NASA COMPENDIUM OF SATELLITE COMMUNICATIONS PROGRAMS

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Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland 20771

Contract Nos. NAS 5-24011 and
NAS 5-24012

DECEMBER 1975

CSC

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COMPUTER SCIENCES CORPORATION
SYSTEM SCIENCES DIVISION
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PREFACE TO 1975 EDITION

During the decade of the 1960s a new industry, satellite communications, was born as one of the products of the space program conducted by the United States of America. As of mid-1974, this new industry has evolved to the point where it serves a major portion of the world's population. The most dramatic illustration of this service is real-time television coverage of major international events, allowing millions to literally be "on-the-spot" to view such activities as the Olympic games and official state visits of world political and religious leaders.

Numerous programs have contributed toward the evolution of satellite communications over the past 15 years and much has been written about them. The primary objectives of this compendium are to summarize the major contributions of each program and to compile an extensive bibliography of the publicly available writings on them. The compendium, first issued in 1971, sponsored by Communications Programs, Office of Applications, was assembled by the Computer Sciences Corporation (Contract NAS 5-21522) under the direction of the Communications and Navigation Division, Goddard Space Flight Center, National Aeronautics and Space Administration. The compendium was reproduced in 1973 as NASA Report X-751-73-178, without updating. However, it incorporated some editorial changes in Section 10 suggested by the Communications Satellite Corporation (COMSAT), on behalf of Intelsat (International Telecommunications Satellite Consortium).

This edition of the NASA Compendium of Satellite Communications Programs contains updated Sections 9 through 18, plus two new sections: Section 19 - Communications Technology Satellite and Section 20 - U.S. Domestic Communications Satellite Systems. The information is current as of mid-1974.

The work was performed by the Computer Sciences Corporation under Contract NAS 5-24011, under the direction of the Communications and Navigation Division, Goddard Space Flight Center, Charles P. Smith, Jr., Technical Officer.

In preparing this edition for printing, English units of measurement have been converted to metric units, using the conversion factors listed in "The International System of Units," NASA SP-7012, dated 1973. The English units have been retained in parenthesis for the convenience of the reader. This work was performed by Computer Sciences Corporation under Contract NAS 5-24012.

Future additions and updates to this compendium are planned to be printed as inserts and/or replacements; hence the metal strap binding for ease of updating. Comments regarding the usefulness and improvement of this compendium, as well as corrections to any errors or omissions are earnestly requested. These should be addressed to Mr. J. M. Turkiewicz, Code 951, Goddard Space Flight Center, Greenbelt, Maryland, 20771.

Charles P. Smith, Jr., under whose technical direction this compendium was assembled in 1971, and reproduced as NASA Report X-751-73-178, died suddenly October 7, 1974. This edition of the compendium is in keeping with the purpose and format of the compendium as originated by C. P. Smith, and is a continuation of the work begun under his direction.

J. M. Turkiewicz
Technical Officer
December 1975

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SECTION 1 - INTRODUCTION

1.1 SCOPE AND ORGANIZATION

This document presents a comprehensive review of worldwide satellite communication programs that range in time from the inception of satellite communications to mid-1974. Particular emphasis is placed on program results, including experiments conducted, communications system operational performance, and technology employed. The background for understanding these results is established through brief summaries of the program organization, system configuration, and satellite and ground terminal characteristics. Major consideration is given to the communications system aspects of each program, but general spacecraft technology and other experiments conducted as part of the same program are, for the most part, at least mentioned summarily. Each program review attempts to be thorough and objective to the maximum extent possible from publicly available literature. In some cases, such literature was not adequate to allow complete reporting to the level of descriptive detail desired. This is particularly true for programs involving foreign, international, or military sponsorship. Program difficulties encountered are viewed as positive contributions towards advancing the state-of-the-art in satellite communications and are presented in that light.

The project reviews presented include all significant past programs in which satellites having some operational capability were successfully launched into orbit and all active programs, as of mid-1974, wherein development and procurement of the necessary space hardware had been approved. Some of the programs described span a considerable period of time and present an evolutionary development of several configurations of ground and space assets. In most such cases, separate discussions of the different segments of the program, each segment of which may encompass several spacecraft, are provided. The approach to program segmentation has, in all cases, been guided by the results-oriented objective of this document. The organizational grouping this provides may not in all cases coincide exactly with the chronological sequence of events or the official program organization based on administrative considerations and initially expected results.

The document is organized and formatted to provide the user with easy access to needed information. It features a chronological ordering of program descriptions, brief concise summaries of each program, including extensive use of tabular presentations, adherence to a consistent format from description to description, and extensive bibliographies of cited and related references from which the reader can do more detailed research on a particular aspect of a program. The consistent format provides consideration of the same items of information in the same order on each program and extends this philosophy from the defining and ordering of major subtopics to the defining and ordering of the tables employed. The bibliographies are incorporated directly following the particular program to which they are pertinent and are composed, in general, of references readily available within the public domain.

The basic format for each description encompasses the following major subtopics: (1) Program Description, (2) System Description, (3) Spacecraft, (4) Ground Terminals, (5) Experiments, and (6) Operational Results. In a few instances, the nature and extent of available information dictated that the "Program" and "System Description" subtopics be replaced by a "General Description" or "Introduction" subtopic. In such cases, information of the type normally included in the first two subtopics is distributed over the introductory, spacecraft, and ground terminal subtopics.

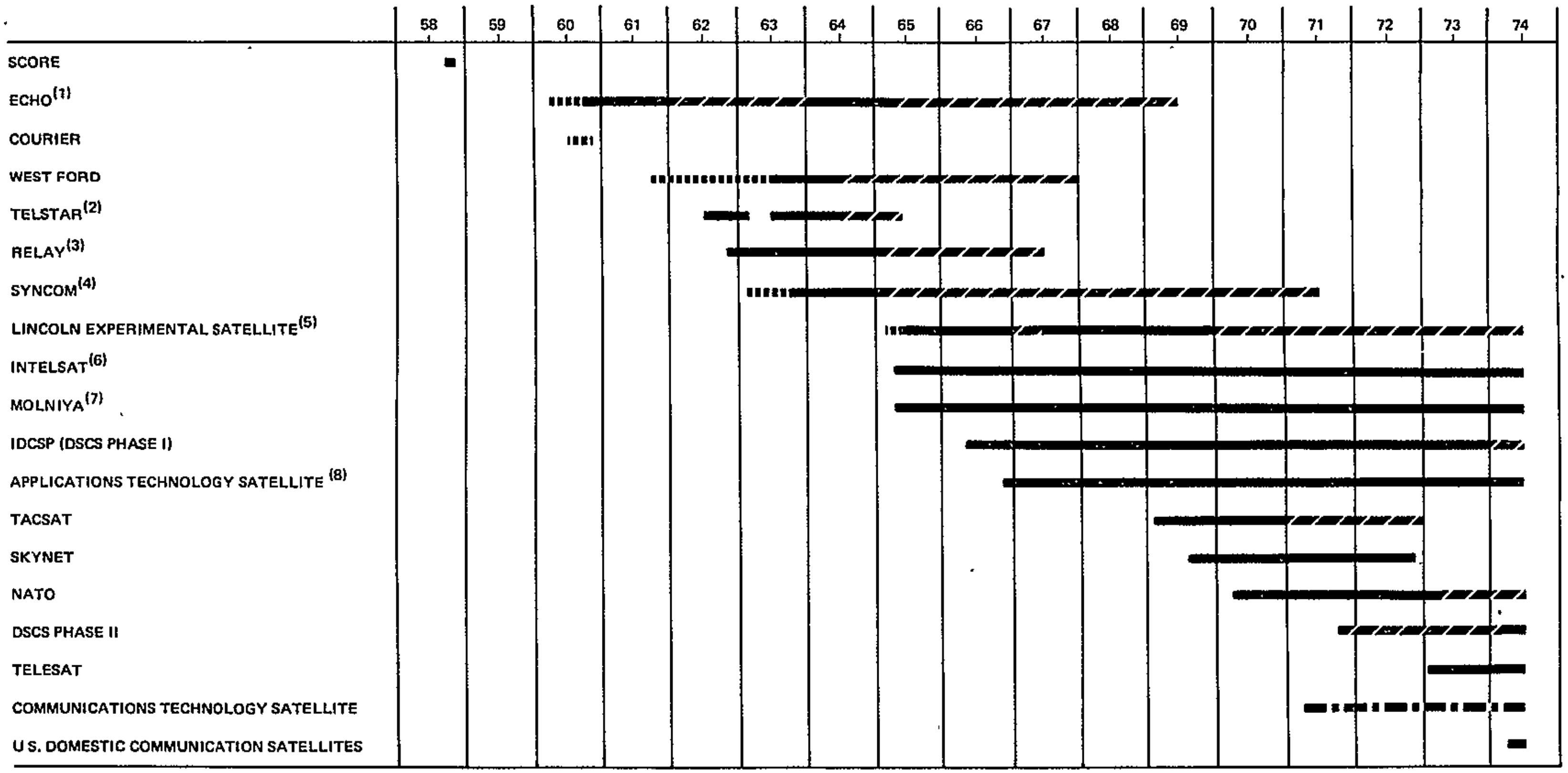
Information, typically, included within each major subtopic is as follows:

- Program Description - Project origin and objectives; spacecraft launch dates, orbital data, and status; extent to which program objectives were accomplished; participating ground terminals; sponsoring organizations; and significant results advancing the state-of-the-art in satellite communications.

- System Description - Ground terminal linking, extent of spacecraft visibilities, operating frequencies, signal processing including modulation and multiple access, system control, and calculated link performance.
- Spacecraft - Major characteristics of antennas and communications repeaters; general satellite features including stabilization, prime power, size and weight; and communications repeater block diagram. Major on-board experiments not directly communications-related are listed but not described in detail.
- Ground Terminals - Major characteristics of antennas, receive system, transmitter, tracking system and physical installation; block diagram of principal subsystems; and any unique aspects.
- Experiments - Definition of major types of experiments, summary of primary experimental results, and descriptions of significant demonstrations and public relations highlights.
- Operational Results - Summary of operational traffic handled, plus operational performance and reliability of the satellites and ground terminals.

1.2 OVERVIEW OF PROGRAMS

Major events, in each of the programs reviewed in this document, are summarized as a function of time in Figure 1-1. The programs illustrated encompass all significant satellite communication activities involving orbiting hardware since the launching of the Score satellite, with the possible exception of Project Oscar. Several active repeater satellites, nicknamed "Oscar," have been launched, starting as far back as late 1961 by the U.S. Air Force, to provide amateur radio communications satellites for use by "Ham radio" operators throughout the world. Some of these satellites were very short-lived and they, by intent, did not push the state-of-the-art in satellite communications.



NOTES: (1) TWO SPACECRAFT OF DIFFERENT STRUCTURAL DESIGN EVALUATED AT SEPARATE TIMES SAME TYPE EXPERIMENTS CONDUCTED IN BOTH CASES.
(2) TWO VERY SIMILAR SPACECRAFT EVALUATED AT SEPARATE TIMES USING SIMILAR TESTS. FIRST SATELLITE FAILED PRIOR TO SECOND LAUNCHING.
(3) TWO VERY SIMILAR SPACECRAFT EVALUATED AT SEPARATE TIMES USING SIMILAR TESTS.
(4) SPACECRAFT TURNED OVER TO DOD IN EARLY 1965 AND HANDLED OPERATIONAL TRAFFIC UNTIL ABOUT 1969.
(5) SPACECRAFT OPERATING AT SHF FREQUENCIES EVALUATED DURING FIRST PERIOD OF ACTIVITY AND UHF SATELLITES DURING SECOND
(6) FOUR GENERATIONS OF SPACECRAFT EVOLVED DURING THE OPERATIONAL PERIOD SHOWN
(7) HISTORY OF SATELLITE FAILURES AND RESULTANT PERIODS WHEN SYSTEM WAS INOPERATIVE ARE UNCERTAIN
(8) SPIN STABILIZED SPACECRAFT EVALUATED DURING FIRST PERIOD OF ACTIVITY AND EXPERIMENTS ON SPACECRAFT DESIGNED FOR GRAVITY GRADIENT STABILIZATION CONDUCTED DURING SECOND. ATS-6, 9 METER (30-FOOT) PARABOLIC ANTENNA, LAUNCHED IN MAY 1974

SATELLITE PROCUREMENT IN PROGRESS. FIRST LAUNCHING HAS NOT OCCURRED.
FIRST LAUNCH UNSUCCESSFUL.
OPERATING SPACECRAFT IN ORBIT. SPACE SEGMENT BEING ACTIVELY EMPLOYED TO MEET PRIMARY PROGRAM OBJECTIVES.
SPACECRAFT IN ORBIT HAVING SOME OPERATING CAPABILITY SPACE SEGMENT, IF USED, IS MEETING REDEFINED OR SECONDARY OBJECTIVES.

Figure 1-1. Historical Summary of Program Activities as of Mid-1974

The figure dramatically displays the very short duration of the Score and Courier programs conducted during the early history of satellite communications. These programs represented the initial attempts to employ active satellites for communications. During this early era, the Echo and West Ford programs also displayed the long life times attainable through employing passive satellites to establish a communications system. However, the Telstar, Relay, and Syncom programs soon proved that highly reliable active satellites were feasible and, in view of the higher system capacities provided, all subsequent programs have followed their lead. Some modest interest in passive satellite technology has been retained by the National Aeronautics and Space Administration (NASA) but no technology developments or future satellite launchings are presently planned.

The technology demonstrated in the Telstar, Relay and Syncom programs led, in a relatively short time, to the development of operational systems. Subsequent programs providing these systems have included Intelsat, Initial Defense Communications Satellite Program (IDCSP), Skynet, the North Atlantic Treaty Organization (NATO) program, the Defense Satellite Communications System (DSCS) Phase II, and Telesat programs. Additionally, a Canadian domestic satellite system is operational, and the U.S. domestic satellite systems, one leasing channels from the Canadian Satellite (Telesat or ANIK), are operational. Satellite experimentation has been continued by the Lincoln Experimental Satellite (LES), Applications Technology Satellite (ATS), and Tacsatcom programs.

A more detailed summary of the programs reviewed in this document is provided in Table 1-1. The table includes an indication of individual program sponsorship and mission. These have been powerful factors dictating the lines along which programs evolved. Accordingly, the programs can be grouped into U.S. military, purely scientific, international commercial, foreign military, and domestic commercial categories.

A considerable amount of scientific investigation has been done by U.S. military programs, but for the most part, it has been channeled towards the specific goals of

Table 1-1. Summary of Program Scope and Status as of Mid-1974 (1 of 4)

Program	Satellites Launched	Sponsor	Mission	Status
Score	One active store and forward	DOD/Army	Experimentation	Communications failed due to battery failure after 12 days in orbit. Orbit decayed after 35 days.
Echo	Three passive	NASA	Experimentation	Two satellites successfuly employed. Experiments completed by early 1965. Orbit of last satellite decayed in 1969.
Courier	Two active store and forward	DOD/Army	Experimentation	One satellite successfully supplied communications for 17 days. Command receiver failure caused satellite to become inactive.
West Ford	Two dispensers of dipole needles	DOD/Air Force	Experimentation	One dispenser successfully dispersed dipoles in passive reflecting belt. Major experiments completed in first year in orbit. Estimated that orbit of last dipoles decayed by early 1968.
Telstar	Two active	AT&T	Experimentation	Both satellites successfully employed. Last satellite turned off in 1967. Experimentation essentially completed by early 1965.
Relay	Two active	NASA	Experimentation	Both satellites successfully employed. Last satellite failed in 1967. Experimentation essentially completed by early 1965.
Syncom	Three active	NASA	Experimentation	Two satellites attained synchronous orbit and successfully supplied communications. Experimentation completed by early 1965. Extensively used for DOD operational traffic from 1965 through 1969. Both satellites still active with no stationkeeping capability. No longer employed.

Table 1-1. Summary of Program Scope and Status as of Mid-1974 (2 of 4)

Program	Satellites Launched	Sponsor	Mission	Status
LES	Three active operating at X-Band and three active operating at UHF all in 5 launches	DOD/Air Force	Experimentation	Two X-Band satellites successfully employed. Last satellite became unusable when its orbit decayed in 1968. X-Band experiments were completed by early 1967. All three UHF satellites successfully employed. Last satellite remains usable. UHF experiments were essentially complete by early 1970. Plans exist for two additional spacecraft to be launched in Spring 1975.
Intelsat	One Intelsat I, four Intelsat IIs, eight Intelsat IIIs, and five Intelsat IV. All active operating at C-Band	Intelsat	Commercial International Communications	One Intelsat I successfully employed. Satellite retired from service in early 1969, reactivated in mid-1969, and finally retired in late 1969. Three Intelsat IIs successfully employed. All three retain some operational capability and have been placed in reserve. Five Intelsat IIIs successfully employed. One has been placed in reserve. Five Intelsat IVs have been successfully placed into operation. Two are operational; one is in reserve over the Atlantic and one is operational over the Pacific, and one is operational over the Indian Ocean. Plans exist for additional Intelsat IVs, a series of modified Intelsat IVs having expanded capabilities, and a series of Intelsat Vs.
Molniya	Twenty-three Molniya-1, six Molniya-2	Soviet Government	Civilian and military communications internal to USSR	Orbits of 12 satellites have decayed. Exact status of remaining spacecraft uncertain but at least 12 are thought to be active. Plans for future satellites are unknown.

Table 1-1. Summary of Program Scope and Status as of Mid-1974 (3 of 4)

Program	Satellites Launched	Sponsor	Mission	Status
IDCSP (DSCS Phase I)	Thirty-four IDCSP, one GGTS 1, one DODGE, and one DATS 1 all in 5 launches	DOD/DCA	Experimentation and strategic military communications for U.S.	Twenty-six IDCSP satellites successfully employed. Eight remain usable. Experimentation for most part terminated six months after first launch of 7 and IDCSP satellites and system declared operational. Automatic satellite turn-offs to start in 1972 and be completed by mid-1974 failed to operate. GGTS 1 and DODGE were employed for a time to evaluate gravity gradient stabilization. DATS 1 provided data on electronically despun phased array antennas.
ATS	Two spin stabilized, and three gravity gradient stabilized. One large aperture antenna spacecraft	NASA	Technical and User Experimentation	Two spin stabilized satellites successfully employed. Both remain usable. Communications experiments essentially completed by early 1969. One satellite designed for gravity gradient stabilization successfully employed. It remains usable. Most experiments that appear likely to be conducted completed by early 1971. One satellite providing 9-meter (30-foot) parabolic antenna operational; plans for second uncertain.
Tacsat	One active	DOD/Air Force	Preoperational Experimentation	One satellite successfuly employed. Operational until December 1972. No definite plans exist for additional satellites.
Skynet	Two Skynet-1 One Skynet-2	British Government	Military Communications for U.K.	One satellite successfuly employed, active through November 1972. Plans exists for at least one additional Skynet-2 satellite.
NATO	Two active	NATO	Military Communications for NATO	Two satellites successfully employed to form NATO Phase II system; one remains active in stand-by status. Plans exist for a Phase III system.

Table 1-1. Summary of Program Scope and Status as of Mid-1974 (4 of 4)

Program	Satellites Launched	Sponsor	Mission	Status
DSCS Phase II	Four active	DOD/DCA	Strategic military communications for U.S.	Six satellites being procured. Launched two at a time. First two satellites never reached full capacity. Second two satellites operational. Plans exist for Phase III system.
Telesat	Two active	Canadian Government	Commercial Domestic communications for Canada	Two satellites operational. Third satellite has been procured; to be launched in 1975.
Communications Technology Satellite (CTS)	None	Canadian Government/ NASA/ESRO	Experimentation and Component Flight Testing	Satellite being procured, launch expected in December 1975. No plans for additional satellites at present.
Domestic Communication Satellites (Domsats)	One active	Numerous U.S. Companies and joint ventures	Commercial Domestic Communications for U.S.	One satellite active, numerous planned.

developing strategic and tactical military communication systems. The evolution of the strategic systems began with the Score and Courier, experimental store-and-forward satellites. It was continued almost 6 years later with the first IDCSP launching. In the interim period, the military attempted to develop three axis-stabilized satellites for launch into synchronous orbits (i.e., Project Advent), developed the system concepts, and designed the space segment for a medium altitude random polar orbit system, and extensively considered the possibility of employing Intelsat for service. Project Advent was terminated in 1962 when the launch vehicle and stabilization technology required proved to be beyond the state-of-the-art at that time. The medium altitude development was suspended when the potential economies of Intelsat service emerged. The latter was dropped for a number of reasons with the principal factor being the military requirement for a high degree of independent system control. The IDCSP concept provided some of the desired system economies by reducing the number of previously planned medium altitude satellites in random near synchronous orbits, using independently programmed and funded Titan IIIC developmental launches. Between the termination of Project Advent and the first IDCSP launching, the military gained operational satellite communications experience by supplying the ground complex and conducting the communication experiments on NASA's Project Syncom. Strategic military communications were advanced when the DSCS Phase II satellites became operational in early 1974. Further advances will be realized in the future when the planned DSCS Phase III satellites are introduced.

Developing tactical systems did not become a formally announced goal of the U.S. military until 1965 when the Tacsatcom program was established. The experimental UHF satellites of the LES program and the Tacsat satellite followed in direct response to that goal. However, some of the major system concepts, and in particular the modulation concepts evaluated in these experiments, began to evolve in the West Ford program and the SHF portion of the LES program. The latter two evaluations also contributed data of general scientific interest and information applicable to the development of strategic military systems but in a larger sense they represented the beginning of tactical military system experimentation.

NASA has been responsible for the purely scientific programs conducted to date. These programs have investigated technology applicable in all types of satellite communications systems. NASA became active in satellite communications at a very early date through the Echo passive satellite program. As the general interest in active satellites intensified in the early 1960s, the Relay and Syncom programs came into being to investigate these types of satellites in medium and synchronous altitude orbits, respectively. Towards the mid-1960s the questions on the type of satellite and orbit to employ had been resolved and approaches to realizing high gain satellite antennas, spacecraft stabilization, and multiple access became the vital issues. An Advanced Syncom program was initially conceived by NASA to study these problems. However, this soon evolved into the ATS program, which added a multitude of other space experiments to those designed to advance communications technology.

The programs oriented toward realizing a system capable of supporting international commercial communications include Telstar and Intelsat. Telstar was an experimental program that contributed to general scientific knowledge. However, it was initiated by the American Telephone and Telegraph (AT&T) Company primarily to demonstrate the feasibility of employing active satellites for commercial communications. Before the program was completed, AT&T was legislated out of international commercial satellite ownership by the Communications Satellite Act of 1962, creating the Communications Satellite Corporation (Comsat). This was followed in 1964 by international interim agreements establishing Intelsat and including Comsat as the U.S. representative in this consortium of international partners. The Intelsat program was initiated immediately based on technology developed in NASA's Project Syncom.

Foreign programs producing systems whose primary objective has been military communications include Molniya, Skynet, and NATO. The experimental beginnings upon which the Russian Molniya program was based are not publicly known. These spacecraft began to be placed in orbit in the mid-1960s and an operational system was soon established to provide military and some civilian communications. This system has been maintained since that time through replacement launches of similar, if not identical, spacecraft. The Molniya II satellite is being used in parallel with the U.S.'s Intelsat for the Hotline, a direct communication link between Washington and Moscow. The Skynet and NATO programs evolved in the late 1960s and early 1970s from technology developed in the U.S. military's IDCSP program. Skynet provided military communications for the United Kingdom (U.K.) and NATO did the same for the NATO countries. Neither system is presently operational, but followon systems are planned for both.

Systems designed strictly to provide internal domestic communications for a particular country are still in their infancy. The first such system, Canada's Telesat program, became operational in 1973. Three U.S. systems were operational by the fall of 1974; additional U.S. systems and a European system are planned.

Looking into the future, a number of potential new programs and continuations of old programs can be discerned. Plans exist for two additional highly classified LES experimental satellites, and it is expected that follow on U.S. military tactical satellite programs will evolve soon within each of the three services. The Communications Technology Satellite (CTS), sponsored jointly by Canada's Department of Communications (DOC) and NASA, is expected to be launched late in 1975. CTS, being developed jointly by Canada and NASA with some involvement by ESRO, will be integrated in Canada. The participants will conduct experiments on a time-shared basis. Intelsat has plans for Intelsat IVA and V, a series of spacecraft to advance their international commercial system. The technology upon which the Intelsat V satellites will be based may be developed by a prototype or experimental satellite flown before the operational satellites are launched in the late 1970s. Some competition for future Intelsat systems is likely to emerge in the form of a Soviet Stationar program. The U.S.S.R. has been granted allocations by the International Telecommunications Union (ITU) for a geostationary satellite system operating at C-Band. Additionally, experimental Franco-German Symphonie and Italian Sirio programs are underway that will provide much of the basis for the intra-European system being developed by the European Space Research Organizaton (ESRO). Finally, a completely new use for satellite communications technology has recently become apparent. This is in the area of air and marine traffic management.

1.3 EVOLUTION OF TECHNOLOGY

The low altitude Score satellite employed simple off-the-shelf VHF hardware to dramatize the potential of satellite communications by broadcasting a prerecorded Christmas message from President Eisenhower in 1958. From this beginning, the interest in satellite communications began to mount in the early 1960s.

Major initial areas of concern centered upon the type of satellite to select, type of orbit to employ, frequencies to utilize, and the development of ground terminal technology compatible with satellite communications. The basic satellite question was whether active or passive satellites should be employed. Either store and forward or real time active satellite repeaters were feasible. Passive reflector systems could be composed of a relatively small number of large single point reflecting structures or belts of multiple dispersed reflective elements. To resolve the orbit selection issue, low, medium and synchronous altitudes had to be considered, as did orbit inclination and degree of ellipticity. Frequencies appropriate for consideration were determined to be in the band from 1 to 10 GHz. Ground terminal technology of particular interest included low noise receive systems, demodulator thresholds allowing detection down to low values of signal-to-noise ratio, accurate satellite tracking so that high gain antennas could be employed, and high reliability operational performance.

Outside of these areas the programs of the early 1960s (including Echo, Courier, West Ford, Telstar, and Relay) employed similar technology that was well within the state-of-the-art at that time. Briefly, the active satellites provided almost omnidirectional antennas with essentially zero gain, low transmitter output power, no stabilization or spin stabilization relative to the sun, and solar cell arrays encircling the outside of the spacecraft to generate prime power. The ground terminals supplied large parabolic reflector or horn antennas, high power klystron or TWT transmitters, and fixed installations. Modulation was conventional analog frequency modulation and multiple access was by frequency division when employed. The active satellites were, in general, expected to support no more than two simultaneous accesses. Communication services handled included analog voice, TTY, low resolution facsimile, and television.

By late 1963, with the aid of data from these initial programs, the questions of type of satellite, frequency band, and ground terminal technology had been resolved. Relay and Telstar had proven that reliable active real time repeaters were feasible and they had become the preferred choice. These repeaters were of the double conversion type with either hard limiting or AGC to ensure a constant input to the output power amplifier operating near saturation. Active repeaters were preferred over the passive systems of Echo or West Ford due to the higher system communication capacities afforded. Real time repeaters were the choice over the store and forward system of Courier because they resulted in simpler more reliable repeaters, and launch vehicle technology had progressed to the point that reasonably sized satellites could be injected into orbits high enough to provide wide areas and relatively lengthy periods of mutual ground terminal visibility.

Satellite communication frequencies had been reserved at 4 and 6 GHz for commercial operations and at 7 and 8 GHz for government operations. The former were the frequencies demonstrated in the Telstar program while the latter were employed on West Ford.

Basic ground terminal technology had been developed on the Echo program including: cooled maser and uncooled parametric amplifier low noise receive systems; FM feedback demodulators for threshold extension; and accurate tracking using programmed inputs, manual steering from optical settings or radar autotracking. This technology was upgraded on Project Telstar to display reliabilities compatible with commercial operations and precision autotracking of beacon or communications signals radiated from active satellites. By late 1963, cooled parametric amplifier low noise receive systems had also begun to appear in Projects Telstar and Relay.

In 1963 and 1964, the orbit question was finally, for the most part, resolved by the results of the Syncom program, in favor of geostationary orbits. This completed the early experimental phase of satellite communications wherein the fundamental system concepts that have continued to apply were established.

Syncom demonstrated launch vehicle and satellite positioning and stabilization technologies to precisely inject spacecraft into synchronous equatorial orbits, to position in longitude and to maintain a satellite's longitudinal position (i.e., station-keep). It further gave a preliminary indication that the long propagation time delay (i.e., 260 ms round trip) and the associated echo problems that it introduces into 2-wire terrestrial telephone facilities were surmountable and, therefore, posed no drawbacks to this approach to satellite communications. With synchronous technology proven, the facts that only three or four satellites were required to provide a system giving world-wide earth coverage between $\pm 75°$ of latitude, that earth terminal tracking requirements were significantly relaxed though not entirely eliminated, and that the problem of hand-over from one moving satellite to another no longer existed, made geostationary orbits the preferred choice for point-to-point communication via satellite.

Syncom further refined the state-of-the-art by providing advancements in satellite stabilization techniques and antennas. Syncom was spin-stabilized, as were Telstar and Relay, but in this case the spin axis was aligned at a 90° angle to the orbital plane and precisely maintained in this orientation by H_2O_2 gas jets. This allowed antennas providing pancake-shaped beams only slightly wider than required to cover the earth from synchronous altitude (i.e., 17°) to be employed. These antennas provided gains of about 6 dB.

With the feasibility of satellite communications demonstrated and the basic system concepts defined, interest turned in the mid-1960s to implementing operational systems, further refinements of spacecraft and ground terminal technologies, and developing advanced modulation and multiple-access techniques, including those designed specifically for handling digital communications traffic. In 1965 and into late 1966, the Intelsat and Molniya programs provided the beginnings of what was later to develop into extensive operational systems. During this same period, the X-Band portion of the LES program began to investigate technology refinements and advanced techniques.

In early 1965, Intelsat I (Early Bird) was launched into a geostationary orbit with the spacecraft located over the Atlantic Ocean and after a short checkout period introduced the first continuous commercial communications services provided by satellite. Early Bird employed satellite technology developed in Project Syncom to provide communications between terminals that were, for the most part, upgraded and modified versions of installations developed during Projects Telstar and Relay. Early Bird provided a duplex high capacity trunk between the United States and Europe. Its main technological contribution was to demonstrate, finally and conclusively, through extensive subjective user evaluations, that time delay and echo are not serious problems in synchronous satellite communications.

Shortly after the Early Bird launch, the first of the Molniya satellites, developed by the U.S.S.R., began to appear in orbit. These spacecraft employed orbits uniquely suited to provide service to regions lying entirely in the Earth's northern hemisphere. The orbits selected are highly elliptical, with 12-hour periods and apogees occurring over the northern hemisphere. These satellites provided the Soviet Union with a long-haul, cross-continent, Moscow-to-Vladivostok communications trunk. Major spacecraft technological innovations included flywheel stabilization, fully sun-oriented solar panels, and antennas that tracked the earth independent of the main body of the satellite.

The X-Band LES Satellites of this period investigated despun satellite antennas, automatic on-board spacecraft attitude control, fully solid state transponders operating at X-Band, and ground terminal digital equipment providing random multiple access. Antenna despinning was of interest as a means of obtaining high gain earth coverage pencil beams on spin-stabilized spacecraft. The X-Band LES satellites provided an initial indication of the feasibility of despinning by switching between elements of a multi-element array encircling the spacecraft spin axis. However, since these satellites were not at synchronous altitudes, the full gain potential of the technique was not demonstrated. Autonomous on-board attitude control to reduce ground control requirements was initially demonstrated on a satellite stabilized relative to the sun.

Accurate on-board control of earth-oriented satellites remained to be proven. Solid-state X-Band transponders were shown to be feasible, but their low efficiencies and power outputs made them relatively unattractive as compared to the TWT output amplifiers being employed on operational systems. Frequency hopping of the center frequency of an MFSK channel was demonstrated to be a satisfactory approach to random multiple access among users handling digital traffic. Frequency hopping was first considered on Project West Ford and was of interest as a means to combat jamming in military systems, resist radio frequency interference, and allow common occupancy of the same frequency/time spectrum by users having low duty cycle random requirements for service. Error correcting sequential decoding of convolutionally encoded messages was also shown to be a powerful means for improving performance in digital systems operating at low signal-to-noise ratios.

By mid-1966, the initial interests of the mid-1960s in operational systems and advanced technology and techniques were supplemented by an interest in new applications. Up to this time, satellite communications had been looked upon, principally, as just another means of providing the kind of communication services commonly available in the military and commercial long-haul telecommunications networks (i.e., analog voice, TTY, low resolution facsimile, and television). It now began to be apparent that powers and bandwidths were available to support wideband digital traffic such as might be produced by high resolution facsimile and computer-to-computer applications. Additionally, the high satellite EIRP made available by advanced TWTs and earth coverage pencil beams made it possible to provide communications and position location for small aircraft, shipborne, remote data platform, and mobile land terminals. Between mid-1966 and late 1968, the Intelsat and Molniya operational systems continued to evolve, and the military IDCSP system was placed into operation. During this same period, a significant portion of the UHF LES testing was conducted, and the ATS program was initiated to investigate new technology, techniques, and applications.

In early 1967, the first successful launching of a second generation of Intelsat spacecraft was accomplished. By late 1967, three Intelsat IIs had been successfully launched, and commercial communications service was being provided over both the Atlantic and Pacific Oceans. The advent of reliable tunnel diode amplifiers to serve as relatively low-noise, high-gain satellite input preamplifiers allowed single RF conversion transponders to be provided on these satellites. Allowable satellite weight and prime power in combination with new high performance earth terminals permitted these transponders to be designed for linear input/output power transfer characteristics. These wideband satellites and an expanded ground complex resulted in extensive satellite multiple access in an operational system for the first time. Conventional FM-FDMA was employed, and system control techniques were developed to provide a high reliability operational system.

Concurrent with these Intelsat activities, continued launches of the Molniya I spacecraft maintained an operational Russian system. With the addition of new ground terminals, service in this system was considerably expanded in 1967 when the U.S.S.R. inaugurated a space television distribution system, allowing people in Siberia, the Far East, and the Far North to view broadcasts from Moscow.

In late 1966, the first group of 7 IDCSP satellites were successfully injected into near synchronous orbits, using a single launch vehicle, and by mid-1968 three more successful launches had established a system including more than 20 satellites. This military system began to meet emergency operational requirements in December, 1966, and by mid-1967 it was declared completely operational. In this system of multiple, near synchronous satellites, outage periods due to no spacecraft being visible and during satellite handovers were overcome by scheduling around these events. The type of system realized was the result of economic considerations dictating that a space segment, initially designed and developed before synchronous technology was proven feasible, be implemented. The system employed conventional modulation and multiple-access techniques, except for high data rate (1Mbps) MFSK modems for facsimile transmission and an operational pseudonoise antijam capability.

Extensive evaluations of approaches to realizing high gain, pencil beam, earth coverage antennas were conducted during this period. Techniques for realizing despun antennas on spin-stabilized spacecraft were exhaustively considered, and gravity gradient stabilization, such that rigidly mounted spacecraft antennas were continuously pointed towards the earth, was seriously investigated for the first time.

Electronically despun phased arrays were flown on a synchronous ATS satellite in late 1966, and on a near synchronous test spacecraft launched as part of the IDCSP program in mid-1967. These tests demonstrated that this type of antenna system was feasible, and gains of up to 14 dB were realized. Electronic switching as a means to realize a despun antenna was given further consideration in the synchronous UHF LES satellite launched in late 1968. The feasibility of this approach was again demonstrated, and a gain of about 10 dB realized. However, questions on the optimum approach to antenna despinning were laid to rest when an ATS spacecraft launched in late 1967 demonstrated the feasibility of mechanically despun antennas. By late 1968, it was apparent that the latter approach provided reliable performance and antenna gains of about 16 dB. Additionally, weight and prime power consumption were competitive with or superior to that realized by other approaches.

Gravity gradient stabilization was of interest because of the potentially high reliabilities available from such a passive system. Launches of medium and synchronous altitude ATS spacecraft, designed for this type of stabilization, were attempted in early 1967 and late 1968, respectively. Additionally, special near synchronous test satellites, included as part of the IDCSP program, were launched in mid-1966 and mid-1967. The ATS evaluations could not be conducted due to launch vehicle failures. The IDCSP tests demonstrated a limited degree of success in initially establishing and maintaining gravity gradient stabilization, but numerous unexplained difficulties were encountered. As a result, by late 1968, the jury was still out on gravity gradient stabilization, but the initial findings were not favorable.

The mid-1966 to late 1968 time period also saw considerable experimentation, at VHF and the lower UHF frequencies, with providing communications to small mobile or remote terminals or both. The existence of extensive conventional small terminal facilities was the primary driving force behind the initial interest in this frequency band. A preliminary evaluation of propagation characteristics had been carried out with the aid of a simple UHF beacon radiating satellite launched as part of the LES program in late 1965. Additionally, a few simple demonstrations had been conducted, using the telemetry and command system on a Syncom satellite.

More extensive experiments were made possible with the inclusion of a VHF transponder on the first spin-stabilized ATS spacecraft launched in late 1966. These experiments were extended further when a UHF LES satellite was launched in mid-1967, and the second spin-stabilized ATS spacecraft, also including a VHF transponder, was launched in late 1967. The emphasis in the LES experiments was on developing a tactical military capability, while the interest in ATS was in demonstrating position location and communications for application to commercial and private aircraft and ships and to remote data platforms. The experiments performed considerably advanced the state of knowledge of propagation and noise at these frequencies while proving that such systems were feasible. In the LES program, the first experimental tactical terminals designed for specific military applications began to emerge.

During this period, the spin-stabilized ATS satellites also demonstrated the feasibility of a signal-processing satellite repeater that provided multiple access through frequency-division multiplexing of independent single sideband uplink signals and down-converting the composite received signal for phase modulation of a single radiated carrier. This system was of interest because it supplied frequency spectrum conservation on the uplink and efficient utilization of available spacecraft power on the downlink. Additionally, a UHF LES satellite demonstrated that an autonomous control system could accurately maintain a spin-stabilized spacecraft's spin axis at a 90° orientation relative to the orbital plane.

Between late 1968 and early 1971, the areas of concern that existed in the years spanning the mid and late 1960s had to be further expanded to include consideration of higher frequencies for providing the same types of services. Interest began to develop in employing L-Band frequencies (i.e., a higher portion of the UHF band) for aircraft and maritime position location and communications in the private and commercial sectors. These frequencies are attractive because of the wider bandwidths and more accurate position location afforded. Further, millimeter wave frequencies started to be considered for commercial telecommunication services. The wider bandwidths available and visions of overuse of the allocated C-Band spectrum were the driving forces behind this interest. During this period, the operational Intelsat system continued to evolve, the Molniya and IDCSP systems continued to supply satisfactory operational service, the Skynet and NATO military systems initiated operational service, the exploration of tactical military communications was continued by the LES program and supplemented by a Tacsat satellite, and the ATS program conducted initial evaluations of L-Band and millimeter wave communications.

In late 1968, Intelsat began to establish a third generation satellite system. By early 1970, five successful launches had been completed, and a truly worldwide system providing service over the Atlantic, Pacific, and Indian Oceans had been completed. These satellites took advantage of the technology developed in the ATS program by employing mechanically despun antennas. The transponders were again linear, single conversion repeaters and FM-FDMA was the main mode of operation. However, experimentation was conducted on a PCM-PSK-TDMA system designed for 12- to 120-channel links and PCM-PSK-FDMA, SPADE, designed for links ranging from fractional requirements to 12 and 24 channels. Both systems were demonstrated to be feasible. The TDMA development extended and confirmed earlier TDMA demonstrations conducted as part of the ATS program.

Between late 1968 and early 1971, two new operational systems came into being. A Skynet satellite was placed into a geostationary orbit providing visibility from Europe and much of Africa, in late 1969, and an operational military system for the United Kingdom was established. The satellite was based on technology developed in the IDCSP program but pseudonoise PSK was used to provide multiple access in the first all-digital operational system. NATO satellites were launched into geostationary orbits in early 1970 and early 1971. They were positioned over the Atlantic to provide operational service for the North Atlantic Treaty Organization countries and employed conventional technology developed in the IDCSP and Skynet programs.

On the LES program, testing of the UHF satellite launched in late 1968 continued. In addition to displaying the switched antenna, this satellite demonstrated the feasibility of high-efficiency, solid-state UHF transmitters operating directly from the unregulated primary power source, autonomous satellite stationkeeping and stationchanging, and reliable pulsed plasma microthrusters. The demonstrated autonomous stationkeeping capability, together with the previously displayed autonomous attitude control system, provided the potential for significantly reducing future ground tracking and command requirements. The spacecraft microthrusters were of interest as a means towards attaining highly precise attitude control and stationkeeping systems. Microthrusters were first considered in the ATS program as a means of providing stationkeeping and stationchanging on gravity gradient stabilized satellites where the attitude correction torques were quite low.

In early 1969, a Tacsat spacecraft was placed into a geostationary orbit and used along with the latest LES satellite to further demonstrate and develop a tactical military satellite communications capability. Tacsat included both UHF and SHF transponders, an input/output switching capability, and an ability to vary transponder bandwidth that afforded multiple commandable modes of operation, including cross-band configurations. By early 1971, prototype operational tactical terminals, at both UHF and SHF, had been demonstrated for aircraft, ship or land mobile use. In addition, operational frequency-hopping MFSK modems had been displayed. This approach was selected over pseudonoise PSK due to shorter acquisition times in a random-access environment, relaxed synchronization requirements, and a greater resistance to the multipath likely to occur in many tactical situations (e.g., as for aircraft communication at elevation angles below 20°).

In late 1969, the final ATS spacecraft designed for gravity gradient stabilization was launched. The launch vehicle performed properly but control of the satellite was lost during an initial spin stabilized period before location on-station in a geostationary orbit. As a result, the spacecraft was left spinning about a longitudinal axis such that it could not be despun and the gravity gradient booms deployed. By early 1971, this final failure to demonstrate reliable gravity gradient stabilization at synchronous altitude, along with the successful development of despun antennas, had caused interest in this technique to wane. In spite of the improper stabilization, L-Band and millimeter wave experiments included on this satellite were performed, and valuable data was obtained that will contribute towards opening these frequencies for future use. The millimeter wave frequencies evaluated were at 15.3 and 31.65 GHz.

Finally, in early 1971, Intelsat successfully launched the first of a fourth generation Intelsat space system. This satellite features earth coverage and fixed narrow coverage antennas on a mechanically despun platform. Additionally, it provides 12 transponders of moderate bandwidth such that separate types of services can be provided in separate channels (e.g., television distribution in one channel, high capacity telephone trunks in another, and low duty cycle individual voice links in still another). Through the introduction of new technology in RF filters, TWTs, and antennas the Intelsat IVA will be able to provide 20 transponders by reusing frequency spectrum in different areas of the coverage zone. Thus, higher capacity will be accomplished without the extension of technology required to develop the Intelsat V satellite.

In 1973, Telesat became operational, providing Canada with a commercial domestic satellite communications system capable of providing communications to small, simple unattended terminals in far northern and arctic remote locations. In addition to serving Canada's long haul and remote location communications needs, Telesat is also providing the satellike link for the initial RCA Globcom U.S. domestic communications satellite system.

Both strategic and tactical military communications progressed with the introduction of operational DSCS Phase II satellites in March 1974. In addition to providing multiple high capacity links between strategic earth terminals with large antennas and high-powered transmitters, these satellites provide similar communication capabilities between mobile or transportable tactical earth terminals with small antennas and low-powered transmitters. Just as significantly, the DSCS Phase II satellites provide the high capacity entry of the smaller tactical terminals into the strategic networks. These highly flexible, high capacity, multiple access capabilities are made possible by cross-strapping two high gain-narrow coverage antennas and a single earth-coverage antenna on the DSCS Phase II satellite. The planned DSCS Phase III satellites can be expected to advance military communications even further.

The latest in the Applications Technology Satellite series, ATS-6, was launched May 30, 1974 and is potentially the most significant step in advancing the technology of satellite communications. A most impressive feature of the ATS-6 satellite is a 9.1-meter (30-foot) diameter parabolic antenna. The ATS-6 also exhibits highly accurate 3-axis stabilization using gas jets and error signals derived from a monopulse receive tracking system, and input/output switching among multiple transponders receiving and transmitting in different frequency bands. To test the feasibility of the Tracking and Data Relay Satellite (TDRS), the ATS-6 will investigate techniques of employing a synchronous communications satellite as a relay for tracking other satellites and transferring digital signals between them and a ground station. Other experiments will be concerned with techniques for aircraft position location, air-to-ground communications using a synchronous satellite, educational TV, and for supplying FM TV reception to small UHF ground terminals with the benefit of the 9.1-meter (30-foot) satellite antenna. Additionally, this spacecraft will investigate uplink RFI at 6 GHz, millimeter wave propagation at 20 and 30 GHz, and signal attenuation at 13 and 18 GHz caused by atmospheric hydrometers.

The CTS satellite will include a super-efficiency power transmitting tube, providing a 200-watt minimum output at 12 GHz, extendable solar power arrays of approximately 1.5-kilowatt initial capability, and three-axis stabilization using flexible appendages. High power RF transmitters at frequencies about 10 GHz and prime power sources of kilowatt size or greater represent technology that will be needed for educational and community TV satellite broadcast systems, interplanetary space probes, and large earth-orbiting platforms. In addition to the advanced technology experiments, CTS will provide the vehicle for investigating numerous user applications. These may include educational TV, biomedical networks, law enforcement networks, and service for the handicapped applications.

The U.S. Domsat program provides the potential for supplying point-to-point trunk and multipoint message telephone; telegraphic and wideband data; and network, educational, and community antenna television services that complement and improve the services presently provided by terrestrial facilities. Eight applicants filed for permits from the Federal Communications Commission (FCC) to construct U.S. domestic satellite systems by the March 15, 1971, filing deadline. The Commission's invitation to file covered systems "for multiple or specialized common carrier services, for lease to other common carriers, for private use, joint cooperative use, or any combination of such services." As of the fall of 1974, five participants were still in evidence on the Domsat scene. Three of these were actively participating in domestic satellite communications, one via its own satellite (Western Union via Westar), the other two via leased circuits on Westar or Telesat (Anik).

Major contributions of the satellite communication programs completed or in progress as of mid-1974 are summarized in Table 1-2.

A whole new industry was brought into being in the 1960s built on technology demonstrated by experimental satellites such as Relay, Telstar, and Syncom. Similarly, rapid growth of existing capabilities and initiation of new space communications applications, such as high rate information transfer, data collection, educational broadcast, and traffic management, are occurring during the 70s, based on the results of experiments described in this document.

Table 1-2. Summary of Major Contributions (1 of 3)

Program	Primary Results
Score	(1) Demonstrated feasibility of employing active orbiting satellites to relay messages over intercontinental distances.
Echo	(1) Displayed feasibility of erecting and maintaining large lightweight structures adequate to serve as passive reflectors in space. (2) Verified that conventional microwave theories for determining path loss could be applied to satellite links. (3) Fostered development of ground terminal technology including low noise receiver preamplifiers, FMFB receivers, accurate tracking techniques and terminal operating procedures.
Courier	(1) Displayed feasibility of high capacity high rate digital store and forward satellite system. (2) Demonstrated difficulty of attaining lifetime and reliability need for operational systems.
West Ford	(1) Showed that X-Band dipoles can be dispersed into a passive reflecting belt. (2) Displayed that belt is predictably affected by solar radiation pressure and does not interfere with radio astronomy. (3) Demonstrated that communications are feasible and multipath time delay and frequency smear are predictable.
Telstar	(1) Demonstrated performance and reliability, adequate for commercial operations can be attained with active satellites. (2) Verified that multipath fading was not significant for operation at 4-6 GHz and elevation angles above few degrees. (3) Displayed accurate and reliable acquisition and autotracking of active satellites.
Relay	(1) N-on-P solar cells shown to be more resistant to radiation than P-on-N cells. (2) Displayed that dew point criteria and leakage tests should be included in power transistor specifications. (3) Indicated that relatively complex command signals are necessary to avoid spurious responses.

Table 1-2. Summary of Major Contributions (2 of 3)

Program	Primary Results
Syncom	(1) Demonstrated feasibility of placing and accurately positioning satellites in synchronous orbit. (2) Provided first, in orbit, demonstration that time delay and echo are not serious problems in synchronous satellite communications.
LES	(1) Displayed feasibility of all solid state X-Band satellite transponders even though power out and efficiency were relatively low. (2) Demonstrated feasibility of X-Band and UHF electronically switched despun antennas. (3) Advanced state of knowledge of UHF propagation and noise including RFI. (4) Displayed workable experimental tactical ground terminals. (5) Demonstrated feasibility of high efficiency UHF satellite transmitters operating from unregulated solar array power supply. (6) Accurate autonomous spin axis attitude control was exhibited. (7) Performance potential of sequential decoding as applied to satellite links was displayed. (8) Frequency hopping was shown to provide satisfactory random access and resistance to multipath and RFI. (9) Demonstrated feasibility of autonomous stationkeeping and station changing.
Intelsat	(1) Demonstrated that time delay and echo are not serious problems in commercial communications through synchronous satellites. (2) Displayed single conversion linear satellite repeaters. (3) Employed first satellite antennas having beamwidths considerably narrower than required for earth coverage. (4) Developed techniques for control and operation of a high reliability operational system. (5) Developed and demonstrated PCM-PSK-TDMA trunking systems. (6) Developed PCM-PSK-FDMA single voice channel system (i. e., SPADE).
Molnyia	(1) Demonstrated feasibility of operational system in northern hemisphere using 12 hour highly elliptical orbits. (2) Displayed electric motor driven, flywheel stabilized spacecraft with earth tracking antennas and capability of orienting solar panels towards sun.

Table 1-2. Summary of Major Contributions (3 of 3)

Program	Primary Results
IDCSP (DSCS Phase I)	(1) Demonstrated operational system composed of large number of simple random orbit satellites can be established and maintained. (2) Displayed feasibility of wide band high data rate (1 Mbps) satellite transmissions of high resolution imagery. (3) Demonstrated a limited degree of success in initially establishing and maintaining gravity gradient stabilization but encountered numerous unexplained difficulties. (4) Displayed operational jam resistant pseudonoise modems.
ATS	(1) Demonstrated feasibility and potential of electronic despinning using phased arrays. (2) Displayed feasibility and attractiveness of mechanically despun antennas. (3) Showed that single-sideband frequency division multiplexing on uplink and phase modulation by the composite received signal on downlink is practical means of multiple access. (4) Demonstrated feasibility of VHF satellite communications among small mobile terminals. (5) Provided data on millimeter wave propagation. (6) Gave initial indication of potential L-Band holds for aircraft and maritime communications. (7) Displayed the difficulties that can be encountered in attempting to deploy and initially stabilize gravity gradient stabilized satellites. (8) Parabolic antenna 9.1 m (30 ft) in diameter unfurled in space.
Tacsat	(1) Demonstrated operational UHF and SHF mobile earth terminals. (2) Displayed feasibility of channelized satellite repeater capable of switched input/output connections. (3) Provided gyrostat satellite stabilization. (4) Demonstrated operational frequency hopping modem.
Skynet	(1) Provided first operational all digital satellite system using spread spectrum multiple access.
NATO	(1) Employed conventional FM-FDMA technology to minimize system risk.
DSCS Phase II	(1) Demonstrated combined use of earth coverage and narrow coverage antennas on one spacecraft, and cross-coupling between the antenna channels.
Telesat	(1) Provided telecommunications and TV service to remote areas with unattended earth terminals. (2) Provided the first domestic satellite communiations link for U. S.

SECTION 2 - SCORE

2.1 PROGRAM DESCRIPTION

The objective of Project SCORE (Signal Communication by Orbiting Relay Equipment) was to place in orbit a 24-meter (80-foot) Atlas missile and to use this as a platform for a communication system capable of spanning intercontinental distances. The ultimate goal was to demonstrate the feasibility of such a system and to explore some of the technical and operational problems that would attend a military satellite communication system. The communications portion of the project was assigned to the U. S. Army Signal Research and Development Laboratory, Fort Monmouth, New Jersey, late in July 1958. SCORE was successfully launched by the Air Force on December 18, 1958, thus becoming the first communications satellite. The orbital parameters are given in Table 2-1.

Table 2-1. Participating Spacecraft

	Satellite	SCORE
	Manufacturer/Sponsor	U.S. Army, ARPA
	Launch Date	December 18, 1958
	Launch Vehicle	Atlas 10-B
Orbital Data	Apogee	1494 km (928 mi.)
	Perigee	185 km (115 mi.)
	Inclin.	30 deg.
	Period	101 min.
	Status	Expected Life of Orbit: 20 days; Actual life of orbit: 35 days; Communications failed December 30, 1958, due to battery failure

This first satellite communications system functioned for approximately 12 days, achieving its desired goals - to demonstrate the feasibility of an orbital relay that could span intercontinental distances. Among the achievements attained during the experiment were:

1. The first successful relay of teletype signals through an orbiting station.
2. The first successful delayed repeater communication from earth to satellite to another point on earth at a later time.
3. The first successful multichannel teletype transmission by a delayed repeater.

2.2 SYSTEM DESCRIPTION

Two complete communications packages were installed in what are normally the guidance pods on the sides of the Atlas missile. Ground equipment installed in army vans with associated support vehicles was located at Fort MacArthur, California; Fort Huachuca, Arizona; Fort Sam Houston, Texas; and Fort Stewart, Georgia. All ground stations were linked by both telephone and HF radio to the system control center at the Signal Corps Laboratory in Fort Monmouth, New Jersey.

The design of the system was based on providing two modes of operation – as a delayed repeater and as a real time active repeater. In the delayed repeater mode, the satellite would record information transmitted to it upon reception of a suitable command signal from a ground station. Upon reception of a different command signal, the satellite would transmit the previously stored information back to the originating ground station. The second mode of operation, that of a real time repeater, was obtained by the use of yet another command signal which activated the satellite as a radio relay repeater station with the recording mechanism bypassed. The capacity of the system was one voice channel or seven 60-wpm teletype channels, frequency division multiplexed.

The satellite receiver was an FM "paging" receiver - the type often used by doctors and salesmen to receive telephone calls when away from their offices. A commercial transistor model was modified extensively through the addition of an RF stage using selected transistors to increase its sensitivity. A vacuum tube transmitter from an FM handie-talkie was repackaged and modified through the addition of a high power (8 watts) output stage. A continuous loop magnetic tape recorder developed at the Signal Corps Laboratory was used as the message storing device. 23 meters (75 feet) of magnetic tape was used to provide 4 minutes of audio recording. The control unit responded to command signals from the ground and activated the receiver, the transmitter, or the magnetic tape recorder. Three modes of operation were commanded - record, playback, and real time. Since the satellite was expected to orbit for only 20 days, a non-rechargeable high capacity zinc-silver oxide battery was employed rather than heavier and more costly solar and nickle cadmium cells.

The Atlas missile itself was used as the antenna and was excited by slots located in the two pod covers. The resulting radiation pattern was similar to a long wire doublet with associated nulls.

Spacecraft characteristics for the SCORE satellite are displayed in Table 2-4. A system diagram of the satellite is shown in Figure 2-1.

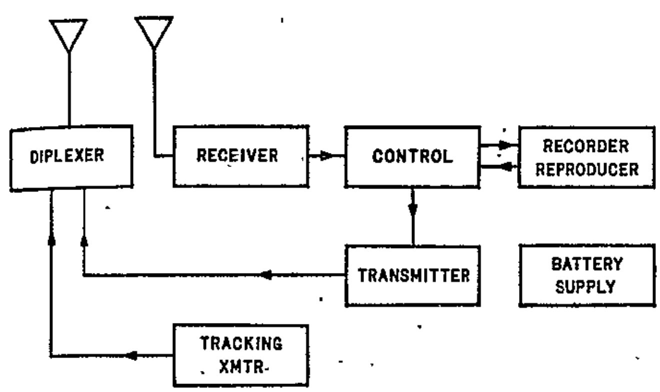


Figure 2-1. SCORE: Communications Interconnect Diagram

VHF frequencies were used to minimize the effects of cosmic noise and ionospheric propagation while still permitting the use of sensitive, transistorized receiving equipment in the satellite. The operating frequencies employed in Project SCORE are given in Table 2-2. The IF bandwidth chosen was as narrow as possible consistent with frequency stability, Doppler shift, maximum audio frequency, and carrier frequency deviation.

Table 2-2. Frequencies Employed in Project SCORE

Uplink	Downlink	Beacon
150 mHz	132 mHz	108 mHz

Narrowband FM was selected as the modulation technique with a deviation ratio limited to 1.0 at 5 kHz. Additional data on the modulation technique is shown in Table 2-3.

Table 2-3. Signal Processing Employed in Project SCORE

Single Access	One Voice Channel or Seven 60-wpm teletype
RF Modulation	Narrowband FM, Deviation = ±5 kHz
Demod. Performance (FM Threshold)	10 dB
Link Margin (Up/Down)	39/19 dB*

*At a slant range of 1609 kilometers (1000 miles).

2.3 SPACECRAFT

The 64.4-kg (142-lb) payload consisted of two complete repeater terminals installed in what are normally the guidance pods on the sides of the Atlas missile. Each package contained a receiver, transmitter, magnetic tape recorder, control unit, beacon transmitter, dc to dc converter, and battery. Communications characteristics of the satellite are summarized in Table 2-4.

Table 2-4. Satellite Characteristics

Antennas		Type	Slot Antenna
		Number	Two receiving, two transmitting
		Xmit. Beamwidth	No Data
		Gain	-1 dB
Repeaters		Frequency Band	VHF
		Type	Store-and-forward/real-time repeater
		Bandwidth	40 kHz
		Number	Two
	RCVR	Type Front End	Transistor
		Front End Gain	No Data
		System Noise Fig.	10 dB
	XMTR	Type	Vacuum Tube
		Gain	No Data
		Power Out	8 Watts
General Features		EIRP	8 dBW*
	Stabilization	Type	None
		Capability	None
	Power Source	Primary	Zinc-silver oxide battery
		Supplement	None
		Comm. Power Needs	53 Watts
		Size	Mounted on Atlas Missile of dimensions of 26 m (85 ft) long by 3.0 m (10 ft) diameter
		Weight	64.4 kg (142 lb)

*Derived value based on available data.

2.4 GROUND TERMINALS

Each of the communication ground terminals noted in Paragraph 2.2 included two transmitters and receivers for communication, each capable of operating on two frequencies; two beacon receivers for tracking and temperature recording; and two control units. The equipment configuration is shown schematically in Figure 2-2; it was housed in an 11-meter (35-foot) semitrailer.

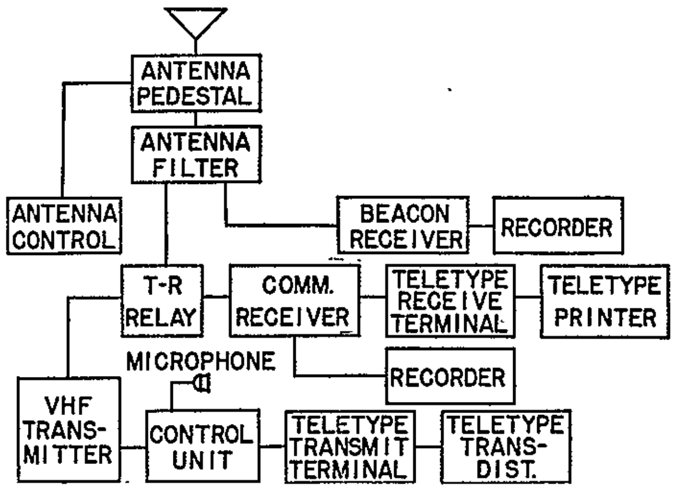


Figure 2-2. SCORE Ground Station Interconnection Diagram

The VHF communications receivers and transmitters in the ground station were commercial FM equipment adapted for use in the SCORE Project. For monitoring the satellite's tracking beacons, receiving equipment was provided which enabled reception of the tracking frequency near 108 MHz. In all but the California station, the ground antenna was positioned by an operator maximizing the 108-MHz signal reception with the antenna positioning controls. At the California station, the azimuth control was slaved to the alidade of an experimental direction-finding equipment while the elevation control was manually varied. The communication characteristics of the ground stations are tabulated in Table 2-5.

2.5 EXPERIMENTS

On the first orbit, attempts were made by the California ground station to interrogate the communication package designated No. 1. An excellent carrier was

Table 2-5. Earth Terminal Characteristics

	Terminal Feature	
Antenna	Type	Quad-helices Array
	Aperture	4 m-square (13-ft-square)
	Gain (108/132/150 MHz)	9/14/16 dB
	Efficiency	No Data
	Rec. Beamwidth	Approximately 30^{o} @ 3 dB Pts*
Receive System	Type Preamplifier	No Data
	Bandwidth	40 kHz
	Noise Temp	6 dB
Transmit System	Type Amplifier	No Data
	Bandwidth	No Data
	Power Output	250 or 1000 Watts
Tracking	Type	Manual**
	Accuracy	No Data
Total Perfom.	G/T	-17 dB/^{o}K*
	EIRP	75 dBm*
Polar-ization	Transmit Feed	Circular
	Receive Feed	Circular
Instal-lation	Random	None
	Type Facility	Transportable

Notes: *Derived value based on available data.

**Except for azimuth control from experimental direction-finding equipment at California station.

received from the communication transmitter, but no modulation. Since no other orbit that day was close enough to the ground station, no further attempts were made to interrogate the communication equipment. On the following day, package No. 2 was interrogated by a temporary site established at Cape Canaveral (now Cape Kennedy) for prelaunch checkout. It responded and the ground crew received the following prerecorded message from President Eisenhower:

> This is the President of the United States speaking. Through the marvel of scientific advance, my voice is coming to you from a satellite circling in outer space. My message is a simple one. Through this unique means, I convey to you and to all mankind America's wish for peace on earth and good will towards men everywhere.

On each of the subsequent days, each function for which the equipment was designed was tested and successfully demonstrated. Among the experiments performed were the following:

1. Initially, transmission of President Eisenhower's prerecorded voice message followed by one channel of teletype code.

2. Direct relay of California's communication site identification in voice, followed by the President's message in teletype code. The Texas site received these signals with two short fades and the Arizona and Georgia sites received portions of the transmission.

3. While clearing the tape recorder, California transmitted in voice to the satellite for storage. Texas interrogated the satellite, and both Texas and Georgia received the voice loud and clear. Then Georgia reinterrogated the satellite and received the message again.

The above tests were performed in other variations using voice and one channel of teletype until the fortieth pass, when the Georgia site sent seven simultaneous multiplexed teletype messages in a single transmission to the satellite for storage. The satellite was then interrogated and good teletypewriter copy was received.

In summary, the communications package was interrogated 78 times, loaded with new material 28 times, and operated as a real time relay for a total of 117 deliberate operations. Until battery-exhaustion on December 30, 1958, the satellite demonstrated conclusively the practical operation of a satellite radio relay system capable of spanning intercontinental distances.

2.6 OPERATIONAL RESULTS

Since Project SCORE was an experimental program, no operational traffic was passed. Further, the operational reliabilities of the satellite and ground terminals were generally good and in agreement with prelaunch expectations. This performance reflected the exclusive usage of state-of-the-art hardware that characterized this system's implementation.

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SECTION 3 - ECHO

3.1 PROGRAM DESCRIPTION

R&D efforts that led to the Echo satellites descended from an IGY program that the National Aeronautics and Space Administration, NASA, had inherited from its predecessor organization, the National Advisory Committee for Aeronautics. The IGY balloon satellite had been conceived and designed primarily for air density experiments. NASA took charge of this activity and reformulated it as Project Echo in late 1958. Major objectives for the Echo program were as indicated in Table 3-1.[1][2]

Table 3-1. Echo Program Objectives

Number	Description
1	To evaluate the communications capability available from large spherical passive satellite reflectors.
2	To study the feasibility of erecting and maintaining large lightweight structures in the space environment.
3	To gather data on solar pressure and the outer limits of the earth's atmosphere as well as evaluating their effects on satellite orbits.

Of three attempts to orbit passive reflecting balloons during this program, two of these efforts were successful. The launches and satellite status are reviewed in Table 3-2.[1][3][4]

Prior to the initial Echo launch, extensive ground, vacuum chamber, and space ballistic tests were conducted.[1][2][5] The ground tests employed prototype spheres to confirm sphericity and structural integrity of basic balloon design. The vacuum chamber tests evaluated balloon release from its containing canister, unfolding, and inflation during free fall at NASA's Langley Research Center. The balloon deployment system was refined and space-qualified during four launches into a ballistic trajectory by modified Sargent rockets from NASA's Wallops Island, Virginia, launch site. These launches were code-named Shotput I through IV. The first launch on 28 October 1959 resulted in the sphere rupturing into a thousand pieces. After two more tests on 16 January 1960 and 27 February 1960 and changing the folding pattern, inflation system, and prelaunch payload conditioning cycle, a successful vertical test was conducted on 4 January 1960.

Table 3-2. Participating Satellites

Satellite		Echo A-10	Echo I	Echo II
Manufacturer & Sponsor		G. T. Schieldahl[1] & NASA		
Launch Date		5/13/60	8/12/60	1/25/64
Launch Vehicle			Delta[2]	Thor-Agena B
Orbital Data[3]	Apogee Perigee Inclination Period	No Orbit Attained	1691 km (1051 mi.) 1514 km (941 mi.) 47.2 deg. 118.2 min.	1313 km (816 mi.) 1033 km (642 mi.) 81.5 deg. 108.8 min.
Status		Satellite lost due to second stage attitude control malfunction	Orbit decayed 5/24/68 resulting in satellite destruction	Orbit decayed 6/7/69 resulting in satellite destruction

Notes: (1) Balloon manufacturer. Beacons on Echo I and II supplied by Radio Corporation of America.

(2) Thor-Delta with the Delta being the improved second and third stages of Vanguard.

(3) At initial injection. Solar pressure and atmospheric drag substantially altered parameters

Subsequent to the failure of the initial launch, a fifth Shotput test was conducted on 31 May 1960 to qualify the sphere with radio tracking beacons attached. These beacons were left off the payload during the initial orbital launch attempt, since they had not been previously qualified by a vertical test. Following these activities, Echo I was successfully launched from Cape Kennedy, Florida, into a near circular low altitude inclined orbit. It was an immediate resounding success, being large and reflective enough to be seen against the nighttime sky with the naked eye. During its lifetime, valuable information was contributed towards meeting all the program objectives listed in Table 3-1. In particular, the feasibility of passive satellite communications was demonstrated.

The one drawback of the Echo I balloon was that it was not rigid enough to remain smooth and spherical under the deforming forces of atmospheric drag and solar pressure after its pressurizing gas leaked out.[1][2][6] Its shape deteriorated significantly within a few weeks after launch. In recognition of this, efforts were inititated in late 1960 to develop a second generation Echo balloon that was rigid enough to withstand the deforming forces.

Once again, static ground tests, vacuum chamber drop tests, and vertical space tests were conducted. The first two groups of tests were again conducted in the dirigible hanger at Weeksville, North Carolina, and at Langley Research Center, respectively. The two vertical launch tests occurred 15 January 1962 and 18 July 1962, employing a Thor rocket from Cape Kennedy. TV and movie cameras mounted in the Thor followed and photographed the payload from ejection through reentry. In the first test, the balloon blew up due to excessive inflation pressure. During the second test, a different balloon inflatant resulted in successful balloon deployment, but pressurization was not great enough to provide a good reflecting surface.

As a result of the suborbital tests, it was concluded that a thorough evaluation of inflation characteristics was necessary by means of full-scale balloon statics ground tests. These were conducted in the dirigible hanger at the Naval Air Station, Lakehurst, New Jersey. Following further refinement of the pressurization system during these tests, Echo II was successfully launched from the Western Test Range (i.e., Vandenberg Air Force Base, California) into a near polar low altitude orbit.

Immediately after the first pass, it was determined that internal pressurization reached no more than 6.895×10^6 newton/meter^2 (1000 psi) as compared to the $34.47 \times 10^6 - 41.37 \times 10^6$ newton/meter^2 (5000-6000 psi) expected, and the balloon was rotating about an inertial axis with a spin period of about 100 seconds.[7] These occurrences produced forces within the satellite shell that caused the surface to wrinkle somewhat. As a result, unexpectedly high scintillations of the reflected RF signals were encountered. In spite of this, the balloon remained an effective passive communications reflector and demonstrated that a lightweight spherical balloon could maintain its shape and surface characteristics, even after the loss of inflatant pressure. Valuable information was contributed towards meeting all the program objectives listed in Table 3-1.

Numerous terminals from various countries conducted communications operations with the Echo satellites in response to an open invitation by NASA for worldwide utilization. Some of the major participating terminals are listed in Table 3-3. (See references 1, 5, and 8 through 12.) Additionally, innumerable terminals distributed over the entire world, at one time or another, conducted radar or optical tracking operations with these satellites. NASA's minitrack network supplied the data from which Goddard Space Flight Center derived orbital tracking information for all interested parties. Satellite launchings were provided by NASA.

The Echo program, which through Echo I provided the first extended satellite communications experiment, made a host of significant contributions to satellite communications technology. First, in reaching its major objective, it demonstrated the feasibility of using passive satellite reflectors for communication purposes and verified the theoretical limitations of such a system. Additionally, it verified the conventional theories for determining path loss on satellite links. Further, it fostered the development of much of the ground terminal technology that continues to be employed. Specific ground terminal items first demonstrated in the Echo project included a large-scale horn reflector antenna at Holmdel, low-noise receiver preamplifiers using solid state masers, frequency modulation feedback receivers, and satellite tracking of sufficient accuracy to allow real-time operational communications. Satellite tracking by radar, telescope, and computer predictions all proved to be quite reliable. Radar tracking operations included successful autotracking.

3.2 SYSTEM DESCRIPTION

The system configuration for the major participants involved in the evaluation of communications via Echo I is depicted in Figure 3-1.[5] Separate transmitting and receiving antennas, each operating at different frequencies, were employed at both Goldstone and Holmdel to provide full duplex operations. A single antenna capable

Table 3-3. Participating Terminals

LOCATION	SPONSOR	ANTENNA DIAMETER (m) (ft)	SATELLITE EMPLOYED
Goldstone, California	Jet Propulsion Laboratory	2.6 (8.5) (2 dishes)	Echo I
Holmdel, New Jersey	Bell Telephone Laboratories	18 (60) & 6.1 (20)	Echo I
Stump Neck, Maryland	Naval Research Laboratories	18 (60)	Echo I & II
Paris, France	Centre Nationale d'Etudes des Telecommunications	9.1 (30)	Echo I
Jodrell Bank, England	University of Manchester	76.2 (250)	Echo I & II
Schenectady, New York	General Electric Laboratories	8.5 (28)	Echo I
Cedar Rapids, Iowa	Collins Radio Corporation	8.5 (28)	Echo I
Dallas, Texas	Collins Radio Corporation	18 (60) & 8.5 (28)	Echo I & II
Columbus, Ohio	Ohio State University	9.1 (30) (4 dishes)	Echo II
Gorky, Russia	Zimenki Observatory	15 (49)	Echo II
Trinidad	United States Air Force	26 (84)	Echo II
Rome, New York	United States Air Force	10 (33)	Echo II

*Operated as phased array

of alternate transmit or receive operation at the same frequency was utilized at Stump Neck. The Goldstone terminal employed a third frequency and its separate transmit and receive antennas to provide a radar tracking capability.(13) Ordinarily, both Holmdel and Stump Neck received from Goldstone during the first part of a satellite pass. After the balloon set for Goldstone, Stump Neck then transmitted to Holmdel. On a few passes, both Goldstone and Stump Neck simultaneously transmitted to Holmdel, using circular polarizations of opposite sense and slightly different transmit frequencies. Echo I provided periods of mutual visibility up to about 15 minutes for Holmdel and Goldstone and 25 minutes for Holmdel and Stump Neck.

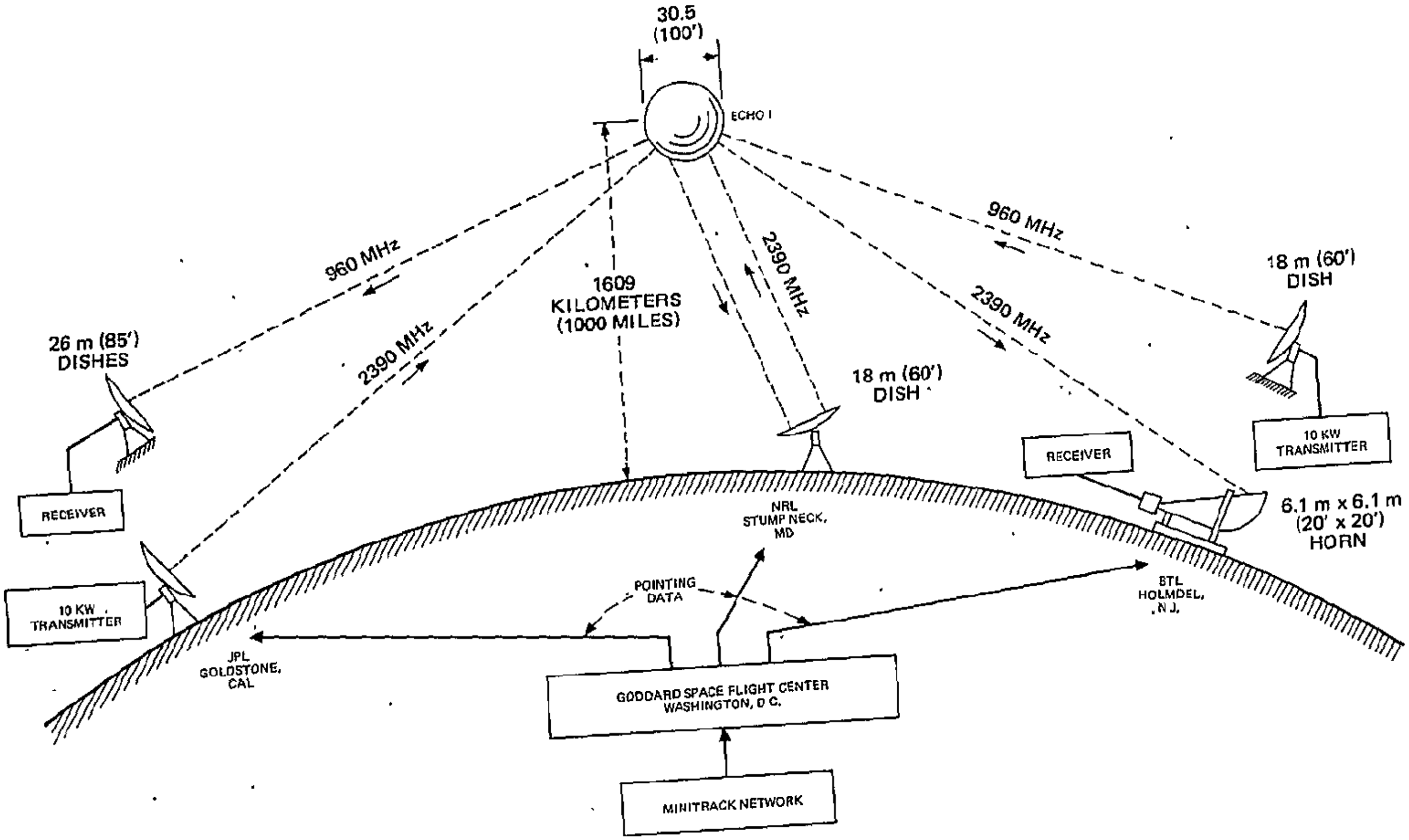

Figure 3-1. General Features of the Echo I Experiment

For the Echo II communication experiments, the system configuration for the principal participants was as illustrated in Figure 3-2.[10] The configuration was such as to provide half duplex communications as the primary mode of operation. Normally, Dallas transmitted while Stump Neck or Columbus or both received. Dallas could transmit on either of two frequencies and Stump Neck could receive either of these frequencies. However, Columbus received on only one of the Dallas transmit frequencies.

The Dallas site included a second transmit antenna used in radar tracking operations to a receiver operating off the communications transmitting antenna. Radar tracking was performed at a separate frequency from the communication frequencies, and Stump Neck included a receive capability at that frequency. Stump Neck also included a communications transmit capability for use in special cases. East Coast to West Coast mutual visibilities were increased over those for Echo I by the higher orbital inclination of Echo II.

Frequencies employed for communications and radar tracking operations with the Echo satellites spanned a wide range extending from VHF to S-band. This was a result of performance as a function of frequency, being, in general, unaffected by these passive reflectors. Strictly speaking, fading, due to scattering from the wrinkled skin of these reflectors, did become more of a problem at the higher frequencies. Operating frequencies for the major participants involved in experiments with Echo I and II are summarized in Tables 3-4 and 3-5, [5][10] respectively. The two GHz frequencies were chosen because they were available for allocation by the Federal Communications Commission and because they were the correct frequencies for future satellite and deep space communications activities. The 960-MHz frequency was chosen because equipment on this frequency existed at Goldstone from an earlier program.

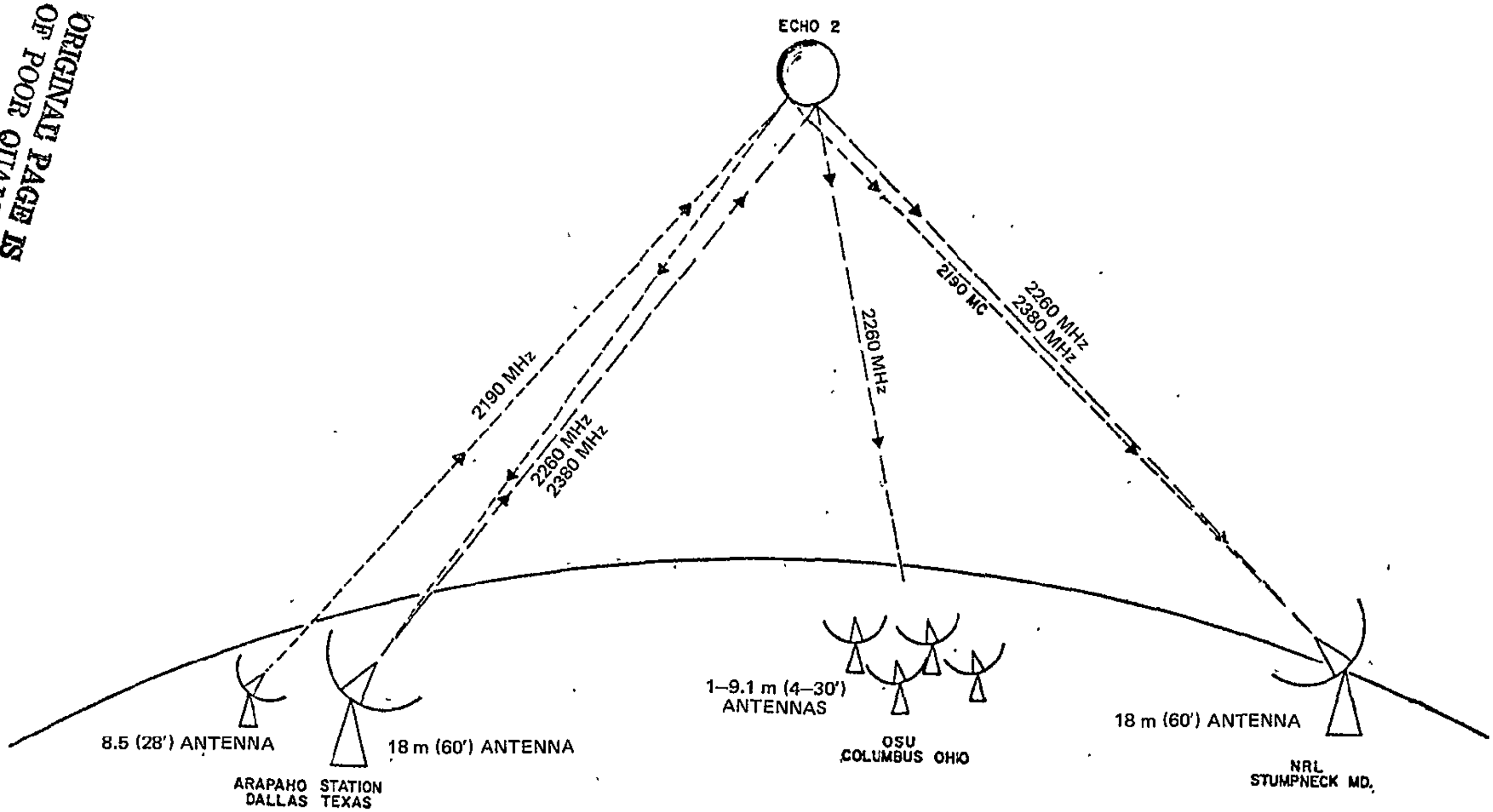

Figure 3-2. Circuit Configuration, Echo II Communications Experiments

Table 3-4. Echo I Operating Frequencies

Goldstone to Holmdel or Stump Neck	Goldstone to Goldstone	Holmdel to Goldstone	Stump Neck to Holmdel
2390 MHz	2388 MHz	960 MHz	2390 MHz

Table 3-5. Echo II Operating Frequencies

Dallas to Stump Neck	Dallas to Columbus	Dallas to Dallas
2260 MHz or 2380 MHz	2260 MHz	2190 MHz

The basic signal processing techniques employed for the Echo I tests are summarized in Table 3-6.[5][14][15] There were no multiple-access restrictions except the normal requirements for signal orthogonality, since the satellite was simply a passive reflector. Therefore, any of the commonly conceived multiple-access techniques (e.g., time, frequency, and code-division multiple access) could have been employed. Frequency division was used because of its ready compatibility with common existing earth terminal technology. For a perfectly spherical reflector with a smooth skin, there are likewise no satellite-imposed restrictions on the RF modulation technique employed. However, for a deformed reflector with a wrinkled skin, both fading and limitations on the coherent bandwidth are imposed. Frequency modulation (FM) is normally effective in the face of fading as long as the coherent bandwidth of the channel isn't exceeded. Large margins are required for an operational system of this sort.

Margins, for a perfectly reflecting sphere, must account for variations in range, atmospheric and ionospheric attenuation and noise, antenna tracking and polarization losses, and ground terminal performance. For an imperfect sphere such as Echo I, margins must be further increased to account for signal fading due to scattering off the balloon surface and changes in the instantaneous reflective cross sectional area.

Signal processing techniques were basically the same for Echo II as for Echo I. Performance was improved somewhat primarily due to an average reflective cross sectional area that was 3 dB larger, slightly shorter ranges to the satellite, and the fact that the balloon shape did not deteriorate as a function of time. Additionally, both frequency and space diversity were tried as means of combating coherent fading.

Table 3-6. Signal Processing for Echo I

Multiple Access	FDMA for an Unlimited Number of Users
RF Modulation	FM,[1] single sideband, narrow-band phase modulation, and conventional amplitude modification.
Ground Demodulator Performance	FMFB receivers employed giving threshold at about 13 dB C/N in 6-kHz bandwidths.[2]
Holmdel Receive Carrier-to-Noise	34.2 dB for Goldstone transmit, satellite midway between terminals, and 6-kHz noise bandwidth.
Holmdel Receive Margin	About 21 dB.[3]

Notes: (1) Frequency modulation was normally used.

(2) In normal 60-MHz RF bandwidth, threshold occurs at 3-dB C/N.

(3) High margin allows successful operation in spite of significant signal fluctuations. Also allows good quality communications employing modulation techniques with considerably less processing gain than FM.

3.3 SPACECRAFT

Echo I was a hollow sphere constructed from gores of 0.0013-cm (0.0005-inch) thick Mylar with the external surfaces coated with vapor-deposited aluminum to provide efficient radio-wave reflectivity.[1] In this design, long cigar-shaped pieces are cut out of sheet material and joined together with "butt" seams. Where the "gores" come together at the two poles of the structure, a reinforcing "pole cap" was used. The sphere was designed to have a 30.5-meter (100-foot) diameter when inflated and weighed approximately 61.2 kilograms (135 pounds).[3]

Before launch, the satellite was evacuated and accordion-pleat folded for packing in the spherical launch container. The launch container, measuring 66 centimeters (26 inches) in diameter, was also evacuated to a rather low vacuum prior to launch.

When the container was placed in orbit, it was explosively separated at its equator and the satellite was initially inflated by the small amount of residual air entrapped within its interior.(16) Inflation was completed and the shape of the inflated satellite was temporarily maintained by the small gas pressure created by sublimating solids (i.e., 9.1 kilograms (20 pounds) of anthraquinone and 4.5 kilograms (10 pounds) of benzoic acid) contained within the satellite.(2) These inflatants could produce a skin stress of about 1.03×10^6 newton/meter^2 (150 psi) in Echo I and the pressurized life of the satellite was approximately 14 days.

Initial tracking of the satellite was greatly aided by two radio beacon transmitters attached to the sphere's external surface. Each of the two assemblies, located diametrically opposite on the equator of the satellite, include one transmitter, its associated antenna, a group of solar cells and one-half of the satellite's storage-batteries.(16) Each of the continuous wave transmitters was designed to provide about 10.5 milliwatts of power at a frequency of 107.94 MHz. Crystals were chosen to provide a frequency separation of 500 to 1000 Hz between the two transmitted signals. The quarter-wave monopole antenna for each beacon transmitter was erected normal to the satellite surface. The radiation pattern provided was somewhat similar fo that of a monopole antenna above an infinite plane.

In Echo II, the basic type of gore construction developed in Echo I was retained.(1) It was made up of 106 gores with each gore measuring 1.2×65.5 meters (4×215 feet).(2) The gores were butt-jointed together, using 2.5-centimeter (1-inch) wide tapes made of the same material as the gores. The gores terminated at the polar areas of the sphere where 137-centimeter (54-inch) diameter pole caps were attached, using a 2.5-centimeter (1-inch) overlapping joint. The material used was a 3-layer sandwich of .00051-centimeter (.00020-inch) sheets of aluminium on each side of a .00091-centimeter (.00036-inch) mylar polyester film. The total skin thickness was

.00191 centimeter (.00075 inch), which was only 50 percent greater than that of Echo I but it produced a rigidity about 100 times greater. This construction resulted in an inflated sphere measuring 41.1 meters (135 feet) in diameter and weighing 250 kilograms (550 pounds).

The structure was folded and packed inside a launch canister having an elliptical vertical cross section and a circular horizontal cross section as mounted for launching.[6] The canister had a 76-centimeter (30-inch) vertical diameter and a 112-centimeter (44-inch) horizontal diameter. The container, as well as the satellite, was evacuated to prevent excessively rapid inflation by expansion of residual air inside. The canister was separated in orbit in the same manner as for Echo I and residual air again provided the initial inflation. However, continued inflation and full pressurization were accomplished in a much more controlled manner. In this system, the inflatant, now pyrozole, was sealed in numerous small packets that were attached to the inside surface of the satellite.[1] The packets were sealed with an adhesive wax that melted just below the equilibrium temperature of the sphere in orbit. The bags, therefore, were not opened to start sublimation and the buildup to higher pressurization until the sun's energy elevated the temperature of the satellite. This occurred long after initial inflation and the danger of rupture due to dynamic loads had passed.

Initial pressurization was designed to be higher than for Echo I. The theory behind the use of the three-layer laminated material and this higher pressurization was that the different moduli of elasticity of mylar and aluminum would result in the aluminum stretching in a nonelastic fashion while the mylar sheet was still within its elastic limit.[1] Thus, after the pressurization escaped, the mylar would tend to return to its original dimensions, placing the aluminum cemented to it under a compressive load. This results in a material that behaves like a prestressed beam and is quite rigid.

Echo II also supported two radio telemetry beacons mounted diametrically opposite one another at the sphere's equator. These beacons served as a tracking aid as well as a means of telemetering data on satellite temperature and pressure. The pressure monitoring capability extended from a minimum of 10^{-5} mm to a maximum of 0.5 mm of mercury.[17] The temperature measurements extended from

153° K (-120° C) to 433° K (160° C). The beacon system included two battery packs, four solar cell panels, and interconnecting cables to give a total weight of approximately 3 kilograms (6 pounds). The carrier frequencies were at 136.020 and 136.170 MHz, and each carrier was amplitude-modulated with three sinusoidal subcarriers bearing the telemetry information. The antenna, supplied with each transmitter, was a quarter-wave monopole made of spring wire. Upon satellite inflation, the antenna erected to a position normal to the surface of the satellite. The effective radiated power of each transmitter was greater than 34 milliwatts under continuous operation. The beacons were designed to operate for 1 year, at which time a mercury cell cutoff circuit terminated radiations.

3.4 GROUND TERMINALS

Characteristics of three of the terminals listed in Table 3-3 as participants in Project Echo are provided in Table 3-7.[5][10][18][19][20] Holmdel and Goldstone were the two major experimenters involved in Echo I testing, while the Stump Neck terminal participated in Echo I tests and was a principal evaluator of communications via Echo II. Major subsystems of the Holmdel and Stump Neck terminals are depicted in Figures 3-3[5] and 3-4[10], respectively.

The configuration of each of these three terminals reflects the considerable concern that existed over the feasibility of accurately acquiring and tracking the passive Echo spacecraft. None of the terminals relied on the satellite beacon for tracking. Beacon tracking was performed by the NASA Minitrack network, and the data contributed towards the generation of program track information by Goddard Space Flight Center. Radar techniques were employed by the communications terminals to give an active tracking capability. However, optical tracking was the preferred method of tracking when the satellite was visible (i.e., at night).

Circular polarization was employed to eliminate the need for polarization tracking. The direction of rotation (i.e., left- or right-hand circular) was selected at each transmit and corresponding receive antenna to account for the direction reversal that occurs upon reflection from the spacecraft.

Table 3-7. Characteristics of Major Project Echo Ground Terminals

	TERMINAL FEATURE		Terminal: Holmdel	Terminal: Goldstone	Terminal: Stump Neck
Antenna	Type		Parabolic Transmit & Horn Receive	Separate Parabolic Transmit & Receive	Single Parabolic Reflector
	Aperture Size		18 m (60 ft) diameter xmit & 6.1 m x 6.1 m (20 ft x 20 ft) receive	26 m (85 ft) diameter xmit & 26 m (85 ft) diameter rec.	18 m (60 ft) diameter
	Gain	Receive			49.7 @ 2380 MHz
		Transmit	43.3 dB @ 2390 MHz	45.5 dB @ 960 MHz	----(4)
	Efficiency	Receive	72%(1)	52%(1)	44%(1)
		Transmit	60%(1)	42%(1)	------(4)
	Beamwidth	Receive	1.2° @ 3 dB Pts.	0.9° @ 3 dB Pts.	0.5 @ 3 dB Pts.
		Transmit	1.2° @ 3 dB Pts.	0.33° @ 3 dB Pts.	-------(4)
Receive System	Type Preamplifier		Maser	Uncooler Parametric Amplifier	Traveling Wave Amplifier
	Bandwidth		7 MHz(2)	5 MHz(2)	200 MHz RF(3)
	Noise Temperature		45° K @ 7.5° El.	300° K	550° K
Transmit System	Type Amplifier		Klystron	Klystron	Klystron(4)
	Bandwidth		1.5 MHz	No Data	No Data
	Amp. Power Out		10 kW	10 kW	10 kW
Tracking	Type		Program track, optical track, manually controlled radar track	Program track, optical track, or monopulse radar autotrack	Program track or optical track
	Accuracy		Program track ±0.2° Optical track ±0.05° Radar track ±0.1°	Program track ±0.15° Optical track ±0.1° Radar track ±0.03° for receive & ±0.1° xmit.	Program track ±0.4° Optical ±0.3°
Total Performance	G/T		26.5 dB/°K(1)	20.5 dB/K°	22 dB/°K
	EIRP		112.5 dBm(1)	122.5 dBm	---(4)
Polarization	Transmit Feed		Left Hand Circular	Right Hand Circular	---(4)
	Receive Feed		Left Hand Circular	Right Hand Circular	Circular
Installation	Radome		None	None	None
	Type Facility		Fixed	Fixed	Fixed

Notes: (1) Derived value based on data available

(2) Front end bandwidth. Predetection demodulator bandwidth was 6 kHz

(3) Predetection demodulator bandwidth was 50 kHz

(4) Terminal did not normally transmit

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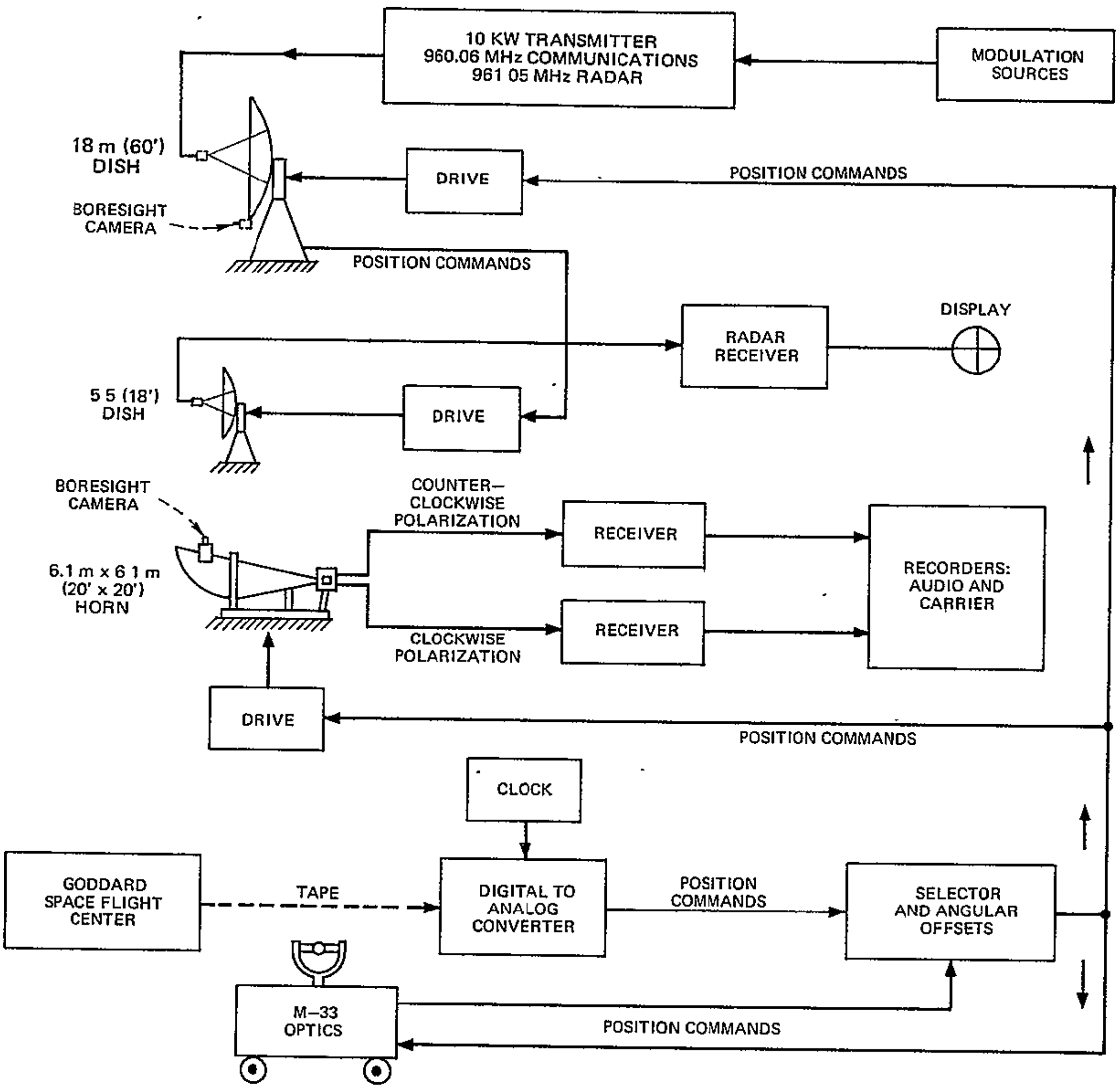

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Figure 3-3. Block Diagram of the Holmdel Facilities

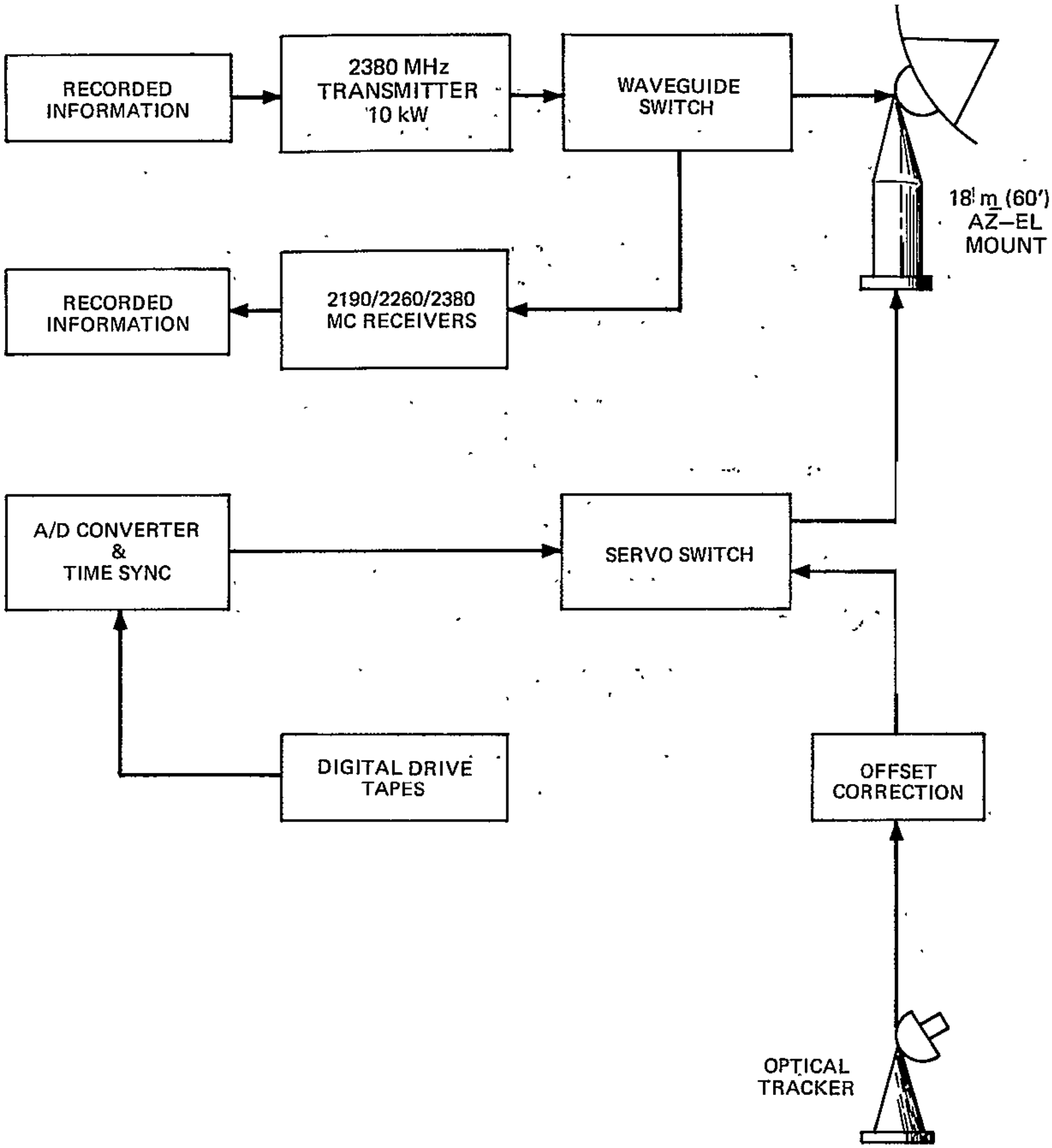

Figure 3-4. NRL Space Communications Facility, Stump Neck, Maryland

3.5 EXPERIMENTS

The premier objective of the Echo program was to evaluate the feasibility of employing satellite reflectors for global communications, and most of the planned experiments were directed towards that end. The second objective listed in Table 3-1 was accomplished through preflight statics tests, ballistic space tests, the TV system on the booster that monitored the deployment of Echo II, optical observations of both spheres over a period of time, and monitoring of reflected received signal levels over a period of time. Received signal level data was obtained in the planned communications tests as well as in independent radar tracking operations. References 21 through 24 provide examples of the type of information analyses completed to verify that large lightweight structures of the Echo type can be successfully deployed and maintained in orbit.

Accurate tracking of the Echo balloons was maintained throughout their lifetime. This gave the basis for accomplishing the third objective in Table 3-1, as well as allowing the balloons to serve as accurate position location measurement references for remote geographic points. References 25 through 28 are examples of the types of analyses and conclusions that have been made possible by the extensive data on the Echo orbits.

The major communications tests performed on Project Echo and a summary of their results are given in Table 3-8.[5][8][10][22][29][30] Items 1 through 4 in the table were tests or analyses employed extensively on both Echo I and II, while the remaining listed tests were conducted mainly with Echo II alone. Results of the first three items, as well as optical data, indicated that Echo I was relatively smooth and spherical during its pressurized lifetime but developed wrinkles and flat areas during the first month in orbit, which tended to become more extensive and severe as time passed. Similar data indicated that Echo II developed a wrinkled skin very quickly after deployment and maintained its shape as a function of time.

Table 3-8. Communications Experiments

TYPE EXPERIMENT	NATURE OF RESULTS OBTAINED
1. Received Signal Level	Levels, in general, agreed with expectations verifying effective balloon cross sectional areas and path loss.
2. Average Scattering Cross Section(1)	Indications were that Echo I was within 1 dB of theoretical(2) during pressurized life of satellite,(3) dropped to about 3 dB down within first month in orbit and gradually decayed to 6 dB down over 3 years. Echo II was 1 dB down from theoretical(2) shortly after launch and held constant as a function of time.
3. Fading Characteristics(1)	On Echo I, 10 to 90 percent fade range(4) was 2 to 4 dB during first month in orbit and gradually increased to 6 dB to 8 dB over 3 years. Echo II range was 11 to 13 dB and held constant as a function of time. On both Echo I after 3 years and Echo II, a Rayleigh probability density function and an amplitude spectrum indicating nearly all power fluctuations occurred at frequencies below 3 or 4 Hz were observed.
4. Voice Transmission	Received quality judged excellent on both Echo I and II for voice. Music also excellent on Echo II. Echo I employed 200-Hz to 3-kHz baseband and frequency deviation of ±30 MHz. Echo II employed 30-Hz to 15-kHz baseband and frequency deviation of ±15 MHz. Capability of reasonable quality on up to 4 voice channels also demonstrated on Echo II.
5. Facsimile Transmission	Standard military machine that normally used 3-kHz voice channel was prerecorded and played back at 4 times normal speed to give 12-kHz baseband. 1000-Hz tone was simultaneously prerecorded for speed control and doppler correction. Using ±15-kHz frequency deviation, good quality with some streaking and distortion due to signal fluctuating below threshold observed.
6. Coherent Bandwidth	Appeared to be greater than 12 MHz but less than 70 MHz. Indications were that frequency diversity became effective at about 190-MHz frequency spacing. Both amplitude and phase correlation analyses applied to tones at separate frequencies to make these determinations.
7. Space Diversity	Little diversity improvement observed for antenna spacings of 724.8 meters (2378 feet).
8. Digital Data Transmission	Alternate ones and zeros transmitted by FM or carrier and conventional detection. Decisions on received signal employed a matched filter (i.e., integrate and dump). Error rates for transmission at 1.2 kbps rate typically ranged between 10^{-2} and 10^{-3} bits/bit.

Notes: (1)Determined from analysis of received communications signals and radar returns.

(2)For Echo I, 729.64 square meter or 28.63 dB relative 1 square meter. For Echo II, 1329.81 square meter or 31.23 dB.

(3)One to two weeks.

(4)Difference between value exceeded 10 percent of time and value exceeded 90 percent of time.

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In addition to the experiments listed in the table, several tests of perhaps somewhat lesser importance were conducted employing primarily Echo 1. Voice transmission evaluations were extended by utilizing single-sideband, narrow-band phase, and amplitude-modulation techniques for comparison with frequency modulation.[5] The performance did not equal that with FM, indicating that the coherent bandwidth of the channel had not been exceeded in the tests; therefore, conventional theories for comparing modulation techniques applied. Measured doppler shift was compared with theory and found to be in good agreement. Performance of FM with feedback receivers was evaluated and found to agree well with previous laboratory measurements and theory. Performance of the ground terminal tracking systems was closely watched. All performed well, and the potential of automatic tracking was demonstrated. In addition, a television signal was transmitted and limited quality reception obtained, using facilities developed for Project West Ford.[31]

Numerous notable demonstrations were also conducted.[5][30] Most of these occurred during the early days of Echo I and tended to dramatize the potential of this type of communications. Included were a tape-recorded voice message by President Eisenhower during the first satellite pass on August 12, 1960; prerecorded 2-way messages by President Eisenhower and Senator L. B. Johnson on August 13, 1960; and the first 2-way live voice transfer between Mr. W. C. Jakes of Bell Telephone Laboratories and Mr. P. Tardani of Jet Propulsion Labs also on August 13, 1960.

Finally, Echo II provided a first in international communications, when Russia agreed to participate in a cooperative experiment with NASA and to supply NASA with tracking data during the early orbits after launch.[11][32][33] The tests were conducted in accordance with the Bilateral Space Agreement between the USSR (Academy of Sciences) and the USA (NASA) reached at Geneva on June 8, 1962. The tracking data consisted of photographs and optical observations that helped to determine that the balloon had been successfully deployed and to establish initial orbital parameters.

The communications experiments were performed between the Jodrell Bank Radio Observatory of the University of Manchester, England, operating on NASA's behalf and the Zimenki Observatory of the Gorki State University northeast of Moscow. The Jodrell Bank facility provided a 76.2-meter (250-foot) diameter steerable antenna and a 1-kW transmitter to radiate signals at a frequency of 164.2 MHz. The Zimenki facility received both this signal and the 136-MHz satellite beacon, using a 14.9-meter (49-foot) diameter antenna. Transmissions included unmodulated carrier, 400-Hz tone modulation, Morse telegraphy, teletype, telephone and facsimile.

Theoretical link calculations showed that performance could only be marginal, but the results obtained were even poorer than expected. This was attributed to inaccurate pointing of the antenna at the transmitting site, refractive and reflective effects on the signal at the low elevation angles and wide beamwidths used, and polarization mismatches between the transmitting and receiving antennas. In spite of this, 34 experiments were conducted between 21 February and 8 March 1964, and the international cooperation displayed made the entire operation a significant diplomatic success.

3.6 OPERATIONAL RESULTS

Project Echo was an experimental program; therefore no operational traffic was carried. Operation of the experimental ground stations was entirely satisfactory as expected. The only difficulty of any significance was caused by occasional errors in the prepass tracking predictions. These errors were of sufficient magnitude to make ground terminal program tracking unsatisfactory. They were a result of the manner in which the orbits of the large lightweight Echo structures were being perturbed from pass-to-pass by solar pressure and atmospheric drag. The tracking difficulties encountered could have been overcome by obtaining more extensive tracking data and updating computed orbital elements more often.

No unexpected operational difficulties of importance were encountered with the Echo I balloon. At the end of a week of operation, a malfunction occurred in the beacon battery supply such that the beacons transmitted only when a solar cell pack was illuminated by the sun. However, the beacons were not designed for a long lifetime, since their primary mission was to assist the tracking operations during the early orbits of the satellite so that accurate initial orbital elements could be generated. This mission was fulfilled.

The only anomalous operation that developed during operations with Echo II was scintillation of the reflected received signal due to wrinkling of the satellite skin. This was caused by the unexpected satellite spin that developed during the first orbit after launch and lower than expected initial inflation pressure. The exact cause of these unusual occurrences was not determined. The beacons on this spacecraft operated for 1 year as planned.

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SECTION 4 - COURIER

4.1 PROGRAM DESCRIPTION

In September 1958, the U.S. Army Signal Research and Development Laboratory (USASRL) submitted a technical proposal for a delayed repeater satellite communication system to the Advanced Research and Development Agency of the Defense Department. In October 1958, USASRL received approval to proceed with Project Courier. The program was undertaken to demonstrate the feasibility and operational capabilities of a store-and-forward (information storage for future retrieval) satellite communications system with potential military application. (1)

Two active delayed repeater satellites, Courier Ia and Ib, were launched before this program was completed, as indicated in Table 4-1. (2) After Courier Ia failed to reach orbit due to a missile malfunction, Courier Ib was successfully injected into a low altitude eliptical orbit. Testing during the 17-day operational lifetime of Courier Ib fulfilled the program objectives. The operational usefulness of Courier Ib came to an end when it ceased to respond to attempts at "turn on."

Table 4-1. Participating Spacecraft

Satellite		Courier Ia	Courier Ib
Manufacturer & Sponsor		Philco Corp. & U.S. Army Signal Corp	
Launch Date		8/18/60	10/4/60
Launch Vehicle		Thor-Able-Star	
Orbital Data	Apogee Perigee Inclination Period	No Orbit Attained	1215 km (755 mi.) 966 km (600 mi.) 28.3^{o} 107 min.
Status		Spacecraft lost due to missile failure	Satellite ceased to respond to "turn on" commands on 10/21/60 leaving VHF beacon as only radiation

The two earth terminals employed in Project Courier are listed in Table 4-2.[3] Satellite launchings were supplied by the U.S. Air Force.

Table 4-2. Participating Earth Terminals

Location	Sponsor	Antenna Diameter (m) (ft.)	Date Installed
Fort Monmouth, New Jersey	USASRDL	8.5 (28)	1960
Camp Salinas, Puerto Rico	USASRDL	8.5 (28)	1960

The major contribution of Project Courier to satellite communications technology was to demonstrate the technical feasibility of a delayed repeater high capacity digital satellite communications system. However, the satellite's early failure clearly demonstrated the need for additional care and effort in designing and testing components and systems intended for operational satellite applications.

4.2 SYSTEM DESCRIPTION

Tests were conducted with Courier Ib on a loop-back or push-to-talk basis by the two terminals indicated in Table 4-2. Both real time and store-and-forward operation was possible. During store-and-forward operation, an earth terminal could load traffic into the spacecraft's tape recorders at the same time it received previously stored messages from the satellite.

The altitude and inclination of the satellite orbit made an average of five workable orbits at the Fort Monmouth station and an average of seven at the Puerto Rico station possible out of approximately 14 orbits per day.[3] The satellite was in view of the ground station during each orbit for a maximum of 19 minutes at Fort Monmouth and 22 minutes at Puerto Rico.[2] Mutual visibilities as long as 15 minutes were available.

Operating frequencies for the Courier satellites were as indicated in Table 4-3.[2] The UHF communications frequencies were chosen for the wide bandwidth and simplicity of equipment design provided in addition to the noise and propagation advantages at these frequencies.[4]

Table 4-3. Courier Frequencies (MHz)

Communications		TT&C	
Uplink	Downlink	Command	Telemetry
1750	1800 to 1900*	135	108**

* Two transmitters, modulated with same information and operating about 20 MHz apart, utilized for frequency diversity.

** Separate acquisition beacon, disabled upon satellite "turn on," operated at same frequency.

The basic signal processing techniques utilized on Project Courier were as indicated in Table 4-4.[2] [5] The modulated uplink signal was detected in the satellite. The detected baseband was recorded in the satellite or retransmitted in real time. During transmission over the downlink, the detected signal modulated the satellite transmitter's radiated carrier. The uplink performance was, in general, superior to the downlink performance indicated in the table. Margins had to be adequate to account for variations in range, rain losses, satellite antenna gain as the aspect angle to the ground terminal changed, and other link parameters that varied to a smaller extent.

Table 4-4. Signal Processing Employed

Multiple Access	None
RF Modulation	FM*
Ground Demodulator Performance	Estimated** threshold at about 10 dB C/N
Ground Terminal Receive Carrier-to-Noise	16 dB for maximum range*** and 100 kHz noise bandwidth
Ground Receive Margin	6 dB at maximum range

* Employed on both the up and down link

** Estimate based on fact that conventional discriminators were employed

*** 5310 meters (3300 statute miles)

4.3 SPACECRAFT

Spacecraft characteristics for the Courier satellites are displayed in Table 4-5.[2] [3] [6] A block diagram depicting the basic electrical configuration of the satellite is shown in Figure 4-1.[3] The considerable redundancy incorporated reflected the concern over spacecraft reliability that existed at that time. The design expectation was for a 1 year in orbit lifetime. A special acquisition transmitter, separate from the telemetry transmitter, was supplied. While in the acquistion mode, the two VHF receivers were alternately activated to "listen" for ground terminal signals, on a part-time basis. The cycling of the receivers was such that an active receiver was listening only about 10 percent of the time.

Table 4-5. Satellite Characteristics

Antennas		Type	UHF - Pair of slotted fin antennas located 180^{o} apart on satellite equatorial band. *	VHF - 4 whip turnstile for TT&C
		Number	One	One
		Beamwidth	Essentially Omnidir-ectional	Essentially Omnidirectional
		Gain	0 dB	0 dB
Repeaters		Frequency Band	UHF	
		Type	Demodulating/remodulating with capability for real time or delayed operation. **	
		3 dB BW	550 kHz	
		Number	One with considerable built in redundancy	
	Receiver	Type Front End	Four receivers, each with a down conversion mixer first stage. Discriminator outputs of receivers combined in baseband combiner.	
		Front End Gain	100 dB IF following down conversion mixer in each receiver.	
		Sys. Noise Fig.	14 dB	
	Xmitter	Type	2 planar triodes, each modulated with the detected uplink signal and operating 20 MHz apart to supply frequency diversity. Redundant pair of transmitters available at ground command.	
		Gain	No data available.	
		Power Out	33 dBm	
	EIRP-UHF Ant.		29 dBm***	
General Features	Stabili-zation	Type	Spin with no active correction capability	
		Capability	Unoriented relative to earth. Initially approximately 90^{o} spin axis aspect to sun.	
	Power Source	Primary	Solar array with 65 watts average output. ****	
		Supplement	2 nickel cadmium batteries - about 12 amp. hr. capacity per battery****	
	Comm. Power Needs		Approximately 200 watts	
	Size		Spherical with 132-centimeter (52-in.) diameter	
	Weight		227 kilograms (500 lbs.)	

* Two receivers and a redundant transmitter connected to each slotted fin. Transmitters on one fin operate at different frequency from those on other. All receivers at same frequency.

** 1 analog and 4 digital tape recorders allow delayed operation.

*** Transmitter to antenna losses are 4 dB including a diplexer and hybrid.

**** At launch.

When one of the receivers detected a ground terminal signal, it came on in full-time operation and the remaining satellite systems could be activated on command.

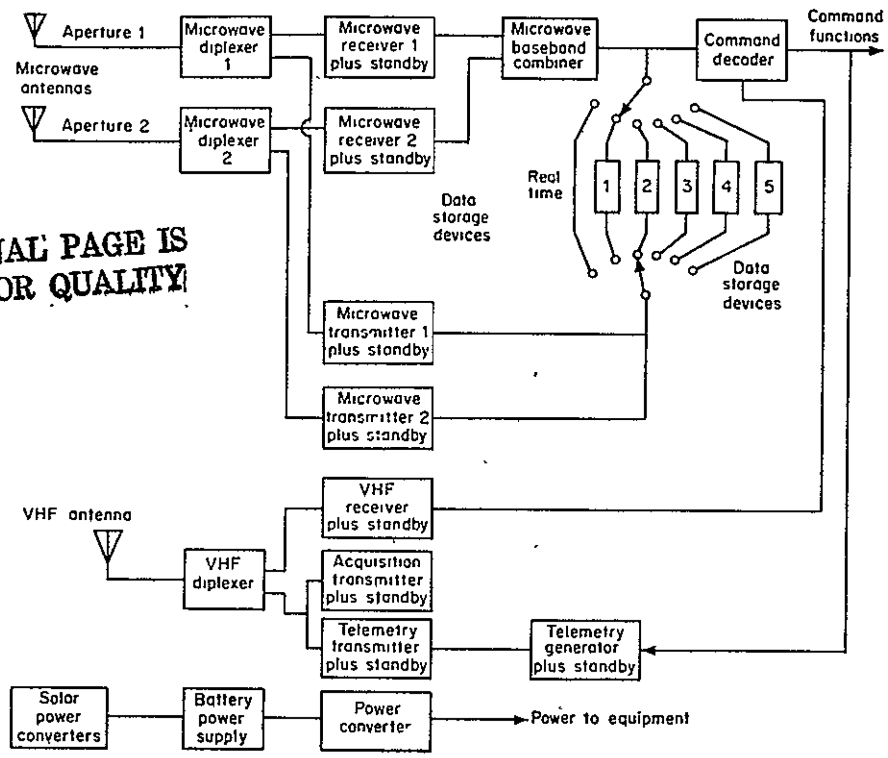

Figure 4-1. Courier: Communications Transponder

4.4 GROUND TERMINALS

The ground terminals employed at Fort Monmouth and Camp Salinas were essentially identical. Major characteristics of these terminals are displayed in Table 4-6.[1] [2] [3] Major subsystems are illustrated in the block diagram of Figure 4-2.[3]

Table 4-6. Characteristics of Earth Terminals

Antenna	Type Aperture Size Receive Gain Efficiency Rec. Beamwidth	Parabolic Reflector 8.5 m (28 ft) Diameter 41 dB 50%* 1.35 at 3 dB pts.
Receive Sys.	Type Preamplifier Bandwidth Noise Temp.	Four receivers each with uncooled parametric amplifier front end. Two receivers operate in linear polarization diversity at each satellite transmit frequency.** 500 kHz*** 640°K
Transmit System	Type Amplifier Bandwidth Amp. Pwr. Out	Klystron 4 MHz**** 1 kW
Tracking	Type Accuracy	Conical Scan Auto track 0.5° at maximum slewing rate of 15°/second
Total Perf.	G/T EIRP	13 dB/°K* 99 dBm*
Polarization	Transmit Feed Receive Feed	Circular Linear Diversity Reception†
Installation	Radome Type Facility	None Fixed because of antenna installation† †

* Derived value based on data available.

** Receivers operating on same frequency combined at RF. Composite signals at separate receive frequencies combined at baseband.

*** 100 and 200-kHz bandwidths also selectable.

**** RF bandwidth. Effective bandwidth of signal from modulator was a maximum of about 200 kHz.

† Crossed dipoles at 45° to horizontal and vertical employed.

† † Terminal included antenna, 3 semitrailers, and a maintenance van plus power generators.

As the figure indicates, the system was primarily designed to handle teletype traffic since digital messages are normally more compatible with store-and-forward operation than analog messages. The terminals included a record and playback speed changing capability in their data storage system such that stored teletype messages could be transferred to and from the satellite at a 55-kbps rate.

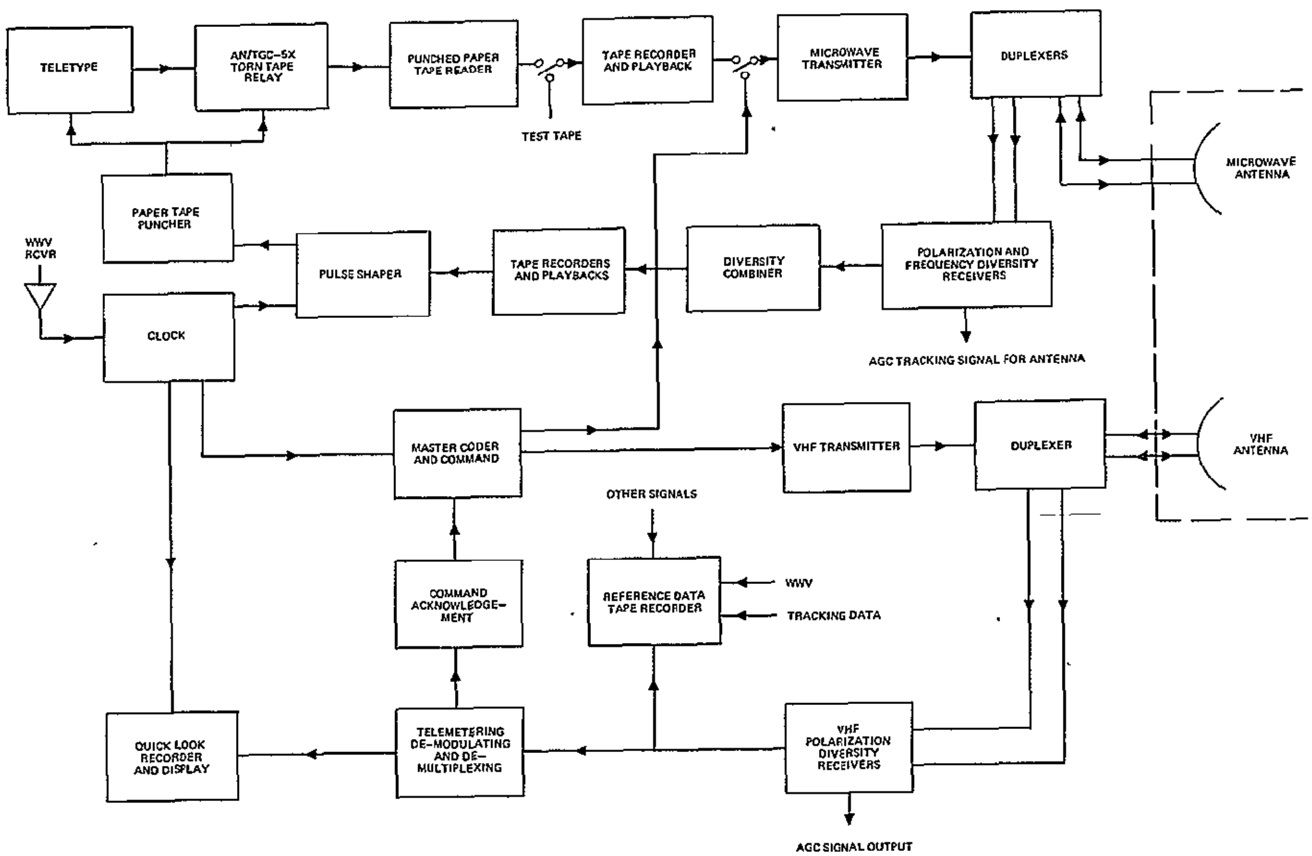

Figure 4-2. Ground Terminal Block Diagram

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The choice of circular polarization for the transmit feed resulted in a 3-dB uplink polarization loss since the satellite antenna's transmit and receive polarization was linear. This loss was avoided on the downlink without resorting to a polarization tracking system by employing crossed dipoles and dual receivers at each downlink frequency to give polarization diversity reception.

4.5 EXPERIMENTS

Experiments conducted on Project Courier can be grouped into the three major categories listed and defined in Table 4-7.[2] Each of these groups of tests contributed to accomplishing the program objectives.

Table 4-7. Summary of Program Experiments

Type	Description
1. Communications Performance	Evaluate link parameters and communications traffic handling capabilities of a delayed repeater satellite.
2. Satellite Performance	Determine capability and reliability of various subsystems of complex signal processing repeater.
3. Jamming Resistance	Measure satellite and communications performance under interference conditions on VHF or UHF uplinks to satellite.

The spacecraft performance tests monitored items such as satellite tape recorder operation, temperature, spin axis attitude, spin rate, solar power supply, and command system performance.[2] During the short operational lifetime of Courier Ib the satellite performance was (in general) good and in agreement with expectations. Spin rate was observed to decay at the rate of about 1 rpm per month. Performance exceptions involved the tape recorders and command system. One of the five tape recorders became stuck at an endstop and further recording or playback was impossible. Command system malfunctions resulted in an operational effectivity of only about 95 to 97 percent. Malfunctions included failure to respond to commands, improper command acknowledgements, response to improper access codes, and in one case improper execution of the command sent.

Jamming resistance tests involved CW interference to the VHF link and both CW and pulse interference with the UHF message link.[2] The system was found to be readily susceptible to jamming of either the UHF or VHF links, as might be expected since no antijamming features were incorporated. UHF link signal-to-jamming ratios of 5 to 7 dB had to be maintained to preserve system operation in the presence of CW jamming. With pulse jamming, the signal-to-jamming ratio required appeared to be somewhat higher.

The communications performance tests described in Table 4-7 are defined in Table 4-8.[2] The table also includes primary results obtained. A precise evaluation of link parameters was not obtained, since spin axis attitude could be determined only from surface temperature sensors and received signal level, and spin rate was determined from the received signal level alone. As a result; highly accurate real time satellite antenna gain data was not available. In both the record and playback modes, delayed repeater operation required 5-second lags before initiating signal transfers to allow tape recorders to reach operational speed. In addition to the tests listed in Table 4-8, Courier Ib was employed in radar range measurement experiments.[7] These experiments contributed the development of techniques for employing ranging data to develop satellite tracking information.

4.6 OPERATIONAL RESULTS

Project Courier was an experimental program; therefore, no operational traffic was carried. Satellite operational results during the 17-day lifetime of Courier Ib were described in the discussion of experiments (Paragraph 4.5). Ground terminal tracking reliability and accuracy were quite good. Communications equipment performance and reliability was easily adequate for the limited duration

Table 4-8. Communications Performance Experiments

Type Experiment	Nature of Results Obtained
1. Received Signal Level	VHF and UHF uplink and downlink levels, in general, appeared to agree with expectations with level variations for most part due to Faraday rotation, satellite spin and changes in spin axis aspect to earth.*
2. Teletype	Delayed repeater and real time performance was the same. Average corrected error rate* was 3.33×10^{-4} bits per bit.
3. Voice	Delayed repeater and real time performance appeared the same. Single channel voice subjectively evaluated to be of commercial quality. Estimated that four or more multiplexed voice could have reasonably been accommodated.
4. Facsimile	Real time performance subjectively evaluated as excellent. Some synchronization difficulties encountered in delayed repeater operation due inadequate speed stability of tape recorders.***

* Exact real time effects of spin rate and spin axis aspect were difficult to ascertain since satellite did not incorporate sensors for their measurement. However, fades did not correlate with atmospheric disturbances that affect more conventional types of long distance radio propagation such as HF.

** Nulls in pattern from two-element satellite antenna caused error bursts twice per satellite spin cycle due to signal level dropping below threshold. Corrected error counts eliminated these bursts from consideration.

*** Synchronization difficulties could be overcome by multiplexing a separate synchronization signal with facsimile signal. However, this resulted in noticeable intermodulation.

experiment conducted. However, reliabilities of the klystron power amplifiers and low noise parametric amplifier receiver front ends employed were not adequate for an operational system.

The major operational difficulty encountered with the Courier system occurred on October 21, 1960, when the satellite ceased to respond to ground terminal "turn on" commands. This left the satellite in an acquisition mode with the UHF communications system and telemetry transmitter deactivated, and only the VHF beacon transmitter remained active. The exact cause of failure was never determined. Erratic command system in-orbit performance on Courier Ib and subsequent life testing of a duplicate satellite model pointed toward a failure of command system circuitry. The circuitry for cycling the VHF acquisition receivers "on" and "off" (i.e., battery saver circuit) was hypothesized as the most likely point of failure. (2)

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SECTION 5 - WEST FORD

5.1 PROGRAM DESCRIPTION

Project West Ford (earlier, Project Needles) was a scientific and technical investigation, sponsored and supported by the U.S. Air Force, into the feasibility of using an orbital array of dipoles as passive reflectors in a global communication system. The communications concept investigated under Project West Ford could, in principle, provide the following:

1. Immediately accessible, continuous, worldwide communication coverage linking widely separated transmitting and receiving terminals without intermediate relay stations.

2. High dependability by virtue of very low vulnerability to disruption by natural or manmade influences.

3. Capability of resisting electronic jamming and compatibility with techniques for providing cryptographic security.

4. Reliability and ease of maintenance and repair, since the space subsystem is passive and the active electronic equipment is on earth, and since relay stations in remote and possibly politically unstable locations are not required.

5. Ability to carry simultaneously a large number of circuits between transmitters and receivers located in widely separated geographical regions.

6. Relative ease of operation, since ground antennas are not required to track the satellite relay medium at high rates over large angles.

7. Relative economy of establishment, since only two successful rocket launches could establish the entire satellite portion of a system to provide the performance indicated.

The principal advantage of the West Ford concept is its great inherent resistance to any damage (natural or other) that could significantly reduce its capability, so worldwide communications could be maintained under any foreseeable circumstances.

The question of possible interference to radio astronomy, optical astronomy, and space travel was under discussion from the outset of Project West Ford. Because of this concern, an ad hoc committee of the National Academy of Sciences was established which subsequently recommended that the project be declassified and disclosed to the scientific community at large. Opposition to the West Ford project was especially concerned with leaving material that might prove to be considerably harmful in the above-mentioned respects dispersed in space.

Late in September 1961, a special panel of the President's Science Advisory Committee concluded that "the United States can proceed with the West Ford communications experiment without danger to science." As a result, a satellite carrying the West Ford dipole dispenser package was launched on October 21, 1961. The attempt failed because of a mechanical malfunction in the dispenser. The dipoles did not disperse: fragments of the package were observed in orbit by a VHF radar but they could serve no useful communications function.

A year and a half elapsed before a second attempt was made on May 10, 1963. The dipole dispenser was carried into orbit as a piggyback payload on a large parent satellite, and the parent satellite was placed in an approximately polar orbit of about 3700-km altitude. The inclination and altitude were selected to ensure that the dipole belt lifetime would be limited by solar radiation pressure. A radio command signal was employed to release the dipole dispenser. However, due to a 30-minute ejection delay imposed by the mission of the parent vehicle, the dipole dispenser was heated unevenly by the sun. This caused imperfect dispensing which resulted in somewhat less than half the dipoles being dispensed individually. Nevertheless, a sufficient number of dipoles were successfully dispensed into orbit to allow experimental investigation.

The subsequent West Ford space experiment demonstrated that the orbiting dipole technique can provide reliable radio communication over large distances. More specifically, this program demonstrated that:

1. Large quantities of fine microwave dipoles can be fabricated, compactly packaged, launched into orbit about the earth, and dispensed.

2. Large quantities of fine dipoles can be made to form a compact belt around the earth of predictable dimensions and within a predictable time period.

3. The orbital perturbations caused by solar radiation pressure and the earth's gravitational field are essentially as predicted by theories developed at Lincoln Laboratory. The spreading of a dipole belt similar to that deployed, over 7 months' time, is no more than about 200 km in a radial direction from the earth and about 60 km in a direction normal to the orbit plane.

4. Solar radiation pressure will limit the lifetime of a dipole belt similar to that deployed to about 3 to 5 years.

5 Propagation effects of the dipole scatter medium are as predicted: a multipath time delay spread of about 100 microseconds and a doppler frequency smear of 1 to 2 kHz were observed several months after dispensing.

6. The various modulation-demodulation techniques operate with a dipole belt at close to their predicted performance; communication rates of several tens of thousands of bits per second were achieved soon after dispensing.

7. The interference of a dipole belt similar to that deployed, with radio astronomy measurements, is negligible as might be theoretically predicted.

5.2 SYSTEM DESCRIPTION

The major experiments performed using the dipole belt were conducted with sites in Massachusetts and California operating as monostatic radars, as a bistatic west-to-east radar, and for west-to-east communications. The eastern site was more heavily instrumented as a receiving station and the western site more as a transmitting station. Propagation measurements and communications experiments including high-speed data, teletype, and voice were performed. Belt-scattering cross-section and dimension measurements were made by both monostatic and bistatic radar experiments. The results of these experiments are discussed in Paragraph 5.5.

The choice of frequency range for Project West Ford was a compromise among many factors. In the upper UHF and SHF region, atmospheric noise is negligible. Galactic noise is not of great concern at frequencies above about 1000 MHz, nor is the influence of the ionosphere, in either a quiet or disturbed state. At frequencies of some 3000 MHz and higher, the noise contributed by atmospheric attenuation is noticeable in sensitive receivers, and precipitation-induced attenuation begins to be important along long slant paths at frequencies above 6000 MHz.

The use of lower frequencies will yield higher values of radiowave cross-section per unit mass for a given dipole thickness; at very low frequencies, however, the dipole thickness must be increased to preserve its shape and the greater mass would increase any possible spacecraft collision hazard. In addition, there are greater numbers of more powerful radio equipments operating at the lower frequencies. Signals scattered from a low frequency belt by these powerful equipments may cause interference.

Consideration of these factors led to the choice of a band of frequencies near 8000 MHz for a test of the orbital scatter technique. The operating frequencies employed in Project West Ford are given in Table 5-1.

Table 5-1. Project West Ford Frequencies

	Millstone		Camp Parks	
	Radar	Communications	Radar	Communications
Transmit Frequency (MHz)	7750	7750	8350	8350
Receive Frequency (MHz)	7750	8350	8350	7750

The experimental program for determining the properties of the dipole belt as a communications medium had two major goals. The first of these was the measurement of the propagation characteristics of the belt in sufficient detail to permit the design of possible future communications systems. The second goal was the achievement of digital data transmission at high rates consistent with the density of the dipoles in orbit. The fact that these two goals were to be achieved at the same point in time required the use of two receivers.

The receiver employed for measuring the propagation characteristics of the dipole belt was essentially of the RAKE-type and is shown in the block diagram of Figure 5-1. The tap unit (tapped delay line) outputs are used to form real-time displays of multipath envelope and doppler spectra and to derive error signals for frequency and delay tracking and for gain control. The communication receiver is essentially of the correlation type using quadrature, full wave, square law detection. The block diagram for this receiver is shown in Figure 5-2.

5.3 SPACECRAFT

Early in May 1963 a package containing 4.8×10^8 copper dipoles, each 0.00178 cm in diameter and 1.78 cm in length, was placed into a nearly circular, nearly polar orbit at a mean altitude of 3650 km. A radio command signal from the ground initiated the release of the dipoles from the package. At first the dipoles formed a rather compact cloud which, due to differential linear velocity increments imparted to each dipole, gradually spread around the orbit. After several months,

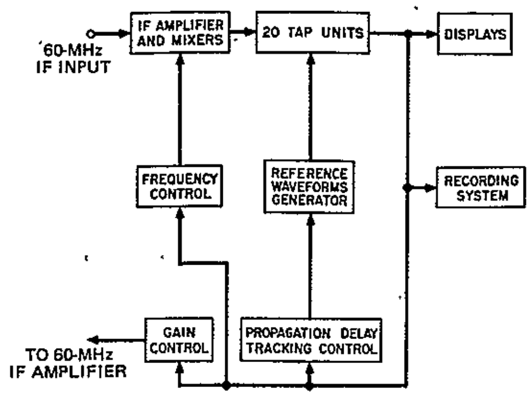

Figure 5-1. Block Diagram of Propagation Experiment Receiver

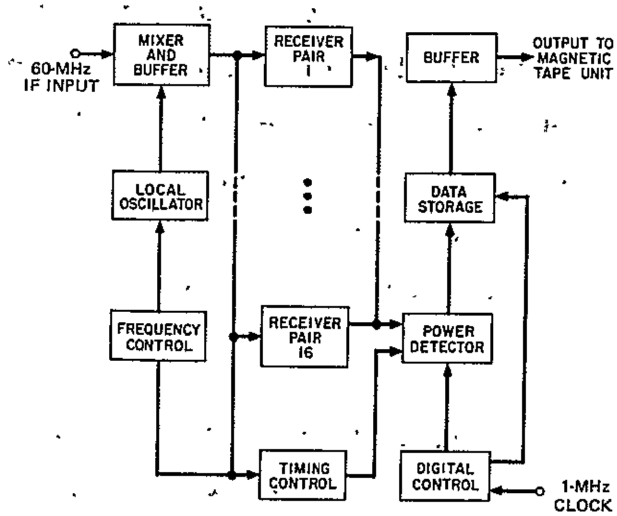

Figure 5-2. Block Diagram of Communications Receiver

the dipole distribution assumed an approximately toroidal configuration with a circumference of 63, 000 km and cross-section that varied along the orbit, with a mean width of about 15 km and a mean depth (in the orbital plane) of about 30 km. In this condition each dipole was separated from its nearest neighbor by an average distance of about 400 m. This tenuous distribution of orbital dipoles is known as the Project West Ford Dipole Belt.

The above description of the dipole belt suggests that it may be considered as a large number of approximately coorbital passive satellite reflectors. Each passive reflector spacecraft takes the form of a short-circuited dipole half-wave resonant at a frequency of 8000 MHz The half-wave dipole was selected as the elemental reflector because it achieves a large gain in scattering cross-section per unit mass (due to resonance effects). In addition, the scattering from a large number of randomly oriented dipoles is essentially nondirectional. Other passive reflectors which also achieve large gain per unit mass are available (e. g., a flat circular plate), but most are extremely directional, a severe limitation for use in a system of worldwide coverage.

As a consequence of the concern that the dipole belt might result in interference to other scientific endeavors, limiting the lifetime of the belt became an important goal of the West Ford program. As a result of extensive studies on the orbital properties of the dipole belt, it was determined that the major influence on the perigee height would be solar radiation pressure. The effect of the solar radiation pressure would be to drive down the perigee height until the orbit pierced the dense portions of the earth's atmosphere where air drag would exert an additional force to drive down the perigee height still further until the orbit intersected the earth's surface.

From an extrapolation of the time behavior of the physical cross-section of the actual belt, it was concluded that 25 percent of the individually orbiting dipoles would cease to orbit after about 2-1/2 years, 50 percent after 3 years, and 100 percent after 5 years. Thus it was expected that the orbits of all separated dipoles would decay by early 1968.

5.4 GROUND STATIONS

Two ground stations were constructed, one in Massachusetts (at Millstone Hill in West Ford) and one in California (at Camp Parks in Pleasanton) to use the dipole belt and to measure its characteristics. The ground stations can transmit and receive CW X-band communications signals simultaneously. In addition, each station can be changed within minutes to a radar capable of tracking and measuring the characteristics of the dipole belt and other satellites. The characteristics of the ground stations are presented in Table 5-2.

5.5 EXPERIMENTS

Two broad investigative programs were established for determining the feasibility of using the orbital dipole belt as a medium for global communications. The first was a measurements program for estimating the belt orbit parameters over an extended period of time, studying dispersion of the belt with time, determining the variation of dipole density along the orbit with time, and estimating the total number of dipoles. The second program, determining the properties of the dipole belt as a communications medium, had two major goals: the first was the measurement of the propagation characteristics of the belt; the second goal was the achievement of digital data transmission at high rates consistent with the density of the dipoles in orbit.

Physical measurements of the dipole belt were obtained by three distinct approaches. The first approach involved monostatic pulse radar operations to measure range, angles, and scattering cross-section. The second approach involved direct measurement of path loss for bistatic CW transmissions from one side to the other via belt scattering. The third approach involved inference concerning belt dimensions which may be made from bistatic measurements of doppler spread.

Table 5-2. Earth Terminal Characteristics

	Terminal Feature	Terminal Millstone	Terminal Camp Parks
Antenna	Type	Parabolic Reflection	Parabolic Reflection
	Aperture Size	18 m (60 ft) dia.	18 m (60 ft) dia.
	Receive Gain	60 dB	60 dB
	Efficiency	40%*	45%*
	Receive Beamwidth	0.15° at 3 dB Pts.	0.15° at 3 dB Pts.
Receive System	Type Preamplifier	Maser	Paramp
	Beamwidth	30 kHz	No Data
	Noise Temp.	60°K	200° K
Transmit System	Type Amplifier	Klystron	Klystron
	Bandwidth	30 MHz	30 MHz/30 MHz
	Amplifier Power Out	20 kW	20 kW/40kW
Tracking	Type	Computer Predicted	Computer Predicted
	Accuracy	0.01°	0.01°
Total Performance	G/T	42dB/°K*	37dB/°K*
	EIRP	132 dBm*	133 dBm *
Polarization	Transmit Feed	Circular	Circular
	Receive Feed	Circular	Circular
Installation	Radome	None	None
	Type Facility	Fixed Terminal	Fixed Terminal

*Derived value based on available data.

Measurements of the orbit parameters verified the important predictions about orbital vehavior, as, for example, the smoothing of the distribution of the dipoles around the orbit from the initial high-peaked cluster at the dispenser. In measuring orbital parameters, rms deviations normal to the orbital plane averaging 7.5 km and rms deviations in geocentric radius averaging 9.5 km were observed. The average nodal period during the first 720 revolutions (the first 80 days of belt life) was found to be 166.455 minutes. From this nodal period the average semimajor axis during this interval was computed to be 1.57 earth radii.

All three physical measurement approaches were employed in determining belt dimensions. Typical results of these measurements are summarized in Figure 5-3. In this figure, perigee and semi-latus-rectum points are marked and each point on the chart indicates the data sources, the 3-dB in-plane dimension and, except for the inferences from doppler measurements, the 3-dB out-of-plane dimension. Experimental estimates of the number of dipoles in orbit indicated that between 16 and 39 percent of the ejected dipoles were properly dispensed. It also appeared that occasionally more than one center of density developed, so that two closely spaced dipole belts were present. This situation is depicted in Figure 5-4.

Measurement of the propagation characteristics of the belt was one of the goals of the second experimental program. The dipole belt provided a channel in which signals were communicated from one point to another by scattering from a large number of dipoles in a volume of space defined by the intersection of two antenna beam patterns with the belt. Each dipole behaves like an independent scatterer, and consequently the received signal at any given time is the sum of the signals scattered by a large number of dipoles. The fact that the dipole scatters are not concentrated at a single point influences the performance of the system in detail. Specification of the received signal-to-noise ratio is not sufficient to characterize a spread channel such as the orbital dipole belt. The minimum additional information that is required to give an adequate description of the communications performance is knowledge of two parameters - multipath spread (L) and doppler spread (B) - which are measures of

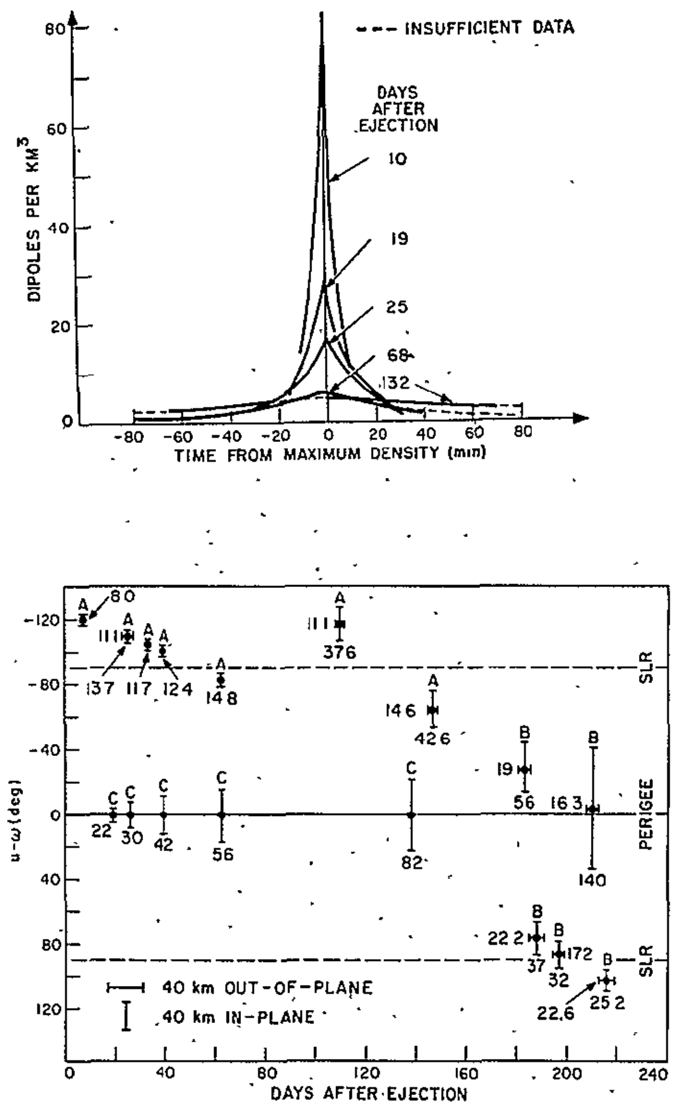

Figure 5-3. In-Plane and Out-of-Plane Belt Dimensions vs Time. A = Monostatic Radar Data. B = Bistatic Radiometric Data. C = Inference from Bistatic Doppler Data. u-w = Angle from Perigee.

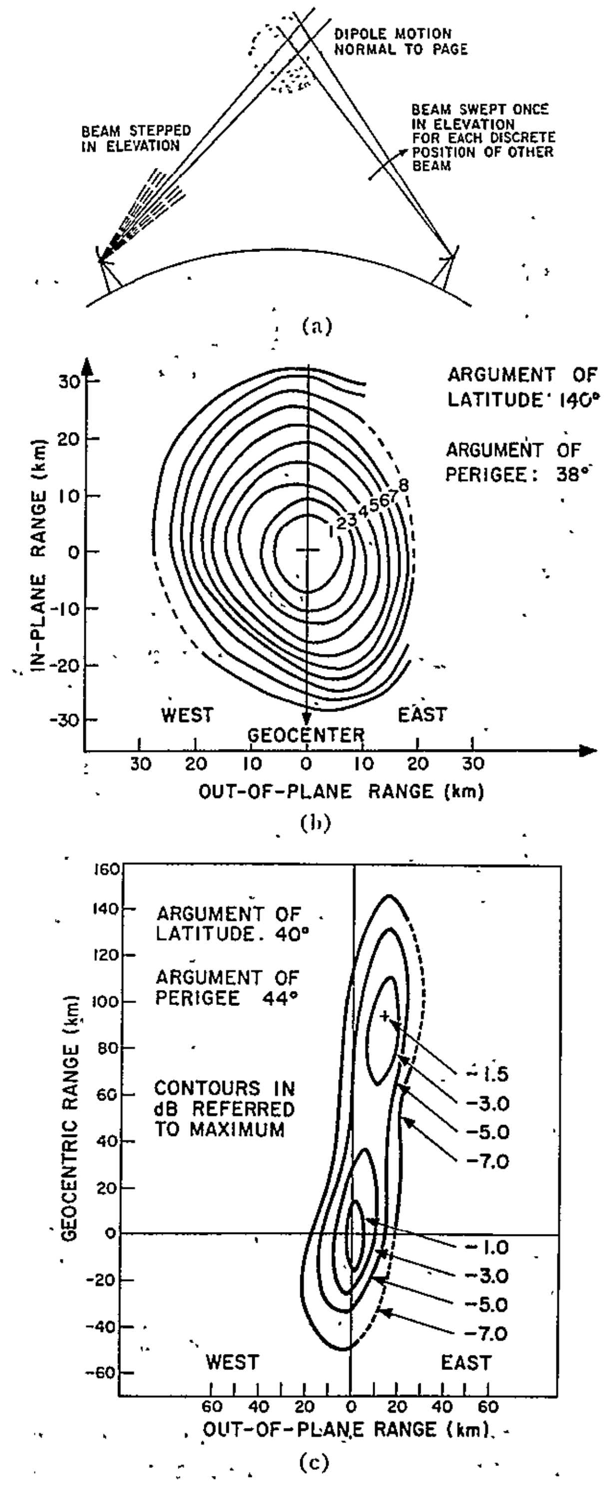

Figure 5-4. (a) Bistatic Belt Mapping. (b) Constant Density Contours (1-dB Increments) 215 Days after Ejection. (c) Contours of Constant Density 209 Days after Ejection

the channel spreading in the time and frequency domains, respectively. If the time and frequency behavior of a dispersive medium is sufficiently well-behaved, the two parameters B and L are an adequate description for the purpose of signal design. A more complete description of the dipole belt is furnished by the so-called scattering function of the medium. This is a function σ of the two variables, time τ and frequency f, and designates the scattering cross-section of the medium at propagation delay τ and doppler shift f. The scattering function of a dispersive channel, together with the spectrum of the additive noise component, constitutes a model of the channel that is sufficiently detailed to allow synthesis of optimum signals and detections and to permit comparative performance of signaling schemes.

The multipath and doppler spreads and path losses as measured by these techniques are summarized in Table 5-3. The strongest overall conclusion of the propagation experiment is that the scattering function is generally well-behaved.

Table 5-3. West Ford Dipole Belt: Channel Characterization

Date of Experiment*	Doppler Spread BW (Hz)	B X L†	Path Loss (dB)	Angle re Perigee (deg)
May 20	630	.031	203	138
May 29	680	.034	207	115
June 19	1600	.080	209	100
July 12	1800	.090	212	82
Sept. 24	2300	.11	215	77
Nov. 13	1200	.060	221	69
Nov 8	960	.048	221	27
Dec. 5	1070	.054	222	2

*Date of ejection,
†L = 50 sec (3-db width)

The second objective in the study of the dipole belt as a communications medium was the achievement of actual communication in the absence of detailed knowledge of the scattering function. Thus, the purposes of the communications experiment were the transmission of digital data, the measurement of the performance of the system, and the comparison of these results with theory. The basic communications technique employed was binary frequency shift keying (FSK) with quadrature, full-wave, square-law detection as indicated in Paragraph 5.2. In order to cope with intersymbol interference due to the dispersive nature of the channel, successive transmissions used different frequency pairs and were detected in separate receivers operating in parallel. Two message sources were available to the transmitter: a fixed word repetition and a standard 60-wpm teletype. In addition, a digitized PCM system was constructed to provide voice communication in the early stages of the experiment.

On May 14 and 15, speech was transmitted using the PCM system. The received speech was intelligible and its general quality varied as the P_R/N_o ratio fluctuated about a mean of about 53 dB. Between May 14 and June 18, eight communications experiments were performed. This covered the period of time from shortly after initial dispensing to roughly closure time. During all the experiments, therefore, the belt was incomplete and in each run that portion of the belt spanning the central densest spot was employed. The experimental results were generally in fairly good agreement with the theory. For the most part, the theory overbounned the actual error probability at most by a factor of 2. In summary, the performance of the data communications system was found to be in substantial agreement with a theory which assumed the use of an optimum receiver. This is consistent with the above result that the scattering function was adequately described by the two parameters B and L, since the signals were designed under that assumption.

5.6 OPERATIONAL RESULTS

No operational traffic was carried by this experimental system. The operational reliability of the space subsystem was quite high due to its passive nature. Finally, the operational performance of the earth terminals employed in the experiments was good, as expected.

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SECTION 6 - TELSTAR

6.1 PROGRAM DESCRIPTION

The Telstar program was conceived by Bell Telephone Laboratories for the primary purpose of demonstrating the feasibility of employing orbiting satellites for commercial communication purposes. Specific objectives were as indicated in Table 6-1.[1][2][3]

Table 6-1. Telstar Program Objectives

Number	Description
1	Demonstrate broadband transmission through communication satellites.
2	Test operational communications satellite reliabilities.
3	Obtain operational experience with satellite ground terminals.
4	Increase knowledge of satellite tracking techniques.
5	Provide scientific measurements of radiation in space.

Two active spacecraft, Telstar I and Telstar II, were successfully launched into medium altitude elliptical orbits during the course of the program as indicated by Table 6-2.[1][2] Numerous communication demonstrations and detailed experiments were successfully conducted with Telstar I during its 7-month lifetime and considerable data on radiation in the inner Van Allen belt obtained. Before Telstar I finally failed from higher than expected radiation (which had resulted from the high altitude nuclear tests), an initial malfunction of the command circuit was successfully diagnosed from the ground and the satellite was commanded back "on." This ground diagnosis represented a first in satellite communications. Program objectives were for the most part met in the Telstar I experiments. Telstar II, launched after the failure of Telstar I, extended the previous experiments and demonstrations.

Table 6-2. Participating Spacecraft

Satellite		Telstar I	Telstar II
Manufacturer & Sponsor		Bell Labs and AT&T	
Launch Date		7/10/62	5/7/63
Launch Vehicle		Delta	
Orbital Data	Apogee	5655 km (3514 mi.)	10804 km (6713 mi.)
	Perigee	953 km (592 mi.)	972 km (604 mi.)
	Inclination	44.8^{o}	42.7^{o}
	Period	158 min.	225 min.
Status		Failed 2/63 due to radiation damage to command decoders	Transmitted until 6/65

Major earth terminals participating in the program are shown in Table 6-3.[1] [2] [4-7] Satellite launchings and the collection of tracking and telemetry data through a worldwide network of Minitrack stations were provided by the National Aeronautics and Space Administration (NASA).

Probably the most important contribution of Project Telstar, to satellite communications technology, was to publicize, through numerous television demonstrations, that orbiting satellites were feasible for use in commercial communication systems. From a purely technical viewpoint, one of the most important achievements was to confirm (in basic agreement with Echo I experience) that standard transmission parameters could be employed to predict performance with no concern about multipath fading for frequencies approaching 4 to 6 GHz and ground antenna elevation angles greater than a few degrees. A second technical achievement of major importance was to demonstrate further that acquiring and tracking a moving satellite was not an overly demanding assignment for a narrow-beam communications antenna equipped with an autotrack system.

Table 6-3. Participating Earth Terminals

Location	Sponsor	Antenna Diameter (m) (ft.)	Date of Installation
1. Andover, Maine	AT&T	20.6 (67.7)	1962
2. Holmdel, N. J.*	AT&T	6.1 × 6.1 (20 × 20)	1962
3. Pleumeur Bodou, France	French Nat'l. Center for Telecommunications Studies (CNET)	20.6 (67.7)	1962
4. Goonhilly Downs, England	British General Post Office	26 (85)	1962
5. Fucino, Italy	Telespazio	9.1 (30)	1962
6. Raisting, Germany	Deutsche Bundespost	9.1/25 (30/82)	1963/ 1964

*Existing terminal with receiver modified for use with Telstar. Terminal employed a pyramidal horn reflector.

6.2 SYSTEM DESCRIPTION

The Andover terminal was the principal terminal involved in the experiments performed, with many of them being conducted on a loop-back basis. Major demonstrations were performed over a link between Andover and terminals in Europe or at Holmdel.

The satellite orbits, described in Table 6-2, were in agreement with plans to provide the maximum realizable visibility per day and per pass while employing a Delta rocket launched from Cape Kennedy. The higher apogee given to Telstar II was to reduce the amount of time spent in the most intense regions of the radiation environment, thereby minimizing damage to radiation sensitive components.

Operating frequencies in the Telstar program were as displayed in Table 6-4.[8] The communication frequencies selected were based on considerations of propagation, link noise, bandwidth, hardware available, and the feasibility of frequency sharing between commercial satellite communications and existing terrestrial services.[3] The bands selected share spectrum occupancy with common carrier line-of-site radio relay systems. The lower frequency band was selected for the downlink because of the reduced effects of precipitation and atmospheric absorption.

Table 6-4. Telstar Frequencies Employed (MHz)

Communications			TT&C		
Uplink	Downlink	Beacon	Command	Telemetry	Beacon
6389.58	4169.72	4079.72	122.9	136.05	Telemetry Carrier Used

Basic signal processing techniques utilized in the Telstar system were as indicated in Table 6-5.[8-11] Power control for multiple access was greatly improved at Andover by employing computer-derived slant range signals to vary the power amplifier output to compensate for changes in the range to the satellite. Power balancing was accomplished manually by coordinating between terminals. Margins provided had to account for variations in satellite antenna gain as a function of satellite aspect angle to the terminal and rain losses as well as various miscellaneous losses.

Table 6-5. Signal Processing Employed

Multiple Access	Frequency division for up to two carriers to support duplex operation
RF Modulation	FM
Demodulator Performance	Conventional Discriminator - Threshold at about 10 dB C/N FMFB Receiver - Threshold at about 5 dB C/N
Andover Receive Carrier-to-Noise (C/N)	13.6 dB * for maximum slant range, ** 7.5° antenna elevation angle, 1 satellite access, and 25-MHz noise bandwidth
Andover Receiver Margin	Conventional Discriminator - 3.6 dB FMFB Receiver - 8.6 dB

*Includes 0.4-dB radome loss.
**Approximately 9173 km (5700 mi.)

6.3 SPACECRAFT

Satellite characteristics for Telstar I and II are displayed in Table 6-6.(12-15) The communications repeater in both satellites was as illustrated in Figure 6-1. The basic repeater design reflects the desire to employ established technology to ensure reliability. Most of the repeater is in broad principle similar to equipment used earlier in land-based microwave systems. Storage batteries and a capability to command equipment "on" and "off" allowed utilizing a solar array too small to meet real-time power demands but within weight limitations. Spin stabilizing relative to the sun reduced temperature equalization and solar array illumination problems. However, it made the selection of an essentially omnidirectional antenna necessary.

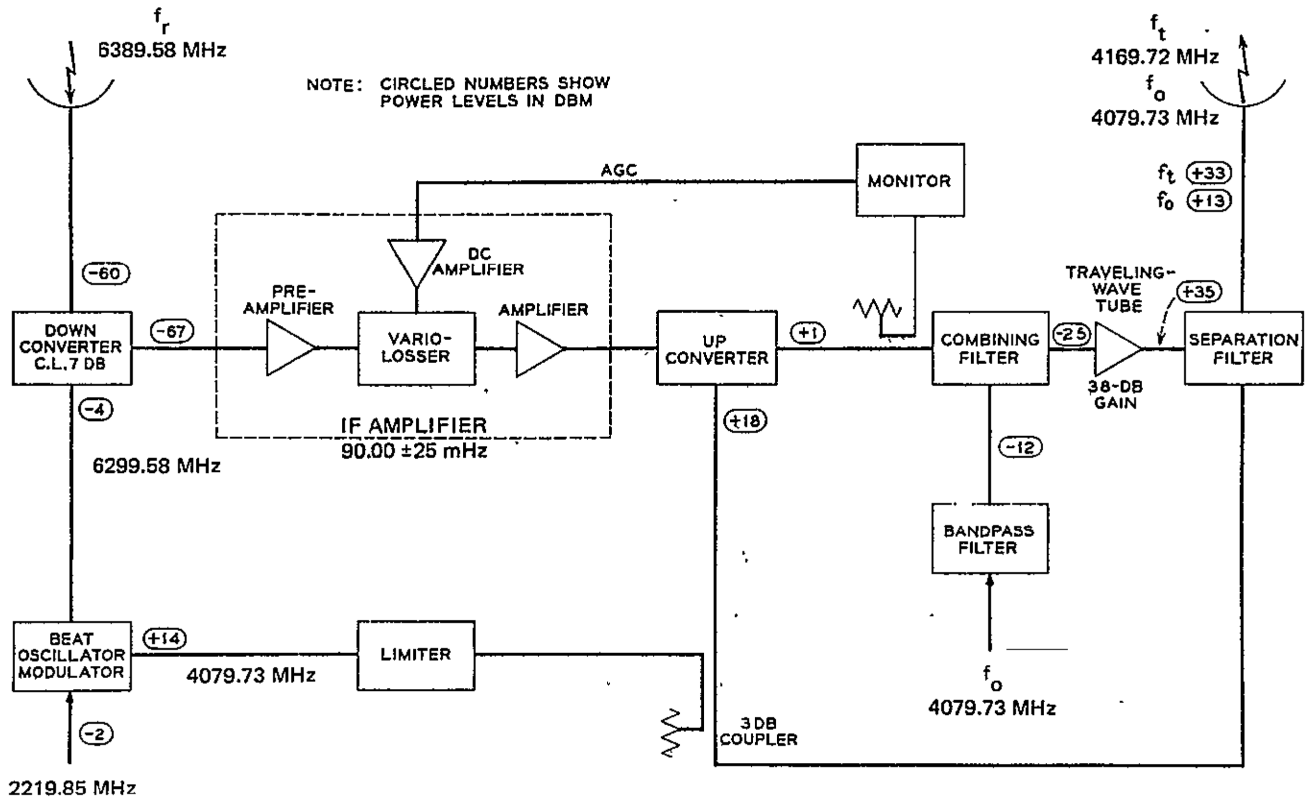

Figure 6-1. Telstar - I, II: Communications Transponder

Table 6-6. Telstar I and II Characteristics

Antennas		Type	C Band with separate multi-port xmit. & rec. girding S/C equator	VHF quadrafiler Helix for TT&C
		Number	One	One
		Beamwidth	About 120° centered on S/C equator *	Essentially Omni-directional
		Gain	0 dB	0 dB
Repeaters		Frequency Band	C Band	
		Type	IF translating with AGC of IF stage	
		Bandwidth	50 MHz at 1-dB points	
		Number	One	
	Receiver	Type Front End	Down Conversion Mixer	
		Front End Gain	7-dB conversion loss into 87 dB ** IF	
		Sys. Noise Fig.	Overall - 12.5 dB. 20 MHz centered on carrier - 16.5 $\pm$ 2 dB	
	Xmiter	Type	Single 6-watt TWT	
		Gain	37.5 dB as operated	
		Power Out	3.5 watt as operated	
	EIRP - C Band Ant.		33 dBm for 1 carrier	
General Features	Stabilization	Type	Spin with magnetic torquing coil	
		Capability	Unoriented relative to earth Normal 90° spin axis aspect to sun	
	Power Source	Primary	Solar array with 14 watts*** average output	
		Supplement****	Nickel cadmium batteries giving about 35 watts***	
	Comm. Power Needs		19 watts maximum including beacon	
	Size		Spherical with 87.6 cm (34.5 in.) diameter	
	Weight		79.4 kg (175 lbs.)	

* Pattern reasonably uniform with smooth dropoff to 6 dB down over $\pm$ 60° from spacecraft (S/C) equator. Deep nulls beyond this.

** Nominal gain varied by AGC.

*** At launch.

**** Furnishes power during peak loads and eclipses.

6.4 GROUND TERMINALS

Primary earth terminals participating in Project Telstar were listed in Table 6-3. Major characteristics of the predominant participating terminals are described in Table 6-7.[(4-7) (17-26)] For communication purposes, circular polarization, corresponding to that of the satellite, was employed at all terminals. This choice avoids the difficulties that Faraday rotation in the ionosphere could present. All of the terminal designs reflect an intense prevailing interest in reducing receive system noise to the very minimum and accurately tracking a moving satellite.

The Andover terminal included three separate tracking antennas with their individual associated autotrack systems in addition to a capability for computer-derived programmed tracking. The autotracking systems were all, broadly speaking, of the monopulse type. Major subsystems of the Andover terminal are shown in the block diagram of Figure 6-2.

