Satellite

Satellite Characteristics and Subsystems

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Radio communications, in one form or another, affect the lives of most of the world's inhabitants. Through radio, the world's population is enlightened and entertained. Radio is a vital tool in promoting international understanding and goodwill, and it's essential to the safety of many people on the ground, in the air, and on the sea. Radio can be a powerful political tool. Our own national security depends on communications. A highly efficient, secure, rapid, and reliable worldwide communications network is the backbone of military operations.

Today the primary means of radio communications for the military are LOS microwave, forward propagation tropospheric scatter (FPTS or tropo), and high frequency (HF). LOS provides high-capacity, reliable communications for about 30 miles; greater distances require relay stations. Tropo can increase the range of high-capacity communications to a maximum of 600 miles. Due to its complexity, tropo is less reliable and harder to set up than LOS. HF radio provides low-capacity communications up to 2,500 miles, but its dependence on ionospheric conditions for propagation makes it the least reliable of the three systems. This limitation, coupled with pressure of near saturation usage of the transmission medium, has caused the military to seek another mode of communications.

The ever-expanding communications requirements of commercial and government agencies, both foreign and domestic, provide constant incentive to explore and exploit every new developments in communications. Communication via satellite is a natural outgrowth of modern technology and the demands for greater capacity and high-quality communications. Relatively recent technical developments have made satellite communications possible. Communications satellites probably won't replace existing communications systems, but they'll offer new ways to satisfy the ever-increasing demand for communications services.

The enlargement of the communications services required by the military was largely due to the compression of time allowed for response to nuclear threat and to the handling and exchange of large volumes of information made possible by computer-controlled automatic data processing systems. The demand for full-time, reliable, long-distance circuits has received special attention by both the civilian and military research and development industry. Improvements have been made in existing systems, but the major problems that affect their reliability or limit their application still prevail. In view of this situation, it’s not surprising that the initial and major emphasis in using satellites for communication should be for long-distance circuits.

Satellite Characteristics and Subsystems

Since the early part of this century, when Marconi developed wireless telegraphy, people have been sending messages through space. Today, the means already exist for communicating as far as the known limits of the solar system. The problems that the space communications engineer is asked to solve aren’t involved with generation and propagation of electromagnetic waves, but rather with problems that arise because of the complexity of the system components and the nature of the host vehicle. Such problems are those involved in allowing for the cubage and mass of the equipment in the host vehicle and in generating electrical power in space. This section acquaints you with the characteristics of satellites.

Passive and active satellite systems

Types of satellites

The first aspect of satellite fundamentals to consider is the type of satellite to be placed in orbit. There are two major categories of satellites—passive and active. As a communications expert, you should be familiar with these categories.

Passive systems

A passive system uses a reflecting surface that can’t amplify or retransmit signals. Some of the advantages of a passive system are its inherent reliability and the possibility of being shared by a large number of users operating over a wide range of frequencies. However, a typical passive system, operating between two locations 2,000 miles apart, requires 24 nonsynchronous passive satellites, 100 feet in diameter, in randomly spaced orbits at 3,000 miles altitude for an outage time of 1 percent. Since substantially more satellites are required to provide longer range or wider coverage than that, such satellites don’t offer an economical solution for truly global communications. Since a passive satellite merely reflects signals transmitted toward it, there’s no “onboard” equipment, and it has no function to perform except to be there. These features give the passive satellite the advantages of economy, simplicity, and reliability.

Active systems

An active satellite is more complex and expensive, with at least a transmitter, a receiver, an amplifier, a power supply, and an antenna on board. Other components are determined by the satellite’s purpose and the designer’s system specification. Active communications satellites receive signals, translate them in frequency, and amplify and retransmit them. They’re like repeater stations in space, letting us use smaller ground terminals that, in turn, enhance the flexibility of military operations. Because of the increased radiated power over that of passive reflectors, the transmission path loss is less and active satellites can be placed in orbit at much higher altitudes.

There are two types of active satellites—delay and real time. A delay satellite has some type of recording device on board. As this type of satellite orbits the earth, certain ground stations “talk” to it. The conversation is stored (or more correctly recorded).

When the satellite comes in view of another earth station and on command, the conversation is retransmitted. In contrast, a real-time active satellite receives a message from an earth station and immediately relays the message to another earth station. There's actually a delay of about 0.6 second from earth to satellite and back to earth, but only in telephone conversations does this cause any problem.

Medium-altitude orbit

Continuous global communications coverage from medium altitudes requires from 18 to 24 satellites in orbit. Even then, there would be a switching problem at ground terminals as one satellite passed from view and a new one approached to take its place. The ground terminals would require steerable antennas as well as computing equipment to calculate trajectories and furnish look-angles (acquisition data) for antenna orientation.

Geostationary orbit

Three satellites, at an altitude of 22,300 miles and equally spaced in 24-hour equatorial orbit, appear to remain fixed to an observer on the earth. Such a satellite system provides complete global coverage except for the extreme polar regions. The high altitude of this orbit makes each satellite visible from 40 percent of the earth's surface. Since the satellite appears to be motionless in the sky, service may begin or continue with only one satellite in orbit and functioning. A disadvantage is the time delay that can be experienced in connection with telephoning. The two-way propagation delay through a geostationary satellite is about .6 second—not objectionable if there's no echo. Proper equipment balancing and echo suppression are solving this problem.

How propagation affects satellite communications

Propagation

Satellite communications systems experience the same propagation problems as the other systems we've discussed, but a few are unique to satellites. In a system that has ground stations communicating with space vehicles, radio signals from a ground transmitter must pass through the earth's atmosphere, the ionosphere, and through outer space. The return trip to the ground receiver must follow the opposite path. This environment subjects signals to attenuation, refraction, rotation, multipath scattering effects, doppler shift, and noise. Many of these effects are functions of the transmission signal frequency; all of them affect the signal as it appears at the receiver input. Accordingly, ground and space vehicle transmitter, receiver, and antenna designs must take these effects into consideration. Figure 5–1 shows the cumulative effect of some of these factors on the frequency spectrum.

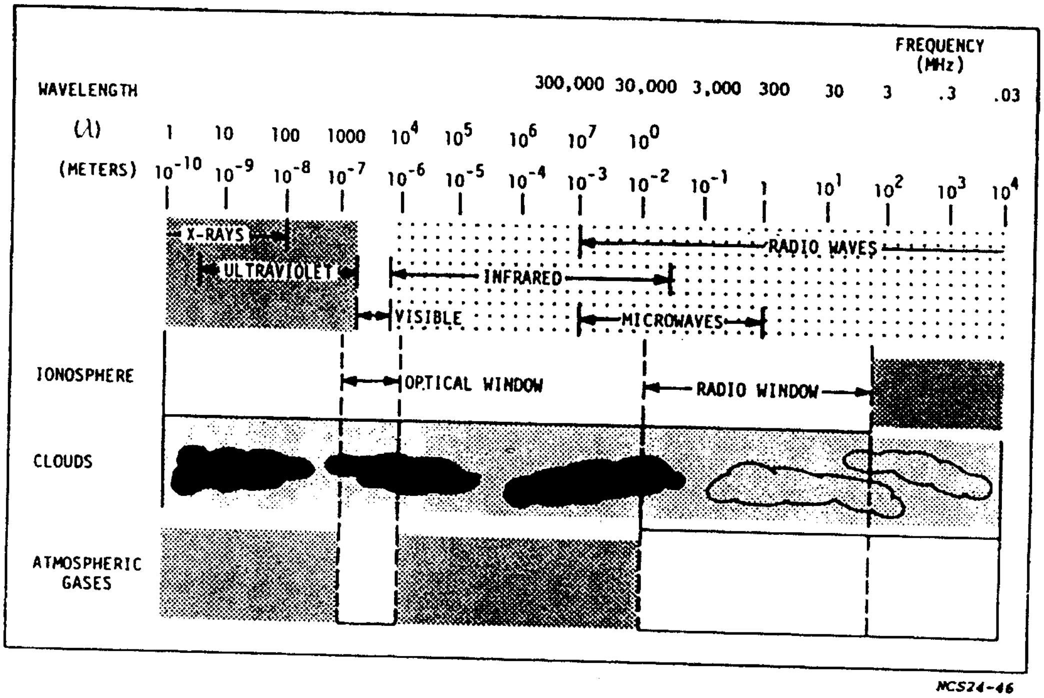

Figure 5-1. Propagation characteristics.

