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Faculty of Engineering

Department of Electrical and Electronic Engineering

DIGITAL SATELLITE COMMUNICATION

Graduation Project
EE- 400

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ABSTRACT

A communications satellite is a spacecraft that carries aboard communications equipment, enabling a communication link to be established between distant points. Satellites are hanged on their orbits as a result of the balance between centrifugal gravitational forces.

A communication satellite permits two or more points on the ground (earth stations) to send messages one to another over great distances using radio waves.

Hundreds of active communication satellites are now in orbit. They receive signals from one ground station, amplify them, and then retransmit them at a different frequency to another station. Satellites use ranges of different frequencies, measured in hertz (Hz) or cycles per second, for receiving and transmitting signals.

The main objective of this Thesis is to represent basic elements of satellite communication systems, including *Frequency Allocation*, *Earth Station*, *Transponder*, *Methods of Access* and some of *Satellite Applications*.

The described topics give the reader enough information for understanding the architecture and principle of *Satellite Communication Systems*.

INTRODUCTION

Satellite communication has evolved into an everyday, commonplace thing. Most television coverage travels by satellite, even reaching directly to the home from space. No longer is it a novelty to see that a telecast has been carried by satellite (in fact, it would be novel to see something delivered by other means). The bulk of transoceanic telephone and data communication also travels by satellite. For countries such as Indonesia, domestic satellite have greatly improved the quality of service from the public telephone system and brought nations more tightly together.

Some of the first communications satellites were designed to operate in a passive mode. Instead of actively transmitting radio signals, they served merely to reflect signals that were beamed up to them by transmitting stations on the ground. Signals were reflected in all directions, so receiving stations around the world could pick them up.

This project consists of four chapters;

Chapter one is Introduction to Digital Satellite Communication; in this chapter we presented the history, development and new technologies.

Chapter two Satellite Communication; here we gave a description for the Satellite Systems and Services, presenting the Satellite Frequency Bands, Orbits, Construction, Launching And Earth Station substructure.

Chapter three Multiple Access; the methods of Satellite Access are explained in this chapter, Multiple Access Methods are: Frequency Division Multiple Access FDMA Time Division Multiple Access TDMA and Code Division Multiple Access CDMA. Comparisons are represented between the former three methods.

Chapter Four application of satellite networks the first part of this chapter reviews the features and generic arrangements of networks independent of the specific use. This provides a cross reference with regard to the applications which are reviewed in detail at the end of this chapter.

CHAPTER ONE

INTRODUCTION TO DIGITAL SATELLITE COMMUNICATION

1.1 Histories and Development

Some of the first communications satellites were designed to operate in a passive mode. Instead of actively transmitting radio signals, they served merely to reflect signals that were beamed up to them by transmitting stations on the ground. Signals were reflected in all directions, so they could be picked up by receiving stations around the world. *Echo 1,* launched by the United States in 1960, consisted of an aluminized plastic balloon 30 m (100 ft) in diameter. Launched in 1964, *Echo 2* was 41 m (135 ft) in diameter. The capacity of such systems was severely limited by the need for powerful transmitters and large ground antennas.

Satellite communications currently make exclusive use of active systems, in which each satellite carries it own equipment for reception and transmission. *Score,* launched by the United States in 1958, was the first active communications satellite. It was equipped with a tape recorder that stored messages received while passing over a transmitting ground station. These messages were retransmitted when the satellite passed over a receiving station. *Telstar 1,* launched by American Telephone and Telegraph Company in 1962, provided direct television transmission between the United States, Europe, and Japan and could also relay several hundred-voice channels. Launched into an elliptical orbit inclined 45° to the equatorial plane, *Telstar* could only relay signals between two ground stations for a short period during each revolution, when both stations were in its line of sight.

Hundreds of active communications satellites are now in orbit. They receive signals from one ground station, amplify them, and then retransmit them at a different frequency to another station. Satellites use ranges of different frequencies, measured in hertz (Hz) or cycles per second, for receiving and transmitting signals. Many satellites use a band of frequencies of about 6 billion hertz, or 6 gig hertz (GHz) for upward, or uplink, transmission and 4 GHZ for downward, or downlink, transmission. Another band at 14 GHZ (uplink) and 11 or 12 GHZ (downlink) is also much in use, mostly with fixed (nonmobile) ground stations. A band at about 1.5 GHZ (for both uplink and downlink) is used with small, mobile ground stations (ships, land vehicles, and aircraft). Solar energy cells mounted on large panels attached to the satellite provide power for reception and transmission. In 500 years, when humankind looks back at the dawn of space travel, Apollo's landing on the Moon in 1969 may be the only event remembered. At the same time, however, Lyndon B. Johnson, himself an avid promoter of the space program, felt that reconnaissance satellites alone justified every penny spent on space. Weather forecasting has undergone a revolution because of the availability of pictures from geostationary meteorological satellites-pictures we see every day on television. All of these are important aspects of the space age, but satellite communications has probably had more effect than any of the rest on the average person. Satellite communications is also the only truly commercial space technology -generating billions of dollars annually in sales of products and services.

In fall of 1945 an RAF electronics officer and member of the British Interplanetary Society, Arthur C. Clarke, wrote a short article in *Wireless World* that described the use of manned satellites in 24-hour orbits high above the world's land masses to distribute television programs. His article apparently had little lasting effect in spite of Clarke's repeating the story in his 1951/52 *The Exploration of Space*. Perhaps the first person to carefully evaluate the various technical options in satellite communications *and* evaluate the financial prospects was John R. Pierce of AT&T's Bell Telephone Laboratories who, in a 1954 speech and 1955 article, elaborated the utility of a communications "mirror" in space, a medium-orbit "repeater" and a 24-hour-orbit "repeater." In comparing the communications capacity of a satellite, which he estimated at 1,000 simultaneous telephone calls, and the communications capacity of the first trans-Atlantic telephone cable (TAT-1), which could carry 36 simultaneous telephone calls at a cost of 30-50 million dollars, Pierce wondered if a satellite would be worth a billion dollars.

After the 1957 launch of Sputnik I, many considered the benefits, profits, and prestige associated with satellite communications. Because of Congressional fears of "duplication," NASA confined itself to experiments with "mirrors" or "passive" communications satellites (ECHO), while the Department of Defense was responsible for "repeater" or "active" satellites which amplify the received signal at the satellite providing much higher quality communications. In 1960 AT&T filed with the Federal

Communications Commission (FCC) for permission to launch an experimental communications satellite with a view to rapidly implementing an operational system. The U.S. government reacted with surprise there was no policy in place to help execute the many decisions related to the AT&T proposal. By the middle of 1961, NASA had awarded a competitive contract to RCA to build a medium-orbit (4,000 miles high) active communication satellite (RELAY); AT&T was building its own medium-orbit satellite (TELSTAR) which NASA would launch on a cost-reimbursable basis; and NASA had awarded a sole source contract to Hughes Aircraft Company to build a 24-hour (20,000 mile high) satellite (SYNCOM). The military program, ADVENT, was cancelled a year later due to complexity of the spacecraft, delay in launcher availability, and cost over-runs.

By 1964, two TELSTARs, two RELAYs, and two SYNCOMs had operated successfully in space. This timing was fortunate because the Communications Satellite Corporation (COMSAT), formed as a result of the Communications Satellite Act of 1962, was in the process of contracting for their first satellite. COMSAT's initial capitalization of 200 million dollars was considered sufficient to build a system of dozens of medium-orbit satellites. For a variety of reasons, including costs, COMSAT ultimately chose to reject the joint AT&T/RCA offer of a medium-orbit satellite incorporating the best of TELSTAR and RELAY. They chose the 24-hour-orbit (geosynchronous) satellite offered by Hughes Aircraft Company for their first two systems and a TRW geosynchronous satellite for their third system. On April 6, 1965 COMSAT's first satellite, EARLY BIRD, was launched from Cape Canaveral. Global satellite communications had begun.

Some glimpses of the Global Village had already been provided during experiments with TELSTAR, RELAY, and SYNCOM. These had included televising parts of the 1964 Tokyo Olympics. Although COMSAT and the initial launch vehicles and satellites were American, other countries had been involved from the beginning. AT&T had initially negotiated with its European telephone cable "partners" to build earth stations for TELSTAR experimentation. NASA had expanded these negotiations to include RELAY and SYNCOM experimentation. By the time EARLY BIRD was launched, communications earth stations already existed in the United Kingdom, France, Germany, Italy, Brazil, and Japan. Further negotiations in 1963 and 1964 resulted in a new international organization, which would ultimately assume ownership of the satellites and responsibility for management of the global system. On August 20, 1964, agreements were signed which created the International Telecommunications Satellite Organization (INTELSAT).

By the end of 1965, EARLY BIRD had provided 150 telephone "half- circuits" and 80 hours of television service. The INTELSAT II series was a slightly more capable and longer-lived version of EARLY BIRD. Much of the early use of the COMSAT/INTELSAT system was to provide circuits for the NASA Communications Network (NASCOM). The INTELSAT III series was the first to provide Indian Ocean coverage to complete the global network. This coverage was completed just days before one half billion people watched APOLLO 11 land on the moon on July 20, 1969.

From a few hundred-telephone circuits and a handful of members in 1965, INTELSAT has grown to a present-day system with more members than the United Nations and the capability of providing hundreds of thousands of telephone circuits. Cost to carriers per circuit has gone from almost $100,000 to a few thousand dollars. Cost to consumers has gone from over $10 per minute to less than $1 per minute. If the effects of inflation are included, this is a tremendous decrease! INTELSAT provides services to the entire globe, not just the industrialized nations.

In 1965, ABC proposed a domestic satellite system to distribute television signals. The proposal sank into temporary oblivion, but in 1972 TELESAT CANADA launched the first domestic communications satellite, ANIK, to serve the vast Canadian continental area. RCA promptly leased circuits on the Canadian satellite until they could launch their own satellite. The first U.S. domestic communications satellite was Western Union's WESTAR I, launched on April 13, 1974. In December of the following year RCA launched their RCA SATCOM F- 1. In early 1976 AT&T and COMSAT launched the first of the COMSTAR series. These satellites were used for voice and data, but very quickly television became a major user. By the end of 1976 there were 120 transponders available over the U.S., each capable of providing 1500 telephone channels or one TV channel. Very quickly the "movie channels" and "super stations" were available to most Americans. The dramatic growth in cable TV would not have been possible without an inexpensive method of distributing video.

The ensuing two decades have seen some changes: Western Union is no more; Hughes is now a satellite operator as well as a manufacturer; AT&T is still a satellite operator, but no longer in partnership with COMSAT; GTE, originally teaming with Hughes in the early 1960s to build and operate a global system is now a major domestic satellite operator. Television still dominates domestic satellite communications, but data has grown tremendously with the advent of very small aperture terminals (VSATs). Small antennas, whether TV-Receive Only (TVRO) or VSAT are a commonplace sight all over the country.

1.2 New Technology

The first major geosynchronous satellite project was the Defense Department's ADVENT communications satellite. It was three-axis stabilized rather than spinning. It had an antenna that directed its radio energy at the earth. It was rather sophisticated and heavy. At 500-1000 pounds it could only be launched by the ATLAS- CENTAUR launch vehicle. ADVENT never flew, primarily because the CENTAUR stage was not fully reliable until 1968, but also because of problems with the satellite. When the program was canceled in 1962 it was seen as the death knell for geosynchronous satellites, three-axis stabilization, the ATLAS-CENTAUR, and complex communications satellites generally. Geosynchronous satellites became a reality in 1963, and became the only choice in 1965. The other ADVENT characteristics also became commonplace in the years to follow.

In the early 1960s, converted intercontinental ballistic missiles (ICBMs) and intermediate range ballistic missiles (IRBMs) were used as launch vehicles. These all had a common problem: they were designed to deliver an object to the earth's surface, not to place an object in orbit. Upper stages had to be designed to provide a delta-Vee (velocity change) at apogee to circularize the orbit. The DELTA launch vehicles, which placed all of the early communications satellites in orbit, were THOR IRBMs that used the VANGUARD upper stage to provide this delta-Vee. It was recognized that the DELTA was relatively small and a project to develop CENTAUR, a high-energy upper stage for the ATLAS ICBM, was begun. ATLAS-CENTAUR became reliable in 1968 and the fourth generation of INTELSAT satellites used this launch vehicle. The fifth generation used ATLAS-CENTAUR and a new launch-vehicle, the European ARIANE. Since that time other entries, including the Russian PROTON launch vehicle and the

Chinese LONG MARCH have entered the market. All are capable of launching satellites almost thirty times the weight of EARLY BIRD. In the mid-1970s several satellites were built using three-axis stabilization. They were more complex than the spinners, but they provided more despun surface to mount antennas and they made it possible to deploy very large solar arrays. The greater the mass and power, the greater the advantage of three-axis stabilization appears to be. Perhaps the surest indication of the success of this form of stabilization was the switch of Hughes, closely identified with spinning satellites, to this form of stabilization in the early 1990s. The latest products from the manufacturers of SYNCOM look quite similar to the discredited ADVENT design of the late 1950s.

Much of the technology for communications satellites existed in 1960, but would be improved with time. The basic communications component of the satellite was the traveling-wave-tube (TWT). These had been invented in England by Rudoph Kompfner, but they had been perfected at Bell Labs by Kompfner and J. R. Pierce. All three early satellites used TWTs built by a Bell Labs alumnus. These early tubes had power outputs as low as 1 watt. Higher- power (50-300 watts) TWTs is available today for standard satellite services and for direct-broadcast applications. An even more important improvement was the use of high-gain antennas. Focusing the energy from a 1-watt transmitter on the surface of the earth is equivalent to having a 100-watt transmitter radiating in all directions. Focusing this energy on the Eastern U.S. is like having a 1000-watt transmitter radiating in all directions. The principal effect of this increase in actual and effective power is that earth stations are no longer 100-foot dish reflectors with cryogenically-cooled maser amplifiers costing as much as $10 million (1960 dollars) to build. Antennas for normal satellite services are typically 15-foot dish reflectors costing $30,000 (1990 dollars). Direct-broadcast antennas will be only a foot in diameter and cost a few hundred dollars.

1.3 Mobile Services

In February of 1976 COMSAT launched a new kind of satellite, MARISAT, to provide mobile services to the United States Navy and other maritime customers. In the early 1980s the Europeans launched the MARECS series to provide the same services. In 1979 the UN International Maritime Organization sponsored the establishment of the International Maritime Satellite Organization (INMARSAT) in a manner similar to INTELSAT. INMARSAT initially leased the MARISAT and MARECS satellite transponders, but in October of 1990 it launched the first of its own satellites, INMARSAT II F-1. The third generation, INMARSAT III, has already been launched. An aeronautical satellite was proposed in the mid-1970s. A contract was awarded to General Electric to build the satellite, but it was canceled--INMARSAT now provides this service. Although INMARSAT was initially conceived as a method of providing telephone service and traffic-monitoring services on ships at sea, it has provided much more. The journalist with a briefcase phone has been ubiquitous for some time, but the Gulf War brought this technology to the public eye.

The United States and Canada discussed a North American Mobile Satellite for some time. In the next year the first MSAT satellite, in which AMSC (U.S.) and TMI (Canada) cooperate, will be launched providing mobile telephone service via satellite to all of North America.

In 1965, when EARLY BIRD was launched, the satellite provided almost 10 times the capacity of the submarine telephone cables for almost 1/10th the price. This price-differential was maintained until the laying of TAT-8 in the late 1980s. TAT-8 was the first fiber-optic cable laid across the Atlantic. Satellites are still competitive with cable for point-to-point communications, but the future advantage may lie with fiber-optic cable. Satellites still maintain two advantages over cable: they are more reliable and they can be used point-to-multi-point (broadcasting).

Cellular telephone systems have risen as challenges to all other types of telephony. It is possible to place a cellular system in a developing country at a very reasonable price. Long-distance calls require some other technology, but this can be either satellites or fiber-optic cable.

CHAPTER TWO

SATELLITE COMMUNICATION

2.1 Satellite Systems

A satellite system consists basically of a satellite in space which links many earth stations on the ground, as shown schematically in Figure 2.1 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 station the base-band signal is processed 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 uplink (earth-to-space) frequency spectrum from all the earth stations in the network, amplifies these carriers, and retransmits them back to earth in the downlink (space-to-earth) frequency spectrum which is different from the uplink 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.

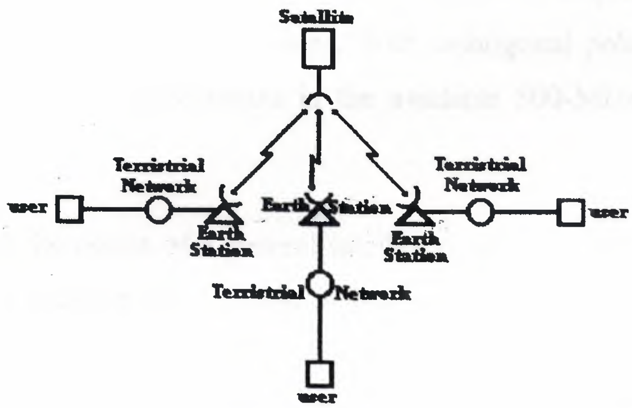


Figure 2.1 Basic Satellite System

Most commercial communications satellites today utilize a 500-MHz bandwidth on the uplink and a 500-MHz bandwidth on the downlink. The most widely used frequency spectrum is the 6/4-GHz band, with an uplink of 5.725 to 7.075 GHz and a downlink of 3.4 to 4.8 GHz. The 6/4-GHz band for geostationary 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 uplink of 12.75 to 14.8 GHz and a downlink 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 bands has also been set aside for Commercial satellite communications, with a downlink of 18.1 to 21.2 GHz and an uplink 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. Modem communications satellites also employ frequency reuse to increase the number of transponders in the 500 MHz allocated to them. 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 at3O dB or more by staggering the center frequencies of the cross polarized transponders so that only sideband energy of the RE carriers overlaps, With orthogonal polarizations a satellite can double the number of transponders in the available 500-MHz 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 2.2 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.

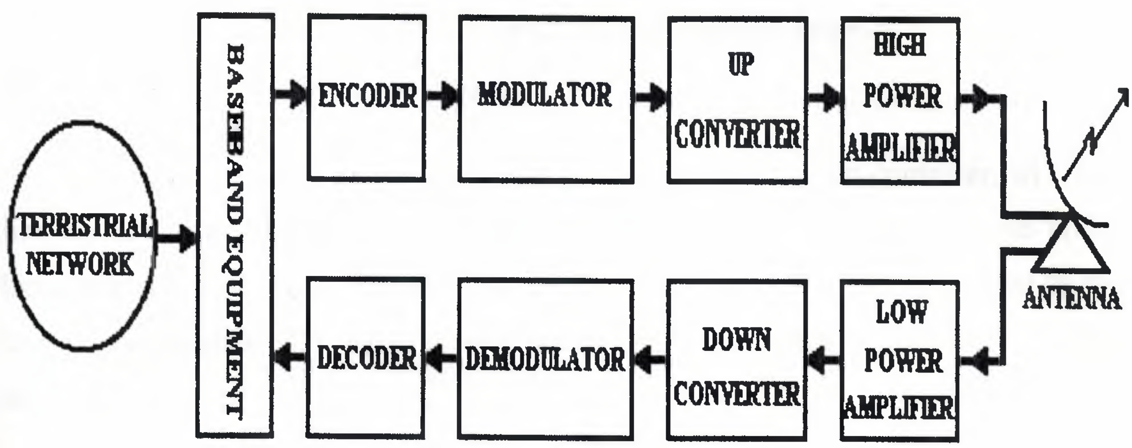


Figure 2.2 Functional Block Diagram of a Digital Earth Station

in order to transmit the base-band digital information over a satellite channel that is a band-pass channel, it is necessary to transfer the digital information to a carrier wave at the appropriate band-pass 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 uplink frequency is chosen because it is difficult to design a modulator that works at the uplink frequency spectrum (6 or 14 0Hz, as discussed previously).

For binary modulation schemes, each output digit from the encoder is used to select one of two possible waveforms. For M-array modulation schemes, the output of the encoder is segmented into sets of k digits, where $M = k^2$ and each k-digit set or symbol is used to select one of the M waveforms. For example, 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 0 is represented by the waveform $s_0(t) = -A \cos \omega_0 t$, where ω_0 is the intermediate frequency. (The letter symbols ω and f will be used to denote angular frequency and frequency, respectively, and will be referred to both of them as "frequency.")

The modulated IF carrier from the modulator is fed to the up-converter, where its intermediate frequency ω_0 is translated to the uplink RF frequency w. in the uplink frequency spectrum of the satellite. This modulated RF carrier is then amplified by the high-power amplifier .(HPA) 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 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 down-converter accepts the amplified RF carrier from the output of the low-noise amplifier and translates the downlink frequency ω_d to the intermediate frequency ω_0. The reason for down-converting 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 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 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° 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° along the equatorial arc instead of 4°. 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 beam-width and thus look at a wider angle in the sky.

The FCC ruling specified that, as of July 1, 1984, all new satellite earth station antennas had to be manufactured to accommodate the spacing of 20 and that, as of January 1, 1987. all existing antennas must be modified to conform to the new standards.

2.2 Satellite Services

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

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

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

(c) Mobile Satellite Services: including communications between a mobile earth station and a fixed station, or between mobile stations.

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

2.2.1 Ground Segment

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

2.2.2 Earth Station

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

2.3 Satellite Frequency Bands

The frequencies used for satellite communications are allocated in super-high frequency (SHF) and extremely-high frequency (EHF) bands which are broken down into sub-bands as summarized in Table 2.1. 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 2.1 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

2.4 Satellite Orbits

When a satellite is launched, it is placed in orbit around the earth. The earth's gravity holds the satellite in a certain path as it goes around the earth, and that path is called an "orbit." There are several kinds of orbits. Here are three of them.

A) LEO, or Low Earth Orbit

A satellite in low earth orbit circles the earth 100 to 300 miles above the earth's surface. Because it is close to the earth, it must travel very fast to avoid being pulled out of orbit by gravity and crashing into the earth. Satellites in low earth orbit travel about 17,500 miles per hour. These satellites can circle the whole earth in about an hour and a half.

B) MEO, or Medium Earth Orbit

Communications satellites that cover the North Pole and the South Pole are placed in a medium altitude, oval orbit. Instead of making circles around the earth, these satellites make ovals. Receivers on the ground must track these satellites. Because their orbits are larger than LEOs, they stay in sight of the ground receiving stations for a longer time. They orbit 6,000 to 12,000 miles above the earth.

C) GEO, or Geostationary Earth Orbit

A satellite in geosynchronous orbit circles the earth in 24 hours—the same time it takes the earth to rotate one time. If these satellites are positioned over the equator and travel in the same direction as the earth rotates, they appear "fixed" with respect to a given spot on earth—that is, they hang like lanterns over the same spot on the earth all the time. Satellites in GEO orbit 22,282 miles above the earth. In this high orbit, GEO satellites are always able to "see" the receiving stations below, and their signals can cover a large part of the planet. Three GEO satellites can cover the globe, except for the parts at the North and South poles.

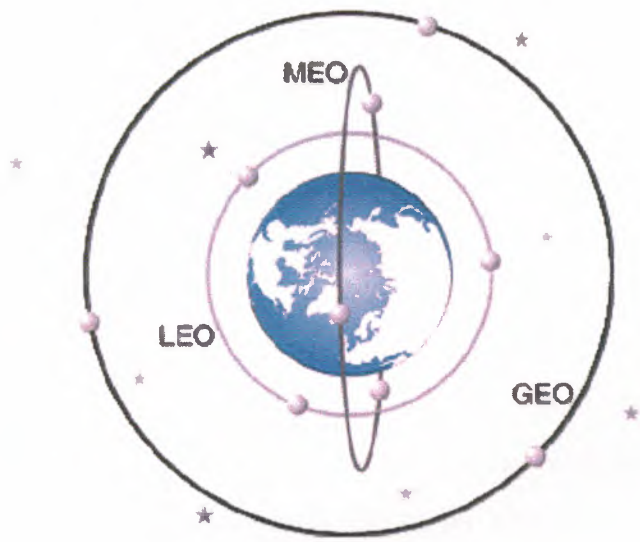


Figure 2.3 Satellite Orbits

2.5 Communication Satellites

2.5.1 Airborne Satellite

2.5.1.1 What's Inside a Satellite?

Satellites have a great deal of equipment packed inside them. A satellite has seven subsystems, and each one has its own work to do.

1) The **propulsion subsystem** includes the electric or chemical motor that brings the spacecraft to its permanent position, as well as small thrusters (motors) that help keep the satellite in its assigned place in orbit. Satellites drift out of position because of solar wind or gravitational or magnetic forces. When that happens, the thrusters are fired to move the satellite back into the right position in its orbit.
2) The **power subsystem** generates electricity from the solar panels on the outside of the spacecraft. The solar panels also store electricity in storage batteries, which provide power when the sun isn't shining on the panels. The power is used to operate the com-munications subsystem. A Boeing 702 generates enough power at the end of its ser-vice life to operate two hundred 75-watt light bulbs.
3) The **communications subsystem** handles all the transmit and receive functions. It receives signals from the earth, amplifies or strengthens them, and transmits (sends) them to another satellite or to a ground station.
4) The **structures subsystem** distributes the stresses of launch and acts as a strong, stable framework for attaching the other parts of the satellite.
5) The **thermal control subsystem** keeps the active parts of the satellite cool enough to work properly. It does this by directing the heat that is generated by satellite opera-tions out into space, where it won't interfere with the satellite.
6) The **attitude control subsystem** maintains the communications "footprint" in the correct location. Satellites can't be allowed to jiggle or wander, because if a satellite is not exactly where it belongs, pointed at exactly the right place on the earth, the televi-sion program or the

telephone call it transmits to you will be interrupted. When the satellite gets out of position, the attitude control system tells the propulsion system to fire a thruster that will move the satellite back where it belongs.

7) Operators at the ground station need to be able to transmit commands to the satel-lite and to monitor its health. The **telemetry and command subsystem** provides a way for people at the ground stations to communicate with the satellite.

2.5.1.2 Satellite Launching

A satellite is launched on a launch vehicle; the satellite is packed carefully into the vehicle and carried into space, powered by a rocket engine.

