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Compendium of
APPLICATIONS TECHNOLOGY SATELLITE USER EXPERIMENTS
1967-1973

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August 1976
Final Report

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Prepared for:
NASA-Lewis Research Center
Cleveland, Ohio 44135

Under Contract:
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16. Abstract

The Applications Technology Satellite (ATS) series was launched in 1966 by National Aeronautics and Space Administration. This report summarizes the achievement of the user experiments performed with these satellites from 1967 to 1973. The experiments summarized in the report include fixed and mobile point-to-point communications experiments involving voice, teletype and facsimile transmissions. Particular emphasis is given to the Alaska and Hawaii satellite communications experiments. The use of the ATS satellites for ranging and position fixing of ships and aircraft is also covered. A brief description of the structure and operating characteristics of the various ATS satellites is given.

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LIST OF ACRONYMS

AANHS - Alaska Area Native Health Service
AFCRL - Air Force Cambridge Research Laboratory
ALOHA - Experimental UHF radio packet switched computer communications network
ANMC - Alaska Native Medical Center
APT - Automatic Picture Transmission
ARC - Ames Research Center
ARINC - Aeronautical Radio Incorporated
ARPANET - Advanced Research Projects Agency Computer Network
ATS - Applications Technology Satellite
BOMEX - Barbados Oceanographic Meteorological Experiment
CHAP - Community Health Aide Program
C + N - Carrier plus Noise
CPB - Corporation for Public Broadcasting
DHEW - Department of Health, Education and Welfare
ECG - Electrocardiogram
EIRP - Effective Isotropically Radiated Power
FAA - Federal Aviation Administration
FDMA - Frequency Division Multiple Access
FM - Frequency Modulation
FSK - Frequency Shift Keying
FT - Frequency Translation
GSFC - Goddard Space Flight Center
G/T - Antenna Gain to System Temperature ratio
HF - High Frequency
IDCS - Image Dissector Camera System
IEEE - Institute of Electrical and Electronic Engineers
IF - Intermediate Frequency
IGY - International Geophysical Year
IRE - Institute of Radio Engineers
LHNCBC - Lister Hill National Center for Biomedical Communications
LOP - Live-of-position
MSSCC - Multicolor Spin Scan Cloud Camera
NAFEC - National Aviation Facilities Experimental Center
NASA - National Aeronautics and Space Administration
NBFT - Narrowband Frequency Translation
NBS - National Bureau of Standards
NIH - National Institutes of Health
NPR - National Public Radio
OCC - OPLE Control Center
OPLE - Omega Position Location Experiment

ORION - Optimum Ranging in Oceanic Navigation
PCM - Pulse Code Modulation
PEACESAT - Pan-Pacific Education and Communications Experiments by Satellite
PEP - Platform Electronics Package
PHS - Public Health Service
PM- Phase Modulation
PSK - Phase Shift Keying
SAMSO - Space and Missile Systems Organization
SAO - Smithsonian Astrophysical Observatory
SCOMB - Satellite Communication Oceanographic and Meteorological Buoy
SHF - Superhigh Frequency
S/N - Signal to Noise Ratio
SSB - Single-Sideband
SSCC - Spin Scan Cloud Camera
TIE - Transcontinental Interconnection Experiment
TTY - Teletype
TWT - Traveling-Wave Tube
UH - University of Hawaii
UHF - Ultrahigh Frequency
UTC - Coordinated Universal Time Scale
VCO - Voltage Controlled Oscillation
VHF - Very High Frequency
VLF - Very Low Frequency
WAMI - Washington, Alaska, Montana, Idaho Medical Program
WARC - World Administrative Radio Conference
WBFT - Wideband Frequency Translation
WEFAX - Weather Facsimile Experiment

SECTION 1

THE APPLICATION TECHNOLOGY SATELLITE PROGRAM

1.1 INTRODUCTION

During the late 1960's, the artificial satellite emerged from the experimental realm to become a valuable operational tool in the fields of communication, navigation, meteorology, and for the acquisition of earth resources data. The Applications Technology Satellite (ATS) program, directed by Goddard Space Flight Center of NASA, was a major contributor to the growth of satellite technology during the 1960's.

The ATS program initiated the use of multi-missioned satellites as an economical approach to space applications development. Five satellites were launched between December 1966 and August 1969; however, only three of the five achieved the desired orbit. The ATS satellites which achieved orbit, along with some of the major contributors to space technology prior to the ATS program, are shown in Table 1.1.

The successful series of passive satellites, which were simpler but required enormous ground transmitter powers for effective communications, were followed by a generation of active wide bandwidth systems capable of carrying a television picture or the equivalent. TELSTAR and RELAY satellites examined the possibilities and proved the feasibility of worldwide satellite communications using medium altitude (up to 10,000 Km) orbits. The major disadvantage of this system was the problem of achieving smooth hand-over from one satellite to another, when the first was passing out of the area visible to both the transmitted and receiving ground stations.

The SYNCOM program was first to investigate the use of satellites in geostationary altitude (about 36,500 Km). At this altitude, the spacecraft remains at or close to a fixed point above the equator. Communications links to all points on earth, except for relatively small areas near the poles,

TABLE 1.1

SATELLITE CONTRIBUTIONS

Satellite/ Department	Date Launched	Contribution
SCORE - DOD	1958	Recorded message from President to world.
COURIER - DOD	1960	Delayed repeater - investigated store-forward and real-time capabilities
WESTFORD - DOD	1960	Tiny resonant dipoles dispersed in orbital belt for communication by reflection.
ECHO I - NASA	1960	Passive communications using inflatable sphere of aluminized mylar.
TIROS I - NASA	1960	Monitored global weather conditions and cloud cover. Television and infrared observation satellite. Predecessor of NOAA series.
TELSTAR - AT&T - BTL	1962	Active wideband communications. Launch and early orbit determination done by NASA.
TELSTAR II - AT&T - BTL	1963	Same as above.
RELAY I, RELAY II - NASA	1962 and 1965	Television and voice experiments between United States, Europe, Brazil, and Japan.
SYNCOM II - NASA	1963	Demonstrated station keeping and orbital control principles. International communications. First use of Goddard range and range-rate.
ECHO II - NASA	1964	Same as ECHO I, plus collaboration with Russia.
SYNCOM III - NASA and DOD	1964	First stationary orbit. Wide and narrow band repeater for all modes of communications between Far East and the United States.
NIMBUS - NASA	1964	Improved over TIROS, incorporated earth stabilization and modular con construction.
EARLYBIRD - COMSAT	1965	Operational communications. Launch and early orbit determination done by NASA.
ATS 1	1966	Stationary orbit. Electronically despun antanna. Multiple-access. High resolution camera.
ATS 3	1967	Stationary orbit. Mechanically despun antenna. Multiple access. High resolution color camera.
ATS 5	1969	Stationary orbit. L-band repeater. Failed to stabilize but still useful in spinning mode.

are then possible using three synchronous satellites. In this case, there are no tracking and hand-over problems. However, because of greater distances, more capability is needed in the electronic equipment. The SYNCOM program demonstrated that the problems of geostationary orbit achievement, station keeping, and the time delays in two-way message traffic were solvable and therefore are considered the forerunners of the present operational geosynchronous wideband communications satellites.

Perhaps the most significant event to influence development of satellite communications systems was the passage of the Communications Satellite Act by Congress in 1962. This act allowed the creation of a private organization, subject to government regulation, "to plan, construct, and operate commercial communications satellite systems." As a result, "The COMSAT Corporation" was formed to develop the commercial aspects of communications satellite systems, while NASA concentrated on advancing the state-of-the-art by continuing the experimental satellite programs.

The ATS program evolved directly from the SYNCOM program, employing many SYNCOM features, including the synchronous altitude technique and spin-stabilization. The underlying rationale of the ATS program was the development of a multi-mission spacecraft with a large adaptable volume for mounting payloads. The entire ATS effort was aimed at advancing technology in the fields of communications, meteorology, and navigation, by improving spacecraft systems.

1.2 OBJECTIVES

The original ATS program had three basic objectives.

- To evaluate the use of gravity-gradient stabilization at medium altitude followed by an evaluation of the technique synchronous altitude.

- To demonstrate the feasibility of visual imaging, communication, and environmental measurement using spin-stabilized spacecraft at synchronous altitude.

- To conduct a set of technological experiments utilizing a gravity-gradient stabilized satellite, in geostationary orbit.

Within the framework of these three initial basic objectives were the following specific objectives for each of the experiment groups.

Systems Performance Experiments

- To obtain data on the performance and life of the spacecraft structures.
- To obtain data on the performance and life of the power supply.
- To obtain data on the performance and life of the spacecraft control subsystems.
- To obtain geodetic data, specifically with regard to improved knowledge of the location of the stationary orbit stable points.
- To obtain data on the disturbing torques and effects of thermal bending of the booms.
- To evaluate the performance of the different damping systems by observing their restoring ability and time constant (when subjected to predetermined disturbances) obtainable from the spacecraft.
- To evaluate the performance and life of the electronically controlled phased array antenna and the mechanically despun antenna.

Communications Experiments

- To evaluate the performance and life of the communications transponder components.
- To evaluate the multiple access capabilities of Single Sideband/ Phase Modulated systems.
- To investigate feasibility of communication with mobile users.
- To obtain propagation data for millimeter wave frequencies.

Navigation Experiments

- To obtain improved range and range rate measurements.
- To evaluate the performance of the ranging altitude technique and Omega position location technique for navigation.

Meteorological Experiments

- To investigate the nature of short-lived meteorological phenomena.
- To make detailed observations of different parts of the earth's cloud coverage using a high resolution camera.

Environmental Measuring Experiments

- To obtain continuous radiation levels both at 6,000-mile altitudes and at synchronous orbit altitude.
- To assess damage caused by the small "space dust" particles to reflective surfaces by erosion processes.
- To measure the density, energy, and directivity of protons and electrons in space.
- To measure the strength of the earth's magnetic field.

This compendium is primarily concerned with user experiments in the areas of communications, navigation and meteorology. Systems performance and spacecraft environment measurements are not classified as user experiments.

1.3 SUMMARY OF ACHIEVEMENTS AND CONCLUSIONS

The ATS program was started in 1966, approximately three years after SYNCOM's successful demonstration of the feasibility of geosynchronous communications. Of the six Applications Technology Satellites launched since then, four achieved orbit and now represent the largest class of geosynchronous communications satellites in use.

After ten years of experimentation, NASA funded a contract to summarize the ATS experiments in order to give the congress and the public an accounting of the expenditures for the ATS-1, 3, 5 program. In order to make such an accounting meaningful, it is necessary to examine the goals of the ATS program, which were as follows.

1. Study the space environment and develop the technology of space communications.

2. Provide an opportunity for the transfer of the technology so that it may be used for new applications.

Those experiments conducted by NASA and its contractors for the purpose of achieving the first goal are usually called science experiments. Those experiments conducted for the purposes of achieving the second goal have become known as user experiments. User experiments are further characterized by the requirement that the experimenter provide the funding for ground equipment, with NASA providing only the time allocation on the spacecraft. The results of the science experiments provided a wealth of new knowledge pertaining to the space environment and the technology required for space communications. However, the value of this knowledge as judged by the congress and the public may be quite different from the value as judged by NASA. This external judgment of the success in achieving the first goal requires an assessment of the value of high technology to the nation.

One function of NASA as defined in the Space Act of 1958 is to develop the technology required for the U.S.A. to maintain world leadership in the peaceful applications of aeronautics and space for the benefit of this country and the world. This means that the U.S. government assumes for its industry and public, the risk of some major research and development programs. As an example, it would have been financially impossible for a single corporation to demonstrate the feasibility of geosynchronous communication satellites. Because the government assumed this risk, a new industry was developed. Now, U.S. corporations involved in this industry market their technology and services in the U.S. and abroad and are presently paying more in taxes than the government is spending for its space communications program. Furthermore, as a result of the ATS program, U.S. industry has developed the MARISAT, AEROSAT and DOMSAT programs which will bring further growth in the space communications industry. These results flow from the first goal; whether they justify the funds spent is a judgment reserved for the public.

Before addressing the second goal of the ATS program, a review of the history leading to the formulation of that goal may be beneficial. During the early 1960's the space agency was committed to President Kennedy's mandate to reach the moon and return before the end of the decade. In addition to the efforts of the Apollo Program, the agency continued its work in researching and developing high technology. In the pursuit of these latter, less publicized efforts, NASA became aware of the potential benefits to be derived from space technology and in particular the benefits to be gained from space communications. In order to accelerate new applications and the transfer of space communications technology from government research programs to development by the private sector, a decision was made to give interested parties outside the agency the opportunity to perform communications experiments with the ATS satellites. The requirements were that the interested party must formulate an experiment plan including an objective, a description of the experiment, a schedule, a method for obtaining the necessary funding, and finally, and most important, to publish a report of the results. In return, if the experiment was approved, NASA agreed to supply time allocation on one or more of the ATS spacecraft.

Corporations, universities, governments and government agencies and a variety of other institutions responded to the opportunity. To date the ATS-1, 3, and 5 user experiments summarized in this document number more than one hundred. Some may appear to have been more successful than others but rather than perform such subjective speculation, it is more important to examine the experiments and results in the context of NASA's goal of providing opportunity for the transfer of technology. The opportunity to participate was made available to all interested parties. There is no doubt that advertising for the program could have been better, but this would have required additional funds. It is also questionable as to whether more and better advertising would have produced more and better experiments.

The ATS 1, 3 and 5 experiments can be divided into the categories of education, health and other. Nearly all of the experiments that could be classified under the category "other" were conducted by engineers and scientists or by an organization with ready access to a scientific and engineering support staff. Such was not the case for most of the experiments classified under health and education. The implications of this did not seem to warrant much attention during the years from 1966 to 1974, but in retrospect seems to be an important item.

The usual characteristics of the education-health experiments consisted of one or more of the following: remote region; low traffic density; wide bandwidth requirements (greater than one telephone line); public services; long distance transmission. These characteristics usually render common carrier service unprofitable and expensive. ATS 1, 3 and 5 clearly demonstrated that there are numerous potential users of this type spread over the entire globe. Usually, the communications industry cannot afford the cost of aggregating this type of market and so the market is neglected because of poor profit potential.

Recalling that some experimenters had technical support while others did not, one would suppose such heterogeneity may be a source of problems. One potential source of problems was the uncertainty concerning the bonds of communications activities which NASA could sanction under the guise of experimentation by ATS 1, 3 and 5 users without becoming a competitor of common carriers. Another problem was that

NASA did not provide funding or technical support to experimenters, and so this often forced users to report to more than one agency. The geography of the user experiments covered nearly all of the western world and added to the complexity of coordination. Despite all of this, there were no serious problems or failures. There were many misunderstandings caused by the complexity and the fact that all parties were learning about an entirely new entity. Experimenters learned what could and could not be done well with satellites. The largest benefit received by NASA was an understanding of the user's needs (both real and perceived). The successes may be attributed to the willingness of the individuals involved to solve the problems and a generous portion of good luck.

Luck came in the form of corporate proposals such as the General Electric/Exxon maritime communications experiment. It is the opinion of this writer that the report given NASA by the GE/Exxon experimenters was the best experiment report submitted to NASA in the ATS 1, 3, 5 user experiment program. Some reasons for the excellence of this and other similar experiments are as follows.

1. G. E. and Exxon are both market oriented organizations.
2. Both have technical capabilities and experience.
3. The experiment was well defined and alternative modes of communication were specified to give a basis of reference or comparison.

Another interesting fact about the G. E. /Exxon report is that it was one of the shortest user experiment reports submitted to NASA and it was very well written.

The characteristics of a "good" experiment (as distinguished from a successful experiment) will be similar to the three reasons cited above for the G. E. /Exxon experiment. In addition to these hoped-for qualities, it would be desirable if NASA could profit from the knowledge gained because NASA must develop or evolve to the next step in the technology transfer process. A background for what NASA seems to be learning from G.E./Exxon and other non-government institutions is provided by a quote from Theodore Levitt's book The Marketing Mode (1969, McGraw-Hill, p. 1).

> "Last year 1 million quarter-inch drills were sold," Leo McGivena once said, "not because people wanted quarter-inch drills but because they wanted quarter-inch holes."
>
> "People don't buy products; they buy the expectation of benefits. Yet narrow production-minded executives and most economic theorists are resolutely attached to the idea that goods have intrinsic properties. A loaf of bread is presumed to be quite obviously something different from a diamond. Each is somehow viewed as having inherent characteristics rather than as conveying benefits to buyers. This accounts in the business world for pricing policies based one-sidedly on costs, and in the world of the economist for microeconomic demand curves that define consumer utility as, at best, indifference functions.
>
> Physics long ago abandoned the notion that things have intrinsic or inherent characteristics. It is time that we do the same in business. People spend their money not for goods and services, but to get the value satisfactions they believe are bestowed by what they are buying. They buy quarter-inch holes, not quarter-inch drills. That is the marketing view of the business process."

If such criticism applies to American business, it applies even more so to the U.S. Government and to an organization such as NASA which, until the end of the 1960's, had been its own customer. Technology spinoffs which resulted from space hardware were fortuitous but unintended benefits until Congress asked the agency to devote a greater effort to technology transfer. The portion of NASA devoted to the development of technology has not been especially product or market oriented and to expect such would be unreasonable, but such is not the case for applications oriented programs.

To paraphrase the quote in terms of our discussion, people do not want satellites or communications technology. They desire to communicate and are merely seeking a service, giving little thought to how the service is being provided. A thorough study of the G.E./Exxon experiment will demonstrate that this service or market orientation made the G.E./Exxon experiment a "good" one and the capabilities of the experimenters made it a successful one. It may be said that because NASA lacked this marketing orientation the utilization of the ATS 1, 3 and 5 satellites was not as good as it might have been. Those organizations without the marketing orientation, likewise, did not utilize their satellite time as well as those with it. This is demonstrated by the trial-and-error approach of many of the experiments. It must also be said that some of the health and education experiments were further hindered by a lack of technical support which could have been provided by the Government (NASA) at the cost of cutting some other program. (NOTE: During most of the ATS 1, 3, 5 years, large cuts were being made in the space program.)

Most of the socially oriented experiments were conducted in the South Pacific and in Alaska as stated previously. Very few alternative communication services were available to these experimenters; usually, the experimenters were not engineers; and the experiments were conducted over a period of years. NASA's lack of a marketing orientation caused some friction with these experimenters because the agency did not genuinely understand that these geographic regions (Alaska and Hawaii) offered few communication service alternatives to meet social problems. The lack of marketing orientation impeded the progress of the experimenters because they were discipline oriented rather than communication product oriented; this caused what appears to be a trial-and-error approach. Experiments and programs were not well defined except in some cases such as PEACESAT's inter-personal communications course at the University of Hawaii and the Alaskan Village Doctor Call. In both instances program content was usually well defined which in turn implies a well defined communications product; the indications of a well defined product are well defined results for the experiment.

The lack of technical support for the socially oriented experimenters simply caused delays and misunderstandings. These matters would have been helped considerably if NASA could have obtained funding for technical support of experimenters; this situation has been changed somewhat in the ATS-6 and CTS experiments.

In order to judge the success or failure of the ATS user experiments program, one must examine the results of the program which now consist of many volumes of reports. An attempt has been made to summarize those results and present them in an orderly fashion in this document. It is beneficial to consider what we have learned from ourselves and our experimenters and to use this knowledge for the development of new technology and as a guide for the resources required to achieve the greatest value from this technology.

The achievements of the ATS 1-5 program, with the exception of the gravity gradient experiments, met or exceeded most of the initial objectives as outlined above. Spin stabilized satellites ATS-1 and 3 were extremely successful, and provided the most useful data, including many significant "firsts" in space. Failure of the three gravity gradient stabilized spacecraft (ATS-2, 4, and 5) to achieve a stable orbit eliminated the possibility of meeting the gravity gradient stabilization experiment objectives. ATS-2 and 4 failed to achieve orbit; ATS-5 did achieve the desired orbit, but in a spinning, stabilization mode. However, by modification of experimental procedures, to account for the spinning spacecraft, substantial data was obtained. As a result of this experimentation, the ATS program underwent a transition from the early emphasis on gravity gradient stabilization and related experiments to emphasis on spin stabilized spacecraft and communication hardware, techniques, and applications compatible with spinning spacecraft. The despun antenna technique became a key feature of the program. Applications to fixed services, mobile services, broadcasting, data collection, and propagation studies as well as navigation applications received increasing attention as the program progressed. Spacecraft life which extended well beyond the three year objective enabled the program to support numerous experimental users for eight years and longer.

The initial environmental measurements objectives of ATS-1 were met essentially as planned. The meteorological experiments related to the spinning satellites met with particular success by obtaining the first spin scan, high resolution, full earth, cloud cover pictures. The communications experiments in Alaska and the South Pacific demonstrated that voice communications using small, inexpensive terminals was possible.

Other services performed by ATS-1 were the relay of special television programs: the first splashdown of the APOLLO moonflight, EXPO 67 in Australia, and the Japanese Prime Minister's visit to Australia; 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.

One of the most notable of the achievements of the ATS-3 satellite was the first ground-to-satellite-to-airplane two way communications link over the Atlantic Ocean. This historic event took place on November 21, 1967, during a Pan American flight from New York to London. The communications engineer aboard the plane was able to maintain conversations with both Pan American officials in New York and with NASA officials at Goddard Space Flight Center. The Mojave ground station handled the experiment control. Transmissions to and from the aircraft via the satellite were monitored at different places around the world as far away as London, Hamburg, Frankfurt, and Buenos Aires. Another particularly notable achievement of ATS-3 was the high resolution color photograph of the full earth obtained from the multicolor spin scan cloud camera. The image dissector camera (IDCS) also obtained many cloud photographs. ATS-3 performed many services including support of the APOLLO missions; television coverage of Pope Paul's visit to Bogota, Columbia; special SHF tests such as for the IEEE International Communication Conference; VHF relay of special commands to ATS-4 from Johannesburg; demonstrations of automatic picture transmission at NASA headquarters by the weather facsimile (WEFAX) experiment on-board the ATS-3; and real-time data support of the OSO-IV satellite.

The NASA/GSFC L-band ranging and position location experiments, conducted from the Mojave ground station, demonstrated the ability to obtain meaningful range measurements using PM tone modulation at L-band carrier frequencies. The 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 evaluated the relative accuracy to which those measurements could be made.

The Alpha II project for the United States Air Force (SAMSO), utilized ATS-5 to demonstrate simultaneous L- and C-band ranging. In the Maritime Administration experiment, L-band ranging signals were transmitted from the Mojave ground station and relayed through ATS-5 to the USS MANHATTAN, a tanker exploring the Northwest Passage to Alaska. Another Maritime Administration experiment 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 ESSO BALTIMORE. Among the other tests and experiments conducted were the ionospheric propagation tests; an 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 Aviation Administration/Boeing Aircraft Company conducted an experiment at L-band frequency from ATS-5 to an aircraft that involved measurements of multipath effects and tone ranging. Other experiments were the millimeter wave experiment for Goddard Space Flight Center concerning the propagation correlation with rain, fading, and weather conditions at 31.65 GHz uplink and 15.3 GHz downlink; and the Applied Information Industries/Wallops Island experiment in relative position (ranging).

Table 1.2 summarizes the major technical achievements of the ATS-1 through ATS-5 spacecraft.

1.4 SPACECRAFT STRUCTURE

Two spacecraft stabilization techniques were used in the ATS program. One was to satisfy spin-stabilized missions where the spacecraft was in constant rotation, and the other the gravity-gradient concept where the spacecraft was passively stable in three axes. These stabilization techniques led to the design of three basic spacecraft structures: one for the spin-stabilized, synchronous altitude configuration; one for the gravity gradient, synchronous altitude configuration; and one for the gravity gradient, medium altitude configuration.

ATS-1 and 3 are cylindrical, spin-stabilized spacecraft with solar-cell arrays around their periphery (see Figure 1.1). The apogee motor is housed in the thrust tube. The communication antenna protrudes from the end of the spacecraft. Spacecraft components and payloads are mounted in the compartment between the outside of the thrust tube and the solar panels. Reaction control tanks and nozzles are located in the plane of the spacecraft center of gravity.

The gravity-gradient ATS-5 spacecraft (see Figure 1.2) is also cylindrical and consists of a central spacecraft compartment with solar panels extending from both ends. The central compartments are thermally insulated and contain an active thermal control system since the satellite was not designed to be rotating. The center bay was used for component and payload mounting. An apogee motor is mounted externally to the aft end of the ATS-5 spacecraft. Table 1.3 lists the general characteristics of ATS-1, 3, and 5.