[fig 5–1]

Frequency spectrum

The earth's atmosphere limits the usable frequencies for satellite systems. The atmospheric radio window includes the frequencies that will pass through the earth's atmosphere—roughly from 100 to 10,000 MHz (MHF to EHF). All frequencies below this range will either be absorbed or reflected by the ionosphere, and those above this range will be absorbed by water vapor and oxygen before they leave the atmosphere. This doesn't rule out eventual use of electromagnetic waves above the radio frequency range, such as infrared and light waves. Selection of specific radio frequencies for communications satellites depends on the demand for maximum traffic capacity, which requires maximum bandwidth. That's why we usually select the upper end of the usable spectrum.

Free space attenuation

Free space attenuation is reduction in amplitude of a radio signal as it travels away from the source through a propagation medium that's free of obstructing, scattering, or reflecting effects. Free space attenuation increases with the square of the distance from the source and the frequency of the transmission signal. This loss can be figured mathematically by using the formula:

P_L = 10 Log PT/Pr

where

P_L = Path Loss

PT = Transmit Power
Pr = Receiver power

Free space attenuation is the major factor used in determining total gains and losses in a satellite system. It’s not uncommon to have 200 dB of free space attenuation on an earth-terminal-to-satellite link. This should give you an idea of how sensitive the satellite receivers must be.

Faraday effect

The Faraday effect is the slow fading caused by the rotation of polarization of radio waves as they pass through the earth’s magnetic field. Since the direction of propagation, the magnitude of the earth’s magnetic field, and the density of the ionosphere changes constantly, so does the rate of fading. Faraday *rotation* can severely distort all frequencies if the antennae used in the system are not circularly polarized.

To combat the Faraday effect, the transmit signal is rotated 90° from a vertical to a horizontal position. This rotation makes the radio wave travel in a spiral or circular path toward the receive antenna. In satellite systems, transmit signals are usually right-hand circularly polarized and the receive signals left-hand. The directions right and left merely indicate the direction the signal is rotated from vertical.

Doppler effect

A satellite communications system design must take into consideration the shift in signal frequency caused by the satellite’s position relative to the transmitting and receiving ground stations. This shift is called Doppler effect. It is similar to the apparent change in pitch of an automobile horn as the automobile approaches, passes by, and continues on its way. In general, since the receiving subsystem must compensate for the shift by providing for sufficient bandwidth or for following the frequency shift, determining the maximum Doppler shift and the rate at which the shift occurs are important design considerations.

Frequency or phase-lock ground receivers are used to overcome the Doppler effect. For wideband satellite communications, a Doppler shift isn’t of primary importance. For example, when a satellite is orbiting at 6,000 miles, the one-way maximum Doppler shift will be less than 35 kHz for a frequency of 5,000 MHz. A Doppler shift may, however, distort the RF bandwidth in broadband systems. Narrowband satellite communications systems are even more seriously affected by a Doppler shift.

Subsystems used in satellite communications

Before we discuss the various satellite programs the Air Force uses, let’s first look at the subsystems that are the backbone of these programs. A satellite serves as a relay station between ground stations, much like an intermediate repeater in a line-of-sight microwave (LOS M/W) link (fig. 5–2). Early communications satellites were passive devices, providing only a reflective surface to redirect radio waves, but most satellites today are active transponders. They receive, amplify, and retransmit signals from ground stations. A satellite link’s major advantage is that it is particularly well-suited for long distance communications. A single satellite can provide the link between ground stations separated by thousands of miles that may have otherwise required numerous terrestrial repeaters. The elements that form the Defense Satellite Communications System (DSCS) are the space, earth, and control segments.

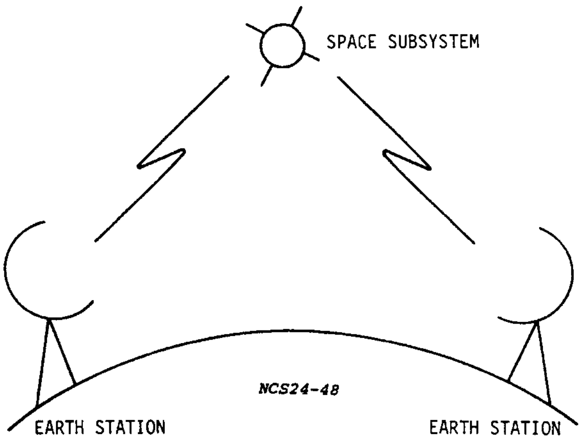

Figure 5-2. Basic satellite communications link.

[fig 5–2]

Space segment

The DSCS space segment consists of DSCS II and DSCS III satellites in a constellation configured to provide maximum mission support. The less versatile DSCS II satellites are being replaced by DSCS III satellites that will occupy the same orbital positions and operate in the same frequency bands. The DSCS III is designed for more effective implementation of a worldwide military communications mission. It provides protected communication services and has greater performance capabilities than the phase II system, particularly in the area of antenna flexibility.

Space subsystems

Unlike microwave repeaters, communications satellites are designed to serve multiple ground stations. Techniques that make this possible are discussed in subsequent sections on multiple access techniques. Figure 5–3 is a block diagram of a typical satellite communications network. In this simple illustration, earth terminal (station) 1 transmits one uplink carrier, which is received by terminal 2. Terminal 2 transmits two carriers, of which one is received by terminal 1 and the other by terminal 3. Terminal 3 transmits three carriers, one to terminal 2 and the other two to terminal 1.

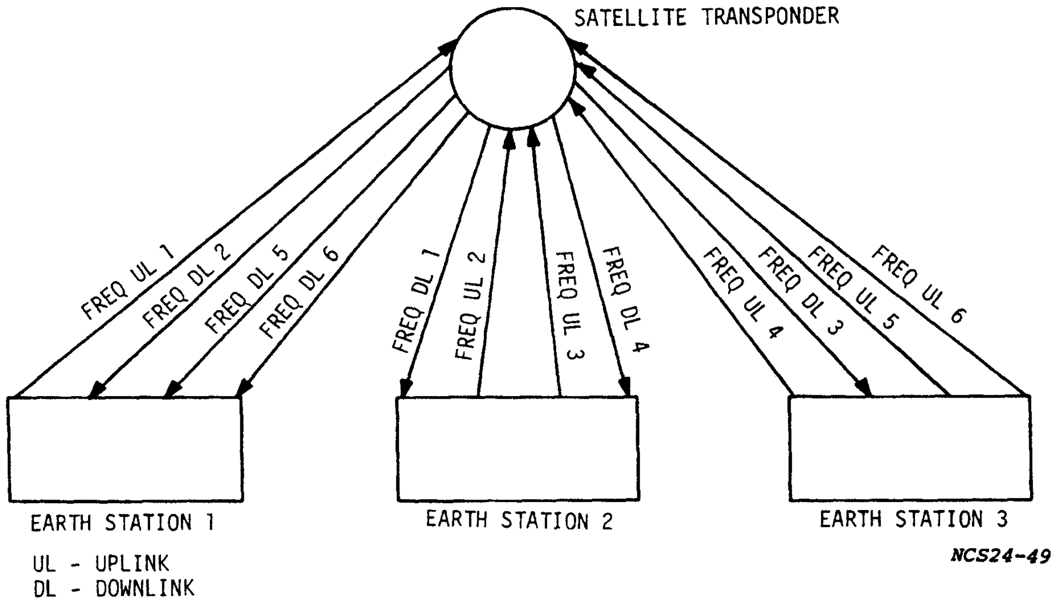

Figure 5-3. Satellite communications network.

