transponder.The powerful television signal lets individual users receive programs with antennas as small as 0.7 m in diameter, which can be mounted on the roof of an average house. The nominal carrier-to-noise ratio is about 14 to 15 dB when used with an earth station 0 T of 10 dB/K.

3.6 Frequency-Division Multiplex Telemetry System

Telemetry, in engineering, the use of electrical or electronic equipment for detecting, collecting, and processing physical data of one form or another at a given site, and then relaying this data to a receiving station at another site where the data can be recorded and analysed. One obvious use of telemetry, for example, is in the measuring, relaying, and recording of physical conditions encountered or produced by high-speed aircraft, rockets, and spacecraft. Such data might include air temperatures, wind speeds, or radiation intensities in outer space.

The matter of distance in telemetry is relative, however, because such systems may also be employed for obtaining data from sites that are near to the receiving instruments but that are difficult, impossible, or dangerous for human observers to encounter. For example, biological sensors of various kinds may be used within the human body to transmit information on medical conditions to detectors placed outside the body. Other examples include the use of telemetry for running tests of engines, for detecting flaws or changing conditions in industrial systems, or for obtaining data from dangerously radioactive sites. Meteorologists make use of a wide range of telemetric devices to obtain information from the upper atmosphere for use in making their weather forecasts. Such meteorological uses were, in fact, the first to which the techniques of radio telemetry were applied.

In any telemetric system, the equipment used must be able to make a measurement of a physical quantity, produce a signal that can be modified in some way to carry the measured data, and relay this encoded signal over some form of transmission link. The receiving equipment must then be able to decode the signal and to display it in some format for analysis and, probably, for recording. Usually more than one signal must be sent over the transmission link at any one time, in which case some form of multiplexing must be used. This can be done by employing different frequency bands for the measurement of different quantities or by splitting up the signal into discrete time intervals to which the quantities to be measured are assigned. The coding techniques used are commonly digital; the use of pulse-code modulation, by which continuous waves are transformed into a binary-code signal, has been enhanced in recent decades by the advances made in the digital computer field and in microelectronics.

The basic operation of a frequency-division multiplex telemetry system is illustrated in the figure below. The measurement signals from transducers modulate "sub carrier" oscillators tuned to different frequencies. The output voltages from the sub carrier oscillators are then summed linearly. The composite signal is used to modulate the downlink transmitter. All types of modulation can be used for both the sub carrier oscillators and the prime carrier. The transmission system for frequency division multiplex systems is designated by first giving the modulation for the sub carriers and then the prime carrier. Thus FM/AM would indicate a frequency-division multiplex system in which the sub carriers are frequency modulated and the prime carrier is amplitude modulated by the composite sub carrier signal.

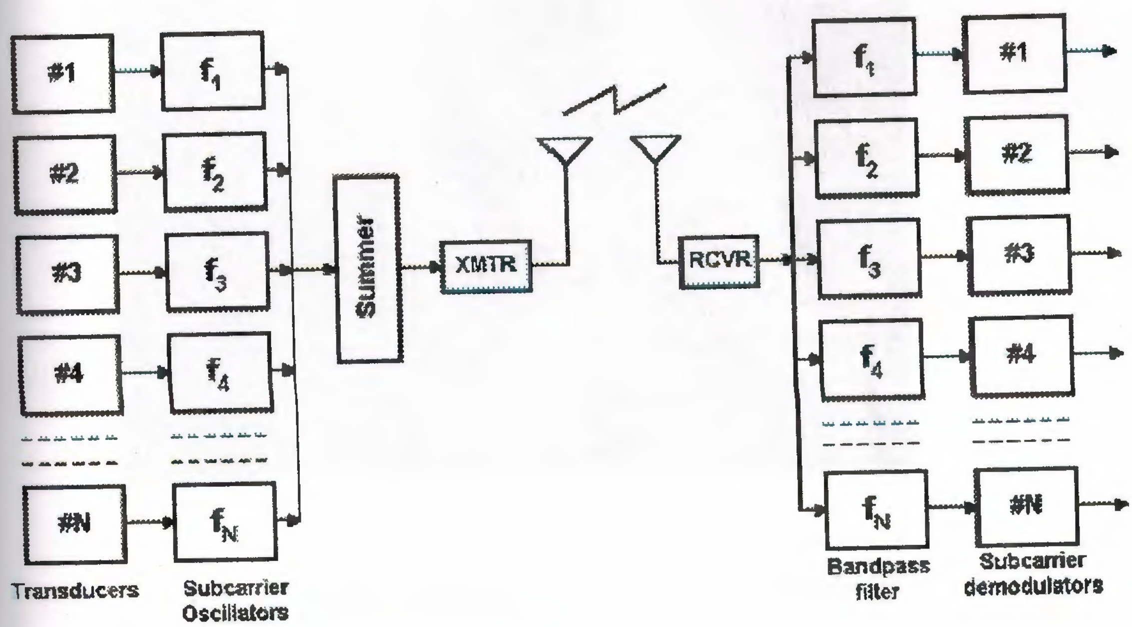


Figure 3.7: Telemetry system

The most commonly used frequency-division multiplex system is FM/FM. Standards were established in the U.S: for FM/FM systems shortly after World War II and they later became known as the Inter-Range Instrumentation Group (IRIG) standards. The FM/FM standard established the center frequency for sub carriers and how much bandwidth each sub carrier can occupy. The table below shows the IRIG FM/FM sub carrier channel assignments.

The most noteworthy variants frequency-division multiplex systems used in addition to FM/FM are FM/PM and SS/FM (for Single-Sideband/FM). An FM/PM system was used in the early days of the U.S. space program under the name of Micro lock, because phase-locked receivers were used to acquire and detect the main carrier. However, the amount of information transmitted in these early systems was very limited.

By using single-sideband sub carrier signals much more data could be compressed in a narrow bandwidth and the SS/FM systems were used in early Saturn 1 flights. The figure below shows about seven seconds of FM/FM telemetry from an Atlas rocket launched from Cape Canaveral in the early 60's.

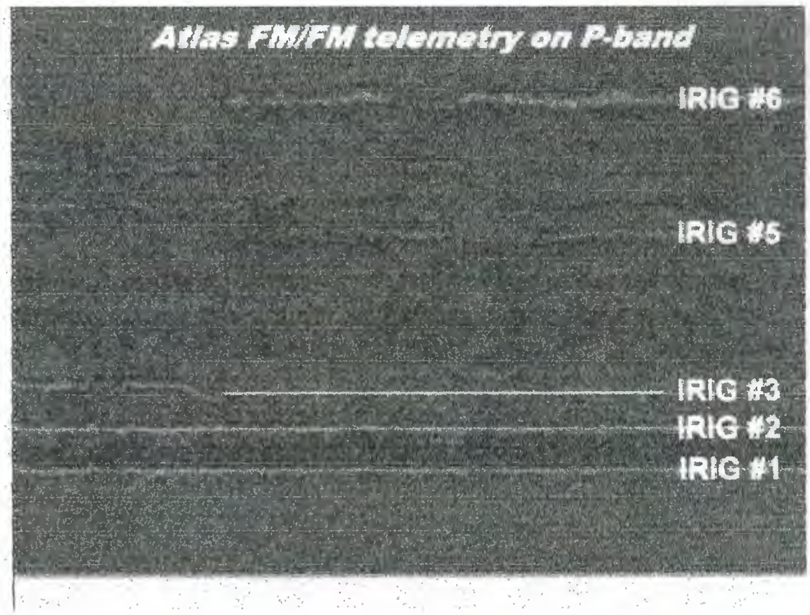


Figure 3.8: Seven seconds of FM/FM telemetry

The carrier frequency was in the P-band region, i.e. 215-260 MHz. The figure shows five sub carriers and their behavior at the time of booster engine separation. We can easily spot IRIG sub carriers 1, 2, 3, 5 and 6. It seems that IRIG 3 disappears at 1.9 seconds into the recording. By clicking on the spectrogram you can hear a sound file with these signals.