Satellites are launched from only a few places in the world, primarily Cape Canaveral, Florida; Kourou, French Guiana; Xichang, China, and Baikonur, Kazakstan. The best places to launch satellites are near the ocean, so that when the launch vehicle falls away, it lands in the water and not on people.

Another launch site actually travels to the perfect launch spot. The Sea Launch company rebuilt a big platform once used for oil drilling at sea. The platform carries satellites from Long Beach, California, to the equator, far out in the Pacific Ocean, where its rocket launches them.

At launch, the launch vehicle's rockets lift the satellite off the launch pad and carry it into space, where it circles the earth in a temporary orbit. Then the spent rockets and the launch vehicle drop away, and one or more motors attached to the satellite move it into its permanent geosynchronous orbit. A motor is started up for a certain amount of time, sometimes just one or two minutes, to push the satellite into place. When one of these motors is started, it's called a "burn." It may take many burns, over a period of several days, to move the satellite into its assigned orbital position.

When the satellite reaches its orbit, a motor points it in the right direction and its antennas and solar panels deploy, that is, they unfold from their traveling position and spread out so the satellite can start sending and receiving signals.

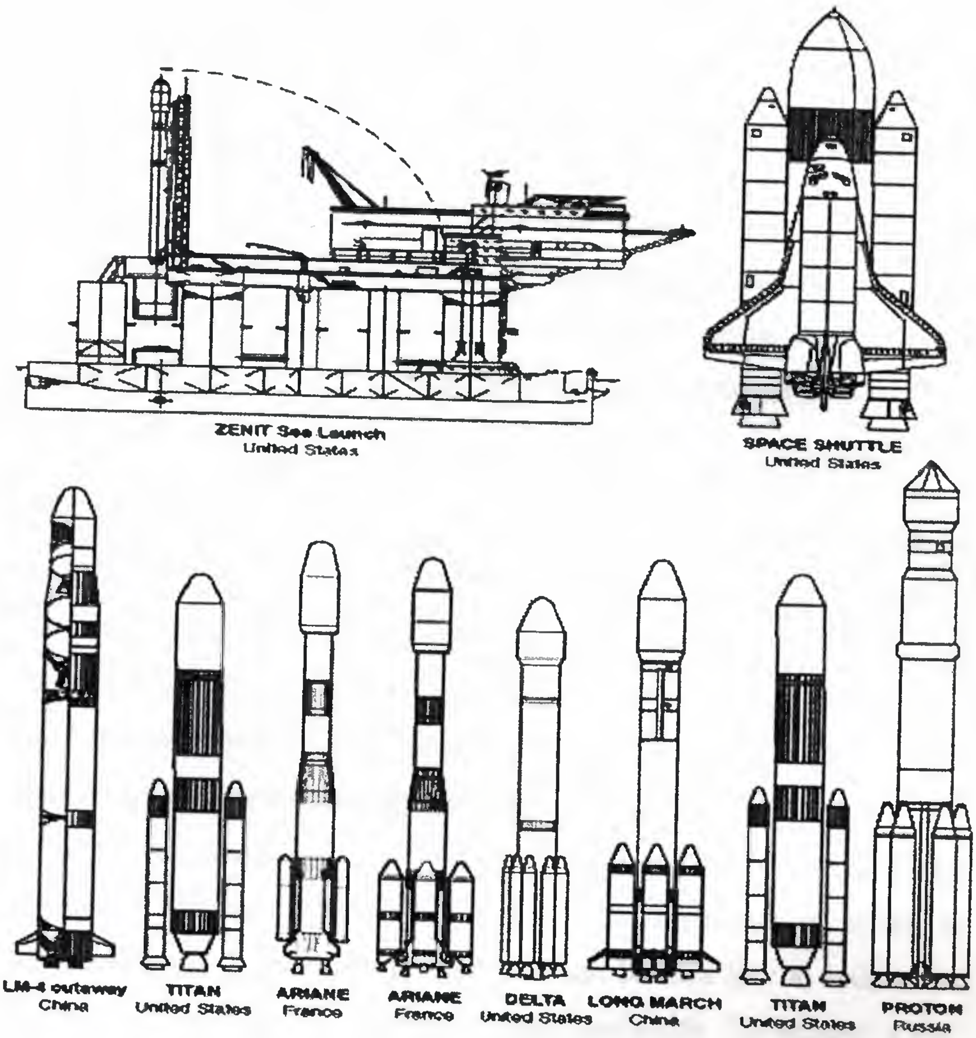


Figure 2.4 Launching Vehicles

2.5.2 Earth Station

2.5.2.1 Introduction

At the beginning we gave a functional description of the digital earth station shown in Figure 2.2 In practice, an earth station is basically 'divided into two parts:

1) A RF terminal, which consists of an up-converter and a down-converter, a high-power amplifier, a low-noise amplifier, and an antenna
2) A base-band terminal, which consists of base-band equipment, an encoder and decoder, and a modulator and demodulator.

The RF terminal and the base-band terminal may be located a distance apart and connected by appropriate IF lines. In this chapter we will focus attention on a discussion of the RF terminal and will consider the base-band terminal from a system point of view only.

2.5.2.2 Earth Station Antenna

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:

1) The antenna must have a highly directive gain; that is, it must focus its radiated energy into a narrow beam to illuminate the satellite antenna in both the transmit and receive modes to provide the required uplink and downlink carrier power. Also, the antenna radiation pattern must have a low side-lobe level to reduce interference from unwanted signals and to minimize interference into other satellites and terrestrial systems.
2) 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 to reduce the noise power within the downlink carrier bandwidth. To achieve a low noise characteristic, the antenna radiation pattern must be controlled in such a way as to minimize the energy radiated into sources other than the satellite. Also, the Ohmic losses of the antenna that contribute directly to its noise temperature must be minimized. This includes the Ohmic loss of the wave-guide that connects the low-noise amplifier to the antenna feed.
3) 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 in position. This is essential for minimizing antenna pointing loss.

A) 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 Figure 2.5. This type of antenna consists of a reflector which is a section of a surface formed by rotating a parabola about its axis, and a 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 a low-noise amplifier through an orthogonal mode transducer (OMT) which is a three-port network. The inherent isolation of the OMT is normally better than 40 dB. On the transmit side the signal energy from the output of the high-power amplifier is radiated at the focal point by the feed and illuminates the reflector which reflects and focuses the signal energy into a narrow beam. On the receive side the signal energy captured by the reflector converges on the focal point and is received by the feed which is then routed to the input of the low-noise amplifier. 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 (spillover energy) illuminates the ground whose noise temperature can be as high as 2900 K and results in a high antenna noise contribution. Paraboloid antennas with a focal point feed are most often employed in the United States for receive-only applications.

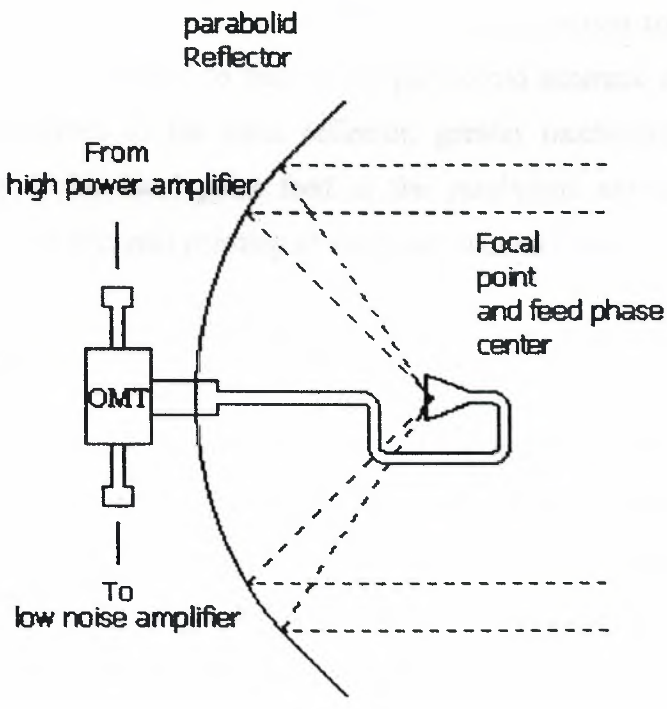


Figure 2.5 paraboloid Antenna

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 sub-reflector, and a feed, whose phase center is at the real focal point of the sub-reflector, as shown in Figure 2.6. On the transmit side, the signal energy from the output of the high-power amplifier is radiated at the real focal point by the feed and illuminates the convex surface of the sub-reflector which reflects the signal energy back as if it were incident from a feed whose phase center is located at the common focal point of the main reflector and sub-reflector. The reflected energy is reflected again by the main reflector to form the antenna beam. 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 a paraboloid antenna because of the addition of the sub-reflector and the integration of the three antenna elements -the main reflector, sub-reflector, and feed- to produce an optimum antenna system. However, the Cassegrain antenna offers many advantages over the paraboloid antenna: low noise 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 3O° K, its contribution to the antenna noise temperature is small compared to that of the paraboloid antenna. Also, with the feed located near the vertex of the main reflector, greater mechanical stability can be achieved than with the focal point feed in the paraboloid antenna. This increased stability permits very accurate pointing of high-gain narrow-beam antennas.

To minimize the losses in the transmission lines connecting the high-power amplifier and the low-noise amplifier to the feed, a beam wave-guide feed system may be employed. A Cassegrain antenna with a beam wave-guide feed system is shown in Figure 2.7. The beam wave-guide assembly consist of four mirrors supported by a shroud and precisely located relative to the sub-reflector, the feed, the elevation axis, and the azimuth axis. This mirror configuration acts as a RF energy funnel between the feed and the sub-reflector and, as such, must be designed to achieve minimum loss while allowing the feed to be mounted in the concrete foundation at ground level. The shroud assembly acts as a shield against ground noise and provides

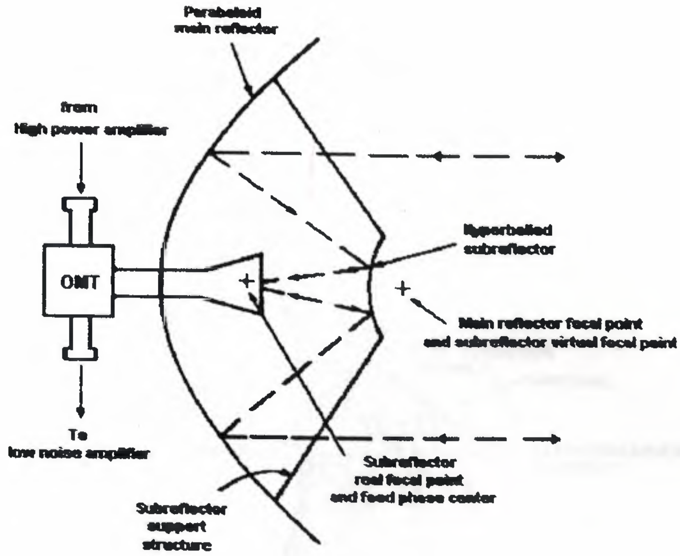
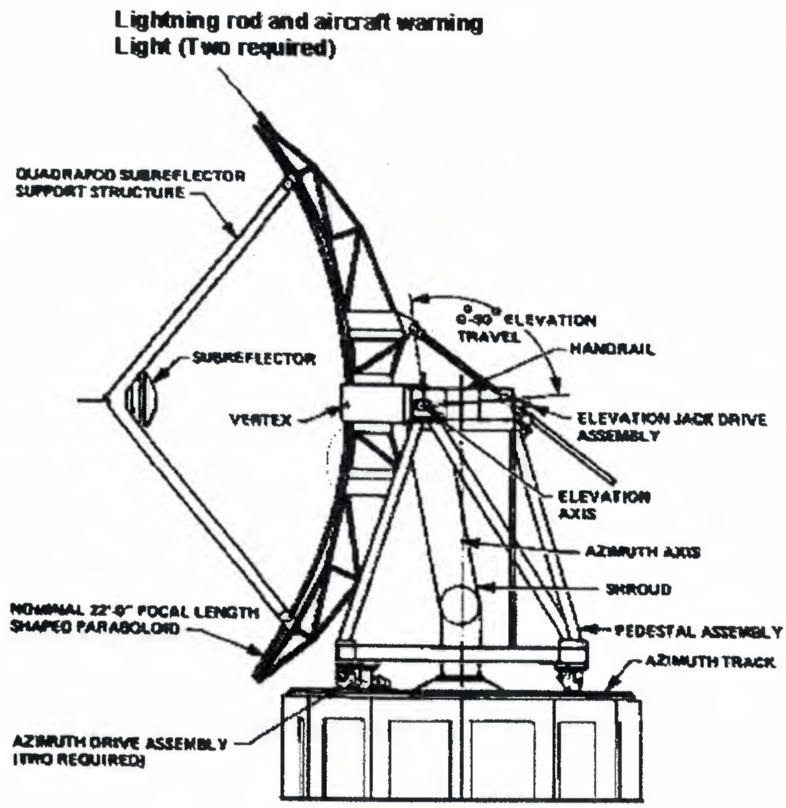


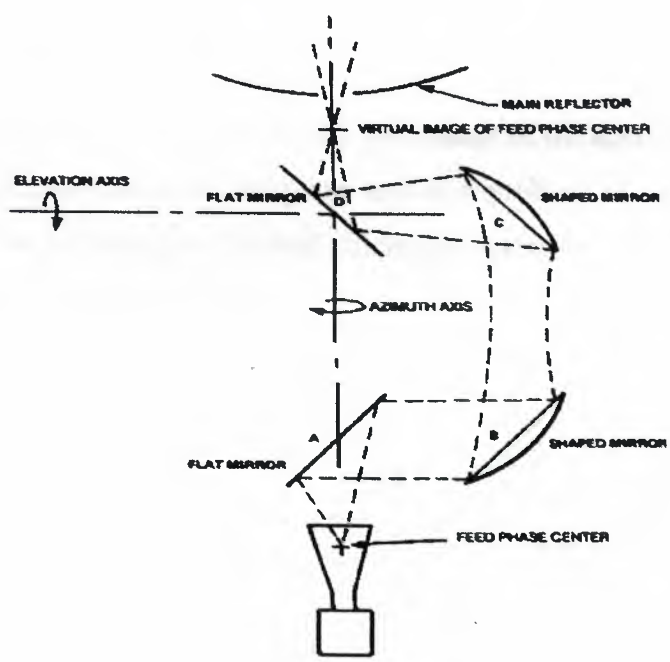
Figure 2.6 Cassegrain Antenna

a rigid structure which maintains the mounting integrity of the mirrors when the antenna is subjected to wind, thermal, or other external loading conditions. The lower section of the shroud assembly is supported by the pedestal and rotates about the azimuth axis. The upper section of the shroud assembly is supported by the main reflector support structure and rotates about the elevation axis. As seen in Figure 2.7.b, the beam wave-guide mirror system directs the energy to and from the feed and the reflectors. The configuration utilized is based on optics, though a correction is made for diffraction effects by using slightly elliptical curved mirrors. For proper shaping and positioning of the beam Wave-guide mirrors, the energy from the feed located in the equipment room is refocused so that the feed phase center appears to be at the sub-reflector's real focal point. In operation, mirrors A, B, C, and D move as a unit when the azimuth platform rotates. Mirror D is on the elevation axis and rotates also when the main reflector is steered during elevation. In this way, the energy to and from the beam wave-guide system is always directed through the opening in the main reflector vertex.

As mentioned previously, modern communications satellites often employ dual polarizations to allow two independent carriers to be sent in the same frequency band, thus permitting frequency reuse and doubling the satellite capacity. Figure 2.7 shows a wideband OMT diplexer type of frequency reuse feed for a Cassegrain antenna that provides horizontal and vertical polarization for a Ku-band operation.



(a)



(b)

Figure 2.7 (a) a complete structure of cassegrain antenna (b) beam wave-guide feed

B) Antenna Gain

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

$$G = \eta \frac{4.\pi.A}{\lambda^2} = \eta \frac{4.\pi.A.f^2}{c^2} \qquad (1)$$

where

A = antenna aperture area (in^2)

λ = radiation wavelength (in)

f = radiation frequency (Hz)

c = speed of light = 2.997925 x 10^8 m/s

η = antenna aperture efficiency ($\eta < 1$)

For a circular aperture, it follows that $A = \pi D^2/4$; therefore

$$G = \eta \left(\frac{\pi.D}{\lambda}\right)^2 = \eta.\left(\frac{\pi.f.D}{c}\right)^2 \qquad (2)$$

where D = antenna diameter (in).

The antenna efficiency η represents the percentage of the aperture area A that is used effectively in transmission or reception and is a product of various efficiency factors that reduce the antenna gain. Typical efficiency factors for a Cassegrain antenna such as the one shown in Figure 2.7.a are

$$\eta = \eta_1 \eta_2 \eta_3 \eta_4 \eta_5 \eta_6 \qquad (3)$$

where

η_1= main reflector illumination efficiency

η_2= spillover efficiency

η_3= phase efficiency

η_4= sub-reflector efficiency

η_5= feed system dissipative efficiency

η_6= reflector surface tolerance efficiency

The illumination efficiency η_1 is determined by the characteristic of the field distribution across the main reflector aperture. If it is uniform over the entire aperture area, then η_1=1. The spillover efficiency η_2 represents not only the energy spilled over the edge of the main reflector but also the energy spilled over the edge of the sub-reflector. To minimize the spillover loss, a feed with low side-lobes in its radiation pattern is desired. To achieve this pattern, multiple modes are used in the design of the feed radiation section that is a horn. Furthermore, the feed angle subtended by the sub-reflector is chosen so that the main beam of the feed radiation pattern intersects the sub-reflector at a low level, minimizing the feed main beam spillover past the sub-reflector. However, the low edge illumination of the sub-reflector normally results in sharply tapered illumination across the main reflector aperture, resulting in a low illuminating efficiency η_1.

With a Cassegrain antenna this condition can be improved substantially by deliberately altering the shape of the sub-reflector to distribute the energy essentially uniformly nearly to the edge of the main reflector but then falling off very sharply. An illumination efficiency η_1 of 0.94 to 0.96 can be achieved in practice with a main reflector spillover efficiency of as high as 0.99. With good feed design, a sub-reflector spillover efficiency on the order of 0.98 can be realized. Thus a spillover efficiency of $\eta_2 = 0.97$ can be achieved in a shaped system.

Distorting the shape of the sub reflector to achieve uniform illumination across the main reflector results in a phase error being introduced into the main reflector. This phase error results in energy being radiated in undesired directions, thus decreasing the gain and increasing the sidelobe level of the antenna. The phase efficiency η_3 identifies this gain loss. Most of this loss can be eliminated, however, by reshaping the main reflector to correct the phase error. In a well-designed Cassegrain antenna the phase efficiency η_3 can be on the order of 0.98 and 0.99 at the design frequency and remain on the order of 0.95 over 70% of the operating 500-MHz band. Blocking of the main reflector aperture by the sub-reflector and support structure results in an effectively smaller aperture, hence a loss in the antenna gain. The sub-reflector blocking efficiency is about 0.97, and that of the support structure is about 0.95 in a well-designed antenna. The dissipative loss of the feed system also reduces the antenna gain. Depending on the feed system structure the efficiency η_5 can be as high as 0.94.

All the above-cited efficiency factors are primarily dependent on the main reflector and sub-reflector geometries and the feed system structure and not on the operating frequency. In practice the main reflector and sub-reflector cannot be built to the ideal shapes without some surface tolerance. This results in a scattering of energy in unwanted directions in a manner similar to that associated with the phase error. The surface tolerance may, in effect, be considered a special type of phase error which limits the maximum achievable gain G_M in the sense that, for a given surface tolerance and antenna diameter, increasing the operating frequency increases the antenna gain until it equals G_M . Further increasing the operating frequency will decrease the antenna gain. The surface tolerance efficiency η_6 imposes an upper limit on the maximum operating frequency, hence on the maximum antenna gain, and is fixed by current manufacturing technology. The reflector surface tolerance efficiency η_6 may be expressed as:

$$\eta_6 = \exp\left[- \left(\frac{4.\pi.\varepsilon}{\lambda} \right)^2 \right] \tag{4}$$

$$= \exp\left[- \left(\frac{\varepsilon}{D} \right)^2 \left(\frac{4.\pi.f.D}{c} \right)^2 \right] \tag{5}$$

where ε = rms reflector surface error (m) and εID = antenna surface tolerance. The factor $(4.\pi.\varepsilon / \lambda)^2$ is in effect the mean-square phase error introduced by the surface error ε. The antenna surface tolerance ε /D within current commercial technology is as follows:

$0^{-3} \leq \varepsilon ID \leq 10^{-4}$	$D \leq 1.2$ m
$2 \times 10^{-4} \leq \varepsilon ID \leq 5 \times 10^{-5}$	$2.5 \text{ m} \leq D \leq 6$ m
$10^{-4} \leq \varepsilon ID \leq 2 \times 10^{-5}$	$9 \text{ m} \leq D \leq 24$ m

The performance of a well-designed Ku-band 20-rn Cassegrain antenna with a beam wave-guide frequency reuse feed system is shown in Table 3.2:

Table 2.2 Parameters of a Ku-band 20-rn Cassegrain antenna

Parameters	11.95 GHz	14.25 GHz
Illumination efficiency	0.96	0.94
Main reflector	0.99	0.99
Sub-reflector	0.96	0.98
Phase efficiency	0.98	0.98
Sub-reflector	0.97	0.97
Support structure	0.95	0.95
Basic feed	0.94	0.93
Diplexer	0.96	0.98
Beam wave-guide	0.91	0.96
Main reflector	0.87	0.83
Sub-reflector	0.97	0.97
Net antenna efficiency	0.57	0.54
Antenna gain (dB)	65.53	66.82

C) 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 Figure 2.8. The antenna pointing loss can be evaluated from the antenna gain pattern, which is a function of the off-axis angle.

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 angels, is derived from the received signal. One of the commonly used antenna tracking systems for the earth stations is a step track that derives the antenna-positioning vector from the signal strength of a satellite beacon.

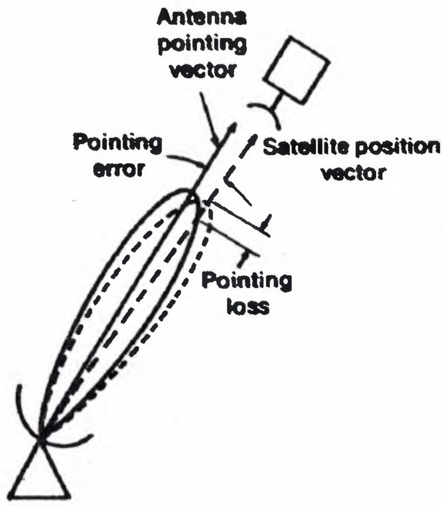


Figure 2.8 Antenna Pointing Error

D) Effective Isotopic 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's 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 station antenna. If we let P (t) denote the input power at the feed of the antenna and G (t) the transmit antenna gain, the earth station's EIRP is simply:

$$EIRP = P(t).\ G(t) \tag{6}$$

E) 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 in receiving the downlink carrier from the satellite. If a piece of wave-guide with a 0.53-dB loss is used to connect the input of the low noise amplifier to the output port of the receive system, the receive antenna gain referred to the input of the low noise amplifier is 65 dB. The parameter T is defined as the earth station system noise temperature referred also to the input of the low noise amplifier.

2.5.2.3 High Power Amplifier

One of the most widely used high power amplifiers in earth stations, the traveling wave tube amplifier. 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 helix. Electrons emitted from the cathode of the tube are focused into a beam along the axis of the helix by cylindrical magnets and removed at the end by the collector after delivering their energy to the RF field. The helix slows down the propagation velocity of the RF signal (the velocity) to that of the electron beam , which is controlled by the DC voltage at the cathode. Those results in an interaction between the electric field include by the RF signal and the electrons, which result 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 the earth station is the Klystron amplifier, which can provide higher gain and better efficiency than the traveling wave tube amplifier but a much smaller bandwidth. For low power amplification GaAs FET amplifiers are used. These are solid state amplifiers and offer much efficiancy than the above two types of amplifiers.

2.5.2.4 Up-converter

The Up converter accept the modulated IF carrier and translate its frequency ω_0 to the uplink frequency ω_u by mixing ω_0 with a local oscillator frequency ω_l.

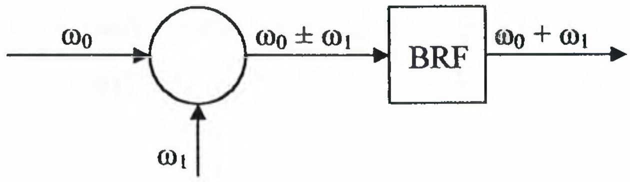


Figure 2.9 Function of up-converter

The up conversion may be accomplished by with a single or double conversion preprocess.

2.5.2.5 Down-converter

the down-converter receives the modulated RF carrier from the low noise amplifier and translates its radio frequency ω_d in the down-link frequency spectrum of the satellite to the intermediate frequency ω_0. Like up-conversion, down-conversion may be achieved with a signal conversion process or with a dual conversion process using mixer.

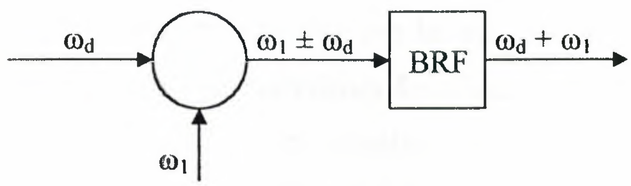


Figure 2.10 Function Of Down Converter

2.5.2.6 Redundancy Configuration

As we have seen in previous sections, except for the antenna all earth stations systems namely, the high-power amplifier, the up-converter, and the down-converter, must employ some sort of redundancy to maintain high reliability which is of utmost importance. When the on-line equipment in the redundancy configuration fails The standby equipment is automatically switched over and becomes the on-line equipment .The process of detecting critical failure modes and resolving all these failure modes by automatic switchover from the failed to the redundant system is called monitoring and control. Reliability 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 sort of redundancy configuration.

