CHAPTER 2

DESCRIPTION OF COMMUNICATION SATELLITE SYSTEM

2.1 ESSENTIAL BASIC SYSTEM COMPONENTS

The essential basic system components of an operational communication satellite system are (1) an orbiting vehicle with a communication receiver and transmitter installed and (2) two earth terminals equipped to transmit signals to and receive signals from the satellite. The design of the overall system determines the complexity of the various components and the manner in which the system operates. The launch and deployment facilities to be used also affect the overall design of the operational system. With the present operational military communication satellite system only two earth terminals can use a satellite at one time, and this has led to the establishment of satellite scheduling or control facilities.

Since the Phase I IDSCS system consists of randomly spaced satellites, the locations of which are changing continuously, a facility for predicting satellite locations is required to provide accurate antenna pointing information.

2.2 ORBIT DESCRIPTIONS AND SELECTION CRITERIA

2.2.1 Types of Orbits

As noted previously in section 1.2, orbits generally are described according to the physical shape of the orbit and the angle of inclination of the plane of the orbit.

a. Physical Shape. All satellites orbit the earth in elliptical orbits that are determined by the initial launch parameters and the later deployment techniques used. (A circle is a special case of an ellipse.) The elliptical path of any satellite has the earth located at one of its foci as shown in figure 2-1.

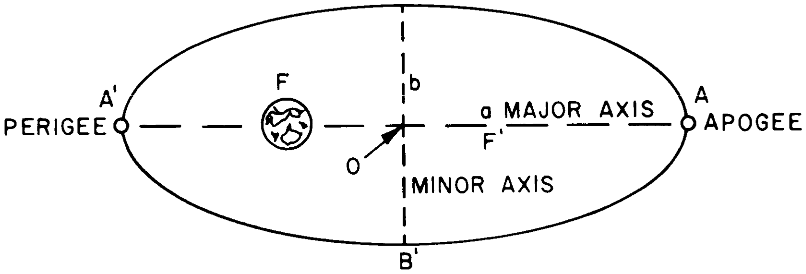

Figure 2-1. Elliptical Satellite Orbit

Perigee and apogee are two of the three parameters customarily used to describe orbital data of a satellite. Perigee is defined as the point in the orbit of a satellite that is nearest to the center of the earth. Apogee is defined as the point in the orbit of a satellite at the greatest distance from the center of the earth. By convention both distances usually are expressed from the surface of the earth in statute miles, although nautical miles usually are used for military systems.

b. Angle of Inclination. The angle of inclination is the third parameter customarily used to describe orbital data of a satellite. Most satellites orbit the earth in orbital planes which are not coincident with the earth's equatorial plane. A satellite orbiting in any plane not coincident with the equatorial plane is in an inclined orbit.

The angle of inclination is the angle between the equatorial plane and the orbital plane as shown in figure 2-2.

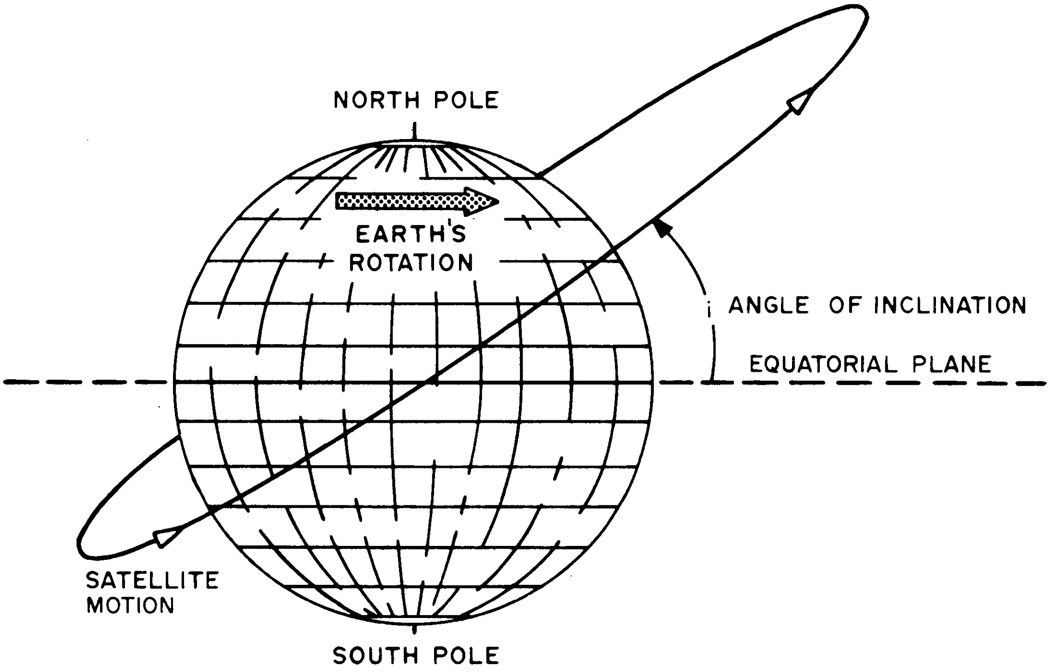

Figure 2-2. Inclined Satellite Orbit

c. Special Types of Inclined Orbits.

(1) Equatorial Orbit. A satellite orbiting in a plane that coincides with the earth's equatorial plane is in an equatorial orbit.

(2) Polar Orbit. A satellite orbiting in an inclined orbit with an angle of inclination of 90 degrees or near 90 degrees is in a polar orbit.

d. Circular Orbits. A circular orbit is a special type of elliptical orbit in which the major and minor axis distances are equal or approximately equal. Mean height above earth, instead of perigee and apogee, is used in describing a circular orbit.

e. Special Types of Circular Orbits.

(1) Synchronous Orbit. A satellite in a circular orbit at a height of approximately 19, 300 nautical miles above the earth is in a synchronous orbit. At this altitude the satellite's period of rotation is 24 hours, the same as the earth's, and the satellite orbits in synchronism with the earth's rotational motion. Although inclined and polar synchronous orbits are possible, the term synchronous, as commonly used now, refers to a synchronous equatorial orbit. In this type of orbit, satellites appear to hover motionlessly in the sky.

(2) Near Synchronous Orbit. A satellite in a circular orbit within a few thousand miles of 19, 300 nautical miles above the earth is in a near synchronous orbit. If the orbit is lower than 19, 300 nautical miles, the satellite's period is less than the earth's and the satellite appears to be moving slowly around the earth from west to east. (This type of orbit is also called sub-synchronous.) If the orbit is higher than 19, 300 nautical miles, the satellite's period is greater than the earth's and the satellite appears to be moving slowly around the earth from east to west. Although inclined and polar near synchronous orbits are possible, common usage of the term near synchronous implies a near synchronous equatorial orbit.

(3) Medium Altitude Orbit. A satellite in a circular orbit from approximately 2000 miles to 12, 000 miles above the earth is considered to be in a medium altitude orbit. The period of a medium altitude satellite is considerably less than that of the earth, causing such satellites to appear to move rather quickly across the sky from west to east.

2. 2. 2 Factors That Affect Choice of Orbits

The early attempts at communication using artificial satellites were severely limited by the state of the art in rocketry and the choices of orbits were quite limited. Improvements in rocket capabilities, new methods of orbital injection, and development of satellite positioning control have removed the original limitations in the choice of orbits.

a. Coverage Desired. The first factor to be considered in choosing the type of orbit for a communication satellite system is the coverage desired to be provided by the system. The area of coverage depends upon the inclination of the orbit, the shape of the orbit, the height of the orbit, and the number of satellites available in the system.

The inclination of the orbit determines the geographic limits of the projection of the path of the satellite over the earth's surface. The greater the inclination, the greater the amount of the earth's surface that is covered by the satellite. This is shown graphically in figure 2-3.

The area of coverage of a satellite at any particular time depends on the height of the satellite above the earth (and possibly may be restricted due to the antenna pattern of the satellite). If a satellite is in an elliptical orbit the area coverage varies with the position of the satellite in the orbit.