Normally, the outputs from the sub carrier demodulators in the receiving station were applied to banks of meters or to multi-channel strip-chart recorders. These recorders were either of the type with ink pens writing on moving paper, ultra-violet light beams drawing traces on UV-sensitive paper or so-called Sanborn recorders which used heat pens (hot wires which made black lines on special paper). I have myself been crawling on the floor at the Swedish rocket base range analyzing strip-chart recordings from a sounding rocket as they rolled out of the recorders in real time as in figure 3.9.

In the early days of telemetry Analogue Time-Division Multiplex systems were used in conjunction with frequency division multiplex systems. A very common type of time-division multiplex was the Pulse-amplitude modulation (PAM) system. The output of the commutator in such a system is a series of pulses, the amplitudes of which correspond to the sampled values of the input channels from the transducers. At the receiving station the process is reversed. The demodulator output from the receiver is passed through a de-commutator that produces outputs corresponding to the sampled measurement.

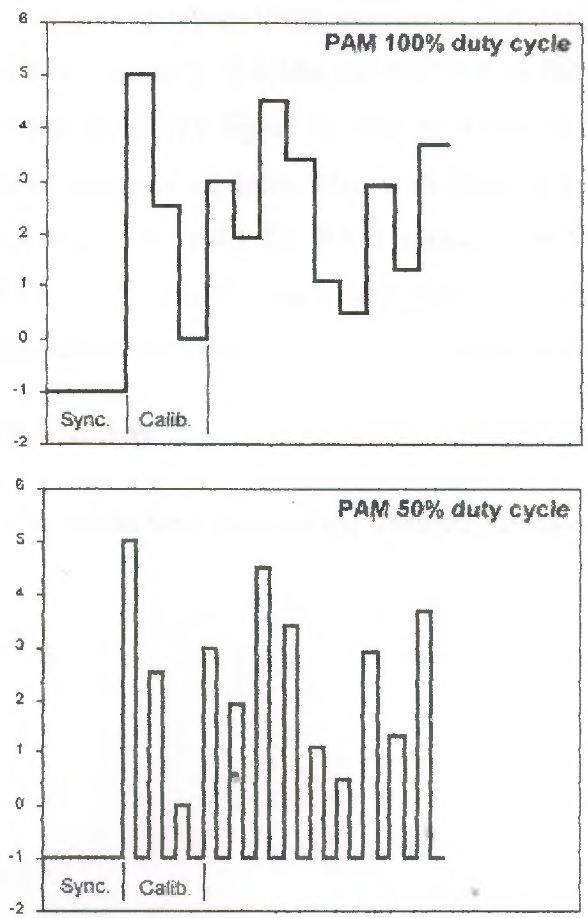


Figure 3.9: Pulse-amplitude waveform

The pulse-amplitude waveform may take several forms as can be seen below. The principle difference lies in the duty cycle of the pulse. In the figure 3.9 on the right the top diagram shows a 100% duty cycle system while the lower diagram shows a 50% duty cycle system signals.

The length of time necessary to sample all channels is called the "frame time". In order to identify the channel corresponding to a sample at the receiving station, it is necessary to provide frame synchronization. Several different methods can be used to designate the beginning of a frame. The method illustrated on the right consists of forcing several consecutive channels to a level below the minimum allowable data value. Since drifts and non-linearities cause errors, it is also common practice to transmit calibration pulses.

In addition to the primary time- and frequency-division multiplex techniques described here, there are cases in which these techniques are combined. One of the most common combinations has been that of PAM and FM/FM to form PAM/FM/FM. In this case a PAM time-division multiplex signal is used to modulate an FM/FM sub carrier. Several other sub carriers may also be modulated with separate PAM signals. Usually the higher frequency sub carriers are used for PAM signals and the lower frequency sub carriers are used for direct measurements. As an example, the PAM sampling rate for IRIG channel 5, with a sub carrier center frequency at 1300 Hz is 10 samples per second.

3.6.1 Example of PAM/FM/AM

The picture 3.10 below shows a piece of the telemetry transmission from Explorer-7.