TABLE 1.2

ATS CHRONOLOGY

				POSITION	MAJOR ACCOMPLISHMENTS AND COMMENTS
1	B	SYNCHRONOUS ALTITUDE SPIN STABILIZED	DEC 7, 1966	150° W LONG	• DEMONSTRATED B & W SPIN SCAN CLOUD COVER CAMERA FOR WEATHER FORECASTING AND TORNADO WATCH • PROVIDED FIRST EARTH DISK PHOTOGRAPH • DEMONSTRATED FEASIBILITY OF ELECTRONICALLY DESPUN ANTENNA TO IMPROVE ANTENNA GAIN • DEMONSTRATED FEASIBILITY OF VHF FOR SMALL STATION COMMUNICATION AND NAVIGATION AND COMMUNICATION FOR AIRCRAFT AND MARITIME SERVICES • DEMONSTRATED SHF SSB/PM TECHNIQUE AS A POTENTIAL CANDIDATE FOR MULTIPLE ACCESS COMMUNICATIONS
2	A	MEDIUM ALTITUDE GRAVITY GRADIENT STABILIZED	APR. 6, 1967		• LAUNCH VEHICLE FAILURE CAUSED ECCENTRIC ORBIT • PERIGEE DECAY -- ATS-2 RE-ENTERED THE ATMOSPHERE ON SEPTEMBER 2, 1969
3	C	SYNCHRONOUS ALTITUDE SPIN STABILIZED	NOV. 5, 1967	47° W LONG	• DEMONSTRATED FEASIBILITY AND RELIABILITY OF MECHANICALLY DESPUN ANTENNA FOR STILL HIGHER ANTENNA GAIN • DEMONSTRATED COLOR SPIN SCAN CLOUD COVER CAMERA FOR WEATHER FORECASTING AND HURRICANE TRACKING • DEMONSTRATED VHF COMMUNICATION CAPABILITY FOR AIRCRAFT AND MARITIME USE • DEMONSTRATED SHF MULTIPLE ACCESS COMMUNICATIONS
4	D	SYNCHRONOUS ALTITUDE GRAVITY GRADIENT STABILIZED	AUG. 10, 1968		• 2ND STAGE LAUNCH VEHICLE FAILED • LOW ORBIT DECAY -- ATS-4 RE-ENTERED THE ATMOSPHERE ON OCTOBER 17, 1968
5	E	SYNCHRONOUS ALTITUDE GRAVITY GRADIENT STABILIZED	AUG. 12, 1969	105° W LONG	• EXPERIMENTED SUCCESSFULLY IN SPINNING FAILURE MODE • INITIAL DEMONSTRATION OF L-BAND AS A POTENTIAL FREQUENCY FOR AIRCRAFT AND MARITIME USE • INVESTIGATED MILLIMETER WAVE AS A POTENTIAL SOLUTION TO FREQUENCY CROWDING

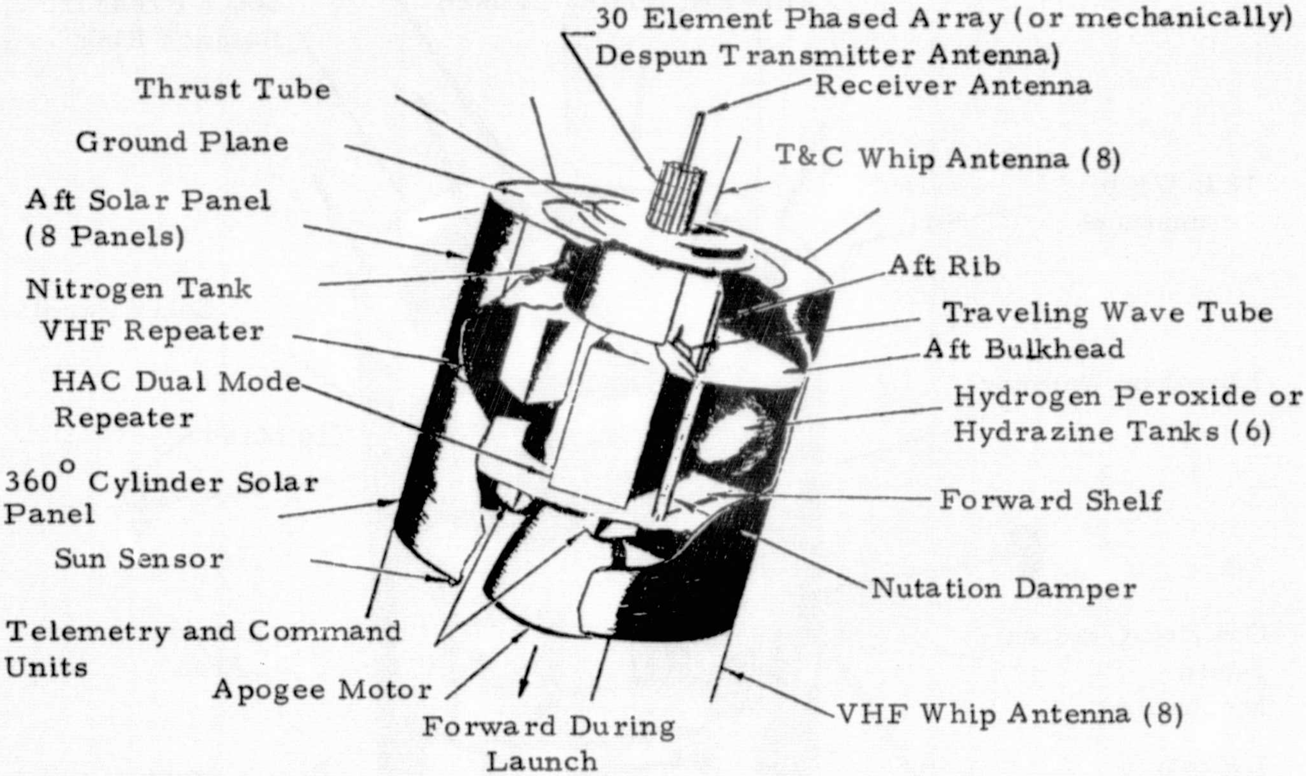

Figure 1.1. Spin Stabilized Spacecraft ATS-1 and 3 with Electronically Despun Antenna

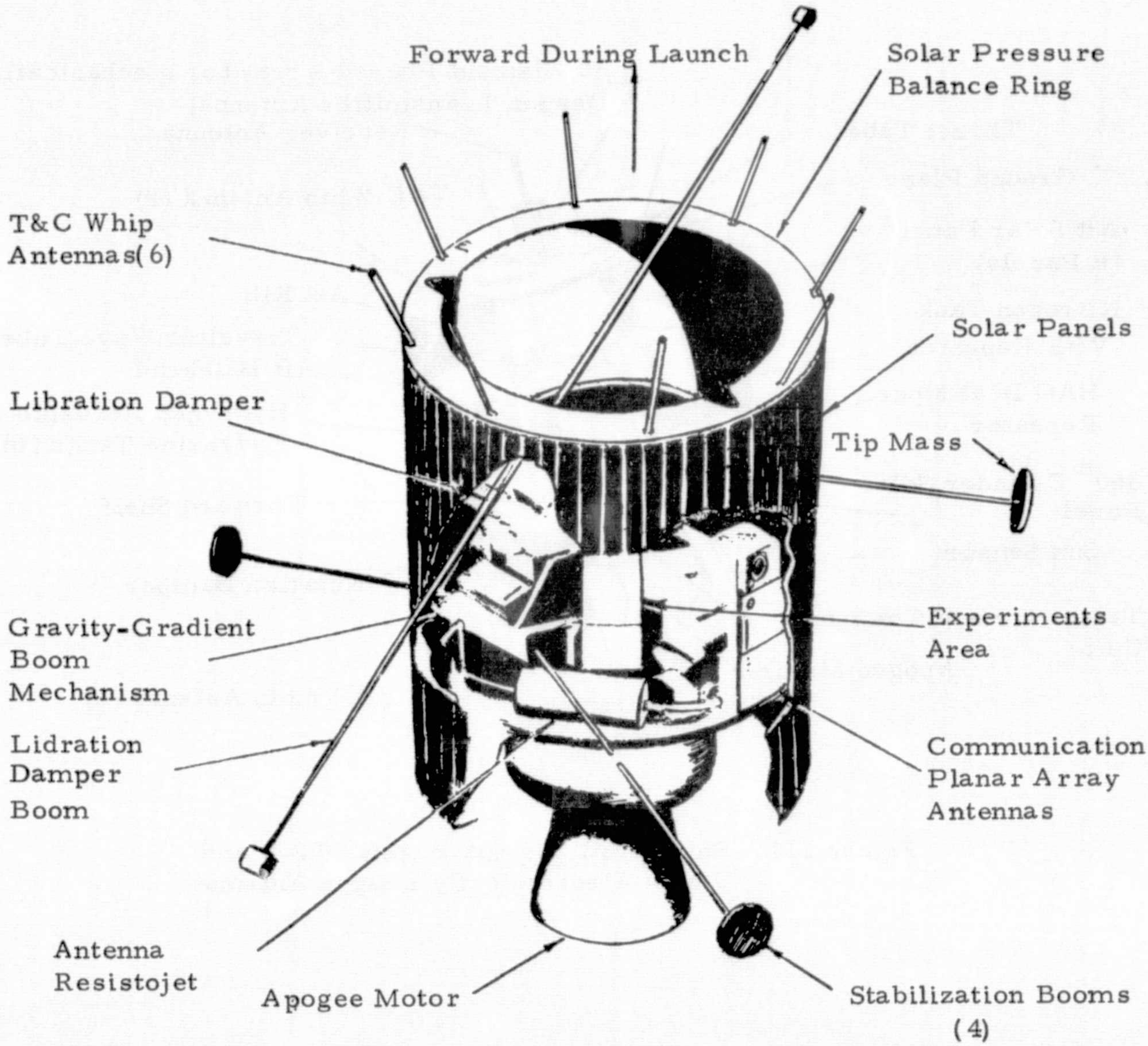

Figure 1.2. Gravity-Gradient Spacecraft ATS-5

TABLE 1.3

GENERAL CHARACTERISTICS OF PRIOR AND CONCURRENT COMMUNICATIONS SATELLITES

CHARACTERISTICS	ATS-1	ATS-3	ATS-5
Launch Date	Dec. 1966	Nov. 1967	Aug. 1969
Orbit (nautical miles)	19,400	19,400	19,400
Diameter (inches)	54	54	56
Length (inches)	53	53	72
Orbital Weight (pounds)	646	671	772
Effective Radiated Power (dbw)	20.5	26.5	23.2*
Repeater Bandwidth (MHz)	25	25	25
No. Voice Channels (one way)	1,200 (SHF)	1,200 (SHF)	1,200 (SHF)
Type Antenna	Electronic-ally Despun	Mechanically Despun	Slotted Wave-guide plannar array
Type Pattern	Earth Coverage Directional	Earth Coverage Directional	Earth Coverage Directional
Multiple Access	FDMA (SSB/PM)	FDMA (SSB/PM)	FDMA (SSB/PM)

* planned value and pattern, not met due to spin

1.5 SPACECRAFT OPERATIONAL SUPPORT SYSTEMS

On board the ATS series spacecraft there are five operational support systems: communications, command, telemetry, reaction control, and power supply. Figure 1.3 is a block diagram of these systems.

1.5.1 Communication System

The communication system, which is completely independent from telemetry, provides the means of transmitting experimental data originated on-board, such as the output of meteorological television cameras, to the ground. The system consists of two transmitters, two receivers, the antenna system, and the necessary associated control subassemblies. These systems operate on a C-band downlink (4 GHz) using the same transmitters and antennas employed in the SHF communications experiments. For use in communications functions for other on-board experiments, such as the spin-scan camera, the downlink is modulated by means of an on-board VCO which replaces the IF signal from the uplink receivers used in the communications experiments. The SHF communications transponder is also used for range and range rate measurements for orbital determination.

1.5.2 Command System

The command system receives and executes the commands directed to the spacecraft by ground terminal stations to control spacecraft systems and experiments. The system consists of two VHF command receivers and two command decoders. The decoders translate the signals modulated on the RF command uplink carriers into signals to control and switch the on-board systems for use in the various experiments. There are two command receivers and two decoders on each satellite, each decoder being capable of operating with either receiver. The command system with two decoders has the capability of 255 redundant commands.

1.5.3 Telemetry System

The telemetry system encodes and transmits the data being generated on board down to ground stations. This system includes two

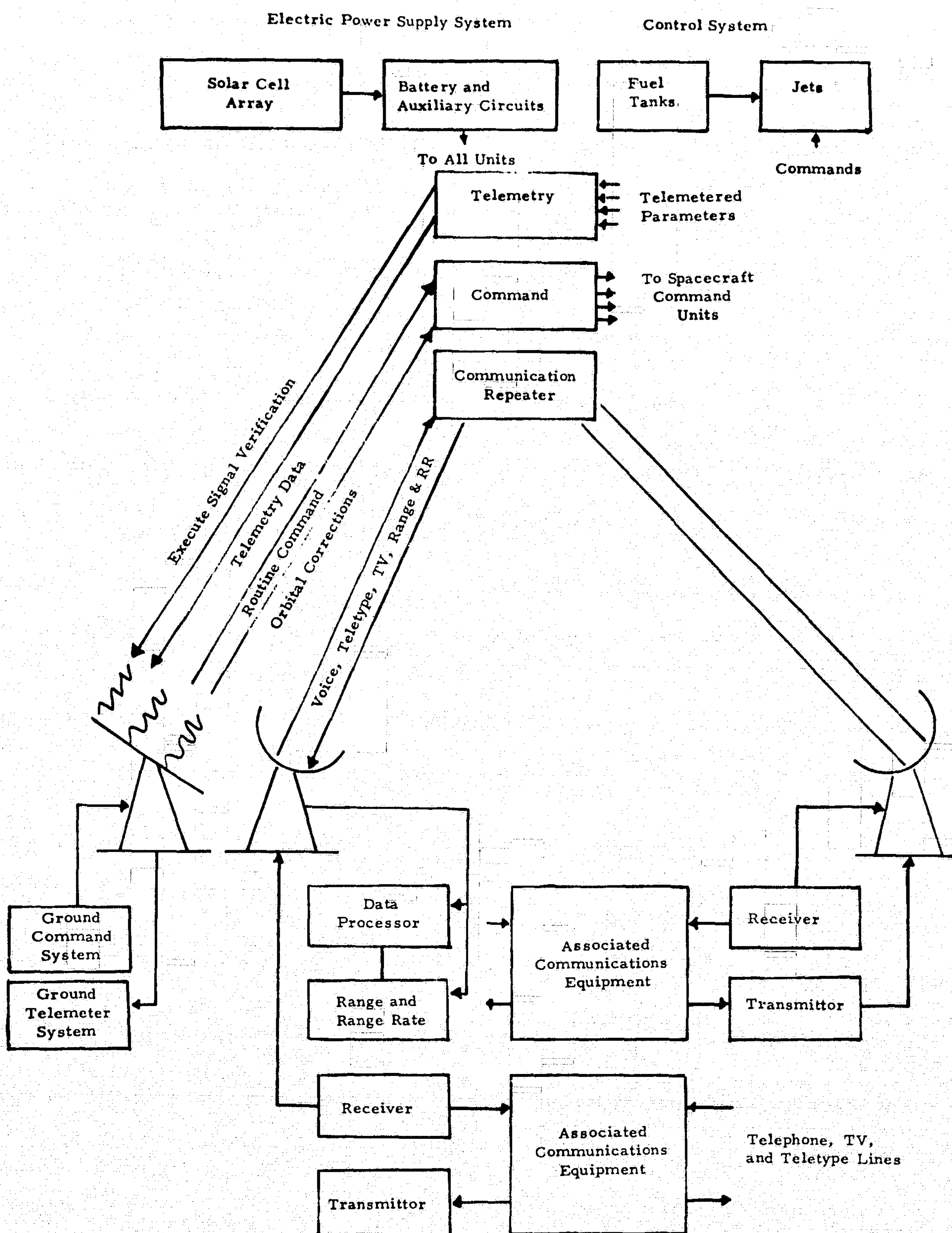

Figure 1.3 Basic ATS Operational Systems

telemetry encoders and redundant transmitters. The encoders process the spacecraft and experiment data and convert it into a form which can be transmitted from the spacecraft at VHF. The telemetry system shares the use of the antennas and the spacecraft clock with the command system. The telemetry transmitters and command receivers are connected through a duplexer to a turnstile antenna. The antenna is constructed of eight quarterwave whips spaced at 45-degree intervals about the spacecraft periphery, inclined 60 degrees to the spin axis, to afford essentially isotropic coverage (equally effective in all directions), and isotropic gain. No attempt was made to add directivity to this VHF antenna, and therefore, the operation of telemetry and command links is totally dependent upon the power of the transmitters and sensitivity of the telemetering receivers, both operating through a directional ground antenna.

1.5.4 Reaction Control System

The Reaction Control System provides the reactive forces necessary for spacecraft maneuvering and stationkeeping. Five different types of thrusters were used.

- Cold nitrogen gas jet to give synchronous satellites the initial spin.
- Hydrogen peroxide or hydrazine jets for placing spacecraft on station and for stationkeeping maneuvering of the spin-stabilized vehicle.
- Subliming solid jet for inversion of the gravity-gradient spacecraft.
- Resistojet for east-west stationkeeping maneuvers for the gravity-gradient spacecraft at synchronous altitude.
- Ion engine as on experimental backup system for east-west maneuvers.

1.5.5 Power Supply System

The power supply system consists of a combination of solar cells, batteries, and related power switching assemblies to provide the electrical power needed to operate all systems on the spacecraft. The primary source is silicon solar cells assembled in arrays on the outside of the satellite, the secondary source is nickel-cadmium batteries within the spacecraft. Normally, the solar cell arrays directly supply the power to the loads, but they can be used to charge the batteries. The batteries provide a secondary source of electrical power during an occasional high power requirement and during solar eclipse intervals when the solar cells are not operating. There are two independent power supply sources on every spacecraft. One is associated with the forward solar cell array and the second with the aft solar cell array. The two distinct subsystems can be combined into a single bus or power line on command. Each subsystem powers an unregulated spacecraft bus maintaining voltage between -32.5 and -24.5 volts. The initial rated power available was 180 watts for the spinning satellites and 125 watts for the gravity gradient spacecraft.

A comparison of the specific hardware carried on the three operational ATS satellites is given in Table 1.4.

1.6 ATS COMMUNICATIONS HARDWARE

The ATS program utilized several types of repeaters for communications with ground stations. ATS-1 and 3 contained two C-band repeaters and one VHF repeater, while ATS-5 contained one L-band repeater, one C-band repeater, and one millimeter wave transmitter and receiver. Since the ATS-5 spacecraft remained anomalously spinning, the L-band antenna illuminated the earth once each revolution for approximately 50 milliseconds between the 3 db points of the radiation pattern.

1.6.1 C-Band Repeaters

The C-band communications repeaters used in the ATS program could be operated in three basic modes. One mode employed an SSB to PM remodulation process and was used for multiple access communications tests. Another mode employed a conventional double-conversion frequency

TABLE 1.4

APPLICATIONS TECHNOLOGY SATELLITE
EQUIPMENT COMPARISON

EQUIPMENT	SPACECRAFT 1	3	5
<u>Communications Experiments</u>			
C-Band Repeater	X	X	X
VHF Communications	X	X	
L-Band Repeater			X
Transmitter and Receiver			X
<u>Meteorological Experiments</u>			
Spin Scan Cloud Cover Camera			
Black and White	X		
Color		X	
Image Dissector Camera System (IDCS)		X	
OMEGA Position Location Experiment (OPLE)		X	
Gravity Gradient			X
Antenna			
Phased Array	X		
Mechanically Despun		X	
Nutation Sensor	X	X	
Subliming Solid Jet			X
Hydrazine Rocket		X	X
Resistojet	X	X	X
Ion Engine			X
Reflectometer		X	
Self-Contained Navigation System		X	
<u>Environmental Measurements Experiments</u>			
Omnidirectional Particle Telescope (UCSD)			X
Omnidirectional Particle Telescope (Aerospace)	X		
Solar Cell Damage (GSFC)	X		
Thermal Coatings (GSFC)	X		
Ion Detector (Rice University)	X		
Magnetometer (UCLA)	X		
Cosmic Radio Noise (GSFC)			X
Electric Field Measurement (GSFC)			X
Trapped Radiation Detector (UCB)			X
Proton/Electron Detector (Lockheed)			X
Spacecraft Charge Measurement (GSFC)			X

translation (FT) technique and was primarily designed for television and multi-channel FDM-FM communications tests. The third mode provided the ability to transmit on-board wide band data or video signals by substituting a VCO input to the IF amplifier in place of the C-band receiver front end.

Because of the integrated nature of the repeater design, much of the circuitry was common to all three modes of operation. Throughout most of the experiments, the low frequency repeaters (6212.094/4119.599) were used, and most tests were performed using two four-watt TWT's. Because the ATS-5 satellite was never despun, the C-band communications experiments were not conducted on ATS-5.

1.6.2 VHF Repeaters

The VHF communications repeaters were the active frequency translation type employing an eight element phased array antenna. Although the ATS-1 and ATS-3 repeaters were functionally identical, several improvements were incorporated in the ATS-3 repeater. The improvements included a new low-loss diplexer, a lower noise figure receiver, an improved up-converter capable of much greater isolation, and a completely new linear VHF transmitter designed to minimize inter-modulation distortion under multi-channel operation. These repeater modifications were reflected in the design performance characteristics. For instance, when subjected to two or more input carriers, ATS-3 did not exhibit the compression characteristics for the weaker input as did ATS-1.

1.6.3 L-Band Repeater

The L-band repeater was designed to operate in several modes which gave the user choices of various bandwidths, a frequency translation or remodulation mode, and cross strap modes with the C-band repeater. The modes included (a) the narrow band frequency translation mode [NBFT], (b) the wideband frequency translation mode [WBFT], (c) a C-band to L-band frequency translation cross-strap mode, and (d) an SSB/FM

L-band/L-band mode. The L-band system employed a planar array antenna consisting of 12 circularly polarized Archimedian spiral radiators giving a nominal gain of about 14 db. This antenna was designed to operate with a gravity gradient spacecraft such that the antenna beam would be constantly pointed toward the earth.

1.6.4 Millimeter Wave Spacecraft Hardware

The millimeter wave experiment flight package was included on ATS-5 to characterize the earth-space propagation paths at the 15.3 GHz and 31.65 GHz space research frequencies. The 31.65 GHz spacecraft receiver system consisted of a horn antenna, a double superheterodyne phase locked receiver and superheterodyne signal processor. The receiver was designed to make absolute amplitude measurements (under controlled conditions) of $\pm$ 0.5 db at signal-to-noise ratios in excess of 5 db. Side-band modulations of 1, 10, or 50 MHz were also received and processed to obtain sideband amplitudes and differential phase between the carrier and the two sidebands, using the carrier as a reference.

1.7 ATS METEOROLOGICAL HARDWARE

NASA developed five space cameras for ATS spacecraft based upon prior experience with TIROS, ESSA, and NIMBUS systems. Spin Scan, Multicolor Spin Scan, and the Image Dissector Camera Systems were developed for the spin-stabilized spacecraft. The Advanced Vidicon and Image Orthicon Camera Systems were developed for the gravity-gradient spacecraft. The camera systems characteristics used on ATS 1 and 3 are shown in Table 1.5.

1.7.1 Spin Scan Camera System

Spin scan cameras were placed on the spin-stabilized ATS-1 and ATS-3 satellites. The monochrome camera system used on ATS-1 consisted of a 5" diameter, 10" focal length Cassegrain telescope having a "pinhole" aperture followed by a photo multiplier detector. A precise

TABLE 1.5

ATS METEOROLOGY SPACECRAFT CAMERA SYSTEMS CHARACTERISTICS

	SSCC	MSSCC	Image Dissector
Spacecraft	ATS-1	ATS-3	ATS-3
Orbit	Geostationary	Geostationary	Geostationary
Altitude			Sync
Resolution	2 nmi.		
Transmission	Real Time	Real Time	Real Time
Scan			
Horizontal Line Scan	S/C Rotation (100 rpm)	S/C Rotation (100 rpm)	Electromagnetic deflection plus Electronic drive (horizontal)
Vertical Line Scan	Mechanical Step (1/rev)	Mechanical Step (1/rev)	Electromagnetic deflection (Only 1/rev)
Lines/Frame	2,048	2,407	1,328
Time/Frame	20 minutes	24 minutes	13.3 minutes
Sensor	Photomultiplier (1) tube	Photomultiplier (3) tubes	Image Dissector
Sync Optics	Sun-Pulse	Sun-Pulse	Sun-Pulse Internal Clock
Focal Length	10 inches	15 inches	16.5 inches
Field of View			
Latitude	6,000 nmi	9,850 nmi.	6,900 nmi.
Longitude	9,850 nmi	9,850 nmi.	6,000 nmi.
Period of Operation	5-3/4 years	Since Nov. 1967	Since Nov. 1967

Common Characteristics:

- All sent video information using SHF wideband data mode.
- All had real time capability.
- Resolution was good on all with respect to their field of view.

east-west scan was generated by the spacecraft spin. The precision north-south scan was generated by mechanically tilting the telescope axis in discrete steps, 2,000 per picture, one step per spacecraft revolution. A picture required 20 minutes of scan time, had 1.9 mile resolution, and a 10^3 dynamic range of brightness resolution. The video information occurred in "bursts" whose duty cycle was only five percent, thus it required the wide band microwave downlink for data transmissions.

The spin scan "cameras" are telescopic photometers consisting of quantitative photomultiplier tubes behind the optics of a small telescope. Thus, they measure the reflected radiance from clouds and the ocean and ground features in selected spectral regions. The spin scan camera technique has several advantages. First, there is no distortion due to the optical system since all measurements are on-axis and the geometry was generated by the highly uniform spin and tilt. Second, the same photometer shows all parts of the picture so the sensitivity is equal everywhere. Third, the detector is a photomultiplier that has a wide dynamic range. Finally, contrast is limited by scatter in the optics only.

On ATS-3, the concept was extended to provide color pictures. In the color camera the three color components were generated by using three in-line pinholes and fiber optics were used to carry the red, blue, and green color information to three separate photomultipliers. The first tube was equipped with a green filter, the second with a red filter, and the third with a blue filter. The signals thus generated were transmitted to the ground on a single wideband video transmitter. Multiplexing of each channel took place in a 500 kHz baseband, and provided for a bandwidth per channel of 150 kHz. The red and green channels also each contained a sun pulse for picture synchronization. The increased usefulness of such color pictures, compared to ATS-1 type black and white pictures, depended largely upon the improved separation of images having approximately the same brightness. Dark clouds showed up as gray while land often showed as a brown or green mass. Similarly, for muddy river water carried large distances into the ocean, the brown river water and the blue-green ocean provided good color contrast. Another improvement was achieved using the red signal component to form a black and white image. This red signal had less atmospheric scattering than the broadband black and white signal of ATS-1 and hence presented a more detailed picture of land structure.

The color image on film was produced on the ground using a cathode ray tube with light output in the green, red, and blue, spectral regions. Each line was produced by triple exposure of the film - first with green light derived from the green digitized video, then red and blue. A synchronized three color filter wheel in the optical path of the film recorder was used to produce the desired color light. This process was repeated each line to form the complete image. The digital tape record contained all the data sent to the film recorder during real time operation and could subsequently be played back to produce a color image equal in quality to the original. An analog tape record was formed by use of a digital-analog converter and to conserve tape produced a bandwidth limited signal somewhat poorer in quality than the digital tape.

