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INTRODUCTION TO SPACE AND SATELLITES

Space, in a physical sense, is the infinite three-dimensional field in which matter exists and radiated energy propagates. In a geographical sense, however, space is the region of the universe that lies beyond Earth's atmosphere. Of course, both of these definitions of space are fundamentally important to satellite communications. But, more importantly, space is the Army's loftiest military "high ground." Historically, whoever held and used the high ground had a significant advantage over his adversaries. This age-old principle is still particularly true today in our fighting the information war from space. The use of space as a strategic location to emplace powerful packages of high technology offers the Army an array of enhanced information capabilities on the battlefield. These space-based capabilities include communications, positioning/navigation data, early warning, weather, environmental monitoring, surveillance, and targeting capabilities. Soldiers today are using space products, sometimes without even being aware of it. *The effective use of space systems and products is critical to successful Army global operations.*

There is nothing really mystical about satellites. Aside from its associated high-tech design, scientific documentation, and costly launch vehicle, a communications satellite is basically just a microwave radio relay station placed on a very high "hill." Communications satellites provide a tremendous network range extension advantage for the Army. Widely separated satellite terminal users within the same very large area of the earth covered by a single satellite's antenna can communicate with each other directly. A single satellite can link together sites that are far beyond the range of a single terrestrial line-of-sight radio link.

Satellites allow the global relaying of important information in a variety of ways, either to a single user or broadcast to many users simultaneously.

Accurate weather data is often obtainable only from satellite systems. Placing a long distance telephone call often involves a satellite transmission. Maps are routinely updated using data acquired by satellites. The Army uses satellite communications primarily for voice and data, but the use of satellite communications (SATCOM) is rapidly developing in other application areas to satisfy broadly ranging needs. Imagery, video teleconferencing, and global broadcast are examples of those needs.

Terrestrial communications systems, even those involving fiber optic cables, cannot duplicate certain functions for which satellites are ideally suited. Mobility and flexibility on the battlefield, and broadcast capability to deployed units throughout an entire theater of operations are unique satellite capabilities that cannot be equaled by fiber optic cable. The integration of satellite and terrestrial networks permits maximum communications flexibility for the warfighter.

Evolution of space and satellite systems is constant. Technology is providing increased capabilities. This section, which is intended to provide a fundamental knowledge of space and satellite systems, will assist in understanding information presented in subsequent chapters.

THE ENVIRONMENT OF SPACE

Orbital space is a vast area. It ranges from 60 miles above the surface of the earth to arbitrary points as far out as 60,000 miles where gravity is reduced to 0.05 percent of what it is experienced on the earth. It is difficult to envision the totality of this region,

Ninety-three miles is the most commonly accepted definition of where space begins, but it is not explicitly stated in any international agreement.

encompassing about 900 trillion cubic miles.

There is no clear line that marks the beginning of space. Gravity and atmospheric density gradually decline as objects move away from the surface of the earth, but both are still present well into what may be thought of as "space." There are several specific estimations of where space begins, ranging between 60 and 100 miles above the surface of the earth. There is more accuracy in saying that space begins at the altitude where the orbital velocity keeping an object in orbit is no longer countered by so much friction of atmospheric drag that the object is immediately brought down by gravity. Atmospheric drag can be a powerful force. It is present and can affect objects as far out as 1,200 miles from the earth's surface. Even objects placed into an orbit at less than 100 miles above the earth's surface will quickly lose speed and fall back to earth if they lack sufficient propulsion.

The earth's atmosphere limits the lowest altitude at which a satellite can be placed into orbit. Satellites launched from earth must pass through the atmosphere in order to attain the proper orbit. The earth's atmosphere is divided into distinct regions . The lines between these regions are not distinct and they blend into each other. Fluctuations occur in the sizes of these regions depending on the time of the day, the season, and the amount of solar activity.

Troposphere

Almost all weather and clouds occur here at the lowest region of the atmosphere. Starting at the surface of the earth, the troposphere extends up to the "tropopause," the upper boundary of this region. Above two miles, a person requires supplemental oxygen or a pressurized environment. The tropopause varies in thickness from 9-12 miles at the equator to about six miles in the polar areas.

Stratosphere

This region extends from the tropopause to the stratopause, the upper boundary, around 30 to 33 miles of altitude. Airflow in the stratosphere is mostly horizontal. This region is characterized by the near absence of water vapor and clouds.

Mesosphere

The mesosphere extends from its lower boundary at the stratopause, to its upper boundary at the mesopause, at about 50 miles of altitude. The mesopause is where the atmosphere reaches its minimum temperature, approximately 130 degrees below zero Fahrenheit. The mesosphere is a rather strange region. It is a transit area through which non-air-breathing rockets power thrust to reach orbital space and beyond. The 30-mile altitude of the mesosphere is low enough in oxygen pressure to require both fuel and an oxidizer to be carried in order to provide burning thrust for the rocket engines. However, the high altitude of the mesosphere contains air that is too thin to provide lift for even a high altitude jet to operate.

Thermosphere

The thermosphere extends from an altitude of 50 miles to between 200 and 375 miles. The temperature increases with altitude from about 30 degrees below zero Fahrenheit to the thermopause where the maximum temperature occurs at 2960 degrees Fahrenheit. An altitude of 93 miles is the lowest altitude at which a satellite in a circular orbit can orbit the earth for at least one revolution without propulsion. At this altitude, it takes 89 minutes to complete one revolution of the earth.

Exosphere

The exosphere, beginning where the thermosphere ends, extends out into space. The density of atoms and molecules that make up the atmospheric gases in this region is so low that all of the particles of atmospheric matter surrounding the earth at an altitude of 1000 miles could be contained in one cubic centimeter at sea level. However, even at this 1000-mile level, satellites orbiting in the exosphere are slowed by atmospheric drag caused by friction from collisions with individual particles.

SATELLITES

Virtually everyone in the Army today, either directly or indirectly, uses satellites. The use of satellites is so extensively embedded in today's global technology culture that it is difficult to find someone not affected by them. The impact of satellites, however, is not intuitively obvious to the average person. Why? For one thing, satellites are not easily visible. A soldier making a phone call does not think about the path his call takes to get to the distant end, nor does he particularly care as long as the call gets through. Secondly, the cost of operating a satellite is spread over so many customers that no one seems to have any claim of responsibility for it. And finally, the design, launch, and operation of a satellite is well beyond the means and knowledge of all but the largest and most well-financed institutions and governmental agencies. The fact remains that in order to support the warfighter in peace or war, satellites must be used and understood to take fullest advantage of their unique capabilities.

What Does A Satellite Do?

Most communications satellites carry active microwave repeaters, or transponders. The satellite receives signals from an earth station transmitter, amplifies them, translates them to another frequency, and then retransmits the signals back down to other terminals on the ground. The signal transmitted by a ground terminal is degraded by the signal's long-distance path through the atmosphere on its way up to the satellite. Amplification onboard the satellite ensures that the weak, distorted signal received at the satellite is restored to an accurate signal with sufficient strength to be relayed back down to and successfully received by an earth station. The signal returning to earth loses a lot of signal strength. As illustrated in figure 1-1, equipment in a ground station amplifies the weak signal received from the satellite, processes it, and provides a signal that is sufficiently clear to the recipient.

Why Use Satellites For Communications?

The importance of satellites for communications is based on several characteristics. Experience has shown that, when used in the proper applications, the features listed below give communications satellites some unique advantages.

Economical, Long Distance Communications

The cost of transmitting information between two users via satellites is essentially the same despite the distance. A signal can be relayed across the country or across the ocean by satellite as cheaply as across the street by satellite.

Broadcast Capability

Satellites can be used as broadcast transmitters. The signals from an earth station relayed by a satellite can be received over a wide area by multiple stations within the coverage area.

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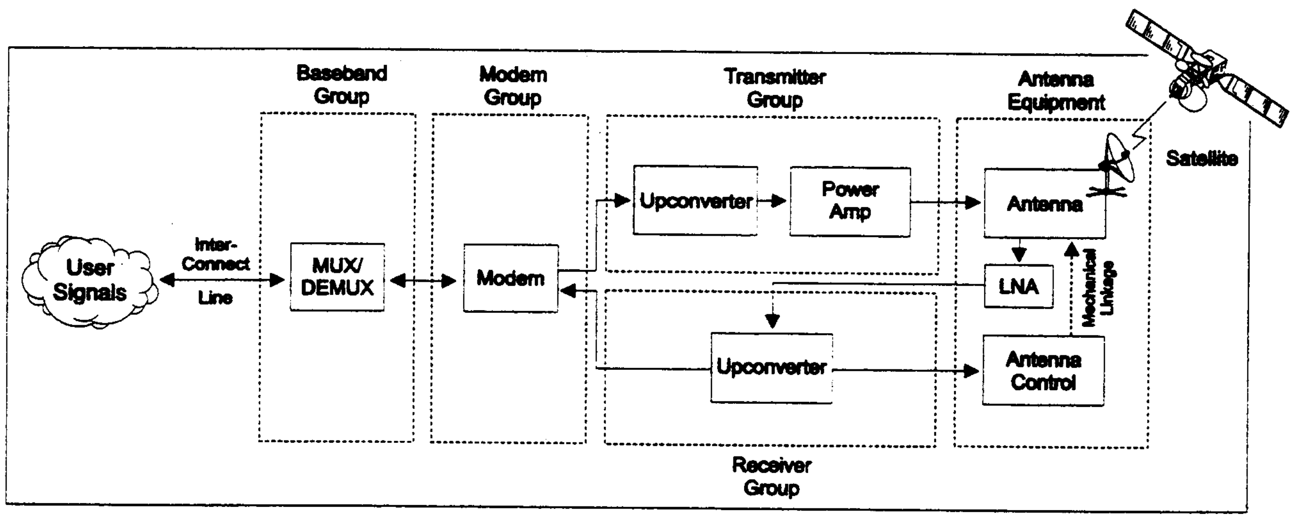

Figure 1-1. SATCOM Ground Terminals Process User Signals for Transmission or Receipt to/from the Satellite

Technically, a satellite can serve any suitably equipped ground station within it's "footprint" or the area of the earth within view of the satellite's antenna.

Although space appears to be a medium where weightlessness provides freedom and the means to roam at will, nothing could be further from the truth.

Uniform Service Characteristics

Satellites can deliver the same consistent set of services at costs that are potentially much lower than those of terrestrial systems.

Wideband Capability

Satellites are usually wideband (high throughput) devices that can relay large amounts of information within a given amount of time.