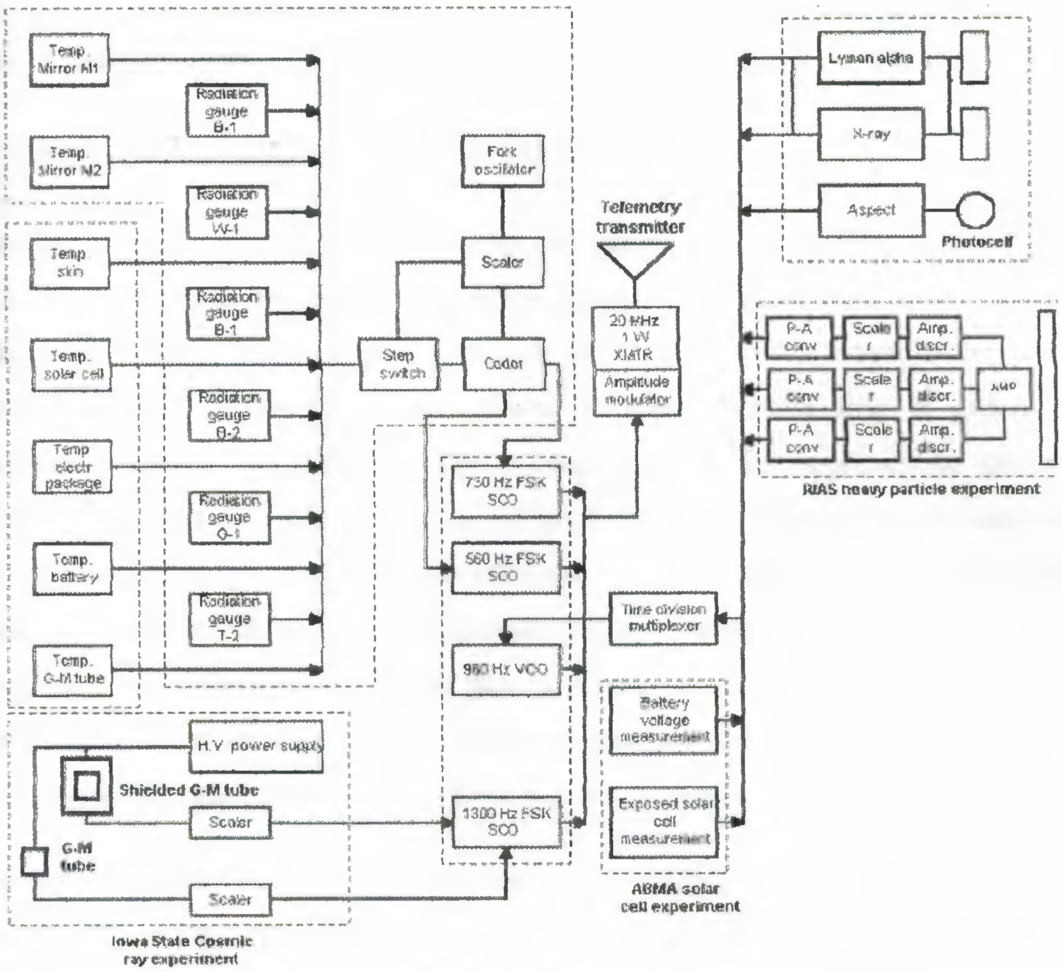


Figure 3.11: Example of telemetry system

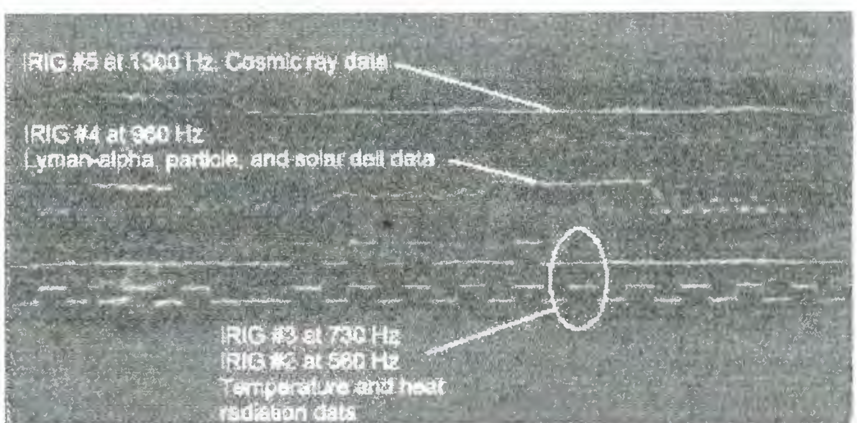


Figure 3.12: Telemetry transmission

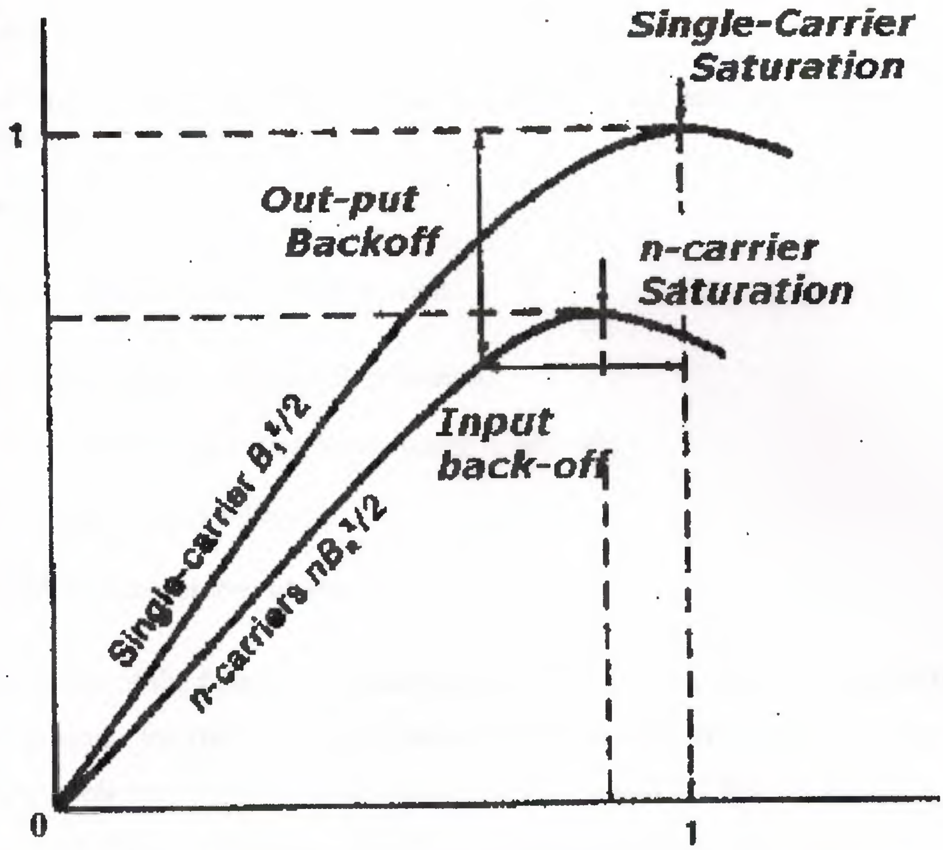
In real-life applications many sensors were multiplexed on each sub carrier. Explorer-7is a good example of this system. This spacecraft was also called S-46 and it used a PAM/FM/AM system on 20 MHz and PAM/FM/PM system on 108 MHz.

3.7 FDM-FM-FDMA Vs SSB-AM-FDMA

System of communication using electromagnetic waves propagated through space. Waves are used in wireless telegraphy, telephone transmission, television, radar, navigation systems, and space communication They are also used in radio broadcasting; the term "radio" is therefore most popularly applied to sound broadcasting in general. The transponder capacity in FDM-FM-FDMA operations can be improved by the use of syllabic compounders. The traditional use of syllabic compounders has been to improve the quality of signal transmission over poor channels. A compounded consists of a compressor at the transmit side of the satellite channel and an expander at the receive side. The compressor is a variable-gain amplifier that gives more gain to weak signals than to strong signals. This results in an improved overall signal-to noise ratio because the low-level speech signals are increased in power above the channel noise.

On the receive side, the expander restores the signals level by attenuating the low-level speech signals. During pauses in the speech signal, the expander, and hence giving further improvement in the overall subjective signal-to-noise ratio reduce channel noise. A 36-MHz transponder can accommodate a single FDM-FM-FDMA carrier of 1100 uncompounded channels. On compounding the channels. The capacity is increased to about 2100 channels. With over deviation beyond its allocated bandwidth (with no loss in the quality of the channels), such a transponder can carry about 2900 channels.

Graph 3.1: FDM-FM-FDMA Vs SSB-AM-FDMA



Recent use of solid-state power amplifiers with sufficiently linear characteristics to replace nonlinear TWTAs allows the use of compounded single-sideband-amplitude modulation-frequency division multiple access (SSB-AM-FDMA) to achieve 6000 channels per transponder of 36-MHz bandwidth for a single carrier.

Besides the high capacity, SSB-AM-FDMA offers another major advantage over FDM-FM-FDMA from a multiple access point of view. The capacity of a satellite transponder using SSB-AM-FDMA is not decreased by multiple accesses. Unlike FDM-FM-FDMA. Also, the capacity of small FDM-FM-FDMA carriers cannot be increased by over deviation, because of the cross talks among the carrier. A transponders carrying 6000 SSB-AM-FDMA channels can be accessed, say by 4 earth stations with 1500 channels, each with no loss in capacity. On the other hand a four-carrier compounded FDM-FM-FDMA transponder can carry about 1500 channels, therefore the high power amplifier in earth stations always implies some sort of redundancy configuration. The most basic redundancy configuration is the 1:1 redundancy.

3.7.1 Advantages

1. Simple algorithmically and from a hardware standpoint.
2. Fairly efficient when the number stations is small and the traffic is uniformly constant.

3.7.2 Disadvantages

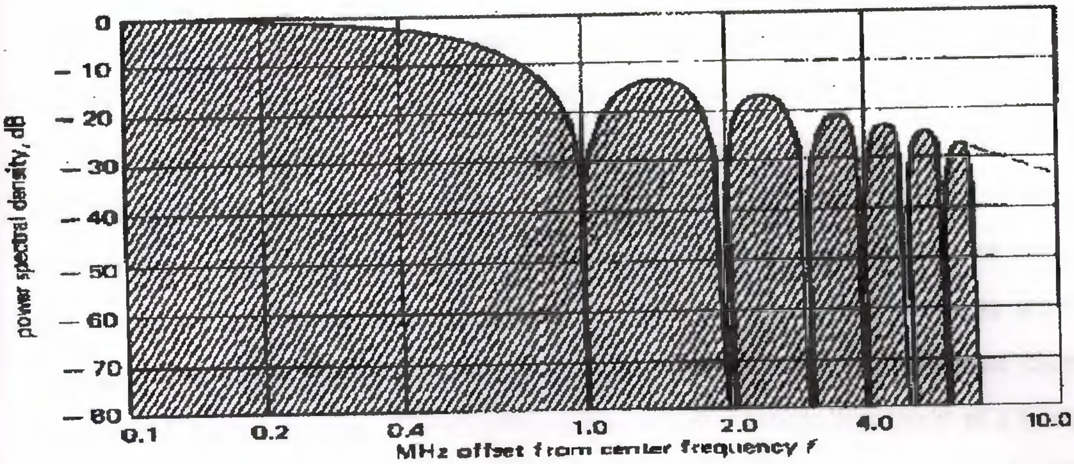
Not conducive to varying station population.

1. If traffic is bursty, bandwidth is wasted.
2. Interfrequency protection bands waste bandwidth.
3. No broadcast capability.

3.8 FDMA Channel Formats

The format of the frequency channel utilized for FDMA depends on signal distortion, adjacent channel interference, and inter-modulation effects caused by the satellite transponder nonlmearities. Following Figure shows a simplified FDMA format for a single channel of a satellite transponder. Each FDMA carrier can either carry a multiplexed set of user data streams, or it can carry only a single user's bit stream as in the SCPC system is described.The carriers can either be destination oriented or a single carrier can carry data destined for several receive earth stations. Guard bands must be used between adjacent frequency channels to minimize adjacent channel interference and these, of course, reduce the frequency utilization efficiency of the transponder channel. The required size of the guard band depends in part on the residual sidebands in each transmitted signal. Following figure shows the power spectral density of a QPSK signal at IM symbol/sec (2M bps).