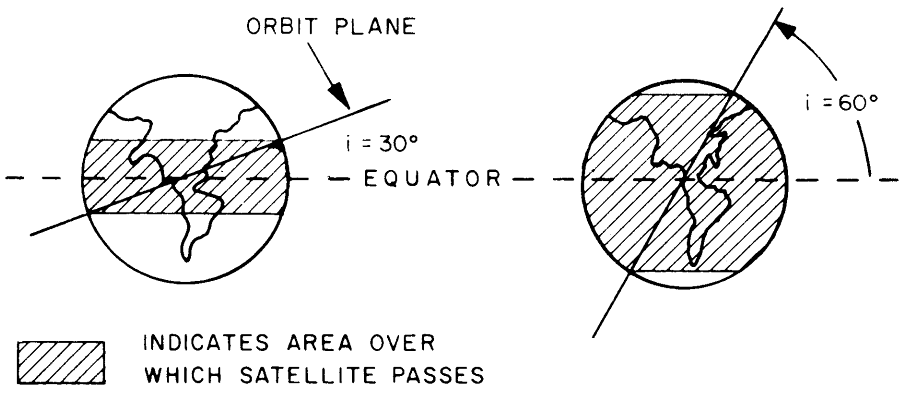

Figure 2-3. Effect of Orbit Plane Inclination on Satellite Coverage

Availability of a satellite at a particular point on the earth's surface varies with the height and shape of the orbit. Availability of a satellite in circular orbit occurs at regular intervals, the frequency of which is determined by the height and inclination of the orbit, whereas the availability of a satellite in elliptical orbit varies in length of time with each passage of the satellite, and the recurrence of availability depends upon the orbital parameters.

All of the above factors must be considered in designing a communication satellite system. Several typical systems are discussed below.

(1) Global Systems. In the design of a global communication satellite system the use of synchronous equatorial satellites is quite advantageous. Figure 2-4 shows how one of these satellites can illuminate almost one-half of the earth's surface.

Three of these satellites can provide coverage over most of the earth's surface (except for the extreme north and south polar regions). A polar projection of the global coverage of such a three-satellite system is shown in figure 2-5.

A disadvantage of such a system is that provisions must be included in the satellites for maneuvering them as necessary to maintain their proper positions (positioning control). Another disadvantage is the length of time that would be required to replace a satellite if one should experience a catastrophic failure.

The Phase II DSCS system design has some special coverage features, but it is basically the same as that shown in figure 2-5.

The Phase I IDSCS communication satellite system, which was designed for continuous global coverage, utilizes a number of satellites in near synchronous equatorial circular orbits. Since the periods of each of these satellites are different, averaging about 22 hours, all of the satellites appear to be moving slowly in a random fashion around the earth from west to east. At least one satellite is available almost continuously for use by adjacent pairs of earth terminals. If a satellite fails, another of the randomly spaced satellites becomes available within an acceptable length of time (without waiting for a replacement launch).

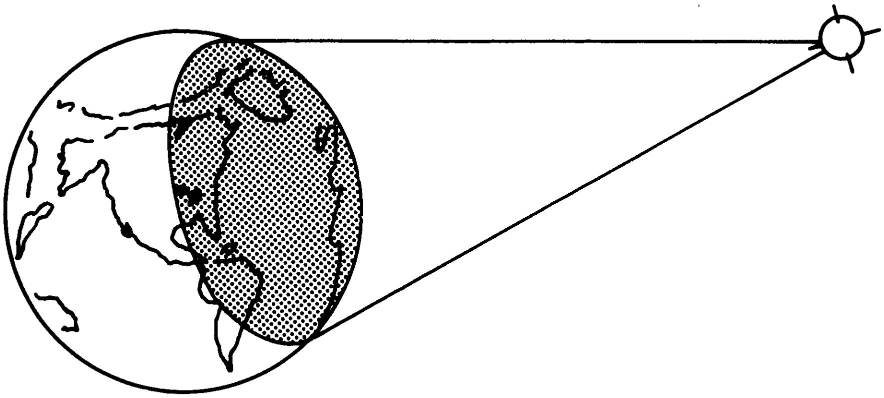

Figure 2-4. Illumination from a Synchronous Satellite

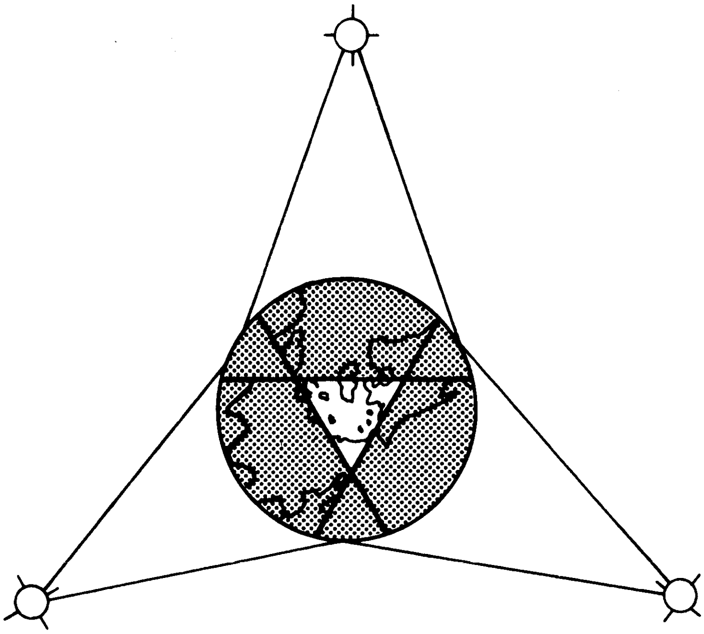

Figure 2-5. Worldwide Synchronous Satellite System Viewed from above North Pole

(2) Northern Hemisphere System. The Russian communication satellite system, which was designed primarily for coverage of the northern hemisphere, utilizes satellites in elliptical orbits with perigees of about 290 statute miles, apogees of about 24, 700 statute miles, and inclinations of about 64°. In this system the satellites are over the northern hemisphere considerably longer than over the southern hemisphere.

b. Effects of Geographic Location of the Launch Pad. Prior to the development of a second start capability in rocket motors, the geographic location of the launch pad determined the minimum inclination of any achievable orbit. Without the technique of dog-legging (described below), the angle of inclination of the orbit cannot be any less than the latitude of the launch site. The reason for this is that the point of injection into orbit is a point on the orbit. Thus, a satellite launched from Cape Kennedy (latitude 28° N.) will return to at least latitude 28° N. and thus the minimum achievable angle of inclination is 28°. To launch an equatorial satellite without using the dog-leg technique, the launch pad would have to be located somewhere along the equator.

After the development of a restart capability in rocket motors, a dog-legging technique was conceived to permit achievement of orbits with inclinations less than the latitude of the launch pad. To obtain less than a 28 degree inclination from Cape Kennedy, an intermediate, or parking, orbit is first required. The intermediate orbit is achieved in the usual fashion. (A due east shot is made from the launching station.) As a result, the inclination angle of the parking orbit will be the latitude of Cape Kennedy — 28 degrees. The thrust of the remaining rocket engine is then applied at right angles to the parking orbit when the satellite and rocket engine are near the equator. In reaction to this thrust, the satellite veers into an orbit of the desired inclination with no change in either altitude or velocity. This is the technique known as dog-legging.

c. Launch Capability Restraints. The size and number of satellites to be launched and the type of orbit desired determine the kind of rocket that is needed to accomplish the launch. The rocket's lift capability must be great enough to carry the payload to its desired orbital injection position and to cause it to have the desired orbital velocity upon injection.

For early launches, in-flight changes were not possible so achievable orbits were limited to those with inclinations equal to or greater than the latitude of the launch site. The development of more sophisticated (controlled multiple burn) rocket motors eliminated the "latitude of launch" restriction; however, more complex and heavier rockets must be used to achieve orbits with inclinations less than the latitude of launch.