Broad Coverage

Technically, a satellite can serve any suitably equipped ground station within its "footprint" or the area of the earth within view of the satellite's antenna. A satellite can provide the same type of service to cities and to rural areas. Transmission from a satellite to a broad area of the earth's surface is not constrained by natural or manmade barriers such as mountains, oceans, or cities. There may be, however, some locales within the broad coverage area where a ground terminal antenna cannot get an unobstructed view of the satellite because of the proximity of mountains or buildings. This can be more of a problem near the fringes of the broad coverage area where the satellite will appear closer to the horizon.

New Services

The unique capabilities of satellites are rapidly giving rise to new communications concepts. Warfighters will have a greater variety of information at their disposal in different forms such as voice, data, video, and imagery. Commanders will be able to conveniently select from a rich variety of satellite-relayed information and services to aid in their decisionmaking processes and to accomplish their missions.

Satellite Orbits

An orbit is a path along which a satellite moves far above the surface of the earth. All earth satellites orbit around a point at the center of the earth. Although space appears to be a medium where weightlessness provides freedom and the means to roam at will, nothing could be further from the truth. The laws of motion and the presence of gravity dictate that every object in space will be trapped in a predetermined motion. It is possible to change this motion, but only after careful planning, great care, and expenditure of a tremendous amount of energy. Every change must be perfectly calculated and absolutely necessary. Satellites are trapped in a predetermined orbit around the earth.

Successfully launching a satellite into the planned orbit is a major technical accomplishment. Normally, users are not concerned with how the satellite gets into orbit but it is useful to have a basic knowledge of the process.

Attaining Orbit

All objects which are propelled into space have a trajectory determined by speed and direction. Some objects are launched fast enough that they escape the earth's gravitational pull enough to head out into space away from the earth. Other objects are launched at a slower speed and eventually fall back to earth. Still others are launched at a very precise speed and go into a "free fall." Objects in free fall, however, instead of falling back toward the earth, actually fall around the earth. They go into an orbit. The object must be launched to an altitude high enough to resist atmospheric drag and be propelled to a rate of speed so fast that as the object falls, it falls completely around the planet. This speed is approximately 19,000 miles per hour. Launching a satellite is a two part process: the launch phase, and the orbit injection phase. In the launch phase, the satellite itself is placed aboard some type of expendable launch vehicle such as the Ariane or Delta rockets (which are destroyed after completing the mission) or the Space Shuttle (more formally known as the Space Transportation System). The rocket is launched into a transfer orbit where the satellite separates from the launch vehicle. To attain a final orbit requires additional energy. This energy is supplied by thrusters onboard the satellite which fire repeatedly in small increments until the correct orbit is reached. This requires careful monitoring from ground controllers. Except for periodic minor adjustments, no more propulsion is necessary to keep the object in orbit. Once in space and stabilized in orbit, most satellites obtain power for their payloads from the sun using solar panels. If a satellite is in deep space, then nuclear power supplies are carried onboard for additional power.

Selection of the proper orbit depends upon the mission and purpose of the satellite. Orbits can be defined in categories depending on altitude (figure 1-2), eccentricity (figure 1-3), inclination (figure 1-4), and synchronization with the sun or other parameters. The major types of satellite orbits are described and shown graphically in figure 1-5.

Selection of the proper orbit depends upon the mission and purpose of the satellite.

Low Earth Orbit (LEO)

A satellite in a low earth orbit is generally considered to have an apogee of no more than approximately 530 miles. Most low earth orbits are nearly circular. LEO satellites travel very fast and need to use frequent propulsion to keep them at the proper altitude. LEO satellites tend to be slowed down by the thin atmosphere that remains at LEO altitudes. Without propulsion, the life span of a LEO satellite is about one year. LEOs are normally used for short, bursty, narrowband communications using radio frequencies below one gigahertz.

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The earliest communications satellites used LEOs mainly because of limited launching capability. Today, LEOs are

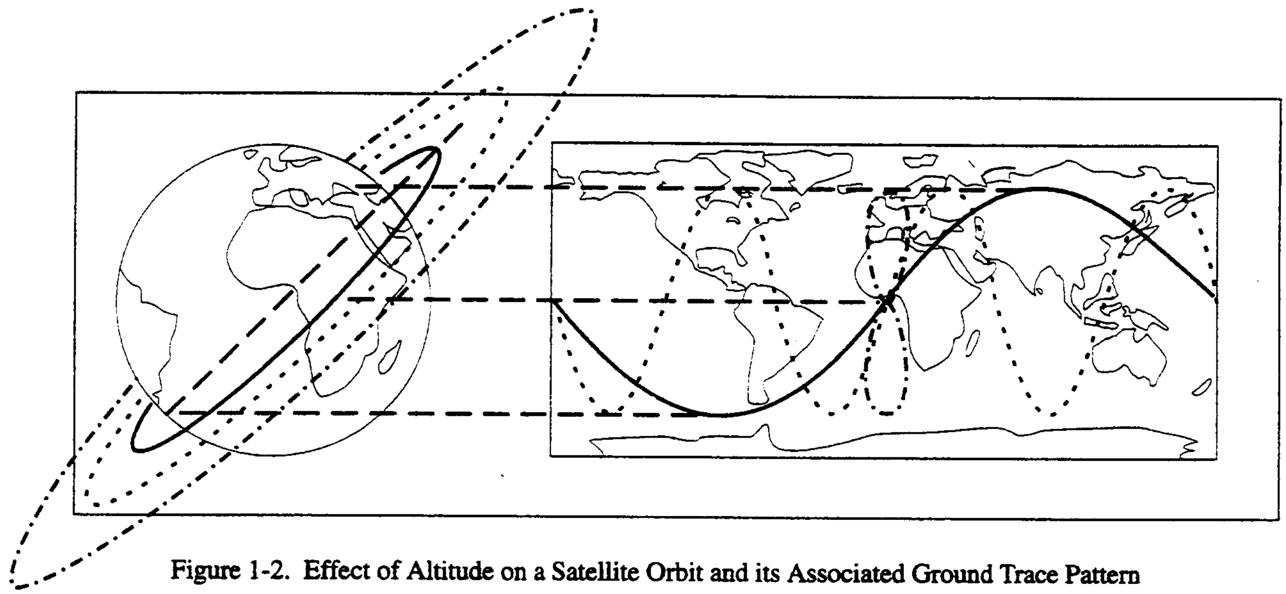


Figure 1-2. Effect of Altitude on a Satellite Orbit and its Associated Ground Trace Pattern

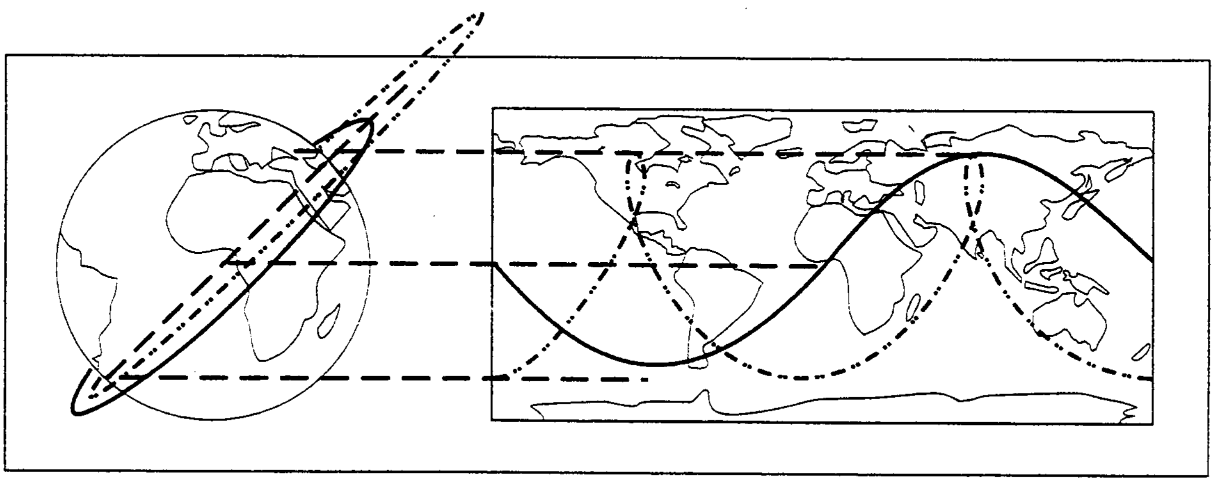


Figure 1-3. Effect of Eccentricity on a Satellite Orbit and its Associated Ground Trace Pattern

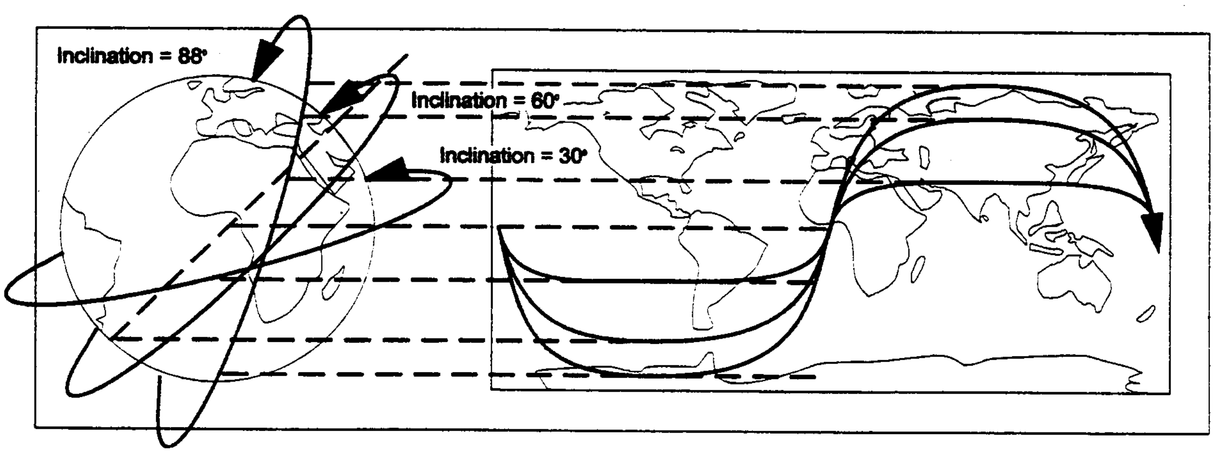


Figure 1-4. Effect of Inclination on a Satellite Orbit and its Associated Ground Trace Pattern