Graph 3.2: Power spectrum of QPSK



Transmission filters can be employed to cut off the signal spectrum at IF bandwidths between 1 and 2 MHz. The smaller bandwidths must utilize some form of equalization. However, these sidebands can build back up when the signal is fed through a non-linearity and envelope fluctuations produced by filtering are reduced. The guard band between adjacent frequencies must also account for the frequency drifts of the oscillators controlling the signal center frequencies at the satellite and earth station frequency translators. Doppler shirts of satellites that are not perfectly synchronized can also be significant for very low data rate transmissions. Satellite beacons used for antenna tracking or pilot signals can be used to reduce this frequency uncertainty if the beacon frequency is coherently related to the translation frequency.

4 TIME DIVISION MULTIPLE ACCESS

Time division multiple access is a multiple access protocol in which many earth station in satellite communications for transmission via each satellite transponder on a time division basis. Al; earth stations operating on the same transponder are allowed to transmit traffic bursts in a periodic time frame-the TDMA frame. Over the length of the burst, each earth station has the entire transponder bandwidth available to it for transmission. Transmit the timing of the bursts is carefully synchronized so that all the bursts arriving at the satellite transponder from a community of earth stations in the network are closely spaced in time but do not overlap. The satellite transponder receives one burst at a time, amplifies it, and retransmits it back to earth. Thus every earth station in the satellite beam served by the transponder can receive the entire burst stream and extract the bursts intended for it. A simplified diagram of a TDMA operation is shown in Fig 4.1.

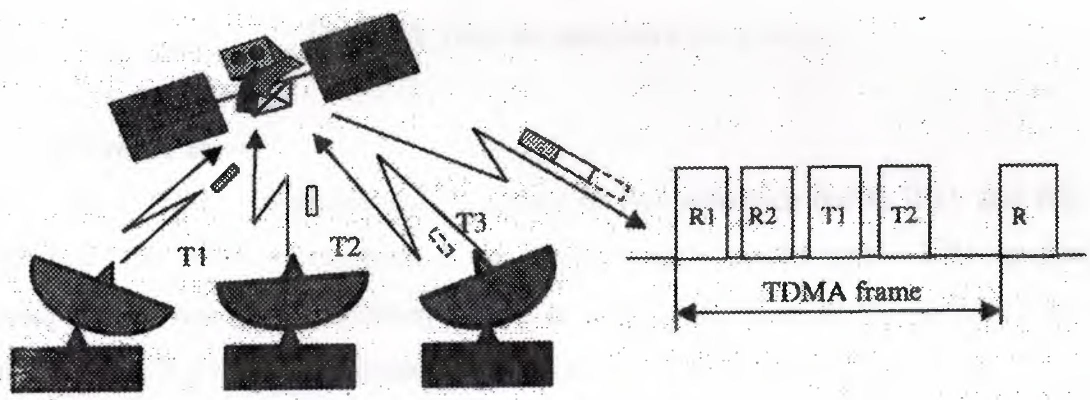


Figure 4.1 TDMA operation.

4.1 TDMA frame structure

In a TDMA network each earth station periodically transmits one or more bursts to the satellite. The input signal to the satellite transponder carrying TDMA traffic thus consists of a set of bursts originating from a of earth stations. This set of bursts is referred as a TDMA frame and is illustrated in fig. 4.2. It consists of two reference bursts RB1 and RB2, traffic bursts, and the guard time between bursts. The TDMA frame is the period between RB1 reference bursts.

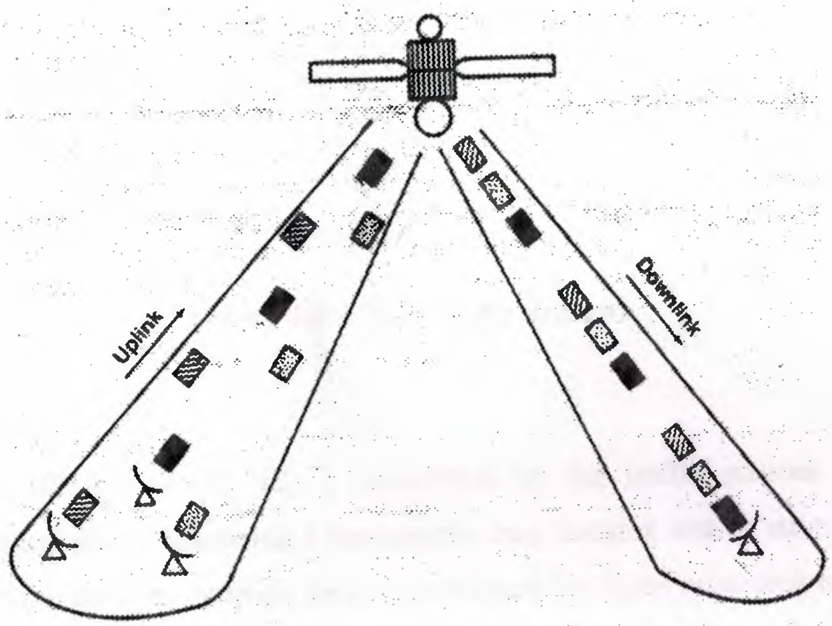


Figure 4.2 Time division multiple access.

4.1.1 Reference Burst

Each TDMA frame normally consists of two reference bursts RB1 and RB2 for reliability. The primary reference burst (PRB), which can be either RB1 or RB2, is transmitted by one of the stations, in the network designated as the primary reference station (PRS). A secondary reference burst (S RB), which also can be either RB1 (if PRB = RB2) or RB2 (if PRB = RB1), is transmitted by a secondary reference station (SRS) which allows automatic switchover in the event of primary reference station failure to provide undisrupted service for the TDMA network. The reference bursts carry no traffic information and are used to provide timing reference for all the stations accessing a particular satellite transponder. This allows satisfactory interleaving of bursts within a TDMA frame. The TDMA traffic stations take their timing reference from the primary reference burst or from the secondary reference burst when there is a failure of the primary reference station.

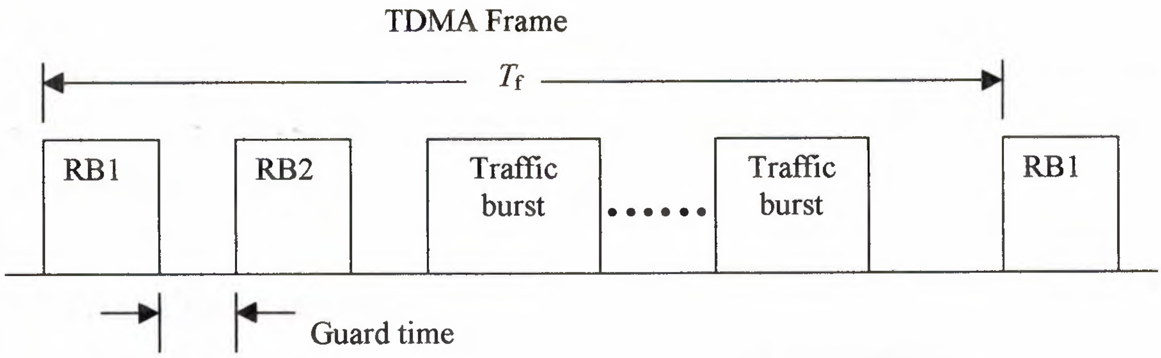


Figure 4.3 TDMA frame structure.

4.1.2 Traffic Burst

The traffic bursts (Tl, T2,...) transmitted by the traffic stations carry digital information. Each station accessing a transponder may transmit one or more traffic bursts per TDMA frame and may position them anywhere in the frame according to a burst time plan that coordinates traffic between stations. The length of the traffic burst depends on the amount of information it carries and can be changed if required. The location of the traffic bursts in a frame is referenced to the time of occurrence of the primary reference burst (RI). By detecting the primary reference burst, a traffic station can locate and extract the traffic bursts or portions of traffic bursts intended to it. Also, it can derive the transmit timing of its bursts precisely, so that they arrive at the satellite transponder within their allocated positions in the TDMA frame and avoid overlapping with bursts from other stations.