The ATS Spin Scan Cloud Camera added a new dimension to meteorological studies. The major advantage of this system was that one-third of the earth and its attendant cloud cover was continuously visible during the daylight hours. Prior to ATS, imaging systems in nonsynchronous orbit could produce only a single or perhaps two overlapping pictures per day of any given area. With the ATS-SSCC system, pictures could be recorded in 30 minute intervals. This was sufficient to study global scale activities in some detail. This scope and coverage provided an important tool in studying phenomena such as global and hemispheric circulation patterns; global scale heat flow and transfer; wind velocity measurements; growth, life and decay of hurricanes, tornadoes, tropical storms, etc; and large scale interactions between land masses and cloud circulations. The SSCC provided useful data not only to meteorologists and scientists concerned with such macroscale events but also, for tracking tornadoes and tropical storms for the benefit of the non-scientific public.

From a space technology standpoint, the SSCC was a success both in terms of simplicity and reliability. The use of a single photo-multiplier eliminated point-to-point calibration problems within a frame. The mechanical systems and bearings which executed the line-to-line stepping functions, were more than adequate for their tasks. The ATS-1 SSCC was operational for almost six years, while the ATS-3 MSSCC system was still producing useful data after more than five years in orbit.

1.7.2 Image Dissector Camera System (IDCS)

The Image Dissector Camera System was first flown on ATS-3 to provide the scientific community with additional information about the earth and its environment. However, its prime technical objective was to demonstrate and discover any unknown limitations of the image dissector camera (IDC). The IDC operation was electronic except for a protective shutter that closed over the face of the image dissector tube when the camera was not operating. The camera was mounted on ATS-3 with its optical axis perpendicular to the satellite rotational axis about the earth. In the primary "longitudinal" scanning mode, the north to south camera sweep deflection signal provided each vertical picture line scan for earth latitudinal deflection while the satellite spin supplied the motion for the horizontal or longitudinal picture deflection. In the secondary "latitudinal" scanning mode the satellite spin motion provided the longitudinal or west to east time scan, while the camera deflection signal supplied successive one-resolution element steps from north to south at the rate of one per spin until a single frame was completed. Spacecraft inputs were power, command, and clock. The camera contained the image dissector, a sun sensor for spin rate, a nutation sensor, the electronics necessary to synchronize camera timing and operation with spacecraft spin, and to retain proper phasing to enable earth viewing once the initial phasing had been commanded from the ground.

In the first year and a half of operation from initial activation in orbit, the ATS-3 IDC sent back over 1,300 cloud cover pictures with near full earth disc coverage per picture. Performance of the camera was good; the pictures produced had good resolution and minimum nutation problems. Sensitivity degradation of less than five percent and no loss of resolution were observed during the first year in orbit. The spacecraft was launched November 5, 1967, and the camera was turned on November 7. The Image Dissector Camera System performed well in the ATS-3 application and produced a large output of useful meteorological pictures as well as pictures defining ATS-3 spacecraft motion. This system provided reliable service with a minimum of ground station complexity and has shown excellent potential for future space applications.

1.8 ATS GROUND STATIONS

The ATS program in space was supported by an extensive ground system which provided for command and control of the spacecraft; collection of range and range rate data for the determination of spacecraft orbit; performance of communications, gravity-gradient, meteorological, and other experiments; scheduling experiments and maintaining data plots and distributing experimental data; tracking and data acquisition, providing computer services and information processing; and general communications and support.

Three ATS ground stations, Rosman, Mojave, and the Transportable Ground Station at Cooby Creek provide the main support to ATS operations for command and control of the spacecraft; for collection of range and range rate data for orbit determination; polarization angle measurements for spacecraft attitude determination, and for performance of communications, gravity-gradient, and meteorological experiment data collection. All spacecraft maneuvers and experiments are controlled by direction from the ATS Project Operations Control Center (ATSOCC) at Goddard Space Flight Center, Greenbelt, Maryland. Except for antenna diameter and source of power, the three principal ground stations are similar; as described in Table 1.6.

TABLE 1.6

ATS GROUND STATION SYSTEMS

ITEM DESCRIPTION		ROSMAN	MOJAVE	COOBY CREEK
Antenna	TYPE	Parabolic Reflector with Subreflector Cassegrain Feed	Parabolic Reflector with Subreflector Cassegrain Feed	Parabolic Reflector with Subreflector Cassegrain Feed
	Diameter/Mount	85 ft/X-Y	40 ft/X-Y	40 ft/AZ-EL
	Receive Gain (4 GHz) (nom.)	58.4 db	51 db	51 db
	Transmit Gain (6 HGz) (nom.)	6.15 db	54.6 db	54.6 db
	Receive System Noise Temperature (at Zenith)	63°K (Paramp)	63°K (Paramp)	55°F (Maser Mode) 55°/65°K (Paramp Mode)
	Tracking Accuracy	±0.05 deg.	±0.015 deg.	±0.057 deg.
	Receive Beam-width (P/2)	0.2 deg.	0.47 deg.	0.42 deg.
	Transmit Beam-width (P/2)	0.13 deg.	0.28 deg.	0.28 deg.
SHF Trans-mitter	Maximum SHF Transmitter Power	Two Redundant 10 kw SHF Transmitters	10 kw	10 kw
SHF Receiver	Simultaneous Capability	Capable of Transmitting Two RF Channels and Receiving Two RF Channels Simultaneously (SSB or FT)	Capable of Transmitting One RF Channel and Receiving Two RF Channels Simultaneously	Capable of Transmitting One RF Channel and Receiving Two RF Channels Simultaneously
	Number of Channels SSB Multiplex	Basic 1200 Channel Capability (One Way) 24 Channels Equipped with 12 ECHO Suppressors and Compandors	Basic 240 Channel Capability (One Way) 24 Channels Equipped with 6 ECHO Suppressors and Compandors	Basic 240 Channel Capability (One Way) 24 Channels Equipped with 6 ECHO Suppressors and Compandors
	TV Tape Recorders	Color and Monochrome Record and Playback	Monochrome - Record and Playback Color - Record Only	Monochrome - Record and Playback Color - Record Only
Overall Capability	G/T ATS-1	38.2 db	32.2 db	32.2 db
	G/T ATS-3	39.6 db	32.2 db	Not visible
Location	Area	Near Brevard, North Carolina	Goldstone Dry Lake, Mojave Desert, near Barstow, California	Near Toowoomba, Queensland, Australia
	Latitude	35° 11' 35.4" North Lat.	35° 17' 48" North Lat.	27° 23' South Lat.
	Longitude	82° 52' 22" West Long.	116° 53' 57" West Long.	151° 57' East Long.

1.8.1 Rosman Ground Station

The Rosman Ground Station is located in western North Carolina, near the town of Brevard. The instrumentation building houses the communications, telemetry, and command subsystems as well as offices, supply and maintenance areas. The 85-foot parabolic communication antenna, located adjacent to the instrumentation building, has a cassegrain type feed system and utilizes monopulse tracking techniques to automatically track the ATS spacecraft. The combined telemetry/receive and command/transmit antenna consists of an array of crossed dipoles. Station power is provided by 10 diesel engine generators; six with an output of 250 KVA and four with an output of 500 KVA.

1.8.2 Mojave Ground Station

The Mojave Ground Station is located in the Mojave Desert, approximately 50 miles north of Barstow, California. Identical to Rosman Station, the Operations and Instrumentation building houses the communications, telemetry, command, and antenna control subsystems, as well as office and maintenance areas. The 40-foot parabolic communications antenna located adjacent to the building has a cassegrain type feed system and utilizes monopulse techniques to develop tracking signals which automatically maintain the transmit/receive beams in alignment with the spacecraft. Polarization tracking is also provided, and received signal preamplification is accomplished by a parametric amplifier and two tunnel diode amplifiers (TDA). Communications signals are transmitted, received, and processed as required to conduct the various ATS experiments.

1.8.3 Transportable Ground Station

The Transportable Ground Station (TGS) is located in Queensland, Australia, near Cooby Creek, approximately 14 miles from the city of Toowoomba. Station equipment is trailer mounted, and the communications antenna can be dismantled and mounted on two flat-bed trailers for relocation. Three 40-foot air conditioned trailers comprise the operational control complex (OCC). Fold-down trailer sides allowed matting to form a single operating area, providing limited access to all ground station electronic equipment, with the exception of telemetry and command (T&C) equipment. T&C equipment is mounted in a separate trailer. Additional vans provide office space, maintenance shop, storage, communications center, and power. The 40-foot parabolic communications antenna has a Cassegrain type feed system and uses pseudo-monopulse techniques to develop tracking signals which automatically maintain the transmit/receive beams in alignment with the spacecraft. Polarization tracking is also provided, and r ecieved signal preamplification is accomplished by maser and parametric amplifiers.

1.8.4 Other Ground Stations

A major contributing station was Kashima, Japan. However, contirubtion by the Small Aperture Ground Station (SAGS), and the many small VHF terminals throughout the world are presented to provide a more complete coverage of the ATS ground stations. It was these small terminals that proved the versatility of ATS.

Kashima Earth Station, belonging to the Radio Research Labs, Ministry of Posts and Telecommunications, was established in August 1963 for the purpose of performing space communications experiments. It is located 90 kilometers to the east-north-east of Tokyo. Its 26 meter SHF communications antenna has the capability of operating on the following frequencies: 6212 MHz and 6301 MHz for transmission, 4119 MHz and 4178 MHz for reception and tracking, and 4135 MHz and 4195 MHz for beacon tracking. For transmission and reception of SHF signals, the antenna and feed system are used in common. Kashima contributions are in the areas of Kashima/NASA Time Division Multiple Access/Pulse-Code Modulation Experiment; a Spread Spectrum Experiment; TV Transmission Experiments; and a Spin Scan Cloud Cover Reception Experiment.

The use of satellites with a network of Small Aperture Ground Stations, was investigated as a potential means of accommodating the expected growth in overseas communications. The SAGS was conceived and developed at the Goddard Space Flight Center to relay a single voice channel via the ATS-3 satellite to a larger ground station or to another SAGS at microwave frequencies. SAGS consists primarily of four assemblies: (a) the antenna and pedestal, (b) paramp and diplexer, (c) TWT power amplifier assembly, and (d) the transceiver. The 15-foot parabolic antenna is an extremely lightweight structure weighing approximately 100 pounds and was enclosed in a radome. It was used to evaluate compatibilities with large stations and to transmit facsimile pictures.

There was much interest in the use of satellites as communication relays to mobile and/or stationery units. Many requests were received by NASA/GSFC, and permission granted to selected small unit VHF stations to utilize a block of ATS satellite time for experimental communications. The results of these communications experiments showed much promise for the future. While the configuration of a VHF terminal varied from station to station, the basic equipment was rather simple and inexpensive which made the VHF terminal attractive. The U.S. Office of Education experimented with ATS-1 to establish a two-way connection to assist teachers in remote native Alaskan villages to improve both their skills and the education they offer their pupils. These regular transmissions were also used to transmit medical information and assistance to these remote areas. In fact, ATS-1 contributed to saving at least one life in Alaska. The University of Hawaii also utilized a portion of ATS-1 time. At the time, ATS-1 was positioned at 149°W, approximately 200 miles south of Hawaii, 23,500 miles in space. This position yielded an earth illumination extending from Chicago to eastern Australia. The Hawaii station proved that an inexpensive system (less than $1,200) could cover approximately half of the earth with little or no fading by utilizing a satellite as a relay station.

SECTION 2
COMMUNICATIONS EXPERIMENTS

2.1 INTRODUCTION

The ATS-1-3-5 series of satellites contained communications equipment in the VHF, UHF, and SHF bands which was used to conduct a large number of experiments applicable to a variety of communications services. These services included such things as broadcasting weather facsimile (WEFAX) and time and frequency signals, as well as providing communication for educational and medical services. In addition, the project included a series of radio propagation experiments which were aimed at investigating the reliability of the propagation paths at the various frequencies and the causes of fading on those paths.

The communications equipment contained on the ATS satellites were as follows:

Satellite	Equipment	Frequency
ATS-1 & -3	Microwave Repeater	6 GHz/4 GHz
	VHF Repeater	149 MHz/136 MHz
ATS-5	Microwave Repeater	6 GHz/4 GHz
	L-band Repeater	1550/1650 MHz
	Millimeter Wave Transmitter and Receiver	31.65/15.3 GHz

The descriptions and characteristics of the repeaters are in Sub-Section 1.6.

In the early stages of the program development, only the "Microwave Communications Experiment" was included in the design. This experiment employed a dual-mode communications repeater which was designed, first, to relay high density multi-channel telephone circuits and television signals between two points. This mode was called the "frequency translation" (FT) mode. The second mode consisted of a remodulation repeater wherein multiple single-sideband (SSB) uplink signals were phase modulated on a single downlink frequency. This mode was called the "multiple access" mode because it could handle a large number of separate uplink signals from widely scattered locations. A third method of operation permitted on-board video signals from a meteorological camera to be transmitted to earth by modulating a VCO in the FT mode. This repeater was included in all five original ATS satellites.

Shortly after the program got underway, a "VHF Communications Experiment" was proposed and incorporated into the design of ATS-1 and -3. This experiment was primarily designed to provide either single channel or very low channel capacity to small, inexpensive airborne or shipboard terminals in the "mobile services". It later became apparent that the same VHF satellite relay could provide communication services to widely scattered, sparsely populated areas such as Alaska and the South Pacific Islands where small, low cost terminals must be used for economic reasons. These low density communications services could provide heretofore unavailable improvements in the educational and medical services in those areas.

The volume of communications services throughout the world has been growing at such a rapid rate that many of the allocated frequency bands are already saturated with assignments and, within the foreseeable future, the entire spectrum of existing communication frequencies will be saturated. The L-band repeater was placed on ATS-5 to provide a means to investigate the feasibility of opening higher frequency bands to the mobile services. Similarly, the Millimeter Wave Experiment was added to the ATS-5 spacecraft to open a new portion of the frequency spectrum to the fixed point-to-point services. This experiment was primarily directed toward evaluation of the propagation characteristics of this band of frequencies where tropospheric anomalies cause serious fading. The spaceborne equipment in these frequency bands provided the impetus for the numerous communications experiments performed under the ATS program. Experiments in which voice communication was the primary interest are described in this section.

2.2 FIXED POINT-TO-POINT EXPERIMENTS

The ATS Fixed Point-to-Point Experimental Program addressed two significant needs of the growing commercial communication satellite field of the early 1960's; the need for increasing information transfer capacity and development of a viable multiple access technique. To provide increased information transfer capacity, higher power microwave travelling-wave tubes, and higher gain spacecraft antenna techniques were developed under the ATS program. The ATS multiple access technique employed a unique remodulation type satellite repeater wherein single-sideband signals were transmitted to the satellite from the several earth stations, then combined and converted to a phase-modulated carrier for retransmission back to earth. In addition to comparing these systems and techniques to more conventional ones, the program evaluated a pseudo-noise random access and a PCM technique for multiple access. These experiments were conducted at microwave frequencies internationally allocated to the Fixed Satellite Service and were more generally known as the "Microwave Communications Experiment".

2.2.1 SSB-PM/FDMA* Experiment

In the SSB-PM/FDMA technique each access transmitted an assigned portion of the standard SSB-FDM multiplex baseband message spectrum, translated to the microwave band, as an SSB suppressed carrier signal. Combined with this message spectrum was a pair of pilot tones individually assigned to each station which were employed for transmitter frequency and level control. In the satellite, a phase modulator converted the SSB-FDM signals to a phase modulated (PM) spectrum which contained a carrier and the sidebands of the SSB-FDM signals produced by the modulator. The earth station receivers demodulated the PM spectrum to recover the total baseband spectrum. The demultiplex equipment then selected the channels desired by the station. A large number of accesses could be

*Single-Sideband-Phase Modulation/Frequency Division Multiple Access accommodated by subdividing the message baseband as required and adding the required pilots for each new earth station. In the implementation of the ATS multiple-access experiment (Reference 454), the major hardware developments were the satellite transponder which contained a unique phase modulator, and the earth station SSB transmitters which contained newly developed level and frequency control circuitry.

The three ATS multiple-access earth stations were similar to a conventional FM earth station in all respects except for the SSB transmitter, the interconnection of the control pilots from the receiver, and a 6 db/octave de-emphasis network to recover PM rather than FM signals (see Figure 2.1).

The characteristics of the earth stations pertinent to the SSB-PM/FDMA experiment are shown in Table 2.1.

2.2.2 Experimental Results

The objective of the SSB-PM/FDMA Experiment was to evaluate the multiple-access capabilities of this system by evaluating voice channel performance, data channel performance, frequency control loop performance, and level control loop performance in a real earth-space environment.

Voice channel performance was evaluated using weighted test tone-to-noise ratio as a criteria with thermal noise and intermodulation noise as individual parameters.

Test tone-to-thermal noise ratio within voice channels of the system is shown in Figure 2.2 as a function of spacecraft EIRP* with the earth station G/T** as a parameter. Overall voice channel thermal S/N performance was found to be limited to about 47 db by the uplink parameters

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*EIRP = Effective Isotropically Radiated Power

**G/T = Antenna Gain divided by System Temperature (Receiving System Figure of Merit)

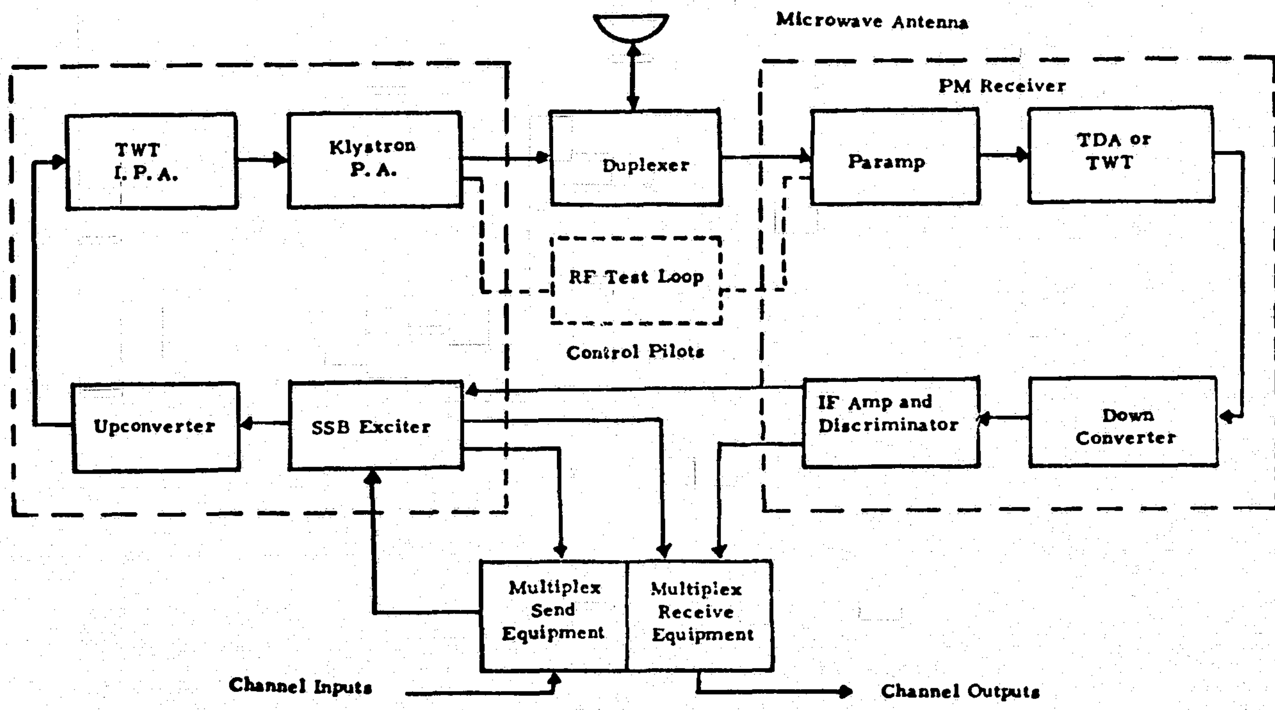

Figure 2. 1. ATS Multiple-Access Earth Station.

TABLE 2.1

EARTH STATION SSB-PM/FDMA CHARACTERISTICS

Parameter	Rosman	Mojave	Cooby Creek
Antenna Diam.	26 meters	12 meters	12 meters
G/T (ATS-1)	38.2 db	32.2 db	32.2 db
G/T (ATS-3)	39.6 db	32.2 db	(not visible)
EIRP (ATS-1)*	46.6 dbm	53.5 dbm	53.5 dbm
EIRP (ATS-3)*	36.5 dbm	43.4 dbm	(not visible)
Loading, 3 sta.	960 chan.	120 chan.	120 chan.

*Single channel test-tone power

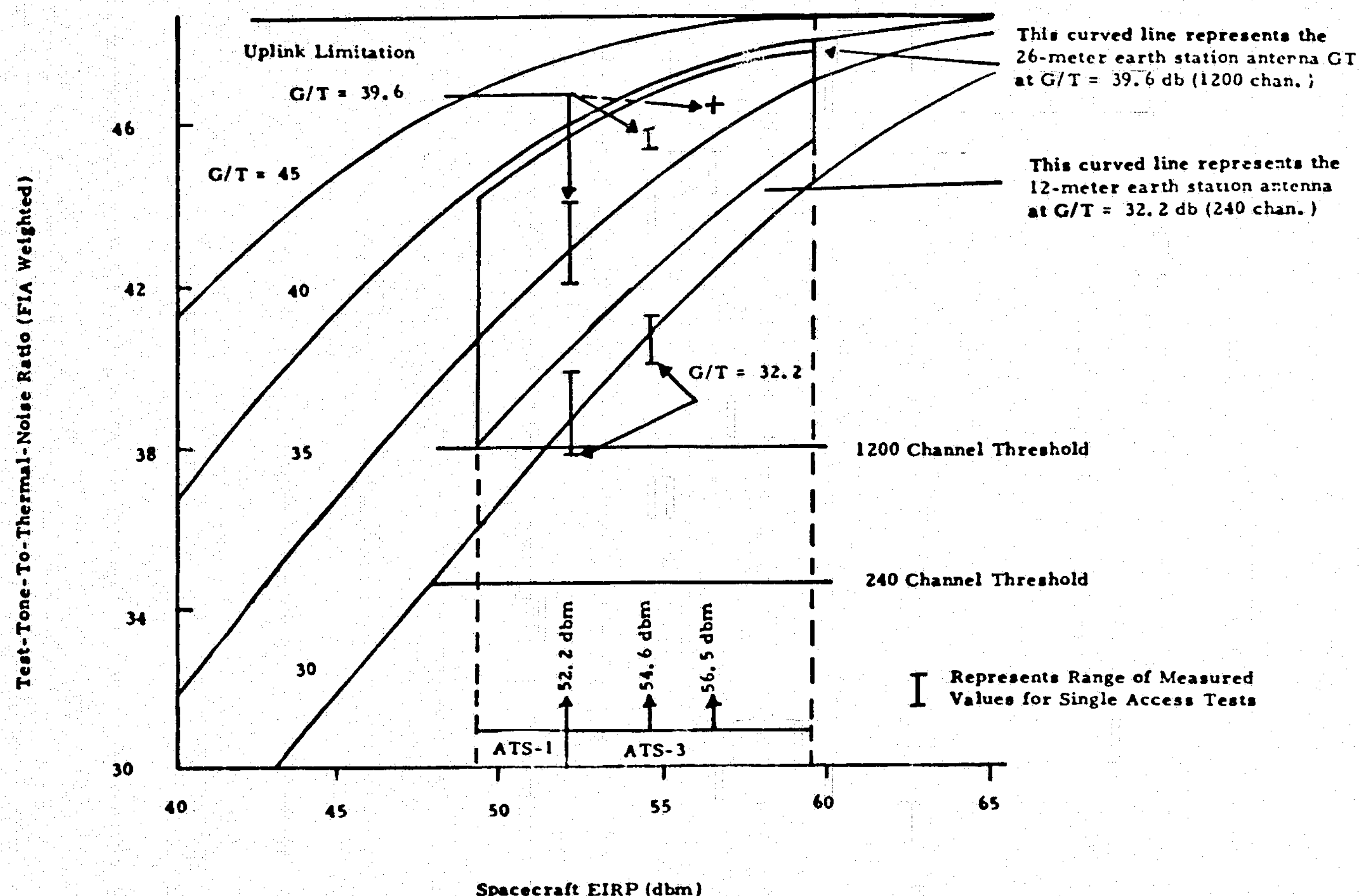

Figure 2.2. ATS SSB-PM/FDMA Test-Tone-To-Thermal-Noise Ratio.

with the satellite EIRP of the order of 1 KW per 1200 channels and earth station G/T of the order of 39 db. The recommended performance is 50 db.

Voice channel intermodulation S/N performance was limited by the SSB transmitter with ATS-1 which has a G/T of -25.5 db. On ATS-3, with a G/T of -15 db, the drop in SSB transmitter intermodulation resulting from the ability to reduce its power output requirement, placed the third-order parabolic group delay intermodulation in the downlink, and the second-order amplitude intermodulation in the spacecraft phase modulator, in the position of limiting the channel performance. Even on ATS-3, the limit was slightly below 50 db; thus, improvements in the linearity of the transfer characteristic of the spacecraft phase modulator and reduction of third-order parabolic delay distortion in the components of the PM downlink was indicated.

The voice channel signal-to-weighted noise ratio resulting from both thermal noise and intermodulation noise was measured to be about 40 db at the earth station with a G/T of 39.6 db. Analysis of the system indicated that to raise this value to 50 db would require improvements beyond the performance observed in the experimental system.

2.3 TRANSCONTINENTAL INTERCONNECTION EXPERIMENT

In 1969 the Corporation for Public Broadcasting formed the Public Broadcasting Satellite Task Force to coordinate with NASA and other interested agencies all domestic satellite activity in behalf of the public and educational broadcasting interests. The Public Broadcasting Satellite Task Force submitted a proposal to NASA to initiate the Transcontinental Interconnection Experiment. The experiment began on January 4, 1970 and ended on March 26, 1970 (Reference 38*).