[fig 5–3]

It is apparent from this illustration that satellite networks offer tremendous potential and flexibility. By reconfiguring the ground stations, you can change the network configuration. Normally, all that's required to establish a new link is to retune the ground station receiver to the distant terminal's corresponding downlink frequency. In systems where more than one satellite is used, it is necessary only to redirect the antenna toward the other satellite and adjust the ground station for the appropriate transmit and receive frequencies.

There are, however, many problems associated with satellite networks. They stem mostly from the satellite transponders that provide frequency conversion and retransmission. The power limitations of transponders, coupled with long transmission paths, result in low receive signal levels (RSL) at earth terminals. This complicates the design of earth subsystems and increases costs. Transponder power limitations also limit the number of users satellites can provide service for. As more and more users access the satellite, the amount of transmitter power available to each user is decreased, thus reducing the quality of communications. Since a satellite is inaccessible once it is placed in orbit, transponders must be designed for maintenance-free operation.

Low-noise-receiver front ends and large high-gain antennas are required for high-quality communications. Ground station design is further complicated by the fact that satellites are not stationary. This is true even of geostationary satellites, although their movements are minimal. An earth terminal must be able to track or constantly keep its antenna directed toward the satellite. Geostationary satellites require this capability because of the narrow beamwidth of the terminal's antenna. The mechanics and electronics involved with a large tracking antenna greatly increase costs. Finally, the aspect that makes a satellite system desirable can also create problems. The satellites' visibility over large parts of the earth's surface makes them susceptible to jamming by hostile forces.

Figure 5–4 depicts an active satellite system with its subsystems. The space subsystem consists of a satellite antenna array and a transponder. There are many other components that make up this subsystem, but we don't cover them individually.
[fig 5–4

Antenna

Antennae on space-borne satellites enable them to receive and transmit signals from earth terminals. Older satellites use a variety of antennae ranging from a collinear array, or phased array, to slot antenna. Newer satellites often use a gimballed dish, which

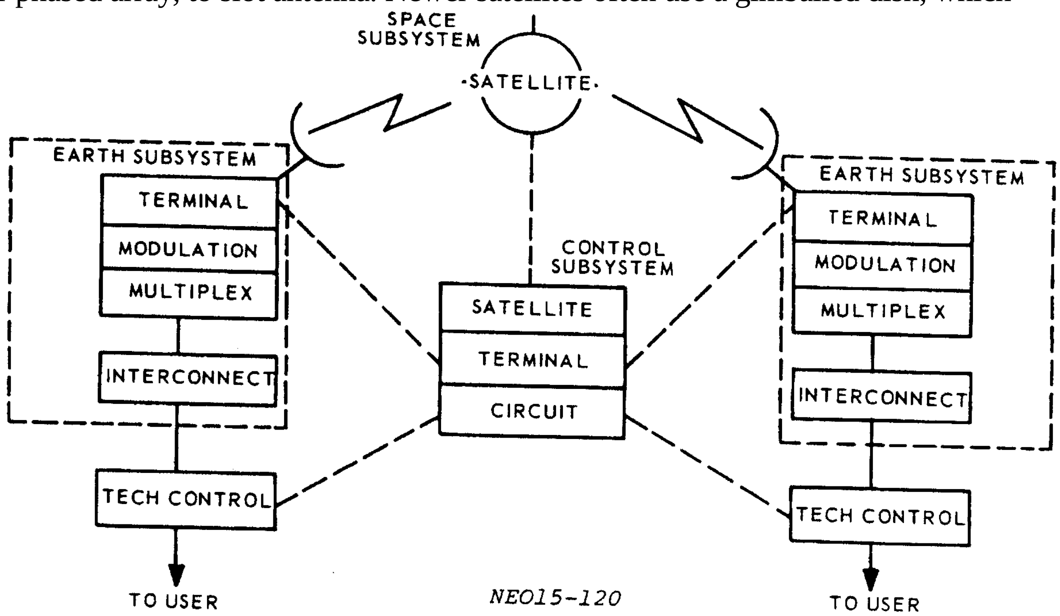

Figure 5-4. Active satellite system block diagram.

[fig 5-4]
resembles a parabolic antenna and provides high gain to transmit radio waves over vast distances. Also used on newer satellites are multibeam antennae, which let ground control terminals adjust the transmit radiation pattern. The radiation pattern for multibeam antennae can be blanked out to deny reception in a nulled area. This radiation pattern resembles a doughnut. The hole in the doughnut representing the nulled area. The control terminal can steer the transmit null, or signal, to anywhere in the coverage area,

Transponder

Satellite transponders receive, amplify, and retransmit signals from earth terminals. Figure 5–5 is a block diagram of three typical types of satellite transponders. The particular type of transponder used is based on bandwidth and gain requirements. Usually, narrow bandwidth requirements are implemented using double-frequency conversion or processing transponders, with the latter providing some improvement against jamming.