4.1.3 Guard Time

A short guard time is required between bursts originating from several stations that access a common transponder to ensure that the bursts never overlap when they arrive at the transponder. The guard time must be long enough to allow differences in transmit timing accuracy and in the range rate variation of the satellite. The guard time is normally equal to the time interval used to detect the receive timing pulse marking the start of a receive TDMA frame at a station. There is no transmission of information during the guard time.

The TDMA frame length is normally selected to be in the range $0.75 \leq T_t \leq 20$ ms for voice service. It is usually a multiple of 0.125 ms, which is the sampling period of PCM

(8000-Hz sampling rate). The frame length is chosen at the outset and remains constant for a TDMA system. However, in the event that a new service requires a change in frame length, it may be altered by redefining the number of bits per frame and storing this count in the network memory.

4.2 TDMA burst structure

In general the structure of the reference burst and the traffic burst are as shown schematically in Fig. 4.3. In the traffic burst, information bits are preceded by a group of bits referred to as a preamble that is used to synchronize the burst and to carry management and control information. The reference burst contains only the preamble, that is, no traffic data. Normally the preamble consists of three contiguous parts: the carrier and clock recovery sequence (CCR), the unique word (UW), and the signaling channel.

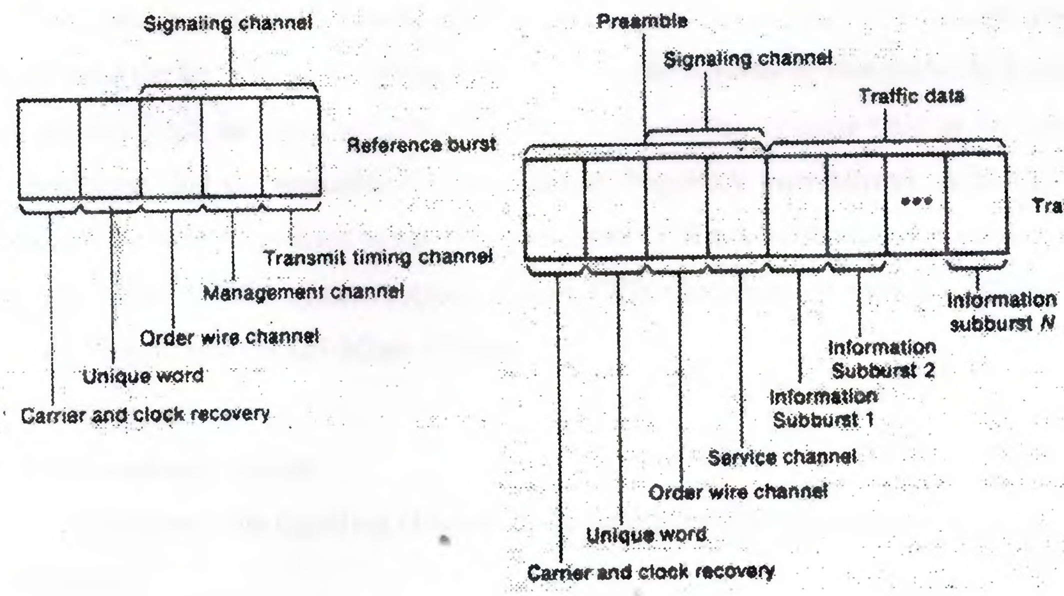


Figure 4.4 TDMA burst structure.

4.2.1 Burst Time Plan

As discussed before, in a TDMA network a traffic station transmits its bursts on time to their allocated positions in the frame at the satellite transponder according to a transmit

Burst time plan and receives bursts in the frame returned by the satellite transponder according to a receive burst time plan. The burst time plan is thus a map that indicates the position and length of bursts in the frame and also the position and length of information sub bursts within a burst. Since bursts and sub bursts carry traffic (voice, data, video) between stations, the burst time plan is simply the traffic assignment within a frame. If the total traffic of a TDMA network exceeds the capacity of one transponder, the network has to operate with more than one transponder. This means that a traffic station might transmit bursts to more than one transponder and might be required to receive bursts from more than one transponder (transponder hopping). In such a multiple-transponder operation, the burst time plan is the assignment of traffic to transponders and time ordering of the assigned traffic within a frame.

4.2.2 Carrier and Clock Recovery Sequence

Each burst begins with a sequence of bits or symbols (for modulation such as QPSK) which enable the earth station demodulator to recover the carrier phase and regenerate the bit or symbol timing clock for data demodulation. Normally the length of the carrier and clock recovery sequence depends on the carrier-to-noise ratio at the input of the demodulator and the acquisition range (carrier frequency uncertainty). A carrier-to-noise ratio and a small acquisition range require a short CCR sequence and vice versa. Typically, a high-bit rate TDMA system requires a long CCR sequence, for example, 300 to 400 bits (150-200 symbols) for 120-Mbps TDMA.

4.2.3 Signaling Channel

In general the signaling channel of the reference burst consists of the following subbursts:

1. An order wire channel carrying voice (telephone), and data (teletype) traffic via which instructions are passed to and from earth stations Order wire is a term used in manual telephone switching to describe a circuit on which operators and maintenance personnel can talk to one another. Operators use the order wire for placing calls.
2. A management channel which is sent by the reference stations to all traffic stations

carrying frame management instructions such as burst time plan changes. The burst time plan describes the coordination of traffic between stations. It identifies the boundaries of the time slots of the frame allocated to the stations, that is, burst positions. It also identifies the position, length, and source or destination stations corresponding to subbursts in the bursts. This channel also carries monitoring and control messages to the traffic stations when the reference station wants to obtain a status report (monitoring) and/or to control the switchover of subsystems at the traffic stations remotely.

3. A transmit timing channel carrying acquisition and synchronization information to the traffic stations which enables them to adjust their transmit burst timing so that transmitted bursts arrive at the satellite transponder within the correct time slots in the TDMA frame. It also carries the status codes which allow the traffic stations to identify the primary reference burst and the secondary reference burst from RB1 and RB2 as shown in Fig 4.3.

The signaling channel of the traffic burst consists of the following subbursts:

1. An order wire channel, which is the same as the reference burst order wire channel.
2. A service channel carrying the traffic Station's status to the reference station, or other information such as the high bit error rate and unique word loss alarms to other traffic stations.

Besides these subbursts in the preamble, both reference and traffic bursts can carry additional subbursts containing the frame identification number (for frame management purposes), station identification number, and type of transmitting bursts (primary reference burst, secondary reference burst, traffic burst). Different types of unique words can be employed to provide burst identification.

4.2.4 Traffic Data

Traffic information is carried by the traffic burst immediately following the preamble. The length of a traffic subburst depends primarily on the type of services and the total number of channels required for each service being supported in the burst. This portion contains information from the calling user being communicated to the called user, whether it is voice, data, video, or facsimile signals. The information for each channel is transmitted as a continuous subburst. The size of each subburst may be selected to be any number of bits to specifically accommodate the actual speed of the voice, data, video, or facsimile signal. For example, one PCM voice channel is equivalent to 64 kbps; if the frame length $T_f = 2$ ms, the resulting subburst of one PCM voice channel is 128 bits long. Each station in the TDMA network normally can transmit many traffic bursts containing different numbers of subbursts per frame and is also capable of receiving many traffic bursts or subbursts per frame.

4.3 TDMA Frame efficiency

The TDMA frame efficiency depends on the percentage of the frame length T_f allocated to traffic data. The higher this percentage, the higher the system's efficiency. In order to achieve this goal, the overhead portion of the frame (e.g., guard times and preambles) has to be lowered, but not to the point of making the design of the system difficult. The carrier and clock recovery sequence must be long enough to provide enough time for stable acquisition of the carrier and to minimize the effect of interburst interference (the tail of the receding burst interfering with the head of the succeeding burst, hence degrading the carrier-to-noise ratio of the latter) caused by a finite filter response in the demodulator. Furthermore, the guard time between bursts must be long enough to allow synchronization tolerance due to the uncertainty of the satellite position and the method of frame synchronization employed. Therefore, trade-offs between TDMA efficiency and system implementation must be carefully considered in any TDMA design.