A principal objective of the Transcontinental Interconnection Experiment (TIE) was to evaluate and optimize the performance of a transcontinental

*Reference numbers correspond to document numbers given in Appendix B.

satellite link for video interconnection--both as an independent operation and as part of a composite service including radio relay and local distribution links. A secondary objective was to evaluate the feasibility of interference-free television reception from satellites by medium-size receiving stations in an urban environment containing radio relay facilities using the same frequency bands.

To achieve the first objective, a series of tests were scheduled using the NASA earth stations at Rosman, North Carolina and Mojave, California, plus the ATS-3 experimental satellite. The two earth stations were connected with the public television network provided by AT&T via radio relay links and other terrestrial facilities. To achieve the second objective, a brief period of testing was scheduled using the Hughes Aircraft Company rooftop terminal in El Segundo, California (adjacent to the Los Angeles International Airport).

Initial setup and checkout of the satellite link was carried out by NASA prior to test commencement on January 4, 1970. Radio relay service was provided by AT&T under regular commerical tariffs, and all operation and maintenance of these facilities remained the responsibility of AT&T. Mr. T.P. Untiedt, Vice President/Engineering, KCET, Los Angeles, was assigned responsibility for routine monitoring of the satellite and terrestrial transmissions and coordination of West Coast activities.

2.3.1 Measurement Techniques

To evaluate the relative and overall performance of the satellite and terrestrial links, a number of special video test signals commonly used in the broadcast industry were routinely transmitted through the system. These include:

> Multiburst: A series of short bursts of unmodulated tones at different frequencies (typically 0.5, 1.5, 2.0, 3.2, 3.58, and 4.2 MHz). Useful in determining amplitude vs. frequency and phase shift vs. frequency response in video transmission links.

Modulated Stairstep: A series of short bursts of unmodulated tones at a single frequency (the 3.58 MHz color subcarrier) but displaced in DC level to resemble a staircase. Particularly useful in identifying nonlinear amplitude distortion which can degrade color quality.

T $\sin^2$ pulse and bar: A video waveform consisting of a 0.125 microsecond pulse, and a 12.5 microsecond bar, both having sinusoidal rise and decay slopes. Used to evaluate the transient response of transmission links, particularly the relative phase response at low vs. high video frequencies.

Color bars: A complex video waveform which, when applied to a color picture monitor, produces a series of bars of different colors (red, green, blue, cyan, magenta, yellow, and white). Used for visual analysis of general color quality or vectorscope evaluation of relative phase and amplitude response of the composite color video waveform.

Three principal instruments were used in conjunction with these special waveforms to monitor video transmission quality. A color picture monitor (essentially a high-quality color television receiver) was used for subjective visual observations. The structural details of received waveforms are examined with a waveform monitor oscilloscope having conventional amplitude versus time display features. Phase shift and amplitude distortions of color reference signals were measured via a vectorscope. To facilitate the recording and interpretation of test results, the IRE scale was employed in all measurements of signal and noise amplitude.

2.3.2 Initial Objectives and Test Results

The ATS satellite had been used previously to relay special-event television programs between earth stations having large (e.g., 85 to 97 feet) antennas, providing excellent quality video transmission (see Table 2.2). However, only a 43 to 46 db signal-to-noise ratio was expected when operating through the 40 ft Mojave antenna. These values are considerably below the Bell System overall objective of 50 db and the INTELSAT overall objective of 54 db. Thus, the initial test objectives were to verify the predicted performance of the satellite link, to make subjective comparisons

TABLE 2.2

ATS-1 AND ATS-3 DEMONSTRATIONS

Date	Demonstration	Origin	Destination
Dec. 13, 1966	1st ATS Press Demonstration GSFC	Goldstone	Rosman
Jan. 14, 1967	Rose Bowl Parade	Mojave & Cooby Creek	Kashima
May 13, 1967	GSFC Open House	Cooby Creek	Rosman
May 31, 1967	Press Demonstration	Kashima	Cooby Creek
June 2, 1967	Press Demonstration	Kashima	Cooby Creek
June 2, 1967	Expo 67 - Australia Day	Rosman	Cooby Creek
June 25, 1967	Our World	U.S. & Japan	Cooby Creek
Sept. 12-19, 1967	America's Cup Race	Rosman	Cooby Creek
	Italian President's Visit	Cooby Creek	Rosman
Oct. 12, 1967	Japanese Prime Minister Sato's Visit	Cooby Creek	Kashima
Dec. 20-22, 1967	Prime Minister Holt's Death President Johnson's Visit	Cooby Creek	Rosman
Dec. 26-28, 1967	Davis Cup Tennis - Brisbane	Cooby Creek	Spain
	1968 Olympics	Rosman	Kashima
Aug. 24, 1968	Pope Paul's Visits	Bogota, Col.	Goonhilly UK, Europe
	1968 World Series	U.S.	Puerto Rico
Oct. 5/8/10, 1968	1968 Olympics	Tulancingo, Mex.	ETAM, Goonhilly, Raisting (Eur.)
Oct. 22, 1968	Apollo 7	Atlantic Ocean	U.S.
Dec. 27, 1968	Apollo 8	Pacific Ocean	US/Japan/Europe
	1968 Election Returns	U.S.	Europe
Mar. 31, 1969	Apollo 9	Atlantic Ocean	
May 26, 1968	Apollo 10	Pacific Ocean	U.S.
July 24, 1969	Apollo 11	Pacific Ocean	U.S.

of the signal quality delivered to KCET via the satellite link and the normal terrestrial service, and to identify any sources of signal degradation which might be subject to improvement within the basic constraints of satellite power and earth station sensitivity.

To achieve these objectives, the initial test plan and schedule was made quite flexible, with considerable allowance for engineering tests and evaluation and modification of operating parameters. Normal programming off the East Coast public television network was relayed between the hours of 7:00 and 10:00 pm EST, Sunday through Thursday of each week. Various video test signals originating from the program source or the Rosman and Mojave earth stations were used at such times as the engineering staffs at KCET, Mojave, or Rosman desired to check out specific link performance. Typically, the period of 7:00 to 8:00 pm was used for setup and test signal transmission, with 8:00 to 10:00 pm transmissions devoted primarily to program material.

Immediately upon initiation of this test program, it was observed that the radio relay service provided by AT&T and two local telephone companies to Rosman and Mojave was introducing a number of serious noise and distortion problems. Incoming signals at Rosman were consistently subjected to phase and amplitude distortions, and a strong horizontal band of interference near the field rate was observed moving up through the video display. Signals fed from Mojave to KCET were subjected to audio distortion, audio/video intermodulation, and frequent occurrences of very high noise levels. Some specific examples of service degradation noted by monitors at Rosman and KCET during these tests are as follows.

Rosman

Video level -	varied between 80 and 95 IRE units, most often near 80; should nominally be 100 units.
Sync level -	varied between 40 and 55 units, should be 40; 55 units observed with video level of 85, making simple correction impossible.

Color burst -	consistently low, on the order of 18-30 IRE units peak-to-peak; should nominally be 40 units.
Multiburst -	consistent roll-off problem, with 4.2 MHz burst typically down 20 units; should be flat response.
Audio level -	subject to wide variation from day to day and occasionally during programs; up to 8 db differences noted at times.
Video Interference -	horizontal interference band running up picture, affecting 8 lines of video, requires 13 seconds to transit monitor face.
Ringing -	up to 7 cycles observed on sync and color burst transitions at times, at fairly high amplitude.
Dropouts -	several occurrences of video and/or audio dropouts during program transmission were noted, at various times.

<u>KCET</u>

Audio -	considerable distortion and clipping observed during first week, occasionally thereafter.
Video -	considerable audio/video intermodulation noted at various times throughout period, believed due to faulty audio/video diplexer.
Multiburst -	considerable peaking at 4.2 MHz during early weeks, later corrected.
Noise -	repeated occurrence of both low and high frequency noise, sometimes adding as much as 6-8 IRE units to the noise level noted at Mojave.

These deficiencies in the radio relay service rendered any direct comparison of program delivery to KCET via satellite and terrestrial links impossible; and also limited evaluation of the satellite link alone to routine S/N measurements and monitoring of standard video test signals. These measurements did indicate that the satellite link performance was as expected. It was also quite consistent and reliable; one brief period of high noise level was observed, which was corrected by changing the receiving antenna to the automatic tracking mode, and one brief outage occurred due to an antenna repositioning problem at Rosman.

The ratio of carrier-plus-noise to noise ($\frac{C+N}{N}$) observed at Mojave ranged from just over 10 db at the beginning to nearly 12 db by the end of this period (see Figure 2. 3). The corresponding weighted signal to noise (S/N) likewise improved, from about 44 db at the beginning to 48 db near the end, corresponding to TASO quality between 2. 0 and 2. 5, considered quite acceptable for viewing. This improvement was the result of several contributing factors, e. g., satellite repositioning and antenna beams reorientation, better tuning of transmitting receiving stations, etc.

The most serious deficiency in the satellite link during these tests was roll-off in frequency response (i. e., down by about 1. 8 db at 4. 2 MHz). While this would not have been serious taken alone, when added to the roll-off on the incoming microwave signal at Rosman, it reduced the 3. 8 MHz color burst sufficiently to degrade the chroma (color) quality of the signal delivered to KCET.

In summary, this initial test phase (January 4 - February 15) served to verify the satellite link calculations but produced very little data on the overall performance of the combined satellite/terrestrial transmission channel. Despite repeated complaints concerning the radio relay service, and sporadic efforts by AT&T toward improving same, this remained the primary source of noise, interference, and distortion over this channel. Though some quantitative data were obtained on the satellite link alone, this by itself was inadequate to determine viewer acceptability of such transmissions.

2. 3. 3 Test Plan Modifications

In early February, it became apparent that a number of modifications needed to be made in the test plan. Accordingly, the following revisions were adopted.

> A fixed schedule of test transmissions was originated from NET New York (Reeves Studios) or from other originating stations when the network originated outside New York. At each interface between radio relay, satellite, and user locations (e. g., Reeves or equivalent,

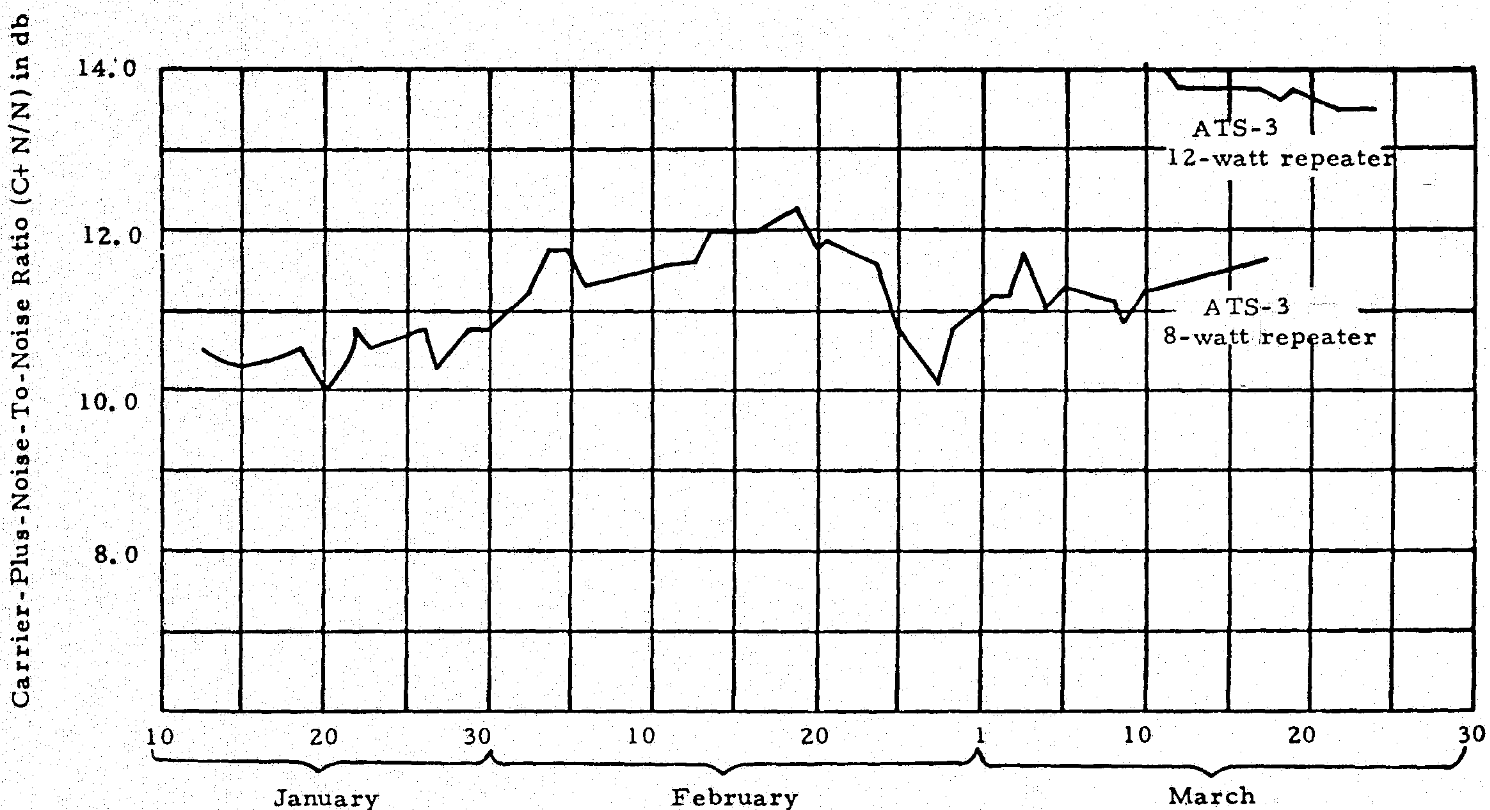

Figure 2. 3. Carrier-To-Noise Ratios Recorded at Mojave.

Rosman, Mojave, and KCET), Polaroid photographs of the appropriate video waveforms and/or displays would be obtained. Appropriate readings (e.g., S+N/N, frequency response, etc.) would also be taken at each location.

All outstanding and future problems with radio relay service on the West Coast would be resolved by KCET, as the recipient of those services and a primary participant in the TIE program. On the other hand, responsibility for seeing that radio relay service into Rosman was improved would fall to CPB.

To further improve satellite link S/N performance, equipment would be developed to remove the sync pulse from the incoming signal at Rosman and replace this with a burst of 5 MHz carrier prior to transmission to the satellite; complementary equipment would be provided at Mojave to reconstitute the sync pulse prior to transmission via the AT&T lines to KCET.

Operations in accordance with the modified test plan officially began on February 15, at which time Reeves initiated the new series of test signals and both Rosman and Mojave began routine collection of polaroid photographs. Due to operational difficulties, KCET did not begin photo collection until some time later, and then only on a sporadic basis. By March 5, considerable improvement had been effected through joint CPB/AT&T efforts; including elimination of the long-standing horizontal interference problem, delivery of proper color bar signal levels, and correction of frequency roll-off. While still just marginal with respect to differential phase and gain, it was expected that use of a normal processing amplifier at Rosman would provide a fully acceptable signal to the satellite link.

During the March 5 tests, the expected improvement in S/N performance using sync-stripping and regenerated equipment was demonstrated; actually, an increase of 6 db was noted; however, at least 2 db and perhaps 3 db of this improvement resulted from increased deviation without altering the sync pulses. Unfortunately, the sync regeneration circuitry installed at Mojave proved overly sensitive to noise on the incoming signal, resulting in loss of sync outgoing from Mojave, thus, the equipment was removed for further development. When further testing of this equipment failed to produce acceptable results, an alternative approach was adopted in which normal sync was merely reduced in amplitude via the standard processing amplifier. As this permitted an increase in deviation which produced a 2 db improvement in video S/N, the sync regeneration technique was dropped from further consideration during this project.

On March 18, tests were run between Rosman and Mojave to determine what improvements could be obtained through use of a special 5 MHz low pass filter in the Rosman modulator chain. Pictures made at Mojave indicated a significant reduction in high frequency noise (about 2:1) with very little effect on the multiburst signal.

Also on March 18, comparison tests were run on the ATS-1 and ATS-3 satellites, using each of the four radio repeaters involved (two per satellite). The $(\frac{C+N}{N})$ ratios were 10.1 and 10.8 db for ATS-1 8-watt repeaters, 11.3 for ATS-3 8-watt repeaters, and 13.8 for ATS-3 12-watt repeaters. Only one S/N reading was obtained, 49.2 db for the ATS-3 12-watt repeaters; with the 2 db improvement in video resulting from sync reduction, this equates to a normal S/N of 51.2 db.

During the final two weeks of testing, the 12-watt repeater aboard ATS-3 was used frequently. The $\frac{C+N}{N}$ readings were improved by about 2 db over those obtained with the 8-watt repeater, which agrees well with the link calculations. Some readings of considerably higher levels (e.g., up to 17 dB $\frac{C+N}{N}$) were noted in the final week; however, these are considered measurement anomalies.

2.3.4 Special Test of Hughes Receiving Station

A factor of considerable interest to the Corporation and other prospective users of satellite communications is the feasibility of operating a small receive-only earth station in an urban environment without harmful interference from radio relay services employing the same frequency band. The TIE project afforded an opportunity to evaluate this possibility in at least one location, since the Hughes Aircraft Company has a 30-ft station atop a 12-story building adjacent to the Los Angeles International Airport in El Segundo, California. Accordingly, arrangements were made with NASA and Hughes to conduct a one-day checkout of reception at the Hughes terminal, using transmissions from Rosman via ATS-3. Arrangements were also made to obtain data from informal monitoring of the ATS-3 transmissions by Hughes over a several week interval.

The Hughes test took place on March 3, at which time a S/N (peak-peak signal to weighted noise) of 46 db was attained. This is quite comparable to that attained at Mojave during the same period, indicating that the lower-noise receiver at Hughes roughly compensates for the higher-gain antenna at Mojave. Other characteristics of the received signal (e.g., frequency response, differential gain and phase, subjective quality) were also judged comparable to those at Mojave.

An interesting observation during both the formal checkout of this station and the several weeks of informal monitoring was the complete absence of interference from radio relay systems operating in the Los Angeles area. This was even more remarkable in that spectrum analyzer displays consistently showed a multi-channel radio relay signal only 25db weaker than the desired satellite signal, and displaced in frequency by only 10 MHz. While this did not constitute a conclusive test, it lends considerable weight to the view that small earth stations can be placed in an urban environment without harmful interference from radio relay systems; particularly considering that no special steps were taken in this case to shield the systems from one another.

2.3.5 Summary and Conclusions

Despite the many extraneous difficulties encountered during the TIE project, a number of important engineering objectives were achieved. First, it was clearly demonstrated to the satisfaction of both video engineers and viewers that high-quality, reliable television transmission via satellite could be provided on a routine basis. At the same time, it was demonstrated that the maintenance of high-quality video service via radio relay links is a demanding assignment requiring full-time attention.

Another significant finding was that even a relatively low-powered satellite such as ATS-3 could produce acceptable quality video (e.g., 45+ db) into modest earth stations having 30 to 40 ft antennas. Considering the possibility of increasing satellite effective radiated power by at least 10 db in a domestic satellite system, there seems little doubt that high-quality signals could be provided via even smaller, less costly stations. Also, the demonstration that suppression or replacement of the normal sync signal could provide a 3 db or greater improvement in S/N performance points the way to future operational procedures in any domestic satellite system for video service.

Finally, the demonstration of interference-free reception at the Hughes rooftop terminal in the Los Angeles basin offers considerable encouragement with respect to the feasibility of siting future receive-only earth stations in the immediate vicinity of the broadcast station, even in a congested urban radio relay environment.

2.4 MOBILE SERVICES EXPERIMENTS

2.4.1 General

Mobile services experiments involve radio communication between stations in which at least one station is intended to be used while in motion or during halts at unspecified points. This "in motion" operation imposes constraints on the antenna configurations and transmitter power capabilities of the station. The challenge of the mobile service people in the 1960's was to achieve the benefits of satellite communications while employing relatively small inexpensive terminals aboard ships and aircraft.

Communication between a satellite and a mobile ship station was first demonstrated between Syncom I and the USNS KINGSPORT in the harbor of Lagos, Nigeria on February 14, 1963 (Reference 318). Communications tests during the ascent of Syncom I to synchronous orbit employed a 30-ft antenna with three-axis stabilization and a 20-KW transmitter aboard the ship which transmitted at (nominally) 7300 MHz and received (nominally) at 1800 MHz (Reference 319).

The first significant aircraft communication satellite demonstration employing a small terminal was conducted in December 1964 when a teletype message was sent to an operational jet aircraft flying over the Pacific Ocean using the telemetry channel of Syncom III. It was from these early demonstrations that the ATS experiments involving the application of space technology to the mobile services were evolved. The ATS VHF experiment was conceived to establish the feasibility of satellite communication with mobile stations employing relatively small antennas and lower transmitter powers. The use of the VHF repeaters on the ATS satellites at approximately 149 MHz and 136 MHz permitted the use of these lower requirements on the vehicle since the so-called "free space loss" was significantly lower at these frequencies than at frequencies commonly used in space communications.

In addition to the basic objective of demonstrating the feasibility of mobile satellite communication using readily available, relatively inexpensive mobile terminal equipment, the VHF repeaters on ATS-1 and -3 provided an opportunity to conduct experiments in the following areas.

- Evaluation of cost-effectiveness of satellite communications in the aeronautical and maritime mobile services.
- Determination of the compatibility and potential problems involved in application of satellite communication in the aeronautical and maritime operating environments.
- Evaluation of the interference potential between a VHF satellite system and existing terrestrial systems.

- Evaluation of transionospheric and earth-reflected multipath propagation between satellites and mobile terminals.

A chronological listing of these experiments is presented in Table 2.3. In addition to the communications experiments, the VHF repeaters were employed for an extensive program of ranging and position-fixing experiments applicable to ship and aircraft radio determination systems. These experiments are described in Section 3.

While the ATS VHF mobile experiments were being conducted on ATS-1 and ATS-3, frequency management authorities were investigating the feasibility of allocating bands in the VHF portion of the spectrum to the mobile satellite services. After much study and debate, it was decided that the high utilization of these bands by terrestrial services limited the potential of expansion of any space services in the VHF bands and that it would be more desirable to establish the aeronautical and mobile satellite services in the UHF band. At the 1971 World Administrative Radio Conference on Space Technology (WARC-ST), a major portion of the band between 1535 and 1660 MHz was allocated to the aeronautical and maritime mobile services. This shift from VHF to UHF led to the development of an "L-band" repeater within the ATS program. This repeater was substituted for one of the C-band repeaters on ATS-5 which was launched in August 1969. The L-band repeater was intended to furnish a space platform for the development of mobile L-band satellite communications, but due to a launch phase problem, the satellite could not be despun to permit proper use of the directive L-band antenna and the full capability of the repeater was never utilized. Despite this problem, some significant navigation and ranging and propagation experiments were conducted at L-band. The only communications tests at L-band on ATS-5 were conducted on the ESSO BALTIMORE by the U.S. Maritime Administration. These tests involved time compression of a low data rate teleprinter circuit such that pulses of a higher data rate could be transmitted through the satellite repeater during a brief period of each satellite spun cycle that the L-band antenna illuminated the earth's surface.

TABLE 2.3

SUMMARY OF ATS MOBILE COMMUNICATION EXPERIMENTS

Date	Agency/ Contractor	Experiment Title	Frequency Band(s)	Type of Test
Nov. 1968 thru May 1971	GSFC FAA	FAA Experiments	VHF L-band	Link interference Multipath Teleprinter & data transfer performance Spin modulation
Feb. 1970 thru July 1970	GSFC ARINC	Airline Industry	VHF	Signal level behavior Antenna performance
Mar. 10, 1967 thru May 20, 1967	GSFC USCG	USCGC Klamath	VHF	Voice communication
July 19, 1967 thru Oct. 23, 1967	GSFC USCG	USCGC Staten Island	VHF	Two-way teleprinter Voice communication Ship-to-ship communication with USCGC Glacier
Oct. 1967 thru April 1968	GSFC USCG	USCGC Glacier	VHF	Two-way radio teleprinter Two-way voice communication
Feb. 1968 thru June 1968	GSFC MARAD	SS Santa Lucia	VHF	Propagation characteristics Voice channel performance Digital data performance Time synchronization performance
April 16, 1968 thru Aug. 2, 1968	NASA Germany	Meteor	VHF	Antenna pattern measurements Link performance - SNR Voice channel performance Data transmission Ship-to-ship communication with GAUSS
Oct. 1967 thru April 1968 & Oct. 1968 thru Jan. 1969	GSFC USCG	USCGC Casco at Ocean Station BRAVO	VHF	Radio-teletype communication Two-way voice communication Ship-to-ship communication with USS Josephus Daniels
Aug. 1970 thru Feb. 1971	NASA Netherlands	SS Nieuw Amsterdam SS Atlantic Crown	VHF	Radio-teletype communication Voice communication Facsimile transmission (NBFM & SSB)
Aug. 17, 1970 thru Dec. 17, 1970	NASA United Kingdom	Atlantic Causeway	VHF	Voice communication Teleprinter communication Facsimile transmission Selective calling tests
Jul. 1973 thru Feb. 1974	GSFC	ESSO Bahamas	VHF	Voice communication Teleprinter communication Facsimile transmission

2.4.2 Aeronautical Experiments

Prior to the launch of ATS-1 in December of 1966, an extensive program of flight testing was developed by a number of U.S. government agencies and industry organizations. In particular, the Federal Aviation Administration (FAA), Aeronautical Radio, Incorporated (ARINC), several individual airlines, and several airline communications equipment suppliers established ground stations and installed various versions of aircraft flight instrumentation packages for the flight tests. The most extensive aeronautical flight tests were conducted by two major experimenters: the FAA and a group of organizations loosely called "airline industry".

The first experiments with aircraft in flight employing the ATS-1 satellite were performed by the FAA just after launch in December 1966. Flight and ground tests involving an FAA aircraft (N-376) and several FAA regional communication facilities were conducted to obtain preliminary information on voice transmission capability, the potential of VHF interference and to establish criteria and procedures for later experimentation. Later in May 1967, the FAA conducted an extended flight test, again using ATS-1, in cooperation with NASA. The test was conducted for the purpose of measuring the communication link performance between a ground terminal and an aircraft equipped with a specially designed VHF SATCOM antenna. The basic objectives of the FAA aeronautical mobile VHF satellite link tests were satisfied. The results showed that voice communication between ground terminal and an aircraft was indeed possible. The results also showed that further equipment modification and tests were required to remove interferences, improve the signal-to-noise ratios, and to evaluate the impact of earth-reflected multipath signals on system reliability (References 320 and 321).