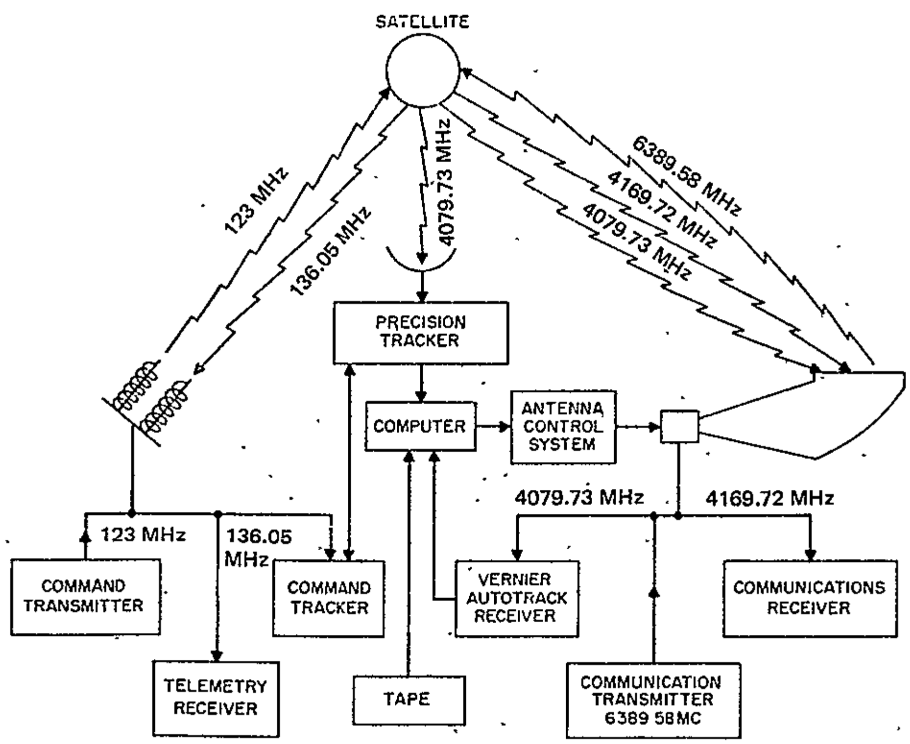

Figure 6-2. Major Subsystems of the Andover Terminal

Table 6-7. Characteristics of Major Earth Terminals

	TERMINAL FEATURE	TERMINAL		
		ANDOVER*	HOLMDEL	GOONHILLY DOWNS
ANTENNA	Type	Conical Horn Reflector	Pyramidal Horn Reflector	Parabolic Reflector
	Aperture Size	21 m (68 ft) Dia.	6.1 m x 6.1 m (20 ft x 20 ft)	26 m (85 ft) Dia.
	Receive Gain	58 dB	48 dB	55.6 dB
	Efficiency	70 – 75%	70 – 75%	Approx. 30%
	Rec. Beamwidth	0.23° @ 3 dB Pts.	0.78° @ 3 dB Pts.	0.2° @ 3 dB Pts.
RECEIVE SYSTEM	Type Preamplifier	Traveling Wave Ruby Maser	Maser	Traveling Wave Maser
	Bandwidth	25 MHz @ 3 dB Pts.	20 MHz @ 1 dB Pts.	25 MHz @ 3 dB Pts.
	Noise Temp.	32°K** @ 90° El.	17°K @ 90° El.	55°K @ 90° El.
TRANSMIT SYSTEM	Type Amplifier	Traveling Wave Tube	No Transmissions Employed	Traveling Wave Tube
	Bandwidth	32 MHz @ 1 dB Pts.		100 MHz @ 3 dB Pts.
	Amp. Pwr. Out	2 kW		5 kW
TRACKING	Type	Autotrack by Command Tracker, Precision Tracker, or Vernier Tracker by Separate Antenna.	Predicted Look Angles plus Manual Correction of Errors Detected on Separate 6-m (18-ft) Dish Tracker.	Programming Tracking
	Accuracy	Command Track $\pm 1^{\circ}$ Precision Track $\pm .01^{\circ}$ Vernier Track $\pm .005^{\circ}$	As good as $\pm 0.05^{\circ}$ can be obtained.	Approximately 0.1°
TOTAL PERFORMANCE	G/T	40.7 dB/$^{\circ}$K	36 dB/$^{\circ}$K	38 dB/$^{\circ}$K
	EIRP	123 dBm	None	Approx. 123 dBm
POLARIZATION	Transmit Feed	Circular	Circular	Circular
	Receive Feed	Circular	Circular	Circular
INSTALLATION	Radome	64.0-m (210-ft.) Diameter Pressurized to 12.1×10^{2} newton/meter^{2} (0.175 lb/in.^{2})	None	None
	Type Facility	Fixed Terminal	Fixed Terminal	Fixed Terminal

*The terminal at Pleumeur Bodou has essentially the same characteristics.
**The noise temperature at a 7.5° elevation angle is about 50°K.

The Holmdel terminal, originally built for Project Echo, included a glint telescope to determine the orientation of the satellite's spin axis and the spin rate. Determinations were made by observing the flashes of sunlight reflected from the three mirrors mounted on the satellite's surface.

6.5 EXPERIMENTS

The experiments conducted on the Telstar project can be grouped into four major categories as displayed and defined in Table 6-8. The radiation experiments, described in the table, contributed considerable data towards characterizing the particles within the inner and outer Van Allen belts. Additionally, valuable knowledge of the effects of radiation upon solid-state devices (i.e., upon solar cells and transistors) was gained. The most spectacular radiation experiment result, however, was the discovery, from the data on Telstar I, that high altitude nuclear testing dramatically intensified the radiation environment in the Van Allen belts.[2][27]

The space experiments, defined in Table 6-8, monitored such items as attitude of the spacecraft spin axis in inertial space, spin rate, temperatures at the spacecraft surface and of critical internal components, satellite RF power levels, and variations in spacecraft circuitry and components. Changes in spin axis attitude, due to the residual magnetic moment of the spacecraft, were recorded. Spin rate decay, resulting from eddy currents generated in the satellite as it rotates in the earth's magnetic field, was observed. The decay was greater on Telstar I because of its lower orbit. Skin temperatures varied between about 247° K (-15° F) and 278° K (40° F).

Table 6-8. Summary of Program Activities

Type Activity	Program Objective Satisfied *	Nature of Activity
1. Radiation Experiments	5	Measure electron and proton spectrums** and spatial distributions as a function of time. Evaluate radiation damage to solid state devices as a function of shielding.
2. Space Experiments	2	Measure spacecraft performance under launch and space stresses.
3. Communication Demonstrations	1	Display broadband transmissions by satellite comparable to conventional commercial transmissions.
4. Communication Experiments	1	Evaluate technical performance of broadband satellite communications.

* Program objectives are numbered and defined in Table 6-1.

** Radiation spectrums characterize the number of particles per unit volume as a function of particle energy level.

Internal temperatures varied between about 289° K (60° F) and 300° K (80° F). The radiated RF power was observed to remain constant as a function of time. The only significant changes observed in circuitry or components were a degradation of solar cell output and the failure of several transistors within the command decoder of Telstar I. Both of these changes were a result of the radiation encountered.

The communication demonstrations, mentioned in Table 6-8, included a variety of tests whose descriptions and results are indicated in Table 6-9. (29)(30) More than 400 demonstrations were conducted in the Telstar program. (31)

Table 6-9. Telstar I and II Communication Demonstrations

Type Demonstration	Nature of Results Obtained
1. One-way monochrome TV	Highly successful. Some loss of picture definition due to baseband bandwidth limitations* in ground terminals. At maximum range, weighted signal-to-noise somewhat less than for normal Bell System commercial service. Transients from camera-switching at originating studios caused noise bursts in received signals.
2. One-way color TV**	With no audio transmitted*** and spacecraft at short to moderate ranges, high quality pictures were obtained.
3. Two-way monochrome TV	Audio signals transmitted in both directions with definite reduction in quality. Picture quality about 20 dB**** poorer than for one-way transmissions.
4. One-way 600 telephone channels	Amount of noise in poorest telephone channel about 6 dB more † than for CCIR commercial grade circuits.
5. Two-way 12-channel telephony	Poorest channel typically had noise performance about equal to that for 600 telephone channel transmissions. Crosstalk between carriers was no problem.
6. High- and low-speed data including facsimile	Data rates from those for 60-wpm teletypewriter signals to 875 kbps were tried. Test results satisfactory to excellent compared to results obtainable on a 6437-kilometer (4000-mile) microwave radio relay system. Changes in absolute time delay caused some timing problems for high-speed data and facsimile. Doppler shift caused some distortion in low-speed data signals.

Notes:
* Filtered to about 2 MHz to allow audio signal to frequency modulate a 4.5-MHz aural subcarrier.
** A color program demonstration with audio was conducted in early January 1963 in which the audio modulation was inserted during the time interval reserved for horizontal blanking.
*** No baseband filter employed.
**** About 16 dB of degradation due to reducing peak frequency deviations from 7 MHz to 1 MHz. Remaining degradation from reduced satellite transmitter power per carrier.
† When satellite is at maximum range.

The communication experiments, noted in Table 6-8, are defined in detail in Table 6-10.[29][30][8] This table includes the general results obtained. In considering received carrier power fading measurements, note that the horizons at Andover and Goonhilly are at about 2° and 0.5° in elevation, respectively. Most of the impairments to signal transmission were determined to be caused by the ground terminals. In addition to the tests mentioned in Table 6-10, a time synchronization test was conducted.[29] Precision atomic clocks in the USA and UK were compared by transmitting pulses simultaneously in both directions. The accuracy of the method was believed to be about 20 μs and a difference in clock time of 2 milliseconds was found.

6.6 OPERATIONAL RESULTS

No operational traffic was handled during this program due to its experimental nature. However, the operational performance of the system, as the various experiments were conducted, was of considerable interest as indicated by Program Objectives 3 and 4 listed in Table 6-1. Operational performance of the two satellites was as discussed in the description of program experiments in Paragraph 6.5. The ground complex operations displayed that satellite communications ground terminals of satisfactory reliability to provide continuous commercial service were feasible. The performance demonstration included showing a capability for dependable satellite acquisitions and accurately tracking moving satellites. Satellite tracking turned out to be less difficult than expected and special purpose tracking antennas were determined not necessary. Perhaps the most spectacular ground operational result was produced by the malfunction of the command circuit on Telstar I on November 24, 1962.[32] Subsequent ground diagnosis and attempts to revive the spacecraft resulted in its being successfully commanded "on" again on January 3, 1963. This was a first in satellite communications. The ability to devise revised command signals to bypass radiation damaged transistors in the command decoder were instrumental in the successful results obtained.

Table 6-10. Telstar I and II Communication Experiments

Type Experiment	Nature of Results Obtained
1. Received Carrier Power	Measured values, in general, agreed with predicted values when range and spin axis aspect angle of satellite are taken into account. Variations in received power clearly showed satellite rotation, changes in aspect angle and changes in range. No noticeable multipath fading observed at Andover for elevation angles above about 4° or at Goonhilly for elevation angles above about 3°.
2. Frequency Responses	Baseband response essentially flat up to 5 MHz when conventional FM receiver was used. For FMFB receiver response flat up to 3 MHz. All of response limitations appeared to be due to ground terminal equipment employed.
3. Noise	Baseband noise performance, for various signals employed, defined in Table 6-9. Measurements for impulse noise indicated only random thermal noise present. Satellite repeater noise spectrum on Telstar I observed to display considerable peaking around communications carrier frequency. This gives effective noise figure over 20 MHz of about 16.5 dB ±2 dB.
4. Amplitude and Phase Distortion	Measurements of envelope delay, differential gain and phase, and intermodulation noise taken. Performance measured for television and 600-channel telephony indicate objectives* for these measurements met. Additionally, no audio to video crossmodulation interference observed and video to audio crossmodulation not significant.
5. Doppler Shift	Measured and calculated curves of Doppler shift agreed within 1 kHz over period of about 45 mins.
6. Absolute Delay	Measured and calculated delay agreed within about 20 μsec.

*Objective for intermodulation noise is maximum 36 dBrn total at 0-dB transmission level divided among various sources. Delay distortion objective corresponds to a differential phase of 4.2°, which is within 5° requirement for N. T. S. C. color television.

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SECTION 7 - RELAY

7.1 PROGRAM DESCRIPTION

The Relay Program was conceived and implemented under the auspices of NASA/Goddard Space Flight Center (GSFC), beginning in 1960. The objectives of the program were:

1. To demonstrate the feasibility of relaying wideband communication signals between ground stations via satellite relays in low altitude orbits
2. To evaluate spacecraft performance and to test the life of communication satellite system components in the orbital environment, and
3. To measure the amount of radiation encountered, its effect on solar cells and diodes, and the effectiveness of various amounts of shielding.

The spacecraft for this program were designed and manufactured by Astro-Electronics Division of the Radio Corporation of America, based on system engineering studies by Thompson-Ramo-Wooldridge Systems Group. The Relay program was directed by NASA (GSFC).

Two active satellites, Relay I and Relay II, were successfully launched into medium altitude elliptical orbits. Relay I was launched on December 13, 1962, and Relay II on January 21, 1964. The orbital parameters for both spacecraft are shown in Table 7-1. Relay I and II were basically of the same design, although certain modifications were introduced into Relay II based on operating experiences with Relay I. These modifications included the use of n-on-p instead of p-on-n solar cells and changes in the wideband repeater high-power regulator circuitry.

The primary earth terminals participating in the Relay Program are listed in Table 7-2. Tracking and telemetry data were provided by the NASA worldwide network of Minitrack stations.

Table 7-1. Participating Spacecraft

Satellite		Relay I	Relay II
Manufacturer & Sponsor		Radio Corporation of America/NASA	
Launch Date		12/13/62	1/21/64
Launch Vehicle		Thor-Delta	Thor-Delta
Orbital Data	Apogee	7422 km (4612 mi.)	7413 km (4606 mi.)
	Perigee	1318 km (819 mi.)	2089 km (1298 mi.)
	Inclination	47.5°	46.3°
	Period	185 min.	195 min.
Status		Last Useful Operation of Transponder: 2/10/65	Last Useful Operation of Transponder: 6/9/67

Perhaps the most significant contributions to space communications from the Relay Program were due to the observed malfunctions of the spacecraft. Major difficulties included the power regulator failure on Relay I and a satellite command receiver susceptibility to spurious signals. As a result of the power regulator failure, it was recognized that dew point criteria and leakage tests had to be included in all future power transistor procurement specifications and that equipment should be tested throughout the temperature range, rather than at specific maximum, minimum, and typical values. The command receiver spurious responses resulted in a recommendation that more complex command signals be designed for all future spacecraft.

7.2 SYSTEM DESCRIPTION

The Relay system consisted of the orbiting satellite, the complex of participating ground and test stations, the Operations Center, and GSFC supporting activities. The satellite itself was basically a microwave repeater which received frequency modulated communication signals on 1725 MHz for translation to 4170 MHz

Table 7-2. Primary Earth Terminals Participating in the Relay Program

Location	Sponsor	Date of Installation	Antenna Diameter (m) (ft.)
Andover (Maine)	AT&T	1962	20.6 (67.7)
Nutley (N.J.)	IT&T	1963	12 (40)
Goonhilly Downs (England)	General Post Office	1962	26 (85)
Fucino (Italy)	Telespazio	1962/1965	9.1/13 (30/44)
Rio de Janeiro (Brazil	Radio International de Brazil	1963	9.1 (30)
Raisting (Ger.)	Deutsche Bundespost	1963/1964	9.1/26 (30/85)
Ibaraki (Japan)	Kokusai Denshin Denwa Co.	1963	20 (65)
Kashima (Japan)	Radio Research Laboratories		30.5 (100)
Pleumeur Bodou (France)	Centre National d'Etudes des Telecommunications (CNET)	1962	20.6 (67.7)
Rao (Sweden)	Scandinavian Committee for Satellite Telecommunications (STSK)	1966	26 (85)
Griñon (Spain)	Compania Telofonica Nacional de España	1964	26 (85)
Mojave (Calif.)	NASA	1960	12 (40)

and retransmission. In the translating process the modulation index was tripled to compensate for the bandwidth limitations of the earth terminal klystron transmitters. The repeater transmitted one-way television signals, when operated in the wideband mode, and 12 simultaneous two-way telephone conversations when operated in the narrow-band mode. In addition to a redundant wideband communication system, the spacecraft had a radiation experiment package, electrical power system, command and telemetry system, and supporting structure. Satellite operating frequencies are given in Table 7-3. The characteristics of the spacecraft and the ground stations are described in Sections 7.3 and 7.4, respectively.

Table 7-3. Project Relay Frequencies (MHz)

Communications			TT&C		
Xmit. Mode	Uplink	Downlink	Beacon	Command	Telemetry
Wideband	1725.0 ± 7.0	4169.7 ± 11.5			
Narrowband	1723.3 ± 0.5 1726.7 ± 0.5	4164.7 ± 1.5 4174.7 ± 1.5	4080	148	136

The orbital parameters for both Relay I and II are described in Table 7-1. The orbit was selected to meet the following requirements:

1. To maximize satellite mutual visibility above a 5-degree horizon between U.S. and Europe. A minimum of 100 minutes per day during the first 30 days was the achieved design objective
2. To provide acceptable mutual visibility times for the test stations and smaller ground stations
3. To traverse a radiation environment suitable for evaluation by the on-board radiation experiments
4. To minimize the simultaneous occurrence of mutual visibility times and eclipses

5. The sun look angle was to lie between 90 $\pm$ 15 degrees for the first 30 days in orbit with a maximum deviation of $\pm$ 31 degrees for a year's orbit

6. The launch trajectory was to be consistent with the range safety requirements at the Atlantic Missile Range.

Relay II was launched into a slightly higher orbit because of improved launch vehicle performance.

7.3 SPACECRAFT

Except as noted, the Relay I and Relay II spacecraft exhibited no essential differences. The principal characteristics of the spacecraft are presented in Table 7-4. Two completely independent microwave transponders were provided for increased reliability; their configuration is shown in Figure 7-1. Two modes of operation were available with the transponder. The wideband mode was utilized for one-way wideband communications such as television or 300 channels of telephony. The narrowband mode was utilized for two-way communications such as 12-channel two-way telephony. In the narrow-band mode, two ground stations could communicate with each other, one transmitting on 1723.33 MHz, the other transmitting on 1726.67 MHz. The spacecraft transponder converted these frequencies to 4165 MHz and 4175 MHz, respectively. As noted previously, the modulation index was tripled to compensate for the bandwidth limitations imposed by the earth terminal klystron transmitters.

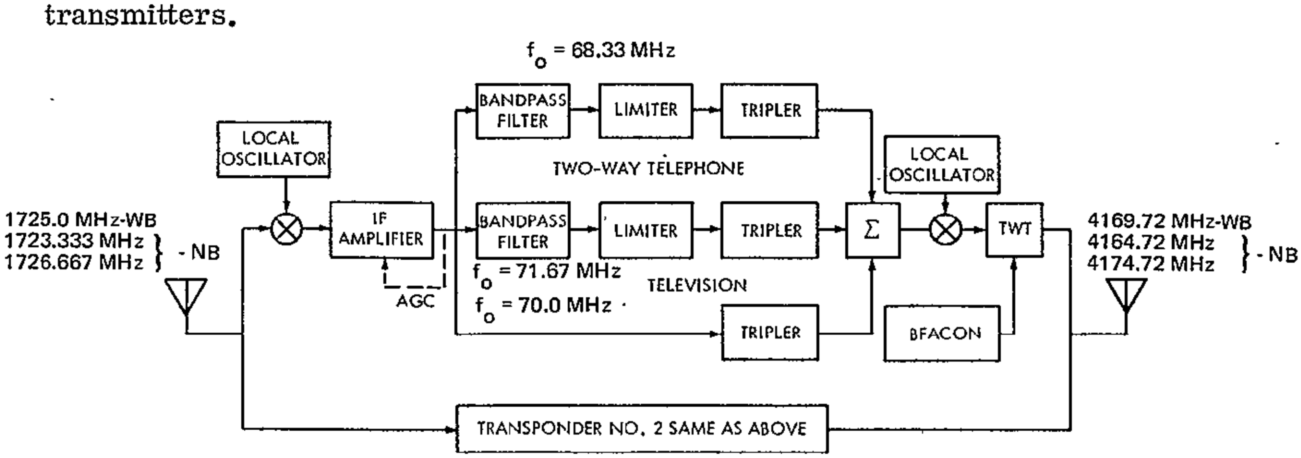

Figure 7-1. Relay - I, II: Communications Transponder

Table 7-4. Satellite Characteristics

Antennas		Type	L,C-Band slotted wave-guide, separate trans-mit and receive	VHF 4 Monopole Array for TT&C
		Number	One	One
		Beamwidth	75° in any place thru the spin axis	Essentially Omnidirectional
		Gain	-1 dB (transmit and receive)	Approximately -1dB
		Polarization	Circular: RHP (receive), LHP (transmit)	Linear in plane parallel to spin axis
Repeaters		Frequency Band	L,C-Band	
		Type	IF Translating	
		Bandwidth	34 MHz @-1 dB Points (Wideband Mode); 2 MHz @-3 dB Points (Narrow-band Mode)	
		Number	Two (Including one spare)	
	RCVR	Type Front End	Down Conversion Crystal Mixer	
		Front End Gain	6 dB Conversion Loss into IF followed by a limiter	
		System Noise Figure	Overall: 13 dB	
	XMTR	Type	Single 11 watt TWT	
		Gain	36 dB	
		Power Out	10 watt	
General Features		EIRP - Microwave	9dBW*	
	Stabil-izator	Type	Spin with Magnetic Torquing Coil, 160 RPM	
		Capability	Unoriented relative to Earth, nominal 90° spin axis aspect to sun	
	Power Source	Primary	Solar Array with 61 watts average output.	
		Supplement	Nickel Cadmium Batteries, each cell having about 3-ampere hour capacity.	
		Comm Power Needs	87 watts	
		Size	Basically Cylindrical, 76 cm (30") diameter, 132 cm (52") height	
		Weight	79.4 kg (175 lbs.)	

*Derived value based on antenna gain and transmitter output power.

The microwave antennas were circularly polarized biconical horns with nominally omnidirectional patterns about the spin axis to prevent amplitude modulation. Vertical coverage (in the plans of the spin axis) extended from 40 to 115 degrees (-1 dB points). In addition, this particular antenna system provided decoupling between the two transmitters and receiver of the spacecraft without any switches, thereby reducing losses and increasing reliability. Further details on the microwave antenna can be found in Appendix 7-A.

The VHF antenna consisted of 4 monopoles extending out from the bottom mounting ring face of the spacecraft. For command reception the antenna elements were fed in phase to produce a dipole-like pattern; while for telemetry and tracking transmission they were fed pairwise in phase quadrature to produce a circularly polarized wave in the plane perpendicular to the spin axis. In any planes parallel to the spin axis the wave was linearly polarized.

All spacecraft power was generated by solar cells. Storage batteries charged by the solar cells were used to supply the peak power necessary for repeater operation. On Relay I the solar cells were boron-doped silicon cells, p-on-n, gridded and covered with 60-mil thick fused sheets. To decrease solar cell degradation due to radiation, n-on-p cells were used on the solar array of Relay II.

In addition to the communications repeaters, and other subsystems needed to support the principal mission of Relay, the spacecraft carried a group of components to obtain data on particle radiation in space. These consisted of six radiation detectors and a collection of isolated solar cells and semiconductor diodes. The latter were accumulated on a "radiation-damage-effects" panel.

7.4 EARTH STATIONS

Some of the major earth stations participating in Project Relay are described in Table 7-5 in terms of their basic characteristics. In the Relay system, the stations at Nutley and Mojave were designated as Test Stations and, as such, had prime responsibility to command the satellite and monitor telemetry. Other stations participating in the program under agreements with NASA were designated as Ground

Table 7-5. Earth Terminal Characteristics

	Terminal Feature	TERMINAL			
		Andover	Nutley/Mojave	Fucino No. 1	Raisting No. 2
Antenna	Type Aperture Dia. Receive Gain Rec. Beamwidth (3 dB) Efficiency	Conical Horn Refl. 20.6 m (67.7') 58 dB 0.23° 70-75%	Parabolic Refl. 12 m (40') 49.1 dB 0.45° 30%*	Parabolic Refl. 9.1 m (30') 48.7 dB 0.55° 45%*	Parabolic Refl. 26 m (85') 57.5 dB 0.20° 45%*
Receiver System	Type Preamplifier Bandwidth Noise Temp.	TW Ruby Maser 25 MHz 32°K/Zenith	Uncooled Paramp 25 MHz 360°K	Cooled Paramp 25 MHz 220°K/Zenith	T.W. Maser 25 MHz 54°K/7.5° elev.
Transmit System	Amplifier Type Bandwidth Power Output	Klystron No Data 10 kW	Klystron No Data 10 kW	TWT 25 MHz 2 kW	TWT 25 MHz 2 kW
Tracking	Type	Autotrack by Command Tracker, Precision (Beacon Tracker, or Communicator Antenna	Programmed Tracking, Monopulse	Programmed Tracking, plus Monopulse	Computer Tracking Monopulse
	Accuracy	Command Tr. ± 1° Precision Tr. ± 0.02° Comm. Ant. ± .005°	Prog.Tr. ± 0.1° Monopulse ± 0.1°	No Data	Computer Tracking ± 0.01° Monopulse ± 0.003°
Total Performance	G/T EIRP	41dB/°K* 120 dBm*	23.5dB/°K* 111 dBm*	25.3 dB/°K* 104 dBm*	40 dB/°K* 112 dBm*
Polarization	Transmit Feed Receive Feed	Circular Circular	Circular Circular	Circular Circular	Circular Circular
Installation	Radome Type Facility	64.0 m (210' Diameter, Rubberized Dacron Fixed Terminal	None Transportable	None Fixed Terminal	48.8 m (160') Diameter, Rubberized Dacron, None Fixed Terminal

*Derived value based on data available.

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Stations. It should be noted that although the Nutley Test Station employed the same communications antenna, they were separate operations.

The Communications Satellite Operations Center was established to handle experimental scheduling, daily operations planning, and data processing. This center also provided a centralized command post to exercise control over the satellite. Supporting activities included telemetry data processing, orbital prediction, and satellite tracking information.

7.5 EXPERIMENTS

Each of the participating stations was asked to submit a detailed experiment plan concerning those tests in which that particular station would participate. The communications experiments were divided into three classifications: wideband performance experiments, narrowband performance experiments, and system demonstration experiments. System performance experiments - wideband and narrowband - were intended as objective tests to obtain quantitative and statistical data on the electrical parameters of the system by analyzing the response to carefully controlled executions. The various major types of experiments prepared for the Relay program are outlined in Table 7-6. Details of the experiments were given in the Relay Communications Experiment Plan (RI-0521A). This plan gave the general purpose and description of the individual experiments, and the test procedures for each of the stations.

In order to make the most effective use of the entire Relay system, which included the complex of participating earth stations as well as the satellite, it was necessary to schedule the communications experiments with some care. Experiment schedules were initially planned over a 1-month period. It was found useful early in the program to assign operational days during each week to designated stations, with the days assigned arbitrarily. Examination of orbital data would then indicate which passes on each day were usable for the station designated for that day.

For detailed experimental results the reader is referred to the bibliography. General conclusions were as follows:

Table 7-6. Major Relay Communication Experiments

I. Wideband Performance Experiments

A. Received Carrier Power

B. Insertion Gain Stability

C. Noise Measurements: Continuous random, impulsive, periodic, baseband, ground terminal IF, and satellite noise

D. Linear Distortion: Field-time, line-time, and short-time distortion plus amplitude-frequency and phase-frequendy characteristic at both baseband and RF.

E. Nonlinear Distortion: Differential gain, envelope delay, synchronization nonlinearity, audio distortion, and intermodulation noise

F. Interference

G. Special Transmission Tests: Doppler shift, absolute delay, and tracking accuracy

H. Television Test Patterns: Monochrome and color.

II. Narrowband Performance Experiments

A. Received Carrier Power

B. Insertion Gain Stability

C. Noise Measurements: Continuous random, impulsive, periodic and satellite noise

D. Linear Distortion: Amplitude-frequency and phase-frequency at baseband

E. Nonlinear Distortion: Envelope delay, intermodulation noise, and intelligible crosstalk

F. Interference

G. Special Transmission Tests: Doppler shift, absolute delay, tracking, clock pulse synchronization, and multiple loop.

III. System Demonstration Experiments

A. Television: Monochrome, color, and narrowband

B. Telephony: One-way and two-way

C. Digital Data Transmission: High and medium rate

D. Program Material: Music

E. Satellite vs. Conventional Communications Comparison: Teletype, facsimile, and high-rate teletype

F. Multiple Satellite Tests.

1. Television - No appreciable degradation of the signal could be attributed to the satellite except for the expected noticeable increase in noise. The received pictures at Pleumeur Bodou were always of excellent quality and were often transmitted over the European network. At Goonhilly Downs good quality of the satellite video channel was obtained; multipath and echo signals were imperceptible. Further, doppler frequency shifts are observed to have no effect on the quality of the received monochrome video signal.

2. Telephony - Links were always excellent with respect to the contact established and noise in the telephone channels.

3. Facsimile - Some deformation (skew) caused by the variation in propagation time during the transmission could be seen. For photographs lacking in fine detail the effect was tolerable; for newspaper pages or drawings the effect could be sufficiently large to be troublesome.

4. Radiation Experiment - The n-on-p solar cells were shown to be more resistant to radiation than p-on-n cells. Some mapping of the electron and proton fields in the Relay orbit was also accomplished.

7.6 OPERATIONAL RESULTS

The objectives of the Relay program were entirely experimental in nature; therefore, no operational traffic was handled. The program was extraordinarily successful with malfunctions in either the satellites or ground complex being infrequent. However, it was not entirely free of operational difficulties. Most troublesome was an inability to turn off one of the high power regulators and its associated wideband repeater on Relay I. Analysis indicated that excessive reverse leakage current in the high power regulator series pass transistors prevented the regulator from being shut off. The cause of this excessive reverse leakage current was apparently moisture precipitating on the active surface of the transistor as the junction temperature passed through the transistor's dew point temperature. After about 12 months operation the problem seemed to disappear, perhaps due to the evaporation of the condensation into the vacuum of space. In addition, spurious responses by the spacecraft were observed rather frequently by noting the satellite equipment being turned on and off in the absence of ground commands.

APPENDIX 7-A. THE RELAY MICROWAVE ANTENNA

The microwave antenna requirement for the Relay spacecraft included:

1. Omnidirectional pattern about the spin-axis

2. Coverage from near 35° to 120° in zenith angle as measured from the spin axis

3. Circular Polarization

4. Sufficient decoupling between the two Relay transmitters to prevent the inactive one from loading the active one

5. Sufficient decoupling between transmitters and receiver.

These requirements were met in a unique slotted waveguide antenna designed by O. M. Woodward of RCA. The transmitting portion of the antenna was comprised of five parts: the mode transducer, the coaxial wavequide transmission line, the quarter-wave plate, the inclined-slot exciters, and the radial waveguide. The mode transducer consists of two de-coupled input ports near the base of the antenna. With this the input coaxial TEM mode line can feed the coaxial TE_{11}-mode waveguide transmission line. The two input ports were oriented at right angles so that the TE_{11} modes excited in the coaxial waveguide would be orthogonal. In addition, the transmitter ports were one guide wavelength apart to reduce direct cross-coupling between them. To provide still further isolation, a quarter-wave plate consisting of two longitudinal metal ridges attached on opposite sides of the coaxial waveguide inner conductor was employed to convert the linearly polarized waves from the separate input ports to circularly polarized waves of opposite rotational sense. The radiator itself consisted of eight slots inclined at an angle of 55° and equally spaced about the outer conductor. Because the radial and tangential components of the field radiated by these slots were observed to be inphase, a radial waveguide, constructed from two parallel metal discs, was employed to obtain the quadrature phasing required for circularly polarized radiation. The phase velocity of the axial component was unaffected by these discs. The phase velocity of the tangential component, however, was a function of the spacing. Hence, by proper choice of spacing and diameter, a differential phase-shift of 90° between these two components was obtained, to produce circular polarization of the plane normal to the spin axis.

The receiving portion of the antenna consisted of three parts: the transmission line, the inclined radiating slots, and the radial waveguide. Only a single port antenna was needed for reception as the two receivers were joined in parallel. The receiving antenna was mounted above the transmitting antenna and connected to the receiving port by a coaxial transmission line residing interior to the coaxial line of the transmitting antenna. The receiving radial waveguide acts similarly to that of the transmitter in causing a 90° phase shift between the orthogonal, axial and tangential, electric-field components. The slots are oppositely inclined to those of the transmitter, resulting in opposite sense, circular polarization.

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SECTION 8 - SYNCOM

8.1 PROGRAM DESCRIPTION

A spin-stabilized synchronous communications satellite was first proposed by Hughes Aircraft Company in the autumn of 1959.[1] Project Syncom was initiated as a joint NASA/DOD development in August, 1961. The major objectives of this program were to develop the capability of launching satellites into earth synchronous orbits and to demonstrate the utility of this type of orbit for satellite communications.[2]

Three spacecraft were launched during the course of completing Project Syncom, as indicated in Table 8-1.[4] [5] [6] Syncom I went totally silent during the firing of its apogee motor in an attempt to complete injection into a synchronous inclined orbit. Subsequent optical sitings revealed that the desired orbit was attained to partially satisfy the program objectives. Syncom II was successfully launched into a synchronous inclined orbit and initially positioned over Brazil at 55° W. longitude. It was later moved to a final location over the Indian Ocean. Numerous experiments and demonstrations were conducted to satisfy all program objectives. Subsequent to the initial successful operations with Syncom II, the Thrust Augmented Delta rocket became available, making possible further improvements in the synchronous orbit injection technology. This launch vehicle allowed Syncom III to be successfully placed into a synchronous equatorial orbit (i. e., a geostationary orbit). The satellite was positioned over the Pacific International Date Line and additional communications measurements and demonstrations were conducted. With all of the Syncom programs' experimental objectives attained, Syncoms II and III were turned over to DOD in early 1965 to provide an operational communications capability serving the Far East, Pacific Ocean and Western United States. This continued until the first worldwide military satellite communications system became operational and was able to assume the communications load (see Section 12).

The principal earth terminals involved in the program were supplied by the U.S. Department of Defense and are indicated in Table 8-2.[3] [4] [6-11] Satellite

Table 8-1. Participating Spacecraft

Satellite.	Syncom I	Syncom II	Syncom III
Manufacturer & Sponsor	Hughes Aircraft & NASA		
Launch Date	2/14/63	7/26/63	8/19/64
Launch Vehicle	Delta		Thrust Augmented Data
Orbital Data*			
Apogee	36,980 km (22,978 mi.)	36,629 km (22,760 mi.)	36,355 km (22,590 mi.)
Perigee	34,126 km (21,205 mi.)	35,521 km (22,072 mi.)	34,726 km (21,578 mi.)
Inclination	33.5^{o}	33.1^{o}	0.31^{o}
Period	1,426.6 min.	1,454 min.	1,423 min.
Status	Spacecraft became inactive during apogee motor firing to attain synchronous orbit.	Spacecraft active. Stationkeeping capability exhausted. Left at about 77^{o} E. longitude.**	Spacecraft active. Stationkeeping capability exhausted. Left drifting West. Circles earth in about 18 months.

NOTES: *At initial injection. Attitude control and stationkeeping produced changes.
**Stable equalibrium point in earth's gravitational field.

Table 8-2. Participating Earth Terminals

Location	Sponsor	Antenna Diameter (m) (ft.)	Date Installed
Ft. Dix, N.J. *	U.S. Army	18 (60)	1962
Camp Roberts, Calif. *	U.S. Army	18 (60)	1962
Lakehurst, N.J. **	U.S. Army	9.1 (30)	1962
Greenbelt, Maryland **	U.S. Army	9.1 (30)	1963
Republic of Viet Nam ***	U.S. Army	9.1 (30)	1964
Thailand ****	U.S. Army	4.6 (15)	1964
Asmara ****	U.S. Army	4.6 (15)	1964
Kingsport†	U.S. Navy	9.1 (30)	1962
USS Canberra†	U.S. Navy	2 (6)	1965
USS Midway†	U.S. Navy	2 (6)	1965
Kashima, Japan††	Japan's Radio Research Lab	10.0 (32.8)	1964
Point Mugu, Calif.†††	U.S. Navy	26 (85)	1964

* Fixed AN/FSC-9 terminals.

** Transportable AN/MSC-44 terminals later relocated to Hawaii and Philippines.

*** Transportable AN/MSC-45 terminal.

**** Transportable. MK-IV terminals.

†U.S. Navy ships.

††Transmitting terminal only.

†††Receiving terminal only.

launchings were provided by the National Aeronautics and Space Administration (NASA). The NASA Worldwide Minitrack network collected tracking and telemetry data. Selected newly procured tracking, telemetry, and command (TT&C) terminals were also provided by NASA. One of the most important of these was located on the Kingsport.

The great contribution of Project Syncom to satellite communications technology was to display the feasibility of placing satellites into synchronous equatorial orbits and maintaining precision stationkeeping and attitude control. The synchronous equatorial orbit significantly reduced the ground terminal tracking requirements and made it possible to establish an essentially worldwide communications system with as few as three or four satellites. The only earth areas without satellite visibility in such a system are the regions immediately around the North and South Poles. The high altitude of the synchronous orbit and the capability to precisely maintain the satellite's spin axis at a 90° attitude relative to the orbital plane made it possible to employ antennas providing pancake-shaped radiation patterns of significantly higher gain than the previous essentially omnidirectional satellite antennas. Finally, the communications experiments verified the link propagation parameters and provided the first indication that round trip time delay and return echo due to two-wire user terminations are not insurmountable obstacles to the use of synchronous satellites in commercial communications applications.

8.2 SYSTEM DESCRIPTION

Initial tests performed while Syncom II was stationed over Brazil involved the Fort Dix, Camp Roberts, Lakehurst, and Kingsport terminals. After the satellite was repositioned over the Indian Ocean, tests were conducted employing principally the Asmara, Philippines, and Thailand terminals. Tests involving Syncom III included the Camp Roberts, Hawaii, Viet Nam, Kingsport, USS Canberra, USS Midway, Kashima, and Point Mugu terminals, among others. Practically all transmissions over either satellite were conducted on a loop-back basis or over a single link between two terminals. Both half and full duplex links were established.

Typical earth coverages supplied by the synchronous orbits of Syncoms II and III are illustrated in Figure 8-1. [9] The significantly smaller area of 24-hour earth coverage provided by Syncom II is due to its inclined orbit resulting in a daily figure eight earth trace of the subsatellite point.

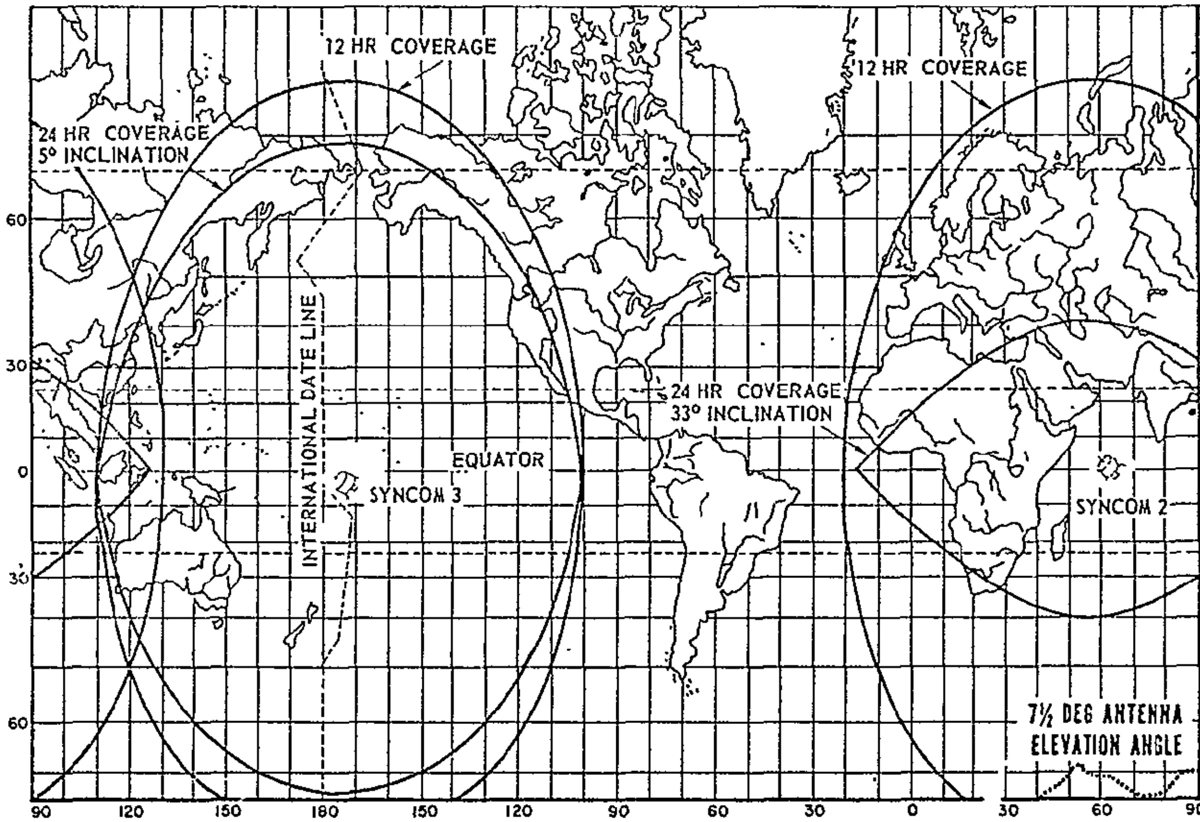

Figure 8-1. Syncom Earth Coverage

Operating frequencies for the Syncom satellites were as indicated in Table 8-3. [5] The communications frequencies were selected to be compatible with the ground complex under development at that time for the Army's Project Advent. [7] Upon termination of this synchronous satellite project, the Fort Dix, Camp Roberts, and Kingsport terminals required only relatively minor modifications to become part of the Syncom program.

Basic signal processing techniques used in the Syncom program were as indicated in Table 8-4. [3] [4] Power balancing for duplex operation was accomplished manually by coordinating between terminals via leased conventional circuits. Margins for duplex operation were quite narrow but had to account only for rain losses, inaccurate

Table 8-3. Syncom Frequencies (MHz)

COMMUNICATIONS				TT&C	
SATELLITE	UPLINK	DOWNLINK	BEACON	COMMAND	TELEMETRY
Syncom II	7361.275* 7363.000* 7362.582	1814.969 1815.794	1820.117	148.260	136.470**
Syncom III	7363.000 7362.138	1815.794 1814.931			136.980**

*Dual channel narrow band repeater
**Redundant transmitters

Table 8-4. Signal Processing Employed

Multiple Access	Frequency Division* for up to two carriers to support duplex operation
RF Modulation	FM and PSK**
Demodulator Performance	Conventional Discriminator – Threshold at about 10 dB C/N FMFB Receiver – Threshold at about 6 dB C/N
Lakehurst Receive Carrier–to–Noise (C/N)	12 dB for 43.2^{o} antenna elevation, one satellite access, and 188–kHz noise bandwidth
Lakehurst Receive Margin	Conventional Discriminator – 2 dB FMFB Receiver – 6 dB

*Spread Spectrum modulation and more than two accesses were displayed in special tests.
**The Advent modem employed in a limited number of tests.

power balancing, and various miscellaneous variations in link parameters of lesser magnitude.

8.3 SPACECRAFT

Spacecraft characteristics for the Syncom satellites are displayed in Table 8-5.(3) (4) (5) (13) All three satellites contained identical apogee motors for final orbit circularization. The basic configuration for the communications subsystem on the Syncom satellites is displayed in Figure 8-2.(4) Each receive channel consists of a mixer, a local oscillator, an IF amplifier, a limiter amplifier, and a mixer connected through a hybrid to the redundant TWTs.

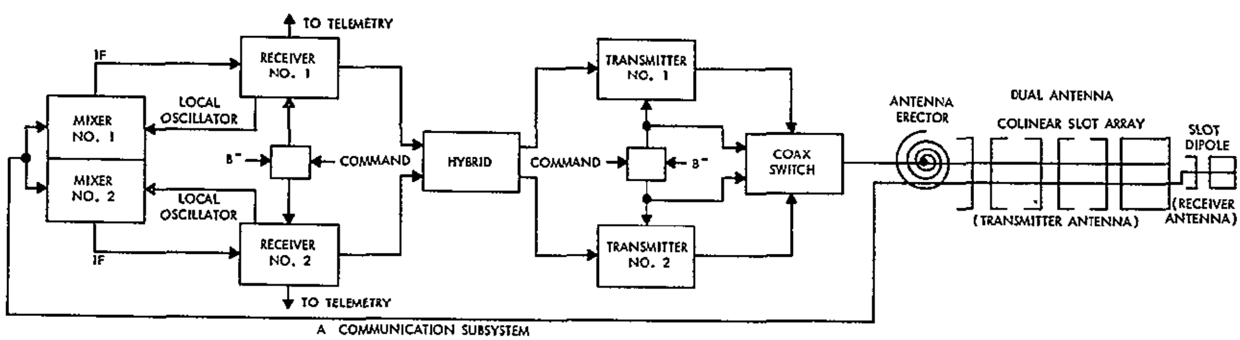

Figure 8-2. Syncom - I, II, III: Communications Transponder

Syncom II differed from Syncom I only in nitrogen tank mounting and internal operating pressure, the wiring harness, and the addition of a standby battery to provide 40 minutes of telemetry should the main power supply fail. These changes resulted from the conclusion that a high-pressure nitrogen tank failure caused the loss of Syncom I.

Based on Syncom II experience, several modifications were also made to Syncom III. N-on-P solar cells with 0.30 mm (12-mil) fuzed silica covers replaced the more radiation sensitive P-on-N solar cells with their 0.15 mm (6-mil) glass covers. A redundant hydrogen peroxide (H_2O_2) system replaced the high pressure nitrogen (N_2) system. The stand-by battery and apogee motor timer were deleted. Two temperature

Table 8-5. Satellite Characteristics

	SATELLITE	SYNCOM I & II		SYNCOM III	
ANTENNAS	Type	UHF Xmit. – collinear array of slot dipoles SHF Recv – slot dipole	VHF–4 whip turnstile for TT&C	Essentially the same as for Syncom I & II	
	Number	One	One		
	Beamwidth	Pancake beam about 25° wide at 3–dB pts for Xmit	Essentially Omnidirectional		
	Gain	Xmit – 6 dB Recv – 2 dB	0 dB		
REPEATERS	Frequency Band	SHF Recv. and UHF Xmit		Same as for Syncom I & II	
	Type	IF Translation Hard Limiting			
	3 dB BW	5 MHz	0 5 MHz*	4 5 MHz	13 MHz or 50 kHz**
	Number	Redundant Xponders of different BW selectable on ground command		Essentially the same as for Syncom I & II	
	Receiver Type Front End Front End Gain Sys. Noise Fig	 Down Conversion Mixer 90 dB IF following down converter 10 dB			
	Transmitter Type Gain Power Out	 Redundant TWTs*** 33 dB 2 watt (nominal)			
	EIRP – UHF Ant.	6 dBW			
GENERAL FEATURES	Stabilization Type Capability	 Spin with H_2O_2 and N_2 reaction control**** Spin axis could be maneuvered to within 1° of normal to orbital plane		Spin with H_2O_2 reaction control****	
	Power Source Primary Supplement	 Solar Array – 29 watt output at launch 2 Nickel Cadmium Batteries – about 0 8 amp-hr per battery at launch		Essentially the same as for Syncom I & II	
	Comm Power Needs	About 15 watt			
	Size	Cylindrical – 39.4 cm (15.5 in.) high and 71 cm (28 in.) diameter			
	Weight	35 7 kg (78 8 lb) initially in orbit		33 5 kg (73 8 lb.) initially in orbit	

*Bandwidth for each of two channels provided for more convenient full duplex narrowband operation
**Either wideband or narrowband mode can be selected
***Either TWT can operate with either transponder Interlocks prohibit parallel operation.
****Gas jets provide both attitude corrections and stationkeeping

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sensors were added. The transponder containing two 0.5-MHz bandwidth IF sections was replaced by a 10-MHz bandwidth channel for television tests with a 50-kHz option for small station testing.

8.4 GROUND TERMINALS

Among the participating earth terminals listed in Table 8-2, the AN/FSC-9, the AN/MSC-44, and the Kingsport terminals were the principal stations involved in the early testing on both Syncoms II and III. Characteristics of these terminals are presented in Table 8-6. [3] [6] [9] [11] [14] [15] Major subsystems of the ground facilities placed aboard the Kingsport are shown in Figure 8-3. [3] The AN/FSC-9 and AN/MSC-44 terminal installations did not, in general, include the TT&C antenna and system.

The transmit and receive polarizations available at the AN/MSC-44 and Kingsport terminals were compatible with those of the Syncom sattellites. In contrast, the receive polarization of the AN/FSC-9 terminals was such that a 3-dB polarization loss was suffered. By choosing circular polarization, however, it was no longer necessary to track variations in the linear polarization received from the satellite.

The AN/FSC-9 and AN/MSC-44 terminals employed two axis (i.e., azimuth and elevation) tracking and control of the antenna. The Kingsport terminal was provided with a three-axis antenna, however, to ensure a capability for near zenith operation from the rolling and pitching ship.

8.5 EXPERIMENTS

Experiments conducted on project Syncom are grouped in five major categories and defined in Table 8-7. Synchronous orbit injection was successfully completed on Syncoms I, II and III. In the latter case, a synchronous equatorial orbit was realized. Spacecraft stationkeeping and attitude control were successfully maintained on Syncoms II and III. In the process of stationkeeping, considerable data on the triaxial nature of the earth and the drift of synchronous satellites was generated. [16] [17] [18]

Table 8-6. Characteristics of Major Earth Terminals

	TERMINAL FEATURE	TERMINAL: AN/FSC-9	TERMINAL: AN/MSC-44	TERMINAL: KINGSPORT
ANTENNA	Type	Parabolic Reflector	Parabolic Reflector	Parabolic Reflector
	Aperture Size	18 m (60 (ft) Diameter	9.1 m (30 ft) Diameter	9.1 m (30 ft) Diameter
	Receive Gain	48 dB	42 dB	40 dB
	Efficiency	50%	50%*	35%*
	Rec. Beamwidth	0.65° at 3 dB Pts.*	1.3° at 3 dB Pts.	1.6° at 3 dB Pts *
RECEIVE SYSTEM	Type Preamplifier	Temperature Controlled Parametric Amplifier	Temperature Controlled Parametric Amplifier	Temperature Controlled Parametric Amplifier
	Bandwidth	100 kHz**	100 kHz**	100 kHz**
	Noise Temp.	230°K at 7.5° El.	200°K at 7.5° El.	200°K at 7.5° El.
TRANSMIT SYSTEM	Type Amplifier	Klystron	Klystron	Klystron
	Bandwidth	100 kHz***	100 kHz***	100 kHz***
	Amp. Pwr. Out	20 kW****	20 kW****	20 kW****
TRACKING	Type	Conical Scan Autotrack.	Conical Scan Autotrack	Spiral Scan Autotrack
	Accuracy	±0.024	±0.05°	±0.05°
TOTAL PERF	G/T	24.4 dB/°K*	19 dB/°K*	17 dB/°K*
	EIRP	128 dBm*;****	123.4 dBm*,****	125.3 dBm*,****
POLARIZATION	Transmit Feed	Circular	Circular	Circular
	Receive Feed	Circular	Linear	Circular or Linear (Interchangeable)
INSTALLATION	Radome	None	None	16 m (53 ft) Diameter Pressurized
	Type Facility	Fixed Terminal	Transportable†	Ship

*Derived value based on data available

**IF bandwidth variable to 10 and 40 kHz RF bandwidth is 10 MHz at 3-dB pts.

***Radiated signal bandwidth. RF bandwidth is 15 MHz at 3-dB pts.

****Peak possible. Operationally the practical limit is 3 dB less.

†Included eight vans, all air-transportable in C124 and C133 aircraft. Total weight about 29,484 kg (65,000 lbs).

Table 8-7. Summary of Program Experiments

Type Activity	Nature of Activity
1. Synchronous Orbit Injection	Demonstrate launch and synchronous orbit injection of spin stabilized satellite.
2. Stationkeeping and Attitude Control	Demonstrate precision control of spin axis attitude and central longitude of earth subsatellite point.
3. Communications Demonstrations	Display feasibility of synchronous satellite communications to live audiences.
4. Communications Performance	Measure overall communications performance of synchronous satellite system.
5. Communications Technical Characteristics	Measure detailed link and communications parameters in synchronous satellite system.

Thousands of successful special tests and demonstrations were performed over the Syncom satellites. These include numerous demonstrations of teletype, telephony, and facsimile. Special demonstrations displayed vocoder operation, multiple access using spread spectrum, real time relaying of satellite telemetry, transmission of oceanographic data, continuous 24-hour auto-tracking, 28 hours of continuous communications with the Kingsport while underway at sea, and direct teletype communications with an aircraft in flight. The latter employed the VHF command receiver and telemetry transmitter on Syncom III. (19)

Special occurrences among the demonstrations included President J. F. Kennedy speaking from the White House to the Prime Minister of Nigeria; President Kennedy's address to the United Nations; conversations between participants in the 1963 Extraordinary Administrative Radio Conference of the ITU in Geneva, Switzerland, and members of the U.N. in New York; and international TV coverage of the Olympics from Japan in October, 1964. The demonstrations also displayed that satellite time delay and echo could be overcome. However, to accomplish the latter it was found necessary to maintain incoming conventional phone line levels at -15 dBm or above with the equipment employed. The time delay presented few psychological problems even with unexpectant speakers.

The communications performance experiments described in Table 8-7 are defined and their basic results presented in Table 8-8.[3] [4] [15] [19] Results indicated are for half duplex operation. The Syncom II television transmissions involved a wideband FM modulator at Fort Dix. At the receive end, the Bell Telephone Laboratory's Andover terminal was outfitted with a maser preamplifier operating at the Syncom frequencies. The Syncom III Japan to California television test was the 1964 TV coverage of the Olympics. Television p-p signal to weighted rms noise ratios would be about 8 dB better than the unweighted values indicated in the table. This means signals were quite viewable but not of high quality.

The communications technical characteristic measurements noted in Table 8-7 are described in Table 8-9.[3] [4] In addition to the tests mentioned, the frequency response of the 50-kHz transponder on Syncom III was measured. It displayed an 87-kHz bandwidth at the 3-dB points. Further, measurements of the Faraday rotation of the 137-MHz telemetry signal from Syncom III provided considerable data on the electron content of the ionosphere.[20] [21]

8.6 OPERATIONAL RESULTS

The communications system operations on Project Syncom displayed that highly reliable synchornous satellite communications systems were feasible. During the initial experimental period of the program, operational responsibility for the Syncom satellites rested with NASA while DOD operated and maintained the ground communications terminals. In early 1965, DOD added the satellites to its operational responsibilities and employed them to provide operational military communications for the Far East, Pacific Ocean area, and Western United States. During all of the time the Syncom satellites were actively employed, no significant operational difficulties were encountered. Minor difficulties included a slight gas leak, a buildup of H_2O_2 pressure, and one receiver occasionally going into oscillation upon turn on under high spacecraft temperature conditions. Ground terminal operation and tracking was, in general, routine.

Table 8-8. Communications Performance Experiments

TYPE EXPERIMENT	NATURE OF RESULTS OBTAINED
1. Telephony	Single channel S+N/N of 35 dB* readily attained with maximum FM deviation** ratio employed. Multichannel*** operation demonstrated on Syncom III at reduction in per channel performance.
2. Data Transmission	Using vestigial sideband modems operating into 4–kHz baseband input to normal FM terminal equipment, 3–kbps rates at low error rates**** were possible Using PSK RF modulation, data rates as high as 50 kbps were possible.
3. Teletype	For single channel operation into 4–kHz baseband input to normal FM terminal equipment, error rates of 0.1% were readily attained For 1 of 16 channels into 4–kHz baseband, error rates less than 1% were attained.
4 Facsimile	Operating into standard FM terminal equipment, overall picture quality numerically rated at 7 on a 0 to 10 scale was commonly obtained Factors degrading quality included bandwidth limitations,† phase delay distortion,† and satellite spin rate modulation
5. Television	Fort Dix to Andover through Syncom II realized 26–dB p–p signal to rms noise ratio †† Kashima to Point Mugu through Syncom III realized 34–dB p–p signal to rms noise ratio.†††
6. Direct Aircraft TTY	Pan American scheduled aircraft to Camp Roberts through Syncom III VHF command receiver and telemetry transmitter realized under proper conditions, up to 60–wpm TTY.††††

NOTES. *Signal was 1–kHz tone; 35 dB provided better than 99% sentence intelligibility.
**Maximum was 10; lower ratios were also selectable.
***Four channel AN/TCC–3 multiplex employed on Syncom III.
****On order of 10^{-5} bits/bit.
†Ground terminal equipment imposed limitations.
††Video baseband bandwidth –2 5 MHz, p–p FM frequency deviation –4.5 MHz, preemphasis –14 dB, and audio signal transmitted separately.
†††Video baseband bandwidth –2 5 MHz, p–p FM frequency deviation –7 MHz, preemphasis –14 dB, sync pulses removed and regenerated at receiver, and audio handled separately.
††††Aircraft had vertically and horizontally polarized Yagi antennas. Roberts used TT&C Yagi antenna

Table 8-9. Communications Technical Characteristics Measurement

TECHNICAL CHARACTERISTICS	NATURE OF RESULTS OBTAINED
1. Spacecraft Transfer Function	Beacon receives total output power for no communications signal present. Communications input must be varied over several dB to completely suppress beacon and capture TWT.
2 Ground Terminal UHF/SHF Beam Alignment	Determined from point of maximum suppression of beacon signal. Good alignment found.
3. Received Carrier Power at Ground	Measured values, in general, agreed with predicted values. For antenna elevation angles above 7.5°, no selective fading due to multipath existed.
4. Received Signal Level at Satellite	Agreed well with predicted values.
5. Frequency Response	For 4–kHz channel, baseband response exceeded the requirements of MIL STD 188B for a 11,112 km (6000–n.mi.) reference circuit.*
6. Envelope Delay	For 4–kHz channel, baseband response exceeded the requirements of MIL STD 188B for a 11,112 km (6000–n.mi.) reference circuit.*
7. Spacecraft Antenna Pattern	Performed with satellite spin axis in plane of orbit. Pattern shapes agreed well with prelaunch measurements and indicated about 1.5° error in measured satellite orientation parameters.
8. Intermodulation	Not performed on Syncom II. Nearly all measured degradation was due to AN/TCC–3 and FM modulation/demodulation.
9. Spacecraft Oscillator Frequency	Measured frequency agreed with prelaunch measurements.

*Ground terminal equipment imposed limitations.

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SECTION 9 - LINCOLN EXPERIMENTAL SATELLITES

9.1 INTRODUCTION

From its inception, the Lincoln Laboratory of the Massachusetts Institute of Technology has had an interest in long-range military communications systems. Early work was with ionospheric and tropospheric scatter systems. The scatter concept was extended, under U.S. Air Force sponsorship, to the West Ford Program. Upon successfully concluding Project West Ford, the Laboratory's program aims were recast, in 1963, towards developing active communications satellite techniques.(1) This program, also under Air Force sponsorship, has made use of the original West Ford ground terminals as well as small mobile ground terminals to communicate through a series of Laboratory-developed satellites designated the Lincoln Experimental Satellitew (LES).

Lincoln Laboratory's active communications satellite program has been concerned with the development and testing of new spacecraft and ground terminal techniques having application to military command and control.(2) The objective of the spacecraft techniques investigations has centered on obtaining the maximum satellite effective radiated power for a given satellite mass. In agreement with this objective, research has been conducted on improved spacecraft power-generation systems, high efficiency spacecraft transmitters, high-gain spacecraft antennas, and spacecraft attitude stabilization and stationkeeping systems. The surface terminal techniques investigation has focused on developing methods of more effectively utilizing a given radio signal strength generated by a communications satellite. Areas of interest have included the development of efficient modulation-demodulation systems, random multiple access techniques having no stringent synchronization and control requirements, source signal encoding techniques that reduce required user data rates, low noise receiving systems, and simple antenna systems suitable for small terminals.

In the first phase of the program, particular attention was given to X-band frequencies in the vicinity of the microwave bands allocated for military communications.

This emphasis was a natural extension of the X-band capabilities developed during the Project West Ford experiment.[3] In the second phase of the program, attention has been focused on frequencies in the 225 to 400 MHz UHF communications band. This band is used for a wide variety of United States government communications services.

To date, six satellites, LES-1 through -6, have been launched as part of this program and employed in experiments. LES-7 was conceived as a high ERP, three axis stabilized, 136- to 227- kilogram (300- to 500-pound) satellite using a lens antenna and a 19 horn feed cluster to provide a composite beam whose shape could be varied by ground command to fit the earth coverage requirements of a particular link. This satellite would have operated at X-band but funding considerations plus a greater interest in experiments at the UHF frequencies resulted in its cancellation. Presently, plans exist for a LES-8 and LES-9 to be launched in the spring of 1975. These are experimental "survivable satellites" which are to be placed into an elliptical 40 degree inclined synchronous orbit. This orbit will result in a fat figure-eight ground track, will provide polar coverage, and will enhance the satellites' survivability by making them harder to locate and track.[3a] The system will employ frequency hopping spread-spectrum techniques to combat enemy jamming.[3b] No further unclassified information is available on the LES-8 and LES-9 satellites.

9.2 X-BAND SATELLITES

9.2.1 General Description

Specific objectives of the satellites and earth terminals included in this portion of the LES program are listed in Table 9-1.

Table 9-1. X-Band Experiment Objectives

Number	Description
1	Investigate X-Band Satellite Communications Performance
2	Display Operation of Solid-State X-Band Transponders
3	Investigate Despun Antennas
4	Evaluate Autonomous Satellite Attitude Control
5	Study Space Radiation Environment
6	Demonstrate Efficient Error Correcting Coding-Decoding Techniques
7	Investigate Minimum Data Rates for Voice Signal Transmission
8	Study Multiple Access Techniques with no Stringent Synchronization Requirements

Three X-band satellites have been launched during the LES program as indicated in Table 9-2[4] [5]. LES-1 was correctly injected, by its launch vehicle, into an inclined medium altitude circular orbit. However, a design flaw in the satellite's ordnance circuity prevented ignition and separation of the rocket motor supplied for final orbit injection. This left the combination in the medium altitude circular orbit instead of a 2,778 by 14,816 km (1500 by 8000 nautical mile) inclined elliptical orbit as planned. At separation from the launch vehicle, the satellite-rocket motor combination was spun up about the axis of least inertia to 180 rpm. When the rocket motor failed to separate, spin axis conversion immediately started to occur. Before it was completed, a few initial communications tests were conducted. The X-band repeater and antenna switching system functioned properly but the tumbling mode that was assumed destroyed LES-1's usefulness.

LES-2 was successfully launched along with the Lincoln Calibration Sphere (LCS)-1 later in 1965. This satellite was almost identical to LES-1. With the benefit of a revision of the satellite's ordnance circuitry, it was placed into the type of orbit that had been planned for LES-1. Numerous communications experiments were conducted with this satellite and all objectives listed in Table 9-1, with the exception of Item 5, were accomplished. The satellite contained no experiment measuring the space radiation environment.

LES-4 was launched along with LES-3, Oscar 4, and OV2-3 as a secondary payload aboard the third flight test of the Titan IIIC. LES-3 was a UHF Lincoln Experimental Satellite operating as a radio signal generator. Oscar 4 was an amateur radio communications satellite for use by "Hams" throughout the world. OV2-3 was a scientific satellite to gather data on solar and geomagnetic activity by measuring changes in cosmic ray and trapped particle fluxes. The objective was to place LES-3 and LES-4 into near synchronous (i.e., 33,706 kilometers (18,200 nautical miles)), circular orbits having a 0° inclination. After a near perfect injection into parking and transfer orbits, the Titan III C third stage failed to ignite and LES-3 and LES-4 were ejected into highly elliptical inclined orbits.

Table 9-2. X-Band Spacecraft

Satellite		LES-1	LES-2	LES-4
Manufacturer & Sponsor		Lincoln Laboratories & U.S. Air Force		
Launch Date		2/11/65	5/6/65	12/21/65
Launch Vehicle		Titan III A		Titan III C
Orbital Data(1)	Apogee	2,807 km (1,744 mi.)	15,102 km (9,384 mi.)	33,619 km (20,890 mi.)
	Perigee	2,778 km (1,726 mi.)	2,828 km (1,757 mi.)	200 km (124 mi.)
	Inclination	32.2°	31.4°	26.6°
	Period	145.7 min.	315.2 min.	589.6 min.
Status		In orbit, solar array degraded, and tumbling with satellite rocket motor still attached	In orbit but was shut down automatically by its internal clock in 1967	Transmission ceased in October 1968. Orbit subsequently decayed and satellite was destroyed

(1) At initial injection. Parameters of LES-4 were altered by atmospheric drag due to the low perigee.

LES-4's initial spin axis orientation was such that solar panel illumination provided telemetry power only. By late 1965, a residual magnetic moment along the spin axis had precessed the spin vector until the sun was only 47° below the satellite equator. This provided sufficient solar power to allow operation of all systems. As a result of the unplanned orbit, one of the two onboard antenna switching control systems and the magnetic spin axis orientation system could not be operated. However, one of the two antenna switching control systems did operate properly and all of the objectives listed in Table 9-1, with the exception of Item 4, were for the most part successfully accomplished.

The principal satellite communications terminals participating in experiments with the X-Band LES satellites are listed in Table 9-3[6] [7]. The terminal at Camp Parks and one of the terminals at Millstone Hill were the facilities originally developed for Project West Ford. Lincoln Experimental Terminal-1 (LET-1) was a transportable ground terminal housed in two vehicles capable of being towed as trailers. One vehicle contained the antenna and RF equipments. The second vehicle contained the signal conditioning and processing equipment necessary for signal generation, modulation and up conversation to IF. The LET-1 terminal was located adjacent to the Lincoln Laboratory's Facilities in Lexington. The other two LET terminals consisted of a LET-1 type signal processing van utilized with existing antennas and RF equipment. LET-2 employed the 18-meter (60-foot) West Ford antenna and X-band RF equipment at Millstone Hill. LET-3 employed the 9.1-meter (30-foot) antenna and X-band RF equipment of the Army's transportable Mark 1A terminal.

The LET-3/Mark 1A combination was initially deployed to Camp Roberts, California for LES tests. After a few months it was moved to Ft. Monmouth, New Jersey for a limited number of LES experiments and subsequent modification for tests with the IDCSP satellites.

Table 9-3. Participating Earth Terminals

Location	Sponsor	Antenna Diameter (m) (ft)	Date Installed
Camp Parks, California	U.S. Air Force	18 (60)	1961
Millstone Hill, Mass. (West Ford)	U.S. Air Force	18 (60)	1961
Lexington, Mass. (LET-1)	U.S. Air Force	4.6 (15)	1965
Millstone Hill, Mass. (LET-2)	U.S. Air Force	18 (60)	1965
Camp Roberts, California (LET-3)	U.S. Army Satellite Communications Agency	9.1 (30)	1966

Tracking and VHF telemetry data was obtained primarily by the Camp Parks and Millstone Hill (West Ford) terminals. The satellite launchings were provided by the U. S. Air Force.

The X-Band LES program was responsible for a number of significant contributions to satellite communications technology. It proved the feasibility of building solidsstate X-band transponders for operation in a communications satellite. A useful communications capability was supplied even though satellite dc to RF power conversion efficiency and RF power output were relatively low. The feasibility and performance capabilities of electronically switched despun antennas were demonstrated. A workable automatic magnetic spin axis torquing system for attitude correction was exhibited. The performance potential available through the application of convolution encoding and sequential decoding to satellite links was displayed. Frequency hopping was shown to be a satisfactory means of multiple access having no stringent synchronization requirements and giving considerable protection against interfering signals. Finally, the capabilities of both pitch-excited and voice-excited vocoders, when used over a satellite link, were demonstrated. The former handled speakers at the satellite ground terminal while the latter allowed remote speakers, connected through the normal switched telephone network, to use low rate digital satellite voice circuits.

9.2.2 System Description

The West Ford terminals contained conventional analog voice signal processing and frequency modulation equipment while the newly developed LET terminals were equipped for digital signal processing. As a result, the three LET terminals interoperated independent of the West Ford terminals. Individual terminal loop back tests plus half and full duplex two-terminal operations were conducted. Extensive multiple access tests were not performed due to the limited number of participating terminals having compatible modulation and signal processing systems. However, the LET terminal approach to modulation made multiple access a real possibility even for operation with hard limiting satellites.

Operating frequencies for the X-band Lincoln Experimental Satellites are shown in Table 9-4[8]. By choosing the X-band frequencies for communications experiments, it was possible to make use of ground terminal facilities previously developed for Project West Ford. More important, however, it afforded the opportunity in accordance with the program objectives, to conduct tests and develop experimental hardware operating at frequencies internationally allocated for military satellite communications.

Table 9-4. X-Band LES Operating Frequencies (MHz)

Communications			Telemetry*
Up Link	Downlink	Beacon	
8350	7750	7740	237

*VHF tracking was also performed on this signal. A command system was not employed.

The two West Ford terminals used conventional FM for their RF modulation and frequency division multiple access when full duplex operations were conducted. Signal processing and link performance for LET operations with LES are summarized in Table 9-5[7] [9] [10]. The signal structure except for the frequency hopping feature is sketched in Figure 9-1[9].

In the LET system, the elementary channel symbol used was a sinusoidal pulse 200 μs in duration on one of 16 frequencies. The received pulse was detected by a bank of 16 matched filters. This modulation-demodulation system was preceded by a convolutional encoder and followed by a sequential decoder. Information rates of approximately 200 bps, 5 kbps, and 10 kbps were achieved.

At the 5-kbps rate, an information bit was fed to the encoder every 200 μs. The encoder generated three parity check bits based on the 60 preceding information bits. These four bits were employed to select one of 16 channel frequencies every 200 μs. At the receiver the match filter outputs were sampled every 200 μs and ordered according to magnitude. The seven samples of largest magnitude were fed to the sequential decoder which recovered the original information bits.

Analogous operation occurred at the 10 kbps rate. In this case, one parity check bit was generated for each input information bit and two information and two check bits were used to select 1 of 16 channel frequencies. At the 200 bps rate, 24 successive 200 μs pulses carried the same information while the 25th pulse was a synchronization pulse. At the receiver, the matched filter outputs were integrated over 24 successive pulses before ordering the samples and decoding.

This signalling system guaranteed accurate transmission at low values of E_b/N_o. To convert this into multiple-access, or anti-interference operation, the block of 16 channel frequencies employed in any 200 μs symbol interval was, itself, pseudorandomly hopped over the 20 MHz bandwidth of the terminal and satellite RF systems. Since the frequency hopping occurred only every 200 μs, the signal acquisition and synchronization requirements were modest as compared to a pseudonoise spectrum spreading system. Acquisition was achieved automatically using time and frequency predictions obtained from a station clock and the satellite ephemeris. The desired synchronization was achieved by transmission of a synchronizing pulse (i.e., a 200-μ s pulse that is frequency hopped but carries no information) every 5 ms. A tracking loop integrated over many of these pulses in sequency to achieve the desired timing and frequency accuracies of 5 μs and 625-Hz, respectively.

Table 9-5. Signal Processing for LET Operation With LES-4

Multiple Access	Code Division through pseudorandom frequency hopping of channel center frequency
RF Modulation	MFSK employing 16 channel frequencies
Ground Demodulator Performance	E_b/N_o (1) of 6 dB required(2) corresponding to 43 dB/Hz signal-to-noise density ratio for a 4.8-kbps voice channel
LET-1 Receive Carrier-to-Noise Density	58 dB/Hz based on operation at synchronous altitude, 2 watt satellite EIRP, & $100^\circ K$ (3) receive system noise temperature.
Margin Required for Link Degradation	5 dB
Margin Available for Multiple Access	10 dB corresponding to 10 potential users of the same type

Notes: (1) Energy per bit to noise density ratio

(2) Gives probability of error of 10^{-3} when matched filter detection and sequential decoding of convolution encoded signal is employed.

(3) Represents LET receiver thermal noise alone. For code division multiple access when almost entire satellite output represents interference, receive system noise temperature was raised a maximum of $12.7^\circ K$.

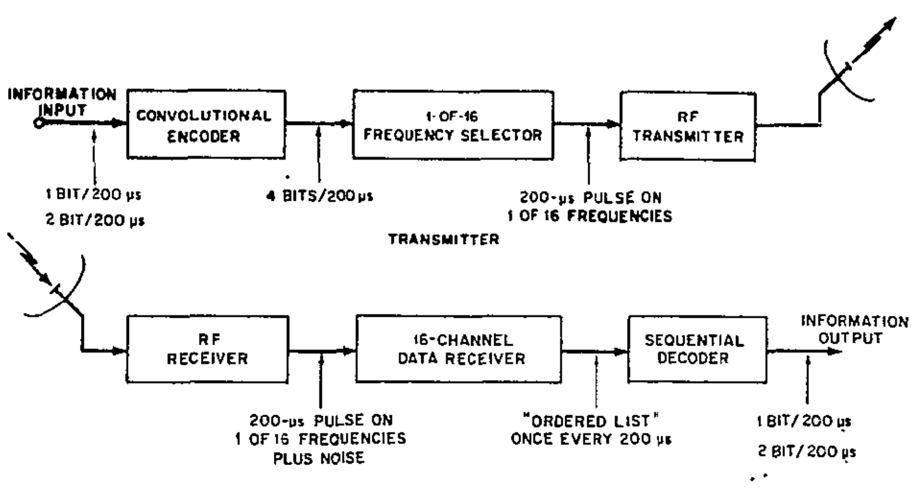

Figure 9-1. Simplified Terminal (Without Frequency Hopping)

The three alternate information rates provided corresponded, in order of ascending rate, to transmission of two 100-wpm teletype channels, a pitch-excited vocoder output (4.8 kbps) plus the two teletype channels, or a voice-excited vocoder output (9.6 kbps) plus two teletype channels, respectively. The two vocoder systems were provided in one unit capable of two modes of operation. Both modes provided a high degree of intelligibility and speaker recognizability. In the pitch-excited mode, a high fidelity input was required as provided by the high quality microphone at the LET terminal. When operated at the higher data rate, the vocoder was used in the voice-excited mode, allowing the use of a degraded input, including a "phone patch" connection to the commercial telephone plant.

9.2.3 Spacecraft

Characteristics of the communications-related subsystems of the LES-1, 2 & 4 spacecraft are given in Table 9-6[1] [8] [11]. The LES-1 and 2 satellites were nearly identical in all respects and the transponder, aboard all three spacecraft, was basically the same. A simplified block diagram of the transponder is shown in Figure 9-2. A 60-MHz IF was employed which made double up conversion necessary to avoid the need for narrow sideband separation filters at the 7.8-GHz output frequency.

LES-1 and 2 were designed to operate with their spin axis normal to the earth-sun line. As a result, the spacecraft orientation relative to the earth varied making a broad range of coverage by the satellite antenna pattern necessary. This was solv solved through the 8-element switched array of antenna elements arranged in two rings. The two 4-element rings girded the upper and lower hemispheres of the satellite, respectively. Sensors operating at the wavelengths of visible light served as inputs to the logic system determining spacecraft spin rate and earth direction. The logic controlled antenna switching. A 2-throw switch selected the ring to be activated while a 4-throw switch performed the despinning within an individual ring. The automatic magnetic torquing system employed solar cells on the upper

Table 9-6. Satellite Characteristics

	SATELLITE	LES 1 AND 2		LES 4	
ANTENNAS	Type	X–Band – Switched array of 8 horn elements* in 2 rings about spin axis	UHF Telem – Four 1/8–wavelength monopoles	X–Band Xmit – Switched single ring array of 8 horn elements X–Band Rec – Biconical horn.	UHF Telem – Circumferential gap between X–Band xmit. and receive antennas.
	Number	One	One	One	One
	Xmit Beamwidth (3 dB)	Pencil Beam a minimum of about 60° wide including switched beam pointing errors	Omnidirectional	Pencil Beam 23° wide at minimum dimension	Toroidal pattern of greater than earth coverage width
	Gain	Xmit. – 3 1 dB Rec. – 3 7 dB	0 dB	Xmit. – 10.6 dB Rec. – 4.4 dB	1.4 dB in equatorial plane of satellite
REPEATERS	Frequency Band	X–band		X–band	
	Type	IF translation hard limiting		IF translation hard limiting	
	Bandwidth (1 dB)	20 MHz		20 MHz	
	Number	One		One	
	Receiver				
	Type front end	Down conversion mixer		Down conversion mixer	
	Front end gain	No Data		No Data	
	System Noise Figure	16 dB		9 dB	
	Transmitter				
	Type	Up converter output radiated		Up converter output radiated	
	Gain	No Data		No Data	
	Power out	115 mW		230 mW	
	EIRP	–7 dBW		3 dBW	
GENERAL FEATURES	Stabilization				
	Type	Spin with autonomous magnetic torquing of spin axis		Spin with autonomous magnetic torquing of spin axis	
	Capability	LES–2 settled to 12° ± 7° from perpendicularity to satellite–sun line		Torquing inoperable due to unplanned orbit	
	Power Source				
	Primary	Silicon solar cell array providing at least 27 watts at launch		Silicon solar cell array providing at least 40 watts at launch	
	Supplement	None		None	
	Comm. Pwr. Needs	No Data		No Data	
	Size	Polyhedron 61 centimeters (24 in.) wide between opposite square faces		10–sided cylinder approximately 64 centimeters (25 in) high and 79 centimeters (31 in) across	
	Weight	31 kg (69 lbs.) for LES–1 and 37 kg (82 lbs) for LES–2		52.6 kg (116 lbs.)	

*Each horn was terminated in a diverging lens and lower halves of the satellite to excite aluminum windings on four torquing rods mounted parallel to the spin axis. The onboard telemetry system utilized direct binary phase shift keying of a UHF carrier. No command system was provided.

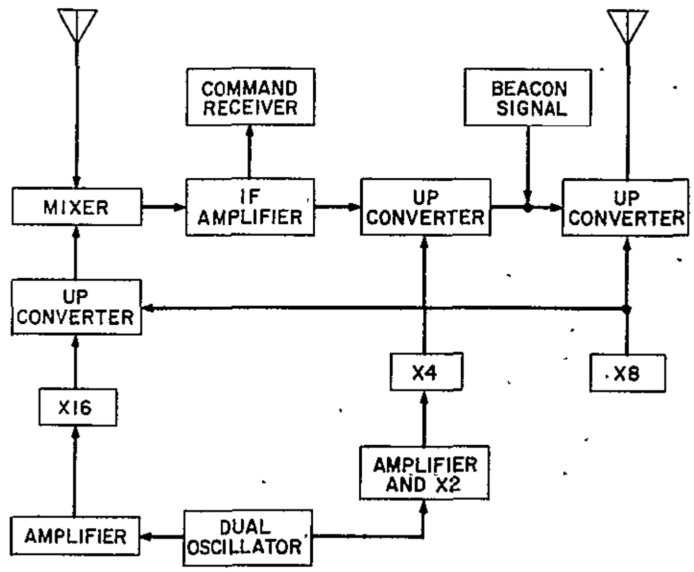

Figure 9-2. LES X-Band Transponder

LES-4 was designed to maintain its spin axis perpendicular to the orbital plane. This allowed all antenna elements to be arranged in one switched ring providing a higher gain. Visual sensors served as inputs to two different antenna-pointing logic systems. One system operated much as that on LES-1 and 2 measuring spin rate and determining direction of the earth center once per revolution. The second measured earth direction at one point in the orbit and time to travel to a second known point in the orbit. Assuming a circular orbit, this allowed predictions of earth direction to be derived as a function of orbital position.

The transponder was the same as that on LES-2 except for changes in the crystal mixer, IF amplifier, directional couplers, and power monitoring circuits. An isolator was eliminated, line lengths reduced, and connectors matched at operating frequencies. These changes increased transmitter power by 3 dB and suppressed spurious frequencies. The autonomous magnetic torquing system generated two orthogonal axes in inertial space and measured spin axis orientation relative to these axes once per orbit at points, 90° apart, where the satellite orbit intersected these fixed axes. LES-4 also included a radiation experiment to measure spatial and temporal variations of the energy spectrum of trapped electrons. The spectrum was measured in five energy ranges from 130 keV to 4 MeV.

9.2.4 Ground Terminals

Among the terminals listed in Table 9-3, the Lincoln Experimental Terminals were the major stations involved in experiments with the X-band Lincoln Experimental Satellites. LET-1 and LET-2 performed most of these tests. The characteristics of LET-1 are summarized in Table 9-7[(9) (12)]. Characteristics of the existing Millstone Hill antenna and RF equipment employed in LET-2 were discussed in the description of Project West Ford ground stations in Section 5.4. A block diagram of the LET-1 system is shown in Figure 9-3[(9)].

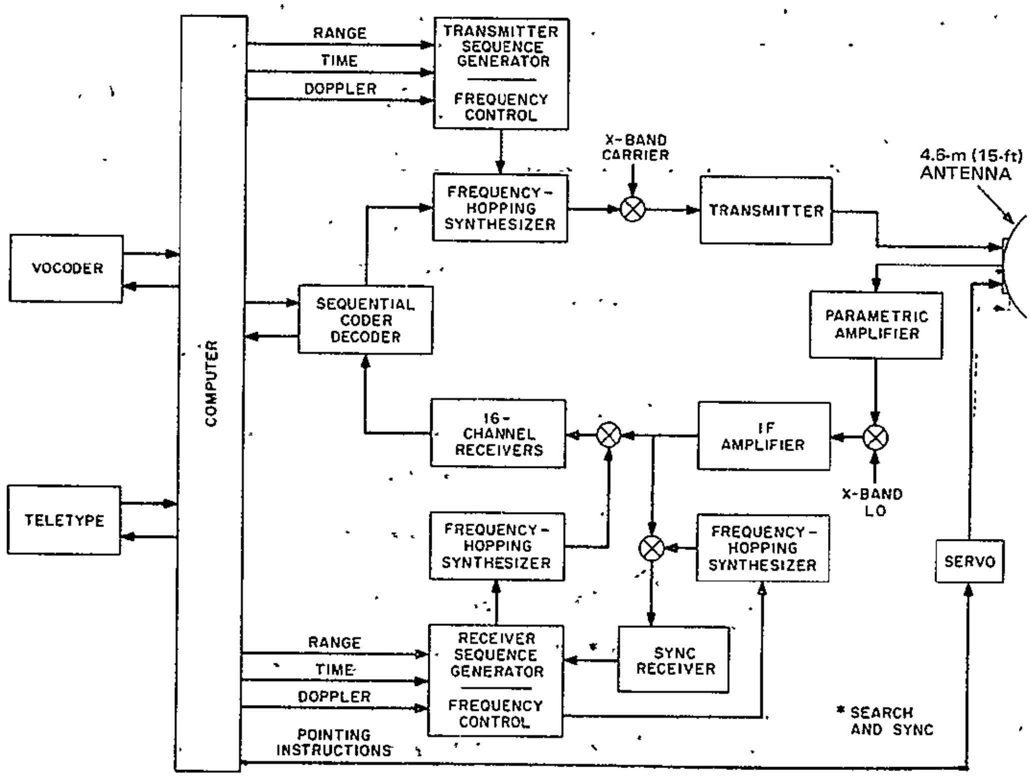

Figure 9-3. LET System

Table 9-7. Characteristics of LET-1 Ground Terminal

Antenna	Type	Cassegrain
	Aperture Size	4.6 m (15 ft) diameter
	Receive Gain	48 dB
	Efficiency	50 percent
	Rec. Beamwidth	0.58° at 3 dB pts.
Receive System	Type Preamplifier	cooled parametric amplifier
	Bandwidth	20 MHz
	Noise Temperature	100°K at 90° elev. in clear weather
Transmit System	Type Amplifier	Klystron
	Bandwidth	20 MHz
	Amp. Pwr. Out	10 kW
Track-ing	Type	computer-aided monopulse autotrack
	Accuracy	no data
Total Perfor-mance	G/T	28 dB/°K *
	EIRP	118 dBm *
Polar-ization	Transmit Feed	right hand circular
	Receive Feed	left hand circular
Instal-lation	Radome	none
	Type Facility	transportable in two trailers **

Notes: * A derived value based on data available.

** An electronics vehicle and an antenna vehicle.

As has been indicated, LET-1 was contained in two vehicles. The electronics vehicle was a modified low-bed commercial van which contained the signal processing equipment, a communications and antenna control console, a prime power generator and its fuel, an air conditioner, and storage for the antenna panels. The second trailer, called the antenna vehicle, contained the transmitter and its heat exchanger, a refrigerated parametric-amplifier receiver, low-level microwave equipment, the antenna backup structure, feeds, and servo-mechanism equipment. The use of circularly polarized antenna feeds made the terminal compatible with the circular polarization employed by the X-band antennas on LES-1, -2, and -4.

In addition to its signal processing, the LET system included another novel innovation. It incorporated a small general purpose digital computer (UNIVAC 1218) as an integral part of the communications terminal. The computer system was assigned four major tasks. It derived pointing angle inputs to the antenna servo system. This computation also produced range and Doppler estimates for use in time and frequency synchronization. The computer generated displays for terminal operators and provided flexible operating controls. Further, it handled vocoder and teletype message traffic multiplexing/demultiplexing.

9.2.5 Experiments

Experiments conducted during the X-band portion of the LES program may be grouped into six major categories as indicated in Table 9-8[1] [4] [9]. The automatic magnetic torquing experiment was a success on LES-2 where, after several months, the spin axis settled into an average 12° position away from perpendicular to the satellite-sun line. The spin axis oscillated ±7° about this position with a period of 135 days[1]. Automatic magnetic torquing of the spin axis could not be accomplished on LES-1 and -4, however, due to the tumbling mode assumed and improper orbit respectively.

The space radiation experiment was conducted on LES-4 exclusively. With the highly elliptical orbit attained, LES-4 supplied extensive data on the energy spectrum of trapped electrons in five energy ranges from 130 keV to 4 MeV and at altitudes from 185 to 33,706 kilometers (100 to 18,200 nautical miles)[1]. Five solid state detectors were employed. A sixth detector was continually exposed to a source of known intensity and served as a calibration sensor such that the degradation of the five detectors due to the space radiation environment could be determined. Three of the five detectors were shielded silicon cells while the other two were CdTe thin film cells. Results on the CdTe cells, as constructed, indicated they could not satisfactorily withstand a space environment[13]. Earth albedo measurements were also made as an additional experiment on the earth environment[14][15].

Table 9-8. Summary of X-Band LES Experiments

Experiment	Program Objective Satisfied*	Nature of Activity
1. LET Terminal & Signal Processing	6,7&8	Evaluate performance of antenna, RF. components, & signal processing system.
2. Satellite X-Band Transponder	1 & 2	Demonstrate feasibility of solid state satellite transponders for operation at X-Band
3. System Performance	1,2,6,7&8	Measure LES/LET capability when operated as a communication system
4. Despun Antenna	3	Study antenna switching as a method of antenna despinning in spin stabilized satellites
5. Space Radiation Environment	5	Determine temporal and spatial characteristics of near earth space radiation
6. Automatic Magnetic Torquing of Spin Axis	4	Evaluate feasibility of magnetic torquing for automatic attitude alignment of spin stabilized satellites.

*Program objectives are numbered and defined in Table 9-1.

The despun antenna experiment was carried on all three X-band satellites. On LES-1, the switched antenna functioned as expected during most of the first 10 orbital revolutions until conversion to the 60-rpm tumbling mode was completed[16]. On LES-2 operation was satisfactory and in agreement with expectations. The use of conventional optics at visible wavelengths in conjunction with logic initially designed for IR sensors resulted in some anomalous operation[1]. Near satellite sunrise and sunset, the logic tended to lock on the sun rather than the earth. Moreover, the logic tended to point antennas toward the middle of the illuminated crescent rather than at the middle of the earth. These difficulties were not crucial as the ground sites operated with daylight at both transmitter and receiver. On LES-4 the antenna system which measured earth direction during every satellite rotation also operated essentially correct. Operation occasionally broke up for typically tens of minutes in a 8-hour pass due to a defective circuit[14]. The second switching logic system on LES-4 could not operate properly at all since the satellite was not in a circular orbit.

Measurements on the LET system included evaluations of the performance of RF equipment, antenna system, and signal processing system. In the two former areas, transmitter output power, receiver noise temperature, system bandwidth, and antenna autotrack capability were particular parameters of interest[17]. These measurements demonstrated performance in agreement with specified values. Performance of the signal processing system was demonstrated in "back-to-back" testing. Both the voice-excited vocoder mode using remote speakers connected to the terminal through the commercial switched telephone network and the pitch-excited vocoder mode using local speakers displayed satisfactory operation. In both modes, familiar speakers could easily be detected. The frequency hopping, MFSK, and convolution encoder-sequential decoder combined signal processing system displayed a threshold in close agreement with the 6 dB E_b/N_o expected [18]. Theory and practice were in almost perfect agreement when 0.3 dB of loss due to non-ideal matched filters and another 0.3 dB of loss due to non-ideal pulsed signals (i.e., the switching time of the frequency synthesizer was 2-4 μs) were taken into consideration. The one-way delay induced by the sequential decoder was about 200 μs[7].

The satellite X-band transponder received considerable operational evaluation on LES-2 and LES-4. Satellite EIRP, receiver noise figure, bandwidth, frequency stability, and beacon performance were all monitored and found to be the same as measured during prelaunch checkouts[19]. LES-1's transponder was operated for a short time until the satellite assumed its tumbling mode and the transponder performed as expected[16].

The satellite system performance tests and their results are summarized in Table 9-9[9] [11] [16] [19] [20]. These tests were conducted with LES-2 and LES-4. Specific results mentioned in the table are for operation with LES-2.

9.2.6 Operational Results

Since these were experimental satellites, no operational traffic was carried. The general performance of all spacecraft was good and in agreement with expectations. The solar array output on LES-1 had degraded significantly by September of 1965 due to the satellite being left in a circular orbit within the Van Allen Belt[19]. With LES-2 being in an elliptical orbit having an apogee out of the area of severe Van Allen Belt radiation, its solar array did not show significant degradation until mid 1966[6]. Even then the difficulties were not severe enough to impair transponder or telemetry operation.

The Lincoln Experimental Terminals provided generally reliable performance. One significant initial difficulty was due to the installation of the general purpose computer. Its inclusion resulted in certain equipment malfunctions being difficult to localize because "everything was so connected."[9] When this became clear, special troubleshooting programs and techniques were designed. With these techniques, the computer became an asset since it could test all interconnecting equipment.

9.3 UHF SATELLITES

9.3.1 General Description

On October 2, 1965 a Deputy Secretary of Defense memorandum titled "Tactical Satellite Communications Research and Development" inaugurated the U.S. military's TACSATCOM experimental program. This memorandum instructed the military departments to initiate studies in R&D to hasten the use of satellite repeaters for tactical communications. Experiments with the UHF Lincoln Experimental Satellites

Table 9-9. Satellite System Performance Experiments

TYPE EXPERIMENT	NATURE OF RESULTS OBTAINED
1) FM Voice & Music	Monostatic plus half and full duplex bistatic tests conducted by Camp Parks and Millstone Hill (West Ford). Quality was excellent.
2) Vocoded Voice & TTY (Full duplex)	LET-1 conducted tests. Transmitter power necessary to attain receiver threshold measured as function of satellite range. Measured values generally agreed* with calculated theoretical values. **
3) Vocoded Voice & TTY (Full duplex)	LET-1 & LET-2 conducted tests. LET-2 transmitter adjusted 8 dB below that of LET-1. Measured performance agreed well with theoretical performance based on projected up and down link parameters, hard limited satellite transfer function, and theoretical receiver threshold. **
4) Interference Sensitivity	With either interfering tone or wide-band noise, no interference to normal transmissions detected until interfering signal substantially exceeded communications signal on satellite up link. Communications failed only when interference forced the communications downlink signal to drop below receiver threshold.
5) Frequency Spread vs. Processing Threshold	Spreading from frequency hopping varied over 2.5, 5, 10, and 20 MHz. No change in signal processing threshold occurred except at the 20 MHz rate. At this rate, bandpass limitations of the satellite and terminals caused some degradation.
6) Vocoder Performance	For operation above threshold, both vocoded modes displayed essentially the same performance as found in LET "back-to-back" tests.
7) Vulnerability to Intelligent Hostile Jamming	Performance compared to pseudonoise for a broad class of jammers. Results classified.

Notes: * Deviations caused by: satellite power varying with temperature, age and inexact aiming of satellite antennas; terminal receive noise temperature varying with weather conditions and antenna elevation angle; path loss varying with weather conditions, satellite range, and antenna elevation angle; terminal calibration changing with age; and satellite and terminal bandpass not being entirely flat.

**Theoretical threshold occurs at a received power to noise density ratio (P_r/N_0) of 43 dB based on an E_b/N_0 of 6 dB and a 4.8 kbps vocoder data rate. This compares to a P_r/N_0 of 52 dB required to obtain comparable quality on a single FM voice channel.

(LES) constituted the initial phases of this program. The program was continued by the successful launching of TACSAT I in early 1969 (see Section 14). Specific objectives of the satellites and earth terminals included in the LES portion of the TACSATCOM program are listed in Table 9-10[21].

Table 9-10. UHF LES Experiment Objectives.

Number	Description
1	Develop and demonstrate space hardware operating in the miliary UHF frequency bands
2	Develop and demonstrate mobile tactical terminals operating at the military UHF frequencies
3	Investigate propagation characteristics of UHF satellite links
4	Determine the extent of RF interference to a UHF tactical satellite communications system
5	Study electronic switching in despun antennas
6	Evaluate high efficiency RF transmitters
7	Demonstrate automatic onboard satellite attitude control
8	Display automatic onboard satellite stationkeeping
9	Study the space radiation environment

Three UHF Lincoln Experimental Satellites were launched as part of the TACSATCOM program as indicated in Table 9-11[22] [23] [24] [25]. LES-3 was launched along with LES-4, Oscar 4, and OV2-3 as indicated in the "General Description" of the X-band LES (see Section 9.2.1). When the improper injection into a highly elliptical inclined orbit occurred, LES-3 was left spinning at 140 rpm with its spin axis inclined about 15° to the orbital plane[14]. This was in contrast with the planned perpendicular orientation. Despite the unplanned orientation, LES-3 operated as designed and, in accordance with its sole mission objective, provided the signals necessary to carry out UHF propagation measurements. Atmospheric drag, resulting from the low perigee of this satellite's highly elliptical orbit, eventually caused the orbit to decay but not before all desired testing had been successfully completed.

Table 9-11. UHF Spacecraft

Satellite		LES-3	LES-5	LES-6
Manufacturer & Sponsor		Lincoln Laboratories and U.S. Air Force		
Launch Date		12/21/1965	7/1/1967	9/26/1968
Launch Vehicle		Titan III C		
Orbital Data*	Apogee	33,619 km (20,890 mi.)	33,626 km (20,894 mi.)	35,785 km (22,236 mi.)
	Perigee	200 km (125 mi.)	33,301 km (20,692 mi.)	35,597 km (22,119 mi.)
	Inclination	26.6°	7.2°	3°
	Period	589.6 min.	1,319 min.	1,431.2 min.
Status		Formal spacecraft observations terminated in late summer 1967. Orbit decayed 4/6/68 and satellite was destroyed.	In orbit but a failure in the final power amplifier driver stage caused radiations to cease in late May 1970.	In orbit and active with output power reduced due to solar array degradation. Stationed at approximately 38.5° West longitude.

NOTES: *At initial injection. Atmospheric drag, solar pressure, and attitude and stationkeeping maneuvers are among causes of parameter changes.

LES-5 along with its companion satellites, IDCSP 16 through 18, DATS 1 and DODGE, constituted the payloads successfully launched by Titan III-C Vehicle No. 14 into planned near-synchronous, near-equatorial orbits[21] [26]. The three essentially identical IDCSP satellites, DATS 1 and DODGE were all part of the Initial Defense Communication Satellite Program (see Section 12). IDCSP 16-18 augmented two earlier successful launches of seven and eight IDCSP satellites respectively and completed the first U.S. global experimental military communication satellite system. DATS 1 was electrically identical to the IDCSP satellites but employed an experimental electronically despun antenna. DODGE was intended to study a number of advanced gravity-gradient stabilization techniques at near-synchronous attitudes and to take color TV pictures.

LES-5 and the ground complex employed with it provided experiments aimed at meeting all of the objectives listed in Table 9-10 with the exception of Items 5, 6 and 8[21]. The satellite was utilized, during its 3-year (approximate) active lifetime, by tactical terminals of all the U.S. armed services and NATO forces. In general, the experiments conducted allowed all of the intended objectives to be accomplished. These successes were attained in spite of a number of minor spacecraft failures. Difficulties included predictable daily periods of abnormally high rate receiver timing signals to the command system and Radio Frequency Interference (RFI) Experiment, predictable yearly periods of reduced receiver sensitivity, failure of one of four sun sensors providing inputs to the automatic attitude control system, and a 1.7 kHz frequency shift in one of two transponder local oscillators resulting in a corresponding change in frequency translation.

LES-6, OV2-5, OV5-2, and OV5-4 were successfully launched into planned orbits by Titan III-C Vehicle No. 5[21] [27]. The launch vehicle's Transtage left LES-6 in an essentially synchronous equatorial orbit. The satellite's onboard cold ammonia thruster system was used for final adjustment into a stationary orbit with the spacecraft positioned at about 86° West longitude[28]. OV2-5 and OV5-2 were launched to collect data on the space radiation environment while OV5-4 provided an experiment on heat transfer in a liquid under zero-g conditions. LES-6 and the ground terminals operating with it provided experiments aimed at meeting all of the objectives listed in Table 9-10.

Shortly after orbital injection it was observed that the satellite was spinning about an axis offset about 2.2° from the axis of symmetry of the cylinder (i.e., nutating). Additionally one solar panel, lying in the plane defined by the actual spin axis and the axis of symmetry, was providing a severely reduced power output[29] The exact cause of these seemingly related difficulties was not determined. It was hypothesized that the satellite unbalance and resultant spin axis offset was produced by about 0.5 kilograms (1.1 pounds) of weight added to the outside surface of the cylinder. One theory suggested that an object was caught on a dipole antenna and was shadowing the solar panel. The net effect was to make the automatic attitude control system unusable and produce a spin rate modulation of the solar array dc power output that resulted in a similar modulation of the RF power output.

A further difficulty was encountered about a week after launch when a relay flip flop failed in the Earth Position register of one of the satellite's two antenna switching logic systems[29]. However, the second switching logic system remained in good working order and was able to successfully handle antenna switching except during periods of darkness of the subsatellite point. The satellite was allowed to drift from its initial position to about 93°W longitude and was maintained at this location by the automatic stationkeeping system for several months. During these initial months in orbit, the satellite was employed by tactical terminals of all of the U.S. armed services in tri-service tests and all of the objectives listed in Table 9-10, with the exception of Item 7, were successfully accomplished.

On July 23, 1969 a program was initiated to move LES-6 further eastward to about 40°W longitude so that the NATO countries of Europe could view the spacecraft[30]. The satellite arrived at its new station in the beginning of December 1969[31]. It is presently located at 38.5°. Sufficient fuel is available on board for station keeping and attitude control at its present longitude until December 1976[31a]. It continues to be employed by the NATO countries and the U.S. armed services.

The major satellite communications ground station involved in testing with all three UHF Lincoln Experimental Satellites was the Lincoln Laboratory's terminal located on the roof of Building B at the Laboratory in Lexington, Massachussetts[29][32]. This terminal employed a 9-meter (30-foot) parabolic antenna and initially came into being in 1965. It was subsequently upgraded in performance capabilities. Lincoln Labs supplemented this terminal in late 1966 with a small truck-based UHF terminal employing a 12-dB gain helix antenna[6]. This terminal was designated LET-4 as it was preceded by three transportable SHF Lincoln Experimental terminals (see Section 9.2.1). LET-4 was a major participant in LES-5 and LES-6 testing.

In addition to these terminals, a host of mobile terminals built by the three major U. S. armed services used the satellites. These included fixed wing aircraft, helicopter, surface ship, submarine, van, small truck, jeep, and manually carried terminals[33][34][35][36]. The latter included small terminals that can be carried by one man and larger terminals carried by a team of men.

Fixed wing aircraft outfitted with these terminals included B-52s, C-135s, and P-3s. Many of the aircraft tests used airplanes based at Wright Patterson Air Force Base in Ohio. Helicopters provided with terminals included the UH-1F and UH-1D aircraft. Surface ship terminals involved in tests included the USS Providence, USS Guadalcanal, USS Threadfin, USS Picuda, USS Pocono, USCGC Glacier, and USS Leahy. Submarine terminals participating in tests included the USS Tullibee and USS Thornback. Army tests of vehicular and manually transported terminals were conducted at Fort Monmouth, New Jersey and Fort Clayton, Panama Canal Zone among other places. Various fixed or semi-fixed stations making some use of LES-5 and LES-6 were located at Rome, New York; St. Petersburg, Florida; San Diego, California; New London, Connecticut; Patuxent River, Maryland and St. Inigoes, Maryland.

Spacecraft telemetry was obtained by Lincoln Laboratory facilities at Camp Parks, California; Millstone Hill, Massachusetts; and Lexington, Massachusetts. Additional locations receiving special installations of telemetry equipment included

Cape Kennedy, Florida and Guam Island. The main command station was Lexington, Massachusetts. Spacecraft launchings were provided by the U. S. Air Force.

The UHF LES program resulted in numerous advancements in technology available to support the design of satellite communications systems. It significantly advanced the state of knowledge of UHF propagation and the UHF noise environment including RF interference. In particular, the studies characterized propagation and noise pertinent to systems involving small mobile aircraft, ship, vehicular and manpack terminals. Workable experimental tactical communications terminals, including antennas and modems, were developed and demonstrated. The feasibility of high efficiency UHF satellite transmitters operating directly from an unregulated solar array power supply was displayed accurate autonomous attitude control of spin-stabilized near-synchronous satellites was exhibited. The feasibility of autonomous stationkeeping and station changing was demonstrated. These two automatic control concepts could ultimately greatly simplify the need for ground control operations and ground tracking requirements. This may become important as the number of satellites in orbit increases and the separation between them decreases. In addition, an electronically switched despun antenna system successfully operating at UHF frequencies was displayed.

9.3.2 System Description

Numerous linking arrangements were devised among the many terminals participating in tests. The tests included individual terminal loop back, two terminal hald duplex, full duplex, and multiple access tests. Many of these tests centered upon the Lexington terminal. The orbit of the LES-5 spacecraft supplied 5 days of visibility at Lexington out of the 11 required for its slight west-to-east drift to produce one revolution of movement relative to a given spot on the surface of the earth[23]. The earth visibility supplied by LES-6 in its initial stationary location is shown in Figure 9-4[33].

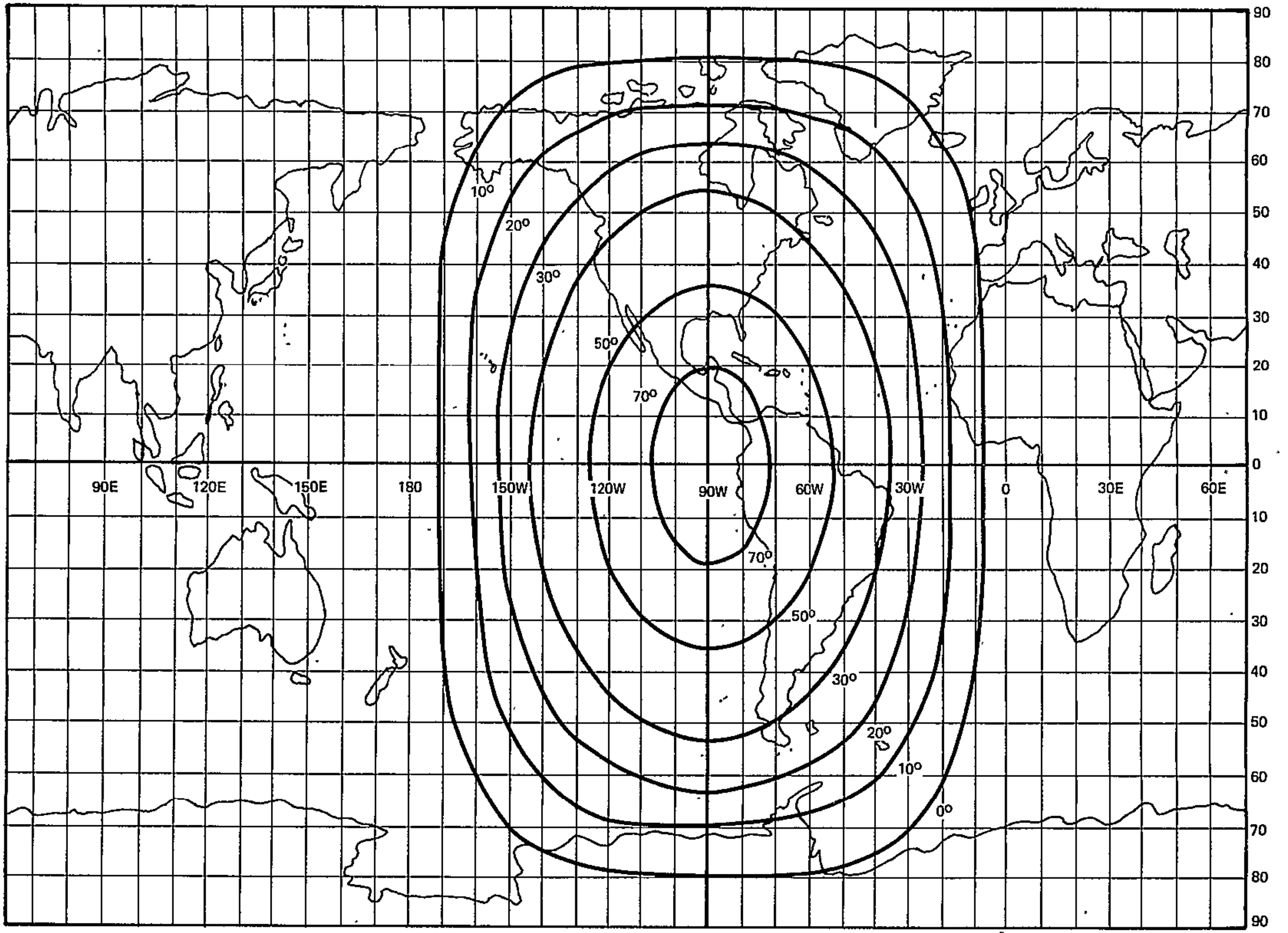

Figure 9-4. LES-6 Earth Visibility as a Function of Antenna Elevation Angle

Operating frequencies for the three UHF Lincoln Experimental Satellites are shown in Table 9-12[14][21][33]. The choice of the UHF frequency band for these studies was governed principally by the antenna problem and the spectrum allocations that were available for military use. In the very constrained physical environment of a small mobile terminal, and in particular in the environment of an aircraft, it is highly desirable to use simple antennas which do not require accurate pointing. Given this requirement, a relatively low frequency is attractive since the receiving cross section of a dipole antenna is proportional to the square of the wavelength[33]. The limitations on the lower end of the spectrum are governed by noise background and spectrum availability

Table 9-12. UHF LES Operating Frequencies (MHz)

Satellite	Communications			Telemetry
	Uplink	Downlink	Beacon	
LES-3	--	--	232.9	No data
LES-5	255-280[1] 255.1[2]	228.2	228.43	236.75
LES-6	290-315[1] 302.7[2]	249.1	254.14	236.75

Notes: (1) Frequency band over which RFI measurements were made. Command receiver operated off RFI receiver.

(2) Center frequency of communications transponder.

The major approaches to signal processing centered upon a triple frequency-time diversity technique conceived by Aerospace Corporation and developed by Electronic Communication Inc., and the frequency hopped Tactical Transmission System (TATS) developed by Lincoln Labs. Conventional analog FM and frequency division multiple access were also occasionally employed. Signal processing and link performance when the frequency diversity technique was employed on a channel perturbed by Gaussian additive noise are summarized in Table 9-13[33][34].

The triple diversity modem handled 60 or 100 word per minute teletype using an asynchronous baudot code. Incoming teletype messages were reclocked to obtain a uniform bit stream which could be split into three chips per bit. The three chips were sequentially transmitted on three different frequencies. There was a constant frequency separation between the three "Mark" and three "Space" frequencies. The data demodulator used a phased lock loop to derive ship timing such that the proper pair of matched filters were sampled at the proper time. The total energy present in the three mark channels was compared with the total energy present in the three space channels for each bit time to decide if a "Mark" or "Space" had been sent. This system was designed specifically for aircraft and with its 100-kHz bandwidth provided good resistance to multipath fading down to an elevation angle of about 4° to the satellite for an airplane flying at about 9144 meters (30,000 feet). The triple diversity also provided protection against RFI.

Table 9-13. Signal Processing Using Frequency Diversity

Multiple Access	Frequency Division but frequency-time diversity[(1)] provides some resistance to interference from other users in same frequency band.
RF Modulation	FSK
Ground Demodulator Performance	E_b/N_o[(2)] of 12 dB required[(3)] corresponding to 31 dB/Hz signal-to-noise density ratio for 75 bps TTY channel
C-135 Receive Carrier-to-Noise Density	44 dB based on operation with LES-5 at maximum range and utilization of blade aircraft antenna with 1-kW transmitter [(4)] and receiver having 4.5 dB noise figure
Link Margin	13 dB

NOTES:
(1) Each bit divided into three chips. Each chip transmitted successively at separate frequency.
(2) Energy per bit-to-noise density ratio
(3) Gives probability of error less than 10^{-3} based on matched filter detection and integration over outputs of each of three filters representing "Mark" and "Space" respectively.
(4) Spacecraft transponder operated at 100-kHz bandwidth and marginally saturated by uplink signal.

Signal processing and link performance when the TATS modem was employed on a channel perturbed by Gaussian additive noise are summarized in Table 9-14[33][37][38]. A functional block diagram of a TATS modem is given in Figure 9-5[37]. This modem was specifically designed for the military tactical communications environment and continued to be used in extensive testing on TACSAT I (see Section 14.5). It was designed to allow a high level of random multiple access with a minimum of acquisition and synchronization difficulties, provide a high degree of resistance to RFI, and supply good performance in the face of multipath fading. As designed, it provided little resistance to jamming.

Table 9-14. Signal Processing Using TATS

Multiple Access	Code Division through frequency hopping of channel center frequency
TATS Demodulator Performance	E_b/N_o (1) of 11 dB required (2) corresponding to 45 dB/Hz signal-to-noise density ratio for a 2.4 kbps vocoded voice channel
C-135 Receive Carrier-to-Noise Density	55 dB based on operation with LES-6 at maximum range and utilization of blade aircraft antenna with 1 kW transmitter (3) and receiver having 4.5-dB noise figure.
Link Margin	10 dB

Notes: (1) Energy per bit-to-noise density ratio
(2) Gives probability of error less than 10^{-3} based on matched filter detection and Reed-Solomon coding of data
(3) Spacecraft transponder operated at 500-kHz bandwidth and marginally saturated by uplink signal.

The basic signaling waveform was a T_c second sine wave pulse on one of eight frequencies spaced at $1/T_c$-Hz increments. Six bits of information corresponding to sixty-four possible states of the input word were coded into a sequence of seven such pulses using the (7, 2) octal Reed-Solomon code[37]. An additional fixed frequency pulse started each seven pulse code word to aid in time and frequency synchronization. Therefore, the time to transmit each code word was 8 T_c seconds. Since each code each word contained six bits of information, the data rate was $0.75/T_c$ bits-per-second. At the two data rates handled by the modem (i.e., 75 or 2400 bits/sec), T_c was 10 msec. or 312.5 μs, respectively.

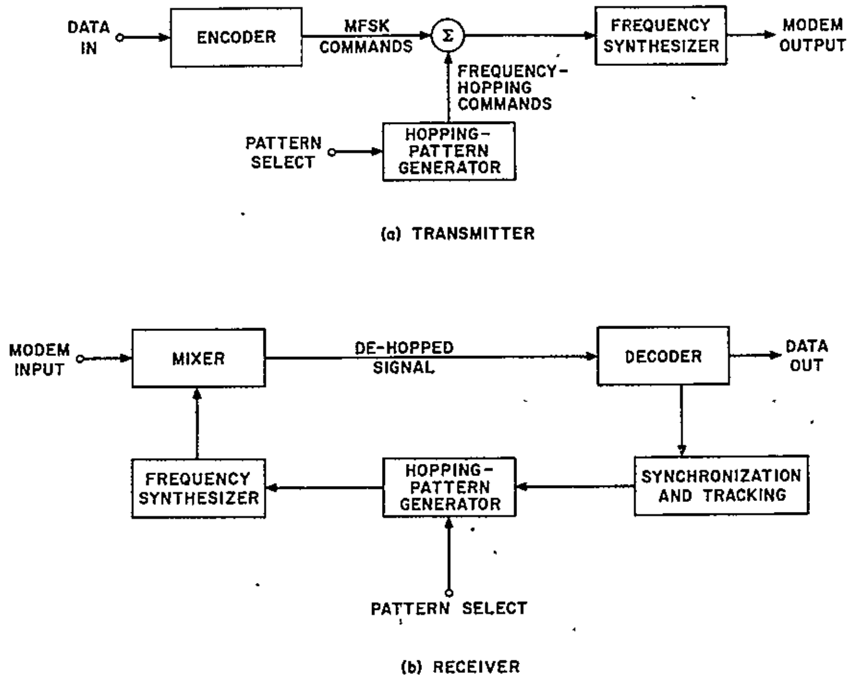

Figure 9-5. TATS Functional Block Diagram

At the receiver, the amplitude of the envelope out of each of eight matched filters was sampled and quantized to one of 16 levels at the end of each T_c-sec pulse interval[37]. Seven sets of these measurements, corresponding to one code word, were used to generate 64 numbers related to the likelihood that each of the 64 possible code words was the one actually being received. The maximum likelihood 6-bit information word was outputed each 8 T_c seconds.

Bandspreading was accomplished by generating a new base or carrier frequency in each pulse interval to which the frequency selected in that interval by the input code word was added[37]. The carrier hopping pattern consisted of a repetitive sequence of seven frequencies chosen from a larger set of possible carrier frequencies. Since the modulation frame contained 8 pulses or chips, the carrier frequency for each chip position within the modulation frame was cycled through the carrier hopping pattern. This guaranteed frequency diversity in the sync measurement in the presence of selective fading.

The hopping patterns were selected such that each pattern used the whole transmitted bandwidth (i.e., 500 kHz or 10 kHz as selected) and the number of pattern overlaps between members of the selected set were small for all possible time shifts. The first property provided the diversity necessary to combat frequency selective fading due to multipath and RFI. The second property minimized the possibility of decoder error due to channel cross-talk.

9.3.3 Spacecraft

Characteristics of the communications related subsystems of the LES-5 and 6 spacecraft are given in Table 9-15. See References 21, 32, and 39 through 42. A block diagram of the transponder on LES-5 is shown in Figure 9-6[39]. The LES-6 transponder was basically the same as that shown for LES-5. Transponder frequencies, powers and bandwidths were different. Additionally, the beacon transmitter served as the third input to the antenna triplexer instead of the telemetry transmitter. The latter employed a separate antenna for signal radiations.

The characteristics of LES-3 are not summarized in Table 9-15 since it did not contain a communications repeater. LES-3 was built to provide an orbiting UHF beacon to be used for propagation measurements. It radiated 28.5 watts biphase modulated by a 15-bit pseudorandom sequence clocked at a rate of 100 kHz [11][14]. Such a signal permitted detailed measurements of the multipath and fading characteristics of the propagation medium.

LES-3 was constructed utilizing the frame, power system, and power amplifiers designed for LES-1 and 2 and was similar in appearance to these satellites[1][19]. The most apparent difference was a lack of optical sensors and X-band antennas on the triangular faces and the presence of a UHF monopole antenna projecting from the top and bottom rectangular surfaces of the spin stabilized satellite. These surfaces

Table 9-15. Satellite Characteristics

		Satellite	LES-5	LES-6	
Antennas		Type	UHF-Array of 16 axial cavity backed slots in 2 rings and 8 full-wave deployable dipoles in 1 ring. (1) Triplexer allowed communication xmit and receive plus telem. to use same antenna system	UHF-Switched array of 16 axial cavity backed slots and 16 axial half-wave extended dipoles. (1) Both slots and extended dipoles in 2 rings of 8 elements each.	Telem-Monopole stub extended from one end along line of spin axis.
Antennas		Number	One	One	One
Antennas		Xmit Beamwidth (3 dB)	Torroidal pattern about 37° wide	Pencil beam 34° x 47°	Omnidirectional
Antennas		Gain	Xmit - 2.5 dB; Rec - 2.2 dB	Xmit - 10 dB; Rec - 10 dB	0 dB
Repeaters		Frequency Band	UHF	UHF	
Repeaters		Type	IF translation hard limiting	IF translation hard limiting	
Repeaters		Bandwidth (3 dB)	100 or 300 KHz switchable on ground command	100 or 500 KHz switchable on ground command	
Repeaters		Number	One	One	
Repeaters	Receiver	Type Front End	Down Conversion Mixer	Down Conversion Mixer	
Repeaters	Receiver	Front End Gain	No data	No data	
Repeaters	Receiver	System Noise Figure	3.6 dB	3.6 dB	
Repeaters	Transmitter	Type	Four hybrid summed transister amplifiers in final stage	Eight hybrid summed transistor amplifiers in final stage	
Repeaters	Transmitter	Gain	About 25 dB for transmitter power amplifier chain	About 10 dB for final stage and 60 dB for total xmit chain	
Repeaters	Transmitter	Power Out	42 watts	122 watt at launch	
Repeaters		EIRP	17 dBW	29 dBW at launch	
General Features	Stabilization	Type	Spin with autonomous magnetic attitude control system	Spin with autonomous magnetic or gas thruster attitude control system plus autonomous station-keeping using cold ammonia gas or pulsed plasma thrusters	
General Features	Stabilization	Capability	Spin axis was kept within 2.6° of orbit normal	Automatic attitude control inoperable because of spin axis misalignment. (2) Stationkeeping displayed capability of keeping satellite within about 2° of desired longitude.	
General Features	Power Source	Primary	Silicon solar cell array providing 136 watts at launch	Silicon solar cell array providing 230 watts at launch	
General Features	Power Source	Supplement	None	None	
General Features		Communication Power Needs	Approximately 70 watts	Approximately 180 watts	
General Features		Size	Cylindrical approximately 168 cm (66 in.) length, 122 cm (48 in.) diameter	Cylindrical approximately 168 cm (66 in.) length, 122 cm (48 in.) diameter	
General Features		Weight	102 kg (225 lbs)	163 kg (360 lbs)	

Notes: (1) Elements in 2-ring arrays employed in collinear pairs made up of one element from each ring. Slot arrays driven in phase quadrature with extended dipole arrays. This in combination with the orthogonal polarization of the two types of arrays produced a circularly polarized antenna system.

(2) System was designed to attain an accuracy of $\pm 0.16^{\circ}$ using gas thruster system.

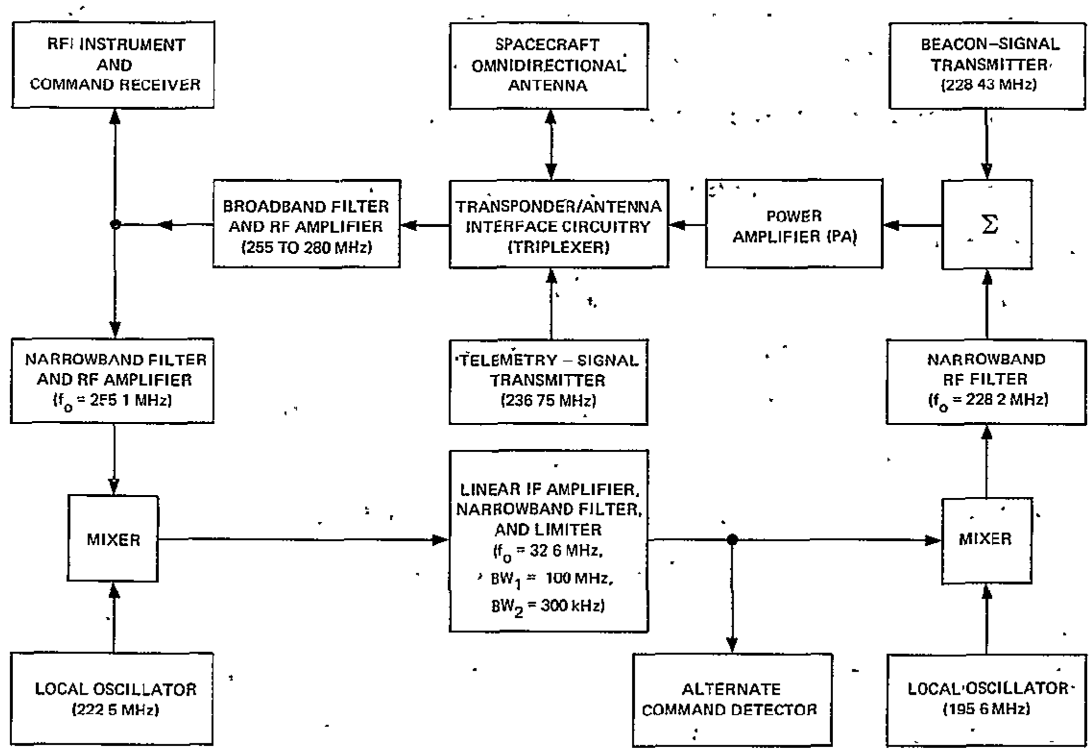

Figure 9-6. LES-5 Transponder Block Diagram

carried no solar cells. The antenna system produced a toroidal pattern with a measured gain of 4-1/4 dB in the direction perpendicular to the spin axis. The spacecraft weighed approximately 15 kilograms (32 pounds).

LES-5 provided, in addition to the features indicated in Table 9-15, a solar cell degradation experiment, an RF interference experiment, and experimental switching logic for antenna despinning although no actual antenna switching was performed[21]. The solar cell experiment included measurements on two 10-ohm cm. silicon cells with 30-mil. cover slides, one 10-ohm cm. silicon cell with 6-mil. cover slide, and two CdS thin film cells[13]. The satellite RFI receiver had a 120-KHz noise bandwidth and was designed to tune from 283 MHz to 253 MHz in 256 steps of approximately 120 KHz each, dwelling at each step for 2.56 seconds[43]. The time for a complete frequency scan was approximately 11 minutes. In the fixed frequency modes, the RFI instrument also functioned as the command receiver for the spacecraft. The onboard experimental switching logic was included to obtain data for the design of the despun antenna system flown on LES-6.

LES-6 provided, in addition to the features indicated in Table 9-15, a solar cell degradation experiment, space radiation environment measurements, an earth albedo experiment, an RF interference experiment, precision spin period measurements, and a communications transmitter making highly efficient use of available dc power[21]. The solar cell experiment studied radiation effects pertinent to solar power arrays made from the standard silicon cells normally used and effects on experimental cells of various types. The latter included lithium-doped cells made from silicon grown by crucible, float zone and Lopex techniques; cells made from silicon grown by the dendretic support process; cells manufactured by ion implant techniques; CdS thin film cells, and Cd Te thin film cells[44]. The space radiation experiment was designed to measure the trapped electron spectrum over the range of 275 keV to 3 MeV[21][45]. The earth albedo experiment measured the reflected optical spectrum from the earth in 6 spectral bands from 0.41 microns to 1.00 microns[21]. The RFI experiment was very similar to that on LES-5 except it measured interference in the band from 290 to 315 MHz[43]. Precision spin period measurements were a by-product of a special clock rate generator included on LES-6 as part of the automatic stationkeeping system. The high efficiency transmitter operated directly from the solar bus. The power amplifier load line was adjusted to be coincident with the locus of maximum power points as the output from the solar array varied with sun illumination and satellite life[21]. There were no dc-dc converter losses in order to obtain proper regulated voltages and no unutilized power for solar array radiation degradation margins.

9.3.4 Ground Terminals

The major station involved in UHF LES testing was Lincoln Laboratory's Lexington terminal. Early military terminals involved in the program were the Electronic Communication, Inc., (ECI) terminals employed by the Air Force[33] and Navy and the Project East vehicular earth terminals[35] developed by the Army. The ECI terminal was an experimental, off-the-shelf, single channel, low data rate, teletype communication system that employed the triple frequency diversity ECI modem. The U. S. Navy version of this terminal was nicknamed a LODUS terminal. The U. S. Air Force version was designated the UHF terminal (ECI 591). The U. S. Army's Project East equipment included two jeep, two 680-kg (3/4-ton) truck, and one 7.9-meter (26-foot) van terminal. They were assembled from off-the-shelf commercial and military equipment and employed conventional frequency modulation for voice and teletype communications. Block diagrams of typical Air Force ECI and Army 680-kg (3/4-ton) truck terminals are shown in Figures 9-7 and 9-8, respectively.

With the experience gained from operating these early terminals, the U. S. Armed Services went on to develop terminals specially designed for operation in a tactical military communications environment. These terminals employed the TATS modem, developed by Lincoln Laboratories and produced by Sylvania Electronics Products Inc., as a major mode of communications. They are described in the discussion of ground terminals employed with TACSAT I (see Section 14.4). Characteristics of the Lexington fixed terminal and a typical C-135 aircraft ECI terminal are delineated in Table 9-16[6][33][34][36][39]. The linear polarization of the blade aircraft antenna resulted in a 3-dB link polarization loss since all of the UHF Lincoln-Experimental Satellites had circularly polarized antennas. The crossed dipole and crossed slot aircraft antennas were circularly polarized.

9.3.5 Experiments

A multitude of small mobile terminals were available for test operations and innumerable measurements, demonstrations, and tests of a wide variety were conducted over the UHF Lincoln Experimental Satellites. Demonstrations even included support of Apollo 9's splashdown by LES-6. Major categories of significant experiments were as indicated in Table 9-17[21][33].

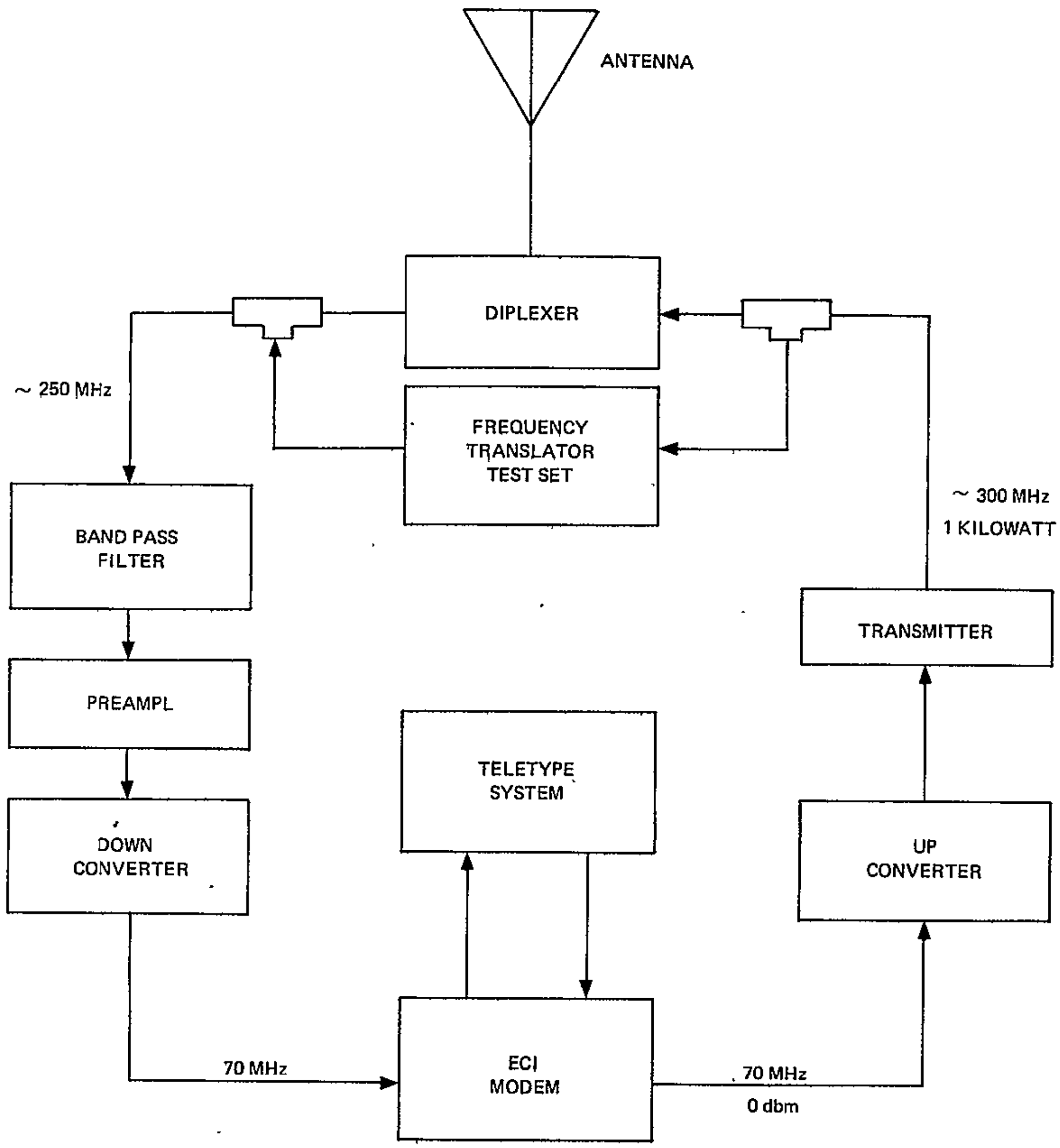

Figure 9-7. ECI UHF Terminal Block Diagram

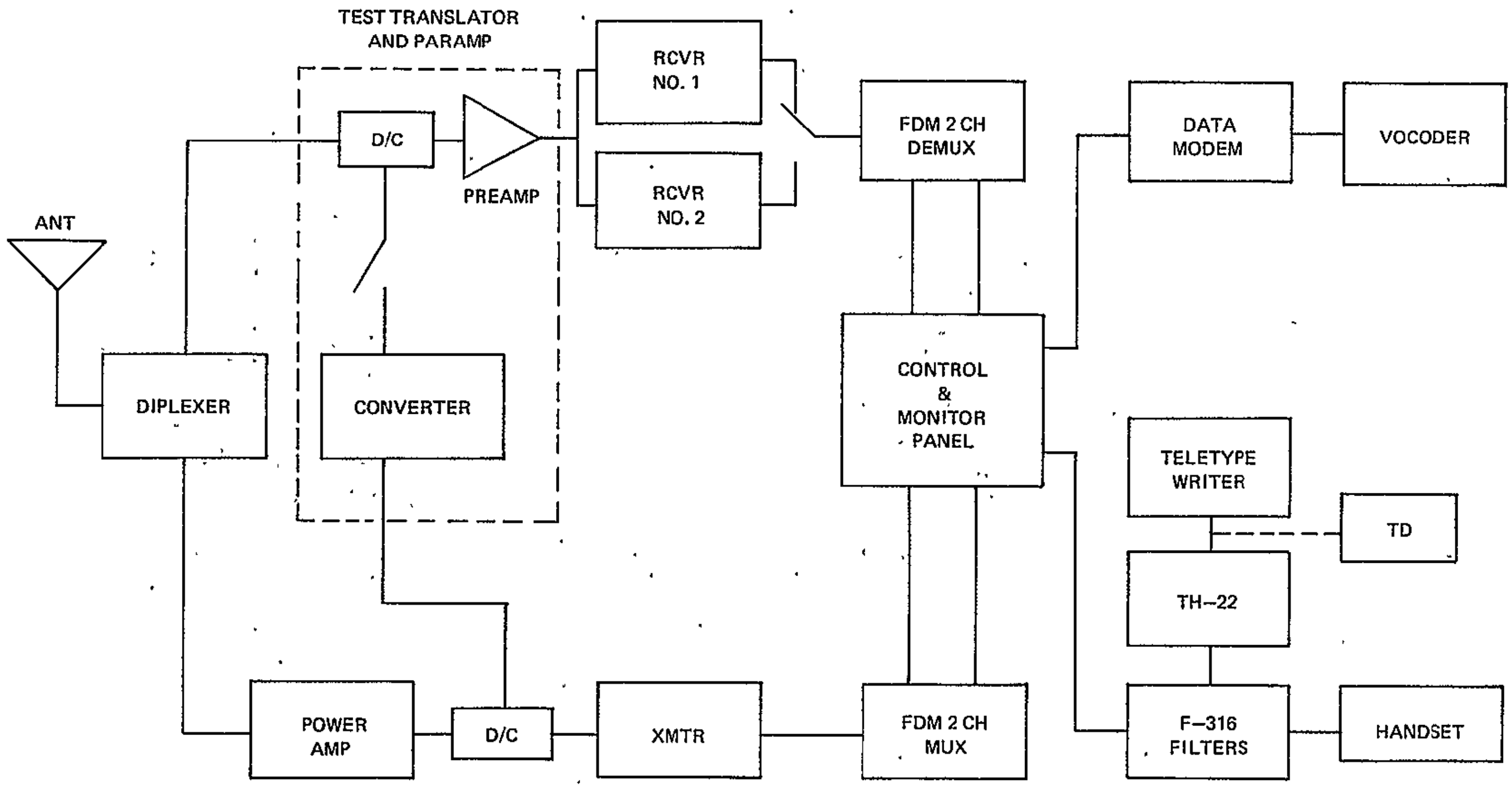

Figure 9-8. Project East 680-Kg (3/4-Ton) Terminal Block Diagram

Table 9-16. Characteristics of Major UHF LES Terminals

Terminal Feature		Lexington	C-135 ECI
Antenna	Type	Parabolic Reflector	Blade(1)
	Size	9.1 m (30 ft) Diameter	13.9 cm x 2.5 cm x 21.6 cm (5-1/2 in. x 1 in. x 8-1/2 in.)
	Receive Gain	23 dB	4 dB
	Efficiency	42%(2)	No data
	Rec. Bandwidth	10° @ 3 dB Pts. (2)	Approx. 35° width for toroidal pattern
Receive System	Type Preamplifier	No data	No data
	Bandwidth	No data (3)	100 KHz
	Noise Temperature	No data	$500\text{-}800^{\circ}K$
Trans-mit System	Type Amplifier	No data	No data
	Bandwidth	No data(3)	100 KHz
	Amp. Power Out	1 kW	1 kW
Track-ing	Type	Autotrack	None
	Accuracy	No data	None
Total Performance	G/T	No data	$-24\ dB/^{\circ}K$ (2)
	EIRP	83 dBm(2)	64 dBm(2)
Polar-ization	Transmit Feed	Circular	Linear
	Receive Feed	Circular	Linear
Instal-lation	Radome	None	None
	Type Facility	Fixed	Aircraft Terminal

Notes: (1) Other antennas such as crossed dipoles and crossed slots were also employed.
(2) Derived value based on data available.
(3) Had to be at least 500 KHz to be compatible with the bandwidth of LES-6.

Table 9-17. Summary of UHF LES Experiments

Experiment	Program Objective Satisfied*	Nature of Activity
1. Aircraft Antennas	2	Evaluate antennas for use on airplane and helicopter satellite communications terminals.
2. Satellite Multiple Access	1,.2&3	Determine system limits and constraining factors for multiple access using tactical terminals.
3. Tactical Modems	2	Measure performance of different tactical terminal modulation/demodulation techniques.
4. Propagation Link Losses	3	Evaluate factors producing variations from link attenuation determined by conventional free space spreading and antenna gain considerations
5. System Noise and Interference	3&4	Measure receive system noise temperatures and RF interference to tactical satellite communications systems.
6. Satellite UHF Transponder	1	Determine performance of solid state satellite repeaters operating at UHF.
7. Solar Cell Degradation	9	Study the effect of the space radiation environment on various experimental solar cells.
8. Earth Albedo	9	Define the spectrum of electromagnetic energy at optical frequencies as reflected by the earth and viewed by a synchronous satellite.
9. Space Radiation Environment	9	Measure temporal and spatial characteristics of near earth, space radiation.
10. Automatic Stationkeeping	8	Evaluate the feasibility of autonomous onboard control employing either cold ammonia gas or pulsed plasma thrusters.
11. Automatic Attitude Control	7	Determine the feasibility of autonomous on board control employing either magnetic torquing or cold ammonia gas thrusters.
12. High Efficiency RF Transmitters	6	Demonstrate the feasibility of satellite transmitters operating directly from a solar array primary power system.
13. Despun Antenna	5	Study use of switching in conjunction with multi-element arrays as a means of realizing a despun antenna on a spin stabilized satellite.

*Program objectives are numbered and defined in Table 9-10.

The despun antenna, indicated in the table, was flown on LES-6 and consisted of an array of 8 elements with each element composed of a pair of collinear axial extended dipoles in combination with a pair of collinear axial slots[21]. Two elements were excited at a time and all combinations of successive elements were sequentially activated as the satellite rotated. Each combination was excited in either of two-phase relationships to produce two beam positions per pair of elements and a total of 16 switched overlapping beams in the array. Post launch measurements of antenna gain indicated it was in the region of 8.5 to 9 dB, which agreed with pre-launch measurements. Pattern ripple due to beam switching was ± 0.5 dB[29].

Two antenna-switching logic systems were included on LES-6 which could be operated independently or in a combined mode[21]. As on LES-4, one system measured the direction to the earth at one point in the orbit and predicted the orbital position of the satellite as a function of time while the second system determined earth direction during every revolution of the spinning satellite. In the combined mode, the earth direction measuring system was employed during the hours of local daylight at the subsatellite point and the orbit storage system was used during the hours of local darkness. All modes of operation worked well for the first week in orbit[29]. Subsequently a relay flip-flop failed in the Earth Position register of the orbit storage system causing inaccurate pointing in both that mode and the mixed mode. The earth direction measuring system continued to work as expected. As on LES-4, however, pointing became inaccurate between local sunset and sunrise as the satellite's optical sensors lost track of the exact location of the earth.

Proper operation of LES-6's high efficiency RF transmitter from a varying dc power source was verified immediately after launch when it was discovered that one solar panel was not delivering the expected power. This failure produced a spin variation of about 1 volt in the solar bus voltage which resulted in about a 0.5-dB spin variation in transmitted power[29]. This variation was superimposed on the ripple due to beam switching. The transmitter has continued to perform properly as solar array output has varied with the season of the year and satellite lifetime in orbit.

Automatic attitude control systems were included on both LES-5 and LES-6. Their principal of operation was basically the same. They measured latitude, of the satellite-earth line, relative to the satellite's equatorial plane at points 90° apart in the orbit, providing a good view of both the sunlit earth and the sun[21][46]. By positioning the measurements 90° apart, X and Y axes of correction were established. In making a limited number of measurements it was assumed that the satellite attitude did not change greatly between measuring points. Proper orbital measurements points were determined by the coincidence of pulses from specially positioned earth and sun sensors. Knowledge of the satellite spin rate, as determined from sun sensor measurements, and X and Y axis errors allowed corrections to be triggered at the appropriate points during every satellite rotation.

The LES-5 attitude control system employed only magnetic torquing for corrections and operated correctly in spite of the failure of one of its four sun sensors. The effect of the failure was to reduce the rate of attitude correction but not its overall accuracy[21]. The system demonstrated a capability of keeping the spin axis within 2.6° of normal to the orbital plane[46]. The LES-6 system provided either magnetic or cold ammonia gas thruster corrective torquing and was designed to maintain attitude within 0.16° when the gas thruster system was employed[21]. The LES-6 system could not be operated when the satellite spin axis was found (immediately after launch) to be offset 2.2° from the axis of symmetry of the cylinder.

The automatic stationkeeping system on LES-6 used an accurate onboard clock to provide an indication of the time at which the satellite should arrive at a given point in its orbit[21][28]. The time of actual arrival, as determined by the clock and the coincidence of sun and earth sensor observations, was compared with the desired time to generate longitude position errors to be corrected by firing thrusters as appropriate. Thrusters firings were activated at satellite orbital points separated by 180° in order to ensure that orbit eccentricity remained constant. Either cold ammonia gas thrusters or pulsed plasma electric microthrusters, using solid Teflon as the propellant, could be employed for corrections.

Both thruster systems displayed proper and reliable operation although some intermittency of the pulsed plasma thrusters was observed after they had fired for several thousand hours[47]. Further, the system displayed a capability of maintaining the spacecraft within about 2° of a desired reference longitude.

The earth albedo and space radiation environment experiments were carried on LES-6 alone. Both experiments have returned considerable data that has been useful in characterizing the space environment. In the case of the radiation experiment, this was accomplished in spite of interference produced when the communication antennas situated closest to the experiment were energized[48]. Data taken during periods of interference were unusable. However, there were times defined by a set of earth and sun angles during which valid data could be obtained.

Solar cell experiments on LES-5 and LES-6 returned valuable data that has contributed towards the design of spacecraft solar arrays. LES-5 silicon cells showed an initial 4 percent degradation and an 8 percent yearly degradation. The CdS cells displayed a 5 percent initial degradation and a 20 percent yearly degradation[13]. LES-6 experiments revealed, among other things, that low energy proton damage effects at the unshielded edges and contact bars of cells do occur in synchronous orbit and are significant and that lithium doped P-N cells fair quite poorly with an initial year's degradation as high as 42 percent[44].

The UHF transponders carried on LES-5 and LES-6, in general, performed well. Measurements taken included received communications signal level, local oscillator frequency stability and transponder frequency translation, bandwidth, receiver sensitivity, transponder total and differential time delay, transponder transfer characteristics, and beacon performance. The receiver on LES-5 showed a 17-dB seasonal decrease in sensitivity which was attributed to an open circuit in the first RF amplifier that was produced as the average temperature of the satellite decreased[21]. The satellite temperature cycle was such that the sensitivity dropped in March and recovered in November of each year. In addition, one of the transponder local oscillators exhibited a sudden 1700-Hz shift in frequency in December

1968. This produced a comparable change in translation frequency. It was hypothesized from ground testing on similar hardware that a capacitor in the LO experienced an abrupt change in value. LES-6 has performed almost exactly as predicted throughout its lifetime except for the output variations due to the spin modulation on the dc power supply. None of the difficulties reviewed significantly handicapped the communications test program.

Results of UHF noise and interference measurements are given in Table 9-18[33][35][43]. As indicated by the table, receiver composite noise temperature measurements were taken on vehicular, shipborne, and airborne terminals while uplink UHF interference levels at a synchronous satellite were measured on LES-5 and LES-6. LES-5's RFI receiver experienced a timing problem which was hypothesized to be due to cross coupling from one of the onboard logic systems that operated on earth-sun inputs. These inputs disappeared around local midnight at the subsatellite point as did the RFI receiver timing problem. As a result, all of the LES-5 RFI data was centered about local midnight. LES-6's data gave a 24-hour distribution of interference but since the satellite was stationary the information obtained was primarily applicable to the North and South American continents alone. In addition to the measurements indicated in Table 9-18, tests of interference generated by the UHF tactical satellite communications terminals were conducted showing that potential conflicts do exist if adequate distances and frequency separations are not maintained.

Propagation link losses experienced by a UHF tactical satellite communications system as determined from experiments on LES-3, -5, -6 are summarized in Table 9-19 (see References 33 through 35 and 49). In addition to the factors indicated in the table, structural blockage during maneuvers was found to be an occasional problem in aircraft and shipboard terminals.

Performance of the three major types of modems evaluated in the tactical satellite communications environment is summarized in Table 9-20[33][34]. In all cases, the table indicates performance on a channel perturbed by additive white Gaussian noise alone.

Table 9-18. Noise and Interference to UHF Tactical Satellite Communications

Test	Nature of Results
1. Vehicular Terminal Receive System Noise Temperature	Receiver noise temperatures varied between 360°K and 530°K. Contributions by environment were as low as 300° K and occasionally an order of magnitude higher. Total system noise temperatures ranged between about 700°K and $3,700^{\circ}$K. RFI was an occasional problem. Both AN/TRC-24 and AN/ARC-27 terminals were sources of interference.
2. Shipborne Terminal Receive System Noise Temperature	Total receive system noise temperatures varied between about 600°K and 2000°K. RFI was not a serious problem but was occasionally encountered. Shipboard radars such as the AN/SPQ-5A, AN/SPS-29, and AN/SPS-43; communications terminals such as the AN/GRC-27; portable electric generators and arc welders could produce interference.
3. Airborne Terminal Receive System Noise Temperature	Total receive system noise temperature including RFI was about 1000°K over water and lightly populated areas, about 2000°K over fairly heavily populated land areas, and about $10,000^{\circ}$K at low altitudes directly over industrialized towns. Specific high power UHF ground communications transmitters and the Time Division Data Link (TDDL) transmitters located around the perimeter of the U.S. caused interference problems.
4. Uplink Interference to Synchronous Satellites	Measured on LES-5 and LES-6.* Largest signals come from TDDL sites in the air-defense system. Many other signals also detected. There was no piling-up of signals from many small common-channel transmitters. Some portions of the bands scanned showed little activity.

*Surface EIRPs as low as 50 to 100 watts detected on LES-5; LES-6 responded to EIRPs of 10 to 25 watts.

Table 9-19. UHF Propagation Link Losses

Parameter	Nature of Results
1. Surface Terminal Antenna Gain	Aircraft antenna gain may vary from +9 to -15 dB over a hemisphere with elevation angle to satellite a major factor determining average gain. Surface vehicular or manpack terminal patterns affected by any metal object within 10 meters.
2. Power Imbalance	Can be significant problem for multiple mobile terminals accessing a hard limiting satellite since individual terminal uplink power levels showed about a ± 2 dB variation. Ability of individual terminal to effect entire system decreased dramatically as number of total accesses became large (i.e., about 10).
3. Intermodulation	In general, was not a significant problem. In case of FM voice signal and frequency hopping signal, however, intermodulation added a noticeable amount of noise to FM signal.
4. Atmospheric Absorption	Attenuation due to atmospheric moisture may vary between 0.5 to 1.5 dB dependent upon the atmospheric path traversed by the signal. Locally heavy precipitation can add several more dB of loss.
5. Multipath Fading	Encountered by aircraft. Two ray model for the most part valid in predicting results. Circularly polarized signals provide degree of protection since multipath fading on horizontally and vertically polarized components is relatively independent. Fading occurs primarily for elevation angles between 0 & 20°; Over water and ice cyclic fades vary between 1 & 10 dB with 5 dB being most common. Over land cyclic fades decrease to 2 to 3 dB with occasional random fades of 5 to 10 dB. Flights over mountains display no multipath.
6. Polarization Losses	Can be up to 3 dB for operation with circularly polarized satellite. Circularly polarized aircraft antenna losses will, in general, vary with elevation angle to satellite.
7. Fast Fading	Occurred at rate 100 times faster than predictable by 2-ray multipath model. Both enhancement and fading occurred. Was frequency selective. Ocurred only over water at look angles greater than 25° when operating within 30° of equator. Did not appear cyclic.
8. Scintillation	Limited data indicated low probability of occurrence for operation above 10° elevation angle in Temperate Zone ($\pm 20°$ to $\pm 65°$ latitude). Can cause fades up to 20 dB. Polar Zone scintillation also observed.
9. Tropical Foliage	4 to 6 dB of loss encountered by vehicular and manpack terminals. Changing moisture content causes variations.
10. Auroral Activity	Limited data indicated little or no effect.

The TATS performance is about 2.5 dB at 2.4 kbps and 4.5 dB at 75 bps above theoretical. This performance was for production model modems optimized for the 2.4-kbps data rate. Lincoln Laboratory prototype TATS modems achieved much nearer to theoretical performance at both data rates. Production TATS modems also displayed poor operational reliability. The triple diversity modem displayed a significant degree of protection against multipath and RFI as did the TATS modem. The TATS modem also supplied as in-band multiple access capability.

Multiple access tests were successfully conducted employing narrowband FM voice, triple diversity teletype, TATS 2400 bps, and TATS teletype separately and in mixed modes[33]. Up to 17 TATS 2400 bps accesses through LES-6 into a C-135 aircraft terminal were demonstrated to be feasible[50]. However, TATS, as designed with its short period frequency hopping pattern (i.e., it repeats every 7 symbols) suffered from considerable interference due to related address codes. With even as few as two common frequencies between two hopping patterns the cross correlation was sufficiently high to make false acquisitions so prevalent that acquiring the proper signal was almost impossible. Therefore, the hopping patterns present in a multiple access environment had to be severly constrained. These restrictions, in some cases, limited the number of premissible users below that theoretically indicated by consideration of available power and bandwidth alone.

Table 9-20. Tactical Modem Performance

Modem	Nature of Results
1. TATS	E_b/N_o of 11.5 dB and 13.5 dB required for 10^{-4} probability of error at 2.4 kbps and 75 bps data rates respectively. At these levels of E_b/N_o acquisition failure rates were less than 10^{-3}.
2. Triple Diversity	E_b/N_o of 12 dB required for probability of error less than 10^{-3} at 75 bps data rate. No acquisition problem existed.
3. FM Voice	Narrowband FM gave acceptable quality at P_r/N_o=50 dB which corresponded to E_b/N_o of about 15 dB for data transmissions over this channel. No acquisition problem existed.

Numerous tests were conducted in attempts to develop aircraft antenna systems providing constant gain and polarization losses over an entire hemisphere. Fixed wing aircraft experiments included evaluations of crossed slot, crossed dipole, and blade antennas[33]. The crossed slot antenna supplied relatively good hemispherical coverage with antenna gain for the circularly polarized antenna varying between -1 dB and +5 dB. The crossed dipole and blade antennas provided complementary patterns with the former displaying good gain at elevation angles above 30° to 40° while the latter supplied its peak gain at elevation angles below 30° to 40°. The crossed dipole supplied circularly polarized signals and the blade linearly polarized signals. The complementary patterns indicated that these two antennas should be employed in a combined system having a switching capability for selecting the appropriate antenna.

Helicopter antenna tests included evaluations of crossed dipole and blade antennas individually and in various combinations mounted above and below the rotor[36]. As in the case of the fixed wing aircraft tests, results indicated that a crossed dipole and blade antenna should be employed in combination. Locating it above the rotor avoided rotor blade modulation caused primarily by blockage of the antenna aperature.

9.3.6 Operational Results

These were not operational spacecraft; therefore, no operational traffic was carried. The experimental tactical ground terminals operated essentially as expected. One difficulty was that production models of the TATS modem displayed poor reliability. The satellites also operated, generally, as expected in spite of a number of minor difficulties, most of which were described in the discussion of "Experiments" in Section 9.3.5.

Problems previously discussed on LES-5 included the sun sensor failure affecting the automatic attitude control system, the high rate timing signal to the RFI and command receiver, the 17-dB degradation in communications receiver sensitivity, and the sudden shift in transponder frequency translation. Additional LES-5 difficulties included intermodulation between the telemetry and commuincations transmitters, an open circuit in one series-connected string on a solar panel, and higher than expected first year degradation of the solar array (i.e., about 22%). The intermodulation was a result of the two signals using the same antenna and was generated in spring finger contacts used at the edges of the slot antenna cavities behind the solar panels. This problem disappeared after the satellite had been in orbit a few months. The solar array power difficulties did not interfere with LES-5 testing.

Problems previously discussed on LES-6 included spinning about an axis 2.2° offset from the axis of symmetry of the cylinder, one solar panel delivering a low power output, a flip flop failure in an Earth Position register of the antenna switching logic, and interference to the radiation environment experiment by radiating communications antenna elements. Additional LES-6 difficulties included intermodulation between the beacon and communications transmitters and the shutter, covering the radiation experiment, operating intermittently. The former was the same problem as experienced on LES-5 and it too disappeared after a brief time of in-orbit operation. The latter was caused by variations in the dc power level and the lack of a power regulator on this spacecraft.

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SECTION 10 - INTELSAT

10.1 PROGRAM DESCRIPTION

The International Telecommunications Satellite Consortium (INTELSAT) is a partnership initially established between 14 member nations in 1964 for the purpose of providing global commercial telecommunications via satellite. Since that time, the organization has expanded to include 85 member nations (as of May 1974). The interim agreements establishing the organization in 1964 provided for two management organs. An Interim Committee on Satellite Communications (ICSC), made up of member nations, served as a policy board, and the U.S. Communications Satellite Corporation (COMSAT) was responsible for system operation and technical management. In this arrangement, COMSAT was also the U.S. representative on the ICSC and under voting weighted according to system ownership was the predominant voice in establishing initial INTELSAT policies.

During negotiations initiated in 1969 and concluded on May 20, 1970, the interim agreements were superseded by permanent definitive international arrangements that will become effective in about 1978. The reorganization required by the new agreements will be phased over a 6-year period. The period began in February 1973, when all member nations ratified the new agreements.

During the 6-year phase-over period, a Board of Governors, composed of 20 to 25 members voting according to ownership percentage, will replace the ICSC. No single member will control more than one-half the votes on this board. The Board of Governors will receive top level political guidance from an Assembly of Parties, consisting of representatives of all member states, which meet at least once every 2 years. The Board will be guided on system operational matters by a Meeting of Signatories, consisting of the telecommunications representatives of all member states. At the start of the 6-year phase-over period, the Board will appoint a Secretary General to handle administrative and financial management of the system. Additionally, the Board will negotiate a 6-year contract with COMSAT to provide system operational and technical management. At the end of the 6-year period, a Director General will be appointed to assume the executive responsibilities of INTELSAT. He will take over administrative, financial, operational, and technical management of the system. The Director General will be responsible to the Board of Governors, but the exact makeup of the Director's office has yet to be determined.

From the time it was established in 1964 to the present, INTELSAT has produced four generations of satellite and ground systems. Development of the initial satellite, nicknamed Early Bird and later designated INTELSAT I, was initiated by COMSAT in November 1963. Just a year earlier, in August 1962, the U.S. Congress had passed the Communications Satellite Act, which authorized the creation of a private corporation (COMSAT) to instigate the development of a global commercial communications satellite system. At the time when Early Bird's development began, the SYNCOM II satellite had just completed demonstrating that reliable communications could be provided through lightweight synchronous satellites. As a result, the SYNCOM satellite design formed the basis for the Early Bird spacecraft. Early Bird was launched in early 1965, as indicated in Table 10-1, and by April 22, 1965, had successfully achieved synchronization into the desired geostationary orbit with the satellite located over the Atlantic Ocean. After a period of satellite performance testing, system parameter evaluation using the operating ground stations, terrestrial and satellite circuit lineup, and public demonstrations, commercial operation was initiated on June 28, 1965. The satellite successfully provided commercial communications service between the United States and Europe until it was retired in early 1969. It was reactivated for a brief period later in 1969 when temporary difficulties were encountered with the antenna system of a third generation INTELSAT satellite.

The second generation of INTELSAT spacecraft was designated INTELSAT II. Even when the INTELSAT I system was under development, it was realized that many of the inherent advantages of space communications could not be exploited. Specifically, its antenna characteristics were such as to embrace only the northeastern part of North America and the western part of Europe, and it did not allow for simultaneous

Table 10-1. INTELSAT I (Early Bird) Spacecraft

Launch Date		April 6, 1965
Contractor		Hughes Aircraft Company
Launch Vehicle		McDonnel/Douglas Three-Stage,
Synchronous Orbit Parameters*	Apogee	36,585 km (22,733 mi.)
	Perigee	35,000 km (21,748 mi.)
	Period	1436.4 min.
	Inclination	0.1°
Status		June 28, 1965 - Operational over Atlantic at 325° E. Long. Jan. 20, 1969 - Retired Reserve June 29, 1969 - Reactivated Aug. 21, 1969 - Retired

*Parameters at initial orbit injection. Attitude control and stationkeeping maneuvers produced changes.

intercommunication among numerous earth stations. By late 1965, it was recognized that the constraints imposed by these deficiencies would be incompatible with a NASA requirement for multichannel communications in late 1966 among its tracking stations at Carnarvon, Australia, Ascension Island, Canary Island, tracking ships in the Atlantic, Pacific, and Indian Oceans, and the Manned Space Flight Center in Houston, Texas. In the past, these circuits had been carried by HF radio, but for manned space flights, improved communications were desired. Consequently, in the fall of 1965 the development for INTELSAT II had begun with the primary goal of satisfying the NASA requirements; excess capacity was to be used for other commercial traffic. Because of the urgency to satisfy the NASA requirement, the INTELSAT II design evolved directly from that of INTELSAT I.

Four INTELSAT II satellites were produced and launched as indicated in Table 10-2. The first launch occurred in October 1966; but when the satellite's apogee motor malfunctioned, the spacecraft was left in a highly elliptical inclined orbit, making it unusable for full-time commercial operations. Subsequent launches in January and September 1967 successfully placed two satellites into operational service over the Pacific Ocean. A March 1967 launch successfully supplemented the INTELSAT I satellite in operation over the Atlantic Ocean. With these three satellites in place, commercial service was available over both the Atlantic and Pacific Oceans. The INTELSAT II satellites continued to meet international commercial communications requirements successfully until third generation replacement satellites allowed them to be retired to the active reserve.

The development of INTELSAT III was initiated in 1964 with a design study and followed 2 years later with the award of a contract for the design, development, and fabrication of the necessary spacecraft. Eight INTELSAT III satellites were launched between September 1968 and July 1970 as indicated in Table 10-3. Launch failures in September 1968, July 1969, and July 1970 made three of these satellites unusable. A successful launch in December 1968 placed a spacecraft in service over the Atlantic. Some difficulties were encountered when this satellite's mechanically despun antenna

Table 10-2. INTELSAT II Spacecraft

Satellite		F-1	F-2	F-3	F-4
Contractor		Hughes Aircraft Company			
Launch Date		26 October 1966	11 January 1967	22 March 1967	27 September 1967
Launch Vehicle		McDonnel/Douglas Three Stage, Thrust Improved Delta			
Orbital Data*	Apogee	37,037 km (23,014 mi.)	35,819 km (22,257 mi.)	35,814 km (22,254 mi.)	35,800 km (22,245 mi.)
	Perigee	3,360 km (2,088 mi.)	35,798 km (22,244 mi.)	35,802 km (22,246 mi.)	35,760 km (22,220 mi.)
	Inclination	17.2°	1.3°	2°	0.9°
	Period	730.1 min.	1436.1 min.	1436.1 min.	1429.5 min.
Status		Failed to achieve synchronous orbit due to malfunction of apogee motor. Employed commercially in December 1966 and January 1967	Placed in service on Jan. 27, 1967 over Pacific at 172° East. Now in reserve at 125° West	Placed in service on Apr. 7, 1967 over Atlantic at 6° West. Now in reserve at 13° West	Placed in service on Nov. 4, 1967 over Pacific at 176° East. Now at 171° West

*Parameters at initial orbit injection. Attitude control and stationkeeping maneuvers produced changes.

Table 10-3. INTELSAT III Spacecraft

Satellite		F-1	F-2	F-3	F-4	F-5	F-6	F-7	F-8
Contractor		TRW Systems, Inc.	TRW Systems, Inc	TRW Systems, Inc.	TRW Systems, Inc.	TRW Systems, Inc.	TRW Systems, Inc.	TRW Systems, Inc.	TRW Systems, Inc.
Launch Date		Sept. 18, 1968	Dec. 18, 1968	Feb. 5, 1969	May 21, 1969	July 25, 1969	January 14, 1970	April 22, 1970	July 3, 1970
Launch Vehicle		Long-Tank Delta	Long-Tank Delta	Long-Tank Thrust Augmented Delta	Long-Tank Thrust Augmented Delta	Long-Tank Thrust Augmented Delta	Long-Tank Delta	Long-Tank Delta	Long-Tank Delta
Orbital Data*	Apogee	No Orbit Achieved	35,819 km (22,257 mi.)	35,784 km (22,236 mi.)	35,673 km (22,166 mi.)	5,398 km (3,355 mi.)	No Data	No Data	No Data
	Perigee		35,798 km (22,244 mi.)	35,752 km (22,215 mi.)	35,227 km (21,889 mi.)	269 km (167 mi.)			
	Inclination		0.71°	1.29°	0.50°	30.3°			
	Period		1436 min.	1436 min.	1436 min.	146.7			
Status		Failed to orbit; pitch rate system malfunction forced payload destruct	Placed over the Atlantic at 30°W and began service on December 24, 1968. Ceased operation June 29, 1969 due to antenna problem. Resumed operation August 1, 1969. Placed in retired reserve status in February 1970	Placed over the Pacific at 174°E and began service on February 16, 1969. Repositioned over Indian Ocean at 62.5° after losing 6 dB of transponder gain due to a malfunction in one stage of the tunnel diode amplifier, and began service there July 1, 1969. Now in reserve at 60°E Long.	Placed in service over the Pacific at 174°E as a replacement for F-3 and began service on May 31, 1969. No longer in service	Unusable because third stage malfunctions placed into incorrect orbit. Subsequently decayed	Placed over the Atlantic at 24°W, and began service on February 1, 1970. No longer in service	Placed over the Atlantic at 19°W, and began service on May 8, 1970. No longer in service	Failed to achieve synchronous orbit due to a malfunction during apogee motor firing

*Parameters at initial orbit injection. Attitude control and stationkeeping maneuvers produced changes.

started sticking in mid-1969. This occurrence made necessary the aforementioned reactivation of Early Bird. The antenna problem was resolved by August 1, 1969, and commercial operations were resumed until a subsequent January 1970 INTELSAT III launch allowed the satellite to be placed in the retired reserve. In April 1970, another successful INTELSAT III launch supplemented the operational capability available over the Atlantic.

An INTELSAT III satellite was first placed into operation over the Pacific in February 1969. This satellite was supplemented by a second spacecraft in May 1969. When the first Pacific INTELSAT III lost 6 dB of transponder gain due to an RF receive amplifier malfunction, it was relocated over the Indian Ocean where the traffic requirements were lighter. As a result, four INTELSAT III satellites were, as of May 1971, providing global commercial service over the Atlantic, Pacific, and Indian Oceans.

Development of the fourth generation of INTELSAT spacecraft, INTELSAV IV, began in the latter portion of the 1960s. These satellites, manufactured by Hughes Aircraft Company, have been designed to provide a substantially greater capability to meet the increased global communication needs of the 1970s. The first, in an expected series of eight satellites, was successfully launched by an Atlas Centaur rocket into a geostationary orbit on January 25, 1971. It was positioned over the Atlantic at 335.5°E longitude. Subsequent INTELSAT IVs were launched for service over the Atlantic, Pacific, and Indian Oceans with an additional two satellites as spares in orbit. Each satellite has a life expectancy of about 7 years. Table 10-4 summarizes the INTELSAT IV launchings up to June 1974.