The TDMA frame efficiency η is usually defined as

$$\eta = 1 - \frac{T_x}{T_f} \tag{4.4}$$

where T_x is the overhead portion of the frame. If there are n bursts in a frame, then T_x can be expressed as

$$T_x = nT_g + \sum_{i=0}^{n} T_{p,i} \tag{4.5}$$

where T_g = guard time between bursts and $T_{p,i}$ = preamble of burst i. It is obvious that the frame efficiency can be increased without lowering the overhead simply by increasing the frame length. But this in turn increases the amount of memory needed to store the incoming terrestrial data at a continuous rate for one frame, to transmit the data at a much higher burst bit rate to the satellite, and to store the receive traffic bursts and convert them to lower continuous outgoing terrestrial data. Furthermore, the frame length has to be kept small compared to the maximum satellite roundtrip delay of about 274ms (5^0 elevation angle) to avoid adding a significant delay to the transmission of voice traffic. For voice traffic the frame length is normally selected to be less than 20 ms.

As an example, consider a TDMA system with frame and burst structures shown in Figs. 4.3 and 4.4, respectively. Calculation of the frame efficiency is based on the following parameters:

1 The TDMA frame length is 15 ms.
2 The TDMA burst bit rate is 90 Mbps.
3 Each of the 10 stations transmits 2 traffic bursts for a total of 20 traffic bursts in the frame plus 2 reference bursts.
4 The length of the carrier and clock recovery.sequence is *352* bits.
5 The length of the unique word is 48 bits.
6 The order wire channel has *510* bits.
7 The management channel has 256 bits.
8 The transmit timing channel has 320 bits.
9 The service channel has 24 bits.
10 The guard time is assumed to be 64 bits.

From the above assumptions, we have

Number of bits in the reference burst preamble: 1486
Number of bits in the traffic burst preamble: 934
Total number of overhead bits: 23,060
Total number of bits in a frame (15 ms $\times$ 90 Mbps): 1.35×10^6
Frame efficiency: 98.29%

Assume that all the traffic data is PCM-encoded voice. Each voice channel data rate is 64 kbps and each channel is carried by a subburst in the traffic burst. The number of bits in a 15-ms frame for a voice subburst is 64 kbps x 15 ms = 960. The maximum number of PCM voice channels carried in a frame is $0.9829 \times 1.35 \times 10^6 / 960 \approx 1382$.

4.4 TDMA Super frame structure

The two most critical functions in a TDMA network are control of the burst position in the frame and coordination of the traffic between stations in such a way that any rearrangement of the position and length of bursts does not cause service disruption or burst overlapping. Control of the position of bursts may be carried out by the reference station using the transmit timing channel, while coordination of traffic is achieved through the management channel of the reference burst.

To provide control and coordination, the reference station has to address all the traffic stations in the network. If there are N stations to be addressed in the network there will be N messages in the transmit timing channel and N messages in the management channel of the reference burst. Furthermore, to provide almost error-free communication for these critical control and coordination messages, some form of coding is normally employed. The most commonly used coding for these channels is the 8:1 redundancy coding algorithm where an information bit is repeated eight times according to a predetermined pattern and then decoded using majority decision logic at the receive end. This effectively increases the time slot allocated to each message eight times and further reduces the frame efficiency. The same reasoning applies to the service channel of the traffic bursts.

In order to reduce the length of the preamble of the reference bursts and the traffic bursts, the reference station can send one message to one station per frame instead of N messages to N stations per frame. To address N stations in the network, the process takes N frames. For example, station 1 is addressed by the reference station in frame 1, station 2 by the one in frame 2, so on, and finally station N by the one in frame N. The procedure is repeated in the same fashion for the next N frames until completion. Similarly, if the status report sent by the traffic station to the reference station, or other information sent to other traffic stations, is sent over N frames and repeated until complitation, the length of the traffic burst preamble will also be reduced, hence the frame efficiency will be increased.

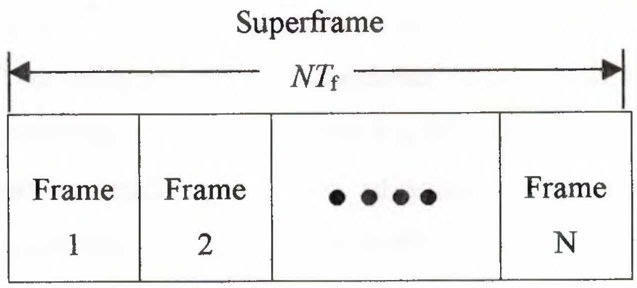


Figure 4.5 Superframe.

In this way, N frames can be put into one group called a superframe, where N is the number of stations addressed by the reference station as shown in Fig. 4.5. To identify the frames in a superframe, a frame identification number may be carried in the management channel or in a separate channel in the reference burst for each frame. Normally the identification number of frame I serves as the superframe marker. Alternatively, different unique words can be employed by the reference bursts and the traffic bursts to distinguish the superframe marker from the frame markers.

When the number of stations N in the network is fixed, or its maximum is known, it is easy to design the service channel of the traffic bursts so that its message can be transmitted over N frames. For example, any -message transmitted by the service channel of the traffic bursts is limited to a maximum of 40 bits. If the 8:1 redundancy coding algorithm is used for the message, it will take 320 bits to transmit it. Suppose N = 10 (i.e., a superframe consists of 10 frames): then a superframe would be needed to transmit the 320-bit message with 32 bits per frame. That is, the service channel occupies a time slot of only 32 bits. Although the rate of message data transmission is now only 4 bits per frame, the frame efficiency is increased significantly as compared to transmitting 320 bits per frame (40 bits of message data per frame).

When the number of stations N in the network is variable, that is, the network can grow, and if demand assignment is employed (to be discussed in Chap. 7), it might be appropriate to transmit the messages in the service channel of the traffic bursts and demand assignment messages in a separate superframe short burst (SS B) at the superframe rate.

That is, each of the N stations in the network transmits a superframe short burst once per superframe. In other words, each frame of a superframe contains a superframe short burst from a designated station; the superframe short burst would be allocated a time slot of 320 bits for a 40-bit message with 8:1 redundancy coding. Note that message data rate is still 40 bits per superfrarme, as in the case where a service channel with 4 bits of massage data per frame-is used in traffic burst. The advantage of putting the service channel in the superframe short burst instead of in the traffic burst is to increase the frame efficiency when a station transmits more than one traffic burst per frame. Since the messages in the service channel of all the traffic bursts in the same frame that originate from the same station are normally identical for ease of design, the redundancy of messages reduces the frame efficiency.

4.5 TDMA Timing

In a TDMA network, the frame timing is established-at the satellite by the reference station which transmits the reference burst at a constant period equal to the frame length T_f. The frame period T_f is derived from a highly stable transmits symbol clock with frequency f_0 equal to the TDMA symbol rate R_s. For example, if R_s = 44.776 Mbps, then f_0 = 44.776 MHz. The clock frequency offset is normally less than 1 part in 10^{11} from f_0. The frame period T_f is derived from f_0 by counting the number of symbols N that must be transmitted per frame; that is,

$$T_f = \frac{N}{f_0} \tag{4.6}$$

For example, if f_0 = 44.776 MHz, and N = 671,640 symbols, then T_f = 15 ms. In this case, the reference station establishes the frame period T_f = 15 ms by counting 671.640 symbol clock periods using the clock of frequency 44.776 MHz.

A geostationary satellite is not perfectly stable in its orbit because of the effects of the moon and the sun, hence its motion induces a different frame period at the satellite and at the traffic stations. Consider two stations in a TDMA network as shown in Fig. 4.6. The reference station R establishes the frame period $T_f = N/f_0$ We will show that the frame length at the satellite and at traffic station N varies with time and how to remedy this problem.