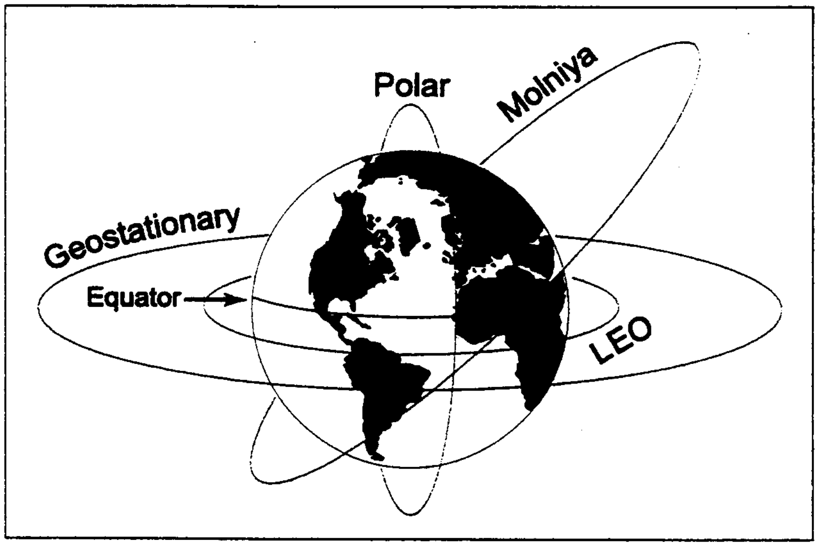


Figure 1-5. Major Types of Satellite Orbits

still used because they have some very attractive features. LEO satellites have the advantage of passing relatively close to areas on the earth. Smaller and simpler antennas can be used with fewer transponders and smaller antennas. Time delay is decreased for communications traffic. As payloads onboard LEO satellites, earth-imaging systems get higher resolution because of lower altitude. LEO radio systems require less transmitter power to successfully send a quality signal because of the shorter signal path to earth. Shorter signal paths also mean shorter signal delays which is an advantage in the responsiveness of services such as cellular telephone or two-way interactive paging systems.

Because of their multiple numbers positioned around the globe, LEO satellites appear to be located higher in the sky. Tall structures are less of an obstruction to small terminals that must communicate directly via the satellite. LEO systems are commonly used for observation, environmental monitoring, small communications satellites, and scientific payloads. Because of their continuous motion relative to the earth and their spot-beam antenna footprints, a disadvantage of satellites in LEO is that they do not provide continuous coverage for a specific location on earth. The satellite is in view from any given portion of its ground trace for only a short period of time before it passes quickly out of view. Because of this, many satellites are required for continuous service. Earth coverage is limited at lower altitudes and tracking antennas or omni-directional antennas are required. NASA's Space Shuttle travels in low earth orbit.

Geosynchronous Orbit

In a geosynchronous orbit, a satellite's motion is synchronized with an area of the earth below it and centered on the equator.

In a geosynchronous orbit, a satellite's motion is synchronized with an area of the earth below it and centered on the equator. The satellite completes an orbit in the same 24-hour period as the earth's rotation. From the earth, such a satellite appears to be stationary in the sky. A satellite with this orbit is considered to be in a high altitude orbit at approximately 22,300 miles above the surface of the earth. At this elevation, the gravitational force pulling a satellite towards the earth is exactly balanced by the centrifugal force pushing it outward. A geosynchronous satellite's orbit can have any inclination. A geosynchronous orbit is said to be inclined when the plane of

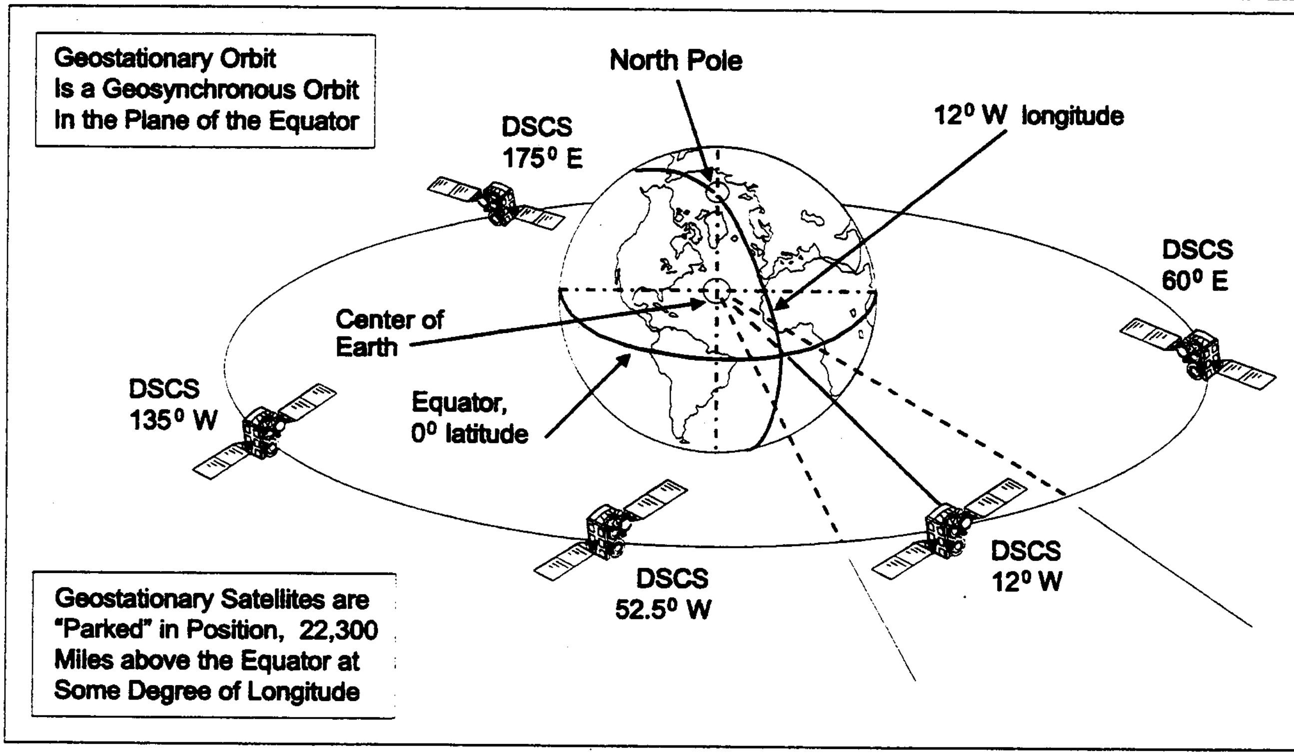


Figure 1-6. Satellites in Geostationary Orbit have Assigned Parking Slots

A GEO is a special type of geosynchronous orbit in which satellites are positioned at approximately 22,300 miles above the surface of the earth.

the satellite's orbit is at an angle to the plane of the earth's equator. For inclinations other than zero degrees, a geosynchronous satellite's ground trace will be a "figure-eight" straddling the equator. Satellites in geosynchronous orbit include communications, weather, and surveillance/warning satellites.

Geostationary Orbit (GEO)

This type of orbit, shown at figure 1-6, is also named the "Clarke Orbit" after the visionary science fiction writer Arthur C. Clarke who, in 1945, first described its use for orbiting communication stations. A GEO is a special type of geosynchronous orbit in which satellites are positioned at approximately 22,300 miles above the surface of the earth. A satellite in geostationary orbit is synchronized with the earth's rotation and therefore the satellite's position remains relatively constant with respect to an equatorial area of the earth below it. The satellite completes an orbit in the same 24-hour period as the earth's rotation with an inclination that is very near to zero. The satellite remains motionless over a single spot on the earth's equator and provides a continuous view of the same portion of the earth. The beams transmitted by the satellite to the earth and from an earth station to the satellite can remain fixed without having to track the satellite. This simplifies the design and operating requirements of both the satellite and the ground stations. It takes more time for a launch vehicle to put a satellite in GEO than for any other type of orbit used for communications satellites. Although, theoretically, a GEO is an orbit in which the satellite does not move with respect to the earth, in reality, this condition would not be true for very long. In the long run, the orbit is degraded from an ideal geostationary balance by disturbances from the moon and solar activity. More fuel is required to keep a satellite in the proper geostationary orbit at near-zero inclination to maintain the orbital plane close to the equator. The uniqueness of a GEO lies in the fact that there is only one and it has become the world's standard for the flying of most communications satellites. There are already many satellites positioned in geostationary orbit and, because of the advantages this orbit provides, the numbers will continue to increase. Therefore, it is difficult for providers to obtain desirable locations for their new satellites. This orbit is highly controlled to prevent overcrowding of the orbit, cluttering of it by space debris, and unauthorized use of this orbital resource.

Molniya Orbit

A highly elliptical orbit first used by Russia is called a Molniya orbit. This type of orbit is characteristically followed by a satellite that is at times closer to the earth and at times further away from the earth. Typically, a Molniya orbit has a perigee of approximately 1000 kilometers, and an apogee (orbit high point) at 39,400 kilometers. The speed of the satellite traveling in such an orbit increases as it gets closer to the earth and slows as it travels away from the earth. A satellite in Molniya orbit is semi-synchronous, "dwelling" about six to eight hours of every 24-hour period over a particular region of the earth. This is ideal for communications satellites used to provide coverage in the extreme northern latitudes where access to geostationary satellites can be difficult. By calculating and setting a Molniya orbit properly, a great deal of control can be gained over how much time the satellite dwells over any given place and at any given altitude. There are systems of other satellites in Molniya orbits in which ground systems switch among three or four such satellites in order to receive continuous coverage. Advantages of Molniya orbits, in addition to providing good coverage in the north polar areas, are long dwell times and economical launches. Disadvantages include the need for multiple satellites for continuous coverage and the poor coverage they provide of the southern hemisphere. There can also be a problem in transmission delays and signal loss when the satellite is at the near-apogee part of the orbit because of the great distance from the surface of the earth.

Polar Orbits

A polar orbit is any orbit which has an inclination of or very close to 90 degrees. Mapping and surveillance satellites are frequently placed in this type of orbit. Because the earth rotates below a polar orbit, the satellite has low-altitude access to virtually every point on the surface of the earth. Much more propellant, or energy, is required to put a satellite into polar orbit. Launch is normally accomplished at or near the equator so that the rotational speed of the earth can help push the launch vehicle to its final speed to attain orbit. Because of the inclination of a polar orbit, the launch vehicle must provide all of the energy needed to attain orbital speed.