A second artificial restraint to early launches was caused by safety precautions. The uncertainties of rocket launching demand, as a matter of public policy, that all rockets contain self-destruct capabilities for use in case of malfunctions and erratic flight paths. The geographic limits of areas where rockets can be safely destroyed severely limit the directions in which rockets can be launched. As rockets developed greater power, the down-range motor-burnout distances became greater, imposing further restrictions on the initial launch directions.

With the rapid development of sophisticated rockets the launch-capability restraints are primarily economic. In the case of military communication satellite systems, technology is available to achieve any chosen orbit; however, budgetary limitations determine the scope of present day operations.

d. Acquisition and Tracking Considerations. In choosing a type of orbit for a satellite communication system, the problems associated with acquisition and tracking of the satellites by the earth terminals must be considered. With elongated elliptical orbits and medium altitude circular orbits the satellites move past the earth terminals at a rapidly changing angular rate; and, searching for and acquiring the particular assigned satellite is a difficult task even though accurate initial antenna pointing information is provided. Contrariwise, with the near synchronous and synchronous orbits the satellites appear to move quite slowly or not at all; and, with proper antenna pointing information, searching for an assigned satellite is quite easy, and tracking is very simple.

With elliptical and medium altitude orbits the satellite transmitted frequencies change depending upon whether the satellite is approaching or receding due to the doppler effect. This also increases the difficulty of acquiring the satellite. In the near synchronous orbits doppler effects are minimized and they are nonexistent with synchronous orbits.

In short, elliptical and medium altitude orbits, which are relatively easy and more economical to achieve, introduce considerable complexities in the earth terminal acquisition and tracking equipments. The near synchronous and synchronous orbits, which are more difficult and more expensive, require much simpler acquisition and tracking equipment for the earth terminal.

2.3 SATELLITE CHARACTERISTICS

a. Size and Weight Considerations. A prime consideration in determining the size and weight of a satellite is the payload that available rockets can accommodate. Early communication satellites were limited to the diameter of the final stage of the rocket that was to be used for launching. Similarly, the weight was determined by the thrust of the rocket motors and the maximum weight that the rocket could lift into the desired orbit.

As the thrust of rocket motors increased and the rocket diameter increased, size and weight restrictions were eased. The maximum size of a satellite is still limited essentially to the diameter of the final stage of the rocket to be used and the space within the nose fairing. Similarly, the maximum weight of a satellite is limited by the maximum thrust of the rocket motor. However, rockets and rocket motors already developed are so large that these factors are not usually the prime considerations that determine the size and weight of satellites in modern systems. This will be discussed further below.

b. Single or Multiple Launch. As soon as the state of the art in rocketry progressed to the point that relatively large payloads could be lifted into orbit, a technique was developed to permit multiple launches from one rocket. As early as June 1960, two satellites were successfully placed in orbit by the same launch vehicle. With the development of this multi-launch capability, additional flexibility was made available in the design options as to size, weight and number of satellites to be included in each launch. These factors must be considered within the context of the desired system parameters.

The Phase I IDSCS communication satellite system was initially designed to consist of fifteen randomly spaced, near synchronous satellites. When the powerful TITAN IIIC rockets became available to lift the IDCSP satellites into near synchronous equatorial orbits, it was determined that the TITAN IIIC could accommodate within its fairing a total of eight satellites, each approximately 36 inches in diameter and weighing 100 pounds. The 26 IDCSP satellites were injected into their orbits as the result of four successful multiple launches which included a few other satellites as well.

The Phase II DSCS communication satellite system will have larger and heavier satellites in synchronous equatorial orbits. Present planning indicates that two of these Phase II satellites will be injected into orbit from a single launch. Figure 2-6 is a drawing of the Phase II satellite.

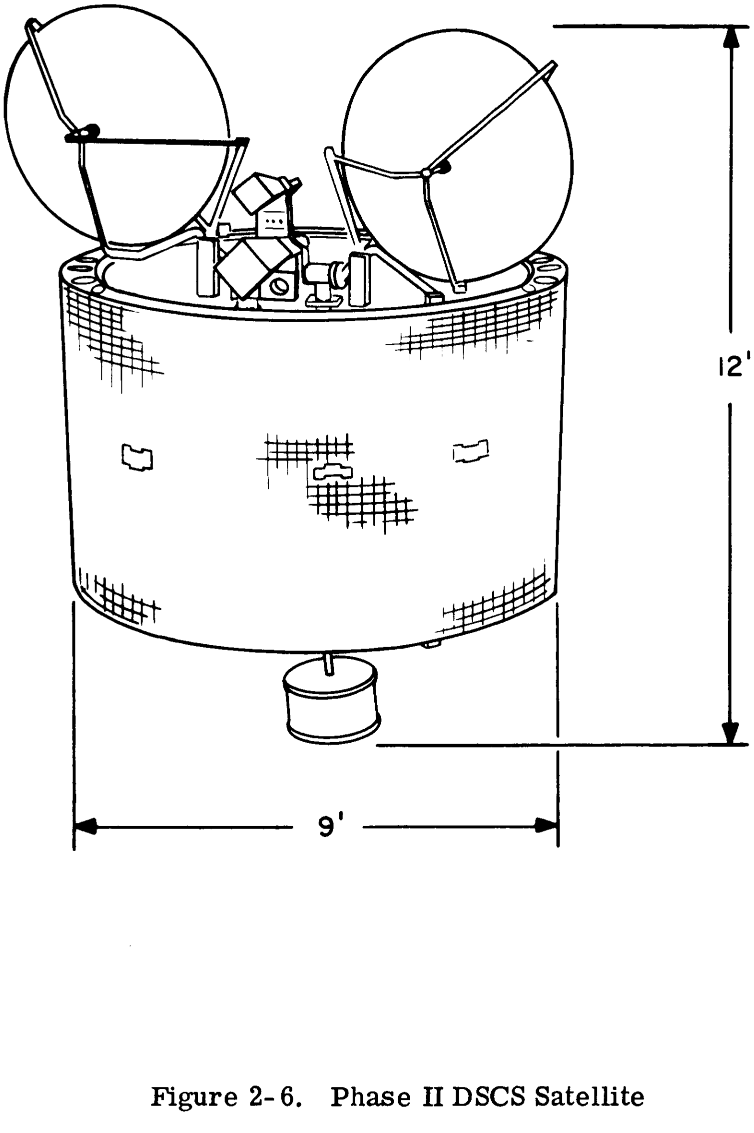

Figure 2-6. Phase II DSCS Satellite

As previously mentioned, early limitations on size and weight of satellites have been removed by advances in technology, and economic considerations have become the primary restraint.

c. Power Sources. Early communication satellites were severely limited by the lack of suitable power sources; this, in turn, severely limited the output power of the satellite transmitter. The only source of power available within early weight restrictions was a very inefficient panel of solar cells without battery backup. A major disadvantage of this type of power source is that the satellite has no power when the satellite is in eclipse. For continuous communications this outage is unacceptable.

A combination of solar cells and storage batteries is a better prime power source for satellites. This is a practical choice at this time, even though the result is far from an ideal power source. Because of the relatively low conversion efficiency of the solar cells, the combination is limited to approximately one watt of deliverable power per pound. About ten percent of the sunlight energy converging on the solar cells is converted to electrical power. Even this low efficiency is further decreased when the solar cells are bombarded by high-energy particles that are sometimes encountered in space.

The IDCSP satellites have over 8500 solar cells mounted on the surface of the satellite. Initially these cells supplied about 42 watts. No battery backup was provided.

The Phase II DSCS satellites will have about 32,000 solar cells, initially supplying about 520 watts, mounted on the surface of the satellite. A nickel cadmium battery will be used for backup power during eclipses.

Although numerous nuclear power sources have been used in space for special purposes, the state of the art has not progressed sufficiently for nuclear power sources to be competitive with the solar cell-battery combination for synchronous communication satellites. With solar cells exposed to the sun continuously (and battery backup for eclipses), the solar cell-battery installations will be lighter in weight, more efficient and less costly than existing nuclear power sources. This situation may change in the future as power requirements increase above 10 kW and, particularly, if low cost nuclear fuels become available.

d. Satellite Orientation. Satellite orientation in space is quite important for two reasons: continuous solar cell orientation and continuous antenna orientation. Since the primary source of power in most satellites is from solar cells, it is essential that the maximum number of the solar cells be exposed to the sun at all times. Moreover, for useful communications, the satellite antenna must be visible to appropriate earth terminals. Early communication satellites used spin stabilization to meet these important requirements.