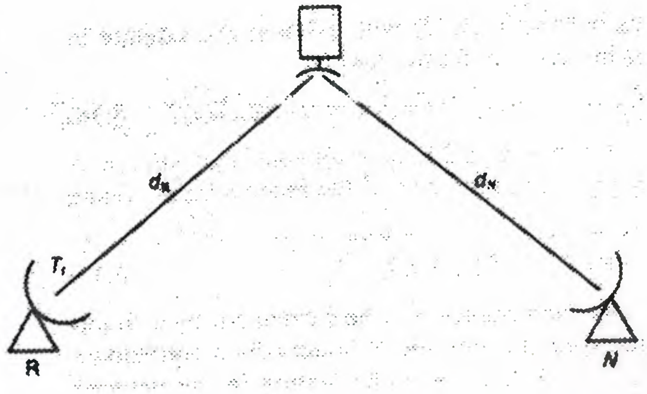


Figure 4.6 Reference station and traffic station.

Consider the two reference bursts transmitted by the reference station at time t and $t + T_f$ as shown in Fig.5.7. These two reference bursts are received by the satellite at time $t + d_R(t)/c$ and $t + T_f + d_R(t + T_f)$ /c, respectively. Because of satellite motion, the distance d_R between the satellite and the reference station varies with time, and therefore the average frame period $T_{f,s}$ at the satellite is

$$T_{t,s} = T_f + \frac{d_R(t + T_R)}{c} - \frac{d_R(t)}{c} = T_f + \Delta T_R \tag{4.7}$$

where the frame period variation $\Delta T_R = \lfloor d_R(t + T_f) - d_R(t) \rfloor / c$ can be positive or negative.

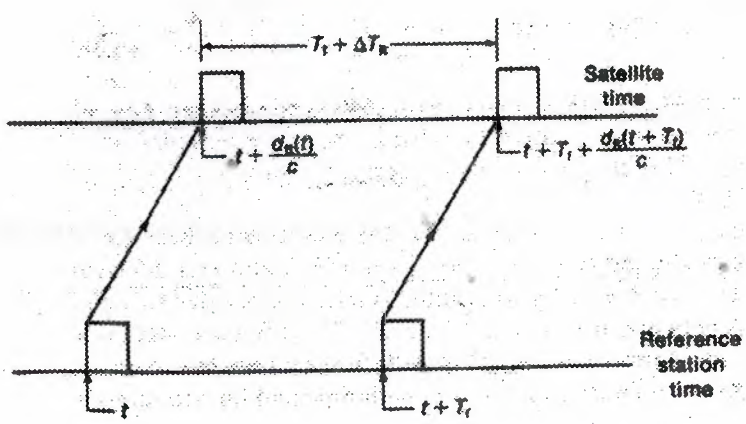


Figure 4.7 Frame period at satellite.

To establish the receive frame period at traffic station N, consider the two reference bursts that appear at the satellite at time t and $t + T_{f,s} = t + T_f + \Delta T_R$ as shown in Fig. 4.8. These two reference bursts are received at traffic station N at time $t+d_N(t)/c$ and $t + T_f + \Delta T_R + d_N(t + T_f + \Delta T_R)/c$ respectively. Since the distance d_N between the satellite and station N may vary with time, the average receive frame period $T_{f,r}$ at station N is

$$
\begin{aligned}
T_{f,r} &= T_f + \Delta T_R + \frac{d_N(t + T_f + \Delta T_R)}{c} - \frac{d_N(t)}{c} \\
&= T_f + \Delta T_R + \Delta T_N = T_{f,s} + \Delta T_N \qquad (4.8)
\end{aligned}
$$

where the frame period variation $\Delta T_N = [d_N(t + T_f + \Delta T_R) - d_N(t)]/c$ can be positive or negative.

To derive the average transmit frame period $T_{f,t}$ at station N, we note that the transmit frame timing is derived from the receive frame timing; therefore the average frame period established at the satellite by station N must be equal to the average frame period

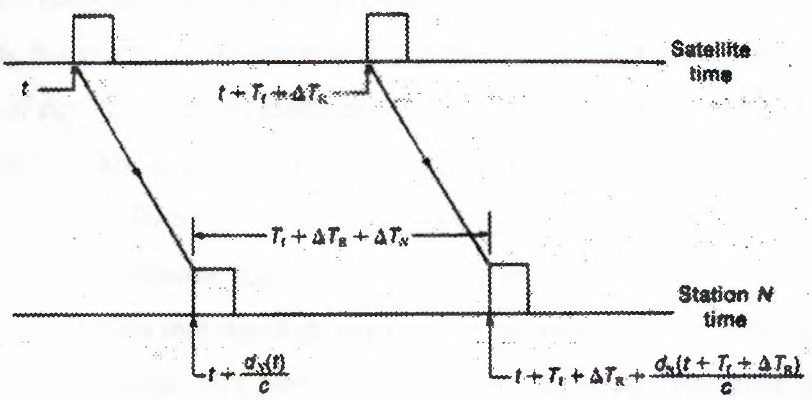


Figure 4.8 Receive frame period at a traffic station.

established at the satellite by the reference station. Thus

$$
T_{f,s} = \frac{T_{f,t} + T_{f,r}}{2} \qquad (4.9)
$$

and therefore

$$
\begin{aligned}
T_{f,t} &= 2T_{f,s} - T_{f,r} \\
&= 2(T_f + \Delta T_R) - (T_f + \Delta T_R + \Delta T_N)
\end{aligned}
$$

$$=T_f + \Delta T_R - \Delta T_N$$

$$= T_{f,s} - \Delta T_N \tag{4.10}$$

4.6 Frame Acquisitions And Synchronization

In 1884 Paul Nipkow, a German engineer, produced an early version of mechanical TV, which provided a primitive solution to the problem of scanning. Nipkow drilled a spiral of holes in a disc, which was made to rotate. Light passing through these holes registered on a selenium cell. A similar disc rotated at the receiving end of the system, and the light projected by the selenium cell reproduced the original shape silhouetted by the light. Besides scanning, the Nipkow system also had the vital feature of synchronization, in that the two discs rotated at the same speed. In Britain, the Scottish engineer John Logie Baird is often credited with the invention of TV. In fact, although Baird was responsible for some important early innovations, and provided the first public demonstration of a 30-line image in 1926, his mechanical system was superseded by electronic systems in the 1930s. At the center of developments in electronic TV was the cathode ray tube, developed in the late 19th century. This is simply a vacuum tube inside which a beam of high-energy electrons focuses on a fluorescent screen to give light. An early Russian innovator, Boris Rozing, modified the cathode ray tube to display images from a mechanical scanner in 1907. It was in the 1920s that developments in TV began to precede quickly. The immense success of radio in the post-1918 period led companies to realize that great profits could be made from the manufacture of communications goods. During this era, TV began to be conceived of as a broadcasting technology rather than as a form of telecommunications, as people began to pursue new forms of leisure activity within the home.

Synchronization deals with the research, design, integration, and application of circuits and devices used in the transmission and processing of information. Virtually unknown just a few decades ago, computer engineering is now the most rapidly growing field, and deals with the design and manufacture of memory systems, of central processing units, and of peripheral devices. Circuits are designed to perform specific tasks, such as amplifying electronic signals, adding binary numbers, and demodulating radio signals to recover the information they carry. Circuits are also used to generate waveforms useful for synchronization and timing, as found in television broadcasting techniques, and for correcting errors in digital information, as in telecommunications. In TDMA system, a traffic station must perform two functions:

On the receive side, the traffic station must be able to receive traffic bursts addressed to it from a satellite transponder (or transponders) periodically every frame. On the transmit side, the traffic station must be able to transmit traffic bursts destined to other stations periodically every frame in such a way that the bursts arrive at a satellite transponder (or transponders) without overlapping with bursts from other traffic stations. As mentioned before, the timing reference in a TDMA system is provided by the primary reference burst. By detecting the unique word of the primary reference burst, the traffic station can establish the receive frame timing (RFT) which is defined as The instant of occurrence of the last bit or symbol of the primary reference burst's unique word. The technical proficiency of the movements. For routines, two panels of judges mark technical merit and artistic impression. Technical marks are given for execution, synchronization, and difficulty of the movements, and marks for artistic impression are awarded for choreography, musical interpretation, and manner of presentation. In all sections, marks are given out of ten.