The airline industry experiments were conducted to determine the technical characteristics of an operational satellite VHF air-ground-air voice and data communications system and to verify that the application of satellites to the VHF aeronautical mobile environment was practical with state-of-the-art spacecraft and avionic equipment. The experiments were designed to measure critical parameters of the VHF signal received from the ATS-1 and ATS-3 satellites by specially equipped aircraft, flying typical over-ocean routes in the Pacific and Atlantic regions and land routes traversing the continental United States. Similar measurements were made at ground observation stations during transmission by both the test aircraft and the NASA ground station.

The results of the initial phase of the airline industry tests conducted between 1967 and 1969 may be divided into two categories. First were the signal level behavior (or propagation) tests which are described in Subsection 3.7. Second were tests to develop aircraft antennas for operation in a VHF satellite communication system. The aircraft antennas tested during this phase of the program suffered various limitations such as: lack of circular polarization (high ellipicity) at the lower elevation angles, low gain at the lower "look-angles", poor efficiency, excessive drag, inadequate power handling capability, compromised bandwidth, and instabilities due to routine exposure to wide changes in moisture and thermal environment. While these early experiments were being conducted, the Airlines Electronic Engineering Committee (AEEC) prepared ARINC characteristic 566 (Reference 322) which defined the technical characteristics of equipment intended to allow implementation of an airborne VHF satellite capability. This characteristic, in addition to other joint efforts within the avionics industry, led to the development of experimentation with VHF SATCOM antennas suitable for use on production aircraft or for retrofit on existing jet fleets. The antenna incorporated unique design features found desirable as a result of experiments with earlier test antennas.

A Boeing 747 aircraft was factory equipped with racks and wiring to accommodate ARINC characteristic 566 and was fitted with a special VHF SATCOM antenna. This led to further significant airline flight testing in 1970 with a Boeing 747 aircraft operating on regularly scheduled

Pan American flights. The limitations of these early antenna designs were largely corrected with the VHF SATCOM antenna. A series of in-flight tests conducted between February and July 1970 appeared to justify the developmental effort which it involved. Its performance indicated that it maintained its circularity of polarization while contributing positive gain at most azimuths and at elevations above 20°. It provided good SATCOM communications against the linearly polarized radiations of ATS-1/ATS-3. The antenna patterns, gain, impedance match, power handling capability, and efficiency, all showed that the slot-dipole served satisfactorily as a VHF satellite communication aircraft antenna. While it was not possible to adequately study the performance of this antenna at the very low look angles, it was apparent that this probably would not be a serious problem. Only one significant test was conducted through ATS-3 with the aircraft at the radio horizon. Classical multipath fading was present with an amplitude of approximately 4 db peak-to-peak, yet was not destructive.

The results of the airline industry experiments conducted on the ATS satellites demonstrated that a VHF aeronautical satellite service was technically feasible and that both spacecraft and avionic equipment required was within the state of the art existing at the time. The results of the propagation experiments indicated that while there were periods when significant ionospheric scintillation could be expected and that multipath fading could produce significant short term fading, a reliable system could be obtained by incorporating system margins within the capability of spacecraft powers available with contemporary technology.

In addition to the two major experimenters discussed above, other agencies conducted significant experiments but of lesser scope. One notable experimenter was the USAF who demonstrated that helicopter/ground and helicopter/air communication links could be established for certain conditions and evaluated the effects due to the helicopter rotor on such links (Reference 469).

In the course of the ATS aeronautical test program at VHF, another notable experiment was conducted in conjunction with the investigation of conjugate auroral phenomena as part of an International Geophysical Year (IGY) scientific project. In this experiment, voice communication was accomplished between two jet aircraft flying at high altitude in opposite hemispheres through the use of the ATS-1 satellite. The flights were conducted to study the seasonal assymmetry of auroras by comparing auroral forms and intensities during equinox periods (Reference 242).

2.4.3 Maritime Experiments

The launch of ATS-1 in December 1966 and the subsequent success of the first VHF aeronautical tests stimulated interest in a number of U.S. government agencies (as well as foreign governments) interested in maritime communication. The agencies first to take action directed toward establishing a VHF maritime satellite test program was the U.S. Coast Guard and the U.S. Maritime Administration.

2.4.3.1 U.S. Coast Guard Tests

Between early 1967 and the summer of 1970, an extensive experimental program in satellite communication was conducted by the U.S. Coast Guard employing the VHF repeaters on the ATS-1 and ATS-3 satellites. The communications portion of the USCG program involved the installation of VHF satellite communications terminals on four ships: the KLAMATH, STATEN ISLAND, GLACIER, and CASCO. The USCG also installed satellite terminals on three other ships--the RUSH, VALIANT, and ROCKAWAY--but these were employed to support noncommunications experiments. The RUSH and VALIANT supported a series of VHF ranging and position-fixing experiments while the ROCKAWAY supported the Barbados Oceanographic Meteorological Experiment (BOMEX), discussed in Section 3.

The USCG communications test program began with the installation of a leased terminal on the CGC KLAMATH in February 1967

(Reference 467). The terminal was fabricated from readily available, relatively inexpensive equipment. The purpose of the KLAMATH tests was to initially evaluate VHF satellite communications between a ground-based station and a ship at sea. The tests included evaluation of voice transmissions (16F3 emission), teleprinter error rate (200 Hz tone shift), and RF carrier level measurements of the satellite signals aboard ship. Tests were conducted between March 10 and May 20, 1967 at Ocean Station NOVEMBER (30°N, 140°W) and in the Gulf of Alaska Aleutian Islands and Bering Sea.

Subsequent to the KLAMATH tests, VHF satellite terminals were installed on two polar icebreakers (the STATEN ISLAND and the GLACIER) and another high-endurance cutter (the CASCO). The STATEN ISLAND performed additional tests between July 17 and October 23, 1967 in the Gulf of Alaska, Bering Sea, Chuckchi Sea, and Arctic Ocean. From October 1967 to April 1968, the GLACIER conducted a series of tests in the mid- and South Pacific, McMurdo Sound, and the Weddell Sea using both ATS-1 and ATS-3 satellites (Reference 472). The CGC CASCO was equipped in August 1968 with a VHF satellite terminal fabricated at the USCG Laboratory which was used to conduct tests from August 12 to September 13, 1968 at OCEAN STATION BRAVO (56°30'N, 51°00'W) and from October 7 to November 7, 1968 at OCEAN STATION DELTA (44°N, 41°W). These tests were conducted to obtain data on the effectiveness of VHF satellite communications from the North Atlantic and to investigate the feasibility of VHF satellite communication between a ground station and a ship on ocean station duty (Reference 475).

The results of the USCG experimental program demonstrated that a satellite relay would improve shipboard communications and that such communications could be achieved by use of readily available, relatively inexpensive equipment operated by shipboard personnel.

2.4.3.2 U.S. Maritime Administration Tests

Early in 1967, the U.S. Maritime Adminstration under the Department of Commerce initiated an experimental program to perform tests aboard the S. S. SANTA LUCIA, a 560 ft, 9313 gross ton general cargo merchant ship (Reference 178). This program resulted in a series of tests employing both ATS-1 and ATS-3 during two voyages between Port Newark, New Jersey and Valparaiso, Chile during the early part of 1968. The test program included the evaluation of voice channel signal-to-noise ratio, 600 bps data transmission, signal propagation characteristics, system noise and interference characteristics and transfer of time synchronization signals between shore and ship. The program demonstrated the feasibility of employing space techniques on board a commercial merchant ship and concluded that such techniques could provide a variety of long-range communications junctions aboard merchant ships on the high seas.

Later in 1971, the U.S. Maritime Administration sponsored an experiment to demonstrate a two-way communications link between a shore based terminal and a ship via the L-band transponder on ATS-5 (Reference 323). This experiment was conducted on the ESSO BALTIMORE and employed a burst type of data transmission to overcome the constraint imposed by the spinning antenna on ATS-5 which scanned the earth approximately once every 783 milliseconds. The data signal was a teletype operating at a nominal rate of 10 characters per second or approximately 100 words per minute. This experiment demonstrated that consistent, reliable communication could be maintained between ship and shore employing L-band except that ship maneuvering would require a stabilized shipboard antenna platform and operational programming might be required to avoid solar blackouts.

2.4.3.3 General Electric/Exxon Tests

Another maritime communications experiment was conducted by the Exxon Corporation and General Electric Company from mid-July 1973 through February 1974 (Reference 292). Voice, teletype, facsimile, and slow-scan television communications were tested between the Exxon offices in New York City and the ESSO BAHAMAS, a 32,000-ton tanker in service between the eastern United States and Venezuela. Position-fixing services were also tested by the use of General Electric's tonecode ranging technique which is discussed in Subsection 3.1.

General Electric's Radio-Optical Observatory, near Schenectady, New York, served as the earth terminal for the communications and position-fixing experiments. Signals from the Observatory were transmitted with narrow bandwidth frequency modulation approximately 3.0 kHz and RF bandwidth of 15 kHz.

Communication signals were received and transmitted from the ship through the crossed yagi antenna with an effective gain of 7 db. The basic unit was a General Electric Master Progress Line transmitter/receiver. A switch provided selection of voice, teletype, facsimile, ranging, and slow-scan television. A four-cavity bandpass diplexer provided for duplex operation, although simplex operation was used most of the time. Teletype operation was provided at ten characters per second with a teletype Model ASR-33 and at ten and thirty characters per second with a General Electric Terminet 300. Facsimile communications were provided by a Xerox Model 400 and a 3M Model 603. Slow-scan television was tested with developmental RCA "Videovoice" units. Videovoice provided slow-scan live camera transmission at 60 seconds per frame. All video transmissions are accomplished in a 3 kHz voice bandwidth.

Voice communications were of high quality. Most were conducted in the simplex mode, but the duplex mode was also used. Nearly all of the test coordination and control was by voice, but it was not the primary mode for operational messages. No significant reduction in voice intelligibility was observed when the satellite was on half power.

Teletype proved to be the most useful, reliable, and error-free transmission mode. It was the least susceptible to satellite power reductions and noisy channel conditions. Transmission time can be efficiently utilized since prepared tapes allow optimum word selection and high-speed transmission. In addition, teletype provides good flexibility in switching and computer access compatibility necessary for efficient processing. Figure 2.4 shows a typical message sent by teletype to the ESSO BAHAMAS. Teletype quality was classified into three categories: No Errors, Some Errors, Badly Garbled. About 90% of the messages fell into the "no errors" category. "Badly garbled" ones were mostly attributed to computer irregularities at the earth station. Messages with "some errors" usually caused little reduction in intelligibility and when numbers were incorrectly transmitted, the errors were indicated by a standard procedure of repeating all numbers in a number correlation sequence at the end of each message.

During most of the experiment, good quality facsimile was exchanged between the ship and shore. Figures 2.5 and 2.6 show several typical facsimile transmissions received by the ESSO BAHAMAS. Considerable reduction in quality was experienced when, in a reduced satellite power mode, interference existed from shipboard electrical equipment, receiving and transmitting facsimile machines were out of phase or synchronization, or noise conditions were present on the telephone line. When these phenomena were absent, the quality was almost as good as when the machines operated with direct connection.

2.4.3.4 Foreign Participation

Following an invitation by NASA, the Bundes-Republic Deutchland carried out an experimental program with the ATS-3 satellite during the summer of 1968 (Reference 300). Communications tests were performed employing the research ship METEOR and a survey and research ship GAUSS. A series of tests involving two-way voice, two-way digital data, determination of propagation characteristics and determination of lines-of-position by ranging were accomplished with the METEOR operating in the North Atlantic and the GAUSS operating in the North Sea. The conclusions drawn from these ship-to-ship tests further confirmed the feasibility

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Figure 2.4. Teletype Message to Ship.

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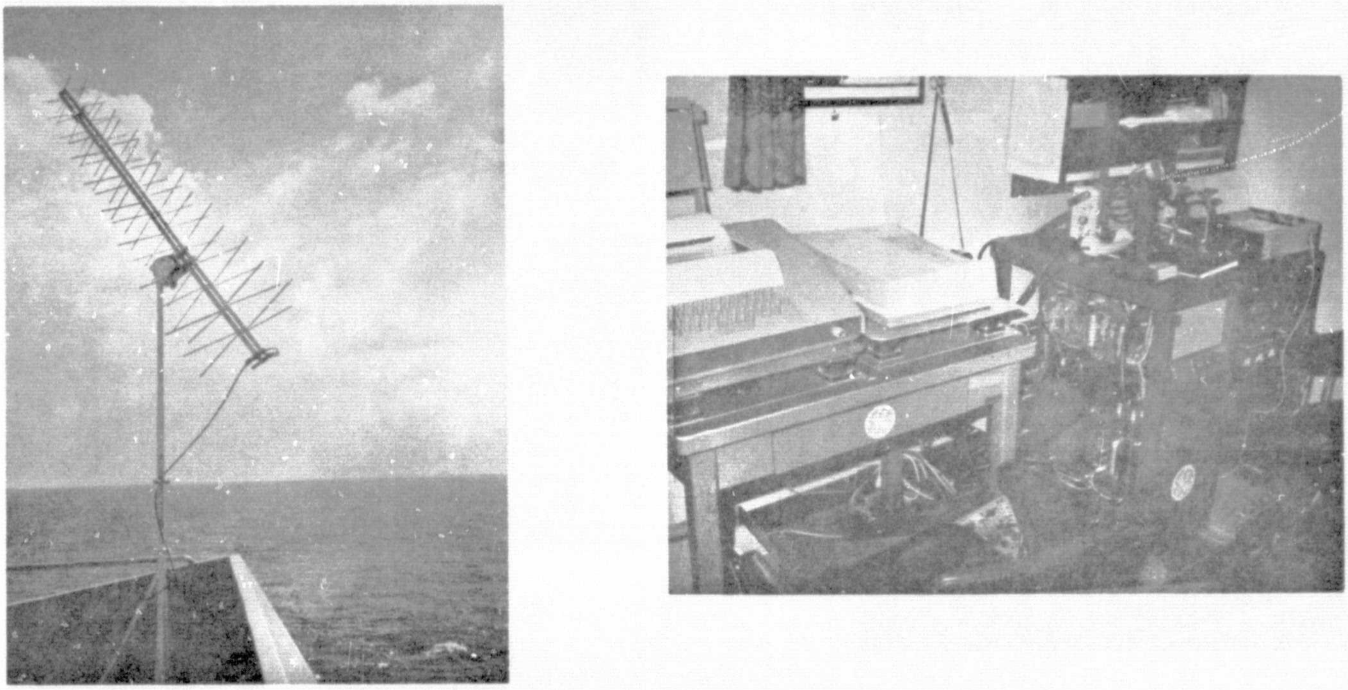

Figure 2.5. Facsimile Transmission of Photos.

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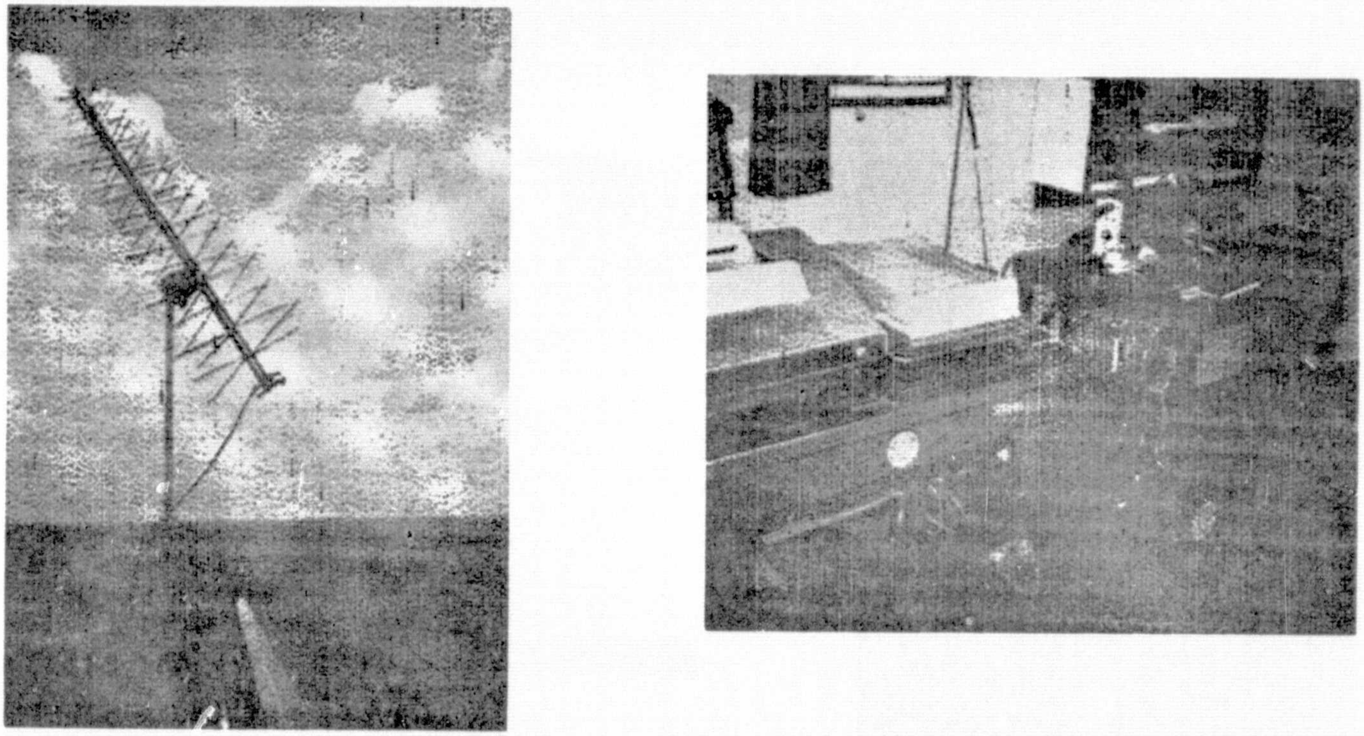

Figure 2.6. Facsimile Transmission of Photos.

of applying satellite communication in the maritime mobile service. These tests also indicated that 300 to 400 watts of effective radiated power and a receiver sensitivity aboard ship of the order of 0.1 to 0.3 uV was necessary for ship-to-ship communications.

Continued foreign participation in the ATS program further demonstrated the feasibility of applying satellite techniques to maritime mobile communications. From August 1970 to December 1970, the U.K. conducted tests on the ATLANTIC CAUSEWAY which evaluated the performance of FM voice modulation as well as several forms of speed processing (Reference 324). From August 1970 to February 1971, the Netherlands conducted tests on the NIEUW AMSTERDAM and the ATLANTIC CROWN. All the tests were performed in the Atlantic Ocean or Carribbean Sea (Reference 325).

2.4.4 Conclusions

The ATS program included many user oriented applications experiments that conclusively demonstrated that satellites could be applied to both the aeronautical and maritime mobile communications and that relatively small and inexpensive mobile satellite terminals could be used to provide voice, teleprinter, data, and facsimile communications.

Although no firm conclusions could be drawn concerning the cost-effectiveness of applying satellite communication techniques to the mobile services, the ATS program provided a means of evaluating many of the system parameters necessary for the definition of an operational system. Thus, one of the first steps toward cost-effectiveness studies was fulfilled by the program.

A number of potential technical and operational problems, such as propagation anomalies, signal processing requirements, mobile terminal antenna systems, equipment compatibility with airframe and shipboard environment, geographic coverage from synchronous altitude, and multiple access requirements, were identified during the ATS experimental program and many experiments were conducted to evaluate potential solutions to these problems.

Interference potential was evaluated and provided information for frequency management studies and sharing criteria requirements in the VHF band.

The results of the VHF experiments clearly demonstrated the feasibility of applying VHF communications techniques to the mobile services. However, the need to investigate similar applications in the L-band region of the spectrum were scarcely begun in ATS-5. Much more experimentation is required to establish the system parameters especially in assessing the potential of multipath and scintillation fading in this band. Also, further developmental work is required to establish that cost-effective airborne and shipboard terminals can indeed be produced.

2.5 ALASKA

2.5.1 Background

The state of Alaska has 16% of the total area of the U.S., but only 0.15% of the population. Of the total population (about 300,000), 20% (about 60,000) are natives (Eskimo, Indian, or Aleut). In some respects, Alaska may be considered as two distinct entities: the urbanized areas (Anchorage, Fairbanks, Juneau, and connecting lands) which are predominately white, and the rest of the territory (Bush Alaska) which is predominately native. Most of the rural communities are small villages, ranging in population from 25 to 1000.

Of the state's 180 native villages, two thirds have access to neither railroad nor highway. In most cases, transportation is by air, or seasonally by boat or snowmobile. These communities, without land transportation to other areas, also lack adequate communications facilities.

Over 100 communities rely on short-wave radio as their only means of communications with the outside world. The most serious problems of education and health persist in these small communities having a median population of about 155 persons.

Because of their small size, most communities in Alaska cannot obtain adequate medical and educational services. Paraprofessional health and education aides often represent the only personnel with any specialized training in the villages.

In the fall of 1969, the state of Alaska responded to an offer by NASA for the use of the ATS-1 satellite for additional communications experimentation by requesting the use of that spacecraft for a number of educational, informational, and health purposes. NASA approved this proposal in the spring of 1970. There followed a year of equipment purchasing and testing, utilizing the ATS-1 satellite. By the fall of 1971, several specific experiments had been identified and prepared which would utilize the ATS-1 satellite.

In August of 1971, a regular radio network was instituted between National Public Radio and the University of Alaska radio station, KUAC(FM). In September of that same year, experiments providing bio-medical communication and educational assistance to Alaska's remote areas utilizing the same equipment were instituted in 16 villages (Reference 52). This consortium was expanded to 22 members during the following year. Table 2.4 lists the participating members during the period 1971-73. As indicated in the table, some villages were deactivated after the first year because of inactivity. The number in parentheses is an estimate of population in 1973.

2.5.2 Rationale

Communications is a problem for everyone in Alaska, but most especially for the residents of rural Alaska. The people living in the remote villages being the most isolated, have the greatest needs for reliable

TABLE 2.4

SATELLITE RADIO GROUND STATIONS IN ALASKA

Village	Population	Installed In:
Allakaket	(168)	August 1971
Anaktuvuk Pass	(97)	August 1971
Anchorage	(5,700)	August 1971
Arctic Village	(82)	August 1971
Barrow	(415)	August 1971
Beaver	(86)	April 1973
Bethel	(9,300)	August 1971
Circle	(32)	April 1973
Chalkyitsik	(123)	August 1971
Emmonak*		August 1971
Fairbanks		August 1971
Fort Yukon	(448)	August 1971
Galena		August 1973
Homer*		August 1971
Hooper Bay*		August 1971
Hughes	(73)	April 1973
Huslia	(151)	August 1971
Juneau		August 1971
Kaktovik*		August 1971
Kanakanak*	(2,980)	August 1971
Kodiak		August 1971
Kotzebue	(5,440)	August 1971
Koyukuk	(124)	April 1973
Nome		August 1971
Nulato	(298)	August 1971
Ruby	(145)	August 1971
St. Paul	(450)	August 1971
Sand Point*		August 1971
Stevens Village	(74)	August 1971
Tanana	(3,170)	August 1971
Venetie	(108)	August 1971

* Dismantled in 1972

communications but enjoy the worst. Added to the generally poor quality of those communications is the additional fact that they must pay the high rates for telephone service where it is available.

The Federal Field Committee for Development Planning in Alaska, in its study Economic Outlook for Alaska: 1971, established poor communications as Alaska's number one inhibitor to social and economic development (Reference 61). The state of Alaska is participating actively in future satellite planning and well recognizes the potential of satellite communications to solve some problems. Any experience that the state can gain through the use of experimental communication satellites will provide additional information which can be put to good use in the design of future operational satellite communication systems for the state.

2.5.3 Goals and Objectives

The state of Alaska's specific goals and objectives with regard to the use of the ATS-1 satellite are stated in outline form:

A. To gain experience in the use of a medical, educational, and informational interchange between remote and urban locations.

B. To isolate the advantages of satellite telecommunications.

C. To develop in-house (in Alaska) satellite communications competence.

2.5.4 Organization

During the period from 1971 to 1973, the Alaska ATS-1 project was composed of three distinct and separate experiments. However, because of equipment sharing, frequent contact among experimenters was common and essential.

An ATS-1 coordinator was named by the Governor in 1971. The Executive Director of the Alaska Educational Broadcasting Commission attempted to provide the necessary coordination between the three experiments.

Unfortunately, due to an overly heavy schedule and other burdensome commitments, it was difficult at best for the coordinator to achieve the kind of results necessary for complete coordination of the project.

Valuable lessons were learned in the 1971-72 experimental period about the organization necessary to carry on satellite experimentation in a coordinated manner. Corrections of this situation were made for the 1972-73 period. Figure 2.7 illustrates the organizational scheme for the 1972-73 experimental period.

A simple explanation of Figure 2.7 is practically impossible. It should be noted here, however, that the opportunity to utilize the ATS-1 satellite for experimentation in Alaska made it necessary for the various experimenters to seek funds outside normal state sources, in most cases, in order to participate. Whenever funds were located and allocated to the project, there was, of necessity, a requirement for a reporting structure and a hierarchy that would include the new funding source.

2.5.5 Biomedical Experiment

As was pointed out above, the Alaska project consists of three separate and distinct experiments. All three experiments contribute to the meeting of the stated goals and objectives. This section of the report will deal with the biomedical experiment. This project provided almost all ground reception and transmission equipment and its technical staff also provided maintenance for the educational experiment.