Spin stabilization operates on the principle that the direction of the spin axis of a rotating body tends to remain fixed in space. A natural example of spin stabilization is the effect of the earth's rotation in keeping its axis fixed in space. A satellite having a spin axis parallel to the earth's axis will maintain this position since both axes are fixed in space. Figure 2-7 illustrates the use of this principle with an equatorial orbit satellite to keep a doughnut-shaped antenna pattern pointing toward the earth.

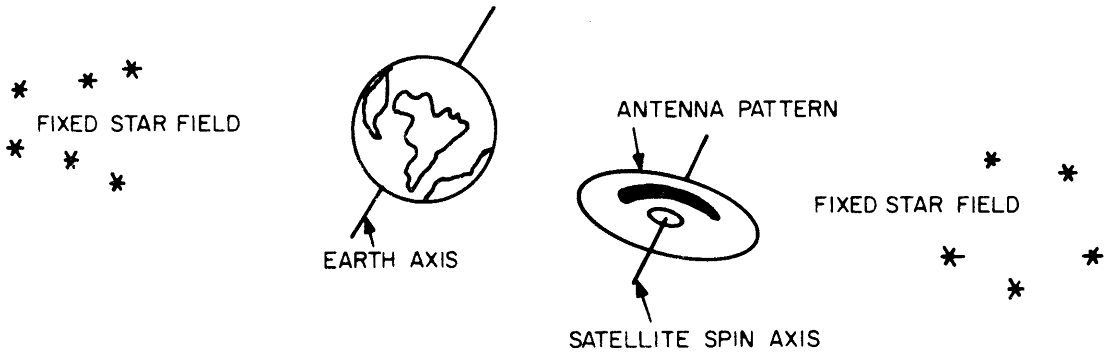

Figure 2-7. Spin-Stabilized Satellite Antenna Pattern

Spin stabilization requires virtually no additional energy or expenditure of mass once the system is in motion. A spin-stabilized satellite is usually constructed like a flywheel with the heavier equipment mounted in the same plane and as close to the periphery as possible. See figure 2-8.

After orbital injection, the radial jets are pulsed to initiate spinning. The satellite spin axis is oriented to the earth's axis by means of the axial jets, which are pulsed at the proper spin phase. The velocity jets, pulsed at the proper spin phase, provide orbit position and velocity correction.

By installing solar cells all around the periphery of the spin-stabilized satellites a large number of solar cells are exposed to the sun at all times (except when the satellite is in eclipse). By installing antennas that radiate in all directions around the spin axis a small part of the total radiated energy is directed toward the earth at all times.

The Phase I IDSCS satellites are spin stabilized, as described above. They utilize solar cells mounted on the periphery of the satellite and have two omnidirectional antennas installed around the spin axis.

In an effort to overcome the disadvantage of omnidirectional antennas, which radiate only a small amount of energy toward the earth, various techniques to achieve an earth-oriented antenna system have been developed and the most promising have been tested in space vehicles. The best system developed to date uses spin stabilization for orientation of the satellite with a despun inner platform for mounting controllable

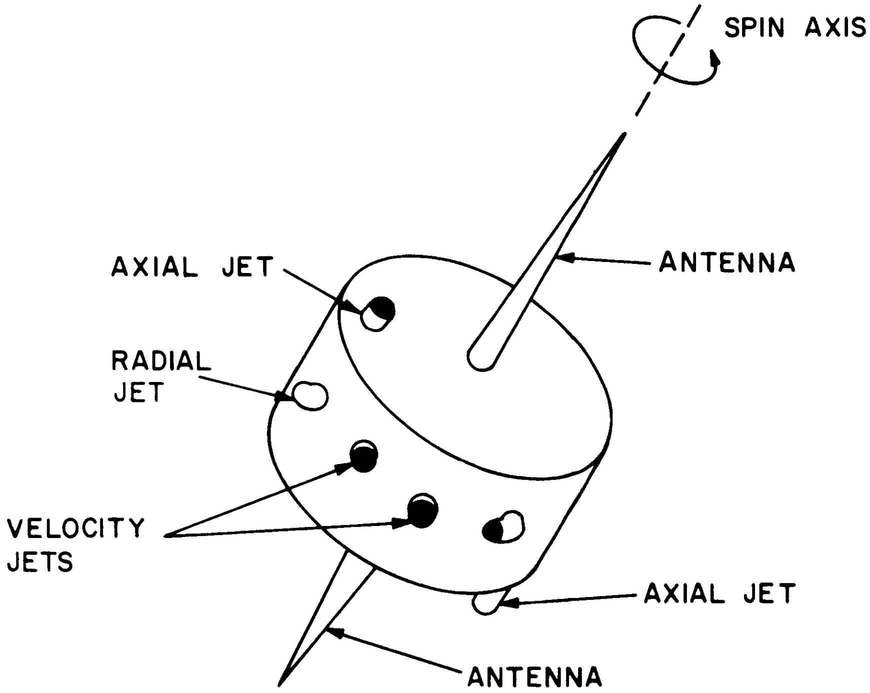

Figure 2-8. Spin-Stabilized Satellite Controls

antennas. The satellite is constructed in two parts with both parts having radial jets. The inner part is concentric with the outer part and contains the communication antennas and the communications package. The satellite is launched and injected into orbit in the usual manner. The whole satellite is spin stabilized using the outer radial jets. After the satellite is stabilized with the desired orientation, the inner radial jets spin the inner part in the opposite direction to counter the initial spin. This results in a despun inner platform, which is stationary with respect to earth. The despun platform is oriented to such a position that the communication antennas point continuously toward the earth. This arrangement allows the use of high gain directional antennas to concentrate the majority of the radiated energy in the direction of the sun.

The Phase II DSCS satellites will use a despun platform with four high gain antennas. Two steerable narrow beam antennas will be used for communications between and within regions of high traffic density. Two horn antennas will provide for earth communications between facilities outside the narrow beam coverage. The antenna arrangement proposed for the Phase II satellites is shown in figure 2-6.

e. Characteristics of the IDSCS Satellites

(1) IDCSP Satellites. These satellites are double frequency conversion, hard-limiting repeaters that are placed into near synchronous equatorial orbits at various altitudes averaging about 18, 200 nautical miles. At this altitude, the satellites drift

from west to east (relative to the earth) at about one degree of longitude per hour. The satellites are spin stabilized and solar-cell powered. The shape of the satellite is as shown in figure 2-9.

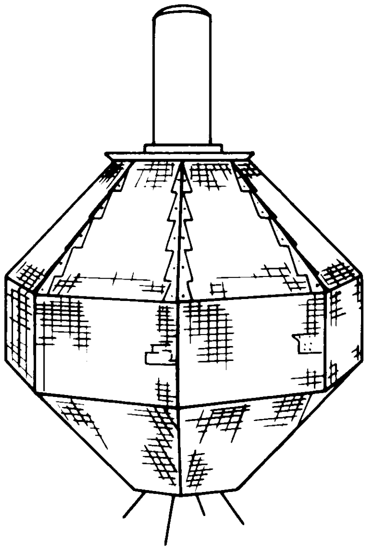

Figure 2-9. IDCSP Satellite

The satellite is 36 inches in diameter, 32 inches high, and weighs about 100 pounds. The upper cylinder contains two bicone antennas with a toroidal pattern (antenna gain 3 to 5 dB). Four telemetry antennas extend from the bottom of the satellite. Frequency modulation of the RF carriers is used on both the up links and the down links. The up-link frequencies vary from about 7986 to 8005 MHz and the down-link frequencies vary from about 7267 to 7286 MHz. The beacon frequency is about 7299 MHz and the telemetry frequency is about 400 MHz. A traveling-wave tube is used for the transmitter RF amplifier.