Two INTELSAT IV satellites are therefore operational over the Atlantic. One of these, as the "primary path," handles one-half of the traffic between large users plus all of the traffic to, from, and between the smaller users. The other satellite operates in a "major path" mode to carry the remaining half of the traffic between large users, thus providing route diversity. The first INTELSAT IV launched is now in reserve over the Atlantic, making a full complement of three in this heavy traffic

Table 10-4. INTELSAT IV Spacecraft

Satellite		F-2	F-3	F-4	F-5	F-7
Contractor		Hughes Aircraft Company				
Launch Date		January 25, 1971	December 19, 1971	January 22, 1972	June 13, 1972	August 23, 1973
Launch Vehicle		General Dynamics, Convair Division Atlas Centaur				
Orbital Data*	Apogee	35,795 km (22,242 mi.)	35,795 km (22,242 mi.)	35,793 km (22,241 mi.)	35,795 km (22,242 mi.)	35,802 km (22,246 mi.)
	Perigee	35,779 km (22,232 mi.)	35,779 km (22,232 mi.)	35,784 km (22,235 mi.)	35,781 km (22,233 mi.)	36,894 km (22,925 mi.)
	Inclination	0.101°	0.301°	0.475°	0.339°	0.492°
	Period	1436.1 min.	1436.1 min.	1436.1 min.	1436.2 min.	1436.3 min.
Status		Placed in service on March 20, 1971 over the Atlantic at 335.5°E Long. Now in reserve at 340.57°E Long.	Placed in service on February 19, 1972 over the Atlantic at 340.5°E Long. Now operational at 336.66°E Long.	Placed in service on February 14, 1972 over the Pacific at 174°E Long. Now operational at 173.72°E Long.	Placed in service on July 30, 1972 over the Indian Ocean at 61.4°E Long. Now operational at 61°E Long.	Placed in service on November 21, 1973 over the Atlantic Ocean. Now operational at 329.54°E Long.

*Parameters at initial orbit injection. Attitude control and stationkeeping maneuvers produced changes.

area. It functions as a reserve, or back-up, for the other two. Two additional INTELSAT IV launches are planned, one each for the Pacific and the Indian Ocean, to provide for additional back-up.

Because of the need to provide for rapidly increasing traffic as well as better utilization of both hardware and the spectrum, yet another generation of spacecraft will be required in the near future. However, this time a number of more extensive changes in technology will be needed. A rigid requirement for INTELSAT is continuity of service; therefore, any uncertainty requires extensive testing under actual operational conditions. The changes involve, principally, the introduction of operations into the recently allocated 11/14 GHz portion of the spectrum. Questions as to the extent of the propagation risk involved and how fast to introduce the service are key to the decision on when and how to proceed. In addition there is a question of the provision of an L-band transponder to provide for maintenance services. These decisions are not expected to be available from the INTELSAT Board of Governors until late 1974; therefore, half of a generation of spacecraft known as INTELSAT IVA has been developed.

INTELSAT IVA will meet the requirements for traffic growth without requiring the extension of technology change demanded by INTELSAT V. INTELSAT IVA is planned for deployment in the Atlantic basin in late 1975. It is an INTELSAT IV with a communications payload that will provide almost twice the traffic capacity of INTELSAT IV. Whereas INTELSAT IV is a 12 transponder satellite, INTELSAT IVA will use new technology in RF filters, TWTs and antennas to provide 20 transponders. This is done by reserving the allocated 500-MHz frequency allocation at 6 GHz (uplink) and at 4 GHz (downlink). A unique antenna design produces beams which will cover the Atlantic basin earth stations with side lobes sufficiently suppressed to provide a minimum of 27 dB of discrimination between the co-frequency transmissions on the east and west beams. Actually this design would permit the total reuse of the spectrum so that, in principle, IVA could provide 24 transponders of 40 MHz each compared with IV's 12. The IVA design actually reserves four transponders for earth coverage service so that only 320 MHz is reused, providing a total of 20 transponders. Two of these earth coverage transponders are to be dedicated, in Atlantic service, to television and to SPADE,* leaving 18 telephony transponders, compared with 10 on INTELSAT IV, or a telephony capacity increase of nearly double. This is accomplished by the changes indicated in Table 10-5.

The INTELSAT program has been a commercial venture and the number of major innovations in the equipment and techniques employed has been limited to those required to provide a reliable service. The intent has been to minimize the risk of spacecraft failure and the exceptional reliability record amassed by the system testifies to the success of this policy. Nevertheless, the INTELSAT program has made significant contributions to satellite communications.

Numerous subjective tests with INTELSAT I demonstrated conclusively that the round trip time delay and echo due to two-wire user terminations were not insurmountable obstacles to the utilization of synchronous satellites for commercial communications. This was in confirmation of preliminary indications obtained on Project SYNCOM.

The INTELSAT II spacecraft demonstrated that tunnel diode amplifiers of operational reliability were suitable for use as RF receive preamplifiers. Utilizing these relatively low-noise, high-gain preamplifiers allowed direct RF to RF conversion in a single stage to be employed. Sufficient spacecraft power and high performance earth terminals allowed these transponders to be designed for linear input/output power transfer characteristics. Additionally, INTELSAT II and an expanded ground complex demonstrated the feasibility of extensive multiple accessing of a single satellite transponder by a group of operational ground terminals.

When the wideband INTELSAT III satellites were placed into operation, it was necessary to introduce a third generation of earth stations to the system in order to

*SPADE: Single channel per carrier-Pulse code modulation-Multiple Access Demand Assigned Equipment.

Table 10-5. INTELSAT IV and IVA Communications Elements Comparison

Element	INTELSAT IV	INTELSAT IVA
Antennas	Global Horns Spot Beam Transmit	Global Horns Shaped Beam Transmit and Receive
Receivers	TDA-TDA-DTWT	Same with lower power DTWT
Filters	INVAR CHEBYSHEV 0.163 cm (0.064 in.) walls	INVAR Elliptic/Directional 0.076 cm (0.030 in.) walls
TWTs	6 watt (30% efficient)	5 watt (36% efficient)
COMM Subsystem		
Mass	161 kilograms (355 pounds)	177 kilograms (390 pounds)
Power Use	310 watts	415 watts

take full advantage of the expanded capabilities of the space subsystem. These terminals employed newly developed 500-MHz bandwidth cooled parametric amplifiers, as well as 500-MHz bandwidth high power traveling-wave tube transmitters, capable of over 6 kW of multicarrier power.

The INTELSAT IV spacecraft have advanced satellite communications technology by demonstrating the feasibility of fixed narrow beamwidth (i.e., 4.5°) antennas mounted on a mechanically despun platform and a highly channelized satellite repeater (i.e., 12 independent transponders). The narrow-beam antennas provide coverage to a fixed, relatively restricted area of the earth with high antenna gain significantly increasing satellite EIRP. The 12 transponders, each having a 36-MHz bandwidth, allow users with substantially different communication requirements to operate independently of each other in separate satellite channels (e.g., television distribution in one channel, high-capacity telephone trunks in another, and low-duty cycle individual voice links in still another).

A fully variable, demand-access, SPADE system was demonstrated for the first time when the INTELSAT IV satellites were placed into operational service.

As implied SPADE is a demand assignment multiple access system. The demand assignment feature is an effective method for increasing network capacity, and telephone companies have used the concept for many years. Thus, 800 satellite channels can be made to service from 2400 to 3200 individual user trunks on a demand basis. The key to this capability of allowing earth stations to operate on the carrier to provide the required channel to two user trunks, is a SPADE channel unit frequency synthesizer. This module is capable of generating any one of 800 carrier frequencies (at IF) on command from a computer or other remote calling source. Thus, when a call is being established, the channel unit is instructed to operate on the allocated frequency. The digitized voice then modulates (quadraphase PSK) that carrier and is translated to 6 GHz together with all other operating channel unit outputs.

With the SPADE operation voice channels are carried at 64 kbps with a bit error rate of 1×10^{-4}. This rate is unacceptable for wideband digital data. For data, therefore, forward-acting error coders are used to enhance that channel performance. 48 or 50 kbps data is passed through a rate 3/4 convolutional encoder, and the net data rate is then SPADE compatible at 64 or 66.7 kbps. The resulting bit error rate is better than 1×10^{-8} at the 48/50 kbps rate using standard SPADE channel power and bandwidth, and several of these channels are presently in service.

10.2 SYSTEM DESCRIPTION

Transatlantic communications via Early Bird were nominally effected through the Andover, Maine, earth station and one of four European earth stations. A Canadian station at Mill Village, Nova Scotia, also served as the North American terminal about 1 day per week after late 1966. In addition, it carried Early Bird traffic during the INTELSAT II launches to release the Andover station for launch support operations. Three of the European stations, located at Goonhilly Downs (England), Pleumeur Bodou (France), and Raisting (Germany), served alternately in the roles of operating station and standby. They were interconnected by terrestrial and submarine cable links that permitted all European traffic to be carried by any one of the stations. The fourth smaller participating European terminal, located at Fucino (Italy), acted as a terminal for weekend traffic. It was linked to the other three terminals via Frankfurt, Germany. The terminals participating in Early Bird operations are summarized in Table 10-6.

The development of INTELSAT II with a bandwidth several times that of Early Bird was accompanied by second generation earth station designs such as those for the Brewster Flats, Washington, and Paumalu, Hawaii, installations. The terminals, in addition to those indicated in Table 10-6, participating in operations with INTELSAT II satellites, as of April 1968, are listed in Table 10-7. INTELSAT II satellites located over both the Atlantic and Pacific Oceans provided multiple-access communications among appropriate groups of these terminals. The wide variety of station antenna sizes stems largely from the fact that many of the smaller ones were

Table 10-6. INTELSAT I Participating Earth Terminals

Location	Owner	Ant. Dia. (m) (ft.)	Date of Installation
Andover (Maine)	Comsat	20.6 (67.7)	1965
Mill Village (Nova Scotia)	Canadian Overseas Telecom Corp. (COTC)	25.9 (85.0)	1966
Goonhilly Downs (England)	General Post Office	25.9 (85.0)	1965
Pleumeur Bodou (France)	Centre National d'Etudes des Telecommunications (CNET)	20.6 (67.7)	1965
Raisting (Germany)	Deutsche Bundespost	25.0 (82.0)	1964
Fucino (Italy)	Telespazio	13.4 (44.0)	1965

Table 10-7. INTELSAT II Participating Earth Terminals

Location	Antenna Diameter (m) (ft.)	Date Installed
Fucino (Italy)	27 (90)	1967
Buitrago (Spain)	26 (85)	1968
Orand Canary Island (Spain)	13 (42)	1967
Ascension Island	13 (42)	1967
Brewster Flats (Washington)	26 (85)	1966
Paumalu (Hawaii) No. 1	26 (85)	1966
Paumalu (Hawaii) No. 2	13 (42)	1968
Carnaroon (Australia)	13 (42)	1967
Tamay (Philippines)	13 (42)	1968
Si Racha (Thailand)	13 (42)	1968
Moree (Australia)	28 (92)	1968
Ibaraki (Japan)	22 (72)	1968
NASA Tracking Ships (3)	9.1 (30)	1967

required on very short notice to provide communications support for NASA's Apollo program. Many of the smaller aperture stations have now been replaced by ones of higher sensitivity. Their existence did, however, provide experience in working with a variety of stations with a wide range of sensitivities.

System planning for the INTELSAT III satellite was completed in 1967, and a third generation of earth stations was designed to provide full operating capability with these spacecraft. Of paramount importance to the INTELSAT III satellite design was the use of two transponders covering nearly the entire 500-MHz band assigned to communications satellite service. The new earth station designs made this entire band available for use so that carrier frequencies could be assigned without regard for narrow-band equipment. This flexibility guaranteed the success of multidestination FM-FDM to provide complete satellite multiple access to all earth stations in the network. A complete list of terminals participating in operations with INTELSAT III satellites, as of January 1971, together with present operating status, is provided in Table 10-6. Multiple access communications nets have been formed among appropriate groups of these terminals to operate with INTELSAT satellites located over the Atlantic, Pacific, and Indian Oceans.

Fourth generation earth terminals have been constructed to operate with the new INTELSAT IV satellites. These terminals provide a large number of carriers to take advantage of the multiplicity of satellite transponders that have become available. As a result, the requirements for linearity in common RF transmitting and receiving elements within these ground terminals have been substantially increased. Additions to the ground complex defined in Table 10-8 that should be operational by the end of 1974 and those projected up to 1978 are listed in Table 10-9, 10-10, and 10-11. INTELSAT IV satellites have assumed responsibility for space segment operations over the Atlantic, Pacific, and Indian Oceans. These satellites and new signal processing techniques allow both fixed assignment and fully variable demand assignment approaches to multiple access to be implemented among appropriate groups of user terminals. (See the above discussion on SPADE.)

Table 10-8. INTELSAT III Participating Earth Terminals (1 of 3)

Location	Region* (Ocean)	Operation Date
Balcarce No. 1, Argentina	A	September 1969
Ascension Island (United Kingdom)**	A	April 1967
Moree, Australia	P	May 1968
Carnarvon, Australia	P	October 1969
Ceduna, Australia**	I	December 1969
Ras Abu-Jarjur, Bahrain	I	July 1969
Tangua No. 1 Brazil	A	February 1969
Mill Village No. 1, Canada	A	October 1969 (Last Mod)
Mill Village No. 2, Canada	A	October 1969
Longovilo, Chile	A	July 1968
Taipei No. 1, Republic of China	P	December 1969
Choconta, Colombia	A	March 1970
Longonot, East Africa***	I	August 1970
Pleumeur-Bodou No. 1, France	I	June 1965
Pleumeur-Bodou No. 2, France	A	November 1969
Raisting No. 1, Germany	I	June 1965
Raisting No. 2, Germany	A	April 1970
Thermopylae, Greece	I	April 1970
Hong Kong No. 1, United Kingdom	P	September 1969
Djatiluhur No. 1, Indonesia	I	September 1969
Asadabad No. 1, Iran	A	October 1969
Fucino No. 1, Italy	A	August 1969 (Last Mod)
Fucino No. 2, Italy	I	July 1970
Ibaraki No. 2, Japan	P	March 1968 (Replaced Ibaraki 1)

Table 10-8. INTELSAT III Participating Earth Terminals (2 of 3)

Location	Region* (Ocean)	Operation Date
Yamaguchi, Japan	I	July 1969
Kum San No. 1, Republic of Korea	P	April 1970
Umm Al-Aish, Kuwait No. 1	I	October 1969
Arbaniveh, Lebanon	I	January 1971
Kuantan No. 1, Malaysia	I	March 1970
Tulancingo No. 1, Mexico	A	January 1969
Sehouls, Morocco	A	December 1969
Utibe, Panama	A	September 1968
Lurin, Peru	A	July 1969
Tanay No. 1, Philippines	P	April 1968
Buitrago No. 1, Spain	A	January 1968
Buitrago No. 2, Spain	I	April 1970
Aguimes, Canary Islands (Spain)	A	April 1971 (Replaced two small antennas)
Si Racha No. 1, Thailand	P	April 1968
Si Racha No. 2, Thailand	I	April 1970
Goonhilly No. 1, United Kingdom	I	June 1965
Goonhilly No. 2, United Kingdom	A	November 1968
Andover, Maine	A	January 1973 (Released first antenna)
Brewster, Washington	P	December 1966
Paumalu No. 1, Hawaii	P	December 1966
Paumalu No. 2, Hawaii	P	December 1968
Etam, West Virginia	A	January 1969

Table 10-8. INTELSAT III Participating Earth Terminals (3 of 3)

Location	Region* (Ocean)	Operation Date
Cayey, Puerto Rico	A	January 1969
Jamesburg, California	P	December 1968
Pulantant, Guam	P	November 1969
Bartlett, Alaska	****	July 1970
Camatagua, Venezuela	P	November 1970

*A-Atlantic, P-Pacific, I-Indian Ocean operational status of station as of March 1974

**Non-standard antenna (small dish)

***Serves Kenya, Uganda and Tanzania

****Reverted to domestic U.S. service

Table 10-9. Ground Complex Additions Installed or Planned in the Atlantic Ocean Area as of March 1974 (1 of 2)

Location	Operation Date
Lakhdaria, Algeria	1974
Cacuaco, Angola	1974
Balcarce No. 2, Argentina	March 1972
Chittagong, Bangladesh	1975
Barbados	October 1972
Lessive, Belgium	August 1972
Tangua No. 2, Brazil	1975
Tangua No. 3, Brazil*	1974
Manaus, Brazil*	1974
Cuiaba, Brazil*	1974
Zamengoe, Cameroon	September 1973
Cambita, Dominican Republic	1974
Sululta, Ethiopia	1976
Trois-Ilets, Martinique	January 1972
Quito, Ecuador	August 1972
Trou-Biran, Guiana	1974
Nkoltang, Gabon	June 1973
Raisting No. 3, Germany	January 1973
Port au Prince, Haiti	1976
Emeq Ha'ela, Israel	May 1972
Lario, Italy	1975
Abidjan, Ivory Coast	November 1972
Prospect Pen, Jamaica	December 1971
Baqa, Jordan	December 1971
Umm Al-Aish No. 2, Kuwait	1976
Philibert Tsiranana, Malagasy Republic	March 1972

Table 10-9. Ground Complex Additions Installed or Planned in the Atlantic Ocean Area as of March 1974 (2 of 2)

Location	Operation Date
Tulancingo No. 2, Mexico	1975
Boane, Mozambique	1974
Burum, Netherlands	August 1973
Managua, Nicaragua	November 1972
Lanlate No. 1, Nigeria	March 1971
Asuncion, Paraguay	1975
Sintra, Portugal	1974
Taif, Saudi Arabia	1975
Bucharest, Roumania	1975
Pretoria, South Africa	1975
Buitrago No. 3, Spain	1973
Aguimes, Canary Islands	April 1971
Umm Haraz, Sudan	1974
Tanum, Sweden*	November 1971
Leuk, Switzerland	January 1974
Matura Point, Trinidad and Tobago	October 1971
Ankara, Turkey	1975
Moscow, USSR	1974
Goonhilly No. 3, United Kingdom	August 1972
Ivanjica, Yugoslavia	1974

*Non-standard station

Table 10-10. Ground Complex Additions Installed or Planned in the Pacific Ocean Area as of March 1974

Location	Operation Date
Lake Cowichan, Vancouver Island, Canada	August 1972
Shanghai, China	August 1973
Peking No. 1, China	June 1973
Surv, Fiji Islands	1975
Noumea, New Caledonia	1975
Papeete, French Polynesia	1976
Ibaraki No. 3, Japan	December 1971
Kuantan No. 2, Malaysia	1975
Warkworth, New Zealand	June 1971
Sentosa No. 2, Singapore	1974
Kwajalein Island	
Djatiluhur No. 2, Indonesia	1976
Ross Island, Antarctica*	February 1972

*Unattended non-standard station with 2.4-m (8-ft) antenna sending unmanned geophysical observatory (UGO) data via Jamesburg, California

Table 10-11. Ground Complex Additions Installed or Planned in the Indian Ocean Area as of March 1974

Location	Operation Date
Bangladesh	1974
Peking No. 2, China	March 1974
Taipei No. 2, China (Taiwan)	January 1974
Pleumeur-Bodou No. 3, France	January 1974
Pleumeur-Bodou No. 4, France	1975
Saint Denis de la Reunion, France	February 1974
Vikram, India	February 1971
Dehra Dun, India	1975
Asadabad No. 2, Iran	1974
Baghdad, Iraq	1975
Kum San No. 2, Korea	1978
Lanlate No. 2, Nigeria	1974
East Malaysia, Malaysia	1975
Deh Mandro, Pakistan	October 1972
Tanay No. 2, Philippines	November 1972
Doha, Qatar	1975
Riyadh, Saudi Arabia	1975
Sentosa No. 1, Singapore	August 1971
Padukka, Sri Lanka	1975
Dabai, United Arab Emirates	1974
Hong Kong No. 2, U.K.	October 1971
Lusaka, Zambia	1974

Operating frequencies for the four and a half generations of INTELSAT spacecraft including IVA are defined in Table 10-12. The bands of utilization indicated accent the fact that the INTELSAT I, II, and III spacecraft contained two, one, and two independent repeaters, respectively. In the case of INTELSAT IV and IVA, the bandwidth shown spans the total operating frequency range of 12 and 20 independent repeaters, respectively: Downlink center frequencies for each of the 12 repeaters of IV are: 3725, 2765, 3805, 3845, 3885, 3925, 3975, 4015, 4055, 4095, 4135, and 4175 MHz, respectively. In IVA the frequencies are reused to increase the capability effectively to 20 independent repeaters as previously explained. Uplink frequencies for each repeater are 2225 MHz above the indicated downlink frequency. The frequencies employed were selected to be compatible with the frequency bands reserved for commercial satellite communications use on a shared basis in 1963. These frequencies were set aside in response to recommendations originated by AT&T during the Telestar program.

With the extensive ground complex and comparatively limited number of spacecraft involved in the INTELSAT program, satellite multiple-access techniques and RF modulation employed have been of vital importance to the system. INTELSAT I incorporated a multiple-access capability, in a sense, by virtue of its sharing a single TWT between two independent frequency-translating transponders. Since each of these transponders was hardlimiting in nature, the number of carriers accessing each was limited to one. For this reason, the mode of communication was point-to-point, and only one duplex link between the United States and Europe was provided. Conventional voice-channel multiplex equipment similar to that employed in the Bell System and frequency modulation of the radiated carriers were employed. This system configuration, in conjunction with the ground terminals available, provided INTELSAT I with a 240-duplex voice-channel capacity.

The INTELSAT II system was designed to provide for frequency-division multiple-access (FDMA) of the satellite by a number of earth terminals. Theoretical studies had shown that for multiple large index FM carriers accessing the transponder: (1) the satellite should be designed for a quasi-linear operation, (2) the maximum

Table 10-12. INTELSAT Frequency Assignments

SPACECRAFT	COMMUNICATIONS		TELEMETRY	BEACON
	Uplink	Downlink		
INTELSAT I (Early Bird)	6288-6314 MHz 6377-6403 MHz	4068-4094 MHz 4148-4174 MHz	4104 MHz 4138 MHz	136, 4104 MHz 137, 4138 MHz
INTELSAT II	6282-6408 MHz	4057-4183 MHz	136 MHz	136 MHz
INTELSAT III	5930-6155 MHz 6195-6420 MHz	3705-3930 MHz 3970-4195 MHz	3933-3967 MHz*	3933-3967 MHz
INTELSAT IV	5930-6420 MHz**	3705-4195 MHz**	3950 MHz	3950 MHz
INTELSAT IV A				

*Telemetry used to phase modulate beacon
**Divided into 12 channels each 36-MHz wide

power input should be limited to 1.5 to 2.0 dB less than that producing transponder saturation, and (3) the level and distribution of the carriers should be such that the intermodulation products are approximately of constant level over the entire transmission band. To ensure compliance with these criteria, carrier control stations were established at Paumalu, Hawaii, and Andover, Maine, whereby the Atlantic and Pacific INTELSAT II systems could be monitored, each from a single point. In early operations with INTELSAT II satellites, FM carriers centered at specific frequencies were preassigned to individual links between two points, thereby retaining the point-to-point mode of operation employed on INTELSAT I. However, multiple point-to-point links were established through the INTELSAT II transponders. The system configuration described, together with the second generation ground complex, produced a 240-duplex voice-channel capacity for each INTELSAT II satellite.

It was recognized, by the time the INTELSAT III satellites started to be put into service, that the satellite capacity could be increased and the system complexity reduced by switching to a point-to-multipoint mode of multiple-access operation. This was implemented by designing each terminal to transmit one preassigned multidestination FM carrier containing channels intended for all users to which it was linked. Baseband channels were preallocated to a particular user as part of a given network plan and were stripped off at each respective receiving site. The INTELSAT III satellite transponders were again designed for quasi-linear operation, and the same type of carrier control concept as utilized for the INTELSAT II system was employed. The described mode of system operation allowed the third generation earth terminals to realize a 1200-duplex voice-channel system capacity when operating through an INTELSAT III satellite. Alternately, the satellites could provide four television channels.

The INTELSAT III approach to modulation, multiple access and system control was continued as the INTELSAT IV satellites were introduced to the system. However, it was supplemented, at an early date, by a full variable demand-access system called SPADE, which operates in a separate transponder of the INTELSAT IV satellite. The

SPADE system features PCM encoding of individual voice channels for quadriphase PSK modulation of a carrier. It includes the ability to deactivate carrier transmission to the satellite during periods of talker inactivity and a decentralized control concept allowing self-assignment of available satellite channels. The SPADE system has been assigned to transponder 10 of INTELSAT IV satellites. This particular transponder does not have access to the spot beam antennas. SPADE is compatible with standard manual or automatic international signaling and switching systems. User applications, where the satellite channel requirements vary widely over the period of a day, find SPADE quite attractive. Each of the INTELSAT IV transponders, in conjunction with the earth coverage satellite antennas and the fourth generation ground complex, provides about 500 full duplex voice channels when FDMA-FM is employed, 800 full duplex voice channels when SPADE is used, or 1 FM color television channel, including the TV audio.

Planning for the INTELSAT IVA system is more complex than IV because of transmission constraints resulting from frequency reuse techniques.

For IVA there are two possible up-link modes: hemispheric (East and West) and global. The down-link has three modes: hemispheric (East and West), spot (NW, NE, SW, and SE), and global. In order to provide such services as SPADE, TDMA, TV, and telephony to earth stations outside the normal hemispheric coverage zones, four transponders have been designated as global beam channels in IVA. With some constraints, the remaining 8 co-transponder pairs (10 transponders) can be switched to either a hemispheric or spot beam on the down-link. That is, of the potential 1,000 MHz bandwidth mode available by frequency reuse techniques, 160 MHz (four 40 MHz transponders) will be lost in order to provide unique services on a global scale. Within these bounds, the 20-transponder INTELSAT IVA is expected to be configured to handle 12,500 voice grade channels (plus one TV and one SPADE transponder) for a typical Atlantic Primary Satellite frequency plan configuration.

In comparison an INTELSAT IV Atlantic Primary Satellite can be configured for 7,500 channels (plus one TV and one SPADE transponder). Therefore the net increase for IVA over IV is about 5,000 channels.

10.3 SPACECRAFT

The Early Bird satellite was very similar to the Syncom III spacecraft. Early Bird's microwave repeater consisted of two independent nonlinear, hard-limiting, frequency translating transponders. Both transponders shared a single TWT output power amplifier. A second TWT was carried on-board the spacecraft for redundancy; however, only one of the tubes was on at a time. A block diagram of the Early Bird repeater is provided in Figure 10-1. The satellite was spin-stabilized for attitude control and the elimination of temperature extremes. The pancake-shaped antenna pattern was squinted to provide high gain coverage of the northern hemisphere alone. Spacecraft design lifetime was only 18 months. However, Early Bird operated successfully for more than 3 years until it was retired from service. Communications characteristics of this satellite are provided in Table 10-13.

The INTELSAT II satellite design evolved directly from that of Early Bird. Among the most significant changes were the adoption of a single redundant wideband linear amplifier and an antenna beam that covered both the northern and southern hemispheres. The transponder bandwidth was 125 MHz compared with the two repeaters of 25-MHz bandwidth, each used in Early Bird. A block diagram of the INTELSAT II satellite's communications system is shown in Figure 10-2. To maintain the 240-circuit capacity of Early Bird, in spite of the wider antenna beamwidth, INTELSAT II employed multiple traveling-wave tubes operating in parallel. Four tubes were included in anticipation that three would be required to meet the EIRP requirements, leaving one tube as a spare. However, the antenna and power efficiencies achieved were such that a two-tube configuration was adequate. The additional power required by INTELSAT II was provided by using a larger solar cell array. In contrast to Early Bird, INTELSAT II was designed to support communication through the

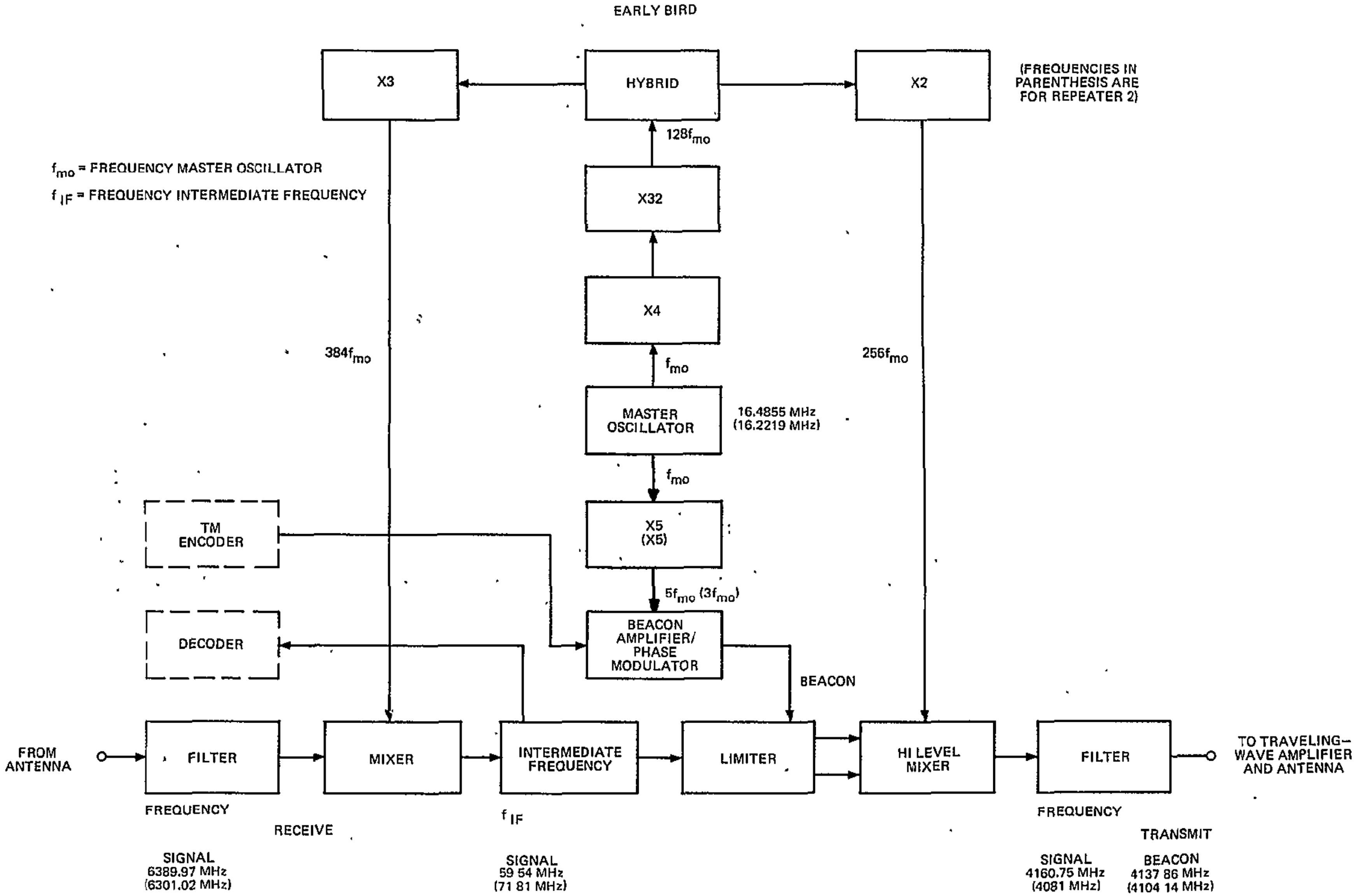

Figure 10-1. Block Diagram of Early Bird Repeater

Table 10-13. Early Bird Communication Characteristics

ANTENNAS	Type		XMTR-Skirted 6-element Collinear Slot Dipoles RCVR - Collinear 3-element Cloverleaf Array
	Number		1 - XMTR 1 - RCVR
	Beamwidth		XMTR - 11° with beam center squinted 7° into northern hemisphere RCVR - 40°
	Gain		XMTR - 9 dB; RCVR - 4 dB
	Polarization		Linear in plane perpendicular to spin axis
REPEATERS	Frequency Band		C-Band
	Type		Hard-limiting, double conversion repeater
	Bandwidth		25 MHz - each repeater @ 0.5-dB points
	Number		Two repeaters sharing a common TWT XMTR
	RCVR	Type Front End	Down Conversion Mixer
		Front End Gain	No Data
		Sys. Noise Figure	Overall - 10 dB
	XMTR	Type	6-watt TWT and identical spare
		Gain	No Data
		Power Out	4.3 watts as operated
	EIRP		10.2 dBW @ beam edge/14 dBW maximum
GENERAL FEATURES	Stabilization	Type	Spin (152 rpm) with H_2O_2 jet attitude & spin rate control
		Capability	No Data
	Power Source	Primary	46.5 watts from 6000 n-on-p solar cells *
		Supplement	1.5 amp-hr. from two 21-cell nickel-cadmium batteries**
	Comm. Power Needs		26.8 watts
	Size		Cylindrical: diameter = 72.1 cm (28.4 in.); height = 58.9 cm (23.2 in.)
	Weight		67.6 kg (149 lbs) at injection, 40-36 kg (89-79 lbs) after apogee fire

* Capability at launch

** Furnishes power during launch. Eclipse operation not possible.

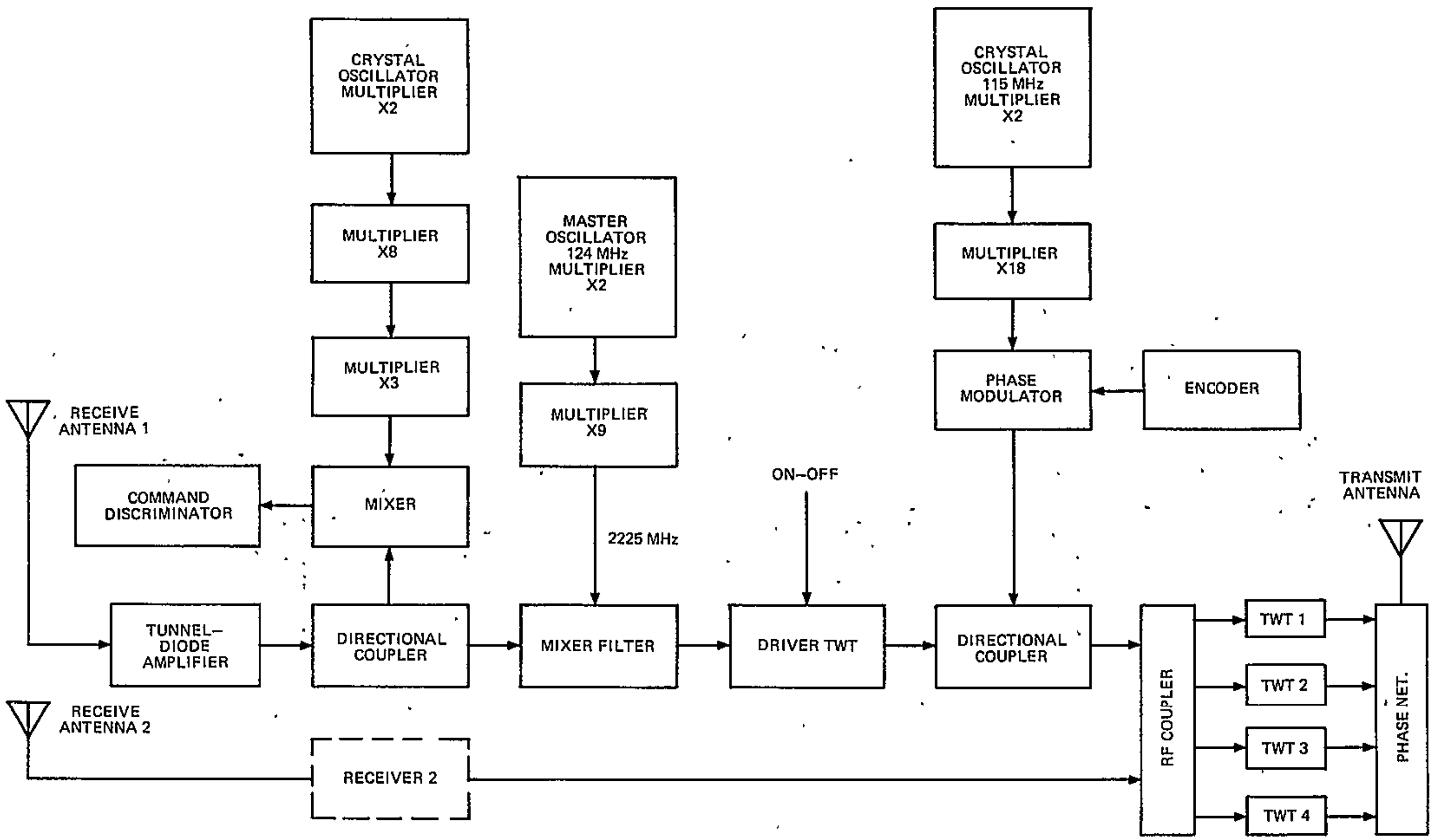

Figure 10-2. Communications System Block Diagram for INTELSAT II

eclipse periods occasionally experienced in the synchronous orbit. The communication characteristics of INTELSAT II are shown in Table 10-14.

Because the communications subsystem of the INTELSAT III satellites provided for two independent transponders, these spacecraft more closely resemble INTELSAT I than INTELSAT II. The most significant difference between the INTELSAT I and INTELSAT III transponders is that whereas the former was a hard-limiting, non-linear, double-conversion repeater, the latter is a linear, single-conversion repeater. This is in agreement with the INTELSAT II design. The INTELSAT III transponder has a bandwidth of 225 MHz. Together two transponders cover most of the 500-MHz bandwidth allocated to the communication satellite service in the 4-GHz and 6-GHz bands. The initial satellites in the INTELSAT III series employed single tunnel-diode amplifiers in the receiver. However, after satellite F-3 lost 6 dB of transponder gain due to a malfunction in one stage of the tunnel-diode amplifier, all subsequent spacecraft were provided with redundant receive amplifiers to enhance the overall subsystem reliability. A block diagram of the satellite communications subsystem is provided in Figure 10-3. Communications characteristics of the satellite are summarized in Table 10-15.

A further important distinction between INTELSAT I and INTELSAT III appears in the communication antennas. The antennas of INTELSAT I were symmetrical about the spin axis to maintain constant antenna gain. INTELSAT III employes a mechanically despun antenna. This mechanically despun antenna is the most important innovation in this series of satellites, and perhaps the most critical. Special lubricants are used for the bearings, which are exposed to the hard vacuum of space and a wide temperature range. Because INTELSAT III has no VHF telemetering and telecommand equipment (these functions are handled at C-band), an additional antenna at 6 GHz with substantially omnidirectional properties has been provided to receive telecommand signals for the initial setting up in orbit. The expected lifetime of the satellite is 5 years.

Table 10-14. INTELSAT II Characteristics

Antenna		Type	Transmit: Multiple Element Biconical Horn
Antenna		Number	One Transmit and 2 Receive
Antenna		Beamwidth	Transmit: $\pm 6^{\circ}$ (centered at equator) Receive: Essentially omnidirectional
Antenna		Gain (4 GHz)	8 dB
Repeater		Frequency Band	C-Band
Repeater		Type	Linear Single RF translation
Repeater		B.W. (dB)	126 MHz
Repeater		Number	2 (1 redundant spare)
Repeater	RCVR	Type Front End	Tunnel Diode Amplifier
Repeater	RCVR	Front End Gain	No Data
Repeater	RCVR	Sys. Noise Figure	6 dB
Repeater	XMTR	Type	4 TWT's
Repeater	XMTR	Gain	No Data
Repeater	XMTR	Power Out	Nominal 10.8 dBW (7.8 dBW/TWT)
Repeater		EIRP (at beam edge)	15 dBW (after back-off for multicarrier operation)
General Features	Stabilization	Type	Spin with H_2O_2 jet attitude control
General Features	Stabilization	Capability	No Data
General Features	Power Source	Primary	85 watts from 12,756 n-on-p solar cells *
General Features	Power Source	Supplement	9.0 amp/hour from two nickel cadmium batteries **
General Features		Comm. Power Needs	No Data
General Features		Size	Cylindrical: Height = 67.3 cm (26.5 in.), Diameter = 142 cm (56 in.)
General Features		Weight	86.2 kg (190 lbs) after apogee fire

* Capability at launch

** Initial capability available for eclipse operation

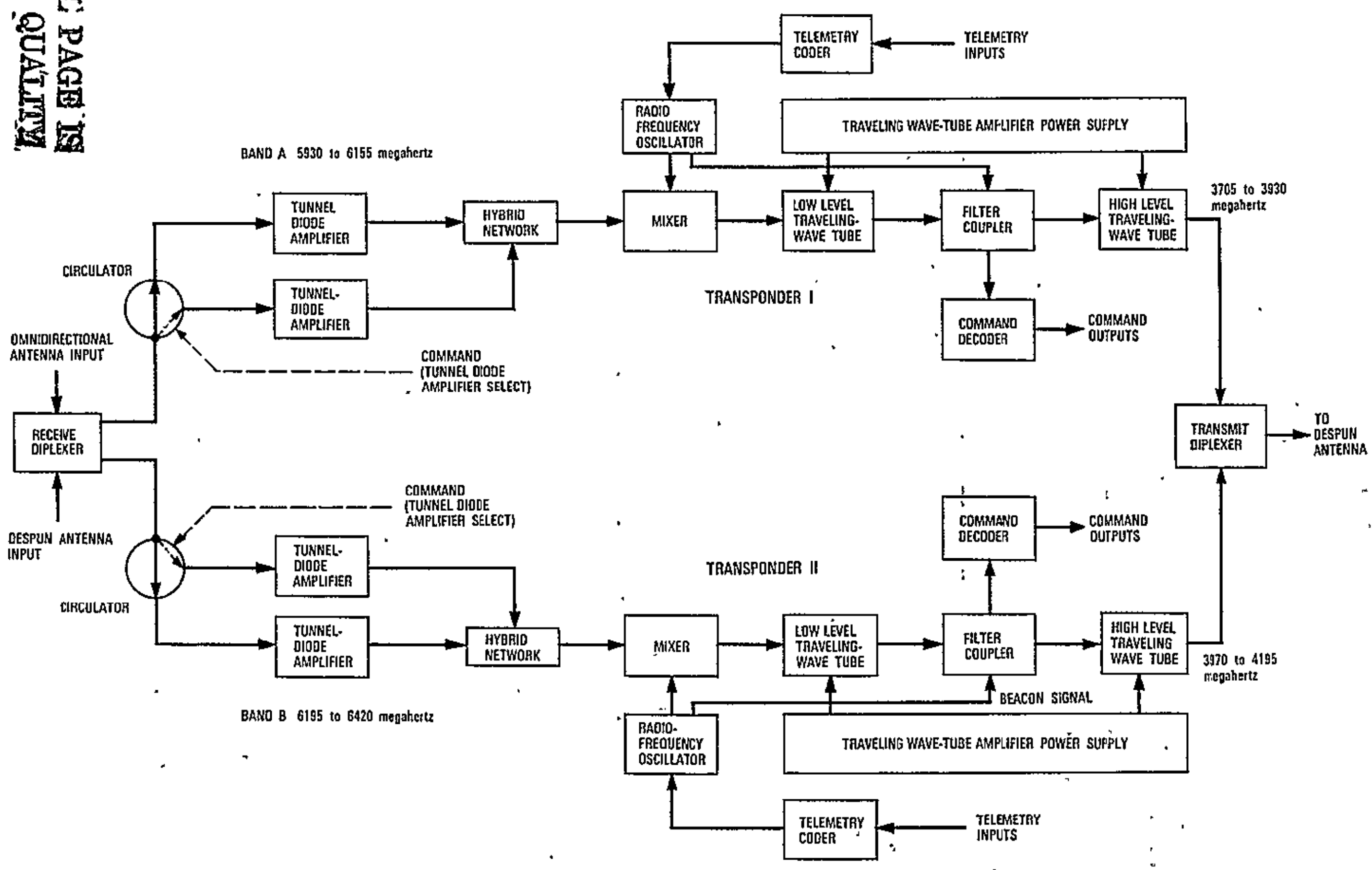

Figure 10-3. Block Diagram of INTELSAT III Communications System

Table 10-15. INTELSAT III Characteristics

Antenna		Type	Conical Horn with flat plate reflector, mechanically despun
		Number	1
		Beamwidth (4/6 GHz)	24/14.5°
		Gain (4/6 GHz)	16/21 dB
Repeater		Frequency Band	C-Band
		Type	Two independent linear single conversion repeaters
		B.W. (3 dB)	225 MHz each transponder
		Number	Two
	RCVR	Type Front End	Two stage tunnel diode amplifier
		Front End Gain	31 dB
		Sys. Noise Figure	7 dB
	XMTR	Type	TWT
		Gain	73 dB
		Power Out	12 watts
		EIRP (beam edge)	22 dBW per transponder
General Features	Stabilization	Type	Spin
		Capability	No Data
	Power Source	Primary	10,720 solar cell array - 161 watts at launch
		Supplement	1 rechargeable 20 cell nickel-cadmium battery
		Comm. Power Needs	99 watts
		Size	Cylindrical 140.7 cm (55.4 in.), diameter, 104 cm (41 in.), height without antenna
		Weight (at liftoff)	287 kg (632 lbs)
		(in orbit)	146 kg (322 lbs)

Polarization: Transmit - RHC
Receive - LHC

The INTELSAT I through III satellite designs produced communications systems that were power limited, even though a high performance ground complex was provided. This situation began to change with the development of the INTELSAT IV spacecraft. When the spot beams of this satellite are employed with high performance ground terminals, a bandwidth limited system results. The INTELSAT IV satellites' communications subsystem consists of global receive and both global and spot beam transmit antennas connected to a 12-channel repeater that provides high power amplification for each channel individually. Each of these 12 channels has a bandwidth approaching 40 MHz, thereby providing capacity for about 500 communications circuits. The satellite has the capability, using the EC antenna, for relaying 6000 half duplex telephone calls, or 12 color television programs, or any equivalent combination of such transmissions. The communication system of INTELSAT IV is depicted in the block diagram of Figure 10-4. Communications characteristics of the satellite are summarized in Table 10-16.

The spot beam transmit antennas represent the most significant departure from the previous satellite designs of the INTELSAT series. Two of these antennas, each a parabolic disc of 127-cm (50-inch) diameter, are mounted on the despun control mast of the satellite. The entire RF portion of the spacecraft is despun. Pointing of the spot beams is prefixed on the ground. These high gain antennas with beamwidths of about 4 degrees, can be used to provide spot coverage in Europe and North and South America, or they can be employed to provide intracontinental coverage within specific countries. The basic physical configuration of the INTELSAT IV spacecraft is depicted in Figure 10-5.

As discussed earlier, the "half-generation" INTELSAT IVA system, for implementation in 1975, is aimed at better utilization of available bandwidth by reuse of the baseband. A sophisticated antenna design produces antenna beams which cover the INTELSAT Atlantic basin earth stations with sidelobes sufficiently suppressed to provide for minimal interference between beams using the same frequencies. Figure 10-6 is a block diagram of the IV communications subsystem. Table 10-17 gives

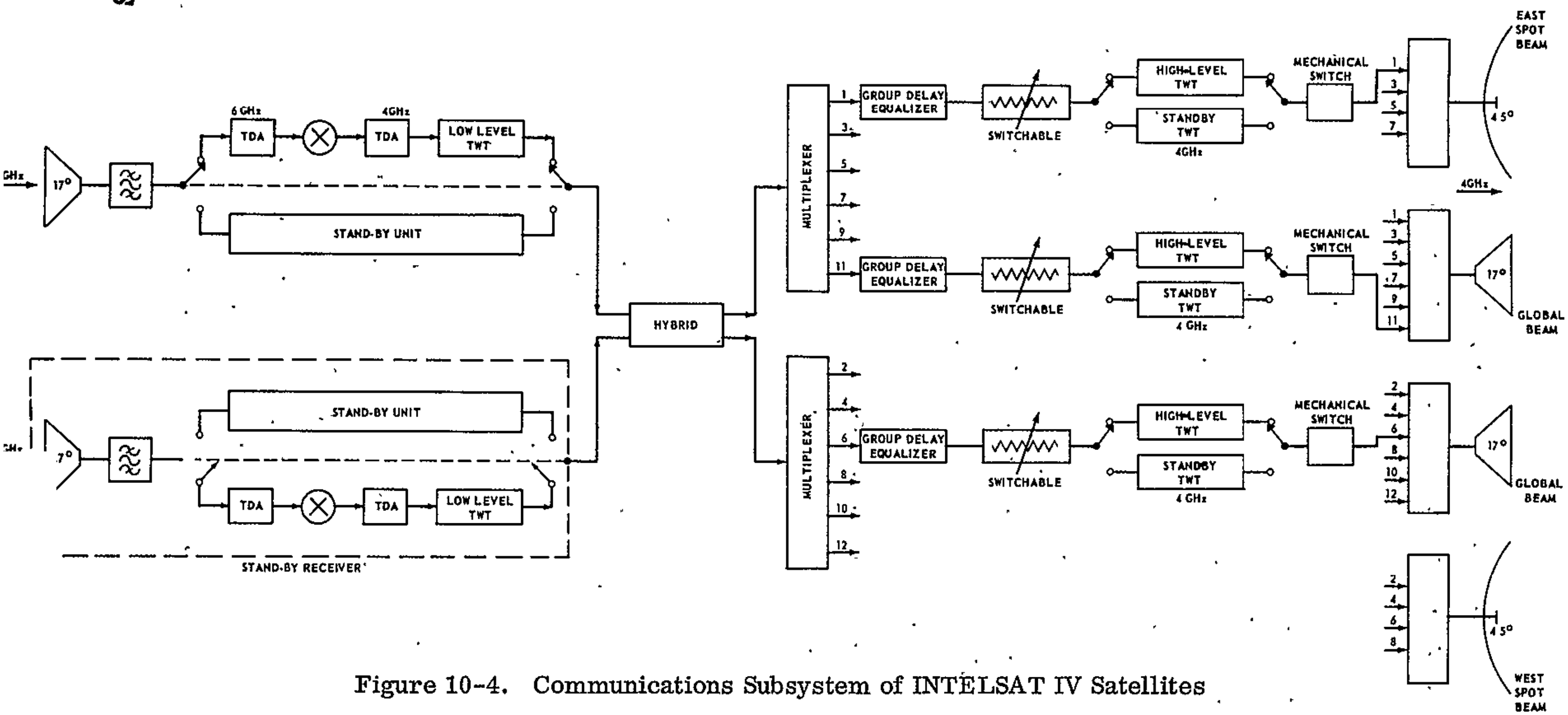

Figure 10-4. Communications Subsystem of INTELSAT IV Satellites

Table 10-16. INTELSAT IV Characteristics

Antenna		Type	Global Receive, Global Transmit: conical horn with flat plate reflection. Spot Beam: 127 cm (50 in.) parabolic reflector *. Omnidirectional command receive antenna and omnidirectional telemetry transmit.
Antenna		Number	2 of each of the above communications antennas
Antenna		Xmit. Beamwidth (global/spot beam)	17/4.5°
Antenna		Xmit. Gain (global/spot)	20.5/31.7 dB
Antenna		Polarization	Circular
Repeater		Frequency Band	C-band
Repeater		Type	Linear or limiting** single RF conversion repeater
Repeater		B.W. (-1 dB)	36 MHz
Repeater		Number	12
Repeater	RCVR	Type Front End	Tunnel Diode Amplifier
Repeater	RCVR	Front End Gain	13.8 dB
Repeater	RCVR	Sys. Noise Figure	8.2 dB
Repeater	XMTR	Type	TWTA
Repeater	XMTR	Gain	58 dB
Repeater	XMTR	Power Out	8 dBW per transponder
		EIRP***(global/spot beam)	22.5/34.2 dBW per transponder at beam edge
General Features	Stabilization	Type Capability	Spin with hydrazine jet attitude & orbital **** control. Stationkeeping to ±0.25° North-South and ±0.12° East-West. Attitude control to ±0.18°.
General Features	Power Supply	Primary	42,240 solar cells - 750 watts at launch
General Features	Power Supply	Supplement	Nickel-cadmium batteries
General Features		Comm. Power Needs	310 watts
General Features		Size	Cylindrical: 238 cm (93.7 in.) diameter, 528 cm (208 in.) height overall, 282 cm (111 in.) solar drum alone
General Features		Weight (at launch)	1415 kg (3120 lbs)
General Features		(in orbit)	730.3 kg (1610 lbs)

Notes: * Beam pointing adjusted prior to launch. Pointing cannot be changed by ground command.

** Selectable by ground command.

*** Measured in anechoic chamber.

**** Both north/south and east/west stationkeeping provided.

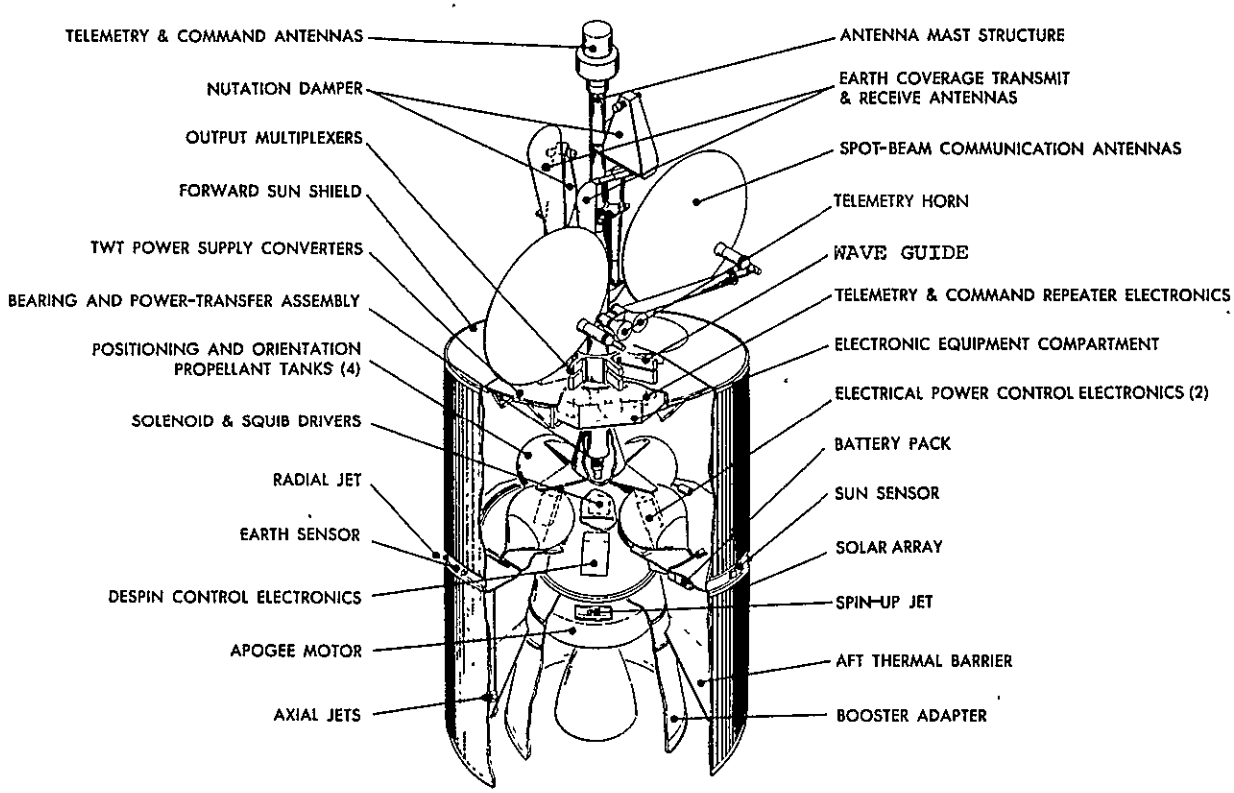

Figure 10-5. Components of the INTELSAT IV Satellites

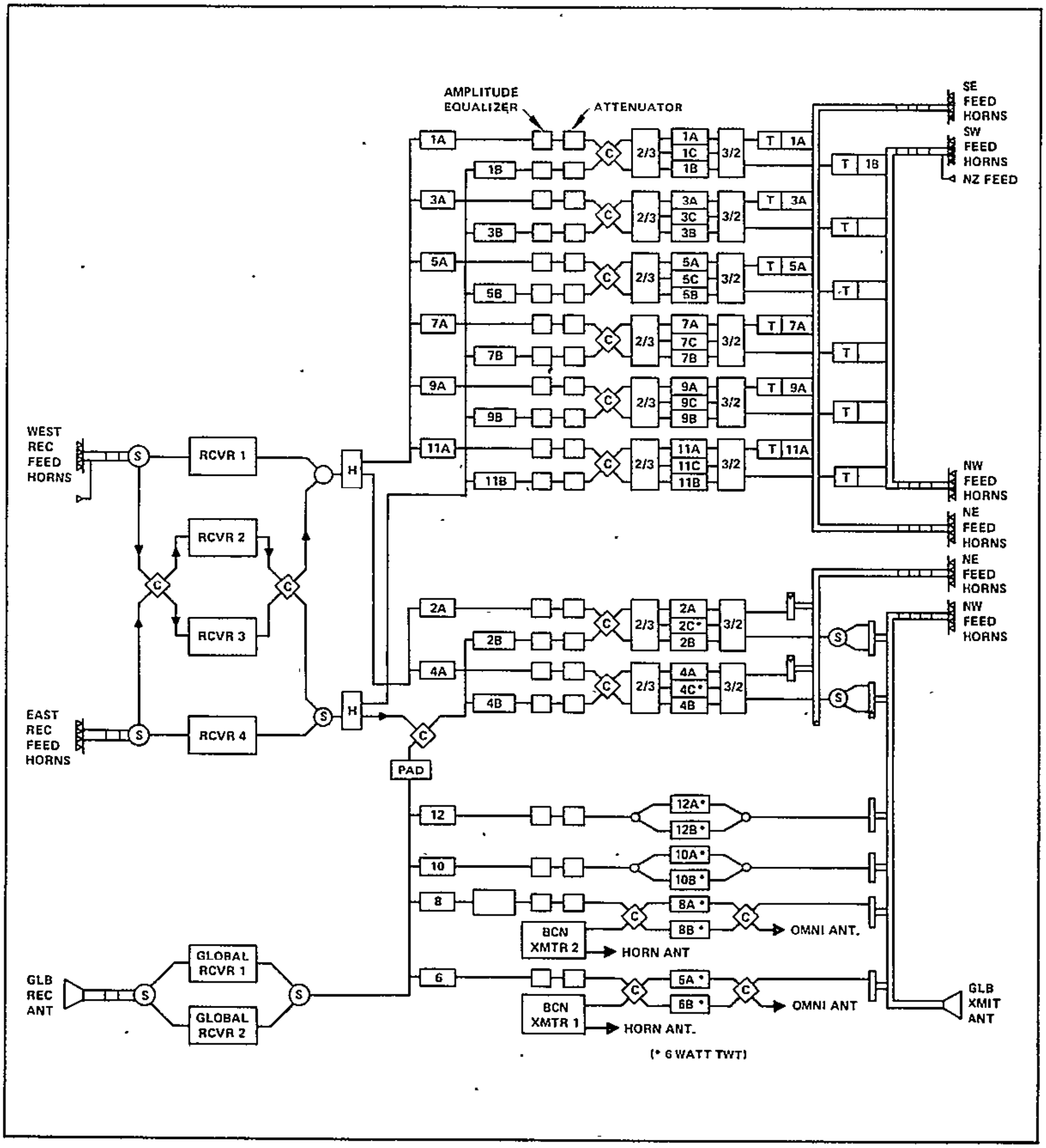

Figure 10-6. Communication Subsystem of INTELSAT IVA Satellites

Table 10-17. INTELSAT IVA Characteristics

Antenna		Type (Number)	Global Receive (1); Global Transmit (1) Hemispheric Receive (2); Hemispheric Transmit (2) Spot Transmit (6) Horn Antennas for Beacons (2) Omnidirectional Telemetry Transmit (2)
		Frequency Band	C-Band
		Usable B/W (MHz)	Single Carrier 36; Multiple Carriers 32.4 (10% Guard Band)
Repeater		Number of Transponders	20
	RCVR	Type Front End Front End Gain System N.F.	TWTA (Hughes low level type 27GH) No Data No Data
	XMTR	Type Gain Power out	TWTA (Hughes 6-watt type 271H or 4.5 watt 275H) No Data No Data
		EIRP (Global/Hemispheric/Spot)	22.0/26.0/29.0 DBW per Transponder (Beam Edge)
General Features	Stabili-zation	Type Capability	Dual Spin No Data
	Power Supply	Primary Supplement	Improved Solar Cells No Data
		Comm. Power Needs Size Weight (At Launch) (In Orbit)	415 watts No Data No Data 771 kg (1700 lbs)

IVA characteristics in a format so that direct comparison to the IV characteristics of Table 10-16 may be accomplished. Figure 10-7 shows the satellite configuration and pinpoints the subsystem of IV which had to be converted to arrive at the communications channel's increased capability offered by IVA.

10.4 GROUND TERMINALS

The INTELSAT ground complex that provided communications through the Early Bird satellite consisted to a large extent of modified versions of terminals initially constructed to participate in Telstar and Relay program experiments (see Sections 6 and 7). The participating terminals were listed in Table 10-6. The Andover earth station, originally built for Telstar, was modified during the period July 1964 through March 1965. The Goonhilly Downs earth station, also an original Telstar terminal, was withdrawn from service in September 1964 for modification to work with Early Bird. Prior to modification, the performance of Goonhilly was about 3 dB down as compared to Andover and Pleumeur Bodou. The modification improved the terminal's performance by reducing profile inaccuracies of the reflector, reducing aperture blocking from the feed support structure, and reducing feeder losses. Characteristics of the Andover, Goonhilly, and Raisting earth terminals, as configured for operation with Early Bird, were as indicated in Table 10-18.

Second generation earth terminals were developed to take advantage of the wider bandwidths of the INTELSAT II satellites. These earth stations employed more advanced equipment than had previously been available, including solid-state designs, masers of wider bandwidth, Cassegrain feed antenna systems, and dual carrier receiving chains. A technical summary of three typical second generation earth stations that participated in operations with INTELSAT II satellites is given in Table 10-19. The original INTELSAT I terminals were also used to operate in the INTELSAT II system. These terminals were not significantly modified from their Early Bird configurations.

In building the third generation stations for operation with INTELSAT III, new 500-MHz bandwidth cooled parametric amplifiers were developed, as well as 500-MHz

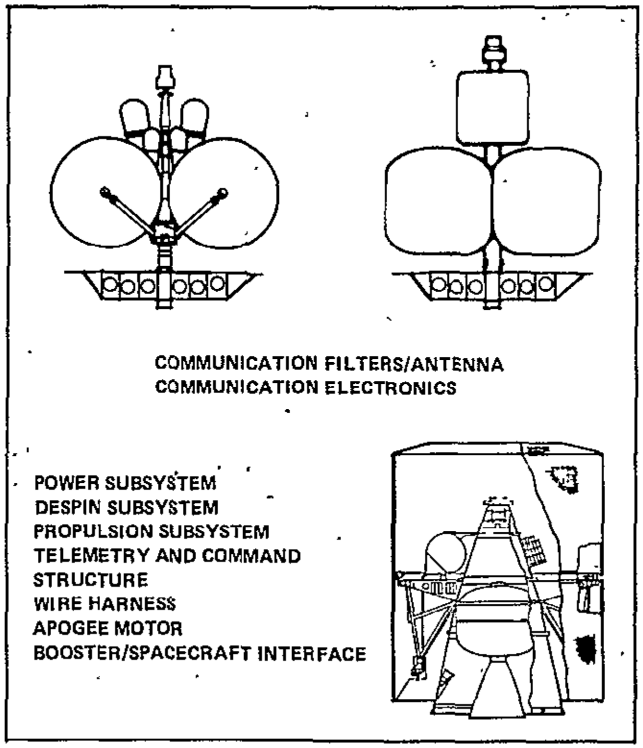

Figure 10-7. INTELSAT IVA Satellite and Subsystems Involved in INTELSAT IV/IVA Conversion

Table 10-18. Characteristics of Typical Early Bird Earth Terminals

Terminal Feature		Andover*	Goonhilly Downs	Raisting
Antenna	Type	Conical Horn Reflector	Parabolic Reflector	Parabolic Reflector
	Aperture Dia.	20.6 m (67.7 ft)	26 m (85 ft)	25 m (82 ft)
	Receive Gain	58 dB	58.5 dB	58.4 dB
	Efficiency	70 - 75 %	55 - 60%**	55 - 60%**
	Rec. Beamwidth (3 dB)	0.23^{o}	0.2^{o}	0.2^{o}
Receive System	Type Preamplifier	Traveling Wave Ruby Maser	Traveling Wave Ruby Maser	Maser
	Bandwidth	25 MHz @ 3 dB Pts.	25 MHz @ 3 dB Pts.	20 MHZ @ 3 dB Pts.
	Noise Temp.	50^{o}K @ 7.5^{o} Elev.	50^{o}K @ 7.5^{o} Elev.	50^{o}K @ 7.6^{o} Elev.
Transmit System	Type Amplifier	TWT	TWT	TWT
	Bandwidth	30 MHz	30 MHz	30 MHz
	Power Output	3 kW	3 kW	2 kW
Tracking	Type	Monopulse Autotrack	No Data	Programmed Tracking
	Accuracy	$\pm .01^{o}$	No Data	$\pm .01^{o}$
Total Performance	G/T	41 dB/^{o}K **	41.5 dB/^{o}K **	41.5 dB/^{o}K **
	EIRP	125 dBm **	124 dBm **	123.5 dBm**
Polarization	Transmit Feed	No Data	No Data	No Data
	Receive Feed	No Data	No Data	No Data
Installation	Radome	64.0 (210 ft) Diameter Rubberized Dacron	None	46.9 m (154 ft) Diameter Rubberized Dacron
	Type Facility	Fixed Terminal	Fixed Terminal	Fixed Terminal

Notes: * The terminal at Pleumeur Bodou had essentially the same characteristics

** Derived value based on data available.

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Table 10-19. Characteristics of Typical Second Generation Earth Terminals

Terminal Feature		Buitrago, Spain	Brewster Flats, Washington	NASA Ship ****
Antenna	Type	Cassegrain	Cassegrain	Cassegrain
	Aperture Dia.	26 m (85 ft.)	26 m (85 ft.)	9.1 m (30 ft.)
	Receive Gain	58.4 dB	58.4 dB	47.8 dB
	Efficiency	60%*	60% *	41%*
	Rec. Beamwidth	0.2^{o}*	0.2^{o} *	0.5^{o} *
Receive System	Type Preamplifier	Cooled Parametric Amplifier	Maser	Cooled Parametric Amplifier
	Bandwidth	No Data	30 MHz (-1 dB)	110 MHz (-3 dB)
	Noise Temp.	58^{o}K @ 10^{o} Elev.	50^{o}K @ 10^{o} Elev.	135^{o}K @ 7.5^{o} Elev.
Transmit System	Type Amplifier	Klystron	Klystron	Klystron
	Bandwidth	60 MHz (-1 dB)	30 MHz (-1 dB)	70 MHz (-3 dB)
	Power Output	10 kW	10 kW	10 kW
Tracking	Type	Autotrack	Autotrack	Monopulse Autotrack
	Accuracy	No Data	No Data	$\pm 0.06^{o}$
Total Performance	G/T	40.8 dB/^{o}K *	41.4 dB/^{o}K *	26 dB/^{o}K
	EIRP	130 dBm *	130 dBm *	122 dBm maximum
Polarization	Transmit Feed	No Data	No Data	Linear **
	Receive Feed	No Data	No Data	Linear **
Installation	Radome	None	None	Inflatable 16 m (53 ft.) diameter***
	Type Facility	Fixed Terminal	Fixed Terminal	Shipboard

Notes: * Derived value based on data available.
** Modified to circular for INTELSAT III operations. Transmit-LHC and Receive-RHC.
*** Not employed operationally.
**** Three of these terminals existed on board the Redstone, Vanguard, and Mercury, respectively.

bandwidth high power traveling-wave tube transmitters capable of over 6 kW of multi-carrier power. Antenna sizes become relatively standardized at 97 feet diameter, partly to compensate for the somewhat higher noise temperatures resulting from the wideband feed systems, and partly to obtain a small performance margin for the terrestrial stations. The characteristics for two third generation earth stations, Paumalu (Hawaii) and Fucino (Italy), are presented in Table 10-20.

With both global and spot beam transponders, INTELSAT IV allows earth stations to operate with a large number of carriers. The result is that intermodulation distortion becomes an increasingly important consideration in earth station performance. The higher capacities associated with INTELSAT IV require existing earth stations to verify a greater linear deviation capability, evaluate their threshold extension demodulator performance at the larger capacities, augment existing group delay equalization to the larger bandwidths associated with higher capacities, and replace certain traffic bearing and monitoring filters whose bandwidths are related to channel capacity.

With the fourth generation of earth stations, new and upgraded terminals, an approach to a "standard" earth station has been achieved. Such stations have typical minimum characteristics as shown in Table 10-21. In general, they are required to provide a receive gain of at least 57 dB and a receive G/T of 40.7 dB/^{o}K. Both the transmit and receive chains provide a 500-MHz RF bandwidth. Terminal transmitting feeds are left-hand circularly polarized and receive feeds right-hand circularly polarized. Each terminal, as a minimum, contains both an autotrack and manual tracking capability. Other mandatory performance characteristics of earth stations in the INTELSAT IV system are shown in Table 10-22.

The existing, under construction, and planned earth stations are listed in Tables 10-6 through 10-11, and are standard, unless otherwise noted. As of the end of March 1974, 89 earth station antennas were tracking and communicating with INTELSAT IV satellites. By the end of 1974, 107 earth station antennas are expected to be in service. The antenna and earth terminal characteristics of stations occasionally

Table 10-20. Characteristics of Typical Third Generation Earth Terminals

Terminal Feature		Terminal: Paumalu, Oahu	Terminal: Fucino, Italy
Antenna	Type	Cassegrain	Cassegrain
	Aperture Diameter	30 m (97 ft.)	27 m (90 ft.)
	Receive Gain	60 dB *	59.9 dB
	Efficiency	60% **	70%*
	Rec. Beamwidth	0.16^{c} *	0.17^{o}*
Receive System	Type Preamplifier	Helium Cooled Paramps.	Helium Cooled Paramps.
	Bandwidth	500 MHz	500 MHz
	Noise Temp.	50^{o}K @ 7.5^{o} Elev.	40^{o}K @ 7.5^{o} Elev.
Transmit System	Type Amplifier	TWT	TWT
	Bandwidth	500 MHz	500 MHz
	Power Output	6 kW	6 kW
Tracking	Type	Autotrack and Manual	Autotrack, Program Track, and Manual
	Accuracy	No Data	Autotrack -0.02^{o}
Total Perfor-mance	G/T	43 dB/^{o}K*	43.5 dB/^{o}K *
	EIRP	129 dBm*	129 dBm *
Polar-ization	Transmit Feed	No Data	Linear or Circular
	Receive Feed	No Data	Linear or Circular
Installation	Radome	None	None
	Type Facility	Fixed Terminal	Fixed Terminal

Notes: * Derived value based on data available.
** Assumed value based on performance typically realized for this type antenna.

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Table 10-21. Typical Characteristics of Fourth Generation Earth Terminals

	Terminal Feature	Typical Terminals Examples: Pulatat; Andover No. 2
Antenna	Type	Cassegrain-fed Parabolic Dish
	Size	30 m (97 ft) Diameter
	Receive gain (dB)	$\geq$ 57 dB*
	Side lobes	$\geq$ 29 dB below the main lobe maximum**
Receive System	Preamplifier	Cooled Parametric Amplifier
	Bandwidth	500 MHz
	Noise Temp.	50^{o}K at 7.5^{o} Elev.
Transmit System	Amplifier	TWT
	Bandwidth	500 MHz (5.925 - 6.425 GHz)
	Power Output	6.3 KW
Tracking	Type	Autotrack and Manual
	Antenna Steerability	Compatible with satellites having $\leq 5^{o}$ orbit inclination, $\pm 10^{o}$ longitudinal drift
Total Performance	G/T	$\geq$ 40.7 dB/^{o}K***
	EIRP	129 dBm
	Required EIRP Stability	$\pm$0.5 dB
Polarization	Transmit	Left-hand Circular
	Receive	Right-hand Circular (The voltage axial ratio does not exceed 1.4:1)

*At 4 GHz
At other frequencies within the 3.705 - 4.195 GHz band: ≥ 57 dB + 20 $\log_{10}$ f/4 (f is the receive frequency in GHz)

**$\geq 1^{o}$ away from the main lobe center

***At 4 GHz
At other frequencies within the 3.705 - 4.195 GHz band: ≥ 40.7 dB/^{o}K + 20 $\log_{10}$ f/4 (f is the receive frequency in GHz)

Table 10-22. Mandatory Performance Characteristics of Earth Stations in the INTELSAT IV System

RF Out-of-Band Emission in Any 4-kHz Band	
Spurious	$\leq$ 4 dBW
Intermodulation	< 26 dBW
Carrier Frequency Stability	
FM Carriers Above 5 MHz	±150 kHz
FM Carriers at or Below 5 MHz	±80 kHz
SPADE and PCM PSK Single-Channel-per-Carrier Preassigned Carriers	±200 Hz
Sense of Video Modulation	Positive
RF Energy Dispersal on FM Telephony Carriers	Low-frequency triangular dispersal waveform calculated so that the maximum EIRP per 4 kHz of the fully loaded carrier is ≤ 2 dB
Pre-emphasis for Telephony, Television, and Program Sound Channels	In accordance with C.C.I.R. and C.C.I.T.T. recommendations
Residual Amplitude Modulation, rms Value Within Any 4 kHz	
4-500 kHz	$\leq -20 (1 + \log_{10} f)$ dB referred to the RF carrier level (f is the carrier frequency, in GHz, of the 4-kHz slot)
> 500 kHz	-74 dB

vary somewhat from the standard 30-meter (97-foot) dish mounted on a 5-meter (16-foot) high pedestal, however, all stations must meet minimum technical characteristics before they are allowed into the system. The antenna structure is about 10-stories high and can be rotated on wheels on a 15-meter (50-foot) diameter track 1° per second to precisely track a satellite 35,881 kilometers (22,300 miles) away to within 0.02°.

10.5 EXPERIMENTS

Since the major objective of the INTELSAT program has been to establish an operational international commercial satellite communications system, the number of experiments and the instances of utilizing innovative equipment types have been somewhat limited. In spite of this, a number of experimental activities of major significance have taken place and indications are that this typeof activity will accelerate in the future.

An example of past activities is the Early Bird tests to evaluate the subjective effects of long transmission delay on telephone subscribers and techniques for reducing echo caused by two wire user terminations to acceptable levels. Although the feasibility of synchronous satellite communications had been successfully demonstrated in the Syncom program, conclusive results in the two areas indicated had not been obtained. Furthermore, prior to Early Bird, the operational experience required for a reliable commercial system was not available. The successful operation of Early Bird (INTELSAT I), for more than 3 years, demonstrated public acceptance of space communications. In so doing, it proved conclusively that, for single synchronous earth satellite repeaters, transmission delay and echo were not serious problems in the realization of an operational commercial system. Earth station experience gained at Andover, Goonhilly Downs, Pleumeur Bodou, and Funico demonstrated that efficient reliable communications could be maintained and heralded the introduction of multistation operations.

Another area of major experimental interest to INTELSAT has been modulation techniques for multiple access of a single satellite transponder. An important inherent advantage of communications via satellite is that a large number of widely separated earth stations can communicate with each other simultaneously through the same satellite. Through multiple access, the potential exists to greatly increase system flexibility and to reduce the size and equipment complexity of the space subsystem. As a result, techniques for multiple access have received a great deal of attention for both military and commercial applications.

At the time of Early Bird, frequency modulation and frequency-division multiple-access (FDMA) were the common approaches to RF modulation and multiple access. Both were favored because of their compatibility with existing hardware. It was also desirable at that time, due to limitations on realizable satellite power and weight in orbit, to operate spacecraft repeaters as hard limiting transponders. This approach to repeater design provided maximum efficiency in converting primary dc power into radiated RF power. However, the nonlinear transfer function of hard limiting transponders results in intermodulation among the various independent carriers existing in an FDMA system and thereby limits the potential system capacity somewhat.

A means of avoiding the nonlinear repeater problem is to operate with only one carrier through the satellite transponder at any one time. This can be accomplished by having the earth stations transmit their information in bursts rather than continuously as in FDMA, and by synchronizing these bursts so that they enter the transponder in a nonoverlapping sequence. Such a system is called time-division multiple-access (TDMA). INTELSAT's interest in TDMA started in the early stages of commercial satellite communications in 1964, and in 1965 work was initiated on the MATE program. This 3-terminal system operated at 6 Mbps and had a preassigned capacity of 72 channels. The field testing of MATE, the first TDMA system to be so tested, was conducted via INTELSAT I in August 1966. The tests clearly demonstrated the feasibility of TDMA and indicated that burst synchronization to accuracies in the low nanosecond region could be achieved if such accuracy were required.

Both the initial FDMA and TDMA systems employed fixed preassigned allocations of satellite transponder time, frequency, and power. Unfortunately, the preassigned approaches to multiple access, while providing excellent quality and service, have a poor working flexibility and use satellite spectrum and power inefficiently by providing a poor "fill factor." Fill factor can be viewed as the relationship of the total voice channel capacity of a satellite transponder to the average number of such channels actively employed during the busy period. When fixed assignments are made, there are numerous instances where channels stand inactive. Recognizing the need for more efficient systems, INTELSAT began to consider demand access approaches to multiple utilization of the same satellite transponder. In demand access, the general concept is to assign nonoverlapping allocations of satellite power and time-frequency spectrum to users, in real time, as their demand for service occurs. Both TDMA and FDMA systems providing demand-access service are theoretically feasible.

The SPADE system is an FDMA demand-access system given extensive consideration by INTELSAT. SPADE has been designed for links ranging from fractional requirements to 12 and 24 channels and is a PCM-PSK-FDMA system. The development of SPADE was begun in 1964. The salient features of the SPADE system include digital PCM encoding of voice on a single channel per carrier, the ability to transmit to the satellite only during talker activity, quadriphase PSK modulation, system self-assignment of channels, and operation with standard manual or automatic international signaling and switching systems. The ability to deactivate earth terminal transmissions during periods of talker inactivity tends to compensate for having to operate satellite transponders in a backed-off mode such that linear transfer functions are provided. The system is compatible with the INTELSAT II, III, and IV satellites. It was tested between Andover, Maine, and Cayey, Puerto Rico, over INTELSAT II; and later between Etam, West Virginia, and Goonhilly Downs, Cornwall, over INTELSAT III. The SPADE system is now operational and has been assigned to transponder 10 of the INTELSAT IV in the Atlantic region, and is serving 12 accesses. It is anticipated that by 1976 as many as 40 stations will be using SPADE.

Following the MATE system success, INTELSAT started planning for the next generation of TDMA systems, with emphasis on extending the state-of-the-art in all technological areas relating to TDMA. The resulting experimental system, called MAT-1, is a PCM-PSK-TDMA system for 12 to 24 channel links. It is based upon a 50-Mbps transmission rate that yields over 700 8-bit PCM channels in a 10-station network configuration. A unique feature of this system is its orientation toward demand assignment.

The Kokusai Denshin Denwa (KDD) Research Laboratory has developed a 50-Mbps TDMA system, called TTT, which has time-assigned traffic blocks, including a block devoted to an experimental pulse-code modulation, time-assignment speech interpolation (PCM-TASI) design. The MAT-1 and the TTT systems are compatible; field tests of these terminals were conducted in July 1970, over INTELSAT III (F-4) among stations in Hawaii, Japan, Australia.

Another technique being actively developed is that of placing a time-division switching capability on-board the satellite itself. This technique will become particularly attractive as satellites providing multiple spot beams come into use. In this technique, known as Satellite-Switched Multiple Access, all stations' transmissions are frame-synchronized by destination as they enter their respective satellite receivers. Following amplification and, perhaps, down conversion, these signals enter the satellite distribution subsystem that acts as a time-division switch. In this switch, all the traffic intended for a particular destination is sequentially directed toward the output amplifier and antenna for that destination. The receiving system demodulates a single carrier, and the frame synchronization is now source oriented rather than destination oriented.

Still another area of major concern to the INTELSAT program has been link propagation. Considerable detailed data on satellite link propagation characteristics at the 4- and 6-GHz frequencies has been obtained. This includes items such as atmospheric absorption as a function of weather conditions; scintillation and faraday rotation as functions of time, geographic location, and sunspot activity; and multipath as a function of antenna elevation angle. As the geostationary orbit has tended to fill up with satellites operating at 4 and 6 GHz, INTELSAT has become interested in link propagation characteristics for spacecraft communications systems operating at frequencies above 10 GHz. This interest is evidenced in the Comsat propagation experiment to be conducted at 13 and 18 GHz by NASA's ATS-6 satellite. This experiment is designed to gather data on satellite signal attenuation at 13 and 18 GHz caused by atmospheric hydrometeors at ground stations located in representative climatological areas. The data obtained from this experiment will provide the basis for establishing minimum power margins needed for operation at 13 and 18 GHz.

10.6 OPERATIONAL RESULTS

Since the INTELSAT program has produced a commercial communications system, the system's operational results obtained during each of the four generations of the space subsystem are of considerable interest. Early Bird was launched on April 6, 1965, and by April 22 it was sufficiently synchronized for the commencement of communications testing. Two groups of tests were conducted concomitantly: the Performance Test Plan to determine how well the spacecraft performance in orbit met contract specifications, and the Experimental Test Plan to determine system parameters when the spacecraft is used with the operating ground stations. The Performance Test Plan was completed in four days and included measurement of the spacecraft's effective isotropic radiated power (EIRP), receiving sensitivity, transponder gain and frequency response, noise power ratios (NPR), intelligible crosstalk, antenna patterns, polarization, and insensitivity of the command system to interference. The only notable failing of the Performance Test Plan was that the specification for intelligible crosstalk of -45 dB could not be met with TWT No. 1. For this reason, TWT No. 2 was used for all commercial operations.

The Experimental Plan tests were conducted for 18 hours per day for a week. System characteristics with a variety of loading conditions were measured for all stations. It was determined that the 240 circuit capacity could be realized by the four high-capacity stations and that a 6-dB margin existed in fair weather. It was also determined that the antenna gain and receiving sensitivity for the four large stations were similar to within 1 dB.

Tests on system characteristics for monochrome TV were performed until all stations reached agreement on the optimum operating parameters.

Three weeks after launch, the spacecraft and the earth stations were properly tested, and the space segment of the system was ready for use. The terrestrial network operators then began circuit lineup. For the 120-channel multiplex system to be used for the first commercial service, it was necessary to allow 4 weeks for adjustments at a circuit level both in the U.S. and in the four countries in Europe. These tests were completed on schedule, and the system was ready for operation in June.

After a series of successful demonstrations with telephone circuits and television service, commercial operation was initiated on June 28, 1965. Figure 10-8 summarizes commercial usage for telephone and television traffic through November 1967. The satellite contribution to out-of-service time was zero in the Early Bird system. All loss of service was attributable to the seven major earth segment elements--the five earth stations and the U.S. and European interconnects. The reliability history of this service through early 1967 is shown in Figure 10-9 in terms of cumulative percentage outage time. Early Bird was placed in retired reserve on January 20, 1969, after INTELSAT III achieved operational status. It was reactivated for a brief period between June 1969 and August 1969 when temporary difficulties were encountered with the despun antenna of an INTELSAT III satellite. The operational lifetime of 3-1/2 years far exceeded the design lifetime of 1-1/2 years for this exceptionally successful satellite program.

The first INTELSAT II satellite (F-1) was launched in October 1966. Although it failed to achieve stationary orbit, the successful functioning of the communications subsystem permitted an 8-hour-per-day voice service to be established between the earth stations in Hawaii and Brewster Flat. The highly elliptical, inclined orbit realized reduced the commercial utility of the F-1 satellite to negligible proportions, but the experience with its functioning subsystem proved to be invaluable in preparing

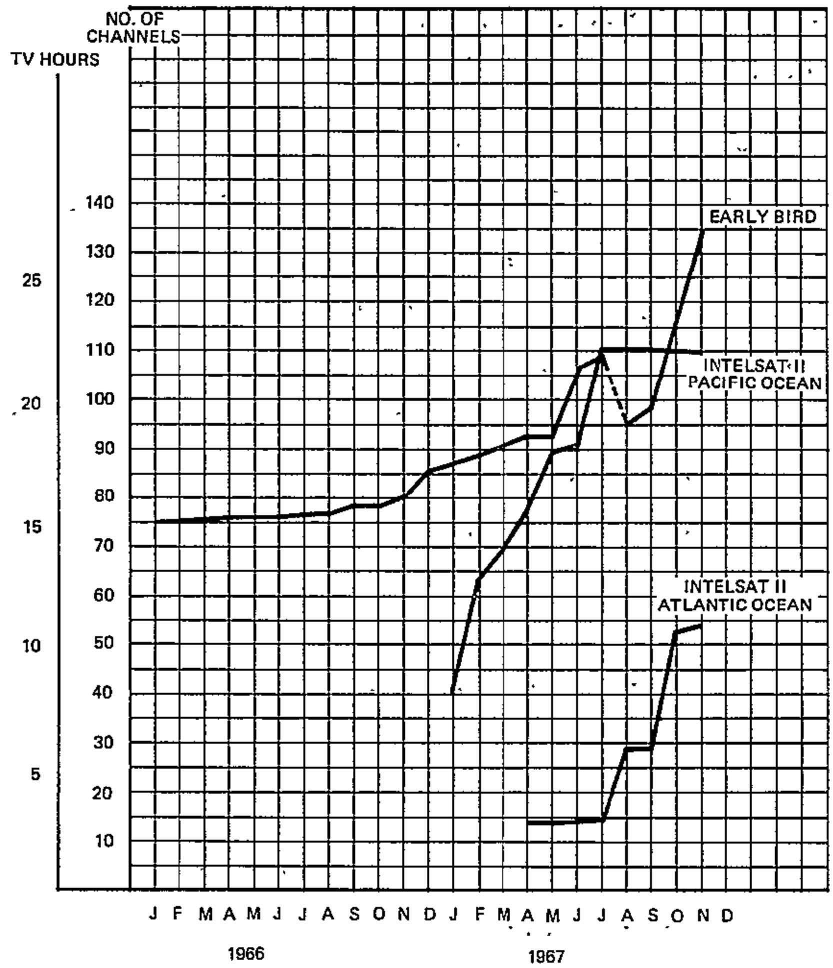

Figure 10-8. Early History of INTELSAT System Usage

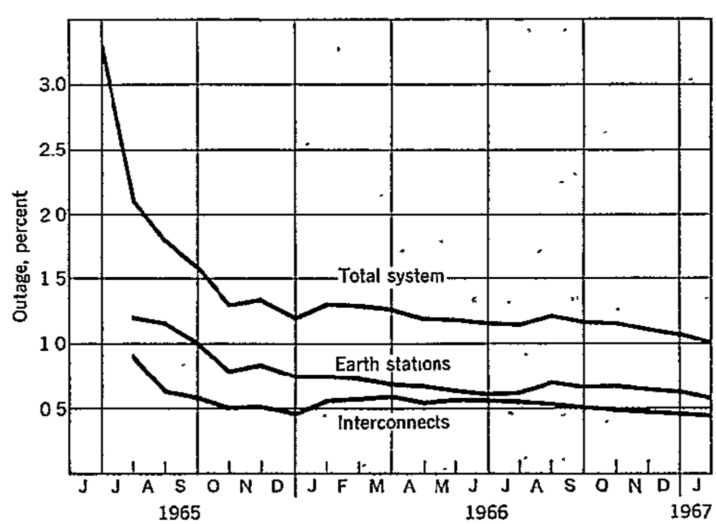

Figure 10-9. Cumulative Outage Performance for Early Bird

for operations with its successors. Live television between Hawaii and the U.S. mainland was inaugurated via F-1 on November 18, 1967.

INTELSAT II satellites (F-2 and F-4) were employed for service in the Pacific area. During the time when the F-4 satellite was undergoing final positioning maneuvers, its longitude was allowed to approach closely that of F-2 for the purpose of making intersystem interference measurements. At Paumalu, the 26-meter (85-foot) antenna was operating with F-2 while the 13-meter (42-foot) antenna was available for experimental work with F-4. Experiments and measurements of interference were made as the satellites approached to within 0.5° of each other. It was concluded from these interference measurements that the INTELSAT II system can be safely operated with a minimum of 1.6° of longitude separation between satellites. Both of these satellites and F-3, which supplemented Early Bird in the Atlantic area by providing wide area service, have operated satisfactorily providing commercial communications service. Multiple-access service was successfully initiated with the INTELSAT II satellite (F-2) on January 27, 1969.

The first INTELSAT III satellite (F-1) was launched in September 1968, but no orbit was achieved. This was followed by the launch of INTELSAT III F-2 on December 18, 1968. This satellite began operational service over the Atlantic on December 24, 1968. It operated satisfactorily until June of 1969, at which time sticking of the mechanically despin antenna was encountered. This was determined to be due to a thermal gradient problem across the bearings of the despin motor. By August of 1969, the satellite was back in operational service. It continued to be employed until February 1, 1970, when INTELSAT III F-6 assumed the operational load over the Atlantic Ocean and F-2 was retired from service. INTELSAT III F-3 was launched into orbit over the Pacific on February 5, 1969. It was placed into operational service on February 16, 1969, and continued to be employed in the Pacific location for about 6 months. F-3 was then repositioned over the Indian Ocean after losing about 6 dB of transponder gain due to a malfunction in one stage of the receiver tunnel diode amplifier. The reduced channel loading associated with operations at the Indian

Ocean location permitted the satellite to continue in a useful capacity. INTELSAT III F-4 replaced F-3 in handling the Pacific Ocean operational traffic. INTELSAT III F-7 was successfully placed into service over the Atlantic on May 8, 1970 to supplement F-6. As of mid-1971 INTELSAT III F-3, F-4, F-6, and F-7 and the associated ground complex continue to perform essentially as expected.

The first INTELSAT IV satellite (F-2) was successfully launched into orbit over the Atlantic Ocean on January 25, 1971. Communications tests began on February 7, and on March 26 earth station antennas in 14 countries, then operating with the INTELSAT III F-6 satellite, began a simultaneous mass pointover to assume operational service through the INTELSAT IV F-2 satellite.

The second INTELSAT IV satellite (F-3) was launched into orbit, also over the Atlantic Ocean on December 19, 1971. It was positioned, tested and then placed into service on February 19, 1972, at 340.5°E longitude. Subsequently, it was moved to 335°E longitude where it continues in service, replacing F-2 which is now in reserve at 340°E longitude. INTELSAT IV F-4 was launched into orbit over the Pacific on January 22, 1972, and placed into service on February 19, 1972, at 194°E longitude, taking over service from INTELSAT III F-4. INTELSAT IV F-5 was launched into orbit over the Indian Ocean on June 13, 1972, and placed into service on July 30, 1972, at 61.4°E longitude replacing INTELSAT III F-3 which is now in service as 60°E longitude. INTELSAT IV F-7 was launched into orbit over the Atlantic Ocean and placed into service at 330°E longitude on November 21, 1973, supplementing INTELSAT IV F-3.

The INTELSAT IVA satellite is expected to be ready for launch in 1975. It is a Hughes product, as is INTELSAT IV, and is presently under construction.

Operational traffic projections for the composite INTELSAT system are shown in Figure 10-10. The figures from 1971 onward reflect the minimum projected yearly growth rate of 15%. Figures show voice channels or half duplex circuits.

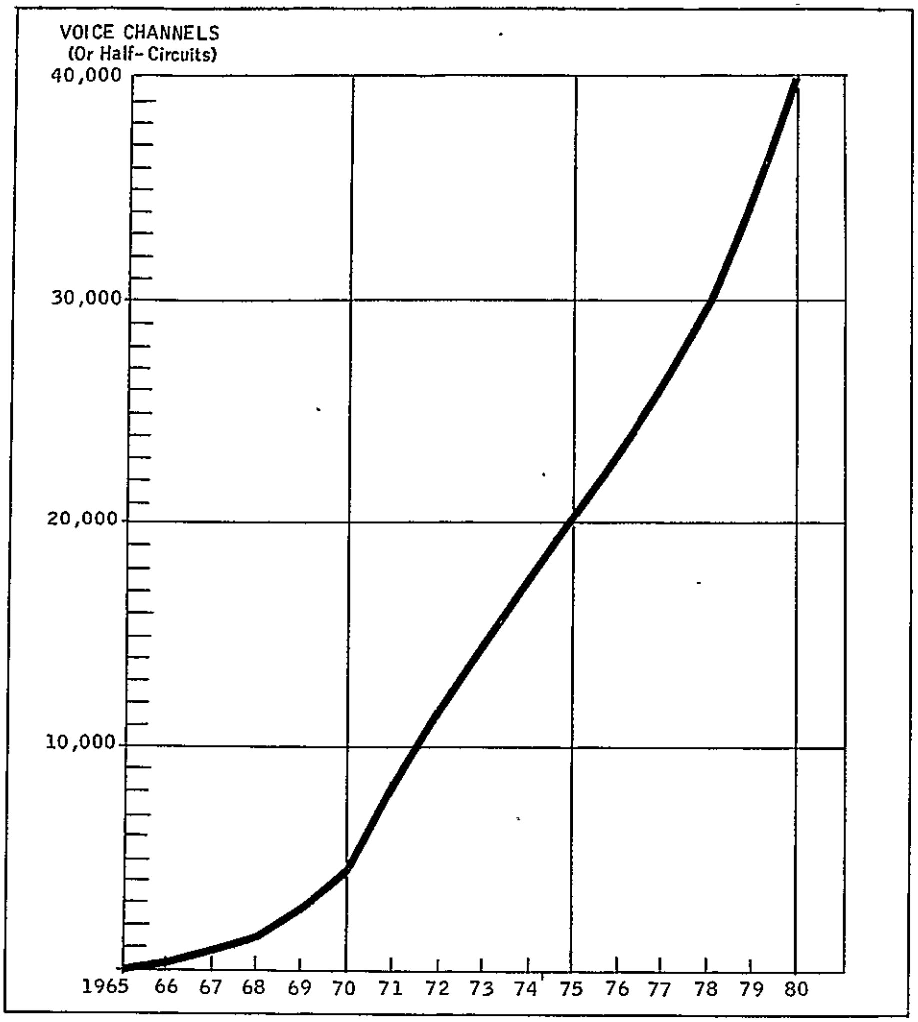

Figure 10-10. INTELSAT Traffic Growth Projection (1965-1980)

Although serving is an operational role, the unattended earth station located near McMurdo Station on Ross Island (166.6°E, 77.8°S), Antarctica, can also be considered a very successful experiment. This station became operational simultaneously with the first Pacific INTELSAT IV in mid-February 1972 and has since transmitted data from the unmanned geophysical observatory (UGO), supported and owned by the National Science Foundation to the continental USA in the Jamesburg, California earth station thence to a computer facility at Stanford University (National Science Foundation contractor) by commercial telephone lines.

Data can be transmitted by the following:

a. A non-return-to-zero, biphase modulated carrier providing a data rate of 833 bps

b. A carrier which is frequency modulated by an analog data signal extending from 100 to 3000 Hz, and an FSK subcarrier (833 bps) at 5.5 kHz

Selection and control can be performed remotely via a 100-bps command data book.

The primary components of the Antarctic station are

a. A fixed pointing 2.4-m (8.0-ft) antenna
b. A 20-watt TWT output amplifier
c. Electronics for data encoding
d. Receiving system for processing command signals and executing operations

The station operates with a G/T of 7 dB/$^{\circ}$K, and EIRP of 52 dBW and an antenna elevation angle to the nominal satellite format (174°E) of 3.35°, in a straight line, or approximately 3.6° with atmospheric bending. Orbital parameters of the satellite have caused it to remain within the 3-dB contour of the earth station antenna pattern, so that PSK transmissions from Antarctica have been received 24-hours per day at Jamesburg with a C/N density of $\geq$51 dB-Hz, the nominal design value, and an error rate of $\approx$1 in 10^7.

The successful operation of the Antarctic terminal, the first unattended terminal to be used with an INTELSAT satellite, has demonstrated the ability of this type of station for special application.

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SECTION 11 - MOLNIYA

11.1 PROGRAM DESCRIPTION

Since the Soviet Union occupies one-sixth of the earth's surface, it requires an efficient space communications system. The country covers nearly 9,656 km (6000 miles) from east to west and over 4,023 km (2500 miles) from north to south. For the Soviet Union, whose territory extends up to 80°N latitude, geostationary orbits are not ideal because they do not ensure communications at earth station elevation angles greater than 7.5° for all areas that lie above 70°N latitude. The Soviet Union's communication satellites system, using the Molniya-1 and the more recent Molniya-2 spacecraft, circumvents this difficulty by employing the highly eccentric elliptical orbits described below.

The orbit chosen for the Molniya satellites is interesting for two reasons. First, it is highly elliptical with an apogee of 39,633 km (21,400 n.mi.) in the northern hemisphere, a perigee of 500 km (270 n.mi.) in the southern hemisphere and an orbital period of nearly 12 hours. Thus, the two daily orbital apogees for any given satellite occur 180° apart over earth longitudes. Second, the angle of inclination of 65° means that the period during which one of the two daily orbits of the satellite can be employed for radio communication between distant points in the USSR is between 8 and 10 hours.

The second daily orbit cuts diagonally across the Western Hemisphere on its ascending pass, and has been used on a limited basis to provide a Moscow-Cuba link. This secondary low utilization orbit (Figure 11-1) provides maximum mutual visibility of Washington and Moscow. In Figure 11-2, the mutual visibility of the Washington-Moscow link is plotted as a function of the ascending node of the orbit. The shaded bar areas indicate the two daily longitudes of the ascending node of the existing Molniya-1 satellites.

Figure 11-3 illustrates the duration of mutual visibility of the Moscow-Washington link for a single 12-hour orbit as a function of the longitude of the ascending node. The

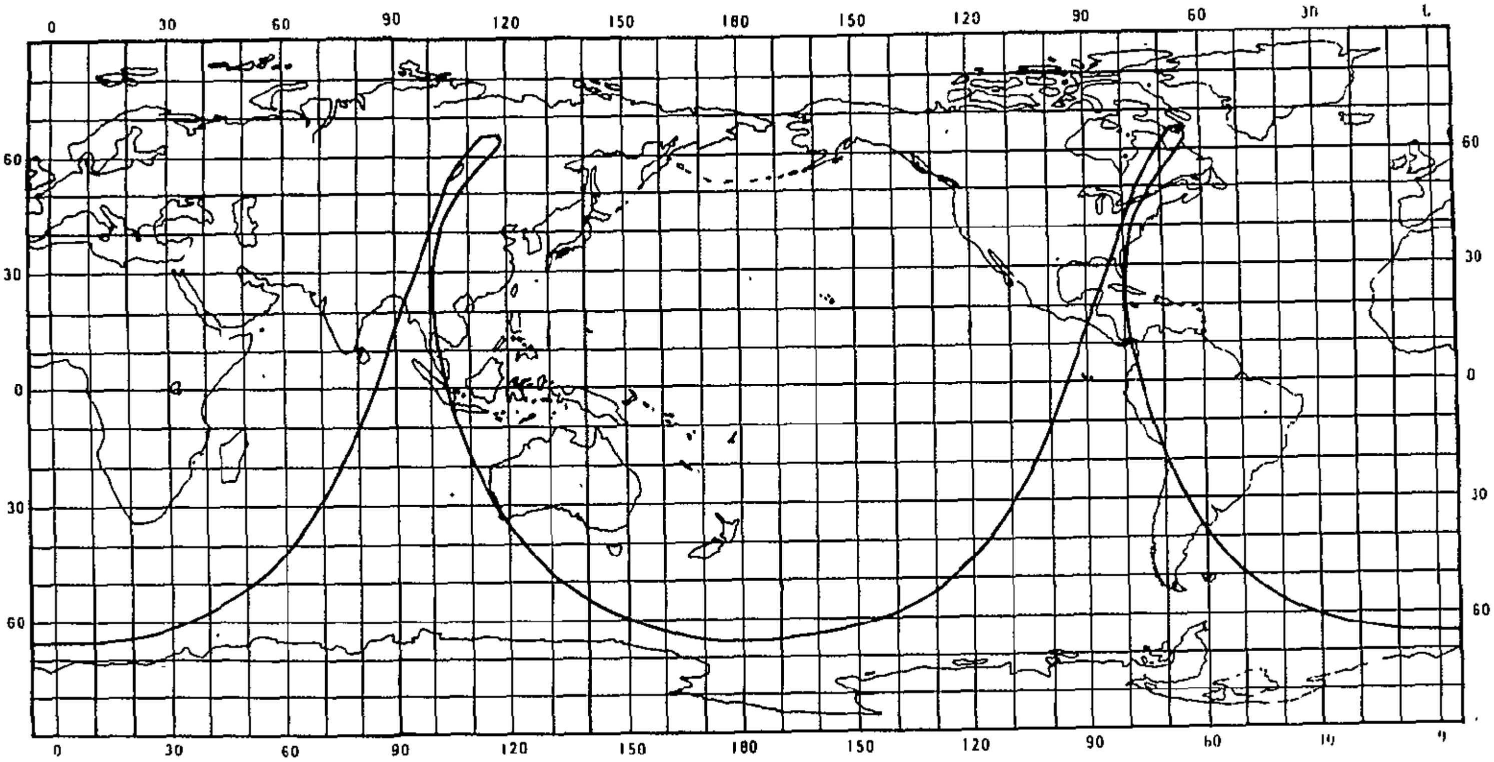

Figure 11-1. Molniya Orbital Ground Track

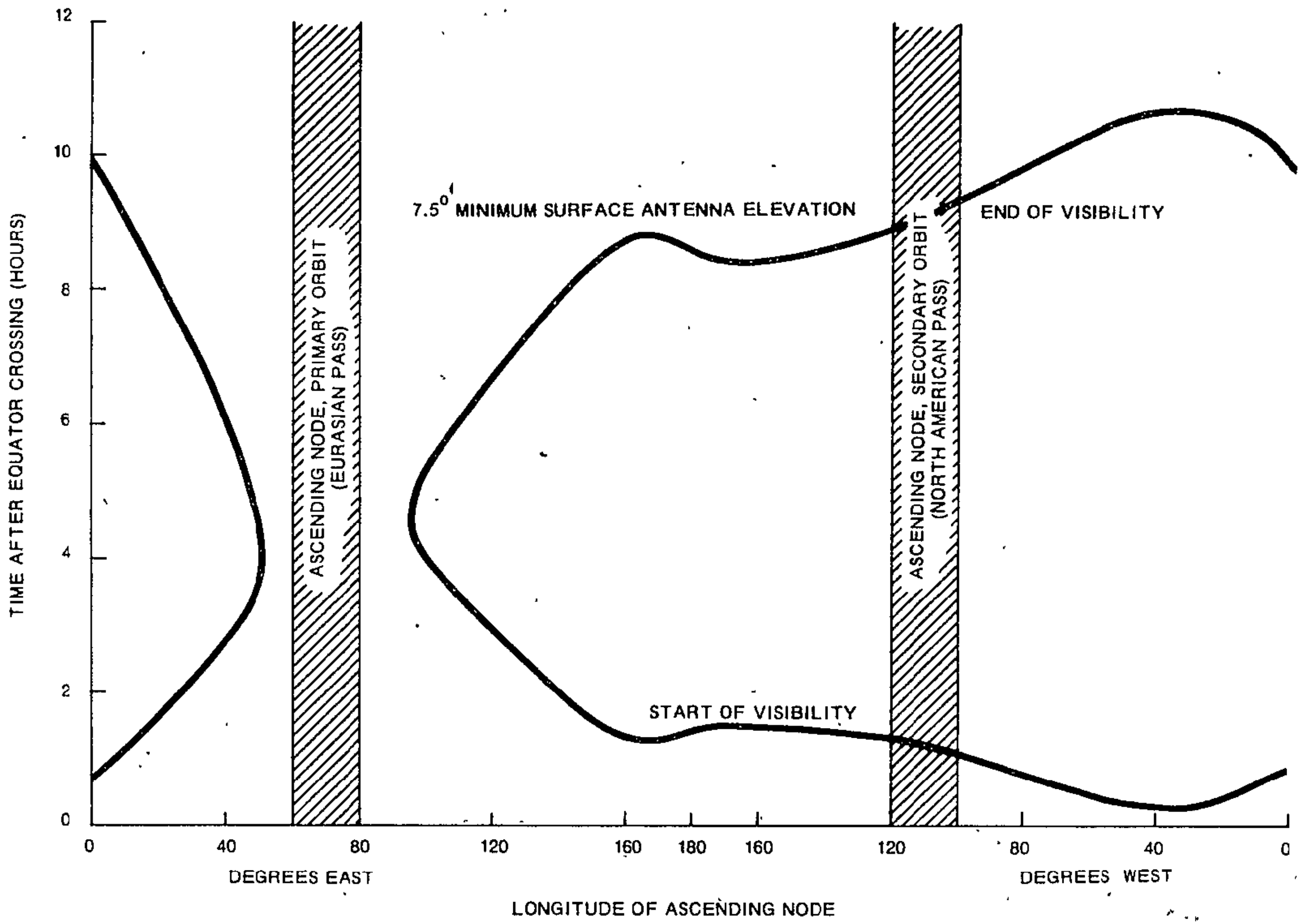

Figure 11-2. Moscow to Washington Mutual Visibility Versus Ascending Node

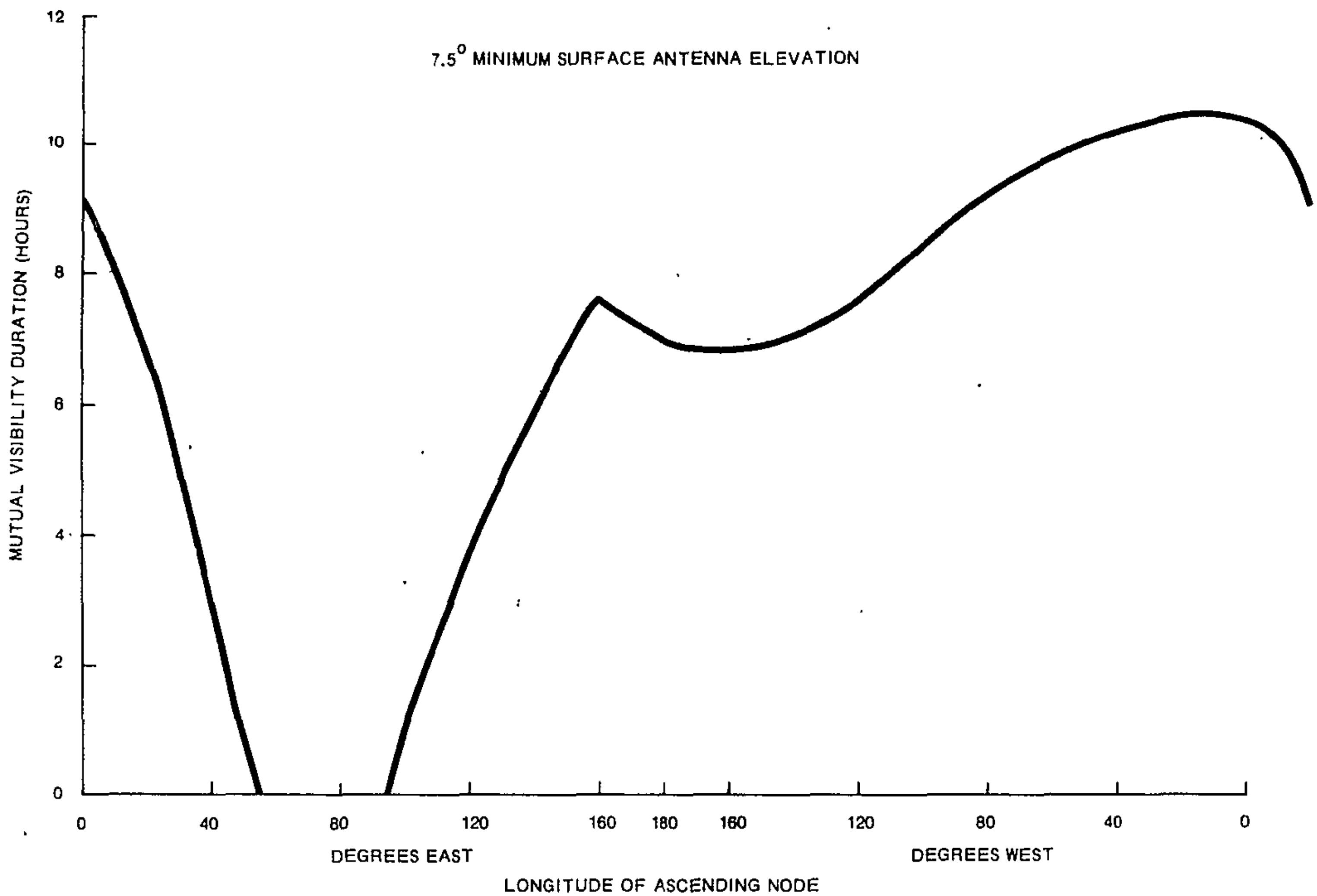

Figure 11-3. Mutual Visibility Duration Versus Longitude of the Ascending Node

graph indicates that the optimum right ascension is approximately 20^{o}W (340^{o}E) longitude, which provides 10.5 hours of continuous coverage from a single satellite.

If three Molniya communication satellites are launched at regular intervals into identical elliptical orbits whose planes are shifted relative to one another by 120^{o}, they will form a system that ensures 24 hour-per-day communications for the entire USSR. It should be noted that this orbit also affords the possibility of continuous communication between the European USSR and North and Central America, thereby establishing communications between most parts of the northern hemisphere, where 75 to 80 percent of the earth's population resides.

It should be noted that an elliptical orbit offers an additional important advantage for the Soviet Union. For a launch vehicle of given thrust operating from the appropriate Soviet launch site, two or three times more weight can be placed into the selected elliptical orbit than into an equatorial synchronous one.

The Molniya program has been responsible for a number of other innovations in satellite communications technology. Major advances demonstrated by the Molniya-1 satellites are: flywheel stabilization, solar panels that were continually maintained in a 90^{o} aspect relative to the sun line by proper positioning of the body of the spacecraft, and parabolic antennas that tracked the earth independent of the main body of the satellite. This program also produced the first system supplying a regular space television distribution service to a large number of receiving terminals which were widely dispersed geographically.

11.1.1 Hotline - Direct Communications Link Between Washington and Moscow

"The U.S. and Russia have reached an agreement on an improved direct communications link. The improvements will provide two independent and parallel satellite communications circuits, each using a separate communication satellite system in each country. The U.S. will provide a circuit via the Intelsat system while the Russians will provide a circuit via the Molniya II system.

The U. S. Satellite portion is a leased duplex voice bandwidth circuit from a Comsat Earth Station at Etam, West Virginia, through an Intelsat IV satellite, to a USSR-provided earth station at Moscow. The USSR satellite portion is a duplex voice bandwidth circuit from a Molniya II earth station at Vladimir, USSR, through Molniya II satellites, to a U. S.-provided earth station at Fort Detrick, Maryland, "[1]

(See Paragraph 11.4.1 for a description of the U.S.-supplied earth terminal.)

11.1.2 Schedule

Satellite launch schedules for Molniya-1 and -2 are shown in Figures 11-4 and 11-5, respectively. From Figure 11-4 it is also noted that six Molniya-1 satellites are currently operational in orbit.

11.2 SYSTEM DESCRIPTION

11.2.1 Control Subsystem

The Molniya command and measuring radio link is a complex of radio technical facilities which provide not only for control of the satellite but also for measurement of the parameters of the satellite movement in orbit as well as for checking on the condition of the satellite's systems. The positional control of the satellite, the switching off of spaceborne apparatus, and the transmission of telemetric data from the satellite are done with the telemetric command system. Commands reach the satellite in an encoded form and are addressed to the corresponding activating mechanisms within the spacecraft.

11.2.1.1 Communications Control

All the operations required for reading the satellite's systems for a communications session (orientation of the antenna platforms, switching on the relay apparatus, control of the power-supply system, thermal regulation, etc.) are handled automatically upon signals from a program-logic device. This device (computer) also determines the length of the communications session. The on-board device is fed with programs sent by command from the ground. When necessary, an operator on earth

PAGE __ OF __ SCHEDULE NO. ____

TITLE	CLASSIFICATION	AS OF DATE
Molniya-1 Communications Satellite Launches and Status	Unclassified	January 1973

CY-65 | CY-66 | CY-67 | CY-68 | CY-69 | CY-70 | CY-71 | CY-72 | CY-73

ITEM NO.	MAJOR MILESTONES		
1	Molniya 1/1	4/23	In Orbit/Retired
2	Molniya 1/2	10/14	Decayed 3/17/67
3	Molniya 1/3	4/25	In Orbit/Retired
4	Molniya 1/4	10/20	Decayed 9/11/68
5	Molniya 1/5	5/25	Decayed 11/26/71
6	Molniya 1/6	10/3	Decayed 3/4/69
7	Molniya 1/7	10/22	Decayed 12/31/69
8	Molniya 1/8	4/21	In Orbit/Retired
9	Molniya 1/9	7/5	Decayed 5/15/71
10	Molniya 1/10	10/5	In Orbit/Retired
11	Molniya 1/11	4/11	In Orbit/Retired
12	Molniya 1/12	7/22	Decayed 6/18/71
13	Molniya 1/13	2/19	In Orbit/Retired
14	Molniya 1/14	6/26	
15	Molniya 1/15	9/29	
16	Molniya 1/16	11/27	
17	Molniya 1/17	12/25	
18	Molniya 1/18	7/28	
19	Molniya 1/19	12/19	In Orbit/Operational
20	Molniya 1/20	4/4	
21	Molniya 1/21	10/15	
22	Molniya 1/22	12/2	
23	Molniya 1/23	2/3	

NOTE: Molniya 1/18 thru 1/23 remain operational in orbit

Figure 11-4. Molniya-1 Satellite Launch Schedule

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PAGE ___ OF ___ SCHEDULE NO. ______

TITLE	CLASSIFICATION	AS OF DATE
Molniya-2 Communications Satellite Launches	Unclassified	July 1973

ITEM NO.	MAJOR MILESTONES	CY-71	CY-72	CY-73	CY-74	CY-75	CY-76
1	Molniya 2/1	11/24					
2	Molniya 2/2		5/19				
3	Molniya 2/3		9/30			Operational	
4	Molniya 2/4		12/12				
5	Molniya 2/5			4/5			
6	Molniya 2/6			7/11			

Figure 11-5. Molniya-2 Satellite Launch Schedule

can interfere with the operation of the satellite and alter the program by sending radio-link commands.

11.2.1.2 Satellite Control

The Molniya satellite carries a special orbit-correction system. This includes two types of power plants - a liquid-fuel rocket engine and a microengine working on compressed gas. Either power plant is used, depending on the nature of the orbital adjustment.

The orbit is corrected at perigee. Prior to each correction, the satellite is oriented in the direction of flight. The change in speed that must be imparted to the satellite for adjusting the period of its orbit by the necessary magnitude is transmitted to a gyroscopic speed-measuring device in the form of a code sent over a command radio link from earth.

11.2.2 Frequencies

The frequencies used for Molniya-1 are in the 800- to 1000-MHz band. However, some of the Molniya-1 satellites also transmitted in the 3400- to 4100-MHz. Frequencies for Molniya-2 are found in Table 11-1. The highest numbered channel has been identified for wideband operation.

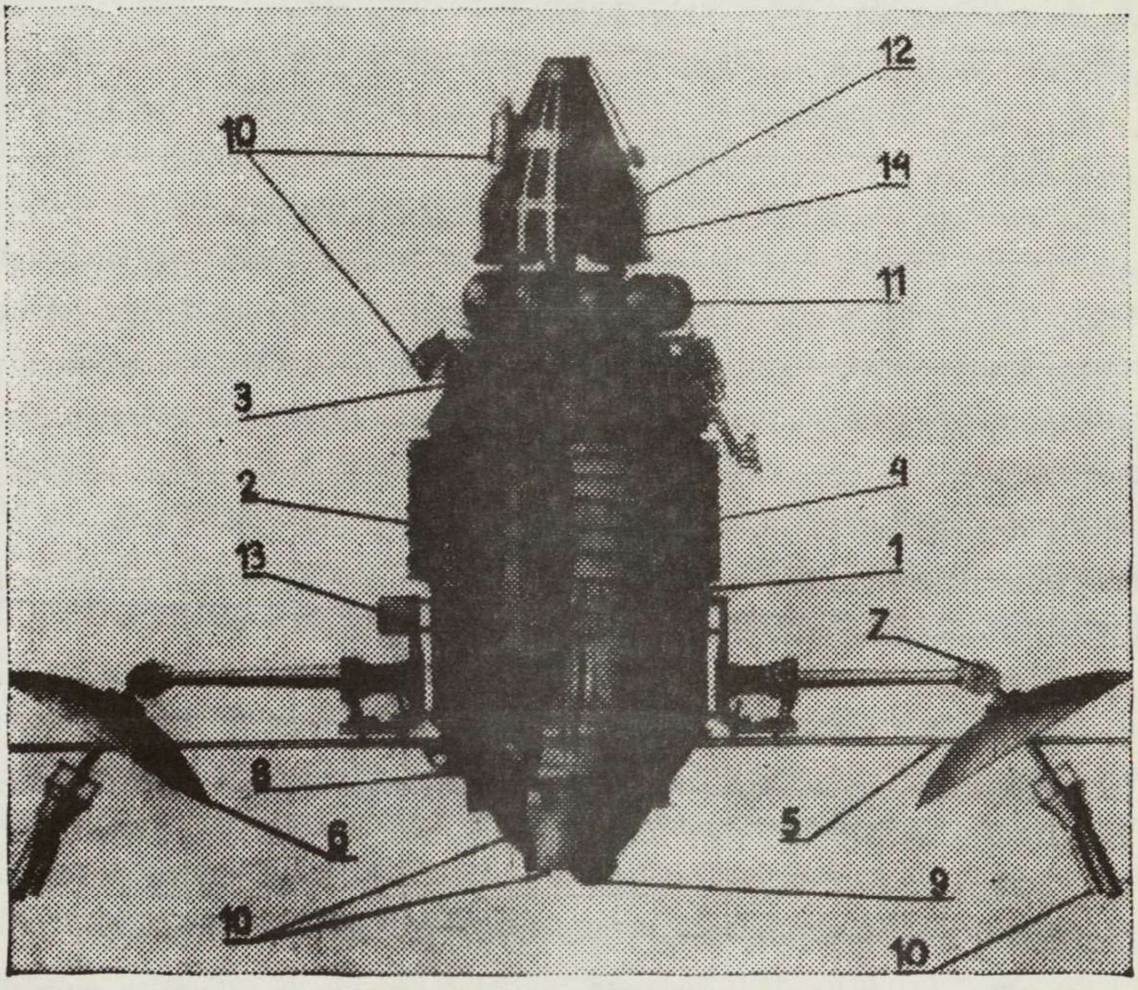
11.3 SPACECRAFT

Figure 11-6 shows the Molniya-1 communications satellite; Table 11-2 summarizes the principal communication parameters for Molniya-1 and Molniya-2. Molniya-1 is cylindrical with conical ends, which have a diameter and height of about 2 and 3.0 meters (5 and 10 feet), respectively. Its more apparent features include the six solar cell panels and the two parabolic communication antennas (one in reserve). Within the hermetically sealed body are the primary transponder (along with the complete spares), an electronic computer for equipment control, a gyrostabilizer, chemical batteries, and various electronic equipment. Since the spacecraft is gyro, and not spin-stabilized, equipment to regulate internal temperature was required, consisting

Table 11-1. Molniya-2 Frequencies as Filed With the ITU

Channel No.	Transmit Frequency (MHz)	Receive Frequency* (MHz)	Allocated ERP (dBW)
1	5730	3405	24.5
2	5744	3419	24.5
3	5772	3447	24.5
4	5786	3461	24.5
5	5814	3489	24.5
6	5828	3503	24.5
7	5856	3531	24.5
8	5870	3545	24.5
9	5898	3573	24.5
10	5940	3615	24.5
11	5954	3629	24.5
12	5982	3657	24.5
13	5996	3671	24.5
14	6024	3699	24.5
15	6038	3713	24.5
16	6066	3741	24.5
17	6108	3783	24.5
18	6122	3797	24.5
19	6150	3825	24.5
20	6164	3839	24.5
21	6205	3880	34.5

*2325-MHz satellite offset.



1 - body; 2 - equipment rack; 3 - heat regulating system rack; 4 - heat regulating system radiators; 5 - solar cell panels; 6 - communications antenna; 7 - antenna drive; 8 - flywheel gyro; 9 - optical solar orientation sensors; 10 - optical earth orientation sensors; 11 - pressurized air containers; 12 - correcting engine; 13 - radiometer; 14 - vacuum shield insulation.

Figure 11-6. Molniya-1 Communications Satellite (Cutaway View)

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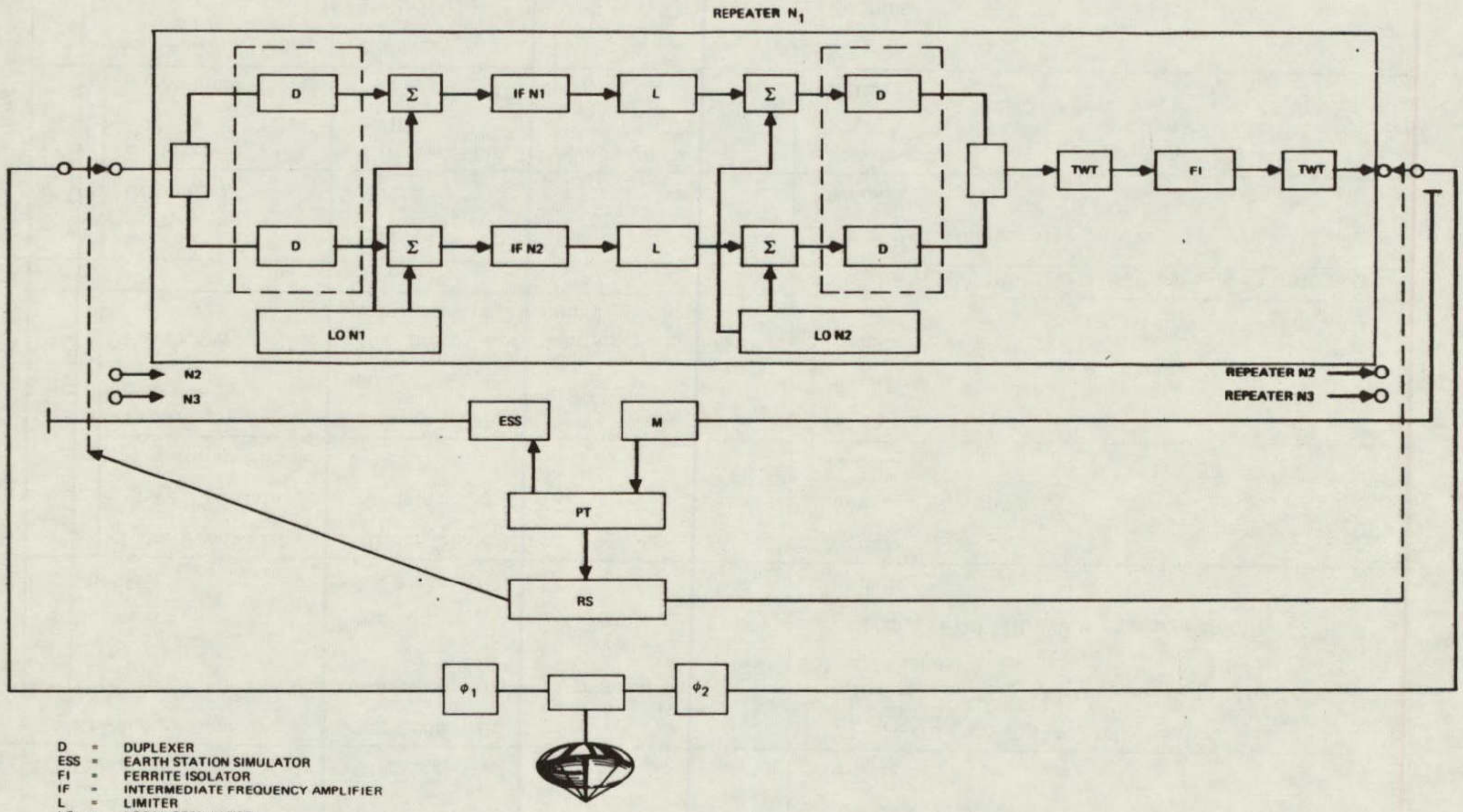
of a radiator-condenser (in a cylindrical configuration about the spacecraft body) and a heat panel (in the form of a flat ring).

The multi-stage launch vehicle, designated A-2-e, provides the necessary service for the satellite from lift off to space orbit. The A-2-e is approximately 42.8 meters (140.5 feet) tall. The first stage consists of the basic Vostok central core plus four tapered strap-on boosters with a total thrust of 4,999,800 newtons (1,124,000 pounds). The combined second and third stage thrust is 1,374,500 newtons (309,000 pounds) for a combined total thrust of 6,374,300 newtons (1,433,000 pounds).

When the spacecraft attains its final orbit and has separated from the last stage of the launch vehicle, the solar cell panels, originally folded along the body of the satellite, are automatically extended. The orientation system is switched on, the satellite's tumbling motion is arrested by gas-jets, and the body of the satellite together with the solar cell panels is oriented toward the sun to maximize the power for the solar cell system. During the entire orbital trajectory, the spacecraft attitude is maintained by a gyro-stabilizer driven by an electric motor so that the solar panels remain directed toward the sun.

After sun acquisition, one of the on-board antennas is directed towards the earth by highly sensitive earth sensors. The earth is acquired, and this antenna continues to track the earth during the entire period of communication. Should it become necessary to switch to the standby antenna, all that is required is to rotate the body of the satellite 180° about its longitudinal axis, using the gas-jet stabilizers.

A block diagram of the transponder "Alpha" used in the Molniya-1 spacecraft is shown in Figure 11-7. The principal communication parameters for Molniya-1 and Molniya-2 are summarized in Table 11-2. Both signal reception and transmission are accomplished with the same parabolic spacecraft antenna; isolation filters are used to separate these signals. The signals received from earth stations operating at two different frequencies are further separated by an input duplexer. After intermediate frequency conversion in a silicon diode mixer, the signals are amplified and then



D = DUPLEXER
ESS = EARTH STATION SIMULATOR
FI = FERRITE ISOLATOR
IF = INTERMEDIATE FREQUENCY AMPLIFIER
L = LIMITER
LO = LOCAL OSCILLATOR
M = MONITOR EQUIPMENT
PT = PROGRAMMED TIMER
RS = REPEATER SWITCHING
ϕ = FILTER
TWT = TRAVELING WAVE TUBE POWER AMPLIFIER

Figure 11-7. Molniya-1 Communications Repeater

Table 11-2. Spacecraft Description

			Molniya-1	Molniya-2
Antennas		Type	Parabolic Reflector 1 m (3 ft dia.)	No data, but estimated same as M1
		Number	2 (including one reserve)	No data
		Beamwidth (-3 dB)	22^{o}	No data
		Gain	16-18 dB	No data
		Polarization	Circular	No data
Repeater		Frequency Band	800-1000 MHz **	5.7-6.4 GHz up; 3.4-4.2 GHz down
		Type	Nonlinear frequency translating	Different than M1, 32 NB channels 14 MHz apart, 1 WB channel
		Bandwidth	No data	NB channels 10 MHz; WB channels 40 MHz
		Number	1 + 2 reserve	No data
	RCVR	Type Front End	Silicon Diode Mixer	No data
		Front End Gain	No data	No data
		Sys. Noise Figure	9-10 dB	10 dB
	XMTR	Type	2-Stage TWT	No data
		Gain	60 dB	No data
		Power Out	40W for TV or 14 watts per channel for duplex multichannel telephony	No data
		EIRP	30 dBW*	NB channel 26 dBW (est.), WB channel 35 dBW (est.)
General Features	Stabilization	Type	Gyro	Estimated same as M1
		Capability	No data	No data
	Power Source	Primary	Silicone Solar Cells, 500-700 watts output	Solar Array
		Supplement	Battery	Batteries
		Comm. Power Needs	No data	No data
		Size	Cylindrical: height - 3 m (10 ft); diameter - 2 m (5 ft)	No data
		Weight	998 kg (2200 lbs)	Estimated same as M1

* Derived value based on antenna gain and transmitter output power.
** Some Molniya-1 satellites operated in the 3400- to 4100-MHz band possibly as a checkout for prototype Molniya-2 downlink equipment.

amplitude-limited. After passing through a parametric-diode up-converter and output duplexer, the signals are amplified in a two-stage TWT amplifier. The first TWT operates in a linear mode, while the second TWT operates in a saturated mode. A ferrite isolator is employed between TWTs for matching. For duplex telephony, the power output is 14 watts per channel; for television, the output power is 40 watts, the maximum available. Design lifetime of the later Molniya-1 spacecraft was about 2 years as compared to 1 year for initial versions.

11.4 GROUND TERMINALS

Selected characteristics for the earth terminals utilizing the Molniya-1 satellites are presented in Table 11-3.

The ground terminal antennas (transmitting and receiving) are 15-meter (50-foot) diameter paraboloids with Cassegrain feeds. They are mounted on rotating units permitting a tracking accuracy of a few angular minutes; tracking is either preprogramed or self-tracking. To decrease losses in the feeder waveguide equipment, buildings are constructed in direct proximity to the rotating units. The parametric amplifiers of the receiver as well as the receiver duplex and directional coupler have been installed in an antenna cabin behind the primary reflector. For the output of the parametric amplifier, the received IF signal is fed to the receiving equipment located in the building. The high frequency power output from the transmitter building is delivered to the antenna feed along a waveguide through the rotating junction.

The transmitting unit consists of an exciter, frequency modulator, power amplifier and supply, monitor, and heat exchanger. The transmitter itself is a 5-kw multicavity klystron. The video bandwidth available for the television mode is 5 MHz. For more efficient transmission of television and telephone signals, there are standard preselection systems. High transmitter carrier frequency stability is achieved by using a quartz master oscillator in the exciter with subsequent multiplication and mixing with the FM modulator signal.

The receiving equipment consists of operating and monitoring receivers. Each consists of a remote parametric amplifier with IF preamplification, IF amplifiers,

Table 11-3. Earth Terminal Characteristics

Terminal Features		Terminal: Moscow/Vladivostok	Terminal: Orbita 1
Antenna	Type	Parabolic cassegrain	Parabolic
	Aperture Size	15 m (50 ft) diameter	12 m (40 ft) diameter
	Receive Gain (3.4 GHz)	52 dB*	50 dB*
	Efficiency	60%**	55%**
	Receive Beam-width (3.4 GHz)	0.4^{o}*	0.5^{o}*
Receive System	Type of pre-amplifier	Two-stage regenerative parametric amplifier (cooled)	Two-stage parametric amplifier (cooled to $-196^{o}K$)
	Bandwidth	No data	15 MHz
	Noise Temp.	$230^{o}K$	$200^{o}K$
Transmit System	Type Amplifier	Klystron	None normally
	Bandwidth	5 MHz	Provided
	Power Out	5 kW	Provided
Tracking	Type	Self-tracking or programmed tracking	Programmed tracking or self-tracking
	Accuracy	No data	3 m (8 ft) of arc
Per-form	G/T	28.4 dB/^{o}K*	27 dB/^{o}K*
	EIRP	130 dBM*	None*
Polari-zation	Transmit Feed	No data	None
	Receive Feed	No data	No data
Total Instal-lation	Randome	No data	None
	Type Facility	Fixed	Fixed

* Derived value based on data available.

** Assumed value based on common performance for this type of antenna.

limiters and demodulators for the television and telephone modes, and supply sources. Moreover, a receiver monitor, video monitor, and received signal level recorder are included as parts of the receiving units. The parametric amplifiers of the receivers are two-stage regenerative amplifier-converters. In the Molniya-1 system, the two-stage parametric amplifiers operate at both normal and liquid nitrogen temperatures. The noise temperature of the uncooled parametric amplifier is $150^{o}K$, and of the cooled is $80^{o}K$. The cooled parametric amplifier is installed ahead of an isolating filter. The frequency passband is sufficient for quality transmission of black and white or color television. For transmission of group spectra, frequency feedback reduces the passband to 1.5 to 2.0 MHz.

The Orbita earth terminals, Figure 11-8, are built according to a standard plan and include a circular, concrete building which serves at the same time as the pedestal for the antenna. This places the antenna well above any local obstruction. The antenna is not protected by a radome; however, it is designed to operate between temperatures of $273.15^{o}K \pm 50^{o}K$ and in wind velocities approaching 96 kmph (60 mph). It is made of aluminum alloy and weighs approximately 4990 kilograms (5-1/2 tons). The total weight of the entire antenna, support, and its various mechanisms is about 45,000 kilograms (50 tons).

The central room in the building under the antenna houses various receiving equipment, the parametric amplifier, etc. Around this room are located offices and the additional services including air conditioning. The arrangements are sketched in Figures 11-9 and 11-10.

As of mid-1971, there were approximately 50 Orbita-1 earth terminals. Some of the known Orbita-1 site locations are listed in Table 11-4.

More recently, Orbita-2 earth terminals have been installed for operation with the Molniya-2 satellites. Although the Orbita-2 terminal is necessarily designed to operate on different frequencies than those required for the Molniya-1/Orbita-1 combination, it is expected that its basic design and size are comparable to its predecessor. Some of the known Orbita-2 site locations are identified in Table 11-5. By

Figure 11-8. Orbita-1 Earth Terminal

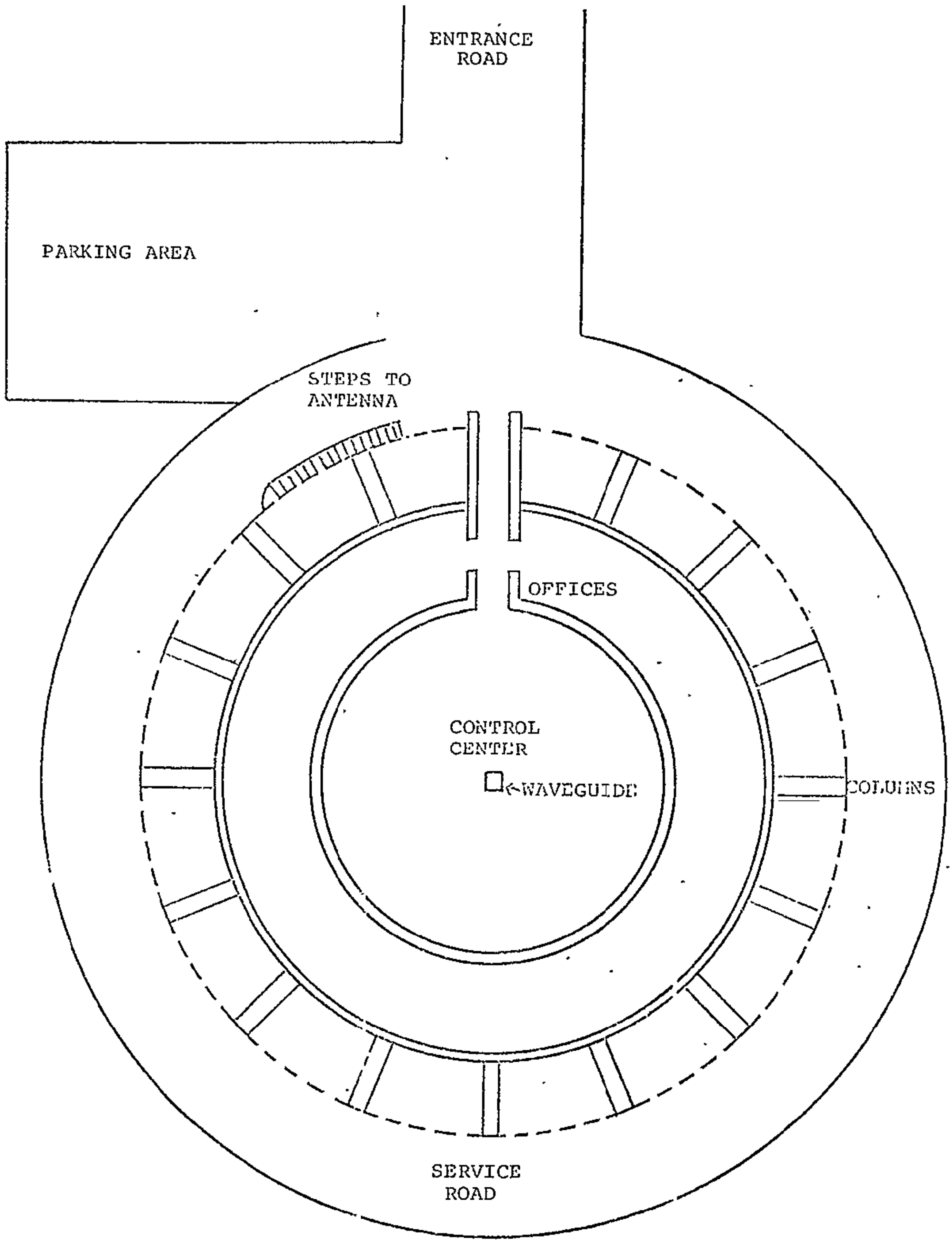


Figure 11-9. Orbita-1 Earth Terminal Center

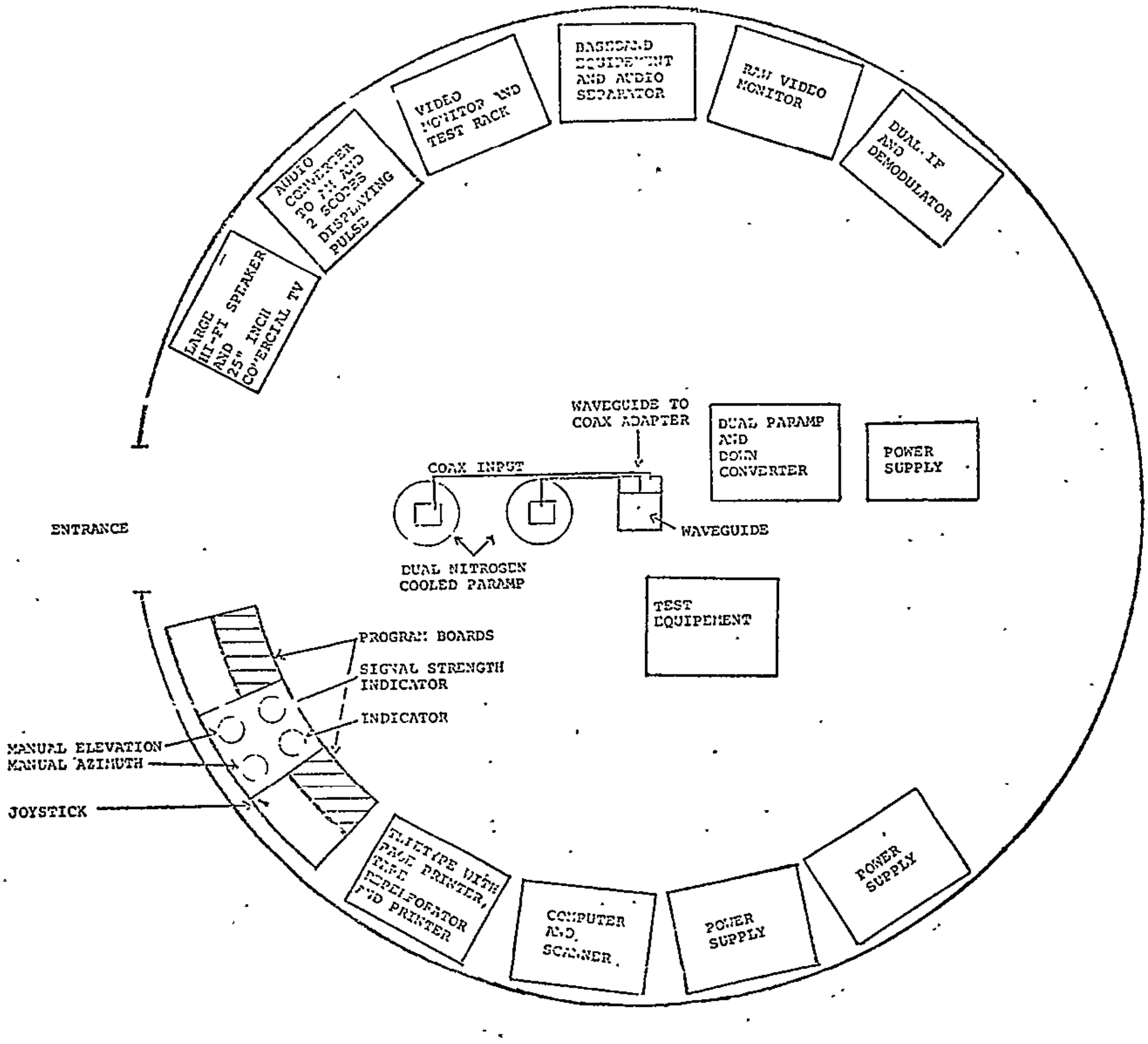


Figure 11-10. Orbita-1 Earth Terminal Control Center Layout

Table 11-4. Orbita-1 Earth Stations

Abakan	Irkutsk	Ourai
Alma-Ata	Kemerovo	Petropavlosk (Kamchatka)
Anadyr (or Bilibino)	Khabarovsk	Salekhard
Arkhangel'sk	Komsomolsk-on-Amur	Sovetskaya Gavan
Ashkabad	Krasnoyarsk	Surgut
Blagoveshchensk	Kyzyl	Syktyvkar
Bratsk	Magadan	Ulan-Ude
Chita	Moscow	Vladivostok
Djezkazgan	Murmansk	Yakutsk
Dudinka	Nebit Dag	Yuzhno-Sakhalinsk
Dzhezkazgan	Noril'sk	Zayarsk
Frunze	Novosibirsk	Zeia
Gremikha	Oka	
Gur'yev		

Table 11-5. Orbita-2 Earth Stations

Arkangelsk	Murmansk
Ashkhabad	Novosibirsk
Chita	Salekhard
Dudinka	Sakhalinsk
Frunze	Surgut
Irkutsk	Syktyvkar
Kemerovo	Tetropavlovsk
Khabarovsk	Ulan-Ude
Komsomolsk	Yakutsk
Magadan	Zatarsk
Moscow	

comparing the site locations in this table with those in Table 11-4, it can be seen that some locations are dual-sited, i.e., both an Orbita-1 and an Orbita-2 terminal are installed in the same general location.

11.4.1 The U.S.-Supplied "Hotline" Earth Station

"In October, 1972, the U.S. Army Satellite Communications Agency awarded a contract to the Radiation Division of Harris-Intertype Corporation to build the complete Earth Station on a 15-acre site at Fort Detrick, Maryland. The USA Earth Station will be this country's part of a link between the United States and the Soviet Union using the USSR's Molniya II satellite system."[1]

"The DCL (Direct Communication Link) Earth Station consists of two identical and independent communications systems providing simultaneous transmission and reception of C-Band, FM modulated signals through 60-foot tracking and communications antennas. Both communications systems interface via baseband processing equipment with government telephone cables that complete the Washington-Moscow connection. Transmission frequency and power are controlled automatically using as a reference a pilot carrier transmitted through the satellite from a USSR Earth Station.

Both DCL antennas have the full hemispherical angular coverage and precision tracking capability needed to direct their narrow beams towards satellites that have eccentric 12-hour orbits. During the daily 8-hour period in which each satellite is mutually visible between Washington and Moscow, its pilot signal is autotracked by the two DCL antennas.

In addition to the two communications systems--including the transmitting, receiving and antenna subsystems--there are the ancillary subsystems that serve the Earth Station as a whole [see Figures 11-11 and 11-12]. These ancillary subsystems include (1) a dual programmer subsystem; (2) a control, monitor, and alarm subsystem; (3) a prime power subsystem; and (4) the earth station building."[1]

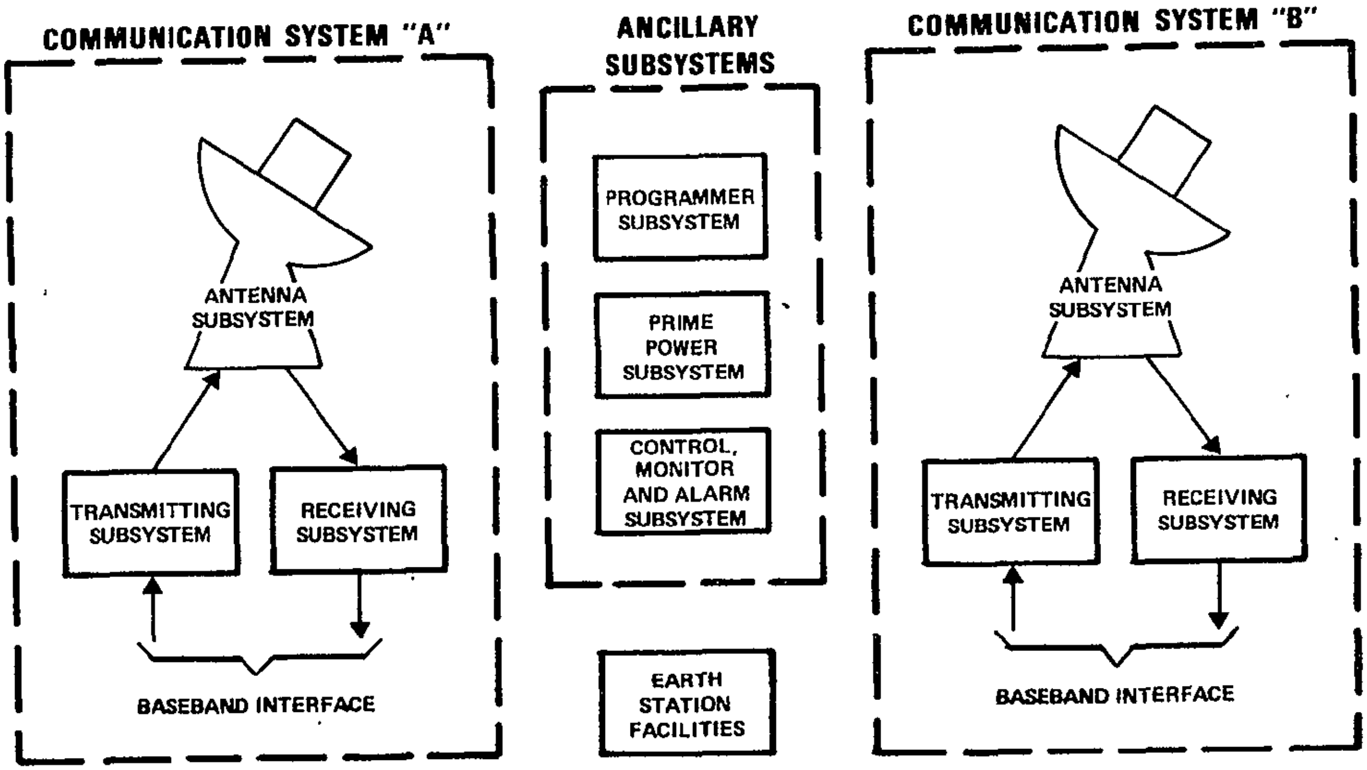


Figure 11-11. DCL Earth Station Coverage[1]

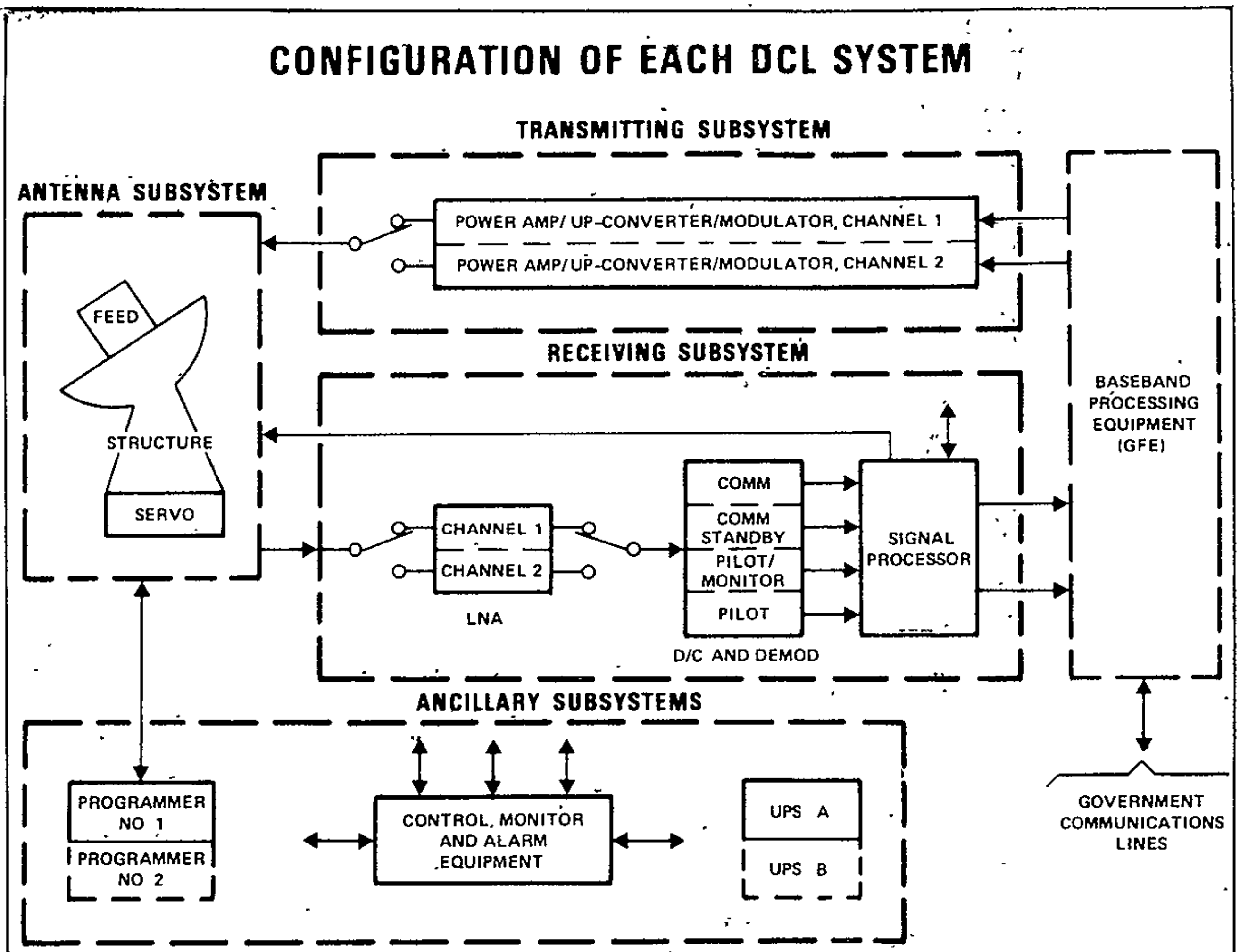


Fig. 4.

Figure 11-12. Configuration of Each DCL System[1]

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11.5 EXPERIMENTS

Since the Molniya program has produced an operational satellite communications system, it might be expected that there has been little emphasis on experimentation. Further, the experiments that may have been conducted are not well documented to the Western World. It is possible that, when the first Molniya-1 spacecraft began to appear in orbit, both the highly elliptical orbit employed and the three-axis stabilized satellite, with its sun-oriented solar panels and tracking antennas, were considered experimental in nature. Obviously, these experiments worked out well, since the operational system continued to incorporate the aforementioned features. Additionally, it is known that the Molniya satellites have been employed to provide measurements of the earth's environment. The orbital paths of these satellites carry them through the earth's radiation belts several times each day, and studies are being made not only of the radiation belts but also of the effects they have on spacecraft equipment, especially solar cells.

11.6 OPERATIONAL RESULTS

The Molniya-1 system was designed for relaying wideband transmission of either duplex multichannel telephone communications (including telegraph and facsimile) or television (black and white or color). Initially, operations were point-to-point between Moscow and Vladivostok to provide regular telephone and telegraph exchange between the center of the country and the Far East, and to transmit central television programs to viewers in the Maritime territory. The first TV transmission via a Molniya-1 satellite was made on April 25, 1965, just 2 days after the launch of the first vehicle. Under a Franco-Soviet research program which used Molniya-1, color television broadcasts have been successfully transmitted between Moscow and Paris since December 1967. This research program was preceded by a successful Moscow-Paris demonstration for which the results were reported in documents of the 1966 URSI (CCIR) Meeting in Oslo, Norway.[2]

Later, experimental transmissions of newspaper pages and television programs were carried out via Molniya-1. Satisfactory imprinting of newspaper pages from

Pravda was achieved via transmissions from Khabarovsk (near Vladivostok). However, the rapid changes in propagation path length on the accent and descent of the elliptical orbit did result in some peculiarities, such as an apparent bending in the received newspaper type page. As of mid-1971, equipment was being added to Orbita stations to further expand their telecommunications capability to permit the relaying of computer data.

In 1967 the USSR inaugurated a space television distribution system, using Molniya-1 satellites to allow people in Siberia, the Far East, and the Far North to see broadcasts from Moscow. As of mid-1971, there were about 50 ground stations in this network; a few of the known receiving site locations are tabulated in Section 11.4. The Orbita stations have achieved an extremely high level of reliability of not less than 99.7 percent. A notable event during 1969 was the building of an Orbita receiving station in Ulan-Bator, Mongolia, which began operation on February 2, 1970. A station has also been proposed for Havana, Cuba. A second generation of ground terminals, Orbita 2, has begun to be implemented.

In addition to the communication functions served by the Molniya-1 satellites, certain spacecraft in the series have been fitted with television cameras and have successfully transmitted detailed photographs of the earth's cloud cover from altitudes ranging between 30,000 and 40,000 km. These pictures were especially important in determining meteorological conditions in conjunction with "Meteor" class weather satellites that photographed the earth's cloud cover from near circular 625-km orbits.

Molniya-1 satellites have also participated in the Soviet manned space program by relaying communications between surface ships in direct contact with Soyuz-6, -7, and -8 and a central control site within the Soviet Union.

11.6.1 System Status

As indicated previously, a single Molniya satellite provides approximately 10 hours of coverage on a single orbital pass. Therefore, three Molniya satellites are sufficient to provide continuous coverage of the Soviet Union for the domestic broadcast system. However, for purposes of redundancy, the Soviet Molniya-1 system appears to be an eight-satellite system consisting of four pairs of satellites spaced 6 hours apart. The system involves four orbital plans in an accurately placed cluster, 90° apart. This assures that two satellites (a pair) are continuously visible over the Moscow-Vladivostok link, which is their primary communications link.

Very little current detail of the Molniya-2 satellite system is known. As seen from Paragraph 11.2.2, the Soviets have filed a total of 21 operating frequencies for their satellite, 20 with a channel bandwidth of 10 MHz and a downlink of 24.5 dBW for each carrier. The twenty-first carrier was filed with a bandwidth of 40 MHz and a downlink ERP of 34.5 dBW. One of the channels (voice) is to be made available by the Soviets for the satellite direct communication link with the United States. The system employs FDM/FM/FDMA for frequency division multiplexing/frequency modulation/and multiple accessing.

It has been shown that each of the two Molniya satellite systems operates on different frequency allocations. It is unlikely that the Orbita earth terminals for one system have a capability for operating with the other system although it is believed that each Orbita-2 terminal possesses both a transmit and receive capability.

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SECTION 12 - PHASE I DEFENSE SATELLITE COMMUNICATIONS SYSTEM

12.1 PROGRAM DESCRIPTION

In 1962, the Secretary of Defense established the Defense Satellite Communications Program (DSCP) to develop a satellite communication system that would provide long-haul links between fixed, transportable, or shipboard terminals. Overall responsibility for the DSCP was assigned to the Defense Communications Agency (DCA). This first major step was called the DSCP Phase I, and, as it was implemented, was an outgrowth of Army participation in NASA's Project SYNCOM and an initial system concept calling for medium altitude satellite orbits. By participating in the SYNCOM Program, the Army gained a nucleus of ground terminals and operating experience applicable in the DSCP Phase I.[1] The satellites resulting from the initial medium altitude system concept were simple state-of-the-art spacecraft. Subsequent to their design, the Titan IIIC became available as a launch vehicle.[2][3] In June 1966, the first seven Defense Satellite Communication System (DSCS) Phase I satellites were successfully orbited by a Titan IIIC booster. The initial objectives of the program are shown in Table 12-1.[4][5]

No ground commands were permitted in developing the hardware for the DSCS Phase I satellite. However, simplicity and conservatism were stressed in the design of the communication subsystem. Thus, there was no active control of position or orientation of the satellite either during deployment or during the life of the system.

The period immediately after the first launch was used for system testing between deployed terminals. In particular, a two-channel full duplex link capability between two AN/MSC-46 terminals was demonstrated. In December 1966, emergency operational links were established between Hawaii-RVN and Philippines-RVN; in July 1967, the Pacific network was placed in operational status, and integration of DCS was begun. Thus, designed as an R&D system, the DSCS almost immediately became an operational system, though some R&D was continued in other portions of the system.

Table 12-1. DSCP Phase I

Number	Objectives
1	Conduct system research, development, testing and evaluation to determine operational compatibility and utility of the Initial Defense Communication Satellite System (IDCSS) to meet user requirements
2	Establish a research and development R&D communications satellite system in being, designed for the most part to be directly convertible and expandable to an operational system through integration and compatibility with DCS and thereby capable of providing service to specified users of the National Communications System (NCS)
3	Provide an emergency capability for supplementing the Defense Communications System (DCS) and improving its assurance of provision of the minimal essential survival communications for the National Military Command and Control purposes

The DSCS Phase I augments the conventional communication methods such as radio, land and submarine cable, microwave, and tropospheric scatter. It provides near-synchronous communication satellites to relay voice and digital communications between fixed and mobile users.

Twenty-six DSCS Phase I satellites were launched into near equatorial orbits at a near synchronous altitude of approximately 33,891,600 meters (18,300 nautical miles) via the four launches shown in Table 12-2.[6][7][8] The Titan IHC was used for the launching vehicle. Satellite dispensers were used and the necessary facilities were available to implement and support the launching operation, the satellite injection into orbit, the ensuing telemetry readout, and the tracking and ephemeris determinations. The technical support of the launching phase was provided by the Air

Force Satellite Control Facility (AFSCF). Since the completion of the launches, the SCF has provided orbital tracking data and telemetry monitoring to determine satellite health. This information is forwarded to the Satellite Communication Control Facility (SCCF) to be used in system control.

Table 12-2. DSCS Phase I Spacecraft Launch Data

Number Launched (IDCSP)	Initial Orbit Data	Launch Date			
		16 June 1966	18 January 1967	1 July 1967	13 June 1968
7	Period (minutes)	1334.2-1344.0	1300-1343	1309.8-1319	1269-1350.6
8	Perigee	33,656-33,714 km (20,913-20,949 mi.)	33,531-33,692 km (20,835-20,935 mi.)	33,006-33,301 km (20,509-20,692 mi.)	30,772-33,758 km (19,121-20,976 mi.)
3	Apogee	33,878-34,359 km (21,051-21,350 mi.)	33,846-34,239 km (21,031-21,275 mi.)	33,548-33,626 km (20,846-20,894 mi.)	33,840-34,442 km (21,027-21,401 mi.)
8	Inclination (degrees)	0.1	0.0-0.1	7.2	0.1

Notes: 1. Status as of May 1974: eight IDCSP satellites operational.

2. The manufacturer and sponsor of the Titan IIIC launch vehicles was Martin Marietta, DOD/DCA/SAMSO.

12.2 SYSTEM DESCRIPTION

Eight of the initial 26 satellites were still operational as of May 1974. The satellites, as viewed from the earth, drift from west to east at about 30° longitude per day. A single satellite stays within view of a particular earth terminal about 4-1/2 days. A varying distribution of satellites encircling the earth exists, since each satellite was released from the dispenser at a slightly different orbital velocity. The differential velocities are arranged to reduce "bunching" of satellites, thus enhancing satellite availability. Originally designed for a mean time to failure (MTTF) of 1.5 years (with a goal of 3 years), the satellites have exceeded this goal.[9] The satellite transmitters were designed to turn off automatically 6 to 6-1/2 years from the date of launch but all of the automatic turn-off devices failed to operate leaving some of the satellites operational beyond that time interval.

There were three types of terminals used in the DSCS Phase I (see Table 12-3). Two AN/FSC-9 terminals were used - one located at Camp Roberts, California, and the other at Fort Dix, New Jersey. They were fixed installations, each equipped with 18-meter (60-foot) diameter antenna. The AN/MSC-46 earth terminals developed for DSCS Phase I are transportable units with 12-meter (40-foot) diameter antennas. The highly transportable AN/TSC-54 terminals were used for extension of the DCS into contingency areas, for tributary-type links to outlying activities, and as Navy shore stations. Local conditions dictate the type of transmission facility used as an interconnect link.

Table 12-3. Participating Terminals

Terminals		Manufacturer and Sponsor	Antenna Diameter (m) (ft)	Power (kW)
Type	Number			
AN/FSC-9	2	Modified by Radiation, Inc./ Army-SATCOM	18 (60)	20
AN/MSC-46	14	Hughes Aircraft/Army-SATCOM	12 (40)	10
AN/TSC-54	13	Radiation, Inc./Army-SATCOM	Four Dish array 6 (18) effective	5

The DSCS terminals are arranged to provide a point-to-point communications circuit. Typical link and terminal types are shown in Figure 12-1.

The following three types of modulation were used in DSCS Phase I: frequency modulation (FM), pseudonoise (PN), and multiple frequency shift keying (MFSK). All earth terminals used FDM/FM and pseudonoise (PN). The AN/TSC-54 terminals and the AN/MSC-46 terminals were capable of operating with MFSK. PN modulation yields a degree of antijam protection to the system.