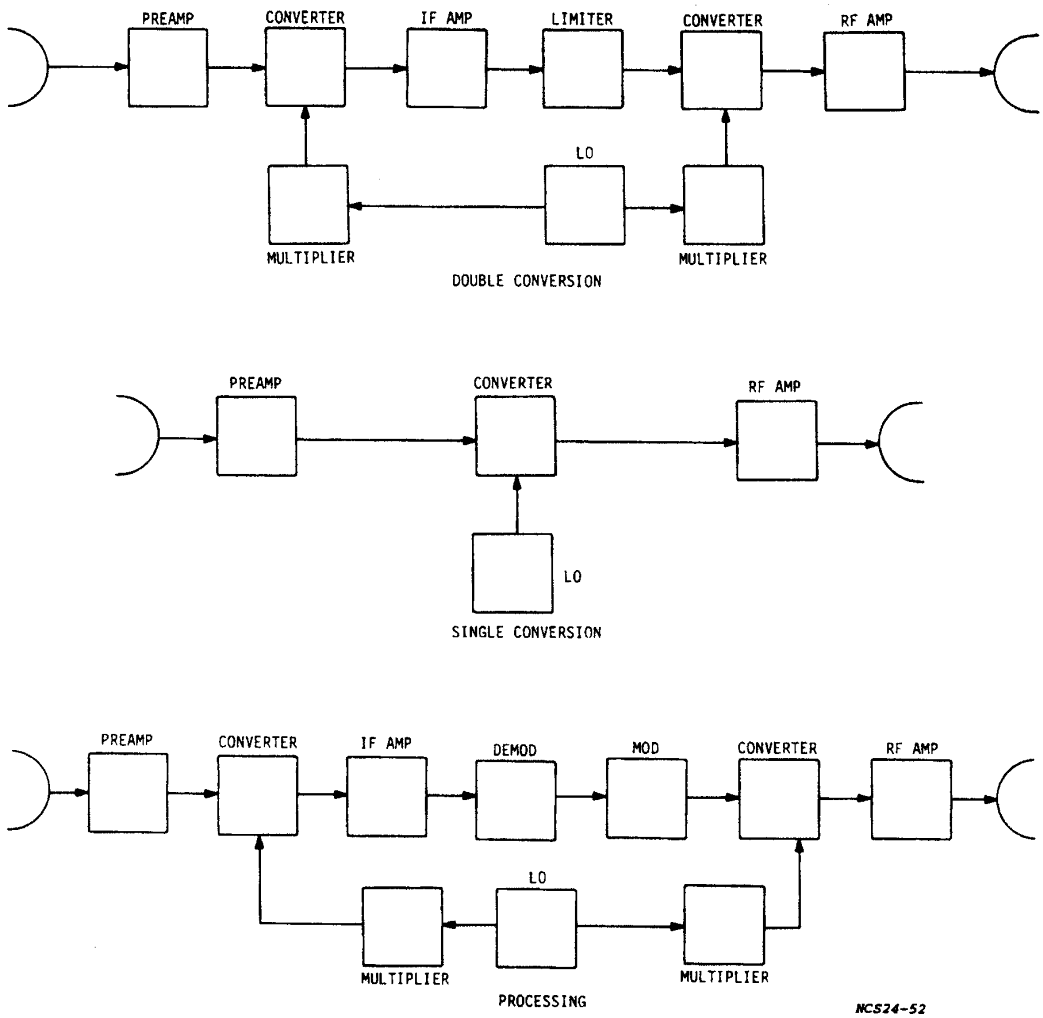

Figure 5-5. Basic satellite transponders.

[fig 5–5]

Satellite transponders provide one or more RF channels with each channel normally required to receive and relay several simultaneous signals. With few exceptions, communications transponders have saturating nonlinear input-output characteristics that result in intermodulation distortion when two or more signals enter the satellite. The magnitude of the intermodulation products is held to acceptable levels by various means. Bandpass filters channelize the transponder to reduce intermodulation distortion. Judicious selection of uplink frequencies also helps reduce distortion. By selecting frequencies properly, you can make many of the intermodulation products lie outside the transponder's operating bandwidth.

Another way to reduce intermodulation distortion is to operate the transponder at a back-off point below saturation. This reduces the intermodulation radiated power (EIRP). The EIRP is a function of the transponder's amplifier output and the gain of the antenna. A satellite's EIRP bears significantly on the quality of the communications. In a system that is already power constrained, only a few dB less radiated power can severely reduce system capabilities.

In addition to relaying signals between earth stations, satellite transponders usually provide a beacon signal that is used for acquisition and tracking by earth terminals. The beacon signal is generated internally or supplied to the satellite by an earth station. Often, the beacon is modulated with telemetry information necessary to perform station-keeping and maintenance functions (switching redundant components in the transponder, orbital correction, repositioning, etc.).

Station keeping is occasional readjustment of a satellite's position to maintain desired orbital characteristics. It's necessary because of disturbing forces that result from gravity irregularities, atmospheric drag, solar radiation, etc. Normally, the satellite is positioned by a system of gas jets that can be controlled via ground station commands.

Earth segment

DSCS earth segments are a network of earth terminals operating in a multipoint, multicarrier network configuration for each satellite. DSCS earth terminals are categorized as fixed, transportable, and equipment. They are further categorized as DSCS standard heavy, medium, light, and other. Other includes DSCS-GMS, airborne, shipborne, and DTS terminals. Some of these terminals are covered in later lessons.

Earth terminals

A satellite communications system uses satellites to relay radio signals between earth terminals. As we've said several times, a passive satellite system merely reflects these signals back to the receiving terminals, while an active satellite amplifies the signals and then retransmits them to a receiving terminal or terminals. A typical link involves an active satellite and at least two earth terminals. One terminal transmits to a satellite on the uplink frequency. The satellite amplifies the signal, translates it to the downlink frequency, and then transmits it back to earth where it is picked up by the receiving terminal's antenna (fig. 5–6). It's apparent from this illustration that satellite networks offer tremendous potential and flexibility. By reconfiguring the ground stations, it is readily possible to change the network configuration. Normally, all that's required to establish a new link is to retune the ground station receiver to the distant terminal's corresponding downlink frequency. In systems with more than one satellite, you must redirect the antenna toward the other satellite and adjust the ground station for the appropriate transmit and receive frequencies.

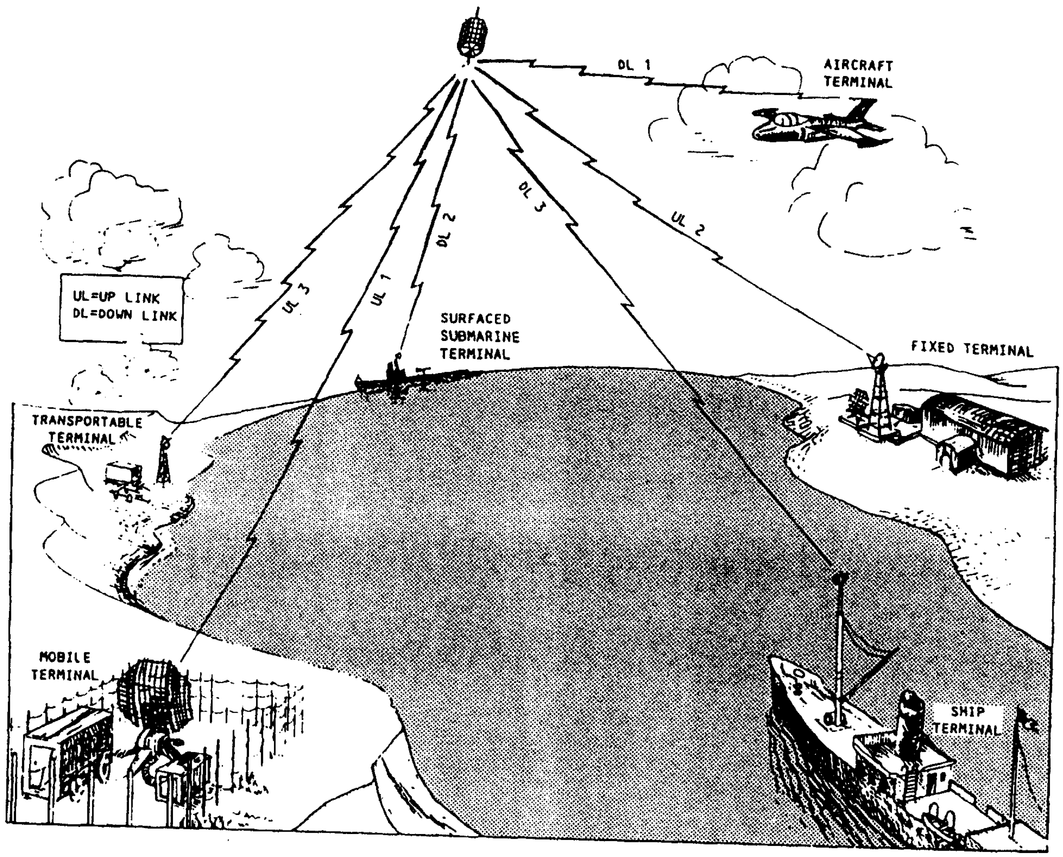

Figure 5-6. Satellite communications system.

[fig 5–6]

Antenna and tracking components

An earth terminal is like a M/W station in many respects, but there are some notable differences. The earth terminal antenna component must be able to track a moving satellite. Where high-gain requirements dictate large antennae and narrow beam widths, the mechanics and electronics necessary for accurate antenna positioning can get very complex. Tracking errors of less than a tenth of a degree can be disastrous to the quality of the terminal's communications. Signals received at an earth terminal are low level due to long transmission paths and the relatively low transmitter power of satellites. This means that the antenna must provide high signal gain while contributing low noise. The measure of an antenna's noise contribution is normally expressed in terms of antenna noise temperature. For large antennae, noise temperatures of about 30 to 80°K (Kelvin) are common, depending on the antenna elevation angle.