The use of hard-limiting RF amplifiers in the receiver results in a requirement for "power balancing" by the earth terminals prior to establishing adequate communications. A characteristic of hard-limiting amplifiers is that two signals of equal strength are amplified equally, but if the two signals are unequal the stronger signal will be amplified more than the weaker, and in some cases the stronger signal will completely capture the amplifier to the exclusion of the weaker signal. Hence, two earth terminals in establishing communications must adjust their transmitter powers to achieve a "power balance" before an optimum communication link can be established.

(2) Phase II DSCS Satellites. These satellites are under construction and only general characteristics are available. These satellites will use tunnel diode receivers and traveling-wave tubes for the transmitter RF power amplifier. They will be launched into synchronous equatorial orbits and will be spin stabilized with a despun antenna platform. The proposed shape of the satellite is shown in figure 2-6. The satellite will be 9 feet in diameter, 12 feet high, and will weigh approximately 1000 pounds. Two high gain, ground controllable antennas will provide large area

coverage. Provisions will be made for generation of about 520 watts of power with backup nickel-cadmium batteries.

2.4 EARTH TERMINAL CHARACTERISTICS

Communication satellite earth terminals generally are located in areas remote from the actual users of these communications. This is necessary to minimize RF interference to the satellite communications. Characteristic of this remoteness is a need for interconnect links to permit communication flow to and from the users of the satellite systems. These interconnect links are usually via telephone cables or microwave radio with normal terminal equipments.

Earth terminals generally have a single large antenna, a highly sensitive receiver, a powerful transmitter, multiplex equipment, modulating-demodulating equipment, and telemetry equipment.

a. Antennas. Earth terminal antennas are highly directional, high gain antennas capable of transmitting and receiving signals simultaneously. Generally, large, high gain, parabolic antennas are used with some form of Cassegrainian feed.

Three sizes of parabolic-type antennas are currently in use with the Phase I IDSCS earth terminals: the AN/FSC-9 uses a parabolic antenna 60 feet in diameter; the AN/MSC-46 uses a parabolic antenna 40 feet in diameter; and the AN/TSC-54 uses a cluster of 4 parabolic antennas, each 10 feet in diameter, which, in combination, are equivalent to a parabolic antenna 18 feet in diameter.

b. Receivers. All satellite communication earth terminals are equipped with specially designed, highly sensitive receivers. These highly sensitive receivers are required to overcome the down-link power limitations mentioned in paragraph 1.7.1 and to permit extraction of the desired communication information from the received signal. All of the terminals currently in use in the Phase I IDSCS system utilize specially designed preamplifiers mounted directly behind the antennas. The preamp noise temperatures vary with the sizes of the earth terminals. The preamp noise temperature of the AN/FSC-9 is 55° Kelvin (K); that of the AN/MSC-46 is 82° K; and the AN/TSC-54 is 120° K.

c. Transmitters. All earth terminal transmitters generate high power signals for transmission to the communication satellites. The combination of high powered transmitters and highly directional, high gain antennas is necessary to overcome the up-link limitations mentioned in paragraph 1.7.2 and to ensure that the signals received by the satellite are strong enough to be detected by the satellite. Although various arrangements of functional components are possible in transmitters, all the transmitters in use in the Phase I IDSCS earth terminals have the same general arrangements. Each IDSCS transmitter has an exciter/modulator and a power amplifier. The modulator accepts the baseband input from the terminal equipment and modulates an IF carrier. The exciter translates the IF signal to the up-link frequency and amplifies it to the level required by the klystron of the power amplifier. All IDSCS transmitters use specially cooled klystrons in their power amplifiers. The output power of the AN/FSC-9 is variable from 10 W to 20 kW; that of the AN/MSC-46 is variable from 100 W to 10 kW; and that of the AN/TSC-54 is variable from zero to 5 kW.

d. Telemetry Equipment. Telemetry equipment is included in all communication satellite systems to permit monitoring of the operating conditions within the satellite. Telemetry can be used also for remote control of satellite operations such as energizing axial jets for changing the spin axis of the satellite. In the Phase I IDSCS system telemetry information is transmitted in the 400-MHz band and is the responsibility of the Air Force. (A normal Navy earth terminal will not have a 400-MHz capability.)

e. General Description of DSCS Earth Terminals. There are three types of earth terminals currently in use in the DSCS: AN/FSC-9, AN/MSC-46, and AN/TSC-54. The two AN/FSC-9 earth terminals were built originally for the ADVENT program, were modified later for the SYNCOM program, and finally were modified for the IDCSP program. The AN/MSC-46 and AN/TSC-54 equipments were built for the IDCSP program.

(1) AN/FSC-9. The AN/FSC-9 terminals are permanent installations located at Fort Dix, New Jersey, and Camp Roberts, California. They are used as the principal terminals for communication links to Europe and to the Pacific respectively. A 60-foot parabolic antenna is mounted on a 60-foot steel antenna tower on a concrete foundation 30 feet deep and 84 feet in diameter. The antenna mount includes a bridge superstructure that acts as a counterweight and serves as a housing for electronic equipment. The estimated weight of the antenna is 190 tons. A 200-foot covered passageway connects the antenna to a 6000-square foot operations building. Additional details are shown in table 2-1. An AN/FSC-9 is shown in figure 2-10.

(2) AN/MSC-46. The AN/MSC-46 is a transportable communication satellite terminal that is housed in three vans. A rigid radome (not supplied with the terminal) is usually installed over the antenna. Power is furnished by three diesel generators (supplied as a part of AN/MSC-46) of 100 kW each, or local commercial power may be used if available. The complete terminal, including the disassembled antenna, weighs 114, 000 pounds but it can be transported by three C-130E aircraft. After arrival on site, the terminal can be assembled by a crew of eight trained men. Additional details are shown in table 2-1. An AN/MSC-46 antenna with its pedestal is shown in figure 2-11.

(3) AN/TSC-54. The AN/TSC-54, the smallest of the Phase I IDSCS earth terminals, is a highly transportable communication satellite terminal. The antenna, klystron and preamplifier are mounted on a trailer and the remainder of the terminal equipment is in an equipment shelter. Power is supplied by a trailer-mounted diesel generator. The complete terminal weighs 19, 500 pounds and can be transported by C-133E aircraft or H-37 helicopter; or it can be towed by suitable trucks over unimproved terrain by attaching "goat" mobilizers (furnished with the terminal) to the equipment shelter. A well-trained, experienced crew of six can set up or dismantle the AN/TSC-54 in less than two hours. A rigid radome (not supplied with the terminal) is available for semipermanent installations where required. Additional details are shown in table 2-1. An AN/TSC-54 is shown in figure 2-12.

2.5 SATELLITE ACQUISITION AND TRACKING

An essential operation in establishing communications via satellite is the acquisition of the satellite by the earth terminal antenna and subsequent tracking of the satellite. Initial acquisition depends upon an exact knowledge of the satellite's position which, in combination with the geographic location of the earth terminal, enables the computation of accurate antenna pointing information. The degree of difficulty in acquiring and tracking a satellite is determined largely by the satellite's orbital parameters.