Other Factors Influencing Orbital Selection

There are two *Van Allen radiation belts* that require spacecraft traveling in and near them to be heavily protected against radiation. Launch costs are increased because the protective shielding required adds a great deal of weight to the spacecraft. The location and size of the two Van Allen belts vary, depending on the season and solar activity. The lower belt starts at between 250 and 750 miles and goes out to about 6,200 miles. After a gap, the second belt resumes at about 37,000 miles and extends out to 52,000 miles. Orbits must be planned outside these belts and the amount of time a satellite might spend in the radiation zones must be kept to a minimum.

There are already many satellites positioned in geostationary orbit and, because of the advantages this orbit provides, the numbers will continue to increase.

Satellite parking slots are assigned by domestic and international agencies giving full consideration to frequency band, power levels, and coverage areas in order to minimize interference with other satellites.

In geostationary orbit, there is only room for a finite number of satellites.

To keep a satellite functioning over its expected lifespan requires almost constant attention through a complex network of equipment and people.

Orbital Parking

A satellite launched into geostationary orbit is said to be "parked" into a preassigned slot. This is similar to parking cars in a parking lot. Some parking slots are better than others and the best slots fill up first. As shown in figure 1-6, satellites can be positioned into slots where they can cover the most area for specific types of communications.

Satellite parking slots are assigned by domestic and international agencies giving full consideration to frequency band, power levels, and coverage areas in order to minimize interference with other satellites. Countries are allocated an "arc" of the geostationary orbit by negotiation with the International Telecommunications Union (ITU). Within the arc assigned, a national regulatory body can assign specific orbital slots. In the case of geostationary satellites over the continental United States, the Federal Communications Commission (FCC) assigns the slots within the allocated arc.

For communications satellites operating in the same frequency bands, the spacing between their orbital slots must be great enough to ensure minimal interference between transmissions to and from adjacent satellites. It is interesting to note that the FCC has progressively reduced the spacing required between satellites due to the demand for orbital slots. This requires the use of very narrow, tightly controlled antenna beams from a ground antenna to such satellites.

Skill and precision are needed to maneuver a satellite into its parking slot and then keep it there. The controllers on the ground must constantly monitor the satellite once it is in position to ensure it does not wander too far away from its assigned position. A geostationary parking slot is designated by the line of longitude over which it is positioned at the equator. A geostationary satellite cannot be allowed to shift position from its assigned parking slot by more than about 1/10th of one degree of orbital arc. This is to ensure that satellites do not interfere with each others' signals.

An important point to remember with orbital parking slots is that in geostationary orbit, *there is only room for a finite number of satellites.* There is a limit to how much technology can increase the capacity of the orbit to accept new satellites with such measures as narrow transmission beams, polarization schemes, and precision launching and positioning. Packing more satellites into geostationary orbit would ultimately affect the efficiency of the orbit's use and the quality of communications it supports.

SPACE SYSTEMS

Space systems are not just launched and then left to perform their missions without any further caretaking. Satellites are complex pieces of equipment that cost millions of dollars to design and launch. To keep a satellite functioning over its expected lifespan requires almost constant attention through a complex network of equipment and people. As shown in figure 1-7, there are three distinct segments in a space system:

Space Segment

There are two parts to the space segment: the satellite platform (the basic frame of the satellite) and the payload. The payload's functions and capabilities are the reasons a satellite is placed in orbit. The payload provides space-based capabilities to the users and distinguishes one type of satellite from another.

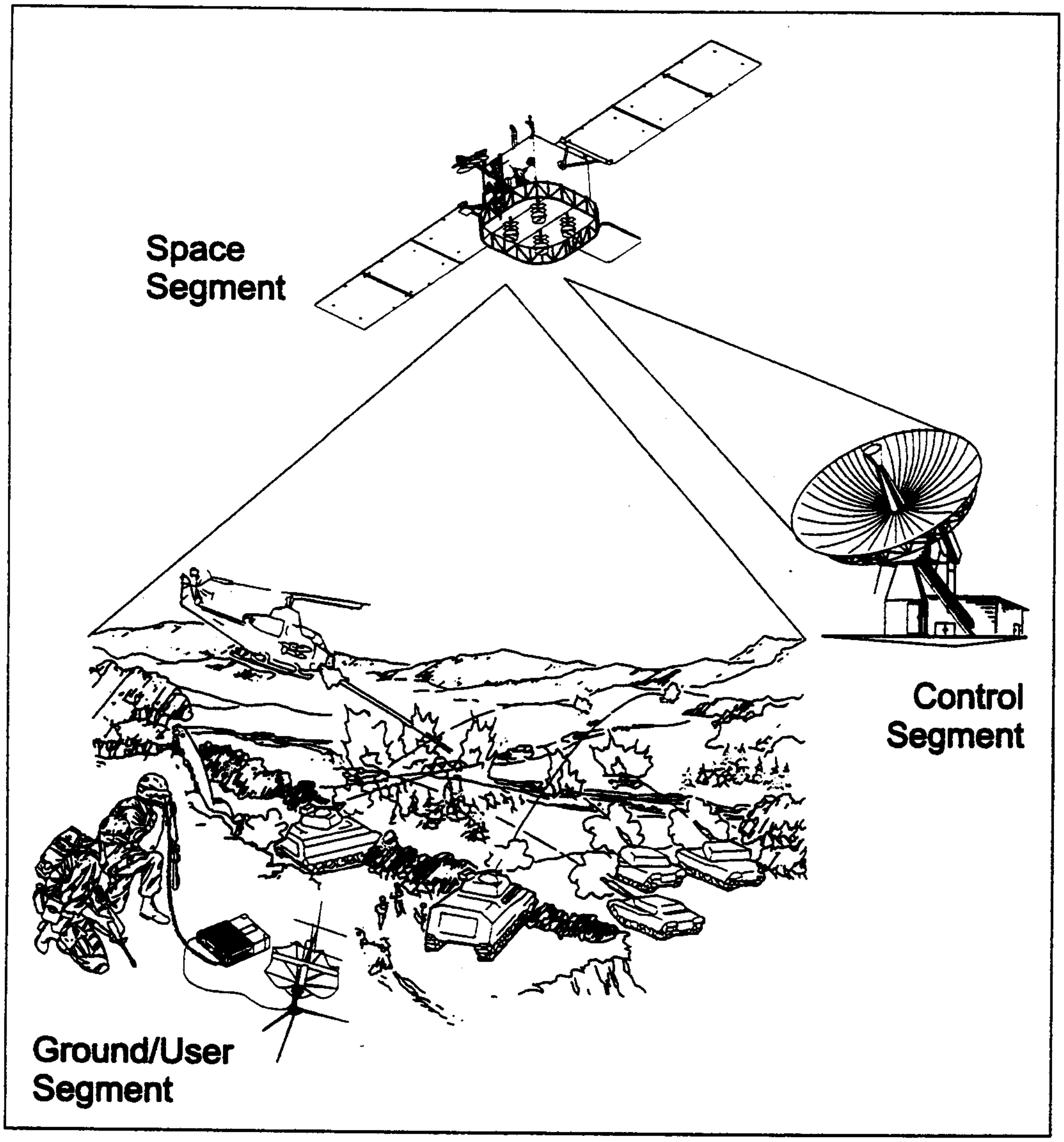


Figure 1-7. Space Systems Have Three Distinct Segments

Control Segment

The control segment is responsible for the operation of the overall system which includes platform control, payload control, and network control. The control segment consists of ground satellite control facilities, systems onboard the satellite, and communications networks linking the control facilities.

Ground Terminal Segment

This segment comprises the actual equipment on the ground that receives and transmits signals to the satellite. Ground terminals can vary from a hand-held or manpackable terminal to a fixed or mobile shelter containing the equipment.

The electromagnetic spectrum can best be described as the entire span of frequencies or wavelengths that can possibly be exhibited by electromagnetic waves.

Electromagnetic waves are used to carry information between the earth and space.

Because it is a fixed resource and must be shared globally, the frequency spectrum is allocated for specific purposes to users throughout the world.

THE ELECTROMAGNETIC SPECTRUM: ESSENTIAL FOR SATELLITE COMMUNICATIONS

The electromagnetic spectrum can best be described as the entire span of frequencies or wavelengths that can possibly be exhibited by electromagnetic waves. The speed of light in a vacuum - 186,000 miles per second, or approximately 300,000 kilometers per second - is the rate of propagation of all electromagnetic waves. The strengths of an electromagnetic wave's electric and magnetic field components, measured in volts per meter and amperes per meter, respectively, vary as sine waves as they are observed over a period of time at a given point in space. The wavelength (in meters) is how far an electromagnetic wavefront will have traveled at the speed of light while its observed electric or magnetic field strength varies through one complete sine wave cycle. The frequency (in cycles per second, or hertz) is how many such cycles will have been counted at the observation point during a one-second period.

Electromagnetic radiation is far more familiar than most people realize. Light is a particular type of electromagnetic radiation at a frequency that can be seen and sensed by the human eye. Visible light makes up only a tiny portion of the entire electromagnetic spectrum and it is the only portion of the spectrum that the unaided eye can see. Many electronic devices, in order for them to perform their intended functions, require energy to be transmitted to them at a distance through the air by other electronic devices (cell phones, pagers, cordless phones, radios, televisions, etc.). Such devices work by using part of the electromagnetic spectrum. The transmitter sends out information carried by electromagnetic waves at a specific frequency or in a small range of frequencies.

Listening to Reba McEntire on the radio may not conjure up visions of electromagnetic waves, but that is how the information of Reba's voice gets carried to the radio receiver. Radio stations emit these waves into the air to be received by stereo tuners and boom boxes which detect and process the information that the waves carry to extract the music which can be enjoyed. X-rays taken by doctors and dentists of their patients use another kind of electromagnetic radiation at a different frequency. In Annex D (Reference Documents) is a diagram of the electromagnetic spectrum showing familiar objects that use or block a particular part of that radiation. This might provide an easier comprehension of the electromagnetic spectrum.

As shown, the electromagnetic spectrum encompasses a broad range of frequencies, many more than the eye can detect, including (in order of increasing frequency) radio frequency (RF), infrared (meaning "below red"), visible light, ultraviolet (meaning "above violet"), X-rays, and gamma rays. These designations describe only different frequencies of the same phenomenon, electromagnetic radiation. The reason this is important to satellite communications is that electromagnetic waves are used to carry information between the earth and space. The bands of interest for satellites lie above about 100 MHz.