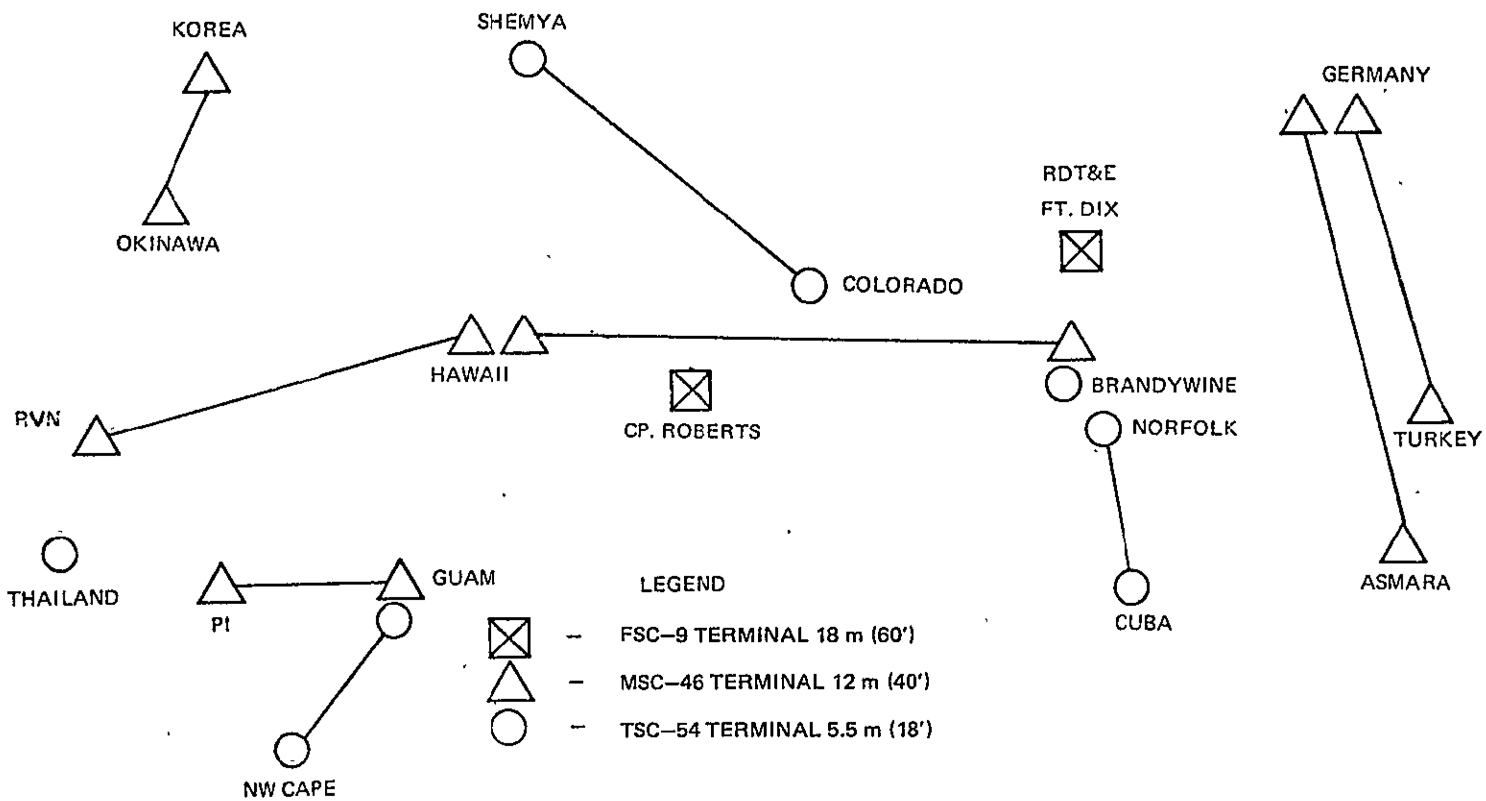

Figure 12-1. DSCS Phase I Satellite Link Configuration (1967)

The control subsystem achieved an orderly allocation of satellites among the terminal pairs. The basic elements of the control subsystem are the SCCF, the Area Communications Control Function (ACCF), and the Earth Station Control Function (ESCF). The SCCF is the focal point of the control subsystem, and is collocated with the DCA Operations Center (DCAOC) in Arlington, Virginia. The primary mission of the SCCF is to prepare and distribute long term (60 days prepared every 30 days), short term (up to 30 days duration), and emergency satellite/terminal schedules in accordance with validated user requirements.

To establish communications between two terminals, it is necessary that a satellite be mutually visible to the terminals. The SCCF is able to provide satellite scheduling data for all links for a 60-day interval. Satellite visibility prediction based on probabilistic analysis for various links is shown in Figure 12-2 as a function of the total number of orbiting satellites. The visibility for the Hawaii-Republic of Viet Nam links is shown both for at least one satellite and for at least two satellites. Two satellites would be required when the channel requirements exceed the capability of one satellite. Thus, with a system composed of 15 satellites, the probability of at least one satellite being visible for the Hawaii-RVN link is 89 percent and that of a second satelite for a second link is 64 percent. Since there is no orbital control to permit repositioning of the satellites, random gaps can occur for the orbital plane. In addition, satellites may become temporarily unusable due to conjunctions with other satellites or with the sun or moon. Also, since the satellites have no batteries, they do not operate during eclipse (while in the earth's shadow).

The satellite frequency plan is contained in Table 12-4. The assignment of the channel (frequency) is a functional responsibility of the SCCF.

12.3 SPACECRAFT

As discussed in Section 12.1, the DSCS Phase I space subsystem consisted of 26 satellites. In addition, an unsuccessful launch with eight satellites occurred on August 26, 1966; however, the plastic shroud encasing the satellites in the nose of

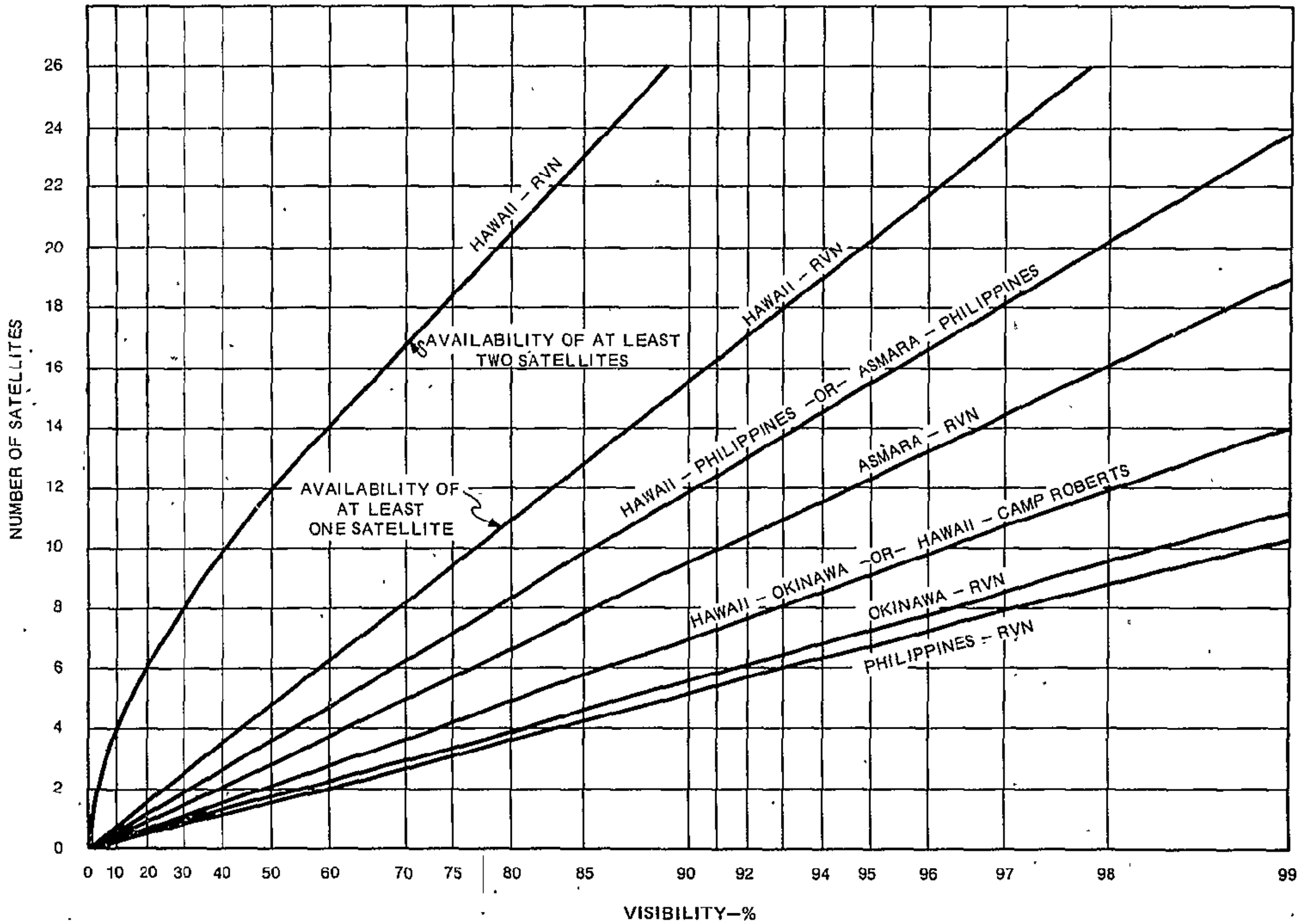

Figure 12-2. DSCS Phase I Satellite Visibility

the booster tore apart after about 80 seconds in flight, and aerodynamic stresses caused a blowup of the entire vehicle and payload.

Table 12-4. DSCS Phase I Access Frequencies

Satellite RF Access Channel	Frequency (MHz)	
	Downlink (Transmit)	Uplink (Receive)
1	7,267.0250	7,985.7450
2	7,271.7125	7,990.4325
3	7,277.9625	7,966.6825
4	7,285.7550	8,004.4950

The Phase I satellites (Figures 12-3 and 12-4) are spin stabilized at approximately 150 rpm (by two nitrogen nozzles) to maintain the spin axis within 5° normality to the earth's equatorial plane. Each satellite weighs approximately 45.4 kg (100 lbs) and is solar powered. No batteries are provided.

The transponder of the DSCS Phase I satellite is a double frequency conversion, hard-limiting repeater operating in the 7- to 8-GHz range. The EIRP has a design minimum of 7 dBW. Each satellite had a beacon signature at its unique telemetry frequency, in the 400-MHz area, for identification purposes.

The repeater, shown in simplified block diagram form in Figure 12-5, is primarily solid state. Amplification and limiting of the signal take place at intermediate frequencies. The mixing frequencies are derived from a basic oscillator and multiplier chains. The output of the IF amplifier/limiter is then summed with the beacon signal, up converted, and fed through the traveling wave tube amplifier (TWTA) and out to the transmitting antenna. A redundant TWTA automatically switches on in case the first TWTA fails. The switchover can occur only once.

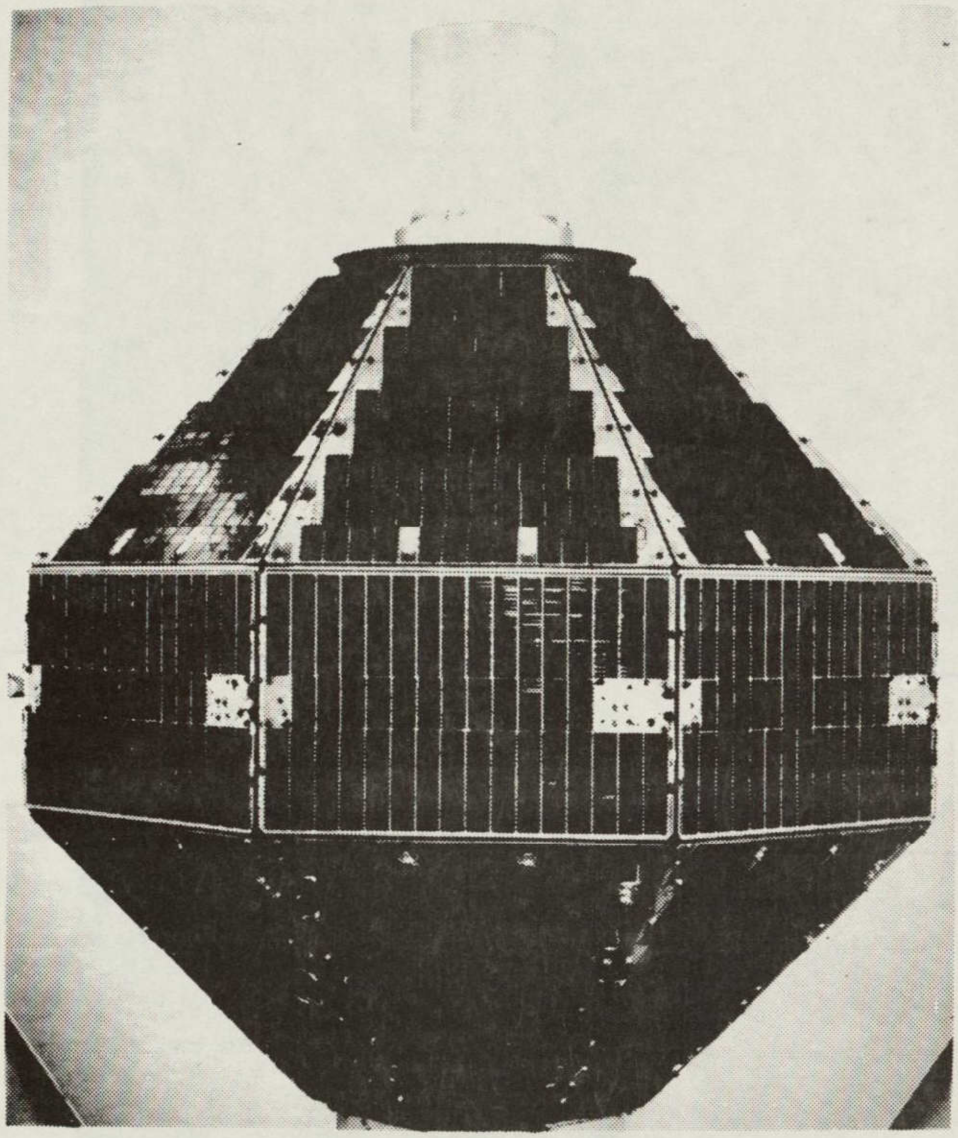

Figure 12-3. Phase I Satellite

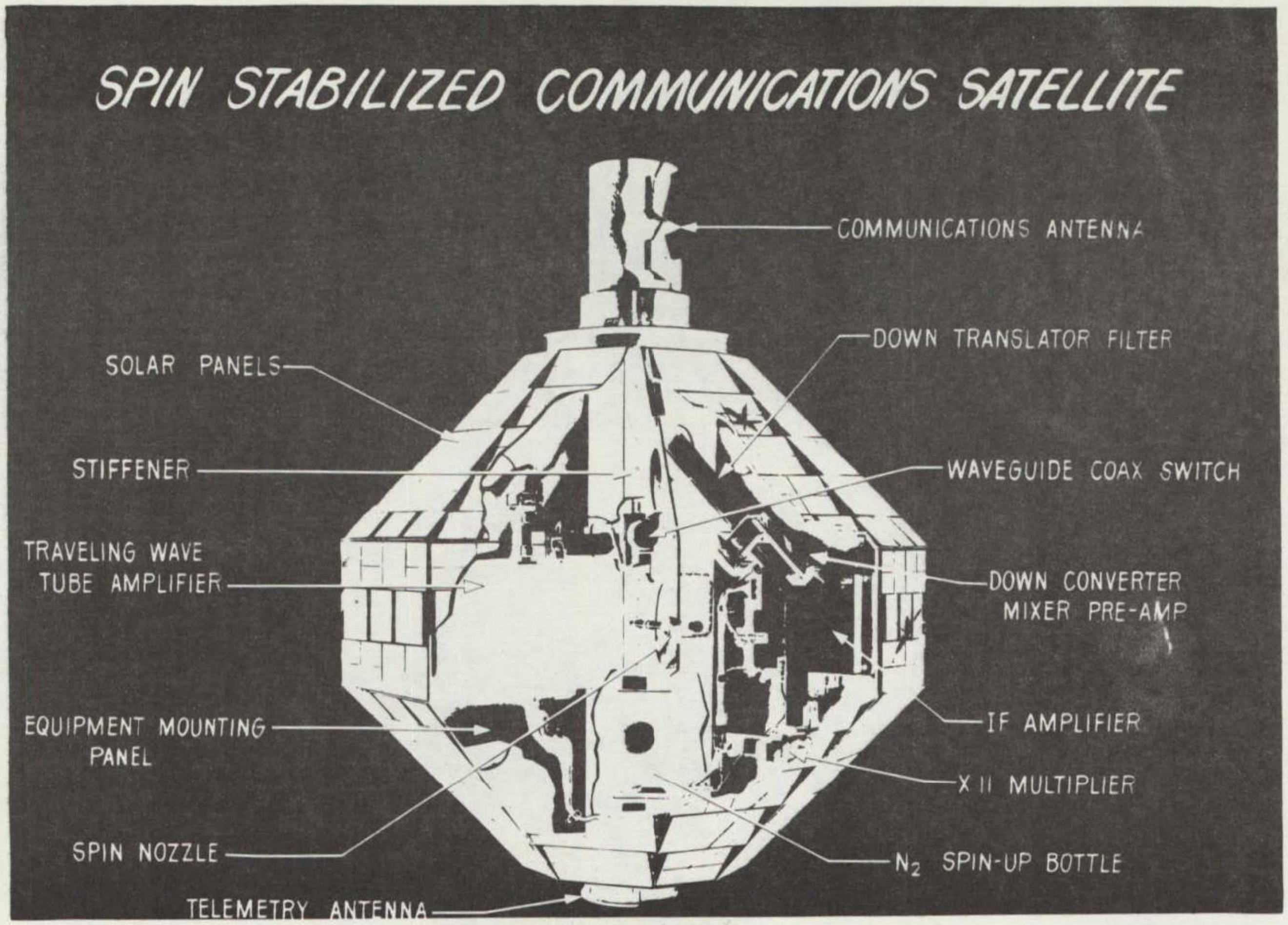

Figure 12-4. Phase I Satellite (Cutaway)

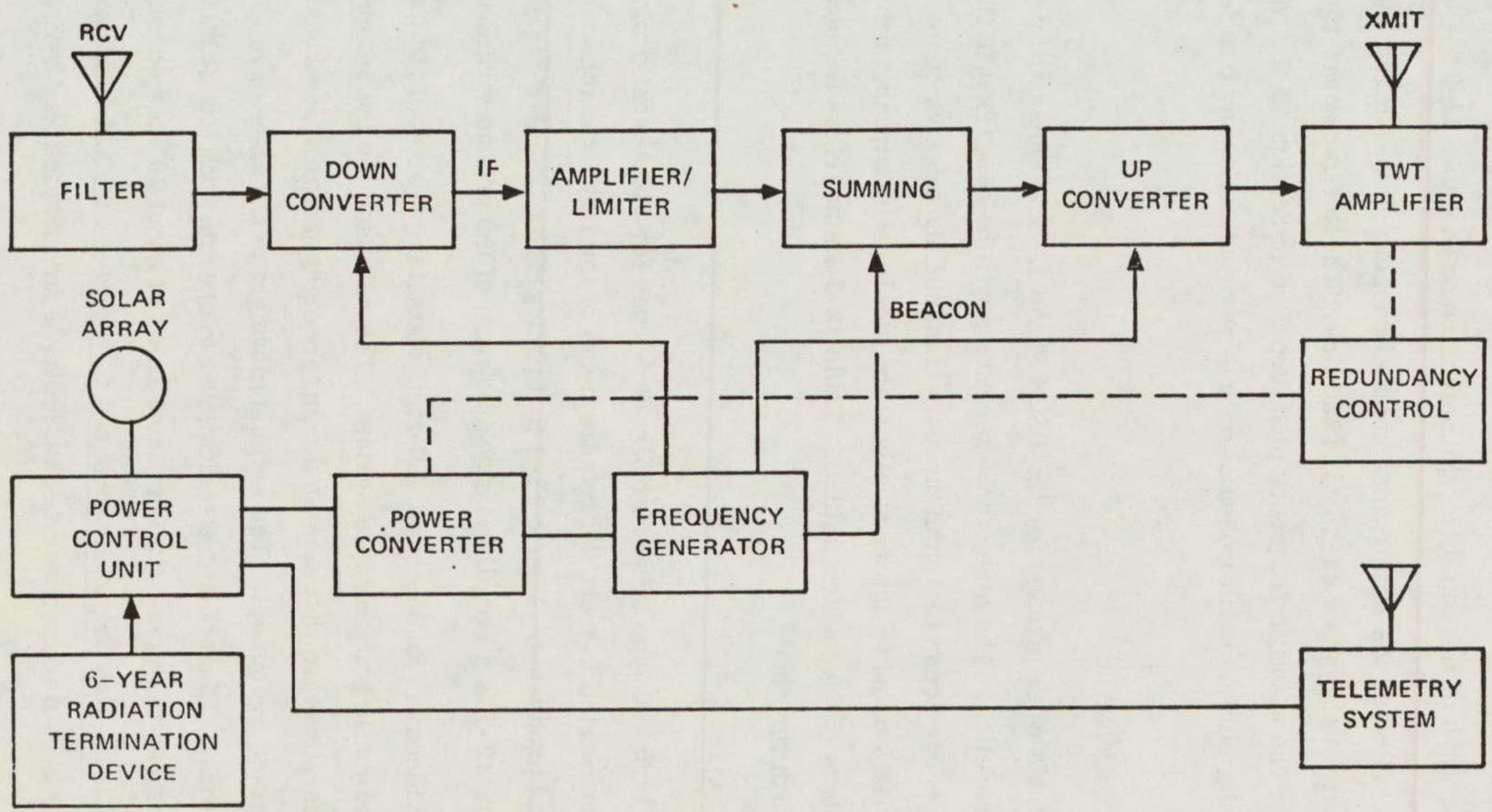

Figure 12-5. DCSC Phase I Transponder Block Diagram

The transmitting and receiving antennas are separate biconical horns with toroidal patterns, omnidirectional in azimuth and earth-coverage (of 28°) in the other plane. Characteristics of the satellites are summarized in Table 12-5.

Table 12-6 indicates the initial voice channel capacity on particular duplex links as a function of terminal type on each end of the link. These figures are for two-terminal access. The satellite frequency plan (depicted in Section 12.2), which was optimized to yield a minimum intermodulation interference, allowed up to four RF accesses.

12.4 GROUND TERMINALS

Four terminals were planned for the DSCS Phase I. The shipboard program AN/SSC-3 was cancelled. The other three terminals will be described in this section. All terminals were developed to simultaneously transmit and receive opposite senses of circular polarization and to automatically track satellites in circular orbits as low as 9,260,000 meters (5000 nautical miles). Table 12-7 summarizes the characteristics of these earth terminals.

1. AN/FSC-9

This terminal type was originally developed for the Advent program and was converted to meet the requirements of the DSCS and other experimental programs. Figure 12-6 is a photograph of the AN/FSC-9 and Figure 12-7 is a simplified block diagram of the ground terminal.

The antenna is an 18-meter (60-foot) diameter paraboloid reflector with an automatic tracking feed system. The reflector for the antenna includes a superstructure that acts as a counterweight and provides housing for electronic equipment. The estimated weight of the antenna is 172,000 kg (190 tons). The antenna was designed to operate with low altitude satellites and hence, the axes have rotational rates of about 10° per second. Also, the antenna was originally designed to operate at SYNCOM frequencies; thus, its gain when converted to the DSCS frequencies was lower than an

Table 12-5. DSCS Phase I Satellite Characteristics

Antenna		Type	Biconical - toroidal pattern
Antenna		Number	Two - RHCP receive, LHCP transmit
Antenna		Beamwidth	Earth coverage, 360^{o} x 28^{o}
Antenna		Gain	5 dB in plane normal to the spin axis. 3 dB minimum in all directions within $\pm14^{o}$ of the plane
Repeaters		Frequency Band	SHF - 7.3-GHz transmit, 8.0-GHz receive
Repeaters		Type	Hard-limiting, double frequency conversion
Repeaters		3 dB Bandwidth	26 MHz
Repeaters		Number	One
Repeaters	Receiver	Type Front End	Down conversion mixer
Repeaters	Receiver	System Noise Figure	10 dB
Repeaters	Trans-mitter	Type	Redundant TWT
Repeaters	Trans-mitter	Power Out	3 watts
Repeaters		EIRP	7 dBW minimum
General Features	Stabili-zation	Type	Spin at approximately 150 rpm
General Features	Stabili-zation	Capability	$\pm5^{o}$ spin axis attitude
General Features	Power Source	Primary	8000 n-on-p solar cells provide 40 watts at launch
General Features	Power Source	Supplemental	None
General Features		Comm. Power Needs	22 watts
General Features		Size	91-cm (36-in.) diameter, 81-cm (32-in.) high
General Features		Weight	46.3 kg (102 lb) or less
General Features	Tele-metry	Frequency	= 400 MHz
General Features	Tele-metry	EIRP	-12 dBW minimum in all directions within $\pm45^{o}$ of a plane normal to the spin axis
General Features	Beacon	Frequency	= 7.3 GHz
General Features	Beacon	EIRP	-5.5 dBW minimum

Table 12-6. DSCS Phase I Duplex Channel Capacity and Performance

Link Terminal Configuration	FDM/FM Mode	
	Number of Global Quality Channels	Number of Tactical Quality Channels
AN/FSC-9 to AN/FSC-9	2	5
AN/FSC-9 to AN/MSC-46	2	5
AN/FSC-9 to AN/TSC-54*	0	1
Improved AN/MSC-46 to Improved AN/MSC-46	5	11
AN/MSC-46 to AN/MSC-46	2	5
AN/MSC-46* to AN/TSC-54	0	1
AN/TSC-54 to AN/TSC-54	0	1

*Power control is used to equalize received C/kT.

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Table 12-7. Characteristics of DSCS Phase I Ground Terminals

Terminal Features		Terminals		
		AN/FSC-9	AN/MSC-46	AN/TSC-54
Antenna	Type	Cassegrain	Cassegrain	4 Cassegrain Dish Array
	Aperture Size	18-m (60-ft) Diameter	12-m (40-ft) Diameter	5.5-m (18 ft) Diameter Effective
	Receive Gain	58.5 dB*	57.5 dB*	50.5 dB*
	Efficiency	30%	55%	55%
	Receive Beamwidth	0.16^{o}	0.24^{o}	0.52^{o}
Receive System	Type Preamplifier	Cooled Parametric Amplifier	Cooled Parametric Amplifier	Uncooled Parametric Amplifier
	Bandwidth	50 MHz (3-dB points)	40 MHz (1-dB points)	40 MHz (1-dB points)
	Noise Temperature	200^{o}K (spec.) @ 7.5^{o} E1	204^{o}K @ 7.5^{o} E1	283^{o}K @ 7.5^{o} E1
Transmit System	Type Amplifier	Klystron	Klystron	Klystron
	Bandwidth	50 MHz (3-dB points)	40 Hz (1-dB points)	10 MHz (1-dB points)
	Amp. Power Out	10 W to 20 kW	100 W to 10 kW	5 kW max.
Tracking	Type	Autotrack	Autotrack	Autotrack
	Accuracy	No Data	No Data	No Data
Total Performance	G/T	34.7 dB/^{o}K	34.0 dB @ 20^{o} E1	25.3 dB/^{o}K
	EIRP	131.2 dBm	128 dBm	119.9 dBm
Polarization	Transmit Feed	RHCP	RHCP	RHCP
	Receive Feed	LHCP	LHCP	LHCP
Installation	Radome	None	Yes	None
	Type Facility	Fixed Terminal	Transportable Terminal	Transportable Terminal

*Derived value based on data available.

Figure 12-6. AN/FSC-9 Satellite Earth Terminal

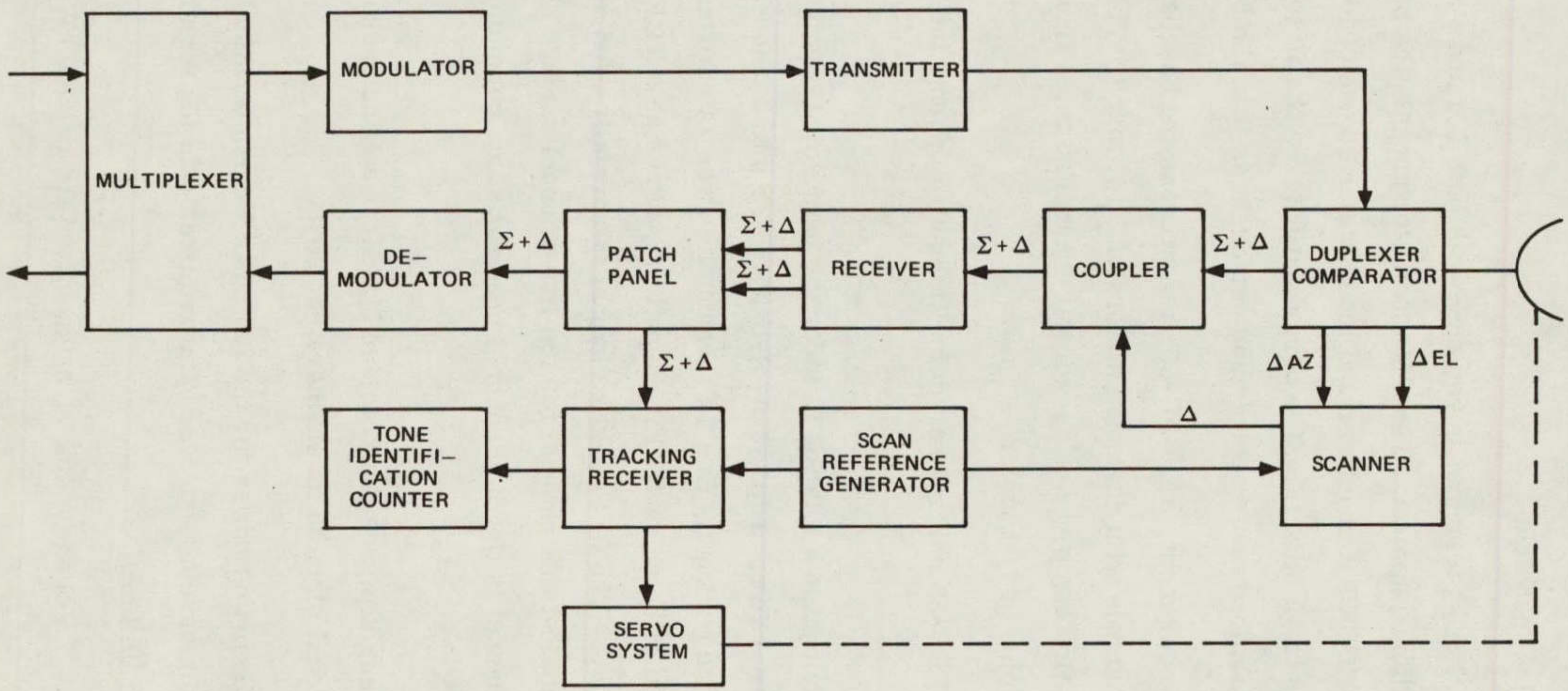

Figure 12-7. AN/FSC-9 Simplified Functional Diagram

antenna specifically designed for DSCS. Improvements during 1971 rectified this problem somewhat. Automatic tracking is provided by a pseudomonopulse technique.

The AN/FSC-9 terminal is equipped with both FM and PN (pseudonoise) modulation equipment. The FM modulator accepts the baseband from the AN/FCC-55 multiplexer and modulates it to one of four frequencies in the 50 to 90 MHz IF. The demodulator takes the 50 to 90 MHz signal from the microwave receiver and demodulates it to the baseband.

The PN equipment, AN/URC-55, can process the baseband of up to four voice channels with deviation factors of 2, 4, and 8. The digital modes of operation can process one digital channel at rates from 75 to 4800 bps in multiples of 75 times 2^N.

An AN/FCC-55 multiplexer/demultiplexer performs the following functions:

a. Multiplies a total of 12 incoming user voice channels, a 0- to 4.0-kHz orderwire, and the out-of-band TTYs into a 300-Hz to 52-kHz baseband package. One TTY channel serves as a terminal orderwire, while the second TTY channel may serve as a TCF-to-TCF orderwire. The 0- to 4-kHz channel is normally used as a voice communications channel for the five-channel mode. The 0- to 4-kHz channel is the only channel used for voice communications with an AN/TSC-54.

b. Demultiplexes the received 52-kHz baseband package into the individual circuits as enumerated above.

The prime power for the AN/FSC-9 earth terminals is supplied by commercial sources. The requirements for terminal operation are as follows:

Voltage = 400 V, 3 Phase, 60 Hz and 700 kW

2. AN/MSC-46

The AN/MSC-46 is a mobile satellite communication terminal that operates with synchronous satellites. It provides an output power of 10 kW in the frequency range from 7900 to 8400 MHz to a 12-meter (40-foot) parabolic antenna. The receive frequency is in the range from 7250 to 7750 MHz. The system contains multiplex equipment with an installed capacity of four duplex voice channels and five duplex teletypewriter channels in a baseband of 0.3 to 20 kHz. Auxiliary wideband baseband inputs 0.3 to 500 kHz or 0.3 to 252 kHz (up to 60 voice channels) can be accommodated. To facilitate operations, an additional teletypewriter channel is used as an orderwire. Figure 12-8 is a simplified block diagram of the AN/MSC-46.

The AN/MSC-46 terminal is housed in a cargo van, a maintenance van, an operations control van (OCV), and an inflatable radome. Power is furnished by three diesel generators of 100 kW each, or local commercial power may be used. The complete terminal, including the disassembled antenna and radome, can be transported in C-124, C-130E, and C-5 aircraft. The total weight is approximately 51,700 kgm (114,000 pounds). After arrival on site, a crew of eight trained men is required to erect the terminal. The operational configuration is presented in Figure 12-9.

The AN/MSC-46 terminal uses a 12-meter (40-foot) diameter Cassegrain type antenna to track medium altitude to synchronous communication satellites. The reflector is mounted on a transportable pedestal which uses a tripod ground support. The RF room, which contains the receiver and high-powered amplifier, is located directly behind the main reflector. The antenna feed is a four-horn (modified) monopulse, circularly polarized feed that is used for both transmitting and receiving. The feed provides sum, elevation error, and aximuth error, signals to the RF receiver for communication signal processing and antenna tracking. The metallic

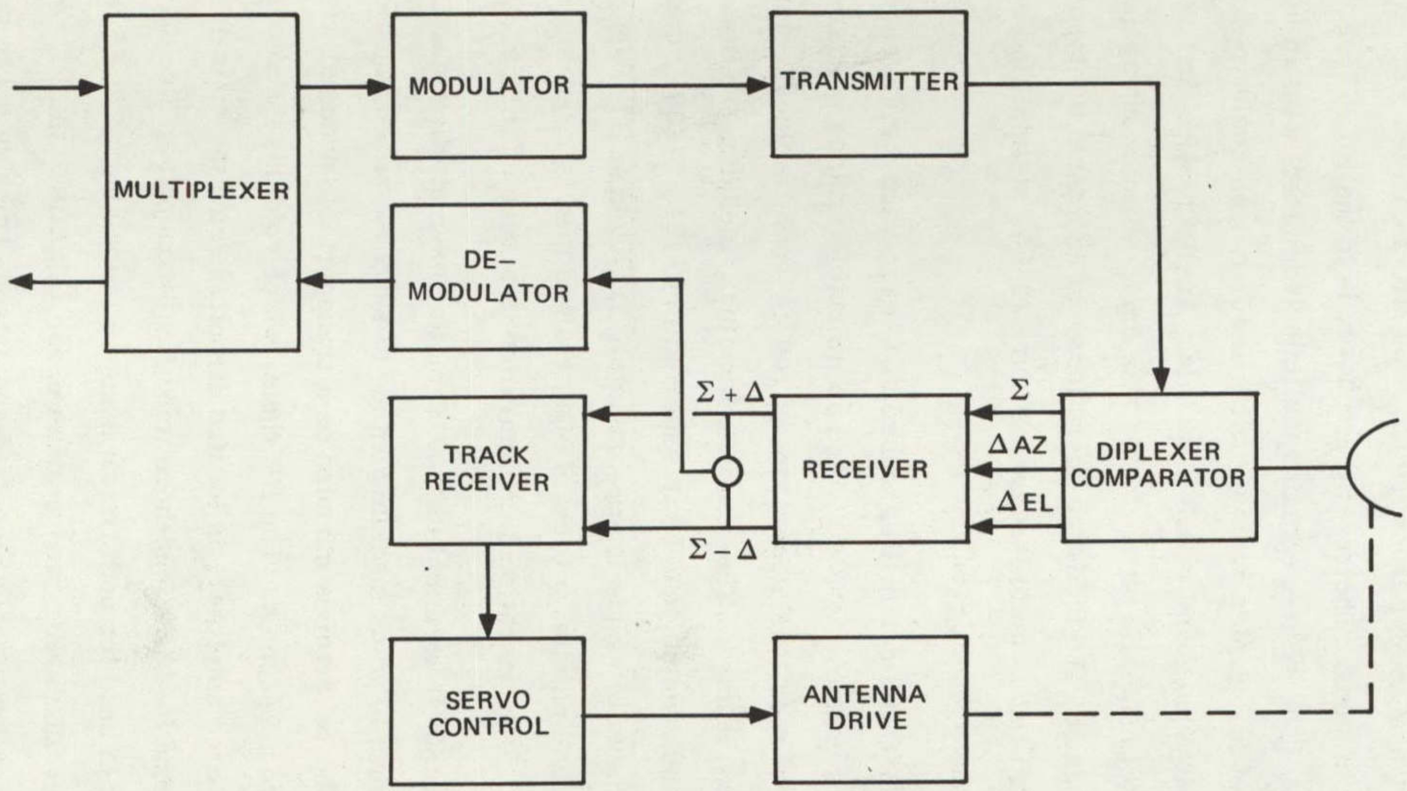

Figure 12-8. AN/MSC-46 Simplified Functional Diagram

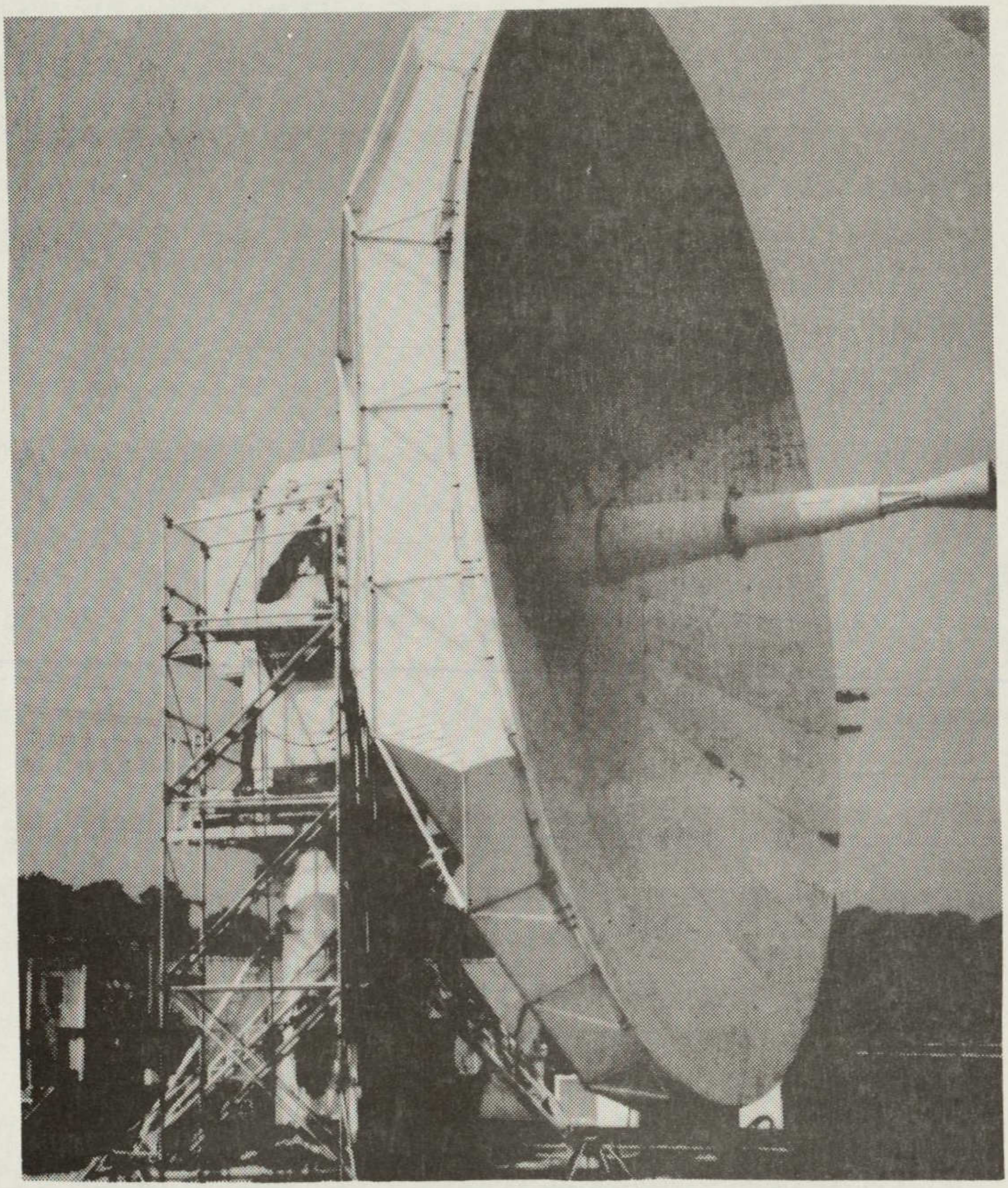

Figure 12-9. AN/MSC-46 Satellite Earth Terminal

subreflector originally used a tripod mount. The AN/MSC-46 antennas have been modified by replacing the subreflector assembly with a single Dielguide (dielectric cone) feed.

The AN/MSC-46 terminal is equipped with the same FM and PN (pseudo-noise) modulation and multiplex equipment as described for the AN/FSC-9.

The AN/MSC-46 terminals also have the AN/TCC-3 five-channel multiplex unit. The baseband configuration of the top four channels is inverted; i.e., the carriers and lower sidebands are suppressed. The baseband configuration of the AN/FCC-55 multiplex is upright; i.e., the carriers and upper sidebands are suppressed. Thus, the AN/TCC-3 baseband is incompatible with the AN/FCC-55 baseband.

The prime power requirements of the AN/MSC-46 terminal are outlined as follows: voltage, 3 phase, 120/208 V ± 10 percent, 50 or 60 Hz ± 5 percent, 175 kW.

These requirements may be filled for most terminals by either local commercial power or by three 100-kW diesel generators which are a part of the terminal configuration.

The radome is a fixed enclosure that offers protection for the antenna against wind, sand, dust, salt spray, rain and ice. It is built to operate with an internal overpressure of 8273.7 newton/meter^2 (1.2 psi) relative to atmospheric pressure. The total weight of the radome is 2540 kilograms (5600 pounds) and its diameter is 18 meters (60 feet).

3. AN/TSC-54

The AN/TSC-54 is a transportable satellite communication earth terminal. It provides the capability for tracking a communication satellite and for transmitting 7900- to 8400-MHz and receiving 7250- to 7750-MHz signals. A six-man crew can erect or dismantle the terminal in 2 hours. Figure 12-10 is a photograph of the AN/TSC-54.

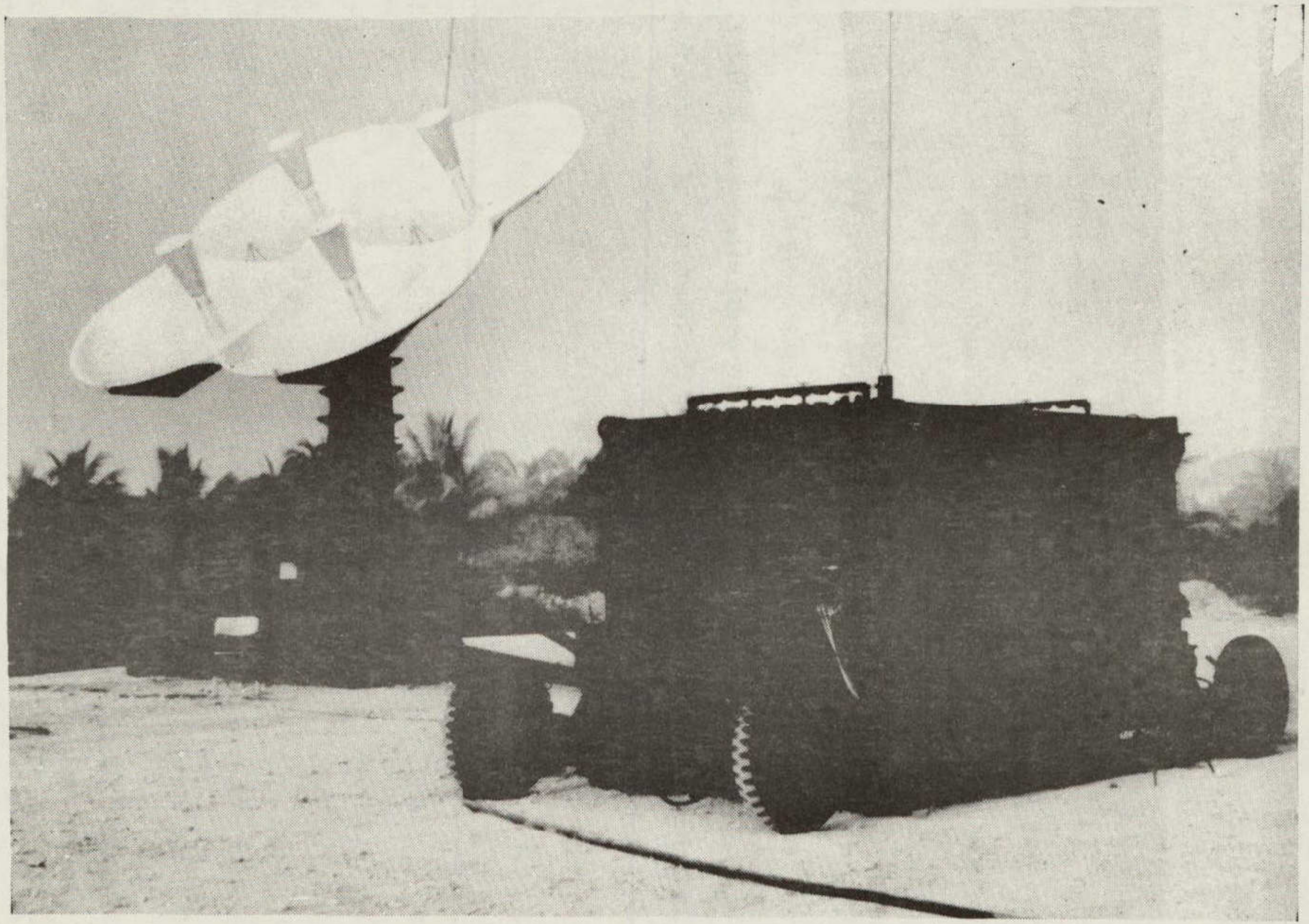

Figure 12-10. AN/TSC-54 Satellite Earth Terminal

The primary elements of the terminal are a modified S-141/G equipment shelter and the antenna assembly. To complete the terminal, a primary power source and suitable mobilizing equipment are supplied.

The equipment is configured to be transported overland with attachment of suitable wheel assemblies. Detachable ground mobilizers (GOAT mobilizer - travels over all terrains) are supplied to tow the terminal over unimproved terrain. The equipment can also be airlifted by helicopter. The entire system weighs less than 7938 kilograms (17,500 pounds) without fuel; no single package weighs more than 2,722 kilograms (6000 pounds). Also, the maximum dimensions and overall weight are compatible with the loading capability of cargo aircraft such as the C-130E.

The AN/TSC-54 terminal uses an array of four 3.0-meter (10-foot) diameter parabolic dishes, each of which has a Dielguide feed for Cassegrain illumination, providing a 5.5-meter (18-foot) effective diameter. The antenna is supported and stabilized in the operational configuration by tripod outriggers. The Klystron power amplifier, exciter and power supplies are mounted in the antenna pedestal base. The parametric amplifier and frequency translators are located directly behind the antenna reflectors. The signal interfaces of the antenna mounted electronics are at 400 MHz. Figure 12-11 is a simplified functional diagram of the AN/TSC-54.

The AN/TSC-54 is equipped with FM and PN modulation equipment. The FM receiver is a phase-lock demodulator with selectable bandwidths (by switch) and additional bandwidths are selectable by module change.

The FM modulator provides for the following modes of operation:

a. One voice plus one duplex out-of-band user, TTY and one out-of-band orderwire TTY.

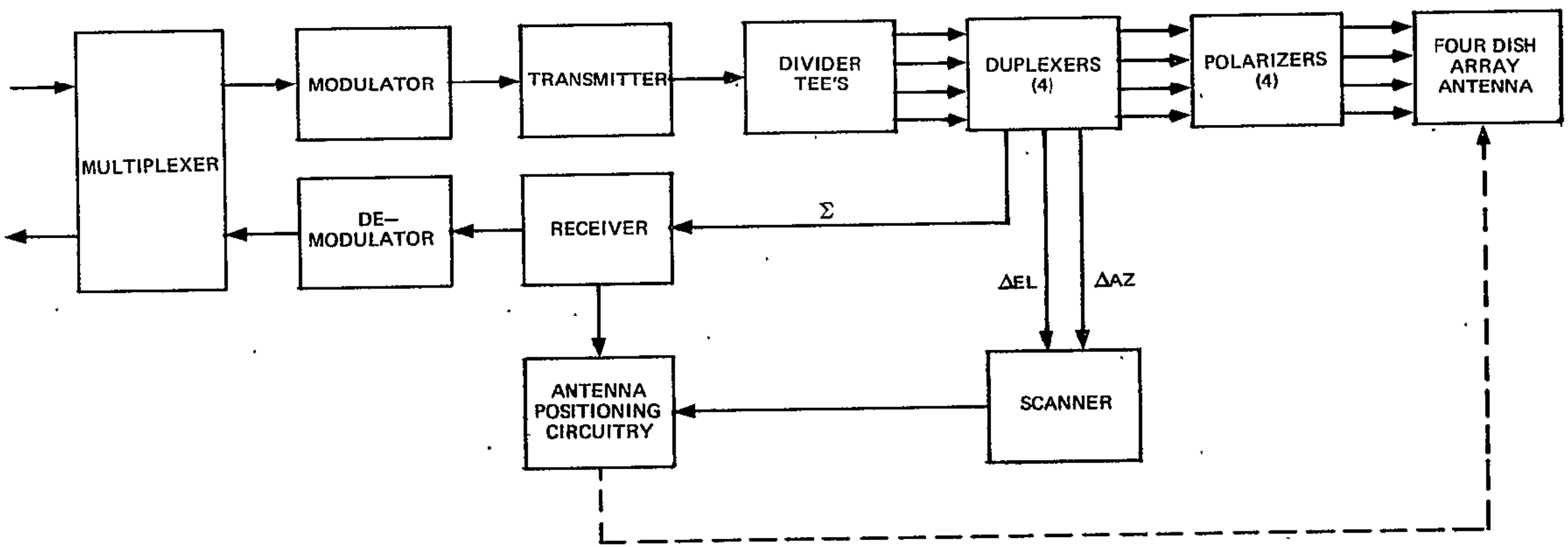

Figure 12-11. AN/TSC-54 Simplified Functional Diagram

b. One in-band TTY (last ditch operation).

c. One, four, eight or 16 multiplex TTY.

d. One truncated voice channel.

Prime electrical power is supplied by a light-weight 45-kW, 400-Hz diesel generator set. The electrical specifications for prime power are: 120/ 208 V ± 5 percent, 400 Hz ± 2 percent, 3-phase, 4-wire.

12.5 EXPERIMENTS

The primary objective of the Initial Defense Communications Satellite Program (IDCSP) was to support developments in military satellite communications and provide a limited operational capability. The experiments and development testing that had been performed through mid-1971 are summarized in Table 12-8.

Although the DSCS Phase I was designed as an R&D satellite system it became almost immediately an operational one. Soon after the first launch a two channel full duplex link capability between two AN/MSC-46 terminals was demonstrated. In July 1967 the Pacific network was placed in operational status, marking the beginning of DSCS integration into the DCS.

12.6 OPERATIONAL RESULTS

The IDCSP has become an operational long-haul satellite communications system. A single satellite is capable of supporting two duplex voice links, each link carrying five voice channels, but operationally, only one duplex link per satellite is allowed to ensure adequate link margins. The system has provided a wideband (450 kbps, 900 kbps under optimum conditions) operational capability for facsimile service over a two-satellite hop link from RVN to Washington, D. C. In addition, the system has provided emergency communications when conventional systems have failed. For example, during the Middle East crisis in May and June 1967, HF radio suffered frequent outages and the West Germany - Ethiopia link provided a primary tracking facility. In September 1967 the Hawaii-RVN link carried five of the highest

Table 12-8. Summary of Program Experiments (1 of 2)

Type Experiment	Nature of Results Obtained
1. Multiple Launch	Successful launch and injection into near synchronous equatorial orbit of up to 8 satellites from one Titan IIIC launch vehicle
2. Voice Transmission	Duplex links carrying up to twelve 4 kHz voice channels at Defense Communication System tactical quality
3. Wideband Data Transmission	Simplex links to 1 Mbps using Multiple Frequency Shift Keying for the transmission of high resolution imagery Duplex links using Phase Shift Keying for the transmission of high data rate digitized voice traffic, providing secure, high quality voice communications
4. Communications to Mobile Terminals	Duplex data links to ships (AN/SSC-3) and aircraft, (Wright Patterson Experimental Terminal), 75 bps to 2400 bps, ship to shore and air to ground
5. Interference and Jamming	With a pseudonoise spread spectrum modulator/demodulator it was demonstrated that duplex communications could be maintained with in-band uplink interference/jammer power very much larger than the uplink signal power. Operational tests demonstrated that the Defense Satellite Communication System would be effective under severe uplink jamming conditions
6. Timing Transfer	Using pseudonoise spread spectrum modulator/demodulators it was demonstrated that timing synchronization could be achieved at satellite earth stations, to better than one microsecond, on a world wide basis

Table 12-8. Summary of Program Experiments (2 of 2)

Type Experiment	Nature of Results Obtained
7. Low Elevation Propagation	Measurements were made of propagation medium effects on wide bandwidths (20 MHz), at 7.3 GHz over satellite to ground paths down to zero degrees elevation. Differential fading results were obtained that could not be explained in terms of any reasonable two component ray propagation model
8. Electronic Despun Antenna	The Despun Antenna Test Satellite (DATS) demonstrated the practicality of an electronically despun phased array antenna on a spin stabilized satellite to produce a continuously earth-direction beam. Successful tests were completed at low data rates (narrow bandwidth tracking loops), showing the effects of despinning on the communication signals
9. Gravity Gradient Stabilization - DODGE (10) (Department of Defense Gravity Experiment)	Successfully detumbled satellite from an initial 0.6 rpm tumble rate. However, oscillations in pitch, roll, and yaw varied widely and only once in 17 satellite passes during 1967 were the oscillations damped to the level predicted by theory and required for a communication satellite. Also a number of times the satellite has resumed tumbling and has had to be restabilized. Causes have not been determined for all these tumbling occurrences

priority military voice channels for a 10-day period while the commercial Trans Pac submarine cable was broken east of the Philippines. Another submarine cable failure between Thailand and RVN in October 1967 was temporarily covered by the IDCSP.

Since the first satellite launch in June 1966, the satellites have performed better than expected. The major cause of failure has been the failure to turn on again after coming out of eclipse, and in some cases such failed satellites have turned on after subsequent eclipses. The next most frequent problem has been failure of the automatic TWT switching system resulting in switched TWTs before they have actually failed. As of mid-1971 valid TWT switching had been experienced on three satellites as a result of failures. However, switching had also occurred on three other satellites for no known reason.

The major failure experienced with the ground terminals was with the maintenance of the cryogenic cooling system in the AN/MSC-46 terminals. These were to be field-maintainable, but had to be returned to the manufacturer for maintenance. The problem was subsequently fixed by modification. Another problem area was an oversensitive tracking system due to its design to track polar orbiting satellites. A modification narrowing the tracking bandwidth solved this problem. For the AN/MSC-46 terminals the MTTF experienced was about 75 hours. For AN/TSC-54 terminals it was about 300 hours.

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SECTION 13 - APPLICATIONS TECHNOLOGY SATELLITE

13.1 INTRODUCTION

The history of this wide ranging program can be traced back to late 1962 when the National Aeronautics and Space Administration (NASA) initiated design studies for what was then known as the Advanced Syncom.(1) This was a proposed second generation synchronous communications satellite for continuation of the experimentation started in the highly successful Project Syncom. In 1964, the program concept was broadened to include experiments pertinent to meteorology, navigation, and general spacecraft technology. The multidimensioned project thus formed was called the Applications Technology Satellite (ATS) program. By consolidating multiple experiments into a single program, NASA realized significant cost reductions and structured a program that was directly responsive to the responsibilities assigned NASA under the Space Act of 1958 and the Satellite Act of 1962.

The ATS program, as initially conceived and approved by Congress, was a multiyear project involving five unique satellites launched into space to conduct some 20 major experiments and a number of related data-gathering studies. Major objectives of the five flights were to: (1) investigate technology common to a number of space applications; (2) investigate technology for the synchronous orbit; (3) develop spacecraft stabilization techniques; and (4) develop experiments for several satellite applications.

The underlying design philosophy, in developing these satellites, was to provide a large and adaptable volume for mounting the various experiment payloads while employing basic satellite configurations appropriate for either spin or gravity-gradient stabilization. Two satellites were designed in the spin stabilized configuration and three were gravity gradient stabilized. Two subconfigurations existed for the gravity gradient stabilized satellites. The first of the three satellites employing this stabilization technique was designed for a medium altitude circular orbit where no stationkeeping was necessary. The two subsequent spacecraft were configured for operation in synchronous equatorial orbits.

Each of the five satellites contained a separate complement of experiments with a relatively low level of experiment repetition from spacecraft to spacecraft.[2] The exception to the latter was the C-Band communications experiments. All five satellites included identical C-Band repeaters for conducting these experiments.

As development and launching of the initial five satellites proceeded, and NASA began to look towards the future, the main thrust of the ATS program objectives became more exclusively communications oriented. NASA's ATS research effort is now directed towards advanced techniques for bringing satellite communications to an ever-increasing number of small, perhaps mobile, users having multiple access to the satellite system; toward broadcast satellite applications, both radio and television; toward more efficient techniques of frequency utilization through investigation of millimeter wavelengths; and toward satellite aids to lunar, planetary, and interplanetary communications.

ATS-6, a high power, three-axis stabilized spacecraft featuring a deployable 9.1-m (30-foot) parabolic reflector antenna, was sent into a near perfect, earth synchronous orbit on 30 May 1974. Paragraph 13.4 discusses the ATS-6 program in detail.[37] ATS-F', a backup to ATS-6, is partially fabricated and is awaiting funding approval.[48]

13.2 SPIN STABILIZED SATELLITES

13.2.1 General Description

The experiments carried on the spin stabilized Applications Technology Satellites can be grouped into seven major categories. These categories are listed and defined in Table 13-1.[3][4] Primary objectives of the SHF (C-Band) communications experiments were to: (1) evaluate a multiple access system having a 1200-channel capacity in voice, teletype, data, and facsimile modes of operation; (2) evaluate wideband transmission techniques;(3) investigate polarization and transmission phenomena; and (4) provide a communications transmission capability in support of other applications technology satellite experiments. Major VHF communications objectives were to demonstrate the feasibility of continuous air-to-ground and ship-to-shore voice communications through a satellite. The satellite VHF transponder also provided the opportunity to: (1) evaluate the feasibility of a meteorological network in which data from small unmanned stations are collected at a central station for dissemination to all interested stations within the satellite coverage area; (2) investigate the feasibility of VHF navigation systems using satellites; and (3) study the practicality of disseminating time via a VHF satellite.

Table 13-1. Experiment Categories

Number	Description
1	VHF & SHF Radio Communications and Propagation
2	Meteorological Concepts, Applications and Techniques
3	Navigation and Position Location Techniques
4	Despun Antenna Systems
5	Measurements of the Earth Environment
6	Technology Applicable to Spacecraft Stabilization and Stationkeeping
7	Miscellaneous Aspects of Spacecraft Design

Two active repeater satellites employing spin stabilization, ATS-1 and ATS-3, were launched during the ATS program as indicated in Table 13-2.[3][4] ATS-1 (i.e., ATS-B prior to launch) was successfully launched into a geostationary orbit and positioned over the Pacific Ocean where it has remained. Its initial program of communications related experiments, including radio communications, propagation, and the electronically despun antenna, were all successfully completed and the spacecraft at this writing is being employed for further experimentation. Concurrently, the remaining scientific experiments were also completed and were successful.[5]

ATS-3 (i. e., ATS-C prior to launch) was successfully placed into a geostationary orbit almost a year after the launching of ATS-1; it was initially positioned over the Atlantic Ocean. The location was later shifted westward to a position over the eastern Pacific Ocean at a longitude near the eastern edge of Mexico; it is now located over South America. The satellite's experiments enjoyed results similar to those attained with ATS-1 and it also is presently being employed for additional experimentation.

Table 13-2. Spin Stabilized Spacecraft

Satellite		ATS-1	ATS-3
Manufacturer & Sponsor		Hughes Aircraft & NASA	
Launch Date		12/6/66	11/5/67
Launch Vehicle		Atlas - Agena D	
Orbital Data*	Apogee	36,886 km (22,920 mi.)	35,814 km (22,254 mi.)
	Perigee	35,851 km (22,277 mi.)	35,773 km (22,228 mi.)
	Inclination	Approximately 0^{o}	
	Period	Approximately 24 hours	
Status		Spacecraft active. Limited Stationkeeping capability left. Solar array output degraded. Located at about 149^{o}W. longitude	Spacecraft active. Solar array output degraded. Located at about 70^{o}W. longitude

*At initial injection. Attitude control and station keeping maneuvers produced changes.

The primary earth terminals involved in the SHF communications experiments conducted with the spin stabilized Applications Technology Satellites are listed in Table 13-3. (5) (6) The three NASA terminals indicated also included crossed dipole arrays for VHF experiments and tracking, telemetry and command (TT&C). A myriad of additional terminals participated in portions of the VHF testing. These included fixed and semi-fixed earth terminals, aircraft terminals, shipborne stations, ocean buoy data platforms, and various fixed and mobile land-based data platforms providing information on earth resources. Terminal locations were widely scattered over portions of the world having visibility of ATS-1 and ATS-3. Entities, in addition to NASA, providing VHF terminals included the Environmental Science Services Administration (ESSA) of the U.S. Department of Commerce, the Federal Aviation Administration, Office of Naval Research, Aeronautical Radio Incorporated (ARINC), Hughes Aircraft, various major commercial airlines, and a number of foreign countries. Satellite launchings were provided by NASA.

Table 13-3. Participating Earth Terminals

Location	Sponsor	Antenna Diameter (m) (ft)	Date Installed
Rosman, North Carolina	NASA	26 (85)	1965/66*
Mojave, California	NASA	12 (40)	1965/66*
Cooby Creek, Australia	NASA	12 (40)	1965*
Kashima, Japan	Radio Research Laboratories Ministry of Posts and Telecommunications, Japan	30.0 (98.5)	1967*

*Date of ATS-related installation alone.

Specific refinements to the state-of-the-art, contributed by the ATS-1 and 3 test programs, were innumerable. There were four contributions of major importance in satellite communication; two of these were in the area of despun antenna technology. ATS-1 demonstrated the feasibility and potential of electronic-despinning using phased arrays while ATS-3 displayed the feasibility and attractiveness of mechanically-despun antennas. The SHF multiple access experiments showed the possibility of the practical implementation of a system employing single-sideband frequency division multiplexing on the uplink and phase modulation by the composite received signal on the downlink. Additionally, the feasibility of VHF communications through a synchronous satellite by small mobile earth terminals was demonstrated.

13.2.2 System Description

The SHF tests with ATS-1 involved all of the terminals listed in Table 13-3. Loop back, half duplex, full duplex, and three terminal multiple access test configurations were all employed. For the ATS-3 tests only Rosman and Mojave terminals had satellite visibility. Tests were therefore performed on a loop back, half duplex, and full duplex basis. VHF tests were conducted in all of these configurations from loop back through full duplex linking. Satellite transponder non-linearity, plus power and bandwidth limitations, tended to limit multiple access capabilities. The NASA-furnished terminals provided two functions in the VHF tests. They conducted base-line evaluations of the satellite VHF transponder and the VHF propagation link to serve as a reference for testing with mobile and remote data terminals. The NASA terminals also participated in the latter tests as central land bases. Typical earth coverages supplied by the geostationary satellites, ATS-1 and ATS-3, are shown in Figure 13-1.

Operating frequencies for the spin stabilized Applications Technology Satellites are shown in Tables 13-4, 5, and 6.[(5)] The 6- and 4-GHz frequencies were selected to be compatible with the international allocations for commercial satellite communications. The VHF frequencies were selected for a communications experiment because of compatibility with existing frequencies employed for spacecraft TT&C and conventional hardware that could readily be supplied for small mobile terminals (e.g., aircraft terminals).

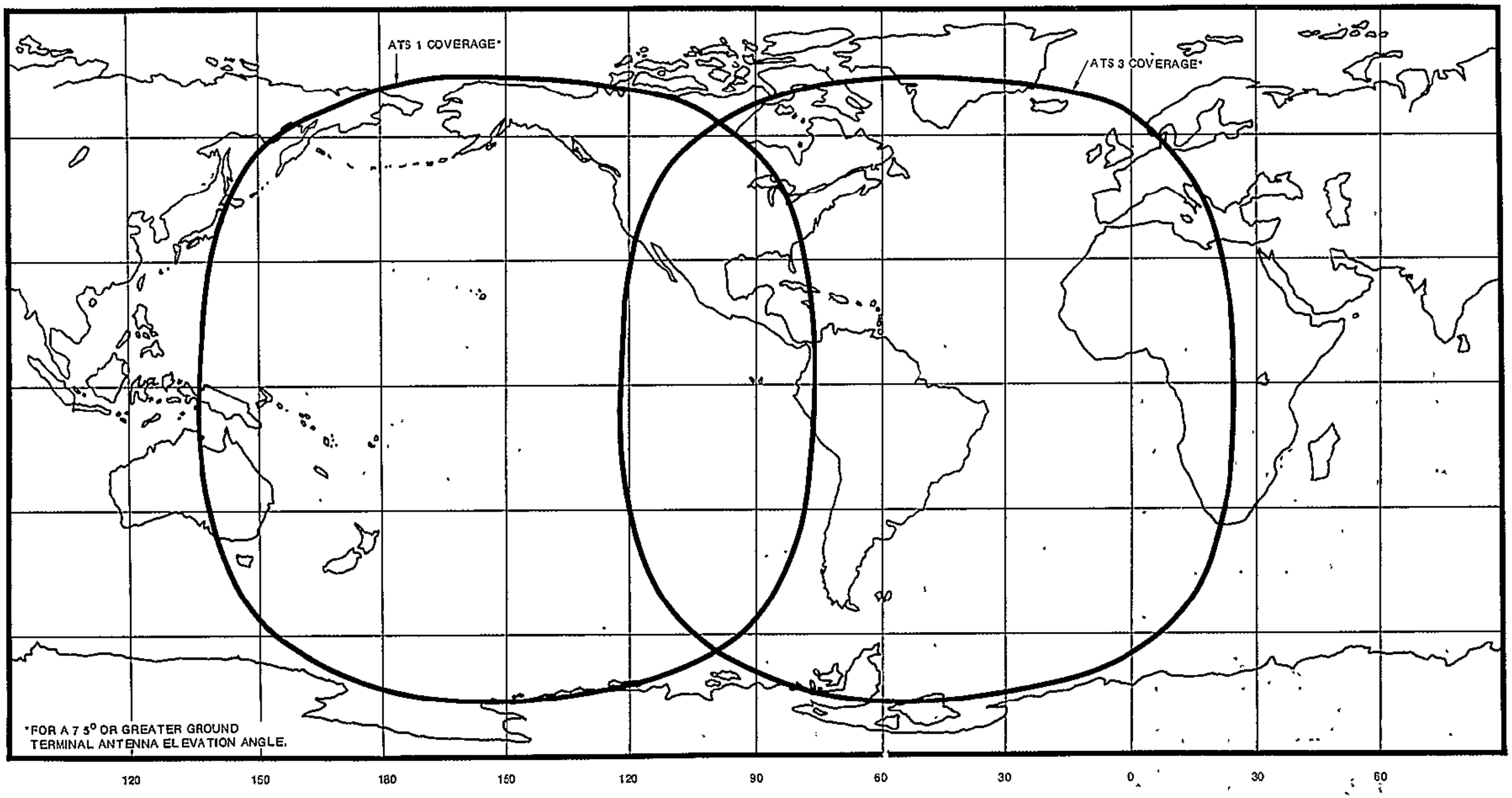


Figure 13-1. ATS 1 and 3 Earth Coverage

Table 13-4. SHF Communications Frequencies (MHz)

Frequency Translation Mode			Multiple Access Mode*		
Uplink	Downlink	Beacon	Uplink	Downlink	Beacon**
6212.094	4119.599	4135.946	6212.294 to 6217.694	4119.599	4119.599
6301.050	4178.591	4195.172	6301.250 to 6306.650	4178.591	4178.591

* Dual frequencies indicated correspond to two independent repeaters

** Communications carrier which is always present serves as beacon in this mode

Table 13-5. VHF (MHz)

Half Duplex Mode		Full Duplex Mode	
Uplink	Downlink	Uplink	Downlink
149.220	135.600	149.195	135.575
		149.245	135.625

Table 13-6. TT&C (MHz)

Command	Telemetry	Beacon
148.260	136.470	137.370
		412.050*

*Third harmonic of 137.350 MHz

Basic signal processing techniques employed with the spin stabilized Applications Technology Satellites, when operated in the SHF multiple access mode, were as described in Table 13-7.[7] When in this mode (i.e., SSB-FDMA/PM) the spacecraft is a signal processing repeater. Single side band (SSB) signals from individual terminals are frequency division multiplexed on the uplink. The individual signals are combined in the spacecraft and down-converted to provide a composite baseband that phase modulates the transmitted carrier. The downlink signal is detected by a discriminator in the ground terminal receiver and demultiplexed to derive the desired individual message. In this system, uplink noise becomes a more significant factor in determining total performance but requirements for frequency spectrum and uplink power control are reduced. The use of SSB modulation on the uplink tended to restrict the traffic handled to conventional 4-kHz voice.

Table 13-7. SHF Signal Processing for SHF Multiple Access Mode

Multiple Access/RF Modulation	SSB on uplink and PM on downlink
Ground Demodulator Performance	Threshold estimated at 10-dB C/N based upon employing conventional discriminators
Rosman Receive Carrier-to-Noise	16.7 dB employing 2 TWTs on ATS-1 and a 12-MHz IF bandwidth
Rosman Receive Margin	6.7 dB

A second SHF communications mode, available on ground command, configures the spacecraft repeater as a standard frequency translation transponder. Signal processing employed for operation in this mode is depicted in Table 13-8. Both television and multichannel voice traffic were commonly handled with the spacecraft configured in this manner.

Table 13-8. Signal Processing for SHF Frequency Translation Mode

Multiple Access	Frequency Division* for a limited number of users.
RF Modulation	FM**
Ground Demodulator Performance	Threshold estimated at 10-dB C/N based upon employing conventional discriminators.
Rosman Receive Carrier-to-Noise	14.4 dB employing 2 TWTs on ATS-1 and a 35-MHz IF bandwidth
Rosman Receive Margin	4.4 dB

* Time division and code division (i.e., spread spectrum) multiple access were employed in special tests.

** Binary phase shift keying and quadraphase shift keying were employed in time division and spread spectrum multiple access tests.

For operations involving the VHF satellite repeater, the basic signal processing techniques employed were as indicated in Table 13-9.[8] A single duplex voice channel was typical of the traffic handled by this frequency translation repeater.

Table 13-9. Signal Processing for VHF Repeater

Multiple Access	Frequency division for a limited number of users.
RF Modulation	FM
Ground Demodulator Performance	Threshold estimated at 10-dB C/N based upon employing conventional discriminators
Ground Terminal* Receive Carrier-to-Noise	20.1 dB with ATS-1 and a 100-kHz IF bandwidth
Ground Terminal* Receive Margin	10 dB

*For common type of VHF ATS terminal deployed at the three NASA ATS terminal sites.

13.2.3 Spacecraft

Characteristics of the communications related subsystems of ATS-1 and 3 are described in Tables 13-10 and 13-11,[3][4][9][10] respectively. With the exception of the high power TWTs on one transponder of ATS-3, the SHF transponders aboard the two spacecraft were virtually identical. Functional diagrams depicting each of the three possible modes of the transponder (i.e., frequency translation, multiple access, and onboard camera) are given in Figures 13-2, 13-3, and 13-4. The VHF transponder on each spacecraft is illustrated in Figure 13-5. As indicated by the figure, the VHF transponder on ATS-3 differed from that on ATS-1 in that a capability existed to cross strap the VHF receiver to the transmitter of one of the SHF transponders. In this mode of operation, selectable by ground command, the SHF transponder was operated in the camera mode and the received VHF signal was down-converted to serve as the input to the SHF transponder's voltage controlled oscillator.

13.2.4 Ground Terminals

Two of the three NASA ATS terminals, Rosman and Mojave, are large multifunctional installations supporting numerous other NASA programs. Characteristics of the ATS related facilities at all three locations are summarized in Table 13-12. (See References 5 through 8 and 11.) Major subsystems of the NASA ATS terminals are depicted in the functional block diagram of Figure 13-6.[6]

Equipment and its characteristics are quite similar at all three sites with the major difference being in the size of the SHF antennas. The linear polarized SHF feeds employed at all three sites were compatible with the satellite's transmit and receive polarization. This polarization selection made polarization tracking necessary. For VHF communications, the T&C antenna was normally configured for circular polarization. With the linear polarization employed on the satellite, this resulted in 3-dB uplink and downlink polarization losses.

Table 13-10. ATS-1

Antennas	Type		SHF xmit.-16 element electronically despun phased array. SHF Rec.-collinear array	VHF Comm-8 element electronically despun phased array.	VHF TT&C-8 whip turnstile
Antennas	Number		One	One	One
Antennas	Beamwidth (3dB)		Pencil beam a maximum of about 21° wide for xmit.	Pencil beam about 60° wide.	Essentially omni-directional
Antennas	Gain		Xmit-14 dB Rec-7.8 dB	Xmit-9 dB Rec-8 dB	0 dB
Repeaters	Frequency Band		SHF		VHF
Repeaters	Type		Triple Mode * supplying: (a) soft limiting IF translation; (b) modulation conversion for multiple access; (c) wideband transmission of onboard data		IF translation hard limiting
Repeaters	3 dB BW		(a) IF translation-25 MHz; (b) modulation conversion-5.45 MHz uplink & 25 MHz donwlink; (c) Onboard data xmit-25 MHz		100 KHz
Repeaters	Number		2 independent repeaters		One
Repeaters	Receiver	Type Front End	Tunnel diode amplifier into down conversion mixer		Down conversion mixer
Repeaters	Receiver	Front End Gain	No data		No data
Repeaters	Receiver	System Noise Figure	6.2 dB		4.0 dB
Repeaters	Transmitter	Type	Two TWTs **		8 solid state amplifiers
Repeaters	Transmitter	Gain	No data		No data
Repeaters	Transmitter	Power out	4 watt per TWT or 8 watt total		5 watt per amplifier or 40 watt total
Repeaters	EIRP		22 dBW with 2 TWTs		23 dBW for 1 carrier
General Features	Stabilization	Type	Spin with redundant H_2O_2 reaction control systems and nitrogen jets for spinup.		
General Features	Stabilization	Capability	Spin axis attitude errors of about 0.2° attained		
General Features	Power Source	Primary	N-on-P solar array with 175 watt output at launch		
General Features	Power Source	Supplement	2 nickel cadmium batteries with 6 amp-hr per battery capacity at launch		
General Features	Comm. Power Needs		Each SHF transponder-35 watts, VHF transponder-90 watts, and electronically despun antenna-8watts		
General Features	Size		Cylindrical - 145 cm (57 in.) high and 142 cm (56 in.) in diameter		
General Features	Weight		352 kg (775 lb) initially in orbit		

* Mode for each SHF transponder independently selectable by ground command.

** Can be operated individually or in parallel.

Table 13-11. ATS-3

Antennas		Type	SHF-mechanically despun cylindrical parabolic collimator illuminated by col linear xmit and recv. line feeds. *	VHF Comm.-8 element electronically despun phased array	VHF TT&C-8 whip turnstile
Antennas		Number	One	One	One
Antennas		Beamwidth (3 dB)	Pencil beam about 20° wide	Pencil beam about 60° wide	Essentially omni-directional
Antennas		Gain	Xmit-16 dB Recv-17.5 dB	Xmit-10 dB Recv-8 dB	0 dB
Repeaters		Frequency Band	SHF		VHF
Repeaters		Type	Triple mode ** supplying: (a) soft limiting IF translation; (b) modulation conversion for multiple access; (c) wideband transmission of onboard data		IF translation soft limiting
Repeaters		3 dB-dW	(a) IF translation-25 MHz; (b) modulation conversion-5.45 MHz uplink and 25 MHz downlink; (c) Onboard data xmit-25 MHz		100 KHz
Repeaters		Number	2 independent repeaters		one
Repeaters	Receiver	Type Front End	Tunnel diode amplifier into down conversion conversion mixer		Down conversion mixer
Repeaters	Receiver	Front End Gain	No data		No data
Repeaters	Receiver	System Noise Figure	6.2 dB		3.5 dB
Repeaters	Transmitter	Type	Two TWTs ***		8 solid state amplifiers
Repeaters	Transmitter	Gain	No data		No data
Repeaters	Transmitter	Power Out	Xponder 1-4 watt/TWT or 8 watt total Xponder 2-12 watt/TWT or 24 watt total		6.3 watt per amplifier or 50 watt total
Repeaters		EIRP	Xponder 1-24.5 dBW with 2 TWTs Xponder 2-29.3 dBW with 2 TWTs ****		25.8 dBW for 1 carrier
General Features	Stabilization	Type	Spin with H_2O_2 or hyrazine reaction control systems and nitrogen jets for spinup.		
General Features	Stabilization	Capability	Spin axis attitude errors of about 0.2° attained		
General Features	Power Source	Primary	N-on-P solar array with 175 watt output at launch		
General Features	Power Source	Supplement	2 nickel cadmium batteries with 6 amp/hr per battery capacity at launch		
General Features		Comm. Power Needs	SHF Xponder 1-35 watts, SHF Xponder 2-90 watt, VHF Xponder-100 watts, and mechanically despun antenna-15 watt		
General Features		Size	Cylindrical: 180 cm (71 in.) high and 147 cm (58 in.) in diameter		
General Features		Weight	365 kg (805 lb) initially in orbit		

* Fail safe mode can be initiated by blowing parabolic reflector off antenna to get pancake pattern and about 7 dB gain.

** Mode for each SHF transponder independently selectable by ground command.

*** Can be operated individually or in parallel.

**** One 12 watt TWT failed to function making 26.5 dBW maximum EIRP available.

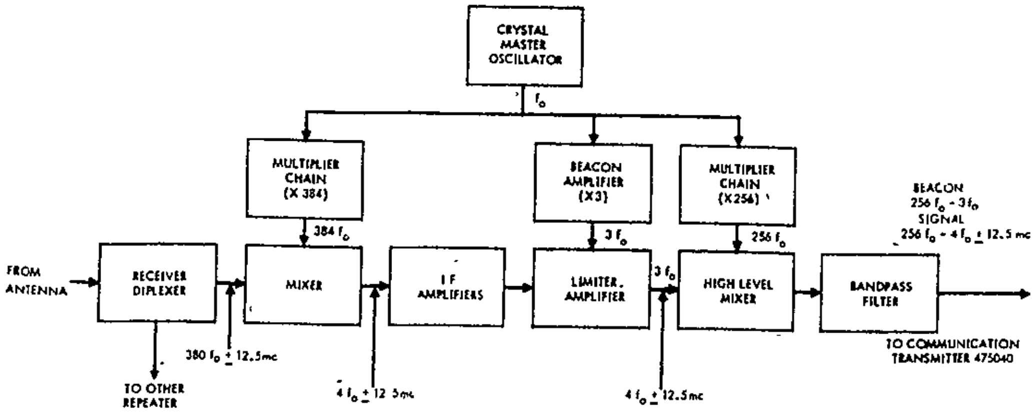


Figure 13-2. ATS-1, 3: Communications Transponder

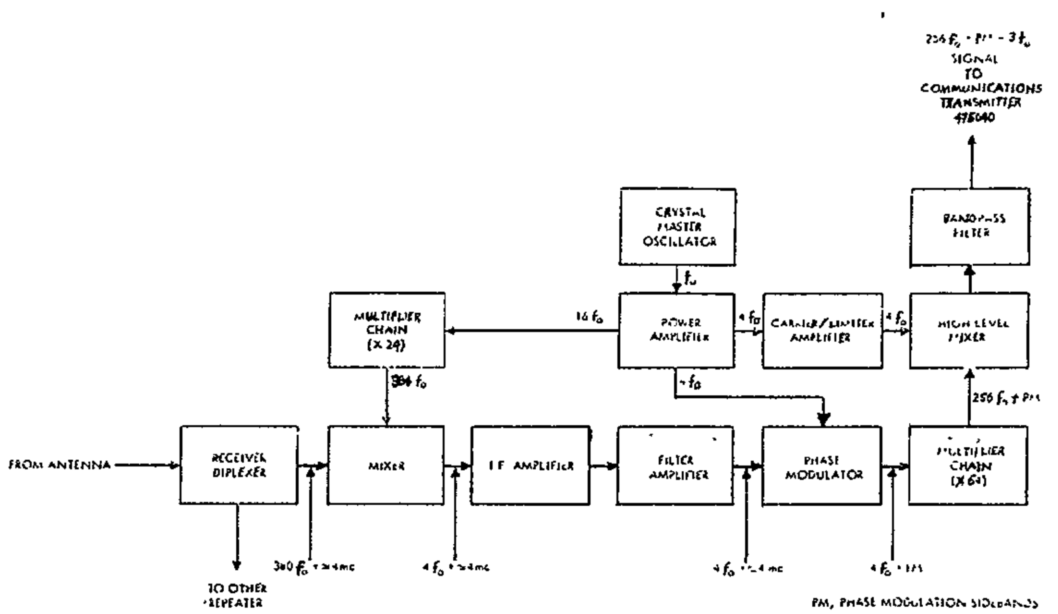


Figure 13-3. Multiple Access Functional Block Diagram

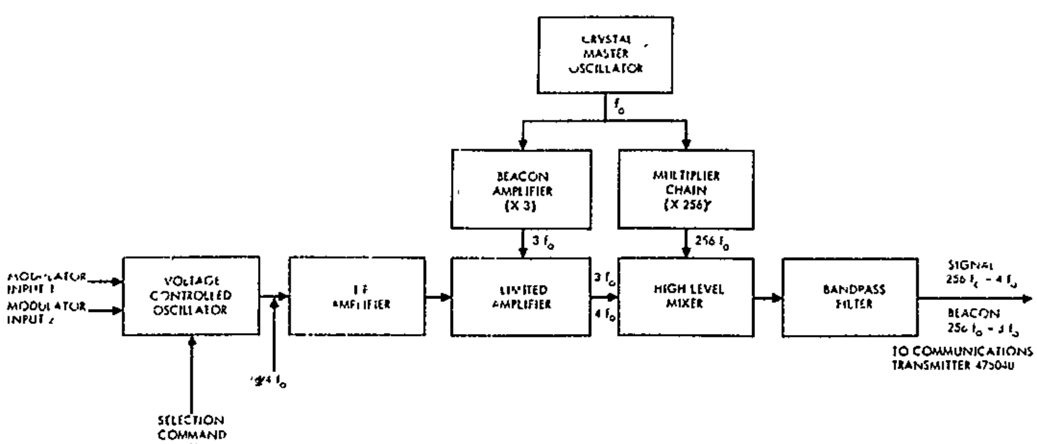


Figure 13-4. Camera Mode Functional Block Diagram

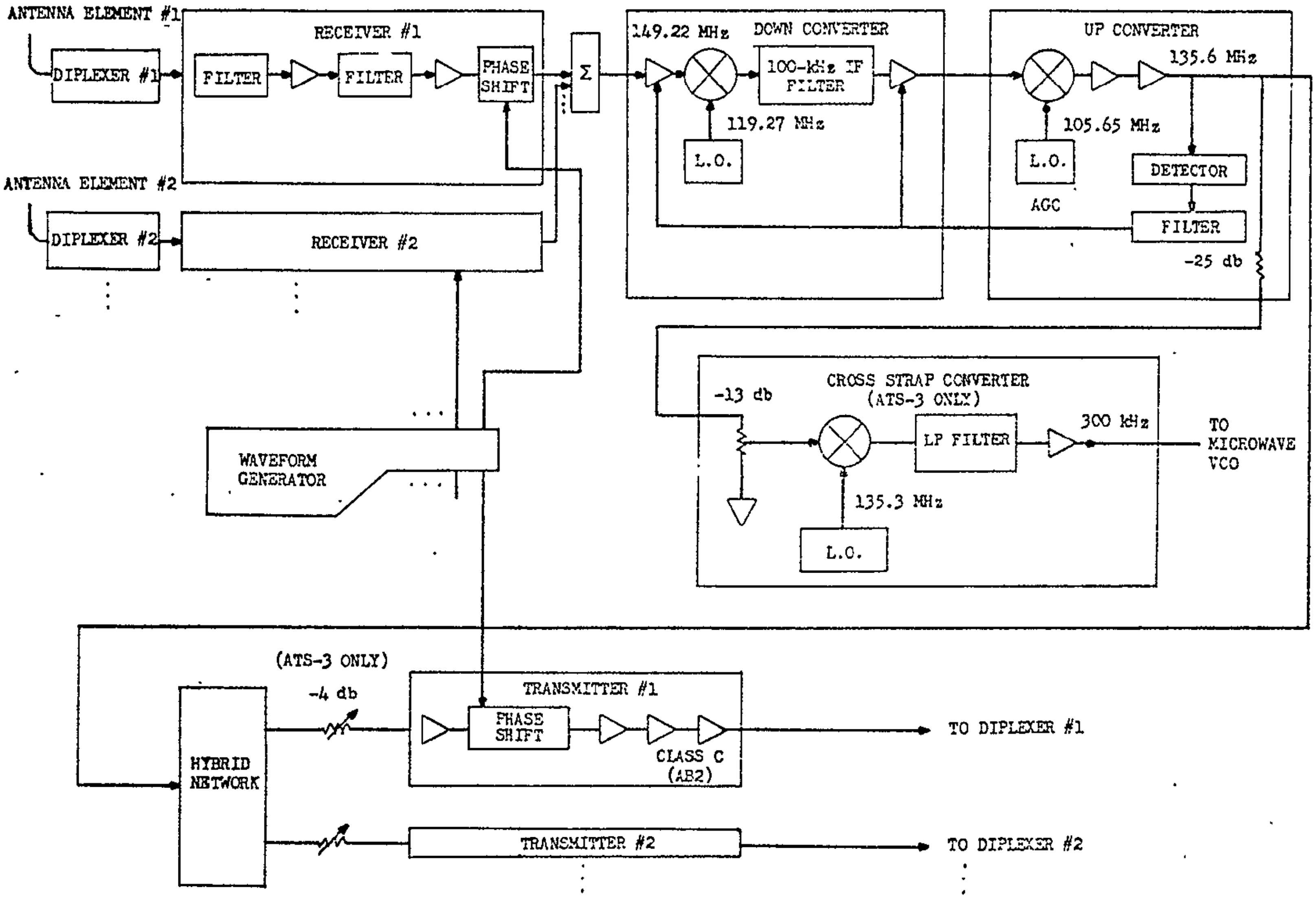
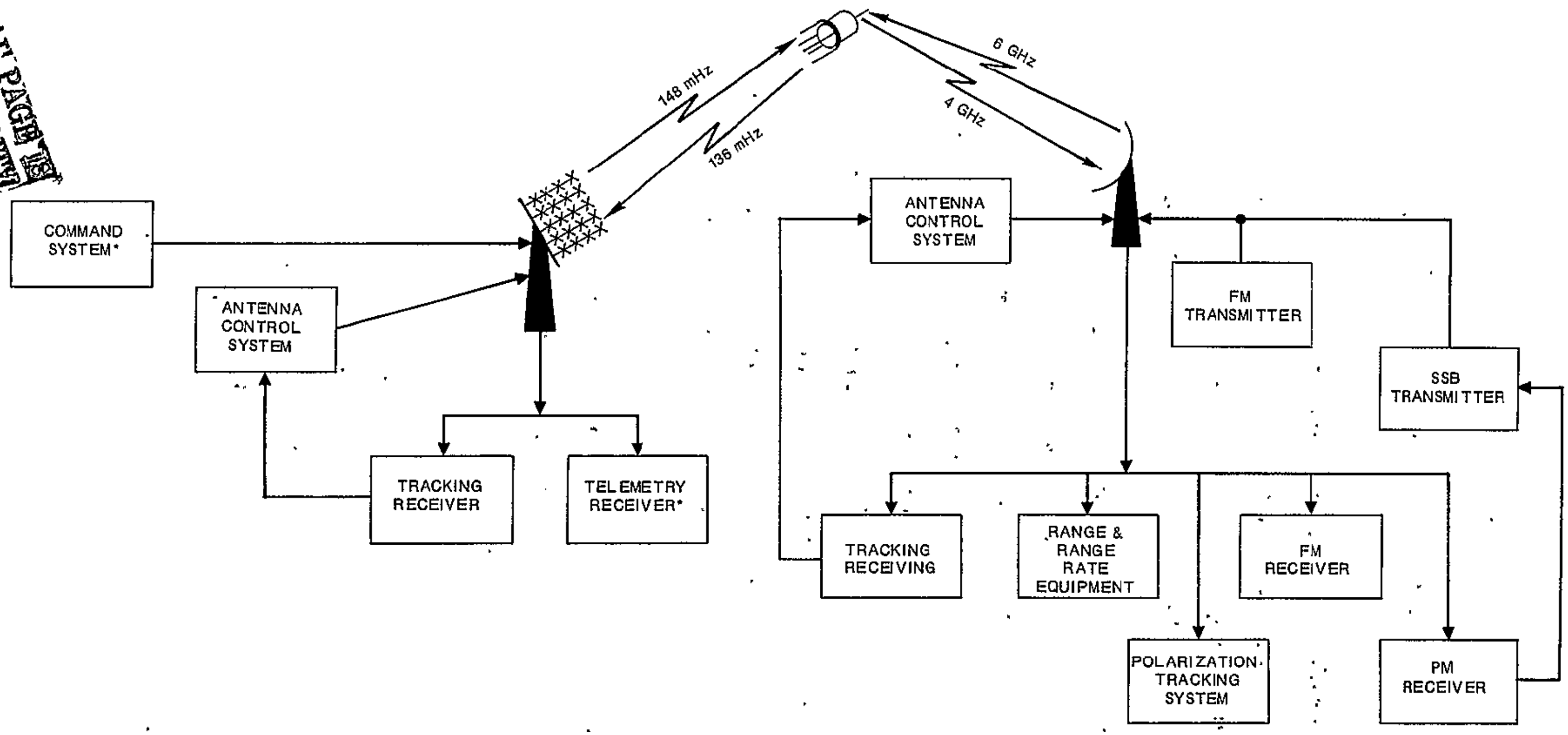


Figure 13-5. VHF Transponder Block Diagram.

Table 13-12. NASA ATS

Terminal Feature		Rosman (SHF)	Mojave (SHF)	Cooby Creek (SHF)	All 3 Terminals (VHF)
Antenna	Type	Cassegrain	Cassegrain	Cassegrain	Cross Dipole Array(4)
	Aperture Size	26 m (85 ft) Diameter	12 m (40 ft) Diameter	12 m (40 ft) Diameter	About 4.6 m × 4.6 m (15 ft × 15 ft)
	Receive Gain	58.4 dB	51 dB	51.5 dB	22 dB
	Efficiency	50%	48%	54%*	65%*
	Receive Beamwidth	$.2^{\circ}$* @ 3 dB Pts.	$.4^{\circ}$(1) @ 3 dB Pts.	$.4^{\circ}$* @ 3 dB Pts.	13°
Receive System	Type Preamplifier	Cool parametric amplifier	Cool parametric amplifier	Cooled parametric amplifier	No data
	Bandwidth	30 MHz	30 MHz	30 MHz	11 MHz*
	Noise Temperature	75°K @ 7.5° El	75°K @ 7.5° El	75°K @ 7.5° El	1230°K
Transmit System	Type Amplifier	Klystron	Klystron	Klystron	No data
	Bandwidth	25 MHz	25 MHz	25 MHz	No data
	Amp. Power Out	1 KW in SSB mode and 2 KW in FT mode***	1 KW in SSB mode and 2 KW in FT mode**	1 KW in SSB mode and 2 KW in FT mode**	2.5 KW
Tracking	Type	Monopulse auto-track on X-Y mount	Monopulse auto-track on X-Y mount	Monopulse auto-tract on Az-El mount	Monopulse auto-track* on X-Y mount
	Accuracy	$\pm 0.03^{\circ}$ in winds up to 20 mph	$\pm 0.04^{\circ}$ in winds up to 20 mph	$\pm 0.04^{\circ}$ in winds up to 20 mph	$\pm 0.5^{\circ}$
Total Perform-ance	G/T	39.6 dB	32.2 dB	32.7 dB	-8.9 dB
	EIRP	122.1 dBM*	115.5 dBM*	116 dBM*	76 dBM*
Polari-zation	Transmit Feed	Linear	Linear	Linear	Circular or linear****
	Receive Feed	Linear	Linear	Linear	Circular or linear***
Instal-lation	Radome	None	None	None	None
	Type Facility	Fixed Terminal	Fixed Terminal	Transportable***	Fixed except at Cooby Creek***

*Derived value based on data available.
**SSB and FM power amplifiers use same model klystron which is capable of up to 10-KW average output.
***13 air-transportable vans in addition to SHF and T&C antenna existed at Cooby Creek.
****Separate Yagi transmit and receive antennas of same type integrally mounted on same base.
*****Selectable bandwidths of 10 KHz, 30 KHz, 100 KHz, 300 KHz, 1 MHz, and 3 MHz are available.
**Manual positioning used at Cooby Creek.
****Non-rotatable in the linear configuration.



*EQUIPMENT IS RECONFIGURED FOR VHF COMMUNICATIONS TRANSMISSION & RECEPTION

Figure 13-6. Major Subsystems of a NASA ATS Terminal.

13.2.5 Experiments

Experiments conducted as part of the spin stabilized ATS program are listed in Table 13-13.[3][4][5] The table shows the seven major experiment categories, listed in Table 13-1, into which the individual experiments can be grouped. In the case of the satellite VHF transponder experiments, some overlap between categories existed. These transponders supported selected meteorology and navigation experiments in addition to the communications and propagation experiments.

Specifically, in the WEFAX experiment, the satellite VHF transponder relayed Environmental Science Services Administration (ESSA) weather data (including ATS SSCC photographs) in facsimile format from Suitland, Maryland to Automatic Picture Transmission (APT) stations in the U.S., Japan, and Australia.[12] As part of OPLE, the spacecraft VHF repeater relayed interrogations and responses between the OPLE Control Center (OCC) and small remote platforms which were sometimes in motion. Responses included data from local sensors and OMEGA navigation system VLF tones received at the remote platforms and up converted to VHF.[13] Various other navigation and postion location experiments employed the spacecraft VHF transponder for ranging measurements.

The meteorological experiments, defined in Table 13-13, produced a vast number of high quality pictures from the spacecraft camera systems and demonstrated the feasibility of weather facsimile through the satellite's VHF repeater. The spacecraft stabilization experiments have displayed that nutation sensing and damping, for nutation angles between 0.001° and 5.0°, can be satisfactorily accomplished and that hydrazine thrusters are feasible; the resistojet stabilization experiment was not as successful. The entire ammonia fuel load was depleted on ATS-1 (probably by a leak at a pressure transducer port) and particle contamination resulted in abnormal valve operation and thrusting performance on ATS-3.[5] Considerable data was obtained on the navigation and satellite technology experiments with the result that all major objectives have for the most part been met. Additionally,

Table 13-13. Summary of ATS 1 and 3 Experiments

Experiment	Spacecraft	Category of Activity
1. Microwave Communications	1 & 3	Communications and propagation evaluation
2. VHF Communications	1 & 3	Communications and propagation evaluation
3. Phased Array Antenna	1	Comparison despun antenna technology
4. Mechanically Despun Antenna	3	Comparison despun antenna technology
5. Spin Scan Cloud Cover (SSCC) Camera	1 & 3	Meteorology concept consideration
6. WEFAX	1 & 3	Meteorology concept consideration
7. Image Dissector Camera System	3	Meteorology concept consideration
8. Nutation Sensor	1 & 3	Spacecraft stabilization investigation
9. Resisto-jet	1 & 3	Spacecraft stabilization investigation
10. Hydrazine Rocket System	3	Spacecraft stabilization investigation
11. Omega Position Location Experiment (OPLE)	3	Navigation techniques study
12. Self-Contained Navigation System	3	Navigation techniques study
13. Reflectometer	3	Satellite technology evaluation
14. Apogee Motor Plume	3	Satellite technology evaluation
15. Supra thermal Ion Detector	1	Earth environment measurements
16. Magnetometer	1	Earth environment measurements
17. Omnidirectional Electron-Proton Detector	1	Earth environment measurements
18. Multielement Particle Telescope	1	Earth environment measurements
19. Solar Cell Radiation Damage	1	Earth environment measurements
20. Thermal Coatings	1	Earth environment measurements
21. Electron Magnetic Deflection Spectrometer	1	Earth environment measurements

the environmental measurements experiments have been providing valuable information that is adding to the pool of knowledge on the space environment in the vicinity of the earth.

The phased array antenna, employed on ATS-1, consisted of 16 antennas arranged around a circle of one wavelength radius with each antenna composed of four collinear dipoles. Phasing of the radiated output was accomplished using eight ferrite phase shifters. Each phase shifter provided two equal amplitude outputs whose phase was varied in an opposite sense by inputs from the Phased Antenna Control Electronics, PACE. The two phase shifter outputs were connected to two diametrically opposite antennas. The PACE derived phase shifter control signals from satellite spin rate inputs and orbital position. This antenna system realized a measured in-orbit gain of about 12.5 dB with a beamwidth of approximately 22° due to the array. Beamwidth due to the stack of dipoles was determined, prior to launch, to be about 17°. The PACE system demonstrated reliable performance and accurate pointing of the radiated beam. The total drive power requirement of the phase shifters was about 2 watts.

The mechanically despun antenna, employed on ATS-3, consisted of a rotating cylindrical parabolic collimator illuminated by a two element collinear array feed. Each array element was a full wave dipole. The parabolic collimator was rotated in opposition to the direction of spacecraft spin by a 128-step synchronous stepping motor and encoder controlled by the Mechanical Antenna Control Electronics, MACE. The MACE system was essentially identical to the PACE system employed on ATS-1. The measured in-orbit gain of this antenna was about 17 dB with a beamwidth of approximately 20°. The PACE system displayed a capability of pointing the antenna beam towards the earth within about ±0.7 degrees. Antenna system reliability was, in general, quite good. During the satellite's first year in orbit, several malfunctions of the despinning mechanism were observed due to stalling of the stepping motor. No thermal effects could be related to this anomaly. It was hypothesized that a failure of the electric damper circuit associated with the stepping motor Regulator

No. 2 was responsible for the abnormal behavior. A switchover to backup electronics eliminated these malfunctions.

Prime objectives of the microwave communications experiments were defined in Paragraph 13.2.1. The final objective, providing support to other onboard experiments, was readily accomplished through numerous transmissions of wideband data from other satellite experiments. The spacecraft television cameras were the chief beneficiaries of this mode of operation.

Multiple access experiments of primary interest and their basic results are described in Table 13-14.(7)(14) Additionally, measurements of system noise power ratio and multiplex channel linearity, envelope delay, harmonic distortion, and frequency response were carried out with satisfactory results. The experiments indicated that CCIR and CCITT standards on communications transmission can be met with this type of system. Frequency control and a high level of inherent frequency stability are necessary to eliminate mutual interference on the uplink and to allow accurate demodulation to baseband of the SSB signal containing no reference carrier. Automatic level control is necessary to assure a proper balance of modulation indexes for all signals accessing the satellite's PM transmitter. Adequate short term frequency stability was found to be the most difficult requirement to meet but numerous special tests at NASA ground terminals indicated that much can be done to reduce instabilities. As expected, the higher receive antenna gain and EIRP of the ATS-3 satellite afforded greater performance capabilities than experienced with ATS-1.

Experiments employing the spacecrafts' wideband frequency translation repeater measured frequency division multiplex and television system performance. The frequency division multiplex tests were conducted employing a simulated loading of up to 1200 one-way voice channels at Rosman and up to 240 one-way channels at Mojave and Cooby Creek. Measurements of RF signal power and propagation losses; baseband frequency response, and envelope delay; system noise power ratio; and multiplex channel frequency stability, level stability, S/N ratio, data error

Table 13-14. SSB-FDMA/PM

Type Experiment	Nature of Results Obtained
1. RF Power Level and Propagation Losses	Good correlation with predicted uplink and downlink values
2. Baseband Frequency Response	S/C degrades performance little if any. Flat from 300 Hz to 6 MHz.
3. Frequency Stability	Long term stability no problem when closed loop * AFC from pilot tone relayed thru satellites is employed. Short term stability found to be a problem. ** Contributers to problem in order of significance were: incidental modulation at power line frequencies, oscillator 1/f phase noise, 1.6 Hz phase modulation due to S/C spin *** and oscillator thermal noise. The latter two were of little consequence.
4. Level Stability	Employing an Automatic Level Control system ****, with a 0.1 dB/S response time, long term level variations were no problem. Short term fluctuations at 1.6 Hz due to S/C spin were not corrected by level control loop but 0.5 dB peak-to-peak variations were no problem.
5. Voice Channel S/N	Rosman tests using 1200-channel spectrum with 600 channel noise loading demonstrated a 40 dB capability with ATS-1 at maximum power. With companders giving a 15 dB improvement, a 55 dB S/N would be obtained
6. Data Error Rate	At 1.2 Kbps using non-coherent FSK an error rate of 6.3×10^{-7} bit/bit was obtained for channel S/N ratio between 30 and 40 dB. At low data rates (i.e., 50, 100, and 300 bps) it was shown that excessive frequency jitter can effect error rates. †

* Open loop correction could not be employed since S/C oscillator frequency offsets were sufficient to cause pilot frequencies to fall in multiplex signal spectrum.

** AFC loop cannot correct these errors due to the 0.27 second lag caused by the propagation delay of the synchronous satellite

*** Caused by antenna phase center being off S/C spin axis

**** Same pilot tone as employed for AFC loop is used.

† Caused by the narrow bandwidths employed at low data rates

rate, linearity, envelope delay, harmonic distortion and frequency response were taken.[7][14] Performance was compared with standards given by the CCIR and EIA recommendation TR-141 and found to be, in general, compatible with the high quality expected for long haul telephony. With 1200-channel loading, compandors would be required to meet S/N ratio requirements. Frequency instabilities were, in this case, almost entirely due to differential doppler but were not significant. An AFC loop was not required.

For the television tests, major system design characteristics were as indicated in Table 13-15.[7][14] Monochrome TV test terminals were installed at all three ATS earth stations and color test facilities were available at Rosman. Experiments conducted and their basic results are described in Table 13-16. In addition to these tests, numerous demonstrations have been conducted and events of interest televised. Included were the "Our World" demonstration in June 1967, the address by Japanese Prime Minister Sato during his Australian visit in October 1967, and coverage of the Olympics in Mexico City in 1968.

Investigations of transmission phenomena included measurements of spacecraft spin modulation, transmit and receive antenna patterns, and repeater saturation characteristics plus ground terminal G/T, antenna pointing accuracy, and transmit and receive antenna patterns. Results were in general agreement with previous independent measurements and theoretical expectations. Investigations of polarization phenomena included evaluations of SHF Faraday rotation as projected from VHF measurements and the effect of satellite antenna beam position on observed polarization at the ground. The latter determined that the ATS-1 polarization angles (polang) changes about 0.11° per degree change in satellite beam position while the ATS-3 polang is constant to approximately ±4° from peak of beam.

Additionally, numerous special tests were performed by NASA ground terminal engineers and the Japanese and Australian governments. The Japanese tests employed the Kashima ground terminal and repeated many of the SSB-FDMA/PM

Table 13-15. TV System Design Characteristics

Parameter	Value
1. RF Carrier Deviations	
a. By video signal	$\pm$ 10 MHz peak
b. By audio subcarrier	$\pm$ 1 MHz peak for 6 MHz subcarrier, $\pm$ 0.715 MHz peak for 4.5 MHz subcarrier, or $\pm$ 1.3 MHz peak for 7.5 MHz subcarrier.
2. Audio Subcarrier Frequencies	6.0 MHz (4.5 or 7.5 MHz optional)
3. Subcarrier Deviation by Audio	$\pm$ 200 KHz peak
4. Video Section Bandwidth	30 Hz to 4.5 MHz (3.5 MHz optional)
5. Audio Section Bandwidth	30 Hz to 13 KHz

Table 13-16. Frequency Translation TV System Experiments

Type Experiment	Nature of Results Obtained
1. Continuous Random Noise	51 dB peak-to-peak signal to weighted rms noise measured at Rosman with peak power on ATS-3. CCIR standards require 56 dB for 99% of time.
2. Periodic Noise (Power supply hum)	S/N of 43 dB with all significant components below 1 KHz obtained to exceed CCIR recommendations by 8 dB.
3. Crosstalk	An initial audio-to-video problem caused by coupling in a common baseband equipment power supply was eliminated to reduce crosstalk level to 75 dB down or more.
4. Linear Waveform Distortion	Frequency response, short time wave form distortion line-time and field-time waveform distortion, and envelope delay evaluated. CCIR recommendations for international TV circuit met and those for system M (Canada and USA) partially met.
5. Non-Linear Waveform Distortion	Differential gain and color vector error (equivalent of differential phase) evaluated. CCIR recommendations for international TV circuit met but those for system M were not met.
6. Insertion Gain Variations	Found to be negligible.

and frequency translation mode tests performed by the NASA ATS terminals. Major differences were a greater emphasis on digital traffic handling capabilities and an investigation of the feasibility of time division multiple access employing frequency translation repeaters. The latter culminated in the demonstration of practical 4-phase and 2-phase systems operating at 13 Mbps and 27 Mbps, respectively.[15] Australian experiments employing the NASA Cooby Creek ground terminal, evaluated digital transmission over satellite voice circuits,[16] telephone signaling systems compatible with satellites,[17] and computer-to-computer communications at bit rates up to 2.4 kbps.[18] The feasibility of operational systems was demonstrated in all cases.

Major objectives of experiments performed using the VHF repeaters of the two satellites were defined in Paragraph 13.2.1. However, prior to conducting the indicated investigations, a series of ground-to-satellite-to-ground tests were conducted employing the VHF facilities of the NASA ATS earth terminals to provide baseline data. These tests and their primary results are described in Table 13-17.[19]

Aircraft to ground communications through the satellite has been successfully demonstrated on a number of occasions by commercial air flights over both the Atlantic and Pacific.[5][20] A number of airlines in the United States plus such foreign carriers as Qantas, Japan Airlines, and BOAC have participated in these tests. Briefly, the aircraft terminals have consisted of a frequency modulation transceiver capable of radiating up to 500 W, data acquisition equipment, and specially designed circularly polarized antenna installations.

Ground-satellite-aircraft tests have demonstrated the feasibility of realizing a high operational reliability in such links. Multipath fading, scintillation, and aircraft antenna anomalies (i.e., variations in gain as function of aspect angle to satellite and polarization ellipticity) have been primary causes of signal fading. High solar and magnetic field activity affected propagation but did not present unmanageable problems. Precipitation static discharges raised normal 1100°K antenna temperatures to 70,000°K. To achieve acceptable communications during these

Table 13-17. NASA Baseline VHF Tests

Type Test	Nature of Results Obtained
1. Receive Signal Level	Good correlation with theory. Diurnal trend indicated showing peak signal level reached in evening hours following sunset. Daily variation is as much as 6 dB.
2. Carrier to Noise Versus Uplink EIRP	Downlink limited region or maximum C/N reached at a ground transmitted EIRP of about 40 dBW. Maximum measured C/N on ATS-1 was 17 dB and on ATS-3 was 20 dB.
3. Signal to Noise, Carrier to Noise & Data Error Rate	Predicted and measured S/N and C/N displayed good agreement. Data error rate at 1.2 Kbps showed that local RFI was a predominant factor.
4. Satellite Transponder Passband Frequency Response	On ATS-1, 2 equal accessing carriers could differ in transmitted power by as much as 9 dB due to gain variations across passband plus compression. On ATS-3, maximum difference was 4 dB. *
5. Satellite Transponder Compression **	On ATS-1, 6 dB of small carrier compression displayed for 10 dB small carrier to large carrier input ratio. No significant compression measured on ATS-3.
6. Carrier Intermodulation **	ATS-1 closely followed theoretical hard limiter performance. Sum of 3rd and 5th harmonics on ATS-1 was 8 dB down. On ATS-3 the sum was 17 dB down.
7. Interference Effects	Various levels and frequency separations for AM and FM interference evaluated as a function of measured voice channel articulation index (AI) of desired signal. *** Results inconclusive due to difficulties in interpreting mechanized measurements of AI.

* Improvement over ATS-1 primarily due to lack of compression in near linear transponder.

** Two input carriers employed.

*** FM employed on desired signal.

disturbances, antenna noise temperatures must be limited to a maximum value of 7000°K. Aircraft receiving from the satellite experienced interference when operating within line-of-sight of aircraft or ground stations transmitting co-channel in the conventional environment.

Aircraft-satellite-ground links have, generally, displayed a lower reliability than the links in the opposite direction. A major cause has been insufficient radiated power from the aircraft and uplink interference caused by conventional VHF communications systems within the satellite's area of earth coverage. The factors producing variations in link performance are, in general, the same as for the ground-satellite-aircraft link. It has been recommended that an operational system employ circularly polarized satellite antennas and linearly polarized aircraft antennas to minimize antenna caused performance variations.

Maritime radio communications via geostationary satellite has been demonstrated to be feasible in a number of ship-to-shore and ship-to-ship communications tests.[(5)] Participating ships have included the Coast Guard cutters Glacier and Klamath, the S.S. Santa Lucia,[(21)] and the German ships Gauss and Meteor. Successful experiments have been conducted with ships operating in the Pacific, the Arctic, the Antarctic and the Atlantic Oceans. Indications were that S/N ratios of about 40 dB could conveniently be attained on a voice channel and data error rates on the order of 10^{-3} and 10^{-4} bits/bit realized at 600 bps transmission rates. Short term fade depths in the order of 12 dB were observed in some tests.

Data dissemination in a meteorological network was displayed in the WEFAX experiment. Data collection from small unmanned stations was demonstrated as part of OPLE. Additionally, special hydrological[(22)] and ocean buoy experiments[(23)] have shown successfully that satellites can be employed for remote station interrogation and data transfer. Signal fading was observed to be a significant factor to be considered in designing operational systems.

VHF ranging experiments have displayed the feasibility of employing satellites operating at these frequencies for navigational purposes. Tests indicated that position fixing accuracies within ± 2 km (±1 n. mi.) were attainable.[24] The satellite's VHF transponder has also been used in time dissemination experiments conducted by ESSA and the National Bureau of Standards. Accuracies of better than 10 microseconds have been demonstrated.[25]

The VHF transponders on ATS-1 and 3 have, additionally, been employed in various special tests and demonstrations. These include communications support for selected Apollo landings and tests of: aircraft to aircraft communications when the two aircraft are operating near opposite poles of the earth,[26] chirp modulation as a means of overcoming multipath effects and doppler shifts,[27] educational and public radio transmissions in Alaska, and VHF propagation phenomena. The latter include measurements of multipath, scintillation, and Faraday rotation effects. Each satellite's telemetry beacon and the Third Harmonic Generator (i.e., third harmonic of telemetry beacon) on ATS-3 have also been employed for such measurements. These measurements, in addition to supplying direct propagation information, have been useful in studies to determine the temporal makeup of the earth's ionosphere.

13.2.6 Operational Results

Since ATS-1 and 3 were experimental satellites, no operational traffic was carried. The operational performance of the NASA ATS ground terminals was good. In general, it was also shown that operational mobile VHF terminals were feasible. However, in specific cases of hastily assembled experimental VHF facilities, operational difficulties including insufficient transmitter power, antenna anomalies, and poor equipment reliability were encountered.

The operational performance of the two spin stabilized satellites was basically quite good. Specific minor difficulties encountered on ATS-1 included a gradual decay of radiated power when both SHF transponders and all four TWTs were energized and occasional SSCC picture streaking. The former was determined to be a temperature problem and operation with three TWTs was found to be sustainable. The latter occurred during periods when the spacecraft load exceeded solar array output to the extent that the batteries were depleted resulting in an abnormally low battery voltage.

Operational difficulties on ATS-3 included the failure of one 12-watt TWT to operate, a spurious SHF emission at 4201 MHz when operating in the FT mode, spacecraft response to commands intended for ATS-1, and a malfunction of the mechanically despun antenna (MDA). The spurious SHF emission was conjectured to be due to thermal effects, occuring during eclipse, creating an electrical or mechanical/electrical path to allow sustained passage of sufficient electrical energy to activate the VCO employed in the SSB-FDMA/PM mode. Responses to ATS-1 commands were determined to be due to the address assignments made and not due to equipment abnormalities. As a result, the address assignments for ATS-4 and 5 were changed. The despun antenna malfunction was verified to be produced by stalling of the MDA motor as discussed in Paragraph 13.2.5.

13.2.6.1 Additional Services ATS-1

Some services performed by ATS-1 in addition to technological and scientific experiments were the relay of special TV programs such as the first splashdown of the Apollo moonflight, EXPO 67 in Australia, and the Japanese Prime Minister's visit to Australia; the performance of special SHF tests such as mass data transfer and antenna beam control during the eclipse; relay of special VHF communications such as emergency communications during the Alaskan flood and magnetic studies at field line base; and relay of special weather facsimile for air operations in the Pacific. ATS-1 also gave real-time data support to the ground stations operating with INTELSAT II and to OGO-IV and OSO-IV satellites.[40]

Educational broadcasting to both Alaska and the Pacific Basin is currently being done through ATS-1. Included are college-level seminars and courses at both primary and secondary levels.

ATS-1 will be used in conjunction with ATS-6 for the Alaska ATS-6 Education Telecommunications Experiment and in the ATS-6 Health Experiments conducted in Alaska.[42]

13.2.6.2 Additional Services ATS-3

ATS-3 performed many services in addition to the technological and scientific experiments. Some of these services included support of the Apollo missions; TV coverage of Pope Paul's visit to Bogota, Columbia; special SHF tests such as the IEEE International Communication Conference; VHF relay of special commands to ATS-4 from Johannesburg; demonstration of automatic picture transmission at NASA headquarters by the weather facsimile (WEFAX) experiment on board the ATS-3; real-time data support of the OSO-IV satellite; and provided an RF collimation source for the Canadians.[40]

Through a series of maritime experiments, involving both ship position location and ship-to-shore communications through the spacecraft, ATS-3 has demonstrated that major improvements in the management of shipping fleets can be made by use of the capabilities of synchronous-orbit communications satellites.

ATS-3 will be used in conjunction with ATS-6 in Health-Education Telecommunications Experiment for both the Rocky Mountain area and the Appalachian Region.[42]

13.3 GRAVITY GRADIENT STABILIZED SATELLITES

13.3.1 General Description

The experiments carried on the Application Technology Satellites that featured evaluations of gravity gradient stabilization can be grouped into six major categories. These categories are listed and defined in Table 13-18.[28], [29], [30] The objectives of the SHF C-Band experiments were the same as indicated in the "General Description" of the spin stabilized ATS (see Section 13.2.1). The objectives of the L-Band experiments were to demonstrate the feasibility of air-to-ground communications at these frequencies and to investigate propagation effects. The objective of the millimeter wave experiment was to investigate propagation at 15 and 32 GHz.

Three active repeater satellites (i.e., ATS-2, ATS-4, and ATS-5) were launched during the ATS program for the express major purpose of evaluating gravity gradient stabilization. The status of these spacecraft is reviewed in Table 13-19.

Table 13-18. Experiment Categories

Number	Description
1	Gravity-Gradient Stabilization at Medium and Synchronous Altitude
2	C-Band, L-Band, and Millimeter Wave Radio Communications and Propagation
3	Meteorological Experiments
4	Measurements of the Earth Environment
5	Technology Applicable to Spacecraft Stabilization and Stationkeeping
6	Miscellaneous Spacecraft Technology

ATS-2 (i.e., ATS-A prior to launch) failed to reach its intended 6000 nautical mile circular orbit when the second stage of the launch vehicle failed to restart leaving the spacecraft in a highly elliptical orbit having a relatively low perigee. This precluded proper testing of the gravity gradient control system although the stabilization booms were successfully deployed. Limited data was obtained on most of the remaining spacecraft experiments including data on the C-Band communications, meteorological, and environment measurements experiment.

Table 13-19. Gravity Gradient Spacecraft

Satellite		ATS-2	ATS-4	ATS-5
Manufacturer & Sponsor		Hughes Aircraft & NASA		
Launch Date		4/5/67	8/10/68	8/12/69
Launch Vehicle		Atlas-Agenda D	Atlas-Centaur	
Orbital Data*	Apogee	11,180 km (6,947 mi.)	773 km (480 mi.)	35,851 km (22,277 mi.)
	Perigee	185 km (115 mi.)	217 km (135 mi.)	35,721 km (22,196 mi.)
	Inclination	28.4^{o}	29^{o}	2.6^{o}
	Period	218.9 min.	94.5 min.	1436 min.
Status		Satellite was shut down 10/23/67. Orbit decayed 9/2/69 resulting in spacecraft destruction	Orbit decayed 10/17/68 resulting in satellite destruction	Satellite spinning around longitudinal axis but in synchronous orbit located at about 105^{o}W longitude

*At initial injection. Altitude control and station-keeping maneuvers produced changes.

ATS-4 (i.e., ATS-D prior to launch) fell short of its intended synchronous orbit when the Centaur failed to re-ignite for a second burn leaving the spacecraft in a low altitude parking orbit with the Centaur still attached. Shortly after second burn failure, the ATS-4-Centaur conglomerate went into a tumble about a traverse axis. Subsequent maneuvers by the spacecraft attitude control systems were unable to completely correct this condition. As a result the gravity gradient system could not be tested and little information was obtained on the other satellite experiments although all subsystems appeared to be operating properly. Among the operations accomplished was a partial deployment of the stabilizing booms, boom scissoring and successful firing of the ion engines.

Table 13-20. Millimeter Wave and L-Band Terminals

Location		Sponsor	Antenna Diameter (m) (ft)	Frequency Band
Bedford, Massachusetts*		Air Force Cambridge Research Labs	8.5 (28)	Millimeter Wave
Cambridge, Massachusetts*		Department of Transportation	3.0 (10) (2 dishes)	Millimeter Wave
Ottawa, Canada	Prime Site*	Canadian Communications Research Center	9.1 (30)	Millimeter Wave
	Secondary Site*		2 (8)	
Rome, New York*		Rome Air Development Center	4.6 (15)	Millimeter Wave
Holmdel, New Jersey*		Bell Telephone Laboratories	6.1 (20)	Millimeter Wave
Lakehurst, New Jersey*		U.S. Army Satellite Communications Agency	9.1 (30)	Millimeter Wave
Greenbelt, Maryland	Receive Site	NASA, Goddard Space Flight Center	4.6 (15)	Millimeter Wave
	Transmit Site		3.0 (10)	
Waldorf, Maryland*		Naval Research Labs	18 (60)	Millimeter Wave
Columbus, Ohio***	Fixed Site*	Ohio State University	9.1 (30)	Millimeter Wave
	Mobile Site*		4.6 (15)	
Rosman, North Carolina** ***		NASA, Goddard	4.6 (15)	Millimeter Wave
Boulder, Colorado*		ESSA Wave Propagation Lab	3.0 (10)	Millimeter Wave
Boulder, Colorado*		Westinghouse Georesearch	3.7 (12)	Millimeter Wave
Orlando, Florida*		Martin Marietta Corp.	3.7 (12)	Millimeter Wave
San Diego, California * ***		Naval Electronics Laboratory Center	18 (60)	Millimeter Wave
Austin, Texas* ***		University of Texas	3.0 (10) (2 dishes)	Millimeter Wave
Rosman, North Carolina**		NASA, Goddard	4.6 (15)	L Band
Mojave, California**		NASA, Goddard	4.6 (15)	L Band
S.S. Manhattan** ****		NASA, Goddard	0.9 (3)	L Band

*Receiver only.
**Transmit/receive installation.
***Active participants in NASA/GSFC Millimeter Wave Experiment. Remaining Millimeter Wave stations are independent experimenters.
****Experimental icebreaking oil tanker.

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ATS-5 (i.e., ATS-E prior to launch) was successfully placed into the planned synchronous orbit but was left spinning about the spacecraft's longitudinal axis. Spin stabilization about this axis was the planned method of satellite control during the transfer orbit, apogee motor firing, and maneuvers to position the spacecraft on station. However, greater than expected nutation during this phase produced loss of spacecraft control and ultimately resulted in the present spin about the proper axis but in a direction opposite (i.e., counterclockwise) to that needed for the planned operation of the two-stage yo-yo despin mechanism. Consequently, a scheduled investigation of gravity gradient stabilization was again left unaccomplished. Modifications to earth terminal equipment, however, have allowed many of the remaining experiments aboard this satellite to be partially successful. In particular, objectives have been partially attained with regard to the millimeter wave, L-Band, and environmental measurements experiments.

The primary earth terminals involved in the few C-Band communications operations conducted included the terminals employed for the testing on ATS-1 and ATS-3 (see Table 13-3) with the addition of the terminal at Ahmedabad, India. The latter became operational in 1967 and conducted tests and demonstrations with ATS-2. The major terminals participating in the L-Band and millimeter wave tests on ATS-5 are defined in Table 3-20.[31, 32, 33] All of these terminals became operational in 1969 and 1970. Tracking, telemetry, and command (TT&C) was provided by separate installations included in the NASA ATS facilities located respectively at Rosman, North Carolina; Cooby Creek, Australia; and Mojave, California. In addition, some telemetry and tracking was provided by terminals at Johannesburg, South Africa; Tananarive, Madagascar; and Kauai, Hawaii. Satellite launchings were provided by NASA.

The launch difficulties on ATS-2 and 4 precluded any significant contributions to satellite communications by the experiments on board these spacecraft. However, ATS-5 did make several contributions, first, its millimeter wave experiment has provided valuable data that will contribute towards opening this band for satellite communications; secondly, its L-Band experiment has given a preliminary indication of the potential that these frequencies hold for aircraft and maritime control, communications, and navigation; and third, this satellite displayed the potential difficulties involved in injecting a gravity gradient stabilized satellite into a synchronous orbit and deploying it to a desired station.

13.3.2 System Description

The SHF (i.e. C-Band) tests conducted were done primarily on a loop back or half duplex basis. The system configuration for the millimeter wave tests was as shown in Figure 13-7. The figure indicates, uplink propagation measurements were performed in the satellite and telemetered to the ground. Downlink measurements are performed on the ground. A system block diagram of the initially planned L-Band communications test configuration is shown in Figure 13-8. Signals are sent from the ground stations to the satellite at C-Band. These signals are combined in the satellite and retransmitted to the aircraft at L-Band. The ground stations monitor the L-Band transmissions from the satellite for frequency control and ground-to-satellite range measurements. Aircraft transmissions arrive at the satellite at L-Band where they are combined and transferred to C-Band for transmission to the ground stations. An L-Band ground station transmit capability is also provided to allow full testing of the satellite from the ground. The earth coverage supplied by ATS-5 for the millimeter wave and L-band tests is shown in Figure 13-9.

SHF, C-Band, operating frequencies on the gravity gradient stabilized spacecraft were the same as on ATS 1 & 3 (see Table 13-4).

The same is true of the TT&C frequencies (see Table 13-6). The millimeter wave and L-Band operating frequencies are shown in Table 13-21.[31, 32] The indicated millimeter wave frequencies are of interest in that they are located at the first two windows in the frequency spectrum above 10 GHz where water vapor and oxygen absorption are low. Millimeter wave propagation, in general, is of interest in that it offers a possible means of reducing overcrowding in the lower bands. Additionally, it offers extremely wideband capabilities, high gain-small aperture antenna

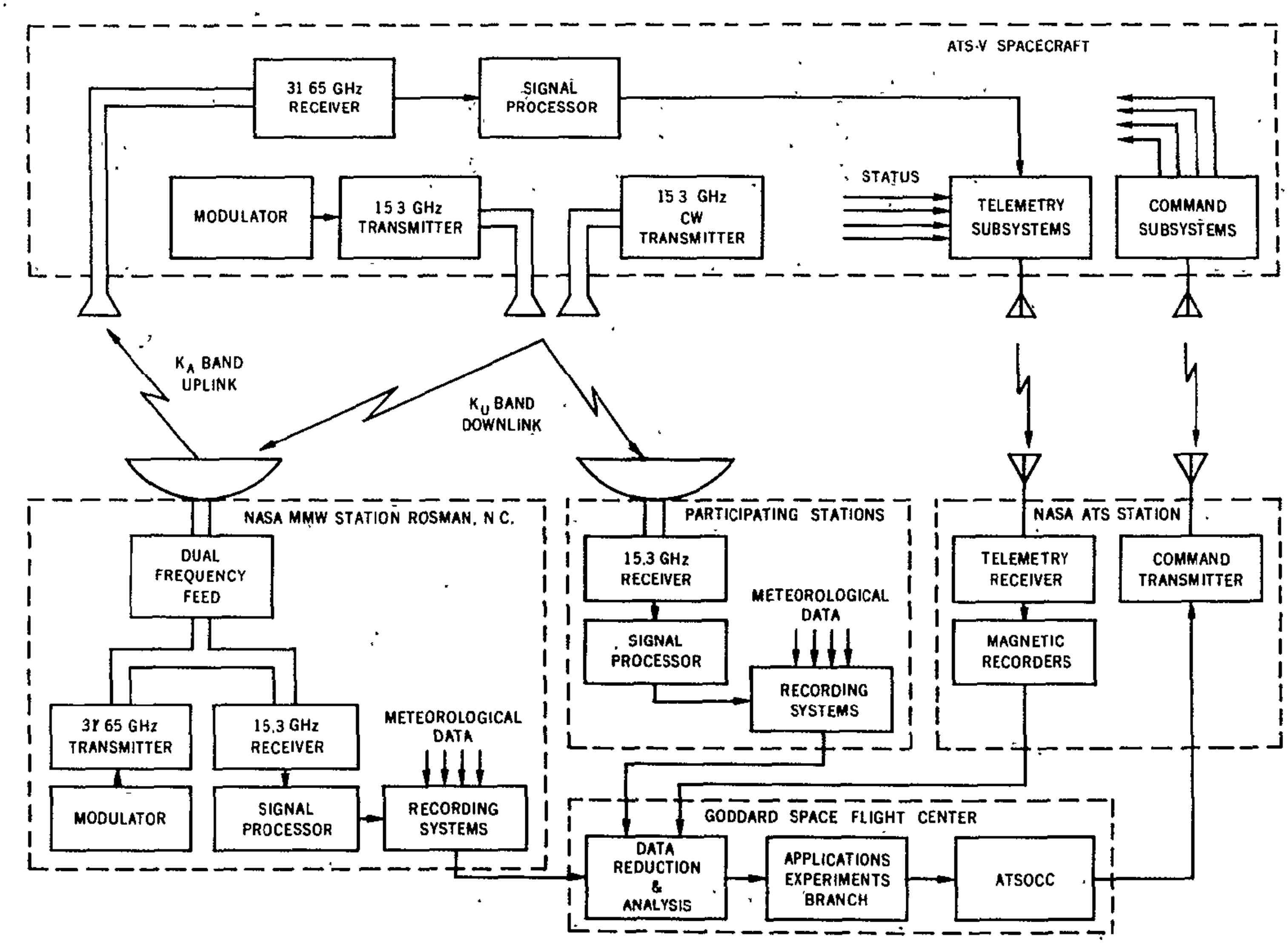


Figure 13-7. ATS-5: System Configuration for Millimeter Wave Tests

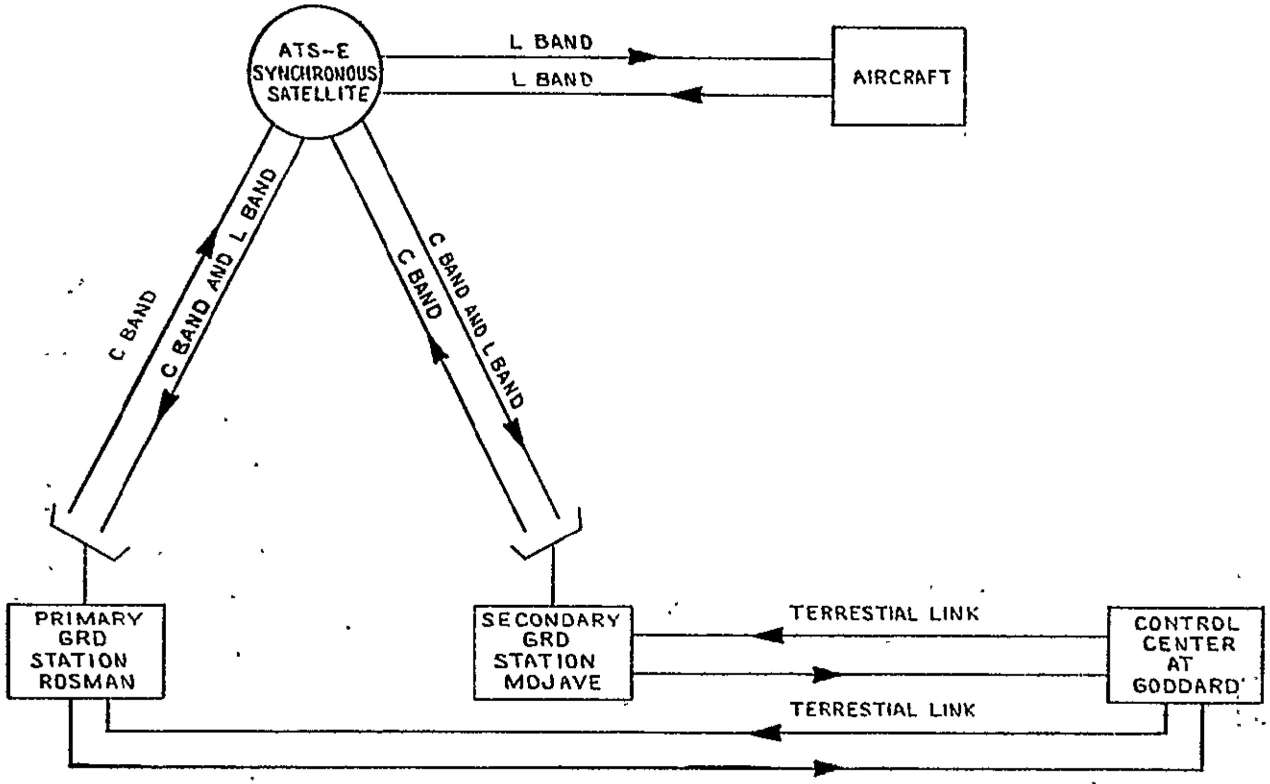


Figure 13-8. System Block Diagram for L-Band Tests

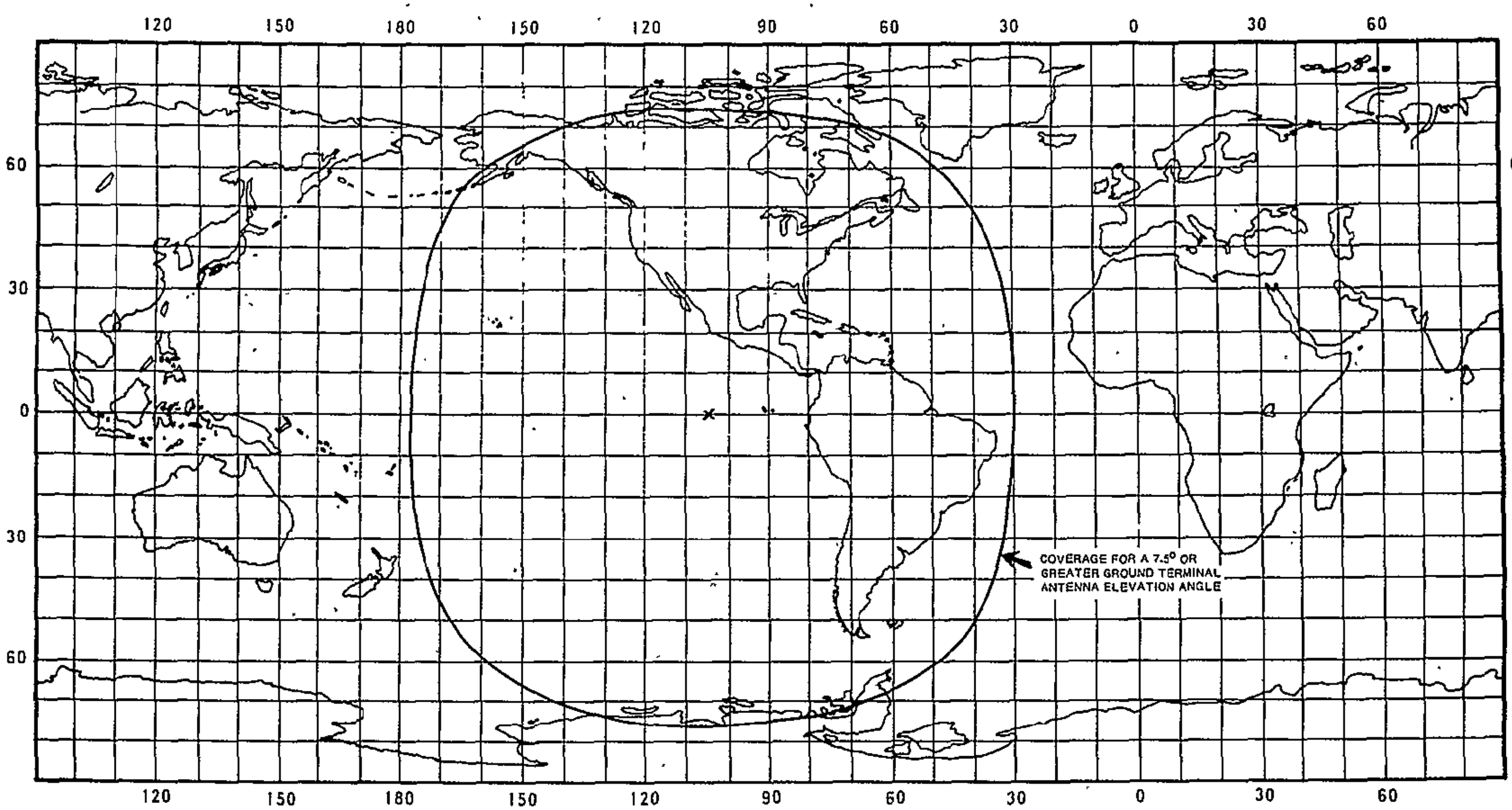


Figure 13-9. ATS-5 Earth Coverage

characteristics, and reduced size and weight of components. The L-Band frequencies are of interest for aircraft control, navigation, and communications. The VHF frequencies are also commonly considered for this purpose since they are compatible with existing equipment. L-Band offers the potential of more accurate satellite ranging and wider bandwidths for multiple access communications and control.

Table 13-21. Millimeter Wave and L-Band Frequencies (GHz)

Millimeter Wave		L-Band	
Uplink	Downlink	Uplink	Downlink
31.65	15.3	1.65	1.55

The basic signal processing techniques employed for C-Band tests were the same as used in ATS-1 and ATS-3 tests (see Tables 13-7 and 13-8). The millimeter wave experiment provided two complete and independent propagation measurement links. Similar signal processing techniques were employed on each link. It basically consisted of modulating a carrier with a single tone such that a carrier and first order upper and lower sidebands all of equal level are produced. This was accomplished by a varactor phase modulator in the satellite and a varactor frequency upconverter, which was capable of AM, FM, or PM modulation, in the ground transmitter. For the uplink, sidebands could be set at $\pm$ 1.0, $\pm$ 10, or $\pm$ 50 MHz from the 31.65 GHz carrier. For the downlink, settings of $\pm$ 0.1, $\pm$ 1.0, $\pm$ 10 or $\pm$ 50 MHz from the 15.3 GHz carrier were possible.(34) Receivers employed down conversion mixing, filtering, envelope detectors, and phase detectors to derive measurements of carrier, upper sideband, and lower sideband amplitude plus relative sideband phase.

The L-Band signal processing employed was dependent upon the modes selected for satellite operation. Four modes were commonly employed as follows:

1. Narrowband L-L (FM/FM)

Spacecraft receives at L-Band and retransmits at L-Band (frequency translation).

2. Cross Strap L-C & C-L

   a. L-C Cross-strap (SSB/FM)

   Spacecraft receives at L-Band (SSB), translates to video (500 to 600 kHz) and uses the video signal to modulate (FM) the spacecraft C-Band VCO; the output of which is then translated to C-Band and retransmitted.

   b. C-L Cross-strap (FM/FM)

   Spacecraft receives at C-Band, frequency translates to L-Band, and retransmits (Frequency translation).

3. L-L (SSB/FM)

Spacecraft receives at L-Band (SSB) translates to video (500 to 600 kHz) and uses the video signal to modulate (FM) the Spacecraft L-Band VCO; the output of which is then translated to L-Band for transmission to the earth station.

4. Wideband Data Mode (FM downlink only)

Video signals from onboard-spacecraft equipment modulates (FM) the satellite L-Band VCO the output of which is upconverted to L-Band for transmission to earth. A fifth possible mode was identical to narrowband L-L (FM/FM) except a wide bandwidth was supplied.

Link performance for modes involving the C-Band downlink and a high uplink S/N was essentially as defined in Tables 13-7 and 13-8. Typical link performance for modes involving the L-Band downlink and a high uplink S/N was as described in Table 13-22 for a narrowband L-L FM/FM link. The frequency translation modes were not designed primarily for multiple access. The planned multiple access modes of operation employed the L-L SSB/FM and the L-C SSB/FM satellite transponder configurations.

Table 13-22. Signal Processing for L-L Satellite Channel

Multiple Access	FDMA for limited number of accesses
RF Modulation	FM
Ground Demodulator Performance	Threshold estimated at 6 dB C/N based upon employing FMFB receivers
Rosman Receive Carrier-to-Noise	9 dB employing 2 TWTs; 2.2 MHz IF bandwidth, and 1 satellite access
Rosman Receive Margin	3 dB

13.3.3 Spacecraft

Characteristics of the communications-related subsystems of ATS-2 and ATS-4 are described in Table 13-23.[10, 28, 29] Block diagrams of the three possible modes of the SHF transponders were shown in Figures 13-2, 3 and 4. The Table displays some of the major system design differences in synchronous-altitude and medium-altitude gravity gradient stabilized communications satellites. These include, for the latter, low antenna gains for earth coverage beams; no need for an onboard apogee motor and spin stabilization prior to positioning "on station;" and no need for stationkeeping during gravity gradient stabilization "on station."

Characteristics of most of the communications-related subsystems on ATS-5 are shown in Table 13-24.[10, 30, 32, 34] A functional diagram depicting the L-Band transponder, and its various selectable modes, is given in Figure 13-10.[32] With the exception of the antenna system, the characteristics of the onboard millimeter wave equipment are not described in the Table since this equipment does not include a millimeter wave communications transponder. Its primary purpose was simply to make propagation measurements.

Table 13-23. ATS-2 and 4 Characteristics

			ATS-2		ATS-4	
		Satellite	ATS-2		ATS-4	
Antennas		Type	SHF-Horns used for both xmit and receive	TT&C-8 whip turnstile	SHF - Planar array used for both xmit and receive	TT&C-Essentially the same as for ATS-2
Antennas		Number	One	One	One	
Antennas		Beamwidth (3 dB)	45^{o} pencil beam xmit and receive	Essentially omnidirectional	23^{o} pencil beam xmit and receive	
Antennas		Gain	10.5 dB xmit and receive	0 dB	16.5 dB xmit and receive	
Repeaters		Frequency Band	SHF (C-Band)		SHF (C-Band)	
Repeaters		Type	Essentially the same as for the repeaters on ATS-1 (see Table 13-10)		Essentially the same as for the repeaters on ATS-1 (see Table 13-10)	
Repeaters		3 dB BW				
Repeaters		Number				
Repeaters	Receiver	Type Front End				
Repeaters	Receiver	Front End Gain				
Repeaters	Receiver	System Noise Figure				
Repeaters	Transmitter	Type				
Repeaters	Transmitter	Gain				
Repeaters	Transmitter	Power Out				
Repeaters		EIRP	18 dBW with 2 TWT's		24 dBW with 2 TWT's	
General Features	Stabilization	Type	Gravity gradient with no stationkeeping capability(2)		Spin initially* with nitrogen jets for spinup and hydrazine gas jet reaction control. Gravity gradient "on station" with microthruster stationkeeping**	
General Features	Stabilization	Capability	No data due to launch failure		No data due to launch failure	
General Features	Power Source	Primary	N-on-P solar array with 140 watts at launch		Essentially the same as for ATS-2	
General Features	Power Source	Supplement	Two nickel cadmium batteries with 6 amp-hr/battery capacity at launch			
General Features		Comm. Power Needs	Each SHF transponder - 35 watts and gravity gradient - 35 watts			
General Features		Size	Cylindrical - 183 cm (72 in.) high and 142 cm (56 in.) in diameter			
General Features		Weight	370 kg (815 lb) initially in orbit		392 kg (864 lb) initially in orbit	

*During the transfer orbit and until the spacecraft is positioned on station.
**Subliming solid jets also available for satellite inversion if stabilization occurs at 180^{o} from desired attitude.

Table 13-24. ATS-5 Characteristics

Antennas		Type	L Band - 12 Helix planar array used for both xmit and receive	Millimeter Wave - Conical horns used for both xmit and receive	SHF (C Band) - Essentially the same as for ATS-4 (see Table 13-23)	TT&C - Essentially the same as for ATS-2 (see Table 13-23)
Antennas		Number	One	One		
Antennas		Beamwidth (3 dB)	24^{o} pencil beam for xmit	20^{o} pencil beam xmit and receive		
Antennas		Gain	Xmit - 14 dB Rec - 15 dB	Xmit - 19 dB Rec - 19 dB		
Repeaters		Frequency Band	L-Band*		SHF (C Band)	
Repeaters		Type	Multiple mode** supplying: (a) narrowband IF translation*** (b) wideband IF translation*** (c) modulation conversation for multiple access (d) wideband transmission of onboard data (e) C-L band**** and L-C† band cross-strap			Essentially the same as for one of the repeaters on ATS-1 (see Table 13-2)
Repeaters		3 dB BW	(a) narrowband translation - 2.5 MHz (b) wideband translation - 25 MHz (c) modulation conversion - 100 KHz uplink and 25 MHz downlink (d) onboard data xmit - 25 MHz (e) cross strap - 25 MHz for C-L and 100 KHz uplink into 25 MHz downlink for L-C			
Repeaters		Number	One			
Repeaters	Receiver	Type Front End	Tunnel diode amplifier into down conversion mixer			
Repeaters	Receiver	Front End Gain	No data			
Repeaters	Receiver	System Noise Figure	8.5 dB			
Repeaters	Transmitter	Type	Two TWT's††			
Repeaters	Transmitter	Gain	No data			
Repeaters	Transmitter	Power Out	12 watt per TWT or 24 watt total			
Repeaters		EIRP	25.4 dBW with 2 TWT's			24 dBW with 2 TWT's
General Features	Stabilization	Type	Spin initially††† with nitrogen jets for spinup and hydrazine gas jet reaction control. Gravity gradient "on station" with microthruster stationkeeping			
General Features	Stabilization	Capability	Excessive nutation with apogee motor attached during spin stabilized phase. No gravity gradient data obtained			
General Features	Power Source	Primary	N-on-P solar array with 175 watts at launch			
General Features	Power Source	Supplement	2 nickel cadmium batteries with 6 amp. hr/battery capacity at launch			
General Features		Comm. Power Needs	C band xponder - 35 watt, L-band xponder - 90 watt, gravity gradient - 35 watt, and millimeter wave experiment - 30 watt			
General Features		Size	Cylindrical - 183 cm (72 in.) high and 152 cm (60 in.) in diameter			
General Features		Weight	433 kg (954 lb) initially in orbit			

*Transponder is an adaption of one of C band transponders appearing on previous Applications Technology Satellites.
**Modes are independently selectable by ground command.
***Soft limiter.
****Wideband IF translation.
†Modulation conversion for multiple access (i.e., SSB-FDMA/FM).
††Can be operated individually or in parallel.
†††During the transfer orbit and until the spacecraft is positioned on station. Subliming solid jets also available for satellite inversion if stabilization occurs at 180^{o} from desired attitude.

A separate unrelated millimeter wave receiver and transmitting system were provided to aid in evaluating propagation at two different frequencies. The transmitting system included a primary and secondary transmitter operating at the same frequency. Additionally, a capability existed to receive and detect a TV signal to be used to modulate the L-Band satellite transmitter.[35] However, the spinning condition of ATS-5 precluded transmissions of TV signals.

The spacecraft millimeter wave receiver utilized a balanced mixer front end with a 17 dB maximum noise figure working into a 1.05 GHz solid state IF amplifier having a 47.5 dB gain.[34] Maximum received signal level was -85 dBm and minimum sensitivity was -120 dBm. The receiver phase locked on the carrier with the aid of a track-and-search circuit providing a $\pm$ 5 kHz minimum pull in range over a $\pm$320 kHz band. The solid state primary millimeter wave transmitter supplied 250 mW (unmodulated) and 70 mW per line (modulated) of downlink power. The secondary transmitter was identical but could not be modulated by a tone.

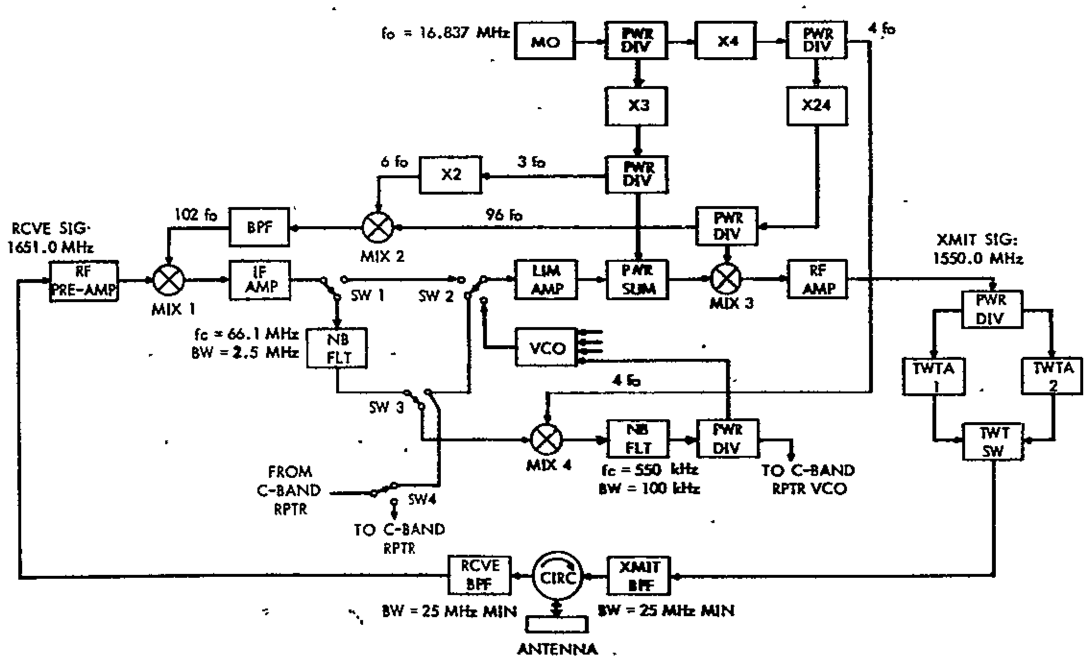


Figure 13-10. ATS-5 L-Band Repeater Block Diagram

In addition to the communications related subsystems, ATS-2 provided[28]: a) two 2.5-centimeter (1-inch) 800-line advanced vidicon cameras, one narrow-angle and one wide-angle, and a tape recorded as a meteorological experiment; b) two 525-line TV cameras measuring boom thermal-bending characteristics plus a power control unit, solar aspect sensor, and two IR earth sensors to support the gravity gradient experiment; c) an environmental measurements package including omnidirectional proton-electron counters, electron magnetic deflection spectrometer, multi-element particle telescope, VLF whistler mode detector, cosmic radio noise receiver, solar cell radiation damage array, thermal coating samples, and electric field experiment; and d) a DOD albedo experiment.

In addition to the communications-related subsystems, ATS-4 provided [29]: a) hydrazine gas jets plus passive and active nutation control systems for spacecraft stabilization and stationkeeping during the period of spin stabilization; b) a two-stage yo-yo despin mechanism; c) resisto jet and cesium ion microthrusters for stationkeeping during gravity gradient stabilization; d) a TV camera monitoring booms plus solar aspect and IR earth sensors to support the gravity gradient experiment; e) an image orthicon day-night camera as a meteorological experiment; and f) a magnetometer sensor measuring spacecraft charge as an environmental measurements experiment.

In addition to the communications-related subsystems, ATS-5 provided [30]: a) essentially the same equipment as listed in items a) through d) for ATS-4; b) an environmental measurements package including a tridirectional particle detector measuring protons with energies between 30 and 250 keV and electrons between 30 and 300 keV, a unidirectional particle experiment to study auroral particle fluxes, a bidirectional particle experiment to map electrons and protons on constant lines of force and determine properties of acceleration within the magnetosphere, an omnidirectional particle experiment measuring electrons in 12 discrete energy ranges and the flux of solar cosmic rays, a radiometer measuring solar radio bursts between 50 kHz and 4 MHz, and an electric field measurements experiment; and c) other experiments in spacecraft technology including a magnetic damper, a solar cell voltage monitor, heat pipes for solar panel thermal equalization, a third harmonic generator similar to that on ATS-3, a solar cell damage experiment and a magnetometer experiment.

13.3.4 Ground Terminals

Major NASA terminals supporting SHF, C-Band, operations were the same as employed on ATS-1 and 3. These terminals were described in Table 13-2. Terminals participating in millimeter wave and L-Band experiments were defined in Table 13-20. The millimeter wave installation at NASA's Rosman, North Carolina facility and the L-band installation at Mojave, California are typical of the earth terminals employed for these two respective groups of experiments. Major characteristics of typical millimeter wave and L-Band terminals are described in Table 13-25.[32],[34] Terminal block diagrams are provided in Figures 13-12[31] and 13-13.[32]

The millimeter wave terminal block diagram displays the interest that existed in finding meteorological measurement techniques which could be useful in predicting propagation losses at these frequencies. The L-Band terminal was configured such as to allow operation in the satellite L- to C-Band cross strapping mode. The linear polarization employed at the millimeter wave terminal and the circularly-polarized feeds of the L-Band terminal were compatible with the spacecraft polarizations making link losses due to this source small.

13.3.5 Experiments

Experiments that were planned for ATS-2, 4, and 5 are summarized in Table 13-26.[28],[29],[30] The Table also indicates the six major experiment categories, listed in Table 13-18, into which the individual experiments can be grouped.

Some data was obtained on most of the experiments onboard ATS-2. The data, generally, was of limited value, however, since a launch vehicle failure left

Table 13-25. Characteristics of Millimeter Wave and L-Band Ground Terminals

	Terminal Feature	Terminal: Rosman (Millimeter Wave)	Terminal: Mojave (L Band)
Antenna	Type	Cassegrain	Cassegrain
	Aperture Size	4.6 m (15 ft) Diameter	4.6 m (15 ft) Diameter
	Receive Gain	54dB	35.5 dB
	Efficiency	45%*	65%*
	Receive Beamwidth	.3°(1) @ 3 dB Pts.	.3°(1) @ 3 dB Pts.
Receive System	Type Preamplifier	Tunnel Diode	Uncooled Parametric Amplifier
	Bandwidth	600 MHz** @ 3 dB Pts.	No Data***
	Noise Temperature	1000°K	340°K
Transmit System	Type Amplifier	TWT	Klystrom
	Bandwidth	450 MHz** 3 dB Pts.	7 MHz @ 3 dB Pts.
	Amp. Power Out	1KW****	1KW
Tracking	Type	Conical Scan Autotrack & Program-Autotrack	Slaved to 40ft. C Band Antenna Autotrack
	Accuracy	No Data	No Data
Total Performance	G/T	22 dB/°K	9.2 dB/°K
	EIRP	116 dBM	93.6 dBM
Polarization	Transmit Feed	Linear	Circular
	Receive Feed	Linear	Circular
	Terminal Feature	Rosman (Millimeter Wave)	Mojave (L Band)
Installation	Radome	None	None
	Type Facility	Transportable	Transportable

NOTE:
- * Derived Value Based on Data Available
- ** RF Bandwidth
- *** 25 MHz Required to Receive Wideband Data from Satellite
- **** Normally Operated at 10 to 100 Watts

Transmitter is Linear to About 200 Watts for Use in Multiple Access Mode

Conical Scan Could Not be Used Due to the Spin Condition of ATS-5

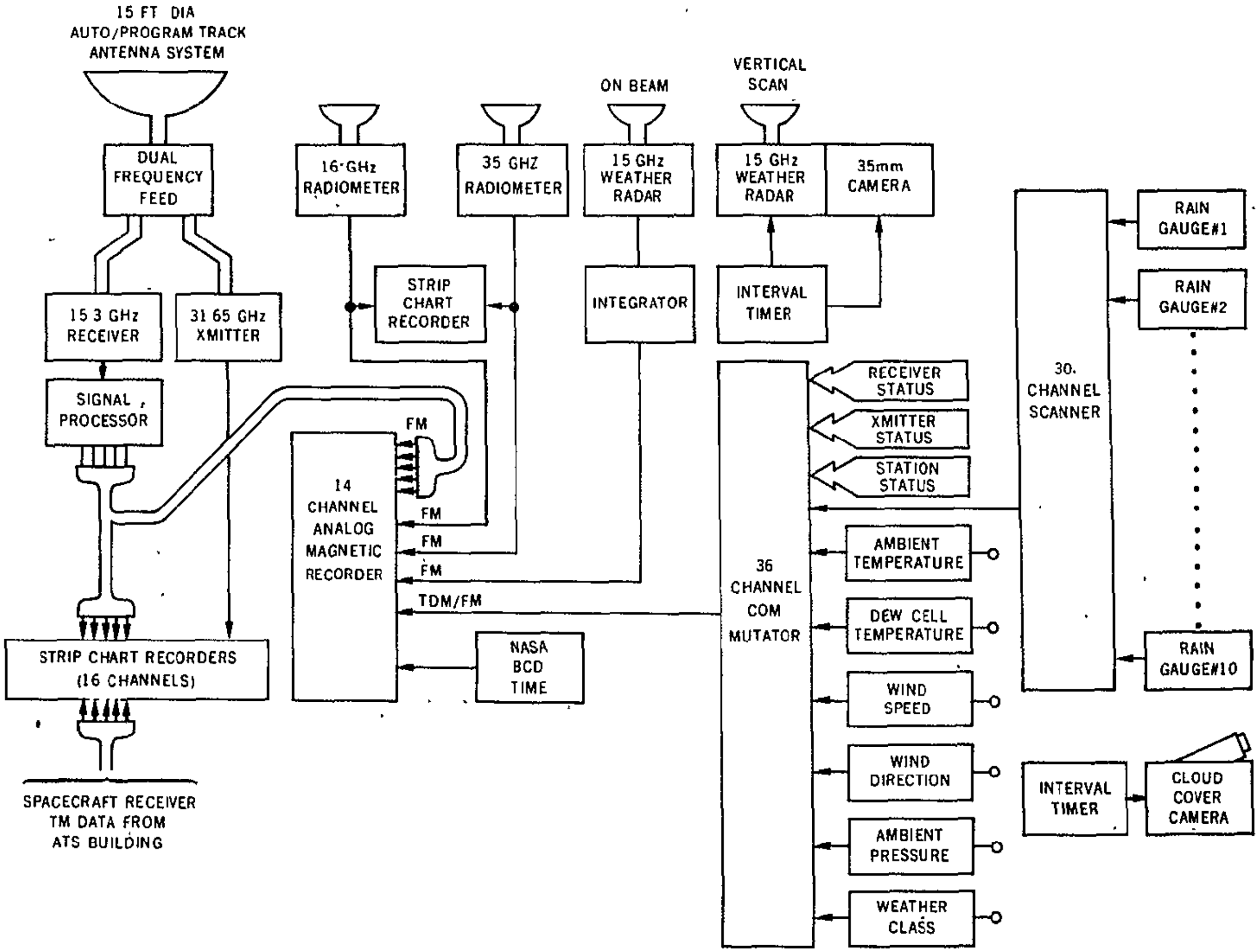


Figure 13-11. The NASA Rosman, North Carolina Millimeter Wave Station

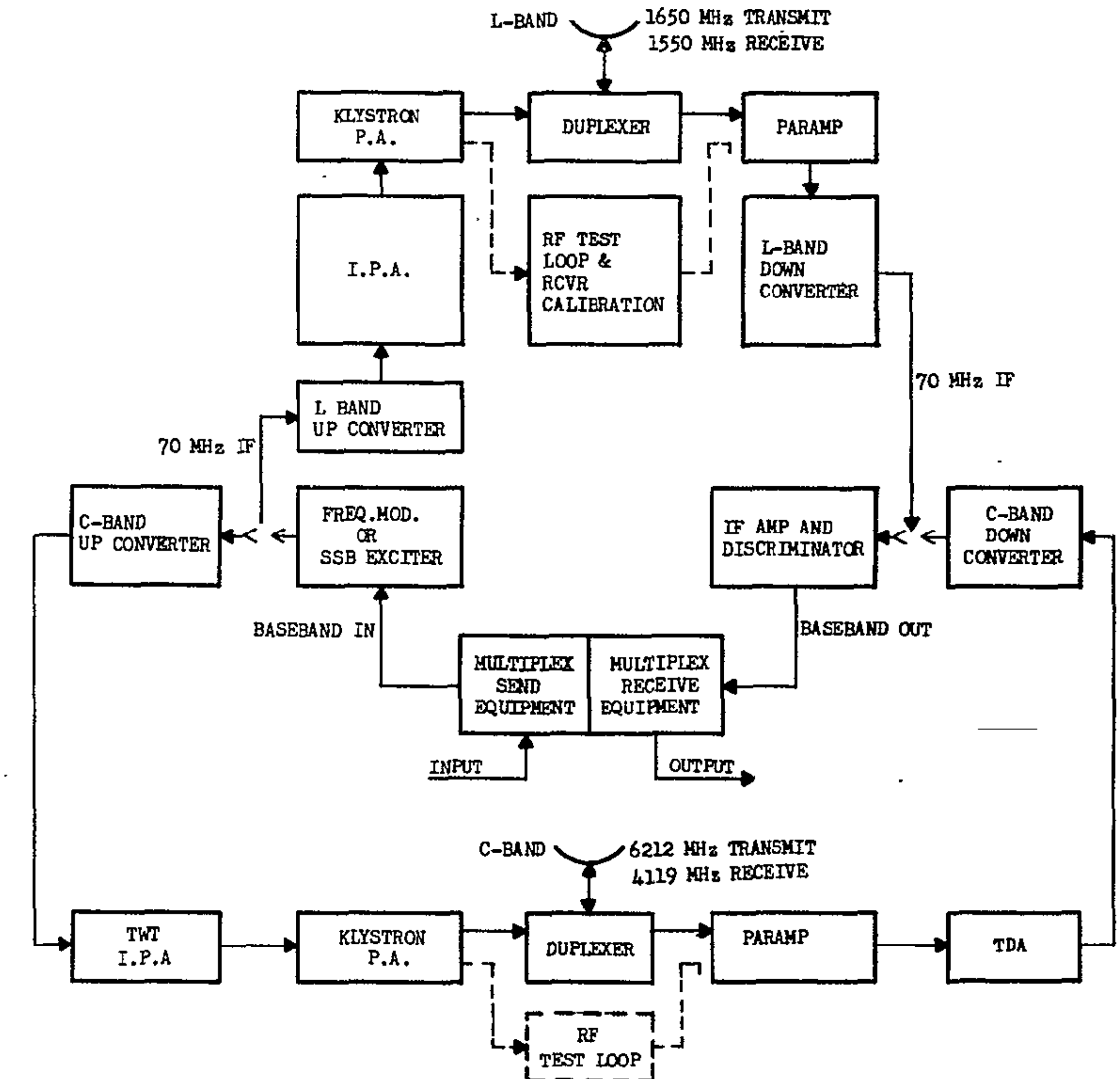


Figure 13-12. L-Band System Earth Station Block Diagram

Table 13-26. Summary of ATS-2, 4 and 5 Experiments

Experiment	Space-craft	Category of Activity
1. Microwave (C-band) Communications	2, 4 & 5	Communications and propagation evaluation
2. Millimeter Wave Propagation	5	" " " "
3. L Band Communications	5	" " " "
4. Gravity Gradient Stabilization	2, 4 & 5	Gravity gradient stabilization investigation
5. Advanced Vidicon Camera	2	Meteorology concept consideration
6. Image Orthicon Camera System	4	" " "
7. Subliming Solid Engine	2, 4 & 5	Study stabilization & stationkeeping technology
8. Resistojet	4 & 5	" " " " "
9. Ion Engine	4 & 5	" " " " "
10. Albedo	2	Miscellaneous spacecraft technology consideration
11. Magnetic Damper	5	" " " "
12. Voltage Monitor	5	" " " "
13. Heat Pipe	5	" " " "
14. Solar Cell Damage	5	" " " "
15. Third Harmonic Generator	5	" " " "
16. Magnetometer	4 & 5	" " " "
17. Omidirectional High-Energy Particle Detector	2 & 5	Earth environment measurements
18. Cosmic Radio Noise Receiver	2 & 5	" " "
19. Electric Field Measurements	2 & 5	" " "
20. Electron Magnetic Deflection Spectrometer	2	" " "
21. Multi-element Particle Telescope	2	" " "
22. VLF Whistler Mode Detector	2	" " "
23. Solar Cell Radiation Damage Array	2	" " "
24. Thermal Coating Samples	2	" " "
25. Tridirectional Medium Energy Particle Detector	5	" " "
26. Bidirectional Low Energy Particle Detector	5	" " "
27. Unidirectional Low Energy Particle Detector	5	" " "

the spacecraft tumbling in a highly elliptical orbit. The stabilization booms were successfully deployed but the tumbling nature of the satellite resulted in the loss of one boom and in another being broken. Operation of the C-Band transponders was demonstrated including transmissions by the earth terminal at Ahmedabad, India. ATS-4 produced even less in the way of successful results than ATS-2. Among the accomplishments were partial deployment and scissoring of the stabilization booms plus successful firing of the ion engines.