Antenna polarization is also an important consideration. Because satellites are normally used by geographically widespread terminals, polarization loss must be independent of the look angle from the ground station to the satellite. Circular polarization has this property and is used in all satellite systems. Losses from polarization mismatches in vertical or horizontal polarization can be as great as 30 dB. The transmitter of a typical earth terminal consists of frequency conversion and amplifier sections. Most DCS terminals have a multiple transmit carrier capability. The AN/FSC–78 earth terminal, for example, can transmit nine separate uplink carriers. The number of transmit carriers possible depends on the RF bandwidth capability of the amplifier sections, the number of frequency converters, and the intermodulation distortion products generated as a result of multiple input frequencies.

Figure 5–7 represents a typical DCS earth terminal receive subsystem. Again, the receive subsystem is like a terrestrial M/W receiver, but there are some differences that bear discussion. The RF amplifier in high-quality earth terminal receivers is normally a low-noise device. Typical noise figures range from .5 to 2.0 dB, versus the 8 to 11 dB noise figures for normal terrestrial M/W receivers. A low-noise, front-end amplifier is located as close as possible to the antenna. Normally, the receiver front end is mounted on an antenna pedestal, reducing carrier-to-noise (C/N) degradation from losses between the antenna and the amplifier input.

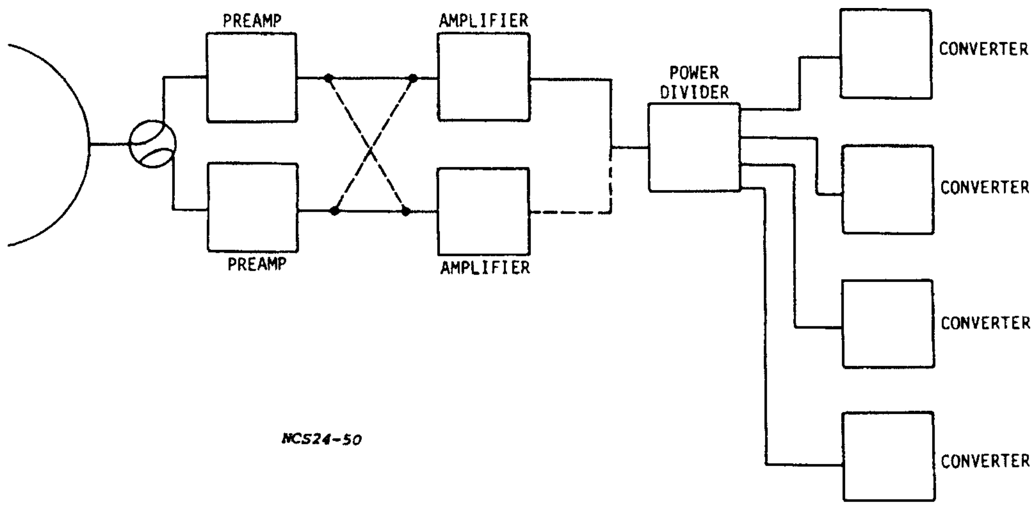

Figure 5-7. Basic earth termincal receiver subsystem.

[fig 5–7]

Control segment

The Defense Communications Agency (DCA) exercises operational direction of the DSCS through the DCA Operations Control Complex (DOCC). A subsystem of the DOCC, the DSCS Operation Control System (DOCS), consists of a hierarchy of control elements that are responsible for the control of space communications via the DSCS. Using computer facilities, the DOCS provides near real-time control to ensure efficient transponder use and rapid DSCS reconfiguration to meet user requirements. The control concept specifies the major control categories as satellite control, communication, payload control, and satellite communications (SATCOM) network control.

Satellite telemetry, tracking, and control (TT&C) is done by the Air Force Satellite Control Facility (AFSCF) at Onizuka AFS (formerly Sunnyvale), California. The AFSCF uses a network of remote tracking stations to keep satellites in their assigned orbital positions, maintain the prescribed satellite attitude relative to earth, and support the housekeeping functions necessary to ensure optimum operation of the satellites.

System Considerations

Our continuous efforts to improve and expand our means of communications can be viewed as an ongoing struggle. Establishing an operational communications system based on satellites in space involves some very familiar factors, but it also introduces new ones we must consider for the first time. We can start by comparing satellite and tropo systems. A tropo system must cope with the meager portion of signal scattered by tropospheric irregularities. This requires a high-power transmitter, highly directional transmitting and receiving antenna, and an ultrasensitive receiver for the system to function. In comparison, a satellite system that deals with the direct path of propagation may seem improper, but due to other (environmental) factors, similar equipment, and special techniques, these systems operate with similar limitations.

Visualize a tropo link, using two repeater stations, that is converted to a satellite system by simply using a satellite to replace the two stations in the middle, as illustrated in figure 5–8. Of course this is an oversimplification, but it does come close to how satellite ground stations function. A tropo link connecting New York and California requires four to six relay stations, while one satellite, in the right position, can satisfy this relay requirement. Also, when this same distance involves stations separated by water, such as Hawaii and California, the long-distance advantage of satellites is fully exploited.

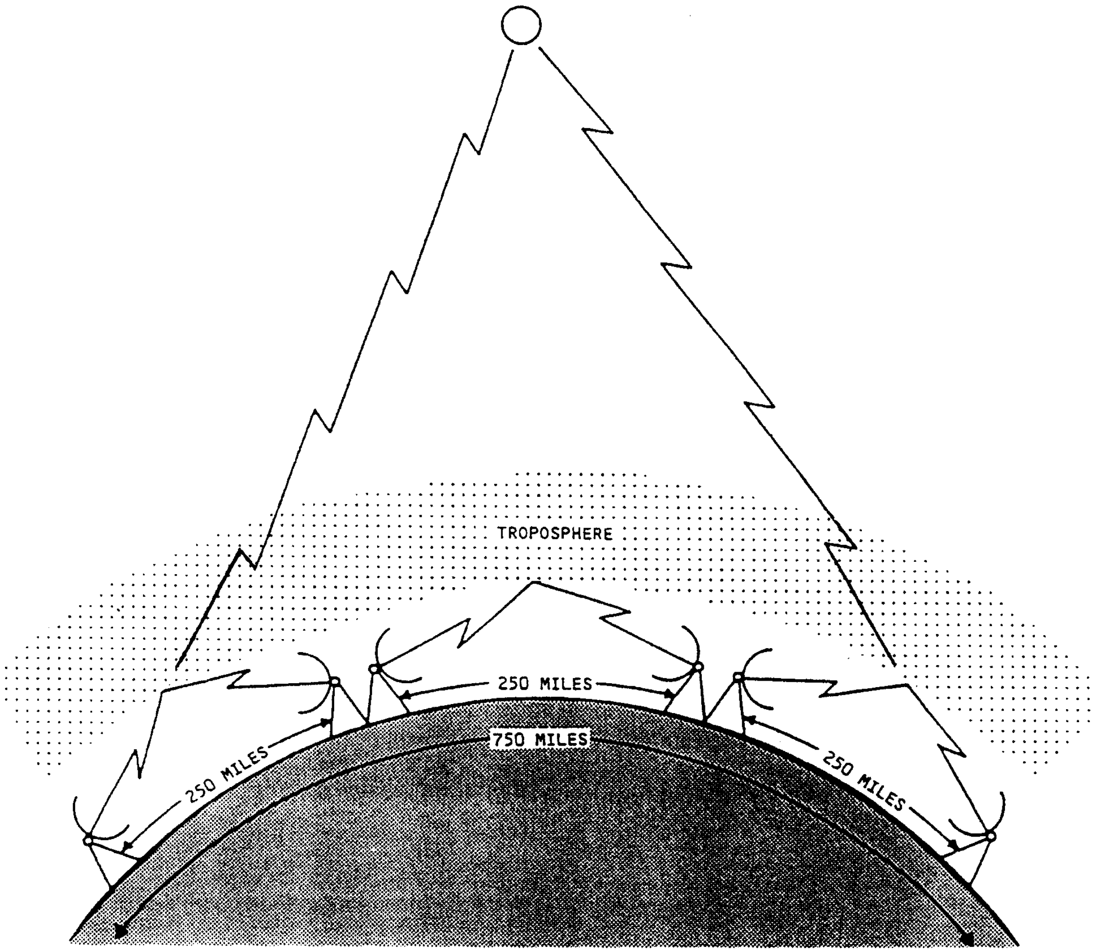

Figure 5-8. Troposcatter vs satellite communications.