Sharing The Spectrum

Because it is a fixed resource and must be shared globally, the frequency spectrum is allocated for specific purposes to users throughout the world by members of the ITU, a United Nations affiliate. The ITU hosts the World Radiocommunications Conference (WRC) every two years in Geneva, Switzerland. The last WRC was conducted in November 1997. At this conference, members representing countries around the world gather to make decisions on requests for approval to use shares of the electromagnetic frequency spectrum. To have the force of law, the decisions made at the WRC must be specified in treaties that are ratified by the member nations of the ITU. The member nations are responsible for making specific assignments of frequencies within their allocations to domestic users in their countries. Satellite signals are no respecters of national borders or terrestrial boundaries. Neighboring countries must coordinate their use of frequencies through the Master International Frequency Register under the auspices of the ITU. If there is a potential for interference, then more formal coordination between countries must be taken.

In the United States, frequency assignments are made by two separate federal agencies. The FCC assigns and regulates the use of allocated frequencies by non-federal government users within the boundaries of the United States. Allocation of frequencies to all federal government users are made by the National Telecommunications and Information Administration (NTIA). The NTIA is directed by the Assistant Secretary of Commerce for Communications and Information. Any assignment of frequencies by either the FCC or the NTIA is fully coordinated between the two agencies.

FREQUENCIES AND BAND DESIGNATIONS

Communications satellites pass information using radio frequencies that have been allocated for specific purposes. Governmental, military, aeronautical, maritime, fixed commercial service, direct broadcast services, and land mobile services all have portions of the radio frequency spectrum designated for their use. Refer to Annex D (Reference Documents) for a pullout chart depicting this spectrum.

Radio frequencies are divided into groups which have similar characteristics, called "bands." The bands are further subdivided into smaller ranges of frequencies called "channels," some of which are allocated for the use of satellite communications.

Many different frequencies are used in satellite communications. The RF portion of the electromagnetic spectrum has physical properties that are particularly advantageous for the practical implementation of radio communication transmission systems. The most useful RF frequencies lie in the microwave bands between approximately 300 MHz and 300,000 MHz. The frequency bands of interest for Army satellite communications are ultra high frequency (UHF), super high frequency (SHF), and, with the advent of Milstar, extremely high frequency (EHF).

Radio frequency bands are commonly designated and referred to with an internationally agreed system of acronyms. These acronyms and their meanings as defined by the ITU are shown in the following table:

Frequency	Acronym	Meaning
3-30 kHz	VLF	Very Low Frequency 30-
300 kHz	LF	Low Frequency
0.3-3 MHz	MF	Medium Frequency
3-30 MHz	HF	High Frequency
30-300 MHz	VHF	Very High Frequency
0.3-3 GHz	UHF	Ultra High Frequency
3-30 GHz	SHF	Super High Frequency
30-300 GHz	EHF	Extremely High Frequency

Also in popular use is another method of referring to particular bands of satellite communication frequencies using letter designations. This letter designation practice started in World War II to keep enemy forces from determining the exact radar frequencies being used. This is also why the letter designations follow no logical sequence. The letter designations for radar frequency bands as defined by the Institute of Electrical and Electronics Engineers (IEEE) Standard 521-1984 (1989) are shown on the next page.

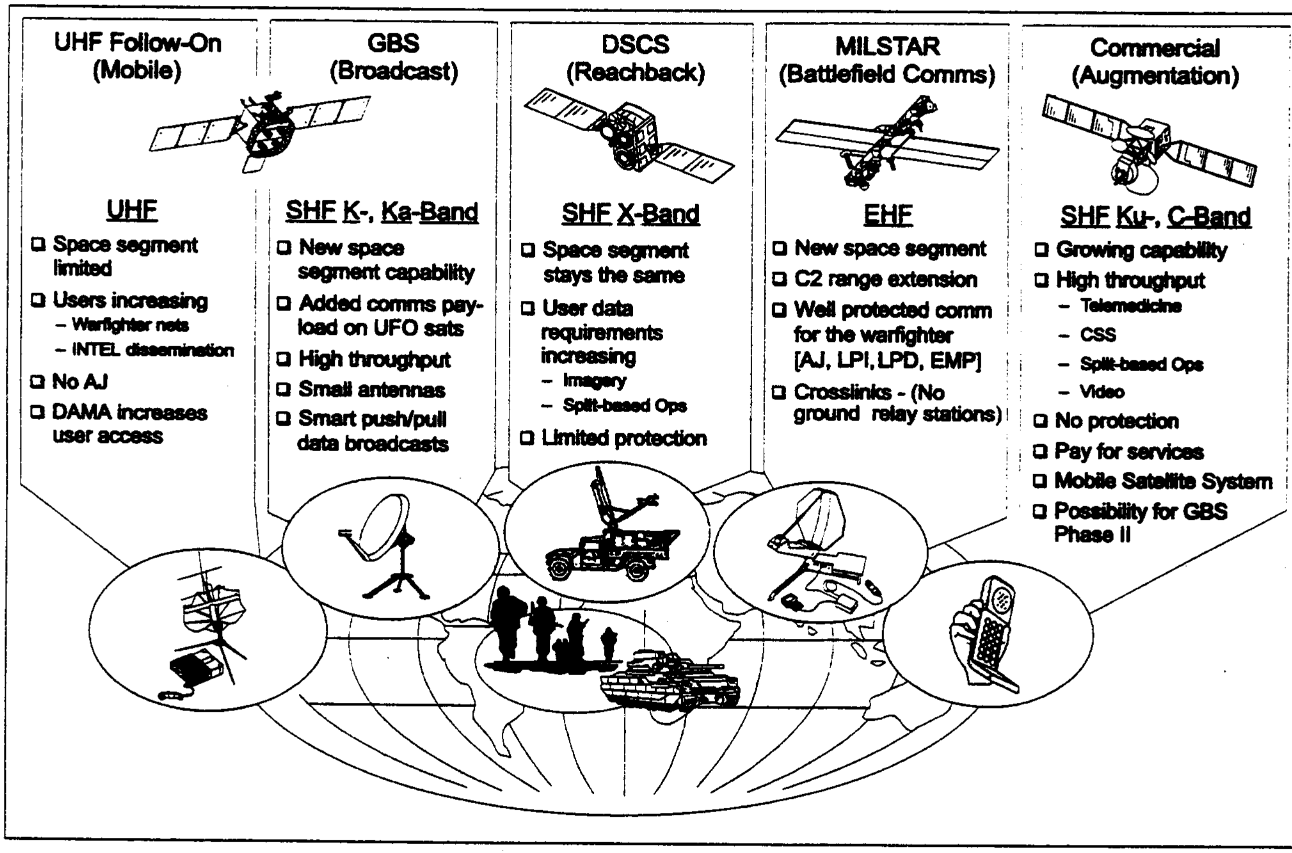


Figure 1-8. Military Satellite Systems are Essential to Provide Assured Communications for a Force Projection Army, with Commercial Systems Augmentation to meet Surge Requirements

The Army uses UHF for its single channel satellite communications.

Letter Designation	Frequency Band
P	225 - 390 MHz
L	1 - 2 GHz
S	2 - 4 GHz
C	4 - 8 GHz
X	8 - 12 GHz
Ku	12 - 18 GHz
K	18 - 27 GHz
Ka	27 - 40 GHz
V	40 - 75 GHz
W	75 - 110 GHz

As illustrated in figure 1-8, the following is a brief overview of the three frequency bands (UHF/SHF/EHF) which are currently the most useful to the Army warfighter:

The Army uses UHF for its single channel satellite communications. Military "UHF" SATCOM in particular refers to communications in the band of frequencies from 225 MHz to 400 MHz. Note that the lower portion of this military "UHF" band is technically in the VHF band according to the ITU definitions. The military uses SHF for multichannel satellite communications.

The SHF frequency band spans the C-, X-, and Ku-bands, and a portion of the Ka-band. The C-band, the most developed frequency band, is used for commercial SATCOM. C-band frequencies are also allocated to terrestrial radio relay microwave systems that are used by telephone companies to interlink switching centers. To minimize interference from satellites into terrestrial radio relay networks, power flux density limits of satellite transmissions are set and enforced by international agreements. The Army will be able to access C-band using the SHF Tri-Band Advanced Range-extension Terminal (STAR-T).

Within the SHF band, the military commonly uses the term "X-band" to mean the specific band of frequencies from 7.25 to 8.4 GHz, which is strictly for military use. Although the lower portion of this band of frequencies actually falls within the IEEE-defined C-band, calling it "X-band" distinguishes it from the rest of the C-band and the Ku-band which are used predominantly for commercial SATCOM. The X-band has been used for years by the U.S. Government for military communications services. Military use includes both fixed and mobile satellite services as well as terrestrial mobile services. In this band, attenuation due to rain and other atmospheric conditions is negligible. The Army uses the X-band for communications via the Defense Satellite Communications System (DSCS) satellite constellation.

The Ku-band's opening as a useful SATCOM spectrum came as a result of the lack of enough available C-band frequencies to meet growing requirements. Greater attenuation due to rain and other atmospheric conditions in this band becomes a factor in designing for adequate satellite communications. Such attentuation is usually overcome by designing extra power margin into the link. This means that additional power must be available onboard the satellite for more powerful transmissions and more sensitive reception to overcome the attenuation caused by rain. The Army's use of the Ku-band is within the capabilities of the STAR-T.

EHF will be used for communications via the newest military satellite constellation, Milstar. There is some interest in extending the use of Ka-band for mobile satellite services to very small terminals such as hand-held personal communications service terminals. Experimentation is being conducted to ascertain the value of the Ka-band for such services.

As shown in figure 1-8, each frequency band used by the Army has special characteristics that differentiate one from another.