Some of the experiments on board ATS-5 were also lost when the spacecraft was left spinning rather than gravity gradient stabilized. In particular, it was not possible to obtain data from the gravity gradient, resistojet, ion engine, solar cell voltage monitor, heat pipe solar panel temperature equalization, cosmic radio noise, or from the electric field measurements experiments. If the booms could be deployed the latter two could be successfully completed. Noteworthy successes have been obtained from the earth environment measurements, L-Band and millimeter wave experiments. The latter two were obtained through ground terminal modifications to accommodate the periodic nature of the received signal, caused by the spacecraft spin.

For the millimeter wave experiment, the spacecraft spin rate (i.e., 76 rpm) resulted in a received signal pulse having a 26 ms time duration between 1 dB down points, that occurred every 789 ms.[36] Ground complex modifications to accommodate this type of received signal included exclusive employment of program tracking rather than autotracking, installing a manual override to prevent the receiver phase lock loop from going into a search mode during deep fades of the peak signal, tripling the data sampling rate to 108 samples-per-second (i.e., one every 9.2 ms) and selecting the maximum valued sample as the only valid data point during any given second. Detrimental effects of the spacecraft spin have included loss of the millimeter wave to L-band TV transmission capability, a loss of fade measurement range which in itself was not of major significance, a serious degradation of the differential sideband phase measurement capability due to spin-induced doppler effect and settling time of the quadrature phase detectors, and loss of the ability to detect short term signal fades occuring at rates greater than about 0.5 Hz. The detrimental effects of spacecraft spin plus a 9 dB drop in primary transmitter outputs, occurring about 3 months after satellite launch, also made it impossible to obtain coherence bandwidth measurements at 15.3 GHz.

Data was obtained on the statistics of long term fades, correlation between various attenuation prediction techniques and actual measured attenuation, effects of site diversity at 15.3 GHz, and coherent bandwidth at 31.65 GHz. Preliminary results are tabulated in Table 13-27.[(31), (34), (36)]

Table 13-27. Preliminary Results Millimeter Wave Experiment

Type Experiment	Nature of Results Obtained
1) Attenuation at 15.3 GHz	1 to 3 dB in light rains or dense fog, 3 to 7 dB in continuous rains (5 to 50 mm/hr) and number of fades exceeding 12 dB in heavy thunderstorms.
2) Evaluation attenuation prediction techniques	Excellent results using radiometer measurements* of sky temperature. Fair results employing radar backscatter readings at millimeter wave frequency. Better results at lower frequencies. Poor results using rain gage measurements of rainfall rate. Results improved with more gages over greater area.
3) Effects site diversity at 15.3 GHz	Durations of 6 to 10 dB fades reduced by approximately two orders of magnitude using simple diversity system with 4 km ground separation between terminals.
4) Coherent bandwidth at 31.65 GHz	Measured relative amplitude variations of sidebands have been within ±2 dB of carrier for sidebands at ±1. ±10, and ±50 MHz.

*Operating at same frequency as propagation link.

For the L-Band experiment, the spacecraft spin produced about a 22 ms sample time during which the received signal was within 1 dB of peak. The impact of the spinning spacecraft upon the original experiment objectives was that: a) all satellite loop tests had to be performed using a sampling technique that was synchronized to the spacecraft spin rate; b) the earth station AGC time constant had to be small compared to variations in the received signal to allow maximization of the sample time; c) fading at rates greater than about one half the sampling rate, but not as great as those that could be observed in one sampling interval, were impossible to record; and d) FDM two-way voice or multiple access voice demonstrations could not be completed. The tests were completed and their results are summarized in Table 13-28.[32] The results indicated that accurate navigation and high quality communications are feasible at L-Band. However, more data may be required to allow refined system designs.

13.3.6 Operational Results

ATS-2, 4, and 5 were experimental satellites, therefore, no operational traffic was carried. Operation of C-Band, L-Band and millimeter wave terminals was quite satisfactory. Spacecraft operation, in the case of ATS-4, was very limited and all equipment appeared to be performing well. On ATS-2 and 5, however, operations were more extensive and some anomalies were encountered.

The anomalies on ATS-2 included a missing and a broken stabilization boom, unplanned environmental measurements package turnoffs, inadvertent gravity gradient regulator turnoffs, and an inability to retract gravity gradient booms. The missing and broken booms were the result of the whipping action produced by spacecraft tumbling. The equipment turnoffs were determined to be due to low battery voltage caused by poor spacecraft aspect angle relative to the sun. No significant problems resulted from the turnoffs. The inability to retract booms was theorized to be due to boom motion preventing a smooth entrance into the rollers of the retraction mechanism.

Table 13-28. L-Band Experiments

Type Experiment	Nature of Results Obtained
1) Spacecraft Antenna Patterns	Half-power beamwidth 24° for transmit and 28° for receive
2) L Band Propagation	Diurnal variations due to ionosphere were less than ±0.3 dB based on four 24 hour test sequences. Observed short term fading and scintillation effects were less than ±0.3 dB on both uplink and downlink
3) Spacecraft Oscillator Frequency Offset	Spacecraft VCO offset from nominal decreased from about -245 KHz at turn on to about -180 KHz 200 minutes later. Spacecraft master oscillator caused offset in earth station baseband signal of about 4 KHz at turn on and stabilized to about 500 Hz 15 hours later
4) Spacecraft Intermodulation Distortion (SSB/FM)	At normal power output levels intermodulation products are approximately 26 dB below either of two test tones
5) Spacecraft Transponder Compression (FM/FM)	The initial point where a 2 dB increase in input power causes only a 1 dB increase in satellite output occurs at an earth station transmit power of 39.6 dBm
6) Spacecraft SSB/FM Modulator Linearity	Response of the SSB/FM L-band modulator to a tone received at several RF levels was linear up to a modulation index of 12 radians rms
7) Spacecraft Frequency Response	In narrow band FM/FM, a 2 MHz 3 dB BW measured. In SSB/FM mode, half power BW was 115 KHz
8) Doppler Due to Spacecraft Spin	At 20 dB down points on spacecraft antenna pattern, varies from +12 Hz at a maximum to -46 Hz minimum
9) Multiplex Channel S/N (SSB/FM)	Signal to thermal noise ratio was measured to be 36 dB* at earth station transmitter power output of 50 dBm. S/N decreased linearly with decrease in SSB transmitter power
10) Spin Modulation Compensation Test	By modulating uplink power in synchronism with spacecraft spin and such as to compensate for variations in satellite receive antenna pattern, usable uplink window was increased from 52 ms to 100 ms

* At Mojave terminal.

The only significant operational difficulties encountered on ATS-5 have involved the primary and backup millimeter wave transmitters.[(35), (36)] The main transmitter functioned perfectly during the first 3 months in orbit. On November 22, 1969, however, the output power was down 6 dB at turn-on. This condition continued until December 17 when a further 3 dB loss was recorded. Transmitter power has remained stable at this level to the present writing. The dc input power has shown no change from pre-launch level during this entire time. Further the 30.6 GHz local oscillator power has shown no significant change. This indicates that the loss is occurring in the solid state multiplier chain above the L-Band portion where the receiver local oscillator power is coupled out. The exact location and cause of the failure has not been determined.

The backup millimeter wave transmitter showed normal power characteristics from launch until October 22, 1969. The transmitter output power was then observed to decrease over time periods as short as 2-1/2 hours and as long as 9 hours to a level between 3 and 4 dB below normal output at which time the output abruptly dropped to zero. A period of nonoperation has always restored the transmitter to normal output. A loss in dc input power that correlates with the loss of RF output power has been recorded. It has been evident that the thermal sensitivity of the transmitter is responsible for the power loss.

13.3.6.1 Additional Services ATS-5

The NASA/GSFC L-band ranging and position location experiments, conducted from the Mojave ground station to the ATS-5 satellite, demonstrated the ability to obtain meaningful range measurements using PM tone modulation at L-band carrier frequencies. This experiment demonstrated the capability of obtaining ranging measurements between an earth station and the ATS-5 satellite at L-band and C-band carrier frequencies, and to evaluate the relative accuracy to which these measurements can be made.

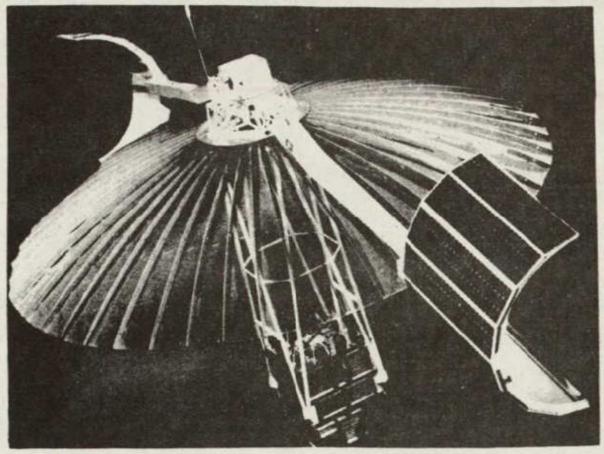
Applied Information Industries (AII) conducted the Alpha II Project for SAMSO, U.S. Air Force, by doing simultaneous L- and C-band ranging using ATS-5. AII also performed a ranging test for the Maritime Administration using the tanker, USS Manhatten. This test was basically a ranging test to determine line-of-position of the ship. L-band ranging signals were transmitted from the Mojave ground station and relayed through ATS-5 to the ship.

The MARAD project (Maritime Administration) was also conducted by AII. This was a successful test of real-time high speed (100 wpm) teletype (TTY) using standard equipment and relayed through ATS-5, two-way (not simultaneous), from Mojave to the Manhatten. The TTY aboard the ship was unattended and running continuously.

Among the other tests and experiments that have been conducted are the ionospheric propagation tests, an on-going experiment involving three ground stations at Quito, Lima, and Mojave that accepted fading and fading rate data from ATS-5 on L-band and VHF simultaneously; the Federal Aeronautics Administration/Boeing Aircraft Company experiment at L-band from ATS-5 to an aircraft involving measurements of multipath effects and tone ranging; the millimeter wave experiment conducted by Westinghouse for GSFC concerning the propagation correlation with rain, fading, and weather conditions at 31.65-GHz uplink and 15.3-GHz downlink; and the AII/Wallops Island experiment in relative position (ranging).[40]

13.4 ATS-6

13.4.1 Program Description



The most versatile, powerful communications spacecraft ever developed was launched by the National Aeronautics and Space Administration at Kennedy Space Center, Florida, May 30, 1974, at 9 a.m. e.d.t.[37] The primary objective of the Applications Technology Satellite-6 (ATS-6) is to demonstrate the feasibility of 9.1-meter (30-foot) diameter deployable spacecraft antenna with good RF performance up to 6 GHz.[38] In addition, the spacecraft is to provide an earth-synchronous-oriented platform stabilized along three axes for advanced technology and scientific experiments. The launch vehicle was a Titan IIIC missile. The life expectancy of the ATS-6 is 5 years, with 2 years at the specified level of performance. An additional year of operation is expected as a result of fuel saving at launching.

Associated with NASA in the Applications Technology Satellite-6 mission are the Department of Health, Education and Welfare, the Federation of Rocky Mountain States, the Appalachian Regional Commission, the Veterans' Administration, the Federal Aviation Administration, the Maritime Administration, the National Library of Medicine, the Indian Health Service, the U.S. Coast Guard, Alaska, COMSAT Corporation, the National Oceanic and Atmospheric Administration, the Universities of Washington, California, and Minnesota, the Canadian Government, the European Space Organization and, later, the Government of India.

The new spacecraft will be used for the next several years to test a variety of new space communications concepts. These include direct broadcast of health and education television programs to small and simple ground receiving units in remote regions over a large geographical area; aeronautical and maritime communications, position-location, and traffic control techniques; and spacecraft tracking and data relay.

The ATS-6 (ATS-F prior to launch) carries equipment for more than 20 technological and scientific experiments, some of them international in scope. The experiments to be performed are described in Section 13.4.5.

No other spacecraft similar to the ATS-6 has ever been placed in orbit. This 1,402 kilograms (3,090 pounds) spacecraft consists essentially of an Earth Viewing Module (EVM) connected to a deployable reflector antenna which measures 9 meters (30 feet) in diameter when deployed. Spacecraft control, communications and experiment systems are located in the EVM.

For its first year of operation, the ATS-6 will be located at 94 degrees west longitude over the equator. At this location, a point over the Galapagos Islands, the spacecraft will be in view of all of the continental U. S. from its geosynchronous altitude of some 35,888 kilometers (22,300 miles).

Shortly after the spacecraft is on this station and checked out, it will be used along with the ATS-1 and ATS-3 now in orbit to conduct the Health-Education Telecommunications (HET) experiment which encompasses both educational and two-way medical tele-conferencing experiments.

The HET experiments are planned in three geographic areas: the Rocky Mountain region, the Appalachian states, and the states of Washington and Alaska. HET will pioneer delivery of high quality educational and health services to millions of Americans in remote parts of these areas.

For the HET experiment, the ATS-6 will be able to relay two separate color TV signals, each accompanied by four voice channels. Thus, programs can be broadcast in several languages simultaneously with the viewer being able to select English, Spanish, or one of several American Indian dialects. The ATS-1 and ATS-3 spacecraft will be used for two-way voice and data transmissions in support of the ATS-6 during both educational and health-medical experiments.

Approximately one year after launch, the ATS-6 will be moved eastward to 35° east longitude which is over the eastern edge of Lake Victoria, located in Kenya, East Africa. From this position, the spacecraft will be "visible" to the subcontinent of India. It will then be used by the Indian Government 4 hours a day for 1 year to conduct the Satellite Instructional Television Experiment (SITE).

For SITE, ATS-6 will be used to broadcast instructional and educational television programs to 5000 villages and cities in seven states throughout India. About 2400 villages will receive the programs directly from ATS-6 using small, low-cost ground stations. The remaining 2600 villages will be located near rediffusion transmitting stations and will receive the programs using conventional VHF television sets. Programs will stress improved agricultural techniques, family planning and hygiene, school instruction and teacher education; and occupational skills. Because of the large number of languages and dialects spoken in India, each video channel will be accompanied by two audio channels in different languages.

In mid-July, 1975 the ATS-6 will be used to track and relay TV and other data from the Apollo-Soyuz spacecraft as they orbit the earth in a 10-day joint U.S.-U.S.S.R. experiment to advance international cooperation in manned flight. (37)

13.4.2 Spacecraft

Figure 13-13 shows the ATS-6 spacecraft's size and structural elements. Figure 13-14 details the communications package located in the Earth Viewing Module (EVM). Spacecraft characteristics are summarized in Tables 13-29 through 13-31. (39) Note that the earth viewing horns, the radio beacon antenna, the interferometer horns, and the VHF antennas are not listed on Table 13-31.

13.4.3 ATS-6 Communications Equipment

The communications subsystem for the ATS-6 satellite consists of a composite antenna feed and the most complex transponder ever developed for use in space. It was designed and built for Fairchild Space and Electronics Company by Philco-Ford Corporation's Western Development Laboratories Division in Palo Alto, California.

The communications system will operate over an unusually broad range of UHF, VHF, L-band, S-band and C-band frequencies--about 17 in all, ranging from 136 MHz to 6 GHz. The system also provides monopulse signals which are used by the spacecraft for attitude stabilization. The system receives up to three signals simultaneously and can transmit one or a combination of these on any of the assigned frequencies.

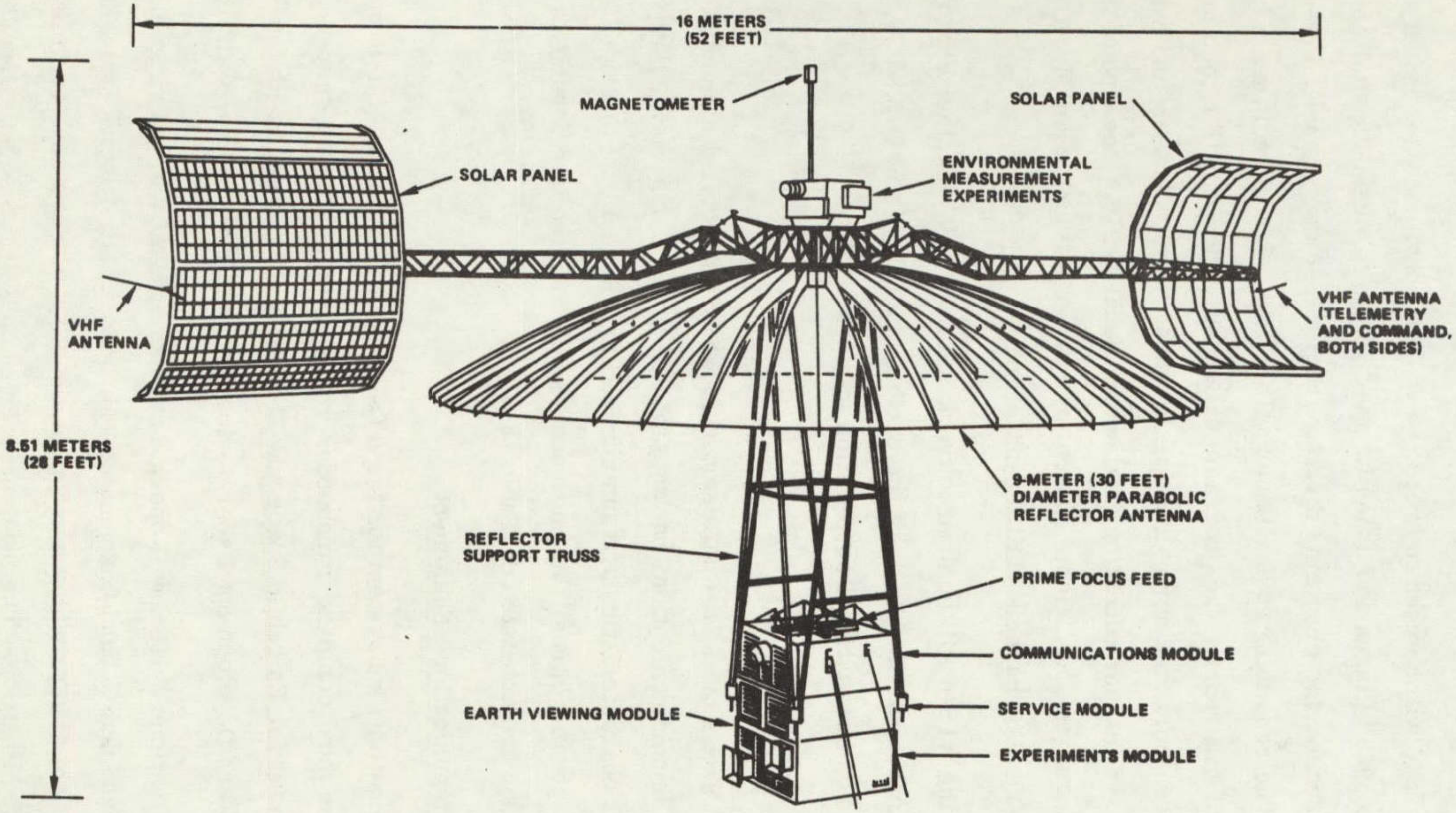
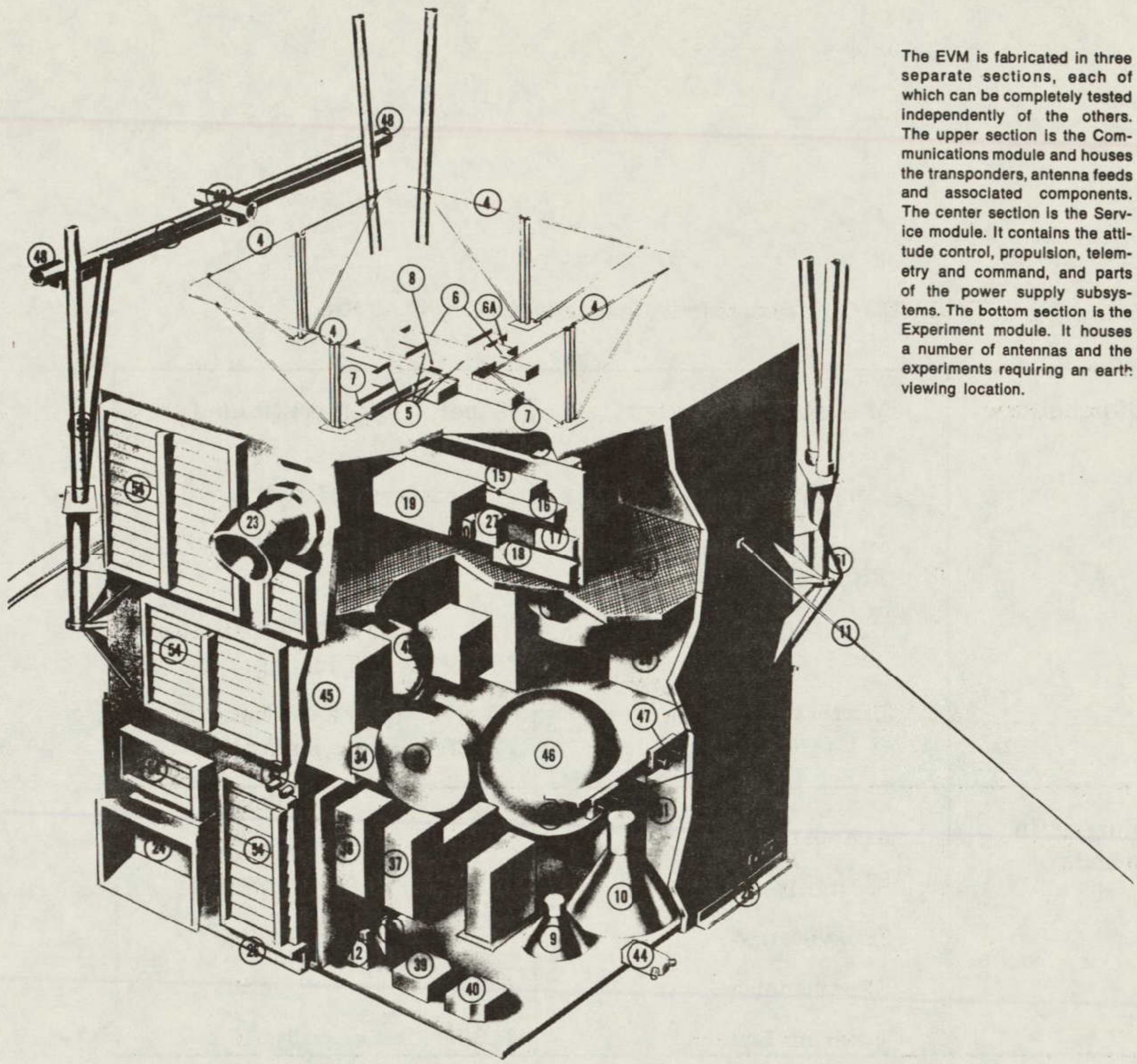


Figure 13-13. ATS-F Spacecraft[39]

The EVM is fabricated in three separate sections, each of which can be completely tested independently of the others. The upper section is the Communications module and houses the transponders, antenna feeds and associated components. The center section is the Service module. It contains the attitude control, propulsion, telemetry and command, and parts of the power supply subsystems. The bottom section is the Experiment module. It houses a number of antennas and the experiments requiring an earth viewing location.



MODULES
1. Communications Module
2. Service Module
3. Experiment Module

30-FOOT PARABOLIC REFLECTOR FEEDS
4. VHF (Monopulse) — Receive & Transmit
5. UHF — Transmit (4 Feeds)
6. L-Band — Receive & Transmit — Fan Beam (7 Feeds)
   6A. L-Band — Receive & Transmit — Pencil Beam (1 Feed)
7. S-Band (Monopulse and Steered Beam) Receive & Transmit (20 Feeds)
8. C-Band (Monopulse) — Receive & Transmit

ANTENNAS
9. Earth Viewing Horn — Receive
10. Earth Viewing Horn — Transmit
11. Radio Beacon Experiment — Transmit
12. Interferometer Reference Horn
13. Interferometer Coarse Horn

COMMUNICATIONS
14. UHF Transmitter
15. S-Band Diplexer
16. S-Band Monopulse Errors Channel Filter
17. S-Band Monopulse Error Channel Preamp.
18. S-Band Preamp. with Redundancy Switches
19. ETV — S-Band Transmitter
20. C-Band Transmitter Output Filter

TELEMETRY
21. Data Acquisition & Control Unit

EXPERIMENTS
22. Ion Engine Electronics
23. Ion Engine Thruster
24. Radiometer Cooler
25. Propagation Experiment Receive Antenna
26. Laser Retroreflector

POWER
27. Shunt Dissipator
28. Power Control Unit
29. Power Regulation Unit
30. Battery No. 1
31. Battery No. 2
32. Battery Test Connectors
33. Load Interface Circuit
34. Shunt Dissipator

COMMAND
35. Command Decoder Distributor

CONTROL
36. Sun Sensor Electronics
37. Polaris Sensor No. 1
38. Polaris Sensor No. 2
39. Earth Sensor Head Ass'y. (Pitch)
40. Earth Sensor Head Ass'y. (Roll)
41. Inertia Wheel (Pitch)
42. Inertia Wheel (Roll)
43. Inertia Wheel (Yaw)
44. Coarse Sun Sensor
45. Actuator Control Electronics
46. Hydrazine Tank
47. Attitude Control Thrusters
48. Orbit Control Thrusters
49. Orbit Control Jets Bar
50. Spacecraft Propulsion System — Fill & Drain Valves
51. Truss Propellant Line Assembly

STRUCTURAL
52. Mounting Plate
53. GFRP Truss

THERMAL
54. Louvers

MISCELLANEOUS
55. RFI Screen

Figure 13-14. EVM Communications Package(39)

Table 13-29. Structural Characteristics of ATS-6

Dimensions	Maximum Diameter	3 meters (9 feet) (folded for launch)	
	Length	8.2 meters (27 feet)	
	Span (Between Deployed Tips of Solar Paddles)	15.8 meters (51.7 feet)	
	Earth Viewing Module	137 x 137 x 165 centimeters (54 x 54 x 65 inches)	
	Earth Viewing Surface	18,813 square centimeters (2,916 square inches)	
Weight (in pounds)		kg	lbs
	Adapter	43	95
	Structure	349	770
	Subsystems	771	1,700
	Experiments	218	480
	Total at Launch	1,381	3,045
Harness	Multi-Harness Construction appropriate for EVM Design	140 kg	308 lb

Table 13-30. Power, Heat and Control Characteristics of ATS-6

Power	Solar array	2 hemi-cylindrical panels
	Total solar panel area	20.3 m^2 (218 $feet^2$) 21,600--2 x 4 cm N on P cells
	Power available at end of 2 years	470 watts plus 340 watt-hours battery power
Heat	Thermal control	Heat pipes, louvers, thermal coatings, and super-insulation
	Controlled experiment	Average temperature $20^{\circ} \pm 10^{\circ}C$
	Environment	Mounting surface temperature $20^{\circ} \pm 15^{\circ}C$
Control	Accuracy attitude pointing	Better than 0.1° in all 3 axes up to 10° off local
	Slewing rate	To 1°/minute with maximum roll and pitch error less than 0.5°
	Stabilization jitter	0.01° maximum excursion
	Yaw reference	Polaris sensors (prime) Gyro/sun sensors (backup)
	Pitch and roll reference	Earth horizon sensors (prime) Interferometer (backup) Monopulse at VHF, S- and C-bands (backup for station pointing)
	Attitude control actuators	Momentum wheels and hydrazine thrusters in all 3 axes
	Station keeping orbit control	Hydrazine thrusters (V = 170 feet/second) total capacity
	Interferometer	
	Operating frequency	6.155 and 6.150 GHz
	Operating field of view	$\pm 12.5^{\circ}$
	Measurement accuracy	$\pm 0.018^{\circ}$ in pitch and roll

Table 13-31. Communications, Telemetry and Command Characteristics of ATS-6 (1 of 2)

Communications	Parabolic antenna	9.1-meter (30-foot) diameter 100 MHz to 10 GHz f/d = 0.44 Stowed dimensions, annulus with 2.0 meter OD x 1.5 meter ID x 0.2 meter (6.6 feet OD x 4.8 feet ID x 0.8 feet) high
	Communication frequency	VHF, UHF, L-, S-, C-, Ku, and Ka-Bands
	Power amplifiers	<u>Solid state transmitters</u> UHF--105 watts (SITE/TRUST) L-Band--40 watts (PLACE) S-Band--20 watts (TDRE) S-Band--15 watts (HET) <u>Traveling Wave Tubes</u> C-Band--12/24 watts
	Repeater operation	Full duplex, coherent linear translation and/or modulation conversion (øM) of up to 3 independent RF channels simultaneously
	Transponder bandwidths	Selectable RF bandwidths 12 and 40 MHz
	Experiment interface	
	Baseband	VCO (5 MHz) Discriminator (6 MHz)
	IF	Bandwidth 40 MHz
	Peak antenna gain	49 dB
	Peak EIRP	54.5 dBW
Telemetry	Telemetry transmission (ERP)	15 dBW (high gain link)--4 dBW (omni-link)

Table 13-31. Communications, Telemetry and Command Characteristics of ATS-6 (2 of 2)

Telemetry (Cont'd)	Telemetry transmitter	2 watt FM/PM		
	Special features	3 channel frequency division multiplex of special data link, EME, and telemetry, frequency diversity omni-link		
	Telemetry			
	Bit rate	390 bps		
	Word length	9 bits		
	Total word capacity	368 words		
	Experiment assigned	136 words		
	Spacecraft assigned	232 words		
Command	Command receive modes	Standard command PCM/FSK/AM/AM, and special data link (AM)		
	Command antenna	Space diversity (switched) omni-link		
	Commands			
		Normal Speed		High Speed
	Word length	28 bits		13 bits
	Discrete commands	512		27
	Magnitude commands	45 addresses-9 bit magnitude		0
	Command rate	2.2 per second		92 per second
	Command assignments			
		Discrete	Magnitude	Discrete
	Experiment assigned	150	20	27
	Spacecraft assigned	362	25	0

Signal switching permits signals received in one frequency band to be transmitted in any of the transmit bands. To ensure the coherence needed to preserve signal quality during frequency conversions, a new technique was developed to directly synthesize 14 of the frequencies from a single frequency standard. Also, from the standpoint of power generated and upper frequency limits, the use of solid-state circuitry surpasses that of previous space communications systems.[40]

Table 13-32 shows the specifications for the ATS-6 Communications Subsystem.

The operation of the communications subsystem is essential to the successful performance of all the experiments on the ATS spacecraft and to the accomplishment of the primary objective of the ATS-6 mission. The transponder provides the basic interface between the experiments in the satellite and ground terminals. In some instances the transponder is itself a part of the experiment. Figure 13-15 is a block diagram of the subsystem. Table 13-33 describes the subsystem characteristics.[41]

The communications subsystem operates to fulfill the requirements of the following modes of operation and experiments:

Coherent mode	VHR radiometer data transmission
Noncoherent mode	Radio beacon
PLACE experiment	Monopulse
Tracking and data relay experiment	RFI experiment
SITE experiment	HET experiment
Millimeter wave reception	TRUST experiment

In the coherent mode all local oscillator signals are derived from a single oscillator phase-locked to the C-band signal carrier transmitted from the ground to the spacecraft.

In the noncoherent mode, the local oscillator frequencies are generated within the spacecraft by a highly stable fixed-frequency oscillator with an initial frequency tolerance of ±10 PPM and a long term stability of better than ±3 PPM in three months.

Table 13-32. ATS-6 Communications Subsystem Specifications[40]

Weight	Transponder - 120 kilograms (265 pounds); Antenna Feed - 27 kilograms (60 pounds)		
Size	142 x 147 x 58 centimeters (56 in. x 58 in. x 23 in.)		
Transmitters (all redundant except HET)			
	Type	Frequencies (Synthesized)	Power Output
	C-Band	3950, 4150 and 3750 MHz	11 watts
	Designed for HET experiment	2569 and 2670 MHz	15 watts
	S-Band	2075 MHz	21 watts
	L-Band	1550 MHz	40 watts
	UHF	860 MHz	105 watts
Receivers	Type	Frequencies (Synthesized)	
	C-Band*	5950, 6150, and 6350 MHz	
	S-Band*	2250 MHz	
	L-Band	1650 MHz	
	VHF	150 MHz	
Special Features	Monopulse operation		
	Coherent phase-lock operation		
	Receipt/transmission of up to 3 frequencies simultaneously		
	17 frequencies,** with direct synthesis of 14 from a single frequency standard		

*Redundant.

**Includes the transmit/receive frequencies listed above, plus satellite telemetry and two internal mixing frequencies for the HET experiment.

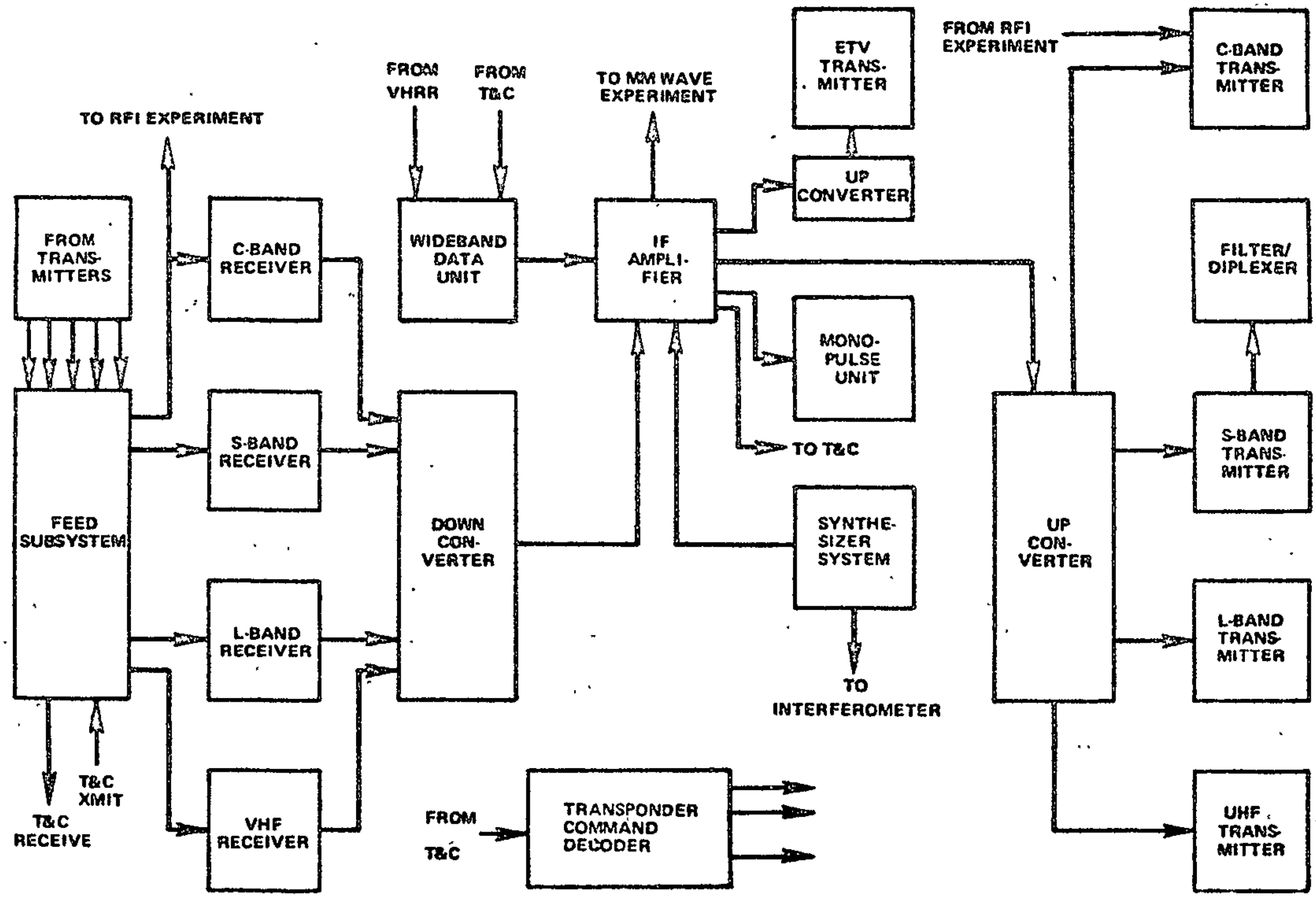


Figure 13-15. Communications Subsystem (Simplified Block Diagram)[41]

Table 13-33. Communications Subsystem Characteristics[41]

Mode	User	Nominal Frequency (MHz)	Bandwidth (MHz)	Polarization	Antenna Field of View (degrees)	Receiver: Peak Antenna Gain (dB)	Receiver: Min G/T Over FOV (dB/K)	Receiver: G/T (Peak) (dB/K)	Transmitter: Transmitter Output Power (watts)	Transmitter: Min FRP Over FOV (dB/W)	Transmitter: ERP (Peak) (dB/W)
9-meter (30-foot) C-Band Receive	MMW Monopulse	63.50 61.50	40 12	Linear	0.4	49.0	10.5	13.5	-	-	-
9-meter (30-foot) C-Band Transmit	MMW	3750 3950	40	Linear	0 6	46.0	-	-	21.0	51.5(1) 47.2(2)	54.5(1) 50.2(2)
Horn C-Band Receive	T&DRE SITE PLACE MMW ATS-R	6350 6150 5950	40 12	Linear	20	16.5	-20	-17	-	-	-
Horn C-Band Transmit	T&DRE Beacon PLACE MMW Radiometer RFI	 3950 3750 4150 3950	 40 500	 Linear Linear	 10 10	 16.6 16.7	-	-	21.0 20.0	25.0(1) 20.7(2)	28.0(1) 23.7(2)
9-meter (30-foot) C-Band Receive	RFI	6150	500	Horizontal Vertical RCP	0 4	48.5	NA	NA	NA	NA	NA
9-meter (30-foot) S-Band Receive Scan	T&DRE	2750	40	RCP	9	40.5	-	-	-	-	-
9-meter (30-foot) S-Band Transmit on Axis	T&DRE	2075	12	RCP	–	39.5	-	-	20 0	-	50.5
9-meter (30-foot) S-Band Transmit Scan	T&DRE	2075	12	RCP	9	39.0	-	-	20.0	49	-
9-meter (30-foot) S-Band Receive on Axis	T&DRE	2250	12 10	RCP	-	40.5	-	9 5	-	-	-
9-meter (30-foot) L-Band Pencil Beam Receive	PLACE	1650	12	RCP	1.5	38.5	2.5	5.5	-	-	-
9-meter (30-foot) L-Band Pencil Beam Transmit	PLACE	1550	40 12	RCP	1.5	38.5	-	-	40.0	49.0	51
9-meter (30-foot) L-Band Fan Beam Receive	PLACE	1650	40 12	RCP	1 x 7.5	31.5	5.0	-2	-	-	-
9-meter (30-foot) L-Band Fan Beam Transmit	PLACE	1550	40 12	RCP	1 x 7.5	31.5	-	-	40.0	42.0	45
9-meter (30-foot) UHF Transmit	SITE/ TRUST	860	40	RCP	2.8	33.0	-	-	105	48.0	51
9-meter (30-foot) VHF Receive	Monopulse	150	6	RCP	15	17	-20	-18	-	-	-
9-meter (30-foot) VHF Receive	Command	148.26 154.2	3	RCP	15	17	-20	-18	-	-	-
9-meter (30-foot) VHF Transmit	Telemetry EME	136.23 137.11	2	RCP	15	17	-	-	2.0	17	20
9-meter (30-foot) S-Band Transmit	ETV	2569.2 2670.0	40 40	LCP	0.9(3)	43.2	-	-	12 12	44.5(3)	53

(1) Single Carrier Operation
(2) Dual Carrier Operation
(3) Either of two offset beams.

For PLACE, a special multiple access capability is provided for simultaneous C-band to L-band and L-band to C-band operation. The receiver linearity is such that received multiple carriers do not produce significant intermodulation components. The received multiple carriers are translated to baseband and then phase modulated onto a single carrier. Baseband information bandwidth is 1.5 kHz to 1.5 MHz. Automatic gain control maintains the phase modulation at a 0.85-radian rms independent of the number of carriers.

In performing the data relay experiment, simultaneous S-band to C-band and C-band to S-band operation is provided. Also the C-band to S-band signal can be repeated on C-band.[41]

Signals for the satellite instructional television experiment are received at C-band and simultaneously transmitted on UHF and C-band. The UHF transmission is for the primary experimental use while the C-band signal can be monitored at ground stations geographically remote from the area covered by the UHF beam.

For the wideband signals used in the millimeter wave experiments, the C-band receiver is used with a demodulator which is essentially flat from 30 Hz to 5 MHz.

Signals from the very high resolution radiometer are used to frequency modulate the C-band transmitter. The VCO used to generate the FM signal is extremely linear (±1%) in order to minimize distortion of the radiometer information.

In order to assist ground stations in directing the high-gain antennas toward the ATS spacecraft, a CW C-band radio beacon signal is transmitted upon command in the earth coverage mode.

A monopulse mode is implemented in the C-band frequency range for determining the attitude of the spacecraft in roll and pitch with an accuracy of about $\pm 0.3^{\circ}$. This signal can be fed directly to the attitude control system and to the telemetry system for transmission to ground stations.

The communication subsystem also provides C-band transmission for signals derived from the RFI experiment. A two-channel TV transmit capability in the

2.5 to 2.69 GHz band will be supplied by the communications subsystem for the ETV experiment.[41]

13.4.3.1 Antennas

The antennas used with the communications system are located in two areas: (1) the prime focus feed, on the top surface of the EVM, which illuminates the 9-meter (30-foot) parabolic reflector, and (2) the earth viewing horns on the bottom surface of the EVM that receive and transmit signals directly to and from the earth. Figure 13-16 shows the antenna layout on the top surface. Figure 13-17 shows the bottom view of the subsystem. The antennas connected with the Radio Beacon and interferometer experiments are not shown on Figure 13-17.

The composite feed assembly shown in Figure 13-16 is used in conjunction with the reflector to provide efficient antenna performance over a broad range of frequencies and a wide variety of beam shapes, sizes, and functions. Although individual feed elements are used for each frequency band to permit optimum performance, a great deal of commonality exists among the radiating elements. To satisfy polarization, weight, and size requirements, cavity-backed cross-dipole elements are used for S, L, and UHF feeds. These elements offer simple and reliable radiators capable of operating at the frequency bandwidths, and polarizations defined by the experiments. With the exception of VHF radiators, the feed layout enables placement of all radiating elements in the parabola's focal plane, and minimizes interaction between neighboring feeds.

13.4.3.2 Physical Description

The components that comprise the communications subsystem are located in the uppermost section of the EVM. The transponder includes the following major subassemblies:

Receivers	Monopulse Processor	Power Supply	Command Distributor
IF Amplifier	Wideband Data Unit	RFI Experiment	
Synthesizer	Transmitters	ETV Experiment	

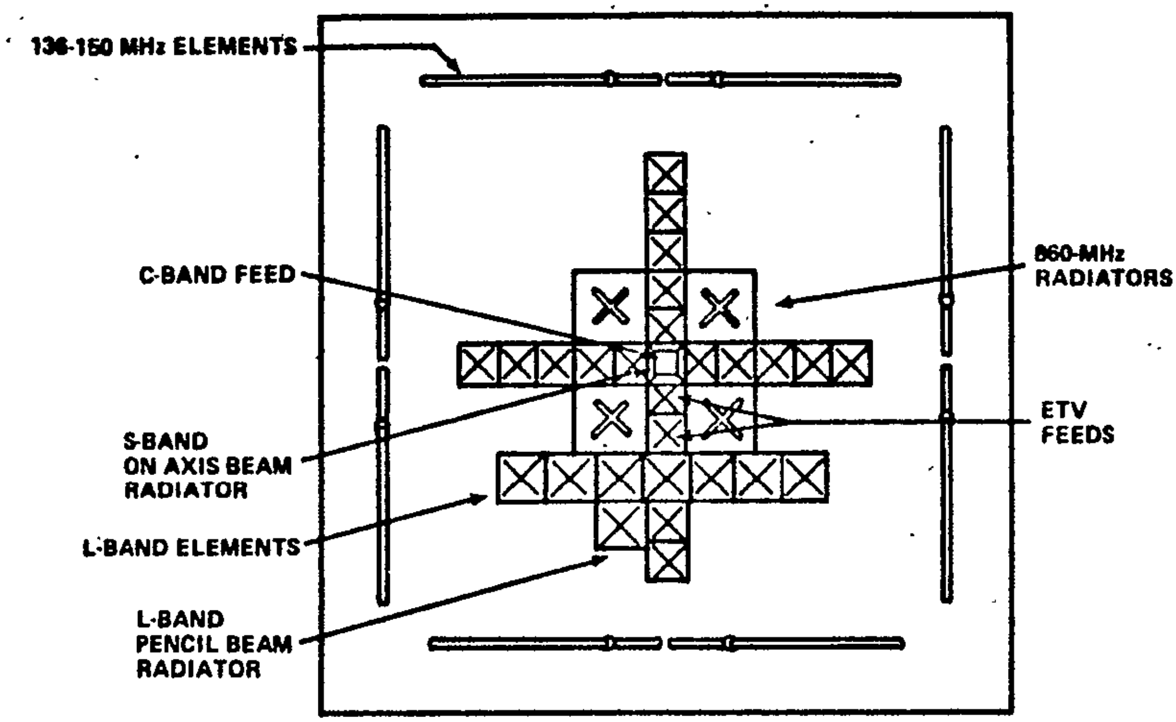


Figure 13-16. Composite Antenna Feed[41]

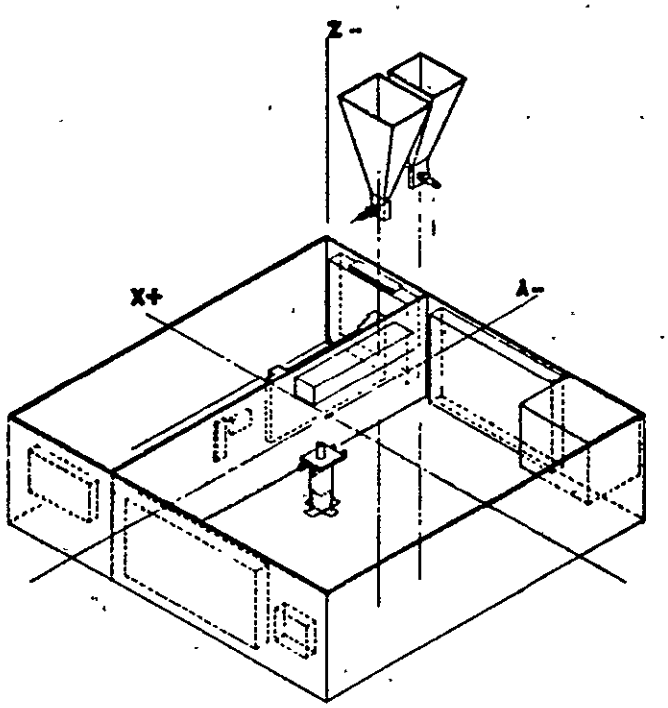


Figure 13-17. Bottom View of Communication Subsystem Box Showing Transponder and Earth Viewing Horns[41]

The composite antenna feed is on the top surface of the communication module which locates it at the focal point of the 9-meter (30-foot) parabolic reflector.

13.4.3.3 Transponder

The transponder can be functionally divided into four major areas: the receivers, the IF amplifier assembly, the frequency synthesizer, and the transmitters. Supporting these major areas are the RF input/output circuitry, wideband data unit, monopulse detector, command distributor, and dc-dc converters. Figure 13-18 shows the signal interfaces.

The receiver includes preamplifiers, monopulse modulators, mixers, filters and the required interconnecting circuits.

The IF amplifier consists of an IF input switch matrix, three identical IF amplifiers (f_c = 150 MHz, Δf = 40 MHz or 12 MHz, on command and an IF output switch matrix).

The synthesizer uses a single frequency (100 MHz) oscillator from which it synthesizes all the other desired frequencies. It can operate in the coherent mode, wherein the VOC and all the frequencies derived from it are phase-locked to the received signal. In the noncoherent mode a temperature compensated crystal oscillator acts as the reference.

The transmitter portion of the transponder is comprised of the up-converter, the drivers and the power amplifiers for C-band, S-band, and L-band.

Tables 13-34 through 13-38 give the signal interfaces, and the expected performance of the transponder.[41]

Figure 13-19 shows the 3 dB and 6 dB footprints of ATS-6 for the Rocky Mountain and Appalachian experiments.

There are two beams, generated by the 9.1-m (30-ft) dish from feeds which lie on the satellite North-South axis. Neither feed lies on the antenna boresight, the separation between the boresight and the nearest feed being about 0.9 degrees and the beam

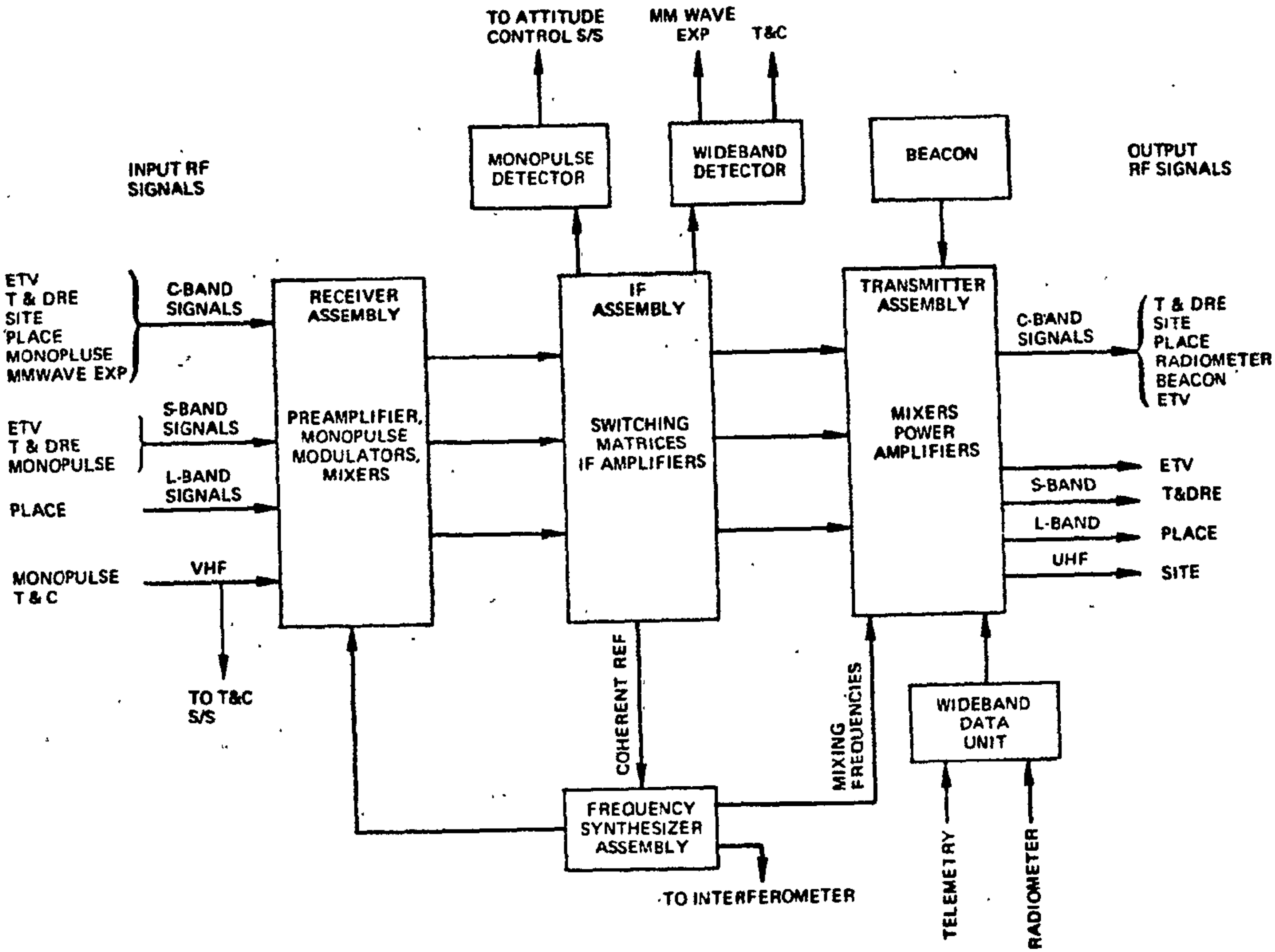


Figure 13-18. Transponder Signal Interfaces(41)

Table 13-34. Transponder Signal Interfaces[41]

Interface Name	Type	Frequency	Signal Level	Impedance
RFI	Experiment Input	5.9-6.4 GHz	+13 dBm	50 ohms
C-Band Output	Signal Output	3750, 3950, 4150 MHz	10 W	50 ohms
S-Band Output	Signal Output	2075 MHz	20 W	50 ohms
L-Band Output	Signal Output	1550 MHz	40 W	50 ohms
UHF Output	Signal Output	860 MHz	105 W	50 ohms
Monopulse Output	Experiment Output	DC	6.5 V	1-k ohm
C-Band Input	RF Signal Input	6350, 6150, 5950 MHz	-40 to -88 dBm	50 ohms
C-Band Monopulse	RF Monopulse Sum and Error	6350, 6150, 5950 MHz	-90 dBm min	50 ohms
S-Band Input	RF Signal Input	2247, 2250, 2253 MHz	-86 to -118 dBm	50 ohms
S-Band Monopulse	RF Monopulse Sum and Error Signals	2247, 2250, 2253 MHz	-128 dBm min	50 ohms
L-Band Input	RF Signal Input	1650 MHz	-82 to -108 dBm	50 ohms
VHF Monopulse	RF Monopulse Sum and Error Signals	150 MHz	-85.5 dBm	50 ohms
Radiometer	Experiment Subcarrier	0.1 Hz to 180 kHz	1 V P-P	75 ohms
HR Camera	Experiment Subcarrier	200 kHz to 1 MHz	1 V P-P	75 ohms
Beacon	IF Input	180 MHz	-20 dBm	50 ohms

Table 13-35. Expected Received Signal Levels

			Received Signal (Isotropic)		Transponder Input Signal (1)	
Mode	Band	Ant.	Max.	Min.	Max.	Min.
Coherent Receive	C	Horn	-90 dBm	-105 dBm	-73 dBm	-88 dBm
PLACE	C to L L to C	Horn Fan Pencil	-75 -120	-100 -110	-58 -88	-83 -108
T&DRE	C to S S to C C to C	Horn Array Horn	-75 -125 -75	-100 -145 -100	-58 -86 -58	-83 -106 -83
SITE/TRUST	C to UHF	Horn Dish	-75	-100	-58 -25	-83 -50
MM, ATS-R	C to C	Horn	-75	-100	-58	-83
VHF Monopulse	VHF	Dish	--	-90	--	-72

(1) Assumes the following nominal antenna gains:

C-band horn - 17 dB	L-band fan - 32 dB
C-band dish - 50 dB	L-band pencil - 38 dB
S-band array - 39 dB	VHF dish - 18 dB

Table 13-36. Frequency Synthesizer Performance Requirements (41)

Phase Lock Loop Performance:

Noise Bandwidth (single sided)	500 Hz 10% nominal (1500 Hz max)
Minimum Capture Range	50 kHz at C-Band
Static Phase Error	2 RMS
Dynamic Phase Error	10 RMS
Acquisition Time	1 min (maximum)
VCNO Drift (open loop)	3 parts in 10^6 (maximum)

RF Input Requirements: 150 MHz IF at 220 mv signal noise
Minimum signal noise (IF BW 40 MHz) 1 dB

RF Output Requirements:	Down Conversion	Up Conversion
Level	3 dBm	13 dBm
Spurious	-100 dBm	-60 dBm

Table 13-37. C-, S-, and L-Band Performance[41] (1 of 2)

	C-Band Performance	S-Band Performance	L-Band Performance
Receive			
Transponder Input to Preamp Losses			
Sum Channel			
Diplexer	0.3 dB		1.1 dB
TDA Switch	0.2 dB		
Filter		0.15 dB	
Preamp Switch		0.2 dB	
Error Channel			
Modulator	1.0 dB	1.0 dB	
Filter	0.3 dB	0.15 dB	
Preamplifiers			
Noise Figure	5.5 dB	3.7 dB	4.4 dB
Gain	15.0 dB	34.0 dB	25.0 dB
Preamp to IF Losses			
Coupler			
Sum Channel	1.2 dB	1.2 dB	
Error Channel	7.0 dB	7.0 dB	
Triplexer	1.0 dB		
Downconverter	8.0 dB	7.0 dB	7.0 dB
IF Switch	0.5 dB	0.5 dB	0.5 dB
Filter			0.1 dB
IF Noise Figure	5.0 dB	5.0 dB	5.0 dB
Overall Receiver Noise Figure*			5.57 dB
Sum Channel and Horn	7.13 dB		
Sum Channel and Cross Array		4.10 dB	
Error Channel	9.5 dB	4.93 dB	

*Includes input to preamp losses.

Table 13-37. C-, S-, and L-Band Performance[41] (2 of 2)

	C-Band Performance	S-Band Performance	L-Band Performance
<u>Transmit</u>			
TWTA Output Power (10 W)	+40 dBm		
Coupler and Waveguide Loss	0.1 dB		
Diplexer Loss	0.2 dB		0.2 dB
Transponder Output Power	+39.45 dBm	+42.8 dBm	+45.6 dBm
Switch Loss	0.25 dB	0.2 dB	
Cable Losses		0.2 dB	0.2 dB
Power Amplifier Output Power		(21 W) + 43.2 dB	(40 W) + 46 dBm

Table 13-38. Transponder Performance

VHF Receive (150 MHz)	
Transponder Input Losses	
Sum Channel	
T&C Diplexer	1.0 dB
T&C Hybrid	3.0 dB
Coupler	1.0 dB
Error Channel	
Modulator	1.0 dB
Filter	0.2 dB
Coupler	7.0 dB
Both Channels Filter	1.0 dB
Line Switch	0.5 dB
IF Switch	0.5 dB
IF Noise Figure	5.0 dB
Overall Receiver Noise Figure*	
Sum Channel	12.0 dB
Error Channel	15.2 dB
UHF Transmit (860 MHz)	
Power Amplifier Output Power (105 W)	50.2 dBm
Switch Loss	0.25 dBm
Cable Loss	0.35 dBm
Transponder Output Power	49.6 dBm

*Includes input to preamp losses.

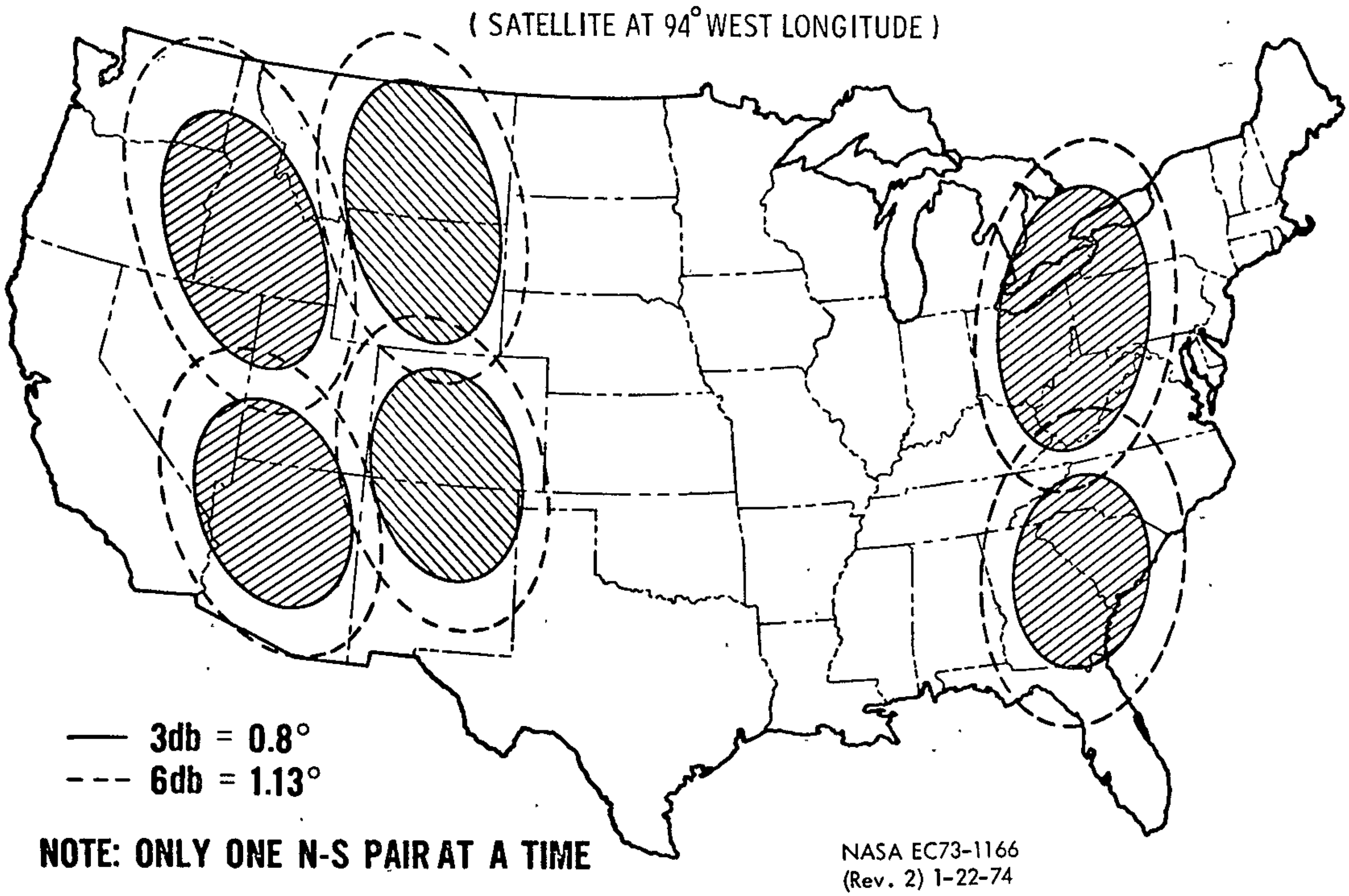


Figure 13-19. ATS-F HET Footprints in Rocky Mountain and Appalachian Regions(42)

separation being 1 degree. The beamwidth is 0.8 degrees. The total coverage at any one time consists of two footprints lying in approximately a North-South relationship, the exact arrangement depending on the subsatellite point and the antenna pointing angle. Either or both feeds can be energized on command; however the frequency is different in each footprint. It can be seen by examining the chart that the two footprints which can be generated cannot cover all of the participating states. As a consequence, a time sharing arrangement is planned in which the Rocky Mountain region is divided into two zones, an Eastern zone and a Western zone; each zone can be approximately covered by the two footprints as shown. It is planned to repeat key elements of the experiment in the Eastern and the Western zones.[41]

13.4.4 Ground Terminals

13.4.4.1 Introduction[41]

Three ATS ground stations provide the main support to ATS operations for command and control of the ATS-6 spacecraft, for collection of range and range-rate data for orbit determination, and for the performance of technological and scientific experiments. One station is located at Rosman, North Carolina and two are collocated at the Mojave site on Goldstone dry lake near Barstow, California. One is a fixed terminal like Rosman and the other is the transportable Hybrid Terminal. The Hybrid Terminal will consist of elements from the ATS Mobile Terminal and the Transportable Ground Station (TGS) which was used in Australia during ATS 1-5 operations. It will initially be operated with ATS-6 while located at Mojave and then moved overseas several months after launch. The Mobile Terminal can be separated from the Hybrid Terminal to provide an RF link when it is desired to remotely locate experimenter's equipment. In either configuration the Hybrid or Mobile Terminals will contain UHF equipment to support the 860-MHz downlink for the SITE experiment.

The Rosman data acquisition facility will be the primary ground station. The two secondary stations, Mojave and the Hybrid Terminal, will have the same basic capabilities as the primary station with regard to performance and evaluation of spacecraft data. The three stations will have functionally identical communications and telemetry and control equipment; the principal difference being that the stations have different C-band antennas. The Rosman facility will use a 26-meter (85-foot) antenna; the Mojave facility will use a 12-meter (40-foot) antenna and the Hybrid/Mobile Terminal will use a 6.4-meter (21-foot) antenna which contains a UHF feed to provide the UHF receive capability.

The millimeter wave experiment unique terminal will be located at the ATS facility at Rosman.

All spacecraft maneuvers and experiments are controlled by direction from the ATS Operations Control Center (ATSOCC) at Goddard Space Flight Center (GSFC) at Greenbelt, Maryland. All test data obtained is forwarded from the ground stations to GSFC for processing, evaluation, and distribution to experimenters.

13.4.4.2 Rosman Ground Station(41)

The Rosman II 26-meter (85-foot) antenna is used by ATS-6 spacecraft for C-band transmission and reception. This high-gain antenna with its feed and low-noise receiver systems provides a relatively quick conversion from space flight tracking and data network to ATS communications use, and vice versa. This allows the antenna to be shared with other projects. Monopulse tracking techniques can be used to automatically track the spacecraft. Polarization tracking at C-band is also provided. Communication signals are transmitted, received, and processed as required by the various ATS experiments. In addition, a communications test and evaluation console (CTEC) is used for evaluation of the spacecraft communications link.

A master control console (MCC) provides a focal point for ground station coordination. At the MCC, the mission director receives status indications and information that enable him to direct operations by issuing voice commands to the subsystem operators.

Spacecraft commands are encoded, transmitted and verified by the T&C subsystem. Spacecraft housekeeping telemetry and discrete real-time functions are also received, processed, recorded and displayed by the telemetry subsystem.

Figure 13-20 below shows the Rosman Block Diagram.

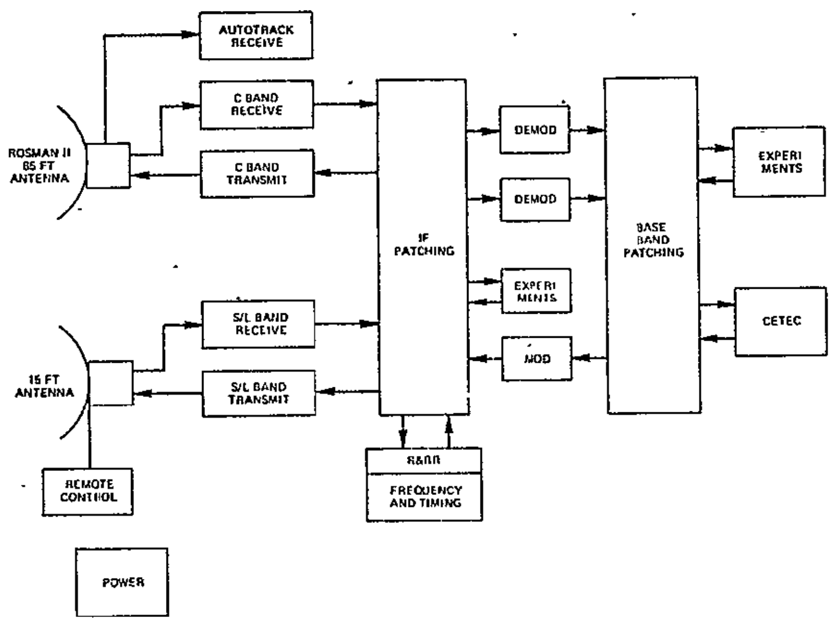


Figure 13-20. Rosman Ground Station Block Diagram

13.4.4.3 Mojave Ground Station(41)

The Mojave facility uses the 12-meter (40-foot) parabolic antenna for C-band and the 4.6-meter (15-foot) antenna (not shown in the photograph) for S- and L-bands. The 12-meter (40-foot) antenna uses monopulse techniques to track the spacecraft at C-band. Polarization tracking is also provided. The C-, S-, and L-band communications system is the same as Rosman except for the size of the C-band antenna.

As in the Rosman station, an MCC is the focal point for coordination within the station. Status indications and information are received at the MCC that enable the mission director to direct operations by voice commands to the operators of the station subsystems. Communication with ATSOCC is accomplished by one voice circuit and one full duplex TTY circuit.

Figure 13-21 shows the Mojave Ground Station Block Diagram.

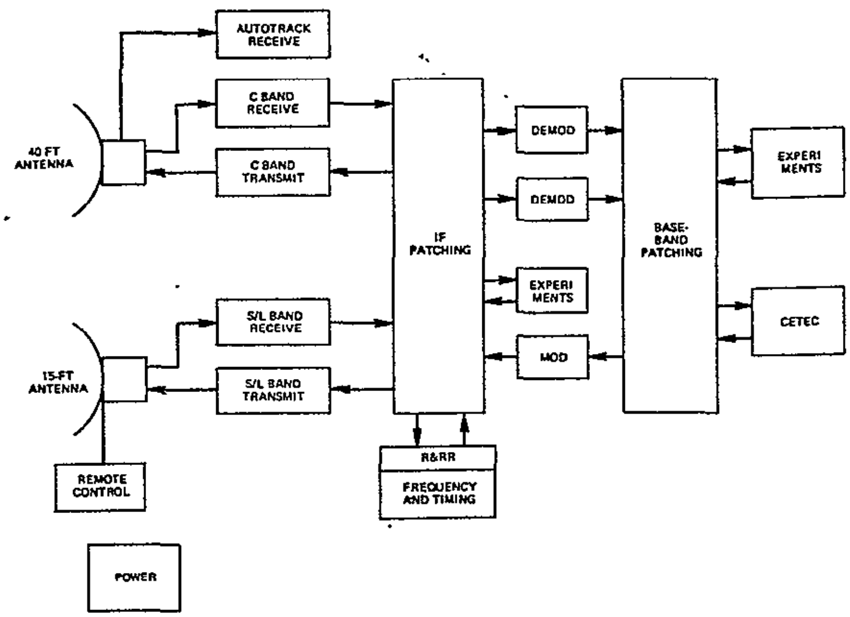


Figure 13-21. Mojave Ground Station Block Diagram

Spacecraft commands are encoded, transmitted and verified by the T&C system. Spacecraft housekeeping telemetry and discrete real-time functions are also received, processed, recorded, and displayed by the telemetry subsystem.

13.4.4.4 Hybrid Terminal(41)

The Hybrid Terminal is operationally quite similar to the Mojave station. The terminal is composed of the Mobile Terminal (less power generation equipment), three personnel vans, and the T&C, ATS-R and computer trailers from the transportable ground station. Two of these trailers have removable sides so that, when on site, they can be mated together side by side to form a single complete operation control complex (OCC) with access to all subsystems, with the exception of T&C. The T&C system is contained in a separate trailer. This system, which is basically the same for all of the ground stations, is integrated with the OCC so that overall control of the station can be maintained from one point. Spacecraft commands are encoded, transmitted and verified by the T&C system. Spacecraft housekeeping telemetry and discrete real-time functions are also received, processed, recorded and displayed by the telemetry subsystem.

The station master control console, from which all monitoring and control functions are handled, is located in the attached trailers. Communications with ATSOCC is is accomplished by one SCAMA voice circuit and one full duplex TTY circuit.

Figure 13-22 shows the Transportable Ground Station (TGS) Block Diagram.

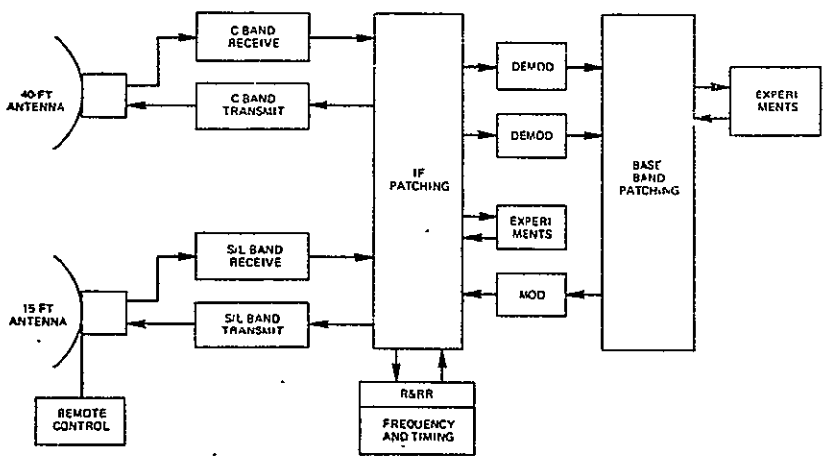


Figure 13-22. TGS Block Diagram

13.4.4.5 Mobile Terminal[41]

The ATS-6 Mobile Terminal will be located at a remote site. It is capable of transportation over normal highways at maximum legal speeds and at low speeds over improved roads to the installation sites. The terminal can be shipped by air or sea.

The Mobile Terminal is equipped to transmit and receive simultaneously on two bands, as shown below.

Operational Bands	Function
C- and S-band	Receive and transmit
C- and L-band	Receive and transmit
C-band and UHF	Receive and transmit on C-band but receive only on UHF

The antenna subsystem is capable of operating with geostationary synchronous satellites. In addition to transmission and reception of communications, the antenna subsystem is also used for range and range-rate signals.

The terminal is required primarily for the following:

- Television Relay Using Small Terminals (TRUST) experiment
- Position Location and Aircraft Communications Experiment (PLACE)
- Ranging
- Emergency support for communications in remote locations
- Demonstrations
- Accommodation of experiments on ATS-G

To accomplish the above, the subsystems, described below, constitute the mobile terminal.

- 6.4-meter (21-foot) polar mount antenna with C-band transmit and receive, and UHF receive focal point feeds
- 4.6-meter (15-foot) polar mount antenna with S- and L-band transmit and receive focal point feeds
- 70-MHz wideband modulator
- 70-MHz wideband demodulator
- C-, S-, L-band transmitters including upconverters, drivers, and power amplifiers
- Test translator and performance monitors

- C-, S-, L-band and UHF receivers including low noise preamplifiers, post amplifiers and wideband modulators
- Power generating and distributing equipment
- Miscellaneous equipment including racks, pallets, intercommunications system, IF patching, baseband patching, and time standardization equipment

Communication with ATSOCC is accomplished by one SCAMA voice circuit and one full duplex TTY circuit.

Table 13-39 lists the transmitter and receiver characteristics, and a station block diagram is shown in Figure 13-23.

Table 13-39. RF Characteristics for the Mobile Terminal

Frequency Bands of Operation	Function	Antenna Gain (dB)	Polarization	Transmit Power	System Noise Temperature (°K)
C-Band		6.4 m (21 ft)			
5925 to 6425 MHz	Transmit	48.9	Rotatable Linear	2 kW	--
3700 to 4200 MHz	Receive	44.8	Rotatable Linear	N/A	100 (cooled mode) 625 (warm, second preamp)
S-Band		4.6 m (15 ft)			
2200 to 2300 MHz	Transmit	36.9	LCP/RCP	100 W	--
2050 to 2400 MHz	Receive	35.7	LCP/RCP	N/A	230
L-Band		4.6 m (15 ft)			
1620 to 1700 MHz	Transmit	34.3	LCP/RCP	1 kW	--
1500 to 1580 MHz	Receive	33.6	LCP/RCP	N/A	200
UHF-Band		6.4 m (21 ft)			
835-885 MHz	Receive only	31.7	LCP/RCP	N/A	450

NOTE: All gain is based on a 50% efficiency across the bands.

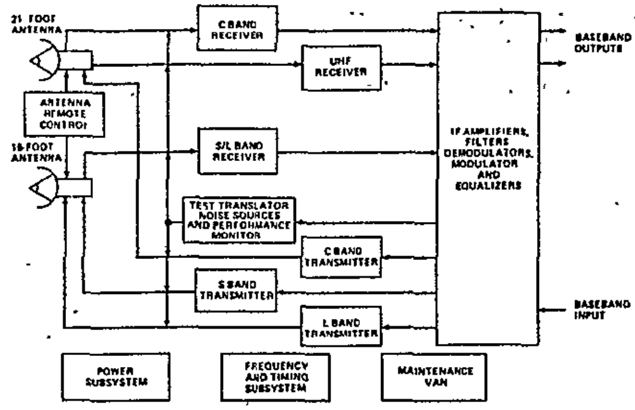


Figure 13-23. ATS-6 Mobile Terminal System Block Diagram

13.4.4.6 Low Cost Earth Terminals[42]

The ATS-6 earth stations are designed to meet the needs of both the health and education communities. After the HEW ATS-F User Policy Committee established the types and characteristics of terminals to be developed, the detailed specifications were written jointly by the Lister Hill National Center for Biomedical Communications, NASA, and the Federation of Rocky Mountain States. A "building block" philosophy was adopted which would permit "receive-only," "intensive," and "comprehensive" stations to be assembled from the basic development components. It was envisioned from the outset that these stations would be designed for operation solely by the health professionals and teachers. It was inconceivable that the system could be cost effective in remote areas if it were necessary to have on hand a full-time technician. The following are characteristics of the hardware:

1. Solid state throughout
2. No high voltages in the equipment
3. Relatively few circuit boards so that first level maintenance would consist of plugging in boards until the defective one is found

4. Very few switches and adjustments

5. Simple go/no-go indications for critical voltages, signal levels, etc.

6. Low cost

The basic station is the receive-only terminal. It consists of an external antenna and amplifier, and an indoor unit which contains the video and four-channel audio output. The four audio channels may be used for voice, physiological information, and data for computer-aided instruction and evaluation. The intensive terminal is made up of a receive-only terminal plus the VHF transmit-receive equipment in use with the ATS-1 satellite network in Alaska. Thus the user of an intensive terminal cannot only receive video and associated voice/data channels, but can reply by voice. The comprehensive terminal is an intensive terminal with added transmission equipment which gives the user the ability to receive and originate full video, audio, and data.

Hewlett-Packard, Hughes Aircraft, Prodelin, and Westinghouse are all involved in developing equipment under contract for the ATS-6 health and education experiments.

13.4.5 Experiments

The ATS-6 spacecraft is scheduled to perform over 20 technological and scientific experiments as shown below.[42]

Communication Experiments

- Health - Education Telecommunications Experiment (HET) (6 Projects)
- Satellite Instructional Television Experiment (SITE)
- Television Relay Using Small Terminals (TRUST)
- L-Band Experiment (also known as Position, Location and Aircraft Control Experiment (PLACE))
- Tracking and Data Relay Experiment/Satellite-to-Satellite Experiment

Communications Technology Experiments

- Radio Frequency Interference (RFI) C-band Experiment
- Millimeter Wave Propagation Experiment (MWE)
- COMSAT Propagation Experiment
- Spacecraft Attitude Precision Pointing and Slewing Adaptive Control Experiment
- Radio Beacon Experiment

Additional Technological Experimentation

- Very High Resolution Radiometer Experiment
- Cesium Bombardment Ion Engine Experiment
- Advanced Thermal Control Flight Experiment
- Environmental Measurements Experiments (EME)
- International Magnetospheric Relay Experiment

Special Investigations

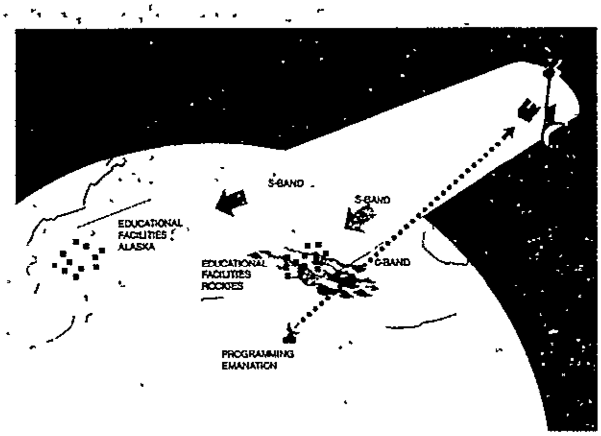
- Spacecraft Vibration Accelerometer
- Quartz Crystal Microbalance Contamination Monitor
- Television Camera
- Interferometer High Data Rate Acquisition System

Since its near perfect orbit achieved with the Martin Marietta Titan III C Transtage left ATS-6 with enough hydrazine propellant for an extra year's operation, additional experiments will most likely be developed but are yet to be published.[43] (For more technical information on the experiments please refer to the ATS F&G Data Book. Principal investigators are listed for reference purposes.)

13.4.5.1 Health-Education Telecommunications Experiment (HET)[42]

Three separate educational experiments will be performed in the HET series.

- Appalachian Educational Satellite Project
- Satellite Technology Demonstration (STD) Rocky Mountain States
- Alaska ATS-6 Educational Telecommunications Experiment



HET. ATS-F will beam *Educational Television* programming direct to unique, low-cost receiving stations located in or near school-houses or community buildings in isolated regions of Alaska and the Rocky Mountains where terrestrial TV coverage is not feasible. ETV transmission will utilize S-band frequency and localized one-degree beam-width spot-beams The Department of Health, Education, and Welfare and the Corporation for Public Broadcasting are cooperating with NASA in the experiment. (39)

Each of the projects explores how to convey educational information, but in different ways. In Appalachia, elementary and secondary-school teachers will receive in-service courses in career education and the teaching of elementary reading. They will also be able to request and receive specialized reference information via satellite. In the Rocky Mountains, junior-high students will have a course in career education, and adults will have some evening programs on topics of interest to them. Also, teachers in that area, instead of having to order videotaped materials for their classes months or weeks in advance, will be able to order those materials in a large number of subjects from a videotape collection in Denver and to receive those materials quickly via satellite. In Alaska, people who live in villages that can be reached only by airplane, and then only when the weather is good, will have a chance to learn about other people and cultures in their State.

The education projects will use the ATS-6's video and audio channels and the audio channels of ATS-1 and ATS-3. For Appalachia, the main broadcast point is NASA's ATS ground station at Rosman, North Carolina. For the Rockies, the broadcast point is Denver, Colorado. For Alaska, it is Fairbanks and Juneau.

13.4.5.2 The Appalachian Educational Satellite Project[42]

NIE's project in Appalachia has been developed by the Appalachian Regional Commission, a Federal-State agency created by the Appalachian Regional Development Act of 1965 to coordinate Federal, State, and local governments' attempts to improve the total economic development (roads, health service, education) of Appalachia. In 1971, the Commission surveyed 32,000 public-school teachers in Appalachia and learned that in-service training, particularly in the teaching of reading and career education, was needed. The Commission, with selected Regional Education Service Agencies (RESAs), and the University of Kentucky are participating in the satellite project.

This summer, the University of Kentucky will offer to elementary-school teachers, via satellite, two graduate-level three-credit courses through the 15 selected RESAs. One course will be in career education; the other, the teaching of elementary reading.

The system will work as follows: the 15 RESAs have been divided into five groups of three each. In each group, the main RESA will have a terminal that receives and sends the material broadcast by satellite. The other two RESAs will have terminals that only receive broadcasts; they will be connected to the main RESA by land lines, so the questions and comments of teachers who are taking the courses at the ancillary RESAs can be relayed to the other students and to the facilities in Kentucky. Figure 13-24 illustrates this experiment.

The sites and types of terminals for the Appalachian Educational Satellite Project[42] are as follows:

Location	Type of Terminal
Alabama	
Huntsville, RESA	Intensive
Guntersville	Receive-only
Rainsville	Receive-only

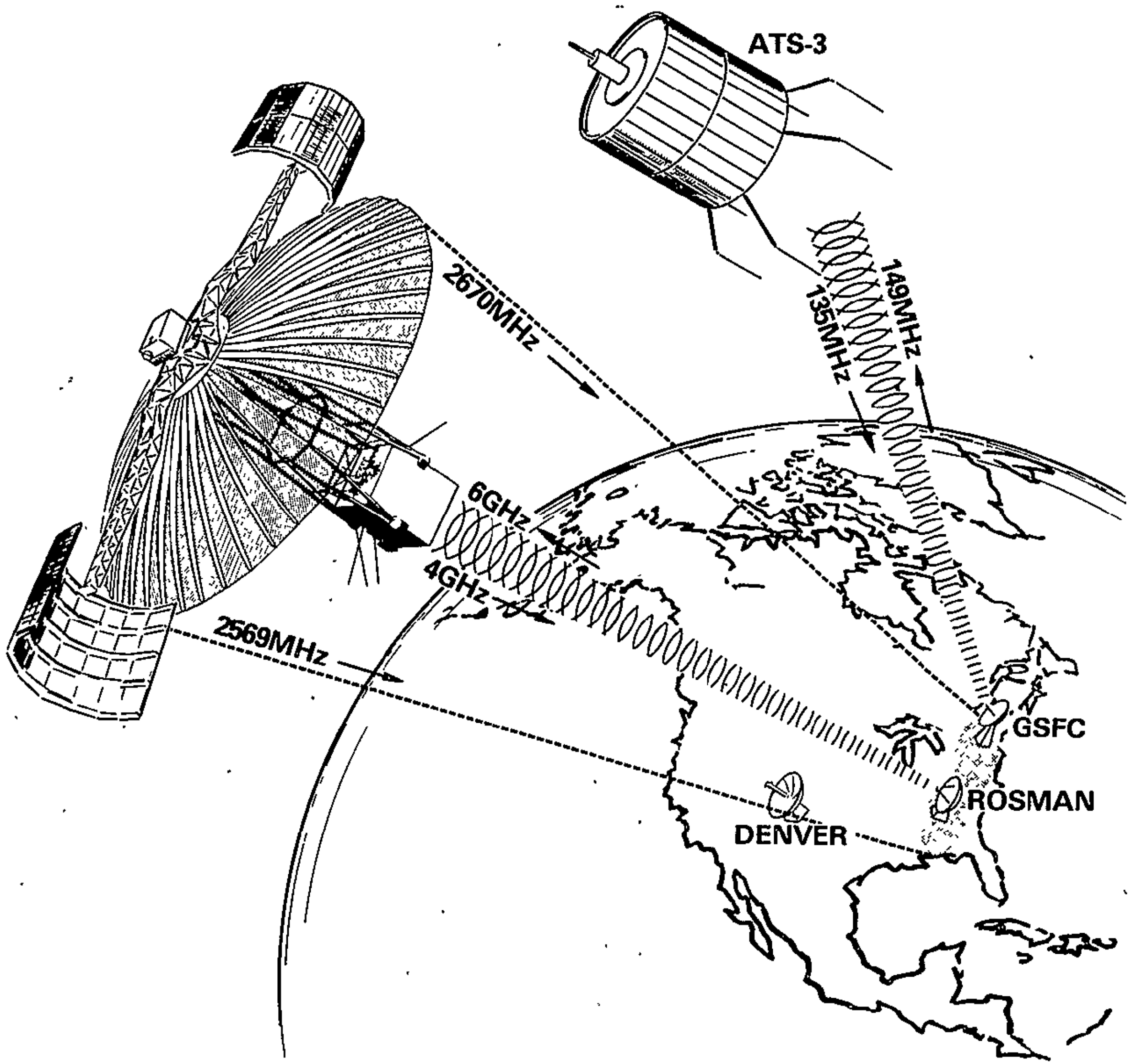


Figure 13-24. Appalachian Regional Commission(42)

Location	Type of Terminal
Maryland	
Cumberland, RESA	Intensive
McHenry	Receive-only
Keyser (W. Va.)	Receive-only
New York	
Fredonia, RESA	Intensive
Olean	Receive-only
Erie (Penn.)	Receive-only
Virginia	
Norton, RESA	Intensive
Stickleyville	Receive-only
Boone (N. C.)	Receive-only
Tennessee	
LaFollette	Intensive
Johnson City	Receive-only
Coalfield	Receive-only

13.4.5.3 The Satellite Technology Demonstration of the Federation of Rocky Mountain States, Inc. (42)

The Rocky Mountain project--labeled the Satellite Technology Demonstration (STD)--will focus on junior-high-school students as its primary audience. Starting in September 1974, about 4,900 students in 56 rural communities throughout Colorado, New Mexico, Arizona, Utah, Nevada, Idaho, Montana, and Wyoming will receive programs in career education directly by satellite. The programming will broadcast from Denver to the schools 35 minutes a day through the satellite. As many as 20,000 more students also will receive the programs through the region's public television stations.

STD terminals will be installed at 68 communities scattered through the eight participating States. Of these terminals, 56 will be at rural schools. The others will be located at the 12 Public Broadcasting Service (PBS) stations in the region, enabling these stations to carry the programs during the actual satellite broadcasts or to videotape and play them at some other time.

Twenty-four of the rural schools, three per State, have been selected as "Intensive Sites." During a segment of live broadcasting, these sites will have two-way audio communication capabilities through the use of the ATS-3 satellite, which has been in orbit since the late 1960s. This enables the programmers to respond instantaneously to and participate in the actual programming. Participants at one Intensive Site will be able to communicate simultaneously both with Denver and with participants at other Intensive Sites. One of the key features of the demonstration, this capability will be studied for its implications on future educational and telecommunications activities.

The other 32 rural schools, as well as the 12 PBS stations, are designated Receive-Only Terminals. They will receive the same radio and color TV signals as the Intensive Sites, but will not have two-way capability.

The STD also will originate adult, community-oriented programming to the 56 participating rural schools one evening every third week, focusing on subjects of concern discovered in surveys of the communities. Subjects already identified include aging, health care, and problems related to alcoholism and drugs.

Figure 13-25 illustrates this experiment.

The sites and types of terminals for the Satellite Technology Demonstration of the Federation of Rocky Mountain States, Inc. (42)

Location	Type of Terminal
Arizona	
Gila Bend	Receive-only
Seligman	Receive-only
Tuba City	Intensive
Hayden	Intensive
McNary	Intensive
Fredonia	Receive-only
St. Johns	Receive-only

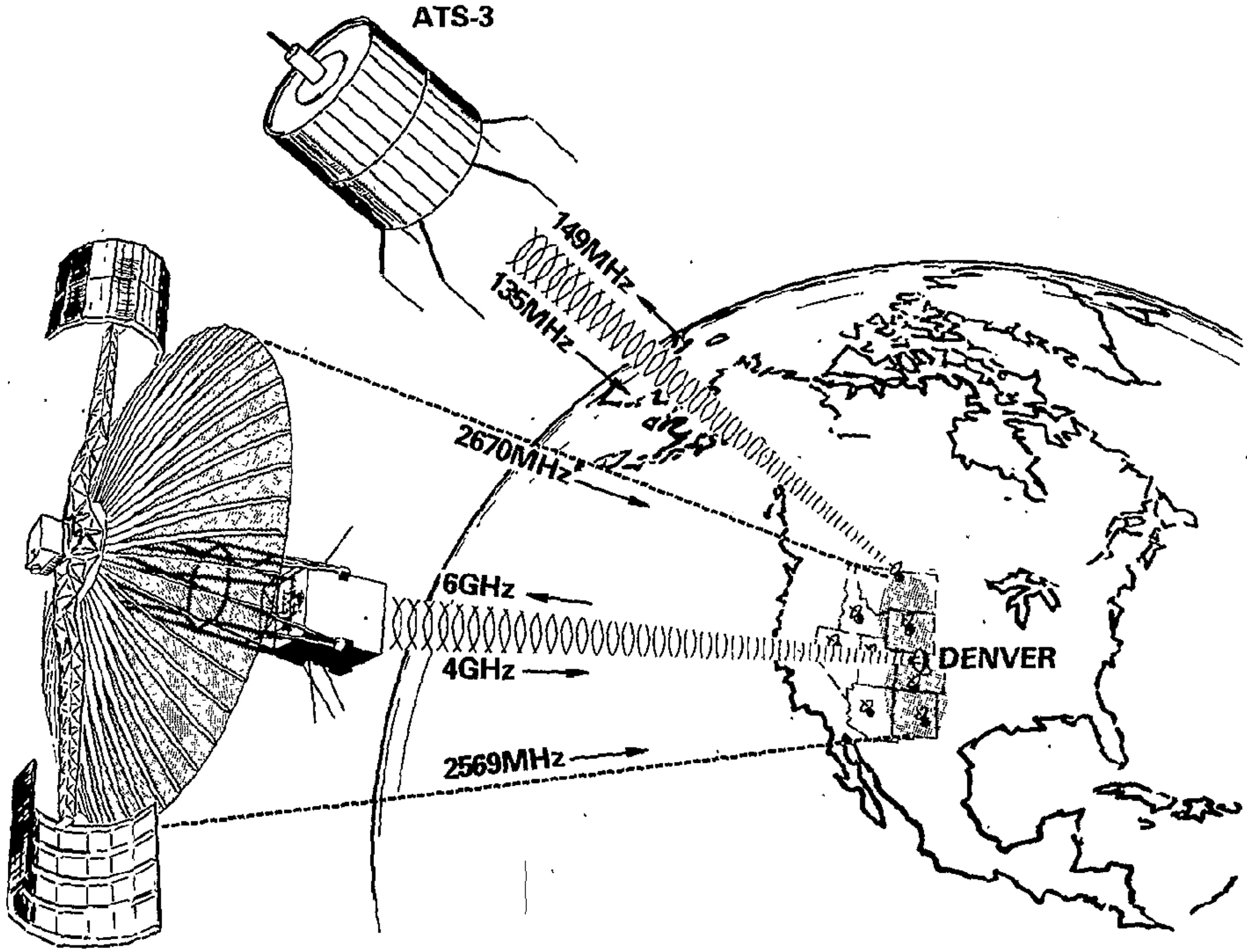


Figure 13-25. Rocky Mountain Region[42]

Location	Type of Terminal
Tempe*	Receive-only
Tucson	Receive-only
Colorado	
Monte Vista	Intensive
Meeker	Intensive
Montrose	Intensive
Craig	Receive-only
Antonito	Receive-only
Naturita	Receive-only
Collbran	Receive-only
Denver*	Receive-only
Pueblo*	Receive-only
Idaho	
Challis	Intensive
McCall	Intensive
Lapwai	Intensive
Vallivue	Receive-only
Salmon	Receive-only
St. Maries	Receive-only
Osburn	Receive-only
Moscow*	Receive-only
Boise*	Receive-only
Pocatello*	Receive-only
Montana	
Colstrip	Intensive
Busby	Intensive
Ft. Benton	Intensive
Roundup	Receive-only
Whitehall	Receive-only
Three Forks	Receive-only
West Yellowstone	Receive-only
Nevada	
Battle Mountain	Receive-only
Carlin	Intensive
Owyhee	Intensive
McDermitt	Intensive
Elko	Receive-only

* PBS station.

Location	Type of Terminal
Winnemucca	Receive-only
Ely	Receive-only
Las Vegas*	Receive-only
New Mexico	
Penasco	Intensive
Cuba	Intensive
Dulce	Intensive
Mora	Receive-only
Springer	Receive-only
Questa	Receive-only
Wagon Mound	Receive-only
Albuquerque*	Receive-only
Las Cruces*	Receive-only
Utah	
Blanding	Intensive
Enterprise	Intensive
Kanab	Receive-only
Panquitch	Receive-only
Heber	Intensive
Morgan	Receive-only
Hyrum	Receive-only
Provo*	Receive-only
Salt Lake City*	Receive-only
Wyoming	
Arapahoe	Receive-only
Lovell	Receive-only
Sundance	Receive-only
Dubois	Receive-only
Saratoga	Intensive
Pinedale	Intensive
Riverton	Intensive

13.4.5.4 The Alaska ATS-6 Education Telecommunications Experiment[42]

To explore as many different ways to use the satellites as possible, the Office of Telecommunications of the Office of the Governor of Alaska plans two major areas

* PBS station.

of activity--instructional programming and public broadcasting. The area of instructional programming is divided into four parts. They are basic oral language development, health education, early childhood education, and in-service teacher training.

Each of the Alaskan earth terminals will have a two-way audio connection through the ATS-1 satellite. This connection will be used in the training of teachers as well as the education of the students, especially in the basic oral language development programs. The television teacher conducting activities involving the children and conversing with them over the satellite radio will be setting a model for the teacher in the classroom, and both can communicate during classtime or during the teacher-training sessions.

The teachers will receive manuals containing program goals and objectives, descriptions of program content, lesson guides, and suggestions for teaching activities. The suggestions will address lesson preparations, viewing and interaction, follow-up activities, and evaluation. Teachers' manuals will be developed for each of the instructional program areas.

The second major activity of the Alaska project is public broadcasting designed for the general population. There are two parts in the public broadcasting activity. The first is a program series called the "Alaska Native Magazine." Each week, the satellite will broadcast a half hour of prepared program material featuring such native concerns as land claims, pipeline impact, and native culture and arts. The programs will have built-in pauses for viewers to express opinions and ask questions. These programs will be followed by a half hour of panel discussions, conversation with village viewers, and suggestions for future programs. The audio part of the programs will be presented in several native languages and English simultaneously.

The other part of this activity will bring television and radio programs to Alaska at the time they are broadcast in the contiguous 48 states.

Figure 13-26 illustrates this experiment.

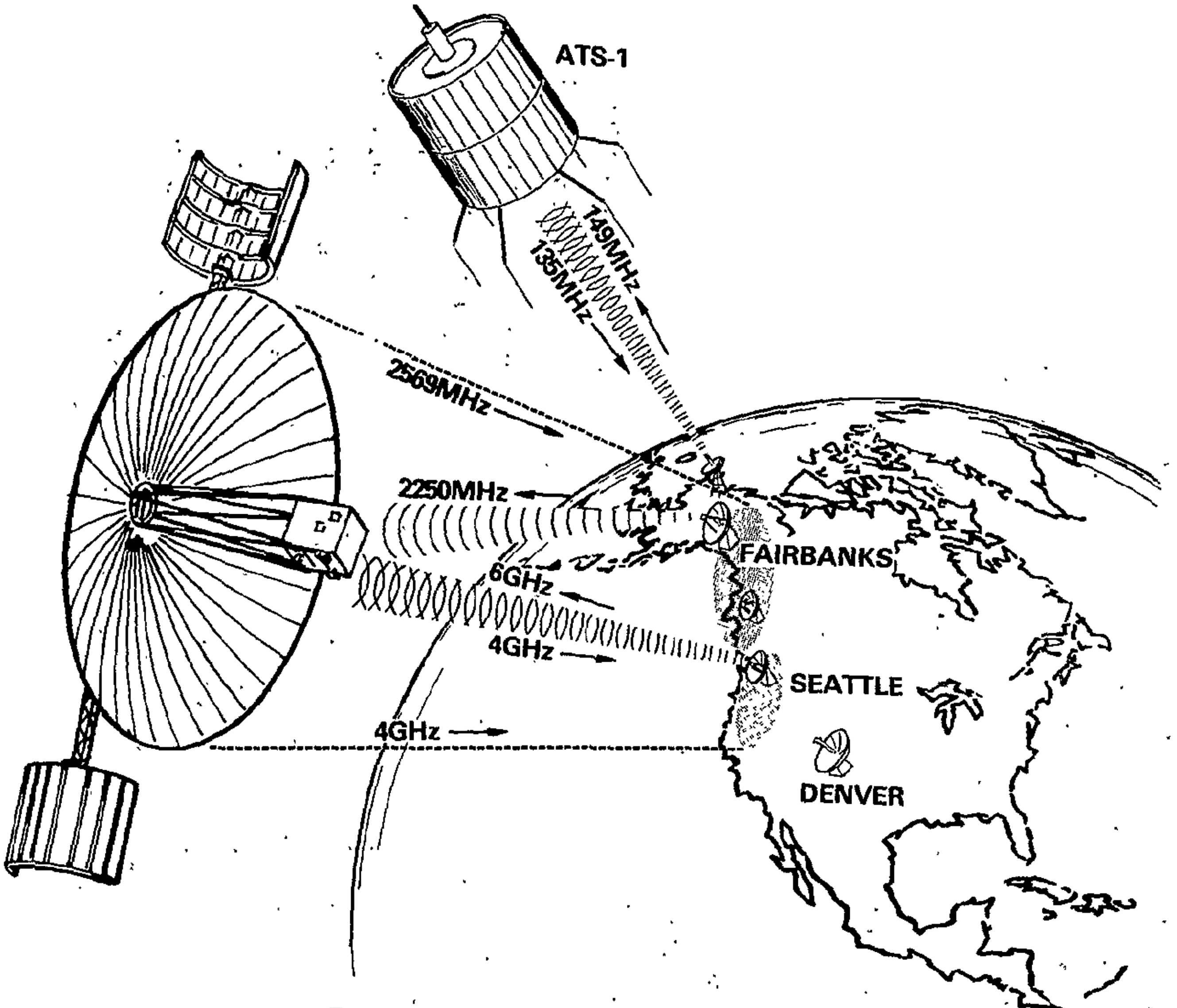


Figure 13-26. Alaska/Northwest[42]

The sites and types of terminals for the Alaska ATS-6 Education Telecommunications Experiment[42] are as follows:

Location	Type of Terminal
Little Russian Mission (Chuathbaluk)	Intensive
Petersburg	Intensive
Sleetmute	Intensive
Valdez	Intensive
McGrath	Intensive
Nikolai	Intensive
Allakaket	Intensive
Minto	Intensive
Aniak	Intensive
Nenana	Intensive
Yakutat	Intensive
Anchorage	Intensive
Fairbanks	Comprehensive
Juneau	Comprehensive
Angoon	Intensive
Craig	Intensive
Tanana	Comprehensive
Galena	Comprehensive

13.4.5.5 Expanded Health Communications Via ATS-6

ATS-6 will also serve the health community with three experiments[42]:

- Alaska Telemedicine
- University of Washington Health Education Programs
- Veterans Administration Medical Information Exchange Program

The objective of the health communications experiments is to demonstrate whether health care in remote areas can be improved by (1) telemedicine--i.e., enabling a physician to see and talk to a patient, listen to his heart, evaluate an EKG, and prescribe a course of therapy, all at a distance via satellite; and (2) health education to train physicians whose undergraduate experiences are rooted in rural America. While the telemedicine experiment will build on the work begun in Alaska with ATS-1, the second objective--health education--involves a consortium of four states: Washington, Alaska, Montana, and Idaho. Only Washington presently has a medical school.

13.4.5.5.1 Telemedicine

The experiment in telemedicine will be conducted at five sites in Alaska. The examining rooms in the small clinics at Fort Yukon (population 630) and Galena (population 425) will be equipped with "comprehensive" earth stations for sending and receiving video, voice, physiological information, and records data. The medics and health aides at these clinics will present patients to the viewing physicians at the Public Health Service Hospital in Tanana. This site is also equipped with a comprehensive terminal. Consultation with specialists will be available from Fairbanks (with a comprehensive terminal) and the Alaska Native Medical Center (ANMC) at Anchorage. The latter will have what is called an "intensive" terminal--equipment similar to the others, but without the capability to transmit video. Medical record data can be transmitted and received via ATS-1 satellite from all sites.

In actual operation, Tanana physicians will call the villages and clinics via ATS-1 to discuss medical problems with the health and medics as they have been doing for the past two years. Patients in the clinics who might benefit from visual consultation will be scheduled for ATS-6 time. Prior to visual consultation, the patient's medical records will be retrieved via ATS-1 from the Indian Health Service Health Information System (HIS) computer in Tucson, Arizona. The patient then will be "seen" by the Tanana physician and therapy prescribed. During presentation of the patient, physiological information such as EKG and heartbeat may be sent simultaneously via one or more of the four aural channels associated with the televised picture. Talk-back to the presenting clinics will be accomplished via ATS-1, since simultaneous two-way transmission through ATS-6 is not possible in this mode. If needed, the Tanana physician will "call in" the specialists at Fairbanks and the ANMC to examine the patient. After the consultation, the physician prepared his report and transmits it via ATS-1 to the patient's medical record stored in Tucson. For the sake of privacy all video and audio associated with the consultation will be scrambled.

Only the presenting clinic and consulting staffs will be able to unscramble the information.

13.4.5.5.2 Health Education

The health education experiment will test the feasibility of providing instruction to medical students via satellite, so that aspiring physicians in states without medical schools will have an opportunity to study medicine on an equal footing with students in other states. The medical education experiment is in two parts: basic science and clinical medicine.

1. Basic Science--Instruction in the basic sciences will involve the faculty at the University of Washington in Seattle and students and faculty at the University of Alaska in Fairbanks. There will be full two-way voice and video interaction for classes in basic sciences (chemistry, biology, etc.), administrative conferencing, counseling, and computer-aided instruction and evaluation of student performance. Lectures, demonstrations, and classroom experiments will originate from both sites, and a lively interchange between students and faculties at both ends is expected.

2. Clinical Medicine--The part of the health education experiment dealing with clinical medicine will involve third and fourth year medical students studying under clinicians at Omak, in central Washington. The students will present patients (by video and voice transmission) to the medical faculty at the University of Washington in Seattle. The faculty, although "seeing" the patient, will be able to respond to the student only by voice. Students will be required to give both formal and spontaneous presentations of patients.

13.4.5.6 Veterans Administration Exchange of Medical Information Program [42]

Ten Veterans Administration hospitals located within the footprint of the ATS-F spacecraft are participating in the VA exchange of medical information program as part of the Health-Education Telecommunications Experiment. The project is being coordinated by the Foundation for Applied Communications Technology.

The hospitals are located in Altoona and Wilkes-Barre, Pa.; Beckley and Clarksburg, W. Va.; Salem, Va.; Fayetteville, Oteen, and Salisbury, N. C.; Dublin, Ga.; and Mountain Rome, Tenn.

Hospital staffs will participate in programs related to clinical problems experienced with hospital patients. VA telecasts are scheduled for approximately 2-1/2 hours weekly for about a year.

Topics will be presented in the following formats:

1. Video seminars with groups at the VA hospitals asking questions and commenting over a return audio channel.

2. Patient case presentations televised from one hospital to other participants, with TV return enabling viewers at all sites to participate.

3. TV tele-consultation in which doctors at VA hospitals consult with specialists at teaching institutions. Patients and clinical material may be televised.

4. Computer-assisted instruction in which physicians and staffers will participate in programmed instruction mediated by computer, including history-taking, diagnosis and management of various clinical problems.

5. Slow-scan, using signals that do not require wideband transmission. TV transmission will include such items as electrocardiograms, and X-rays. VA physicians will be able to obtain specialist consultation in making diagnoses.

Figure 13-27 illustrates this experiment.

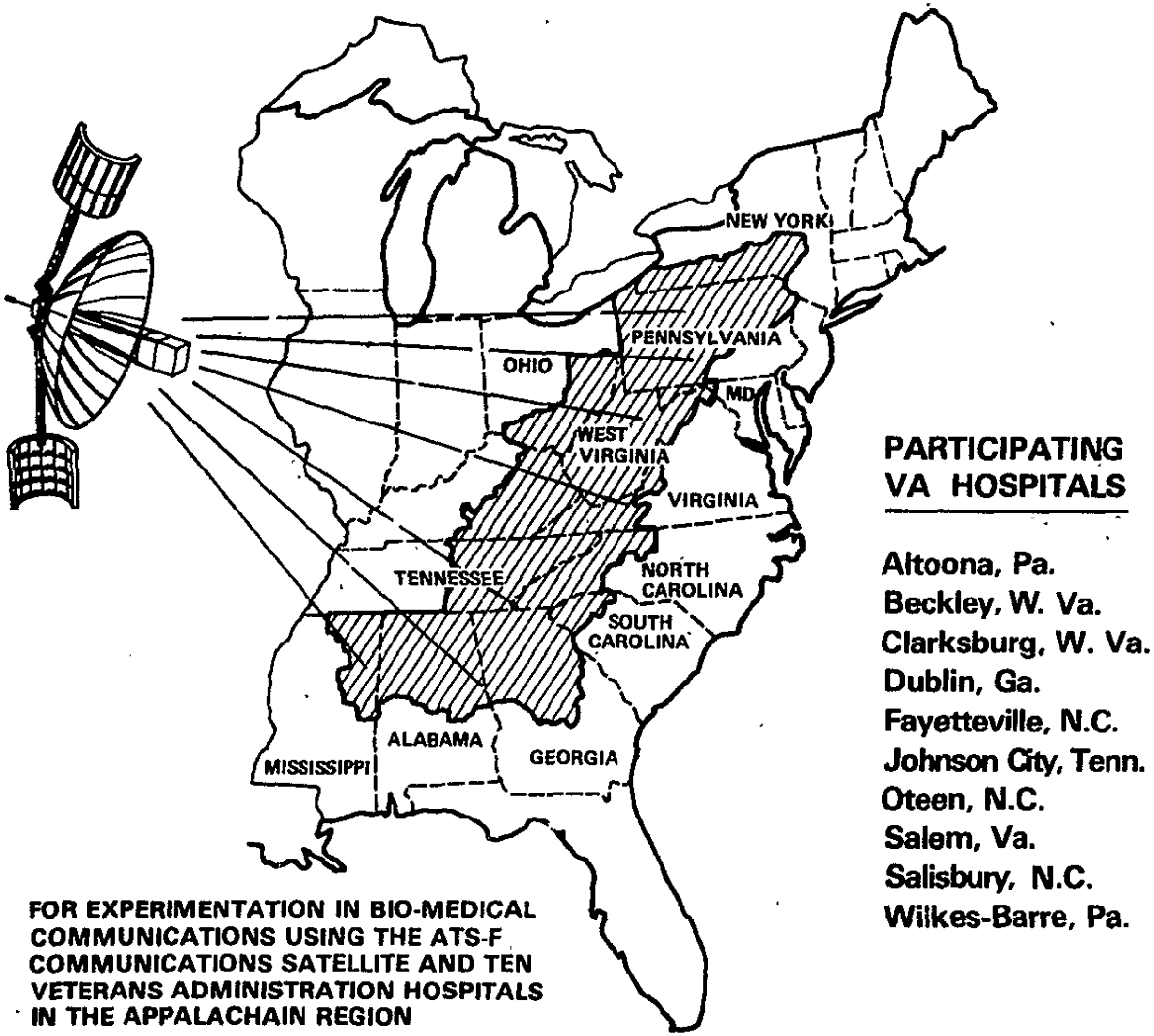
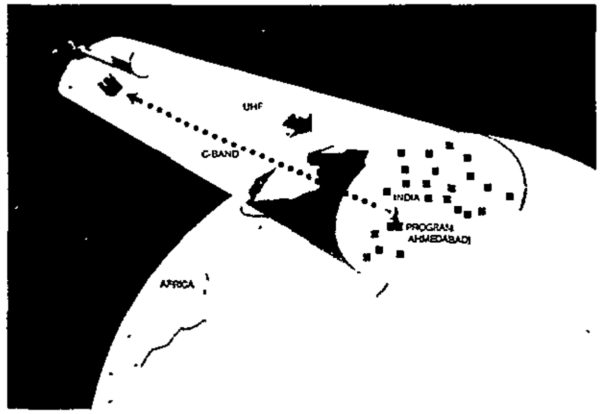


Figure 13-27. Health Education Telecommunications Experiment Veterans Administration's Exchange of Medical Information Program Applications Technology Satellite-F[42]

13.4.5.7 Satellite Instructional Television Experiment (SITE)

This is a joint experiment by NASA and the Indian Space Research Organization of India, by an agreement entered into September 18, 1969. Its central objective is to demonstrate the potential value of a direct broadcast TV system for education purposes, primarily in rural and remote areas, using a geosynchronous communications spacecraft in conjunction with low-cost ground terminals.



SITE. The Governments of India and the U S are cooperating in the *Instructional Television* experiment. After ATS-F has been in orbit one year, the spacecraft will be moved from its original position at 94 degrees west longitude to 35 degrees east longitude. Thrusters located on the truss structure will propel it to a new location at a rate of 45 feet per second There it will transmit instructional material designed to improve occupational skills, increase food producton, assist in family planning, improve health and hygiene and train teachers. A ground station at Ahmedabad, India, will transmit programs at C-band to ATS-F, which will relay video and voice signals via UHF to a network of some 3,000 inexpensive community receivers in rural and remote villages (39)

NASA responsibilities for this experiment include provision of adequate operating time on ATS-6's communications transponder as well as positioning and pointing of the spacecraft from the ATS mobile ground station near Madrid, Spain. All other aspects of the experiment, including the design, development, and maintenance of the ground transmitting and receiving stations and all programming, are the responsibility of India. India's Space Research Organization (ISRO) is producing all the hardware, while All India Radio (AIR), of the India Ministry of Information and Broadcasting, has prime responsibility to develop the programming.

This experiment will begin approximately one year after launch, when NASA will move ATS-6 to 35 degrees east longitude over the equator, a position over the eastern edge of Lake Victoria in Kenya, East Africa. Requiring about 45 days, this maneuver will place the spacecraft in a position where it will be "visible" to the Indian subcontinent, yet remain in communications view of Madrid for control purposes.

Programs will be transmitted 4 hours a day for 1 year from the primary Indian ground station in Ahmedabad or the secondary station in Delhi to ATS-6 for relay to villages and cities throughout India.

Because of the large number of languages and dialects spoken in India, the video channel will be accompanied by two audio channels in different languages.

Daily programs will stress improved agricultural techniques, family planning and hygiene, school instruction and teacher education, and occupational skills. Children's programs will be shown from 10:00 to 11:30 a.m. while general broadcast materials and adult education programs will be transmitted from 6:30 to 9:00 p.m., Indian local times.

The basic ground terminal costs about $600 and consists of a 3-meter (10-foot) diameter antenna made of expanded aluminum mesh, a converter, and a TV receiver. About 2,400 of these terminals will be located in six clusters of 400 in various parts of India for direct reception from the ATS-F.

Another 2,600 or more standard TV receivers will be located near rediffusion transmitting stations where the signals relayed through the ATS-6 will be retransmitted over conventional TV for the benefit of people in villages near the larger cities.[(42)]

The experiments will operate on these frequencies:

- C-band for ground to-ATS-6-to ground, 6 GHz up and 4 GHz down with bandwidth of 40 MHz.

- UHF from ATS-6 to ground TV receiving terminals, 860 MHz.

SITE will transmit two audio channels simultaneously with the video. The two FM audio signals will use separate subcarriers at 5.5 MHz and 6.0 MHz. The video (625 lines CCIR system B) and audio subcarriers are summed at baseband, and the composite baseband signal frequency modulates the uplink C-band carrier with a peak-to-peak deviation of about 18 MHz. The ATS-6 spacecraft will receive the signal on the earth-coverage horn and will retransmit at 860 MHz without processing the signal, using the 9.1-meter (30-ft) reflector. At the same time, it will retransmit to monitoring stations having 12-meter (40-ft) dishes on the C-band, using the earth-coverage horn.

The entire experiment will be evaluated by India in accordance with a mutually agreeable plan during the broadcasting period and after it is completed its technical and social impact will be assessed. This information will then be available to aid other developing countries desiring to implement such a program.

The organization of the project is as follows:

1. Program Managers

   DOS - Dept. of Space, India

   Prof. E. V. Chitnis
   Indian Space Research Organisation
   Space Applications Centre
   Ahmedabad-380015, India

   NASA - National Aeronautics and Space Administration, U.S.A.

   Mr. Wasyl M. Lew
   Experiment Manager for Communications Programs
   NASA Headquarters, Code ECS
   Washington, D.C. 20546, U.S.A.

2. Project Managers

   DOS - Dept of Space, India

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   Space Applications Centre (ISRO)
   Ahmedabad-380015, India

   Lt. Col. N. Pant
   Project Manager Earth Stations
   Experimental Satellite Communication
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   Ahmedabad-380009, India

   NASA - National Aeronautics and Space Administration, U.S.A.

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3. Principal Investigators

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TBD

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Mr. J. E. Miller
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Director
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Mr. P. P. Kale
Head
Electronic Systems Division
Space Applications Centre
Ahmedabad-380015

NASA

Mr. K. Kissin
ATS Mission Operations Manager
Goddard Space Flight Center
Greenbelt, Maryland 20771, U.S.A.

Figure 13-28 illustrates this experiment.

13.4.5.8 Television Relay Using Small Terminals (42)

The purpose of this experiment is to test and evaluate the performance of small, low-cost ground terminals for the reception of quality color TV and television test signals in the Ultra High Frequency band (UHF) using ATS-6.

Developing nations interested in the use of such a system for national educational TV purposes will be given an opportunity to participate in the tests and demonstrations.

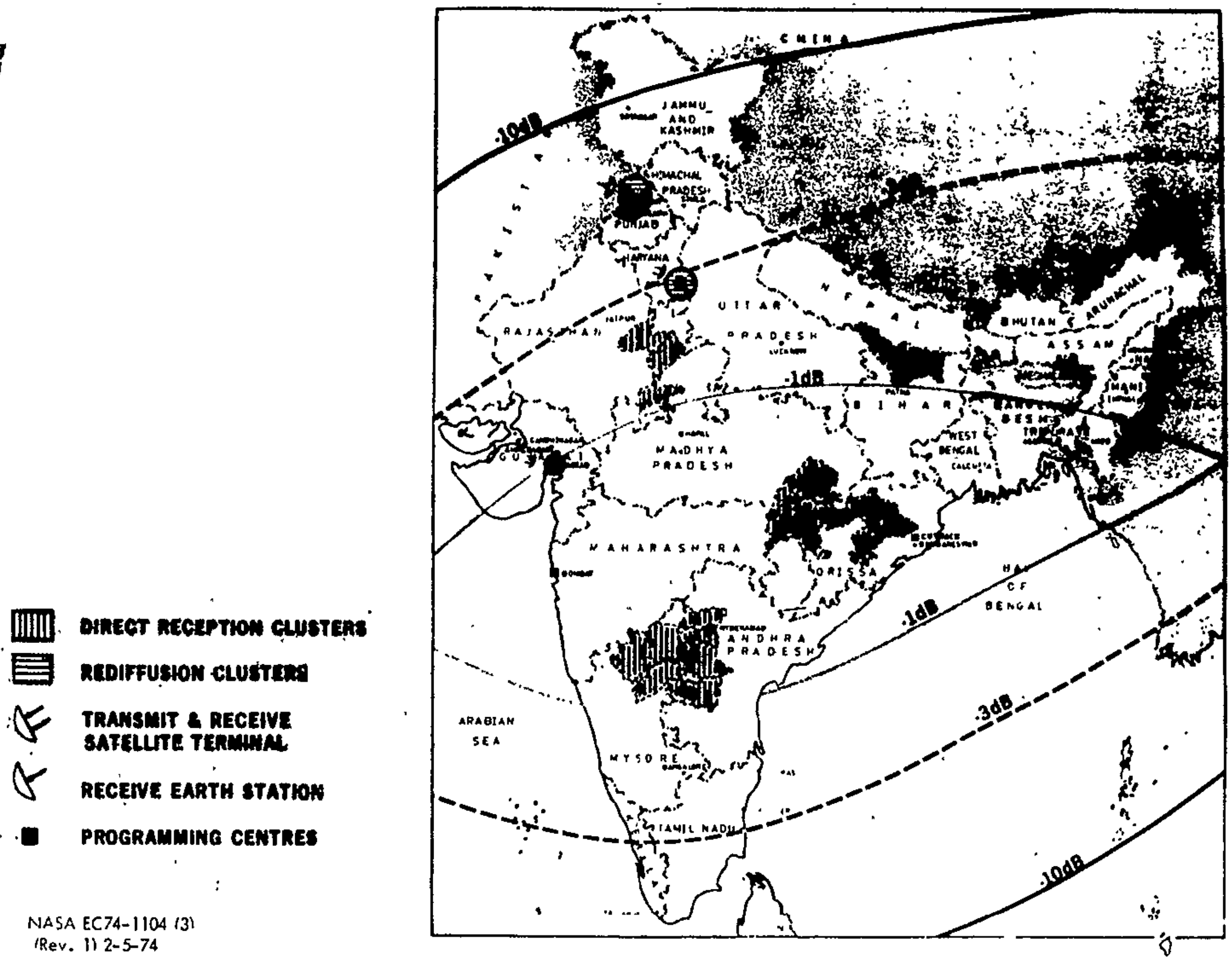


Figure 13-28. SITE Activities in India[42]

Advice and consultation will be provided to each country in the design and implementation of suitable receivers for such a system.

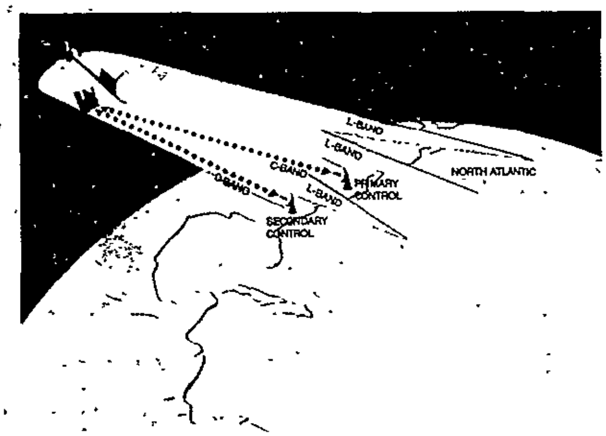
This experiment will be conducted during the spacecraft's first year of operation while it is located at 94 degrees west longitude over the equator and in view of the U. S.

For the tests, the ATS ground station at Rosman, N. C., or Mojave, California, will transmit frequency modulated (FM) TV signals accompanied by multiple audio channels to ATS-F for relay as UHF signals to a pilot receiving unit located at Goddard. The pilot unit consists of a 3-meter (10-foot) diameter parabolic antenna coupled to a low-cost receiver. Objective performance measurements will be made on this unit using internationally recognized and accepted standards for TV transmissions.

Principal Investigator: John E. Miller, Goddard Space Flight Center.

13.4.5.9 L-Band Experiment

The L-Band Experiment, also known as Position Location and Aircraft Communication Experiment (PLACE),(42) will demonstrate and evaluate the application of a geosynchronous orbit spacecraft for aeronautical and maritime communications and traffic control using the L-Band frequencies (15 to 17 GHz). Certain frequencies in the L-Band range were allocated for aeronautical and maritime mobile-satellite communications by the United Nation's World Administrative Radio Conference in 1971.



PLACE. Safer operation of the increasing number of aircraft flying international over-ocean routes requires more precise navigation and altitude measurement than currently available as well as continuous communications between these aircraft and ground control stations The *Position Location and Aircraft Communications Experiment* will be the forerunner of satellite air traffic control systems of the future. Aircraft flying the North Atlantic now are assigned a 120-mile-wide flight corridor and spaced at least 15 minutes apart. The goal is to allow each traffic lane to be narrowed to 30 miles with five-minute spacing between aircraft.(39)

The information and experience gained from this experiment will provide the basis for several future operational spacecraft systems intended for day-to-day aeronautical and maritime communications, traffic control, and search and rescue operations.

Organizations participating in this experiment include:

1. NASA/Goddard Space Flight Center

2. Department of Commerce/Maritime Administration (MarAd)

3. Department of Transportation

    a. Federal Aviation Administration (FAA)
    b. U.S. Coast Guard (USCG)
    c. Transportation Systems Center (TSC)

4. European Space Research Organization (ESRO)

5. Canadian Department of Communications and Ministry of Transport

During this experiment, performance tests will be conducted on several communications and position-location techniques using the ATS-6 and ATS-5 spacecraft with airborne planes and ships at sea. Other tests will include ground-based simulation and engineering exercises.

From its position at 94 degrees west longitude over the Galapagos Islands, ATS-6 will provide two-way communications between mobile units and ground stations located in a 1,081-kilometer (672-mile) wide area extending from the east coast of the U.S. two thirds of the way across the mid-Atlantic Ocean.

Tests conducted between the ground stations and the aircraft and ships underway are designed to determine the effects of ionospheric, noise, and multipath disturbances as well as the geographic location of the tracked units on both L-Band communications and position location techniques. Tests will encompass:

- Communications link performance
- Multi-access performance

- Power and frequency control techniques
- Quality and ranging precision for the various techniques under test

Position location tests require altimeter readings from aircraft and accurate range measurements from each of the two ATS spacecraft and the aircraft or ship being tracked be known.

Precise spacecraft location is obtained by a trilateration technique in which accuratemeasurements of the distance from three ground stations to each spacecraft are used. ATS-F trilateration technique in which accurate measurements of the distance from three ground stations to each spacecraft are used. ATS-6 trilateration measurements will be made from the three NASA tracking stations at Rosman, N. C.; Mojave, California; and Santiago, Chile. ATS-5 trilateration stations will be located in Schenectady, N. Y.; Hawaii, and Buenos Aires, Argentina.

The ATS ground station at the Rosman, N. C., site will serve as the primary L-Band experiment support facility for communicating with the ATS-6 and the ATS-5 spacecraft. A terminal at the National Maritime Research Center, Kings Point, N. Y., also will serve to communicate with ATS-6.

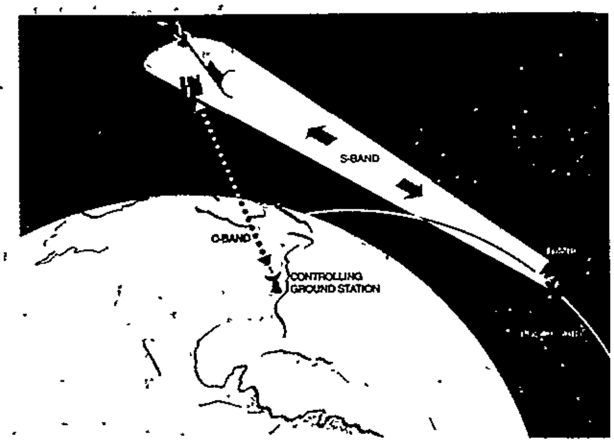
Other ground facilities planned for monitoring ATS-6 L-Band transmissions include the FAA's National Aviation Flight Experiments Center at Atlantic City, N. J.; the Transportation Systems Center's facility at Westford, Mass.; and the Canadian Communications Research Centre's facility in Ottawa, Canada.

Four jet aircraft and five ships will be provided for this experiment by the United States, ESRO, and Canada. All these units will be equipped with special L-Band communications and ranging equipment. An ESRO-provided ship also will be equipped to test an L-Band emergency buoy designed to provide search and rescue teams with a distressed ship's final position, information vital to locating survivors.

Principal Investigator: Dr. Ahmad Ghais, Goddard Space Flight Center.

13.4.5.10 Tracking and Data Relay Experiment

ATS-6 will be used to conduct tracking and data relay experiments with at least two other NASA spacecraft, both planned for launch in 1974. One is the Nimbus-F meteorological research spacecraft to be placed into a polar orbit some 1,110 kilometers (690 statute miles) above earth. The other is the GEOS-C geodetic research spacecraft which will be launched into a highly inclined orbit (65 degrees from the equator) at an altitude of 843 kilometers (524 statute miles).



TDRE. Satellites in near-earth orbit collect valuable weather and geophysical data However, transfer of information is difficult since low-orbit spacecraft are out of range of controlling ground stations much of the time, and determination of the precise orbit parameters also is a problem. The *Tracking and Data Relay Experiment* will use ATS-F and its steerable 30-foot parabolic antenna to demonstrate the advantages of performing these functions via a synchronous satellite. This will be accomplished by tracking and maintaining S-band communications with the low orbiting NIMBUS weather satellite. The data received from NIMBUS will be relayed to the ground station on C-band, using the ATS-F spacecraft's earth coverage horn. (39)

The information and experience provided by these experiments will have scientific as well as practical application. For example, the highly precise tracking information (range and range rate) will contribute to studies of earth's gravitational field. This information will have further application to studies of the steady-state shape of earth.

All the tracking and data relay information collected will be valuable for the future transition from a totally ground based tracking system to a Tracking and Data Relay Satellite System (T&DRSS) under investigation for the late 1970s. This system would employ two synchronous orbit spacecraft to relay command, tracking, and telemetry data between a few centrally located ground stations and multiple spacecraft in low earth orbit.

Extensive networks of tracking stations have been established around the world in present tracking techniques to obtain relatively complete global tracking coverage for low-orbit spacecraft. Such networks are costly in terms of the instrumentation and the manpower involved in the operation. Also, because of the geographical location of the stations, these networks are unable to provide adequate coverage of spacecraft in some orbits.

The T&DRSS would help solve many of these problems. Such a system could perform many of the key functions of the ground-based tracking stations, thus reducing the instrumentation and manpower requirements. In addition, each synchronous-orbit spacecraft in the tracking system would be able to track a particular spacecraft for a much longer period of time than an earth-based station. This would reduce the difficulties involved in sequential tracking by multiple ground stations.

For either the Nimbus-F or the GEOS-C experiment, ATS-6 will be commanded first by the ATS ground station at Rosman, N. C., to point at and lock onto one of the spacecraft orbiting beneath it.[42]

The R&RR system uses a series of tones to modulate an RF carrier; the modulated carrier is transmitted from the ground station to ATS-6, then down to Nimbus, up to ATS-6, and then back down to the ground station. The phase delay and doppler shift of the returning signal yields the total four-way range and cumulative range rate over the signal path from which the orbit of Nimbus can be determined. The transmission link between the ATS spacecraft and the ground is at C-Band; between the ATS and Nimbus spacecraft S-Band signals are employed.[44]

T&DRE design objectives for uncertainties in raw tracking data are 4.0 meters in range and 0.6 centimeters/s in range rate. Based on the availability of long-arc tracking data, studies have shown that it should be possible to determine the Nimbus orbit to within 50 meters in a total elapsed time of several hours. This constitutes a substantial improvement over ground-based tracking systems which typically require days and weeks of data processing to determine orbits which at best are known only to within hundreds of meters. Verification of these theoretical studies is considered the major scientific and application goal of the T&DRE.[44]

Figure 13-29 illustrates this experiment.

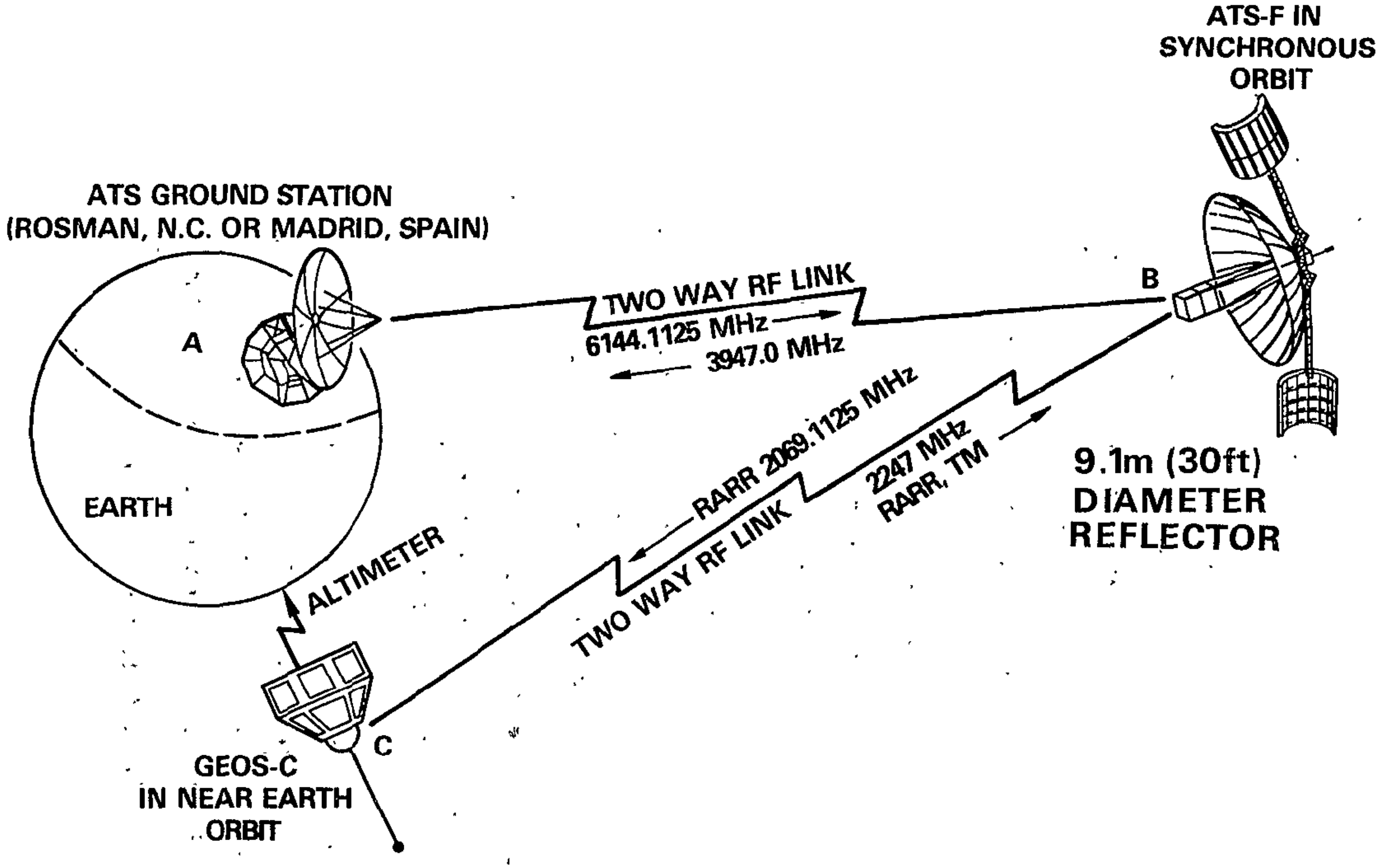


Figure 13-29. Satellite-to-Satellite Experiment Configuration[42]

The GEOS-C will be equipped with a radar altimeter, cubed-corner reflectors used for LASER tracking, a doppler transponder, and C-Band radar transponders. Consequently, the orbit of this spacecraft can be determined with high precision for geodetic purposes.[42]

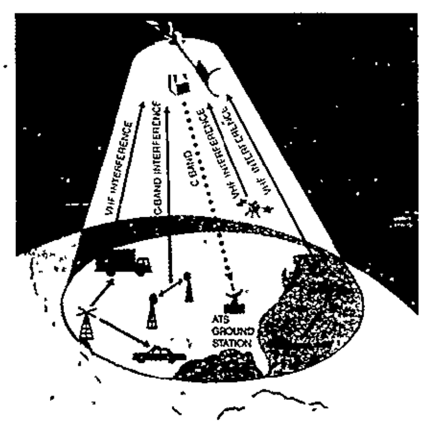
To accomplish the second objective, that of developing the technology and demonstrating the feasibility of a data relay system, data from Nimbus will be relayed via ATS-6. The data transmission capacity of the Nimbus to ATS-6 link is determined by the power of the transmitter and antenna gain available on the Nimbus spacecraft; this capacity is more than sufficient to provide highly reliable transmissions of normal 4 kbps data from Nimbus to the ground via ATS-6. To perform a more meaningful evaluation of T&DRE return link performance, test data will be transmitted at rates of 50, 100, 200, and 400 kbps. Signal detection at the ATS ground station will be done using a high-performance carrier tracking phase demodulator which will track the residual carrier component of the transmitted signal under all system doppler conditions.[44]

Principal Investigators: Dr. Friedrich F. O. VonBun, Goddard Space Flight Center, Nimbus-F experiment; H. Ray Stanley, NASA/ Wallops Station, GEOS-C experiment.

13.4.5.11 Radio Frequency Interference Experiment

The major purpose of this experiment is to investigate the mutual Radio Frequency Interference (RFI) in the 6-GHz common carrier frequency band shared between spacecraft and terrestrial telecommunications systems.

Information gained from this experiment will provide for more effective use and regulation of radio transmissions. It will thus aid the development and implementation of advanced spacecraft communications systems.



RFI. Information gained from the *Radio Frequency Interference* experiments will enable more effective use and regulation of radio transmissions. The experiment will measure the mutual interference between satellite and terrestrial communications systems and the data obtained will be used to improve the design of future communications satellites. Two separate RFI experiments are planned, one at C-band and the other at VHF. (39)

For this experiment, ATS-6's 9.1-meter (30-foot) parabolic antenna will be used to collect microwave RF signals in the 5925 to 6425 MHz frequency bands that reach the synchronous-orbit altitude from earth. These signals will be transmitted to a wide-band RFI transponder (500 MHz) onboard the spacecraft, automatically converted to a 4 MHz signal, and relayed to the ATS ground station at Rosman, N. C. At Rosman the signals will be fed to a computerized receiver analyzer for initial data processing and recording prior to delivery to Goddard for final analysis. All other communications systems on the spacecraft will be turned off during the RFI experiment to minimize local interference.

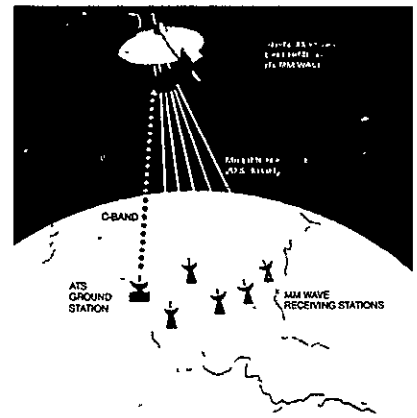
Initially, ATS-F will scan the entire U.S. to identify "hot spots" of RFI. Then a narrow band analytical system will be used to determine the frequency, power level, and the geographic location of each area of interference. By positioning the 9-meter antenna such that its "shadow" covers the hot spot from three different angles, triangulation techniques can be used to pinpoint locations within an area of 16 kilometers (10 miles) radius.[42]

The RFI measurements will be performed using standard noise-power-ratio (NPR) tests with the earth terminal configured in a back-to-back loop through the satellite. The reference NPR measurements will be made using the earth coverage (low gain) antenna of the satellite with the main beam of the high gain 9-meter (30-foot) antenna pointed to a quiet spot on the earth. In order to relate the interference levels to the wanted-to-unwanted signal ratios (C/X), the system carrier-to-noise and baseband signal-to-noise ratios will also be measured. The main beam of the high gain antenna will then be pointed toward a high density population area such as the northeastern coastal region of the United States and the measurement technique repeated. This set of measurements now contains both the simulated desired signals (and basic noise) plus the real (unwanted) noise signals from all earth sources within the field of view of both satellite antennas. These unwanted noise signals, sharing the same common carrier frequency as the simulated system, can now be determined by remeasuring the system NPR, carrier-to-noise, and baseband signal-to-noise ratios. The measurements will be repeated to determine the interference noise levels as a function of source latitude, frequency, and time.[41]

Principal Investigator: Varice Henry, Goddard Space Flight Center.

13.4.5.12 Millimeter-Wave Propagation Experiment (MWE)

The central objective of this international experiment is to evaluate the effects of earth's atmosphere on space-to-earth communications signals centered at the frequencies of 20 to 30 GHz, primarily during heavy precipitation such as rain, hail, or wet snow. Data collected from this experiment is expected to aid in the design of future space systems operating in the millimeter-wave bands--10 to 300 GHz.



MILLIMETER WAVE. This experiment is designed to provide propagation data at 20 GHz and 30 GHz over a 1 44 GHz bandwidth. It will define the earth's space and near-earth propagation path characteristics and the information will be used in the design of future communications satellites. (39)

Most present terrestrial and space communications are operated in the frequency bands below 10 GHz. These grequencies are rapidly becoming overcrowded, and the increasing communications demands of our expanding society require the systems designer to look toward higher frequencies. While the millimeter-wave bands offer a promising area to alleviate this crowding, these frequencies can be more severely affected by adverse atmospheric conditions than the lower frequencies.

During this experiment, signals will be generated by ATS-6's millimeter-wave experiment system and recorded on earth by a number of special ground stations located in the U.S. and Canada. Weather conditions also will be monitored at each station.

Table 13-40 shows the data parameters for the experiment.

ATS-6's millimeter-wave experiment package essentially consists of four traveling-wave-tube transmitters tuned to the 20 and 30 GHz frequencies and each

Table 13-40. Data Parameters for the ATS-F Millimeter Wave Experiment

Test Period Mode		Item	Signal Source	Digital Sample Rate (per second)	Digital Dynamic Range (digital counts)	Parameter Dynamic Range (engineering units)	Number of Separate Parameters Recorded
CW	Multitone						
		Propagation Parameters					
X	X	20 GHz Carrier Amplitude	Receiver	20	8 bits	45 dB	1
	X	20 GHz Sideband Amplitude (8)	Receiver	20	8 bits	45 dB	8
	X	20 GHz Sideband Phase (4)	Receiver	20	8 bits	0-360 degrees	4
X	X	30 GHz Carrier Amplitude	Receiver	20	8 bits	45 dB	
	X	30 GHz Sideband Amplitude (8)	Receiver	20	8 bits	45 dB	
	X	30 GHz Sideband Phase (4)	Receiver	20	8 bits	0-360 degrees	4
		Meteorological Parameters					
X	X	20 GHz Sky Temperature	Receiver	20	8 bits	0-350K	
X	X	30 GHz Sky Temperature	Receiver	20	8 bits	0-350K	1
X	X	Ground Ambient Temperature	Transducer	1	8 bits	0-110F	1
X	X	Ground Wind Velocity	Transducer	1	8 bits	0-100 mph	1
X	X	Ground Wind Direction	Transducer	1	8 bits	0-360 degrees	1
X	X	N-Band Radar Backscatter	Radar	1/Range Interval	16 bits	80 dB	100
X	X	S-Band Radar Backscatter	Radar	1/Range Interval	16 bits	80 dB	100
X	X	Rainfall (Gauges 1-10)	Rain Gauge	1/Gauge	Tip No Tip Single Bit	.01 inches tip	10
		Spacecraft Parameters					
X	X	20 GHz Power Monitor	S/C Telemetry	1/3 Seconds	9 bits	0-3000 MW	2
X	X	30 GHz Power Monitor	S/C Telemetry	1/3 Seconds	9 bits	0-3000 MW	2
X	X	Multitone Mode	S/C Telemetry	1/3 Seconds	Discrete	ON OFF	1
X	X	CW Mode	S/C Telemetry	1/3 Seconds	Discrete	ON OFF	1
		Experiment Status					
X	X	Grd. Antenna Azimuth Angle	Antenna	1	1 bit - BCD	0.00-360.00	1
X	X	Grd. Antenna Elevation Angle	Antenna	1	1 bit - BCD	0.00-90.00	1
X	X	Greenwich Mean Time	Time Code Translator	1	36 bits	Day/Hr/Min/Sec	1
X		20 GHz, CW Mode	Control Panel	1	Discrete	Hi Low Off	1
	X	20 GHz, Multitone Mode	Control Panel	1	Discrete	Hi Low Off	1
X		30 GHz, CW Mode	Control Panel	1	Discrete	Hi Low Off	1
	X	30 GHz, Multitone Mode	Control Panel	1	Discrete	Hi Low Off	1
X	X	20 GHz, Calibrate Test Mode	Control Panel	1	Discrete	Cal Test	1
X	X	30 GHz, Calibrate Test Mode	Control Panel	1	Discrete	Cal Test	1
X	X	S/C Beam Pointing Earth Longitude	Voice	1	4 bit - BCD	0.00-180.00	1
X	X	S/C Beam Pointing Earth	Voice	1	4 bit - BCD	0.00-90.00	1

developing 2 watts of power. Two antenna systems located on the EVM are used for this experiment. One of the antennas is a narrow-beam unit which will be used to direct wide band signals such as TV to specific locations. The other is a horn antenna designed to cover the U.S. and Canada for multistation participation.

The primary ground station for this experiment is located at the ATS ground station near Rosman, N. C. It consists of a 4.6-meter (15-foot) diameter parabolic reflector coupled to low noise receivers tuned to 20 and 30 GHz frequencies. Also included are weather radars, radiometers, rain gauges, and other meteorological equipment to monitor the weather conditions at the site.

Other ground stations are presently planned for the following locations:

Austin, Texas--University of Texas

Blacksburg, Va.--Virginia Polytechnic Institute and State University

Clarksburg, Md.--COMSAT Corp.

Columbus, Ohio--Ohio State University

Ft. Monmouth, N. J.--U.S. Army Satellite Communications Agency

Greenbelt, Md.--Goddard Space Flight Center

Holmdel, N. J.--Bell Telephone Laboratories

Ottawa, Canada--Communications Research Centre

Richland, Wash.--Battelle Northwest Laboratories

Waldorf, Md.--Naval Research Laboratories

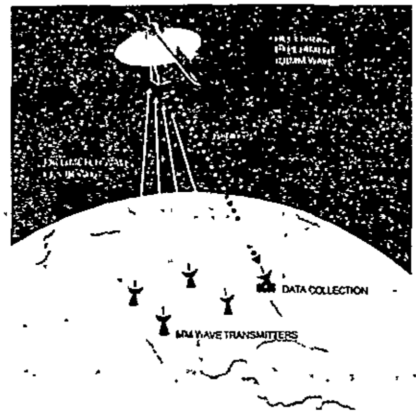
A number of European countries and India have expressed interest in participating in this experiment during the spacecraft's second year of operation while ATS-6 is located over Africa at the equator.

Each ground station will record and process its own propagation data to develop detailed statistics on signal attenuation and amplitude and phase effects caused by adverse weather. Data collected by the Rosman station will be transferred to Goddard via wide-band data line for processing and evaluation.[42]

Principal Investigator: Louis Ippolito, Goddard Space Flight Center.

13.4.5.13 COMSAT Propagation

This experiment will gather data on satellite signal attenuation, caused by atmospheric hydrometeors (mostly rain), at ground stations located in different climatological areas throughout the U.S. The data will be most useful in determining parameters needed for future spacecraft communications systems operating at frequencies in the millimeter-wave range.



PROPAGATION. Data regarding radio propagation characteristics at 13 GHz and 18 GHz will be obtained and analyzed to determine propagation attenuation due to rainfall. Several geographically separated ground stations will be used to gain a sample distribution of climatic conditions (39)

Transmitting terminals, a spacecraft transponder, a receiving terminal, and data reduction equipment comprise the principal elements of the experiment.

The 24 transmitting terminals will transmit a total of 39 randomly staggered carriers in the 13- and 18-GHz bands. The transponder will receive signals from the transmitting terminals, translate them to approximately 4 GHz, and then retransmit them. The receiving terminal and data reduction equipment will receive the 4-GHz signals, separate the individual carriers, and record the carrier powers for future analysis.

There will be 24 transmitting terminals (15 dual-frequency and 9 diversity) located throughout the eastern half of the United States. The dual-frequency terminals will be spaced at least 161 km (100 miles) apart and will transmit signals around both 18 GHz and 13 GHz. Those transmitting terminals are now installed. Three 18 GHz transmitters will be located 3-39 km (2-24 miles) from three dual frequency sites to investigate the use of site diversity to avoid the high single site margins required to operate in these frequency bands.

The transmitting terminals consist of small parabolic-reflector-type antennas (positioned manually), a power amplifier, a frequency generator, a power-monitoring system, a rain gauge, a strip-chart recorder, and an auxiliary power system for recording rain data during the time the A/C power is not available.

The transponder is a single-frequency conversion repeater with separate inputs at 13 and 18 GHz. Its combined outputs will be amplified and retransmitted at 4.150 GHz ± 20 MHz. The transponder consists of redundant 13- and 18-GHz frequency translators, two bandpass filters, a combiner hybrid, two 3-stage tunnel diode amplifiers, and two traveling-wave-tube amplifiers. The transponder has been delivered to NASA and is installed in the spacecraft.

The receiving terminal will be located at Andover, Maine, and will consist of the horn antenna, a low-noise amplifier, a calibration unit, and a down-converter unit, and will receive amplify, and convert the signals to the 70-MHz range. The converted signals will be processed and converted to DC voltages which are proportional to the input power of the received carrier signal. These signals will be scanned and applied to the data acquisition section which calculates the power of each carrier signal and records it on magnetic tape. These magnetic tape recordings can be processed on any large computer and displayed on a teletypewriter to permit a statistical comparison between the measured attenuation at a site and general meteorological parameters such as rainfall rate, number of thunderstorm days, and total precipitation. The data analysis will be performed at COMSAT Labs. [42]

Principal Investigator: Goeffrey Hyde, COMSAT.

13.4.5.14 Spacecraft Attitude Precision Pointing and Slewing Adaptive Control Experiment [42]

The primary objective of this experiment is to evaluate the feasibility of a computer-controlled ground system for long term attitude control and determination as well as orbit determination of a geosynchronous spacecraft via radio command and telemetry.

For this experiment, a ground-based computer is programmed to put ATS-6 through a series of attitude maneuvers utilizing the spacecraft's Radio Frequency

Interferometer, the Attitude Control System, and the Spacecraft Propulsion System. These include precision pointing to fixed targets, slewing between targets, tracking of moving targets, and the generation of prescribed ground tracks.

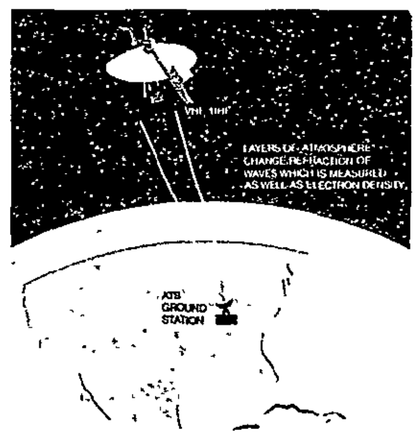
This experiment is expected to lay the necessary foundation for the development of future ground-based spacecraft control systems which would perform many of the essential functions now performed onboard the spacecraft. As a result, reliability could be improved because the ground-base systems could be repaired or replaced in case of malfunction. Further, the weight and space savings resulting from smaller onboard control systems could be used for redundant or improved power and sensor systems.

Future ground-based control systems could provide more versatility in that new tasks could be programmed and performed as requirements or technology changed.

Principal Investigator: William C. Isley, Goddard Space Flight Center.

13.4.5.15 Radio Beacon

This international experiment is designed to provide data for studies of the effects of particles on radio signal propagation beyond the earth's atmosphere. Such investigations not only increase man's scientific knowledge about the space environment, but provide designers with vital data necessary for the development of new communications systems.



RADIO BEACON. This experiment will investigate ionospheric particles which affect radio propagation beyond the atmosphere. Data for the radio beacon will be collected by small ground stations at various geographical locations. With the radio beacon in geostationary orbit aboard ATS-F, measurements can be made from a position where the influence of the magnetosphere and solar wind environments is easily interpreted. (39)

The Radio Beacon experiment package, contained in the EVM consists of a low-power, three-frequency transmitter and an array of whip antennas. Each transmitter is amplitude modulated by one or two frequencies and is driven by a common oscillator. Signals will be generated at 40, 140, and 360 MHz frequencies.

Research organization from a number of countries will conduct studies of the radio beacon using ground receivers based on a unit designed by the National Oceanic and Atmospheric Administration. Ground stations ranging from computer-controlled to simple manual units will be located at points in North and South America, Europe, the Middle East, India, and Africa. Many of the units are mobile and will be moved from continent to continent to keep the spacecraft in sight when its orbit is shifted along the equator.[42]

Principal Investigator: K. Davies, NOAA, Environmental Research Laboratories, Boulder, Colorado.

13.4.5.16 Additional Technological Experimentation

13.4.5.16.1 Very High Resolution Radiometer Experiment

Located in the Experiments Module, the radiometer will provide both visible and infrared images of day and night cloud cover over about one-fifth of the earth. Information from these images will be used for the determination of cloud motions, storm life cycles, small scale phenomena such as thunderstorms, etc., and cloud climatology studies.

Operating through an eight-inch Cassegranian telescope, the radiometer generates an image in 20 minutes with resolutions as low as 5.5 km (3.4 miles).

While the ATS-6 is in view of the United States, data collected with this radiometer will be recorded on magnetic tape and selected frames will be supplied to the Principal Investigator in near real-time. Data reduction and analysis will be accomplished by means of a combination of digital computer and photo imaging techniques.[42]

13.4.5.16.2 Cesium Bombardment Ion Engine Experiment

The experiment flight hardware consists of two identical cesium ion thrusters, each weighing about 16 kilograms (35 pounds) and requiring less than 150 watts of power. Each unit has a thrust capability of 4.45×10^{-3} newtons (one one-thousandth of a pound).

The objective is to verify and obtain operational data on the use of an ion micro-thruster electric propulsion system for station keeping and attitude control maneuvers.(4

13.4.5.16.3 Advanced Thermal Control Flight Experiment

This experiment will evaluate the performance of several new thermal control devices for stabilizing the temperature of spacecraft components. Simpler and more effective thermal control techniques for future space applications could result from the knowledge gained.

In essence, this experiment is designed to control the temperature of an equipment package subjected to heat dissipated from a simulated electrical component during a normal duty cycle. Solar energy will be used as the energy source in lieu of an electrical component.

Solar energy will be collected while the spacecraft is in sunlight by an absorber located on the east side of the EVM.

This energy will be transmitted through a one-way thermal diode (heat pipe) to the equipment package, which houses a heat reservoir consisting of a container of paraffin. Once the paraffin melts at 295° K (72° F), the excessive heat reaching it will be transmitted via a feedback-controlled, variable-conductance heat pipe to a space radiator located on the east side of the EVM.

The rate of heat removal is controlled electronically by the reservoir temperature, hence the term "feedback control."

When the spacecraft is in earth's shadow, the heat contained in the reservoir will maintain the temperature of the simulated equipment package within the proper temperature range.[42]

Principal Investigator: John P. Kirkpatrick, NASA/Ames Research Center.

13.4.5.16.4 Environmental Measurements Experiments (EME)

The EME package consists of eight experiments carried on top of the ATS-6 to view deep space. Primary purpose of the EME is to collect information on the spacecraft environment at the synchronous altitude as well as on electromagnetic-ionospheric interactions.

The EME experiments are:

- The Low Energy Proton-Electron experiment is designed to study intensity time fluctuations of low-energy electrons and protons impacting the geostationary orbit.
- The Low Energy Protons experiment is designed to determine where in local time protons are injected into the magnetosphere, and how closely in time such injections are associated with auroral substorms.
- The Solar Cosmic Ray experiment is designed to study solar cosmic rays, their entry and propagation in the magnetosphere and to measure parameters of trapped electrons.
- The Auroral Particles experiment is designed to correlate studies between particle fluxes and the visible aurora to determine the nature of the accelerating mechanism in the magnetosphere.
- The Particle Acceleration Measurement experiment will investigate the origin of the Van Allen radiation belts encircling the earth.
- The Magnetometer experiment will provide data for a study of the properties of various magnetohydrodynamic phenomena in the magnetosphere, its tail, and the magnetosheath.
- The Omnidirectional Spectrometer experiment is designed to measure the omnidirectional fluxes and spectra of electrons and protons.
- The Solar Cell Radiation Damage experiment is a continuation of previous ATS engineering studies into solar cell degradation mechanisms. [42]

13.4.5.16.5 The International Magnetospheric Relay

This experiment is designed to collect simultaneous data on the earth's geomagnetic field from a synchronous world-wide network of earth-based magnetometer stations operated concurrently with the EME magnetometer onboard the ATS-6 during the spacecraft's second year of operation.

It will require the cooperation of research organizations in Africa, the Middle East, Europe and the USSR.[42]

13.4.5.17 Special Investigations[42]

13.4.5.17.1 Spacecraft Vibration Accelerometer (GSFC)

This experiment will provide data for use in updating the analytic model of the ATS-6 spacecraft as well as for detecting and diagnosing anomalies during powered flight. It will be used further as an aid in the design of future spacecraft to be launched by the Titan III-C launch vehicle.

Three vibration accelerometers are mounted on the spacecraft to sense spacecraft movement in lateral and vertical directions. An additional accelerometer is mounted on the Titan III-C third stage for vertical movement sensing. The accelerometers data will be telemetered to ground stations and delivered to Goddard for analysis.

13.4.5.17.2 Quartz Crystal Microbalance Contamination Monitor (GSFC)

The objective of this experiment is to provide data on sources of possible contaminants on the spacecraft. This includes outgassing, ejecta from the spacecraft propulsion subsystems and ion engine experiment.

13.4.5.17.3 Television Camera (GSFC)

A subminiature television camera is mounted inside the EVM with the lens attached through a hole in the prime focus feed plate to provide by ground command a view of the 9.1-meter (30-foot) parabolic reflector after deployment. Its primary purpose is to verify that the reflector is properly deployed and indicate possible damage or determine any change in the status of the reflector. This information will be used in operating and analyzing the communications system.

13.4.5.17.4 Interferometer High Data Rate Acquisition System (GSFC)

The purpose of this system is to provide the Spacecraft Attitude Precision Pointing and Slewing Adaptive Control (SAPPSAC) experiment with data for long-term evaluation of spacecraft vibrations, flexible motions, and thermal distortions as well as for calibrating the spacecraft's interferometer in flight.

13.4.5.18 Operational Results

Since these are experimental satellites no operational traffic will be carried.

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SECTION 14 - TACSAT

14.1 PROGRAM DESCRIPTION

The Air Force has the long-range objective to provide combat forces with satellite communications between mobile tactical terminals.(1) A series of prior successful satellite developments and experiments in the Lincoln Experimental Satellite Program (see Section 9) led to a contract in January 1967 for the development of a prototype version of an operational satellite, the Tactical Communications Satellite (TACSAT).

Specific objectives of the Tactical Satellite Communications (TACSATCOM) program were as listed in Table 14-1.(2)(3)(4)

Table 14-1. TACSATCOM Objectives

Number	Description
1	Develop, test, and experiment with space and surface hardware in UHF and SHF bands.
2	Develop, demonstrate, and evaluate operational concepts for use with many mobile tactical terminals. These include problems of multiple—access and power control.
3	Provide UHF voice link between the Apollo spacecraft and recovery aircraft, ships, and ground stations.

An active repeater satellite was launched into a geostationary orbit (Table 14-2) and positioned over the United States. A successful testing program was conducted using this satellite, called TACSAT 1. The experiments involved a number of mobile terminals, specifically developed for the program, that can be divided into UHF and SHF types and subdivided by platform type. These are listed in Table 14-3.(5)(6) In addition, various other existing terminals were used for the TACSATCOM experiments. TACSATCOM is no longer a functioning system. TACSAT 1 provided service until

December 1972. Its 3-3/4 years of active life represented a longer period than that originally planned for experimental and operational testing. Up to the present there are no definite plans for a TACSAT 2, and it appears that Tactical Satellite Communications development will continue for the time being by the three services under their individual programs; for example, FLTSATCOM.

Table 14-2. Participating Spacecraft

Satellite		TACSAT 1
Manufacturer and Sponsor		Hughes Aircraft and AF Space and Missile Systems Organization
Launch Date		February 9, 1969
Launch Vehicle		Titan IIIC
Orbital Data*	Apogee	36,045 km (22,397 mi.)
	Perigee	35,938 km (22, 331 mi.)
	Inclination	0.6^{o}
	Period	Approx. 24 hrs.
Status		Spacecraft Active until December 1972

*At initial injection. Attitude control and stationkeeping produced changes.

The design of TACSAT 1 represented some major advances in spacecraft technology. It was a prototype for new high power communication satellites as well as a test vehicle for tactical communications. Features included use of the gyrostat stabilization principle (allowing more flexibility in spacecraft design), more complex repeater design, a newly developed 20-watt SHF TWT, and developments in load-bearing solar panels. The design of families of UHF and SHF earth terminals based on extensive commonality of equipment represented another advancement. The feasibility of UHF and SHF communications through a synchronous satellite by small mobile earth terminals was demonstrated. Use of the tactical transmission system (TATS) frequency-hopping modem for multiple access and overcoming multipath interference was also demonstrated and the attendant problem areas investigated.

Table 14-3. Participating Terminals

Type	Sponsor	Frequency Band	Antenna
AN/TSC-80 Shelter Terminal	US Army Satellity Comm. Agency (USASCA)	SHF	1.2-m (4.0-ft) diameter parabola
AN/MSC-54 Vehicular Terminal	USASCA	SHF	0.9-m (3.0-ft) diameter parabola
AN/TSC-79 Teampack	USASCA	SHF	0.9-m (3.0-ft) diameter parabola
AN/TRR-30 Alert Receiver	USASCA	SHF	0.3-m (1.0-ft) diameter parabola
AN/ASC-14 Airborne Terminal	USASCA	SHF	0.8-m (2.75-ft) diameter Cassegrain
AN/ARC-146 Airborne Terminal	AF Electronics Systems Div. (AFESD)	UHF	Blade; crossed dipole
AN/WSC-1 (V) Shipboard Terminal	AFESD	UHF	Large ship - 4-element array crossed dipole Small ship - single element crossed dipole Submarine - dipole; Helix
AN/TRC-157 Shelter Terminal	AFESD	UHF	Short backfire
AN/MSC-58 Vehicular Terminal	AFESD	UHF	Short backfire
AN/TRC-156 Teampack	AFESD	UHF	Short backfire
AN/TRR-32 Alert Receiver	AFESD	UHF	Monopole

14.2 SYSTEM DESCRIPTION

The UHF and SHF tests were conducted on a half and full duplex basis. The TACSAT 1 spacecraft was designed to operate in a variety of modes to accommodate the planned tests with terminals of different capabilities. Functionally, the communications subsystem consisted of a UHF frequency translating repeater and an SHF frequency translating repeater, each capable of operating with selectable bandwidths from UHF to SHF and from SHF to UHF.

The modes were under control of commands transmitted by the satellite control ground station. In keeping with the concept of mobile terminal simplicity, the satellite performed system frequency control by transmitting UHF and SHF beacon signals for use as references for all transmit and receive function frequencies generated at the terminals, and for antenna pointing.

Table 14-4 shows the operating frequency bands at UHF and SHF for communication and T and C purposes.