[fig 5–8]

In developing operational tropo systems, a tremendous technological base was established that was directly transferable to communications satellites. The basic systems are the same and differ only in the need for greater expertise in developing a satellite communications system. An advantage of satellites is that one satellite may relay information to several ground stations. There are several ways to get this multiservice capability. Let's look at some of the system characteristics that determine whether a satellite system is more feasible than one of the other systems we've discussed.

Satellite system considerations

Orbits

First, a systems designer must consider the satellite's orbit. To achieve orbit, a satellite must be lifted above the atmosphere and started moving around the earth at the exact speed required to produce a centrifugal force just equal and opposite to the gravitational force at that altitude. Since the earth's gravitational attraction decreases with altitude, high-altitude satellites don't have to circle the earth as fast as low-altitude satellites to stay in orbit or to achieve it.

The basic design of a satellite communications system depends, to a great extent, on the parameters of the satellite's orbit. Traditionally, an orbit is identified by its shape, the inclination of its orbital plane (in relation to the earth's equatorial plane), and the altitude of the orbiting satellite.

All artificial satellite orbits are circular, elliptical, parabolic, or hyperbolic. The initial launch parameters and later deployment techniques determine the orbit. Communications satellite orbits are either elliptical or circular, and deep space probes and rockets have circular orbits.

Orbital control

The two types of orbital control for satellites are attitude control and station keeping. Attitude control, which is used on practically all satellites, can be implemented about one axis, two axes, or all three axes. The attitude control system used has a great effect on the design of directionally sensitive satellite subsystems, such as antennae for communication and solar cells for prime power generation. Station keeping refers to the maintaining a fixed-satellite position relative to the earth (in the case of a geostationary satellite) or to another satellite (in the case of several satellites spaced along the same nonsynchronous orbit). Station-keeping control is not used for one satellite in a nonsynchronous orbit, but it is normally used in geostationary satellite systems.

Attitude control

Required pointing accuracy, system lifetime, reliability, weight, and cost are some of the factors involved in attitude-control system design. Early satellites, which were designed for long-term operation, were spin stabilized. The more stringent requirements of present space missions demand more precise control. The five types of attitude control systems used are spin stabilization, gravity-gradient, momentum storage, mass expulsion, and mixed systems. They're somewhat complicated to explain, but they're all, in some way, based on the torque forces that affect a satellite's position.

Station keeping

Station keeping keeps the satellite in a desired position in orbit within acceptable limits. For example, a geostationary satellite is given occasional commands that adjust its position so that it stays in a fixed position within a few degrees relative to the earth. Station keeping is necessary to offset the effects of perturbing forces on the satellite's orbit. These forces include solar radiation, atmospheric drag, gravity perturbations from the sun and moon, and gravity perturbations due to the earth's not being quite round. Advantages of station keeping include simplifying acquisition and tracking (with narrow beam earth antenna) and providing a satellite that permits continuous or predictable links between selected earth terminals. A mass expulsion system is used for station keeping and can be integrated with the attitude control system. Certain combinations of gas jets are fired simultaneously for attitude control, and other combinations are fired simultaneously for station keeping. The satellite is allowed to drift slowly between limits imposed by system requirements. Station-keeping function is done periodically, every few weeks or months.

Satellite ground tracks

The orbits of all satellites lie in planes that pass through the center of a theoretically spherical earth. Each plane intersects the surface of the earth in a great circle (fig. 5–9). A satellite's ground track is traced by the intersection of the earth's surface and a line between the center of the earth and the satellite. As the space vehicle moves in its orbit, this intersection traces out a path on the ground below. The last important aspect we'll consider is how the ground tracks will communicate and control the satellite itself.

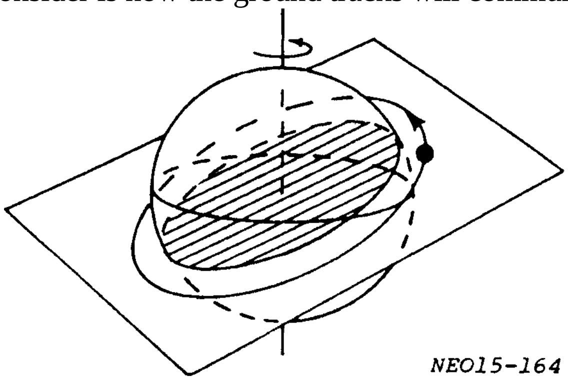

Figure 5-9. Satellite ground track geometry.

[fig 5–9]

Multiple-access service and system control used in satellite communications

Frequency-division multiple access

Frequency division multiple access (FDMA) is the most common technique used today and the easiest to implement. In this technique, each uplink carrier is assigned a separate frequency within the transponder's frequency band. The transponder acts like a common amplifier and frequency translator to relay signals back to the earth (fig. 5–10). One of the method's shortcomings is that the power available to retransmit signals must be shared by all users of the satellite. This reduces the power available for each downlink signal. As the number of users accessing the satellite increases, the quality of communications decreases.

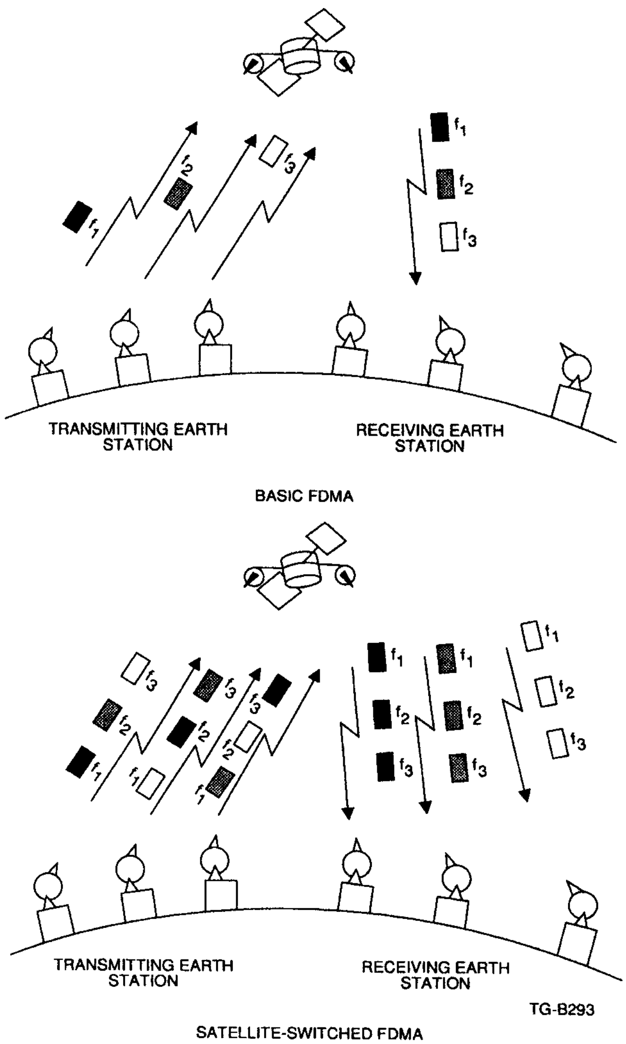

Figure 5-10. FDMA models.