Also, the last bit or symbol of the traffic burst's unique word marks its receive burst timing (RBT). Since the receive frame timing marks the start of a received frame, the position of a traffic burst in a received frame is determined by the offset between the receive frame timing and the receive burst timing. This offset (in bits or symbols) is contained in a receive burst time plan which is stored in the foreground memory of the traffic station. Using the receive burst time plan, the traffic station can extract any traffic burst intended for it in a received frame. To transmit a traffic burst so that it arrives at the satellite transponder within the allocated position in the frame, the traffic station must establish a transmit frame timing (TFT), which marks the start of the station's transmit frame, and a transmit burst riming (TBT), which marks the start of transmission of the traffic burst to the satellite. The position of the traffic burst in a transmitted frame is determined by the of' l'sel between the transmit frame timing and the transmit burst timing. This offset is contained in a transmit burst time plan stored in the foreground Memory of the traffic station. If the traffic station transmits a traffic burst at the transmit frame timing, it will arrive at the satellite transponder at the same time as the primary reference burst that marks the start of a frame at the transponder. Any traffic burst transmitted at its transmit bunt timing will fall into its appropriate position in the TDMA frame at the transponder. In this way, traffic bursts from many stations that access a particular transponder will fall into their reassigned positions in the frame at the transponder and burst overlapping will not occur.

4.7 Advanced TDMA Satellite Systems

So far we have studied basic TDMA satellite architecture where there are only a few spot beams and beam interconnections are static. To increase satellite capacity, spot beams must be employed so that the same frequency band can be spatially reused many times. Theoretically, if the United States is covered by *N* non overlapping spot beams, the satellite capacity will increase *N*-fold over that achieved using one beam. In addition, the use of a narrow antenna beam provides a high gain for the coverage area, hence permits power savings in both the uplink and downlink channels.

Satellite-switched TDMA (SS-TDMA) such as that planned for *INTELSA T VI* employs multiple spot beams. One inherent problem in multiple spot beam operation is the interconnectivity of upbeams (U Bs) with downbeams (DBs). This is accomplished by dynamic satellite switching using a microwave switch matrix on-board the satellite. An illustration of the connectivity for three upbeams and three downbeams and the corresponding SS-TDMA frame is shown in Fig. 4.9. During a SS-TDMA frame the satellite switch is controlled by a sequence of switch states of various durations. The duration of a given switch state is selected to accommodate a segment of the total traffic between earth stations. The sum of the segments provided by the switch sequence is equal to the total traffic of the network. In essence, SS-TDMA operates as a set of parallel TDMA frames on the uplink, which are then switched by a sequence of switch states into a set of parallel TDMA frames on the downlink.

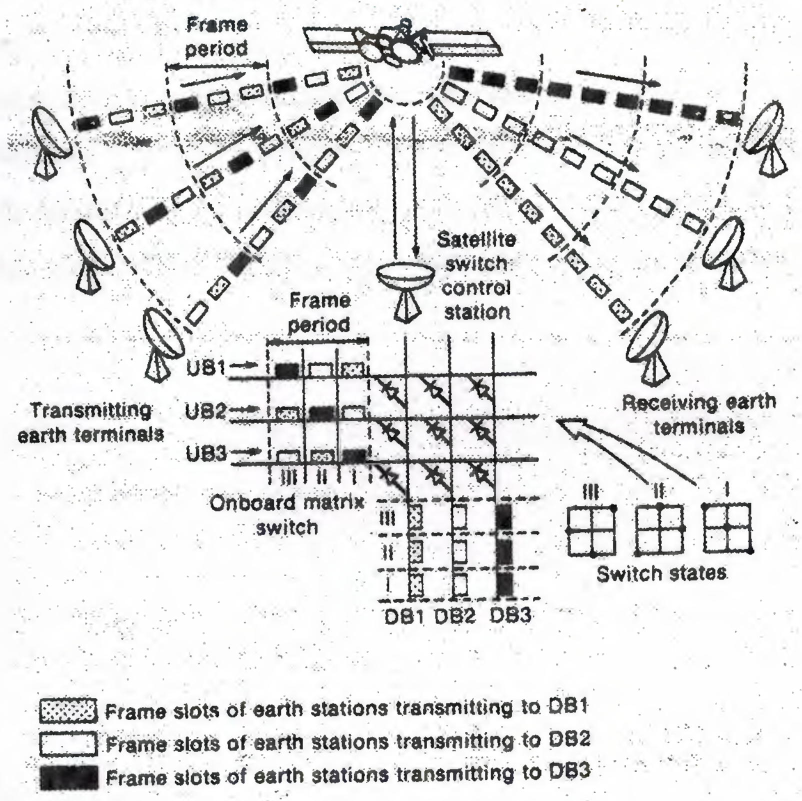


Figure 4.9 Satellite-switched TDMA.

Another advanced TDMA satellite system is beamhopping TDMA which is very useful for serving areas in which traffic is spread out geographically and where traffic in no single area is sufficient to justify the use of a stationary spot beam. Beam hopping TDMA works as follows: The on-board phase-away antenna points a particular spot beam in the direction of a new burst and dwells for the duration the burst plus guard time needed for burst position uncertainty. After the first burst in the frame has been received and stored in the uplink memory, the beam is steered in the direction of the second burst, the second burst is stored, and so on until all the bursts in the TDMA frame are stored, then the hopping sequence is repeated for a new TDMA frame. The stored uplink bursts are then processed by an on-board processor which performs demodulation of the uplink carriers followed by reconfiguration of the uplink bursts into new downlink bursts each for a particular downbeam dwell followed by remodulation on downlink carriers. On-board demodulation and remodulation decouple the uplink noise and interference from the downlink noise and interference to improve the bit error rate. Reconfiguration of bursts allows the grouping of all traffic into one burst destined for a particular region, thus avoiding the interburst interference associated with conventional TDMA. A combination of beam-hopping TDMA and SS-TDMA permits a mixture of low, medium and high bit rates. The planned NASA Advanced Communication Technology Satellite (ACTS) will employ on-board switching with beam hopping and may set a future trend for satellite communications.

CONCLUSION

Advances in satellite communication system and application have always been evolutionary in nature. The beginning of the industry was technology driven, with the development of the spacecraft design and the providing of this feasibility in the early 1960s. In approximately 15 years the satellite communication industry has early come along way. Once seen as technical feat and curiosity, the geostationary communication satellite is now common place and indispensable in many sectors. There has been a maturation process at work: first the technology had to be made economical, and second the applications for satellite communication had to prove themselves in a competitive.

The availability of the service is high and can be as high as 99.5%. The difficulty of the enterprise should not be forgotten. Satellite communication increasing competition of fiber optic ground network. Installation of these networks has started and, in time, the most industrialized countries will be entirely cabled. Such networks offered both bandwidth and high capacity; these features have so far been characteristic of satellites. However one can also imagine that competition will force the operators of satellite systems to offer specialized services which will use the characteristic of satellite communication more specifically; example are broadcasting and data collection, access to mobile vehicles, radio location and so on.

Transmission delay can be good further research topic, since data communications operate on the premise that the arrival of data at their destination needs to be acknowledged by return massages, transit delay between user terminals becomes a critical element for the efficient use of the transport medium.

Satellite communication of this century provides many services currently available. For example, the distribution of television programming will certainly be by way of satellites. It is the new applications, not yet introduce, which will be the most exciting, providing the base for expansion of the industry in new directions. Satellite communication will be an important part of the evolving picture of this century.

REFERENCES

[1] Fakhreddin Mamedov, *Telecommunication,* Near East university press, Nicosia, 2000.

[2] Tri T. Ha., *Digital Satellite Communications,* McGraw-Hill, International edition, 1992.

[3] Shanon, C.E., "Communication theory of Satellite Communication Systems", *Bell System Technical Journal,* Vol.27, 1948, pp. 379-423 and 623-656.

[4] Elbert, Bruce R., *Introduction to Satellite Communication*, Artech house, Norwood, 1987.

[5] Pritchard, wilburl, *Satellite Communication System Engineering*, Prentice hall, New York, 1993.

[6] Maral G., M. Bousguet, *Satellite Communication systems,* Wiley, New York 1993.

[7] Michael J. Mileer, *Satellite Communication, Mobile & Fixed services*, Klower Academic Publisher, Boston, 1993.

[8] Passons J. D., *Mobile Communication*, Hall shed Press, New York,1989.