Table 14-4. TACSAT Frequencies

Purpose	Uplink (MHz)	Downlink (MHz)
SHF Communications	7977.5 to 7987.5	7252.5 to 7262.5
SHF Beacon	--	7298.5
UHF Communications	302.5 to 312.5	249.3875 to 249.8125
UHF Beacon	--	254.1
T&C	2200	2300

The UHF band had three modes of operation, although all ground terminals could not use all modes. The modes were narrow-band FM voice, TATS, and broadcast alert. Table 14-5 presents the signal-processing techniques utilized in each mode.

Table 14-5. Signal Processing for UHF Modes

Mode	Narrow-band FM Voice	TATS	Broadcast Alert
Multiple Access	FDMA - 11 channels available	See Section 9.3	Only one warning transmission at any one time
RF Modulation	FM	MFSK and frequency hopping	FSK
Ground Demodulator Performance	Threshold estimated at 10-dB C/N based upon employing conventional discriminators	Threshold is 8 dB for $P_E = 1 \times 10^{-3}$	Threshold estimated at 10-dB C/N based on employing conventional disc
Ground Terminal* Receive Carrier-to-Noise	29.3 dB** 16.7 dB.	24.1 dB*** 11.5 dB	21.7 dB**
Ground Receive Margin*	19.3 dB 6.7 dB	16.1 dB 3.5 dB	11.7 dB

*Higher value is for strongest UHF terminal pair and lower value is for weakest UHF terminal pair. All results for single access.

**Based on 15-kHz IF bandwidth.

***Based on 50-kHz detection bandwidth for high data rate TATS mode.

The SHF band had a frequency plan that permitted great versatility in modes of operation. The frequency plan is shown in Figures 14-1 and 14-2.(5) In Figure 14-1, the composite plan for utilizing the 10-MHz satellite bandwidth is shown. Figure 14-2 shows the specific carrier frequencies for Bands A and B, which are the 50-kHz and 1-MHz satellite operating bandwidths, respectively. The center of these bands is coincident with channel 3 shown in Figure 14-1.

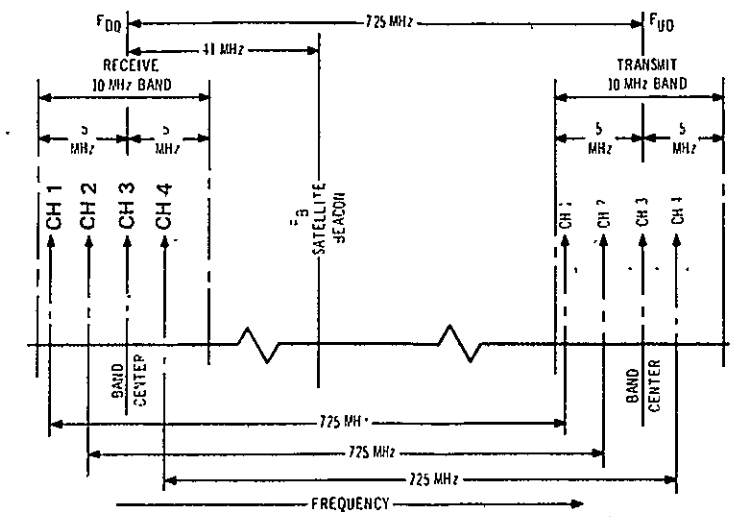

Figure 14-1. Ground Terminal RF Channel Frequency Plan*

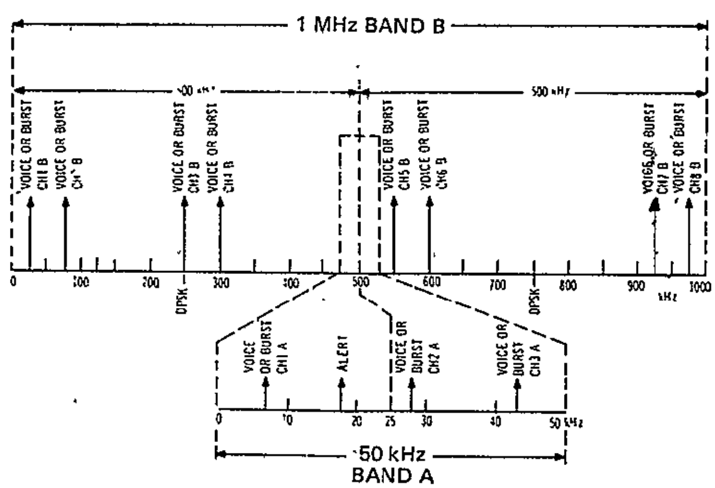

Figure 14-2. Typical Frequency Allocation Chart*

*DCA, Satellite Communications Reference Data Book

The SHF band had four modes of operation, although all ground terminals could not use all modes. The modes were frequency modulation for voice or data, TATS, DPSK, and broadcast alert. Table 14-6 presents the signal-processing techniques utilized in each mode.

14.3 SPACECRAFT

Characteristics of the TACSAT 1 communications subsystem are described in Table 14-7. A block diagram of the communications repeater is shown in Figure 14-3. There are eight ground commandable modes corresponding to the four filter bandwidths at each frequency band. Two of the modes represent cross-coupled operation between the UHF and SHF repeaters.

TACSAT 1 was the first U.S. spacecraft stabilized with gyrostat technology.[(4)] This means that the satellite does not have to be spun about its maximum moment of inertia design constraints.

The spacecraft consisted of a large spinning cylinder within which was mounted a cone-shaped structure. A bearing assembly attached to the cone structure supported, on its housing, a despun platform containing antennas and communications and telemetry equipment. The spinning section contained solar cells, batteries, auxiliary telemetry, tracking, and command equipment, despin control electronics, the hydrogen peroxide propulsion system, and the nitrogen spinup system. A pendulum liquid damper was used for nutation damping.

The intent of the program was to provide experimental hardware for testing tactical satellite communications and, therefore, to be conservative in the spacecraft development approach. Space-proven technology was used wherever possible. However, the satellite requirements could not be met without some major advances in spacecraft technology. These included: use of the gyrostat stabilizing concept; intricacy of the repeater design; use of beryllium within the structure; development of a new 20-watt TWT; and development of load-bearing solar panels.

Table 14-6. Signal Processing for SHF Modes

Mode	FM	TATS	DPSK (288 kbps)	Broadcast Alert Warning
Multiple Access	FDMA	See Section 9.3	FDMA	Only one warning transmission at any one time
RF Modulation	FM	MFSK plus frequency hopping	DPSK	FSK
Ground Demodulator Performance	Threshold estimated at 6-dB C/N based upon employing phase-lock demodulator	Threshold is 8 dB for $P_E = 1x10^{-3}$	Threshold is estimated at 6-dB C/N based upon employing phase-lock demodulator	No Data
Ground Terminal* Receive Carrier-to-Noise	26.7 dB** 11.4 dB	21.5 dB*** 6.2 dB	12.1 dB†	No Data
Ground Receive Margin*	20.7 dB 5.4 dB	13.5 dB -1.8 dB****	6.1 dB	No Data

NOTES: *Higher value is for strongest SHF terminal pair and lower value is for weakest SHF terminal pair. All results for single access.
**Based on 15-kHz IF bandwidth.
***Based on 50-kHz detection bandwidth for higher data rate TATS mode.
****TATS modem was not used by teampack (weakest link).
†Based on 432-kHz IF bandwidth. Shelter terminal was only station equipped with DPSK modem.

Table 14-7. TACSAT Characteristics*

Antennas		Type	UHF - Five element helical array for transmit and receive	SHF - Separate fin loaded horns for transmit and receive	T & C - Biconical Horn
		Number	One	One	One
		Beamwidth	Earth coverage (19°). Receive and transmit patterns not identical and not symmetrical	Earth coverage (19°). Receive and transmit patterns not identical and not symmetrical	Approximately 30°
		Gain	Receive: peak 17.58dB, minimum over coverage area 12.79dB Transmit: peak 17.12dB, minimum over coverage area 14.67dB	Receive: peak 19.3dB, minimum over coverage area 15.2dB Transmit: peak 18.4dB, minimum over coverage area 15.2dB	No data
Repeaters		Frequency Band	UHF	SHF (X-BAND)	
		Type	Hard limiting IF translation. Adjustable bandwidth and crossover to SHF repeater by command	Hard limiting IF translation. Adjustable bandwidth and crossover to UHF repeater by command	
		3dB Bandwidth	Straight through modes 50kHz, 100kHz and 425kHz; crossover modes 425kHz and 10MHz	Straight through modes 50kHz, 1MHz and 10MHz; crossover mode 425kHz	
		Number	One with some redundancy	One with some redundancy	
	Receiver	Type Front End	Transistor preamplifier into down conversion mixer	Tunnel diode amplifier into down conversion mixer	
		System Noise Figure	3.7dB	6.9dB	
	Transmitter	Type	16 parallel transistor amplifiers with summing of any number possible	3 TWTs - Any 2 summed in an output TWT switch	
		Power Out	Carrier power (16 power amplifiers) 23.6dBW Beacon power (16 power amplifiers) 8.0dBW	Carrier power (2 TWTs) 14.6dBW Beacon power (2 TWTs) 0.2dBW	
		EIRP	Carrier 40.7dBW Beacon 25.1dBW	Carrier 33.0dBW Beacon 18.6dBW	
General Features	Stabilization	Type	Gyrostat - consists of spinning cylinder containing solar cells and a despun platform containing communications equipment. Bearings and slip rings used between the 2 sections. Nitrogen spinup system, hydrogen peroxide reaction jets and nutation damper are used		
		Capability	Overall pointing capability is approximately 0.1 degree rms. However, intermittent nutation of about 1 degree occurs. Has been investigated and confirmed theoretically and can be corrected on future spacecraft		
	Power Source	Primary	Solar array with 980 watts output		
		Supplement	Battery capacity - over 20 ampere-hours		
		Size	Cylinder 7.6 m (25 feet) long and 3 m (9 feet) in diameter		
		Weight	About 726 kg (1600 lb) in orbit		

*DCA, Satellite Communications Reference Data Handbook

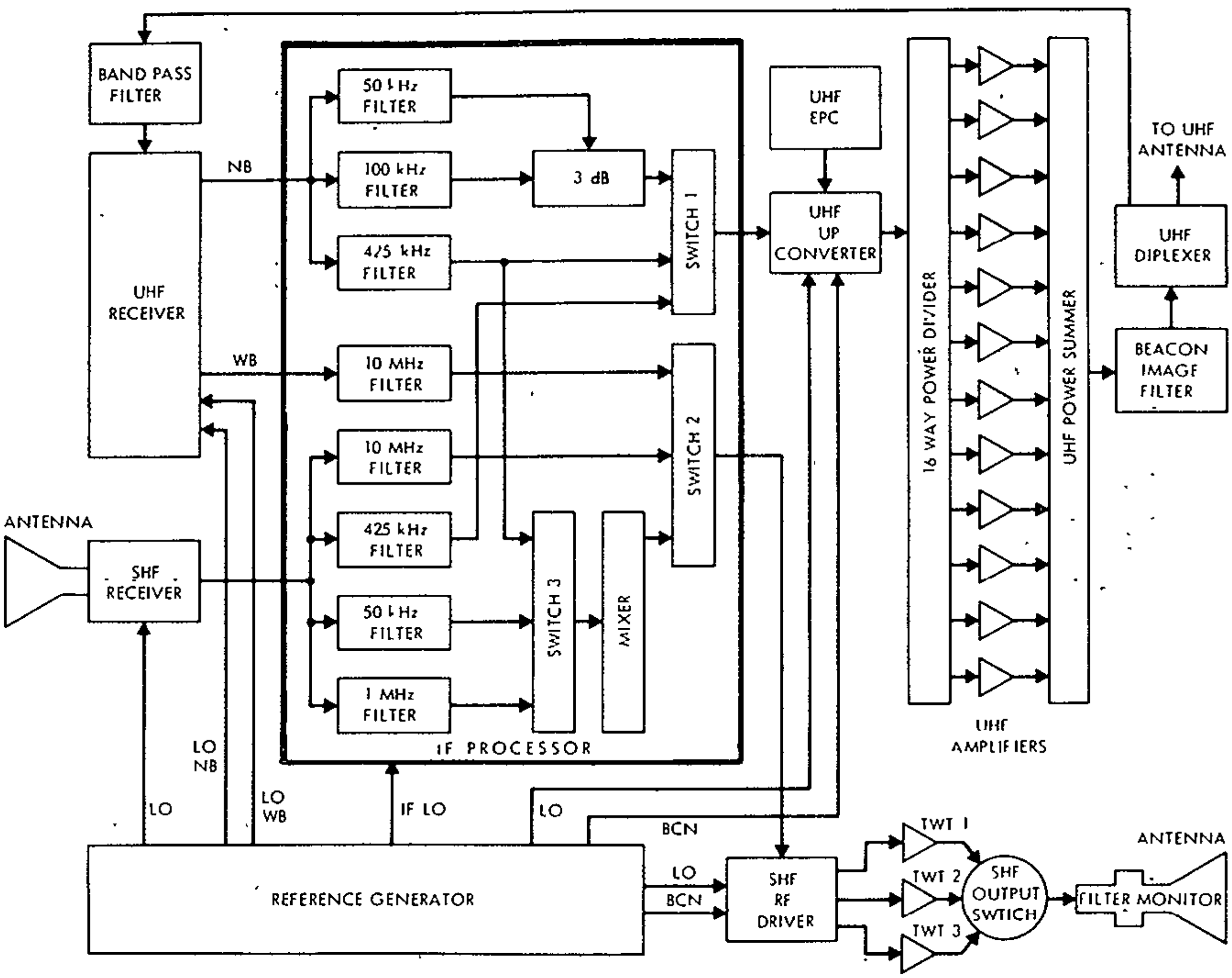

Figure 14-3. TACSAT 1 Communications Repeater Block Diagram*

*DCA, Satellite Communications Reference Data Handbook

Biphase digital modulation beacon signals were associated with each of the repeaters. The modulating signal was a pseudorandom binary bit stream that could be used at the ground stations for synchronization or timing functions. In addition, the beacon frequency was used as a reference frequency for all tactical ground terminals.

The satellite UHF receiver processed the received RF signal, which varied in level from -150 to -105 dBW. The signal was split into two channels, one for narrow-band and the other for wideband operation.

The wideband channel was downconverted to a band around 92.5 MHz, hard-limited and cross-coupled to the SHF transmitter. The narrow-band channel was downconverted to a band around 16.6 MHz, hard-limited and then coupled to the various filters. A ground commandable mode selection switch routed the desired channel output to the UHF transmitter.

The SHF received signal level varied from -150 to -85 dBW. The signal was downconverted to a band around 92.5 MHz. This signal was split into two paths, one of which was amplified in the 10-MHz channel and limited. The signal in the other path was downconverted to a band around 16.6 MHz for the SHF narrow-band channel modes. A ground commandable mode selection switch routed the desired channel output to the SHF transmitter.

14.4 EARTH TERMINALS

Two families of tactical terminals were developed for use in the two TACSAT frequency bands as listed in Table 14-3. Each family employed considerable commonality of equipment with terminal-specific equipment mainly in the categories of antenna, preamplifier, transmitter, and number and types of modems. Figures 14-4 and 14-5 show block diagrams of the UHF and SHF terminals, with all the possible modes of operation in each frequency band included.

As discussed previously, the satellite beacons at UHF and SHF were used as frequency references for all ground terminals. In the UHF receivers, the ground terminal reference oscillator was compared to the beacon and adjusted manually once a week.

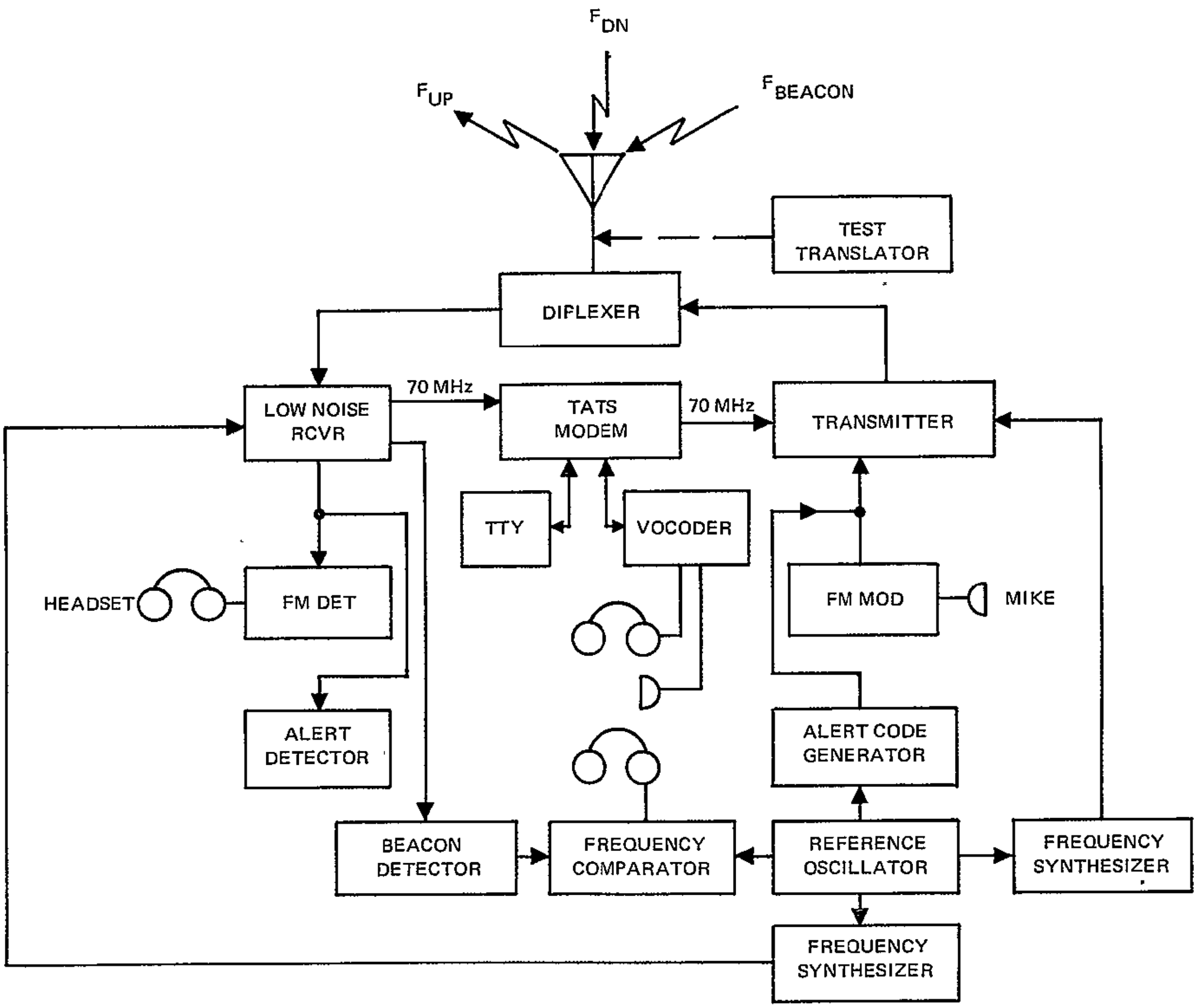

Figure 14-4. Block Diagram of UHF Ground Terminal Used With TACSAT 1

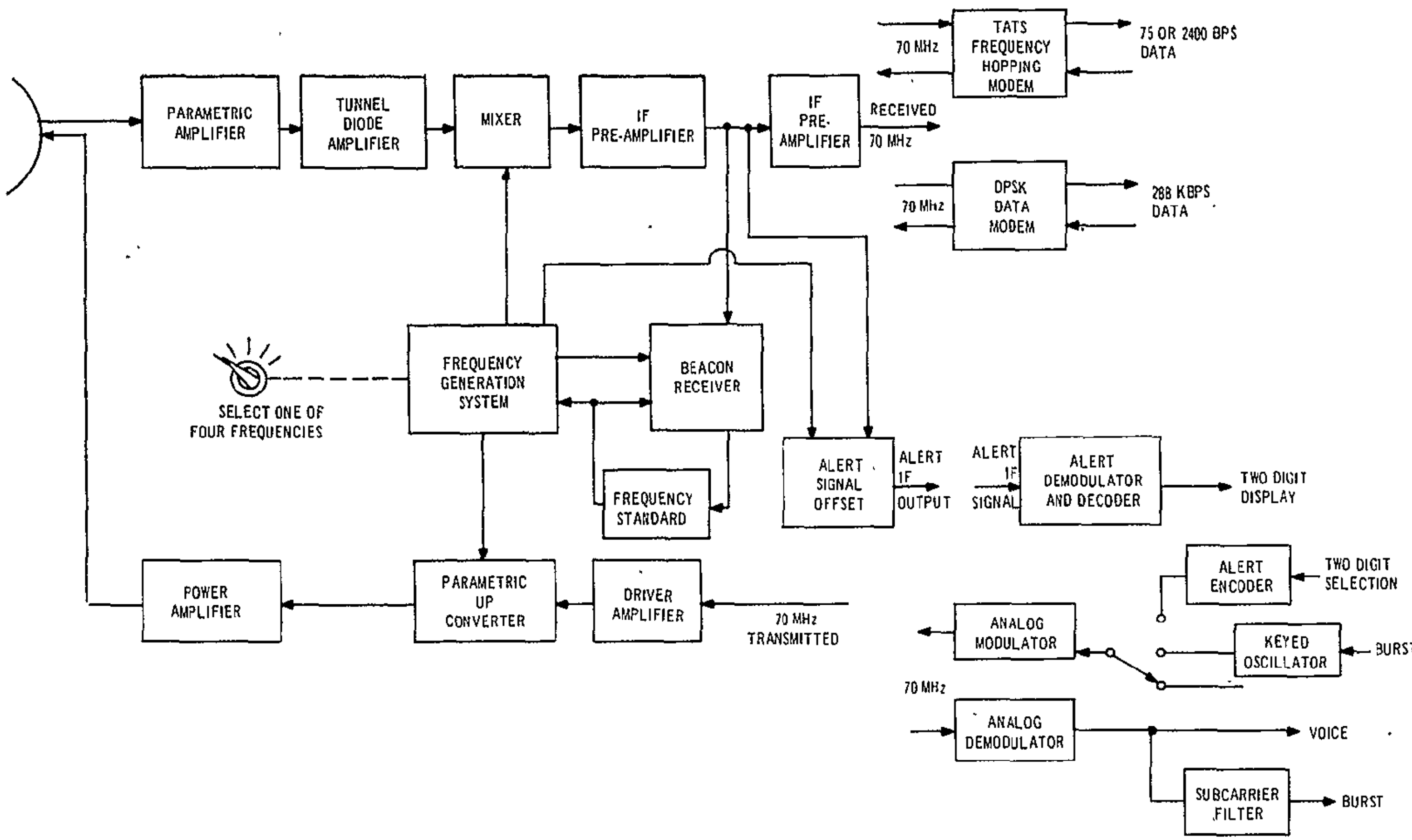

Figure 14-5. Block Diagram of SHF Ground Terminal Used With TACSAT 1

In the SHF receivers, a phase-lock loop was used to keep the ground terminal frequency standard locked to the beacon frequency. Major characteristics of the terminals are shown in Tables 14-8 and 14-9.

14.5 EXPERIMENTS

The experiments performed can be grouped under two general types: technical and operational. The technical experiments investigated satellite and ground terminal performance characteristics and system performance characteristics with the various modems employed singly and under multiple-access conditions. The operational experiments evaluated TACSATCOM performance during armed force operational exercises. In addition, there were various special tests employing TACSAT-1.

It was originally intended that technical experiments be performed before operational experiments but late equipment delivery necessitated that the two types be performed concurrently in some cases. Table 14-10 presents the major technical experiments together with the salient results obtained.

The operational experiments, conducted by the Navy, were termed a Fleet Operational Investigation (FOI) and were intended to investigate tactical concepts, operating procedures, and techniques. These overlapped, to some degree, technical experiments but were intended to determine effects of operationally imposed factors. The following categories of operational experiments were established:

1. Multiple-access capability
2. Operational techniques and procedures
3. Environmental influences on operational characteristics
4. Special purpose operational applications

The specific experiments were of three types: teletype, voice, and simultaneous voice and teletype

Table 14-8. Characteristics of UHF Earth Terminals (1 of 2)

	Terminal Feature	Terminal					
		AN/ARC-146	AN/WSC-1 (V)	AN/TRC-157	AN/MSC-58	AN/TRC-156	AN/TRR-32
Antenna	Type	Blade for low elevation angles up to 30°, crossed-dipole for higher elevation angles	Large ship antenna - four element crossed dipole array over a ground plan; small ship antenna - single element crossed dipole over a ground plane	Short backfire; balun-fed crossed sleeve dipoles with front reflector and rear ground-plane reflector	Short backfire; balun-fed crossed sleeve dipoles with front reflector and rear ground-plane reflector	Short backfire; balun-fed crossed sleeve dipoles with front reflector and rear ground-plane reflector	Monopole
	Aperture Size	Blade - contained in structural members 13 cm (5-1/6 in.) by 2 cm (13/16 in.) by 22 cm (8-5/8 in.), crossed dipole - contained in structural member 33 cm (12-15/16 in.) by 41 cm (15-31/32 in.) by 21 cm (8-5/16 in.)	Large ship - ground plane square 110 cm (55-1/4 in.) on a side, small ship-ground plane circular 97 cm (38 in.) diameter	Ground plane - 213 cm (84 in.) by 213 cm (84 in.)	Ground plane similar to AN/TRC-157	Ground plane similar to AN/TRC-157	28 cm (11 in.) long(1)
	Receive Gain	Blade - nominal 0 dB Crossed-dipole - 6 dB at zenith	Large ship - 12 dB Small ship - 7 dB	13.5 dB	13.5 dB	8.5 dB minimum	2 dB
	Efficiency	No data	No data	No data	No data	No data	No data
	Receive Beamwidth	No data	No data	40° minimum	40° minimum	Similar to AN/MSC-157 and -58	No data
Receive System	Type Pre-amplifier	Transistor(1)	Transistor(1)	Transistor(1)	Transistor(1)	Transistor(1)	Transistor(1)
	Bandwidth	RF - 240 to 260 MHz IF - 500 kHz to 0.5 dB pts	RF - 240 to 260 MHz IF - 500 kHz to 0.5 dB pts	RF - 240 to 260 MHz IF - 500 kHz to 0.5 dB pts	RF - 240 to 260 MHz IF - 500 kHz to 0.5 dB pts	RF - 240 to 260 MHz IF - 500 kHz to 0.5 dB pts	4 kHz
	Noise Temperature	630° K	900° K(2)	530° K	530° K	600° K	Less than 440° K
Transmit System	Type Amplifier	No data	No data	No data	No data	No data	
	Bandwidth	RF - 300 to 315 MHz IF - amplitude response within 10 MHz of band center frequency: 1 to 10 watts - ±2.0 dB, 10 to 100 watts - ±0.5 dB, 100 to 1000 watts - ±0.8 dB	RF - 300 to 315 MHz IF - amplitude response within 10 MHz of band center frequency. 1 to 10 watts - ±2.0 dB, 10 to 100 watts - ±0.5 dB, 100 to 1000 watts - ±0.8 dB	RF - 300 to 315 MHz IF - amplitude response within 10 MHz of band center frequency: 1 to 10 watts - ±2.0 dB, 10 to 100 watts - ±0.5 dB, 100 to 1000 watts - ±0.9 dB	RF - 300 to 315 MHz IF - amplitude response within 10 MHz of band center frequency. 1 to 10 watts - ±2.0 dB, 10 to 100 watts - ±0.5 dB	RF - 300 to 315 MHz IF - amplitude response within 10 MHz of band center frequency is ±1.0 dB	No transmit capability
	Amp. Power Out	Continuously adjustable from 1 watt to 1000 watts	Continuously adjustable from 1 watt to 1000 watts	Continuously adjustable from 1 watt to 1000 watts	Continuously adjustable from 1 watt to 100 watts	Two output levels selectable - 2 watts and 20 watts	

Table 14-8. Characteristics of UHF Earth Terminals (2 of 2)

	Terminal Feature	Terminal					
		AN/ARC-146	AN/WSC-1 (V)	AN/TRC-157	AN/MSC-58	AN/TRC-156	AN/TRR-32
Tracking	Type	None(3)	Non-manual positioning aided by signal strength meter(4)(5)(6)	Non-manual positioning aided by signal strength meter	Non-manual positioning aided by signal strength meter	Non-manual positioning aided by signal strength meter	Non-manual positioning
	Accuracy	Not applicable	No data on positioning accuracy	No data on positioning accuracy	No data on positioning accuracy	No data on positioning accuracy	No data on positioning accuracy
Total Performance	G/T(7)	Blade: -28 dB/°K Crossed dipole: -22 dB/°K	Large ship: -17.5 dB/°K Small ship: -22.5 dB/°K	-13.8 dB/°K	-13.8 dB/°K	-15.8 dB/°K	-30 dB/°K
	EIRP	Blade: 30 to 60 dBm Crossed dipole: 36 to 66 dBm	Large ship: 42 to 72 dBm Small ship: 37 to 67 dBm	43.5 to 73.5 dBm	43.5 to 63.5 dBm	15 dBm and 25 dBm	No transmit capability
Polarization	Transmit Feed and Receive Feed	Blade - linear Crossed dipole - circular	Circular	Circular	Circular	Circular	Linear
Installation	Radome	Yes	None	None	None	None	None
	Type Facility	Airplane mounted	Shipborne	Transportable by truck or aircraft	Mobile - jeep mounted	Transportable - two or three men	Transportable one man

Notes:
(1) Estimated from data available.
(2) Nominal value. Ranged up to 2000° K on some ships.
(3) Antenna switched depending on elevation angle.
(4) After positioning, antenna is slaved to ship's gyro-system to follow movement in azimuth plane.
(5) On some large ships a dual antenna system, one forward and one aft of the ship's superstructure is used. The antennas are automatically switched to provide an unobscured satellite view.
(6) Submarine used UHF SATCOM antenna system employing a helix antenna (4 to 5 dB gain) for high elevation angles and a dipole antenna (2 dB gain) for low elevation angles.
(7) Derived value based on data available.

Table 14-9. Characteristics of SHF Earth Terminals

Terminal Feature		AN/ASC-14	AN/TSC-80	AN/MSC-57	AN/TSC-79	AN/TRR-30
Antenna	Type	Cassegrain	Parabolic	Parabolic	Parabolic	Parabolic
	Aperture Size	84 cm (33 in.) diameter	122 cm (48 in.) diameter	91 cm (36 in.) diameter	91 cm (36 in.) diameter	31 cm (12 in.) diameter
	Receive Gain	33.1 dB	36.5 dB	33.5 dB	33.5 dB	23.8 dB
	Efficiency	52% (1)	54% (1)	54% (1)	48% (1)	46% (1)
	Receive Beamwidth	3.5° @ 3 dB pts.	2.4° @ 3 dB pts.	3.4° @ 3 dB pts.	3.4° @ 3 dB pts.	10.3° @ 3 dB pts.
Receive System	Type Preamplifier	Uncooled parametric amplifier followed by tunnel diode amplifier	Uncooled parametric amplifier followed by tunnel diode amplifier	Uncooled parametric amplifier followed by tunnel diode amplifier	Tunnel diode amplifier	Tunnel diode amplifier
	Bandwidth	10MHz	10MHz	10MHz	10MHz	10MHz
	Noise Temperature	(2) -325°K	230 - 315°K	(2) -325°K	(2) -920°K	896 - 915°K
Transmit System	Type Amplifier	No data	Klystron	Travelling wave tube	Travelling wave tube	No transmit capability
	Bandwidth	10MHz	10MHz	10MHz	10MHz	
	Amp Power Out	1400 watts maximum (3)	Adjustable from 1 5 watts to 450 or 500 watts	80 to 100 watts maximum	Selectable 3 watts or 10 watts	
Tracking	Type	Modified conical scan plus gyros to remove attitude changes	None-manual positioning aided by signal strength meter	None-manual positioning aided by signal strength meter	None-manual positioning aided by signal strength meter	No data
	Accuracy	No data	Setting accuracy of better than ±0.5°	Setting accuracy of better than ±0.5°	Setting accuracy of better than ±0 5°	
Total Performance	G/T	(2) to 8dB/°K (1)	12.9 to 11 5dB/°K (1)	(2) to 8.4dB/°K (1)	(2) to 3 9dB/°K (1)	-5.7 to -5 8dB/°K (1)
	EIRP	95 6dBm (1) maximum	Adjustable from 69.3dBm to 94 0 or 94.5dBm (1)	83.5 to 84 5dBm (1) maximum	Selectable 69 3dBm or 74.5dBm (1)	No transmit capability
Polarization	Transmit Feed	Circular	Circular	Circular	Circular	Circular
	Receive Feed	Circular	Circular	Circular	Circular	Circular
Installation	Radome	Yes	None	None	None	None
	Type Facility	Airborne	Transportable by truck or aircraft	Transportable by small vehicle and accessory trailer for prime power supply	Transportable by two or three men	Transportable by one man

Notes: (1) Derived value based on data available.
(2) No data on lower limit
(3) At power amplifier flange

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Table 14-10. Technical Experiment Results

Experiment Type	Experiment Configuration	Nature Of Results Obtained
1. Limits Of Satellite Coverage Area	UHF and SHF shelter terminals in Maryland. UHF and SHF teampack terminals in various Pacific Island locations. Used FM voice channel employing special data modem	At UHF no degredation above 10^{o} elevation angle. At lower angles signal deteriorated but data was obtained to at least 4^{o}. At SHF no representative data is available.
2. Parameters of TACSAT Operating Modes	Using CW transmission to measure parameters.	All test results agreed closely with theoretically predicted values or equipment specifications.
3. Terminal Antennas	Ground, ship, submarine and aircraft mounted antennas were tested.	Ground, ship and submarine antennas performed well. Data was obtained on performance of various antenna designs for fixed wing aircraft and helicopters
4. Terminal Characteristics	Standard tests were used to determine the characteristics	Basically the terminals performed within nominal limits and met most of the electrical and mechanical requirements. Shipboard UHF terminals had considerably higher noise temperatures (up to 2000^{o}K) than other UHF terminals (below 1000^{o}K).
5. FM Voice Modem	Single satellite access voice link at UHF and at SHF	Both the UHF and SHF FM voice links performed satisfactorily and had sufficient system margin.
6. Single TATs Modem With Ground Terminals	Single transmitting modem configuration using every UHF, SHF and cross-strap mode capable of supporting TATs modem.	Under stable conditions modem performance via satellite is within 1dB (as determined by E_b/N_ovs. error rate) of back-to-back performance. Interference appears to be unavoidable in 10MHz bandwidth UHF uplink and is present in 500 kHz UHF band at times. Variations along the radio-wave propagation path also contribute to variations of several dB.
7. Single TATs Modem With Aircraft Terminal	Single transmitting modem configuration using UHF from ground transmitter to aircraft terminal. A ground receive terminal used to provide a reference data base.	In general, the tests demonstrated the capability of the TATs modem to operate satisfactorily with a aircraft communication system including its multipath environment. About 3dB maximum fade, with a period of about 3.5 seconds, observed at elevation angle to the satellite less than five degrees. When using blade antenna modem lost lock during 360-degree turns and with aircraft heading directly away from sub-satellite point. Using reference data base antenna system gain vs. elevation angle was calculated for the two onboard antennas.
8. Multiple TATs Modem	Up to five transmitting modem signals are combined and transmitted. The test was performed using the satellite and in a back-to-back setup.	Unexpectedly poor performance was noted during several of the runs using the satellite relay. No results are reported for tests using the satellite. Back-to-back tests which eliminate on-orbit signal fluctuation, intermodulation, and possibly interference were performed. They gave information on limitations in use of address codes to prevent false acquisition and maintain adequate link margin.
9. DPSK Modem (288kbps)	6-channel PCM communications using TD-660 and the 288-kbps modem. SHF shelter terminal-to-SHF shelter terminal full duplex.	The 1-MHz satellite bandwidth was used with carriers spaced 500kHz apart. This resulted in spectrum overlap and test results showed that the present system will not support 6-channel PCM.

Successful communications were maintained during typical maneuvers such as helicopter operations from a ship, destroyer maneuvers, aircraft launch and recovery operations aboard a carrier, and orbit of a C-130 aircraft. The FM voice mode was of high quality and very reliable. Secure digitized voice was more cumbersome and less reliable and intelligible than FM voice, but provided a high level of security. Secure teletype communication was excellent, provided synchronization was achieved. The probability of achieving synchronization was not as high as desired, due to some incompatibility between the TATS modem and the cryptographic equipment. The teletype mode was considered the most useful because of the large number of simultaneous accesses and security.

Complete random access to the satellite repeater is complicated by the necessity to control the uplink power of the users. Joint Service Monitor/Control experiments were performed to determine tradeoffs involved between a system that is too costly or unreliable (no control) and a system that operationally is too restrictive in use (complete control). The experiments were conducted using the TACSAT UHF mode. The primary control concept allowed complete random access for all 75-bps TTY, TATS users and for all alert message users subject only to EIRP restrictions. All other communications modes had to obtain prior approval from the real-time monitor/control agency before accessing the satellite. A schedule of priorities in user communication modes was set up, and each service was allocated a portion of the satellite EIRP for nonrandom access communication modes. For power control, all UHF terminals were allowed one of two radiated power magnitudes, depending on the receiving and transmitting antenna gains. Experimental results were obtained that will be useful in the design of an operational system.

The development of different modulation and multiple-access techniques led to an investigation of the capability and compatibility of simultaneous use of different techniques. One experiment involved simultaneous use of TATS and FM/FDM with the TACSAT 500-kHz bandwidth UHF mode. Only certain TATS codes were used such that the TATS signal energy did not fall in a selected portion (81.6 kHz wide) of the repeater bandwidth. This allowed use of FM channels one through seven. Twelve low data rate

TATS at 18 dBW per access, two high data rate TATS at 29 dBW per access, and three FM accesses at 31 dBW per access were used. Results showed a C/kT of 59 dB for the FM accesses and a test tone plus noise-to-noise ratio of 26 dB.

Members of the Avionics Laboratory of the ECOM conducted digital data transmission tests with TACSAT, using the TATS modem and the UHF-equipped helicopter. The purpose was to determine the effects of the helicopter environment on the capability of the TACSAT 1 system to relay digital data that could be extrapolated to simulate air traffic control data.

The power level was varied in steps and the digital error rates recorded. Aircraft engines and rotor and aircraft heading all affected the error rate versus power level. However, the results showed that with sufficiently high transmitted power levels no errors occurred.

A series of tests using the USS Independence and NELC successfully demonstrated the feasibility of establishing automatic digital data links between remotely located participants.

The technical feasibility of transferring real-time ASW operational display data to and from a computer-equipped P-3 aircraft and a ground-based computer terminal was demonstrated. The experiment was performed at UHF, and the modulation was 2400-bps because the TATS modems were unavailable.

A two-way UHF-TDM communication mode used for air traffic control and carrier landing operated successfully through the TACSAT 1 repeater.

Vocoder voice word intelligibility experiments using the TATS modem were conducted using TACSAT 1. The word intelligibility versus c/N_o values reached a maximum of 80 percent in some tests and 90 percent using other terminals.

Experiments were performed to determine degree of improved traffic flow in a star net using automatic control. Functions, such as addressing of members and assignment of channels, were performed by a computer installed at the net control station in Bedford, Massachusetts. Automatic Net Control units were installed at ground-based terminals and Eastern Test Range C-135 aircraft.

Although the experiments were considered preliminary and additional work remains, the results showed that automatic polling significantly improved traffic flow in star nets.

Experiments with terminals located in Panama were performed to determine the effect of tropical environment, particularly attenuation due to foliage, on UHF and SHF communications. The average attenuation at UHF in foliage was about 8 dB. At SHF no signal acquisition was obtained in the foliage. There were equipment problems directly related to temperature and humidity.

14.6 OPERATIONAL RESULTS

One of the objectives of the TACSATCOM program was the support of Apollo missions. TACSAT 1 was used to support Apollo missions 10 through 13 in the following capacities.

1. Command and control of the Apollo Range Instrumentation Aircraft while enroute and at their staging bases.
2. Astronaut voice relay from the spacecraft to Mission Control Center in Houston during orbit, translunar injection burn, and recovery operations.
3. Following the aircraft transporting the lunar samples to Houston.
4. Recovery ship-to-shore communications.(7)

High-power UHF ground-based transceivers were used and the aircraft and ships were equipped with TACSAT terminals. Communications during all operational phases were outstanding.

In addition, the TACSAT SHF communication band was used to provide satellite relay of live television coverage of the moon landing from the continental United States to Alaska. A modified army SHF terminal in Anchorage, Alaska, was used for this purpose.

After termination of the formal test program and special operations described above, TACSAT 1 was used for actual operational military circuits until December 1972.

From launch to December 1972 (when active use of the TACSAT 1 ceased), all major satellite subsystems performed well with two exceptions: a nutation anomaly and a drop in UHF ERP. It was found that the nutation angle, instead of decaying after separation, maintained a fairly steady level of about 1 degree. The nutation disappeared eventually but reappeared at intervals. A study indicated that certain rotor destabilizing forces were much larger than anticipated. These can be decreased by minor changes in the design of future spacecraft. The nutation angle is not large enough to affect communication system performance.

The UHF ERP dropped after several months from 38.4 dBW to 35.4 dBW ± 2 dB with erratic variation about the mean. In addition, the transmitting antenna pattern changed significantly. Laboratory tests demonstrated that all the phenomena observed could have been caused by a short circuit to the ground plane or an open circuit on the first turn of any of the four outer helix antennas.

In addition, there were three component failures, none of which affected system operation; one of the four earth sensors behaved erratically, one of the redundant decoders of the TT and C subsystem produced extraneous outputs at times, and one SHF TWT suffered a reduced power level, probably due to helix current changes caused by temperature sensitivity.

The UHF terminals developed for the TACSATCOM program were considered as advanced development models, while the SHF terminals were considered as feasibility models. Basically, the terminals met most of the electrical and mechanical requirements. The UHF equipment was fairly reliable, but the reliability of the SHF terminals and the TATS modem designed for TACSATCOM use were not as high as desired.

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SECTION 15 - SKYNET

15.1 PROGRAM DESCRIPTION[1]

In 1962, the first tentative studies were started to determine the feasibility of a satellite system to meet the United Kingdom's military needs. During 1963 and 1964 subsequent studies proceeded toward a goal of choosing an optimum system. Meanwhile, the U.S. was planning the deployment of its Interim Defense Satellite Communication System (IDSCS).. The U.S. intended to devote the first year of IDSCS to testing, and the U.K. was invited to participate in the test phase.

The U.K. program to participate in the IDSCS testing consisted of building five earth stations and work began on these stations in 1965. Three, with 12-meter (40-foot) dishes, were designed by Marconi, Ltd., to have an operational capability within the SKYNET program. The fourth was designed and developed by the Admirality Surface Weapons Establishment. This terminal was entirely experimental to test and confirm the basic design requirements for shipborne terminals. The fifth station - a mobile land terminal - was built by the Signals Research and Development Establishment. This terminal was also an experimental tool.

The first Marconi station was completed in the middle of 1966, and the other four stations were all working and participating in testing before the end of that year. During the testing a large number of R&D tests - typically, measurements of propagation conditions, path loss, earth station performance, and experiments on advanced modulation techniques - were accomplished to aid in the design of the SKYNET System.

In 1966 a Memorandum of Understanding was signed between the U.K. and the U.S. whereby the U.S. would build and launch two satellites required by the SKYNET Program. Philco-Ford was to build the satellites and the USAF Space and Missile System Organization (SAMSO), with technical support from the Aerospace Corporation, was to act as the procurement agent for the U.K.

Two satellites were to be launched in 1969-70, with one satellite acting as a backup for the other to provide a 5-year system capability. SKYNET I "A" was successfully launched into synchronous orbit in November 1969. SKYNET I "B" was launched in August 1970 and was a total loss when it failed to reach synchronous orbit. It was generally believed that the apogee kick motor used to circularize the orbit exploded. Table 15-1[(1)(2)(3)] summarizes launch and status information on the SKYNET satellites. Note that there is no SKYNET operational satellite at this time.

The U.K. is proceeding with the SKYNET II program which will consist of a larger spacecraft with a considerably higher EIRP. (20-watt TWT versus 3.0-watt TWT.) The first attempt at launching a SKYNET II satellite in January 1974 resulted in a mission failure when the second stage of the Delta rocket misfired preventing achievement of a proper orbit. A second launch is tentatively scheduled for late 1974.

The operational requirements dictated the use of nine earth stations, five of which were to be stationary and four mobile. The stationary stations are in the U.K., Cyprus, Bahrain, Gan and Singapore. Although the stations are considered stationary, all stations with the exception of the U.K. station have been designed so that they can be moved if necessary. Two of the mobile stations are fitted in ships - the assault headquarters ships HMS Fearless and HMS Intrepid. The last two stations are mobile stations ashore. These two terminals are to be held in strategic reserve and deployed for contingency operations. Table 15-2[(2)(4-9)] is a summary of the terminals participating in the SKYNET Program.

The operational aims are to provide long distance strategic point-to-point digital communications and to meet selected tactical communication needs with the mobile terminals.

The central requirement of the system is for multiple access. It was deemed essential that any stationary terminal to be able to communicate with any other, subject to the limitation of satellite effective radiated power and the amount of terminal

Table 15-1. Participating SKYNET Spacecraft

Satellite		SKYNET IA	SKYNET IB	SKYNET II
Manufacturer		Philco-Ford (U.S.)		Marconi, Ltd. (U.K.) under license to Philco-Ford (U.S.)
Sponsors		United Kingdom Ministry of Technology, United Kingdom Ministry of Defense		
Launch Date		November 21, 1969	August 19, 1970	January 17, 1974
Launch Vehicle		Augmented Thrust Thor-Delta		
Orbital Data	Apogee	34,696.6 km (21,559.5* mi.)	No orbit achieved	Very low short-lived orbit. Mission failure
	Perigee	36,679.7 km (22,791.7* mi.)		
	Inclination	Less than 3°		
	Period	Approximately 24 hrs		
	Position	$47^{\circ}E \pm 3^{\circ}E$		
Status		Nonactive. One TWT failed, data unknown. Second TWT failed 29 November 1972	Spacecraft lost due to apogee kick motor failure	Second stage of Delta rocket misfired

*Value at initial injection. Subsequent stationkeeping maneuvers have produced changes.

Table 15-2. Participating SKYNET Earth Terminals

Location	Antenna Diameter (m) (ft)	Utilization	Type	Date Installed	Manufacturer	Comments
UK (Oakhanger)	12 (40)	Static-operational traffic	I	1969	Marconi, Ltd.	Main Station
Cyprus	12 (40)	Static-operational traffic	II	1966		
Singapore	12 (40)	Static-operational traffic	II	1966		
Bahrain	6 (21)	Static-operational traffic	III	1969	GEC-AEI Electronics, Ltd.	Air Transportable
Gan	6 (21)	Static-operational traffic	III	1969		Air Transportable
Contingency	6 (21)	Contingency	IV	1969		Helicopter Transportable
Contingency	6 (21)	Contingency	IV	1969		Helicopter Transportable
HMS Fearless	2 (6)	Shipborne	V	1970	Plessey Radar, Ltd.	
HMS Intrepid	2 (6)	Shipborne	V	1970		
HMS Grenville	2 (6)	Shipborne	V	1971	Marconi, Ltd.	
Christchurch	12 (40)	Testing	-	1966		
Oakhanger	18 (60)	Telemetry, Command and Control	-	1969	Radiation, Inc.	Same design as USAF satellite tracking station

equipment available for the link in question. In a real sense the central requirement goes beyond multiple access and includes an element of random access.

15.2 SYSTEM DESCRIPTION

It was decided that two independent satellite bands (20 MHz and 2 MHz) would be required, based on the two types of communication requirements: long distance strategic point-to-point digital communications for the larger terminals, and selected tactical communications with mobiles (ship and land). Table 15-3[2][3] gives the frequencies of the two bands.

Table 15-3. SKYNET Frequencies

	2 MHz Channel (MHz)	20 MHz Channel (MHz)	Beacon (MHz)
Uplink	7976.02 to 7978.02	7985.12 to 8005.12	-
Downlink	7257.30 to 7259.30	7266.40 to 7286.40	7299.50

With two independent bands, modulation and multiple access could be tailored to satisfy all system requirements. Other specified features to be included in the system were reliability of communications and flexibility in terms of interconnections and traffic.

The requirements of SKYNET communications fix the choice of terminals. The satellite antenna pattern was designed for coverage from the United Kingdom in the West to Singapore in the East. The U.K.'s other areas of interest fall between these two extremes.

Traffic requirements were telegraphy, speech, and medium speed data circuits. It was decided that the strategic system would be designed specifically for digital signals at rates of 75×2^n bits per second (where n equals 1, 2, 4, or 5), and would use the 20-MHz channel. Once the digital philosophy was adopted, a telegraph time division multiplex was developed, capable of assembling synchronous and nonsynchronous telegraph signals into a single synchronous data stream.

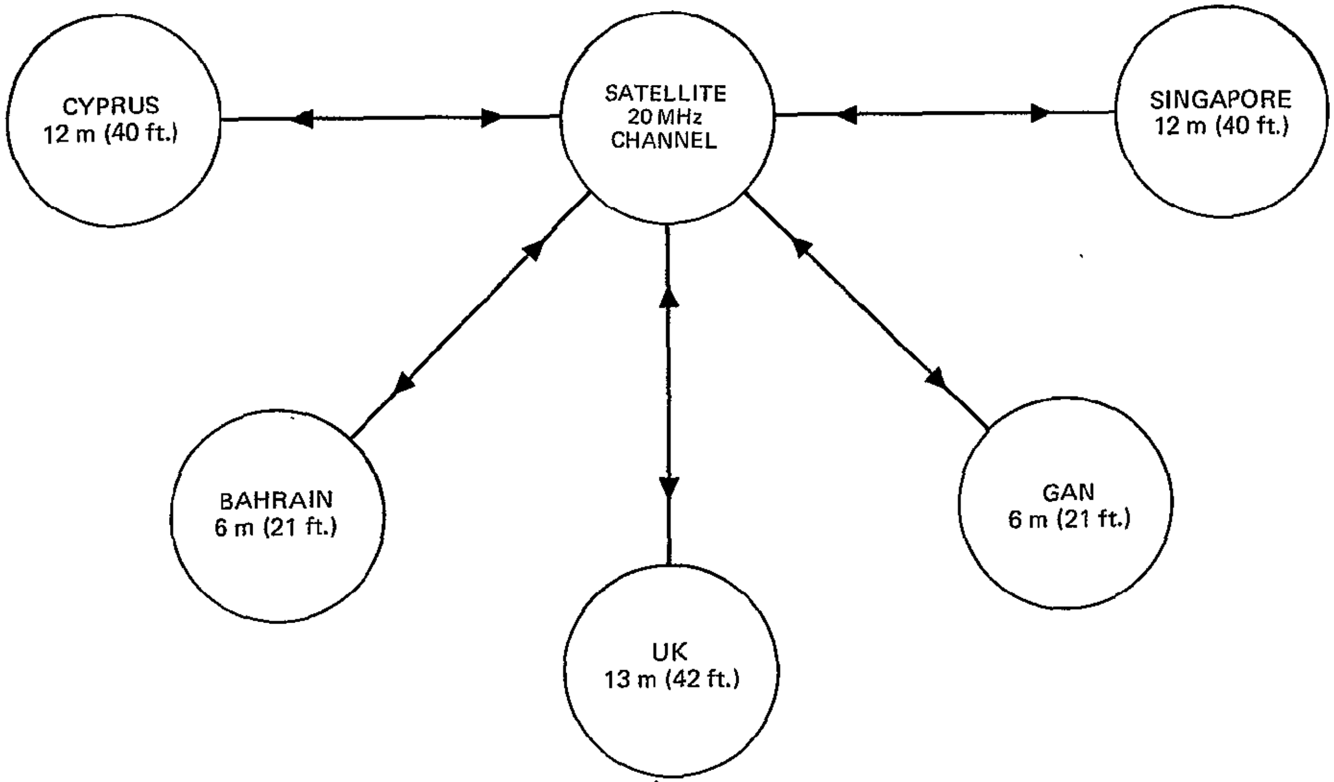
For the 20-MHz channel, Pseudo-Noise Spread Spectrum Multiple Access (PN/SSMA) was chosen over FDMA, which eliminated the need for frequency planning. Additional advantages of this choice were: (1) PN/SSMA signals are virtually immune to intermodulation effects except for the small loss of useful power, and (2) inherent interference protection is provided. Figure 15-1[2][10] indicates the PN/SSMA links established among the fixed terminals operated in the 20-MHz channel. Table 15-4[2] summarizes the typical link performance in the 20-MHz band.

In the mobile terminal case, it was decided to use FDMA in the 2-MHz satellite band. In addition, the 2-MHz channel was to be used to provide engineering teletype orderwire facilities between fixed stations. Figure 15-2[2] indicates the FM links to be established in the 2-MHz band. Link power limitations dictate that the mobile and shipborne terminals communicate only with a 12-meter (40-foot) station. Table 15-5[5][6][9] gives the FM performance characteristics of the demodulators used by the mobile and shipborne terminals.

Since communications reliability is of paramount importance, adequate link margins were allowed for unpredictable losses due to weather, misalignments and equipment degradation. Estimates of 2 dB for excess path attenuation and 110°K for excess noise were used for earth stations in the U.K. and Singapore which are served by a suitably placed geostationary satellite. Losses were greater for an earth station with a radome because of the attenuation of a water film on the surface. Reductions in signal/noise ratios of up to 6 dB have been observed with a radome under wet conditions. Margins for both "up" and "down" links had to be allowed if a local rain squall were not to upset the power balance of the entire system.

15.2.1 Control Subsystem

The SKYNET System exercises control of the spacecraft, the earth station complex, and the traffic. Accurate control of the spacecraft is essential for successful

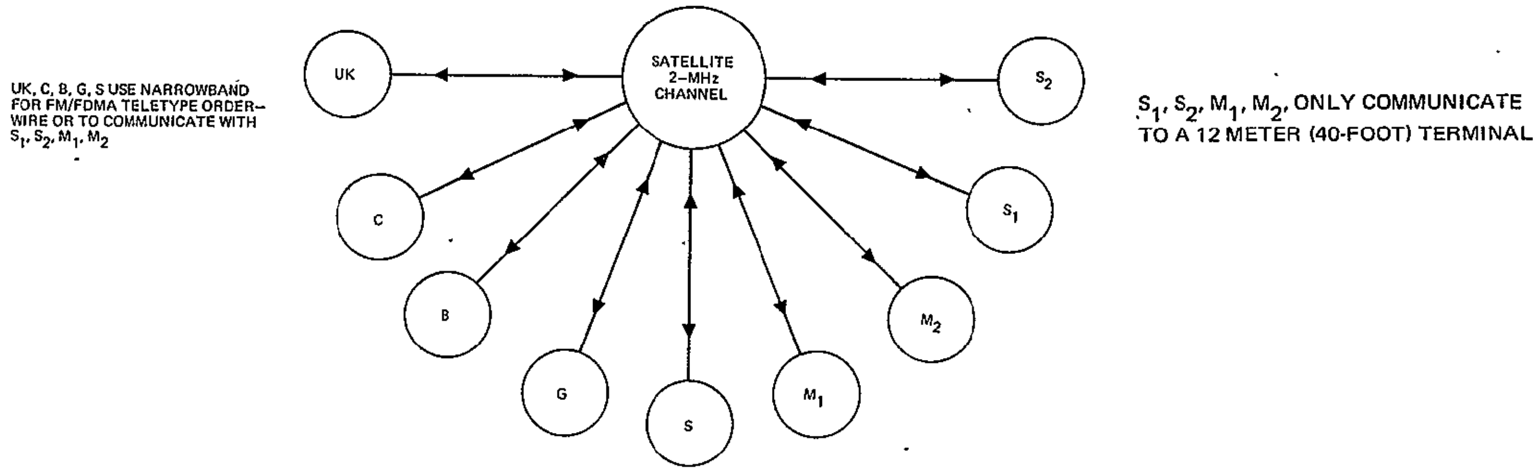


NOTE: ALL STATIONS CAPABLE OF COMMUNICATION WITH ONE ANOTHER

Figure 15-1. SKYNET PN/SSMA Links

Table 15-4. Power Budget for Typical SKYNET PN/SSMA Links

Uplink	Received power at satellite (dBm)	-72.8
	Receiver noise level for a 2750 noise temperature (dBm/Hz)	-165.2
	Signal/noise ratio at receiver (dB) in 20-MHz bandwidth	19.4
Downlink	Received power (dBm)	-99.2
	PN/SSMA noise density (dBm/Hz)	-169.2
	Thermal noise density (250°K) (dBm/Hz)	-174.6
	Total noise density (dBm/Hz)	-168.1
	Signal/noise power density (dB/Hz)	68.9
	Required signal/noise power density (dB/Hz) using DPSK modulation with 2400-bps channel for error rate of 1 to 1000	42.0
	Intermodulation loss (dB)	1.0
	Margin (dB)	8.0
	Residue (dB)	17.9
	This indicates that 62 digital streams of 2400 bps can be accommodated	



UK	=	12 m (40 ft) TERMINAL AT OAKHANGER	M_1 & M_2	=	6 m (21 ft) CONTINGENCY TERMINALS
C	=	12 m (40 ft) TERMINAL AT CYPRUS	S_1	=	2 m (6 ft) SHIPBORNE TERMINAL
B	=	6 m (21 ft) TERMINAL AT BAHARAIN	S_2	=	2 m (6 ft) SHIPBORNE TERMINAL
G	=	6 m (21 ft) TERMINAL AT GAN			
S	=	12 m (40 ft) TERMINAL AT SINGAPORE			

Figure 15-2. FM/FDMA Links (2-MHz Channel)

Table 15-5. FM Demodulator Performance

FM	Maximum Baseband Frequency (kHz)	Peak Frequency Deviation (kHz)	Equivalent Carrier BW (kHz)	Carrier BW (dB/Hz)	Threshold of Conventional Discriminator C/N_o (dB/Hz)	Threshold of Phase-Lock Loop Used in SKYNET System (dB/Hz)
		4	16	42	52.	50.7
	4	7.5	23	43.6	53.6	52.1
		13	34	45.3	55.3	53.3

operation of the communication system. It is necessary to maintain spacecraft position and attitude by on-board control systems and to switch spare repeater subsystems if malfunctions occur. The control is exercised at Oakhanger by the Telemetry and Command Station on the basis of computations performed at Royal Aircraft Establishment, Farnborough. SKYNET I uses UHF unprotected commands. SKYNET II will use a crypto-protected command system compatible with the U.S. Air Force Space Ground Link System (SGLS).

Engineering control of the communication system is exercised from the Master Engineering Control Center (MECC) collocated with the Type I earth station at Oakhanger. At this station the status of each earth station in the system is displayed and instructions on power levels, frequencies, and operating modes to be used as well as positional information relating to the spacecraft are broadcast over engineering orderwire circuits. Traffic control takes place at speech and telegraph facility control centers which are remote from the earth stations and connected to them by telephone lines.

15.3 SPACECRAFT

Spacecraft characteristics for the SKYNET-I and -II satellites are displayed in Tables 15-6[2][3] and 15-7, respectively. Figure 15-3[3] is a simplified block diagram of the SKYNET-I communications configuration.

As shown in Figure 15-3, the SKYNET I communications subsystem receives, translates in frequency, amplifies, and retransmits X-band signals. Two channels, 20- and 2-MHz bandwidth (1 dB), are provided. The total output power is divided equally between the two channels. Figure 15-3 indicates the single thread path. The complete equipment redundancy and cross-strapping that is employed to achieve reliability is not shown. Selection of either set of communications equipment, operating with either traveling wave tube amplifier, is accomplished by ground command.

Table 15-6. SKYNET-I Satellite Characteristics

Antennas	Type	X-Band mechanically despun	UHF array for TT&C with redundant UHF transponders and command/telemetry processing equipment
	Number	One	Two
	Beamwidth	19^{o}	Essentially omni-directional
	Gain (dB)	18.5	0.7
Repeaters	Frequency Band	X-Band	
	Type	Hard-limiting dual channel	
	1 dB Bandwidth	20 MHz and 2 MHz channels	
	Receiver		
	Type Front End	Down-conversion mixer into linear amplifier*	
	Front End Gain	No data	
	Noise Figure	10.2 dB @ 275.0^{o}K	
	Translation	718.72 MHz	
	Transmitter		
	Type	Redundant TWT (3 watts)	
	Gain	No data	
	Power Output (dBm)	31.0	
	EIRP (dBm) peak of beam	49.5 (in each channel)	
General Features	Stabilization		
	Type	Spin 90 rpm 5 years	
	Capability (stationkeeping)	$\pm 3^{o}$ for 5 years	
	Power Source		
	Primary	Cylindrical array of silicon solar cells, capable of providing 97 watts of prime power throughout five years of orbit life	
	Supplement	Two redundant 16-cell nickel cadmium batteries for operation during eclipse (6 AH per cell)	
	Communication Power Needs (watts)	64	
	Size	137 cm (54 in.) diameter, 152 cm (60 in.) high	
	Weight	Launch 243 kg (535 lbs)/orbit 127 kg (280 lbs)	

*Dynamic range (a) 20 MHz channel: -90 to -45 dBm
(b) 2 MHz channel: -400 to -45 dBm

Table 15-7. SKYNET-II Satellite Characteristics

Antennas	Type	X-Band mechanically despun	TT&C SGLS compatible
	Number	One	Two
	Beamwidth	No data	Essentially omni-directional
	Gain	No data	No data
Repeaters	Frequency Band	X-Band	
	Type	Hard-limiting, dual channel	
	1 dB Bandwidth	20 MHz and 2 MHz channels	
	Receiver		
	Type Front End	No data	
	Front End Gain	No data	
	Noise Figure	9-10 dB	
	Translation	718.72 MHz	
	Transmitter		
	Type	Redundant TWT (20 watts)	
	Gain	No data	
	Power Output (dBm)	No data	
	EIRP (dBm) peak of beam	20 MHz - 53; 2 MHz - 47	
General Features	Stabilization		
	Type	No data	
	Capability (stationkeeping)	No data	
	Power Source		
	Primary	Cylindrical solar cell assembly	
	Supplement	Two nickel-cadmium batteries	
	Communication Power Needs (watts)	No data	
	Size	191 cm (75 in.) diameter, 135 cm (53 in.) height	
	Weight	Launch 425 kg (937 lbs)/orbit 227 kg (500 lbs)	

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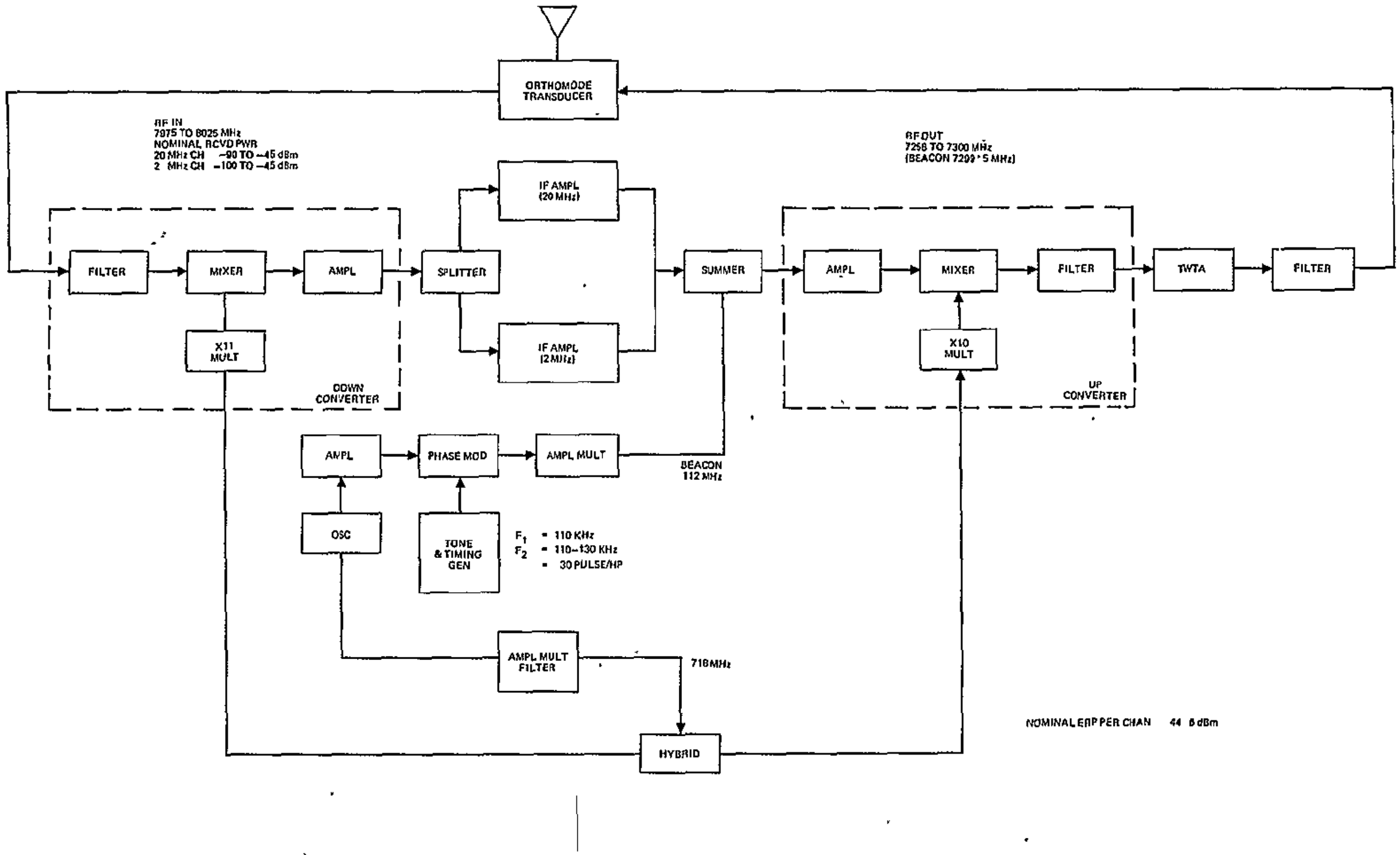


Figure 15-3. SKYNET-I Communications Transponder

The received signal is

1. Isolated by polarization diversity in the orthomode transducer
2. Downconverted to IF
3. Split into separate channels for amplification and hard-limiting
4. Recombined and up-converted to output frequency
5. Amplified to output power in the TWT
6. Introduced into the communications antenna through the orthomode transducer

A signature tone timing signal is frequency modulated on the beacon carrier and introduced into the communication band in the channel summer.

The communications antenna consists of the RF assembly and the motor drive assembly (MDA). RF energy is circularly polarized, collimated into a plane wavefront and focused upon the flat plate reflector. The beam axis, reflected through a 90° angle, is continuously directed toward the subsatellite point by the despun motion of the radiating aperture. A rotary choke joint at the lower end of the MDA housing permits efficient transfer of energy between the spacecraft fixed and despun waveguide sections. A hydrazine reaction control subsystem provides for attitude control and stationkeeping and, in addition, permits the relocation of the SKYNET satellite to a more optimum location if system requirements change.

Three redundant antenna pointing control systems are provided - earth horizon sensors, sun angle sensors, and a backup earth-to-satellite command link. A UHF subsystem, also redundant, is provided for telemetry tracking and command services (TT&C).

Figure 15-4[12] is a sketch of the SKYNET II spacecraft. Figure 15-5[13] shows a block diagram of the SKYNET II spacecraft subsystem and communications subsystem. Although the SKYNET II satellite is similar in design to SKYNET I, it is larger and heavier, satellite power has been increased, the design life has been extended

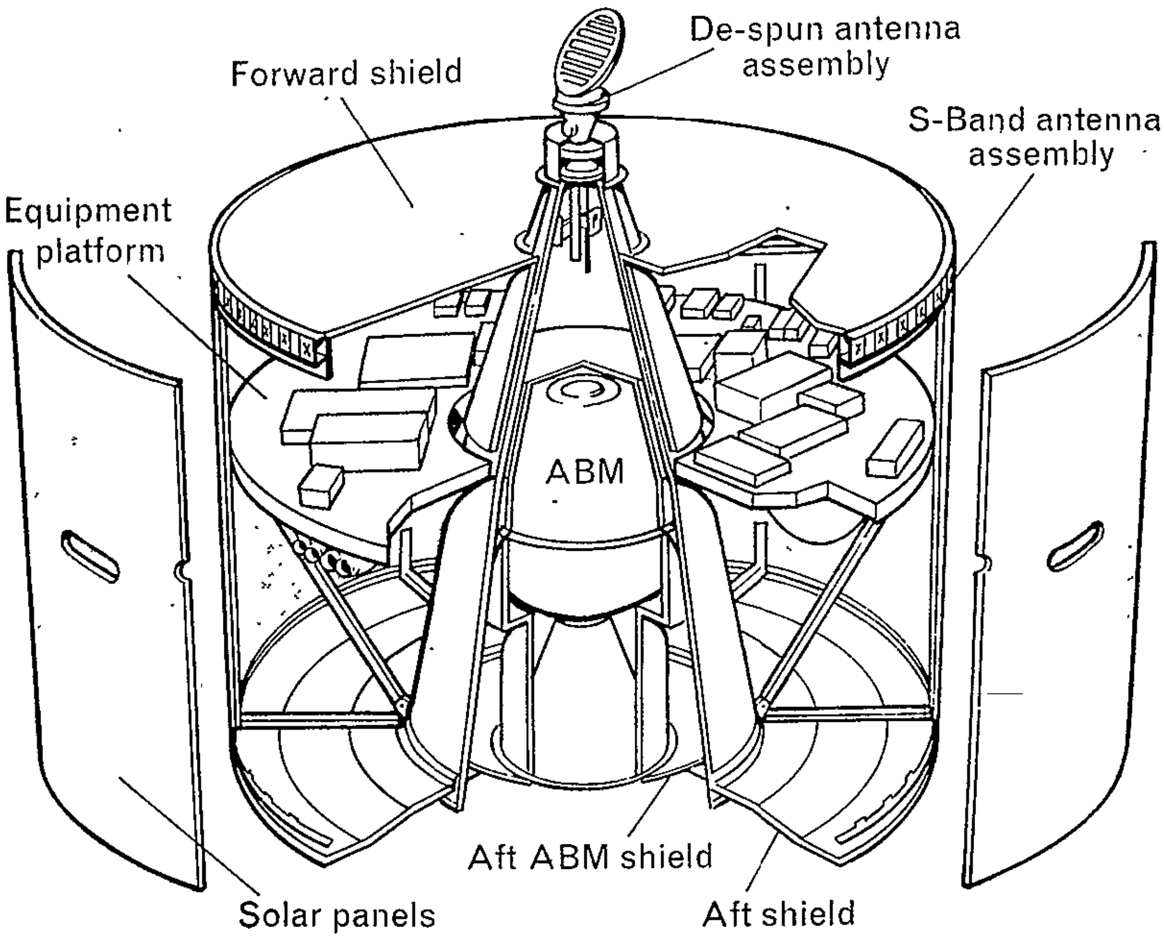
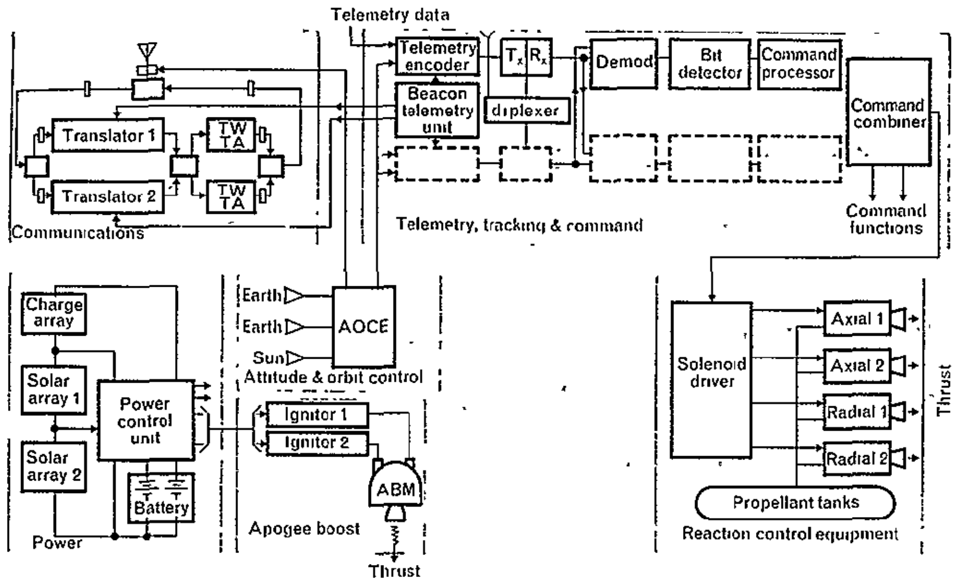
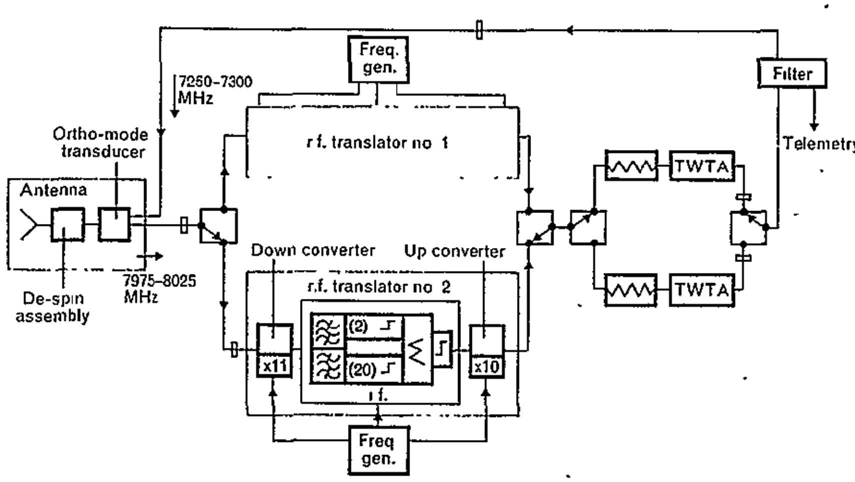


Figure 15-4. SKYNET-II Spacecraft



Block diagram of the spacecraft sub-systems



The communications sub-system

Figure 15-5. SKYNET-II Spacecraft Subsystem and Communications Subsystem to 5 years, and protection against enemy interference has been included. The TT&C system is USSGLS compatible.

15.4 GROUND TERMINALS

The major characteristics of the ground terminals employed in the SKYNET system are shown in Table 15-8[4][5][6][9].

15.4.1 Types I and II Earth Terminals

The Type I station at Oakhanger is the master station of the SKYNET system. Most electrical design features, apart from redundancy, are commonly used with the Type II stations to simplify training and maintenance support.

The Type I antenna is a 13-meter (42-foot) diameter parabolic reflector with a Cassegrain feed system mounted on a fully steerable azimuth elevation mount which is installed on a three-legged gantry. Azimuth rotation is accomplished by two dc motors driving in a countertorque configuration to minimize backlash. The elevation drive consists of two mechanically coupled recirculating ball screws.

The Type II antenna mount is fundamentally different. To meet the original air transportability specification, a double-walled inflatable radome was used with a non-orthogonal mount. This mount allowed the antenna to be more readily demounted into pieces of a size suitable for the aircraft, and also produced a smaller swept volume than a standard azimuth-elevation mount, thus requiring a smaller radome.

The profile of the Type I main and subreflectors has been shaped from the paraboloid to ensure a nearly uniform illumination of the main reflector. With this technique, overall antenna efficiency and gain are increased. The composite four-horn feed consists of four horns, four circular polarizers and diplexers, transmit power dividers and static split combination networks.

The Type I and II station receiving systems are similar except that the system is duplicated in the Type I station, with a remotely controlled waveguide changeover

Table 15-8. Characteristics of SKYNET Earth Terminals

Terminal Type		I	II	III	IV	V
Antenna	Type	Cassegrain (paraboloid reflector)	Cassegrain (paraboloid reflector)	Cassegrain (shaped surface)	Cassegrain (shaped surface)	Cassegrain (paraboloid reflector)
	Mount	Az. Elev.	Nonorthogonal	Az. Elev.	Az. Elev.	Three axis
	Aperture Size	13 m (12 ft)	12 m (40 ft)	6 m (21 ft)	6 m (21 ft)	2 m (6 ft)
	Receive Gain (dB)	56**	56	52	52	40.5
	Efficiency (%)	54*	50*	73	73	63*
	Receive Beamwidth (°)	0.23*	0.24*	0.4	0.4	1.6*
Receive System	Type Preamplifier	Two stage uncooled parametric	Two stage uncooled parametric	Two stage liquid nitrogen cooled parametric	Two stage liquid nitrogen cooled parametric	Ambient temperature parametric
	Gain (dB)	30	30	30	30	20
	1 dB Bandwidth (MHz)	50	50	50	50	50
	Tuning Capability (MHz)	500	500	500	500	500
	Noise Temperature (°K)	120	120	50	50	220
Transmit System	Type Amplifier	Klystron	Klystron	Klystron	Klystron	Klystron
	Bandwidth (MHz)	50	50	50	50	No Data
	Amp Power Output (kW)	20	20	5	5	5
Tracking	Type (monopulse)	Automatic	Automatic	Automatic	Automatic	Automatic
	Accuracy (3σ)	0.05	0.05	0.09	0.09	0.15
Freq. Control	Long Term (1 yr)	1 in 10^7	1 in 10^4	1 in 10^7	1 in 10^7	No Data
	Short Term (1 s)	1 in 10^9	1 in 10^9	1 in 10^9	1 in 10^9	
Total Perf.	Sys. Noise Temp. °K	250	230	120	120	300
	G/T dB/°K	32.0*	32.4*	31.2***	31.2***	15.7*
	EIRP (dBW)	100*	100*	90*	90*	78*
Polarization	Transmit Feed	Right Hand Circular	Right Hand Circular	Right Hand Circular	Right Hand Circular	Right Hand Circular
	Receiver Feed	Left Hand Circular	Left Hand Circular	Left Hand Circular	Left Hand Circular	Left Hand Circular
Installation	Radome	Yes	Yes	No	No	No
	Type Facility	Fixed	Fixed but movable	Fixed but air transportable	Mobile helicopter transportable	Shipborne

*Calculated from other measured parameters.
**Actual gain is 57 dB. 1 dB is lost in cable runs that allow maintenance and repair on paramps while station is still operating. This was done to accomplish high reliability.
***G/T of 28.8 dB when parametric amplifier is run at ambient temperature.

switch in the signal path. Figure 15-6[4] is a simplified diagram of the essentials of the communications chain.

The low noise receiver is preceded by a "waffle-iron" type low pass filter giving 93 dB of protection against the transmitter signal spaced only 500 MHz away. The duplicated transmitter subsystem is designed to provide accurate control of power output from 100 W to 20 kW, with control of power shared between the FM and PN paths. Channel combining is performed at SHF to avoid the risk of FM and pseudo-noise intermodulation that could arise with a common upconverter stage.

The operational requirements of frequency flexibility and high stability are met by deriving the local oscillator signals from frequency synthesizers in the 100- to 150-MHz band, which are locked to a high stability (1 part in 10^{10}) master oscillator at 1 MHz. The Type I and Type II stations have a duplicated master oscillator and one spare synthesizer (as a compromise between full redundancy and economy) for the three operational local oscillator sources (receive, PN, and FM transmit).

15.4.2 Type III and IV Earth Terminals

The SKYNET Types III and IV earth terminals have 6-meter (21-foot) diameter antennas. Both types of stations are identical, but the Type IV is helicopter transportable, whereas the Type III is only transportable by standard aircraft. A simplified block diagram of the signal paths in the Type II and IV earth terminal is shown in Figure 15-7[5][6]. A five-horn static split system is used for tracking, and all the microwave equipment is mounted on the back of the antenna disk. The antenna mount is a simple two-axis elevation/azimuth system.

The received signals pass through a diplexer and a band-stop filter to reject transmitted frequencies, and then into a two-stage liquid nitrogen-cooled parametric amplifier. Subsequently, they pass to a mixer/IF preamp combination and then to an IF amplifier where the FDM and spread spectrum signals are separated. The combined uplink IF signal is fed into the transmitter unit where it is converted to the final frequency, and amplified first in an intermediate power amplifier and then in a

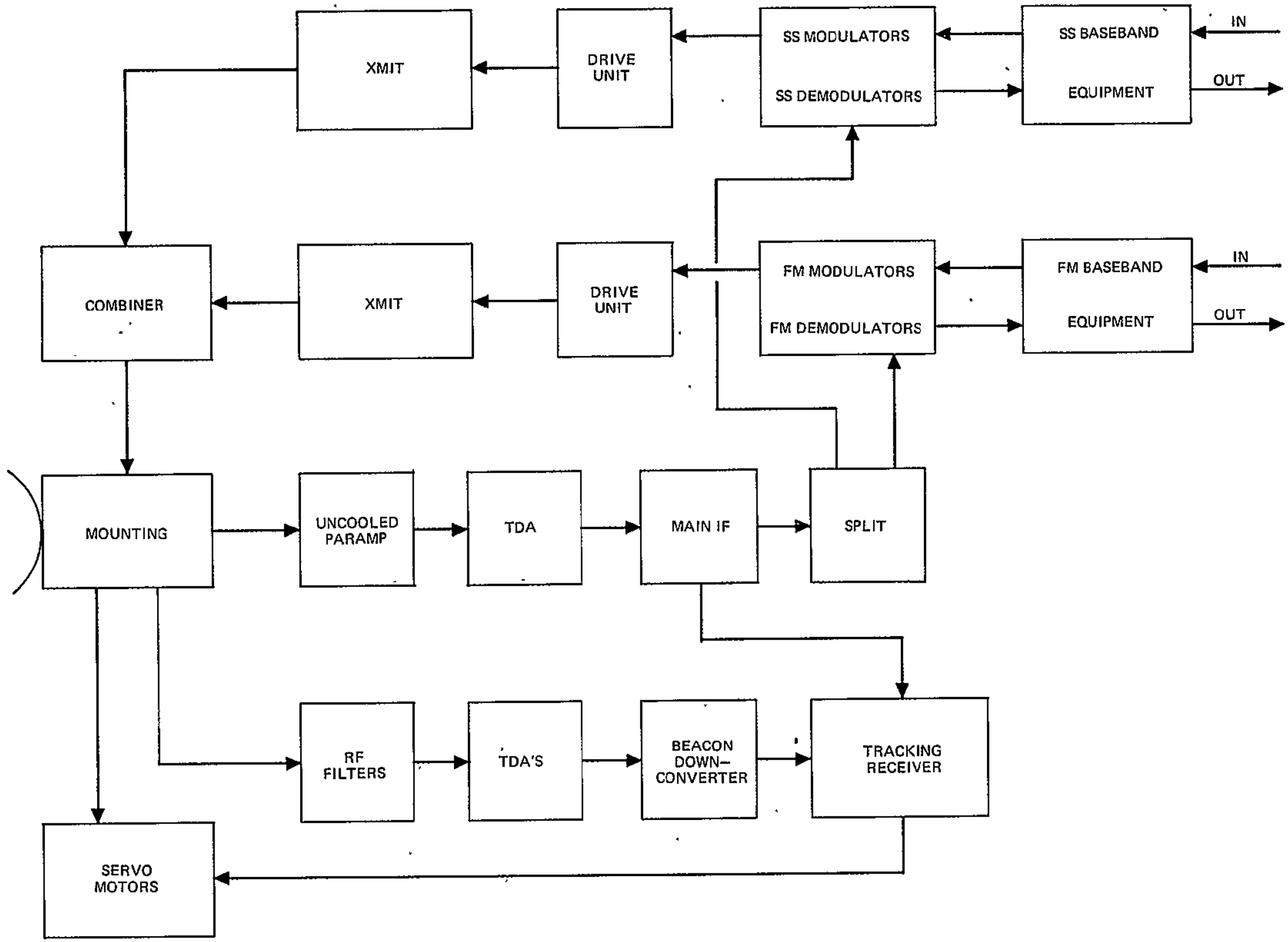


Figure 15-6. Type I and Type II Earth Terminal Simplified Block Diagram

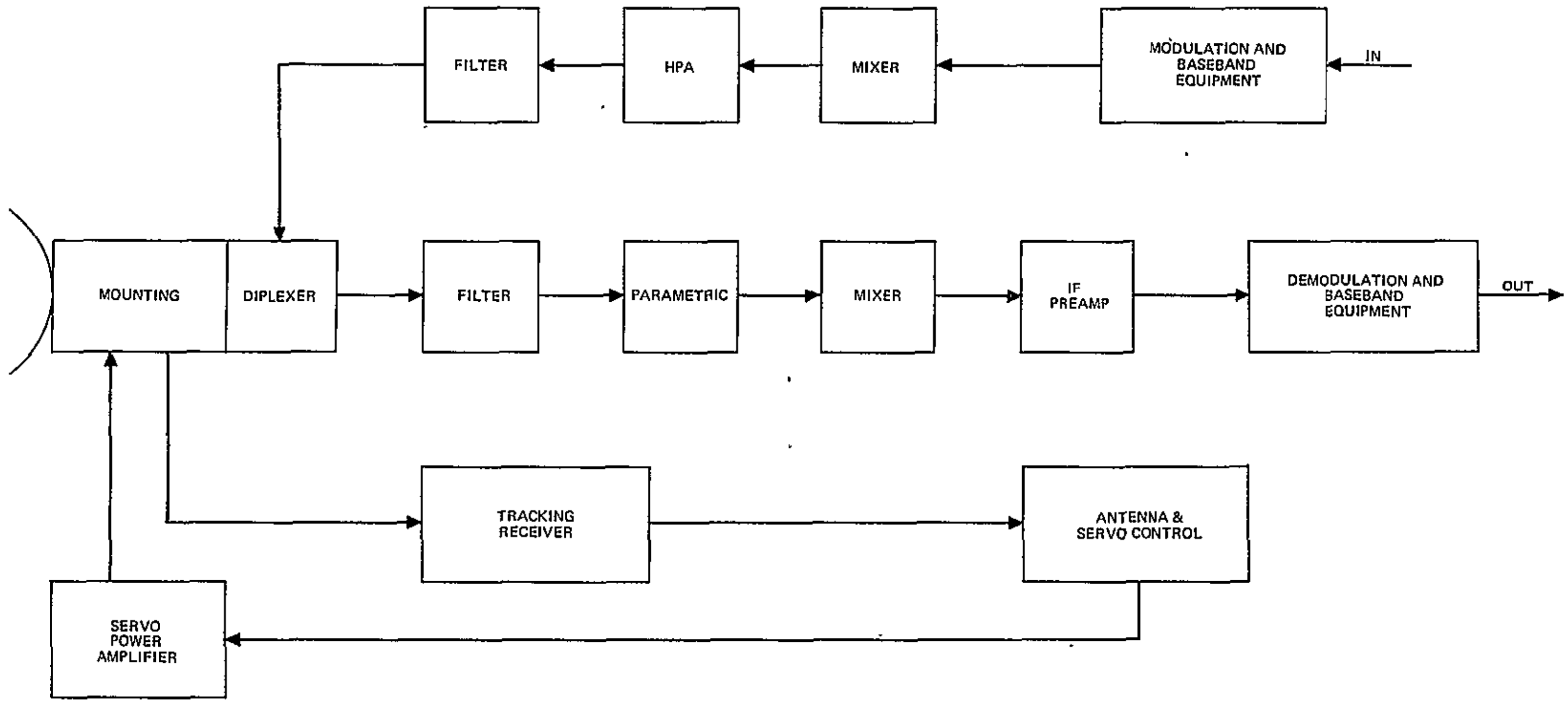


Figure 15-7. Type III and Type IV Earth Terminal Simplified Block Diagram

higher power, liquid cooled, five-cavity klystron (VA925E). Frequency control is the same as in the Type I and II terminals.

15.4.3 Type V Shipborne Terminal

Figure 15-8[9] illustrates the essentials for the Type V terminal.

Information signals to be transmitted by the terminal are passed through the baseband equipment to the exciter, which produces a low power microwave carrier modulated by the baseband signal. The microwave signal is amplified to a level of a few kilowatts and fed to the waveguide system and the antenna.

The waveguide system contains the necessary filter and diplexers for separating received from transmitted signals. It also contains a monopulse comparator for deriving angular misalignment signals which are fed to the tracking receiver. Received communications signals are first amplified in a low-noise preamplifier and then demodulated in the receivers after being down-converted to a suitable intermediate frequency and filtered to select the wanted carriers. The receivers feed the baseband equipment with outputs to the user equipment (telephone; telegraph, etc.).

Stabilization of the antenna beam is by reference to the gyro assembly, which provides an inertial reference pointing angle. Any misalignment of the beam with respect to this reference is sensed by the gyro pickoffs, and corrections are applied by power servo and drive motors. The inertial reference point angle is updated by signals derived from the tracking receiver so that the beam always points at the satellite. Manual pointing data for initially acquiring the satellite may also be fed to the gyro assembly.

A terminal located on a ship has a three-axis mount since pitching and rolling motions make a two-axis mount inadequate for tracking the satellite.

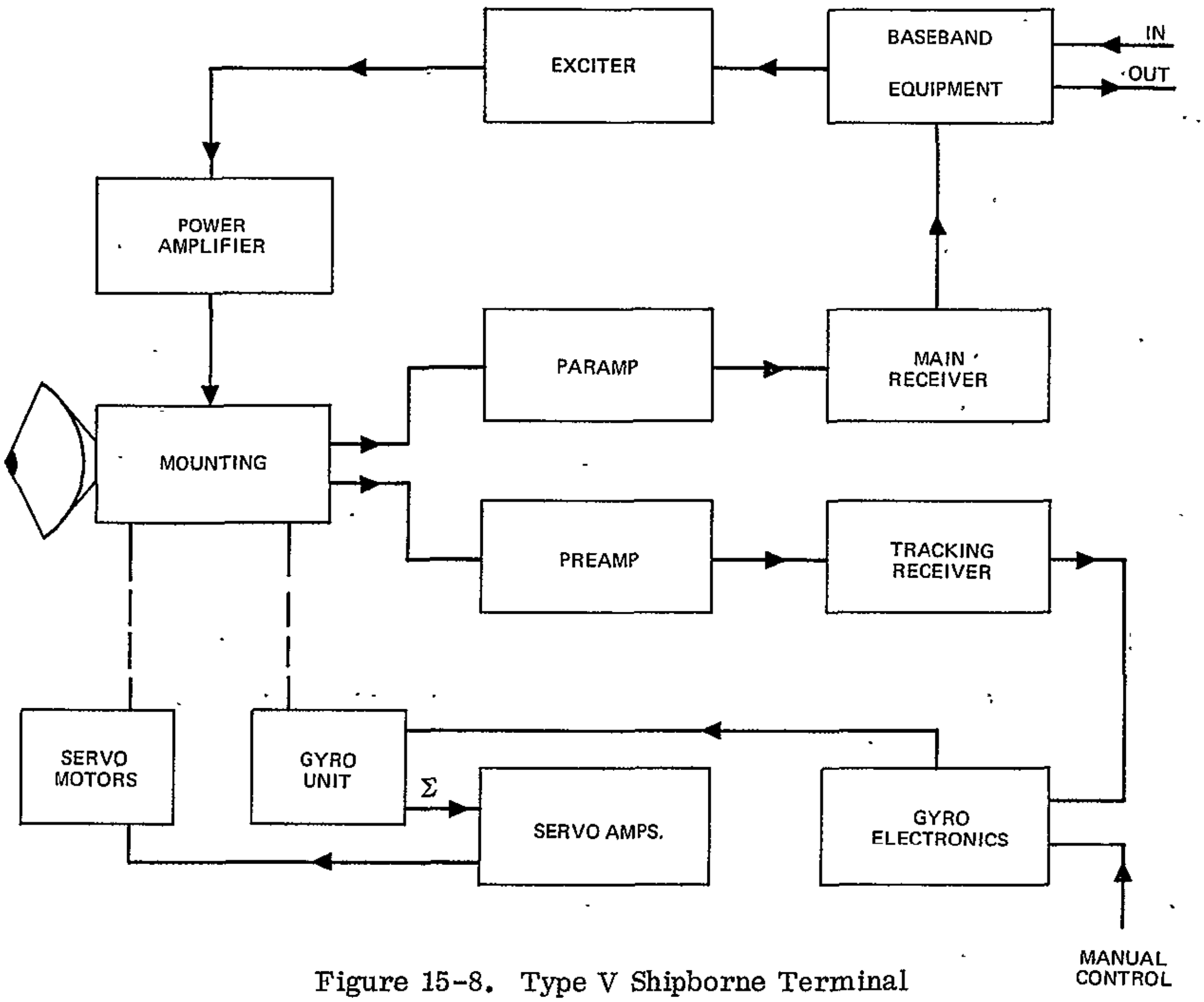


Figure 15-8. Type V Shipborne Terminal

15.5 EXPERIMENTS

Since this is an operational system, few experiments have been conducted. The repeater performance, which is crucial to the performance of the entire system, has been measured in orbit by means of the special earth station test facility at SRDE (Christchurch, U.K.). To date no significant change from the performance measured by Philco-Ford in the laboratory before launch has been observed.

15.6 OPERATIONAL RESULTS

The SKYNET system was designed in a conservative manner and the satellite and ground terminals developed met their specifications. As a result, the operational performance has been within the limits that were anticipated. The only spacecraft malfunction of significance was the failure of one TWT after a year of in-orbit operation.

15.6.1 System Status

There is no SKYNET operational satellite. The SKYNET-IA satellite launched and orbited in November 1969 ceased operating in November 1972. No orbit was achieved for the SKYNET-IB satellite. Subsequent to November 1972, the SKYNET-I earth terminal network scheduled the U.S. DSCS Phase I satellite on "as available" and "not-to-interfere" basis. During 17 February to 2 June 1973, the U.K. and U.S. shared the satellite capacity of the U.S. DSCS Phase II Atlantic satellite. Subsequent to the failure of the Atlantic satellite on 2 June, the U.K. reverted to scheduling the use of the U.S. DSCS Phase I satellites.

The first attempt at launching a SKYNET II satellite, in January 1974, resulted in a mission failure when the second stage of the Delta rocket misfired preventing achievement of a proper orbit. A second launch is tentatively scheduled for late 1974. A SKYNET III program is planned as a follow-on replacement for SKYNET II.

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SECTION 16 - NATO

16.1 PROGRAM DESCRIPTION

The NATO Satellite Communications (SATCOM) Program consists of three phases as follows:

1. Phase I was conducted during 1967-1970 as a test and evaluation to determine the feasibility of using satellite communications in support of NATO operations. The tests were conducted successfully with positive results.

2. Phase II implementation commenced in March 1970 to provide an operational system during 1971-1974. Two satellites were launched successfully into synchronous orbit, with one satellite acting as a backup to provide an expected 5-year system capability. Table 16-1 summarizes launch and status information on the NATO SATCOM Phase II satellites. The satellites were procured and launched by the USAF, with technical support from the Aerospace Corporation, under terms of an agreement reflected in a Memorandum of Understanding signed in 1967 by the U.S. and NATO. Satellite telemetry, tracking and command services are also provided by the USAF Space Ground Link System (SGLS).

   The satellite technology developed for U.K. SKYNET I satellites was used in NATO SATCOM Phase II satellites. Two minor changes were made to provide a more effective system for NATO. The first modification changed the equal power division between the 20-MHz and 2-MHz channels to a 6:1 ratio, respectively. The second modification shifted the antenna aiming point from the equatorial subsatellite point to a point on earth between 40^{o} and 45^{o}N latitude since all NATO earth terminals were to be located north of the equator. This yielded a more effective power spread for NATO coverage over the Northern Hemisphere.

Table 16-1. NATO SATCOM Phase II Spacecraft

		NATO IIA	NATO IIB
Satellite		NATO IIA	NATO IIB
Manufacturer		Philco Ford (USA)	
Sponsors		North Atlantic Treaty Organization (NATO), Brussels, Belgium Supreme Headquarters, Allied Powers Europe (SHAPE), Casteau, Belgium	
Launch Date		3/20/70	2/3/71
Launch Vehicle		Augmented Thrust Thor-Delta	
Orbital Data	Apogee*	36,402 km (22,619 mi.)	37,054 km (23,024 mi.)
	Perigee*	34,472 km (21,420 mi.)	34,492 km (21,432 mi.)
	Inclination	Less than 3°	Less than 3°
	Period	Approximately 24 hrs	Approximately 24 hrs
	Position ($^{\circ}$W)	18 ± 3**	26 ± 3** initially 18 ± 3 after NATO IIA failed
Status		Satellite inactive. TWT #2 (WJ) failed 25 Oct. 70. Earth sensor failed 7 Jul. 71. TWT #1 (Varian) failed 21 Apr. 72	Placed on Standby on 28 Mar. 73. Operating normally. TWT #1 failed 19 Jun. 72. TWT #2 (Varian) still operational

*At initial orbital injection. Attitude control and stationkeeping maneuvers change orbital parameters.

**Positions were chosen so that at the extremities (i.e., 15°W and 29°W) the minimum elevation angle from any NATO ground terminal would be greater than 10°.

The operational requirements dictated the utilization of 12 stationary earth terminals located near the capital cities of the 12 participating countries. Although the terminals are fixed, they can be disassembled and relocated to a prepared site. Table 16-2 is a summary of the 12 earth terminals of the NATO SATCOM Phase II system.

The operational objective of the NATO SATCOM Phase II system has been to provide readily available voice and telegraph communication circuits between the NATO countries and the military and political headquarters. All terminals have been installed, tested and accepted. System acceptance was completed in February 1973.

3. NATO SATCOM Phase III is being planned as an evolutionary follow-on to the Phase II system to provide satellite communications during 1975-1980. Higher powered satellites, comparable in capability to the U.S. DSCS Phase II satellites, were procured in early 1973 to replenish the space subsystem by late 1975. Ten earth terminals 13-meter (42-foot) antennas) will be added to the Phase II ground system at the following locations:

- Azores
- Bodo, Norway
- Halifax, N.S.
- Iceland
- Izmir, Turkey
- Landau, Germany
- Latania, Italy
- Puerto Rico
- Perth, Scotland
- Verona, Italy

Two large transportable terminals (6.1-meter (20-foot) antennas) will also be procured to provide satellite communications in contingency situations. Some U.S. and U.K. national ships, when under the operational command of NATO, will be equipped with terminals for communicating through the Phase II satellite. The NATO SATCOM system will be used primarily as a transmission subsystem to provide trunks between the tandem telephone circuit switches and store-and-forward message switches

Table 16-2. NATO SATCOM Earth Terminals

Location	Description	Ant. Dia. (m) (ft)	Utilization	Date Installed	Manufacturer
Belgium**	L1	13 (42)	Operational traffic and primary system control	1970/ 1972	Standard Electric Lorenz* (Germany), prime contractor, led a consortium of companies from the NATO countries to build ground terminals, modulation, multiplex, control, and interconnect facilities
Germany**	L2		Operational traffic and backup system control		
United States	L3		Operational traffic		
U.K.	L4				
Norway	L5				
Turkey	L6				
Italy	L7				
Canada	M2				
Netherlands	M3				
Denmark	M4				
Greece	M5				
Portugal	M6				
Hague, Netherlands	--	9.1 (30)	Testing	1968/ 1969	SHAPE Technical Center

*SEL is a subsidiary of International Telephone and Telegraph Corporation.
**Main station interconnect by LOS microwave.

when the several NATO communications systems are integrated and automated to form the NATO Integrated Communications System (NICS) commencing in 1973.

Satellite milestone events for the satellite are as follows:

- Contract award - 4 March 1973
- Satellite launch - August 1975

Milestone events for the earth terminals are as follows:

- Complete specification and issue ICB - April 1974
- Contract award - April 1975
- Install first terminal - May 1977
- Accept earth terminal - September 1978

16.2 SYSTEM DESCRIPTION

16.2.1 Phase II

System studies based on the requirements for communications within the NATO system indicated that FDMA would be sufficient for Phase II. It was configured so that seven large-capacity terminals would operate in the 20-MHz band, each transmitting a single multidestination, 24-voice channel FM carrier, and that five medium-capacity terminals would operate in the narrowband (2-MHz) channel, each transmitting a single multidestination, 3-channel FM carrier. Each large- and medium-capacity station receives and demodulates a number of carriers dependent on that station's connectivity. Figure 16-1 indicates the interconnectivity of the NATO SATCOM Phase II system. Table 16-3 shows the RF operating frequencies for the 2-MHz and 20-MHz channels.

Table 16-4 gives the FM performance characteristics of the demodulators used in the Phase II system. The number of modes provided allow the system to change capacity and configuration as long-term requirements vary.

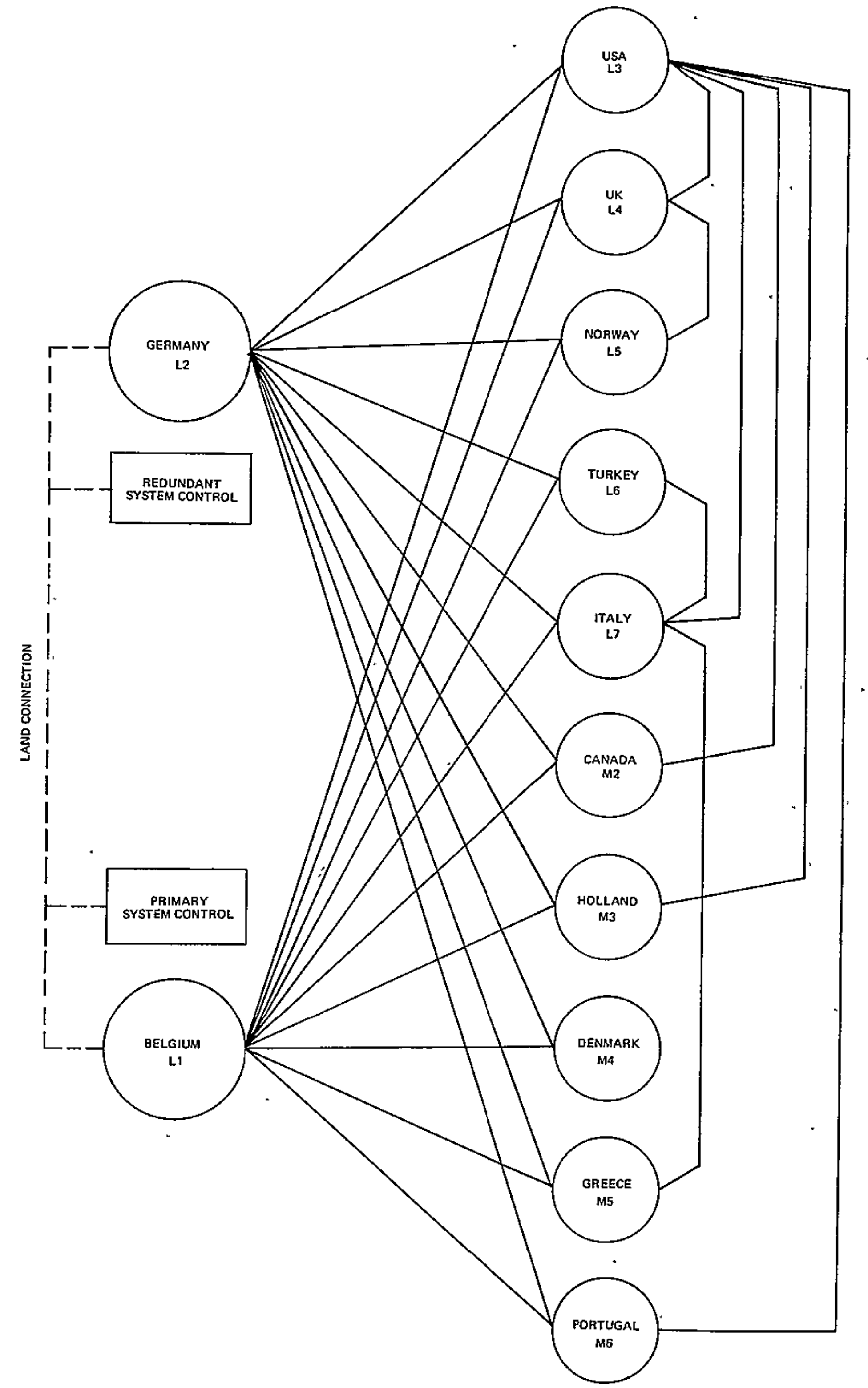


Figure 16-1. NATO SATCOM Phase II Interconnectivity

Table 16-3. NATO SATCOM Phase II Frequencies

	2-MHz Channel (MHz)	20-MHz Channel (MHz)	Beacon (MHz)
Uplink	7976.02 to 7978.02	7985.12 to 8005.12	---
Downlink	7257.3 to 7259.3	7266.4 to 7286.4	7299.5

Table 16-4. FM Demodulator Performance

Mode	Number of Voice Channels	Carrier-to-Noise Density Ratio at Threshold (dB/Hz)	Carrier-to-Noise Density Ratio for -30 dBmOp Weighted Noise in Worst Channel (dB/Hz)	Nominal IF Bandwidth (kHz)
1	24	64.3	68	575
2	18	63.2	67	475
3	12	60.8	65	325
4	6	58.3	62	150
5	3	56.1	60	100
6	2	54.6	59	50
7	1	49.7	55	15

Table 16-5 gives a typical downlink power budget for the NATO system for conditions that should exist 99 percent of the time at the worst geographically located station. Margins at all other stations are 0.1 to 2.7 dB higher than those shown in the table. Since reliability of communications is of paramount importance, margins are allowed for unpredictable losses due to weather, power control, misalignments, and equipment degradation.

Control of the NATO SATCOM Phase II system is provided in a number of different areas. These are spacecraft control, earth terminal complex (ground) control, and communications or traffic control.

Table 16-3 shows the operating frequencies for the 2-MHz and 20-MHz channels.

1. Spacecraft control is exercised by the USAF Satellite Control Facility (AFSCF), Sunnyvale, California, through its worldwide network of satellite monitoring facilities. The satellite control system receives and processes telemetry data and generates and transmits commands for the control of the spacecraft. Spacecraft control includes altitude control, station keeping and other command functions of the space segment. Control is exercised by the AFSCF in a manner mutually agreed upon by SHAPE and AFSCF, thus minimizing system interference and maximizing overall effectiveness.

2. Earth terminal control is exercised by allocating to the terminal a portion of the satellite output power in such a way that the overall system performance is optimized.

   Control of the distribution of satellite output power is exercised manually from the Primary Control Center (PCC) collocated with the Belgium earth station or from the Secondary Control Center (SCC) collocated with the German earth station.

   Equipment has been provided for the continuous monitoring and measuring of the system. The information from each terminal is forwarded

Table 16-5. Power Budgets for Typical NATO FM Performance at the Worst Geographic Position

	Parameter	20-MHz Band*	2-MHz Band*
Uplink	1. Received power at satellite (dBm)	$-74.4^{+0.5}_{-1.3}$	$-71.4^{+0.5}_{-1.3}$
	2. Satellite receive noise (dBm)/Hz power density (2750°K)	-165.2	-165.2
	3. Carrier/noise ratio (dB)	$+19.5^{+0.5}_{-1.3}$	$+28.9^{+0.5}_{-1.3}$
Downlink	1. Satellite EIRP (minimum) (dBm)	+50.3	+42.8
	2. Intermodulation loss (dB)	-1.2	-1.3
	3. Power sharing (dB)	-8.5 ± 1.0	-7.0 ± 1.0
	4. Carrier uplink uncertainty (dB)	$0^{+0.5}_{-1.3}$	$0^{+0.5}_{-1.3}$
	5. Power control (dB)	0 ± 1.0	0 ± 1.0
	6. Net EIRP/carrier (dBm/carrier)	$+40.6^{+1.5}_{-1.9}$	$33.3^{+1.5}_{-1.9}$
	7. Downlink losses (dB)	$-203.0^{+0}_{-1.3}$	$-203.0^{+0}_{-1.3}$
	8. Receive antenna gain (dB)	$+58.0^{+0.3}_{-0.1}$	$+58.0^{+0.3}_{-0.1}$
	9. Receive input carrier power (dBm)	$-104.4^{+1.5}_{-2.3}$	$111.7^{+1.5}_{-2.3}$
	10. Receive thermal noise power density (220°K) (dBm/Hz)	-175.2	-175.2
	11. Intermodulation Noise Density (dBm/Hz)	-178.2	-174.6
	12. Total Noise Density (dBm/Hz)	-173.4	-171.9
	13. Receive carrier to noise (dB/Hz)	$69.0^{+1.5}_{-2.3}$	$60.2^{+1.5}_{-2.3}$
	14. Minimum margin to threshold (dB)	2.4**	1.8**

*99 percent of the time values will be within these limits.
**All other stations should have margins that are from 0.1 to 2.7 dB better.

continuously to the system controller by means of an automatic data reporting network. The system control stations at Belgium and Germany receive and process the same information independently, and are interconnected via a land data link so that the system can be controlled from either station by using the equipment provided at the other station. In effect, there is redundancy in the control system. Each control center is provided with computation and display equipment for the analysis and display of the incoming data. A TTY orderwire network via the satellite has been provided to allow the controller to forward specific control instructions to any station.

3. Communications or traffic control originates at the technical control centers in accordance with applicable NATO directives. This control is under the operational direction of SHAPE for the NATO SATCOM Phase II system.

16.2.2 Phase III

Table 16-6 shows the principal requirements that were selected as the basis for planning NATO SATCOM Phase III.

Communications service will be provided by voice, data and teletype using FM modulation as in Phase II. In addition, each link will be equipped with CDMA equipment to provide vocoded voice/data and several teletype channels on each link during jamming conditions.

Ten additional fixed type earth terminals will be procured to augment the 12 Phase II earth terminals, and two medium-capacity transportable 6-meter (20-foot) antenna terminals will be procured for use by the Alternate Shape Headquarters and the Allied Mobile Forces.

Two high-power satellites--one to be used as an in-orbit spare--were procured in early 1973 for launch in late 1975. These satellites will contain two separate communication repeaters and antennas. One repeater will be connected to a widebeam

Table 16-6. NATO SATCOM Phase III Requirements

1. Communication Service:	• Clear mode = voice, data (2400 bps) and teletype • Jamming mode = 1 vocoded voice/data + 8 TTY per link
2. Earth Terminals:	• Fixed (12 m (40 ft)) = 22* • Transportable (6.1 m (20 ft)) = 2 • Shipborne (2 m (6 ft)) = 3 (possibly more)
3. Modulation:	• Clear mode = FM • Jamming mode = CDMA
4. Multiplex:	• Voice = FDM • TTY = VFCT • CDMA = TDM
5. Space Segment:	• Two high-power, two-channel satellites. (One satellite as backup) • WB and NB antennas on satellite • Available for launch August 1975

*Includes 12 Phase II terminals modified for Phase III.

(WB) antenna to provide coverage of the entire NATO area while the other repeater will be connected to a narrowbeam (NB) antenna to provide coverage of the European coun tries. Figure 16-2 shows the coverage of the WB and NB antennas. The WB antenna will be pointed to 42°N latitude and 18°W longitude to concentrate the power in the geographical area of interest to NATO, as in the case of the Phase II satellite.

Under this concept, all transmissions from ground stations will be received by the satellite WB antenna. However, the satellite downlink transmissions will be routed through the satellite WB antenna repeater or NB antenna repeater depending on the radio frequency transmitted by the ground station. The filters installed in the satellite receiver will be set to accept that frequency assigned to the WB or NB.

All terminals in the European area will receive the satellite NB downlink transmissions while those in the Atlantic will receive only the WB downlink transmissions.

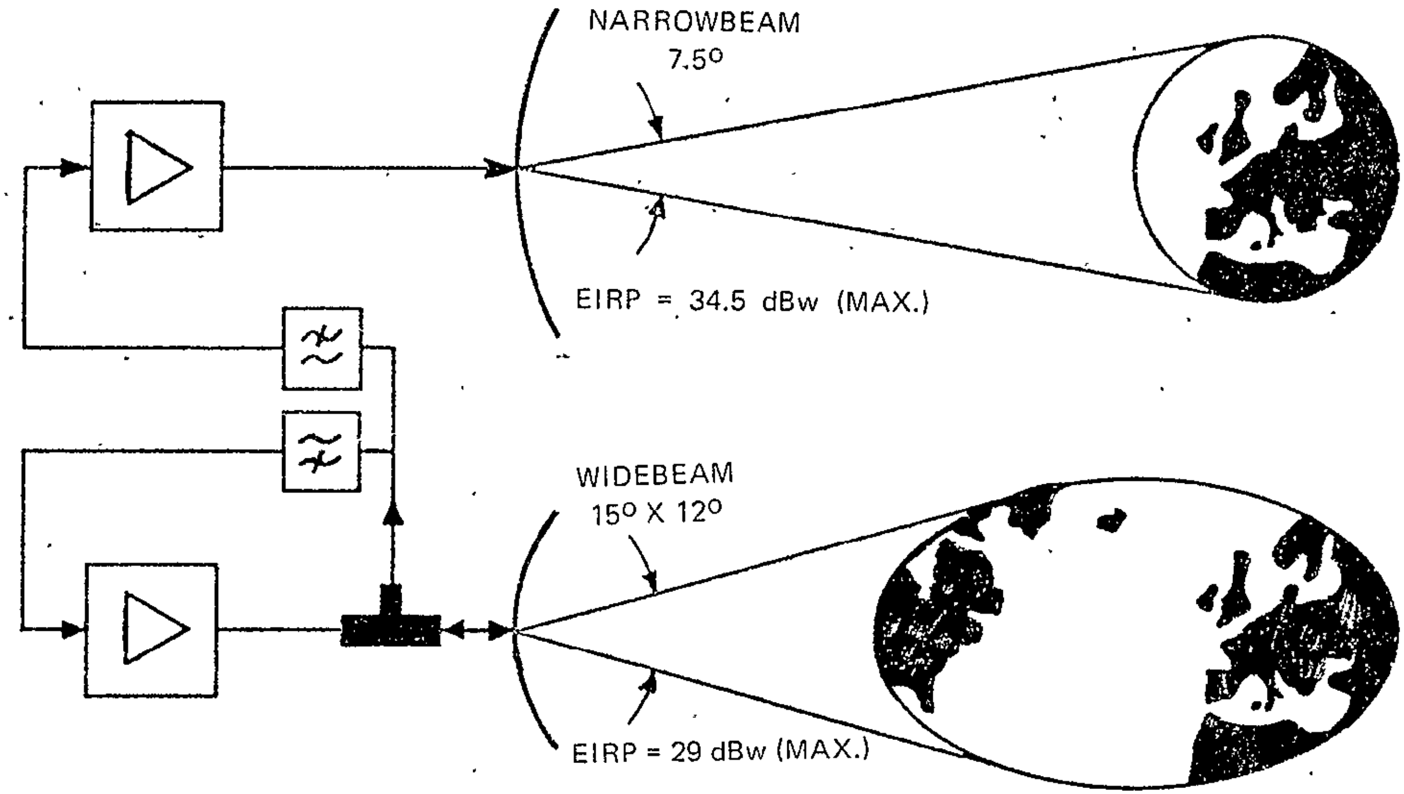
The increased gain of the NB antenna will result in the NB channel having about 3-1/3 times the EIRP of the WB channel. This increased power will meet the larger SATCOM requirements in the European area.

Figure 16-3 shows the 188 links to be provided between the 22 fixed station terminals and shows the fixed stations to be equipped to handle shipshore communications.

Each link will be equipped to handle voice, data and teletype channels by FM modulation as needed to meet requirements in a no-jamming environment. Also, each link will be equipped with CDMA and TDM equipment to handle up to one vocoded voice or data at 2400 bps and/or several teletype channels under jamming conditions.

Table 16-7 summarizes the links and channels to be provided in the NB European net and the WB Atlantic-European net by use of various types of earth terminals.

A total of 206 links (162 in European net and 44 in the Atlantic net) containing 676 voice equivalent channels will be provided by use of 100 percent of the satellite



1. SATELLITE RECEIVES ALL CARRIERS VIA WB ANTENNA
2. ALL TERMINALS IN EUROPE RECEIVE FROM NB TRANSPONDER
3. ALL TERMINALS IN ATLANTIC RECEIVE FROM WB TRANSPONDER

Figure 16-2. NATO SATCOM Phase III Satellite WB and NB Antenna Coverages

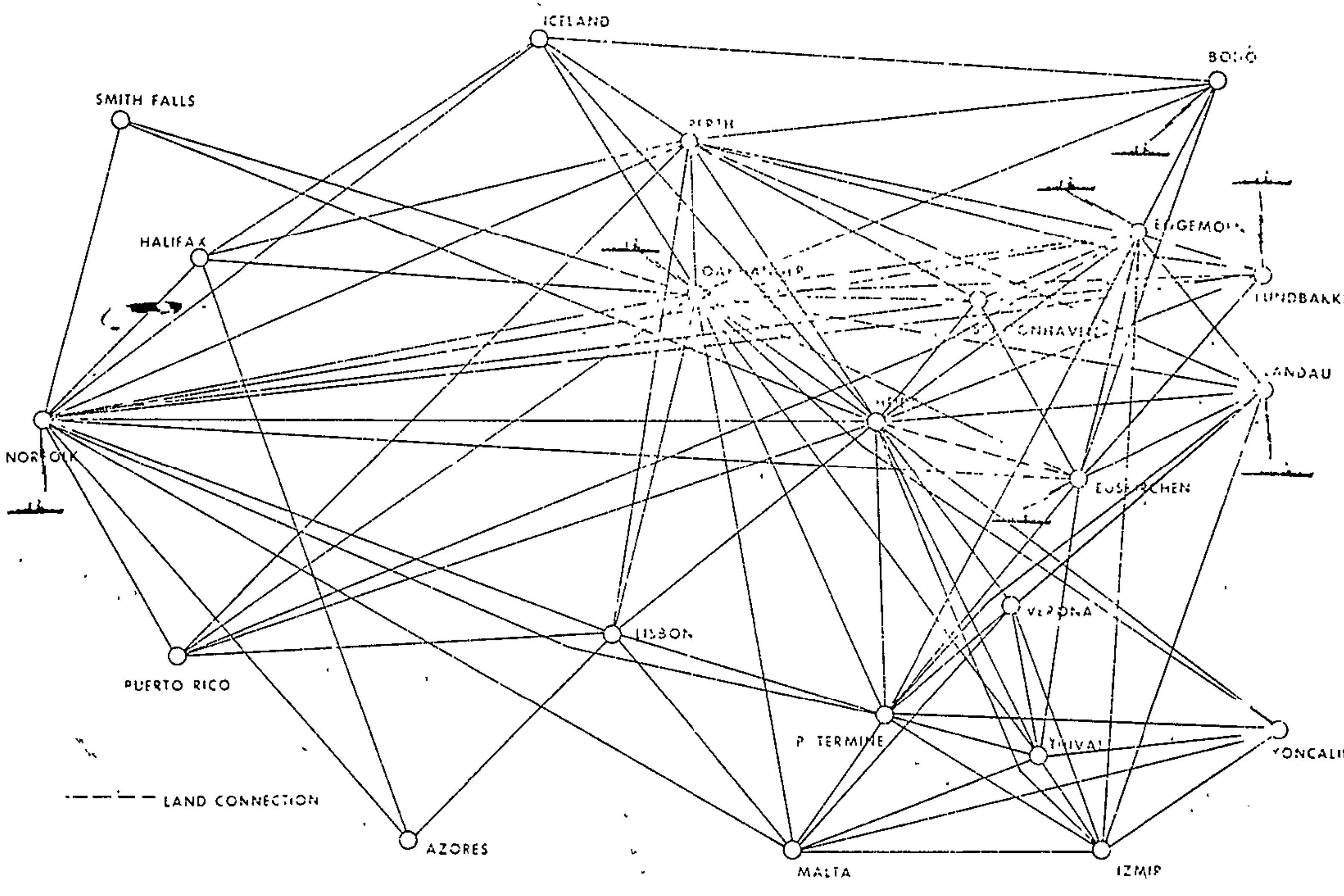


Figure 16-3. NATO SATCOM Phase III Link Connectivity

downlink power in the WB and NB antenna channels. High quality channels of 45 dB TT/N will be capable of being switched through the NATO integrated communications system.

Table 16-7. NATO SATCOM Phase III Performance Summary

Links and Channels (Half Duplex)	NB Europe Net		WB Atl-Eur Net	
Terminals	Links	4-kHz Chan.	Links	4-kHz Chan.
Fixed-Fixed	150	458	38	144
Fixed-Transportable	6	33	-	-
Transportables-Fixed	6	33	-	-
Fixed-Ships	-	-	3	4
Ships-Fixed	-	-	3	4
Total:	162	524	44	152

Locations: 22 Fixed Terminals (16 in Europe, 6 in Atlantic)
2 Transportables in Europe
3 Shipborne in Atlantic

Satellite Power Consumed: 100% in both "NB" and "WB" antenna channels.

The frequencies assigned for NATO SATCOM Phase III satellites are shown on Figure 16-4.

16.3 SPACECRAFT

1. Phase II. Spacecraft characteristics for the NATO satellites are displayed in Table 16-8.

2. Phase III. A specification extract summary for spacecraft communications subsystem characteristics of the Phase III satellites is shown in Table 16-9.

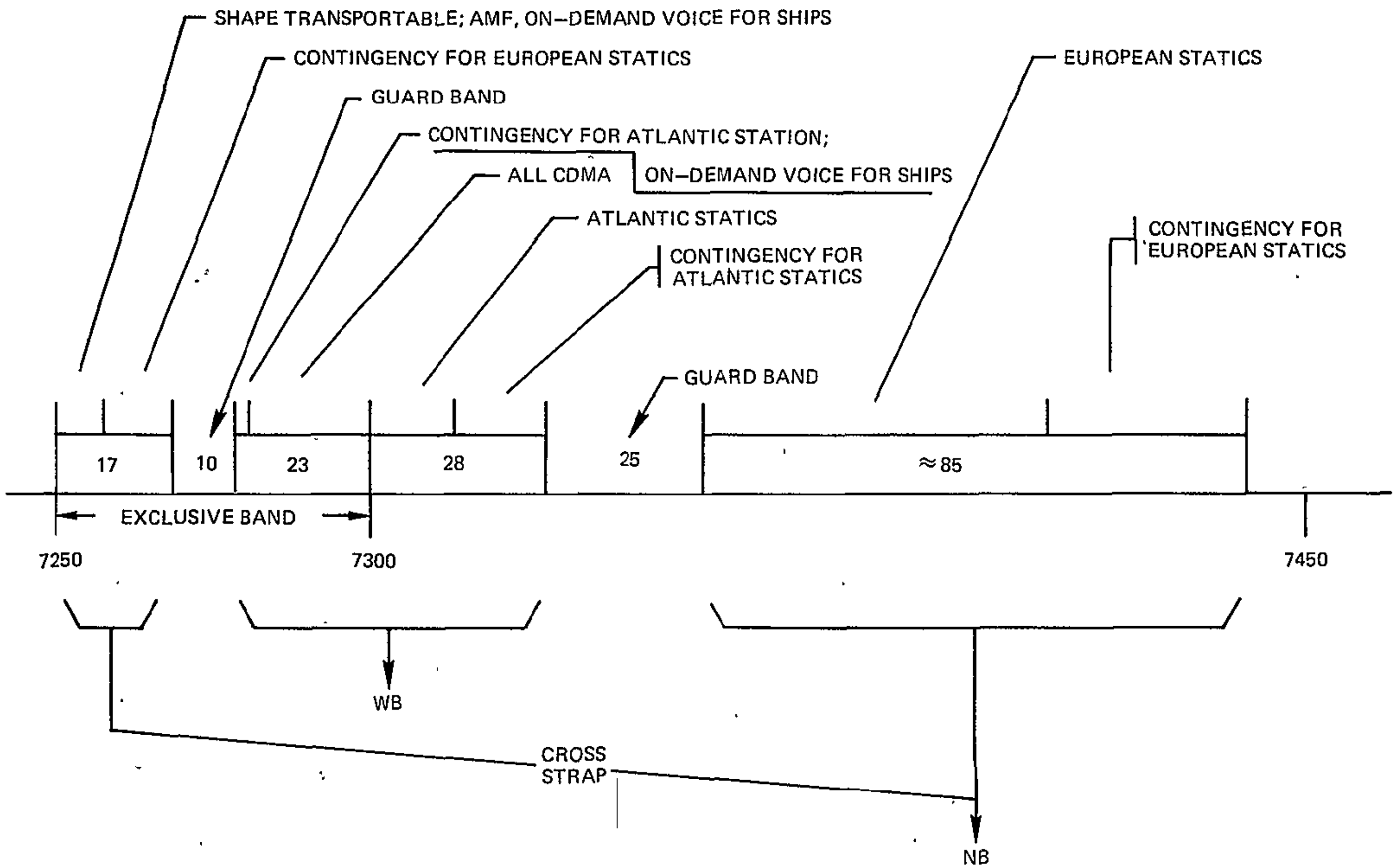


Figure 16-4. Frequency Plan for NATO SATCOM Phase III Satellites

Table 16-8. NATO SATCOM Phase II Satellite Characteristics

Antennas	Type	X-band mechanically despun with lens to aim center of beam at 42^{o}-45^{o}N	UHF array for TT&C with redundant UHF transponders and command/telemetry processing equipment
	Number	One	Two
	Beamwidth	Elliptical $17^{o} \times 11^{o}$	Essentially omnidirectional
	Gain (dB)	17.5	-0.7
Repeaters	Frequency Band	2-MHz uplink (7976.02-7978.2); downlink (7257.3-7259.3) 20-MHz uplink (7985.12-8005.12); downlink (7266.4-7286.4)	
	Type	Hard-limiting dual channel	
	1 dB Bandwidth	20-MHz and 2-MHz channels	
	Receiver		
	Type Front End	Down conversion mixer into linear amplifier*	
	Front End Gain	No data	
	Noise Figure	2750^{o}K (10.2 dB)	
	Transmitter		
	Type	Redundant TWT	
	Gain	No data	
	Power Output (dBm)	33.0 (20-MHz), 24.5 (2-MHz) channel	
	EIRP (dBm) peak of beam	50.5 (20-MHz) channel, 42.0 (2-MHz) channel	
General Features	Stabilization		
	Type	Spin 90 rpm - 5 years	
	Capability (stationkeeping)	$\pm 3^{o}$ for 5 years	
	Power Source		
	Primary	Cylindrical array of silicon solar cells, capable of providing 97 watts of prime power, throughout 5 years of orbit life	
	Supplement	Two redundant 16 cell nickel cadmium batteries for operation during eclipse (6 AH per cell)	
	Communication power needs (watts)	64	
	Size	137 cm (54 in.) diameter, 152 cm (60 in.) high	
	Weight	Launch 243 kg (535 lbs), in orbit 127 kg (280 lbs)	

*Dynamic range: (a) 20-MHz channel: -90 to -45 dBm
(b) 2-MHz channel: -100 to -45 dBm

Table 16-9. NATO SATCOM Phase III Communications Subsystem Satellite Characteristics

Antennas	One WB - $15^{\circ} \times 12^{\circ}$ One NB - 7.5°
Bandwidth	50 MHz (WB) 17 and 85 MHz (NB) (cross-strapped)
RF Frequency (Down)	17 MHz (7250-7267) 50 MHz (7277-7327) 85 MHz (7352-7437)
RF Frequency (Up)	17 MHz (7975-7992) 50 MHz (8002-8052) 85 MHz (8077-8162)
Frequency Translation	725 MHz
Power Amplifier	.4 TWTs (Hughes 265H) 22 watts each*
Effective Radiated Power	
• EIRP (Saturated) EC (50 MHz)	29 dBW**
• EIRP (Saturated) NB (85 MHz)***	35 dBW**
• EIRP (Saturated) NB (17 MHz)***	35 dBW**
• Beacon (Independent Power Source)	6.5 dBW
One Receiver Antenna (Elliptical Beam Earth Coverage)	18.6 dB gain
Two Transmitter Antennas (WB Elliptical Coverage) (NB Elliptical Coverage)	 19.0 dB gain 24.9 dB gain
Gain Noise Figure	8 dB
Access Technique	FDMA or CDMA

*Two TWTAs, one as a backup for the other, are connected to the WB antenna. The other two TWTAs can be connected to either the NB antenna, one as a backup to the other, or to the WB antenna, with either TWTA functioning as a backup to the first two TWTAs which are connected only to the WB antenna.

**The ERP's given for the 50-MHz, 17-MHz and the 85-MHz transponder channels are based on operating the TWTAs at saturated power output. During no-jamming conditions and when operating by FM/FDMA, the TWTAs will be operated in the linear mode at about 5 dBW less than that shown to reduce intermodulation and conserve bandwidth.

***The "NB 17-MHz channel" will use the same TWTA and NB antennas as the "NB 85-MHz channel"; therefore, the two channels will share the EIRP (35 dBW) available from the common TWTA and NB antenna.

16.4 GROUND TERMINALS

1. Phase II. The NATO SATCOM Phase II system utilizes 12 ground terminals. The ground terminals at Belgium (L1) and Germany (L2) are the master stations of the network. Table 16-10 summarizes the characteristics of the NATO ground terminals. The antenna is a 13-meter (42-foot) diameter Cassegrain with a reflector shaped to provide high efficiency. It is mounted on a fully steerable azimuth/elevation mount.

   A simplified diagram of the essentials of the communications chain is shown in Figure 16-5.

2. Phase III. Specifications for the ten additional Phase III earth terminals have not yet been released.

   The following design considerations apply to the Phase III earth terminals:

   - A major objective of Phase III terminal design will be to minimize future modifications.
   - Insofar as is possible, the new terminals should share the same subsystems as the Phase II modifications. This will increase cost effectiveness by reducing training, logistics, design and operational maintenance costs.
   - The transmitter and receiver should be fully capable of supporting a 40-megahertz PN link.
   - Both 13- (42-) and 6.1-meter (20-foot) terminals should be designed to employ subsystem redundancy wherever practical to achieve the high degree of availability required.
   - The receiver should be designed so that carriers anywhere in the satellite frequency band (7250 to 7750 MHz) can be received simultaneously.

Table 16-10. Characteristics of NATO SATCOM Phase II Earth Terminals

Antenna	Type	Cassegrain Shaped Surface
	Mount	AZ ELEV
	Aperture Size	13 m (42 ft)
	Receive gain (dB)	58
	Efficiency (%)	75
	Receive Beamwidth (^{o})	0.23*
Receive System	Type Preamplifier	Varactor diode
	Gain (dB)	No data
	1 dB Bandwidth (MHz)	50
	Tuning Capability (MHz)	500
	Noise Temperature (^{o}K)	90-100
Transmit System	Type Amplifier	Klystron
	Bandwidth (MHz)	50
	Amp Power Output (kW)	5-6
Track-ing	Type (monopulse)	Automatic
	Accuracy (3σ)	0.025**
Freq. Control	Long term (1 yr)	1 in 10^9
	Short term (1 sec)	1 in 10^{11}
Total Perf.	Sys. Noise Temp. ^{o}K	210
	G/T dB/^{o}K	34.8*
	EIRP (dBW)	94*
Polari-zation	Transmit Feed	Right hand circular
	Receive Feed	Left Hand circular
Instal-lation	Radome	Yes***
	Type Facility	Fixed****

*Calculated from other measured parameters.
**This can degrade to 0.05 per channel if manual track is required.
***All except L2 Germany.
****Can be relocated to prepared site.

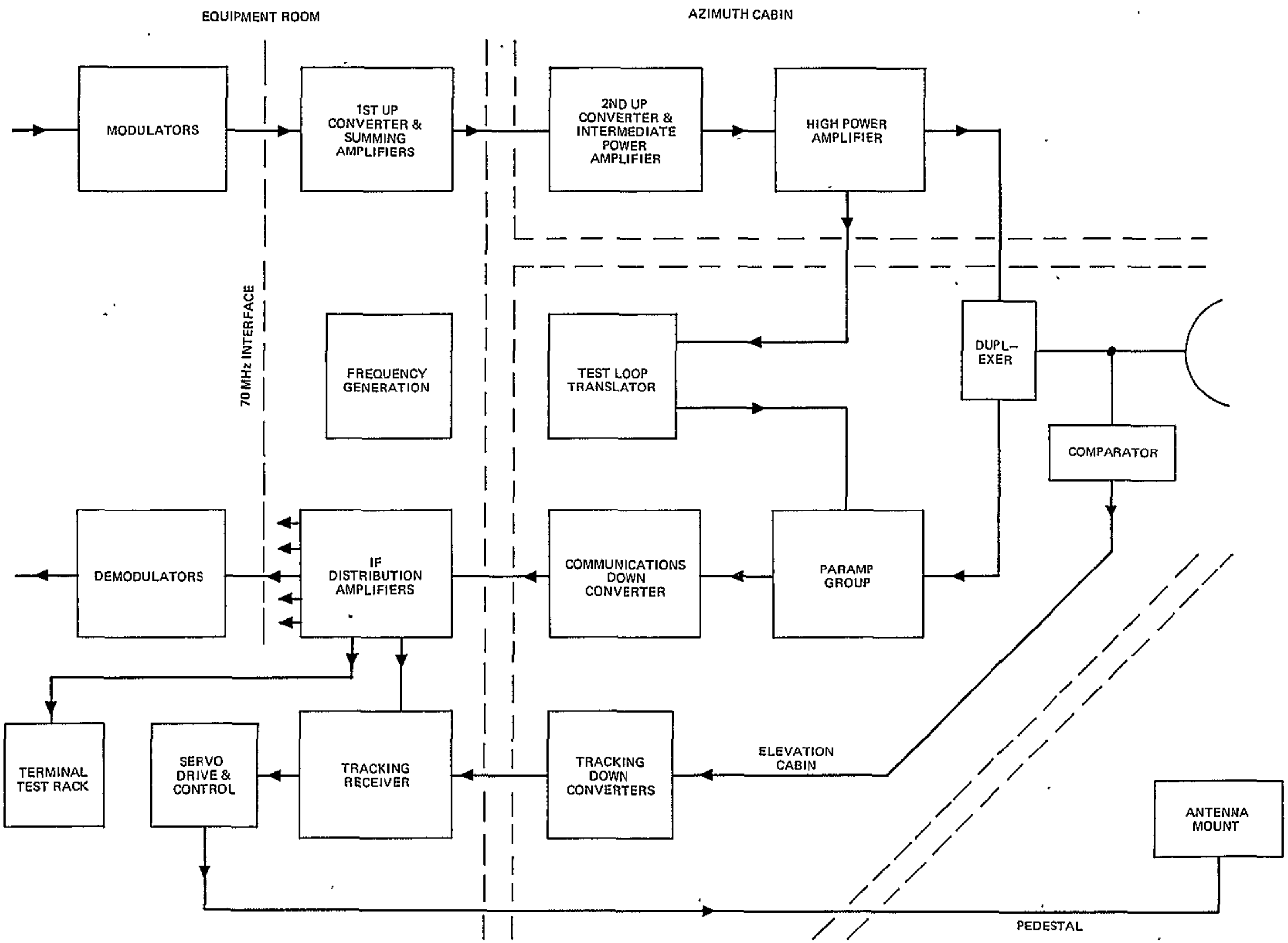


Figure 16-5. NATO Ground Terminal Simplified Block Diagram

- The transmitter instantaneous bandwidth should be as large as possible Klystrons with a bandwidth of 250 MHz may become available in the 1975-1980 period.
- The redundant transmitters should be capable of being operated in parallel so that their combined power can be used.

16.5 EXPERIMENTS

The repeater performance, which is crucial to the performance of the system, has been measured in orbit by means of the special earth station test facilities at SRDE (Christchurch, U.K.) and the SHAPE Technical Center (STC), The Hague. No significant change was observed from the performance measured by Philco-Ford in the laboratory prior to launch.

In general, the NATO satellite system is to be an operational system, not an experimental one. Tests and evaluations are made only to the extent of assuring operational capabilities. Such tests have been successful in showing the feasibility of using satellite communications in support of NATO operations.

16.6 OPERATIONAL RESULTS

NATO Phase I, a test and evaluation system, is no longer operational. A subsequent Phase II system was implemented to provide an operational system during the 1971-1974 time period although only one of two satellites in space remains operational and has been placed in a ready condition. All 12 system acceptance tests have been completed. A Phase III follow-on system is planned for the 1975-1980 time period. Large satellites are being procured to replenish the space subsystem in late 1975. NATO is endeavoring to fill the expected gap in satellite communications (Phase II to Phase III) by making arrangements for sharing of the U.S. DSCS Phase II Atlantic satellite. Ten additional earth terminals are also expected to be acquired for the Phase III system.

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3. TRW Space Log, Volume 10.

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SECTION 17 - PHASE II DEFENSE SATELLITE COMMUNICATIONS SYSTEM

17.1 PROGRAM DESCRIPTION

Experience with the Phase I DSCS (Section 2) demonstrated that satellite communications can meet the essential worldwide communications needs of the Department of Defense (DOD). Planning for a Phase II DSCS has been a continuing process conducted concurrently with the implementation of Phase I. Therefore, in June 1968, the DOD announced its decision to acquire six new satellites and additional earth terminals as the second phase of the DSCS. Phase I had successfully completed its research and development objectives and since late 1967 had been providing a limited operational capability. The basic objectives for the Phase II DSCS are found in Table 17-1. The Phase II DSCS remains an integral part of the global DCS, and is designed to provide vital communications service to the United States and Allied Forces throughout the world by means of satellites. It is composed of space, earth and control subsystems.

Table 17-1. Phase II DSCS Objectives

Number	Objectives
1	Establish an operational military satellite communications system which will provide substantial increases in capacity and performance, together with a wider variety of services for users.
2	Satisfy approved requirements for DOD users, both DCS and Tactical, Presidential Communication, Diplomatic Telecommunications System, North Atlantic Treaty Organization (NATO), and other specified allies.
3	Provide the following types of service: 1. Protected service for high priority users 2. Unprotected trunking and wideband service 3. Contingency service for crisis situations on a global basis.

The initial Phase II DSCS spacecraft procurement package consisted of six satellites, which were designed and manufactured by TRW, Inc., under contract to the Space and Missile Systems Organization (SAMSO) Air Force Systems Command. The Phase II satellites are spin stabilized and have two steerable narrow beam (NB) ($2^{o} \times 2^{o}$) and one earth coverage (EC) (17^{o}) antennas on a despun platform. The effective radiated powers per antenna are 40 dBW (NB) and 28 dBW (EC). The antennas can be cross-strapped to permit any antenna to receive and transmit via any other. The various transponders and cross-straps have different band widths selected on the basis of expected needs. The satellites have tunnel diode inputs and TWT output amplifiers.

The first launch of two satellites from the initial procurement of six occurred on November 2, 1971. The Titan IIIC was used as launching vehicle for lifting the two satellites into synchronous orbit. Both of the satellites in the initial launch have failed. This left four spacecraft of the original procurement to undergo extensive redesign before a second launch attempt. The redesign included balancing of the design platform and a major change in the power distribution. The redesign was completed and two more Phase II DSCS satellites were launched on December 13, 1973.(1) These satellites have undergone extensive testing and were placed into operation in March 1974. Another dual-satellite launch is tentatively scheduled for late 1974.

17.2 SYSTEM DESCRIPTION

The Phase II DSCS will have several distinct periods or stages, each providing different communications capabilities. In the first period, Stage 1a, Phase II operates in the FDMA and code division multiple access (CDMA) modes, and provides a point-to-point operational capability after completing essential on-orbit satellite tests.

In Stage 1a, the point-to-point terminal linking arrangement results in an operational system similar to that of Phase I. However, in this case, many links will be handled simultaneously by each satellite. During this initial stage of the Phase II DSCS, only the upgraded Phase I terminals will be included in the system. The traffic will range from one analog voice channel between AN/TSC-54 terminals to 12 analog voice channels between AN/MSC-46 terminals. A few selected links will provide a wideband digital traffice capability to support such requirements as wideband digital data and digitized voice signals. These digital links will be time-shared with FM voice circuits. The baseband and modulation equipment (i.e., FM modems, multiplex, digital modems, etc.) will be those which are presently in use in the Phase I. A typical system configuration for Stage 1a is shown in Figure 17-1.

A protected traffic capability (i.e., circuits resistant to RF jamming) will be provided during Stage 1a on a terminal-to-terminal basis using existing CDMA (spread spectrum) equipment. These links will be dedicated lines between selected users and will pass vital designated traffic only. Communications control of the system during Stage 1a will consist of scheduling the coordinated system and the maintenance of discipline by a controller. One controller will be established for each satellite.

Three to four satellites may be needed to supply a complete global communications capability among the geographical locations dictated by military requirements.

A limited number of AN/TSC-54 terminals will be equipped to provide a contingency capability in Stage 1a. These terminals will be self-contained in that they will be provided with FM modems, multiplex, and ancillary equipment to handle 12 voice channels. The FM modems will be capable of modulating an RF carrier with up to 72 voice channels delivered to the terminal in a baseband form from a separate technical control facility. Operation of contingency terminals during this stage will be via the satellite NB antennas.

In Stage 1b the Phase II system will operate in the FDMA mode to provide a multipoint network satellite communications capability and the code division multiple access (CDMA) mode to provide point-to-point protected (i.e., jam resistant) communications. New FM and PSK modems and FDM multiplexers will be purchased to provide the capacity required to fulfill the Stage 1b requirement. The PSK modems will replace MFSK modems for wideband data and secure voice services. A number of earth terminals will provide a multiple carrier transmission/reception capability. These terminals will be deployed to locations (defined as nodal locations) to satisfy specific DSCS requirements.

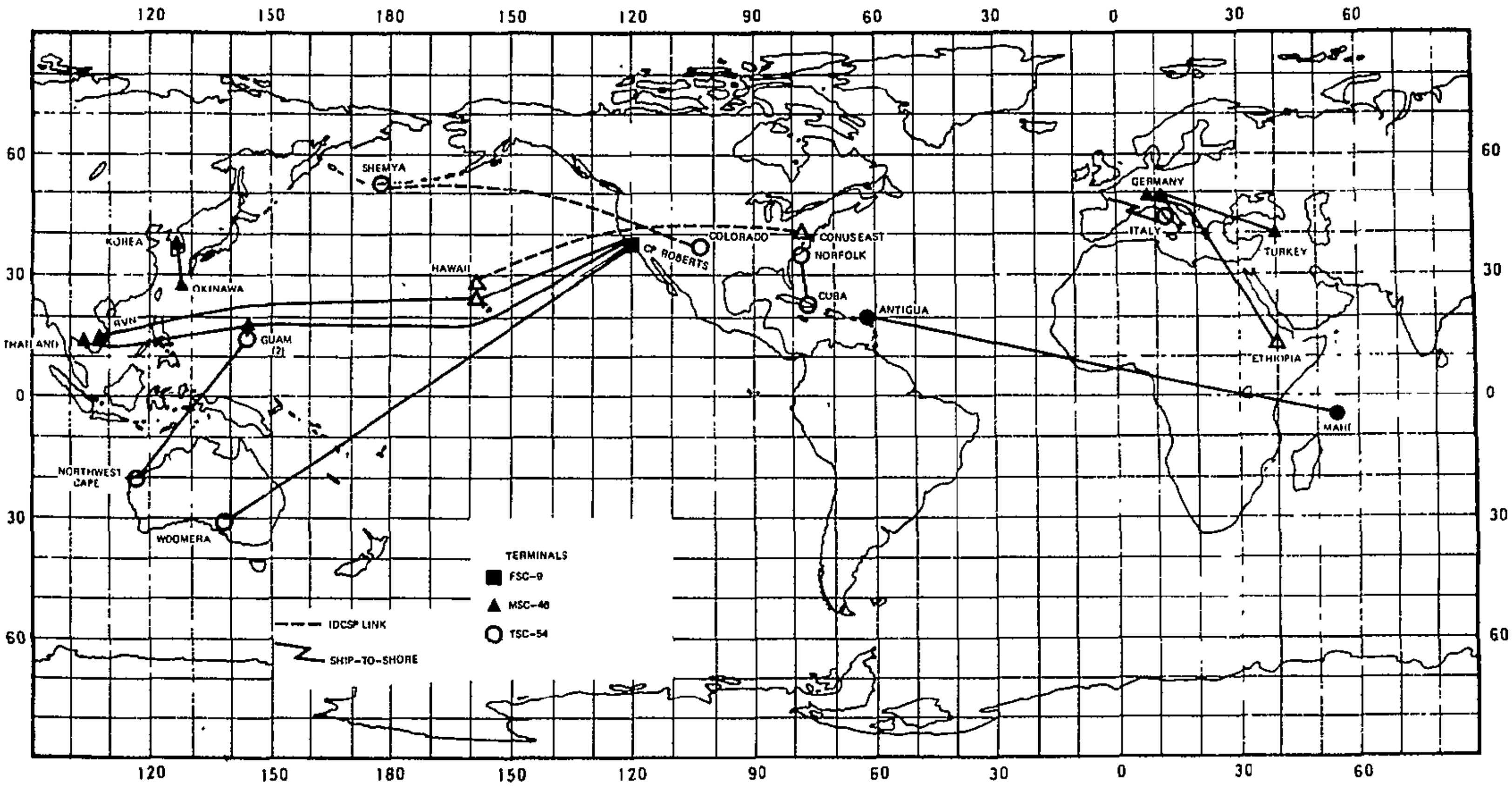

Figure 17-1. A Typical System Configuration for Stage 1a

Stage 1b will use multiple receive and transmit carriers at selected locations (nodes) to support links in a multipoint network operating via a single satellite. Traffic will range from 12 to 24 voice channels on the AN/MSC-46 pairs to three voice channels between the AN/MSC-46 and AN/TSC-54 terminals. A few links will be used to provide wideband digital traffic between selected areas in support of wideband data and digitized voice requirements as in Stage 1a. A typical DSCS Phase II Stage 1b link configuration is given in Figure 17-2. The four satellite configuration is a typical link plan pending the next scheduled dual launch during the first half of 1975. A two satellite configuration is currently in operation.

AN/TSC-54 terminals will be available for contingency operation as described for Stage 1a. In Stage 1b all of the AN/TSC-54 terminals will have been modified for contingency operation through the satellite NB. They will be provided with PN equipment to achieve an antijam capability. Note that operation with the satellite's narrow coverage antennas, in itself, provides jammer rejection when the beam can be placed so as not to include the jammer.

Stage 1c will begin when new development in digital equipment (PCM, TDM, PSK and later, coding equipment) is introduced into the system and the analog system is converted to a digital system. FDMA will still be used to the satellite. The introduction of digital operation will result in increased system capacity through a more efficient combination of different types of traffic (voice, TTY, secure voice, data, and wideband data) than is possible in an analog system, and through the use of coding, which allows more efficient use of satellite power. As the time division multiplex (TDM) and pulse code modulation (PCM) equipment becomes available, the system will phase from an analog system to a hybrid, and finally into a digital system. Protected traffic will continue to be provided using pseudonoise equipment. However, the CDMA modems employed will be of an advanced model specifically designed to meet the Phase II system requirements. A full complement of the modified Phase I and the newly procured terminals is expected to be available for use during this stage.

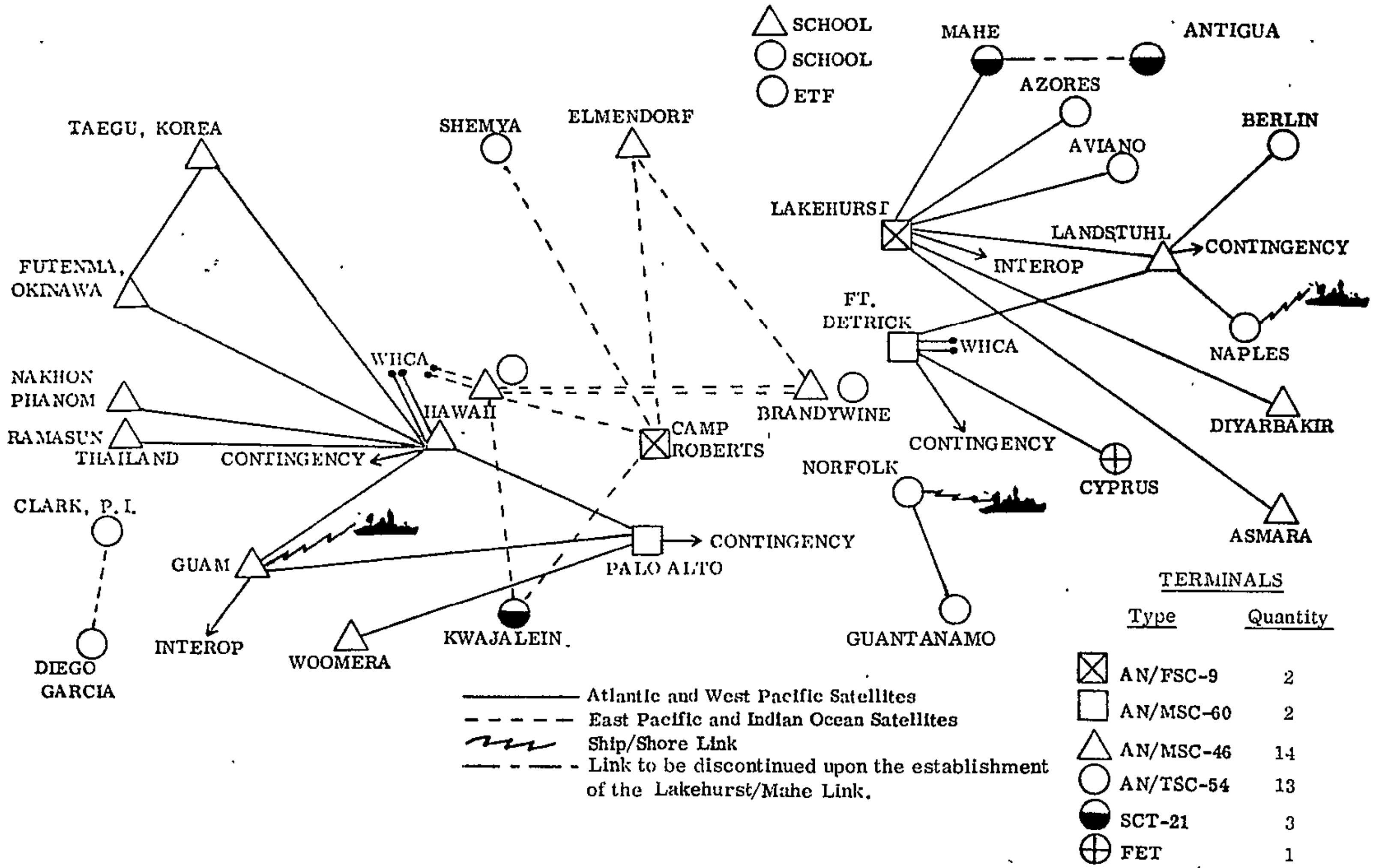

Figure 17-2. Typical DSCS Phase II, Stage 1b, Link Configuration

The introduction of the digital equipment into the DSCS during Stage 1c will be a beneficial experience which will be very useful when TDMA equipment appears. The arrival of TDMA equipment into the DSCS will signal the beginning of Stage 2 Phase II DSCS. With the TDMA complementing the other digital equipment, more effective use of the Phase II satellites and significantly greater system capability are expected to be achieved. All links will be established on a time base (rather than frequency) allowing each terminal to function as a multiple link or nodal terminal. A full complement of modified Phase I and newly procured terminals will be available for use during this stage.

Protected traffic will continue to be provided using PN equipment. However, the modems employed will be an advanced model designed to meet the Stage 2 system requirements.

Table 17-2 presents a summary of the terminals which will participate in the Phase II DSCS.(3)

17.3 SPACECRAFT

The Phase II DSCS satellite is portrayed in Figure 17-3 and the spacecraft characteristics are displayed in Table 17-3. A block diagram of the communications transponder is found in Figure 17-4.

The Phase II satellite transponder consists of a multichannel repeater with the channels cross-linked, a receive and a transmit EC antenna, and two steerable NB antennas, each capable of receiving and transmitting simultaneously.

This arrangement will provide four different modes of operation:

1. Earth coverage to earth coverage (EC-EC)
2. Earth coverage to narrow beam (EC-NB)
3. Narrow beam to earth coverage (NB-EC)
4. Narrow beam to narrow beam (NB-NB)

The basic interconnection for these four modes is shown in Figure 17-4.

Table 17-2. Characteristics of Existing and Planned Earth Terminals

Terminal Type	Antenna Size (m) (ft)	G/T (dB)	EIRP (dBm)	Power Amplifier Output (kW)	Instantaneous Bandwidth (MHz)		If Interface Frequency Bandwidth	
					P. A.	LNA	TX	ICX
AN/MSC-60 (HT)	18 (60)	39	124 127 (AJ)	TWT (5 kW) TWTs (10 kW) (AJ)	500	500	70/40	70/40
AN/MSC-61 (MT)	12 (40)	34	120 123 (AJ)	TWT (5 kW) TWTs (10 kW) (AJ)	500	500	70/40	70/40
AN/FSC-9	18 (60)	37	128	KLY (12.5 kW)	125	500	70/40	70/40
AN/MSC-46	12 (40)	34	117 123 (AJ)	TWT (3 kW) KLY (12.5 kW) (AJ)	500 125	500	70/40	70/40
SC-2 (DTS)	11 (35)	31	118	KLY (2 kW)	50	50	70/40	70/40
NSA	10 (33)	31	117	KLY (3 kW)	50	500	70/40	70/40
AN/TSC-54	5.5 (18) (EQ.)	26.5	117	KLY (5 kW)	50	500	70/40	70/40
AN/TSC-86	2 (8)	18	103	KLY (1 kW)	50	500	70/40	70/40
AN/TSC-86	6.1 (20) (Nom.)	27	111	KLY (1 kW)	50	500	70/40	70/40
AN/TSC-85 (V)	2 (8)	17	100	KLY (0.5 kW)	50	500	70/10	70/10
AN/MSC-59	2 (8)	17	93.5	TWT (0.1 kW)	500	500	70/10	70/10
AN/SSC-6	2 (6)	15	110	KLY (12.5 kW)	125	500	70/40	70/40
AN/WSC-2	2 (8)	18	101 107 (AJ)	KLY (3 kW)	500 50 (AJ)	500	70/40	70/40
AN/ASC-18	0.838 (2.75)	7	104	KLY (12.5 kW)	125	500	70/40	70/40
SC-1A (DTS)	2 (8)	26	104	KLY (0.5 kW)	20	50	70/20	70/20
S-1A (DTS)	2 (6)	17.5	94	KLY (0.5 kW)	20	50	70/20	70/20
Special DSCS Transportable	1.9 (6.3)	16	99	KLY (0.5 kW)	50	50	70/40	70/40

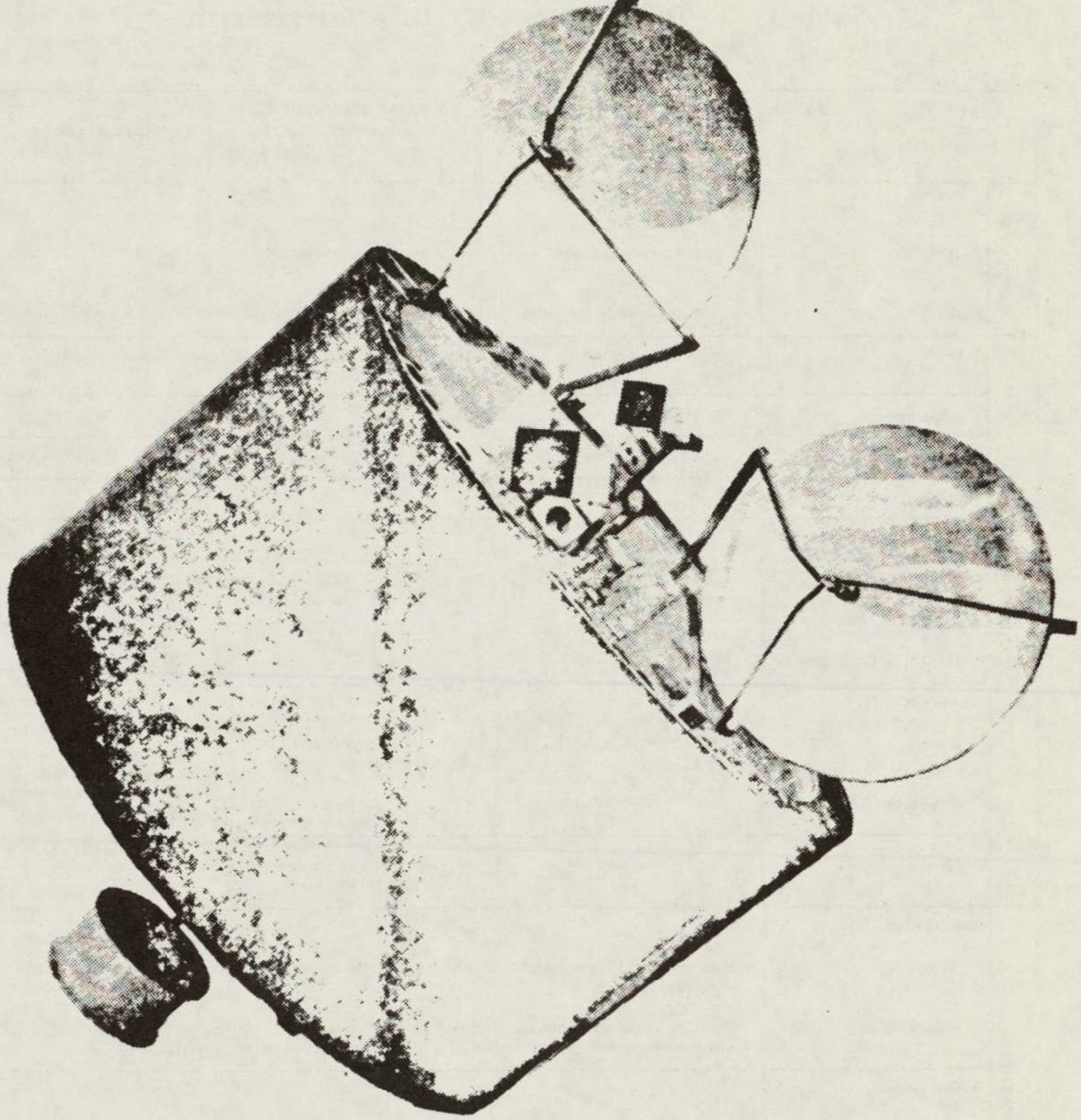

Figure 17-3. DSCS Phase II Satellite

Table 17-3. DSCS Phase II Satellite Characteristics*

	TYPE	X BAND MECHANICALLY DESPUN HORN	X BAND MECHANICALLY DESPUN PARABOLOID REFLECTOR	S BAND BICONICAL HORN FOR TT&C	
ANTENNAS	Number	1	1	1	
	Beamwidth	Earth Coverage Beam - 18^{o}	Narrow Beam - nominal 2.5^{o}	Toroidal 32" wide	
	Gain	Xmit. - 16.8 dB (Edge)	Xmit. - 33 dB (Edge)	3 dB (Peak)	
REPEATERS	Type	Single conversion with each of 4 channels operating in a linear, quasi-linear, or hard-limiting mode			
	Configuration	EC-EC*	EC-NB *	NB-NB*	NB-EC*
	Bandwidth (1 dB)	125 MHz	50 MHz	185 MHz	50 MHz
	Number	One	One	One	One
	Receiver				
	Type Front End	Tunnel Diode common to EC-EC & EC-NB channels		Tunnel Diode common to NB-NB & NB-EC channels	
	Front End Gain	No Data		No Data	
	System Noise Figure	8.3 dB		12.8 dB	
	Transmitter				
	Type	TWT common to EC-EC & NB-EC channels	TWT common to EC-NB & NB-NB channels	This channel shares a transmitter with EC-EC channel	
	Power Out	20 Watts	20 Watts		
	EIRP	28 dBW	40 dBW (Each of 2 antennas) 43.1 dBW (1 antenna)**		
GENERAL FEATURES	Stabilization				
	Type	Spin stabilized - nominal 60 RPM with hydrazine thrusters for stationkeeping and attitude corrections			
	Capability	Pointing accuracy of despun platform $\pm 0.14^{o}$. That of NB antenna $\pm 0.2^{o}$. East-West stationkeeping to within $\pm 3^{o}$ of designated subsatellite point for 5 years.			
	Power Source				
	Primary	Right cylindrical array of solar cells, capable of providing 520 watts at launch and 357 watts after 5 years.			
	Supplement	Three nickel-cadmium batteries			
	Communication Power Needs	235 watts			
	Size	3-meter diameter (9-foot diameter) 4.0-meter height (13-foot height)			
	Weight	508.0 kg (1120 lb)			

*Denotes uplink and downlink antennas that channel interconnects.