[fig 5–10]

Problems also arise from the fact that the traveling-wave tube (TWT) used in most satellite transponders is a hard-limiting device that reaches saturation abruptly. When a hard-limiting device is driven into saturation by multiple input signals, large amplitude intermodulation products are generated. For efficient use a TWT should be operated near saturation. In an FDMA satellite system, this necessitates strict power control over all the satellite's users. Normally, in order to exercise adequate control and keep intermodulation products at acceptable levels, the transmit power from ground stations is monitored and maintained at an equivalent transponder input level that keeps output 1 to 3 dB below TWT saturation. This necessary back-off reduces the transponder's EIRP, thus reducing system capabilities.

Another detrimental characteristic of using transponders with FDMA techniques is signal capture—the tendency of larger signals to suppress weaker ones. Although this does have some limited advantages where jamming protection is required, it can create problems in normal use. FDMA techniques also require careful selection of uplink frequencies to void the generation of unnecessary intermodulation products. By judiciously selecting frequencies, you can make many of the intermodulation products fall outside the transponder's bandpass.

Time-division multiple access

The most efficient form of multiple access is time-division multiple access (TDMA), in which each earth terminal has exclusive use of the satellite transponder for a specified time interval (fig. 5–11). Assuming that four ground stations are using the satellite, the figure shows that each one has a specific time interval in which to transmit information. Each of the terminals has access to all of the downlink transmission, but processes information only during the interval in which the desired distant terminal is transmitting.

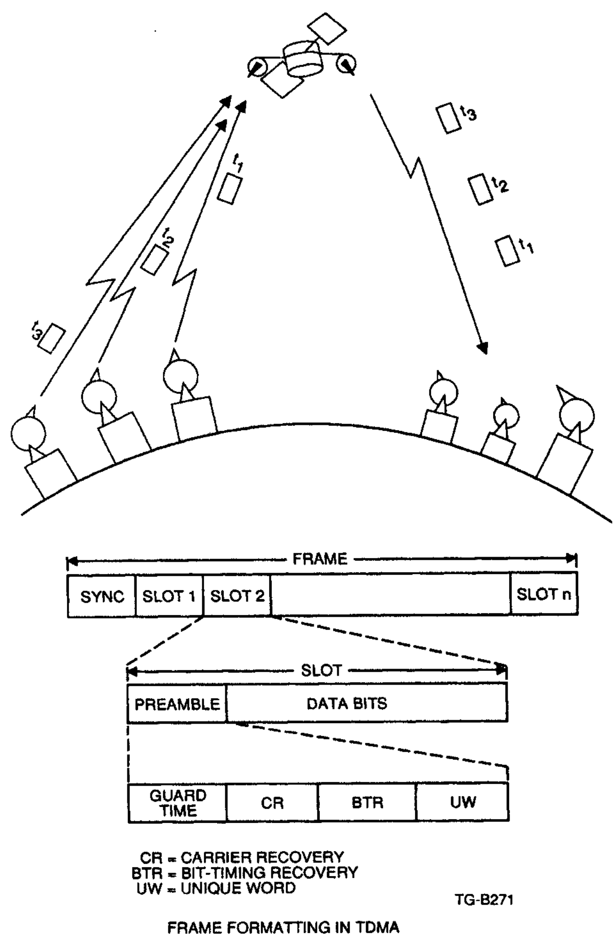

Figure 5-11. TDMA satellite system model.

[fig 5–11]

One problem with TDMA is that it requires accurate network timing and all terminals must be in sync with one another. Another problem is that all information must be in digital form; analog information must be digitized before transmission. Since there's no continuous information path between terminals, buffering (storage capability) is also required at the earth stations. Even considering these problems, TDMA is the approach that most future systems will take.

Spread-spectrum multiple access

Spread-spectrum multiple access (SSMA) is like FDMA in that users share satellite power. The difference is that several users occupy the same frequency spectrum in the transponder simultaneously. Each user's carrier is modulated twice at the ground station, first by the information and then by a high-frequency band-spreading signal. The band-spreading signal (usually digital) has the effect of dispersing the power in a carrier over a wide band of frequencies, resulting in a spectrum that appears noise-like (fig. 5–12). The pattern of the spreading signal (the code) is a pseudorandom sequence. An identical code generated at the receiving terminal and synchronized with the transmitting end allows the information signal to be recovered. If different codes that show a low cross-correlation are assigned to different users, then transmissions by several users are possible with only a small amount of interference. This interference does, however, increase with the number of simultaneous users and, therefore, limits the number of ground stations sharing the same transponder. As with FDMA methods, the total power available also restricts the number of users.

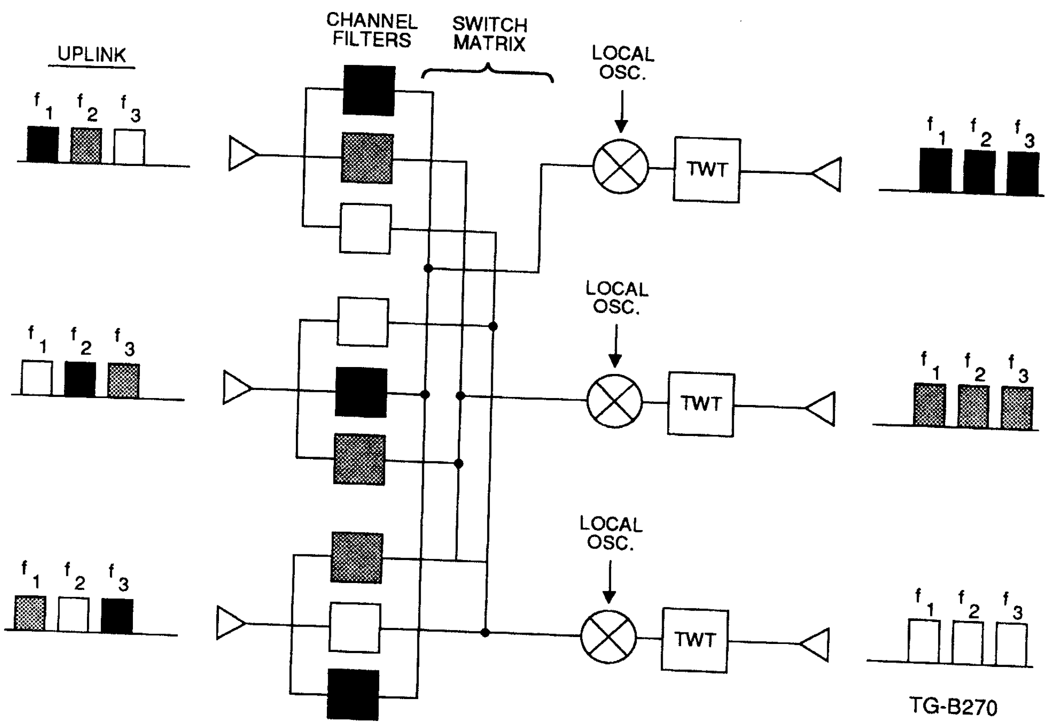

Figure 5-12. SS-FDMA satellite block diagram.