CHAPTER THREE

MULTIPLE ACCESS

3.1 Overview

One advantage of communications satellites over other transmission media is their ability to link all earth stations together, thereby providing point-to-multipoint communications. A satellite transponder can be accessed by many earth stations, and therefore it is necessary to have techniques for allocating transponder capacity to each of them. For example, consider a transponder with a bandwidth of 72 MHz. Assume that the bit duration-bandwidth product T_bB in (1.5) is chosen to be 0.6; that is, every 0.6 Hz of the transponder bandwidth can be used to transmit 1 bps. Then the transponder capacity is 120 Mbps, which can handle about 3562 voice channels at 32 kbps, assuming the transponder efficiency is 95%. It is unlikely that a single earth station would have this much traffic, therefore the transponder capacity must be wisely allocated to other earth station. Furthermore, to avoid chaos, we want the earth stations to gain access to the transponder capacity allocated to them in an orderly fashion. This is called multiple access. The most commonly used multiple access schemes are frequency division multiple access (FDMA), time division multiple access (TDMA) and code division multiple access (CDMA).

3.2 Frequency Division Multiple Access

FDMA has been used since the inception of satellite communication. Here each earth station in the community of earth stations that share the transponder capacity transmits one or more carriers to the satellite transponder at different center frequencies. Each carrier is assigned a frequency band in the transponder bandwidth, along with a small guard band to avoid interference between adjacent carriers. The satellite transponder receives all the carriers in its bandwidth, amplifies them, and retransmits them back to earth. The earth station in the satellite antenna beam served by the transponder can select the carrier that contains the messages intended for it. FDMA is illustrated in Figure 3.1. The carrier modulation used in FDMA is FM or PSK.

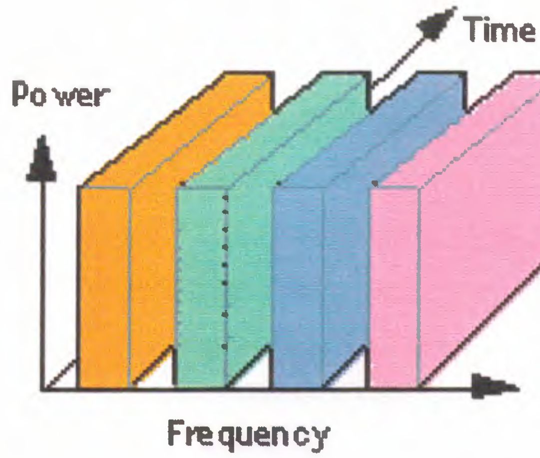


Figure 3.1 Concept of FDMA

The following are the features of FDMA:

1) If channel not in use, sits idle
2) Channel bandwidth relatively narrow (30kHz), ie, usually narrowband systems
3) Symbol time >> average delay spread .little or no equalization required
4) Best suited for analogue links bits needed
5) Requires tight filtering to minimize interference
6) Usually combined with FDD for duplexing

3.3 Time Division Multiple Access

In TDMA the earth stations that share the satellite transponder use a carrier at the same center frequency for transmission on a time division basis. Earth stations are allowed to transmit traffic bursts in a periodic time frame called the TDMA frames During the burst, an earth station has the entire transponder bandwidth available to it for transmission. The transmit timing of the bursts is carefully synchronized so that all the bursts arriving at the satellite transponder 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. TDMA is illustrated in Figure 3.2. The carrier modulation used in TDMA is always a digital modulation scheme. TDMA possesses many advantages over FDMA, especially in medium to heavy traffic networks, because there are a number of efficient techniques such as demand assignment and digital speech interpolation that are inherently suitable for TDMA and can maximize the amount of terrestrial traffic that can be handled by a satellite transponder. For example, a 72-MHz transponder can handle about 1781 satellite PCM voice channels or 3562 32-kbps adaptive differential PCM channels. With a digital speech interpolation technique it can handle about twice this number, 3562 terrestrial PCM voice channels or 7124 32-kbps adaptive differential PCM voice channels. In many TDMA networks employing demand assignment the amount of terrestrial traffic handled by the transponder can be increased many times. Of course these efficient techniques depend on the terrestrial traffic distribution in the network and must be used in situations that are suited to the characteristics of the technique. Although TDMA has many advantages, this does not mean that FDMA has no advantages over TDMA. Indeed, in networks with many links of low traffic, FDMA with demand assignment is overwhelmingly preferred to TDMA because of the low cost of equipment.

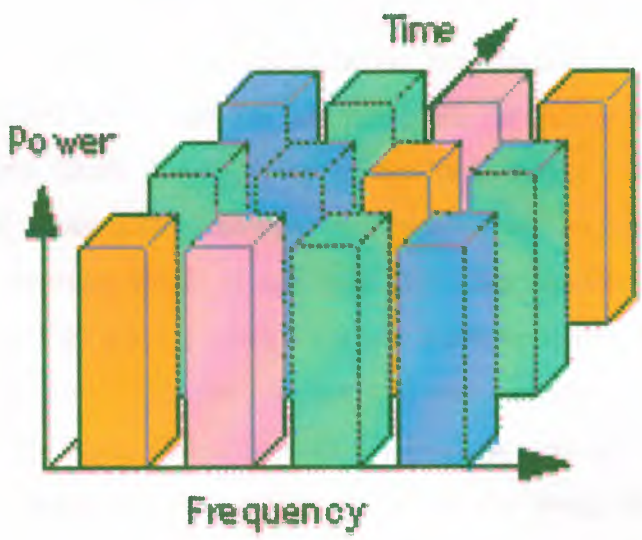


Figure 3.2 Concept of TDMA

Besides FDMA and TDMA, a satellite system may also employ random multiple access schemes to serve a large population of users with bursty (low duty cycle) traffic.

Here each user transmits at will and, if a collision (two users transmitting at the same time, causing severe interference that destroys their data) occurs, retransmits at a randomly selected time to avoid repeated collisions. Another type of multiple access scheme is code division multiple access, where each user employs a particular code address to spread the carrier bandwidth over a much larger bandwidth so that the earth station community can transmit simultaneously without frequency or time separation and with low interference.

TDMA has some advantages that are, In addition to increasing the efficiency of transmission, TDMA offers a number of other advantages over standard cellular technologies. First and foremost, it can be easily adapted to the transmission of data as well as voice communication. TDMA offers the ability to carry data rates of 64 kbps to 120 Mbps (expandable in multiples of 64 kbps). This enables operators to offer personal communication-like services including fax and voiceband data, as well as bandwidth-intensive applications such as multimedia and videoconferencing.

Unlike spread-spectrum techniques which can suffer from interference among the users all of whom are on the same frequency band and transmitting at the same time, TDMA's technology, which separates users in time, ensures that they will not experience interference from other simultaneous transmissions. TDMA also provides the user with extended battery life and talk time since the mobile is only transmitting a portion of the time (from 1/3 to 1/10) of the time during conversations. TDMA installations offer substantial savings in base-station equipment, space, and maintenance, an important factor as cell sizes grow ever smaller. TDMA is the most cost-effective technology for upgrading a current analogue system to digital. TDMA is the only technology that offers an efficient utilization of hierarchical cell structures (HCSs) offering pico, micro, and macrocells. HCSs allow coverage for the system to be tailored to support specific traffic and service needs. By using this approach, system capacities of more than 40-times AMPS can be achieved in a cost-efficient way. Because of its inherent compatibility with FDMA analogue systems, TDMA allows service compatibility with the use of dual-mode handsets.

Also TDMA has some disadvantages, one of these disadvantages of TDMA is that each user has a predefined time slot. However, users roaming from one cell to another are not allotted a time slot. Thus, if all the time slots in the next cell are already occupied, a call might well be disconnected. Likewise, if all the time slots in the cell in which a user happens to be in are already occupied, a user will not receive a dial tone.

Another problem with TDMA is that it is subjected to multipath distortion. A signal coming from a tower to a handset might come from any one of several directions. It might have bounced off several different buildings before arriving which can cause interference.

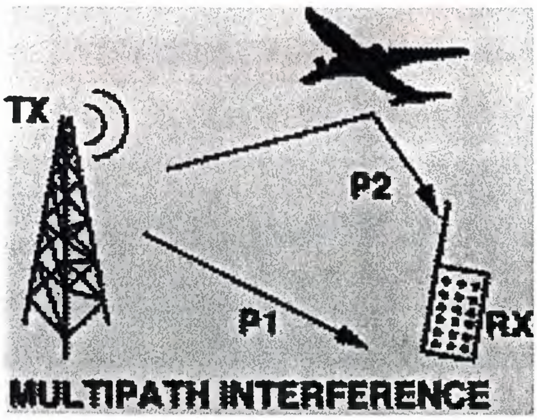


Figure 3.3 Multi-Path Inter-Face

One way of getting around this interference is to put a time limit on the system. The system will be designed to receive, treat, and process a signal within a certain time limit. After the time limit has expired, the system ignores signals. The sensitivity of the system depends on how far it processes the multipath frequencies. Even at thousandths of seconds, these multipath signals cause problems.

3.4 Code Division Multiple Access

Code division multiple access (CDMA) is actually a hybrid combination of the use of FDMA and TDMA. Users are assigned to different codes which govern the time slot and frequency band for the signal transmission, see Figure 3.4. At one instant (time slot), a user is only allowed to use one of the frequency bands which is unoccupied by the others. By this scheme, the channel capacity can greatly increase with the minimum degree of interference by the other users.

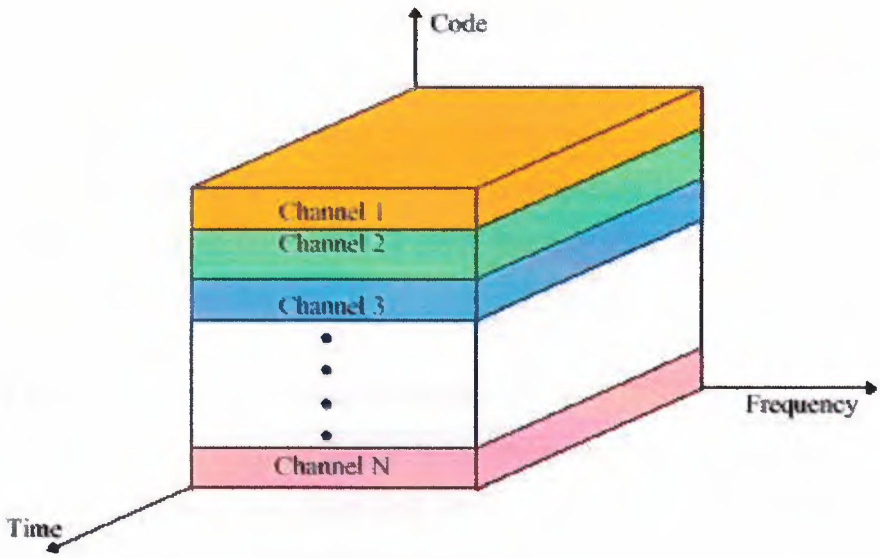


Figure 3.4 Concept of CDMA

CDMA is an application of spread spectrum (SS) techniques which can increase the channel capacity for signal transmission and reduce interference by the other users.

CDMA has some advantages over TDMA & FDMA; Since each user is assigned a unique code for transmission and reception, without this code one cannot receive the signal transmitted by the other user. Therefore, communication privacy can be achieved by eliminating the interception of unauthorized users without the code. Below are the advantages of CDMA over TDMA & FDMA.

1) **Anti-jamming capability:** In direct sequence CDMA system, the narrow band signal is spreaded by a spreading code over a wide band. Since the original signal is spreaded over a wide band with very low power, without knowing the exact code, the spreaded signal is a noise-like spectrum Intended jammers would not know what frequency to interfere the signal. This is also true for frequency hopping CDMA since the carrier is in pseudo-random pattern.
2) **Flexibility:** This is an obvious advantage of CDMA over TDMA system. Since the codes between different users are orthogonal to each other, there is no need for precise time coordination among the various simultaneous transmitters. It is important to design a set of codes based on the criteria of its autocorrelation and cross-correlation.

3) **Fading Immunity:** This is an obvious advantage of CDMA over FDMA system. If a particular frequency band suffer from severe channel fading, an user assigned to this band by FDMA would experience high degradation in communication. However, in frequency hopping CDMA, since the carrier is shifting, only a small fraction of time the signal is affected by the channel fading.

3.5 Advantages Of Digital Transmission

Communications by digital signaling is an increasingly important technique for radio communication by satellite relay and other means. Digital transmission has a number of advantages over other techniques. These include:

1) the ease and efficiency of multiplexing multiple signals or handling digital messages in "packets" for convenient switching;
2) The relative insensitivity of digital circuits to retransmission noise, commonly a problem with analogue systems;
3) potential for extremely low error rates and high fidelity through error detection and correction;
4) communications privacy;
5) the flexibility of digital hardware implementation, which permits the use of microprocessors and miniprrocessor, digital switching, and the use of large scale integrated (LSI) circuits.

Digital transmission techniques are gaining increased usage for satellite communication, microwave relay, and cable or wave-guide transmission. However, the original and final forms of the information transmitted by the digital link may be analogue voice or video and therefore the analogue/digital interface is an important element of the communications system.

Most satellite communication is at microwave frequencies largely because the available bandwidth is substantial. However, transmission in the UHF frequency band has important application to relatively low data rate mobile users where near-omni directional antennas are employed.

CHAPTER FOUR

APPLICATION OF SATELLITE NETWORKS

4.1 Overview

The purpose of operating a satellite in orbits is clearly to provide connections between earth stations, which in turn deliver or originate various types of communications service. Application of such satellite networks, are broken down into the broad categories of video, telephone, and data. The first part of this chapter reviews the features and generic arrangements of networks independent of the specific use. This provides a cross reference with regard to the applications which are reviewed in detail at the end of this chapter.

4.2 Connectivity

The manner in which points on the earth are linked between each other is called "connectivity". There are three generic forms of connectivity: point-to-point, point-to-multi point, and multipoint –to-point. Each of these connectivities, reviewed in the following paragraphs, can be established through one satellite and two or more earth stations. Comparisons are made with implementations of the same connectivities using terrestrial communications technology .It is shown that while terrestrial systems compete favorably on a point-to-point basis, satellite networks have a decided advantage whenever a multipoint connectivity is needed.

4.2.1 Point –to- Point

The simplest type connectivity is point-to-point, illustrated in Figure 4.1 with two earth stations both transmitting simultaneously to the satellite .A pair of earth stations transmit RF carriers one to another (and receive each others carriers), creating what is called a duplex link. The parties being served can thereby talk or transmit information in both directions at the same time the uplink sections of the satellite repeater receives both transmissions and after translation to the downlink frequency range, transmits them back toward the ground. Reception by and earth station of the opposite ends transmission completes the link. In most cases, transmission between earth stations through the satellite repeater are continues in time. If the satellite provides a single footprint covering both earth stations, then a given station can receive in the downlink its own information as well as that of its communicating partner. This supplementary ability provides a unique way for stations to verify the content and equality of satellite transmission.

Atypical network of several earth stations and a satellite provides many duplex point-to-point links to interconnects the locations on the ground. There are many possible circuit routings between the locations. In a fully interconnected "mesh" network. The maximum number of possible links between N earth stations is equal to N(N-1)/2.To prevent harmful RF interference; all stations cannot be on the same frequency at the same time. The technology which allows the needed simultaneous transmission without RFI through the satellite repeater is called multiple access.

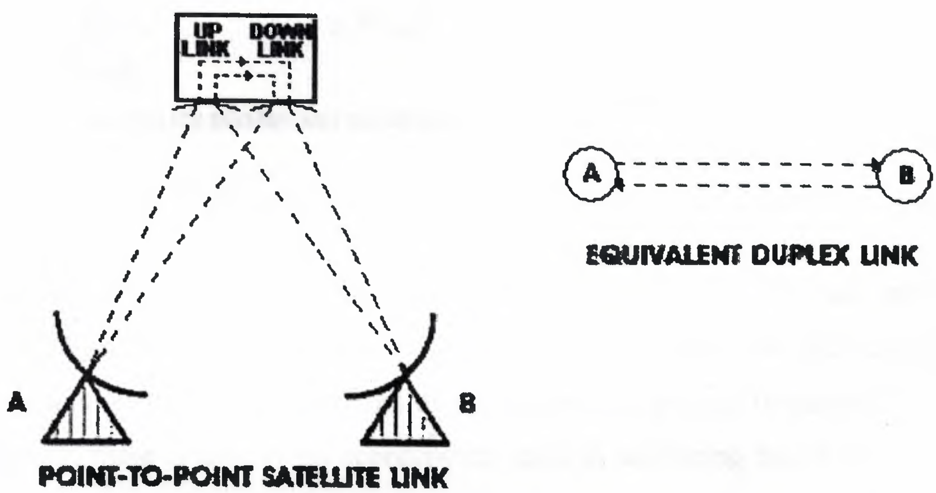


Figure 4.1 Point-to-Point Connectivity Using Full Duplex Satellite Link

4.2.2 Point-to-Multipoint

While point-to-point links are easily achieved by satellite, it is the point –to-multipoint link which takes full advantage of the wide area coverage of the satellites footprint. Figure 4.2 indicates how satellite broadcasting is accomplished with one transmitting earth station (called the uplink in common practice) and many receives – only (RO) earth stations. The satellite repeater retransmits the single RF carrier containing the information to be distributed. It is usually advantageous to use the highest satellite transmit power possible, because this allows the use of smaller diameter (less expensive) RO antennas on the ground. As the number of RO s increase in to hundreds of thousands or millions, the optimum transmitter power to use in space becomes much larger than that permitted at C band by the ITU. BSS segment of Ku band is available for such high-power broadcast applications. The cost of the more expensive BSS satellite is shared among more and more users, who than saves substantial amounts on the cost of their ground equipment. This is an economic tradeoff between the cost of the satellite and that of the ground segment.

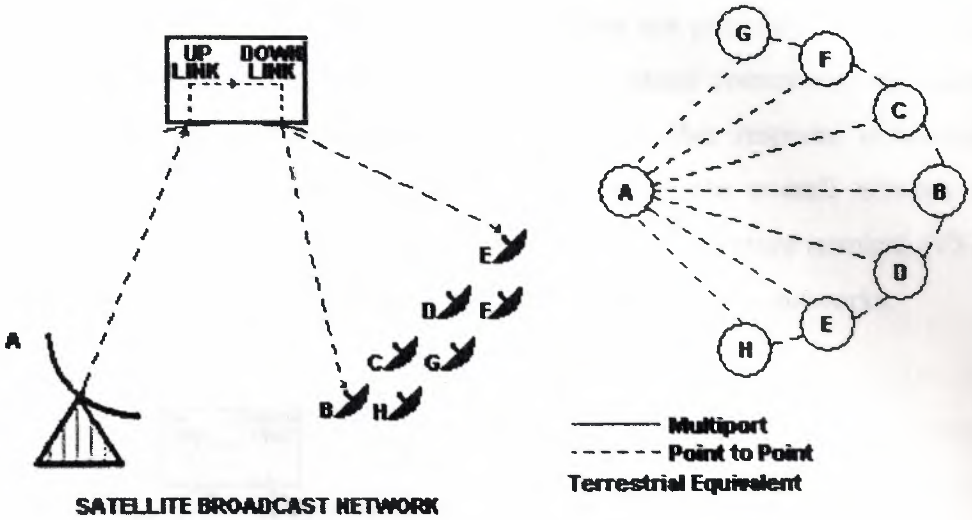


Figure 4.2 point-to-Multipoint Connectivity Providing a one-way Broadcast Capability.

Achieving point-to-multipoint connectivity with a terrestrial network is extremely expensive, since the cost of adding cable or microwave facilities to reach service points is roughly proportional to the number of points. In contrast to satellite broadcasting, there is usually no economy on scale in delivering broadcast information terrestrially. There is a terrestrial approach, wherein the receiving points are chained together. This tends to be less reliable on an overall basis because users are delivered the signal along the route of the system (i.e., a chain is no stronger than its weakest link). The first use of terrestrial microwave for TV distribution was accomplished in this manner. In data communication, a terrestrial chain of this type using telephone circuits is called a multidrop line.

4.2.3 Multipoint-to-Point

A multipoint-to-point satellite network compliments the broadcast approach by allowing remote stations to send information back to the central station. As shown in figure 4.3, this type of connectivity provides two-way communication because the remotes receive the broadcast from the central station and can transmit back over the same satellite. It is different from a point-to-point network because the remote stations cannot communicate directly with one another but must do so through the central station, commonly referred to as the hub. In figure 4.3, the remotes efficiently transmit packets of data toward the satellite on the same frequency but timed such that the packets do not overlap when they enter the satellite repeater. Multipoint-to-point networks are an important extension of point-to-point because of the relatively small antenna size and simplicity of the remote station. These are afforded by using a more sophisticated hub station with a large-diameter antenna. Many commercial applications can effectively use this type of connectivity where subscriber response is necessary. Modern intelligence to the remote stations while keeping the overall network cost competitive with modern terrestrial networks. The very small aperture terminal (VSAT) is type of inexpensive earth station used in large multipoint-to-point networks.

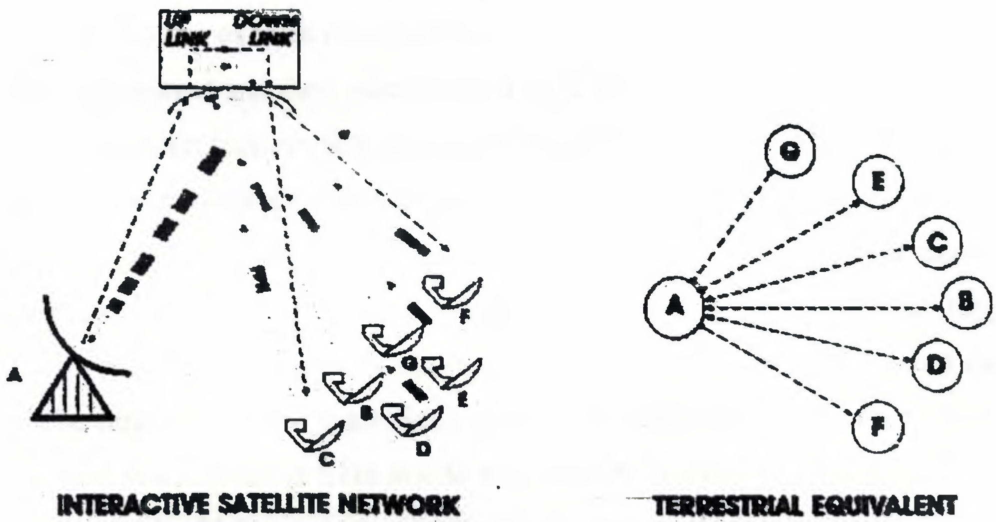


Figure 4.3 Interactive Satellite Network Using Multipoint-to-Point Connectivity.

4.3 Flexibility

A satellite-based network is inherently very flexible from a number of perspectives, which are described in the following paragraphs.

4.3.1 Implementation of Satellite Networks

To begin with, the implementation of the ground segment of a satellite network is relatively simple primarily because the number of physical installations is minimal. To put in a satellite network, a planner need only consider the sites where service is required.

Installation of a fiber optic cable system requires first that the right-of-way be secured from organizations such as governments, utility companies, and railroads. Hundreds or even thousands of sites must be provided with shelter and power (and even access roads in the case of terrestrial microwave). After the entire system is installed and tested, all of the equipment must be maintained to assure continuous service. Even still, one outage along the route will probably put the entire chain out of services until a crew and equipment can arrive on the scene to effect repair.

In contrast, the time to install an earth station network is relatively short, particularly if the sites are close to where service is provided. This assumes that a space a space segment already exists. In the past, implementation times for earth stations were lengthened, not because of sites construction, but rather because electronic equipment had to be special ordered and then manufactured. The low production volumes (because satellite communication requires less equipment in general than terrestrial) discouraged manufacturers from mass production standardized equipment and holding inventory for future sales. In today's larger and more competitive earth station equipment marked, higher manufacturing volumes along with the arrival of more standardized digital systems have allowed equipment suppliers to reduce cost and maintain on-the-shelf inventory. The time to implement satellite networks and add stations has been reduced from one to two years down to from one to two months. In contrast, a terrestrial fiber network is like a major highway project and will take years to design and construct.

4.3.2 Expansion of the Network

With a proper network architecture, new earth stations can be added without affecting the existing stations. This reduces the expansion timeframe to a few months or weeks, since all that needs to be done is to purchase the equipment, prepare the site, and then install the stations. Increasing the number of ROs is particularly easy and economical, and operation of existing stations is not affected. Satellite networks of the 1970s providing point-to-point links could not be modified easily because of the old, inflexible analogue technology employed.

To add an earth station to an old analogue point-to point network would require dismantling the equipment at each station to be linked with the new station. This major drawback of the older system has been eliminated with programmable digital technology. These more flexible digital approaches, can now be assumed in virtually every future application involving two-way communication.

4.3.3 Simplification of Network Routing

Rather than purchasing new long distance facilities for their exclusive use, many users lease voice and data circuit from terrestrial network operation (called *common carries* in North America). Therefore, the "backbone" network would already exist, and the only time necessary for implementation of such a private network is that needed to run local cable loops or to make appropriate wiring changes in the telephone offices. Time delays of many weeks month or still involved, however, beginning from the moment when service order are placed. The common carrier must then perform the network engineering install equipment if necessary and make the required wiring change. And then test the resulting circuit for proper operation. If the circuit or circuits cross the bond-aries between the terrestrial networks of different providers, then the process must be run simultaneously by the various organizations and coordination between them must be handled in some manner. In a modern satellite network, only the end connections are involved, because the satellite itself provides all of the intermediate routing.

Terrestrial networks must deliver multipoint connectivity by extending terrestrial links to each and every point to be served. There are terrestrial radio techniques which limit satellites by placing omnidirectional (i.e., wide, circular area coverage) repeaters on tours or mounting tops. Broadcast radio and TV work on a point-to-multipoint basis, and cellular mobile telephone is an excellent multipoint-to-point system. All such terrestrial techniques, however, are severely restricted as to range because of light-of-sight radio propagation. To extend will beyond this geographical limitation, less reliable point-to-point links must be established between the radio tours to change the broadcast of cellular stations together.