**With 2 NB antennas employed. TWT output power is split. With 1 antenna, full power goes to that antenna.

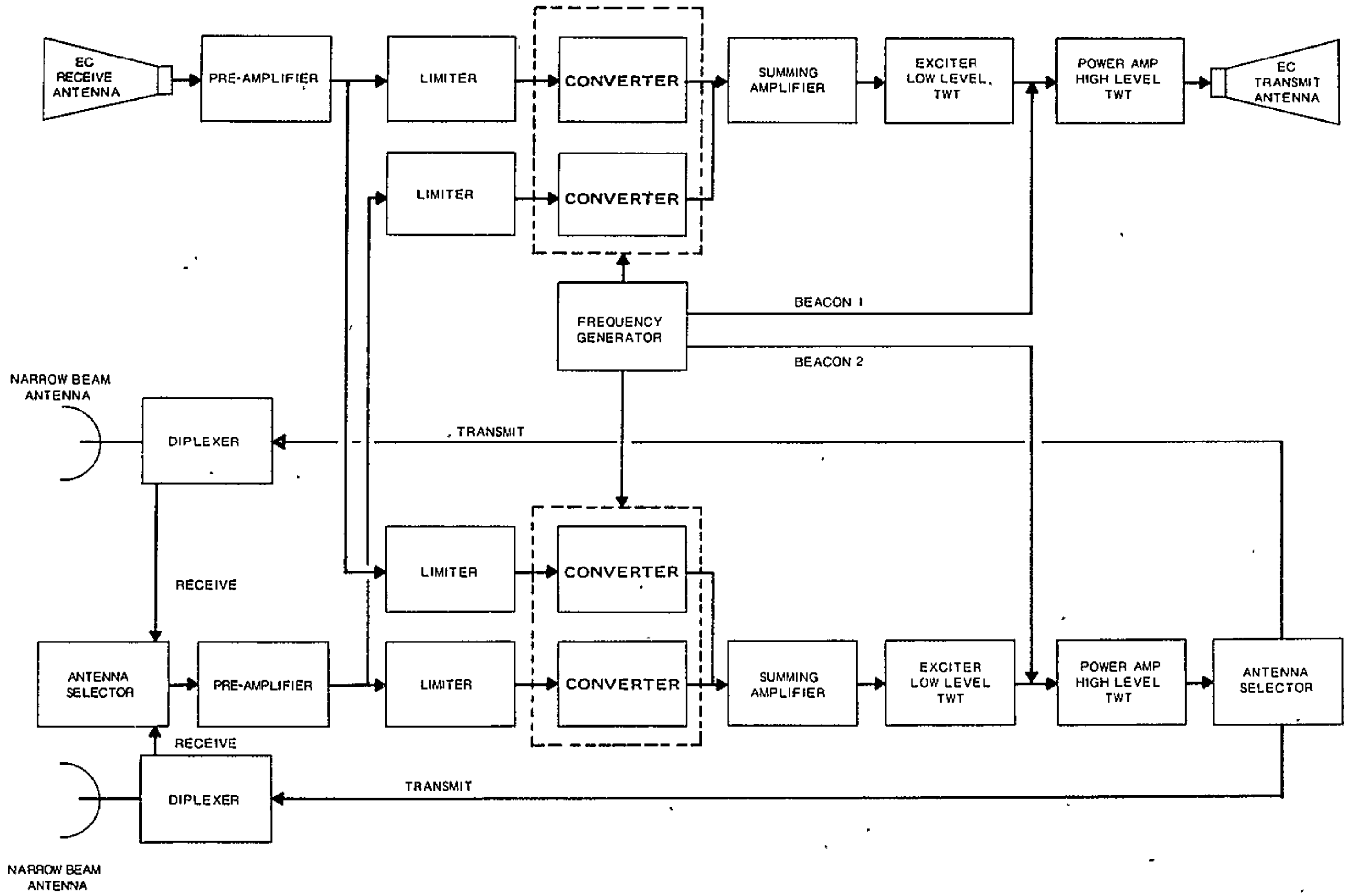

Figure 17-4. DSCS Phase II Transponder Block Diagram

The uplink frequency transmitted by a Phase II earth terminal determines which of the four modes will be used. (This assumes that an earth terminal planning to use either the NB-NB or NB-EC channels is within the geographical area covered by one of the NB antenna patterns.) The received signal is amplified and retransmitted in the 7250- to 7750-MHz band. A simplified frequency diagram presented in Paragraph 17.2.1 relates the various channel nodes, together with their related frequency translations and satellite antennas. Both the EC-EC and NB-EC channels share the output power of a 20-watt TWT amplifier, using the EC antenna. Likewise, the NB-NB and EC-NB channels are combined and transmitted via a second 20-watt TWT, using either one or both of the narrow coverage antennas. The bandwidth of each channel is presented in Paragraph 17.2.1 and represents 410 MHz of usable bandwidth. The satellite EIRP is 28 dBW for the EC mode and 43 dBW for an NB antenna (or 40 dBW each if two are used). This allows a marked increase in capacity and flexibility compared with the 7 dBW of the Phase I satellite. The Phase II synchronous satellites will be maintained with $\pm 3^{\circ}$ of their designated orbital positions; however, they can be repositioned at least once during their operational life to any other equatorial point at a rate of 15° per day. Table 17-3 provides a summary of the major characteristics of the Phase II satellite.

All active components within the transponder are redundant. The selection of the active components and NB antenna switching and steering is done by ground command. To achieve maximum in-orbit usage of the Phase II satellite, all onboard systems have been sized to provide a minimum 5-year operational lifetime.

All transmitting antennas are left-hand and circularly polarized, whereas the receiving antennas are right-hand and circularly polarized. The two NB antennas are capable of being independently steered $\pm 10^{\circ}$ from each of two orthogonal directions, and the half-power beamwidth covers an area approximately 750 miles in diameter near the subsatellite point. The EC antennas (transmit and receive horns) provide coverage to approximately one-third of the earth's surface. Electrical power is supplied to the satellite from solar arrays. In addition, batteries are provided for eclipse operation.

17.4 GROUND TERMINALS

The two major groups of earth terminals to be employed in the Phase II DSCS include modified Phase I terminals and new terminals to be procured as a follow-on to the current developmental effort. The major characteristics of the Phase I earth terminals are found in corresponding Paragraph 12.4. Modifications and additions being made to these terminals and the major characteristics of the new terminals are subsequently discussed. Table 17-4 summarizes the modifications and additions by stages and Table 17-5 portrays the major characteristics of the forthcoming new terminals.

17.4.1 AN/FSC-9 Terminals

The two AN/FSC-9 terminals were rehabilitated and upgraded during 1970 and 1971 by STRATCOM under contract to the Philco-Ford Corporation. These modifications ensure compatibility with Phase II Stage 1a. Frequency compatibility was achieved by procuring new crystals. Frequency synthesizers will be used for the subsequent stages and for providing the proper frequency increments to change transmit and receive frequencies in 1-kHz steps over the entire satellite transmit and receive bands. Other modifications will provide a multiple transmit and receive carrier capability. This modification will allow the AN/FSC-9 to handle the following number of signals pending the particular nodal carrier requirements at each location:

1. Transmit

   FM/FDMA - Up to three uplink RF carriers

   SSMA - Up to seven SS carriers using a common RF frequency

2. Receive

   FM/FDMA - Up to seven downlink RF carriers

   SSMA - Up to seven SS carriers using a common RF frequency

   Beacon - One signal on its own RF carrier frequency

Table 17-4. Summary of Modifications and New Equipment for DSCS Phase II (1 of 2)

Modifications	Stage 1a	Stage 1b	Stage 1c	Comments
Earth Terminal			None Required	
Frequency	X			Phase I terminals - new crystals to allow operation with the Stage 1a frequency plan
		X		All terminals - new frequency synthesizers to allow operation with the Stage 1b frequency plan
Paramps	X			Four* AN/MSC-46 terminals - interim uncooled 500 MHz paramps
	X			AN/TSC-54 terminals - uncooled 500 MHz paramps
		X		AN/MSC-46 terminals - cooled 500 MHz paramps
Multiple Carriers	X			AN/TSC-54 terminals - provide two independently tunable carriers
		X		AN/MSC-46 and 2 AN/FSC-9 terminals - FDMA - up to three transmit and seven receive carriers, SSMA - up to seven transmit and receive signals on a single RF carrier
Control	X			All Phase I terminals - provide own power output monitoring capability, all AN/MSC-46 terminals to provide satellite beacon tracking capability, four AN/MSC-46 terminals to demodulate beacon provide readout of satellite data (telemetry) for satellite control, two AN/MSC-46 terminals and SEN to have spectrum analyzers for measuring relative satellite carrier powers and frequencies
Modulation AN/URC-55 and 61		X		Standardization to ensure compatibility

*Ft. Monmouth ETM, Ft. Monmouth Training, Germany (Landstuhl), and Hawaii (Helemano).

Table 17-4. Summary of Modifications and New Equipment for DSCS Phase II (2 of 2)

Modifications	Stage			Comments
	1a	1b	1c	
Interconnection				
TCF	X	X	X	Modifications will be made on an as-required site-by-site basis
ICF	X	X	X	A determination has been made for the operational capability of the ICFs on a site-by-site basis. Appropriate modifications will be made where required and are being initiated during Stage 1a.
Communication Subsystem				
Analog				
Modem		X		All nodal and AN/TSC-54 terminals - FM modems capable of operating with three to 72 voice channels.
Multiplex		X		All terminals - new FDM equipment to provide a wider range of capabilities.
Digital				
Modems		X		Terminals providing imagery - PSK modems will replace MFSK modems
			X	All DCS terminals - new developmental PSK modems to provide a wide variety of data rates.
			X	All terminals - new developmental AN/USC-28 spread spectrum equipment
Multiplex			X	All DCS terminals - new developmental flexible TDM equipment and PCM equipment to convert 4-kHz analog voice to 64-kbps digital voice
New Terminals			X	New developmental AN/MSC-60 and AN/MSC-61 terminals
Coding			X	New developmental convolutional encoding/maximum likelihood decoding equipment

Table 17-5. Summary of Earth Terminal Characteristics (Expected) (1 of 2)

	Terminal Features	Terminals		
		AN/MSC-60 (HT)	AN/MSC-60 (MT)	AN/TSC-86 (LT)
Antenna	Type	Cassegrain	Cassegrain	
	Aperture Diameter	18 m (60 ft)	11 m (35 ft)	2 m (8 ft)
Receive System	Type Preamplifier	Cooled Paramp	Cooled Paramp	Uncooled Paramp
	Bandwidth (MHz)	500	500	500
	Frequency Range (MHz)	7250-7750	7250-7750	7250-7750
Transmit System	Power Amplifier	2 TWT (Parallel)	2 TWT (LPA) (Parallel)	Klystron
	Bandwidth (MHz)	500	500	40 (1 dB point)
	Amp Power Out	8 kW	5 kW each	10 kW
	Frequency Range (MHz)	7900-8400	7900-8400	7900-8400
Tracking	Type	Beacon Autotrack	Beacon Autotrack	Beacon Autotrack
Total Performance	G/T (dB/^{o}K)	39	34	18
	ERP (dBm)	127	121	102
Polarization	Polarization	Circular	Circular	Circular
Power	Voltage	120V/208 3ϕ	120V/208 3ϕ	120V/208 3ϕ
	Frequency	50 to 60 Hz	50 to 60 Hz	50 to 60 Hz
	Watts (Max)	400 kW	300 kW	10 kW
Installation	Radome	None	None	None
	Facility	Fixed Plant	Fixed Plant	Transportable
Miscellaneous	Weight (approximate)	181,437 kg (400,000 lbs)	45,359 kg (100,000 lbs)	2268 kg (5000 lbs)

Table 17-5. Summary of Earth Terminal Characteristics (Expected) (2 of 2)

	Terminal Features	Terminals		
		AN/FSC-9	AN/MSC-46	AN/TSC-54
Antenna	Type	Cassegrain	Cassegrain	4 Cassegrain Dish Array
	Aperture Size	18 m (60 ft Diameter	12 m (40 ft) Diameter	5.5 m (18 ft) Diameter Effective
	Receive Gain	58.5 dB*	57.5*	50.5*
	Efficiency	30%	55%	55%
	Receive Beamwidth	0.16^{o}	0.24^{o}	0.52^{o}
Receive System	Type Preamplifier	Cooled Parametric Amplifier	Cooled Parametric Amplifier	Uncooled Parametric Amplifier
	Bandwidth	50 MHz (3-dB points)	40 MHz (1-dB points)	40 MHz (1-dB points)
	Noise Temperature	200^{o}K (spec.) @ 7.5^{o} El	204^{o}K @ 7.5^{o} El	283^{o}K @ 7.5^{o} El
Transmit System	Type Amplifier	Klystron	Klystron	Klystron
	Bandwidth	50 MHz (3-dB points)	40 Hz (1-dB points)	10 MHz (1-dB points)
	Amp. Power Out	10 W to 20 kW	100 W to 10 kW	5 kW max.
Tracking	Type	Autotrack	Autotrack	Autotrack
	Accuracy	No Data	No Data	No Data
Total Performance	G/T	34.7 dB/^{o}K	34.0 dB @ 20^{o} El	25.3 dB/^{o}K
	EIRP (dBm)	131.2 dBW	128 dBW	117.9 dBW
Polarization	Transmit Feed	RHCP	RHCP	RHCP
	Receive Feed	LHCL	LHCP	LHCP
Installation	Radome	None	Yes	None
	Type Facility	Fixed Terminal	Transportable	Transportable

*Derived value based on data available.

17.4.2 AN/MSC-40 Terminals

For the Stage 1a operation, the AN/MSC-46 terminals will have received sufficient crystals to achieve Phase II frequency compatibility. This group of earth terminals is provided with transmit carrier power monitoring equipment to control its own transmit signal power. Modifications to the AN/MSC-46 tracking receivers will permit tracking the biphase modulated beacon signal from the satellite. Four of these earth terminals will also receive the capability to demodulate and provide alphanumeric readout of the beacon data (telemetry). Two of these AN/MSC-46 earth terminals will receive spectrum analyzers to monitor the satellite downlink frequencies.

In Stage 1b seven of the AN/MSC-46 will receive additional up and down converters to provide a multiple carrier capability as nodal terminals. Both the up and down converters will interface at 70 MHz. The multiple carrier modification will permit these terminals to handle signals indicated in Paragraph 17.4.1. The remaining Phase I terminals not slated for nodal service and which were not modified in Stage 1a will be modified to provide a paramp instantaneous bandwidth of 500 MHz spectrum analyzers and CNR meters.

17.4.3 AN/TSC-54

Crystals will also be provided to all the AN/TSC-54 terminals to achieve frequency compatibility with Phase II. During Stage 1b, synthesizers will be added. Stage 1a modification will further include equipping these terminals with new uncooled paramps capable of receiving within a 500-MHz bandwidth. The AN/TSC-54 terminal modifications are designed to fulfill two Stage 1 missions. The terminals will be equipped to handle up to 12 voice channels for DSCS trunking, using the EC satellite repeater channel. Additionally, the terminals will be used as contingency terminals employing the satellite NB channel. The contingency terminals will include 12 channels of self-contained multiplex equipment but will be able to handle a baseband consisting of up to 72 channels.

17.4.4 New Terminals

17.4.4.1 AN/MSC-60, Heavy Transportable (HT)

Table 17-5 presents major characteristics of the AN/MSC-60. The prototype model AN/MSC-60 earth terminal shown in Figure 17-5 is a transportable terminal designed as a semifixed installation, which requires a prepared site and about 45 days to install. Figure 17-6 is a block diagram of an HT/MT prototype terminal. The model has been developed by the Philco-Ford Corporation under a contract to the Army SATCOM Agency. The prototype terminal has completed acceptance testing and is currently operational. The production specification for HT will provide for:

- A fixed plant terminal installation that would eliminate the need for vans.
- Parallel operation of the two traveling wave tube (TWT) power amplifiers which would allow deletion of the high power klystron amplifier (HPA).
- Relaxation of the frequency conversion subsystem specifications to approximately those requirements applying to the AN/MSC-46 multiple carrier modification equipment.

The antenna reflector system consists of a solid-surface, 18-meter (60-foot) diameter, high-efficiency main reflector and a subreflector. The HT terminal G/T and EIRP capabilities are 39 dB/^{o}K and 127 dBm, respectively, and the terminal has a multiple transmit and receive carrier capability.

The AN/MSC-60 terminal interfaces with a communications subsystem at IF frequencies of 70 or 700 MHz for both transmit and receive carriers. Tuning of transmit and receive carriers in increments of 1 kHz over the full 500-MHz uplink and downlink satellite frequency bands is provided. An automatic carrier balance capability provides automatic leveling of each transmitted carrier with an accuracy of ±0.2 dB. The AN/MSC-60 terminal has been designed with extensive and sophisticated automatic fault location, monitors and alarms. An interface has been provided for remoting the analog and digital signals relating to the many parameters that are monitored.

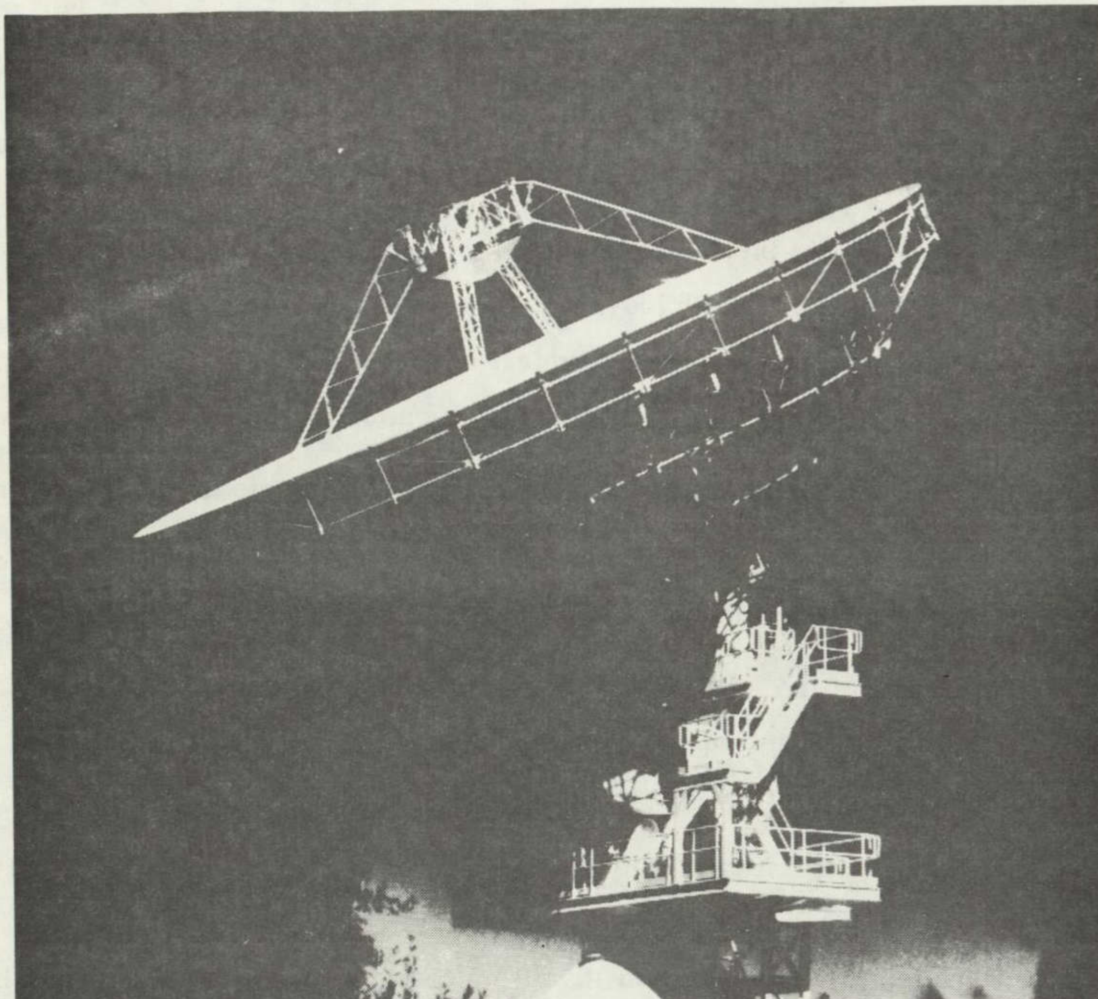

Figure 17-5. AN/MSC-60 (HT)

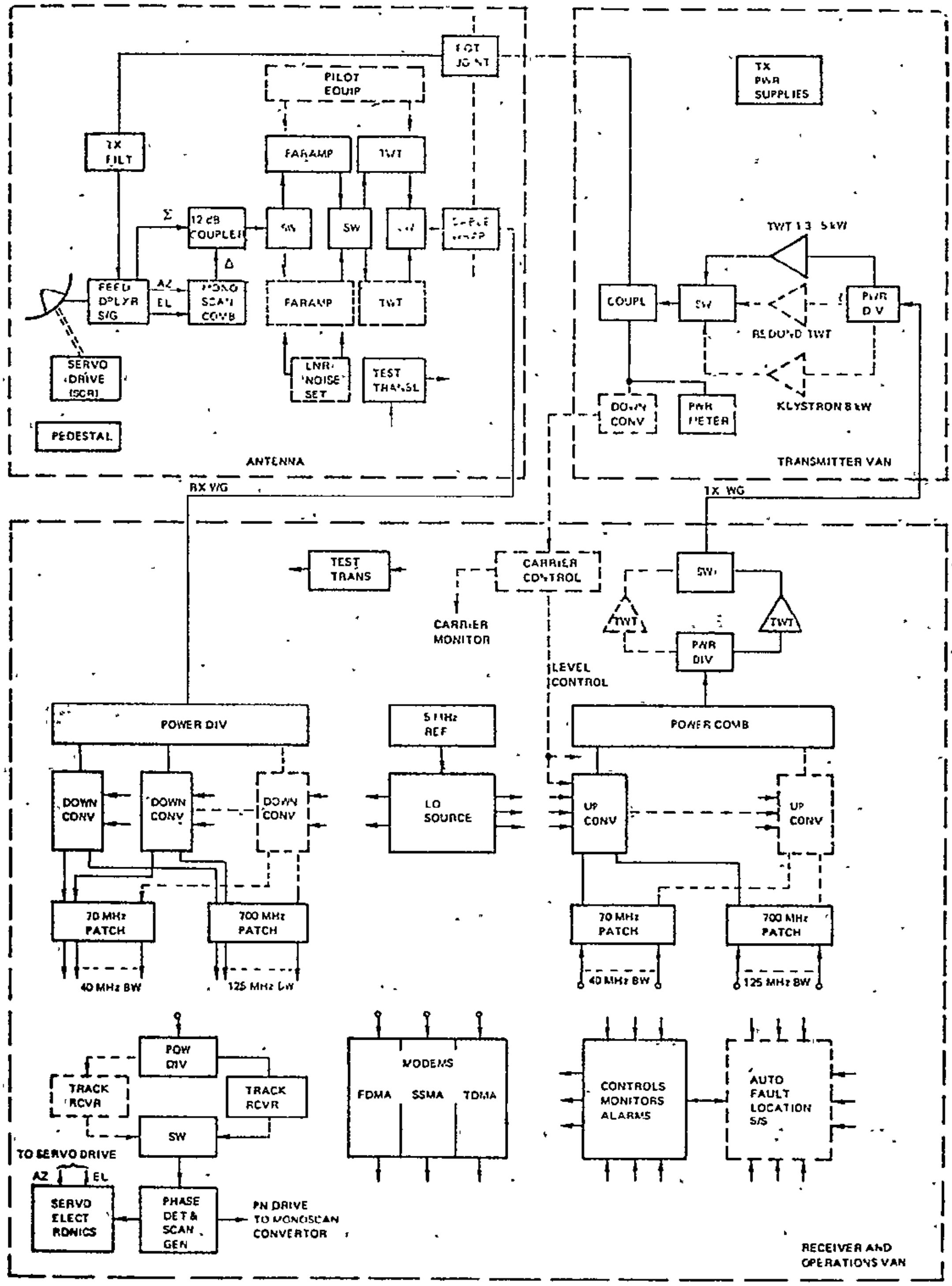

Figure 17-6. Block Diagram of an HT/MT Prototype Terminal

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The AN/MSC-60 can be equipped with up to nine transmit and 12 receive frequency converters. However, the initial models procured will be equipped with five transmit and nine receive converters. These terminals are designed to be deployed to nodal locations, replacing selected AN/MSC-46 terminals. The higher inherent availability of these terminals, together with their performance capability, will increase the overall performance of Phase II.

17.4.4.2 AN/MSC-60, Medium Transportable (MT)

The AN/MSC-60 (MT) was to be the medium-weight counterpart of the AN/MSC-60 heavy terminal. Both terminals are basically similar in electronic design and have the same interfaces, redundancy and availability. Hence, Figure 17-6 is also the block diagram for the MT as well as the HT. A primary difference is that the AN/MSC-60 (MT) prototype terminal was equipped with a 5.5-meter (18-foot), aluminium, cloverleaf antenna that is used with the AN/TSC-54. This increased the transportability of the terminal but decreased the G/T from 39 to 27 dB/^{o}K. It is anticipated that in production of the MT, the 5.5-meter (18-foot) cloverleaf antenna will be replaced by an 11-meter (35-foot) parabolic dish antenna. As shown in Table 17-5 the characteristics of the MT are based on an 11-meter (35-foot) antenna. The prototype specification change discussed for the AN/MSC-60 terminal procurement in Paragraph 17.4.4.1 also applies to AN/MSC-60 (MT) terminal procurement.

17.4.4.3 AN/TSC-86 Light Transportable (LT)

This earth terminal has not yet been completely defined; however, the terminal is to be capable of rapid deployment. Table 17-5 presents typical parameters for the LT terminal, which will have one transmit and one receive converter. The terminal is intended for special user service and contingency, but, for the most part, is intended for FDMA operation while the DSCS uses FDMA. When TDMA is introduced into the DSCS, either a channelized satellite repeater will have to be used or a special low-cost TDMA modem will have to be developed for the small user.

17.4.5 Other New Equipment

The Phase I AN/TSC-54 terminals were equipped with only one voice channel. Equipping two of these terminals with additional FM modems and an FDM multiplex to provide a limited capability during Stage 1a began prior to the first satellite launch. These modified terminals will be self-contained in that they will be provided with FM modems, FDM multiplex, and ancillary equipment to handle up to 12 voice channels. Operation of contingency terminals during Stage 1a will be via the satellite's NB-to-NB satellite communications channel.

Protected traffic (i.e., antijam) will be provided during this stage on a terminal-to-terminal basis using existing AN/URC-55 and AN/URC-61 PN equipment. This equipment will operate using PN/PSK/CDMA. These links will be dedicated between selected users. The protected traffic on these lines will be commensurate with the capabilities of the present AN/URC-55 and AN/URC-61 equipment.

New FM modems will be provided for all Stage 1b nodal terminals and all AN/TSC-54 terminals. These modems will be capable of providing 3, 6, or 9 4-kHz analog circuits at a lower quality (e.g., TTNR = 33 dB) or 3, 6, 9, 12, 24, 36, 48, 60, or 72 DSC quality (e.g., TTNR = 44 dB) 4-kHz analog circuits. Up to three modulators and up to seven demodulators will be installed at nodal terminals to provide service for the number of transmit and receive carriers required. A single modem will be installed in non-nodal terminals.

New PSK modulation equipment will be used in Stage 1b to support the wideband digital and imagery traffic requirements in a PSK/FDMA mode of operation. This new PSK modulation equipment will allow a more efficient use of the satellite's RF bandwidth than do the present MFSK modems. These modems will be capable of operating at a number of data rates from 19.2 kbps to 1.8 Mbps.

Stage 1b protected traffic will be provided on a terminal-to-terminal basis using existing AN/URC-55 and AN/URC-61 PN equipment. As in Stage 1a, dedicated links will be provided between selected users and will pass low data rate hardcore traffic only. It will be necessary to locate multiple PN equipment at a node if more than one protected link is to be established between the node and other terminals. The capacity on these links will be commensurate with the capabilities of the present AN/URC-55 and AN/URC-61 equipment and the satellite power split with the analog traffic.

Stage 1c begins with the introduction of the PCM, TDM, and PSK modulation equipment on the first Phase II satellite communication link. No further modifications to the Phase I terminals beyond those made in Stages 1a and 1b are considered necessary to accommodate this new future equipment. Since this new digital equipment will be phased into the Phase II DSCS over an extended period of time, the initial period of Stage 1c will be a hybrid operation; i.e., a mixture of analog and digital operation on separate RF carriers. The extent of this period will depend on the availability of the equipment and the necessary procurement of funds.

To improve the efficiency of the digital transmissions in Stage 1c, error correction coding equipment will be procured. This coding equipment will allow the transmission of digital data using smaller amounts of satellite power with increased bandwidth, thus allowing larger amounts of digital communications to be processed through the Phase II satellites.

Contingency operations will continue to be handled in Stage 1c as they were in Stage 1b by using the AN/TSC-54 terminals and operating via the satellite's NB-to-NB or cross-strap channels.

Unprotected traffic will be transmitted in Stage 1c using either analog FM or digital PSK transmissions, depending on the requirements and the availability of the digital equipment.

Protected traffic will be provided in the early period of Stage 1c at it was in Stage 1b by using the AN/URC-55 and AN/URC-61 PN equipment. However, later in Stage 1c, the new AN/USC-28 PM equipment should be available and will be deployed in all DCS/DSCS earth terminal locations. In addition to increased antijam protection, the AN/USC-28 will provide the operational capability to establish a protected network orderwire. This network orderwire will not only provide the capability of a real-time SATCOM control, but will provide a systemwide timing capability imperative to a future TDMA operation. As more digital equipment is procured and deployed in the DSCS, Stage 1c will evolve over a period of time into an all-digital communications system (Stage 2 with TDMA equipment) satisfying all DCS/DSCS traffic requirements using PCM and TDM/PSK.

17.5 EXPERIMENTS

The DSCS Phase II is an operational, not an experimental system. Although no experiments have been performed as such, an extensive evaluation program has been successfully conducted verifying the operational capabilities of the system under multi-link conditions.

17.6 OPERATIONAL RESULTS

"The first two DSCS spacecraft were launched in November 1971. Both spacecraft worked well for a limited period; however, one month after launch, a loss of power to the despun platform in the No. 2 spacecraft caused the despun platform to spin up and rotate at the same speed as the body of the spacecraft. Because of the imbalance of the despun platform, the spacecraft in this mode tipped 11 deg from its normal attitude. In this condition it was found that a complicated dynamics problem, not understood at the time of launch, resulted in an ultrastable minimum momentum vector configuration. The normal torque provided by the despun motor was insufficient to bring the spacecraft back to normal operation, i.e., to again despin the platform. Extensive analytical effort and many computer simulations uncovered the problem and finally enabled the re-erection of the spacecraft to an operational configuration. Following this successful operation, other deficiencies appeared in this spacecraft and it subsequently failed. The second spacecraft in this launch provided communications capability for a period of months, but it finally failed due to a power distribution problem. Four spacecraft remain from this procurement and a major redesign activity was started to ensure that these spacecraft would operate properly. This redesign included balancing of the despun platform and a major change in the power distribution. The redesign has been completed and the next two of the DSCS spacecraft were launched on 13 December 1973."[1]

The two satellites of the December 1973 launch underwent evaluation during January and February of 1974 and were placed into operation in March 1974.[2] A typical multilink configuration is shown in Figure 17-2. At least three satellites are needed to provide the global coverage dictated by military requirements. A third DSCS Phase II dual satellite launch is scheduled for the first half of 1975, which if successful would make such coverage possible.

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SECTION 18 - TELESAT, THE CANADIAN SATELLITE COMMUNICATIONS SYSTEM

18.1 PROGRAM DESCRIPTION

Telesat, a commercial venture dedicated to operate as a private corporation, was established by an Act of Parliament in the Telesat Canadian Act of 1969. Its charter called for the establishment of a commercial, domestic satellite system to provide telecommunications services throughout the nearly 10 million square kilometers (4 million square miles) of Canada extending across six time zones. Telesat is owned jointly by the Canadian government, Canadian telecommunications common carriers, and the public. The Telesat communications satellites were manufactured by Hughes Aircraft Company and initial earth terminals were manufactured by Canadian companies.

The importance of Telesat can be understood when it is realized that hundreds of small towns, hamlets and clusters of isolated communities in northern areas have very limited communications. Some areas have depended on high-frequency radio links for contact with government, business and neighbors in other northern areas and with the larger cities in southern parts of Canada. The Canadian microwave system provides interconnecting links but is concentrated primarily near the United States-Canadian border. Extending this system to the isolated areas would be very costly, and practically impossible in some parts of the northern regions. The extension of television and communications into the northern two-thirds of the country will pave the way for settlement and resources development. Telesat's major initial customers are the Canadian Broadcasting Corporation, the Trans-Canada Telephone System, and the Canadian National and Canadian Pacific railways, which operate extensive communications systems.

Telesat, unlike the U.S. Communications Satellite Corporation, is authorized to sell to any bulk customer the equivalent of one television channel or more.

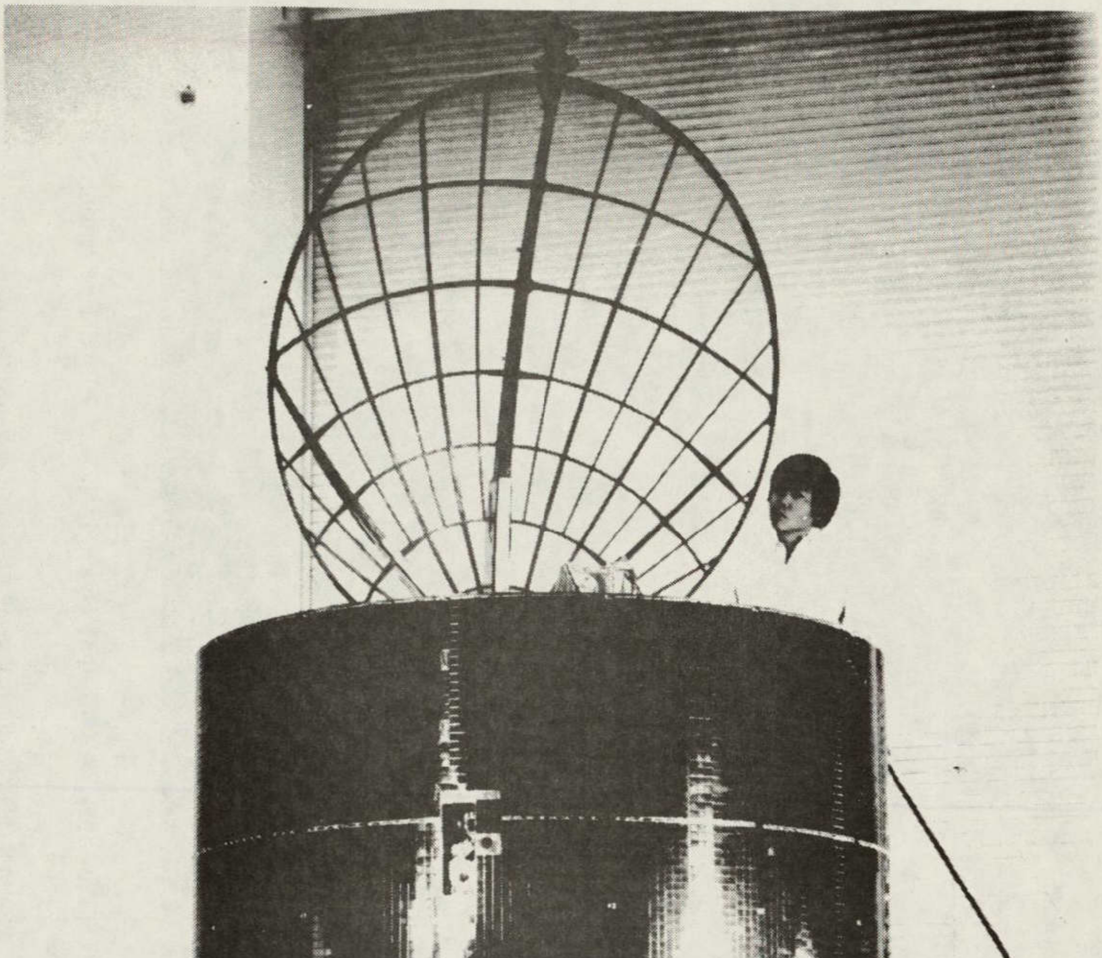
The first Telesat satellite was successfully launched from Cape Kennedy by a new Delta launch vehicle on November 9, 1972. This satellite was named ANIK which is the

Eskimo word for "brother." ANIK I (Figure 18-1) was placed into synchronous orbit 42,596 kilometers (23,000 nautical miles) above the equator and was positioned at 114° W longitude. It was first used for commercial service on January 11, 1973, providing coverage throughout Canada as illustrated in Figure 18-2. A second satellite, ANIK II, was launched on April 20, 1973, and was positioned at 109° W longitude. ANIK I and ANIK II have the same communications packages. Design features are summarized in Table 18-1. A third satellite has been procured and is intended to be used initially as an earth spare. However, if neither of the in-orbit satellites fails, the third satellite will be launched early in 1975 and will be positioned at 104° W longitude to accommodate plans for expansion of the system. The ANIK is capable of providing 12 television channels or various mixes of TV, data, and voice.

The initial communication services include three RF channels for TV distribution, two RF channels for telephone message traffic between Vancouver and Toronto, one RF channel for North-South communications using the FDM/FM/FDMA technique, and one RF channel for thin route application using the Δ-mode/PSK/FDMA technique. Early in 1974, the eighth transponder was assigned to a two-carrier FM/FDMA system which provides 240 circuits between Allan Park, Ont. ($G/T = 37$ dB/$^{\circ}$K) and Harrietsfield, N.S. ($G/T = 31$ dB/$^{\circ}$K). This message link carries a portion of the traffic from the CANTAT II Trans-Atlantic Cable System. Subsequently, this FDMA link will be replaced by a double-access TDMA system which will increase the capacity to 400 circuits.

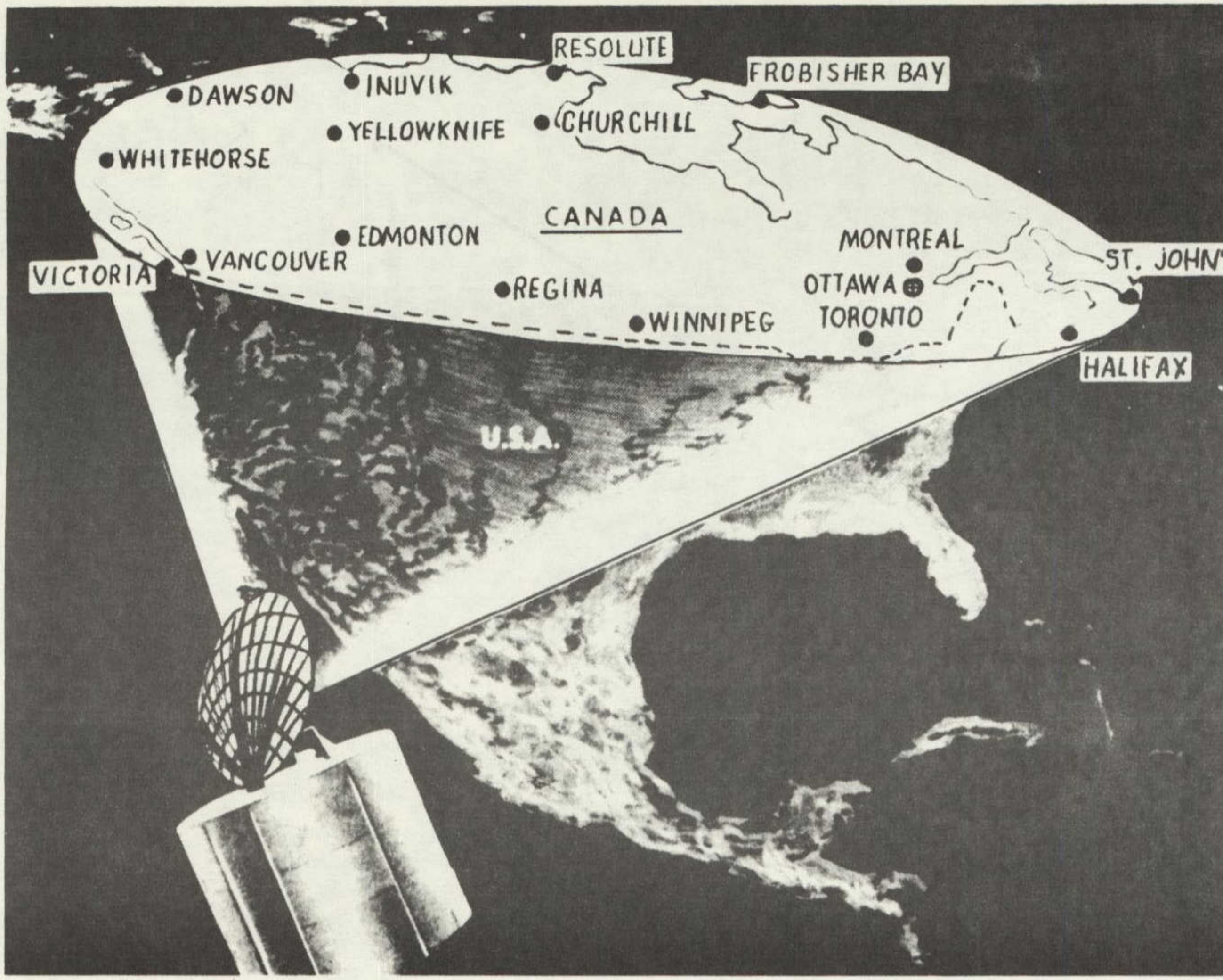
18.2 SYSTEM DESCRIPTION

The system, in its overall configuration, includes spin-stabilized satellites in geostationary orbit; tracking, telemetry and command facilities; a control center and numerous earth stations of several different types. As a multi-purpose telecommunications system providing television, radio, voice, data and facsimile transmission services, it was originally designed to meet the initial requirements of Telesat's customers and to be interlinked with existing terrestrial systems. However, as further requirements have been raised, changes have been made to some of the earth stations and many additional facilities are being implemented.



*"ANIK Launch Handbook," Hughes Aircraft Company, October 1972

Figure 18-1. ANIK, the Canadian Telesat Communications Satellite*



*"Canadian Domestic Satellite (Telesat), A General Description," Lloyd Harrison et al., Hughes Aircraft Company

Figure 18-2. The ANIK Elliptical Spot Beam Antenna Pattern*

Table 18-1. ANIK Design Features Summary

CONFIGURATION - Spinner with despun antenna and feeds. Total height 3.5 meters (11.4 feet); weight < 544 kilograms (< 1200 pounds).
ANTENNA - Shaped beam solar-transparent 152-centimeter (60-inch) parabolic antenna for transmit, receive, and track when on station. Omnidirectional antenna for side beam telemetry and toroidal for command.
ROTARY JOINTS - Circular waveguide transmit; concentric coax receive.
COMMUNICATIONS REPEATER - All microwave channelized transmitters, utilizing lightweight Invar waveguide filters; amplitude and phase equalization performed at ground station. Twelve high efficiency 5 watt traveling-wave tubes (TWT).
TELEMETRY AND COMMAND SUBSYSTEMS - 24 telemetry functions in PAM-FM, real-time sensor pulses; 64 command functions; ranging.
CONTROL SUBSYSTEM - Redundant hydrazine systems; 8-year stationary stationkeeping capability.
POWER SUBSYSTEM - Solar panel and batteries, 200 watts minimum, with full eclipse capability.

The Telesat satellites are active spin-stabilized multichannel repeater communications satellites for use in geostationary orbit. Each satellite has twelve high capacity microwave channels and each channel is capable of relaying one color television program or up to 960 multiplexed voice signals using a single carrier. Multi-carrier voice modulated signals can also be accommodated within a microwave channel with some reduction in total capacity. Each channel has a bandwidth of 36 MHz and provides not less than 33 dBW EIRP throughout Canada. The communications antenna beam pattern is shaped and aimed to provide optimum coverage of Canada and the coverage area as seen from the satellite at the 114° W longitude position is shown in Figure 18-3.

The spaceframe consists of a 76-centimeter (30-inch) diameter thin wall cylinder coaxial with the satellite, and a 185-centimeter (73-inch) diameter honeycomb sandwich platform. The cylinder surrounds the apogee motor and supports the spin platform, on which is mounted the communications repeater, telemetry and command electronics, and the batteries. The platform supports the cylindrical solar panel at its periphery and the despin motor by a pedestal-type support at its center. The solar panel substrate is a honeycomb sandwich with fiberglass laminates, on the interior of which are mounted three dynamic balance mechanisms 120° apart.

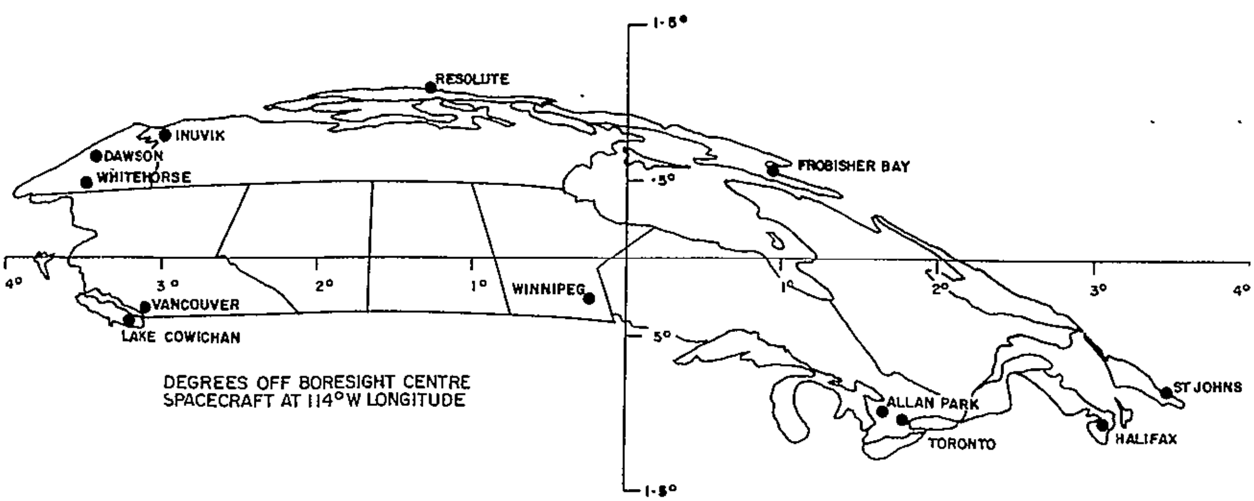


Figure 18-3. Projection of Canada From Geostationary Altitude

The initial Telesat ground station complex is comprised of approximately 49 Canadian-built stations in five classes whose functions are shown in Table 18-2. This is the baseline system on which the corporation will build and expand as customer requirements and new user contracts for services increase. Table 18-3 includes the names of cities, towns, and settlements near which the terminals are located. A map of the earth terminals is shown in Figure 18-4. Performance characteristics of the Telesat space and earth subsystems are summarized in Table 18-4.

The communications system provides for uplink transmission in the 5.925- to 6.425-GHz band and downlink operation in the 3.7- to 4.2-GHz band. TT&C functions required for satellite stationkeeping and positioning are accommodated in the same frequency spectrum.

The major contribution of this system to satellite communications technology is that it is the first operational domestic satellite system and, as such, is the forerunner of future domestic systems. Additionally, it will develop and demonstrate earth terminals suitable for unattended operation under severe climatic conditions, including those existing in Arctic regions.

18.3 SPACECRAFT

The most significant innovation of the ANIK satellite is the antenna which produces an elliptical spot beam pattern to cover Canada from its synchronous equatorial orbit (Figure 18-5). The satellite's 152-centimeter (60-inch) antenna is covered with a fine gold mesh, making it optically transparent and, in effect, reducing what otherwise would be a significant disturbance of the satellite by solar pressure. The feed assembly consists of a three-horn aperture which accommodates both receive and transmit frequencies.

The arrangement of the horns in the horizontal dimension assures that the antenna pattern, approximately 3° by 8°, is wider in that plane than in the perpendicular one. The shape of the pattern in the wide dimension is determined by the separation between the feed centers. The beam is pointed toward Canada about 7.6° off the equator.

Table 18-2. TELESAT Baseline Ground Station Subsystem

Station Class	Function	Station Locations
Heavy Route (HR)	Manned stations with 30-meter (98-foot) antennas capable of handling all types of communications	Allan Park, Ontario, and Lake Cowichan, Near Victoria
Network Television (NTV)	Regional distribution of network programming. Equipped to transmit and receive television	St. Johns, Newfoundland; Halifax, Novia Scotia; Montreal; Winnipeg; Regina and Edmonton
Remote Television (RTV)	25* stations to provide live TV programming to isolated communities not served by Canada's Terrestrial Facilities. Initially equipped for receive only	See Figure 18-4 for RTV Station Locations
Northern Telecommunications (NTC)	Provide two-way telephone service between the NTC stations and Allan Park and receive TV and radio programs for broadcasting to local communities	First two stations planned for Frobisher Bay, North of Hudson Strait, and resolute in the Queen Elizabeth Islands near the 75th parallel
Thin Route (TR)	Provide telephone service to the small Arctic communities and reception of radio programs for rebroadcasting within the community NOTE: These two will be the first of approximately 17 similar stations planned for installation by the end of 1974	Pangnirtung on Baffin Island, and at Igloolik off the Melville Peninsula above the Arctic Circle

*Includes Frobisher Bay

Table 18-3. Telesat Facility Locations (1 of 3)

The locations at which Telesat has, or will have, facilities are listed below together with an indication of the services provided at each. These locations are shown in Figure 18-4.

Locations	Service
1. Ottawa, Ont.	Corporate Head Offices Satellite Control Center Transportable stations base
Manned Stations	
2. Allan Park, Ont.	Transmit and receive television Transmit and receive on all message links Satellite tracking, telemetry and command
3. Lake Cowichan, B.C.	Transmit and receive television Transmit and receive message Satellite ranging and backup T&C
4. Frobisher Bay, N.W.T.	Receive television Transmit and receive message
Supervised Stations	
5. Bay Bulls, Nfld.	Transmit and receive television
6. Harrietsfield, N.S.	Transmit and receive television Transmit and receive message
7. Riviere Rouge, Que.	Transmit and receive television
8. Belair, Man.	Transmit and receive television
9. Qu'Appelle, Sask.	Transmit and receive television
10. Huggett, Alta.	Transmit and receive television
11. Resolute, N.W.T.	Transmit and receive message
Remote Stations	
12. Baker Lake, N.W.T.	Transmit and receive message
13. Big Trout Lake, Ont.	Transmit and receive message
14. Cape Dorset, N.W.T.	Transmit and receive message

Table 18-3. Telesat Facility Locations (2 of 3)

Locations	Service
Remote Stations (Cont'd)	
15. Cassiar, B.C.	Receive television
16. Chesterfield Inlet, N.W.T.	Transmit and receive message
17. Churchill, Man.	Receive television
18. Clinton Creek, Y.T.	Receive television
19. Coral Harbour, N.W.T.	Transmit and receive message
20. Dawson, Y.T.	Receive television
21. Elsa, Y.T.	Receive television
22. Eskimo Point, N.W.T.	Transmit and receive message
23. Faro, Y.T.	Receive television
24. Fort Chimo, Que.	Receive television Transmit and receive message
25. Fort George, Que.	Receive television
26. Fort Nelson, B.C.	Receive television
27. Fort Severn, Ont.	Transmit and receive message
28. Fort Simpson, N.W.T.	Receive television
29. Fort Smith, N.W.T.	Receive television
30. Goose Bay, Nfld.	Receive television
31. Igloolik, N.W.T.	Transmit and receive message
32. Inuvik, N.W.T.	Receive television
33. Magdalen Islands, Que.	Receive television
34. Norman Wells, N.W.T.	Receive television
35. Pangnirtung, N.W.T.	Transmit and receive message
36. Pine Point, N.W.T.	Receive television
37. Pond Inlet, N.W.T.	Transmit and receive message
38. Port au Port, Nfld.	Receive television

Table 18-3. Telesat Facility Locations (3 of 3)

Locations	Service
Remote Stations (Cont'd)	
39. Port Harrison, Que. (Inoucdjouac)	Transmit and receive message
40. Poste de la Baleine, Que.	Receive television Transmit and receive message
41. Povungnituk, Que.	Transmit and receive message
42. Rankin Inlet, N.W.T.	Receive television Transmit and receive message
43. Sanikiluaq, N.W.T.	Transmit and receive message
44. Sept Iles, Que.	Receive television
45. Uranium City, Sask.	Receive television
46. Watson Lake, Y.T.	Receive television
47. Whitehorse, Y.T.	Receive television
48. Winisk, Ont.	Transmit and receive message
49. Yellowknife, N.W.T.	Receive television

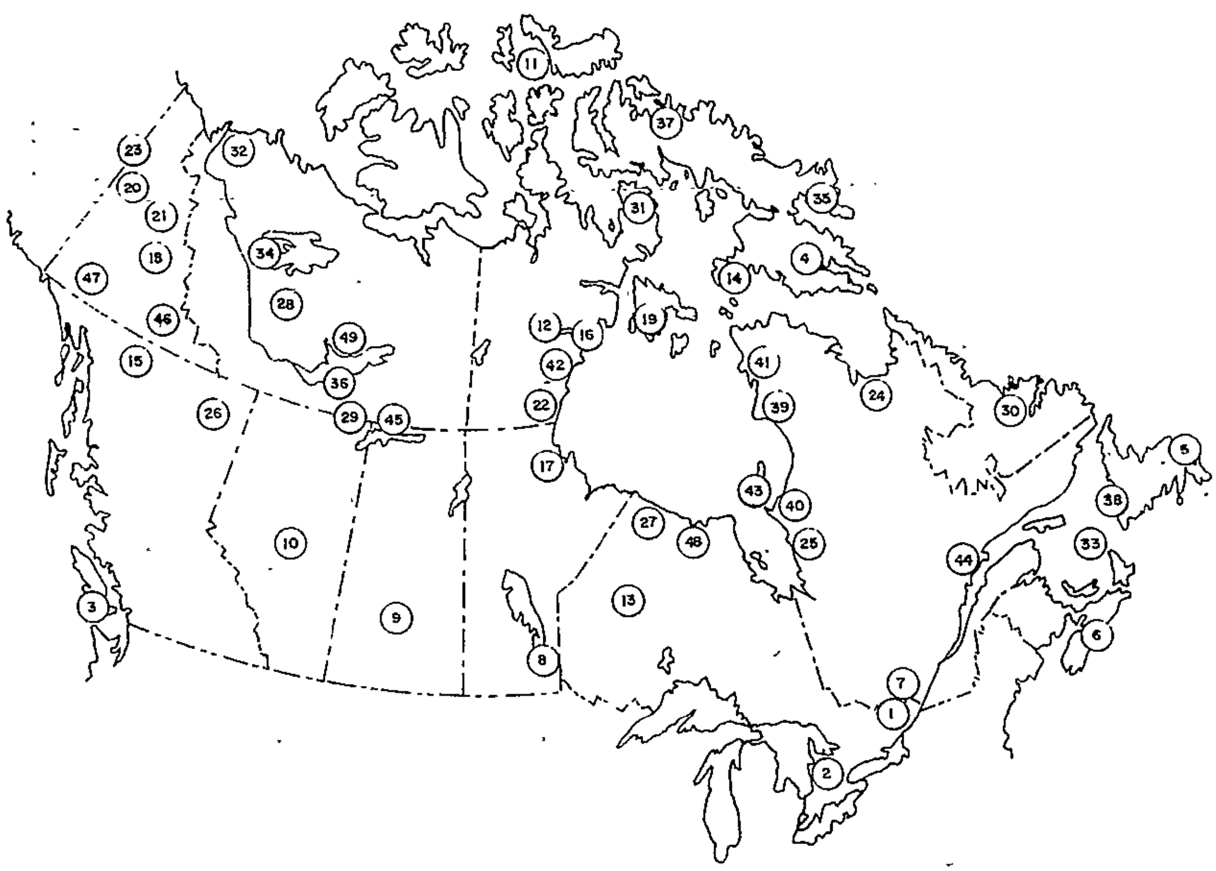


Figure 18-4. Locations of Telesat Canada's Earth Stations

Table 18-4. Major Characteristics of Telesat Space and Earth Subsystems

ANIK Satellite	Size	3.4 meters (11 feet) high, 2 meters (6 feet) in diameter
	Weight	Approximately 544 kilograms (1200 pounds) at liftoff; 272 kilograms (600 pounds) in orbit
	Channels	5000, two-way telephone circuits or 12 color TV channels
	Channel Bandwidth	36 MHz
	Life	8 years
Baseline Earth Stations	Classes	Five classes of earth stations;-HR, NTV, NTC, RTV, and TR
	Antenna Sizes	Antennas vary from 7.9 meters (26 feet) in diameter to 30 meters (97 feet)
	Tracking	Simplified tracking for 30-meter (97-foot) antenna; all other manually steerable
	Frequencies	Uplink 5.9 to 6.4 GHz; downlink 3.7 to 4.2 GHz

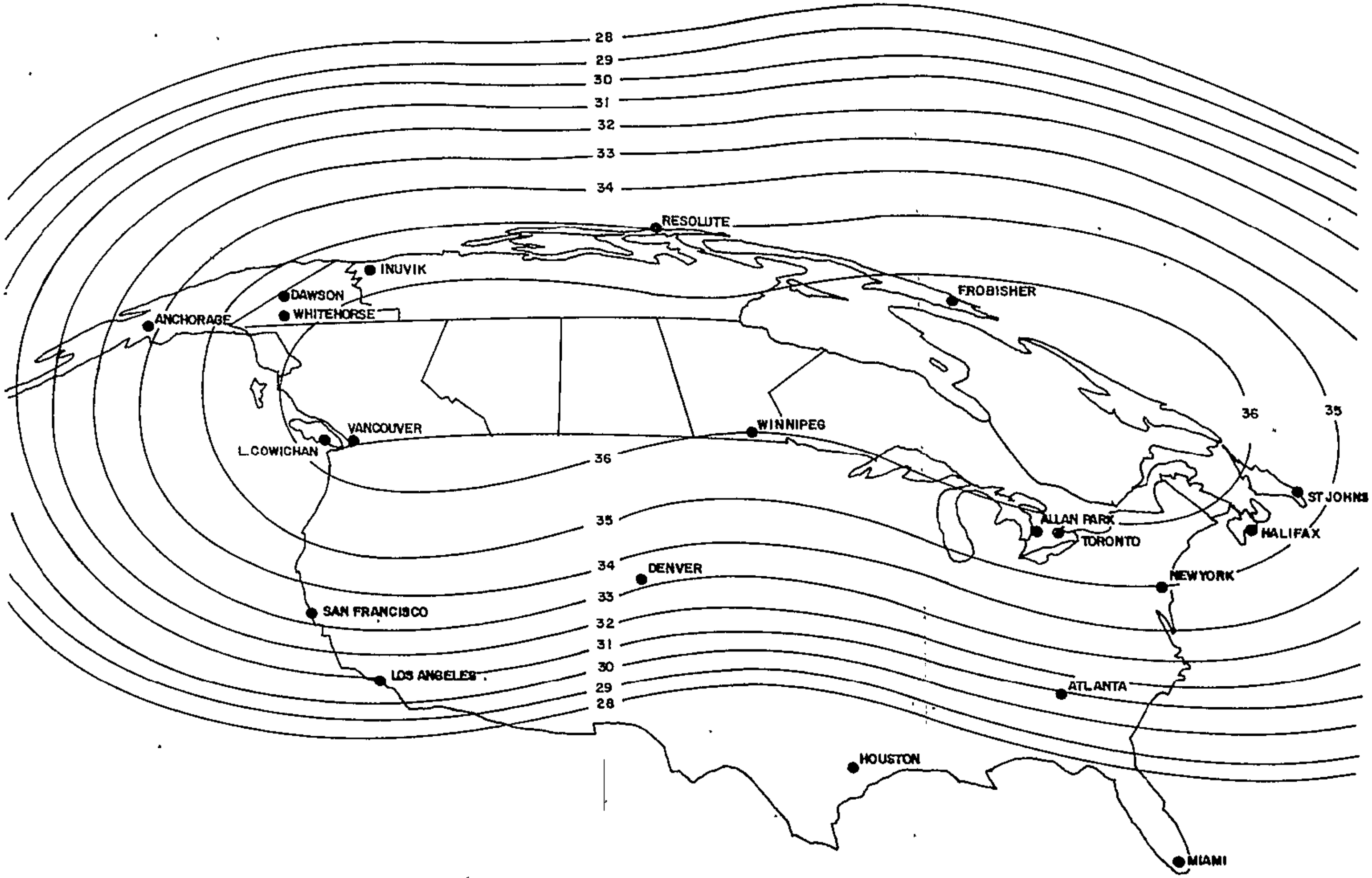


Figure 18-5. Typical ANIK EIRP Contours in dBW

The parabolic antenna also supports the torodial beam command and telemetry antenna used during the transfer orbit. The antenna pattern covers Canada--the second largest country in area in the world--from St. John's, Newfoundland, and Halifax, Nova Scotia, on the east to beyond Vancouver to the Alaskan border on the west, and north to such remote communities as Resolute and Igloolik above the Arctic Circle.

In orbit, ANIK's 4-kilogram (9-pound) antenna remains stationary, pointed toward Canada, as the 2-meter (5-foot) high cylindrical body of the satellite revolves at 100 rpm.

Two omnidirectional antennas--a cloverleaf to receive commands and a bicone to send telemetry information--are mounted atop the parabolic reflector.

Antenna despin control is achieved by a signal processor comprised of a directional antenna receive feed assembly acting on a ground-generated pilot signal.

Economies in system design have been realized through several steps taken to lessen the satellite's weight and hence its cost in orbit. These steps include satellite attitude determination on the ground rather than by on-board spacecraft hardware, extensive use of thin-walled invar filter waveguides, and affixing the squared solar cells to panels attached to the outer cylindrical body of the spacecraft with rubber cement rather than epoxy. Figure 18-6 shows the Telesat general configuration.

The design provides for 10-channel operation during sun eclipse periods when the system must be powered by an on-board battery system. During normal sunlight operation only 10 channels would be in operation, with the remaining two channels used for standby operation.

ANIK I has a capacity of more than 5,000 telephone circuits or 12 color TV channels. Approximately 20,000 solar cells, each 2 centimeters square, are attached to the cylindrical body of the satellite. The cells provide about 300 watts of dc power. In addition to the solar panel arrays, the satellite is equipped with two nickel-cadmium batteries made up of four separate seven-cell packs. These provide electrical energy

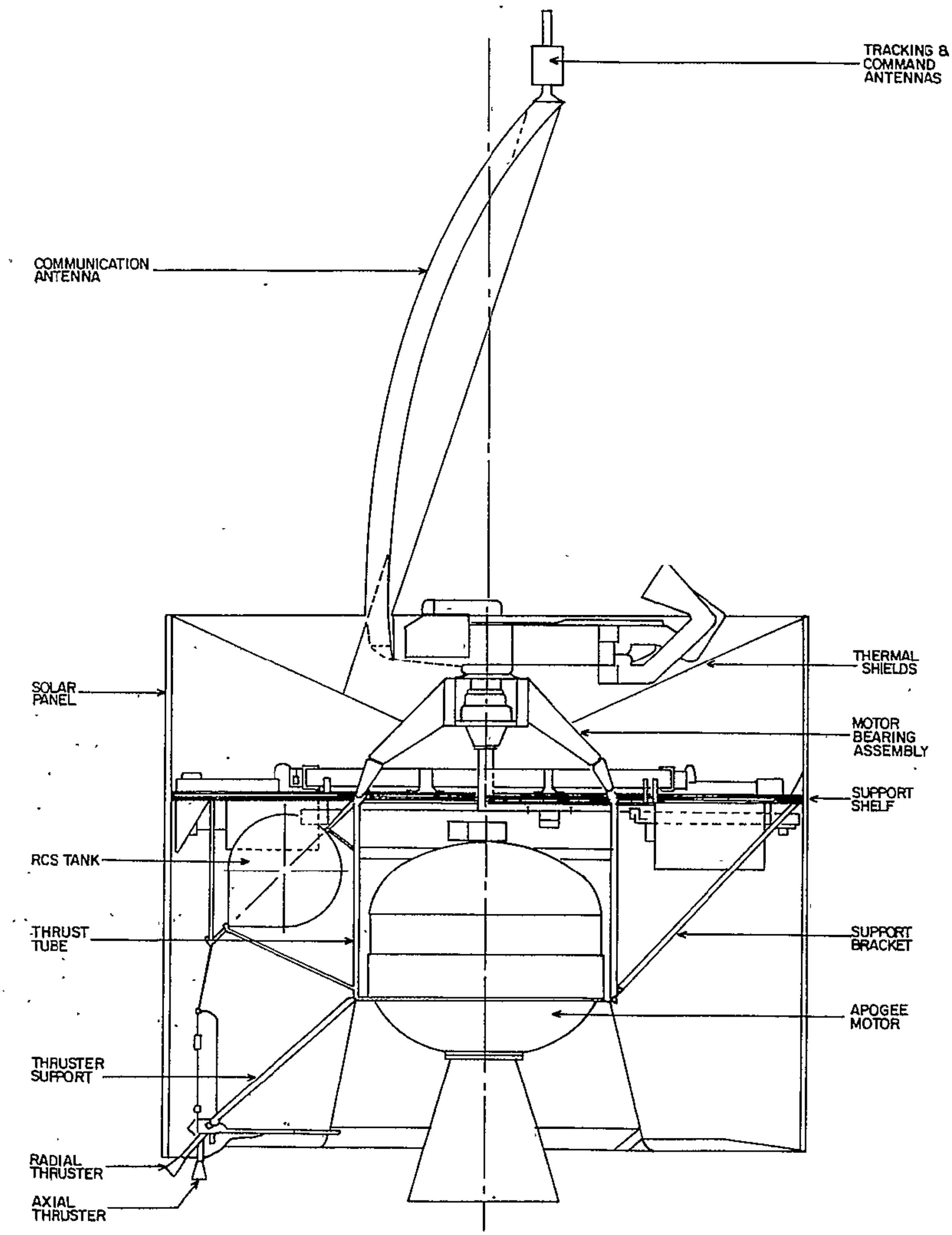


Figure 18-6. Telesat Satellite - General Configuration

during the prelaunch, launch to separation, transfer orbit, and the two annual 46-day eclipse periods when the earth is between the satellite and the sun.

The main body of the satellite is 191 centimeters (75 inches) in diameter and 152 centimeters (60 inches) high and consists of a 76-centimeter (30-inch) diameter thin-walled cylinder housing the spacecraft's solid propellant apogee motor. The cylinder supports the satellite's 185-centimeter (73-inch) electronics platform.

The platform contains the spacecraft's communications repeater, telemetry command electronics, and batteries. At the center of the platform is a pedestal-type support and motor-bearing assembly. The communications antenna is despun at a rate equivalent to the 100 rpm spin rate of the satellite.

The communications repeater receives signals sent from ground stations in the 5925- and 6425-MHz band and downconverts these to 3700 to 4200 MHz for retransmission to other earth stations.

The attitude of the spacecraft spin axis is determined on the ground by processing the telemetered sun and earth sensor pulses. The sun sensors are redundant, spinning, vee-beam sensors which determine the spin phase angle and sun line angle. The earth sensors are spinning infrared telescopes having a bolometer detector and a video amplifier.

Two independent orbit and orientation hydrazine reaction control systems are carried aboard the satellite, each consisting of two diametrically opposed titanium tanks, interconnecting gas and liquid lines, and two thrusters mounted just inboard aft of the solar panel. The nozzle of one thruster is oriented to fire nearly parallel with the spin axis and is used for orbital inclination control when fired in a steady state and for spacecraft orientation control when pulse-fired. The nozzle of the second thruster is oriented to fire through the satellite's average center of gravity. It is used only in the pulsed mode for orbital period and eccentricity control. Sufficient hydrazine is stored in the two systems to enable more than 7 years of stationary, zero-inclination stationkeeping.

The Telesat satellite is intermediate in size between the Intelsat III and Intelsat IV satellites. As in the Intelsat IV, the Telesat repeater is a single conversion with a wideband receiver and a transmitter having 12 separate channels. The 12 transmitter channels are capable of handling 12 television channels (10 eclipse conditions) or various mixes of television, data, and voice. The satellite has a design life of 8 years.

Table 18-5 summarizes the Telesat spacecraft characteristics. Table 18-6 summarizes the general characteristics of ANIK's communication and T&C subsystems. Figure 18-7 is a block diagram of the ANIK on-board communications repeater. The frequency and polarization plan is given in the table in Figure 18-8.

The tracking, telemetry, and command facilities required for Telesat missions are at three locations: the Allan Park station in Ontario, the Lake Cowichan station on Vancouver Island, and the island of Guam in the Pacific. The latter is a tracking station which is used only during the transfer orbit phase of a mission. All TT&C activities are controlled from Telesat's Satellite Control Centre in Ottawa.

18.4 GROUND TERMINALS

The five types of fixed ground terminals for the Telesat program are

1. Multi-purpose communications facilities--Heavy Route (HR)
2. Main television receive and transmit--Network Television (NTV)
3. Message and television receive--Northern Telecommunications (NTC)
4. Television receive--Remote Television (RTV)
5. Message--Thin Route (TR)

In addition, Telesat is implementing a transportable television transmit station and a transportable message station.

The capacity of each RF channel on a Telesat satellite is such that it is capable of supporting up to 960 one-way voice circuits, or one color television video signal with two 5 KHz audio circuits and one cue and control circuit. When the accessing earth stations have a G/T of 37.5 dB/^{o}K, such as with the Heavy Route stations, the voice circuit noise performance for a 960 channel carrier is 37.5 dBrncO. The

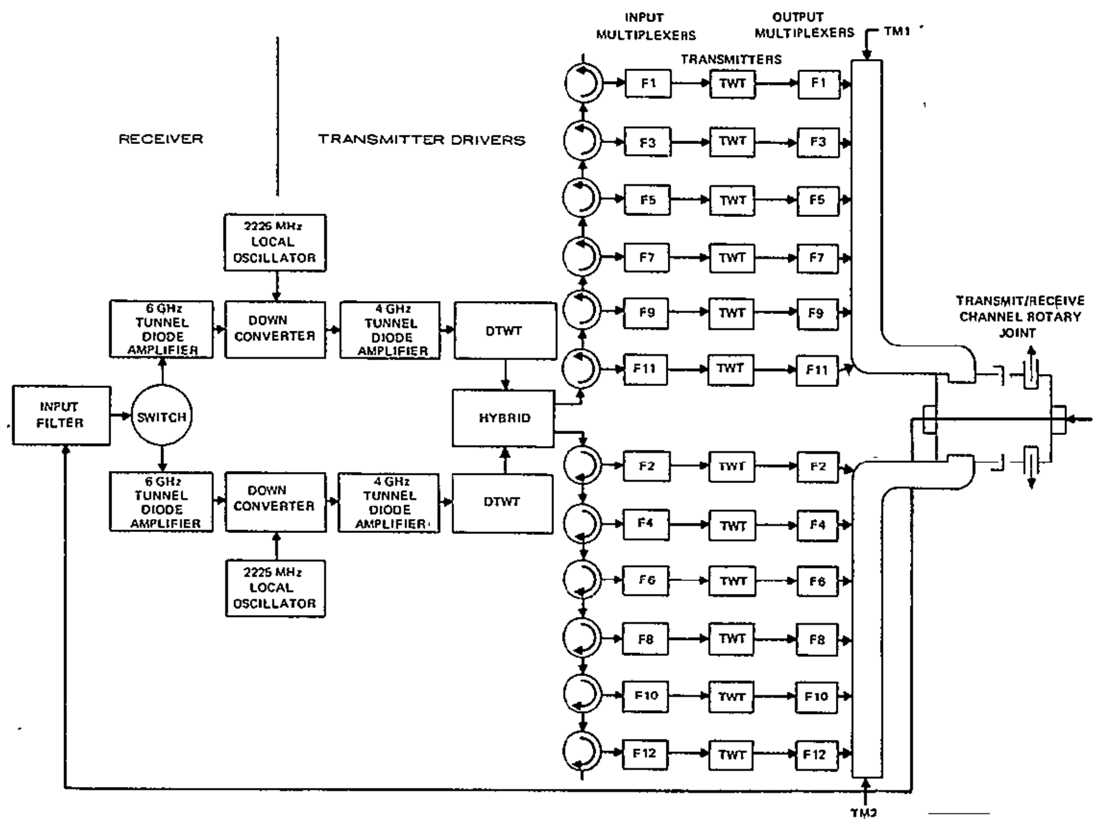
Table 18-5. Telesat Spacecraft

Satellite		ANIK I	ANIK II	ANIK III
Manufacturer and Sponsor		Hughes/Telesat		
Launch Date		November 9, 1972	April 20, 1973	1st qtr. 1975
Launch Vehicle		Delta 1914		Delta 2914
Orbital Data(1)	Apogee (mi.)	37,015 km (23,000 mi.)	37,015 km (23,000 mi.)	37,015 km (23,000 mi.)
	Perigee (mi.)	--	--	--
	Inclination	--	--	--
	Period (min.)	Synchronous		——
Status		January 11, 1973 1st commercial service at 114° W longitude	Spare for ANIK I at 109° W longitude	To be launched to increase system capacity

Table 18-6. Telesat Characteristics

Antenna	Type		Dual mode with shaped beam, parabolic reflector of 2-meter (5-foot) diameter, plus bicone for telemetry and a cloverleaf for command during the launch and transfer orbit phase
	Number		One
	Beamwidth		$3^{\circ} \times 8^{\circ}$ to give coverage of Canada
	Gain		27 dB over coverage area*
Repeater	Frequency Band		C band: 5925-6425 MHz (RCV); 3700-4200 MHz (XMT)
	Type		Non-linear single conversion
	B.W. (3dB)		36 MHz per channel
	Number		12 RF channels including 2 on standby
	RCVR	Type Front End	Tunnel diode amplifier
		Front End Gain	No data
		Sys. Noise Fig.	Approximately 9 dB*
	XMTR	Type	TWT
		Gain	No data
		Power Out	5 W per channel
	EIRP		33 to 34 dBW within coverage area per channel
	G/T		-7 dB/$^{\circ}$K
General Features	Stabilization	Type	Spin with hydrazine jet stationkeeping and attitude control
		Capability	Stationkeeping to within $\pm 0.1^{\circ}$ of 0° orbit inclination and proper longitude
	Power Source	Primary	20,448 solar cell array providing 300 watts power at launch and 230 watts at end of 7 years
		Supplement	Two 28 volt nickel-cadmium batteries
	Comm. Power Needs		220 watts
	Size		Total height = 3.47 m (11.4 ft); cylinder 191 cm (75 in.) diameter
	Weight		90.7 kg (200 lb) in transfer orbit, 286 kg (630 lb) after firing of apogee motor

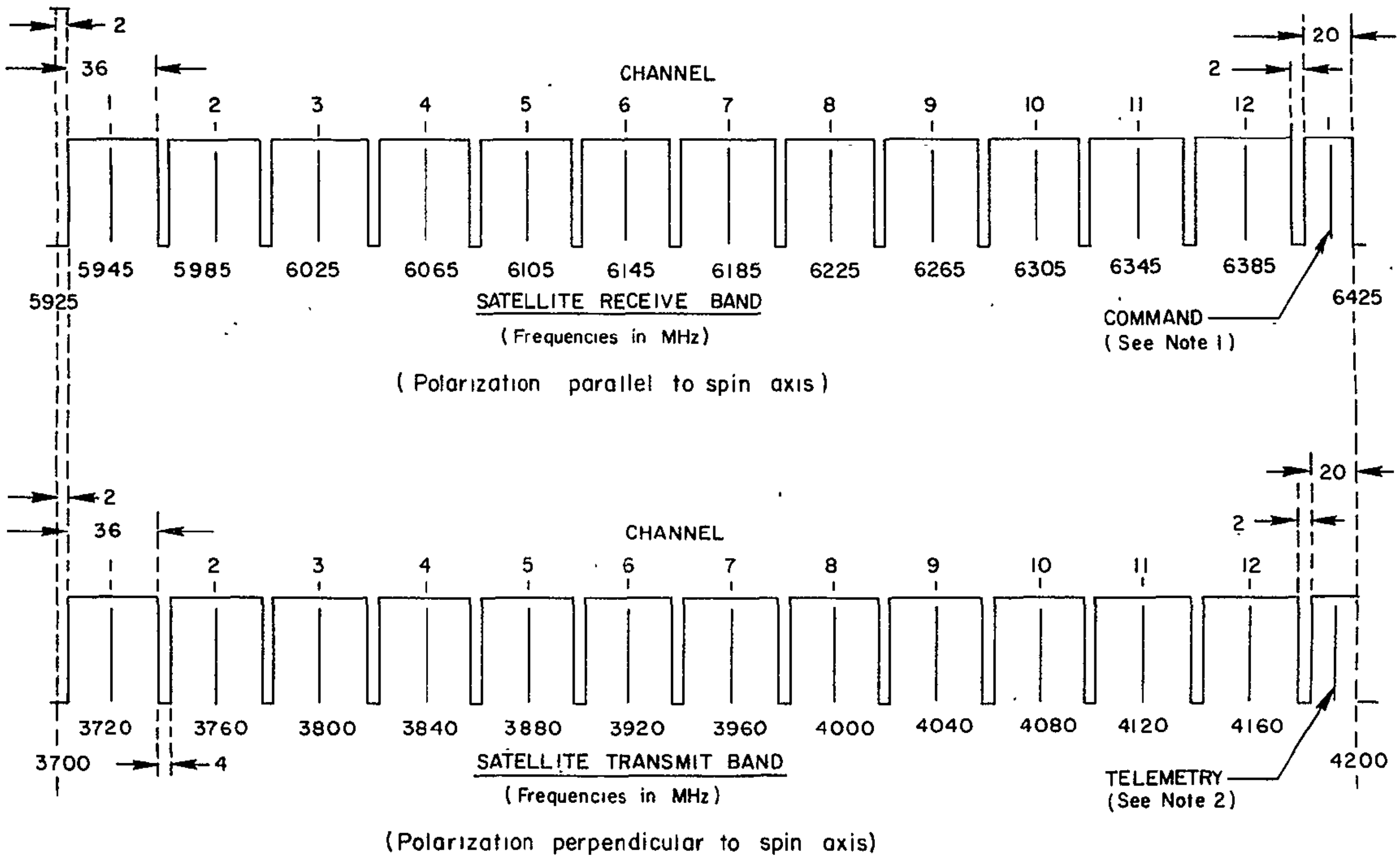
*Value derived from other data available.



The satellite communications repeater includes certain design improvements not heretofore developed for spacecraft usage. Among these is the successful development of thin-wall Invar waveguide filters, providing a large reduction in weight without degratation in performance.

The repeater is an all-microwave, fixed gain, 12 channel design where each channel is essentially an independant amplifier with a bandwidth of 36 MHz. The only active equipment common to all channels is a wideband receiver which establishes the system noise temperature, translates the 6 GHz carriers to 4GHz, and amplifies the 4 GHz carriers to an intermediate power level prior to channelization. Separation into channels is accomplished by two multiplexers for the even and odd numbered channels, each of which consists of a bank of six circulator-coupled waveguide filters. A high efficiency TWT amplifier with a saturated output power of 5 watts is provided in each channel for final power amplification. After power amplification, the channels are summed by two low loss multiplexers, again odd and even, each of which consists of a bank of six waveguide filters. Receiver redundancy is provided, and two spare channels are available since the satellite is sized for ten channel operation at the end of the 7 year mission life.

Figure 18-7. The ANIK Communications Repeater



Note 1 – Command polarization will be perpendicular to spin axis when using omni antenna

Note 2 – Telemetry polarization will be parallel to spin axis when using omni antenna

Figure 18-8. Frequency and Polarization Plan video signal-to-noise ratio at Heavy Route and Network Television stations is 54 dB or better and at Remote Television stations is 48 dB or better.

When an RF channel is operated in a multiple access mode under the frequency division multiple access (FDMA) technique, the number of voice circuits per carrier is partially a function of the number of carriers and the G/T of the accessing earth stations. For example, five RF carriers could support a total of 110 two-way voice circuits between one earth station having a G/T of 37.5 dBrncO, and four other earth stations having a G/T of 28 dB. Presently, one of the RF channels is utilized in this manner with three carriers providing message service between Allan Park and Frobisher Bay and Resolute. Another application of this technique provides 240 two-way circuits between Allan Park and Harrietsfield. In addition, Telesat will be implementing time division multiple access (TDMA) techniques in the near future, which will significantly increase message capacity. Another RF channel is used in a multiple access mode for Thin Route service, however, in this case, each RF carrier is modulated by a single voice circuit using phase shift keying with delta modulation and in this type of service, up to 120 one-way circuits can be provided between earth stations with a G/T of about 20 dB.

Technical characteristics of the antenna, the receive and transmit assemblies, and the overall performance of these types of earth stations and the control subsystem Tracking Telemetry, and Command (TT&C) stations are summarized in Table 18-7.

18.4.1 The Allan Park and Lake Cowichan Stations

The Allan Park Station, which is the primary station in the entire Telesat network, contains three separate antennas and a large central building to house the necessary support facilities. The communications system, is a multi-purpose communications facility providing television and message services. It also provides a beacon signal and carries all TT&C functions for the satellites.

The Lake Cowichan Station has basically the same communications aspects as the Allan Park Station except that its role in TT&C is only that of providing ranging and acting as a backup for other TT&C functions for the satellites.

Table 18-7. Earth Terminal and TT&C Stations Characteristics

		Heavy Route (HR)	Network Quality Television (NTV)	Northern Telecommunications (NTC)	Remote Television (RTV)	Thin Route (TR)	Tracking, Telemetry & Command (TT&C)
Antenna	Type	Cassegrain	Cassegrain	Cassegrain	Cassegrain	Cassegrain	Cassegrain
	Aperture Size	30 meters (98 feet)	10 meters (33 feet)	10 meters (33 feet)	8.1 meters (26.5 feet)	8.1 meters (26.5 feet)	10 meters (32 feet)
	Gain	63 dB transmit 59 dB receive	52.5 dB transmit 50.5 dB receive	53.5 dB transmit 50.5 dB receive	48.5 dB	51.5 dB transmit 48.5 dB receive	54.5 dB transmit 51.0 dB receive
Receive System	Type Preamp	Uncooled preamp	Uncooled preamp	Uncooled preamp	Uncooled preamp	No data	
	Bandwidth/Channel	36 MHz	36 MHz	36 MHz	36 MHz	No data	36 MHz
	Frequency Range	3700-4200 MHz	3700-4200 MHz	3700-4200 MHz	3700-4200 MHz	3700-4200 MHz	
Transmit System	Type Amplifier	Klystron	Klystron	Klystron	(Initially receive only station)	No data	
	Bandwidth/Channel	36 MHz	36 MHz	36 MHz		No data	36 MHz
	Amp Power Output	3 kW	3 kW	1.5 kW		No data	
	Frequency Range	5900-6400 MHz	5900-6400 MHz	5900-6400 MHz		5900-6400 MHz	
Tracking	Type	Simplified tracking	Manually steerable	Manually steerable	None	None	Auto track or program track pointing accuracy .014° RMS
Total Performance	System Noise Temperature	150°K @ 5° elevation	150°K @ 5° elevation	No data	150°K @ 5° elevation	No data	No data
	G/T	37 dB/°K	28 dB/°K	28 dB/°K	26 or 22 dB/°K	26 dB/°K	28 dBW @ 4 GHz
	EIRP Per Carrier	84 dBW	83 dBW	70 dBW	Receive only	53 dBW	85 dBW
	Polarizations	Circular	Circular	Circular	Circular	Circular	Circular
	Communication Capability	960 channels or one color TV channel plus 2 audio channels	One television 2 audio channels	Up to 132 voice channels	Receive one or two network TV channels	Up to 120 one-way voice channels	Transmit command and signal for despin control. Receive tracking error and telemetry signals

Each of these facilities is equipped with a 30-meter (98-foot) diameter antenna, which in conjunction with a parametric amplifier provides a minimum G/T of 37 dB. These antennas incorporate a wheel-and-track type of mount to provide rotation in azimuth, and contain a simplified tracking system operating on the principle of maximizing the received signal as the antenna is moved through a series of discrete steps under the command of an antenna control unit. An elevated equipment room mounted near the antenna elevation axis houses most of the transmitting equipment, as well as the receiver low-noise parametric amplifiers. The antennas are also provided with automatically controlled electrical de-icing.

Each station is equipped to transmit and receive on several RF channels, with Allan Park having seven transmit chains each capable of producing an EIRP of 84 dBW, and eight receive chains, while Lake Cowichan has two transmit chains and five receive chains. Hot standby transmit and receive chains are provided which switch into service automatically in the event of failure of the operating equipment.

Power for these stations, from commercial sources, is provided through an uninterrupted power supply incorporating a rotary converter, a battery bank with a 15-minute reserve capacity, and a diesel generator which starts automatically if the commercial primary power fails.

The primary power equipment, the control consoles and the major portions of the receiving equipment are housed in a building connected to the antenna through a covered passageway. The Lake Cowichan building has a floor area of 743 square meters (8,000 square feet), while at Allan Park a building of 1,115 square meters (12,000 square feet) is required. The buildings are also provided with appropriate facilities for their staff, as both the Allan Park and Lake Cowichan Stations are manned twenty-four hours a day.

The communications antenna at the Allan Park Station is shown in the photograph in Figure 18-9 and an overall view of the Allan Park Station is shown in Figure 18-10 with the microwave back-haul tower in the background.

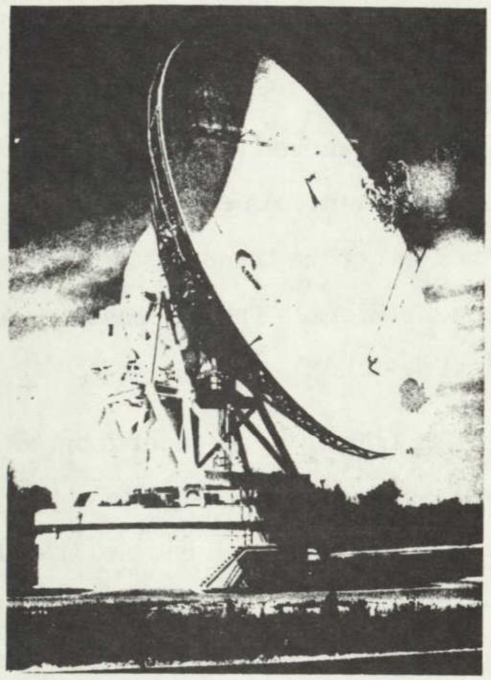


Figure 18-9. The Heavy Route Antenna at Allan Park

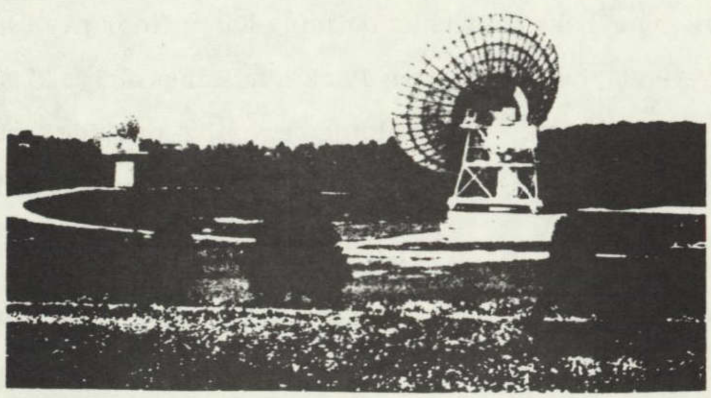


Figure 18-10. The Allan Park Station, Allan Park, Ontario

A block diagram of the communications equipment is given in Figure 18-11 and details of the transmit and receive chains in Figures 18-12 and 18-13.

18.4.2 The Network Television (NTV) Stations

A total of six Network Television Stations have been located across Canada and a photograph of the one located at Huggett, Alberta is shown in Figure 18-14. The five other stations are at: Bay Bulls, Nfld.; Harrietsfield, N.S.; Riviere Rouge, Que.; Belair, Man.; and Qu'Appelle, Sask.

These stations are engineered to provide high quality transmission and reception of television signals. As these stations are also designed for unattended operations, they are equipped with a supervisory system which permits them to be monitored and controlled from a maintenance center located remotely from the station site.

All NTV stations are equipped with a 10.2-meter (33.3-foot) diameter antenna, which in conjunction with a low-noise parametric amplifier provides a minimum G/T of 28 dB/^{o}K. Basically, these antennas are fixed (with the exception of the Harrietsfield Station which has recently been outfitted with a step-track system, similar in nature to the systems at Allan Park and Lake Cowichan) and require no tracking facilities; however, they can be steered by remote drive over a limited range in the event that they have to be readjusted to a new satellite orbital position. Accurate satellite station-keeping ensures that the satellite remains near the peak of the antenna beam.

The communications equipment at each NTV station, with the exception of the one at Riviere Rouge, includes four TV receivers and a single TV transmit chain, enabling each station to receive four RF channels simultaneously, and to transmit on any one of the RF channels in use for television. Normally, however, three receivers are set up for program reception and the fourth is on standby and is automatically switched in, should any one of the three fail. The Riviere Rouge Station is equipped with two additional TV transmit chains. The transmitters and receivers can be tuned to any of the RF channels in use for television by means of control signals transmitted from the Heavy Route stations over a cue and control channel which accompanies each

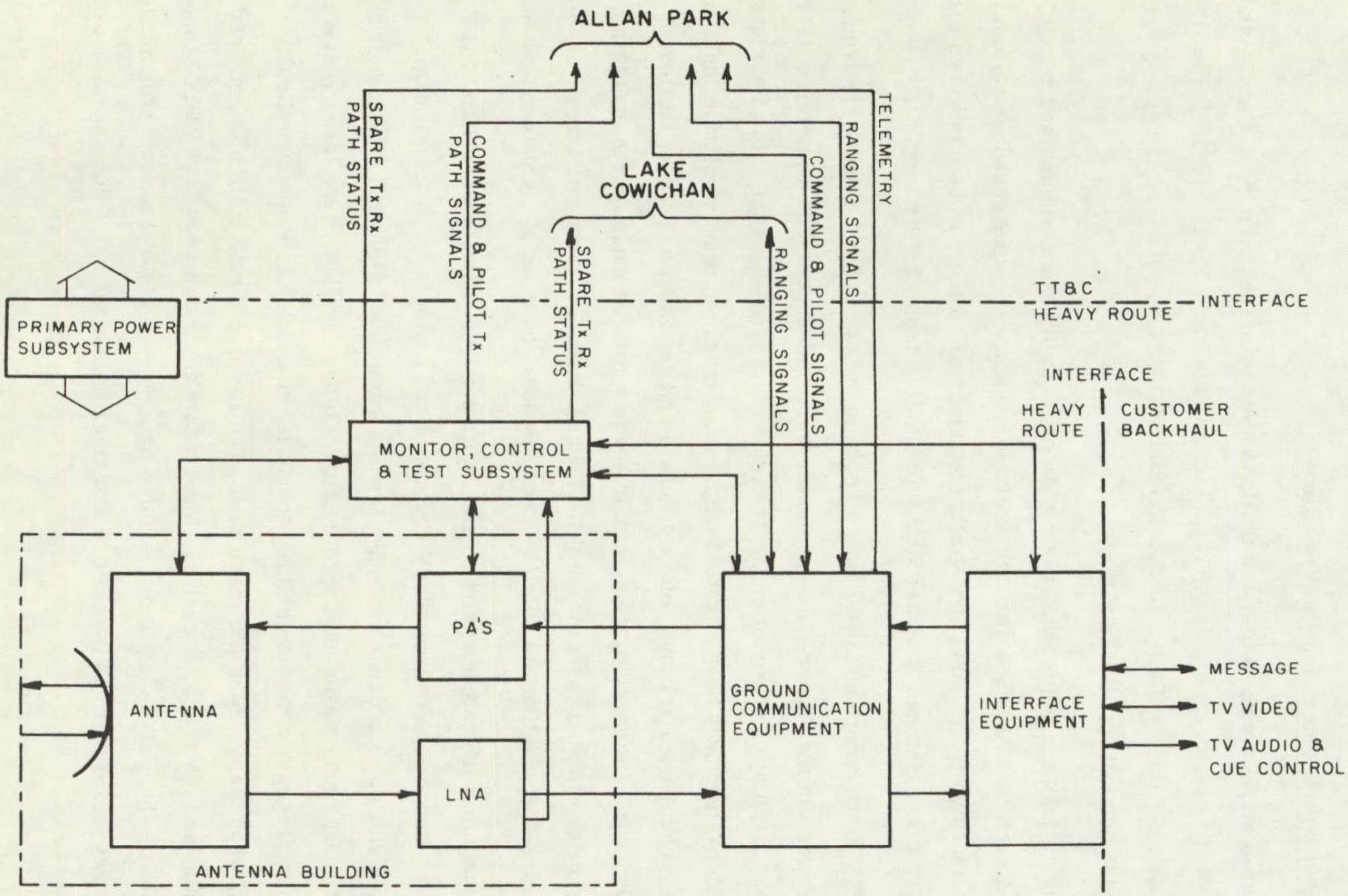


Figure 18-11. Allan Park/Lake Cowichan - Block Diagram

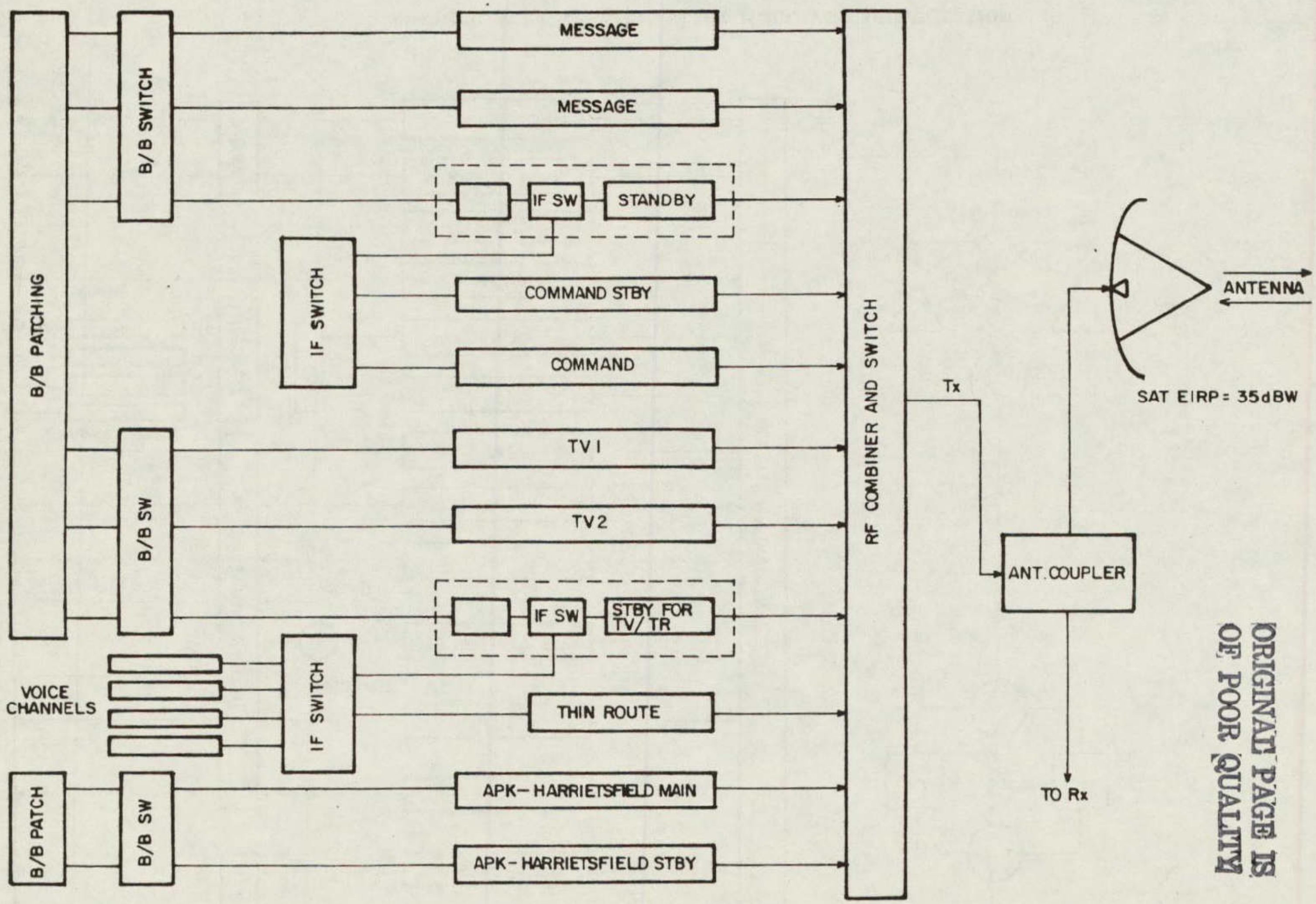


Figure 18-12. Allan Park Transmit Configuration

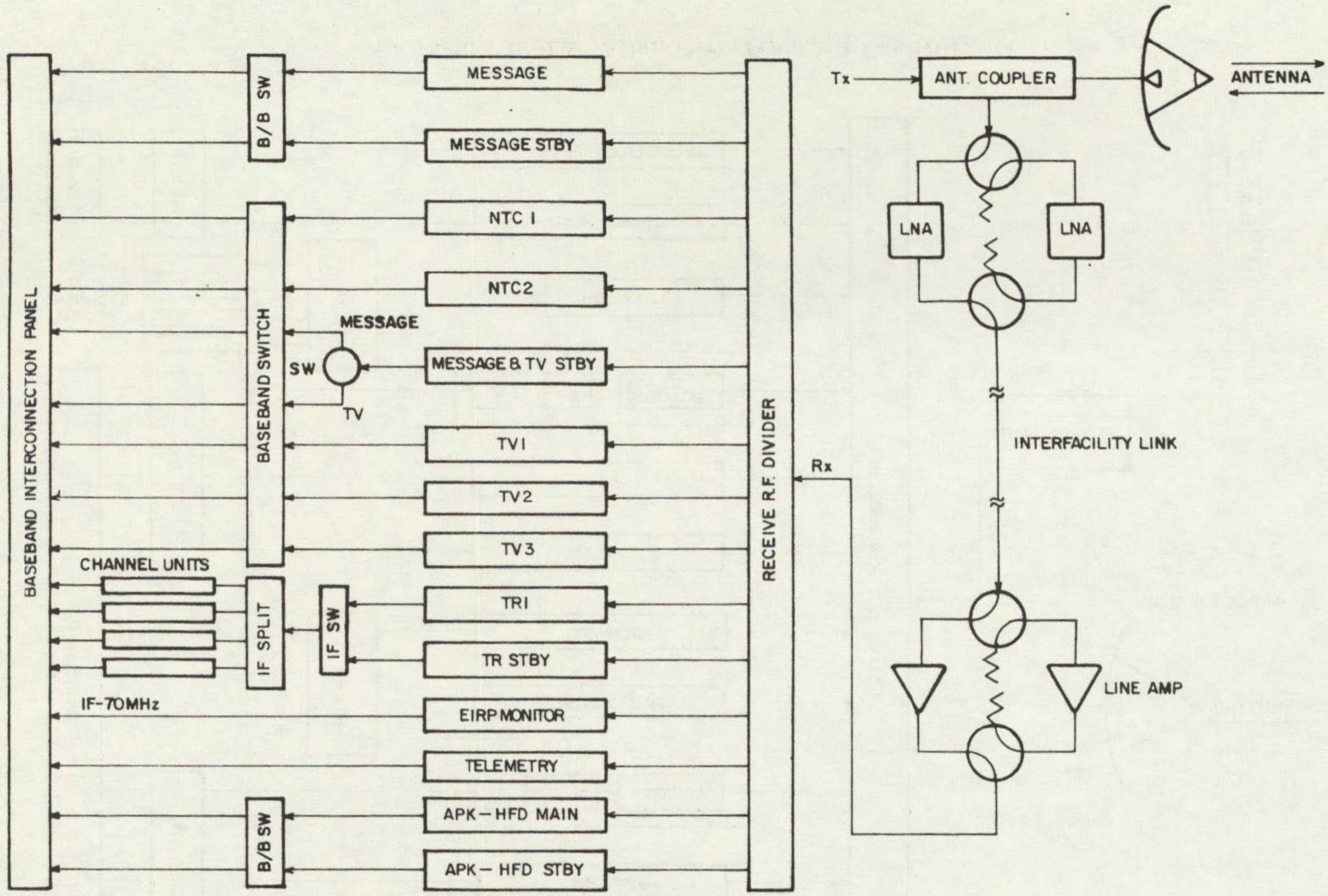


Figure 18-13. Allan Park Receive Configuration

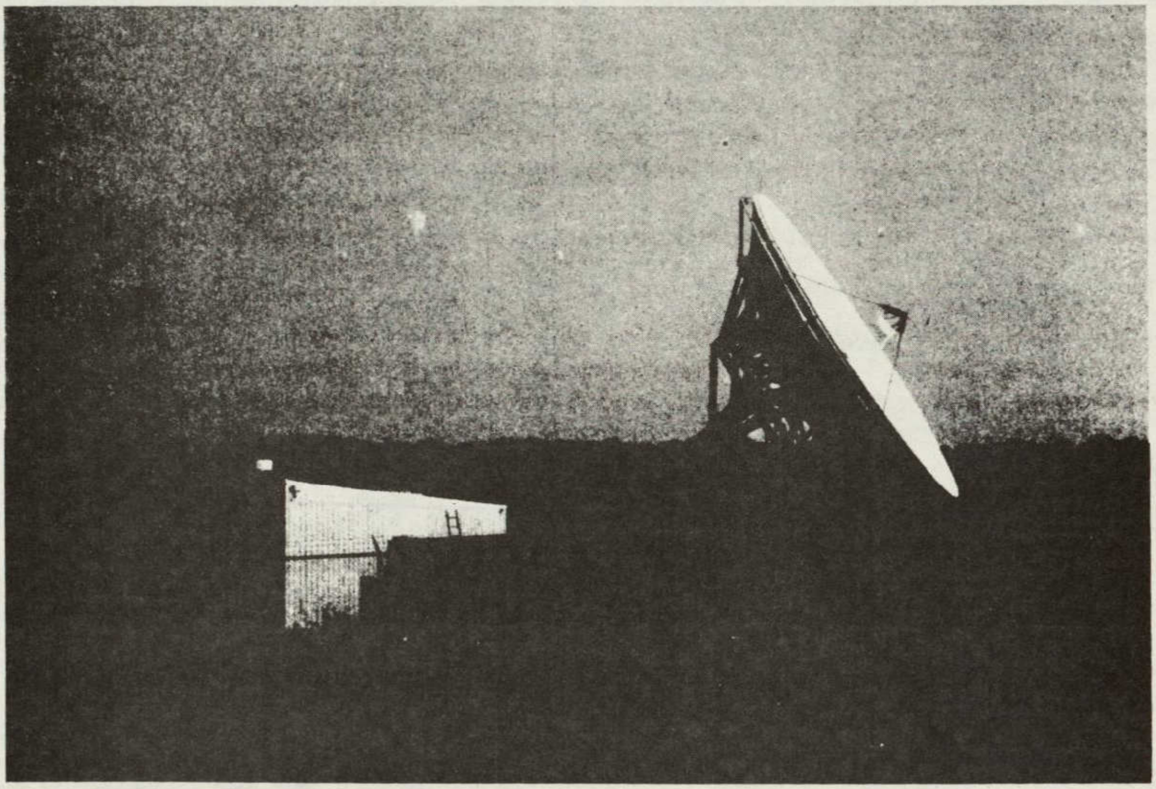


Figure 18-14. A Typical Network Television Station, Huggett, Alberta

television signal, or by means of remote controls from the Maintenance Centre. Figure 18-15 shows a block diagram of a Network Television Station.

18.4.3 Northern Telecommunications (NTC) Stations

Two stations of this type are in operation at present, one at Frobisher Bay and one at Resolute, and they share one satellite RF channel in a multiple access mode. The services provided at the Frobisher Bay Station include the reception of television and radio as well as complete message service. The Resolute Station, on the other hand, has only been equipped to provide message service. These stations are also designed for unattended operation and are equipped with a supervisory system.

The NTC stations are equipped with a 10.2-meter (33.3-foot) diameter antenna which, in conjunction with an uncooled low noise parametric amplifier, provides a G/T of 28 dB/^{O}K. The antennas are non-tracking, but may be steered by means of a remote drive control over a limited range, should they have to be adjusted to a new satellite orbital position. Each station is equipped with redundant transmit and receive chains.

A photograph of the station at Resolute is shown in Figure 18-16. Block diagrams of the two NTC stations are given in Figures 18-17 and 18-18.

18.4.4 The Remote Television (RTV) Stations

These are unattended stations engineered to provide for the reception of television signals in remote communities which are usually equipped with a low power television transmitter providing limited coverage of the surrounding area. The 25 RTV stations provide the means of making available to remote centers the same television programming as is available in the larger population centers.

The majority of the stations are provided with a single non-redundant receive chain, however, some are equipped with two receive chains to provide for the simultaneous reception of two television channels.

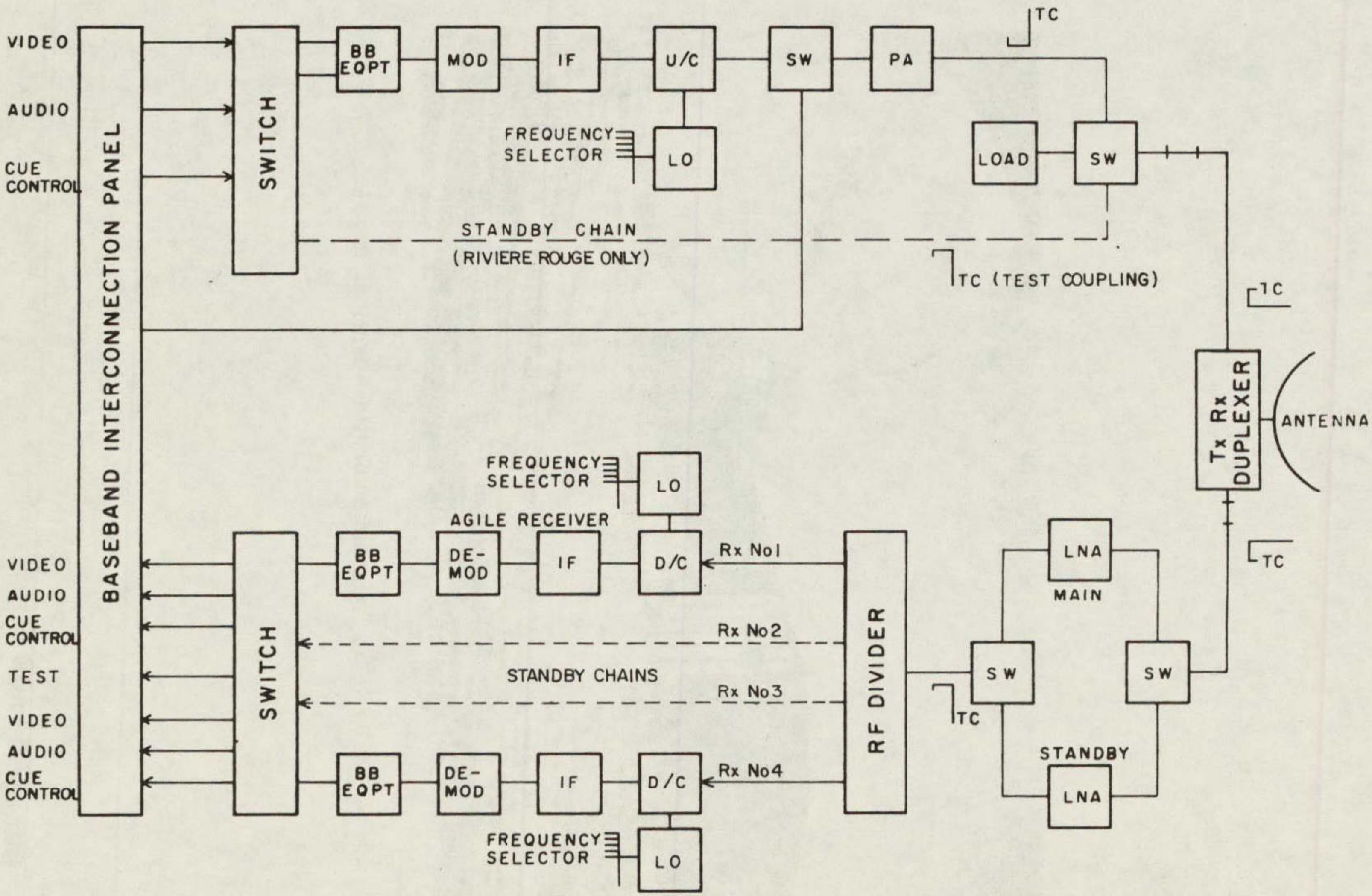


Figure 18-15. A Typical Network Television Station - Block Diagram

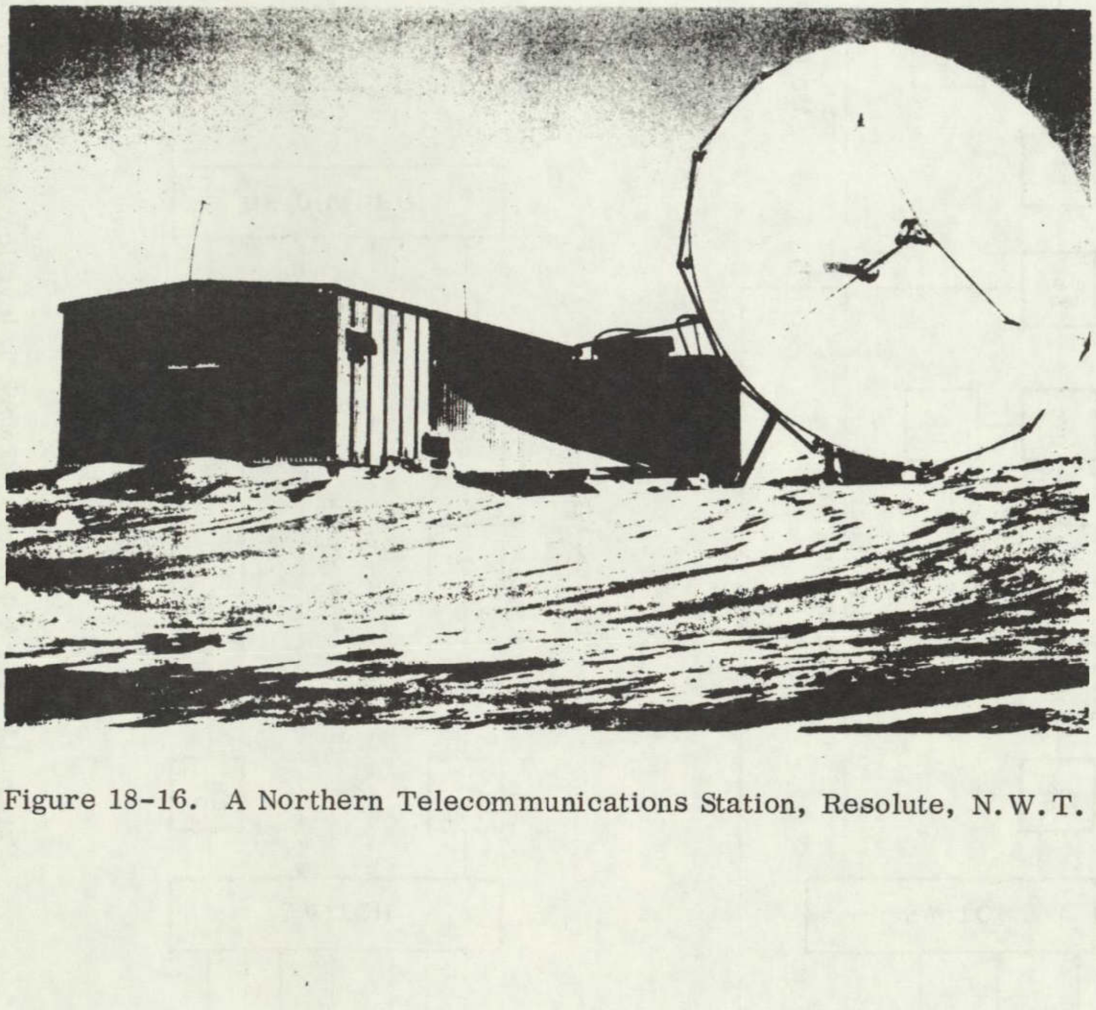


Figure 18-16. A Northern Telecommunications Station, Resolute, N.W.T.

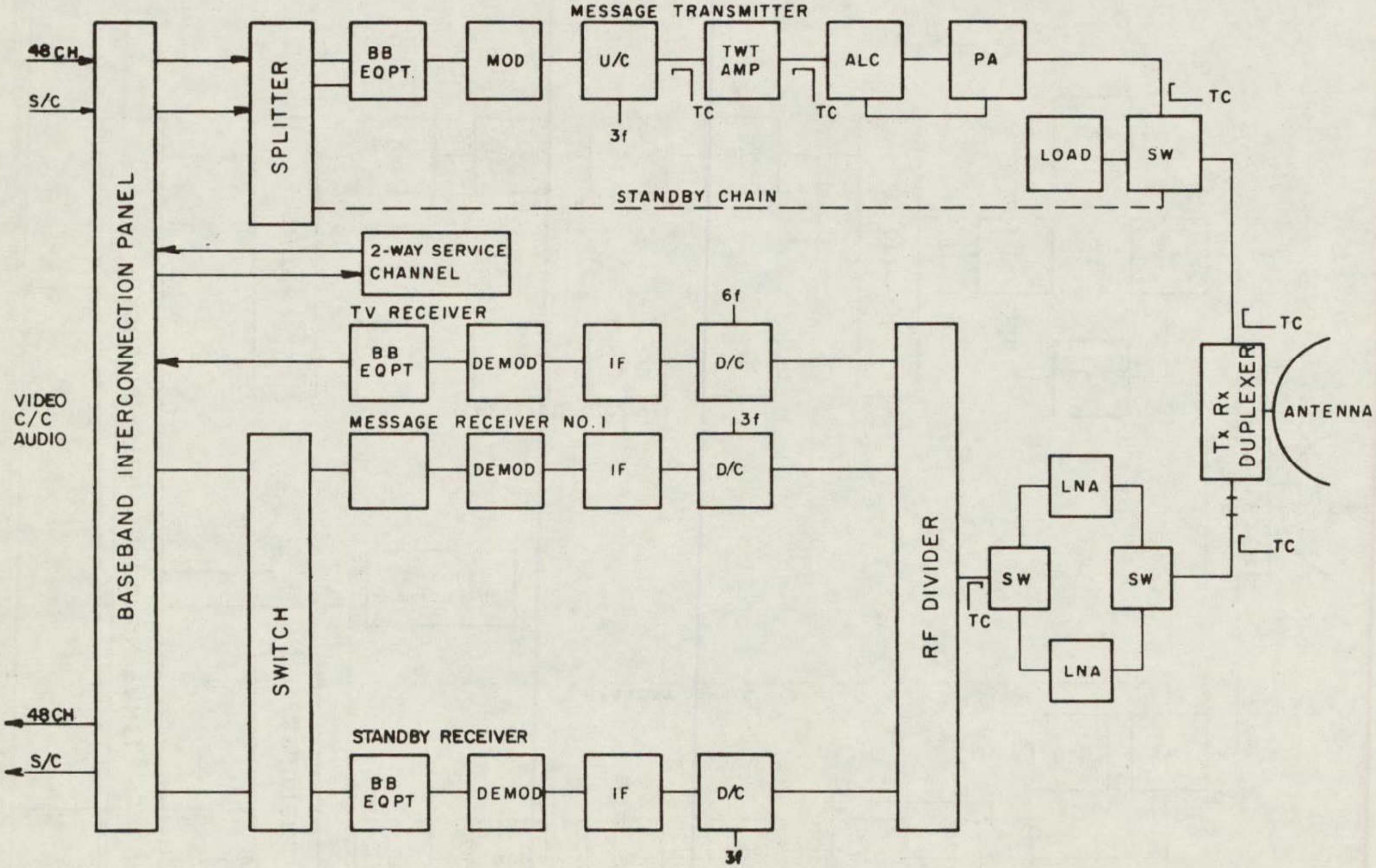


Figure 18-17. Northern Telecommunications Station at Frobisher Bay - Block Diagram

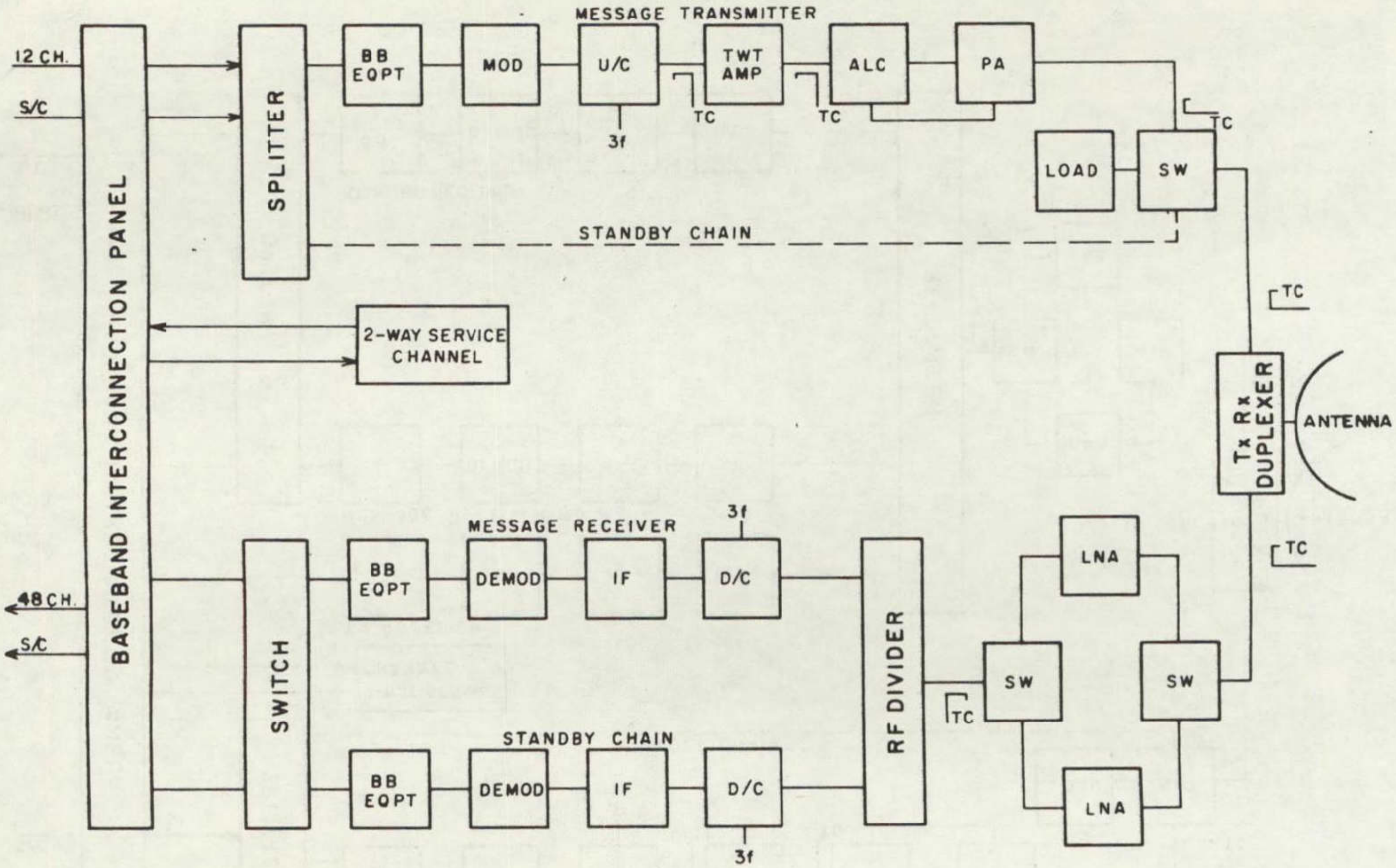


Figure 18-18. Northern Telecommunications Station at Resolute - Block Diagram

An 8.1-meter (26.5-foot) diameter antenna provides a G/T of 26 dB/^{o}K or 22 dB/^{o}K depending upon the type of low voice amplifier used. The antennas are fixed as no tracking capability is required because of the accuracy of the satellite station-keeping. Either G/T provides a video signal-to-noise ratio greater than 48 dB and an audio signal-to-noise ratio greater than 53 dB. All of these antennas are provided with sub-reflector de-icing and some, where icing conditions are severe, are equipped with electrical de-icing for the main reflector.

A photograph of a typical Remote Television station is shown in Figure 18-19 and a block diagram is given in Figure 18-20.

18.4.5 The Thin Route (TR) Stations

The Thin Route stations are engineered to provide message service to small communities where the traffic demand can be satisfied with a relatively few number of telephone circuits, typically in the order of two to eight. These stations utilize single voice channel per carrier techniques with delta modulation and biphase PSK (digital) transmission. Frequency division multiple access (FDMA) is used to access the satellite. Initially, the carriers are on pre-assigned frequencies; however, demand assignment techniques and voice activation may ultimately be used to increase system flexibility and capacity.

As an alternative to telephone message service, these stations are capable of data transmission at 2400 bps, and in addition, they have the capability of expansion to provide for television receive and radio program transmit and receive.

A photograph of a typical Thin Route station is shown in Figure 18-21. Figure 18-22 shows a block diagram of a Thin Route station with television and radio program features that could be added at a later date shown in dashed lines.

18.5 TRANSPORTABLE EARTH STATION FACILITIES

Transportable earth station equipments have been acquired for television transmission and message communications in order to increase the flexibility in the provision of communications services. The facilities have been designed as two complete

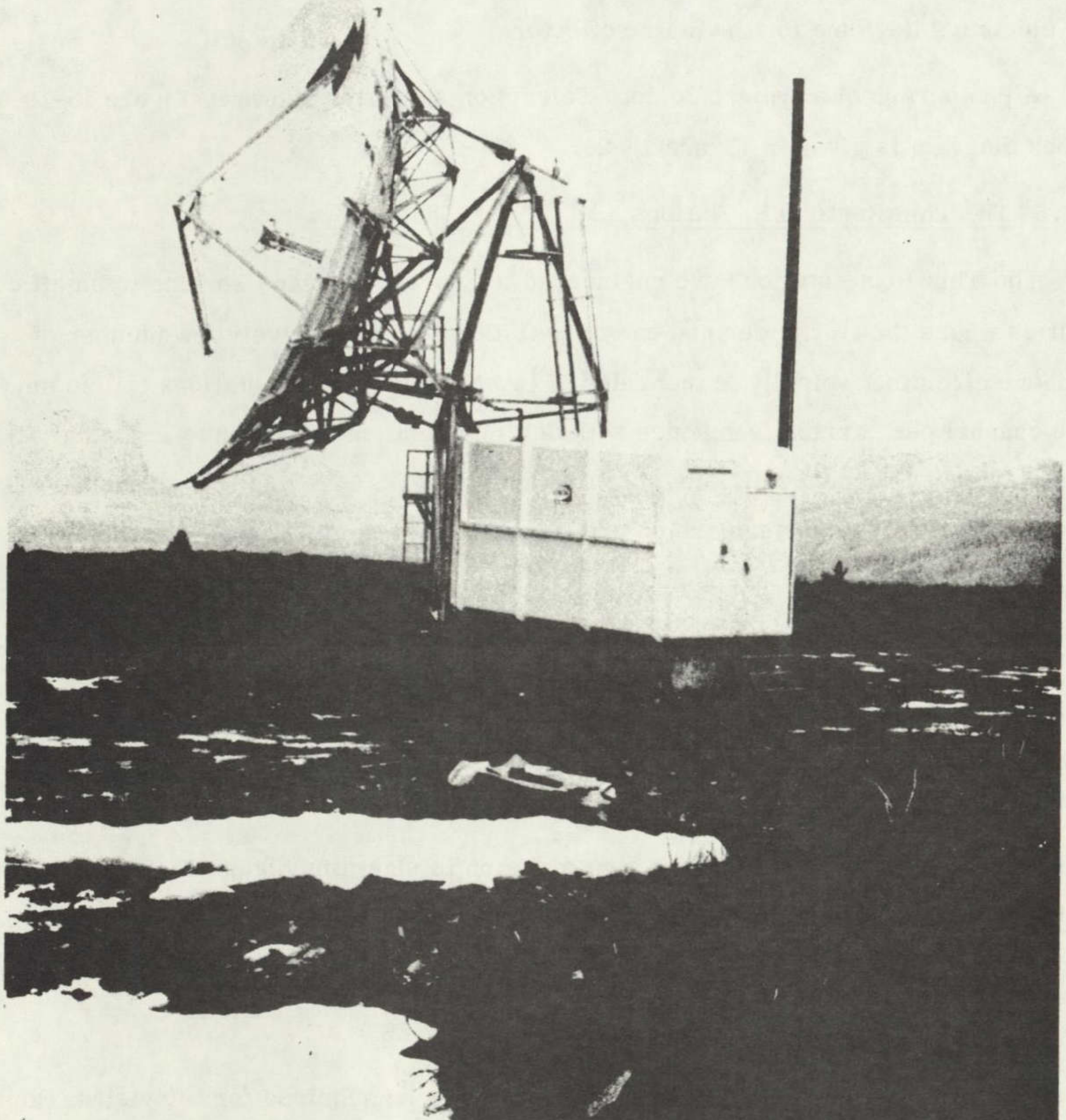


Figure 18-19. Remote Television Station, Watson Lake, Yukon

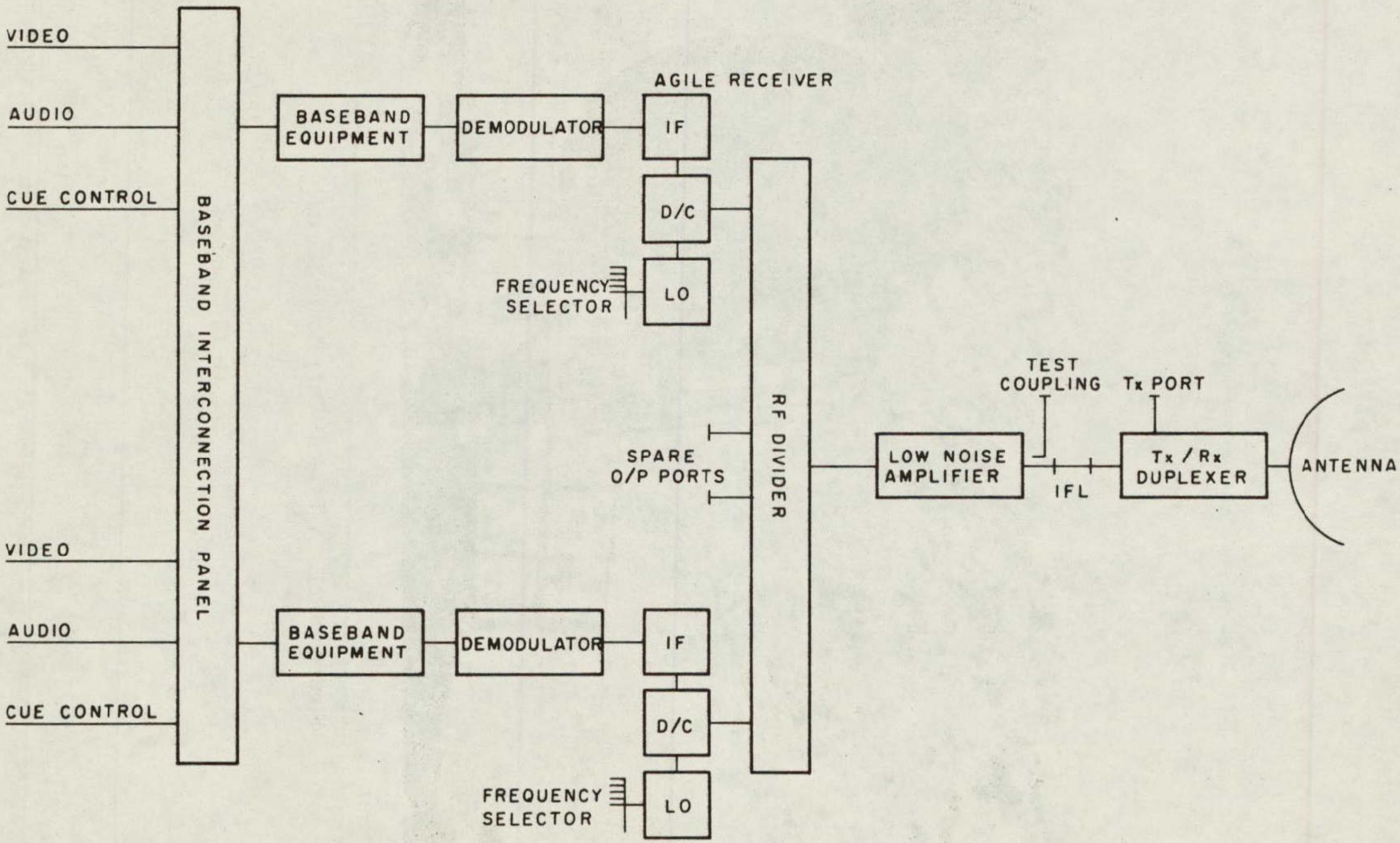


Figure 18-20. A Typical Remote Television Station - Block Diagram

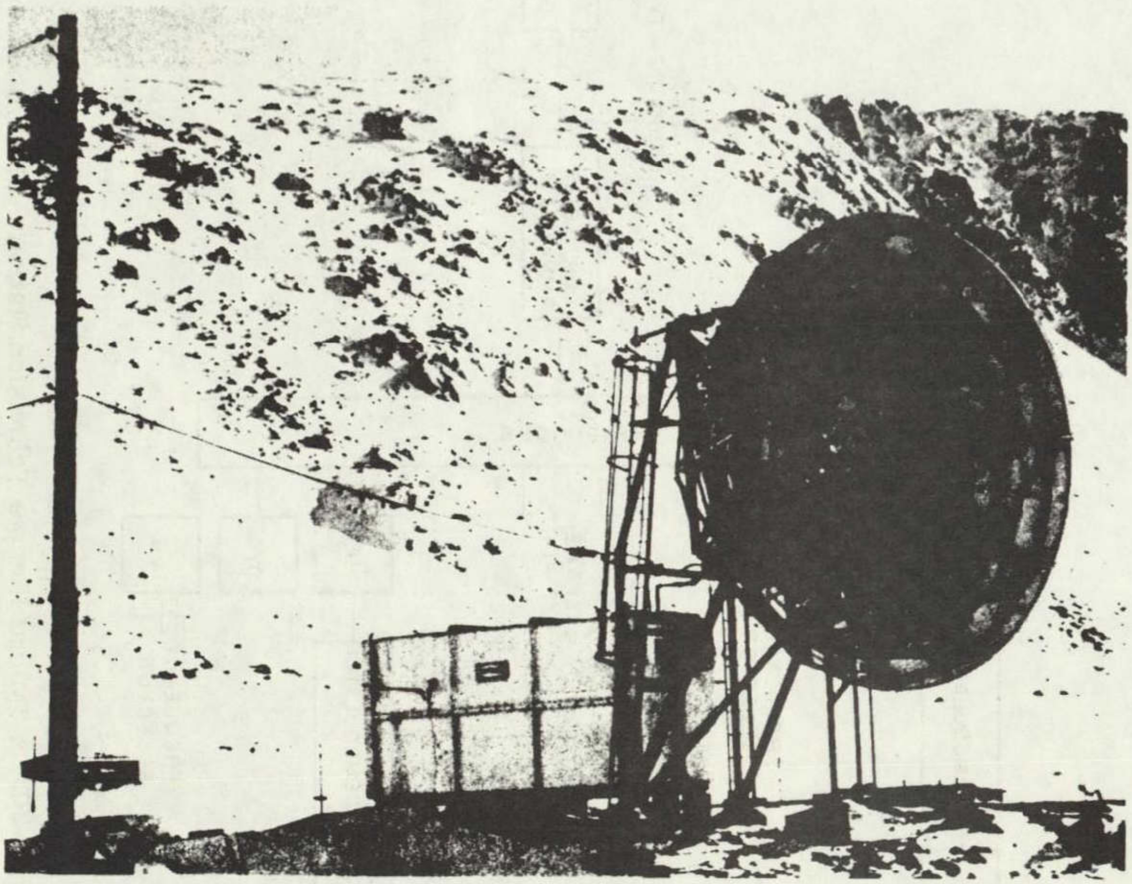


Figure 18-21. A Typical Thin Route Station

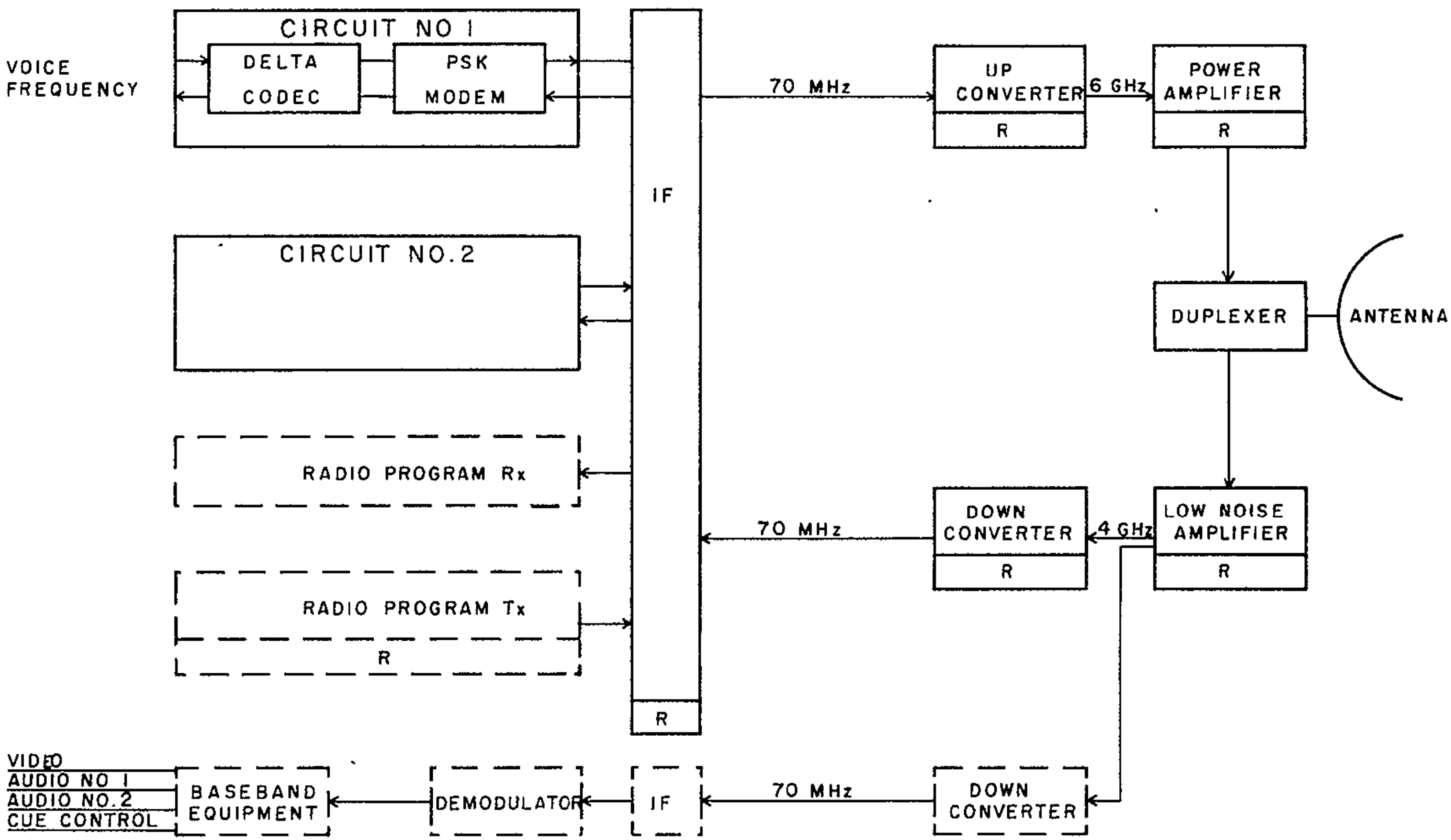


Figure 18-22. A Typical Thin Route Station - Block Diagram

stations, but in a modular fashion such that any one or a group of subsystems could be transported to any location desiring service. For example, in addition to having a complete television station, should television transmission be required from an existing fixed station not presently equipped for this function, a complete television transmission up-chain consisting essentially of modulator, up-converter and high power amplifier could be air shipped together with the necessary interconnection items and quickly installed in the existing building. The provision of message service is covered by a small facility configured to transmit and receive two voice channels. These two stations are to be operational by mid-1974.

The transportable television station has as basic requirements, the ability to be road transported and the ability to provide two simultaneous television transmissions with associated audio. The transmission quality from this station is less than the highest quality available in the Telesat system. It can be set up and made ready for service within two working days with a technical crew of two to set up and operate the communications facilities, however, additional support is required during antenna erection and dismantling. The television station is comprised of the following equipment:

1. A 9.8-meter (32-foot) diameter focal fed antenna which has been designed for ease of erection on a variety of locations. When dismantled, the antenna is assembled in a configuration which can be towed on any highway by a standard haulage unit.

2. A communications trailer, also road transportable, housing the equipment mentioned in paragraphs 1 to 5.

3. Two complete up-chains capable of taking two television feeds and associated audio in standard format and levels and modulating, up-converting and amplifying the signals to the appropriate frequencies, levels, etc. Frequencies corresponding to any of the twelve satellite RF channels may be selected by means of a front panel switch. This multi-frequency capability allows great flexibility in achieving frequency coordination at any location and permits the use of any RF channel assigned for use.

4. A frequency agile receiver capable of monitoring any of the twelve channels. This is used essentially as an operational monitoring device; however, the station could be equipped to receive network quality television by substitution of a higher performance low noise amplifier.

5. Picture and waveform monitoring equipment.

6. A completely self-contained diesel-electric power generation and distribution system to operate the entire station. This unit, together with its fuel tank and control system, is also trailer mounted.

The transportable message station is designed in a form which is suitable for air transportation by small aircraft such as the Twin-Otter. The station consists basically of the following:

1. A 3.7-meter (12-foot) diameter focal fed antenna so constructed as to be readily erected by two technicians in a few hours. Provision is made to permit the antenna to be mounted on a variety of sites by the inclusion of various ground anchoring arrangements. The antenna reflector is assembled from four horizontally sliced segments for ease of storage in a Twin-Otter. The total weight of the complete antenna is less than 272 kg (600 lb).

2. An equipment shelter of cube form of 2-meter (6-foot) sides is constructed of relatively light foam filled fiberglass panels some 1 meters x 2 meters (3 ft x 6 ft). The roof and floor are strengthened to take snow/ice and equipment/people loads respectively. It can be erected by two men in about half an hour by virtue of its light prefabricated sections which are locked in place by a wedge inserted by hand into fittings mounted on the panels.

3. Message communications equipment, identical to that which is used in the Thin Route stations, as described previously, except that it is packaged in shorter equipment racks to permit easy transportation and set up, and which is powered by a standard incoming 110V 60 Hz supply.

The whole package is kept within operating temperatures by provision of a self-regulating heater/blower fan arrangement. The total power requirement in a typical Arctic environment is 5 KVA including lights and a 1.5 KW heater.

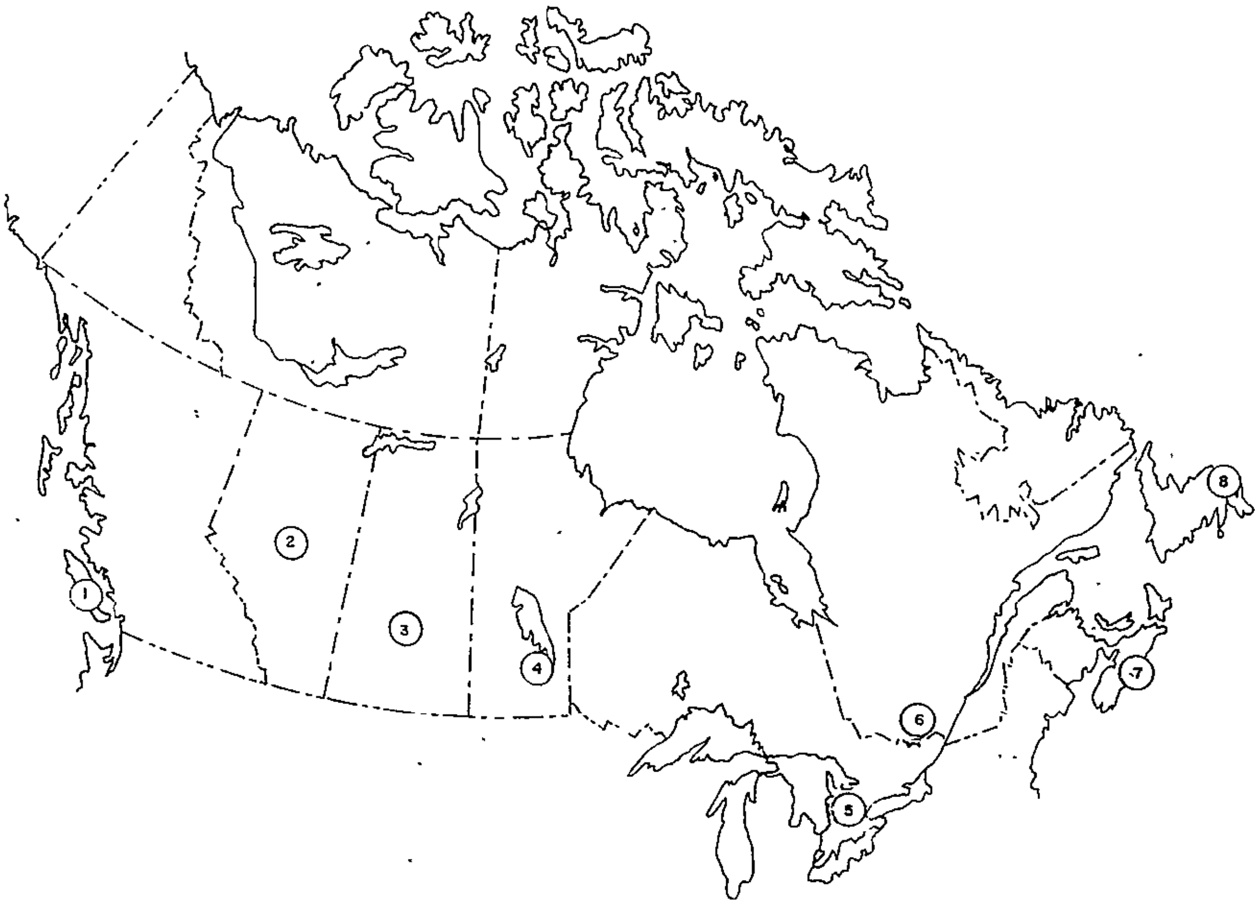
18.6 OPERATIONAL RESULTS

18.6.1 Television Services for the CBC

The television services provided to the CBC accommodate the distribution of network-quality television to major centers across Canada for redistribution on terrestrial systems, and permit the extension of television to individual communities in the remote regions of the country. The eight stations which support the network service are shown in Figure 18-23 and the twenty-five stations used for the remote service are shown in Figure 18-24.

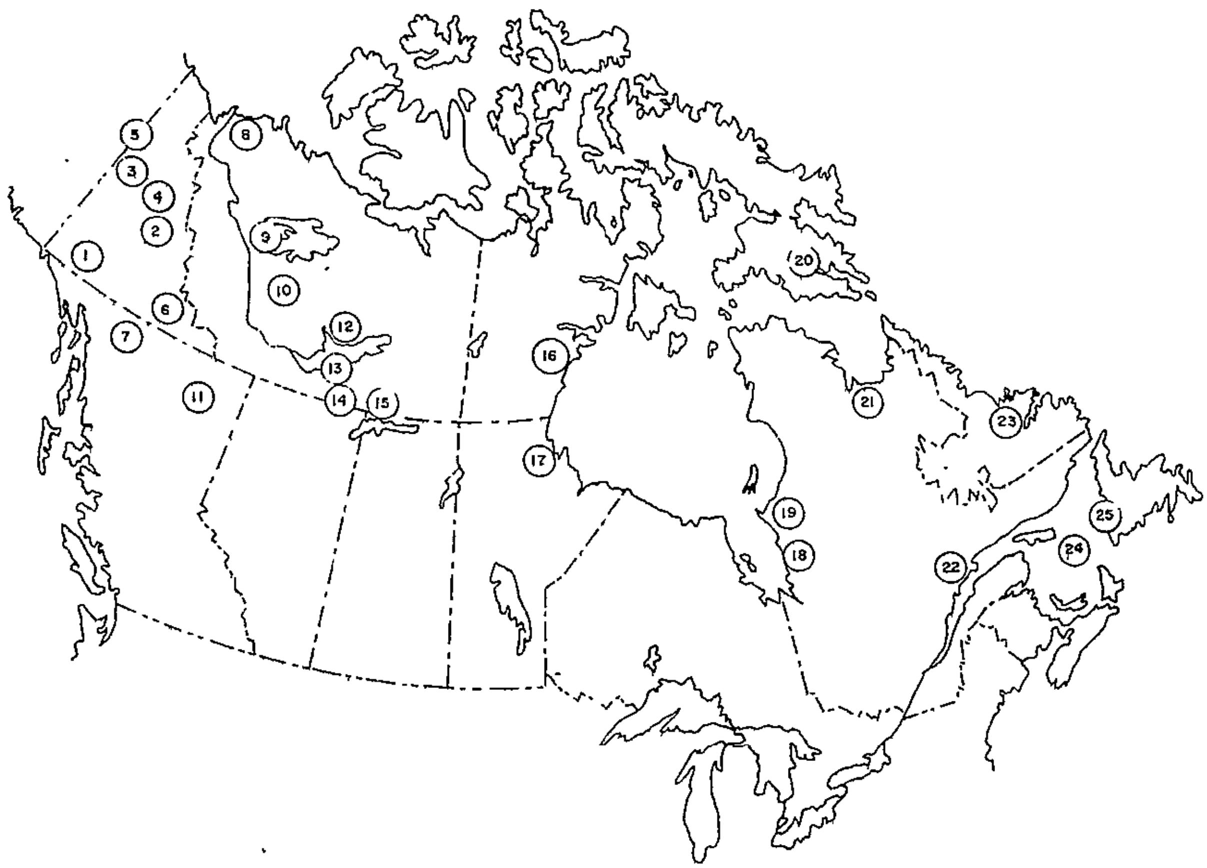
All eight of the stations supporting network service are currently capable of receiving three television channels simultaneously, and although the Allan Park, Riviere Rouge and Lake Cowichan Stations are used to transmit programs on a full-time basis, all are equipped with a transmit capability for occasional use.

To provide the CBC with the desired flexibility in program origination and reception for the entire television service, a Cue and Control System embodying remote switching of transmit and receive chains was designed and implemented by Telesat. The system took into consideration the CBC's programming constraints and the fact that the majority of earth stations in support of their services were equipped as receive stations only and as such, lacked the ability to give status feedback to control centers. It permits the complete control of program distribution by either manual or automatic means from either of the two identical control centers at the CBC premises in Toronto and Montreal. The circuit carrying the cue and control commands, which are specifically addressed for each station in the network, is multiplexed into the audio portion of the television baseband and transmitted along with the video and audio signals. Additionally, since both of the control centers have equal access to the network and since each is automatically updated on commands regardless of the point of origin, the Cue



Telesat Earth Station Locations for CBC Network Television Service	Centres Served for the CBC
1. Lake Cowichan	Vancouver
2. Huggett	Edmonton
3. Qu'Appelle	Regina
4. Belair	Winnipeg
5. Allan Park	Toronto
6. Riviere Rouge	Montreal
7. Harrietsfield	Halifax
8. Bay Bulls	St. John's

Figure 18-23. Telesat Earth Station Locations for CBC Network Television Service



1. Whitehorse
2. Clinton Creek
3. Dawson
4. Elsa
5. Faro
6. Watson Lake
7. Cassiar
8. Inuvik
9. Norman Wells
10. Fort Simpson
11. Fort Nelson
12. Yellowknife
13. Pine Point
14. Fort Smith
15. Uranium City
16. Rankin Inlet
17. Churchill
18. Fort George
19. Poste de la Baleine
20. Frobisher Bay
21. Fort Chimo
22. Sept Iles
23. Goose Bay
24. Magdalen Islands
25. Port-au-Port

Figure 18-24. Telesat Earth Station Locations for CBC Remote Television Service and Control System offers the CBC a form of redundancy for command execution and information storage.

18.6.2 Telecommunications Service for TCTS & CN-CP

The Trans-Canada Telephone System (TCTS) and Canadian National-Canadian Pacific (CN-CP) Telecommunications are jointly leasing two RF channels to provide message facilities between Telesat's Heavy Route stations at Allan Park, Ontario and Lake Cowichan, British Columbia. These two RF channels, each of which can carry 960 one-way message circuits, effectively provide a 960 two-way circuit capability. The circuits can be used for any combination of signals including voice, data and facsimile. Figure 18-25 depicts this service.

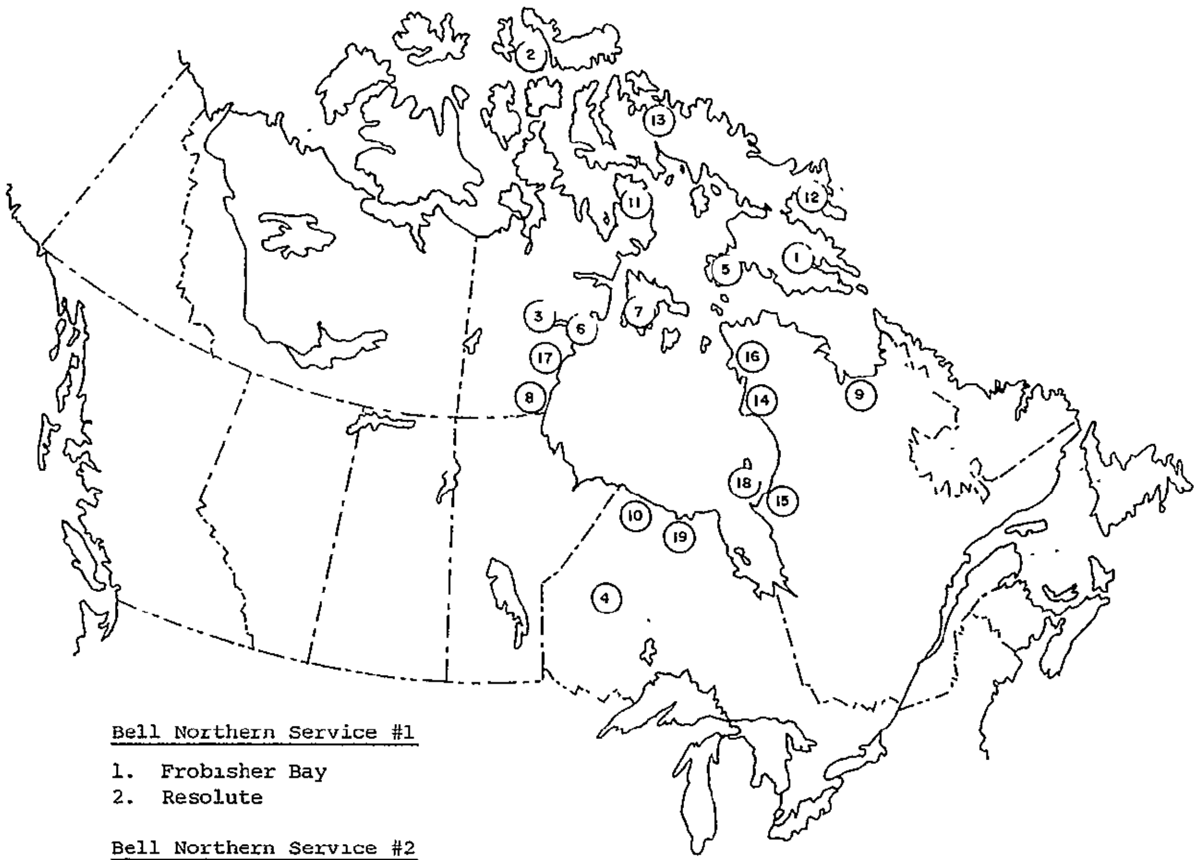
18.6.3 Telecommunications Services for Bell Canada

The telecommunications services provided to Bell Canada, utilize two RF channels and several earth stations, the locations of which are shown in Figure 18-26. Bell Canada, in extending their telephone message facilities in Northern Canada, has arranged their services as follows:

1. One RF channel is being used to provide high quality telephone trunks to locations requiring six or more circuits. The initial service, from Allan Park to the NTC stations at Frobisher Bay and Resolute, is referred to as "Bell Northern Service #1."

2. The second RF channel is being used for the "Bell Northern Service #2" (Thin Route). This is designed to provide from one to six voice circuits and a radio program capability at smaller northern communities. The first two stations, Igloolik and Pangnirtung, went into service in February 1973; seven additional locations will have service provided in 1974, and a further eight locations will be operational in 1975.

Figure 18-25. Telecommunications Service for TCTS & CN-CP



Bell Northern Service #1

1. Frobisher Bay
2. Resolute

Bell Northern Service #2

3. Baker Lake
4. Big Trout Lake
5. Cape Dorset*
6. Chesterfield Inlet*
7. Coral Harbour
8. Eskimo Point*
9. Fort Chimo
10. Fort Severn*
11. Igloolik
12. Pangnirtung
13. Pond Inlet*
14. Port Harrison*
15. Poste de la Baleine*
16. Povungnituk
17. Rankin Inlet
18. Sanikiluaq*
19. Winisk

* indicates stations to be implemented in 1975.

Figure 18-26. Telecommunications Services for Bell Canada

18.6.4 Message Service for COTC

One RF channel will be used by the Canadian Overseas Telecommunication Corporation (COTC) when the CANTAT II trans-Atlantic cable is put into service in 1974. Telesat will provide the link between the western terminal of the cable at Beaver Harbour, which is north of Halifax, Nova Scotia and a COTC switching center in Toronto, using the earth stations at Harrietsfield and Allan Park, respectively (see Figure 18-27).

The initial requirement which is for 240 2-way circuits, will be upgraded to 400 circuits in 1975, by the introduction of TDMA techniques.

18.6.5 DOMSAT Service for U.S.

Beginning in July 1974, RCA Globcom/Alascom began using one Telesat transponder to link earth stations in the Washington-New York corridor, the San Francisco area, and Juneau and Anchorage, Alaska. For more details, see Section 20.

18.7 EXPERIMENTS

The Telesat program has included several experimental activities, including a TDMA Study Program. This study was initiated in the summer of 1971. Although results of theoretical analysis indicated that the TDMA system design could be implemented, there remained two major areas which needed experimental verification--the first being the effect of adjacent channel interference, and the second, the in-band digital performance of the TDMA channel. The first question was associated with the effect of the TDMA signal on its adjacent transponders which may carry a variety of signals. This type of interference is due primarily to energy spreading of the TDMA signal caused by satellite TWT nonlinearities, and post TWT filters. In this case, Telesat was concerned with the interference level in an analog FM channel since the two neighboring transponders have been assigned to this type of traffic. Experiments were conducted at the Hughes Aircraft Company in Los Angeles in November 1972 to investigate the effects of adjacent channel interference. Results indicated that the ANIK transponder could support a bit rate of 61 Mb/s without causing any noticeable

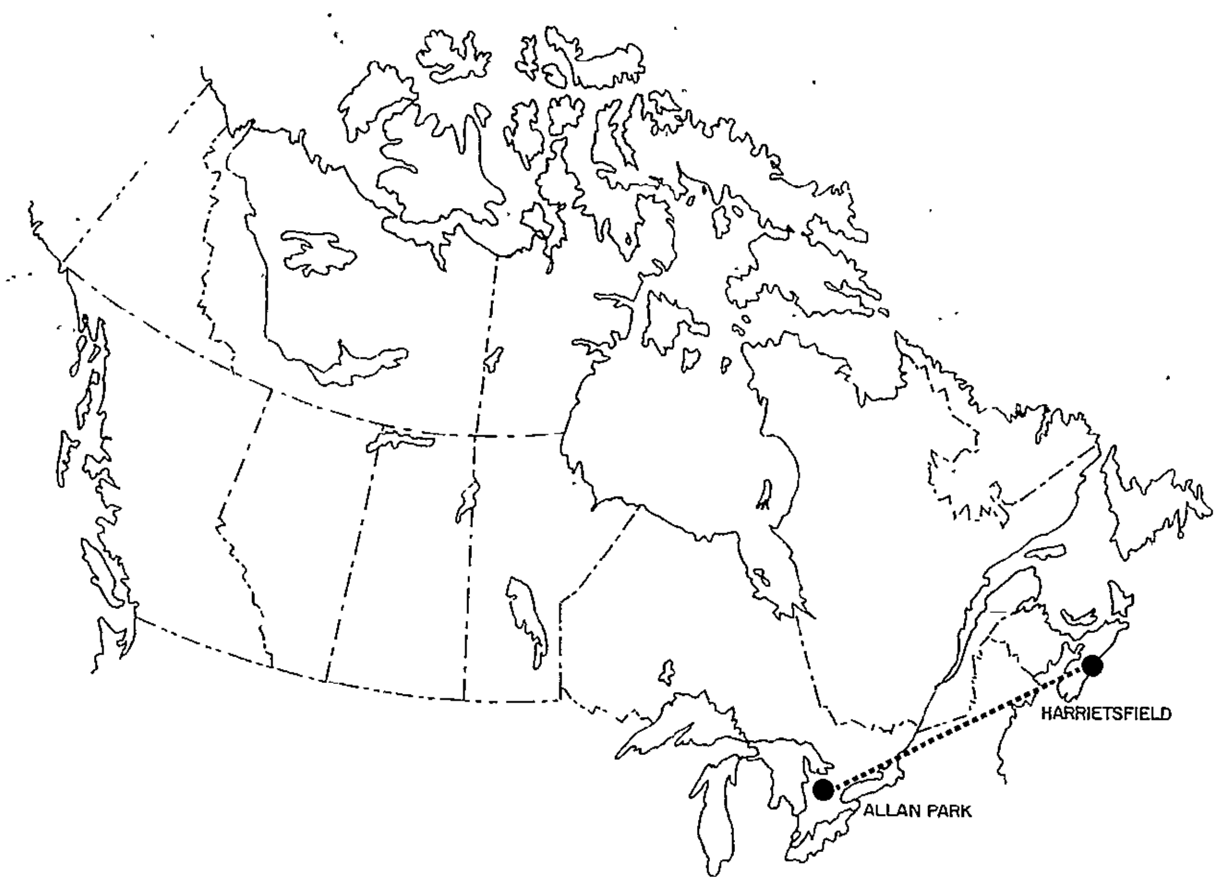


Figure 18-27. Message Service for COTC

degradation, both objectively and subjectively, in the neighboring analog channels carrying either video or high-capacity message traffic. A similar experiment was repeated in February 1973 at the Allan Park Earth Station in a more realistic environment (i.e., including the transmit and receive chain, and the satellite in orbit) and results confirmed the laboratory measurements. As to the TDMA in-band digital performance, experiments were carried out at Allan Park in March 1973. It was found that the bit error rate performance of the proposed TDMA link at 61 Mb/s was practically achievable. A Link Budget for this TDMA system is presented in Table 18-6. This table shows that the link will meet the specified noise performance of 1000 pWp0 with an excess operating margin in the order of 2.7 dB.

The implementation plan will include a three-to-six-month field trial period prior to the actual cutover of the TDMA services. This field trial will provide not only the system operating experience but also an opportunity to verify the results of previous TDMA experiments.[2]

Table 18-8. TDMA System Performance Analysis[2]

Parameters	Allan Park-Harrietsfield	Harrietsfield-Allan Park
1. Bit error rate required		
Satellite channel	4×10^{-4}	3×10^{-6}
After error correcting decoder	3×10^{-6}	-
2. Equivalent noise contribution in each 3 kHz channel (pWp0)	1000 (Note 1)	1000 (Note 1)
3. Satellite Output Backoff (dB)	0	0
4. Carrier to noise temperature ratio (dBW/^{o}K)		
a. Up-link	-125.0	-125.0
b. Down-link	-131.5	-125.2
c. Total	-132.4	-128.1
5. Available E_b/N_o (Fairweather)		
a. Calculated (dB)	18.3 (Note 2)	22.6 (Note 2)
b. Measured (dB)	-	23.4 (Note 3)
6. Required E_b/N_o (dB) (Total)	15.6	19.8
a. Theoretical E_b/N_o required	8.0	10.4
b. Modem plus earth station equipment	2.6	4.4
c. Satellite effects	2.0	2.0
d. Fade margin (99.9%)	3.0	3.0
7. Excess link margin (5i-6) (dB)	2.7	2.8

NOTES:
1. Loading is specified by -12 + 10 log N dBmO (where N = 400 channels)
2. E_b/N_o = C/T -10 log k - 10 log R (where R = 61.248 Mb/s and 10 log k = -228.6 dBW/^{o}K-Hz)
3. Obtained during TDMA experiments at Allan Park in March 1973

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SECTION 19 - COMMUNICATIONS TECHNOLOGY SATELLITE

19.1 INTRODUCTION

Under an agreement announced on April 20, 1971 the United States and Canada established the Communications Technology Satellite (CTS) program to explore the communications potential of the recently allocated 12/14 GHz region. The United States portion of the project will be administered by NASA and will provide the launch vehicle, launch support, environmental test support, and a high power ($\approx$ 200 watts) TWT amplifier. The Canadian effort, directed by the Department of Communications, will be responsible for the design and construction of the spacecraft. Pursuant to this goal, Canada entered into an agreement on May 18, 1972 with the European Space Research Organization (ESRO) which provides for European cooperation in the CTS project through the development and supply of two 20 watt traveling wave tubes (TWT), a parametric amplifier, and the solar cell blankets to be used on CTS.

The primary objective of the CTS program is to provide a vehicle for experimentation on the flexibility of satellite communication systems in the 12/14 GHz region. The program is expected to (1) demonstrate the feasibility of TV transmission at 12 GHz from satellite to low cost ground terminals, (2) demonstrate the feasibility of TV transmission at 14 GHz from transportable and low cost fixed terminals to the satellite, and (3) develop and flight test components for use in future communications satellites. Additionally, the CTS program will include experiments with audio broadcasts, two way telephony, and wideband data links.

To meet these objectives the United States and Canada have agreed to initiate experimental programs designed to illustrate the adaptability of satellite systems to the distribution of information to sparsely settled areas. The programs are to be implemented by various independent experimenters who have designed experiments in two categories; those which advance space systems technology and those which demonstrate the suitability of space systems to the solution of social problems. The actual experiments planned are discussed in Section 19-4.

Current plans postulate that the CTS will be launched into geostationary orbit in January 1976 by a Delta 2914 vehicle. The orbit envisioned for CTS is 116° W longitude with a variation in East-West position not to exceed ± 0.2 degrees over the two year lifetime. The launch window will be selected to provide an inclination less than one degree for satellite life with the inclination remaining below 0.65 degree as long as possible.