A brief discussion of the health care delivery system for the remote areas of Alaska is a useful preliminary to a discussion of the medical experimentation carried out in the ATS-1 project. There are four main medical sectors in Alaska--U.S. Public Health Service, State of Alaska Department of Health and Social Services, Private Sector, and Military Sector. There are a multitude of smaller groups and organizations having something to do with health care delivery. For example, in the 1972 Health Directory published by the Alaska Medical Society, there are 21 volunteer

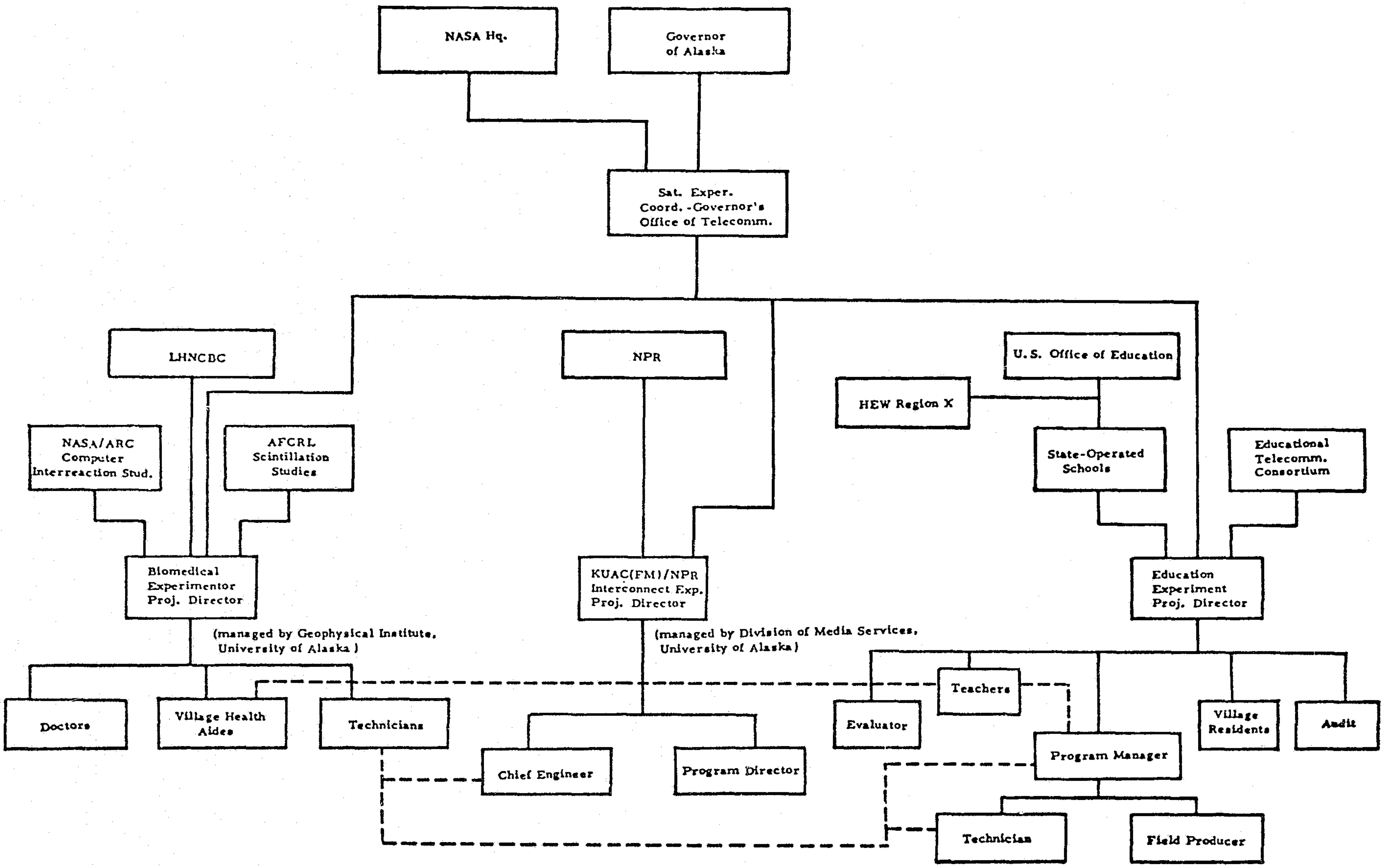

Figure 2.7. Organization of Alaska ATS-1 Project, 1972-73.

organizations listed, none of which are the local boards of health. In general, however, health care for residents of remote areas is provided by the Alaska Area Native Health Service (AANHS).

The health care delivery system organized by the AANHS in the last few years is a result of the problems peculiar to Alaska. The primary health care personnel are medical aide residents in the remote communities who are equipped with small amounts of drugs and medical supplies. The medical aide is employed by the village council with funds supplied by the Native Health Service. The responsibility for health aide training primarily rests in the hands of the Community Health Aide Program (CHAP) of the AANHS headquartered in Anchorage. Secondary responsibility rests with the state of Alaska. The health aide training program consists of a series of seminars and workshops presented in Anchorage by the staff of the AANHS. Itinerant nurses of the Alaska Division of Public Health provide some in-service training to medical aides.

The secondary care centers of the system are Public Health Service (PHS) Service Unit Hospitals located in seven Service Unit Districts throughout the state of Alaska. The Service Unit Hospitals are small, with 20 to 50 beds each and 2 to 6 physicians resident at the hospital. The physicians at the Service Unit Hospital supervise the care of the patients in their Service Unit District with the assistance of the medical aide who lives in the village. Until the advent of the ATS-1 system, most communications, including emergency requests for evacuation of patients, were handled by HF radio. Communications between the hospital and the peripheral group of villages was less than 20% effective when attempted by HF radio.

With the advent of the ATS-1 satellite, it was possible to establish reliable communication between the remote communities and the Service Unit Hospitals. In addition, it was possible to establish communications between the medical centers in Fairbanks and Anchorage and small hospitals in the private sector of Alaska. The basic premise of the experiment may be simply stated: given reasonably reliable communication between urban and remote areas, determine what useful information may be transmitted between these areas to improve health care delivery to the public.

In the spring of 1971, the Geophysical Institute of the University of Alaska negotiated a contract with the Lister Hill National Center for Biomedical Communications (LHNCBC); National Institutes of Health (NIH); U.S. Department of Health, Education, and Welfare (HEW) for the conduct of an experiment to explore some of the problems of remote areas and to attempt to determine solutions (Reference 61). The goals of that project were as follows:

A. Establish a ground station network of approximately 25 stations in Alaska. These stations were to be capable of communicating with each other using the VHF transponder on the ATS-1 satellite;

B. Operate and maintain the ground station network;

C. Conduct certain propagation studies;

D. Coordinate the use of the network by various experimenters; and

E. Evaluate utilization of the network with particular emphasis on the medical problem.

Further negotiations with LHNCBC and the Office of Education (OE, HEW) added two requirements:

- Establish remote terminals in school classrooms at a selected number of the ground stations for use by the local community.

- Evaluate the use of the educational programming conducted over the network.

An extension of the contract with LHNCBC was negotiated in the spring of 1972. An amended series of goals based on previous experimentation was agreed to. The goals and objectives under the new contract (effective from June 11, 1972 to December 21, 1972) were as follows:

- Continue the coordination, operation, and maintenance of the ground station network with the following restriction: the task will be confined to medical traffic only;

- Design and conduct additional experiments in continuing education of health aides in remote communities;

- Assist in the evaluation effort being conducted by Stanford University;

- Design and install an alarm system for remote villages to alert satellite controllers and operations centers that a medical emergency exists;

- Remove unused ground stations to new locations; and

- Assist in the Washington, Alaska, Montana, Idaho (WAMI) medical program.

As may be seen from the above list, the experiment, or series of experiments, evolved during its conduct. At the outset, the Geophysical Institute was charged with evaluation of the operation of the network. The addition of more and more participants in the program was clearly beyond the scope of the organization. The Lister Hill Center negotiated a contract with Stanford University to conduct an evaluation and audit of the medical portion of the experiment.

During the summer of 1971, ground stations were installed in 26 communities in Alaska for two-way audio communication via the NASA ATS-1 experiment satellite. Nine of these stations were located in villages in the Tanana Service Unit which are served by native health aides. Other ground stations in the Unit were installed at the Tanana Hospital and Fort Yukon where there is a nurse. Ground stations were also located at the Alaska Native Medical Center (ANMC) in Anchorage and in 13 other communities, several of which had doctors. The Alaska control station (Minitrack) is at the University of Alaska near Fairbanks. In 1972, six ground stations were moved from sites where they had received little use to five other villages in the Tanana Service Unit (Reference 52).

The primary use of the ATS-1 network has been for a daily doctor call between the doctor at Tanana and the remote health aides in the Tanana Service Unit. Prior to the installation of the satellite radios in the villages, the doctors at the Tanana Hospital tried to conduct the daily doctor call through HF radio.

In an attempt to isolate the effects of the introduction of the new technology from other factors influencing health care delivery in rural Alaska, a group of nine villages, equipped with satellite-radio, were designated as the "experimental villages". These were Allakaket, Anaktuvuk Pass, Arctic Village, Chalkyitsik, Huslia, Nulato, Ruby, Stevens Village, and Venetie.

To examine the difference attributable to the satellite radio, statistics were gathered for the year immediately before the introduction of the satellite ground stations. Some of the changes from one year to the next might have occurred without the introduction of the satellite-radios however. To provide an appropriate baseline for comparison, a group of villages in the Tanana Service Unit which did not have satellite radio were studied during the same three-year period. Mid-August of 1971, the average date of satellite ground station installation, was used as the dividing point for the before/after comparison in the control villages. Doctor-initiated doctor call sessions were held before and after the satellite installation in all villages, experimental, and control units. No turnover of health aides occurred to affect the experimental data.

The radio logs at Tanana Hospital and at the Minitrack Station at College were examined to determine the frequency of radio contact between Tanana and each of the villages during the three-year period. For the nine experimental villages, the data presented below include the calendar year immediately before and after the installation in each village, and a second year, beginning in October 1972.

For the four control communities of Beaver, Hughes, Koyukuk, and Rampart, the radio contact is reported for the year before and after the average installation date of August 17, 1971 (Table 2.5). Only four control villages were used for this analysis because the villages of Birch Creek, Circle, and Eagle did not appear in the radio logs for this period. The percentage of days with radio contact was calculated on the basis of a 365- or 366-day year, even though there were a number of days when the satellite was not available.

The change in radio contact in satellite villages amounts to an increase of more than 400% for the first year and more than 500% for the second year following satellite radio installation. These differences are statistically significant despite the small number of villages involved (first year: $t = 14.1$, $df = 8, p < .001$; second year: $t = 22.3$, $df = 8, p < .001$). The percentage drop in the control villages with high-frequency radio contact is not statistically significant, and may be just random fluctuation.

In April 1973, satellite radios were installed in four additional villages at the request of the residents. This group of villages--Beaver, Eagle, Hughes, and Koyukuk--offered an additional possibility of comparison between this new group and the villages where the satellite had been operating for more than a year. These "old" satellite villages were used, therefore, as a control group, and the four "new" satellite villages were the experimental ones.

The results of this study, which are presented in Table 2.6, confirm the previous analysis--that the installation of satellite radios increases dramatically both the number of contacts completed and the number of medical cases treated.

Doctors at Tanana Hospital communicated daily with health aides at 13 villages and with the registered nurses in charge of the clinics at Fort Yukon and Galena. Of the 13 villages, 9 had been using satellite radios since August 1971 and 4 since April 1972.

TABLE 2.5

DAYS OF RADIO CONTACT WITH DOCTOR
BEFORE & AFTER INSTALLATION OF SATELLITE GROUND STATION

	BEFORE		AFTER			
	(1970-1971)		(1971-1972)		(1972-1973)*	
	average number of days	% of poss. days	average number of days	% of poss. days	average number of days	% of poss. days
Experimental Villages (9)	51.7	14.0	270.2	74.0	310.0	85.0
Control Villages (4)	44.0	12.0	24.3	7.0	N/A**	N/A**

*10-1-72/9-30-73

**Three of these four villages (Beaver, Hughes, and Koyukuk) had satellite radios installed in mid-April 1973. The fourth, Rampart, continues operation with HF radio, but no record of contact appears in the Tanana Hospital log.

TABLE 2.6

"OLD" AND "NEW" SATELLITE VILLAGES

	Before	First Year After
Days with Radio Contact w/Doctor		
New satellite villages (4)*	44.0 (12%)	278 (76%)
Old satellite villages (9)	51.7 (14%)	270 (74%)
New Medical Cases Treated (average and episodes per 1000 inhabitants)		
New satellite villages (4)*	24.7 (286)	158.4 (1,604)
Old satellite villages (9)	47.1 (330)	184.6 (1,291)

*In the sample of four villages, one of them (Rampart) was replaced in the analysis for the "first-year-after-satellite" period by another village (Eagle)

All the health aides had performed similar tasks with satellite or HF radio for communication prior to the year under analysis. Two doctors at the hospital had been working with the satellite radio system since early 1972, and a third doctor was added as a radio consultant in mid-1973.

Traffic with medical content occurred on 67% of the total village days and the average health aide discussed or exchanged medical messages (either patient consultation and/or medical administrative matters). January and February had the lowest percentage of medical content (on about 53% of the total days).

The variation among villages is notable. There was one village (pop. 159) with content to transmit on 88% of all the days of the year, while another village (pop. 84) had medical traffic on only 48% of all days. On 19% of all days (or 34% of the "completed contacts"), there were "neither patient consultations nor administrative matters to exchange that day". In colder months, there tended to be more contact days without medical traffic than in milder months.

The radio logs at Tanana and the Minitrack station at College also permitted an analysis of the number of new episodes discussed by the doctor with the health aide in each of the villages contacted during the doctor call. Compared to HF contacts in the year previous to satellite installation, the number of cases managed by satellite radio showed almost a 300% increase in the first year, and more than 400% for the second year, against a background of a slightly declining number of patients treated in the HF radio villages. Table 2.7 shows the number of new episodes in the expiermental and control villages in the year preceding and in the two years following introduction of the satellite radio. (A "new episode" is any form of patient contact other than follow-up visits within a few days.) The increase in the satellite cases was statistically significant (first year: $t = 12.5$, $df = 8$, $p < .001$; second year: $t = 23.4$, $df = 8, p < .001$). (see Table 2.7).

TABLE 2.7

NEW EPISODES HANDLED BY TELECONSULTATION

	Before Satellite (1970/71)	After Satellite: 1st Year After (1971/72)	After Satellite: 2nd Year After (1972/73)
9 Satellite Villages	47.1 (330)*	184.6 (1,291)*	290.0 (2,021)*
4 HF Radio Villages	24.7 (286)*	15.0 (173)*	NA

*Episodes per 1,000 inhabitants

Consultation was sought in about 2/3 of the cases seen by the health aide. The health aides of the 13 villages made 3,020 patient consultations in 1973. Given that the total population of these villages is 1,700 and four villages entered the system in April, this amounts to about 2.0 radio-consultations per person annually, or around 10.6 radio-consultations per average family (5.3 persons). (U.S. rate for doctor visits: 4.3 per person.)

There are large intervillage variations in the rate of ratio-consultations per capita (maximum 3.7, minimum .95). Not enough information is available to relate this in any way to the health or sanitation conditions of the village. Variables in the behavior of the health aide are probably the major factor of the difference in the rate.

In 43% of all possible contacts (number of days per year times number of villages), there was at least one patient consultation; in some villages, patient consultations occurred on 2/3 of the days; in some others, on only 1/4 of the days.

Each village discussed an average of 282 items per year, or .95 items per possible contact (maximum 1.9, minimum 0.5). The variation across months of the year was not seasonal (maximum 1.2, minimum 0.7). Twenty-three percent of the total contacts had administrative matters as their only content.

During 1973, the 13 villages used 13,944 minutes (232 hours) of satellite time. This was an average of 4.3 minutes per average day per village (4.8 minutes on weekdays and 2.6 minutes for weekend days), or about 9.3 minutes per person per village annually. Out of that time, 72% was used for patient consultations.

The lack, for the village aide, of immediate contact with the hospital in emergency cases was a factor in disabilities and deaths. An analysis done by Brian Beattie, M.D. (Reference 252) on emergency cases showed that:

1. Lack of communication within a reasonable time made a difference in the outcome of four cases out of a total of ten deaths which occurred in the period he studied; and

2. For emergency contacts, the villages where satellite radio was in use had a better percentage of contacts achieved within a reasonable time than those equipped with HF radio.

However, at the time of the study, the health aides in the "satellite villages" had to wait to be called in order to have contact with the doctor. They could not call him. After this study, "alarm buttons" were installed in the health aides' houses to call the hospital in emergency situations. After the installation of those buttons in late 1972, no case was recorded as not having been achieved within a reasonable time.

During 1973, there were 45 emergencies recorded, some of which involved more than one patient. Seventy percent of the emergencies resulted in evacuation of the patient to the hospital, and 20% were resolved by consultation with the doctor. The remaining 10% were either labelled as "nonmedical emergencies" or no information about their nature was recorded.

The following is a list of some typical emergencies for which the alarm buttons were activated:

1. Koyukuk activated the medical alarm signal at 1800Z on May 2. An 18-year-old in labor; arrangements were made for air evacuation to Tanana.

2. Nulato activated the medical alarm signal at 1730Z on May 6. A patient with chest pain; treatment recommended; nine minutes used.

3. Nulato activated medical alarm signal at 0538Z on May 14. Patient in severe pain and depression. Recently had surgery and radiation treatment for cancer. Air transportation to Tanana arranged for following morning.

4. Hughes activated the medical alarm signal at 0604Z on May 29. Patient with lower abdominal cramps. Treatment advised and air evacuation to Tanana arranged.

Table 2.8 shows a breakdown of the severity of the cases consulted during the latter half of 1973. During this period, only 0.5% of the cases were considered very severe or acute.

In half of the cases (categories 1 and 2), the health aide, in the opinion of the doctors, had planned, or could have planned, correctly on his own judgment. Of the remaining cases, 20% required minor changes and 30% major changes (Table 2.9).

In 70% of the 2,004 cases, the doctors recorded their assessment of the effect of the consultation on the outcome of the patient's problem. Criteria included effects on symptoms, well-being, and disability. In most of the judged cases (58.2%), a definite effect was predicted.

It is important to provide quick transportation service to the hospital when needed. The satellite radio has provided reliable means to call for that service.

The issue of travel authorization was considered in 9% of the cases. Travel was authorized to a central facility in 19% of these cases, or 2% of the total. This means there were about five authorizations per month, one urgent and four routine.

2.5.6 Educational Experiment

Educational broadcasting via ATS-1 satellite to remote Alaskan communities began in October of 1971 (Reference 61). Two hours a day were available for educational broadcasts. Since no provisions had been made for program production, the educational project director drew upon other organizations as well as the rural listeners for help in programming.

The initial months were critical in program development and acceptance of programs by the satellite villages. Of the 22 potential villages

TABLE 2.8

SEVERITY-COMPLEXITY OF THE CASES CONSULTED

	Number of Consultations	Percentage
1. Simple question about medication, reaction, or use of household remedy, etc.	71	4.1
2. Patient conseling about proper health habits, social or psychological problems	61	3.6
3. Routine screening, history, and physical on an asymptomatic individual, e.g., school or athletic evaluations	79	4.6
4. Followup of and resolving acute acute problem that has been under treatment	302	17.6
5. Evaluation of new minor, but symptomatic problems related to a particular organ system, URI, urinary tract, etc., with little potential to become severe problem or chronic disease process with little potential for morality	1108	64.7
6. Evaluation of new moderately severe problem with potential for deterioration to severe problem or to disability or chronic disease process with moderate potential for mortality	84	4.9
7. Evaluation of acute problem producing severe symptoms or potential disability or a chronic process with high potential for mortality	6	.4
8. Evaluation of continuing severe problems of life threatening proportions requiring analysis of several diagnostic and therapeutic possibilities and frequent evaluation of course and therapy	1	.1
	1712	100.0
Unreported severity	292	
Total cases	2004	

TABLE 2.9

HEALTH AIDE VS. DOCTOR TREATMENT

	Number of Consultations	Percentage
Confirm health aide treatment	481	30.4
Suggested treatment, but aide could have managed	331	20.9
Made minor treatment change	288	18.2
Significant change or addition to management	484	30.6
Total reported cases	1584	100.0
Unreported	420	

within the network, a core of 14 participating villages made up the educational network. Characteristically, each participating village shared the attributes of remoteness, lack of any radio communication, and cultural unity with other participating villages. The programs that were developed came from the people within the network, and these programs reflected the needs of the villagers. At the same time, urban organizations were quick to see how their programs could be extended to rural areas, and added their participation in the planning and development of programs. In this way, the Alaska Library Association, Tanana Service Unit Board of Health, and the Fairbanks Native Community Center became involved in satellite broadcasting. By the end of December of 1971, educational programs were exploring audience needs for information, instruction, and communication. Programs maintained a consistent schedule from December until June, when many villagers left for summer subsistence activities or seasonal employment. During the summer months, educational broadcasts were on the air for one hour due to the small village audience.

A measure of the utilization of the satellite by the rural villages is shown in Table 2.10. These data were obtained by monitoring broadcast and recording the number of responses from each village for a two-year period. Clearly, some villages were more active than others. In most cases, the participation remained fairly constant from one year to the next.

From the early months of broadcasting, two distinct kinds of programs emerged: service programs which followed the format of telephone interchanges, and instructional/educational programs for the community and the school.

Instructional programming was at first rudimentary and undirected as the satellite project explored the educational needs of listeners. A series of radio programs that had been produced for the University of Alaska FM radio station was chosen as the first material for instructional "Crossroads in Time" was a series of 13 radio programs about the Athapaskan Indians.

TABLE 2.10

PARTICIPATION BY SITE
JULY 1972 THROUGH MAY 1973

Village	Number of Responses	July 72-May 73 Percent of Participation	Oct. 71-May 72 Percent of Participation
Allakaket	40	35	35
Anaktuvuk	133	64	51
Arctic Village	12	6	23
Barrow	30	14	7
Barter Island*	3	2	10
Beaver*	12	31	--
Chalkytsik	31	15	22
Fort Yukon	6	3	11
Hughes*	27	52	--
Huslia	78	37	34
Koyukuk	14	27	--
Nulato	91	44	41
Ruby	83	40	41
St. Paul	3	1	2
Stevens Village	16	8	16
Tanana	92	44	32
Venetie	52	25	44

The first of a series of programs for classroom instruction was produced from the Nulato Stick Dance in March 1971. This week-long classroom unit was broadcast live from Nulato, one of the satellite villages. The classroom units represented the major programming effort of the satellite staff during 1972-73. This was in response to criticism in the first evaluation report (Reference 148) that the Action Study was not successful in instituting educational broadcasting to a substantial number of classrooms. The classroom programs were to some degree successful during the second project year and a good response was developed to several of these unit efforts.

The general format followed for most of the classroom units was to select one week during the month and broadcast steady one unit each day until the entire unit was finished. Whether this technique is best or whether it is better to broadcast one or two units a week spread through most of the month could not be determined.

The other aspect which was difficult to evaluate is the amount of interaction that the units created in the classroom. Since many units were taped and had printed material and photographs accompanying them, it was possible for the classroom to have a good deal of interaction with the unit without saying much, if anything, over the satellite radio.

Table 2.11 shows the type of classroom units that were used throughout the 1972-73 school year. Only two of the subject areas were utilized for classroom units during the first project period. These units have been prepared as a kit that can be utilized either via the satellite or by using tapes.

There was little cultural interaction between Eskimo and Indian speaking areas evidenced during this program with the exception of Anaktuvuk which participated to some degree in almost all the units. This same situation prevailed during the first year of the Action Study.

TABLE 2.11

CLASSROOM UNIT UTILIZATION 1972-73

Subject	Month Broadcast	Number Broadcasts	Maximum Sites One Broadcast	Most Active Site
Fishing	Sept.	4	4	Huslia
Caribou Hunting	Oct.	5	3	Anaktuvuk
AFN Convention	Nov.	4	2	Barrow
Christmas in Barrow	Jan.	2	2	Anaktuvuk
Dog Mushing	Feb.	2	3	Tanana
Stick Dance	Mar.	5	3	Ruby
Trapping	April	4	2	Hughes Tanana
Hearing	May	4	7	Anaktuvuk Ruby Tanana
Whaling	May	2	3	Anaktuvuk Barrow

The overall response of the teachers to the classroom units, as determined by interviews and questionnaires, ranged from great enthusiam to extreme coolness. Some teachers were already planning their next year's efforts in native studies to incorporate the units while others felt that better results could be obtained by making videotapes in these subject areas and mailing them to the schools.

In March 1973, contact was established with the PEACESAT ATS-1 Project at the University of Hawaii and some exploratory talks began on a classroom exchange between Alaskan and Hawaiian schools. This finally culminated in classroom exchanges between the Lunalilo elementary school in Honolulu and the schools at Hughes, Chalkytsik, and Tanana. The majority of the exchanges were between Hughes and Lunalilo.

A good interchange was secured between the two schools and eventually a real information exchange between students developed. The general pattern was to present a couple of programs to break the ice before student participation began. There can be little doubt that new vistas of life in other places were opened for the participating students in both classrooms. The students at Chalkytsik participated in a similar experiment in the previous year with students from Barstow, California.

2.5.6.1 Health Related Programs

Health oriented programs were able to attract a good listening audience during both project years (Reference 49). It is to be expected that these programs should have a relatively high level of success since their most likely audience is the group having the satellite radio closest at hand - the village health aides.

The health aides most active in responding to these programs were those in the interior Alaska Athabascan speaking villages. No participation was observed from any Eskimo speaking villages with the exceptions of Anaktuvuk Pass and Barter Island. Due to technical problems, both in 1972 and 1973, participation by the latter site was minimal. Anaktuvuk is an anomaly in that it is the only Eskimo speaking village in the Tanana hospital service area which is otherwise composed of Athabascan speaking villages.

Due to the above reasons, responsibility for health programs was handled by the Tanana Chiefs Conference Board of Health during the second project year. During 1972, programming had been provided by efforts of federal, state, and local health agencies with the project staff handling program coordination. It was felt that the Board of Health could provide the kind of input that was needed by the health aide to supplement the medical education programs being supplied by the ATS-1 Medical Communications Project. Programs were provided in such areas as village cleanups, venereal disease, alcoholism, and family planning.