4.3.4 Introduction to Services

Expansion of a satellite network can add new services, many of which can not currently be accommodated terrestrial. Perhaps clearest example is the long distance transmission of full motion color television, which, as noted earlier, could not be carried over transoceanic telephone cables. It was until the advent of terrestrial microwave radio in North America that cost-to-cost TV transmission was possible. Satellite repeaters in the FSS have sufficient bandwidth to carry several TV channels along with an array of voice and data traffic. On a local level, the local telephone loops which bring voice and low-speed data services into the office and home are currently very limited in their capacity. Home cable television service is made possible only with a separate coaxial cable, and interactive two-way video teleconferencing is only provided on a very limited basis over terrestrial systems. Any and all of these services can be included in, or added to, the current generation of small earth station, particularly the VSAT operating at Ku band. Therefore, flexibility of satellite communication takes on added dimensions with new services which can not currently be offered on a single terrestrial network.

The three generic types of connectivity were covered in the previous section. It is very noteworthy that a given satellite network can achieve these connectivities individually or simultaneously. While a terrestrial network is usually restricted to a point-to-point capability. It is not uncommon for a user to implement a point-to-point satellite network involving from 10 to 50 earth stations and then add a broadcast capability to extend the network to hundreds or even thousands of receiving points. Any one of the point-to-point stations could then be used as an uplink site to broadcast digital information or video programming on an occasional basis. The multipoint-to-point capability can be installed in the future by adding transmit "retrofit" package to many of the smaller receive only stations.

4.4 Reliability

The remaining features to be described are more difficult to explain and quantify: they can, however, ultimately be the factors, which decide in favor of satellite transmission over terrestrial. The mere fact that a satellite link requires only one repeater hop, or a maximum of two in the case of international services, tends to make the satellite connection extremely reliable. The engineering of the link, must properly take into account the frequency band and fade margin requirements. When this is done and an establish satellite is employed, the link will be up and usable for well in excess of 99% of the time. In fact, satellite engineers normally talk of the link reliabilities of 99.99%, which equates to an outage or downtime of nine hours in an entire year. Normally, this outage is segmented into duration's of a few minutes distributed mainly through the rainiest months.

Long distance terrestrial systems normally provide reliabilities in the range of from 95 to 98%, where outage can be produced by fades on any of its radio paths (in the case of terrestrial microwave) and by equipment outage at any of the hundreds of repeater sites along the route. Cable systems are susceptible to accidental breakage or detection of the cable itself, and outages of several hours or even days at a time do occur. A single buried cable or microwave system is relatively unreliable due to the inevitable breakage or failure. Therefore reliable means of communication, although the cost of implementation would only be within the range of relatively wealthy organizations (AT&T. govern- ments , and major industrial corporations).

Equipment failures on satellite links do occur, and for that the reason backup systems are provided. A communication satellite contain essentially 100% backup for all of its critical subsystem to prevent a catastrophic failure. The individual transponders to transmitters within the repeater section will usually not be speared 100%, so that a fractional loss of capacity is possible at some time in the useful orbital life. Experience with modern commercial satellite ahs been excellent, and users have come to except near perfection in the reliability of these spacecraft. The principle cause of communication outage is not failure of satellite hardware but rather is due to double illumination problem described in chapter1 Harmful radio frequency interference (RFI) is a fairly routine occurrence and satellite operators are reasonably well equipped respond to and identify the source of the problem (which is almost always accidental and of short duration).

The reliability of satellite communication is enhanced by the fact that virtually all of the ground facilities can be under direct control of one using organization. If a problem occurs with equipment or its interface with other facilities such as telephone switches or computer, the user's technical support personnel can easily identify and reach the trouble spot. Restoration of service can thus be accomplished conveniently and quickly, Terrestrial linkups can involved many organizations which provide services in section of the country or city, complicating the necessary troubleshooting and follow-up. For example, the former AT and T Bell System was broken up in the United State in 1983, resulting in the creating of seven independent corporation, each controlling roughly one-seventh of the local telephone service of the country. AT and T

NEAR EAST UNIVERSITY

Faculty of Engineering

Department of Electrical and Electronic Engineering

DIGITAL SATELLITE COMMUNICATION

Graduation Project
EE- 400

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Finally, Special thanks for all my friends and companions who supported me at all times and for all the pleasant moments that we enjoyed in our course of study in the NEU."

ABSTRACT

A communications satellite is a spacecraft that carries aboard communications equipment, enabling a communication link to be established between distant points. Satellites are hanged on their orbits as a result of the balance between centrifugal gravitational forces.

A communication satellite permits two or more points on the ground (earth stations) to send messages one to another over great distances using radio waves.

Hundreds of active communication satellites are now in orbit. They receive signals from one ground station, amplify them, and then retransmit them at a different frequency to another station. Satellites use ranges of different frequencies, measured in hertz (Hz) or cycles per second, for receiving and transmitting signals.

The main objective of this Thesis is to represent basic elements of satellite communication systems, including *Frequency Allocation*, *Earth Station*, *Transponder*, *Methods of Access* and some of *Satellite Applications*.

The described topics give the reader enough information for understanding the architecture and principle of *Satellite Communication Systems*.

INTRODUCTION

Satellite communication has evolved into an everyday, commonplace thing. Most television coverage travels by satellite, even reaching directly to the home from space. No longer is it a novelty to see that a telecast has been carried by satellite (in fact, it would be novel to see something delivered by other means). The bulk of transoceanic telephone and data communication also travels by satellite. For countries such as Indonesia, domestic satellite have greatly improved the quality of service from the public telephone system and brought nations more tightly together.

Some of the first communications satellites were designed to operate in a passive mode. Instead of actively transmitting radio signals, they served merely to reflect signals that were beamed up to them by transmitting stations on the ground. Signals were reflected in all directions, so receiving stations around the world could pick them up.

This project consists of four chapters;

Chapter one is Introduction to Digital Satellite Communication; in this chapter we presented the history, development and new technologies.

Chapter two Satellite Communication; here we gave a description for the Satellite Systems and Services, presenting the Satellite Frequency Bands, Orbits, Construction, Launching And Earth Station substructure.

Chapter three Multiple Access; the methods of Satellite Access are explained in this chapter, Multiple Access Methods are: Frequency Division Multiple Access FDMA Time Division Multiple Access TDMA and Code Division Multiple Access CDMA. Comparisons are represented between the former three methods.

Chapter Four application of satellite networks the first part of this chapter reviews the features and generic arrangements of networks independent of the specific use. This provides a cross reference with regard to the applications which are reviewed in detail at the end of this chapter.

CHAPTER ONE

INTRODUCTION TO DIGITAL SATELLITE COMMUNICATION

1.1 Histories and Development

Some of the first communications satellites were designed to operate in a passive mode. Instead of actively transmitting radio signals, they served merely to reflect signals that were beamed up to them by transmitting stations on the ground. Signals were reflected in all directions, so they could be picked up by receiving stations around the world. *Echo 1,* launched by the United States in 1960, consisted of an aluminized plastic balloon 30 m (100 ft) in diameter. Launched in 1964, *Echo 2* was 41 m (135 ft) in diameter. The capacity of such systems was severely limited by the need for powerful transmitters and large ground antennas.

Satellite communications currently make exclusive use of active systems, in which each satellite carries it own equipment for reception and transmission. *Score,* launched by the United States in 1958, was the first active communications satellite. It was equipped with a tape recorder that stored messages received while passing over a transmitting ground station. These messages were retransmitted when the satellite passed over a receiving station. *Telstar 1,* launched by American Telephone and Telegraph Company in 1962, provided direct television transmission between the United States, Europe, and Japan and could also relay several hundred-voice channels. Launched into an elliptical orbit inclined 45° to the equatorial plane, *Telstar* could only relay signals between two ground stations for a short period during each revolution, when both stations were in its line of sight.

Hundreds of active communications satellites are now in orbit. They receive signals from one ground station, amplify them, and then retransmit them at a different frequency to another station. Satellites use ranges of different frequencies, measured in hertz (Hz) or cycles per second, for receiving and transmitting signals. Many satellites use a band of frequencies of about 6 billion hertz, or 6 gig hertz (GHz) for upward, or uplink, transmission and 4 GHZ for downward, or downlink, transmission. Another band at 14 GHZ (uplink) and 11 or 12 GHZ (downlink) is also much in use, mostly with fixed (nonmobile) ground stations. A band at about 1.5 GHZ (for both uplink and downlink) is used with small, mobile ground stations (ships, land vehicles, and aircraft). Solar energy cells mounted on large panels attached to the satellite provide power for reception and transmission. In 500 years, when humankind looks back at the dawn of space travel, Apollo's landing on the Moon in 1969 may be the only event remembered. At the same time, however, Lyndon B. Johnson, himself an avid promoter of the space program, felt that reconnaissance satellites alone justified every penny spent on space. Weather forecasting has undergone a revolution because of the availability of pictures from geostationary meteorological satellites-pictures we see every day on television. All of these are important aspects of the space age, but satellite communications has probably had more effect than any of the rest on the average person. Satellite communications is also the only truly commercial space technology -generating billions of dollars annually in sales of products and services.

In fall of 1945 an RAF electronics officer and member of the British Interplanetary Society, Arthur C. Clarke, wrote a short article in *Wireless World* that described the use of manned satellites in 24-hour orbits high above the world's land masses to distribute television programs. His article apparently had little lasting effect in spite of Clarke's repeating the story in his 1951/52 *The Exploration of Space*. Perhaps the first person to carefully evaluate the various technical options in satellite communications *and* evaluate the financial prospects was John R. Pierce of AT&T's Bell Telephone Laboratories who, in a 1954 speech and 1955 article, elaborated the utility of a communications "mirror" in space, a medium-orbit "repeater" and a 24-hour-orbit "repeater." In comparing the communications capacity of a satellite, which he estimated at 1,000 simultaneous telephone calls, and the communications capacity of the first trans-Atlantic telephone cable (TAT-1), which could carry 36 simultaneous telephone calls at a cost of 30-50 million dollars, Pierce wondered if a satellite would be worth a billion dollars.

After the 1957 launch of Sputnik I, many considered the benefits, profits, and prestige associated with satellite communications. Because of Congressional fears of "duplication," NASA confined itself to experiments with "mirrors" or "passive" communications satellites (ECHO), while the Department of Defense was responsible for "repeater" or "active" satellites which amplify the received signal at the satellite providing much higher quality communications. In 1960 AT&T filed with the Federal

Communications Commission (FCC) for permission to launch an experimental communications satellite with a view to rapidly implementing an operational system. The U.S. government reacted with surprise there was no policy in place to help execute the many decisions related to the AT&T proposal. By the middle of 1961, NASA had awarded a competitive contract to RCA to build a medium-orbit (4,000 miles high) active communication satellite (RELAY); AT&T was building its own medium-orbit satellite (TELSTAR) which NASA would launch on a cost-reimbursable basis; and NASA had awarded a sole source contract to Hughes Aircraft Company to build a 24-hour (20,000 mile high) satellite (SYNCOM). The military program, ADVENT, was cancelled a year later due to complexity of the spacecraft, delay in launcher availability, and cost over-runs.

By 1964, two TELSTARs, two RELAYs, and two SYNCOMs had operated successfully in space. This timing was fortunate because the Communications Satellite Corporation (COMSAT), formed as a result of the Communications Satellite Act of 1962, was in the process of contracting for their first satellite. COMSAT's initial capitalization of 200 million dollars was considered sufficient to build a system of dozens of medium-orbit satellites. For a variety of reasons, including costs, COMSAT ultimately chose to reject the joint AT&T/RCA offer of a medium-orbit satellite incorporating the best of TELSTAR and RELAY. They chose the 24-hour-orbit (geosynchronous) satellite offered by Hughes Aircraft Company for their first two systems and a TRW geosynchronous satellite for their third system. On April 6, 1965 COMSAT's first satellite, EARLY BIRD, was launched from Cape Canaveral. Global satellite communications had begun.

Some glimpses of the Global Village had already been provided during experiments with TELSTAR, RELAY, and SYNCOM. These had included televising parts of the 1964 Tokyo Olympics. Although COMSAT and the initial launch vehicles and satellites were American, other countries had been involved from the beginning. AT&T had initially negotiated with its European telephone cable "partners" to build earth stations for TELSTAR experimentation. NASA had expanded these negotiations to include RELAY and SYNCOM experimentation. By the time EARLY BIRD was launched, communications earth stations already existed in the United Kingdom, France, Germany, Italy, Brazil, and Japan. Further negotiations in 1963 and 1964 resulted in a new international organization, which would ultimately assume ownership of the satellites and responsibility for management of the global system. On August 20, 1964, agreements were signed which created the International Telecommunications Satellite Organization (INTELSAT).

By the end of 1965, EARLY BIRD had provided 150 telephone "half- circuits" and 80 hours of television service. The INTELSAT II series was a slightly more capable and longer-lived version of EARLY BIRD. Much of the early use of the COMSAT/INTELSAT system was to provide circuits for the NASA Communications Network (NASCOM). The INTELSAT III series was the first to provide Indian Ocean coverage to complete the global network. This coverage was completed just days before one half billion people watched APOLLO 11 land on the moon on July 20, 1969.

From a few hundred-telephone circuits and a handful of members in 1965, INTELSAT has grown to a present-day system with more members than the United Nations and the capability of providing hundreds of thousands of telephone circuits. Cost to carriers per circuit has gone from almost $100,000 to a few thousand dollars. Cost to consumers has gone from over $10 per minute to less than $1 per minute. If the effects of inflation are included, this is a tremendous decrease! INTELSAT provides services to the entire globe, not just the industrialized nations.

In 1965, ABC proposed a domestic satellite system to distribute television signals. The proposal sank into temporary oblivion, but in 1972 TELESAT CANADA launched the first domestic communications satellite, ANIK, to serve the vast Canadian continental area. RCA promptly leased circuits on the Canadian satellite until they could launch their own satellite. The first U.S. domestic communications satellite was Western Union's WESTAR I, launched on April 13, 1974. In December of the following year RCA launched their RCA SATCOM F- 1. In early 1976 AT&T and COMSAT launched the first of the COMSTAR series. These satellites were used for voice and data, but very quickly television became a major user. By the end of 1976 there were 120 transponders available over the U.S., each capable of providing 1500 telephone channels or one TV channel. Very quickly the "movie channels" and "super stations" were available to most Americans. The dramatic growth in cable TV would not have been possible without an inexpensive method of distributing video.

The ensuing two decades have seen some changes: Western Union is no more; Hughes is now a satellite operator as well as a manufacturer; AT&T is still a satellite operator, but no longer in partnership with COMSAT; GTE, originally teaming with Hughes in the early 1960s to build and operate a global system is now a major domestic satellite operator. Television still dominates domestic satellite communications, but data has grown tremendously with the advent of very small aperture terminals (VSATs). Small antennas, whether TV-Receive Only (TVRO) or VSAT are a commonplace sight all over the country.

1.2 New Technology

The first major geosynchronous satellite project was the Defense Department's ADVENT communications satellite. It was three-axis stabilized rather than spinning. It had an antenna that directed its radio energy at the earth. It was rather sophisticated and heavy. At 500-1000 pounds it could only be launched by the ATLAS- CENTAUR launch vehicle. ADVENT never flew, primarily because the CENTAUR stage was not fully reliable until 1968, but also because of problems with the satellite. When the program was canceled in 1962 it was seen as the death knell for geosynchronous satellites, three-axis stabilization, the ATLAS-CENTAUR, and complex communications satellites generally. Geosynchronous satellites became a reality in 1963, and became the only choice in 1965. The other ADVENT characteristics also became commonplace in the years to follow.

In the early 1960s, converted intercontinental ballistic missiles (ICBMs) and intermediate range ballistic missiles (IRBMs) were used as launch vehicles. These all had a common problem: they were designed to deliver an object to the earth's surface, not to place an object in orbit. Upper stages had to be designed to provide a delta-Vee (velocity change) at apogee to circularize the orbit. The DELTA launch vehicles, which placed all of the early communications satellites in orbit, were THOR IRBMs that used the VANGUARD upper stage to provide this delta-Vee. It was recognized that the DELTA was relatively small and a project to develop CENTAUR, a high-energy upper stage for the ATLAS ICBM, was begun. ATLAS-CENTAUR became reliable in 1968 and the fourth generation of INTELSAT satellites used this launch vehicle. The fifth generation used ATLAS-CENTAUR and a new launch-vehicle, the European ARIANE. Since that time other entries, including the Russian PROTON launch vehicle and the

Chinese LONG MARCH have entered the market. All are capable of launching satellites almost thirty times the weight of EARLY BIRD. In the mid-1970s several satellites were built using three-axis stabilization. They were more complex than the spinners, but they provided more despun surface to mount antennas and they made it possible to deploy very large solar arrays. The greater the mass and power, the greater the advantage of three-axis stabilization appears to be. Perhaps the surest indication of the success of this form of stabilization was the switch of Hughes, closely identified with spinning satellites, to this form of stabilization in the early 1990s. The latest products from the manufacturers of SYNCOM look quite similar to the discredited ADVENT design of the late 1950s.

Much of the technology for communications satellites existed in 1960, but would be improved with time. The basic communications component of the satellite was the traveling-wave-tube (TWT). These had been invented in England by Rudoph Kompfner, but they had been perfected at Bell Labs by Kompfner and J. R. Pierce. All three early satellites used TWTs built by a Bell Labs alumnus. These early tubes had power outputs as low as 1 watt. Higher- power (50-300 watts) TWTs is available today for standard satellite services and for direct-broadcast applications. An even more important improvement was the use of high-gain antennas. Focusing the energy from a 1-watt transmitter on the surface of the earth is equivalent to having a 100-watt transmitter radiating in all directions. Focusing this energy on the Eastern U.S. is like having a 1000-watt transmitter radiating in all directions. The principal effect of this increase in actual and effective power is that earth stations are no longer 100-foot dish reflectors with cryogenically-cooled maser amplifiers costing as much as $10 million (1960 dollars) to build. Antennas for normal satellite services are typically 15-foot dish reflectors costing $30,000 (1990 dollars). Direct-broadcast antennas will be only a foot in diameter and cost a few hundred dollars.

1.3 Mobile Services

In February of 1976 COMSAT launched a new kind of satellite, MARISAT, to provide mobile services to the United States Navy and other maritime customers. In the early 1980s the Europeans launched the MARECS series to provide the same services. In 1979 the UN International Maritime Organization sponsored the establishment of the International Maritime Satellite Organization (INMARSAT) in a manner similar to INTELSAT. INMARSAT initially leased the MARISAT and MARECS satellite transponders, but in October of 1990 it launched the first of its own satellites, INMARSAT II F-1. The third generation, INMARSAT III, has already been launched. An aeronautical satellite was proposed in the mid-1970s. A contract was awarded to General Electric to build the satellite, but it was canceled--INMARSAT now provides this service. Although INMARSAT was initially conceived as a method of providing telephone service and traffic-monitoring services on ships at sea, it has provided much more. The journalist with a briefcase phone has been ubiquitous for some time, but the Gulf War brought this technology to the public eye.

The United States and Canada discussed a North American Mobile Satellite for some time. In the next year the first MSAT satellite, in which AMSC (U.S.) and TMI (Canada) cooperate, will be launched providing mobile telephone service via satellite to all of North America.

In 1965, when EARLY BIRD was launched, the satellite provided almost 10 times the capacity of the submarine telephone cables for almost 1/10th the price. This price-differential was maintained until the laying of TAT-8 in the late 1980s. TAT-8 was the first fiber-optic cable laid across the Atlantic. Satellites are still competitive with cable for point-to-point communications, but the future advantage may lie with fiber-optic cable. Satellites still maintain two advantages over cable: they are more reliable and they can be used point-to-multi-point (broadcasting).

Cellular telephone systems have risen as challenges to all other types of telephony. It is possible to place a cellular system in a developing country at a very reasonable price. Long-distance calls require some other technology, but this can be either satellites or fiber-optic cable.

CHAPTER TWO

SATELLITE COMMUNICATION

2.1 Satellite Systems

A satellite system consists basically of a satellite in space which links many earth stations on the ground, as shown schematically in Figure 2.1 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 station the base-band signal is processed 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 uplink (earth-to-space) frequency spectrum from all the earth stations in the network, amplifies these carriers, and retransmits them back to earth in the downlink (space-to-earth) frequency spectrum which is different from the uplink 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.

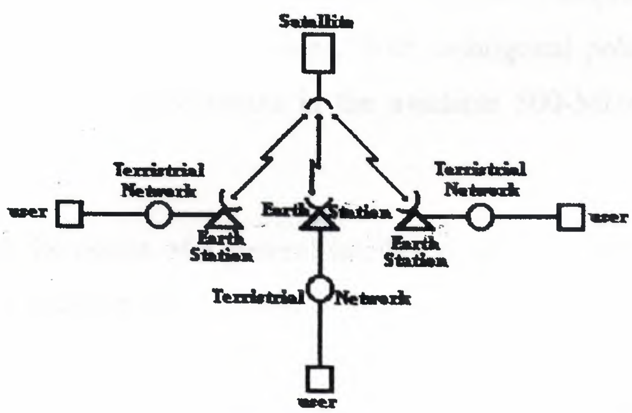


Figure 2.1 Basic Satellite System

Most commercial communications satellites today utilize a 500-MHz bandwidth on the uplink and a 500-MHz bandwidth on the downlink. The most widely used frequency spectrum is the 6/4-GHz band, with an uplink of 5.725 to 7.075 GHz and a downlink of 3.4 to 4.8 GHz. The 6/4-GHz band for geostationary 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 uplink of 12.75 to 14.8 GHz and a downlink 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 bands has also been set aside for Commercial satellite communications, with a downlink of 18.1 to 21.2 GHz and an uplink 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. Modem communications satellites also employ frequency reuse to increase the number of transponders in the 500 MHz allocated to them. 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 at3O dB or more by staggering the center frequencies of the cross polarized transponders so that only sideband energy of the RE carriers overlaps, With orthogonal polarizations a satellite can double the number of transponders in the available 500-MHz 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 2.2 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.

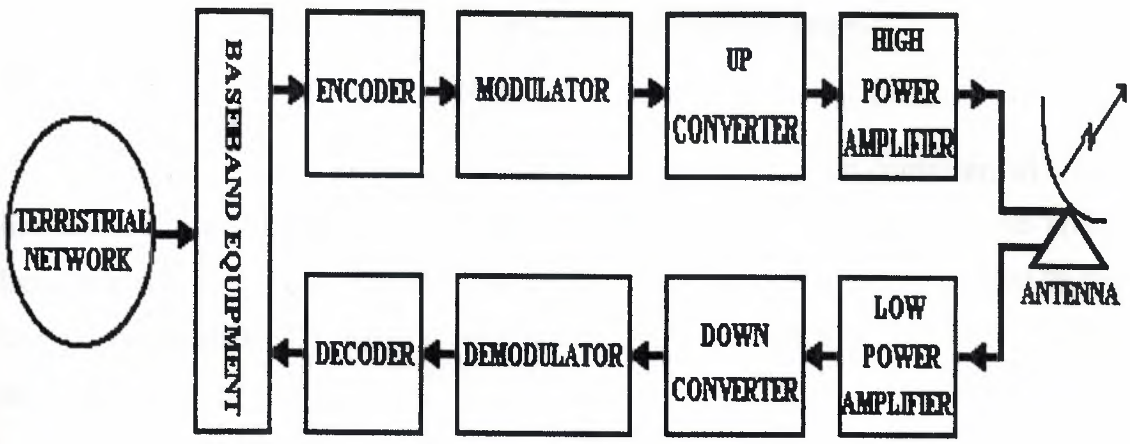


Figure 2.2 Functional Block Diagram of a Digital Earth Station

in order to transmit the base-band digital information over a satellite channel that is a band-pass channel, it is necessary to transfer the digital information to a carrier wave at the appropriate band-pass 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 uplink frequency is chosen because it is difficult to design a modulator that works at the uplink frequency spectrum (6 or 14 0Hz, as discussed previously).

For binary modulation schemes, each output digit from the encoder is used to select one of two possible waveforms. For M-array modulation schemes, the output of the encoder is segmented into sets of k digits, where $M = k^2$ and each k-digit set or symbol is used to select one of the M waveforms. For example, 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 0 is represented by the waveform $s_0(t) = -A \cos \omega_0 t$, where ω_0 is the intermediate frequency. (The letter symbols ω and f will be used to denote angular frequency and frequency, respectively, and will be referred to both of them as "frequency.")

The modulated IF carrier from the modulator is fed to the up-converter, where its intermediate frequency ω_0 is translated to the uplink RF frequency w. in the uplink frequency spectrum of the satellite. This modulated RF carrier is then amplified by the high-power amplifier .(HPA) 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 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 down-converter accepts the amplified RF carrier from the output of the low-noise amplifier and translates the downlink frequency ω_d to the intermediate frequency ω_0. The reason for down-converting 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 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 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° 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° along the equatorial arc instead of 4°. 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 beam-width and thus look at a wider angle in the sky.

The FCC ruling specified that, as of July 1, 1984, all new satellite earth station antennas had to be manufactured to accommodate the spacing of 20 and that, as of January 1, 1987. all existing antennas must be modified to conform to the new standards.

2.2 Satellite Services

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

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

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

(c) Mobile Satellite Services: including communications between a mobile earth station and a fixed station, or between mobile stations.

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

2.2.1 Ground Segment

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

2.2.2 Earth Station

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

2.3 Satellite Frequency Bands

The frequencies used for satellite communications are allocated in super-high frequency (SHF) and extremely-high frequency (EHF) bands which are broken down into sub-bands as summarized in Table 2.1. 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 2.1 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

2.4 Satellite Orbits

When a satellite is launched, it is placed in orbit around the earth. The earth's gravity holds the satellite in a certain path as it goes around the earth, and that path is called an "orbit." There are several kinds of orbits. Here are three of them.

A) LEO, or Low Earth Orbit

A satellite in low earth orbit circles the earth 100 to 300 miles above the earth's surface. Because it is close to the earth, it must travel very fast to avoid being pulled out of orbit by gravity and crashing into the earth. Satellites in low earth orbit travel about 17,500 miles per hour. These satellites can circle the whole earth in about an hour and a half.