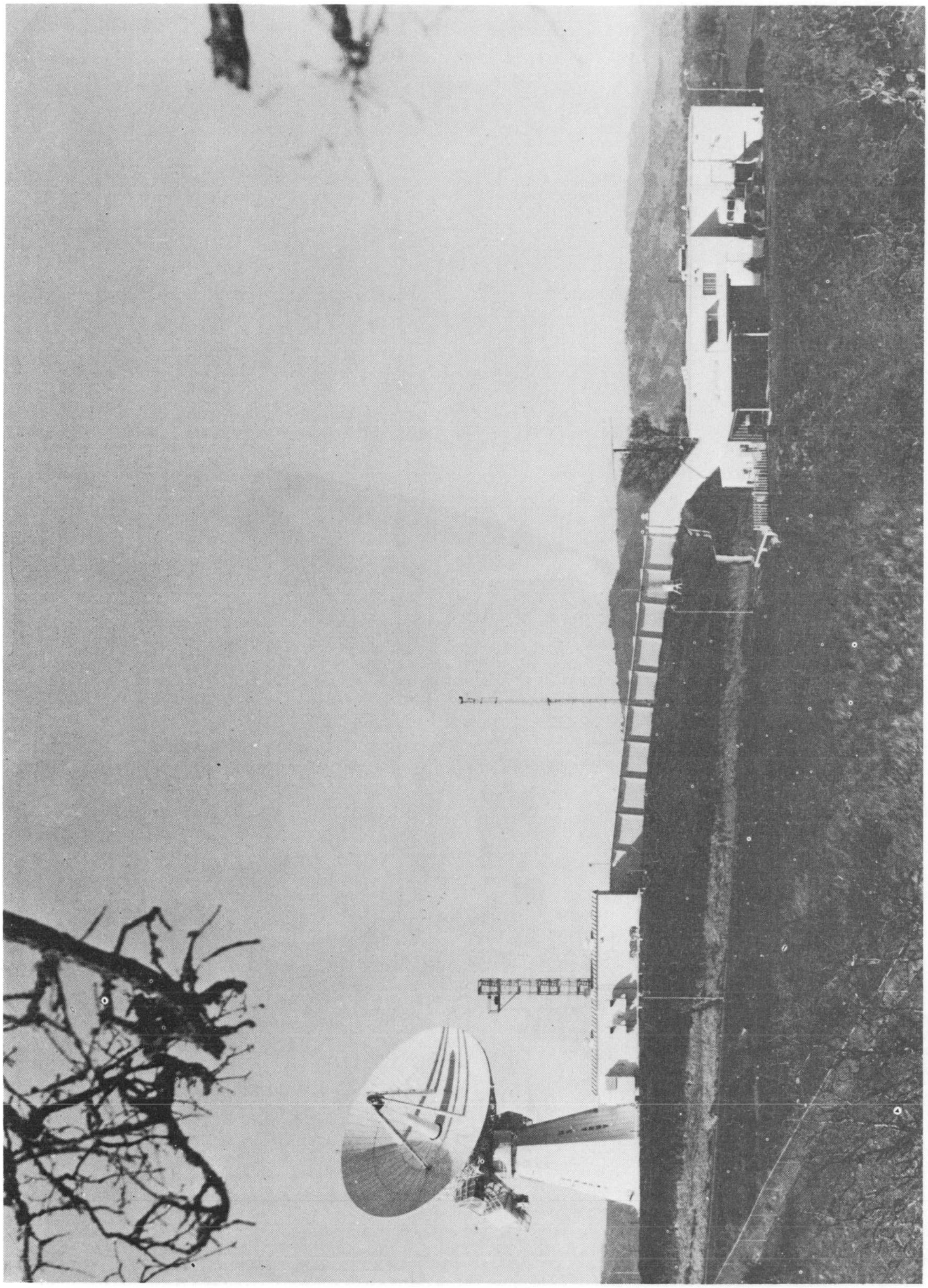

Figure 2-10. AN/FSC-9 Satellite Earth Terminal

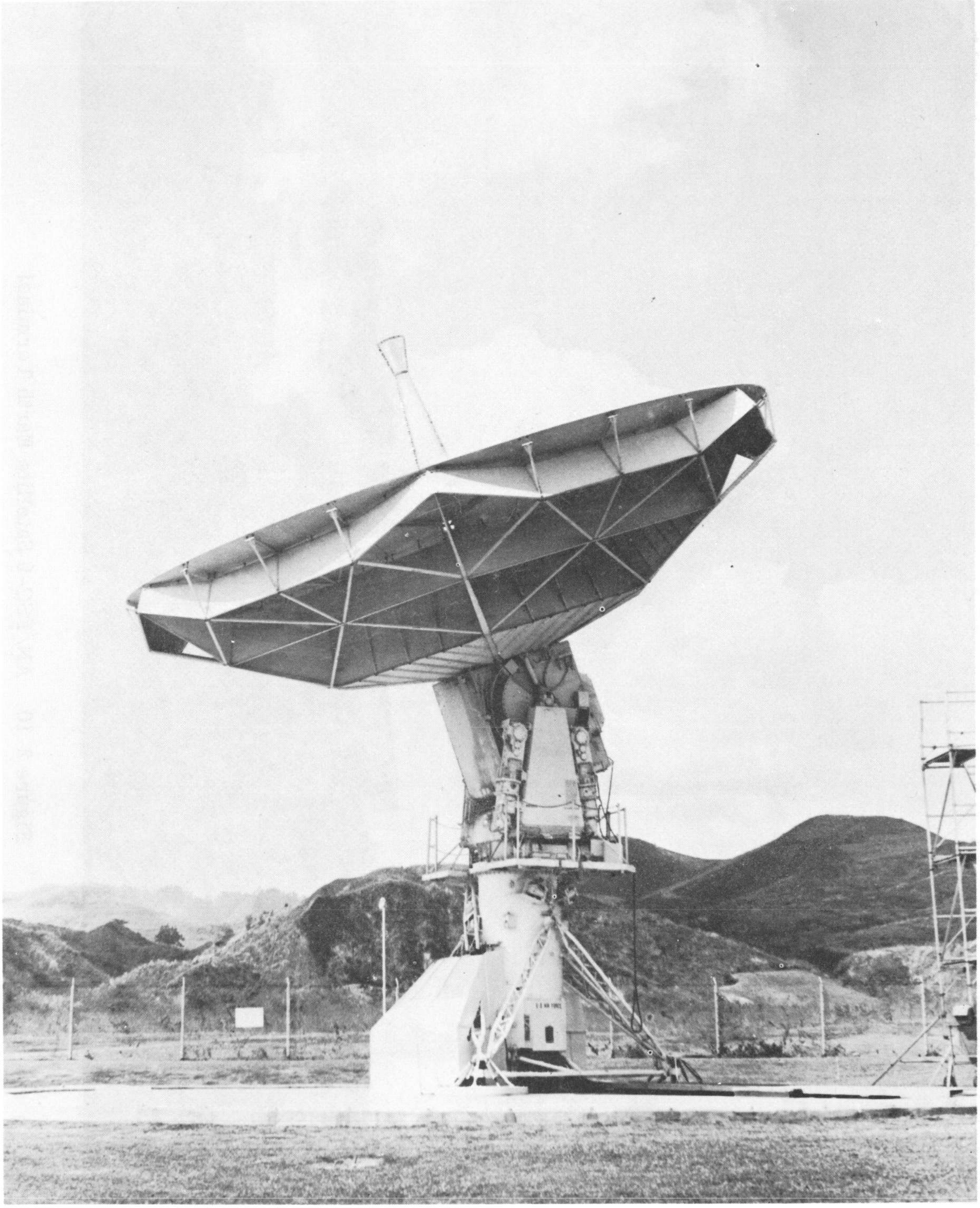

Figure 2-11. AN/MSC-46 Antenna and Pedestal

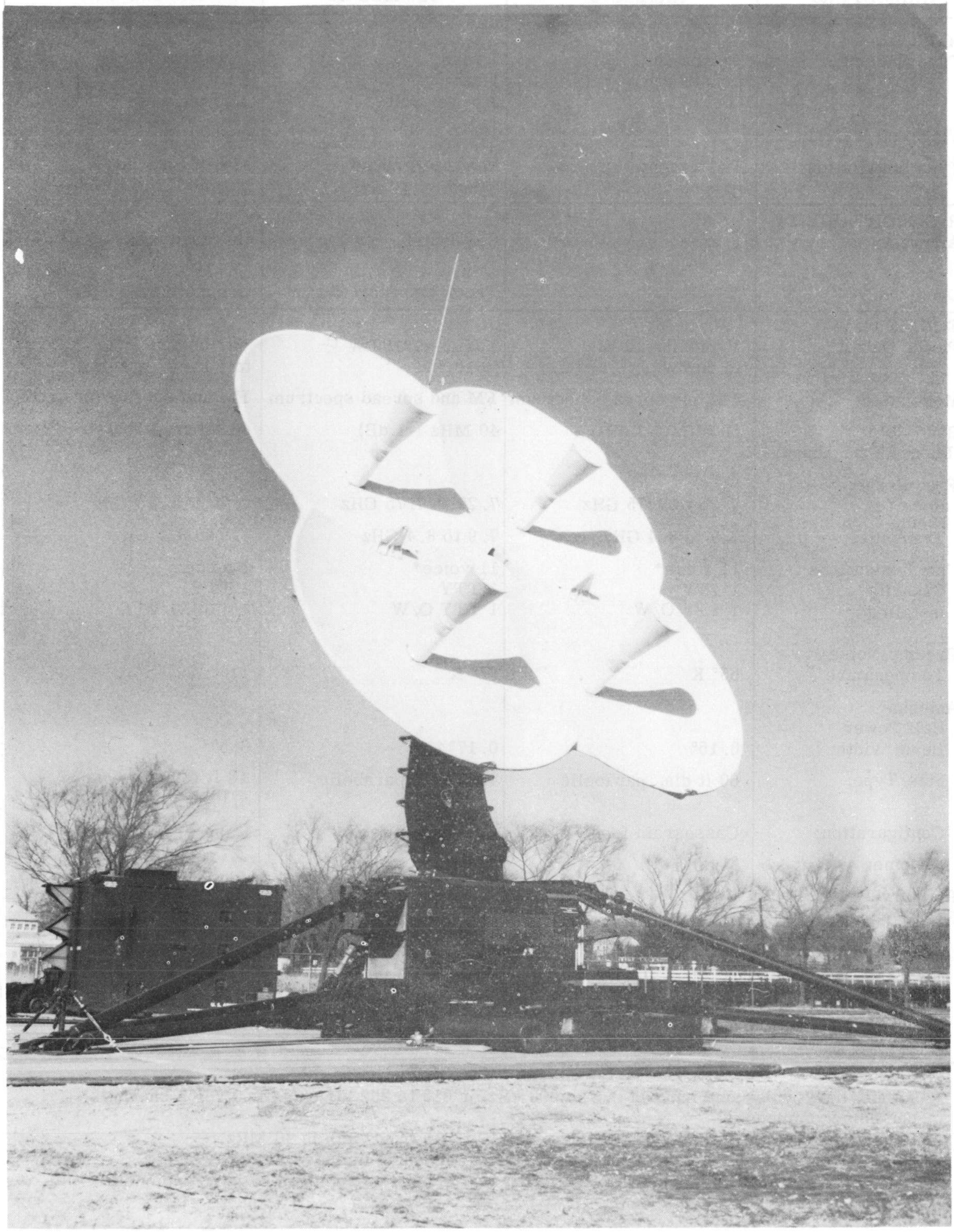

Figure 2-12. AN/TSC-54 Satellite Communication Terminal

Table 2-1. Principal Characteristics of DSCS Earth Terminals

EQUIPMENT PARAMETERS	AN/FSC-9	AN/MSC-46	AN/TSC-54
PHYSICAL			
Type Housing:	Permanent construction	3 vans 1 antenna 3 power units	1 shelter 1 antenna 2 power units
Terminal Weight:	-	114, 000 lb	19, 500 lb
Type Installation:	Permanent/ ground based	Movable/ground based	Mobile/ground based
TRANSPORTABILITY			
Aircraft:	-	C-130E(3)	Helicopter or C-133E
Overland:	-	Truck transported	Ground transported
TECHNICAL			
Power Output:	Variable, 10 W to 20 kW	Variable, 100 W to 10 kW	Variable, 0 W to 5 kW
Modulation:	FM and spread spectrum	FM and spread spectrum	FM and spread spectrum
Bandwidth: (Max. RF baseband)	50 MHz (-3 dB)	40 MHz (-1 dB)	40 MHz (-1 dB)**
Freq Range			
Receive:	7.25 to 7.75 GHz	7.25 to 7.75 GHz	7.25 to 7.75 GHz
Transmit:	7.9 to 8.4 GHz	7.9 to 8.4 GHz	7.9 to 8.4 GHz
Communications Capacity Installed:	11 voice* 1 TTY 1 TTY O/W	11 voice* 1 TTY 1 TTY O/W	1 voice 1 TTY 1 TTY O/W
Preamp Noise Temperature	55° K	82° K	120° K
Antenna			
Half Power Beam Width:	0.15°	0.17°	0.5°
Size/Type:	60 ft dia, parabolic	40 ft dia, parabolic	18 ft effective dia, 4 10-ft dish clutter
Configuration:	Cassegrain feed	Cassegrain feed	Cassegrain feed
Radome:	None	*** Rigid, 68 ft dia	**** Rigid, 41.4 ft dia
Primary Power Requirements			
Voltage:	440 V	120/208 V ±10%	120/208 V ±5%
Phase:	3	3	3
Frequency:	60 Hz	50/60 Hz ±5%	400 Hz ±2%
KVA:	750	less than 200	45

* An auxiliary wide-band input of 0.3 to 500 kHz or 0.3 to 252 kHz (up to 60 voice channels) can be accommodated.

** Receive bandwidth limited by IF filter to 10 MHz, RF bandwidth is 40 MHz.

*** Rigid radome is not furnished with terminal, but weight is included in total weight.

**** Rigid radome is not furnished with terminal, but is used as required by environmental conditions.

Acquisition and tracking of a synchronous satellite are relatively simple because the satellite appears to be stationary. Acquisition of a near synchronous satellite is relatively simple because of the slow relative motion of the satellite; however, the satellite's relative movement is enough that accurate tracking is required to keep the narrow beam antenna pointed toward the satellite. Satellites in medium altitude circular orbits or in elliptical orbits are more difficult to acquire and also to track because of their relatively rapid changes in position.

2.5.1 Orbital Prediction