Approximate Frequency Range	(Band)	Typical Usage
225 MHz - 1.5 GHz	(P, L)	Mobile Satellite Service
2.0 - 2.7 GHz	(S)	Broadcasting Satellite Svc
3.7 - 7.25 GHz	(S, C)	Fixed Satellite Service
7.25 - 8.4 GHz	(C, X)	Military/Government Svc
10.7 - 18 GHz	(X, Ku)	Fixed Satellite Service
18 - 31 GHz	(K, Ka)	Fixed Satellite Service
44 GHz	(V)	Government Service

Bandwidth

A satellite transponder is built to receive and transmit signals within a specific, limited band of radio frequencies. The number of hertz (Hz) spanned by this limited band of frequencies describes the transponder's radio frequency bandwidth. The greater a transponder's bandwidth, the greater will be its *potential* channel capacity (in bits per second) to convey information at higher throughput rates. The mathematical relationship between the bandwidth (in hertz) of a transmission channel and the channel's information throughput capacity (in bits per second) is described by the Shannon-Hartley theorem. This theorem tells us that for a signal being transmitted through a channel of a given bandwidth, the channel capacity increases as the signal's power can be made greater than the noise power in the channel. Characteristic of electronic devices and electromagnetic transmissions, however, is that the noise power in a channel will increase as the channel's bandwidth increases. Wider bandwidth does not necessarily mean greater throughput capacity unless the conditions in all parts of the transmission signal path can be made just right to minimize the noise or to make the signal more powerful than the noise. So, there is a natural limit to the channel capacity that can be achieved practically in a transmission channel of a given bandwidth. This is why, in

Within the SHF band, the military commonly uses the term "X-band" to mean the specific band of frequencies from 7.25 to 8.4 GHz, which is strictly for military use.

A satellite transponder is built to receive and transmit signals within a specific, limited band of radio frequencies.

Throughout the satellite communications industry the term "wide bandwidth" is commonly used to mean "high throughput capacity" and "high channel capacity," although (strictly speaking) these terms are not necessarily equivalent.

The idea of efficiently used wide bandwidth is analogous to a superhighway with many lanes (channels).

practice, the transmitted signal power, the gain of the antennas, and the efficiency of the receiver must be carefully designed to sufficiently overcome the effects of noise in the transmission channel in order to get the most throughput capacity from it.

The point of discussing bandwidth is that satellite design and use is directly tied to how much channel capacity, or information throughput, a satellite transponder can accommodate. Throughout the satellite communications industry the term "wide bandwidth" is commonly used to mean "high throughput capacity" and "high channel capacity," although (strictly speaking) these terms are not necessarily equivalent. Most communications traffic over satellites is devoted to telephone calls. It is impractical to devote one transponder to one telephone call. Today's satellite transponders are designed to provide "wide" bandwidth, which with highly optimized links with ground terminals to achieve high throughput capacity, can accommodate thousands of voice circuits in both directions at once. The idea of efficiently used wide bandwidth is analogous to a superhighway with many lanes (channels). The more lanes that are present, the greater will be the highway's capacity to handle greater volumes of traffic.

Signal Polarization and Frequency Reuse

The demand for satellite resources and spectrum far exceed the availability. There are methods to make more efficient use of available frequency bandwidth. One important set of these methods is called "frequency reuse." A particular technique of frequency reuse, called "polarization diversity," takes advantage of the polarization qualities of transmitted signals and the antennas designed to transmit and receive them. For each particular type of signal polarization, there is a corresponding type of polarization that has the exact "opposite-sense." Signals having such "opposite-sense" polarizations are said to have *orthogonal* polarizations. A communications satellite can, for example, serve two sets of user terminals in the same geographical area using the the same frequency band without interference by employing orthogonal polarizations. Frequency reuse through polarization diversity within the same satellite footprint is limited, however, to only a single reuse because there are basically only two kinds of orthogonal polarization: linear (horizontal versus vertical), and circular (right-hand versus left-hand).

The polarization of an electromagnetic wave is determined by the orientation of its electric field component. Recall that the electric field component is always oriented at right angles (or "orthogonal") to the magnetic field component. The electric field is said to have *linear polarization* when the electric field's lines of force stay wholly in one plane that contains the electromagnetic wave's direction of propagation during its entire length of travel. There are several different ways to define whether the electric field of a linearly polarized signal is oriented vertically (*vertical polarization*) or horizontally (*horizontal polarization*), depending on the frame of reference that is chosen for the convenience of analysis. A usual method when considering communication with a geostationary satellite, for example, is to define vertical polarization as having the electric field oriented parallel to the earth's north-south axis. Horizontal polarization, of course, would have the electric field oriented perpendicular to that, or in the earth's equatorial plane. An important fact that allows frequency reuse through polarization diversity is that an antenna designed and oriented to transmit or receive only vertically polarized signals will not at the same time transmit or receive horizontally polarized signals, and vice versa. For example, a horizontal linear dipole antenna at the surface of the earth will transmit or get maximum reception of only horizontally polarized signals while having maximum rejection of vertically polarized signals. A linearly polarized ground station antenna usually must have a servo-control oriented feed in order to keep the antenna's polarization maximally matched to the satellite's linearly polarized signal as the antenna tracks the satellite.

The other kind of orthogonal polarization is circular polarization. Consider a signal beamed down by a geostationary satellite in which the electric field is oriented neither vertically nor horizontally. If, as the signal travels, the electric field's orientation nevertheless stays in a single plane perpendicular to the direction of travel while the magnitude of its field strength varies as a sine wave, the signal is linearly polarized. But if, instead, the electric field's orientation continously rotates about the line of travel while the magnitude of its field strength remains constant, the signal has circular polarization. If the rotation is to the right around the direction of travel, the signal has right circular polarization. If the rotation is to the left, the signal has left circular polarization. A crossed dipole antenna will generate a circularly polarized signal if one of its dipoles is fed a signal that is ninety degrees out of phase with the signal that is fed the other dipole. Circular polarization is better suited than linear polarization for mobile SATCOM applications because it does not require the ground terminal to monitor and continually adjust the antenna feed orientation as does the use of linear polarization.

Polarization diversity has widespread use throughout the satellite communications industry, but its use requires special considerations in its engineering. Frequency reuse through polarization diversity works quite well, but signals at frequencies below 10 GHz are especially susceptible to being degraded by atmospheric conditions, especially those occuring in the upper atmosphere and in the ionosphere. Signal passage through precipitation, especially rain, as well as through upper atmospheric ice crystals and regions of elevated ion density in the ionosphere can actually have a depolarizing effect on polarized signals. In view of such conditions, it is important that alignments of the critical parts of a polarization diversity SATCOM system be constantly monitored to keep the links maximized and to prevent interference with adjacent channels using overlapping frequencies. Figure 1-9 illustrates some of the concepts of signal polarization.

Polarization diversity has widespread use throughout the satellite communications industry, but its use requires special considerations in its engineering.

ANTENNAS

Antennas are essential components of a satellite system. They are located aboard the satellites and as part of the ground equipment suites.

A common question which often arises concerns the distance of the transmitter (satellite) from the receiver (earth station) and the signal quality which makes up that specific link. Consider a local radio station that has a radiating power of 50 kilowatts. At 70 miles distance from the radio station's transmitter, a runner wearing AM/FM receiver headphones can easily pick up that station's broadcast using a simple antenna on the headphones. A satellite in geosynchronous orbit possesses nowhere near thousands of kilowatts of power to transmit, yet that satellite's signal must travel thousands of miles using no more than from 20 to 50 watts of radiated power. How is this possible? Part of the answer lies in the fact that microwave frequencies are used and the signal power of the satellite is concentrated into a more narrow, directed beam. The energy of the beam is focused by the shape of the antenna and transmitted in one direction (instead of broadcasting in all direc-

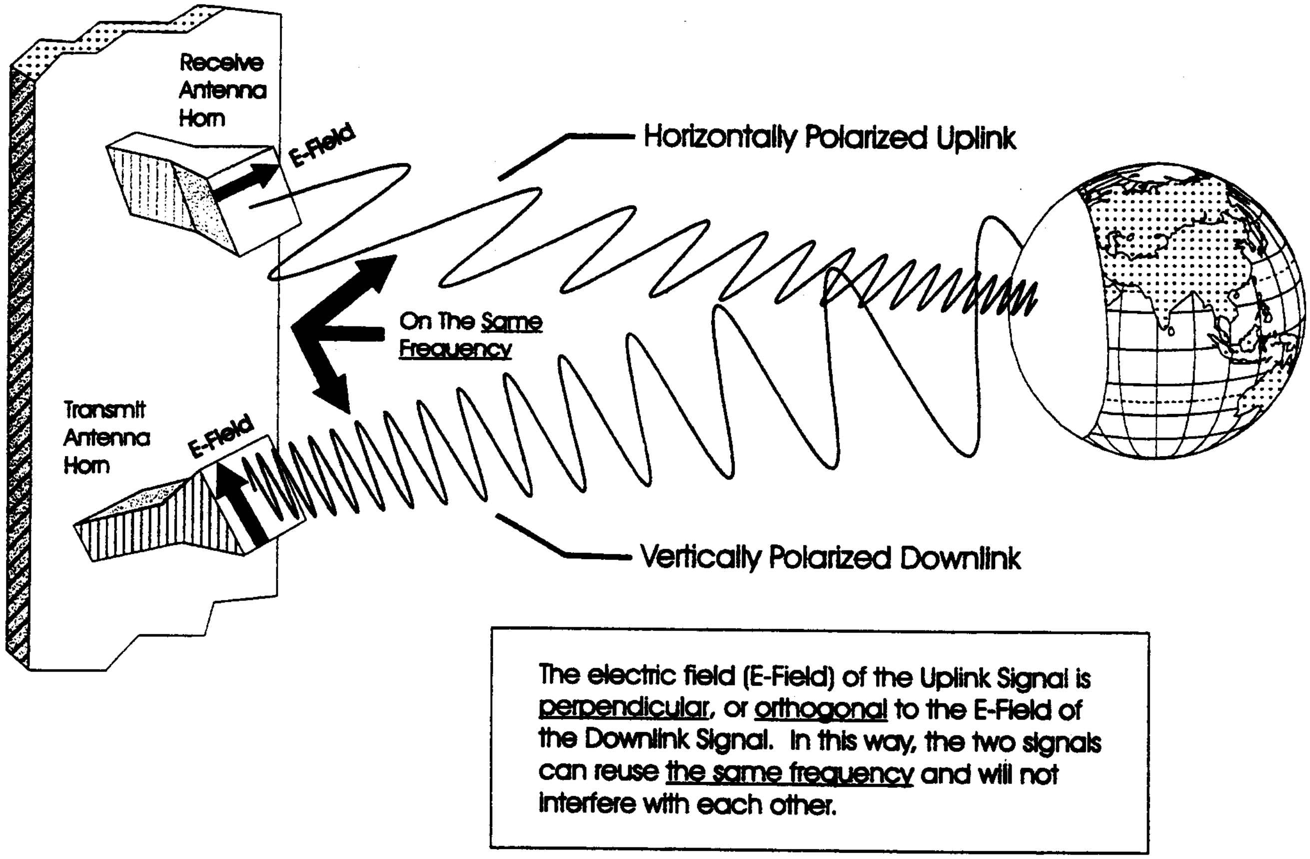


Figure 1-9. Signal Polarization

The frequencies of the uplink and downlink are always different from each other. The uplink frequency is normally a higher frequency than the downlink.