The health aides seem to appreciate the information received from this source since it is usually provided by people different from those they encounter in their everyday medical contacts. The programs provide them with a means to seek further input to problems they may have already discussed with Alaska Native Health Service personnel and also to find out that the problems of their village are found outside the village in many other parts of Alaska and of the world. It also provides them with input on medical programs being developed in the private sector or by other public health agencies of which they may not be yet aware.

Some public health programs have also been utilized in the classroom. There has not been enough of an effort in this regard to evaluate any possible role that health programs could play in the school curriculum.

2.5.6.2 Programs Sponsored by Native Organizations

The same Alaska Native organizations that sponsored programs for the first project year were also active in the second. It was not possible to involve other regional groups and native associations because after stations were moved the configuration of the satellite network was almost exclusively within the Tanana Chiefs Conference area (14 villages). There were also three terminals still remaining in the Arctic Slope Native Association area. Other terminals were widely scattered throughout the urban areas and larger towns in the state.

The most serious problem in this category of programs for both project years was the continued failure of the persons responsible for the broadcasts to make good their commitments. The percentage of "no-shows" is given in Table 2.12.

2.5.6.3 School Administration

The satellite radio in its second year became a firm fixture in the daily routine of the Tanana Area Schools. The addition of Hughes and Koyukuk late in the second school year made it possible to contact 8 out of 14 schools by satellite radio. Teachers in the Tanana School District utilized the radio twice a week to talk with their administrator in Tanana. In the past, generator failures, furnace blow-outs, or deficiencies in instructional materials would cause the whole school to shut down while a written message was mailed out. With the satellite radio, teaching conditions were greatly improved and teachers could call for immediate emergency parts during the critical winter months. The communication link between schools and the area administrator supported and encouraged the efficient operation of the schools.

2.5.6.4 Alaska Library Association Programs

The Alaska Library Association (AKLA) sponsored a wide variety of programs aimed at both schools and the general village audience. It also experimented with a functional exchange between state library offices. Some library programs generated intense enthusiasm and requests for books but often there was little or no reponse or demands for books and information. The general impression gained was that there was

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TABLE 2.12

PROGRAM RELIABILITY FOR PROGRAMS OFFERED BY NATIVE ORGANIZATIONS, OCT 1972-MAY 1973

Group	Broadcasts Scheduled	Broadcasts No-Show	Percentage No-Show
Arctic Slope Native Association	6	1	179
Alaska Federation of Natives	6	3	50
Fairbanks Native Community Center	13	4	31
Tahetan (University of Alaska Student Group)	3	1	33
Tanana Chiefs Conference	12	4	33
Total	40	13	32

a need but that it was quickly and easily satisfied. Also, the teachers have several alternate sources for ordering materials from within the school system.

The librarians' information exchange provided a means of coordination between the state library headquarters, the regional librarians, and local librarians. A high degree of participation was attained and the program seemed to fill a need for this conference type communication. It provided a forum for presenting new library ideas, new source funds, and generally keeping everyone up to date on what was going on in the world of libraries.

2.5.6.5 Conclusions

Evaluation of the educational experiment was contracted to Stanford University. Dr. Walter B. Parker was the primary evaluator of the Action Study of Educational Uses of Satellite Communications in Remote Alaskan Communities during the period 1971-73. His final evaluation report (Reference 49) to Project Director Mervin Charlie in 1973 included the following observations.

> 1. The Action Study was successful in expanding concepts and methods of educational broadcasting to the schools of rural Alaska. Educational broadcasting involvement was expanded at three schools: Tanana, Nulato, and Barrow; remained generally the same at the other active sites, and diminished in one village: Venetie. One new site, Hughes, was involved very successfully in the project, but the other sites, Koyukuk and Beaver, have not as yet been substantially involved.
>
> 2. Community service programming declined from the levels achieved during the preivous year. Part of this was due to the shifting of the primary responsibility for health broadcasting to the medical communications project, but the major failure was due to sponsors not making good their commitments and the project's inability to find anyone who would put together a comprehensive effort on Native Claims Settlement.

3. Maintenance of equipment was more of a problem than in the previous year. One site, Fort Yukon, was out of service the entire year while others such as Arctic Village missed most of the vital part of the spring programming. Other sites were out of service for periods up to a month.

4. Coordination improved between the Action Study and its companion medical communications project on the ATS-1 satellite except in the area of maintenance.

5. Coordination became less effective within the Action Study due to fewer Consortium meetings and being without funding or an Executive Director for so much of the project year. Another factor inhibiting relationships for a time was the adjustment to the removal of the ATS coordinating function to the Office of the Governor in Juneau. Everyone has now adjusted to this new situation as far as can be determined.

6. It was confirmed that there is a substantial listening audience in the village both at the health aide location and at the school that does not indicate presence by participation in the program.

7. It was confirmed that there is little cross cultural interest among Alaska at this time. This was just as strongly noticeable this year as last. Anaktuvuk is the only exception and the schoolteacher's interest is probably a major reason so much interest is shown there.

8. Full power is necessary for successful programming of all types on a continuing basis.

9. The continuance of satellite communications is desired in the Tanana Area.

10. Classroom units involving Alaska Native culture do interest students where there is some cultural relevancy.

11. There are strong indications that 30 minutes is the maximum amount of educational broadcasting that can be absorbed at one time in the rural schools except for strong interactive programs such as the classroom exchanges.

12. There are strong indications that four villages are a maximum number that can participate effectively in many types of programs. Others may participate passively but will not secure the same value from the program as the active participant.

2.5.7 Public Radio Experiment

The use of ATS-1 for public radio networking began in April of 1970 (Reference 61) with a broadcast originated at KUAC, College, Alaska, and received in the lower 48 states. Regular programming did not begin until the fall of 1971. The public radio experiment consisted of a public affairs program to KUAC on a five-day-per-week basis.

The principal purpose of the experiment was to demonstrate the use of communication satellites in the transmission of radio programs from the network to an NPR member station and to test the kinds of equipment required to provide viable transmission and reception of such a program service. Specific attention was planned in the minimizing of ground station costs.

An ancillary purpose of the experiment was to permit examination of the effect on satellite reception of certain interference factors peculiar to the Alaskan location over an extended period of time. Previous tests had been conducted on an occasional basis in an attempt to ascertain the impact of high latitude location and interference from the auroral phenomenon.

In addition to NPR which provided the experiment program vehicle, major involvement was performed by the University of Alaska through its Geophysical Institute and its noncommercial, NPR-member FM radio station, KUAC-FM. The University was instrumental in receiving a commitment of a portion of the ATS-1 use-time previously allocated to the state by NASA.

An early participant was the Stanford Electronics Laboratory at Stanford, California, which provided the ground transmission station used during the initial phases of the experiment. The location of the transmission was moved later in the experiment to the Lister Hill National Center for Biomedical Communication, part of the National Institutes of Health, Bethesda, Maryland.

The primary regularly scheduled current events program distributed by NPR to its member stations, "All Things Considered...", was used as the program vehicle for the experiment. This 90 minute magazine-type program provides in-depth information concerning the events and issues of each day. It is transmitted to NPR stations in the Eastern and Central Time Zones at 5:00 pm, Eastern Time, and to stations in the Mountain and Pacific Time Zones at 8:00 pm, Eastern Time.

The initial transmissions to Alaska from Stanford coincided with the western system feed of the program; i.e., 8:00 pm Eastern Time when transmissions were shifted to Bethesda coinciding with the end of Daylight Savings Time in 1971. The schedule moved back from 8:00 to 9:30 pm, Eastern Time, with the onset of Daylight Savings Time in April 1972. All of these changes were necessitated to conform to the satellite-use schedule which does not fluctuate with Daylight Savings Time.

The initial phase of the experiment sought to obtain data on reliability and quality of transmission employing existing ground-station facilities involved in other ATS-1 experiments. Stanford University's Electronics Laboratories installation provided a relatively uncomplicated means of attaining that end (Reference 49). Transmission began on July 14, 1971. The method used to feed the ground station with NPR program material is shown in Figure 2.8. The NPR western network feeds program material from NPR Washington via leased long-line facilities to member stations throughout the West. One NPR station, KQED-FM, San Francisco, provides primary coverage to the Palo Alto area. An FM receiver was employed to pick up the broadcast of NPR's "All Things Considered..." and feed the audio input of the ground station transmitter, a GE communications transceiver feeding a 12 db gain crossed dipole antenna.

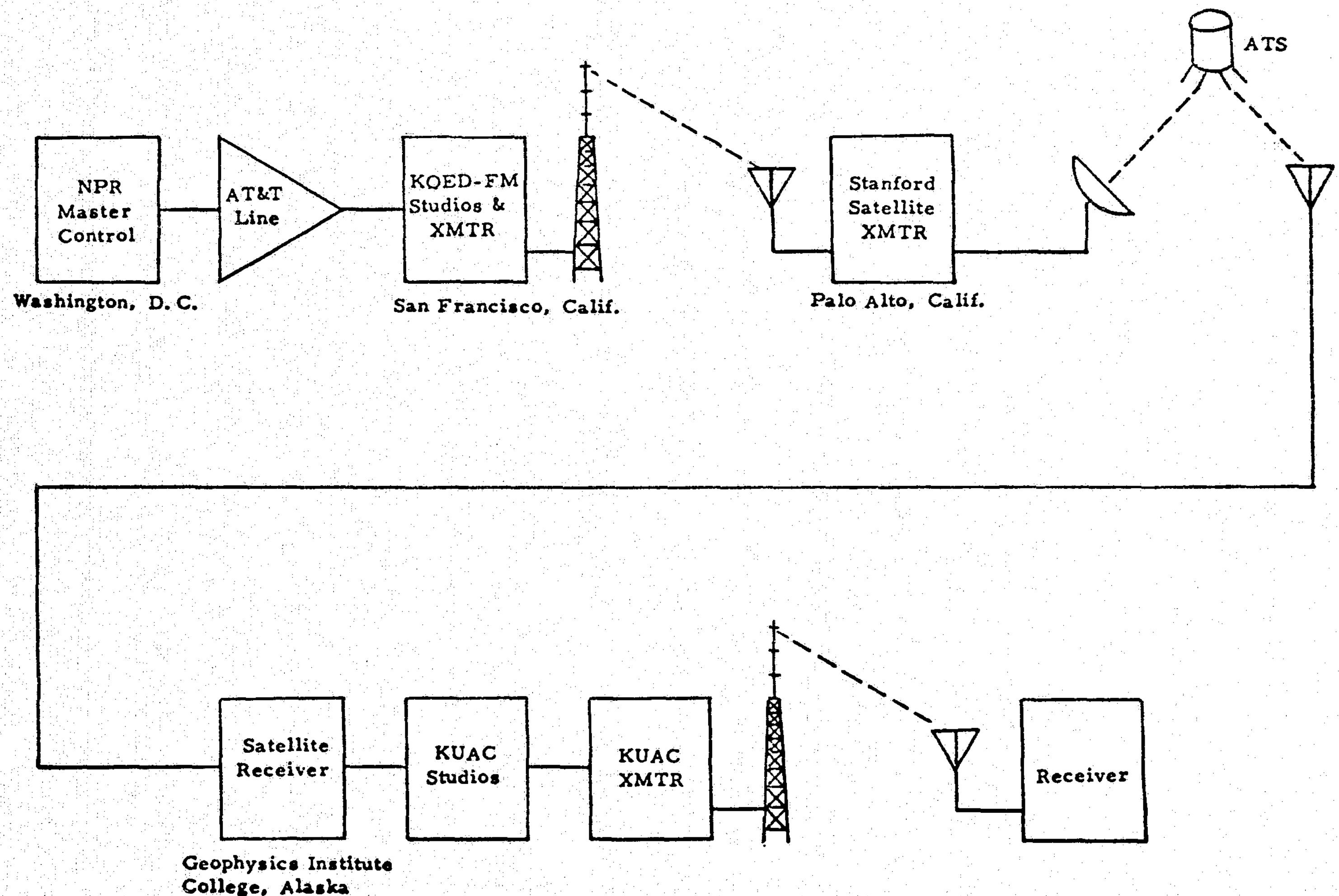

Figure 2. 8. Satellite Transmission of NPR Program, Stanford University to College, Alaska.

The program was received at the minitrack station at the Geophysical Institute in College, Alaska, on a crossed dipole antenna and Mod-1 receiver and fed via phone line to the studio facilities of NPR member station KUAC, from which the program was retransmitted as an on-the-air program through the station's regular FM transmission facilities.

Inasmuch as the transmission and reception facilities were intended for two-way communications experiments and not for sustained, high-quality audio transmissions, the quality of the transmission as compared to regular FM performance standards was rather poor. Signal-to-noise ratios, rather than being in the order of 60 db were, rather, about 26 db--more than adequate for two-way communications uses, but not optimal for high-quality audio transmission. The audio bandwidth of the transmitter was limited to 300-3000 Hz, and the modulation index was low. The Stanford transmitter saturated the spacecraft, but the full-power mode was required to obtain even the 26 db signal-to-noise ratio. In the half-power mode, only about 21.5 db signal-to-noise ratio was possible.

2.5.7.1 Bethesda - Phase I

It became evident that if NPR were to attempt experimentation with improvement of audio quality, the 5 kHz network lines would not serve the purposes of the experiment. Further, since NPR engineering personnel work from the home office in Washington, D. C., it would be feasible to conduct experiments from a more convenient location than Stanford University. The facility at Lister Hill Center in Bethesda, Maryland, offered a convenient means of continuing with the NPR experiment to Alaska. NIHLC offered use of their ground station facilities which, for all practical purposes, were identical to the Stanford University facility. So, although no improvement in transmission quality was realized initially when NPR began transmitting through the NIH ground station on November 1, 1971, NPR was in a position to make changes in equipment and transmission parameters and readily evaluate their results shown in Figure 2.9. In reality, equivalent signal strength was measured in College, Alaska, and equivalent narrow-band performance was realized (both ground stations saturated the spacecraft).

Inasmuch as the ATS-1 has a 100 kHz bandwidth capability, the next phase of the experiment was to consider increasing peak FM deviation from ±5 kHz to about ±40 kHz. With assistance from several NASA engineers, link calculations for several different transmission modes were carried out. Audio quality would be improved by increasing the base-band bandwidth from 300-3000 Hz to 50-8000 Hz. This would still give a modulation index of 5, much greater than the narrow band value of 1.5.

All conditions for reception remained the same, except that the 100 kHz wideband output from the Mod-1 receiver would be employed. On January 13, 1972, a test was transmitted from the NASA ground station facilities at the Goddard Space Flight Center. A GE 300-watt transmitter and a 12 db gain antenna, similar to that employed at Stanford and NIH were employed except that the narrow band exciter was bypassed and an FM signal generator, audio oscillator, and tape recorder to simulate program material were used.

The test was received in College, Alaska, and a significant improvement in overall performance was realized. Excellent flat audio response between 50 Hz and 8 kHz was realized and the signal-to-noise ratio was 32 db, fairly close to the calculated value of 35 db. Some overmodulation of the spacecraft was noted which indicated that a peak limiter would be required for subsequent tests to prevent overmodulation.

Based on the results of this test, it was felt equipment should be located at NIH which would permit regular wideband transmission at full power. Since funds for the project were pratically nonexistant, arrangements were made to borrow necessary gear. CCA Electronics Corporation offered to make available a standard FM broadcast exciter which could be modified for operation at 149.22 MHz. This exciter would meet or

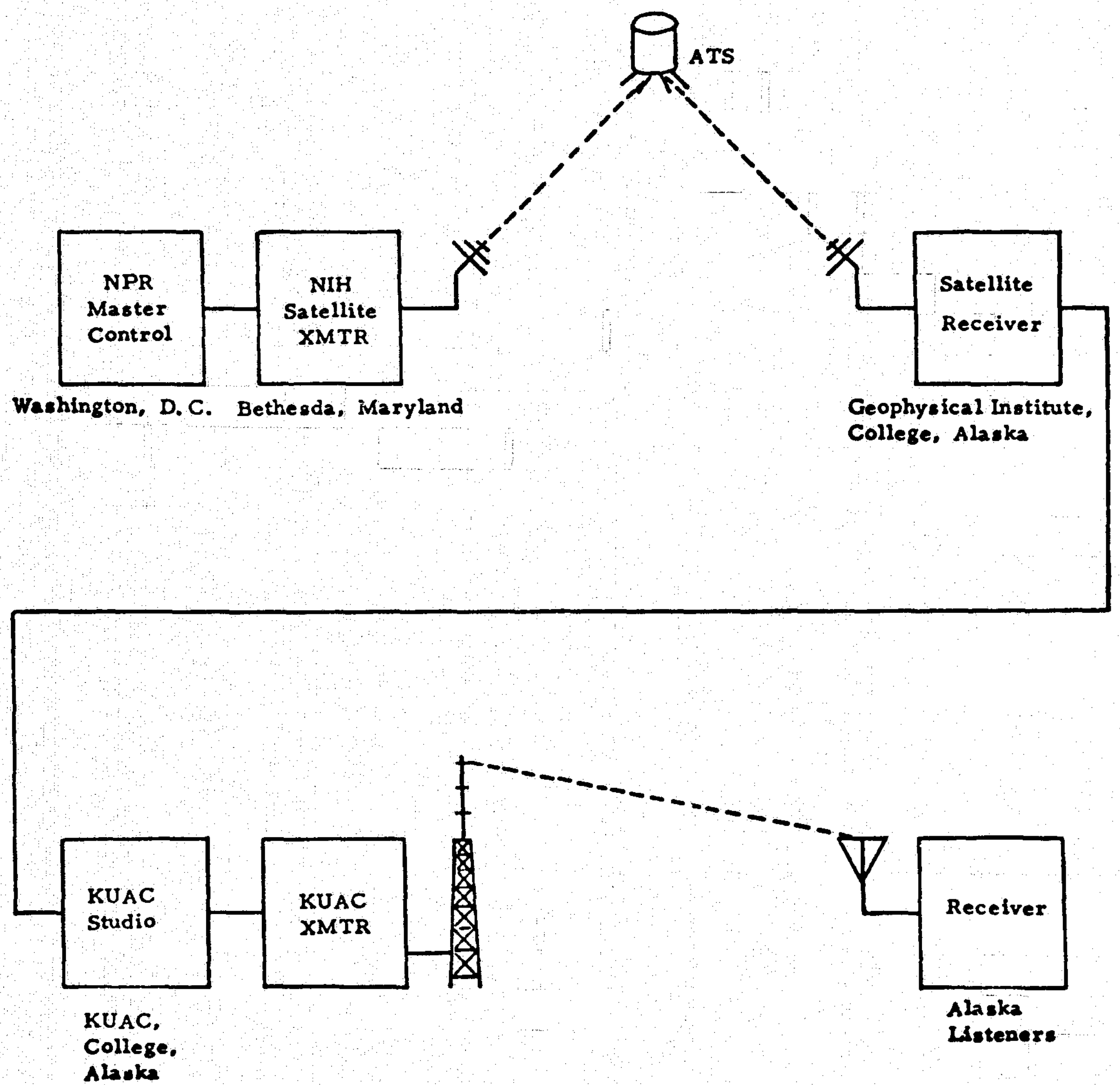

Figure 2.9. Narrowband Satellite Transmission of NPR Program from Bethesda, Maryland to College, Alaska.

exceed all specifications for the transmission setup that was planned; maximum FM deviation, signal-to-noise, distortion, and the like were excellent. A test of the wideband capabilities of the GE power amplifier was made; the amplifier operated linearly out to 250 kHz peak deviation. An FM limiter was borrowed from an NPR member station, WUOM, Ann Arbor, Michigan, and a test of the proposed system was again carried out at the Goddard Space Flight Center in mid-April. Unfortunately, atmospheric disturbance prevented measuring any meaningful results. However, a closed loop test from transmitter to monitor receiver was carried out in the lab, and results were in fair agreement with calculated values. It was decided at this point to install the wideband equipment at the NIH ground station site.

2.5.7.2 Bethesda - Phase II

The installation at NIH is shown in Figure 2.10. Initially, the Dolby noise reduction shown was not incorporated. Transmission in the wideband full-power mode began on May 23, 1972.

Atmospheric disturbances were severe during the initial wideband full-power transmissions. The percentage of time that the signal strength fell below FM threshold was greater than anticipated. In fact, it became apparent that, although the advantages of wideband transmission became quite obvious during periods when signal strength was above threshold with a 32 db average signal-to-noise ratio and improved (8 kHz) audio quality under wideband conditions, threshold level was not obtained often enough for reliable, consistent, high-quality transmission.

2.5.7.3 Bethesda - Phase III

Although acceptable performance up to this time was never obtainable with the satellite operating at half power, the power drain on the satellite for the daily 90-minute period was considerable, and other experimenters were desiring full-power time on ATS-1. So an experimental quad helix antenna was developed by the Geophysical Institute in College, Alaska that had approximately 5 db greater gain than the crossed dipole antennas that had been employed previously. It was hoped that the increased

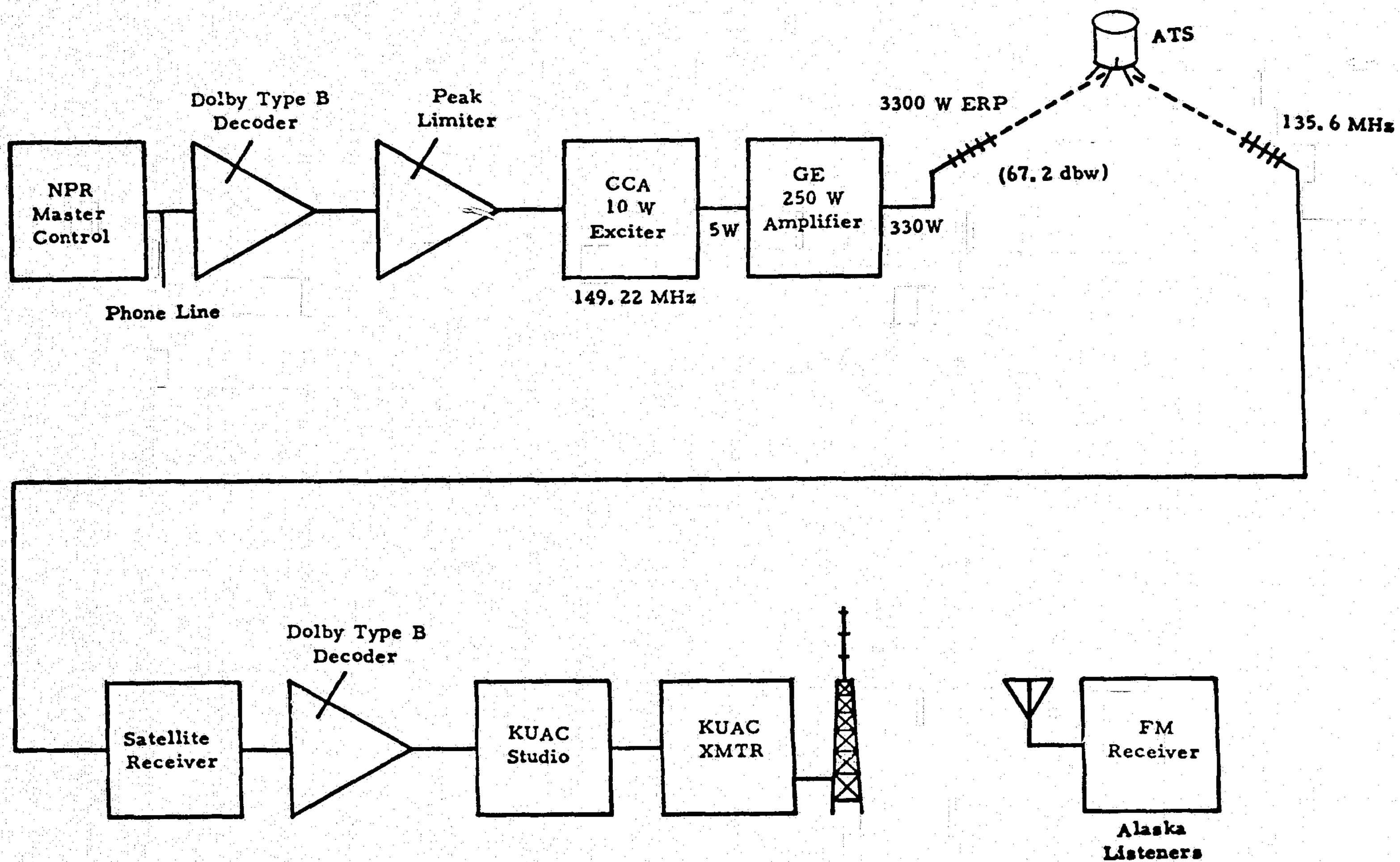

Figure 2.10. Wideband Transmission of NPR Program from Washington, D.C. to College, Alaska.

gain would overcome the 6 or 7 db degradation in signal strength when operating at half power. Initial tests at half power, which began shortly after the full-power wideband transmission in late May, proved the feasibility of operating at half power using the quad helix antenna.

In addition, it was determined that a compromise between the narrowband and wideband modes at half power might provide optimal performance. Transmission employing ±15 kHz peak deviation at half power began the first week of June.

Operating in the half-power mode and utilizing the quad helix array, the average signal level appearing at the Mod-1 receiver input measured about -110 dbm. This is quite close to the calculated value of -111.5 dbm. A nominal 12 db carrier-to-noise ratio is obtained which does give a signal-to-noise ratio of about 25 or 26 db average. Under the most favorable conditions, the signal-to-noise ratio measured 32 db. The results have proved fairly consistent on a daily basis, except during periods of extreme sunspot and aurora activity.

The actual setup in Alaska employs a 17 db preamp and power splitter being fed to the Mod-1 receiver. A chart showing relative carrier-to-noise with varying relative signal inputs and a -128 db reference noise level (30 kHz bandwidth) is shown in Figure 2.11. Note the knee at approximately -110 db input, the FM threshold point. Normally, the signal is about 5 db above this point, and acceptable performance occurs unless the signal falls below this level.

In an effort to explore other methods whereby the audio quality could be improved, NPR began using the type A Dolby noise reduction unit the latter part of July 1972. The unit is a compander which divides the audio frequency spectrum into four bands. Encoding the signal prior to transmission at NIH, and decoding at the output of the Mod-1 receiver, the signal-to-noise ratio was improved another 10 to 13 db giving a signal-to-noise ratio of about 33 to 43 db.