[fig 5–12]

System control

Any communications system requires some sort of system control for optimum performance. This is especially true in satellite systems where several users share a common transponder. The operation of each terminal directly affects all other users in the system. Misaligned or defective equipment at one ground station requires more satellite power, and it can degrade performance for the whole system. Hence within a satellite system, the type of control required can be divided into two categories—satellite control and communications control.

Satellite control includes whatever is done to maintain correct orbital characteristics and optimum transponder performance. Without periodic adjustment of the satellite's position, orbital characteristics would be unpredictable and system planning impossible. Likewise, it's just as important to be able to switch to redundant equipment in case of component failure or to change amplifier gains within the transponder to meet customer demands.

Communications control involves monitoring system performance and future planning. The input signal level to a satellite must be closely monitored to make sure the transponder isn't driven into nonlinear operation. Frequency assignments within the system must be carefully planned to prevent unnecessary interference between users. In TDMA systems, synchronization must be monitored and maintained. Satellite loading and capacity must be judiciously monitored and planning for new communications requirements constantly considered.

Space and earth subsystem trends

Space subsystem trends

In the relatively short time that satellite communications systems have been in use, great progress has been made. There are continually expanding requirements for more high-speed global circuits. This means relaying greater amounts of traffic through satellites with increased reliability. The requirement for more powerful and versatile satellites calls for increased launch-vehicle payloads and places greater demands on the finite orbit and usable frequency spectrum.

Satellite position

Developments to date have shown advantages in using geostationary orbits for communications satellites. However, present satellites aren't exactly stationary with respect to the earth. DSCS satellites orbit in a figure-eight pattern, moving as far as 3° north and south of the equator. Hence, many of the earth terminals using a satellite are equipped with costly automatic-tracking devices. To offset this, station keeping can maintain a satellite within limits so that tracking isn't required once the antenna is properly oriented.

Higher frequency bands

Today's commercial communications satellites use the 4- to 6-GHz band, and the military uses the 7- to 8-GHz band for global communications. These bands, like the lower frequency UHF band, are becoming crowded from both a satellite and terrestrial viewpoint. The trend for satellite, as well as for other means of communications, will be toward higher frequencies. Action is already underway in the 11- to 15-GHz and 30- to 35-GHz regions. These higher frequencies open new areas and provide greater bandwidths for high-data-rate links, but they also introduce problems. The 1- to 10-GHz region is favored because of its low-propagation loss as a result of oxygen and water absorption. These two losses become very serious above 10 GHz. Additionally, the capability to generate adequate power at the higher frequencies requires new development. These frequencies do permit smaller and more directional antenna with a resultant increase in antenna gain. This is partially counteracted by the accompanying increase in free space loss.

Antenna

Satellites have both earth coverage (EC) antennae for global communications and narrow-beam (NB) or spot-beam (SB) antennae for requirements concentrated in specific areas. SB antennae are more directive. By concentrating transmitter power in a smaller area, thereby compensating for space loss, system reliability is increased.

Satellite-to-satellite links

For a truly global capability, it's desirable to establish links directly from satellite to satellite, thus eliminating the use of earth relay terminals. Studies are underway and experiments are planned using optical frequency devices in an attempt to do this. It's realistic to expect such a capability within the next few years.

Improved capacity

To meet the challenge of growing requirements, satellites have increased in power and bandwidth. Additionally, recent satellites have taken advantage of the design feature of using separate transponders for the varied requirements, such as TV, voice circuits, demand assignments networks, etc. This channelization separates the different modes of operation, thus greatly reducing intermodulations. Future satellites will undoubtedly be configured to continue this trend. The gain in transmission capacity of satellites and their associated ground systems is evidenced by the increase in traffic-carrying capability.

Earth subsystem trends

Like the space subsystem, the earth subsystem has experienced improvements during its initial years of operation. Larger and more reliable terminals have been developed. These improvements will continue.

Receive system G/T

The receive system's capability can be measured by its figure of merit (G/T), the ratio of the receive antenna gain to the system-noise temperature. This figure of merit depends on several parameters in areas subject to further research and development.

Antenna

The design for large fixed-plant antennae is not expected to change radically. The size is limited by cost, with pointing accuracy and smoothness of the antenna surface being the major factors for large antenna. Limited progress is being made in increasing the nominal 54 percent efficiency of large parabolic antenna, but for other DOD uses, such as aboard aircraft, there should be notable improvement. Blade and phased-array antennae are research areas that should improve the gain of airborne antennae.

Intermediate radio frequency (IRF) modulation and multiple access techniques

The majority of traffic today, as in the past, is analog. With the advent of data processing, computers, and other digital devices—including encoders for secure voice circuits and wideband data units—the volume of digital traffic is growing at a far faster rate than analog requirements. As we said, the DSCS will be evolving from an analog system to a hybrid analog-digital system and, finally, to an all digital system. Much work and development effort have already gone into developing base and TDM/PCM equipment, and DOD is presently procuring such units. The TDM/PCM equipment will sample and quantize analog signals and feed them to a TDM unit to be multiplexed into a composite serial stream for transmission. The TDM output can be sent via satellite using either FDMA or time division multiple access. This trend toward digital communications will accelerate and result in the majority of DCS trunking being handled on a digital basis.

For the signals transmitted via satellite to remain digital, the present DSCS RF modem (which is FM) will be replaced with a phase-shift keying (PSK) modem. Such units are under development for the DSCS. During the coming decade, it's reasonable to assume that such units will gain in reliability, simplicity, and in ability to handle more and higher data rates. PSK offers the advantage of permitting power, bandwidth, and error rate tradeoffs, adding flexibility in circuit and system design.

Although either FDMA or TDMA can be used to transmit the PSK signal, the future will see a trend toward TDMA. Such satellite systems have already been tested and proven practical. Although, at this time, TDMA is not a common mode operationally in either the commercial world or DCS, its advantages are recognized, and plans and programs have been established to use TDMA when the PCM, TDM, and PSK units are operational and the TDMA synchronizing and control systems are in production. This trend will result in PSK/TDMA largely replacing FM/FDMA for satellite transmission of nontactical traffic. Other modulation and multiple access techniques of particular interest to the military communicator are SSMA and high-peak power/TDMA.

The SSMA field is just reaching the practical operational stages; thus, growth and improvements in data rate, jamming-to-signal ratio, and bit error-rate performance are to be expected. The basic idea behind the high-peak power amplifier is to provide a very high-level signal on the uplink to overpower jamming signals. Peak power levels of 1 MW with average power of 1 to 10 kW are under consideration.

Demand assignment multiple access

Just as switches concentrate traffic and increase use of interswitch trunks, demand assignment techniques can improve the efficiency and use of the satellite's traffic-carrying capability. This is particularly true for low-duty-cycle users. Demand assignment is simply a system whereby a user requests use of satellite power, bandwidth, and frequencies when required and releases them for others to use immediately on completion of a call. SATCOM personnel have developed, tested, and begun installing such a system under the code name "Spade." This is a single-carrier-per-circuit FDMA system. Several other organizations are also developing and testing demand assignment systems using TDMA. This very flexible and efficient system should grow and be a part of satellite communication networks within the next 5 to 10 years.

Coding

Another new and exciting technical development of the past 10 years has been the theoretical analysis of error-correcting techniques and codes. This new field is moving from the theoretical to the practical era and is providing a new tool for the system engineer. Coding permits tradeoffs among power, bandwidth, bit error rate, and information transmission rate. Analytical results have shown the potential of various coding techniques. The practical hardware is now entering the field to use the benefits of coding. Further research and hardware development will result in improved performance in this emerging field.