Ground antennas come in different sizes and shapes and are designed for a specific purpose.

tions) to a receiving earth antenna. Even when these signals reach the earth, they are very weak. Reflectors, low noise amplifiers, and sophisticated receivers as part of the antenna suite can restore the signal to a useful level at which it can be detected and processed.

The signal transmitted from a ground terminal antenna up to a satellite is called an uplink, and the transmission from a satellite to a ground terminal antenna is called a downlink. The frequencies of the uplink and downlink are always different from each other. The uplink frequency is normally a higher frequency than the downlink. The reason for this is that it is easier to generate radio frequency power on the ground rather than aboard the satellite where weight and power are limited. For a large dish reflector antenna on the ground, using the higher frequency (which has shorter wavelength) for the uplink will maximize the signal power that is transmitted to the satellite where the signal will be received by a much smaller antenna that is more efficient for receiving the shorter wavelength signals. This is important because the satellite's communications suite, being much smaller and much less powerful in comparison to the ground terminal, will be more disadvantaged in its ability to strongly receive and transmit signals. Again, the larger ground antenna will have the advantage to more strongly collect the weaker, lower frequency downlink signals transmitted by the satellite.

Ground antennas come in different sizes and shapes and are designed for a specific purpose. The most basic antenna the Army has is the *omni-directional or whip antenna* that transmits in every direction and

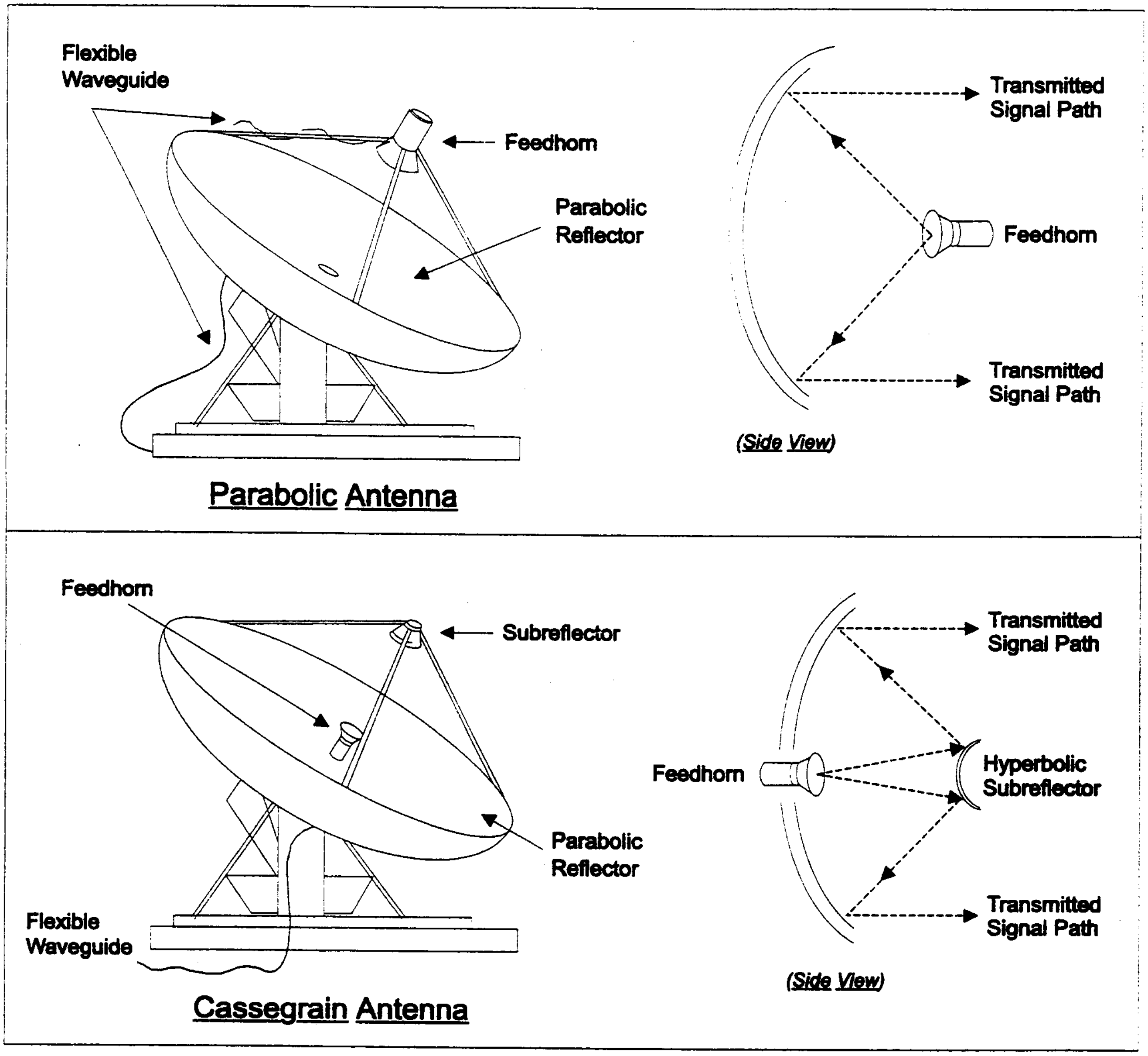


Figure 1-10. Parabolic "Dish" Antennas have a Direct Feed Focused on the Middle of the Antenna to the Receive and Transmit Signals

disperses the signal with equal intensity to every possible receiver. For SATCOM, an omni-directional whip antenna is most commonly used as a "receive-only" antenna. An Army Global Positioning System (GPS) receiver is a good example of this. A whip antenna is not normally used for uplink transmissions from a two-way satellite communications terminal because it cannot direct enough concentrated signal power toward a satellite to provide a useful link.

The most common type of Army SATCOM ground antenna, the *parabolic antenna*, is shaped like a dish or bowl which focuses the radio waves it collects into the opening of a microwave waveguide (figure 1-10). This waveguide aperture is called the "feed horn." From the feed horn, the signal is directed into an "amplifier." The best amplifiers for satellite communications are called "low noise amplifiers

The antennas onboard the satellite use the majority of the available onboard power to transmit and receive signals to and from earth.

A satellite antenna can be designed and shaped to focus and concentrate a signal into a desired geographical area (its "footprint").

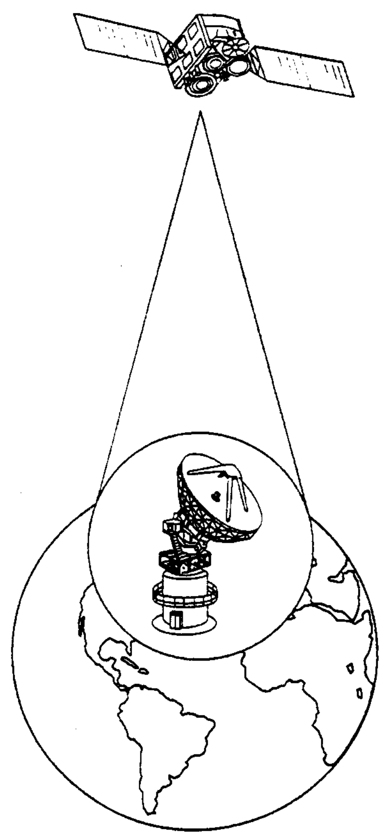
A gain of an antenna is a measure of its ability to concentrate energy being beamed to or from the satellite.

(LNA)." An LNA takes the received signal and boosts it while contributing as little noise of its own as possible to the signal. The amplifier then passes the signal to some type of a converter. The converter changes the modulated radio signal into electrical signals that are more easily processed for use by various end user devices which extract the useful information that was carried by the transmitted signal. If a signal is for a telephone call, the recovered telephone signal will be connected to the telephone network. If it is for a television program, it is converted into a form that can be displayed on a television. Although this is a simplistic explanation for what occurs, the basic idea is similar for transmitting a signal. The process is just reversed.

There are trade-offs in ground terminal antenna technology that can affect the power of the satellite.
Satellite antennas have two basic missions. One is to receive and transmit communications signals to support users on the ground. The other very important mission is to communicate telemetry, tracking, and control (TT&C) signals by which ground control systems and their operators ensure the satellites are properly maintained in orbit. The antennas onboard the satellite use the majority of the available onboard power to transmit and receive signals to and from earth. Satellites have communications equipment that perform essentially the same functions as the ground stations to receive, process, and transmit signals. The antennas on the satellites used for communications services are the largest and most complex while the TT&C antennas are usually horn-shaped and smaller. A satellite antenna can be designed and shaped to focus and concentrate a signal into a desired geographical area (its "footprint"). An important characteristic of a satellite communications antenna is its gain. The gain of an antenna is a measure of its ability to concentrate energy being beamed to or from the satellite. Higher gain contributes significantly to enhanced communications capacity and performance. The chart at figure 1-11 shows the tradeoffs for satellites assuming that two satellites are capable of relaying the same kind of signal.

Coverage Areas

Coverage refers to that portion of the earth's surface over which SATCOM services are provided. Global coverage is defined as that coverage of all longitudes and latitudes and geographic regions. There are five primary overlapping geographical regions to which common reference is made regarding Army SATCOM (figure 1-12). These regions are called the CONUS, Atlantic, Indian Ocean, Pacific, and North Polar regions. A sixth region, the South Polar Region has not had any Army SATCOM requirements to date but it may receive increased emphasis as new requirements emerge for that part of the world. Worldwide coverage encompasses the first four mid-latitude regions and is defined as the surface of the earth between 65 degrees south latitude and 65 degrees north latitude and at all longitudes. The North Polar region is defined as the area above 65 degrees north latitude and at all longitudes. The South Polar region is the area south of 65 degrees latitude. (Note: A minimum practical elevation angle for an earth station antenna is 5 degrees. So, for communication with a geosynchronous satellite, the maximum practical latitude, either north or south, for an earth station would be about 76 degrees. All of the earth coverage pattern maps for geosynchronous and geostationary satellites shown in this book reflect this 76 degrees maximum limit. The 65 degrees limits mentioned in the worldwide coverage definition above take into account many additional factors to approximate a region in which reliable link closure with a geosynchronous satellite can normally be expected.)