B) MEO, or Medium Earth Orbit

Communications satellites that cover the North Pole and the South Pole are placed in a medium altitude, oval orbit. Instead of making circles around the earth, these satellites make ovals. Receivers on the ground must track these satellites. Because their orbits are larger than LEOs, they stay in sight of the ground receiving stations for a longer time. They orbit 6,000 to 12,000 miles above the earth.

C) GEO, or Geostationary Earth Orbit

A satellite in geosynchronous orbit circles the earth in 24 hours—the same time it takes the earth to rotate one time. If these satellites are positioned over the equator and travel in the same direction as the earth rotates, they appear "fixed" with respect to a given spot on earth—that is, they hang like lanterns over the same spot on the earth all the time. Satellites in GEO orbit 22,282 miles above the earth. In this high orbit, GEO satellites are always able to "see" the receiving stations below, and their signals can cover a large part of the planet. Three GEO satellites can cover the globe, except for the parts at the North and South poles.

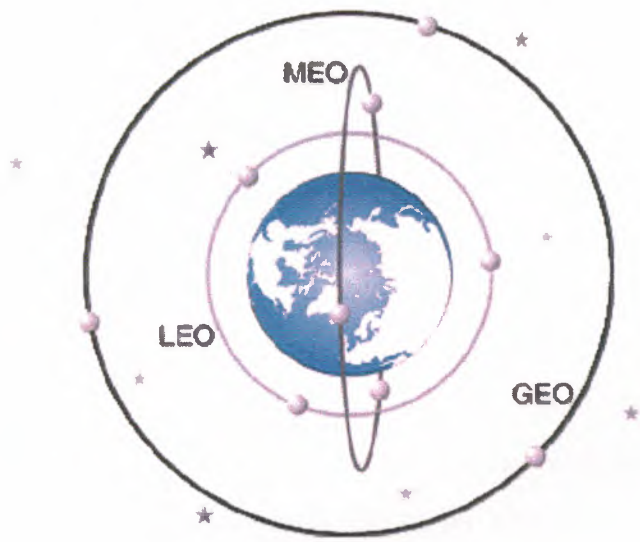


Figure 2.3 Satellite Orbits

2.5 Communication Satellites

2.5.1 Airborne Satellite

2.5.1.1 What's Inside a Satellite?

Satellites have a great deal of equipment packed inside them. A satellite has seven subsystems, and each one has its own work to do.

1) The **propulsion subsystem** includes the electric or chemical motor that brings the spacecraft to its permanent position, as well as small thrusters (motors) that help keep the satellite in its assigned place in orbit. Satellites drift out of position because of solar wind or gravitational or magnetic forces. When that happens, the thrusters are fired to move the satellite back into the right position in its orbit.
2) The **power subsystem** generates electricity from the solar panels on the outside of the spacecraft. The solar panels also store electricity in storage batteries, which provide power when the sun isn't shining on the panels. The power is used to operate the com-munications subsystem. A Boeing 702 generates enough power at the end of its ser-vice life to operate two hundred 75-watt light bulbs.
3) The **communications subsystem** handles all the transmit and receive functions. It receives signals from the earth, amplifies or strengthens them, and transmits (sends) them to another satellite or to a ground station.
4) The **structures subsystem** distributes the stresses of launch and acts as a strong, stable framework for attaching the other parts of the satellite.
5) The **thermal control subsystem** keeps the active parts of the satellite cool enough to work properly. It does this by directing the heat that is generated by satellite opera-tions out into space, where it won't interfere with the satellite.
6) The **attitude control subsystem** maintains the communications "footprint" in the correct location. Satellites can't be allowed to jiggle or wander, because if a satellite is not exactly where it belongs, pointed at exactly the right place on the earth, the televi-sion program or the

telephone call it transmits to you will be interrupted. When the satellite gets out of position, the attitude control system tells the propulsion system to fire a thruster that will move the satellite back where it belongs.

7) Operators at the ground station need to be able to transmit commands to the satel-lite and to monitor its health. The **telemetry and command subsystem** provides a way for people at the ground stations to communicate with the satellite.

2.5.1.2 Satellite Launching

A satellite is launched on a launch vehicle; the satellite is packed carefully into the vehicle and carried into space, powered by a rocket engine.

Satellites are launched from only a few places in the world, primarily Cape Canaveral, Florida; Kourou, French Guiana; Xichang, China, and Baikonur, Kazakstan. The best places to launch satellites are near the ocean, so that when the launch vehicle falls away, it lands in the water and not on people.

Another launch site actually travels to the perfect launch spot. The Sea Launch company rebuilt a big platform once used for oil drilling at sea. The platform carries satellites from Long Beach, California, to the equator, far out in the Pacific Ocean, where its rocket launches them.

At launch, the launch vehicle's rockets lift the satellite off the launch pad and carry it into space, where it circles the earth in a temporary orbit. Then the spent rockets and the launch vehicle drop away, and one or more motors attached to the satellite move it into its permanent geosynchronous orbit. A motor is started up for a certain amount of time, sometimes just one or two minutes, to push the satellite into place. When one of these motors is started, it's called a "burn." It may take many burns, over a period of several days, to move the satellite into its assigned orbital position.

When the satellite reaches its orbit, a motor points it in the right direction and its antennas and solar panels deploy, that is, they unfold from their traveling position and spread out so the satellite can start sending and receiving signals.

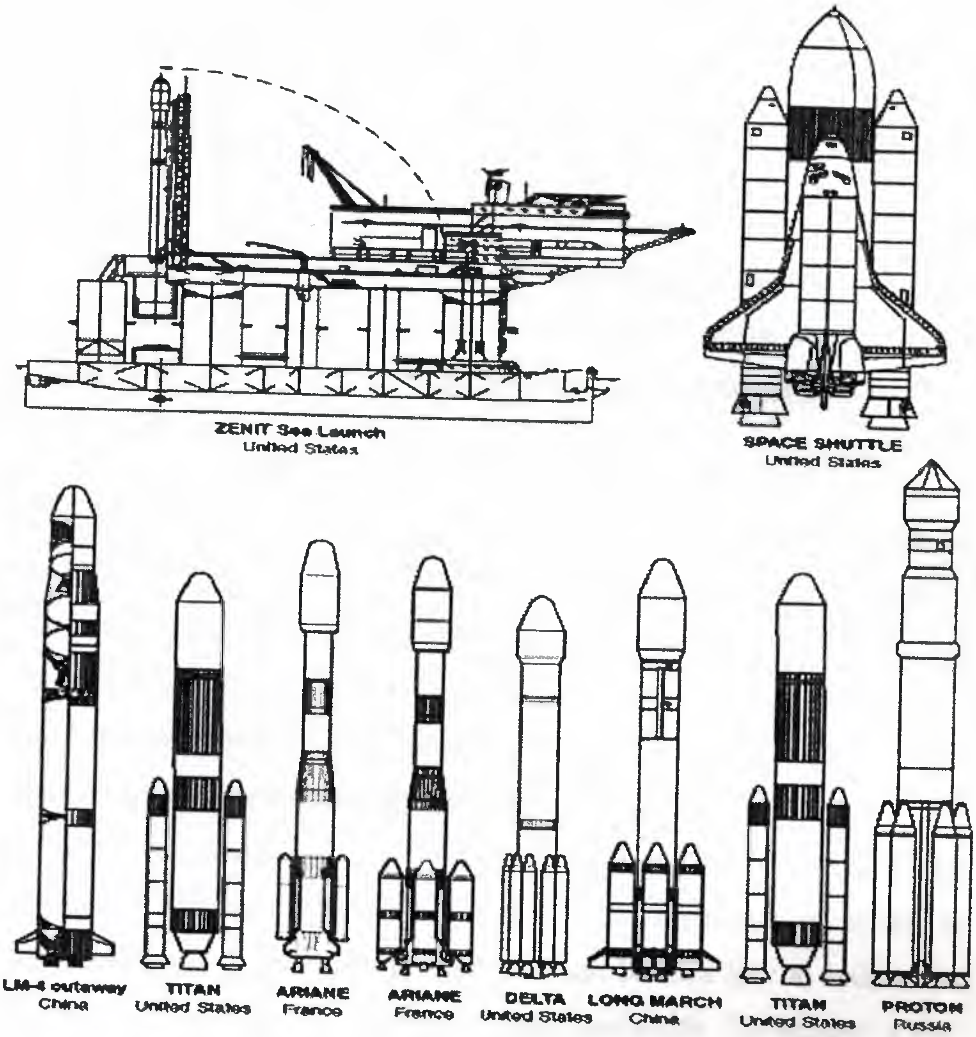


Figure 2.4 Launching Vehicles

2.5.2 Earth Station

2.5.2.1 Introduction

At the beginning we gave a functional description of the digital earth station shown in Figure 2.2 In practice, an earth station is basically ‘divided into two parts:

1) A RF terminal, which consists of an up-converter and a down-converter, a high-power amplifier, a low-noise amplifier, and an antenna
2) A base-band terminal, which consists of base-band equipment, an encoder and decoder, and a modulator and demodulator.

The RF terminal and the base-band terminal may be located a distance apart and connected by appropriate IF lines. In this chapter we will focus attention on a discussion of the RF terminal and will consider the base-band terminal from a system point of view only.

2.5.2.2 Earth Station Antenna

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:

1) The antenna must have a highly directive gain; that is, it must focus its radiated energy into a narrow beam to illuminate the satellite antenna in both the transmit and receive modes to provide the required uplink and downlink carrier power. Also, the antenna radiation pattern must have a low side-lobe level to reduce interference from unwanted signals and to minimize interference into other satellites and terrestrial systems.
2) 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 to reduce the noise power within the downlink carrier bandwidth. To achieve a low noise characteristic, the antenna radiation pattern must be controlled in such a way as to minimize the energy radiated into sources other than the satellite. Also, the Ohmic losses of the antenna that contribute directly to its noise temperature must be minimized. This includes the Ohmic loss of the wave-guide that connects the low-noise amplifier to the antenna feed.
3) 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 in position. This is essential for minimizing antenna pointing loss.

A) 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 Figure 2.5. This type of antenna consists of a reflector which is a section of a surface formed by rotating a parabola about its axis, and a 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 a low-noise amplifier through an orthogonal mode transducer (OMT) which is a three-port network. The inherent isolation of the OMT is normally better than 40 dB. On the transmit side the signal energy from the output of the high-power amplifier is radiated at the focal point by the feed and illuminates the reflector which reflects and focuses the signal energy into a narrow beam. On the receive side the signal energy captured by the reflector converges on the focal point and is received by the feed which is then routed to the input of the low-noise amplifier. 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 (spillover energy) illuminates the ground whose noise temperature can be as high as 2900 K and results in a high antenna noise contribution. Paraboloid antennas with a focal point feed are most often employed in the United States for receive-only applications.

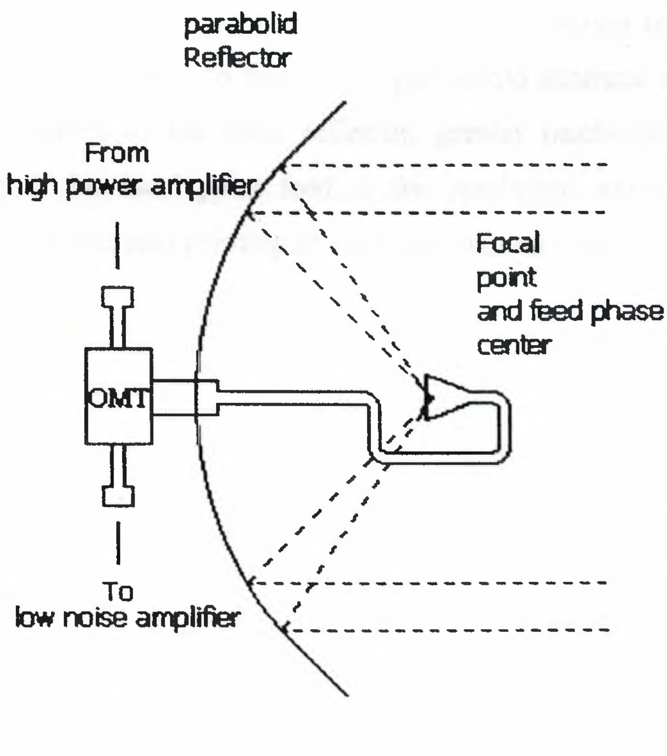


Figure 2.5 paraboloid Antenna

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 sub-reflector, and a feed, whose phase center is at the real focal point of the sub-reflector, as shown in Figure 2.6. On the transmit side, the signal energy from the output of the high-power amplifier is radiated at the real focal point by the feed and illuminates the convex surface of the sub-reflector which reflects the signal energy back as if it were incident from a feed whose phase center is located at the common focal point of the main reflector and sub-reflector. The reflected energy is reflected again by the main reflector to form the antenna beam. 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 a paraboloid antenna because of the addition of the sub-reflector and the integration of the three antenna elements -the main reflector, sub-reflector, and feed- to produce an optimum antenna system. However, the Cassegrain antenna offers many advantages over the paraboloid antenna: low noise 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 3O° K, its contribution to the antenna noise temperature is small compared to that of the paraboloid antenna. Also, with the feed located near the vertex of the main reflector, greater mechanical stability can be achieved than with the focal point feed in the paraboloid antenna. This increased stability permits very accurate pointing of high-gain narrow-beam antennas.

To minimize the losses in the transmission lines connecting the high-power amplifier and the low-noise amplifier to the feed, a beam wave-guide feed system may be employed. A Cassegrain antenna with a beam wave-guide feed system is shown in Figure 2.7. The beam wave-guide assembly consist of four mirrors supported by a shroud and precisely located relative to the sub-reflector, the feed, the elevation axis, and the azimuth axis. This mirror configuration acts as a RF energy funnel between the feed and the sub-reflector and, as such, must be designed to achieve minimum loss while allowing the feed to be mounted in the concrete foundation at ground level. The shroud assembly acts as a shield against ground noise and provides

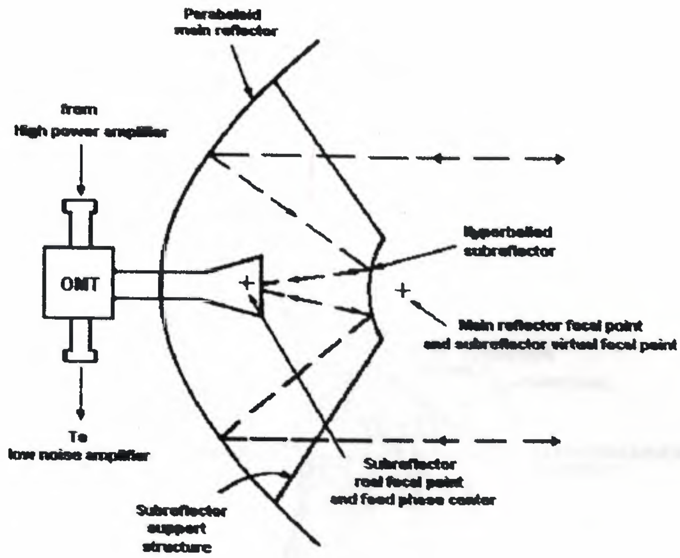
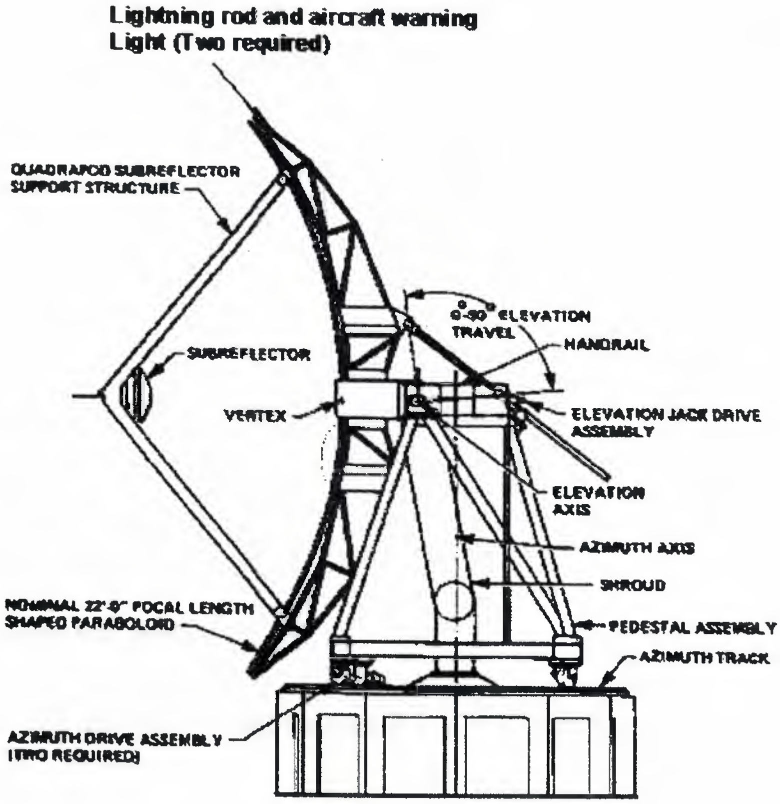


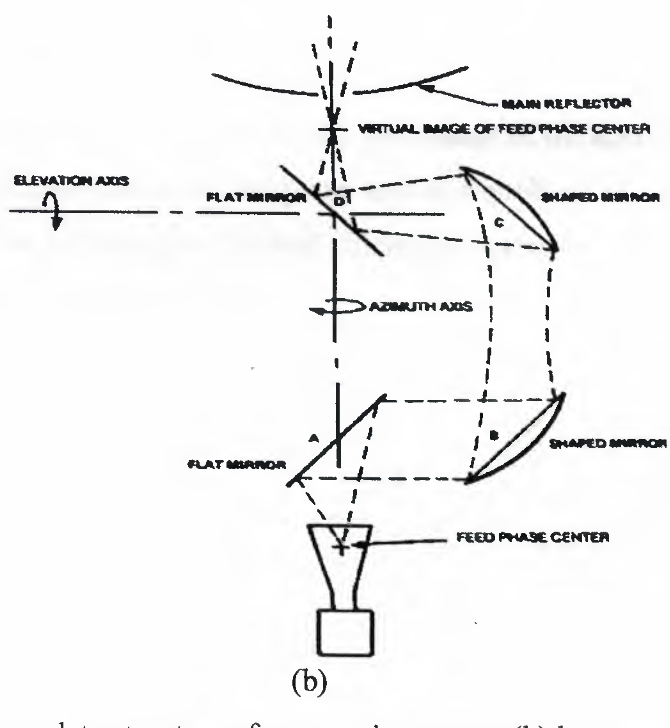
Figure 2.6 Cassegrain Antenna

a rigid structure which maintains the mounting integrity of the mirrors when the antenna is subjected to wind, thermal, or other external loading conditions. The lower section of the shroud assembly is supported by the pedestal and rotates about the azimuth axis. The upper section of the shroud assembly is supported by the main reflector support structure and rotates about the elevation axis. As seen in Figure 2.7.b, the beam wave-guide mirror system directs the energy to and from the feed and the reflectors. The configuration utilized is based on optics, though a correction is made for diffraction effects by using slightly elliptical curved mirrors. For proper shaping and positioning of the beam Wave-guide mirrors, the energy from the feed located in the equipment room is refocused so that the feed phase center appears to be at the sub-reflector's real focal point. In operation, mirrors A, B, C, and D move as a unit when the azimuth platform rotates. Mirror D is on the elevation axis and rotates also when the main reflector is steered during elevation. In this way, the energy to and from the beam wave-guide system is always directed through the opening in the main reflector vertex.

As mentioned previously, modern communications satellites often employ dual polarizations to allow two independent carriers to be sent in the same frequency band, thus permitting frequency reuse and doubling the satellite capacity. Figure 2.7 shows a wideband OMT diplexer type of frequency reuse feed for a Cassegrain antenna that provides horizontal and vertical polarization for a Ku-band operation.



(a)



(b)

Figure 2.7 (a) a complete structure of cassegrain antenna (b) beam wave-guide feed

B) Antenna Gain

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

$$G = \eta \frac{4.\pi.A}{\lambda^2} = \eta \frac{.4.\pi.A.f^2}{c^2} \qquad (1)$$

where

A = antenna aperture area (in^2)

λ = radiation wavelength (in)

f = radiation frequency (Hz)

c = speed of light = 2.997925 x 10^8 m/s

η = antenna aperture efficiency ($\eta < 1$)

For a circular aperture, it follows that $A = \pi D^2/4$; therefore

$$G = \eta \left(\frac{\pi.D}{\lambda} \right)^2 = \eta.\left(\frac{\pi.f.D}{c} \right)^2 \qquad (2)$$

where D = antenna diameter (in).

The antenna efficiency η represents the percentage of the aperture area A that is used effectively in transmission or reception and is a product of various efficiency factors that reduce the antenna gain. Typical efficiency factors for a Cassegrain antenna such as the one shown in Figure 2.7.a are

$$\eta = \eta_1 \eta_2 \eta_3 \eta_4 \eta_5 \eta_6 \qquad (3)$$

where

η_1= main reflector illumination efficiency

η_2= spillover efficiency

η_3= phase efficiency

η_4= sub-reflector efficiency

η_5= feed system dissipative efficiency

η_6= reflector surface tolerance efficiency

The illumination efficiency η_1 is determined by the characteristic of the field distribution across the main reflector aperture. If it is uniform over the entire aperture area, then $\eta_1=1$. The spillover efficiency η_2 represents not only the energy spilled over the edge of the main reflector but also the energy spilled over the edge of the sub-reflector. To minimize the spillover loss, a feed with low side-lobes in its radiation pattern is desired. To achieve this pattern, multiple modes are used in the design of the feed radiation section that is a horn. Furthermore, the feed angle subtended by the sub-reflector is chosen so that the main beam of the feed radiation pattern intersects the sub-reflector at a low level, minimizing the feed main beam spillover past the sub-reflector. However, the low edge illumination of the sub-reflector normally results in sharply tapered illumination across the main reflector aperture, resulting in a low illuminating efficiency η_1.

With a Cassegrain antenna this condition can be improved substantially by deliberately altering the shape of the sub-reflector to distribute the energy essentially uniformly nearly to the edge of the main reflector but then falling off very sharply. An illumination efficiency η_1 of 0.94 to 0.96 can be achieved in practice with a main reflector spillover efficiency of as high as 0.99. With good feed design, a sub-reflector spillover efficiency on the order of 0.98 can be realized. Thus a spillover efficiency of $\eta_2 = 0.97$ can be achieved in a shaped system.

Distorting the shape of the sub reflector to achieve uniform illumination across the main reflector results in a phase error being introduced into the main reflector. This phase error results in energy being radiated in undesired directions, thus decreasing the gain and increasing the sidelobe level of the antenna. The phase efficiency η_3 identifies this gain loss. Most of this loss can be eliminated, however, by reshaping the main reflector to correct the phase error. In a well-designed Cassegrain antenna the phase efficiency η_3 can be on the order of 0.98 and 0.99 at the design frequency and remain on the order of 0.95 over 70% of the operating 500-MHz band. Blocking of the main reflector aperture by the sub-reflector and support structure results in an effectively smaller aperture, hence a loss in the antenna gain. The sub-reflector blocking efficiency is about 0.97, and that of the support structure is about 0.95 in a well-designed antenna. The dissipative loss of the feed system also reduces the antenna gain. Depending on the feed system structure the efficiency η_5 can be as high as 0.94.

All the above-cited efficiency factors are primarily dependent on the main reflector and sub-reflector geometries and the feed system structure and not on the operating frequency. In practice the main reflector and sub-reflector cannot be built to the ideal shapes without some surface tolerance. This results in a scattering of energy in unwanted directions in a manner similar to that associated with the phase error. The surface tolerance may, in effect, be considered a special type of phase error which limits the maximum achievable gain G_M in the sense that, for a given surface tolerance and antenna diameter, increasing the operating frequency increases the antenna gain until it equals G_M . Further increasing the operating frequency will decrease the antenna gain. The surface tolerance efficiency η_6 imposes an upper limit on the maximum operating frequency, hence on the maximum antenna gain, and is fixed by current manufacturing technology. The reflector surface tolerance efficiency η_6 may be expressed as:

$$\eta_6 = \exp\left[- \left(\frac{4.\pi.\varepsilon}{\lambda} \right)^2 \right] \tag{4}$$

$$= \exp\left[- \left(\frac{\varepsilon}{D} \right)^2 \left(\frac{4.\pi.f.D}{c} \right)^2 \right] \tag{5}$$

where ε = rms reflector surface error (m) and εID = antenna surface tolerance. The factor $(4.\pi.\varepsilon / \lambda)^2$ is in effect the mean-square phase error introduced by the surface error ε. The antenna surface tolerance ε /D within current commercial technology is as follows:

$$0^{-3} \leq \varepsilon ID \leq 10^{-4} \qquad D \leq 1.2 \text{ m}$$

$$2 \times 10^{-4} \leq \varepsilon ID \leq 5 \times 10^{-5} \qquad 2.5 \text{ m} \leq D \leq 6 \text{ m}$$

$$10^{-4} \leq \varepsilon ID \leq 2 \times 10^{-5} \qquad 9 \text{ m} \leq D \leq 24 \text{ m}$$

The performance of a well-designed Ku-band 20-rn Cassegrain antenna with a beam wave-guide frequency reuse feed system is shown in Table 3.2:

Table 2.2 Parameters of a Ku-band 20-rn Cassegrain antenna

Parameters	11.95 GHz	14.25 GHz
Illumination efficiency	0.96	0.94
Main reflector	0.99	0.99
Sub-reflector	0.96	0.98
Phase efficiency	0.98	0.98
Sub-reflector	0.97	0.97
Support structure	0.95	0.95
Basic feed	0.94	0.93
Diplexer	0.96	0.98
Beam wave-guide	0.91	0.96
Main reflector	0.87	0.83
Sub-reflector	0.97	0.97
Net antenna efficiency	0.57	0.54
Antenna gain (dB)	65.53	66.82

C) 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 Figure 2.8. The antenna pointing loss can be evaluated from the antenna gain pattern, which is a function of the off-axis angle.

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 angels, is derived from the received signal. One of the commonly used antenna tracking systems for the earth stations is a step track that derives the antenna-positioning vector from the signal strength of a satellite beacon.