a. Ephemeris Data. In order to be able to supply antenna pointing information to earth terminals, it is necessary to know with a high degree of accuracy the orbital parameters of the satellite. A table showing the calculated positions of a satellite (or any heavenly body) at regular intervals of time is called an ephemeris. The ephemeris of a satellite is calculated from its orbital parameters and a knowledge of the physical laws of motion. After the ephemeris data of a satellite are determined it is possible to predict, for any given location, the apparent track of the satellite as viewed from that location.

b. Orbital Tracking. The constants defining an orbit are initially obtained by the process of tracking. At the time of launch, the rocket is tracked by radar from "lift off" to injection, and then until it passes out of sight. The recorded tracking data obtained in this way is sufficient for making rough predictions of the orbit. These predictions are made rapidly with a computer and sent to other tracking stations in other parts of the world. The other tracking stations around the world watch for the satellite during its first trip and record additional data which enables more precise predictions to be made. Thus, during the first week of orbiting, tracking stations all around the world are obtaining progressively more accurate data concerning the satellite. These data are put into a computer where corrections of earlier estimates of the orbit are made.

Once the initial predictions are complete and the satellite link becomes operational there is very little change in these calculations. The orbits will change slightly over a period of time; however, these changes are so gradual that predictions will be accurate enough to be used for weeks or even months without further corrections. When the orbits are known precisely, an ephemeris can be calculated for each satellite of the system.

2.5.2 Antenna Pointing

Antenna pointing instructions are derived from the ephemeris of a satellite. These instructions must, however, be computed separately for each ground station location. A satellite which bears due south of station A at an elevation of 25 degrees may simultaneously bear due southeast of station B at an elevation of 30 degrees. Antenna pointing instructions are determined by taking into consideration the orbital prediction and the latitude and longitude of each ground station.

a. Ephemeris Coordinate Transformation. It is convenient to express the ephemeris in terms of a geocentric coordinate system; that is, a coordinate system whose center is the center of the earth rather than some point on the surface of the earth. Pointing instructions are obtained by converting the geocentric coordinates to local coordinates by a further calculation. The latitude and longitude of the earth terminal must be accurately known in order to make this conversion.