During its operational life the CTS spacecraft will demonstrate several subsystems which constitute advances in the state-of-the-art of satellite communications. The most significant advance expected is the development of a high efficiency, 12 GHz, 200 watt TWT. Successful flight qualification of such a tube will measurably enhance current TWT technology and provide a solid basis for future high power satellite systems. Two expected spacecraft systems applications advances are the use of an accurate three-axis stabilization on a spacecraft with flexible appendages and the use of an extendable solar array with greater than 1 kilowatt power output. Each of these innovations represents significant application of current technology.

The ground segment of the CTS project also represents a significant application of current technology. The primary experimental program calls for the use of a low cost TV transmission station equipped with a 3.0-m (10-ft) dish to broadcast from remote areas, and the use of remote TV receivers. The demonstration of the economic feasibility of such services may herald new educational opportunities for those citizens inhabiting the remote areas of both the United States and Canada.

19.2 SPACECRAFT DESCRIPTION

Spacecraft characteristics for the CTS are displayed in Table 19-1. The remaining portions of this section are devoted to an elaboration of the significant features of the various subsystems.

Table 19-1. Characteristics of the CTS Spacecraft (1 of 2)

General Data	Sponsors	United States, Canada		
	Launch Date:	December 1975		
	Launch Vehicle:	Delta 2914		
	Orbit:	116° W $\pm 0.2^{\circ}$ E-W		
Spacecraft	Size	$117.2 \times 171.7 \times 180.3$ cm (with sails stowed excluding apogee motor nozzle and "dish" antenna)		
	Sails:	131.2×653.4 cm		
	Weight:	308.4 kg (679.8 lbs) (usable wt. in orbit)		
	Stabilization	Station acquisition: spin stabilized at 60 rpm On orbit: 3 axis stabilization $\pm 0.1^{\circ}$ pitch/roll $+1.1^{\circ}$ yaw		
Antenna System	Type	71.1 cm paraboloid reflectors for SHF	Helix for TT&C	32 element belt array for TT&C
	Polarization	Orthogonal (with 25 dB isolation)	Circular	
	Transmit beam width	2.5°, capable of steerage with 14.5° cone normal to yaw axis with $\pm 0.2^{\circ}$ accuracy	Conical beam $16^{\circ} \times 16^{\circ}$ (Helix and belt array combine to give cardioid pattern)	Torodial
	Gain	xmit } 36.2 dB max receive } 33.2 dB beam edge	Telemetry: 3 dB Command: 2 dB	Telemetry: -3 dB Command: -5 dB

Table 19-1. Characteristics of the CTS Spacecraft (2 of 2)

Communications System	Frequency	Up: 14.010-14.296 GHz Down: 11.843-12.123 GHz	Telemetry: 2277.5 MHz Command: 2097.198 MHz	Beacon: 11.7 GHz
	Bandwidth	Four 85 MHz channels (2 xmit, 2 receive)	Telemetry: 10 MHz Command: 1.5 MHz	
	Power Amp	Primary mode: 20 w TWT drives 200 w TWT Alternate: 20 w TWT		SHF beacon solid state in 200 MW or 12 mW mode
	EIRP	Max 60 dBw		
	System Noise	Noise figure < 9 dB system temp < 2000°K with possibility of one parametric amplifier to reduce to < 1000°K		
Power Source	Spin Stabilized	Body mounted solar array with N: -cd batteries provides 77 W for housekeeping		
	3 Axis Stabilized	Two sail mounted solar arrays (25,272 cells) with sun tracking mechanism provide 1260 W BOL (1040 W experiments, 220 W housekeeping) reduces to 1000 W EOL		
	Solar Cells	N/P, one or two ohm/cm, 2 x 2 cm, 8 mil thick, 4 mil cerium doped cover glass		

19.2.1 Structure

The CTS spacecraft with solar sails extended is illustrated in Figure 19-1. In an undeployed configuration the CTS is basically four sided with a low profile and large diameter to present a favorable moment of inertia ratio for stable spin during the transfer orbit.[1] The structural design emphasizes readily removable components to facilitate the integration of units or subsystems. The core of the design is a central thrust tube to which are mounted the apogee motor and the forward and aft equipment platforms. The forward platform is thermally isolated from the rest of the structure to insure a stable surface for the antenna mounts while the aft platform contains the apogee motor nozzle and reaction control system. Surrounding the structural core are the north and south equipment platforms with jettisonable enclosures outside which provide the stowage for the extendible solar array. The east and west faces of the spacecraft carry the majority of the body mounted solar cells which provide housekeeping power until station acquisition and the deployment of the solar sails. The east and west faces also contain the spinning attitude sensors.

Upon station acquisition the solar sails are deployed. They consist of 30 panels, 26 active and 4 blank, which are extended concertina fashion. Deployment is accomplished by means of a single 0.02-cm (0.007-in.) thick stainless steel Bi-Stem boom with 3.5 cm (1-3/8 in.) diameter and deployed length of 762 cm (300 in.) located on the shadowed side of each sail.

19.2.2 Thermal Subsystem

Throughout the various phases of the CTS mission there will be a wide variation in the amount of heat dissipated by spacecraft components. This necessitates the use of protective devices such as super insulation blankets, jettisonable covers, radiator plates, second surface mirrors, thermal coatings, heat pipes, and heaters to insure the proper operation of spacecraft systems throughout the mission. All major heat dissipating components are mounted on the north-south panels which are covered with silvered quartz second surface mirrors to provide high infra-red emissivity (> 0.8)

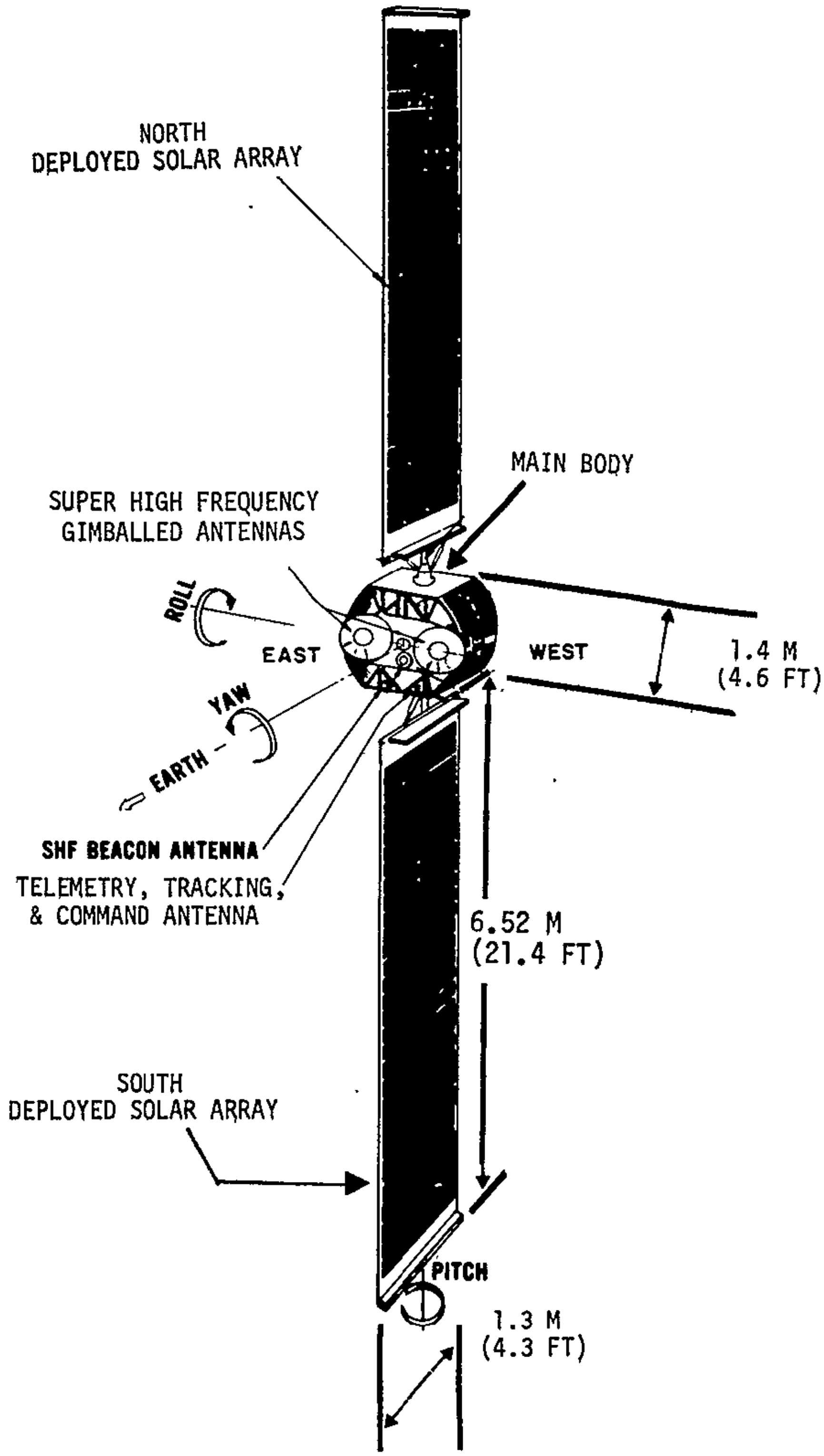


Figure 19-1. CTS Configuration On Station Showing Extendible Array Fully Deployed

and lower solar absorptivity (< 0.08). The two most critical thermal problems are maintaining the dimensional stability of the forward deck and providing for the dissipation of heat from the high power TWT. The forward deck must be stable to reduce the pointing error of the antenna system so it is thermally isolated from the rest of the spacecraft structure and insulated from space by multi-layer insulation blankets. The TWT waste heat dissipation problem is to be solved by direct radiation cooling from radiator plates connected to the multi-stage depressed collector (MDC). The MDC assembly extends beyond the aft platform directly exposed to the space environment to enhance the direct radiation cooling.

19.2.3 Antenna Subsystem

The SHF communications antenna system consists of two gimballed 71.1 cm parabolic reflectors with 2.5° beamwidth mounted on the front deck and capable of positioning the electrical boresight anywhere within a 14.5° cone about the normal to the deck. The pointing error relative to the deck is less than $\pm 0.1^{\circ}$ which is sufficient to provide an overall boresight pointing accuracy of $\pm 0.2^{\circ}$.

Each antenna is capable of simultaneous transmission and reception of orthogonal linearly polarized signals. Isolation between the polarization is at least 25 dB. The antenna pattern generated by each antenna creates sidelobe levels expected to be -14 dB and -25 dB for the first and second sidelobes respectively.

The primary TT&C antenna is a circularly polarized helix configuration mounted on the front deck. Boresight gains of 3 dB for telemetry and 2 dB for command are expected. During the station acquisition, and as an alternate during the synchronous phase, the TT&C data will be radiated through a 32 element circularly polarized belt array located at the aft end of the spacecraft thrust tube and providing a toroidal shaped pattern. An SHF beacon antenna mounted on the forward deck is the last component of the antenna package.

19.2.4 Attitude Control Subsystem

The CTS attitude control subsystem consists of two basically distinct systems, one used during the station acquisition phases of the mission and the other during the synchronous operation phase. During the station acquisition phase the spacecraft is spin stabilized about its yaw axis at a rate of 60 rpm and a nutation damper controls disturbance torques. On station attitude control is accomplished through three-axis stabilization which utilizes the "momentum bias" principle of storing momentum normal to the orbit plane to provide gyroscopic stiffness in the orbit plane. Aboard the CTS angular momentum will be stored in a 3,740 rpm, 20 Nms (15 ft-lb-sec) fixed momentum wheel whose spin axis is parallel to the spacecraft pitch axis. Pitch control is obtained by varying the speed of the wheel. Roll and yaw attitude errors are corrected by operation of off-set hydrazine thrusters which create a component of control torque in the yaw and roll axes. This results in gyroscopic precession which, within one quarter orbit, removes the yaw and roll errors.

19.2.5 Electrical Power Subsystem

Prior to deployment of the extendible solar arrays the CTS will be powered by two Ni-Cd batteries and body-mounted solar cells. There are approximately 5070, 2 x 2 cm, 8 mil thick, silicon solar cells in the body mounted array which are capable of delivering a power output of 77 watts at 29 volts.

The main power array consists of 25,272 solar cells mounted on two sails. Each sail consists of 30 panels, 26 active and 4 blank, on flexible Kapton substrate, with a cell packing efficiency of 0.93. The cells are negative on positive (N/P), 1 to 2 ohm/cm 8 mil thick, 2 x 2 cm with 4 mil cerium doped cover glass. The cells have an initial efficiency of 10.5% but the total power output is expected to be reduced by 16% after two years as a result of radiation damage.

The main array will provide a total of 1260 watts at beginning of life in two buses. The experiments bus will have 1040 watts at 76 volts while the housekeeping bus will have 220 watts at 28 volts. Assuming the initial power estimates are achieved, the blankets will have a power to mass ratio of 93 watts/kg (42 watts/lb), while the entire subsystem power to mass ratio is 25.1 watts/kg (11.4 watts/lb).

To obtain maximum power from the cells while on station each sail will be equipped with a sun tracking mechanism. The sails will rotate one revolution per day in increments of 0.125°.

The final components of the subsystem are the two Ni-Cd batteries containing twenty-four 5 amp-hour (AH) cells mounted in aluminum or magnesium blocks for heat sinking. The batteries will have the means to recondition by discharging to a specified level but normally the batteries will be continuously charging. The normal charge rate is C/20, where C is ampere hour capacity at $298.1^{\circ}K$ ($25^{\circ}C$), although higher rates to C/10 will be provided.

19.2.6 Communications Subsystem

The communications subsystem of the CTS is illustrated in Figure 19-2. The experiment package consists of SHF communications transponder, SHF communications transmitter experiment package (TEP), SHF beacon, and antenna subsystem. The communications transponder portion of the experiment consists of the basic communications system on the CTS; an input multiplexer, receiver, and two 20 watt traveling wave tube amplifiers. Two significant innovations in this transponder system are the use of Field Effect Transistor (FET) amplifier instead of Transferred Electron Amplifiers (TEA) and the first space use of a low noise parameteric amplifier (noise figure of 3.3 dB). The primary technological experiment of the CTS program, however, is in the transmitter experiment package (TEP). The TEP consists of a high efficiency SHF 200 watt TWT and its power processor. The tube is being constructed along techniques developed at NASA's Lewis Research Center for multi-stage depressed collectors. The output of the 200 watt TWT is based on a 50% efficiency at 12 GHz. The successful operation of such a tube would significantly advance high power satellite technology. The specifications for the 200 watt TWT are given in Table 19-2 and a typical schematic of this type tube is shown in Figure 19-3.

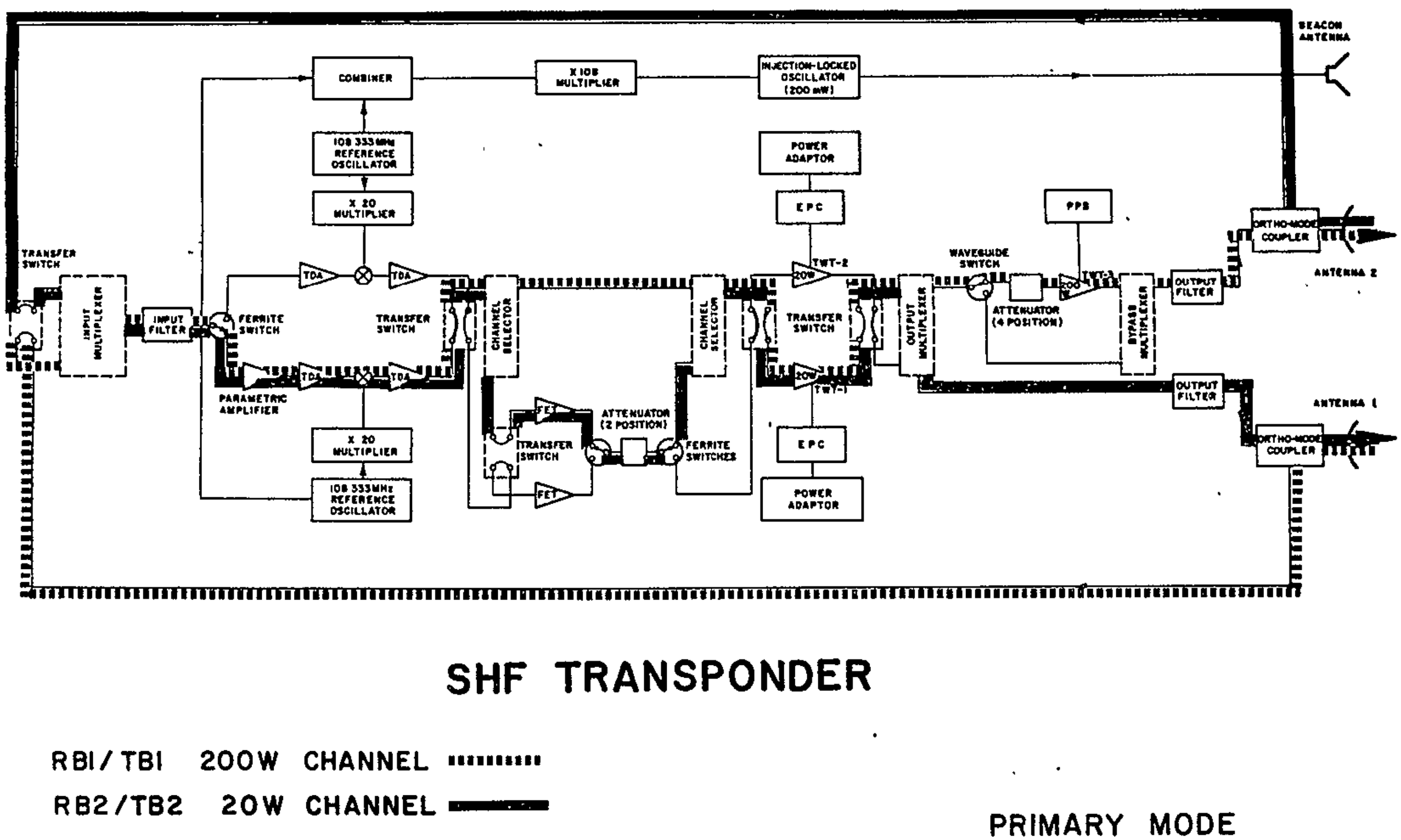


Figure 19-2. SHF Communications Experiment

Table 19-2. 200 Watt TWT Specifications

1. Maximum weight 13 kg (28 lb)

2. Maximum size 51 cm (20 in.) x 25 cm (10 in.) x 25 cm (10 in.)

3. Efficiency - approximately 50%

4. RF and power characteristics

   a. Center frequency 12.0805 GHz.

   b. rf power output at saturation 200 w.

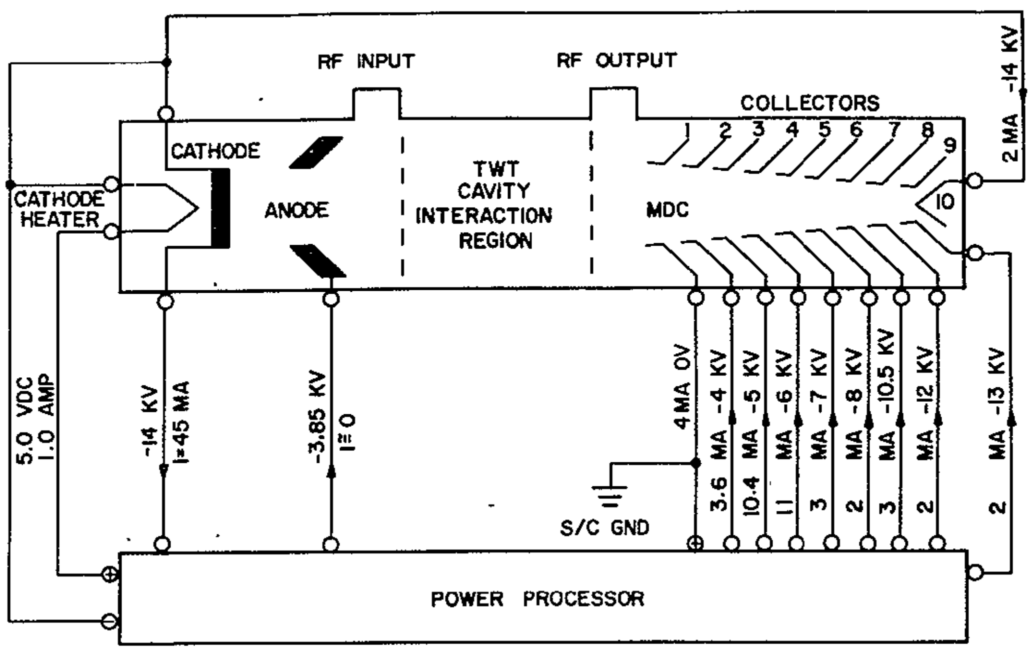
   c. Three db small signal bandwidth 85 MHz minimum, 250 MHz maximum.

   d. Saturated gain in pass band 29 db $\pm$ 1 db.

5. Mechanical and thermal characteristics

   a. The TWT body thermal design shall employ a common heat bus. The bus will be connected by a heat conductor to a base plate on the spacecraft.

   b. The MDC cooling shall be by direct radiation to its vacuum enclosure.



CATHODE, ANODE, AND COLLECTOR VOLTAGES ARE REFERENCED TO GROUND

Figure 19-3. Typical Traveling Wave Tube Elements and Power Processor Electrical Interfaces

The primary mode of operation for the CTS is to drive the 200 watt TWT with one of the two 20 watt TWTs. Under this scheme the CTS transponder receives a TV transmission at 14 GHz from the Ottawa control station via antenna No. 1 and rebroadcasts through antenna No. 2 via the 200 watt TWT. Simultaneously a signal from a low cost remote transmitter is received via antenna No. 2 and rebroadcast to Ottawa from antenna No. 1 via the other 20 watt TWT. The alternative mode of operation, and backup in the event the 200 watt TWT is inoperative, is to use the 20 watt TWT in place of the 200 watt TWT. In both modes the transponder has two uplink and two downlink pass bands, each 85 MHz bandwidth, as shown in Figure 19-4.

The SHF beacon is the final portion of the SHF communications experiment package and it consists of a solid state transmitter feeding a single horn. The beacon operates at either 12 mW or 200 mW and broadcasts a single unmodulated carrier at 11.7 GHz.

19.2.7 TT&C Subsystem

The TT&C Subsystem utilizes S-band transponders compatible with the Space Tracking and Data Network (STDN) unified S-band system. Command signals will be in PCM/FSK/AM format at a frequency between 2025 and 2120 MHz. The telemetry system is PCM/FM/PM format at a frequency between 2200 and 2300 MHz.

19.3 GROUND STATIONS

One of the prime objectives of the CTS program is to demonstrate the feasibility of using low cost ground stations in satellite communication systems. The motive behind this objective is twofold; first, to illustrate that broadcasts to remote areas are economically practical, and secondly, to encourage the participation in the experimental program of independent experimenters with limited financial resources but worthwhile experiments. Since the CTS program envisioned for the United States requires that each individual experimenter acquire the necessary ground equipment for his experiment, the availability of low cost ground terminals influences the number of potential experimenters. In light of this, the ground stations are configured to use commercially available components. Both the United States and Canadian experiment programs

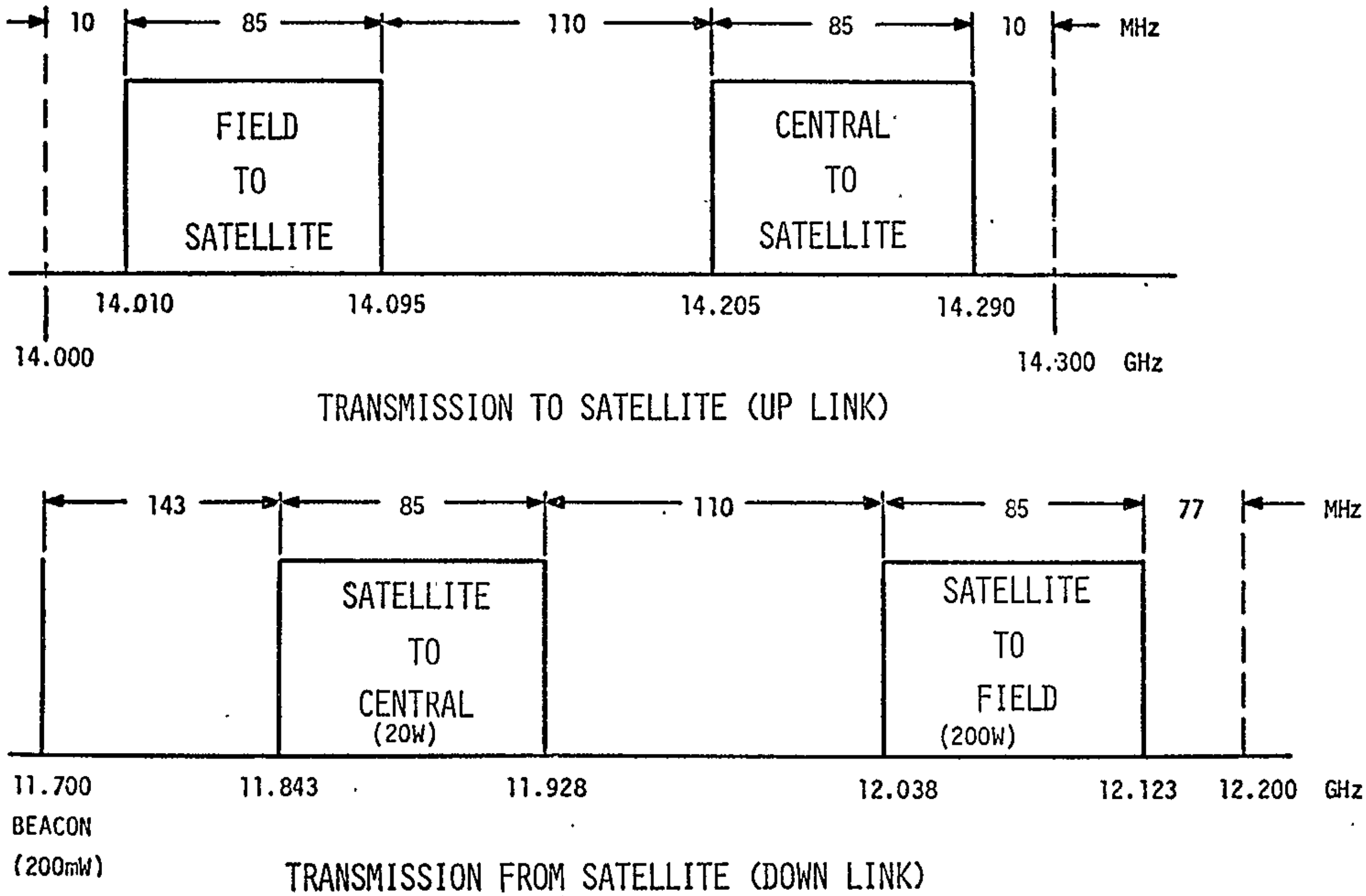


Figure 19-4. SHF Frequency Plan

currently intend to have the basic terminal equipped with a 2 m to 3 m (8 ft to 10 ft) dish and tunnel diode amplifier. Such a configuration provides the figure of merit necessary for TV reception from the CTS. The antenna system will include both a dish and control mechanism. To keep the cost as low as possible the antenna mount will be of a type where the initial set-up is easily accomplished. A few experimenters are expected to have tracking mechanisms.

Properties of the proposed Canadian terminals are given in Table 19-3, which also gives characteristics of the CTS antenna in Ottawa.

19.4 EXPERIMENTS

Under the CTS agreement the United States and Canada share the experiment time on an equal basis. Each country's tentative program is described in Table 19-4. In general, the experiments are in two classes; technical and social. The technical experiments are to evaluate the performance of the spacecraft and ground stations while the social experiments are to test the usefulness of a satellite communications network in solving social problems.

Table 19-3. Summary of Proposed SHF Terminal Characteristics (12-14 GHz)

Terminal	Properties							
	Antenna			RCVR		Figure of Merit G/T, db/°K	Max. Transmitter Power, w	Antenna Control
	Diam	Peak Gain, db	3 db Beamwidth	Type	Noise Temp. °K			
Control (Ottawa)	9.1 m (30 ft)	57	0.2°	Uncooled paramp	200	32.8	200	Fully steerable auto-track
TV remote transmission	3.0 m (10 ft)	49	0.5°	Uncooled paramp	200	22.8	1200	Step-track
TV receive only and two-way voice	2 m (8 ft)	47	0.7°	Tunnel diode amplifier	670	16.6	20	Manually adjustable
Two-way voice and/or FM sound broadcast receive	1 m (3 ft)	38	1.8°	Tunnel diode amplifier	670	8.2	20	None (fixed)

Table 19-4. CTS Experiments (1 of 8)

Title	Organization	Country	Objective
Communication Link Characterization	GSFC	U.S.	To test operational hardware, link performance and link characteristics. Also to provide near real time characterization of EMP environment and long term variation to advance technology.
College Curriculum Sharing	ARC, Carleton, Stanford	U.S.	To demonstrate the ability to expand instruction by sharing classes between universities and to optimize class presentations and interactive techniques to promote curriculum sharing. In addition the experiment will be used to develop, demonstrate, and evaluate cost effective video compression techniques in conjunction with efficient channel coding and modulation.
Transportable Earth Terminal	COMSAT	U.S.	To demonstrate the feasibility of providing quick-reaction emergency communications to areas isolated by disaster or geographic conditions. CTS will be used to interconnect a base earth station with a remote highly portable terminal which has been dropped or transported to an area of simulated emergency. The link will be capable of providing two-way TV and/or voice.

Table 19-4. CTS Experiments (2 of 8)

Title	Organization	Country	Objective
Biomedical Communications	Lister Hill, HEW	U.S.	Promote wide dissemination of information between research institutions and the medical community; evaluate broad band teleconference to support continuing education among health care professionals.
Satellite Library Information Network (SALINET)	SALINET	U.S.	To demonstrate the feasibility of extending library services to rurally isolated communities. Included would be an extension of library services to local officials, small businessmen, and paraprofessionals; as well as the maintenance of a regional bibliographic data bank.
Satellite User Network (SUN)	Federation of Rocky Mountain States	U.S.	This is a follow-on to the STD experiment on ATS-6 and will provide for the distribution of career counseling information to grades 9, 10, 11. The experiment will also disseminate information to state services and promote land use planning.
Propagation	Communications Research Centre	Canada	The following propagation factors will be measured: polarization isolation, low angle effects, and precipitation attenuation.
TDMA	Communications Research Centre	Canada	The performance of a novel synchronization technique will be tested and used as the basis for implementing a TDMA (Time-Division Multiple-Access) experimental system. Data from the synchronization experiment will be used to make very accurate determinations of the satellite position and orbit.

Table 19-4. CTS Experiments (3 of 8)

Title	Organization	Country	Objective
Demand Assignment	Communications Research Centre	Canada	This experiment will evaluate a Frequency-Division Multiple-Access Demand Assignment (FDMA/DA) system for small terminal remote area satellite communications with particular application to two-way voice communications.
High Rate Data	Communications	Canada	A simple modulation-demodulation equipment (modem) at a high rate of transmission (about 65 Mb/s) will be evaluated for use in data experiments and particularly, the transmission of digital TV.
Small Terminal Evaluation	Communications Research Centre	Canada	An experiment will be undertaken by CRC with the cooperation of CTS experimenters to evaluate installation, operation and maintenance factors in the use of the Voice and Audio Program Remote User Experimental Terminal and the Video Interactive Remote User Experimental Terminal.
Signal Reception in Metropolitan Environments	Canadian Broadcasting Corp.	Canada	This experiment will evaluate the reception, in a metropolitan environment, of 12 GHz TV signals transmitted by CTS.
Applications of Radio Broadcasting	Canadian Broadcasting Corp.	Canada	The usefulness and technical feasibility of the CTS Radio Broadcast System for (1) delivery of network service to remote communities, (2) transmissions of broadcast material from one remote community to another, (3) transmission of special-interest material for direct reception and (4) transmission of news or information back to main network points for inclusion in network programs will be tested.

Table 19-4. CTS Experiments (4 of 8)

Title	Organization	Country	Objective
TV Special Demonstration	Canadian Broadcasting Corp.	Canada	CTS will be used during the Olympic Yachting competitions to relay TV signals from Kingston to Montreal to test the suitability of the facilities of CTS for remote TV broadcasting and its control and to assess the flexibility and handling efficiency of portable ground stations under the pressure of operations.
Train Location	Queen's University	Canada	The objective of this experiment is to investigate the feasibility of using a synchronous communications satellite to transmit the position of a train on rail lines of low capacity.
Digital Video Curriculum Sharing	Carleton University/ Stanford University NASA/ARC	Canada	Carleton University with Stanford University and NASA-Ames Research Center will develop, demonstrate and evaluate college curriculum sharing techniques using a digital video-compression system.
Community Interaction	Newfoundland Communications Technology Committee	Canada	Community Interaction which will contribute to continuing development of small Newfoundland communities.
Telemedicine	Newfoundland Communications Technology Committee	Canada	Telemedicine focusing on continuing medical education programs, consultation services, and continuing health education.

Table 19-4. CTS Experiments (5 of 8)

Title	Organization	Country	Objective
Telemedicine, Education, Administration	Province of Quebec	Canada	In addition to the cultural exchange experiment co-sponsored by the University of Saskatchewan (U-9), the Quebec Ministry of Communications is coordinating experiments in the province involving: 1. Community communications for Eskimo groups - radio and TV with voice return. 2. Telemedicine - transmission of ECG's and radiographs. 3. L'Universite du Quebec - tele-education, document delivery and teleconference. 4. Telephony to temporary camps in the James Bay development area. 5. Transmission of data by Hydro-Quebec to investigate applications in remote areas.
Signal Processing Techniques for Data Communications	University of Waterloo	Canada	The purpose of this experiment is to study signal code and signal processing techniques and to evaluate their effectiveness in data communications over a satellite channel.
Multi-Ministry Administrative & Operational Experiments	Government of Ontario	Canada	The Ontario Government will study and evaluate the capability (actual and potential) of satellite communications to improve the delivery of government services to remote areas in the following modes: 1. Point-to-point communications - two-way voice, facsimile, slow-scan TV transmission. 2. "Broadcast" - facsimile and teletypewriter transmissions.

Table 19-4. CTS Experiments (6 of 8)

Title	Organization	Country	Objective
Educational and Social Development in Indian Committee	Ontario Educational Communications Authority (OECA)	Canada	In what is essentially a user-oriented project, the OECA will provide assistance to Indian communities in Northwestern Ontario to develop voice and video programs. These will be used in an experiment to determine the educational and social implications of the use of satellite transmissions.
Government Teleprocessing Network	Province of Manitoba, Management Committee of Cabinet	Canada	With a view to the future decentralization of government data processing, the Manitoba Government Computer Centre is investigating various aspects of terminal-to-computer and computer-to-computer communications.
Very Long Baseline Interferometry	University of Toronto	Canada	In this experiment, the satellite will be used to provide a link between two radio telescopes (one in Canada and one in the U.S.) to form a radio interferometer which will provide information on the structure and position of astronomical radio sources.
Digital Modems for High Rate Data	McMaster University	Canada	The purpose of this experiment is to study the performance of modems for high-rate digital data transmission via CTS.
CAI in Native Languages	University of Western Ontario	Canada	This experiment will test the value to native people in the Yellowknife Area in the Northwest Territories of access to a large computer in the south using their own language.

Table 19-4. CTS Experiments (7 of 8)

Title	Organization	Country	Objective
Telemedicine	University of Western Ontario	Canada	Various aspects of telemedicine will be investigated: 1. Transmission of radiographs, slow-scan TV and ultrasound images from a northern nursing station. 2. Audio-video supervision of professional services at a remote hospital by specialists at a southern hospital. 3. Remote psychiatric services, consultations, data storage and retrieval, nursing and staff education.
Upgrading Mathematical Competence of Elementary School Teachers	Lakehead University	Canada	The use of a communications satellite to provide courses in mathematics and mathematics education to elementary teachers in remote areas will be evaluated.
Cultural Exchange	University of Saskatchewan/ Quebec	Canada	The purpose of the experiment is to make use of CTS to link two communities in the north of Saskatchewan and in Quebec. These two regions, although widely separated geographically, have common aspects and problems and will benefit from the interchange of cultural and educational programs.

Table 19-4. CTS Experiments (8 of 8)

Title	Organization	Country	Objective
Transportable Terminals	Bell Canada/Telesat	Canada	The transmission capabilities, station portability, reliability and maintainability of the two-way voice terminals will be investigated by conducting experiments using a terminal at Frobisher Bay on Baffin Island.
Digital Transmission of Color TV	Bell Northern Research	Canada	Technical aspects of the transmission of commercial color TV signals in digital format at a bit rate of approximately 45 mbit/sec will be investigated.
Health Care Delivery to Remote Areas	Queen Charlotte Islands General Hospital	Canada	This experiment will determine the optimum use of two-way television in providing for operation and management of a primary health delivery system in a remote rural area by performing remote diagnosis, training and on-the-job supervision of medical and paramedical personnel.
Communications in Native Communities	Alberta Native Communications Society (ANCS)	Canada	Interactive communications will be evaluated between remote native communities in social development, education/training, health/medical, legal and cultural/entertainment fields.

NOTE: The Canadian Experiment data was furnished by Ms. Doris Jelly of Communications Research Centre.

Table 19-5. U.S. CTS Experiments as of November 1975

Category	Title	Organization	Principal Investigator
Health Care/ Medicine	Biomedical Communications	Lister Hill, HEW*	Henderson
	Health Communications**	Veterans Admin.*	Shamaskin
	Decentralized Medical Education	Washington, Alaska, Montana, Idaho*	Schwarz
	Health Education TV	Assoc. Western Hospitals	Allen
Education	College Curriculum Sharing**	ARC, Carleton, Stanford	Lumb
	SECA Experiment	Southern Educational Communications Assoc.	Morris
	Project Interchange**	Archdiocese of San Francisco	Gibbs
Community Services	Satellite Library Information Network	Salinet	Goggin
	Comm. vs. Transportation**	Westinghouse	Nunnally
Special Services	Transportable Earth Term.**	Comsat Corp.	Kaiser
	Interactive Techniques for Intra-NASA Applications	Goddard	Chitwood
Technology	Comm. Link Characterization**	Goddard*	Ippolito
	12-GHz Broadcast Ground Station Technology Experiment	NHK, Tokyo, Japan Goddard*	Konishi Miller

*Experimenters using ATS-6

**Final acceptance

REFERENCES

1. "Communications Technology Satellite Support Instrumentation Requirements Document," NASA Lewis Research Center, Cleveland, Ohio, 1973.

2. "Preliminary CTS/Experiment Considerations," Computer Sciences Corporation for NASA Lewis Research Center, Falls Church, Virginia, 1973.

3. Davision, E. H. and C. A. Franklin, "A High-Power Communications Technology Satellite for the 12 and 14 GHz Band," AIAA Paper No. 72-580, Washington, D.C., 1972.

4. "Third Quarterly Progress Report for CTS User Requirements Study (30 June 1973-28 September 1973)" Computer Sciences Corporation for NASA Lewis Research Center, Falls Church, Virginia, 1973.

5. "Communications Experiments Guide - Communications Technology Satellite," NASA Lewis Research Center, Cleveland, Ohio, 1972.

SECTION 20 - U.S. DOMESTIC COMMUNICATIONS SATELLITE SYSTEMS

20.1 INTRODUCTION

The four U.S. domestic communications satellite (Domsat) systems described in this section are sponsored by the

1. American Satellite Corporation
2. American Telephone and Telegraph/Comsat General Corporation/GTE Satellite Corporation
3. Radio Corporation of America
4. Western Union

Each Domsat description includes (1) program description, (2) system description, (3) spacecraft, (4) ground terminals, and (5) operational results.

The information on these Domsat systems is based mainly on applications before the Federal Communications Commission (FCC) and may become out of date as the systems become operational. The data on earth terminals especially may change as the systems progress. The FCC applications are listed as References 1 through 6.

20.2 AMERICAN SATELLITE CORPORATION (ASC)

20.2.1 Program Description

ASC's program is planned to evolve in three phases. The first phase involves the leasing of up to three satellite channels from Telesat Canada or Western Union and the construction of four earth terminals. The second phase includes the procurement and launch of at least two Hughes-built 12-channel satellites and the addition of eight earth terminals. The third phase includes plans to utilize 24-channel satellites. Phase I can be of considerable duration.

20.2.2 System Description

ASC leases radio frequency (RF) transponder channels on the Western Union Westar satellite. The earth segment is provided by ASC. Earth terminal locations near New York, Chicago, Los Angeles, and Dallas are planned or exist. Additional terminals are to be placed to serve certain military bases such as Offutt Air Force Base near Omaha, Nebraska.

20.2.3 Spacecraft

The Westar satellite, used in the ASC Domsat system, is described in Section 20.5.3.

20.2.4 Ground Terminals

An ASC ground terminal includes a 10.1-meter (33-1/3-foot) diameter antenna and associated electronic communication equipment. Each ground terminal has the capability of receiving and transmitting multidestination FDM radio carriers which establish connections with the other stations. In Phase I plans, there are four terminals so that each will transmit one FDM carrier and receive three FDM carriers. In Phase II of ASC plans, the capability of interconnecting with two satellites simultaneously will be added. The ASC system is also to include receive-only terminals which will be capable of being located in regions congested with interfering signals so that operation will be possible over only a portion of the allocated band. A photograph of an ASC terminal is shown in Figure 20-1. The Phase I, Phase II, and receive-only terminal characteristics are

Figure 20-1. Photograph of an ASC Earth Terminal

summarized in Table 20-1. Major receive function and transmit function block diagrams of the ASC Phase II earth terminals are presented in Figures 20-2 and 20-3, respectively.

20.2.5 Operational Results

The ASC domestic system has been in operation since August 1974. Facsimile, voice, and data transmissions are carried through the operational system.

Table 20-1. ASC Earth Terminal Characteristics

	Phase I	Phase II	Receive Only
Total Performance			
G/T	33 dB/^{O}K	33 dB/^{O}K	30.5 dB/^{O}K
EIRP	85 dBw	85 dBw	----
Frequency Plan	5.9-6.4 GHz and 3.7-4.2 GHz	5.9-6.4 GHz and 3.7-4.2 GHz	Less than 500 MHz Rec. BW
Polarization	Transmit Vertical; Receive Horizontal	Transmit Vertical; Receive Horizontal	----
Antennas			
Type	Cassegrain	Cassegrain	Cassegrain
Diameter	10.1 m (33-1/3 ft)	10.1 m (33-1/3 ft)	10.1 m (33-1/3 ft)
Gain	50.5 dB (Rec); 52.5 dB (Xmit)	50.5 dB (Rec); 52.5 dB (Xmit)	50.5 dB (Rec); 52.5 dB (Xmit)
Efficiency	----	----	----
Beamwidth	0.5^{o} (Rec) at -3 dB	0.5^{o} (Rec) at -3 dB	0.5^{o} (Rec) at -3 dB
Receive Subsystem			
Type Preamplifier	Cryogenic Cooled Paramp	Cryogenic Cooled Paramp	Thermo Electric Cooled Paramp
Noise Temperature	20^{O}K (Rec)	20^{O}K (Rec)	55^{O}K (Rec)
Bandwidth	500 MHz	500 MHz	< 500 MHz
Transmit Subsystem			
Type Power Amplifier	Klystrons	Klystrons	None
Power Output	~3 kw	~3 kw	None
Bandwidth	~40 MHz Tunable	~40 MHz Tunable	None
Ground Communication Equipment	Transmit: 960-ch Voice, 2 TV Carriers; Receive: 3 960-ch Voice, 2 TV Carriers	Transmit: 2 960-ch Voice, 3 TV Carriers; Receive 9 960-ch Voice, 3 TV Carriers	4 Digital Carriers Each 1.792 Mbps; Quadriphase PSK Demodulator
Tracking			
Type	Step	Step	----
Accuracy	----	----	----

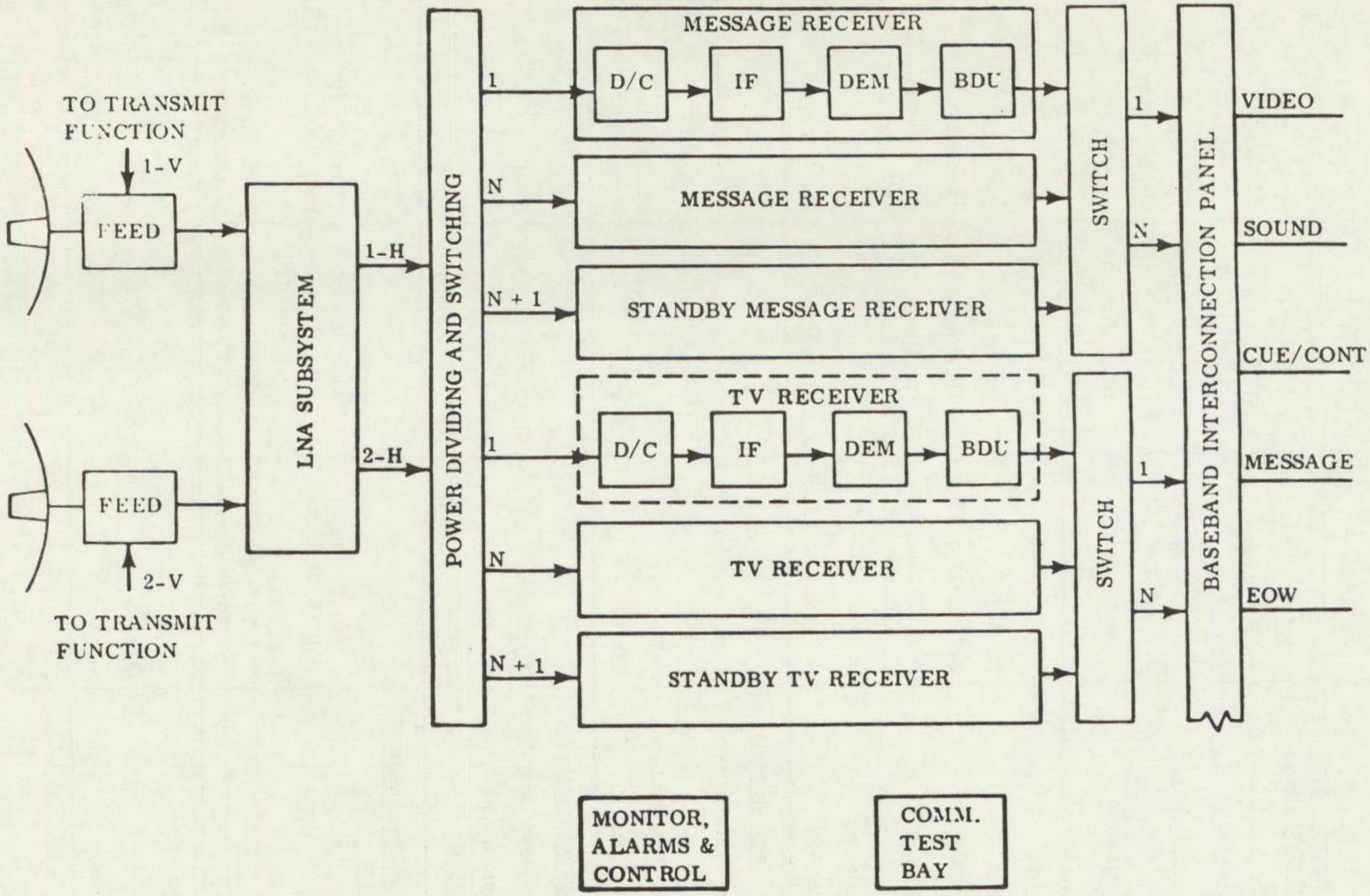


Figure 20-2. ASC Earth Station, Main Function Block Diagram

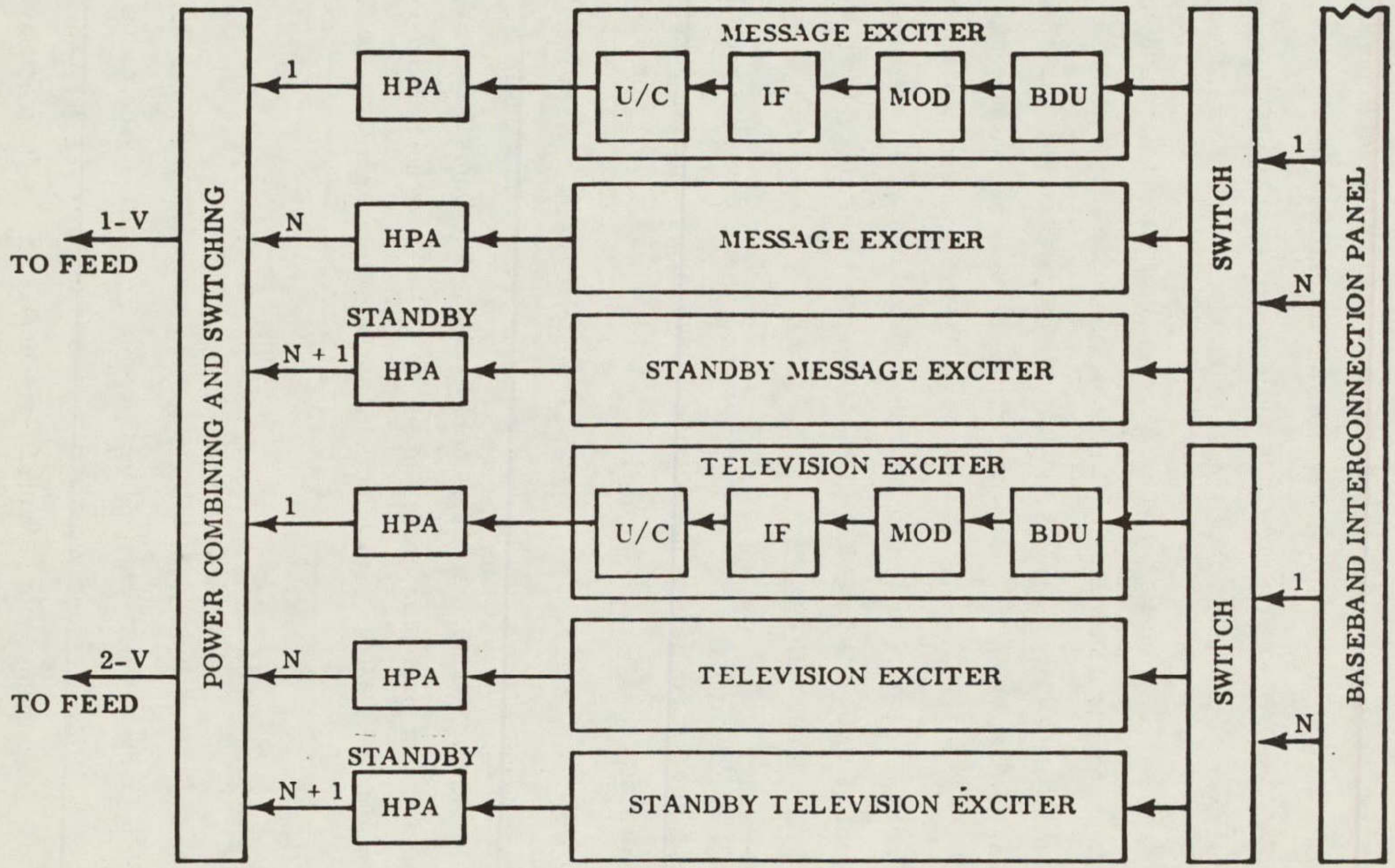


Figure 20-3. ASC Earth Station, Transmit Function

20.3 AMERICAN TELEPHONE AND TELEGRAPH/COMSAT GENERAL CORPORATION/ GTE SATELLITE CORPORATION

20.3.1 Program Description

The American Telephone and Telegraph Company (AT&T) is developing a Domsat system which will be integrated into the entire AT&T communications network. The earth terminals will be owned by AT&T, while the satellites will be owned and operated by the Comsat General Corporation. AT&T will lease satellite channels from Comsat General.

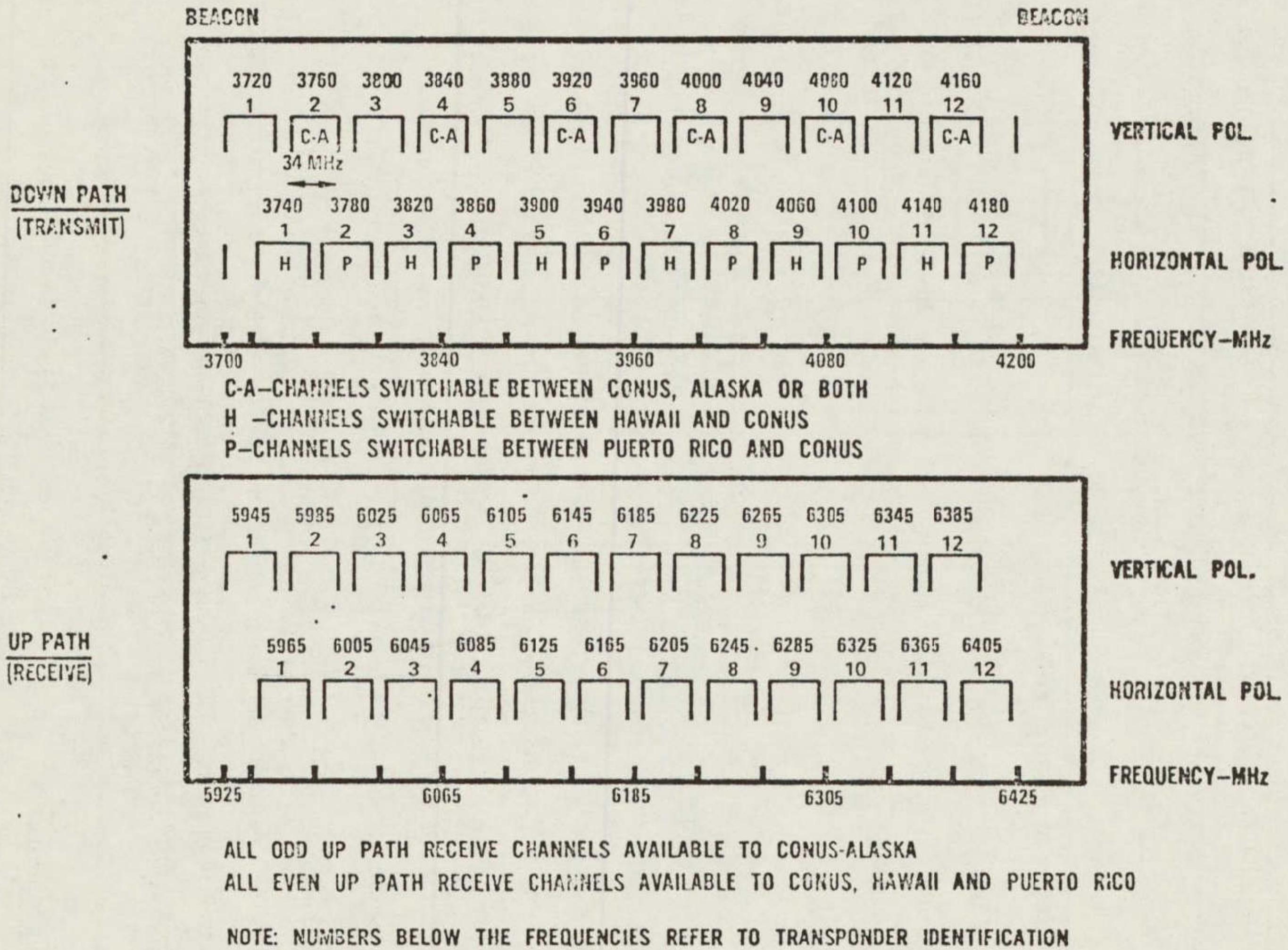
On February 28, 1973, an agreement for provision of domestic communications satellites was signed between AT&T and the Communications Satellite Corporation (now Comsat General Corporation). The FCC subsequently authorized the construction of the satellite system proposed by AT&T whereby the satellite system would be integrated into the existing AT&T system, except for private line service. Comsat then placed an order with Hughes Aircraft Company to design and build the modified Intelsat IV satellites to be used in the AT&T satellite system. The first of these satellites, Comstar I, should be ready for launch in early 1976.

The General Telephone and Electronics Company, now GTE Satellite Corporation (GSAT), initially filed an application in December, 1970, for a separate Domsat system with Hughes Aircraft Company as a partner.

On April 18, 1974, AT&T, GTE, and GSAT requested authorization from the FCC to combine the two separate systems into one joint Domsat system whereby four AT&T earth terminals and three GSAT earth terminals would use the Comsat General satellites to provide domestic communications satellite service. As of the publication date, the FCC has not reached a decision concerning the joint Domsat system (FCC Docket No. 20201).

20.3.2 System Description

The system will initially involve three satellites and seven earth terminals. The satellites operate in the 6/4 GHz band and will provide 24 channels each with a usable RF bandwidth of 34 MHz. Frequency reuse by means of orthogonal polarization is used to obtain this RF channel spectrum; Figure 20-4 indicates the frequency-polarization



FREQUENCY PLAN

Figure 20-4. AT&T/Comsat General/GSAT Domsat System Frequency/Polarization Plan

plan. The earth terminals with 30-meter (98-foot) diameter parabolic antennas will be capable of providing 1200 one-way voice circuits through a transponder, under single carrier per transponder operation.

20.3.3 Spacecraft

The Comsat General satellites will be spin stabilized with feedhorns arranged to provide spot beam coverage to the continental United States (CONUS), Alaska, Hawaii, and Puerto Rico. A photograph of a satellite model is shown in Figure 20-5. The CONUS beam coverage service area is indicated in Figure 20-6, and the Alaska beam coverage service area is indicated in Figure 20-7.

A summary of the characteristics of the satellite is given in Table 20-2. A block diagram of the communications subsystem is provided in Figure 20-8. Especially noteworthy are the beam-channel feed arrangements and the presence of equalizers in each transmit channel.

20.3.4 The AT&T/GSAT Ground Terminals

The proposed joint AT&T and GSAT Domsat system involves seven earth terminals: four AT&T terminals near San Francisco, New York, Chicago, and Atlanta; and three GSAT terminals near Hawaii, Los Angeles, and Florida. Thus, AT&T has proposed to withdraw one of its original applications (the Los Angeles terminal) and GSAT has proposed to withdraw two of its original applications (the New York and Chicago terminals). The AT&T and GSAT terminals will have paraboloid antennas 30 meters (98 feet) in diameter. The characteristics of these earth terminals are summarized in Table 20-3.

A drawing of the GSAT terminal antenna is shown in Figure 20-9 and a functional block diagram of the GSAT station is shown in Figure 20-10. The one-for-two redundancy of the cooled paramp and one-for-one redundnacy of the power amplifiers are typical for such stations. A functional block diagram of the AT&T earth station is shown in Figure 20-11.

20.3.5 Operational Results

The AT&T/Comsat General/GSAT Domsat system is not operational. The first satellite for this system, Comstar I, is scheduled to be launched in early 1976.

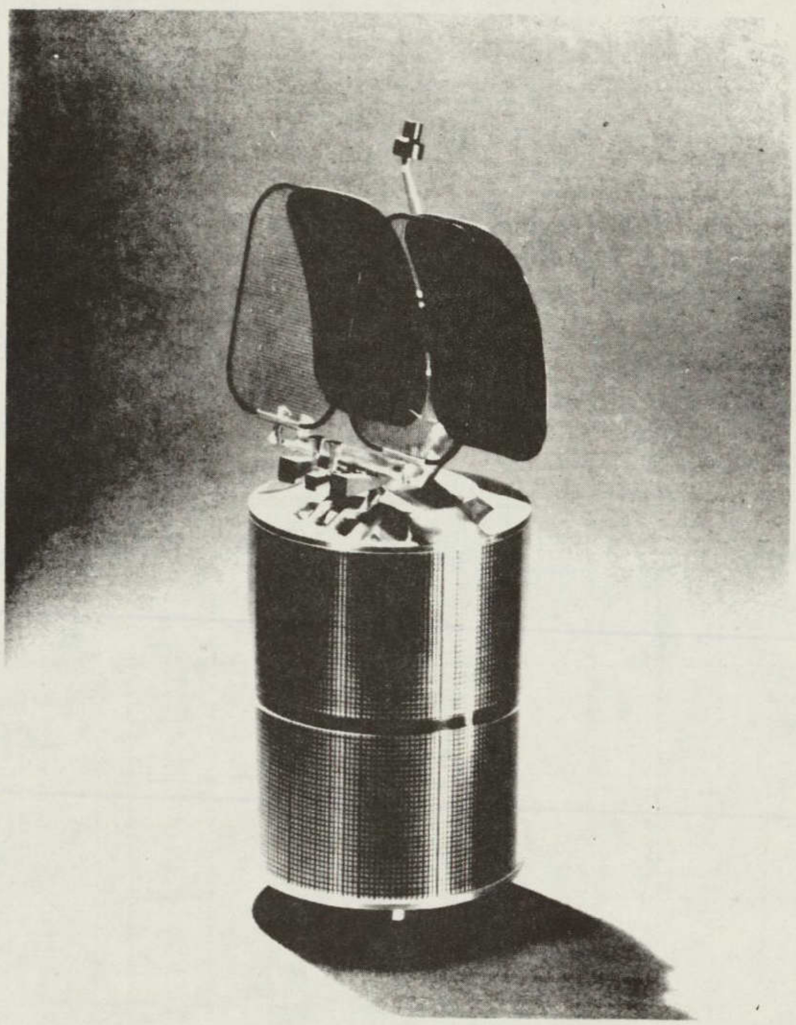


Figure 20-5. A Scale Model of the Comsat General Satellite for the AT&T/Comsat General/GSAT Domsat System

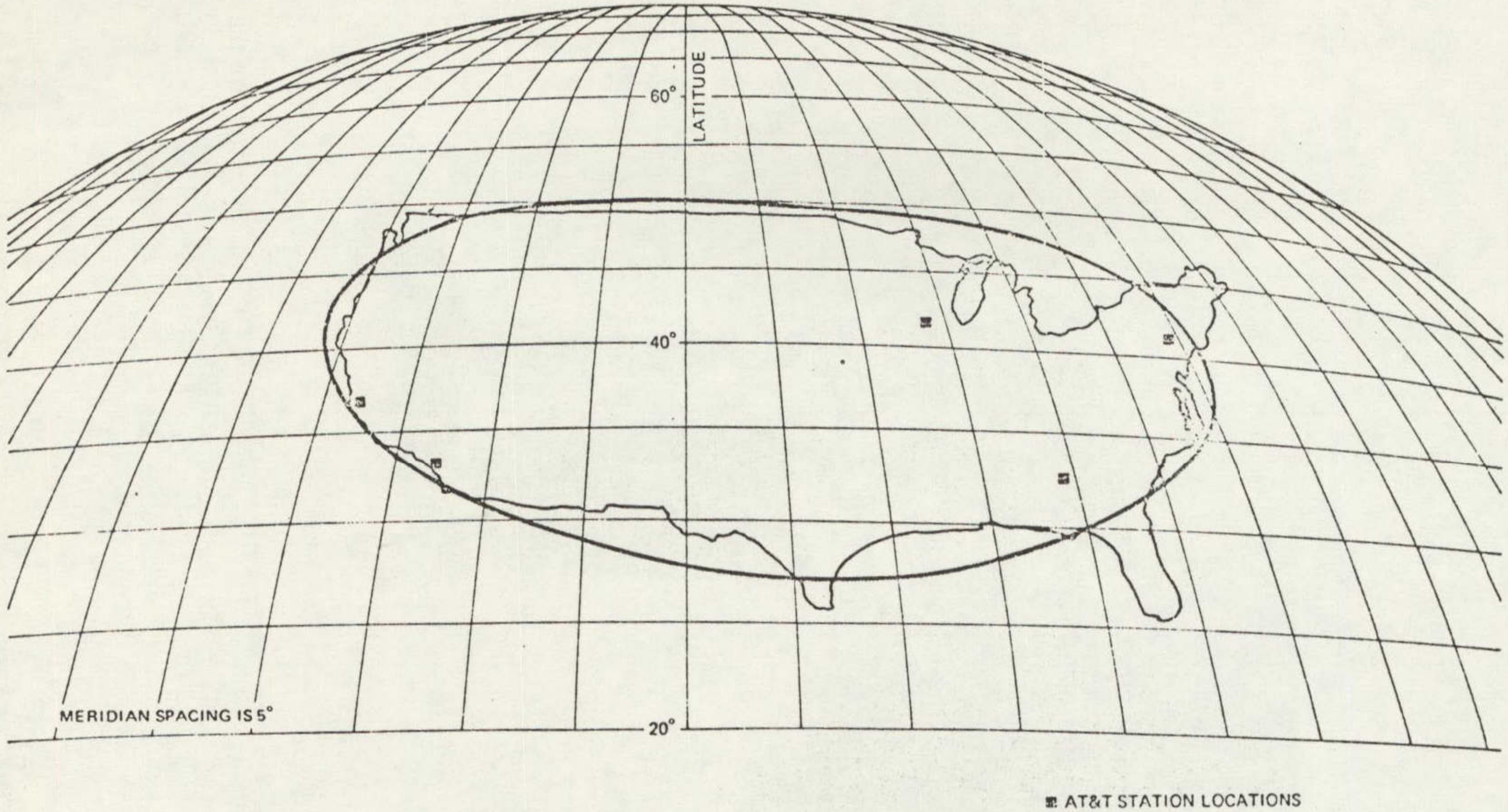


Figure 20-6. CONUS Service Area of AT&T/Comsat General/GSAT Domsat System

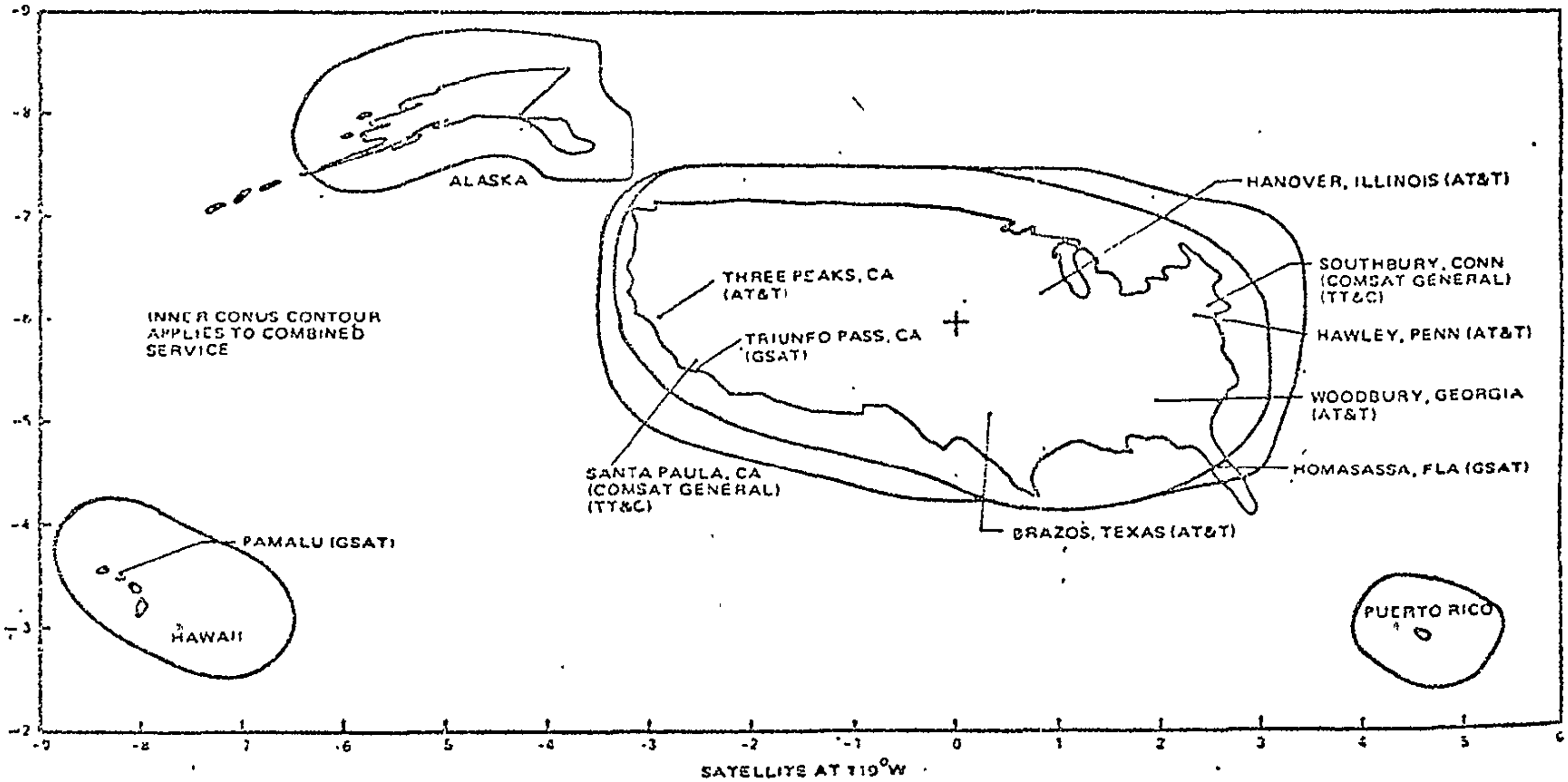


Figure 20-7. AT&T/Comsat General/GSAT Domsat System Communications Service Areas and Proposed Ground Stations

Table 20-2. Summary Chart of the Comsat General Satellite for the AT&T/Comsat General/GSAT Domsat System

Satellite Characteristics	
Genre'	Similar to Intelsat IV
On-Orbit Weight	667 kg (~1471 lb.)
Launch Vehicle	Atlas-Centaur
Stabilization	Spin Stabilized
Propulsion	Hydrazine
DC Power	~760 Watts BOL Power
Communications Subsystem	
Total Performance	
RF Frequency and Polarization Plan	See Figure 20-4; 12 Channels Vertically Polarized 12 Channels Horizontally Polarized 24 Channels Total
EIRP	33 dBw: CONUS, Hawaii, Puerto Rico, Alaska only 31 dBw: Combined Alaska and CONUS
G/T	-9 dB/^{o}K
Antennas	
Type	Two reflectors with multiple feedhorns and polarization screens
Number of Beams	CONUS Elliptical; Alaska, Hawaii; Puerto Rico
Beamwidth	----
Gain	----
Repeater	
Configuration	Single conversion; 2 wideband working receivers with one-for-one protection, each working receiver driving 12 transmit channels
Receiver	Similar to Intelsat IV
Transmitter	Similar to Intelsat IV. Also carried onboard are 19 and 28 GHz Experimental Transmitters.
T.T.&C.	
Tracking	Similar to Intelsat IV
Telemetry	Similar to Intelsat IV
Command	Similar to Intelsat IV

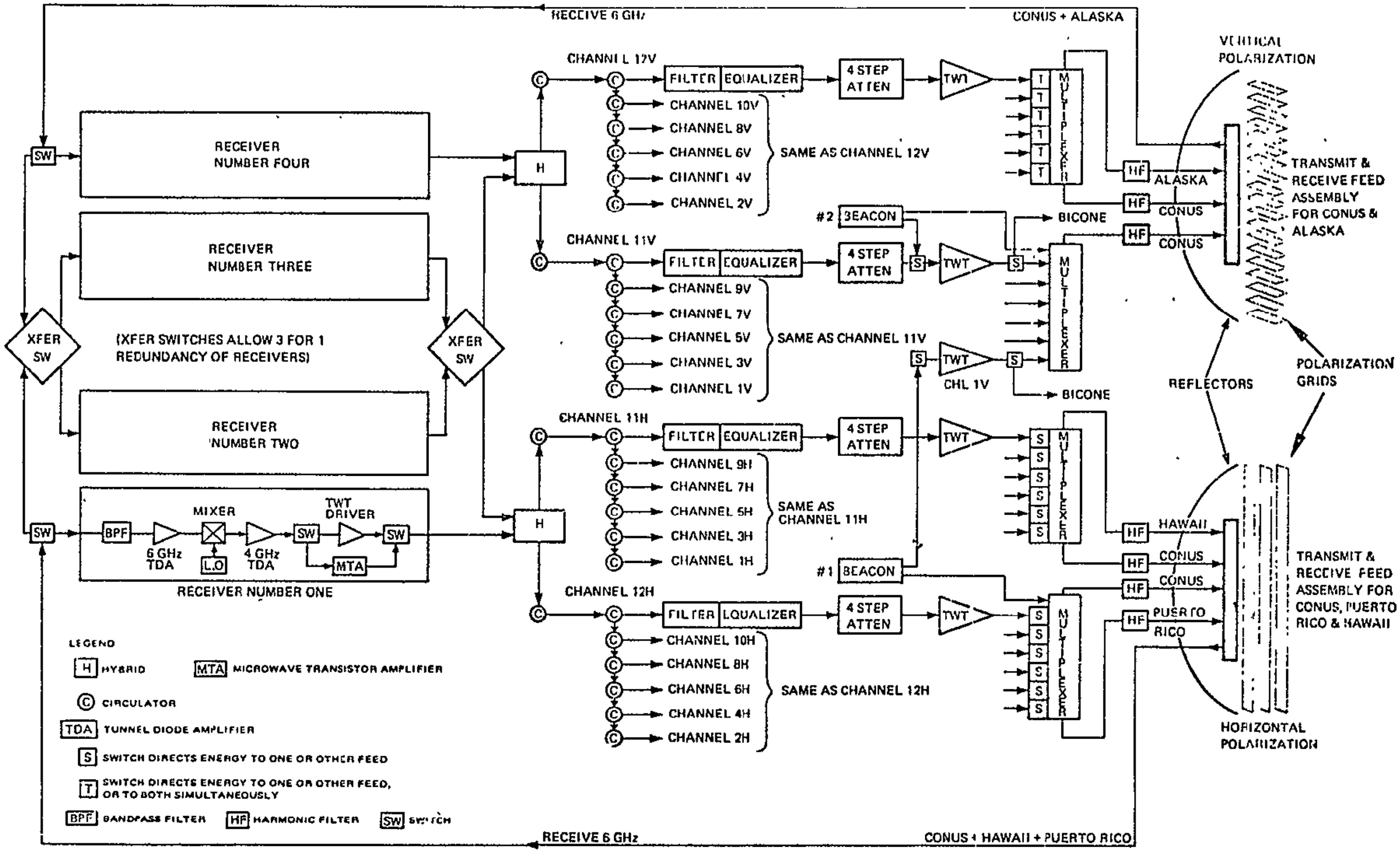


Figure 20-8. Communication Subsystem of Comsat General Satellites for the AT&T/Comsat General/GSAT Domsat System

Table 20-3. AT&T/GSAT Earth Terminal/Characteristics

	AT&T*	GSAT
Total Performance		
G/T	41.4 dB/^{o}K at 20^{o} elevation	41 B/^{o}K
EIRP per carrier	90 dBw	> 90 dBw max
Frequency Plan	5.9-6.4 GHz and 3.7 - 4.2 GHz	5.9-6.4 GHz and 3.7-4.2 GHz
Polarization	Horizontal and Vertical	Rotatable Linear
Antennas		
Type	Cassegrain	Cassegrain
Diameter	30 m (98 ft)	~31 m (~100 ft)
Gain	60.4 dB (Rec); at 20^{o} elevation 62.8 dB (Xmit)	59.5 dB (Rec); 63 dB (Xmit)
Efficiency	----	----
Beamwidth	0.18^{o} (Rec); 0.12^{o} (Xmit)	----
Receive Subsystem		
Type Preamplifier	Cooled Paramp	Cooled Paramp
Noise Temperature	79^{o}K (Syst) 20^{o} elevation	22^{o}K (Rec)
Bandwidth	500 MHz	500 MHz
Transmit Subsystem		
Type Power Amplifier	Klystron	5 Cavity Klystron
Power Output	2000 W (nominally)	3 kw
Bandwidth	40 MHz, Tunable Over 500 MHz	----
Ground Communication Equipment	FM Modulators and Demodulators Digital Modulators and Demodulators	FDM-FM Equipment
Tracking		
Type	Autotrack	Manual and Autotrack
Accuracy	Direction and Polarization	.04^{o} Pointing; < .01^{o} Tracking

*Specification numbers

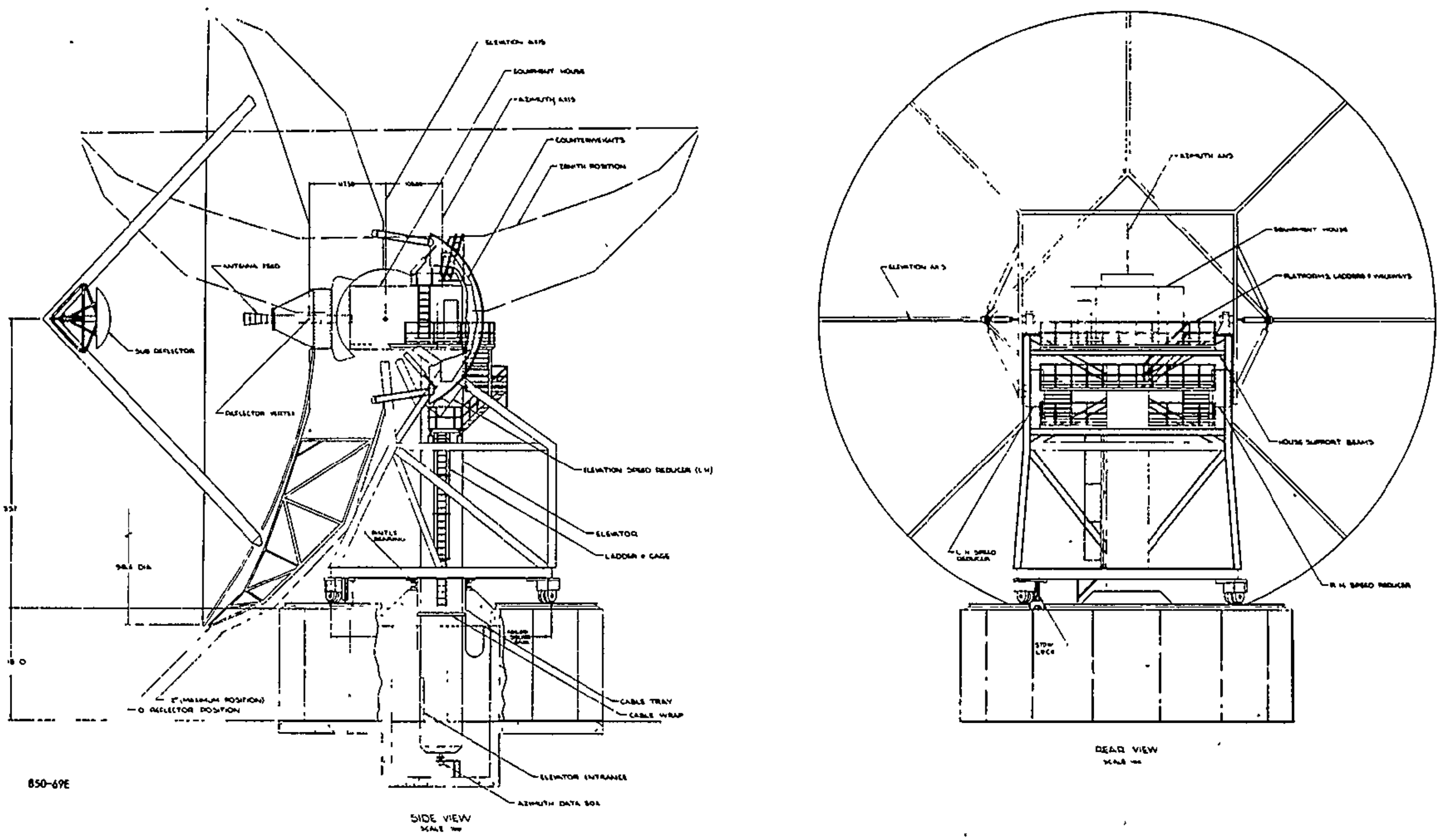


Figure 20-9. The GSAT Terminal Antenna

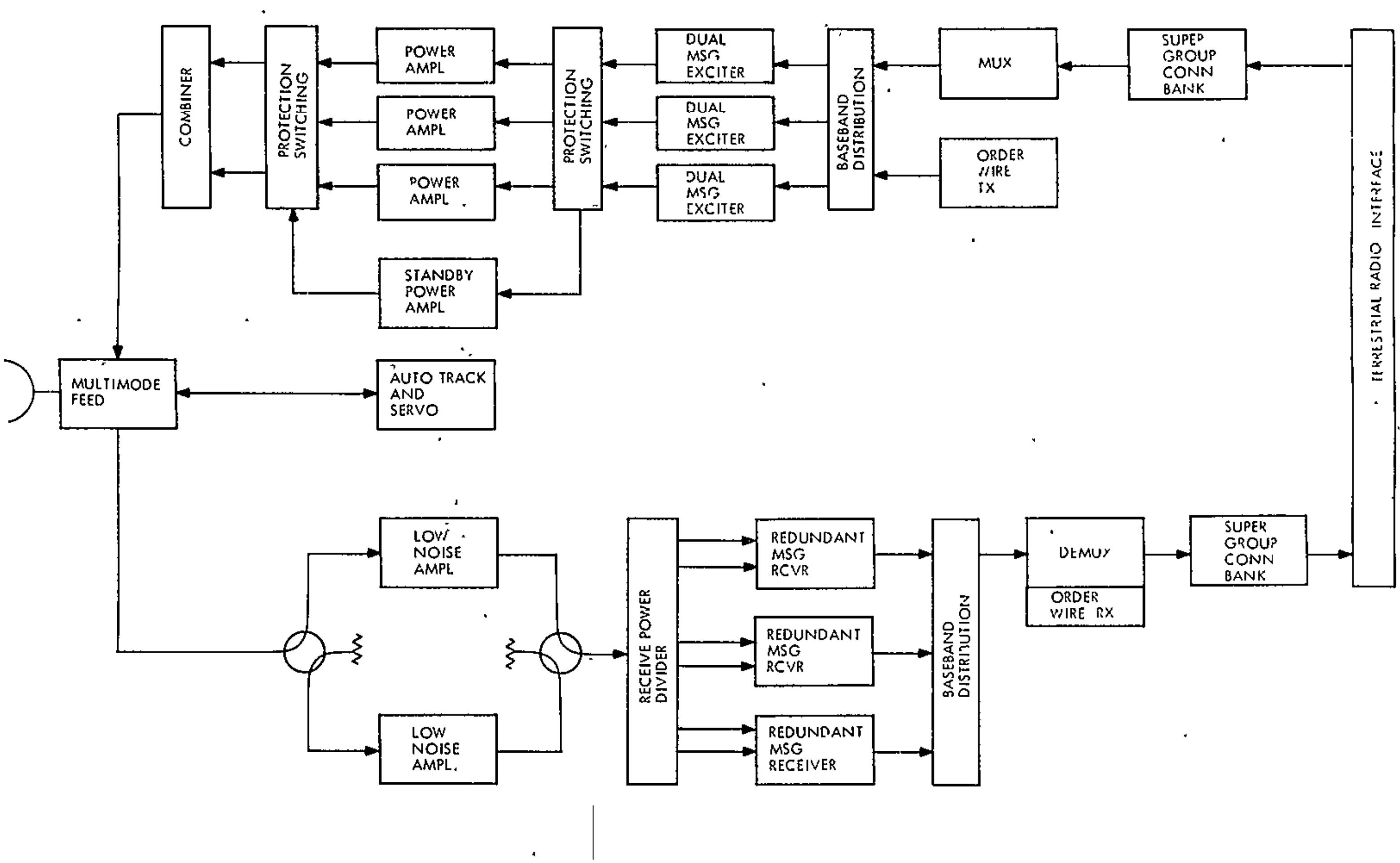


Figure 20-10. Functional Block Diagram of GSAT Earth Station

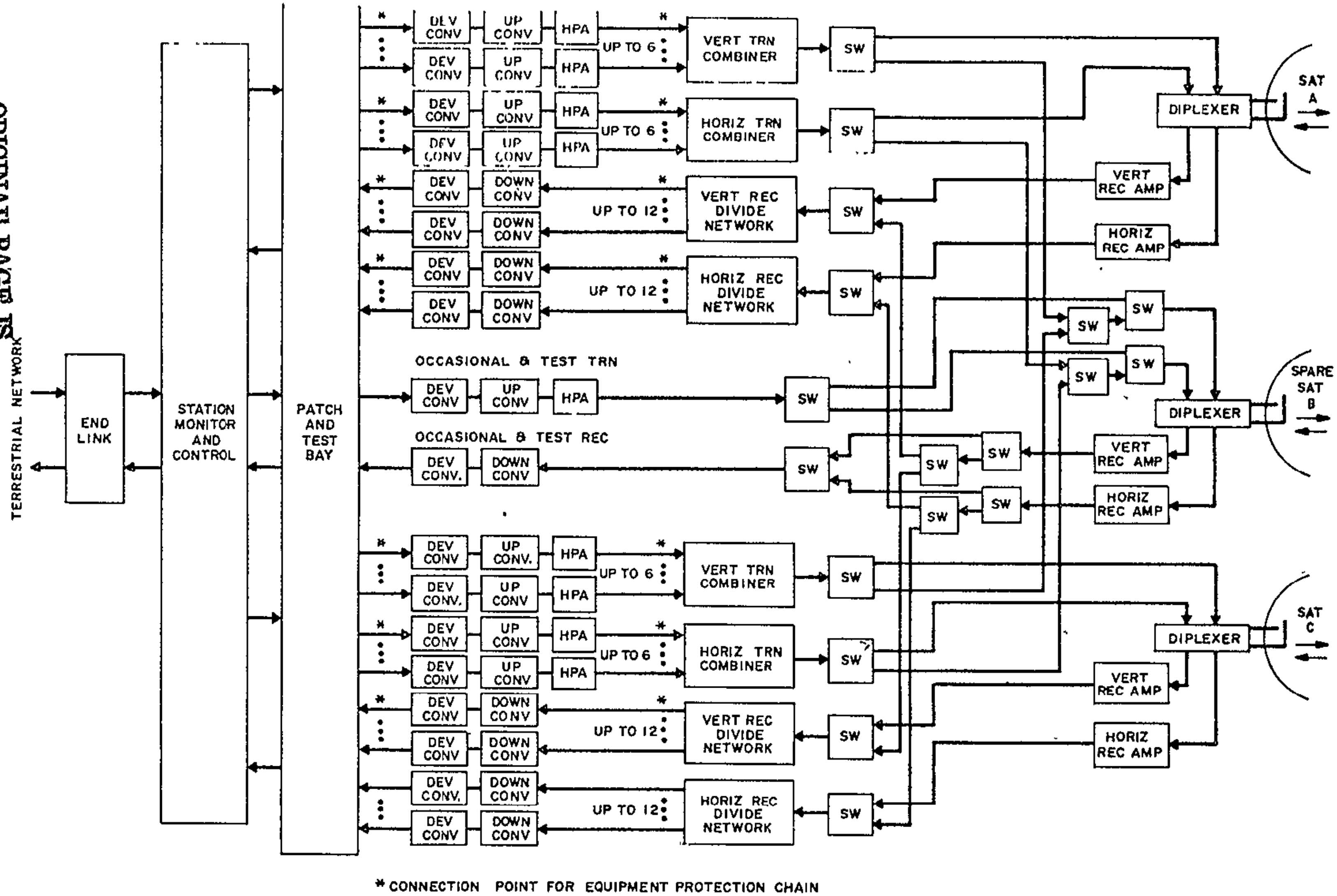


Figure 20-11. AT&T Earth Station Functional Block Diagram

20.4 RADIO CORPORATION OF AMERICA

20.4.1 Program Description

The Radio Corporation of America (RCA) Domsat program includes:

1. Procuring earth terminals

2. Leasing channels from the Canadian Anik Satellite (the FCC subsequently ordered transfer of RCA traffic to the Westar satellite)

3. Entering into an agreement with McDonnel Douglas for the latter to develop an upgraded Thor-Delta 3914 launch vehicle

4. Designing and fabricating several Satcom domestic satellites at RCA Astro Electronics Division and RCA Ltd. of Montreal, Canada

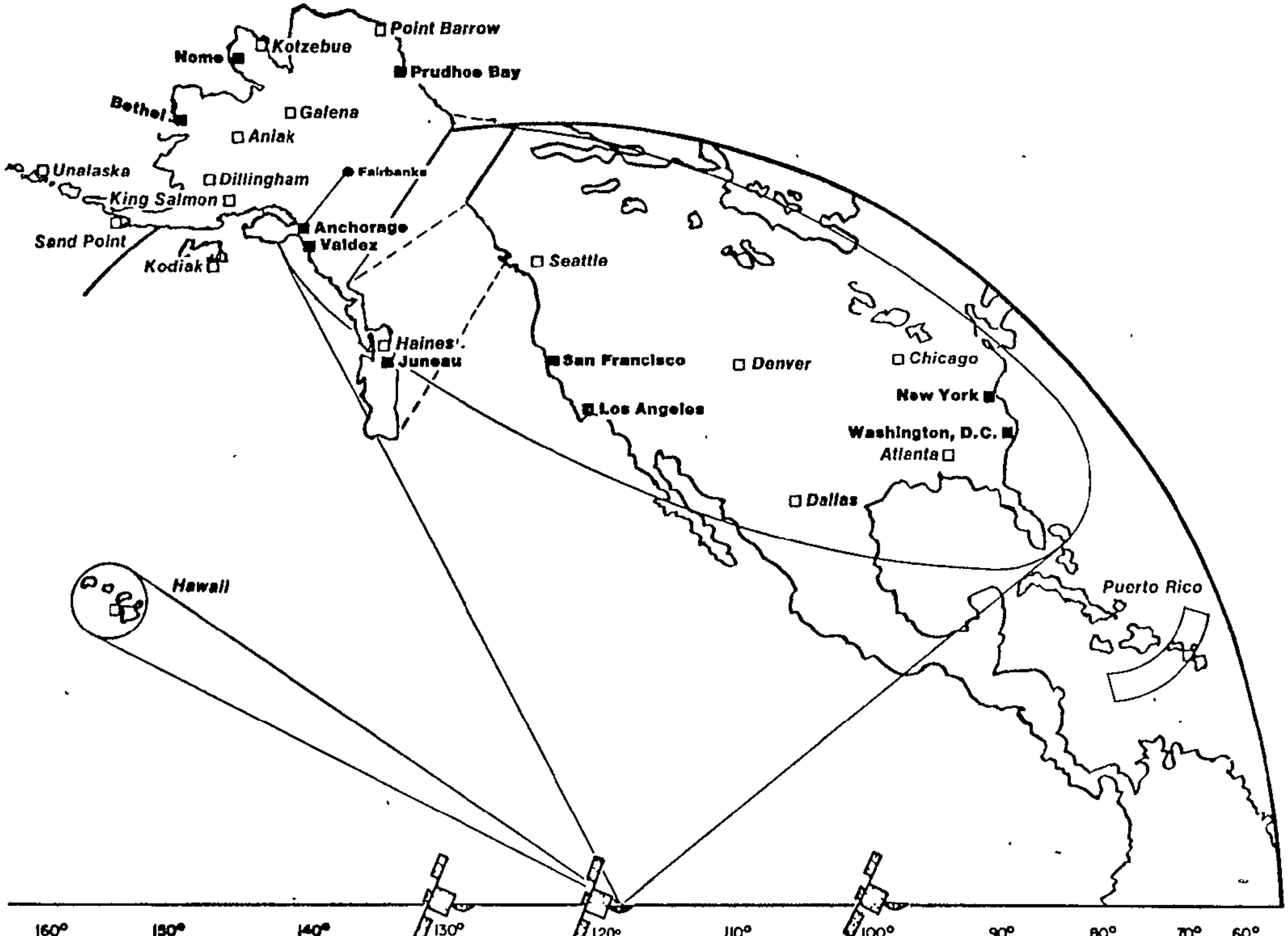
RCA Global Communications, Inc. (RCA Globcom) will offer various private line services to the 48 states including voice, data, and television distribution. RCA Alaska Communications, Inc. (RCA Alascom) will offer public message service and private line services to Alaska. Alaska is one of the key aspects of the RCA Domsat program.

20.4.2 System Description

The system operates in the 6/4 GHz band with each satellite providing 24 channels with an RF bandwidth of about 34 MHz each. Orthogonal polarizations with 12 channels per polarization enable the reuse of frequency in the 500 MHz band. The earth terminals will be of various sizes having antenna diameters varying from 5 to 30 meters (15 to 98 feet). Separate beam coverage areas are provided for: (1) the continental United States (CONUS) and Alaska, and (2) Hawaii; these are shown in Figure 20-12.

20.4.3 RCA Spacecraft

The Satcom satellite is specifically designed for the Delta 3914 Launch Vehicle and will provide 24 RF channels of 34 MHz usable bandwidth and 32 dBW EIRP each. The Satcom will employ the new techniques of three-axis stabilized and oriented solar panels to generate sufficient DC power. A picture of the Satcom satellite showing the



■ **Phase One:** initially will operate through leased transponders in the Telesat Canada System.
□ ***Phase Two:*** Will utilize RCA Satellites as shown.

Figure 20-12. RCA Satcom System

extended solar panels as well as the intricate antenna system is shown in Figure 20-13. A diagram of the Satcom as stowed on the Delta 3914 is given in Figure 20-14.

A summary of the Satcom general characteristics as well as its communications and TT&C subsystems is presented in Table 20-4. The novel features are (1) the three axis stabilization system which uses magnetic torques as well as a momentum wheel and jets and (2) the antenna which consists of four gridded rectangular reflectors with some overlap to allow for greater effective aperture within the 3914 envelope constraint. The overlap is possible since a horizontally gridded reflector is transparent to vertical polarization. The Satcom support subsystem characteristics in Table 20-5 and the weight and power summary of Table 20-6 provide more detail on the satellite.

The Satcom satellite communications subsystem is described in more detail by the antenna beam coverage diagram in Figure 20-12, the block diagram of Figure 20-15, and the beam assignments in Table 20-7.

20.4.4 The RCA Ground Terminals

The earth segment of the RCA Domsat system is operational in part and is being used in conjunction with leased channels first on the Canadian Telesat (Anik) satellites and presently on the Western Union Westar satellites. There are several kinds of terminals in the earth segment. These terminals and their characteristics are listed in Table 20-8 facilitating comparision between the CONUS, Alaska, and bush terminals which were planned; and the large Talkeetna terminal which was purchased from Comsat; and the transportable terminals which were already available. A notable feature of certain earth terminal electronics is the single (voice) channel per carrier (SCPC) equipment which results in great operational flexibility for small users. A summary of the antenna characteristics and capabilities is given in Table 20-9 which applies to both the RCA 10-m (32-ft.) and 11-m (35-ft.) antennas. The earth terminal electronics is described for the various terminals in Figure 20-16 which is a block diagram of an 11-m (35-ft.) dual feed antenna terminal, and Figure 2-17 which is for a 10-m (35-ft.) single feed antenna terminal; and Figure 20-18 which shows the relative simplicity of a receive only earth terminal.

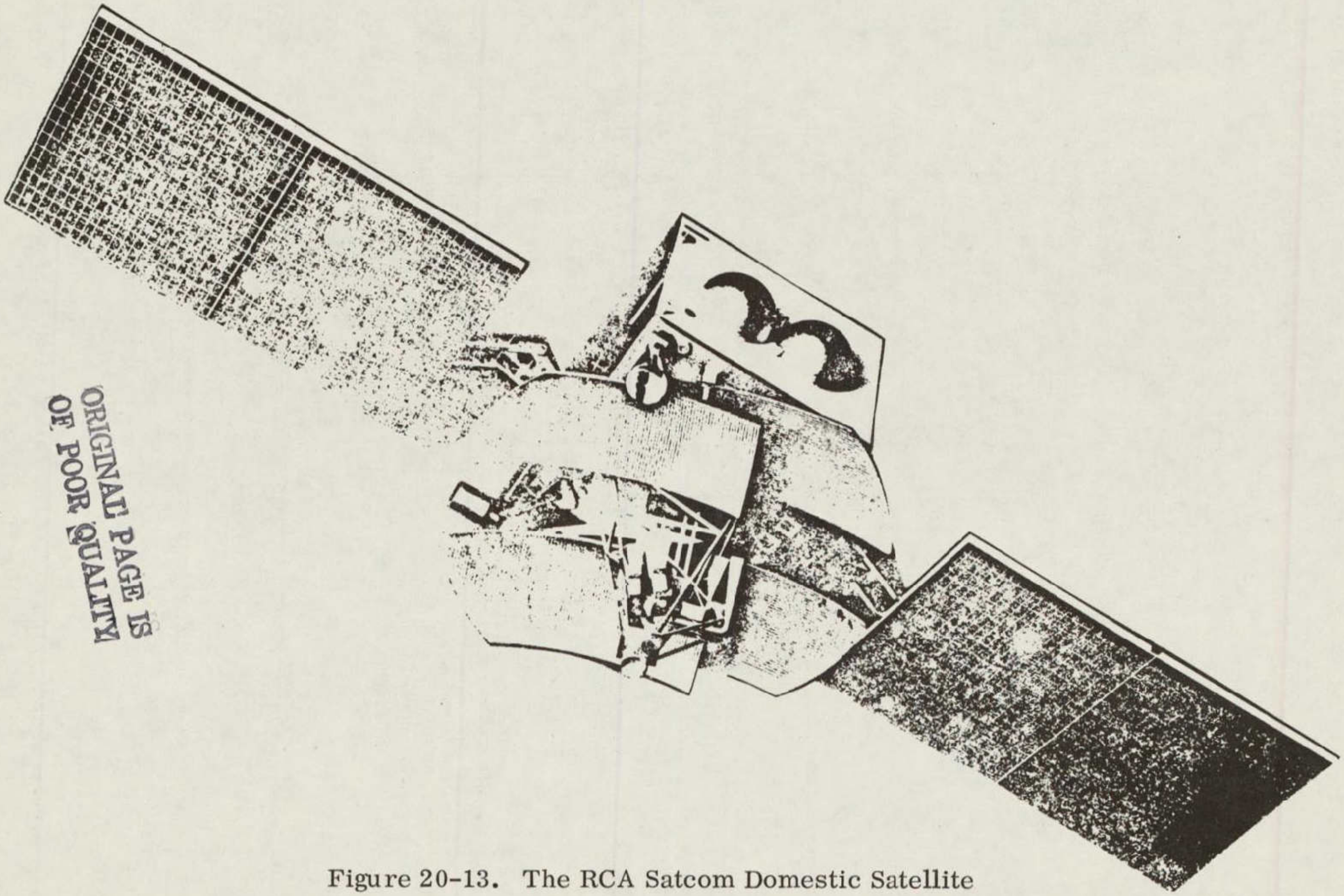


Figure 20-13. The RCA Satcom Domestic Satellite

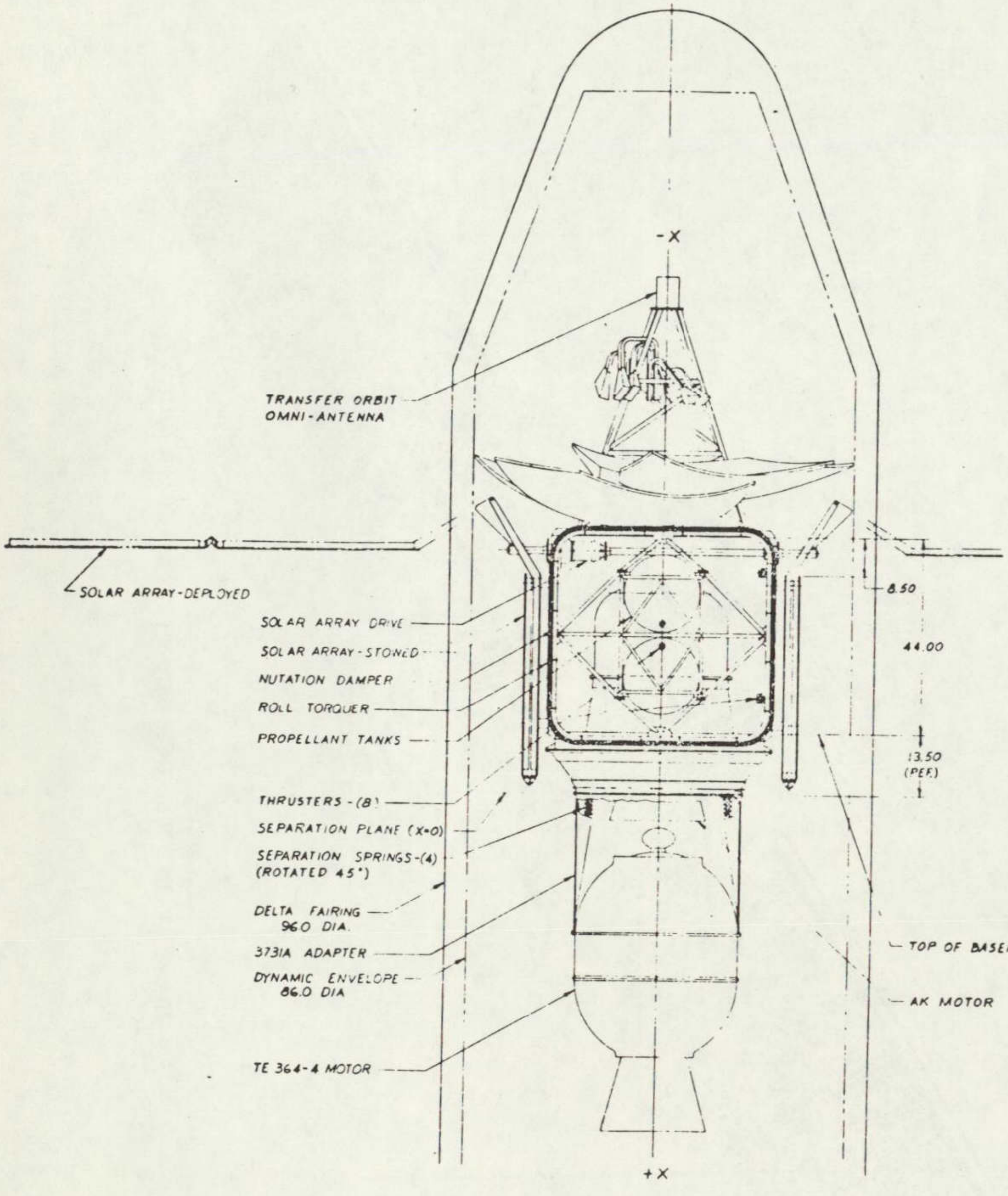


Figure 20-14. Stowed Configuration of RCA Satcom Satellite and Delta 3914

Table 20-4. RCA Satcom Satellite Summary Chart

Satellite Characteristics	
Genre'	New design - being built by RCA AED/Montreal
On-Orbit Weight	~454 kg (~1000 lb)
Launch Vehicle	Delta 3914
Stabilization	3-axis stabilization
Propulsion	8-year stationkeeping to 0.10 N-S & E-W
DC Power	Sun oriented array; ~700 watts array power BOL
Communications Subsystem	
Total Performance	
RF Frequency & Polarization Plan	See Figure 20-15; 12 channels "vertically" polarized[1] 12 channels "horizontally" polarized[1] 24 channels total
EIRP	32 dB: CONUS - Alaska. 26 dBW Hawaii
G/T	2-7 dB/$^{\circ}$K CONUS - Alaska. ~-10 dB/$^{\circ}$K Hawaii
Antennas	
Type	4 polarization-gridded "rectangular" reflectors with overlap and offset feed tower
Number of Beams	Two: a CONUS-Alaska tilted elliptical beam and a Hawaii Spot Beam
Beamwidth	$8.4^{\circ} \times 3.2^{\circ}$ CONUS - Alaska
Gain	~30 dBi on-axis
Cross pol. Isol.	33 dB
Repeater	
Configuration	Single conversion; two wide band receivers; each driving 12 channelized transmitters
Receiver	6 GHz TDA, mixer, transistor driver amplifier
Transmitter	24 unequalized channels; a 5-watt type, 275 H TWT per channel
T. T. & C.	
Tracking	Loop around multi-tone ranging. FM uplink, PM downlink
Telemetry	PAM/FM/PM Format - 128 available points
Command	PCM/FSK/FM Format - 248 command capability

[1]Inclined 20° to the orbital plane

Table 20-5. RCA Satcom Support Subsystems Characteristics

Subsystem	Key Performance Features
Command, Ranging and Telemetry	• 248-Command Capability with False Command Rate $<10^{-22}$ • 121-Channel Telemetry Capacity with Accuracy of ±2.5%
Apogee Motor	• Mass Fraction $\frac{\text{Propellant Wt}}{\text{Total Wt}}$ = 0.939 • Motor Weight to Synchronous Spacecraft Weight Ratio = 0.951
Reaction Control	• Blowdown Monopropellant Hydrazine System Incorporating Surface Tension Propellant Management Provides 1957 m/sec (1500 ft/sec) ΔV • Operational Redundancy
Attitude Control	• Autonomous Three-Axis Body Stabilized Control System Providing Pointing Accuracies of ±0.16° E-W, ±0.21° N-S; E-W Offset Pointing from 0° to ±5° also provided • Spacecraft is Nutationally Stable During all Modes
Power	• Efficient Power System Providing over 465 Watts Throughout 10-year design life
Thermal	• Maintains all Components in suitable Thermal Operating Environment (e.g., Batteries 0° to 10°C, Reaction Control 5° to 15°C and Communications 0° to 50°C)
Structure	• Lightweight Design of 7% of Transfer Orbit Weight • Satisfies all Frequency and Dynamic Envelope Constraints of Booster

Table 20-6. RCA Satcom Satellite Weight and Power Summary

Subsystem	Weight kg (lb)	Avg Power (watts)
Structure	59.8 (131.9)	-
Power (including Harness)	93.7 (206.5)	9.4
Propulsion	21.9 (48.5)	-
Apogee Motor Case	21.9 (48.5)	-
Reaction Control (Dry)	17.0 (37.6)	0.01
Thermal Control	7.6 (16.8)	0
Attitude Control	29.6 (65.4)	14.4
Command, Ranging and Telemetry	15.0 (33.1)	10.6
Communications		
Transponders	75.1 (165.6)	429
Antennas	22.8 (50.3)	-
Miscellaneous	5.1 (11.3)	-
Spacecraft Margin	18.1 (40.0)	-
Maximum Spacecraft Dry Weight	366.0 (807.0)	463.4
Reaction Control Propellant	95.0 (209.5)	
Apogee Motor Expendables	412.1 (908.5)	
Launch Vehicle Adapter & T/M	34.0 (75.0)	
Booster Transfer Orbit Capability	907.2 (2000.0)	

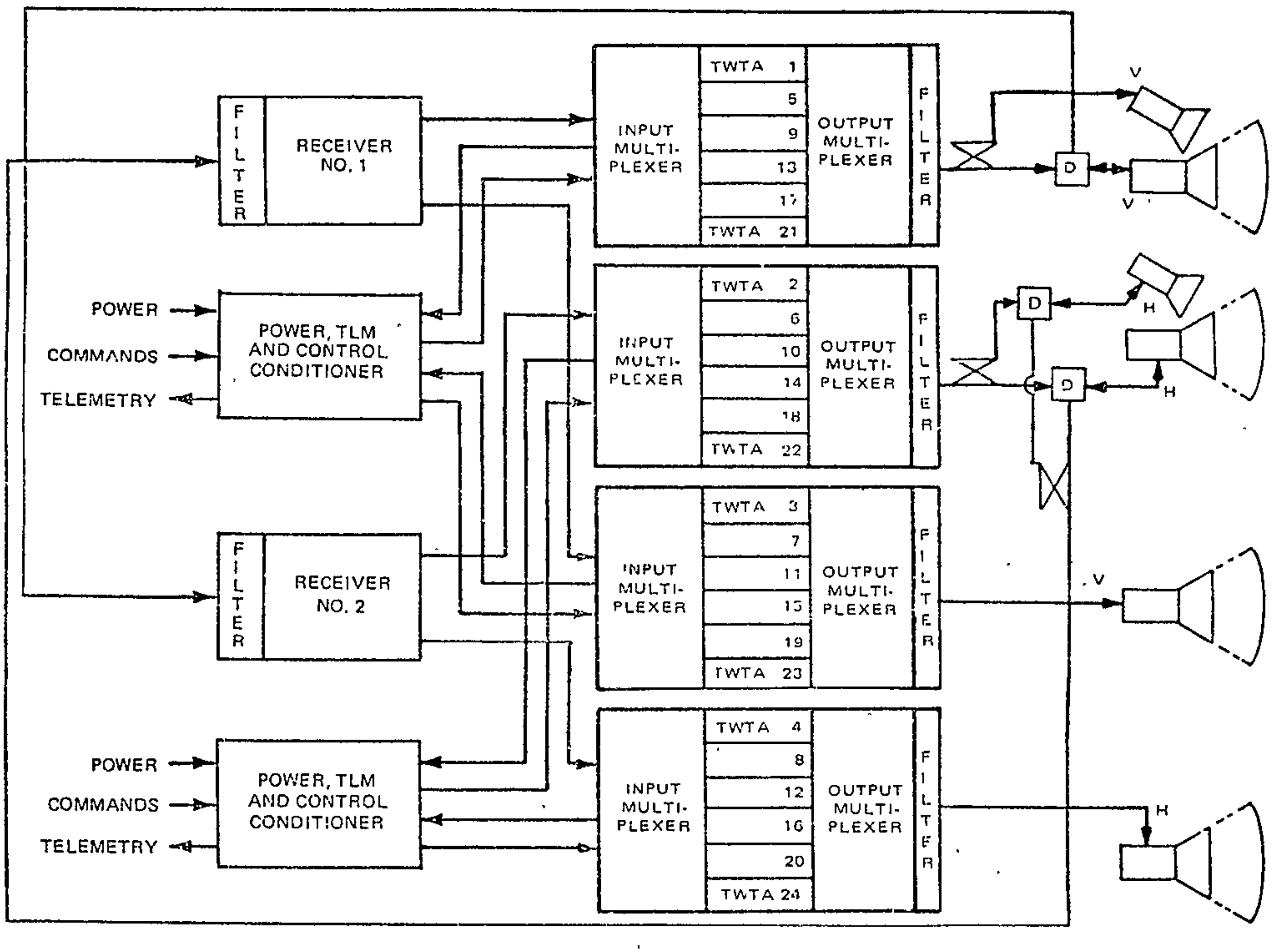


Figure 20-15. RCA Satcom Satellite Communications Subsystem Block Diagram

Table 20-7. RCA Satcom Satellite Beam Assignments

Beam No.	Coverage	Beam Size	Channels	Reflector	Polarization	Gain (dB)	
						On Axis	Beam Edge
1	CONUS & Alaska	8.4° × 3.2°	12 Receive 6 Transmit	West - H	Horizontal	29.9 29.9	26.5 26.5
2	CONUS & Alaska	8.4° × 3.2°	12 Receive 6 Transmit	West - V	Vertical	29.9 30.2	26.5 26.5
3	CONUS & Alaska	8.4° × 3.2°	6 Transmit	East - H	Horizontal	29.9	26.5
4	CONUS & Alaska	8.4° × 3.2°	6 Transmit	East - V	Vertical	30.2	26.5
5	Hawaii	2.6° × 1°	12 Receive 6 Transmit	West - H	Horizontal	32.5 29.4	31.5 28.9
6	Hawaii	2.6° × 1°	6 Transmit (Coupled Service)	West - V	Vertical	29.4	28.9

Table 20-8. RCA Globcom/Alascom Earth Terminal Characteristics

	Talkeetna Terminal	Conus Terminal	Alaska Terminal	Transportable Terminal	Bush Terminal
Total Performance					
G/T	32 dB/°K	32.4 dB/°K	30.3 dB/°K	29 dBW/°K	21.5 dB/°K
EIRP	88 dBW	86 dBW	76 dBW	-	66.5 dBW
Freq. Plan	5.9-6.4 GHz and 3.7 - 4.2 GHz	same	same	same	same
Polarization	Linear, any orientation	same	same	same	same
Antennas					
Type	cassegrain	cassegrain	same	same	same
Diameter	30 m (98 ft.)	10 m (33 ft)	same	11 m and 5 m (36 ft. and 16 ft.)	5 m (15 ft.)
Gain	60 dB (Rec.); 63 dB(xmit)	51 dB(RCC), 54 dB (xmit.)	same	-	43dB (Rec.); 46.5 dB (xmit.)
Efficiency	54%	68%, 55%	same	-	-
Beamwidth	.18°, .12°	.53°, .36°	same	-	1.2°; .81°
Receive Subsystem					
Type Preampl.	cooled paramp	cooled paramp	uncooled paramp	uncooled paramp	uncooled paramp
Noise temp.	64 dB/°K (syst)	85 dB/°K (syst.)	118°dB/°K(syst.)	-	140 dB/°K (syst.)
Bandwidth	500 Mhz	same	same	same	same
Transmit Subsystem					
Type Power Ampl.	Klystron, TWT	Klystron	TWT	Klystron	TWT
Power Output	3 kw ; 300 w	3 kw	400 w	3 kw	100 w
Bandwidth	Tunable, 500 MHz	tunable over 500 MHz	500 MHz	tunable	500 MHz
Ground Communication Equipment	SC pc 200 ch and FDM-FM 600 ch	FDM-FM and Future TDMA	SCpc 68 ch and FDM-FM 60 ch	-	SCpc one channel
Tracking					
Type	Elev. over Azimuth	-	-	non-tracking	non-tracking
Accuracy	Pointing .03°; tracking .01°	Tracking .01°	Tracking optional		
Installation	Deicing provisions	-	deicing provisions	-	-

Table 20-9. RCA 10-Meter (32-Foot) Antenna System and 11-Meter (35-Foot) (Dual Feed) Antenna System

MAJOR COMPONENTS	1. A main reflector and the pedestal.	
	2. A feed sub-system including subreflector with subreflector support.	
MAIN REFLECTOR		
Type	Solid Surface	
Size	10 m (32 ft.) Diameter	
Surface Accuracy 0.2 cm	1.7 cm (0.65 in.) RMS full operational 0.2 cm (0.100 in.) RMS degraded operational. No in-elastic yield in survival environment.	
PEDESTAL		
Adjustment Capability	Manual and Motor-Driven	
Azimuth Range	$\pm 8^{\circ}$ Vernier $\pm 60^{\circ}$ In Steps	
Elevation	$\pm 3^{\circ}$	
FEED SYSTEM		
Polarization	Linear	
Pressurization	Provided	
Deicing Capability	As required by the location	
Power Handling Capability	20 kw	
Insertion Loss	0.2 dB	
ELECTRICAL PERFORMANCE		
Gain		
Receive Band	50.8 + 20 log (F/4) dB minimum	
Transmit Band	53.0 + 20 log (F/6) dB minimum where F is the operating frequency in GHz	
VSWR	Not greater than 1.25 in either band for any polarization setting	
Noise Temperature	Approximately 17 dB at 10° look angle	
Efficiency	10 m (32 ft.)	11 m (35 ft.)
Receive Band	68%	60%
Transmit Band	55%	44%
Beamwidth	0.53° between half power points	
Sidelobe Pattern	Conforms to minimum requirement of 32-25 log ø	

MECHANICAL PERFORMANCE	
Tracking Accuracy	
Normal (0.01°)	
Degraded (0.02°)	
ENVIRONMENT	
Normal Operation	
Wind	30 mph, gusts to 45 mph
Precipitation	3 cm (1 in.)/hr. rain, or 0.6 cm (1/4 in.)/hr. freezing rain, or 3 cm (1 in.)/hr. snow
Static Load	0.6 cm (1/4 in.) radial ice, or 10 cm (4 in.) vertical snowfall
Temperature	As required per location
Humidity	0% to 100%, relative
Degraded Operation	
Wind	60 mph, gusts to 85 mph
Precipitation	5 cm (2 in.)/hr. rain, or 1 cm (1/2 inc.)/hr. freezing rain, or 3 cm (1 in.)/hr. snow
Static Load	1 cm (1/2 in.) radial ice, or 15 cm (6 in.) vertical snowfall
Temperature	As required per location
Humidity	0% to 100%, relative
Survival	
Wind	125 mph gusts
Static Load	3 cm (1 in.) radial ice, or 31 cm (12 in.) vertical snowfall
Temperature	As required per location
Earthquake	Intensity IX (Mercalli Modified) with 30 mph wind and no ice
Survival in Storage	
Temperature	$-60^{\circ}F$ to $+150^{\circ}F$
Humidity	0% to 100%, relative

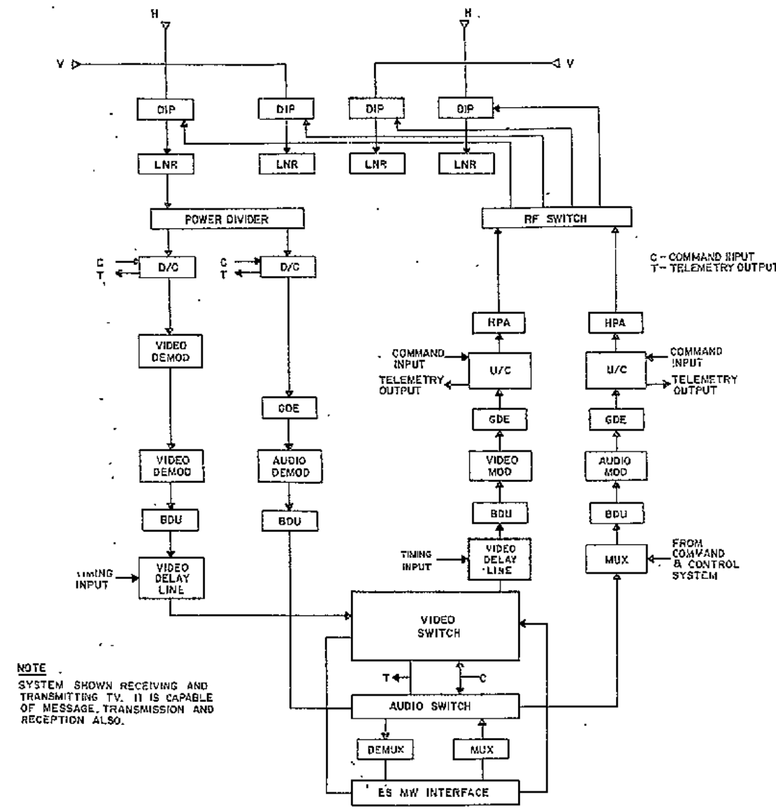


Figure 20-16. Functional Block Diagram of RCA 11-Meter (35-Foot) Dual Feed Antenna System

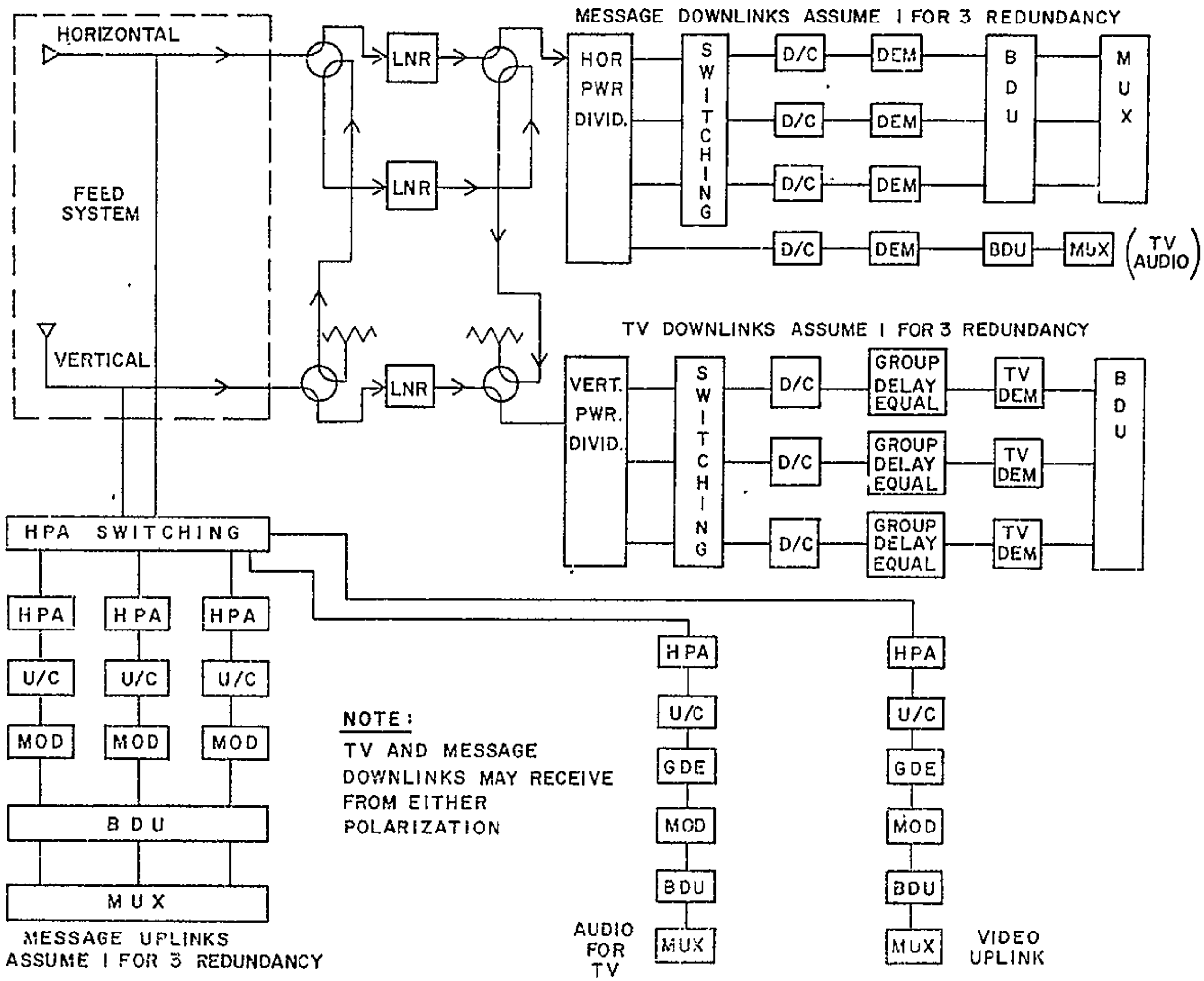


Figure 20-17. RCA 10-Meter (32-Foot) Single Feed Antenna System - New York, Hawaii

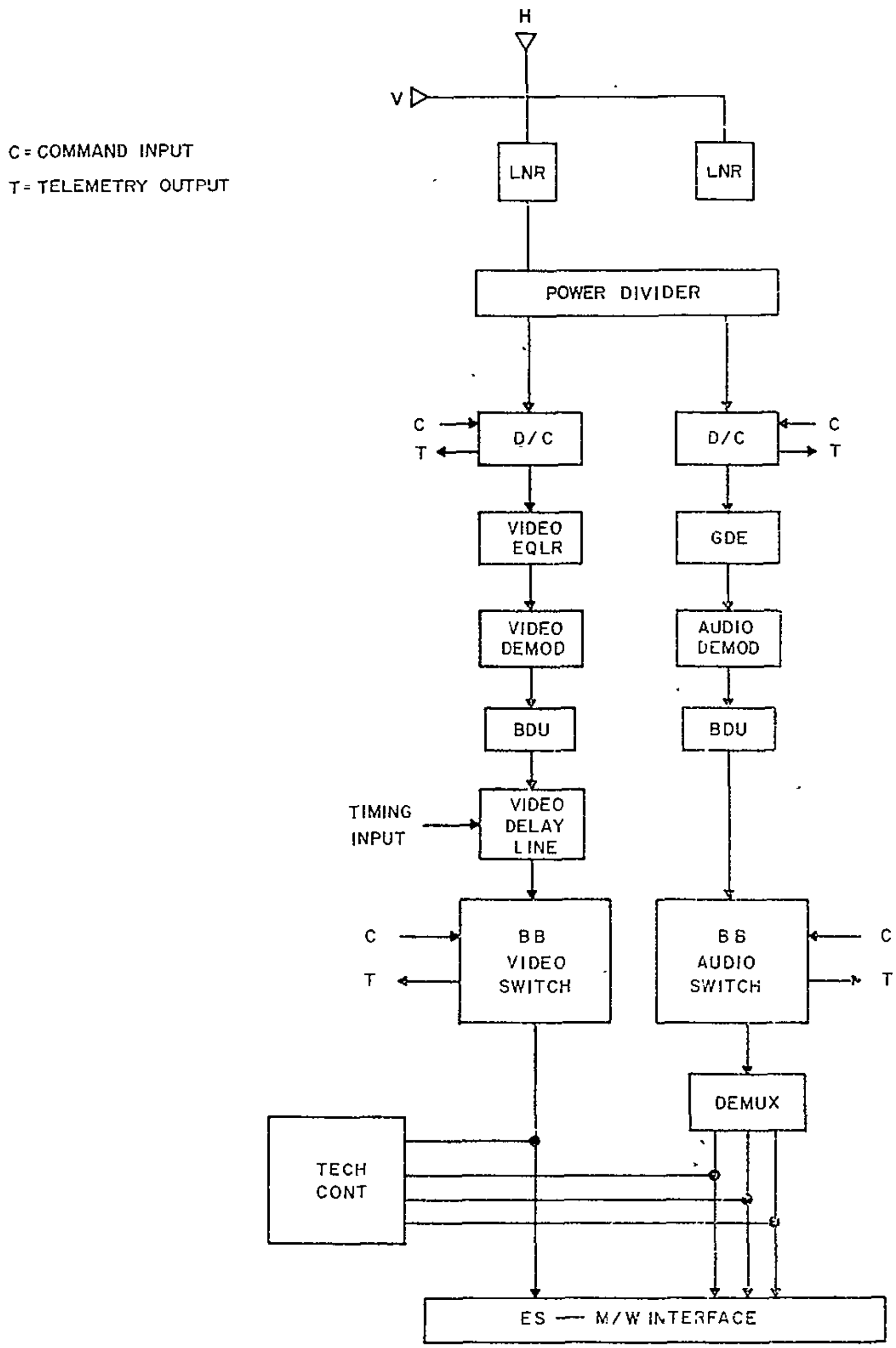


Figure 20-18. RCA Receive Only Terminal Functional Block Diagram

20.4.5 Operational Results

The RCA Domestic Satellite System has been in operation since late December 1973, using RCA earth terminals and leased satellite channels first on the Canadian Telesat (Anik) satellites and presently on the Western Union Westar satellites. Communications services for voice and data traffic within and between Alaska and the 48 contiguous states are provided by RCA Alascom and RCA Globcom.

NOTE: The RCA communications satellite, Satcom I, was launched December 12, 1975. Transponder testing is scheduled to begin in January 1976, and commercial traffic is scheduled to begin in late February.

20.5 WESTERN UNION

20.5.1 Program Description

The Western Union domestic satellite system program was aimed at providing an early entry into the U.S. marketplace. Satellites almost identical to the Anik were ordered from Hughes. The five earth terminals were ordered from ITT Space Communications. Operations began in July 1974 after launch and initial checkout of Westar I.

20.5.2 System Description

The Westar system augments Western Union's extensive microwave relay system which runs across the United States from east to west and also into Texas. The microwave relay system is shown in Figure 20-19. Also shown are the Westar earth station locations.

The initial Westar system includes two geostationary satellites in orbit, each with 12 RF channels of 36 MHz bandwidth, and five major earth stations. Each satellite RF channel has a capacity of 1 video channel or 1200 voice channels or 50-60 Mbps digital data in the single-carrier-per-transponder mode. The 12 channel frequency plan is diagrammed in Figure 20-20.

20.5.3 The Space Segment--The Westar Satellite

Westar I is on-orbit at 99°W longitude. Westar II was launched in October 1974 and was stationed at 91°W longitude. It is presently operating at 123.5°W longitude, providing service for RCA. These satellites are almost identical to the Canadian Telesat Anik Satellites. The most significant improvement is an onboard backup despin system which prevents spin-up on loss of pilot. While the early Aniks were designed for launch by a Delta 1914 vehicle, Westars were designed for launch by a Delta 2914 vehicle. A diagram of the satellite is presented in Figure 20-21, and a weight breakdown is given in Table 20-10.

A summary of the Westar general characteristics as well as its communications and TT&C subsystems is presented in Table 20-11. A noteworthy innovation is the ground processing and retransmission of sensor-data to attain proper synchronization for the despun antenna.

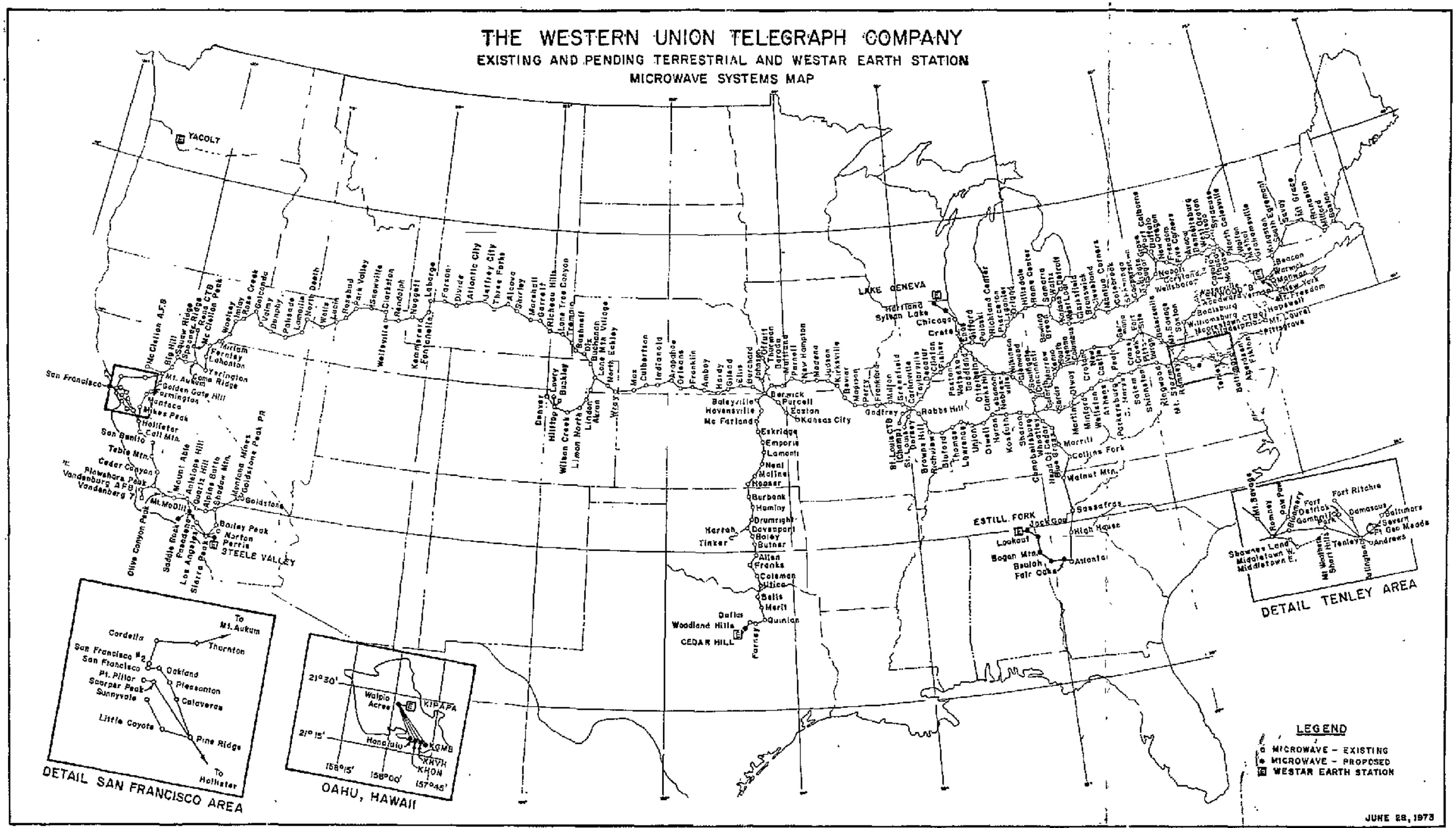


Figure 20-19. Western Union Microwave Relay System

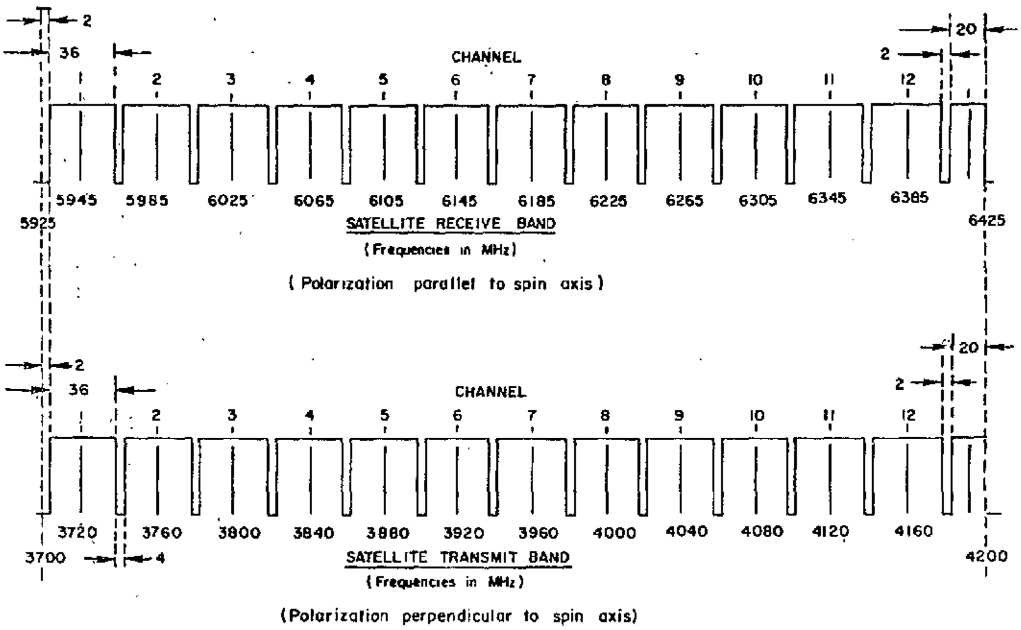


Figure 20-20. Western Union 12-Channel Frequency/Polarization Plan

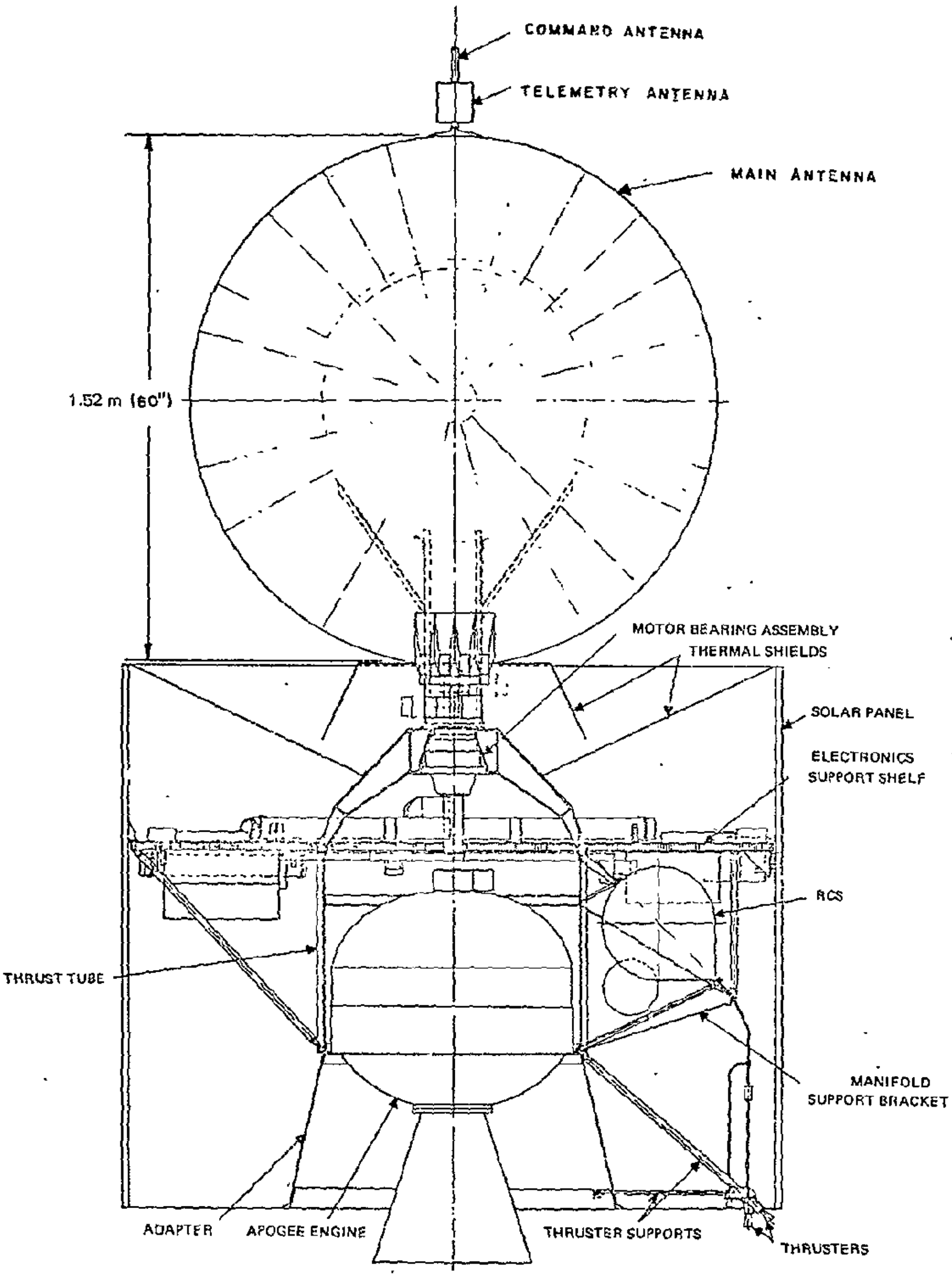


Figure 20-21. Western Union Satellite Configuration

Table 20-10. Westar HS 333A Weight Summary by Major Subsystem

Subsystem	Weight (kilograms)		Weight (pounds)	
Communications	43.71		96.50	
Antenna	10.12		22.36	
Telemetry and command	16.03		35.39	
Bicone antenna	0.792		1.75	
Attitude determination and control	17.03		37.60	
Spun elements		14.54		32.10
Despun elements		2.49		5.50
Electrical power	54.62		120.58	
Wire harness	8.80		19.44	
Reaction control	9.20		20.33	
Apogee motor (burnout)	28.38		62.65	
Structure	44.50		98.25	
Spun elements		38.07		84.04
Despun elements		6.43		14.21
Thermal control	10.61		23.44	
Spun		8.71		19.24
Despun		1.90		4.20
Balance weights, spun	1.68		3.72	
Final orbit condition	245.53		542.01	
Expendables	327.51		722.99	
Total spacecraft	573.04		1265.00	

Table 20-11. Westar Satellite Summary Chart

Satellite Characteristics	
Genre'	Hughes HS-333, almost identical to ANIK
On-Orbit Weight	~263 kg (~580 lb.)
Launch Vehicle	Delta 2914
Stabilization	Spin stabilized. Ground processing and pilot tone gen. Attitude sensor data. ± 0.10° for Attitude Determination
Propulsion	Restationing and Hydrozine for 7 yr. stationkeeping to ± 0.10° N - S and E-W
DC Power	~300 watts array power BOL Ni-Cd batteries give eclipse capability for 10 channels.
Communications Subsystem	
Total Performance	
RF Frequency & Polarization Plan	C-band frequency allocation 34-36 MHz RF channels, see Figure 3-1; 12 channels linear polarization.
EIRP	33 dBw Conus; (26 dBw Alaska, Hawaii)
G/T	-7 dB/°K Conus (-14 dB/°K Alaska, Hawaii)
Antennas	
Type	Mechanically despun 152.4 cm (60 in.) parabolic reflector with multiple feeds to provide a shaped beam.
Number of Beams	
Beamwidth	6.8° x 3.5° Conus. (2-8° Alaska, 2-8° Hawaii)
Gain	~27 dB edge of coverage gain.
Repeater	
Configuration	Single conversion; wideband receiver driving channelized transmitter.
Receiver	6 GHz TDA; downconv., 4 GHz TDA, Driver TWT.
Transmitter	12 unequalized channels; 5 watts 275H TWTAs.
T.T. & C.	
Tracking	Loop around multi-tone ranging.
Telemetry	PAM telemetry format - 22 functions.
Command	Multitone command format - 32 commands.

Another noteworthy innovation is the implementation of the shaped beam antenna pattern covering CONUS. An example of the coverage pattern is shown in Figure 20-22. The pattern is produced by the 1.52 m (60") reflector and a special multihorn feed which employs four dual polarized horns, three 90° hybrid splitters on the transmit function, and 180° magic tees for the receive function. These components operate in conjunction with a rotary joint.

A block diagram of the Westar communications transponder is shown in Figure 20-23.

20.5.4 <u>The Western Union Earth Segment</u>

The Western Union earth stations are at Glenwood (also containing the satellite control center), Estill Fork, Lake Geneva, Steele Valley, and Cedar Hill. A diagram of the 51-foot cassegraine antenna used is given in Figure 20-24.

Four of the five earth stations have been designed to operate unattended. The fifth, at Glenwood, serving New York City, is continuously manned, and monitors and controls the others by means of a fault monitoring and control (F/C subsystem), thus assuring economical and reliable operation.

The Glenwood terminal can also be characterized by its three antennas which it needs to fulfill its dual role of communications terminal and operations control center. Two of these antennas, 15.5 m (51 ft.) diameter each, are for communications purposes and for ranging and telemetry of in-service satellites. A pictorial diagram of a 15.5 m (51 ft.) diameter antenna is shown in Figure 20-24. The third, known as the Tracking, Telemetry, and Control (TT&C) Antenna, was used for the Westar I and II launches, and will be used for future launches. It also functions as a backup TT&C and test antenna for in-service satellites.

The other terminals contain two antennas, one for each Westar satellite. The major characteristics of the communications and TT&C earth terminals are summarized in Table 20-12. Further description is given in the Glenwood earth station block diagram shown in Figure 20-25. The block diagrams for the other major terminals are

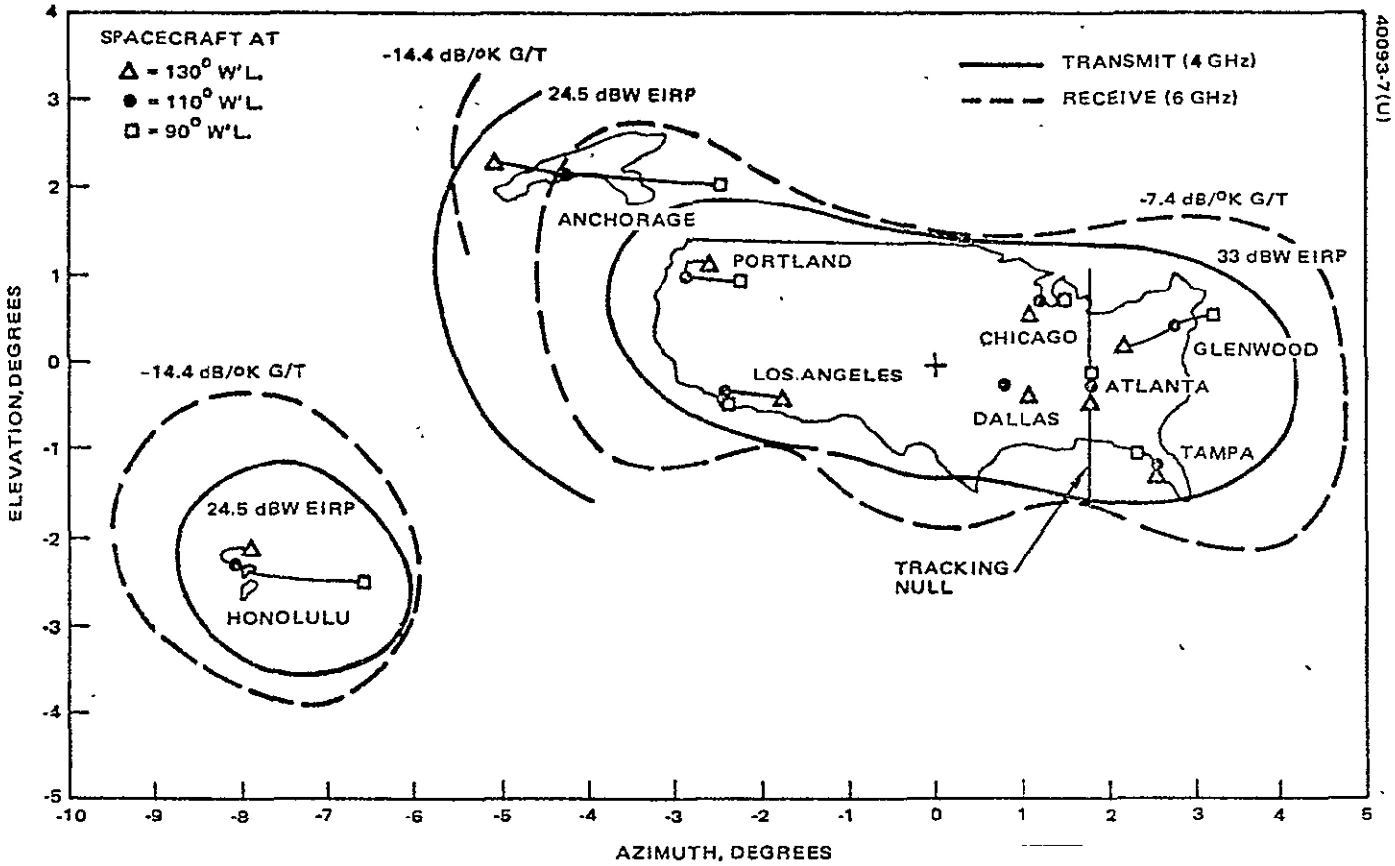


Figure 20-22. Western Union Satellite Four-Feed Horn Array Beam of U.S. Coverage

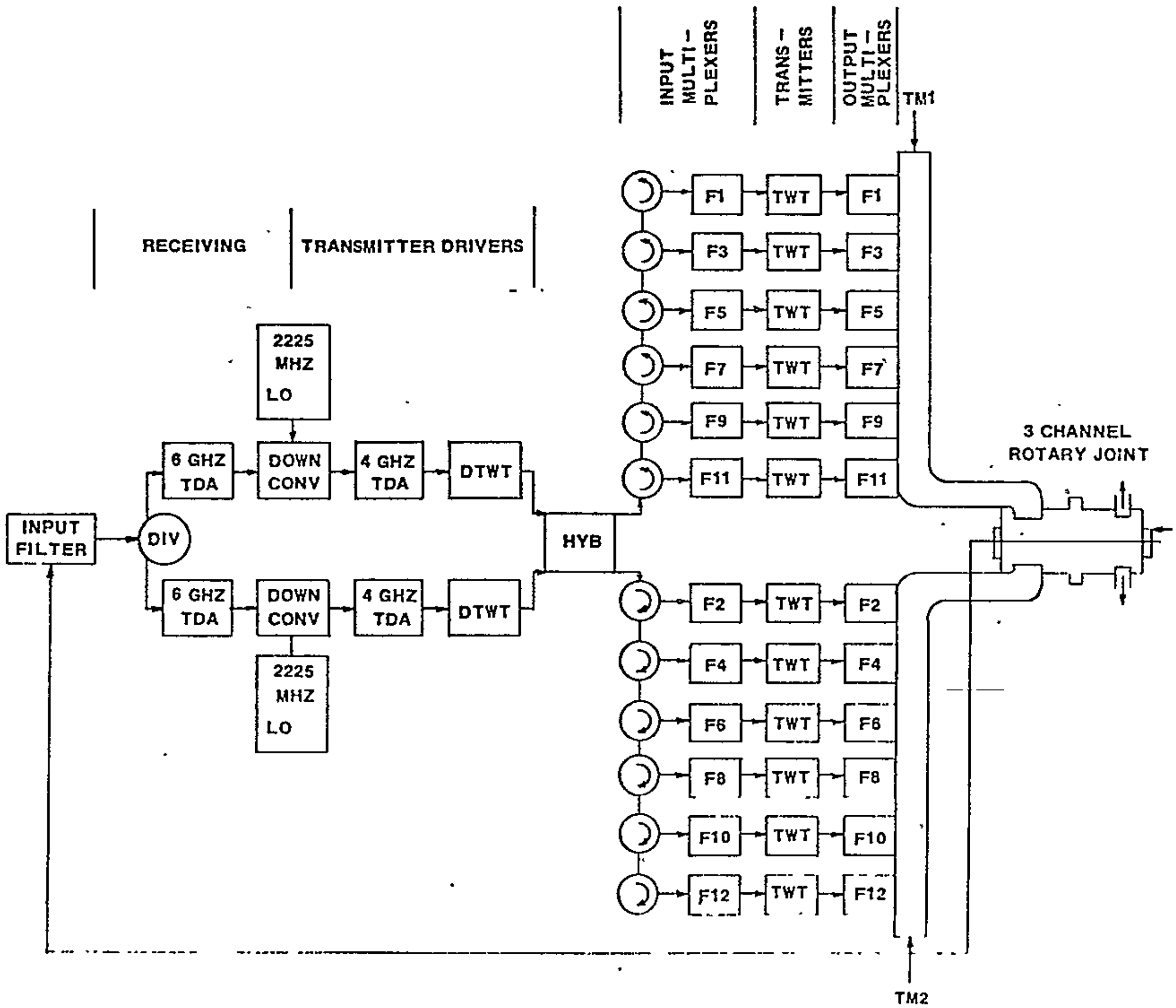


Figure 20-23. Westar Communication Transponder

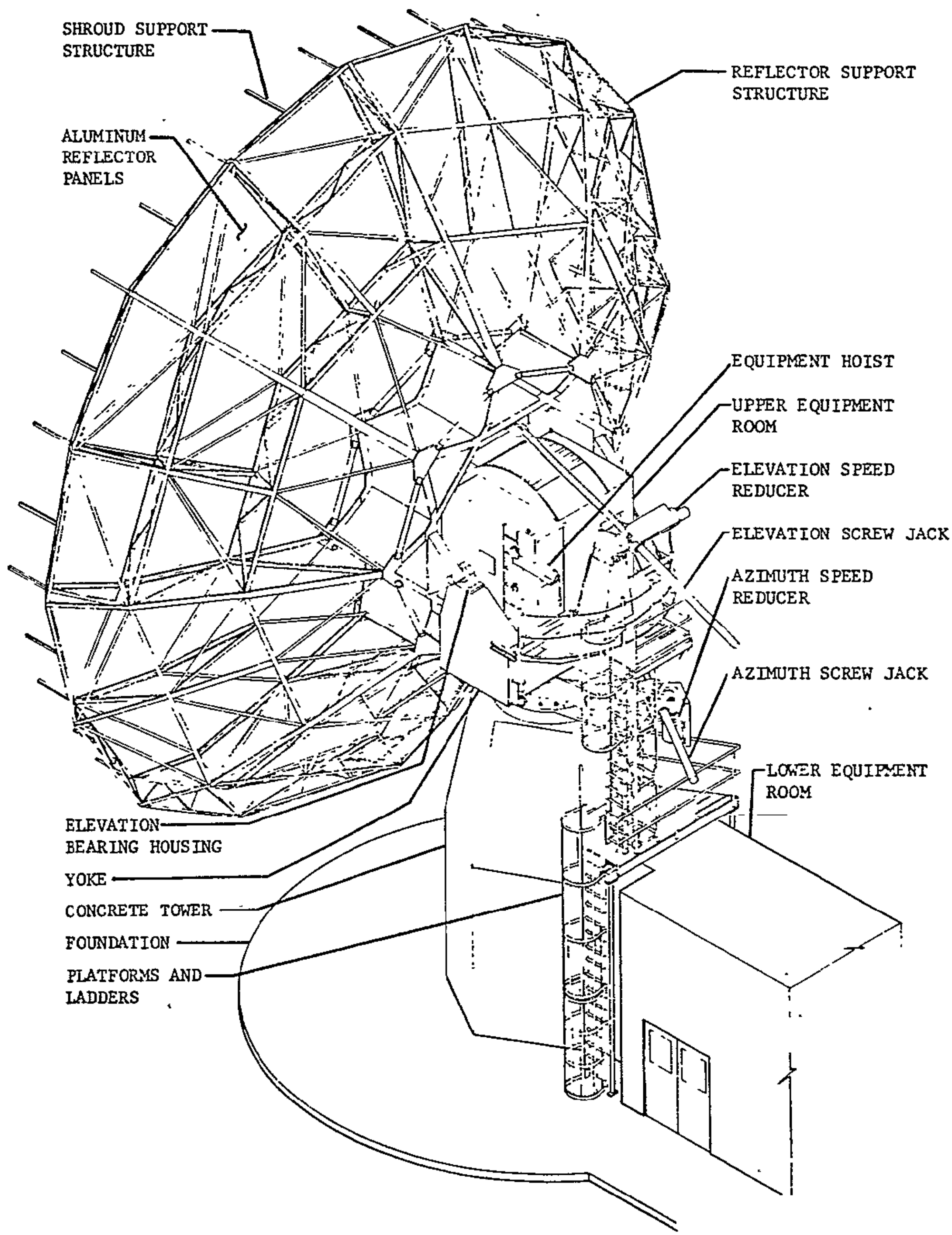


Figure 20-24. Western Union Domsat 15.5 m (51 ft.) Diameter Tracking Antenna

Table 20-12. Western Union Earth Terminal Summaries

	Major Terminal, With Operation Control: Glenwood	TT&C Terminal: Glenwood
<u>Major Parameters</u>		
G/T	37.4 dB/^{o} K (cooled) 34.5 dB/^{o} K (uncooled)	29 dB/^{o} K
EIRP	83 dBW	87 dBW
Freq. Plan: Transmit Receive	5.9 - 6.4 GHz and 3.7 - 4.12 GHz	5.9 - 6.4 gHz 3.7 - 4. gHz
Polarization	Linear Orthogonal. $\pm$ 135^{o} Adjust.	Linear, Orthog. $\pm$ 95^{o} Adjust.
<u>Antennas</u>		
Type	Two shaped paraboloids, Cassegraine Feeds Elev. over Azimuth	One paraboloid, Cassegraine Feed Elev. over Azimuth
Diameter	15.5 m (51 ft.)	10 m (33 ft.)
Gain: Receive Transmit	54.3 dB 57.3 dB	50.4 dB 53.5 dB
<u>Receive Subsystem</u>		
Type Preampl.	Cooled and uncooled parametric amplifiers.	Uncooled
Noise Temp.	20^{o} K Cooled 55^{o} K Uncooled	90^{o}
Bandwidth	500 MHz	500 MHz
<u>Transmit Subsystem</u>		
Type Power Ampl	Klystron	Klystron. Two in parallel
Power Output	3 KW	3.3 KW each.
Bandwidth	50 MHz	50 mHz
<u>Ground Communication Equipment</u>		
	Baseband-70 MHz IF-RF Single carrier mode Video and 1200 FDM Messages	Tracking, Telemetry and Command. Also, transponder test uplink and downlink.

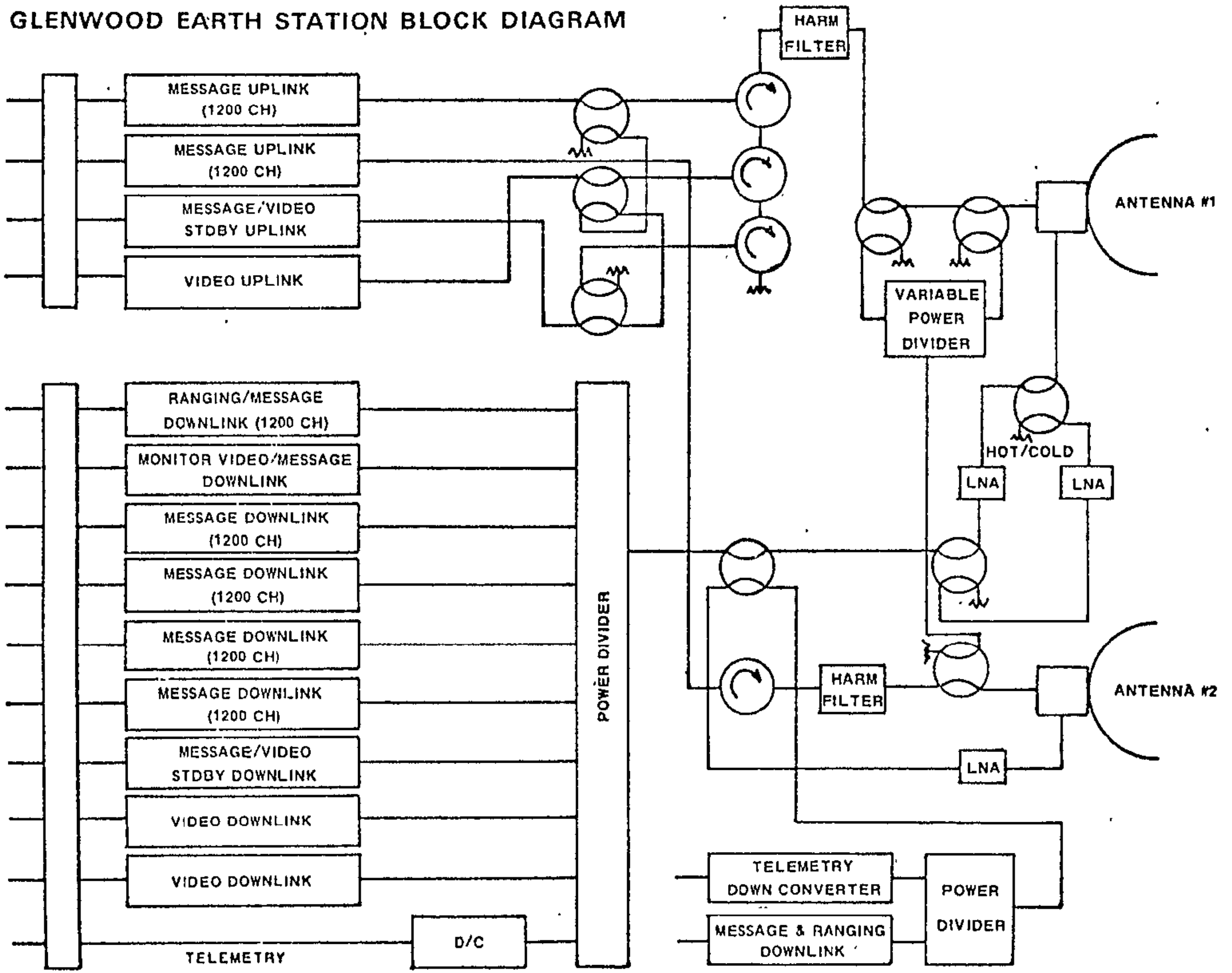


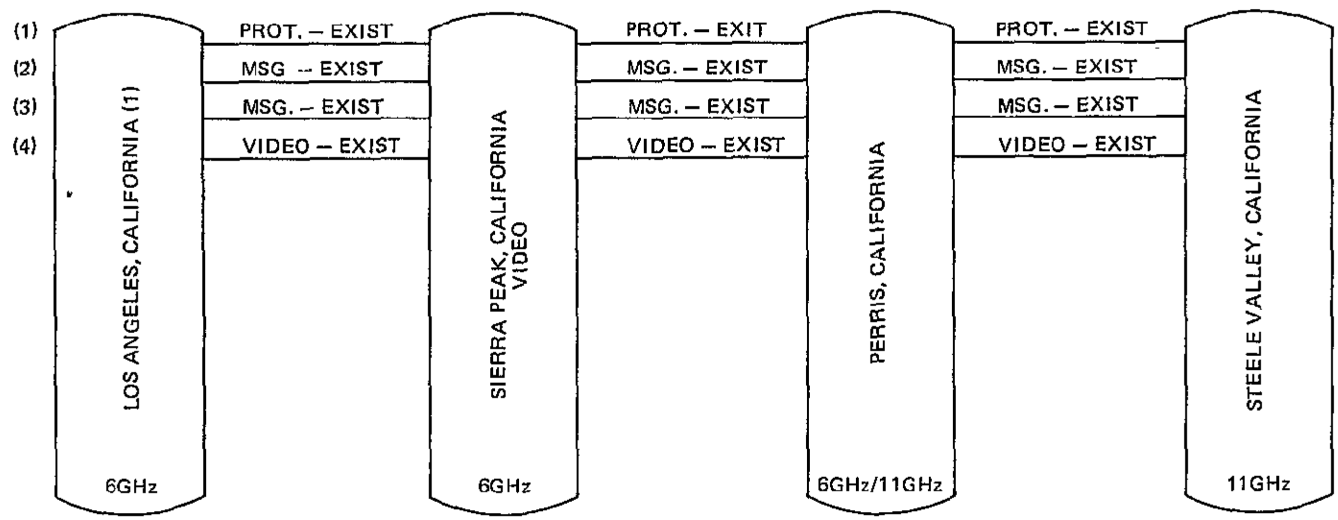
Figure 20-25. Western Union Glenwood Earth Station Block Diagram

similar except that there are fewer operational inputs and outputs of video and message signals.

The discussion of the earth segment has dealt thus far with satellite earth terminals. Another essential part of the earth segment is the interconnection links from the earth terminals to the major population centers which they serve and which may be up to a hundred miles or so away. Several microwave repeaters can be involved in this link. As an example, the Western Union interconnection between the Steele Valley earth terminal and the population center of Los Angeles is shown in Figure 20-26.

20.5.5 Operational Results

Western Union was the first commercial organization to apply to the FCC for authorization to construct and operate a Domestic satellite system in the United States. In April 1974, Westar I was successfully launched, and commercial service was inaugurated in July 1974. The Western Union system became the first complete U.S. operating system and currently provides the space segments for all domestic satellite systems. It is multipurpose in that both message and television traffic are carried.



EXISTING WESTAR CHANNELS

1. ONE FDM DUPLEX MESSAGE PROTECTION CHANNEL.
2. ONE FDM DUPLEX MESSAGE CHANNEL.
3. ONE FDM DUPLEX MESSAGE CHANNEL.
4. ONE DUPLEX VIDEO CHANNEL.

Figure 20-26. Western Union Steele Valley-Los Angeles Terrestrial Microwave Repeater Interconnection Links

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