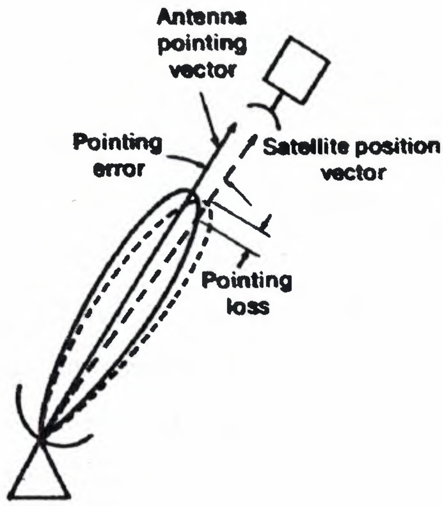


Figure 2.8 Antenna Pointing Error

D) Effective Isotopic 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's 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 station antenna. If we let P (t) denote the input power at the feed of the antenna and G (t) the transmit antenna gain, the earth station's EIRP is simply:

$$\mathrm{EIRP} = P(t) . G(t) \tag{6}$$

E) 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 in receiving the downlink carrier from the satellite. If a piece of wave-guide with a 0.53-dB loss is used to connect the input of the low noise amplifier to the output port of the receive system, the receive antenna gain referred to the input of the low noise amplifier is 65 dB. The parameter T is defined as the earth station system noise temperature referred also to the input of the low noise amplifier.

2.5.2.3 High Power Amplifier

One of the most widely used high power amplifiers in earth stations, the traveling wave tube amplifier. 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 helix. Electrons emitted from the cathode of the tube are focused into a beam along the axis of the helix by cylindrical magnets and removed at the end by the collector after delivering their energy to the RF field. The helix slows down the propagation velocity of the RF signal (the velocity) to that of the electron beam , which is controlled by the DC voltage at the cathode. Those results in an interaction between the electric field include by the RF signal and the electrons, which result 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 the earth station is the Klystron amplifier, which can provide higher gain and better efficiency than the traveling wave tube amplifier but a much smaller bandwidth. For low power amplification GaAs FET amplifiers are used. These are solid state amplifiers and offer much efficiancy than the above two types of amplifiers.

2.5.2.4 Up-converter

The Up converter accept the modulated IF carrier and translate its frequency ω_0 to the uplink frequency ω_u by mixing ω_0 with a local oscillator frequency ω_l.

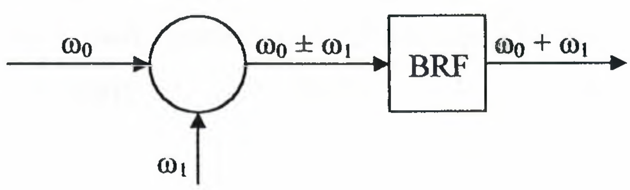


Figure 2.9 Function of up-converter

The up conversion may be accomplished by with a single or double conversion preprocess.

2.5.2.5 Down-converter

the down-converter receives the modulated RF carrier from the low noise amplifier and translates its radio frequency ω_d in the down-link frequency spectrum of the satellite to the intermediate frequency ω_0. Like up-conversion, down-conversion may be achieved with a signal conversion process or with a dual conversion process using mixer.

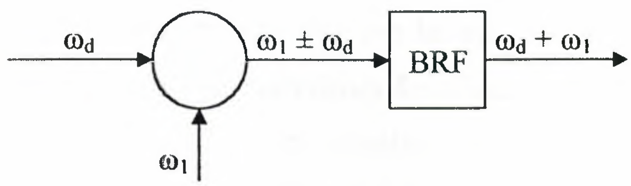


Figure 2.10 Function Of Down Converter

2.5.2.6 Redundancy Configuration

As we have seen in previous sections, except for the antenna all earth stations systems namely, the high-power amplifier, the up-converter, and the down-converter, must employ some sort of redundancy to maintain high reliability which is of utmost importance. When the on-line equipment in the redundancy configuration fails The standby equipment is automatically switched over and becomes the on-line equipment .The process of detecting critical failure modes and resolving all these failure modes by automatic switchover from the failed to the redundant system is called monitoring and control. Reliability 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 sort of redundancy configuration.

CHAPTER THREE

MULTIPLE ACCESS

3.1 Overview

One advantage of communications satellites over other transmission media is their ability to link all earth stations together, thereby providing point-to-multipoint communications. A satellite transponder can be accessed by many earth stations, and therefore it is necessary to have techniques for allocating transponder capacity to each of them. For example, consider a transponder with a bandwidth of 72 MHz. Assume that the bit duration-bandwidth product T_bB in (1.5) is chosen to be 0.6; that is, every 0.6 Hz of the transponder bandwidth can be used to transmit 1 bps. Then the transponder capacity is 120 Mbps, which can handle about 3562 voice channels at 32 kbps, assuming the transponder efficiency is 95%. It is unlikely that a single earth station would have this much traffic, therefore the transponder capacity must be wisely allocated to other earth station. Furthermore, to avoid chaos, we want the earth stations to gain access to the transponder capacity allocated to them in an orderly fashion. This is called multiple access. The most commonly used multiple access schemes are frequency division multiple access (FDMA), time division multiple access (TDMA) and code division multiple access (CDMA).

3.2 Frequency Division Multiple Access

FDMA has been used since the inception of satellite communication. Here each earth station in the community of earth stations that share the transponder capacity transmits one or more carriers to the satellite transponder at different center frequencies. Each carrier is assigned a frequency band in the transponder bandwidth, along with a small guard band to avoid interference between adjacent carriers. The satellite trans-ponder receives all the carriers in its bandwidth, amplifies them, and retransmits them back to earth. The earth station in the satellite antenna beam served by the transponder can select the carrier that contains the messages intended for it. FDMA is illustrated in Figure 3.1. The carrier modulation used in FDMA is FM or PSK.

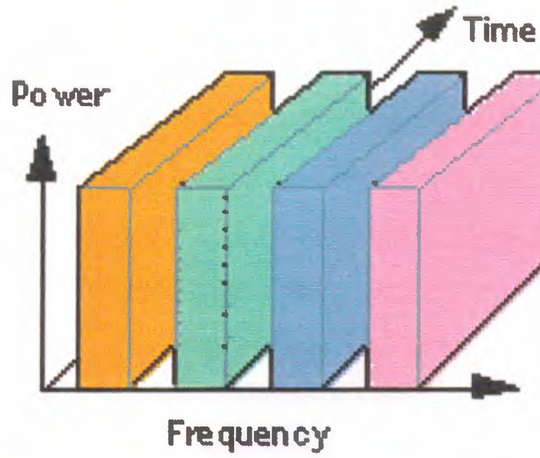


Figure 3.1 Concept of FDMA

The following are the features of FDMA:

1) If channel not in use, sits idle
2) Channel bandwidth relatively narrow (30kHz), ie, usually narrowband systems
3) Symbol time >> average delay spread .little or no equalization required
4) Best suited for analogue links bits needed
5) Requires tight filtering to minimize interference
6) Usually combined with FDD for duplexing

3.3 Time Division Multiple Access

In TDMA the earth stations that share the satellite transponder use a carrier at the same center frequency for transmission on a time division basis. Earth stations are allowed to transmit traffic bursts in a periodic time frame called the TDMA frames During the burst, an earth station has the entire transponder bandwidth available to it for transmission. The transmit timing of the bursts is carefully synchronized so that all the bursts arriving at the satellite transponder 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. TDMA is illustrated in Figure 3.2. The carrier modulation used in TDMA is always a digital modulation scheme. TDMA possesses many advantages over FDMA, especially in medium to heavy traffic networks, because there are a number of efficient techniques such as demand assignment and digital speech interpolation that are inherently suitable for TDMA and can maximize the amount of terrestrial traffic that can be handled by a satellite transponder. For example, a 72-MHz transponder can handle about 1781 satellite PCM voice channels or 3562 32-kbps adaptive differential PCM channels. With a digital speech interpolation technique it can handle about twice this number, 3562 terrestrial PCM voice channels or 7124 32-kbps adaptive differential PCM voice channels. In many TDMA networks employing demand assignment the amount of terrestrial traffic handled by the transponder can be increased many times. Of course these efficient techniques depend on the terrestrial traffic distribution in the network and must be used in situations that are suited to the characteristics of the technique. Although TDMA has many advantages, this does not mean that FDMA has no advantages over TDMA. Indeed, in networks with many links of low traffic, FDMA with demand assignment is overwhelmingly preferred to TDMA because of the low cost of equipment.

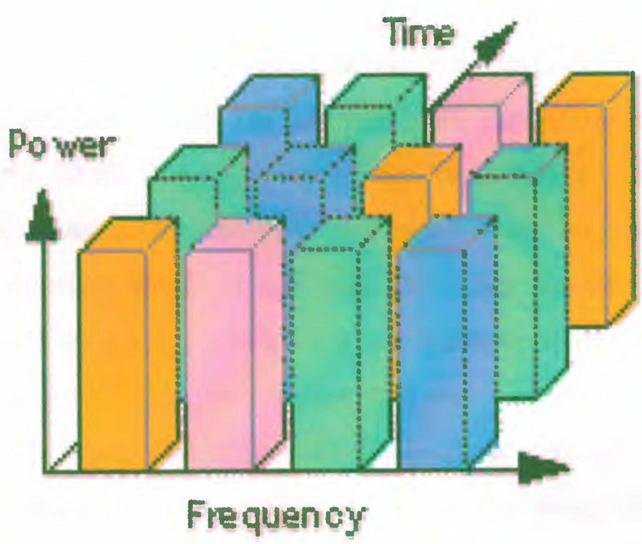


Figure 3.2 Concept of TDMA

Besides FDMA and TDMA, a satellite system may also employ random multiple access schemes to serve a large population of users with bursty (low duty cycle) traffic.

Here each user transmits at will and, if a collision (two users transmitting at the same time, causing severe interference that destroys their data) occurs, retransmits at a randomly selected time to avoid repeated collisions. Another type of multiple access scheme is code division multiple access, where each user employs a particular code address to spread the carrier bandwidth over a much larger bandwidth so that the earth station community can transmit simultaneously without frequency or time separation and with low interference.

TDMA has some advantages that are, In addition to increasing the efficiency of transmission, TDMA offers a number of other advantages over standard cellular technologies. First and foremost, it can be easily adapted to the transmission of data as well as voice communication. TDMA offers the ability to carry data rates of 64 kbps to 120 Mbps (expandable in multiples of 64 kbps). This enables operators to offer personal communication-like services including fax and voiceband data, as well as bandwidth-intensive applications such as multimedia and videoconferencing.

Unlike spread-spectrum techniques which can suffer from interference among the users all of whom are on the same frequency band and transmitting at the same time, TDMA's technology, which separates users in time, ensures that they will not experience interference from other simultaneous transmissions. TDMA also provides the user with extended battery life and talk time since the mobile is only transmitting a portion of the time (from 1/3 to 1/10) of the time during conversations. TDMA installations offer substantial savings in base-station equipment, space, and maintenance, an important factor as cell sizes grow ever smaller. TDMA is the most cost-effective technology for upgrading a current analogue system to digital. TDMA is the only technology that offers an efficient utilization of hierarchical cell structures (HCSs) offering pico, micro, and macrocells. HCSs allow coverage for the system to be tailored to support specific traffic and service needs. By using this approach, system capacities of more than 40-times AMPS can be achieved in a cost-efficient way. Because of its inherent compatibility with FDMA analogue systems, TDMA allows service compatibility with the use of dual-mode handsets.

Also TDMA has some disadvantages, one of these disadvantages of TDMA is that each user has a predefined time slot. However, users roaming from one cell to another are not allotted a time slot. Thus, if all the time slots in the next cell are already occupied, a call might well be disconnected. Likewise, if all the time slots in the cell in which a user happens to be in are already occupied, a user will not receive a dial tone.

Another problem with TDMA is that it is subjected to multipath distortion. A signal coming from a tower to a handset might come from any one of several directions. It might have bounced off several different buildings before arriving which can cause interference.

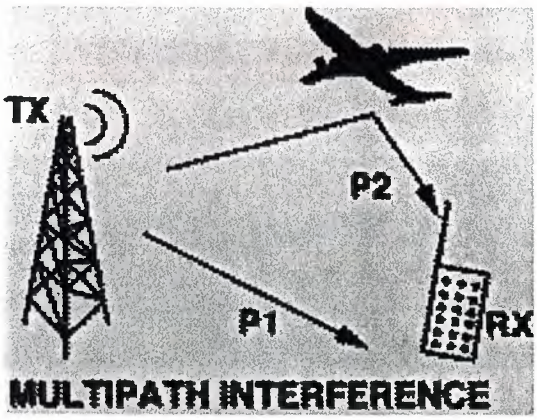


Figure 3.3 Multi-Path Inter-Face

One way of getting around this interference is to put a time limit on the system. The system will be designed to receive, treat, and process a signal within a certain time limit. After the time limit has expired, the system ignores signals. The sensitivity of the system depends on how far it processes the multipath frequencies. Even at thousandths of seconds, these multipath signals cause problems.

3.4 Code Division Multiple Access

Code division multiple access (CDMA) is actually a hybrid combination of the use of FDMA and TDMA. Users are assigned to different codes which govern the time slot and frequency band for the signal transmission, see Figure 3.4. At one instant (time slot), a user is only allowed to use one of the frequency bands which is unoccupied by the others. By this scheme, the channel capacity can greatly increase with the minimum degree of interference by the other users.

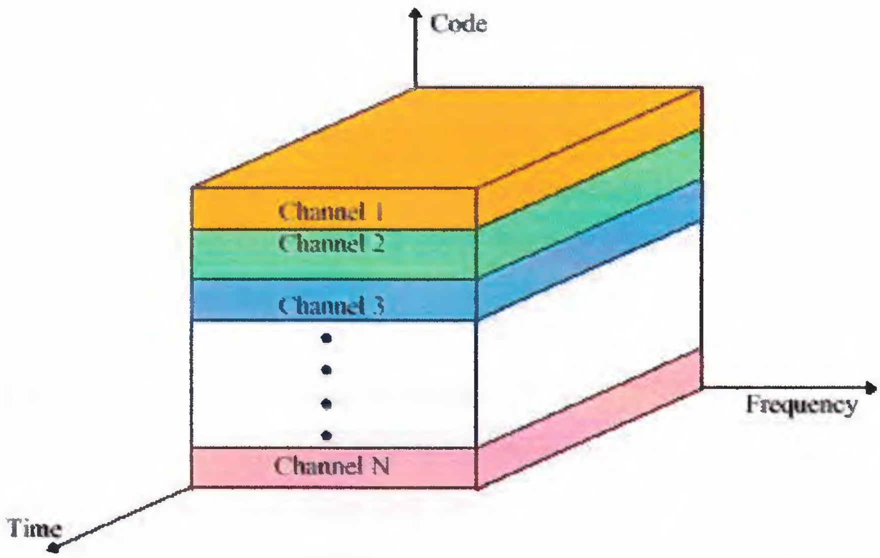


Figure 3.4 Concept of CDMA

CDMA is an application of spread spectrum (SS) techniques which can increase the channel capacity for signal transmission and reduce interference by the other users.

CDMA has some advantages over TDMA & FDMA; Since each user is assigned a unique code for transmission and reception, without this code one cannot receive the signal transmitted by the other user. Therefore, communication privacy can be achieved by eliminating the interception of unauthorized users without the code. Below are the advantages of CDMA over TDMA & FDMA.

1) **Anti-jamming capability:** In direct sequence CDMA system, the narrow band signal is spreaded by a spreading code over a wide band. Since the original signal is spreaded over a wide band with very low power, without knowing the exact code, the spreaded signal is a noise-like spectrum Intended jammers would not know what frequency to interfere the signal. This is also true for frequency hopping CDMA since the carrier is in pseudo-random pattern.
2) **Flexibility:** This is an obvious advantage of CDMA over TDMA system. Since the codes between different users are orthogonal to each other, there is no need for precise time coordination among the various simultaneous transmitters. It is important to design a set of codes based on the criteria of its autocorrelation and cross-correlation.

3) **Fading Immunity:** This is an obvious advantage of CDMA over FDMA system. If a particular frequency band suffer from severe channel fading, an user assigned to this band by FDMA would experience high degradation in communication. However, in frequency hopping CDMA, since the carrier is shifting, only a small fraction of time the signal is affected by the channel fading.

3.5 Advantages Of Digital Transmission

Communications by digital signaling is an increasingly important technique for radio communication by satellite relay and other means. Digital transmission has a number of advantages over other techniques. These include:

1) the ease and efficiency of multiplexing multiple signals or handling digital messages in "packets" for convenient switching;
2) The relative insensitivity of digital circuits to retransmission noise, commonly a problem with analogue systems;
3) potential for extremely low error rates and high fidelity through error detection and correction;
4) communications privacy;
5) the flexibility of digital hardware implementation, which permits the use of microprocessors and miniprrocessor, digital switching, and the use of large scale integrated (LSI) circuits.

Digital transmission techniques are gaining increased usage for satellite communication, microwave relay, and cable or wave-guide transmission. However, the original and final forms of the information transmitted by the digital link may be analogue voice or video and therefore the analogue/digital interface is an important element of the communications system.

Most satellite communication is at microwave frequencies largely because the available bandwidth is substantial. However, transmission in the UHF frequency band has important application to relatively low data rate mobile users where near-omni directional antennas are employed.

CHAPTER FOUR

APPLICATION OF SATELLITE NETWORKS

4.1 Overview

The purpose of operating a satellite in orbits is clearly to provide connections between earth stations, which in turn deliver or originate various types of communications service. Application of such satellite networks, are broken down into the broad categories of video, telephone, and data. The first part of this chapter reviews the features and generic arrangements of networks independent of the specific use. This provides a cross reference with regard to the applications which are reviewed in detail at the end of this chapter.

4.2 Connectivity

The manner in which points on the earth are linked between each other is called "connectivity". There are three generic forms of connectivity: point-to-point, point-to-multi point, and multipoint –to-point. Each of these connectivities, reviewed in the following paragraphs, can be established through one satellite and two or more earth stations. Comparisons are made with implementations of the same connectivities using terrestrial communications technology .It is shown that while terrestrial systems compete favorably on a point-to-point basis, satellite networks have a decided advantage whenever a multipoint connectivity is needed.

4.2.1 Point –to- Point

The simplest type connectivity is point-to-point, illustrated in Figure 4.1 with two earth stations both transmitting simultaneously to the satellite .A pair of earth stations transmit RF carriers one to another (and receive each others carriers), creating what is called a duplex link. The parties being served can thereby talk or transmit information in both directions at the same time the uplink sections of the satellite repeater receives both transmissions and after translation to the downlink frequency range, transmits them back toward the ground. Reception by and earth station of the opposite ends transmission completes the link. In most cases, transmission between earth stations through the satellite repeater are continues in time. If the satellite provides a single footprint covering both earth stations, then a given station can receive in the downlink its own information as well as that of its communicating partner. This supplementary ability provides a unique way for stations to verify the content and equality of satellite transmission.

Atypical network of several earth stations and a satellite provides many duplex point-to-point links to interconnects the locations on the ground. There are many possible circuit routings between the locations. In a fully interconnected "mesh" network. The maximum number of possible links between N earth stations is equal to N(N-1)/2.To prevent harmful RF interference; all stations cannot be on the same frequency at the same time. The technology which allows the needed simultaneous transmission without RFI through the satellite repeater is called multiple access.

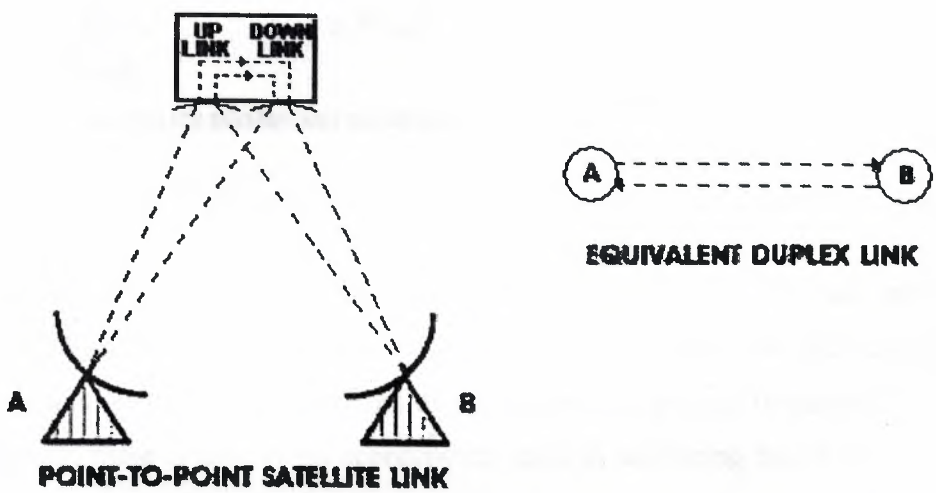


Figure 4.1 Point-to-Point Connectivity Using Full Duplex Satellite Link

4.2.2 Point-to-Multipoint

While point-to-point links are easily achieved by satellite, it is the point –to-multipoint link which takes full advantage of the wide area coverage of the satellites footprint. Figure 4.2 indicates how satellite broadcasting is accomplished with one transmitting earth station (called the uplink in common practice) and many receives – only (RO) earth stations. The satellite repeater retransmits the single RF carrier containing the information to be distributed. It is usually advantageous to use the highest satellite transmit power possible, because this allows the use of smaller diameter (less expensive) RO antennas on the ground. As the number of RO s increase in to hundreds of thousands or millions, the optimum transmitter power to use in space becomes much larger than that permitted at C band by the ITU. BSS segment of Ku band is available for such high-power broadcast applications. The cost of the more expensive BSS satellite is shared among more and more users, who than saves substantial amounts on the cost of their ground equipment. This is an economic tradeoff between the cost of the satellite and that of the ground segment.

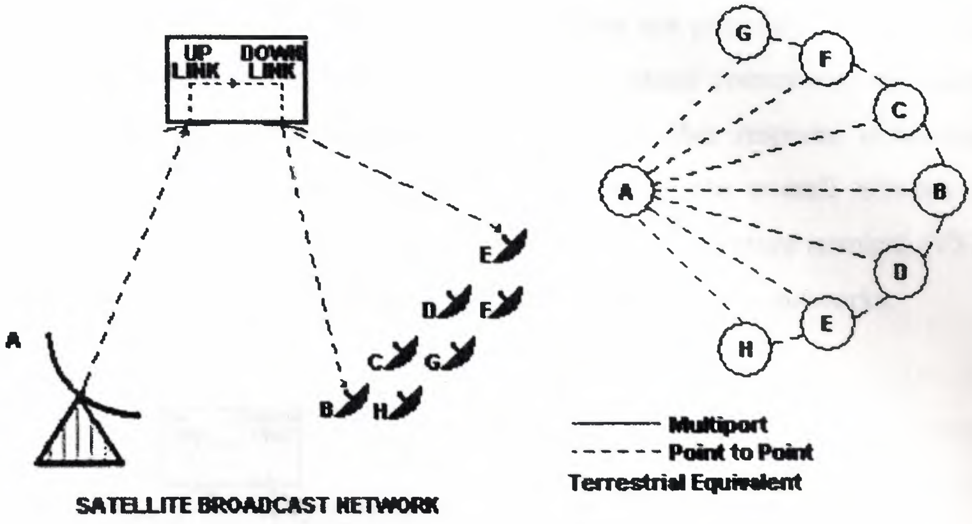


Figure 4.2 point-to-Multipoint Connectivity Providing a one-way Broadcast Capability.

Achieving point-to-multipoint connectivity with a terrestrial network is extremely expensive, since the cost of adding cable or microwave facilities to reach service points is roughly proportional to the number of points. In contrast to satellite broadcasting, there is usually no economy on scale in delivering broadcast information terrestrially. There is a terrestrial approach, wherein the receiving points are chained together. This tends to be less reliable on an overall basis because users are delivered the signal along the route of the system (i.e., a chain is no stronger than its weakest link). The first use of terrestrial microwave for TV distribution was accomplished in this manner. In data communication, a terrestrial chain of this type using telephone circuits is called a multidrop line.

4.2.3 Multipoint-to-Point

A multipoint-to-point satellite network compliments the broadcast approach by allowing remote stations to send information back to the central station. As shown in figure 4.3, this type of connectivity provides two-way communication because the remotes receive the broadcast from the central station and can transmit back over the same satellite. It is different from a point-to-point network because the remote stations cannot communicate directly with one another but must do so through the central station, commonly referred to as the hub. In figure 4.3, the remotes efficiently transmit packets of data toward the satellite on the same frequency but timed such that the packets do not overlap when they enter the satellite repeater. Multipoint-to-point networks are an important extension of point-to-point because of the relatively small antenna size and simplicity of the remote station. These are afforded by using a more sophisticated hub station with a large-diameter antenna. Many commercial applications can effectively use this type of connectivity where subscriber response is necessary. Modern intelligence to the remote stations while keeping the overall network cost competitive with modern terrestrial networks. The very small aperture terminal (VSAT) is type of inexpensive earth station used in large multipoint-to-point networks.

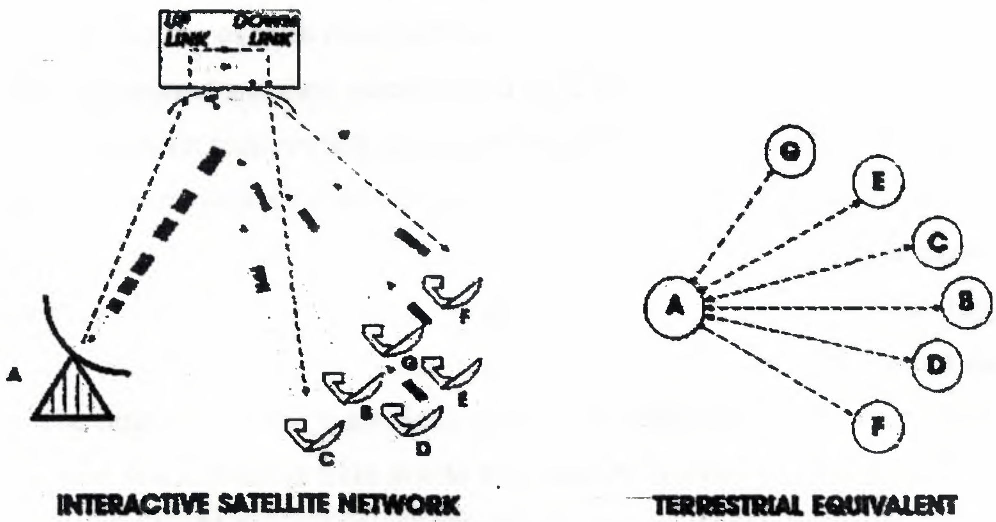


Figure 4.3 Interactive Satellite Network Using Multipoint-to-Point Connectivity.