While the use of modern computers for orbital calculations permits rapid calculations in any coordinate system desired, an ephemeris should be considered to be a table giving satellite position relative to the earth as a whole. The calculations that convert geocentric coordinates to local coordinates are called coordinate transformations.

From the standpoint of acquiring radio contact with a satellite, the only important local coordinates of position are bearing and elevation. Knowledge of the bearing and elevation of a satellite at the time planned for acquisition permits the antenna to be properly pointed. In addition to position, the operator of an earth terminal requires knowledge of the velocity at which the satellite is approaching, in order to properly adjust the receiver for the doppler shift. Thus predictions of both position and velocity must be taken from the ephemeris and transformed into local coordinates. Since the Phase I IDSCS satellites are in near synchronous orbits, their relative motions are quite slow; therefore, the change in frequency due to the doppler effect is very small and poses no significant problem.

b. Control Center Information. The use of satellites to set up particular communication links requires planning. Varying and contingent needs of users must be considered. With a limited number of either random orbit or quasi-synchronous satellites, it is possible that there may be no satellite in the common view of certain pairs of ground stations for minutes or hours at a time. Also, there may be a failure of electronic equipment. Planners must take all of these things into consideration in order to make best use of the satellites.

Antenna pointing instructions are calculated for planned satellite acquisitions and for additional acquisitions to provide reliability in event of satellite equipment malfunction. In the IDSCS a central computer in the Air Force Satellite Control Facility (SCF) performs these calculations for each earth terminal location. The SCF computer printouts, distributed at least a month in advance, list antenna pointing and beacon identification information for each satellite that will become visible to each terminal.

The Satellite Communications Control Facility (SCCF), operated by the DCA, schedules operating time for the use of the various satellites by the three services. The Navy Satellite Operations Center (NSOC), under the direction of the Naval Communications Command, allocates Navy-assigned operating time to Communications Area Master Stations (CAMS) which in turn designate pairs of earth terminals to use the assigned time.

2.5.3 Acquisition

The acquisition of satellite signals by a ground station equipped with large antennas and operated at microwave frequencies places severe requirements on the acquisition system, particularly if the satellite is in a medium altitude circular orbit or in an elliptical orbit.

These requirements can be divided into two problem areas: spatial-time uncertainties and frequency variations. The spatial-time acquisition (acquisition of a signal at some point in space at some instant in time) must also involve acquisition of the signal frequency.

a. Spatial-Time Factor. Very accurate antenna pointing data will be available to the earth terminal from the SCF. However, due to equipment limitations it is necessary to conduct a small search about the predicted location of the satellite in order to make initial contact. This searching involves either manually or automatically scanning a small area around the point where the satellite appearance is predicted. Upon initial reception of the beacon signal from the satellite, the tracking receiver generates error signals which direct the servo mechanism of the antenna to automatically position the antenna in the direction of maximum signal; at this time the system is transferred to the auto-track mode of operation.

b. Timing Control. Timing signals for the entire system are transmitted by the Army satellite terminal at Camp Roberts, California, to Fort Dix, New Jersey, and Helemano, Hawaii. Fort Dix retransmits these timing signals to all terminals in the Atlantic-European-African area, and Helemano transmits the signals to all Pacific sites.

c. Frequency Control. The frequency of a radio signal received from a satellite generally is not exactly the assigned down-link frequency. Since doppler effect is the principal cause of variations in the received frequency, the extent of these frequency variations is quite dependent upon the orbital geometry of the satellites. The greatest frequency variations are observed in signals from satellites in medium altitude, circular orbits and from those in elliptical orbits. The smallest frequency variations are observed in signals from satellites in near synchronous and synchronous orbits where the doppler effect is minimal or nonexistent. Considerable doppler effect can be caused in aircraft earth terminals by the high speeds of the aircraft. Additional relatively small frequency variations in satellite signals are caused by instabilities in ground- and satellite-generated frequencies. Regardless of the causes of these frequency variations they do complicate the acquisition of the satellite RF baseband signal.

Numerous elaborate electronic circuits have been designed to automatically compensate for large frequency variations in satellite received signals. The designs that provide compensations for large doppler effects are the most complicated. Nearly all of these designs include circuits for comparing the received satellite signal with a highly accurate frequency standard tuned to the satellite's assigned frequency and circuits for using the results of this comparison to modify the tuning of the earth terminal receiver. In some designs a comparison of the received beacon frequency with the assigned beacon frequency has been used to generate an RF receiver tuning correction.

Because the IDCSP satellites are in near synchronous orbits, doppler effects are minimal and elaborate tuning of the RF receivers is not necessary. Since standard FM modulation is used for modulating the RF baseband, the phase-lock loop (or automatic phase-control) circuit can be used to ensure proper RF tracking of the received satellite signal. Variations in the received satellite signal do not exceed the operating range of the phase-lock feedback technique so no further tuning correction systems are required.

2.5.4 Tracking

When a particular satellite has been acquired, the earth terminal antenna must continue to track that satellite for as long as it is to be used as the communication relay. Two of several methods of tracking are programmed tracking and automatic tracking.

a. Programmed Tracking. In programmed tracking the known orbital parameters of the satellite are fed into appropriate computation equipment to generate antenna pointing angles. The antenna pointing angles are fed as commands to the antenna positioning servomechanisms which point the antenna in the required direction. The amount of data and computation involved in using programmed tracking to point narrow beamwidth antennas is quite extensive. In addition, some deviations from calculated pointing angles arise as a result of antenna mount flexure and atmospheric and ionospheric bending of radio waves. Since these uncertainties exist, programmed tracking is not wholly satisfactory and is not used extensively.

b. Automatic Tracking. In automatic tracking antenna pointing information is generated by comparing the direction of the antenna axis with the direction from which an actual satellite signal is received. Since automatic tracking systems track the apparent position of the satellite — that is, the direction of arrival of the radio signal — knowledge of the real position of the satellite is not required. The automatic tracking system is a servomechanism and, once acquisition has been accomplished, it continually generates its own pointing data, thus eliminating the requirement for data input and computation.

Systems for automatically tracking with steerable parabolic dishes fall into two classes: sequential lobing (conical scan is an example) and simultaneous lobing (monopulse is an example). Both of these systems are employed in satellite communications applications. Both depend on the generation of an error signal when the satellite is not in the desired part of the antenna pattern and on the use of this error signal to drive the antenna pointing servomechanism.

c. Satellite Outage Time. The system specification for the DSCS allocates 120 seconds for slewing the earth terminal antennas, acquiring the satellite signal, and checking for circuit continuity at handover. This represents the minimum outage time. However, for several reasons a satellite may not be immediately available, and these reasons may combine to increase the outage time. The difference of drift velocities of the Phase I IDSCS satellites will lead to bunching of satellites with gaps causing increased outage times. In addition, when two or more satellites simultaneously occupy the common volume of the link terminal antennas, they will mutually interfere and prevent reliable communication. Other factors leading to increased outage times are satellite-sun conjunction (increased noise from the sun prevents communication), satellite eclipse (absence of power from solar cells), and satellite failures. Hence, the distribution of outage times is a complicated function of time and earth-station locations.

2.6 GENERAL TECHNICAL SUMMARY

The technology used in designing the existing Phase I IDSCS communication satellite system was the state-of-the-art technology of 1962. A conservative approach to the system design resulted in a system that will operate, but only under carefully controlled conditions. The numerous limitations outlined in the preceding paragraphs were the results of limitations of available techniques involved in the design, construction, launch, deployment and operation of the IDCSP satellites.

The states of the art affecting these techniques have all progressed at a rapid rate and improvements are possible in all major components of satellite communications systems. Technology has advanced to the point that economic restraints are the principal considerations in the design of new communication satellite systems.

Satellites presently under construction for INTELSAT IV, Phase II DSCS, and TACSATCOM all incorporate much later design techniques which will overcome many of the shortcomings of the Phase I IDSCS operations and should provide an "order of magnitude" improvement in capability and capacity.

> NOTE: For a much more comprehensive discussion of general design considerations for satellite communications systems and a glossary of terms the reader is referred to reference 5.