Satellite Design and Performance Trade-offs

If Satellite Has	Then	If Satellite Has	Then
High Power	Small ground antenna is needed	Low power	Large ground antenna is needed
Narrow footprint	There are few potential receivers or senders	Wide footprint	There are many potential senders and receivers
Single purpose	Only one kind of signal can be carried	Multipurpose	Many signals can be be carried (Voice, video, etc.)
All of the above	It will be expensive to build, but the earth stations will be relatively inexpensive	All of the above	It will be inexpensive to build, while the earth stations will be expensive

Ground Terminal Design and Performance Trade-offs

If	Then	If	Then
The dish is large	It will pick up more signals from space and be able to transmit with less power to transmit	The dish is small	It will pick up fewer signals from the satellite and require more power
The low noise amplifier is powerful	The dish can be smaller and less expensive	The low noise amplifier is not so powerful	The dish must be bigger and more expensive
The dish is close to the center of the footprint	The dish can be small and the low noise amplifier does not need to be so powerful	The dish is far from from the center of the footprint	The dish must be larger and the low noise amplifier more powerful
All of the above	Transmission and reception will be easy, reliable, and of high quality	All of the above	Transmission and reception will be difficult, unreliable, and of low quality

Figure 1-11. Basic Satellite and Ground Terminal Design and Performance Trade-offs

Footprints

The area of coverage on the earth's surface that is effectively irradiated by a satellite's antenna is called its "footprint." This footprint is also the earth coverage area from which a satellite's antenna can effectively collect signals transmitted to it. Theoretically, like the beam from a flashlight, a footprint should be circular. However, the earth's terrain is uneven, the thickness of the atmosphere changes, and different satellite antennas may have differently shaped beam patterns. The footprint, in reality, usually has an irregularly shaped beam pattern with signal intensity strongest in the central parts of the projected ground coverage pattern and tapering off towards the edges of the pattern.

Signals transmitted from a satellite can be unevenly distributed. It is impractical to build a satellite whose antenna coverage area is large and whose signal strength is entirely uniform across the footprint. The cost would be enormous. Instead, ground terminals have larger dish antennas to catch more of the signal the farther away they are from the center of the satellite footprint.

Special antennas onboard the satellite can project "spot beams" to more efficiently direct concentrated signals to specific locations. For instance, spot beams may be pointed to cover Hawaii and Puerto Rico, so that power is not wasted covering the oceans that separate them from the mainland. Some satellites use motor-driven antennas that can steer spot beams

Special antennas onboard the satellite can project "spot beams" to more efficiently direct concentrated signals to specific locations.

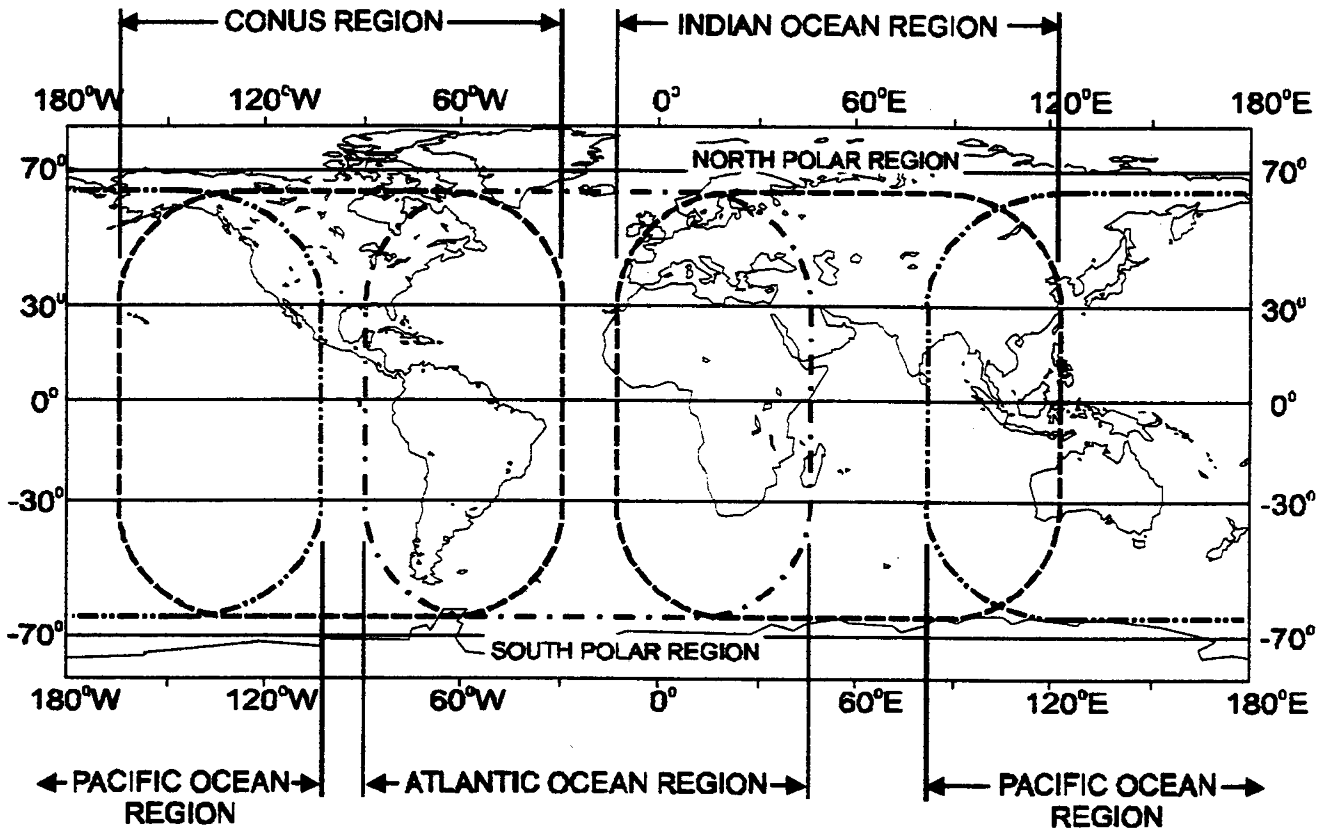


Figure 1-12. Satellite Coverage Areas

towards specific areas on the earth upon demand. "Steerable beam antennas," which can shift a satellite's coverage area, are particularly suitable for supporting the warfighter since changing missions demand flexibility in SATCOM coverage. Milstar satellites have this capability.

Army SATCOM Antennas

Omni-Directional/Whip Antenna: A whip antenna consists of a simple wire or a mast made of material that is a good conductor. Such an omni-directional, low-gain antenna is used, for example, on GPS terminals that receive in the L-band frequency range.

Helical Antenna: The helical antenna is constructed with a conductive material formed into a helix (such as wire coiled into a cylindrical spiral shape) with or without a center core. This kind of highly directional antenna (120 degrees of approximate beam width) is used in manpacked, shipboard, and tactical UHF terminals where size is a major consideration. It is designed for high gain at specific frequencies.

Parabolic Antenna: This dish-shaped antenna, normally used at UHF and SHF frequencies, has high gain and efficiency. An advantage of a parabolic antenna is that it works over a wide range of frequencies. A parabolic antenna has a direct feed focused on the middle of the antenna to receive and transmit signals. The dish is used as a reflector. When transmitting, the signal is propelled from the feed horn to bounce off the surface of the reflector which directs the signal out into space. When receiving, a collected signal is focused by the reflective dish into the feed horn that conveys the signal into the electronic systems of the receiver. The gain of a parabolic antenna depends on the diameter of the antenna's reflective dish and the frequency of the signal. If either is increased, then the antenna's effective gain will increase also. A variant of the parabolic antenna, used extensively by the Army as a DSCS antenna, is the Cassegrain antenna. This kind uses a sub-reflector as a secondary focal point from the main reflector. This sub-reflector propels the signal into a rear feed located behind the main dish. This type of feed system blocks less of the surface area of the dish and is less bulky and stressful on the antenna. This improves the antenna's signal-to-noise ratio and efficiency.

There are many other types of antennas used in both military and commercial satellite systems. The types of SATCOM antennas described here are just a few of the most common ones. A detailed description of a greater variety of antennas can be found in Defense Communications Agency Circular 800-70-1, supplement 2, Volume 1, *Satellite Communications Reference Data Handbook*, section 6.

SUMMARY

Satellites are designed to operate reliably and dependably throughout their expected operational lifespans. Satellites generally have a projected lifetime of about ten years. New generation satellites that were beginning to be launched in 1997 can have estimated lifetimes of 12-15 years. This is achieved through quality control and thorough testing of parts and subsystems before they are actually installed on a satellite and launched. Often, redundancy of components are built into key parts of the satellite so that if one part fails, another can perform its functions.
Communications satellites are launched and maneuvered into their proper orbits by rockets. Today the overwhelming percentage of communication satellites are maintained in geosynchronous orbit approximately 22,300 miles above the earth. There are other satellites in other kinds of orbits that perform specific functions or cover areas of the earth in ways that cannot be done with geosynchronous satellites.

A space system has three parts: a space segment, a control segment, and a ground terminal segment. The space segment consists of the actual satellites and their components. The control segment entails the ground facilities responsible for controlling the operation of the overall satellite communications system. The ground terminals transmit and receive signals to and from the satellite.

Antennas located on the satellites and on the ground terminals receive and transmit microwave signals. The antennas on a satellite have two basic missions. One is to receive and transmit signals to support the warfighter's communications requirements. The second mission, which is no less important, is to communicate TT&C signals for maintaining the operation of the satellite. The antennas employed on the ground terminals come in a variety of forms. Their basic function is to transmit and receive signals to and from a satellite.

CONUS
Continental United States

DSCS
Defense Satellite Communications System

EHF
extremely high frequency

FCC
Federal Communications Commission

GEO
geostationary earth orbit

GPS
Global Positioning System

HZ
Hertz

IEEE
Institute of Electrical and Electronics Engineers

ITU
International Telecommunications Union

LEO
Low Earth Orbit

LNA
low noise amplifier

NASA
National Aeronautics Space Administration

NTIA
National Telecommunications and Information Administration

RF
radio frequency

SATCOM
Satellite Communications

SHF
super high frequency

STAR-T
SHF Tri-Band Advanced Range-extension Terminal

TT&C
telemetry, tracking, and control

UHF
ultra high frequency

VHF
very high frequency

WRC
World Radiocommunications Conference