4.3 Flexibility

A satellite-based network is inherently very flexible from a number of perspectives, which are described in the following paragraphs.

4.3.1 Implementation of Satellite Networks

To begin with, the implementation of the ground segment of a satellite network is relatively simple primarily because the number of physical installations is minimal. To put in a satellite network, a planner need only consider the sites where service is required.

Installation of a fiber optic cable system requires first that the right-of-way be secured from organizations such as governments, utility companies, and railroads. Hundreds or even thousands of sites must be provided with shelter and power (and even access roads in the case of terrestrial microwave). After the entire system is installed and tested, all of the equipment must be maintained to assure continuous service. Even still, one outage along the route will probably put the entire chain out of services until a crew and equipment can arrive on the scene to effect repair.

In contrast, the time to install an earth station network is relatively short, particularly if the sites are close to where service is provided. This assumes that a space a space segment already exists. In the past, implementation times for earth stations were lengthened, not because of sites construction, but rather because electronic equipment had to be special ordered and then manufactured. The low production volumes (because satellite communication requires less equipment in general than terrestrial) discouraged manufacturers from mass production standardized equipment and holding inventory for future sales. In today's larger and more competitive earth station equipment marked, higher manufacturing volumes along with the arrival of more standardized digital systems have allowed equipment suppliers to reduce cost and maintain on-the-shelf inventory. The time to implement satellite networks and add stations has been reduced from one to two years down to from one to two months. In contrast, a terrestrial fiber network is like a major highway project and will take years to design and construct.

4.3.2 Expansion of the Network

With a proper network architecture, new earth stations can be added without affecting the existing stations. This reduces the expansion timeframe to a few months or weeks, since all that needs to be done is to purchase the equipment, prepare the site, and then install the stations. Increasing the number of ROs is particularly easy and economical, and operation of existing stations is not affected. Satellite networks of the 1970s providing point-to-point links could not be modified easily because of the old, inflexible analogue technology employed.

To add an earth station to an old analogue point-to point network would require dismantling the equipment at each station to be linked with the new station. This major drawback of the older system has been eliminated with programmable digital technology. These more flexible digital approaches, can now be assumed in virtually every future application involving two-way communication.

4.3.3 Simplification of Network Routing

Rather than purchasing new long distance facilities for their exclusive use, many users lease voice and data circuit from terrestrial network operation (called *common carries* in North America). Therefore, the "backbone" network would already exist, and the only time necessary for implementation of such a private network is that needed to run local cable loops or to make appropriate wiring changes in the telephone offices. Time delays of many weeks month or still involved, however, beginning from the moment when service order are placed. The common carrier must then perform the network engineering install equipment if necessary and make the required wiring change. And then test the resulting circuit for proper operation. If the circuit or circuits cross the bond-aries between the terrestrial networks of different providers, then the process must be run simultaneously by the various organizations and coordination between them must be handled in some manner. In a modern satellite network, only the end connections are involved, because the satellite itself provides all of the intermediate routing.

Terrestrial networks must deliver multipoint connectivity by extending terrestrial links to each and every point to be served. There are terrestrial radio techniques which limit satellites by placing omnidirectional (i.e., wide, circular area coverage) repeaters on tours or mounting tops. Broadcast radio and TV work on a point-to-multipoint basis, and cellular mobile telephone is an excellent multipoint-to-point system. All such terrestrial techniques, however, are severely restricted as to range because of light-of-sight radio propagation. To extend will beyond this geographical limitation, less reliable point-to-point links must be established between the radio tours to change the broadcast of cellular stations together.

4.3.4 Introduction to Services

Expansion of a satellite network can add new services, many of which can not currently be accommodated terrestrial. Perhaps clearest example is the long distance transmission of full motion color television, which, as noted earlier, could not be carried over transoceanic telephone cables. It was until the advent of terrestrial microwave radio in North America that cost-to-cost TV transmission was possible. Satellite repeaters in the FSS have sufficient bandwidth to carry several TV channels along with an array of voice and data traffic. On a local level, the local telephone loops which bring voice and low-speed data services into the office and home are currently very limited in their capacity. Home cable television service is made possible only with a separate coaxial cable, and interactive two-way video teleconferencing is only provided on a very limited basis over terrestrial systems. Any and all of these services can be included in, or added to, the current generation of small earth station, particularly the VSAT operating at Ku band. Therefore, flexibility of satellite communication takes on added dimensions with new services which can not currently be offered on a single terrestrial network.

The three generic types of connectivity were covered in the previous section. It is very noteworthy that a given satellite network can achieve these connectivities individually or simultaneously. While a terrestrial network is usually restricted to a point-to-point capability. It is not uncommon for a user to implement a point-to-point satellite network involving from 10 to 50 earth stations and then add a broadcast capability to extend the network to hundreds or even thousands of receiving points. Any one of the point-to-point stations could then be used as an uplink site to broadcast digital information or video programming on an occasional basis. The multipoint-to-point capability can be installed in the future by adding transmit "retrofit" package to many of the smaller receive only stations.

4.4 Reliability

The remaining features to be described are more difficult to explain and quantify: they can, however, ultimately be the factors, which decide in favor of satellite transmission over terrestrial. The mere fact that a satellite link requires only one repeater hop, or a maximum of two in the case of international services, tends to make the satellite connection extremely reliable. The engineering of the link, must properly take into account the frequency band and fade margin requirements. When this is done and an establish satellite is employed, the link will be up and usable for well in excess of 99% of the time. In fact, satellite engineers normally talk of the link reliabilities of 99.99%, which equates to an outage or downtime of nine hours in an entire year. Normally, this outage is segmented into duration's of a few minutes distributed mainly through the rainiest months.

Long distance terrestrial systems normally provide reliabilities in the range of from 95 to 98%, where outage can be produced by fades on any of its radio paths (in the case of terrestrial microwave) and by equipment outage at any of the hundreds of repeater sites along the route. Cable systems are susceptible to accidental breakage or detection of the cable itself, and outages of several hours or even days at a time do occur. A single buried cable or microwave system is relatively unreliable due to the inevitable breakage or failure. Therefore reliable means of communication, although the cost of implementation would only be within the range of relatively wealthy organizations (AT&T. govern- ments , and major industrial corporations).

Equipment failures on satellite links do occur, and for that the reason backup systems are provided. A communication satellite contain essentially 100% backup for all of its critical subsystem to prevent a catastrophic failure. The individual transponders to transmitters within the repeater section will usually not be speared 100%, so that a fractional loss of capacity is possible at some time in the useful orbital life. Experience with modern commercial satellite ahs been excellent, and users have come to except near perfection in the reliability of these spacecraft. The principle cause of communication outage is not failure of satellite hardware but rather is due to double illumination problem described in chapter1 Harmful radio frequency interference (RFI) is a fairly routine occurrence and satellite operators are reasonably well equipped respond to and identify the source of the problem (which is almost always accidental and of short duration).

The reliability of satellite communication is enhanced by the fact that virtually all of the ground facilities can be under direct control of one using organization. If a problem occurs with equipment or its interface with other facilities such as telephone switches or computer, the user's technical support personnel can easily identify and reach the trouble spot. Restoration of service can thus be accomplished conveniently and quickly, Terrestrial linkups can involved many organizations which provide services in section of the country or city, complicating the necessary troubleshooting and follow-up. For example, the former AT and T Bell System was broken up in the United State in 1983, resulting in the creating of seven independent corporation, each controlling roughly one-seventh of the local telephone service of the country. AT and T continues to be the largest long distance service provided as the regional Bell companies are currently restricted from this type of business. To reach customer location in two different regions requires that he facilities of three different companies be used: two regional Bell companies and AT and T. A competing long distance company such as MCI may provide a more advantageous service at perhaps a lower coast and can be used in lieu of AT and T. The facilities of the regional Bell companies, however, must still be arranged for the end-to-end service will be amplified in time duration as three entities work to locate and rectify the problem.

4.5 Quality

The following paragraphs identify different approaches to measuring quality of transmission. Emphasis is usually placed on human perception, which is particularly valid for analogue signals such as voice and video. Quality in data communication boils down to the quantity of valid data, which reaches the distant end.

4.5.1 Signal Reproduction

For a signal of transmission. A satellite is nearly ideal for delivering a signal of the highest quality. Modern satellite system radiate sufficient power into the geographical footprint to be received by ground antenna of diameters in the range of 0.8 to 10 meter (3 to 32 feet). Because satellite use line-of-sight transmission in direction nearly perpendicular to the atmosphere, the frequency and duration of link fades are reduced as compared to terrestrial microwave, many terrestrial network suffer from man-made noise and various kinds of short interruptions (glitches), while satellite links experience primarily receive noise which is constant and easily compensated for with power. All of these factors allow the satellite communication engineer to design link of the highest possible circuit quality and to select equipment, which will provide this quality with confidence. The communication application where these aspects of quality play the greatest role is in point-to-point and point-to-multipoint video. Essentially all video programming destined to North American homes is carried long distance by satellite the perceived quality of the delivered video signal is for all practical purposes identical to that of the signal created at the studio or played from the originating video tape machine.

4.5.2 Voice Quality and Echo

The issue of quality of voice transmission has received a lot attention. Particularly in the United States where many large communication companies compete for customers. The use of the GEO for the communication relays was controversial to pick prior to the first use of SYNCOM in 1962 because of the delay of one-quarter second introduced by the long transmission path. The impact of this delay on voice communication continues to be debated even today; particularly as high-capacity fiber optic systems are installed in the developed world. Voice communication over satellite can be made acceptable to over 90% of telephone subscribers, as has been proven by numerous quality surveys. Terrestrial systems do not suffer as much from delay and hence are potentially more desirable, other factors being equal.

The mechanism that produces echo, Which can be the most objectionable result of delays illustrated in figure 4.4 echo is present in any terrestrial or satellite telephone link, because electrical signals are waves and thus are reflected by the far end back over the return path. Echo becomes objectionable, however, when the talker hears his own speech delayed by more than a few milliseconds. Shorter delays produce a hollow sound, like that heard in a long hallway or tunnel. At the left of figure 4.4 speech from a female talker is converted into electrical energy in the voice frequency rang (300 to 3400 Hz) by the handset and passes over the signal pair of wires to the telephone equipment used to connect to a long distance circuit. The same pair of wires allows the speech from distant end (where the male talker is listening at the moment) to reach the female talker. In contrast, the long distance circuit breaks the two directions in half, segregating the sending and receiving wire pairs. The device that routes the energy properly between the two wire (local loop) and four wire (trunk) lines is called a hybrid. The typical configuration has hybrid on each end: figure 4.4 however; show that the male talker is connected through an undefined terrestrial network within which several hybrids could exits. The echo path is produced within one or more of these unseen hybrids, allowing some of the female talker's speech energy to make a U-turn and head back towards the female talker. Since the echo is the result of uncontrollable factors in the terrestrial network. It must be actively blocked or else a negative impact on quality will result. Obviously, a satellite circuit with its one-quarter second (250ms) delay is subject to her first word.

The simplest and most effective type of echo control is to use a voice activated switch. As shown in figure 4.4. Whenever the female talker is speaking, the control circuits of the switching detect the presence of the incoming speech on the upper wire pair, and the switch on the lower wire pair opened. When she stops talking, however, the switch closes automatically. And the male talker is free to speak and be heard by the female talker. A similar switching would have to be placed on the basic type of echo control device is called an echo suppressor and has been on terrestrial and satellite circuit for decades. Other features are necessary to make the switch respond to characteristics of human conversation, such as when one party needs to interrupt the other, One of the biggest problems with satellite voice circuit of past years has been the difficulty of getting these old-fashioned echo suppressor to work correctly.

With the advent of high-speed digital circuit and microprocessors, a much superior echo control device has appeared. This is the echo canceller, which works the way the name implies, instead of switching in or out, an echo canceller works with digitalized version of the speech and mathematically eliminates the echo from it, It is an active control device and has the ability to

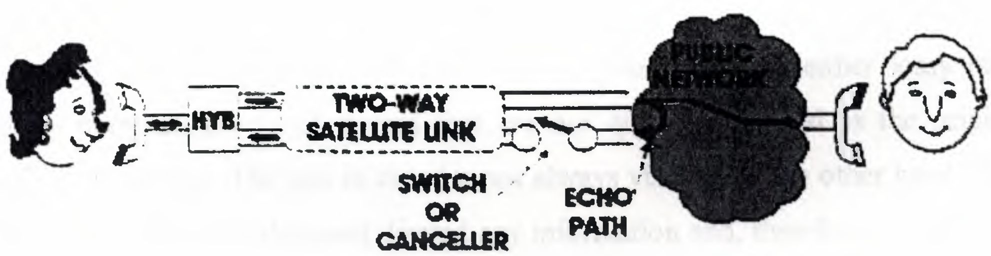


Figure 4.4 Telephone Echo a Satellite Is Caused By Electrical Reflection at the End where it can Be Eliminated by an Echo Canceller.

Characterize the echo path through the hybrid or terrestrial network. From this information, the canceller determines how to abstract a sample of the incoming speech from the return path to the distant talker. The details of how this technology works are beyond the scope of this chapter. The important point, however, is that there is strong evidence that an advance digital voice communication link with modern echo cancellation will be rated higher in quality by telephone subscribers than a traditional analogue voice link on a long distance terrestrial network.

4.6 Satellite Video Applications

Television or video services, which are one and the same, is perhaps the most popular source of entertainment and information for the public. The broadcasting industry has embraced satellite communication as the primary means of carrying programming from the program originator (TV Networks, cable TV programmers, and program syndicators) to the final point of distribution (broadcast TV station, cable TV system operators, and home dishes) in this section, the way in which programmers and distributors use satellite in there business is explained in some detailed

4.6.1 Video Compression

Video traffic tends to require high bandwidth as compared with other forms of traffic such as data and voice. For example, delivering uncompressed full-screen (640x480 pixels), full-color (24 bits per pixel), full-motion (30 frames per second) video equires 221 Mbps.

This large bandwidth is for only one video stream. Multiple streams would debilitate a network with even a gigabit per second capacity. Thus, there is a need for video compression.

Video compression techniques can be categorized as either lossy or lossless. Lossy compression yields frames that are not quite as detailed as the original frame prior to encoding. The loss of detail is not always visible. On the other hand, the lossless compression process does not discard any information and, therefore, produces an exact copy of the original frame. The following sections discuss compression methods which produce variable bit rate video and constant quality. Lastly, a section lists adaptive video compression techniques.

A) Joint Photographic Experts Group

The Joint Photographic Experts Group (JPEG) developed from a merger of the ISO Subcommittee 2, working group 8, with the CCITT (now ITU) study group VIII. The JPEG group issued ISO Draft 10918 in 1991 and an international standard in 1992. The JPEG specification can be used for still image compression and for video sequence compression called Motion-JPEG. There is a "lossy" mode based on the Discrete Cosine Transform (DCT) and a lossless" mode based on intraframe (same frame) prediction, entropy and run-length coding.

Pictures can range between 1x1 and 65,535x65,535 pixels and each pixel can range between 1 and 255 colors [SCHÄ95].

B) H.261

The CCITT (now ITU) developed the H.261 standard, in 1989, for low bit rate color video transmission. The primary use of the H.261 standard is for video delivery over ISDN at p x 64 Kbps, where p=[1,30], for multiple channel transmission. This recommendation specifies a hybrid scheme using DCT and Differential Pulse Code Modulation (DCPM) with motion compensation. In the H.261 approach, the source encodes the first frame in the intraframe mode to produce an I-picture (low compression ratio). Each subsequent frame is encoded using interframe prediction, based only on the previous frame, to yield a P-picture (high compression ratio). Real-time applications, like video-conferencing, can use H.261 since future frames rely only on adjacent previous frames and the entire video segment does not need to be stored prior to encoding. Finally, the H.261 standard utilizes conditional replenishment; the ability to update a macroblock (8x8 grid of pixels) only if current content differs from previous content in the same macroblock.

C) Moving Picture Experts Group

The Moving Picture Experts Group (MPEG) formed under the ISO subcommittee 2 in 1988. The charge of the group was to develop a video coding standard for digital Storage media and bit rates at up to about 1.5 Mbps [SCH95ۋ]. The MPEG-1 (ISO 11172) standard was released in 1992. Today it is common to see MPEG-1 coding used in video clips available on the Internet and CD-ROM applications. Features include random access of video, fast-forward/fast-rewind searches, reverse playback, and editing capability.

The MPEG-1 interframe coding method is similar to the H.261 coding scheme. There are I-pictures which are coded independently of any other frame. The I-pictures can serve as reference points for arbitrary access or "step" points for fast-forward and fast-rewind.

The P-pictures are predicted from previous I- or P-pictures. The B-pictures are bidirectionally predicted or bidirectionally interpolated from past or future I- or P-Pictures.

C) Adaptive Video Compression

Adaptive video compression techniques differ from previously mentioned techniques in that adaptive methods adjust their output based on changing network load conditions. In other words, when the network is congested, the encoding algorithm will decrease its output but when congestion abates, the algorithm will increase its output.

4.6.2 Methods Applicable To Any Algorithm

Gupta and Williamson suggest the following approaches to adaptively compress video [GUPT95].

- Window Size - The encoding algorithm can vary the horizontal and vertical picture dimensions. For example, a factor of four load decrease is obtained if the picture size is reduced from 640x480 pixels to 320x240 pixels. The end user at the destination, however, may become annoyed if such spatial variations are frequent.
- Frame Rate - The algorithm can decrease the frame rate by lowering the rate that it releases frames into the network. Full-motion video at 30 fps can be scaled down to 24 fps, which is movie quality or further, to 15 fps, for a factor of 2 decrease in bandwidth.
- Color Depth - The compression algorithm can decrease the number of colors, e.g.,16.7 million (24-bit) to 256 (8-bit) producing a factor of three decrease.
- Coding Algorithm - This approach differs from the methods above in that it involves not just one, but multiple algorithms. The source could progressively switch from using no compression, to algorithms with low, medium, and high compression ratios.

This approach increases decoder complexity at the destination.

4.6.3 Methods Applicable To MPEG

- Group of Pictures Pattern and Size - The MPEG-1 algorithm encodes video according to a periodic sequence of frames. This repeated pattern is called Group of Pictures (GOP). The GOP size as well as GOP pattern can be dynamically adjusted.

For example, let a given GOP pattern be the set of ten I's. This sequence produces thebest resolution and random access capability but achieves the lowest compression. The algorithm can replace the second through tenth I-pictures with B-pictures. The resulting GOP sequence (IBBBBBBBBB) sends reference I-pictures every ten frames. Further compression can be achieved if the GOP size is increased, i.e., reference I-pictures are sent less often. In the example above, the GOP size could increase from 10 to 15 to decrease the encoder's output bandwidth..26

- Selective Discard of B- and/or P-pictures - There are two locations where selective discarding can be implemented: at the network or at the source. The network approach requires network intelligence. The network must be able to identify cells belonging to B- and P-pictures and then mark these as less important than cells belonging to I-pictures. For ATM networks, this means marking these cells with CLP = 1. Also, discarding at the network does not alleviate congestion on the link between the source and the network ingress. A more effective approach would be to have the source discard the entire MPEG picture. In this research, the latter approach is chosen. Entire MPEG frames are discarded at the source. Measurements are made of the effectiveness of dropping B-frames only and P- and B-frames.

4.6.4 TV Broadcasting

To explain the importance of the current role of satellites, this section begins with review of the general characteristics of the TV broadcasting industry as it exists in North America. Table 4.1 summarizes the participants in the US broadcasting industry. Broadcasting is the commonplace medium whereby local TV stations employ VHF or UHF frequencies to transmit programming to the community. The range of reception is usually limited by line-of-sight propagation to approximately 50 to 100 miles. To conserve frequency channels, the same channel is assigned by the government to another station some safe distance away. Individuals use directional antenna (yagis and reflectors dipoles) to maximize signal strength and to suppress reception of unwanted distant stations operating on the same or adjacent channels. A given station only transmits a single channel and hints are constrained to offer only on program at a time.

TABEL 4.1 Comparison of Programming Services in Use for Over-the-Air Television in the United States

PART OF INDUSTRY	EXMPLES
COMMRECIAL NETWORK	ABC, CBS, NBC, FOX
NETWORK AFFILIATE STATION	WABC, KCBS, KNBC, KTTV
INDEPNDENT STATION	WWOR, KTLA, WGN
PUBLIC BOADCASTING NETWORK	PUBLIC BROADCASTING SERVIC
PUBLIC BOADCASTING STATION	WNET, KCET, WGBH
SYNDICATION COMPANY	BUENA VISTA TELEVISION
SYNDICATED PROGRAMMING DELIVERY	WOLD, SYNSAT

4.6.5 Networks, Affiliates, and Independent Stations

There are national television network (ABC, CBS, NBC, and FOX in the US) to provide programs to affiliated TV station for broadcasting over their assigned frequency channel either in real time or by replay from video tape. The term "NETWORK" in the context is capitalized to distinguish it from the generic term. Independent station (i.e., those not affiliated with network) can also obtain programming from the outside from syndication companies, which sell programs either individually or as packages. While most syndicated programs are in fact old network programs (reruns), syndicators often deliver now programs and movies. For example "Wheel of Fortune" and "Entertainment Tonight" are two very popular syndicated programs not offered by the networks. Networks affiliates also obtain much of their programming from syndicators.

All station operates their own studios so that they too can originate programs, particularly local news, special events, and most importantly to the success of the station, advertising. In North America, the revenues of the stations and the Networks are derived from the sale of advertising, because individual viewers do not pay for the right to watch over-the-air television (except of course when they buy the advertised product or service). Subscription television (STV), an exception to this rule, employed scrambling to control viewing of broadcasts and assures that monthly fees were paid. In the United States, however, STV was only successful for a short while between 1980 and 1982 until competition from videocassettes recorders and cable television undermined their profitability.

Networks offer the advertiser the important advantage over the local station of being able to deliver a nation wide audience. Which is important to products link GM Automobiles and Time Magazine the revenues of the station and Networks are tied to relative size of their respective audience, which is evaluated by respected polling organizations such as A. C. Nielsen Company. Therefore the programmers need to deliver programming of sufficiently high quality to attract the largest possible audience.

Their profitability is constrained "however" by the cost of producing this programming and of delivering it to the affiliated stations.

4.6.6 Satellite Program Distribution

This then brings us to the importance of satellite in providing the needed low cost and highly reliable means of delivering the programming. A single satellite can employ point-to-multipoint connectivity to perform this function on a routine basis. To receive programming, every TV station in the United States owns and operates at least one receiving earth station and many own stations usable as uplinks. To achieve very high reliability during an extremely high value (in terms of advertising dollars) event such as the Olympics or the Super Bowl, a Network will "double feed" the program on two different satellites at the same time.

In the United States, there exist public television stations, which are neither operated for a profit nor obtain income from advertising. The Public Broadcasting Service (PBS) is nonprofit television Network that distributes programming to these public television station. Most of the funds for PBS and the stations raised through individual and corporate contributions rather than advertising. Stations also PBS and ach other for program production and rights for broadcasting. This has allowed the development of a narrower slice of programming (i.e., not of mss appeal) which caters to an audience more interested in education, public affairs, and classical culture.

Because of budget constraints, PBS was the first to adopt satellite delivery in 1976, using the Westar 1 satellite.

The benefits of satellite delivery having been demonstrated, the commercial Network then began of moving quickly in the same direction during the following years. As indicated previously. By 1984 all Network programming and most syndicated programming was being delivered by satellite links over the INTELSAT system for providing coverage of overseas events.

The technical means by which the TV broadcast industry uses satellite is illustrated in figure 4.5 predominant frequency band employed is C band for the simple reason that more ground antennas and satellites are available than at Ku band. The program distribution satellite shone on the left is used to broadcast the edited program feed on a point –to –multipoint basis. The downlink is received at each TV station by its own receive-only earth station and from there it is either transmitted over the local TV channel or stored on videotape. In the case of live broadcast from the network studio, the signal is connected from the camera to the uplink earth station and over the program distribution satellite. A video switching capability in the studio and t each TV station allows technicians to insert taped advertising and computer-generated graphics. Even though most programs are played from videotape, it is generally more economical to distribute tape programs by satellite to the TV stations where they are again recorded rather than mailing the tape (process called bicycling) around the country. Whether the programs are live or taped, the local TV stations are able to insert their own paid advertising in time slots left for that purpose by the network or syndicator

4.6.7 Backhaul of Event Coverage

All sports events and much news coverage is brought to the studio over separate point-to-point satellite link called a "backhaul". In the case of football games, for example, stadiums in North America have access via terrestrial microwave to a local earth station which c uplink the telecast to the backhaul satellite, illustrated in Figure 4.5. The Network or stations pay for the use of satellite and uplinking earth station by the minute or hour. The galaxy satellite system, owned and operated by Hughes Communications, Inc., is used extensively for this purpose and calls its occasional use business the Video Timesharing Service. Anyone with a receiving earth station can pick up the backhaul, which does not yet include the "commentary" and advertising spots that are interested at the studio prior to reuplinking to the program distribution satellite.

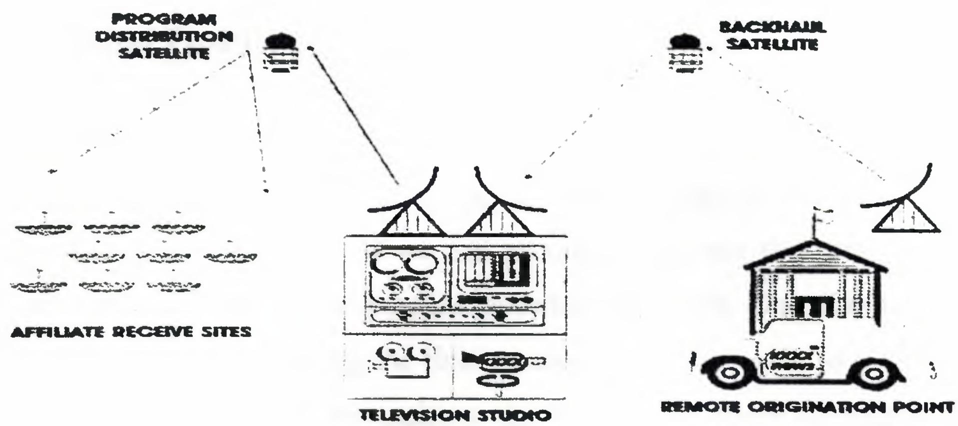


Figure 4.5 The Use of Satellite Transmission in the Commercial Television Industry for Backhaul of Event Coverage and Program Distribution to Affiliates

If coverage is of a one-time even such as a natural disaster or Olympic race. Then a truck-mounted transportable earth station is driven to the site and erected prior to Transmission. The use of a KU-band (14/12 GHz) backhaul has become particularly attractive for this type of rapid deployment service, and is called station news gathering (SNG). A KU-band SNG transportable is much more compact and mobile than its C-band equivalent and can be operated almost immediately after it has been parked on location. In addition, the use of non-shared KU-band frequencies eliminates any need for prior frequency coordination. Whether C or KU band, the time demands an economics of even converge can mean that backhaul satellite link will be attractive where the distance to the studio is anywhere from 50 to 5000 miles. For example, a backhaul was used during the Los Angeles Olympics of 1984 to reach from Lake Casts to Hollywood, a distance of approximately 60 miles.

4.6.8 A Ground Antenna Utilization

A Network affiliated TV station will use one fixed-mounted earth station antenna to receive full-time Network programming from the point-to-multipoint.

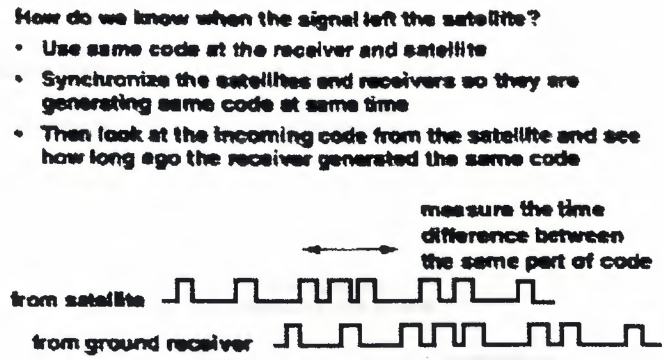
Program distribution satellite, some "roving" among other satellites can be done with a movable antenna to pick up special program provided by syndicated and to receive live coverage of sport events of interest only to the local community (for example, when the local baseball team is playing an away-from-home game in another city). Antennas used by the Network in backhaul service would therefore need to be movable, since events and satellite change from time to time.

4.7 The Global Positioning System (GPS)

4.7.1 GPS, How it Works

The whole idea behind GPS is to use satellites in space as reference points for locating positions here on earth. If we can accurately measure the vector from three objects we can "triangulate" our position anywhere on earth. Our distance from the satellite is measured by calculating the time it takes for a radio wave to travel from the satellite to our GPS receiver. We multiply this time by the speed of light to get our distance. Because radio waves travel at 300 million meters a second, the clocks used to measure the travel time must be extremely accurate (i.e.: hundredths of a nanosecond, 1 nanosecond = 1 billionth of a second).

For one satellite, the distance *(d1)* of a GPS unit is equal to the time its takes the radio signal to travel between the two, multiplied by the speed of the radio signal (the speed of light). The time of the signal is determined by measuring the difference between the same parts of the coded signals, as shown in the figure below. The set of all points where our GPS receiver could be at that distance *(d1)* can now be represented as the surface of a sphere in figure 4.6.



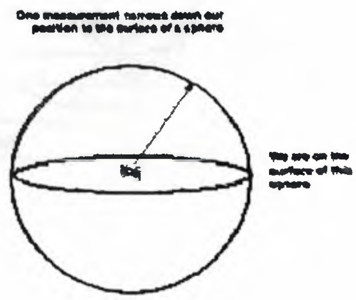


Figure 4.6 Sphere formed using time to calculate a distance from a receiver position to a Satellite

If we measure our distance to a second satellite and find out that it is *(d2)* meters away. That tells us that we're not only on the first sphere but we're also on a sphere at its respective distance from the second satellite. Or in other words, we're somewhere on the circle where these two spheres intersect. This intersection is the circle as seen in Figure 4.7 below

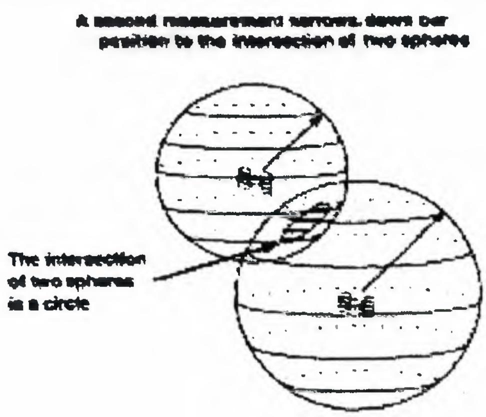


Figure 4.7 Figure 2 Circle formed by measuring the distance from our position to two satellites

If we make another measurement to a third satellite at distance *(d3)*, this narrows our possible positions down to two points shown in Figure 4.8. So by ranging from three satellites we have narrowed our position down to two points in space.

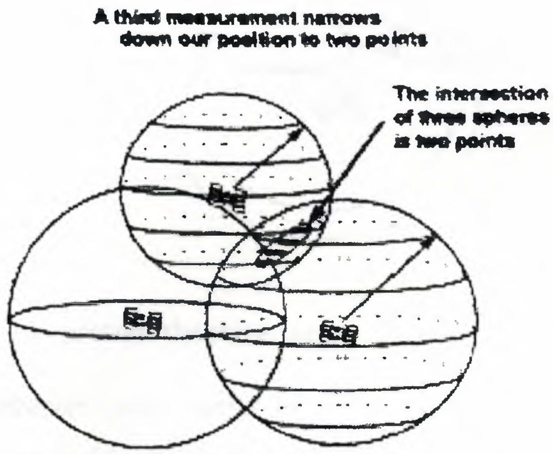


Figure 4.8 Two points formed by measuring the distance from our position to three satellites

To decide which of these two points is our true location we could make a easurement from a fourth satellite. However, usually one of the two points is a ridiculous answer (either out in space, underground, or traveling at an impossible velocity) and can be rejected without a measurement.

To be able to fix our position with only three satellites requires that there be accurate clocks not only in the satellites but also in the receiver units. A clock at the receiver unit is needed to ensure that the signals are perfectly synchronized. Because these clocks are so expensive, it is impossible to put them in receivers. Instead, receivers use the measurement from a fourth satellite to remove clock errors. Figure 4.9 shows how the receiver senses the error.

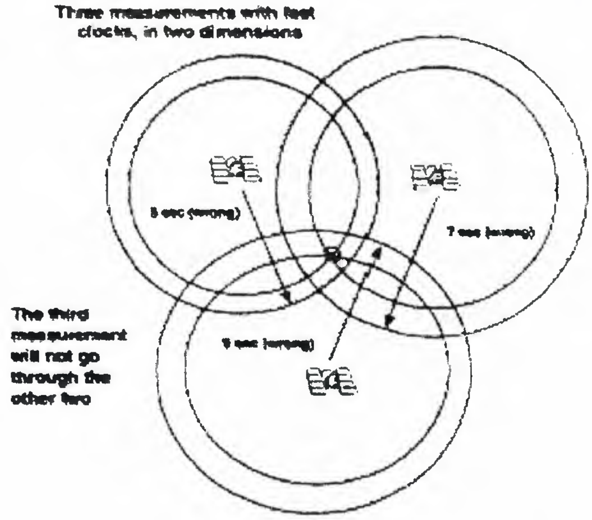


Figure 4.9 Clocks errors prevent the three ranges from intersecting in a single point

When a GPS receiver gets a series of measurements that do not intersect at a single point, the computer inside the receiver starts subtracting (or adding) time until it arrives at an answer that lets the ranges from all satellites go through a single point. It then works out the time offset required and makes appropriate adjustments. Because of this, four satellites are required to cancel out time errors if you require three dimensions. Figure 4.10 shows the employment of a fourth satellite for 3D work.

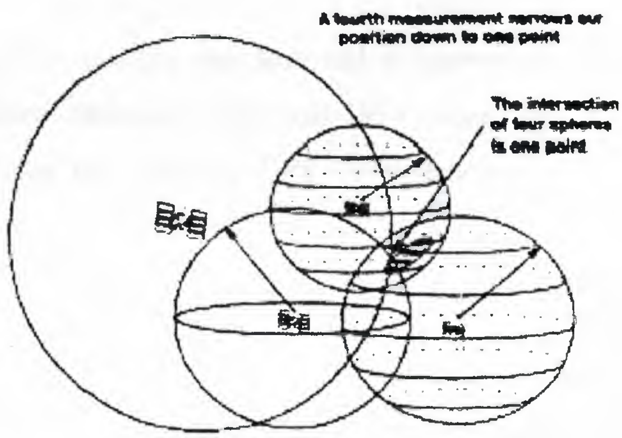


Figure 4.10 Fourth satellite used to solve the four unknowns, X, Y, Z, and time

Because no system is perfect, it is important to analyze specific sources of error that can exist in our GPS measurements. The typical error sources and values for most receivers are shown in Table 4.2.

Table 4.2 Error sources that must be considered when calculating position with GPS.

Error Sources	Size of Error
Satellite Clocks	< 1 Meter
Ephemeris Error	< 1 Meter
Receiver Errors	< 2 Meters
Ionosphere	< 2 Meters
Troposphere	< 2 Meters
Selective Availability(SA)	< 33 Meters

Theses values correspond to averages of many readings rather than the error which might result from a single reading. Although experimentation shows that the more fixes you record the better the data become, the increase in accuracy after collecting about 180 fixes at a given location is minimal and seldom worth the extra time it takes to record them.

4.7.2 GPS Satellites

The U.S. GPS satellite design calls for a total of 24 solar-powered radio transmitters, forming a constellation where several are "visible" from any point on earth at any given time. The first satellite was launched in secrete on February 22, 1978. Additional satellites were launched until mid-1994 when all 24 satellites were broadcasting. This became the standard GPS constellation of 24 satellites, which includes three spares..

The satellites are at a "middle altitude" of 20,000 kilometers (km), or roughly 12,600 statute/10,900 nautical miles (nm), above the earth's surface. This put them above standard orbital heights of the space shuttle and most other satellites but below most geosynchronous communication satellites. The constellation of satellites is called NAVSTAR their paths are neither Polar nor equatorial, but slice the earth's latitudes at about 55 degrees. Each satellite orbits the earth in about 12 hours, and an observer on earth will see the satellite rise and set 4 minutes earlier each day. There are four satellites in each of six distinct orbital planes. The orbits are almost exactly circular and produce a wide variety of tracks across the earth's surface. Figure 8 shows what the constellation looks like from space.

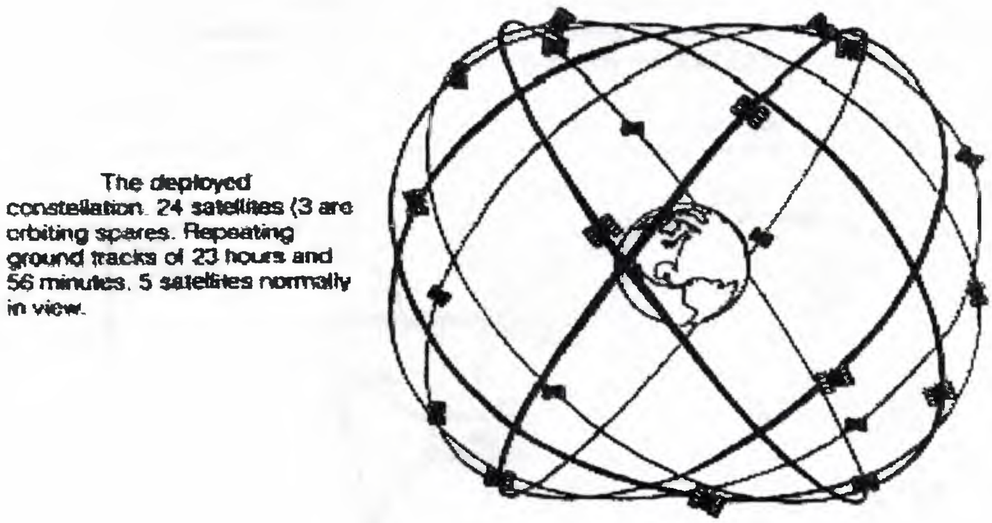


Figure 4.11 Satellite constellation

4.7.3 Ground Stations

While the GPS satellites are free from drag by the air, their tracks are influenced by the gravitational effects of the moon and the sun, and by the solar wind. Further, they are crammed with electronics. Because of this their tracks and inner workings require constant monitoring. This is accomplished by four ground base stations, located on Ascension Island, at Diego Garcia, in Hawaii, and at Kwajalein atoll in the Pacific. Each satellite passes over at least one monitoring station twice a day. Information developed by the monitoring station is transmitted back to the satellite, which in turn re-broadcasts to GPS receivers. The broadcasts contain information on the health of the satellite's electronics, how the track of the satellite varies from what is expected, the current almanac for all the satellites, and other information. Other ground-based stations exist, primarily for uploading information to the satellites. The master control station is in Colorado Springs, Colorado at the Air Force Space Command Center.

The MCS is the central processing facility for the network and is manned 24 hours per day, 7 days per week. It is tasked with tracking, monitoring, and managing the GPS satellite constellation and for updating the navigation data messages.
The task of the monitor stations is to passively track all GPS satellites in view

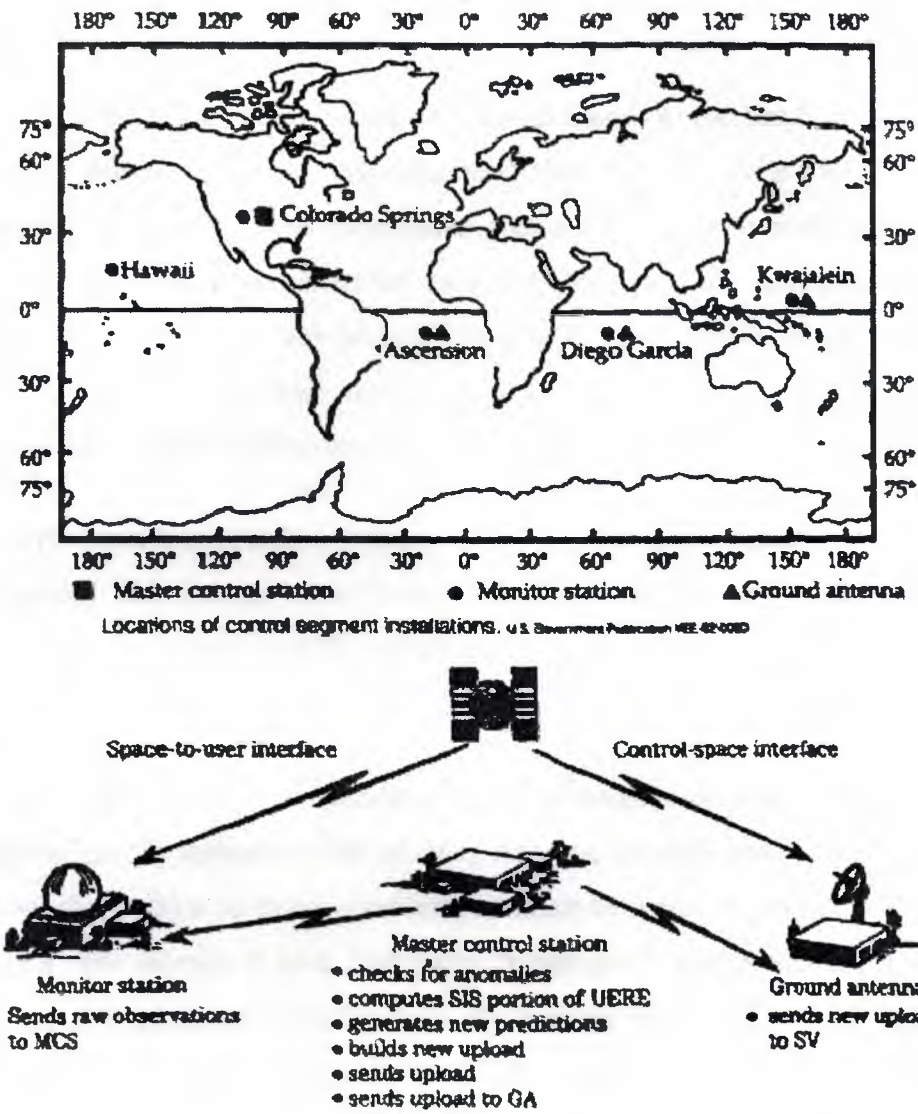


Figure 4.12 Ground Station and their locations

4.7.4 GPS Modes, Methods, and Receiver Types

GPS receivers are available in a wide range of configurations and price levels. Receivers may be purchased for as little as $99 or as much as $50,000. This range in cost is directly related to the features and precision that are achievable with the given unit. Users need to be wary of any low price unit that claim to be accurate to ±10 or better, as the advertised precision of a unit is often based on the best case scenario, which may or may not be achievable in the field.

The precision of a GPS receiver is determined based on the signals the receiver utilizes to calculated its position as well as the methods and modes used while it is in operation.

Please note that the **precision** of a unit is based on the smallest significant unit (centimeter, decimeter, meter, tens-of-meters) that the receiver is able to repeatable measure. The **accuracy** of the coordinates obtained from the receiver is a function of both the receiver/antenna combination used and the projection, datum, and coordinate system selected by the user (see Section 1.5). Use of an unsuitable datum, projection, or coordinate system may degrade the accuracy of the data collected by the receiver or make it unusable when the data are downloaded and entered into a GIS.

GPS receivers calculate location based on the radio signals received through their antenna. The antenna should be positioned in such a way as to maximize its visibility to the open sky, as GPS signals will not penetrate vegetation, metal roofs or human bodies!

Note that the position calculated by the receiver is actually the phase-center of the antenna, not the location of the receiver. As such, the GPS antenna should be placed on or over the position to be surveyed and the offset between the antenna and the known object (e.g., the antenna is on a 2.00 meter "range pole" and the tip of the range pole was set on top of the well head cover). By keeping track of these offsets, the GPS derived locations may be corrected to obtain the actual X, Y, Z, location of the point of interest.

The GPS user should be aware of the limitations inherent with the receiver/antenna configuration they are using, as the combination required often varies based on the type of survey being conducted.

4.7.4.1 GPS Modes

An individual GPS receiver may be able to operate within several different positioning modes. In order of precision these modes are autonomous, differential, kinematical, and static.

Autonomous positioning is a mode of operation of a GPS receiver where the receiver calculates position in real-time from satellite data alone without reference to data supplied from another receiver that is located at a fixed, known, location (i.e., base station). This is the least precise mode of operation. Point coordinate accuracy of ±100 m RMS is obtainable when selective availability is in effect and ±10 m when it is not..14

Differential positioning is a mode of GPS surveying that uses two or more receivers with one receiver acting as a base station that is located at a known, fixed location and the other receiver roving to unknown points. The base station computes corrections based on the differences between its known location and its location as computed from the satellite C/A code. These corrections are applied to positions collected by the roving unit. This correction can be done in real-time via a radio link or during post processing back in the office. Point coordinate accuracy of ±30 m RMS is obtainable when selective availability is in effect and ±1 m when it is not.

Kinematical positioning is a mode of GPS surveying that uses two or more receivers with one receiver acting as a base station that is located at a known, fixed location and the other receiver roving to unknown points. The receivers use the L1/L2 carrier-phase observation (including both the C/A code and P-code) and requires short (1 second to 10 minute) occupation times at the locations being visited by the roving GPS receiver. This method uses baselines to calculate position and has the potential to obtain greater accuracy than is possible with differential positioning methods. Point coordinate accuracy of ±1 m RMS is obtainable when selective availability is in effect and ±0.02 m when it is not.

Static positioning (a.k.a., geodetic survey) is a mode of GPS surveying that uses two or more receivers. The receivers monitor the L1/L2 carrier-phase observations (including both the C/A code and P-code) and use long occupation times (> 20 minutes). This method uses baselines to calculate position and has the potential to obtain greater accuracy than is possible with differential and kinematical positioning methods. Location is determination when the receiver's antenna is stationary on the earth. Point coordinate accuracy of ±0.05 m RMS is obtainable when selective availability is in effect and better than ±0.01 m when it is not. At least three of the points visited during the survey should have known horizontal and vertical position.

These known points are held fixed when calculating the baselines and insure that the newly surveyed points are tied into the local geodetic control network.

4.7.4.2 GPS Methods

The three methods used by GPS receivers to obtain position information are autonomous, post processed, and real-time. The autonomous method occurs when the GPS receiver is used as a stand-alone data collector and no further processing of the data will be done on return to the office. The location information collected is transcribed onto paper in the field or stored in the GPS unit for later transfer in the office to a database for mapping purposes. This method is the simplest and the least accurate of the three methods. The post processing method is used when the GPS receiver is used as a data collector and further processing of the position data will be completed after down loading the data at the office. This method assumes that a base station receiver (located at a known, fixed, position) was collecting data simultaneously with the roving unit. Based on the types of 15 receivers and antennas used during the survey and the positioning data collected either the differential, kinematical, or static processing mode may be used. The real-time method occurs when the GPS receiver is used as a data collector and the positions obtained are corrected on-the-fly based on information received via radio signal received from a base station (located at a known, fixed, position). Based on the types of receivers and antennas used during the survey either the differential or kinematical mode may be used.

4.7.4.3 GPS Receiver Types

As the previous description of positioning methods and modes may have indicated, both the receiver and antenna directly impact the precision to which one may survey. For example, the Coastal Monitoring and Analysis Group within the Shorelands and Environmental Assistance Program currently has two Trimble 4400 survey grade receivers. These receivers are able to track both the C/A code and P-code and monitor both the L1 and L2 frequency of the GPS satellite signal. These receivers are used with L1/L2 Geodetic Antennas with a removable ground plain (a device that minimizes the effects of multi-path on position calculations) and a real-time radio link.

The Trimble 4400 receiver configured as the base station uses a L1/L2 antenna with ground plain. In this configuration the base station commonly obtains a point position precision of ±0.01 m. When the second receiver is used as a rover (i.e., the ground plain is removed from the antenna), and real-time kinematical positioning method is used positions good to ±0.05 to 0.02 m are obtained. However, if we had used an L1 Compact Antenna (often used with Trimble mapping grade receivers) on the rover instead of the L1/L2 Geodetic Antenna, we would have obtained positions accurate of about ±0.5 m.

Table 4.3 shows in a general sense, the relative positioning accuracy that can be expected by different receiver types when using different modes of operation. Remember that the reported accuracy is usually reported as a RMS error and that any single GPS measurement may vary significantly from the mean.

Table 4.3 Common horizontal accuracy of different GPS receiver configurations based on different modes of operation. There is a 95% probability that a single measurement will fall within a circle of the diameter shown (values in meters).

	Mode			
Receiver Type	**Autonomous**	**Differential**	**Kinematic**	**Static**
Navigation Unit Using L1 C/A Code($99 to $1,000)	±100 (10)	±30 to 10 (5)	n/a	n/a
Mapping Unit Using L1 C/A and P Code ($1,000 to $8,000)	±30 (5)	±10 to 1	± 0.50	n/a
Survey Grade Unit Using L1 C/A, L1 P, and L2 P Code ($8,000 to $50,000)	± 30 (5)	±10 to 0.5	± 0.02	±0.001

The range of accuracy's shown in Table 2 are controlled by two major factors, the status of SA and anti-spoofing (on or off) and the codes and frequencies the receiver uses to calculation position. For example, most mapping grade units only use the C/A and P Code from the L1 GPS signals to calculate position. Since they do not monitor the L2 frequency these units are unable to correct for position error introduced by atmospheric delay effects. In addition, the autonomous and differential modes of operation often use the Course Acquisition (C/A) code to calculation position. As the name indicates, use of the C/A code limits the maximum obtainable precision to ±30 m in autonomous mode and ±1 in differential mode.

SA was turned off by order of the President of the United States on May 1, 2000. Removal the SA "random error" from the GPS signal has increased the accuracy of standalone and autonomous GPS receivers by a factor of 10, improving the predicted accuracy of GPS for civilian users from within 100 m to within 20 m. This performance boost will enable GPS to be applied in its most basic form to a variety of civilian activities.

CONCLUSION

A satellite system consists basically of a satellite in space which links many earth stations on the ground. The satellite can be thought of as a large repeater in space. it receives the modulated RF carriers in its uplink (earth-to-space) frequency spectrum from all the earth stations in the network, amplifies these carriers, and retransmits them back to earth in the downlink (space-to-earth) frequency spectrum which is different from the uplink 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

One advantage of communications satellites over other transmission media is their ability to link all earth stations together, thereby providing point-to-multipoint communications. A satellite transponder can be accessed by many earth stations, and therefore it is necessary to have techniques for allocating transponder capacity to each of them. It is unlikely that a single earth station would have this much traffic, therefore the transponder capacity must be wisely allocated to other earth station. Furthermore, to avoid chaos, we want the earth stations to gain access to the transponder capacity allocated to them in an orderly fashion. This is called multiple access. The most commonly used multiple access schemes are frequency division multiple access (FDMA), time division multiple access (TDMA) and code division multiple access (CDMA).

Satellite communication has evolved into an everyday, commonplace thing. Most television coverage travels by satellite, even reaching directly to the home from space. No longer is it a novelty to see that a telecast has been carried by satellite (in fact, it would be novel to see something delivered by other means). The bulk of transoceanic telephone and data communication also travels by satellite.

To keep the satellite steady and pointing in the right direction we are using pointing control system. The system uses sensors, like eyes, so the satellite can see where it's pointing.

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