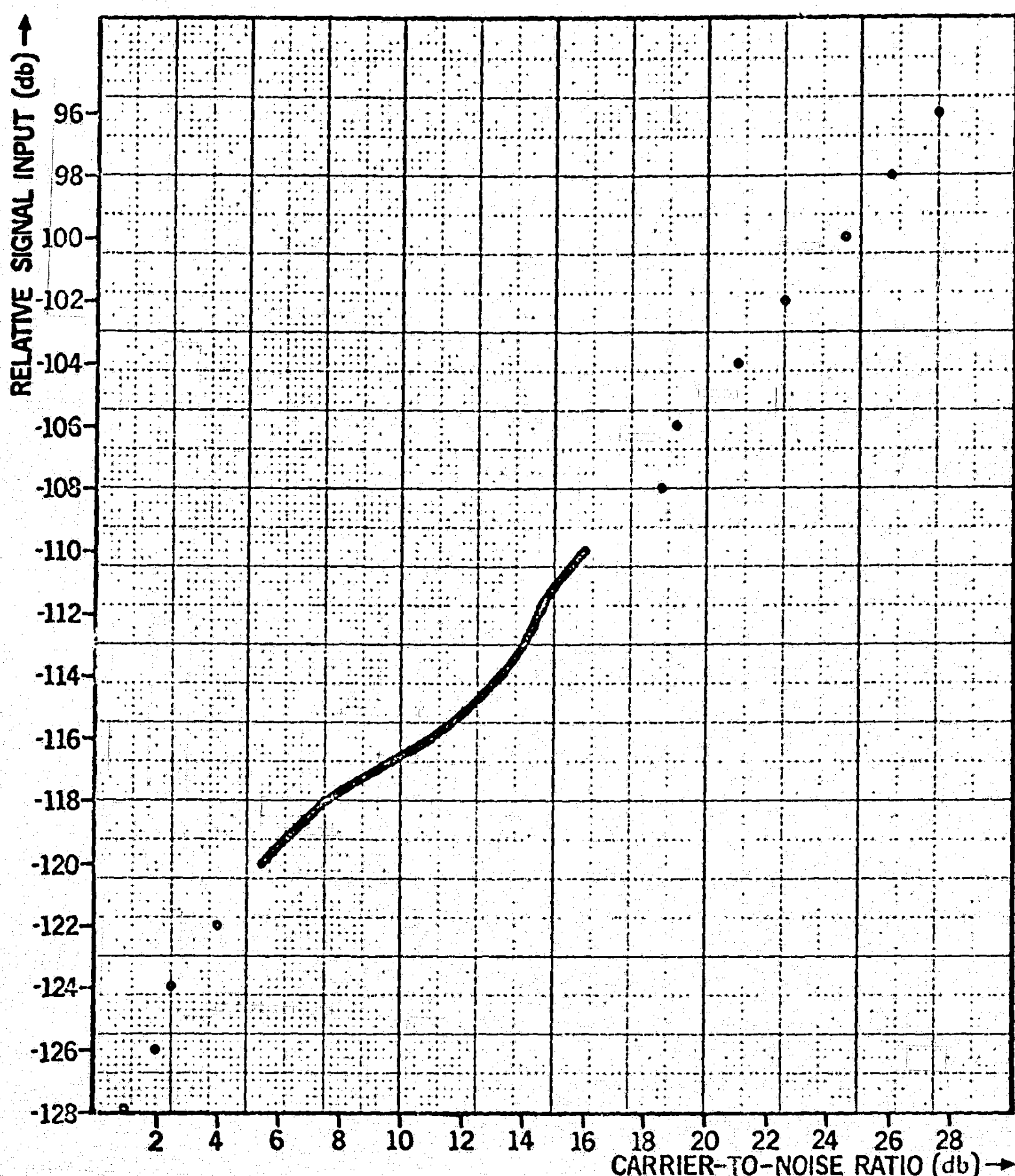

Figure 2.11. Relative Carrier to Noise (Noise Measured at -128 db).

2.5.7.4 Summary and Conclusions

In January of 1973, NASA appeared concerned about how the KUAC activity seemed more operational than experimental in nature. A request was made for further details for continuation of this experiment.

NPR was experiencing, during this time, a great number of technical problems in transmitting wideband via the NIH facilities. The technical quality received in Alaska was so marginal about 50% of the time that the NPR program could not be aired. Much of the problem was attributable to reception difficulties caused by the signal strength in Alaska falling below FM threshold. Severe transmitter reliability problems at NIH were also causing loss of service. It was at this phase of the experiment that the primary limitation of this project became evident--limited resources. Neither NPR or NIH had the necessary manpower to dedicate a man, on a daily basis, to be on hand during the broadcast to assure proper operation. NPR could control only the on/off function of the NIH transmitter from its master control in Washington, D.C. Tuning of the transmitter unit, it appeared, was required due to marginal operation of the P.A. amplifier which did not show up under either wideband or narrowband operation alone. The instability of this unit necessitated the frequent readjustment of tuning. Neither NPR or NIH could send a man to retune daily, nor did either participant have the funds to invest in the test equipment necessary to discover the instability problem or maintain the transmitter in perfect alignment.

The reliability problems did not seem readily solvable given the limitations noted above. Even if the transmitter problems were resolved, the problem of signal strength still remained as the signal often fell below the threshold in the wideband mode. It was felt that a return to narrowband transmission for purposes of increased "airability" of the problem by KUAC would not be justified under the basic authorization. The decision would be based only on operational consideration since narrowband transmission experiments had been carried out the year before.

For these reasons, it was jointly agreed by NPR and the Alaskan experimenter to terminate transmission of "All Things Considered..." on May 25, 1973.

2.6 PEACESAT

2.6.1 Background

The PEACESAT Project (Pan-Pacific Education and Communication Experiments by Satellite) at the University of Hawaii was initiated in 1969 to investigate the communications needs of the Pacific Basin. In October 1970, the University of Hawaii submitted a proposal to NASA to use ATS-1 to facilitate the sharing of scarce, costly resources and improve professional services in the Pacific Basin. The proposal was approved by NASA in February 1971.

To a large extent the first year of the project (Phase I) was spent developing low-cost, portable, two-way equipment that was easy to operate and maintain and arranging for funding for the support of the project. Even so, the system became operational in April 1971 when terminals were activated at the University of Hawaii campuses at Hilo and Manoa.

During 1972 (Phase II), equipment testing was completed and six more terminals were established to form the PEACESAT network. Table 2.13 indicates the participating stations and the date of entry into the PEACESAT network (Reference 134). Management and operation of terminals was development through cooperative involvement of the members. Once all of the indicated terminals were activated, the system was in use approximately 12.5 hours/week. Also during this period, local funding was sought and obtained.

In May 1972, PEACESAT was funded by the National Institute of Health to undertake pilot experiments of library exchange via satellite to assist in determining the most effective systems for a Pacific-wide library. Work on this contract was completed in August 1973.

TABLE 2.13

STATIONS PARTICIPATING IN PEACESAT EXPERIMENT

STATION	DATE OF ENTRY INTO SERVICE
Manoa (Honolulu) Campus, University of Hawaii	April 1971
Hilo Campus, University of Hawaii	April 1971
Maui Community College	July 1972
Wellington Polytechnic Institute Wellington, New Zealand	January 1972
University of the South Pacific Suva, Fiji	February 1972
University of the South Pacific Center Nuku 'Alofa, Kingdom of Tonga	April 1972
Department of Education ETV Center Pago Pago, American Samoa	March 1972
Papua and New Guinea Institute of Technology Lae, New Guinea (connected by land lines to the University of Papua and New Guinea, Port Moresby)	August 1972

In comparison to the first two years of operation, the third year of PEACESAT was somewhat chaotic. A proposal was submitted to NASA to continue experimentation by expanding both the number of terminals and the time available for exchanges. The argument was that these additions were needed to provide a larger data base for evaluation of the project. There was resistance by NASA to continue the PEACESAT experiment for another year without some evidence that it was an experiment and not an operational system. Through most of 1973, NASA extended time to PEACESAT on a month-to-month basis. Without a long-term commitment to use ATS-1, PEACESAT funding subsided and modifications had to be made in the program. To a large extent, personnel spent most of the third year attempting to evaluate the first two years' efforts. As a result of the uncertainty of the PEACESAT project, interest in starting new terminals also subsided.

In some respects, the PEACESAT project was very similar to the Alaska experiment; i.e., they were both concerned with communications for education and health services in isolated areas. There are three primary differences in the projects, namely size of area, funding, and management. As Figure 2.12 shows, the PEACESAT network covered a large portion of the Pacific Basin. The distances between participants were, therefore, vastly greater than in Alaska. This is significant in the health care function since it makes evacuation of a critically ill patient impractical. On the other hand, the available health facilties in the PEACESAT network seemed to be more complete than those encountered in the Alaskan villages. The second difference was in funding. While the Alaska project was largely funded by federal agencies, PEACESAT relied almost totallv upon local funds. For example, in 1971-72, $220,000 of the PEACESAT budget of $270,000 came from local and private sources. The remainder was from the National Library of Medicine. Thirdly, PEACESAT was organized so that participants could have as much local control as possible. This was, to a large extent, due to the fact that the network had an international membership and the various governments resisted the possibility of domination by other cultures.

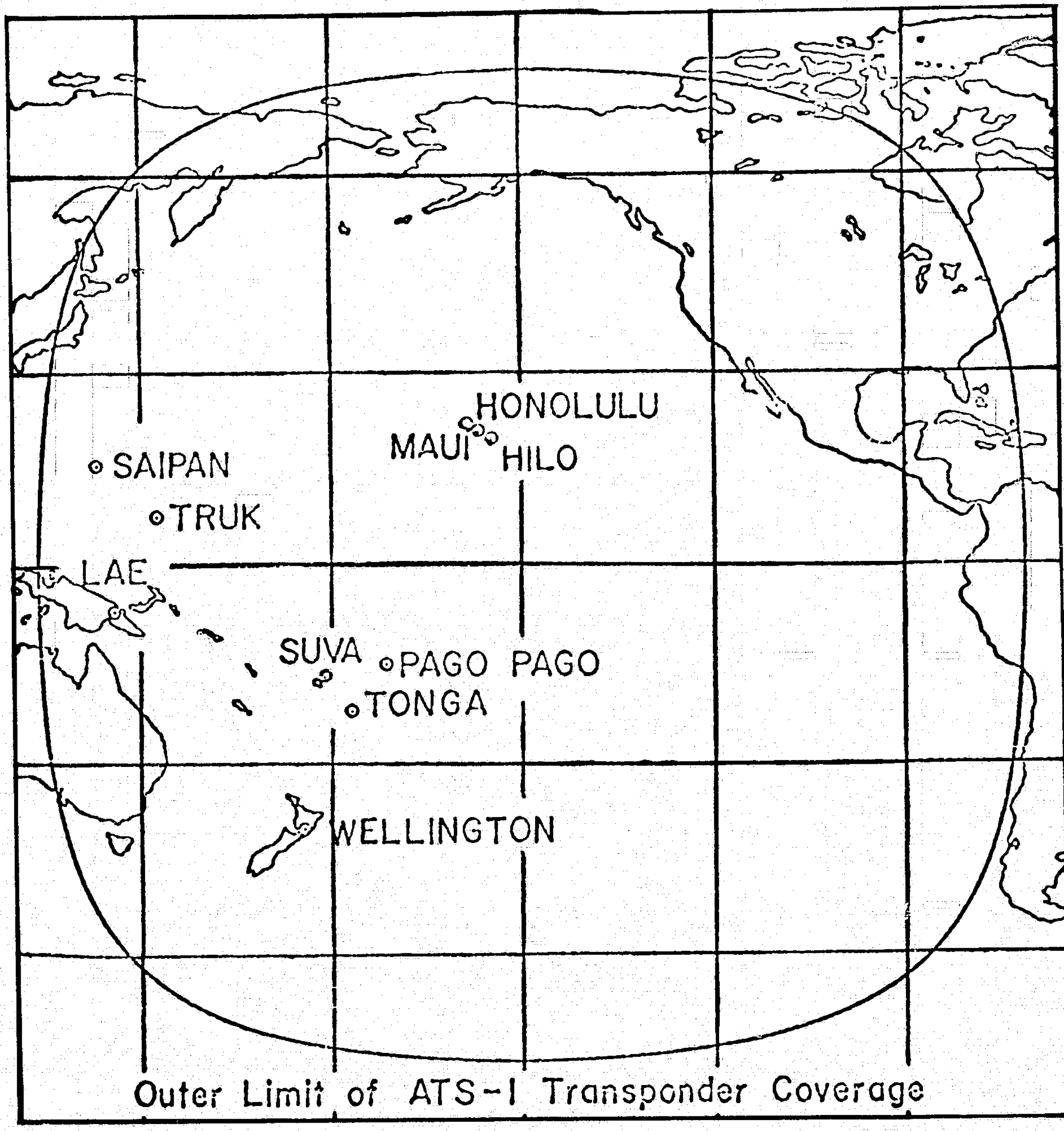

Figure 2.12. Map Showing ATS-1 Transponder Coverage and Stations in PEACESAT Network.

2.6.2 Rationale

It is impossible for many of the peoples of the Pacific Basin to sustain adequate levels of education, health care, and technically based services. Often populations are small in size and divided by great distances. Inadequate communications constitute a principal barrier to community development. This is a condition that prevails over much of the Pacific Basin and is a serious deterrent to social development. The PEACESAT project seeks to serve as an intercontinental laboratory for planning and improving communications for education, health, and community services in the Pacific Basin area. The knowledge gained should have application to the sparsely populated areas of the United States and throughout the less developed areas of the world.

Nations in the South Pacific, many of which are newly independent, are sensitive to the advances of cultural imperialism. They want to exercise control over their own development, especially when it involves industrialization and the inculcation of the ideas of western urban society. Therefore, the PEACESAT project stresses a two-way exchange capacity; station terminals transmit as well as receive. They are locally controlled and operated so there is no central production center from which programs are delivered to passive receivers. To reinforce the idea of interaction, the word "program" is not used; transmissions are referred to as "exchanges".

Medical and educational processes especially require two-way communications and to be effective, services provided in remote areas must be linked to highly developed centers. The PEACESAT network provides the capacity to call up information when required by events such as medical emergencies.

2.6.3 Objectives

The objectives of the PEACESAT project as stated in the original proposal (Reference 216) are given below.

1. To demonstrate a satellite communication system to have scale application for sparsely populated areas and areas of low industrial development.

2. To demonstrate utilization of the system to potential participants in the Pacific by undertaking curriculum experimentation and increased exchange of educational communications between the University of Hawaii campuses.

3. To assist in adapting the potential of satellite technology to peaceful public services.

4. To increase the quality and capacity of educational institutions in the Pacific by sharing scarce, costly resources, material and intellectual, and extending the availability of education to remote areas.

5. To provide a telecommunication support system for professional and technical operating services in the Pacific.

6. To show that international exchange of higher education resources is feasible and desirable.

7. To lay the basis for an intercontinental laboratory which undertakes experimental and developmental activities in the use of telecommunication interconnections.

2.6.4 Management and Operation

General management of the project was under a Director, assisted by a Technical Director. Terminal development and construction was under a Manager for Ground Terminal Development. Initially the project was implemented by a team of University of Hawaii faculty on a volunteer basis. A full-time System Coordinator and a Manoa Terminal Manager were hired in September 1971. A roster of key personnel is given in Table 2.14.

The concept of the PEACESAT system is one based on cooperation among equals in areas which are politically and culturally diverse. Since the terminals are owned and operated by the local institution, they make decisions with regard to their participation in exchanges. Coordination

TABLE 2.14

PEACESAT PROJECT MANAGEMENT

John Bystrom	Director
Paul Yuen	Technical Director
Katashi Nose	Manager for Terminal Development
James McMahon	System Coordinator
Manoa Terminal	
Carol Misko	Terminal Manager
Maui Terminal	
Walter Ouye	Project Manager
Sadami Katahara	Terminal Technician
Lafayette Young	Terminal Manager
Jean Wright	Exchange Coordinator
Hilo Terminal	
Roger Baldwin	Terminal Manager
New Zealand Terminal (Wellington Polytechnic Institute)	
Anthony Hanley	Terminal Manager
Fiji Terminal (University of the South Pacific, Suva)	
Alan Cutting	Terminal Manager
Kingdom of Tonga Terminal (University of South Pacific Centre)	
Margaret Blundell	Terminal Manager
New Guinea Terminal (Papua New Guinea University of Technology, Lae)	
Steven Seumahu	Terminal Manager
(University of Papua New Guinea, Port Moresby)	
Francis Johnson	Terminal Manager
American Samoa Terminal (Department of Education)	
Stewart Cheifet	Terminal Manager

of schedule is handled at the Manoa terminal. The Manoa Terminal Manager chairs all discussions on scheduling. General policy is guided by an operating committee made up of three terminal managers.

PEACESAT experiments originate in two ways. Uses of the system which appear likely to be of value are encouraged by approaching suitable organizations and soliciting their cooperation for project studies. The other important class of system users are those who on learning of the project come forward with proposals for trial uses of potential value to them. Information on the proposals for trials or studies is advised to the network by the initiating terminal at 'Proposal Enquiry' periods held twice weekly, and the terminal managers then approach local groups in their communities and invite them to attend a network Preplanning Meeting' to discuss the proposed trial, decide on the problem topics of common interest, decide on an agenda, agree on a session chairman, and decide on a date for the working meeting.

2.6.5 PEACESAT Terminals

A typical PEACESAT station consisted of a solid-state, two-meter amateur transmitter-receiver modified to respond to satellite frequencies; a one-kilowatt linear amplifier designed by Professor K. Nose of the University of Hawaii; and separate circularly polarized, multiple-element, crossed-dipole yagi antennas for receiving and transmitting. Each site had two transceivers since repair had to be done in most cases by sending the unit back to Hawaii. The equipment cost for each station was approximately $5000. Figures 2.13 and 2.14 show the equipment in use.

Signal quality appears to have been better than in the Alaska experiment. This was probably due to the fact that higher elevation angles tend to decrease signal degradation due to atmospheric noise and ground reflection. However, there were times when the signal quality made communications difficult. Table 2.15 shows the fraction of exchange time at Wellington (Reference 206) for which the reception was judged poor. The

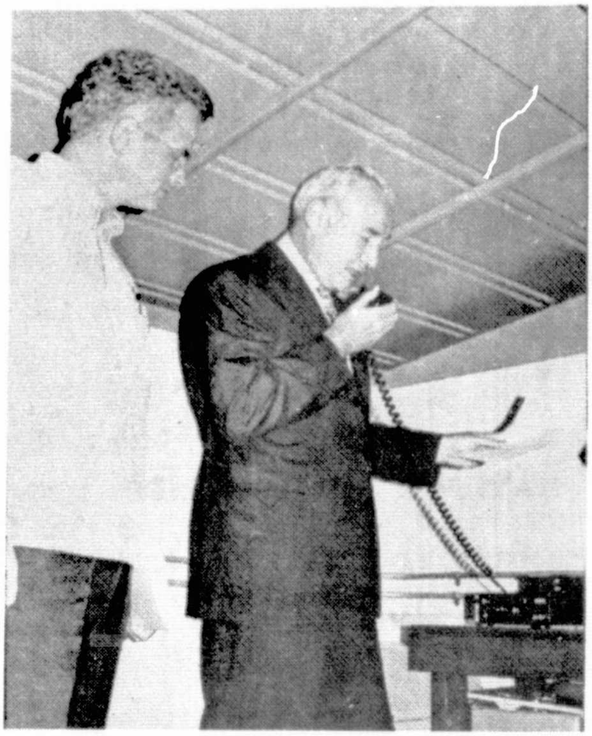

Figure 2.13. Network Operation began April 1971. HU President Harlan Cleveland (Right), and Dr. John Bystrom, PEACESAT Director, inaugurate system.

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OF POOR QUALITY

Figure 2.14. One variation of ground terminal operates from a car battery. Katashi Nose, Manager for Ground Terminal Development, with project participants from the Kingdom of Tonga.

TABLE 2.15

PEACESAT SYSTEM: QUALITY OF RECEPTION*

	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
Fraction of total broadcast time of poor quality	0.13	0.15	0.16	0.08	0.11	0.11	0.05	0.16

*Reference 206

large part of the degradation was attributed to local storm conditions and ignition noise from unshielded internal combustion engines. However, there were times when the degradation could not be explained.

Another measure of the quality of reception is contained in Figures 2.15 and 2.16. In 1972, participants in PEACESAT exchanges at Wellington were asked to respond to the questions, "the voices were clear enough", and, "the voices were loud enough". A positive answer to the first question was given by 95% of the participants and 89% answered positively to the second. These same two questions were asked to a group of 47 users in 1973. In this case, 83% responded positively to the first and 94% to the second.

Another study of equipment performance was made at the end of Phase II by Anthony Hanley at Wellington Polytechnic Institute, New Zealand. This study was made to determine, if possible, the performance of both the high-power (300 watt) and low-power (100 watt) receiver terminals. Terminal managers at Manoa, Saipan, Suva, and Lae were requested to estimate the percentage of received signals at three levels of effectiveness: excellent (E), satisfactory (S), and unsatisfactory (U). Reference was made to terminal logs, but the judgment is essentially the subjective opinion of an experienced listener. The results of this survey are shown in Table 2.16.

Manoa, Saipan, and Suva are high-power terminals. The low-power terminal is at Lae. The percentage of received signals classified excellent at Lae is always less than the other stations and the percentage classified unsatisfactory is always greater. Since only one lower power station is involved, it is difficult to draw any valid conclusions as to the effect of low power on receiving signals. The degraded performance at Lae could be caused by low power, but it could also be caused by other characteristics present at Lae.

A review of time use during the period of February 1972 to July 1973 indicates that 730 (85%) of a total 857 available hours were utilized

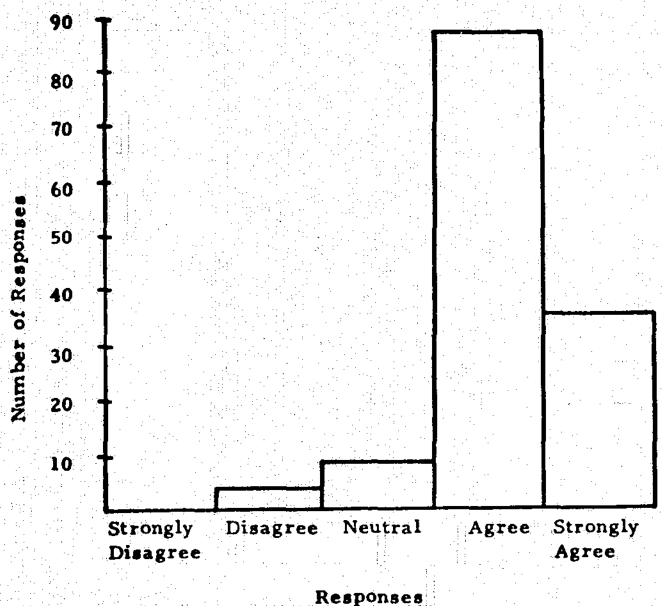

Figure 2.15. Subjective User Response to the Statement, 'the voices were clear enough'.

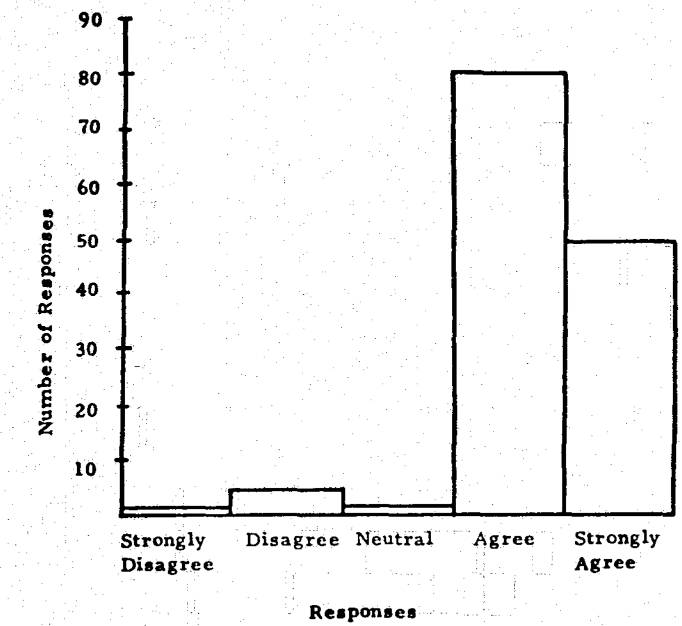

Figure 2.16. Subjective User Response to the Statement, 'the voices were loud enough'.

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TABLE 2.16

RECEIVE TERMINALS

Stations Transmitting	Lae	Manoa	Saipan	Suva
American Samoa	5% - E 75% - S 20% - U	15% - E 75% - S 10% - U	10% - E 80% - S 10% - U	32% - E 58% - S 10% - U
Hilo	-----	85% - E 15% - S 0% - U	------	85% - E 15% - S 0% - U
Lae	-----	45% - E 45% - S 10% - U	90% - E 10% - S 0% - U	42% - E 57% - S 3% - U
Manoa	60% - E 35% - S 5% - U	-------	95% - E 5% - S 0% - U	92% - E 8% - S 0% - U
Maui	10% - E 70% - S 20% - U	95% - E 5% - S 0% - U	100% - E 0% - S 0% - U	91% - E 9% - S 0% - U
Saipan	50% - E 45% - S 5% - U	98% - E 2% - S 0% - U	--------	96% - E 4% - S 0% - U
Suva	65% - E 30% - S 5% - U	95% - E 5% - S 0% - U	100% - E 0% - S 0% - U	------
Tonga	10% - E 75% - S 15% - U	70% - E 25% - S 5% - U	95% - E 5% - S 0% - U	75% - E 22% - S 3% - U
Wellington	50% - E 40% - S 10% - U	85% - E 15% - S 0% - U	95% - E 5% - S 0% - U	83% - E 17% - S 0% - U

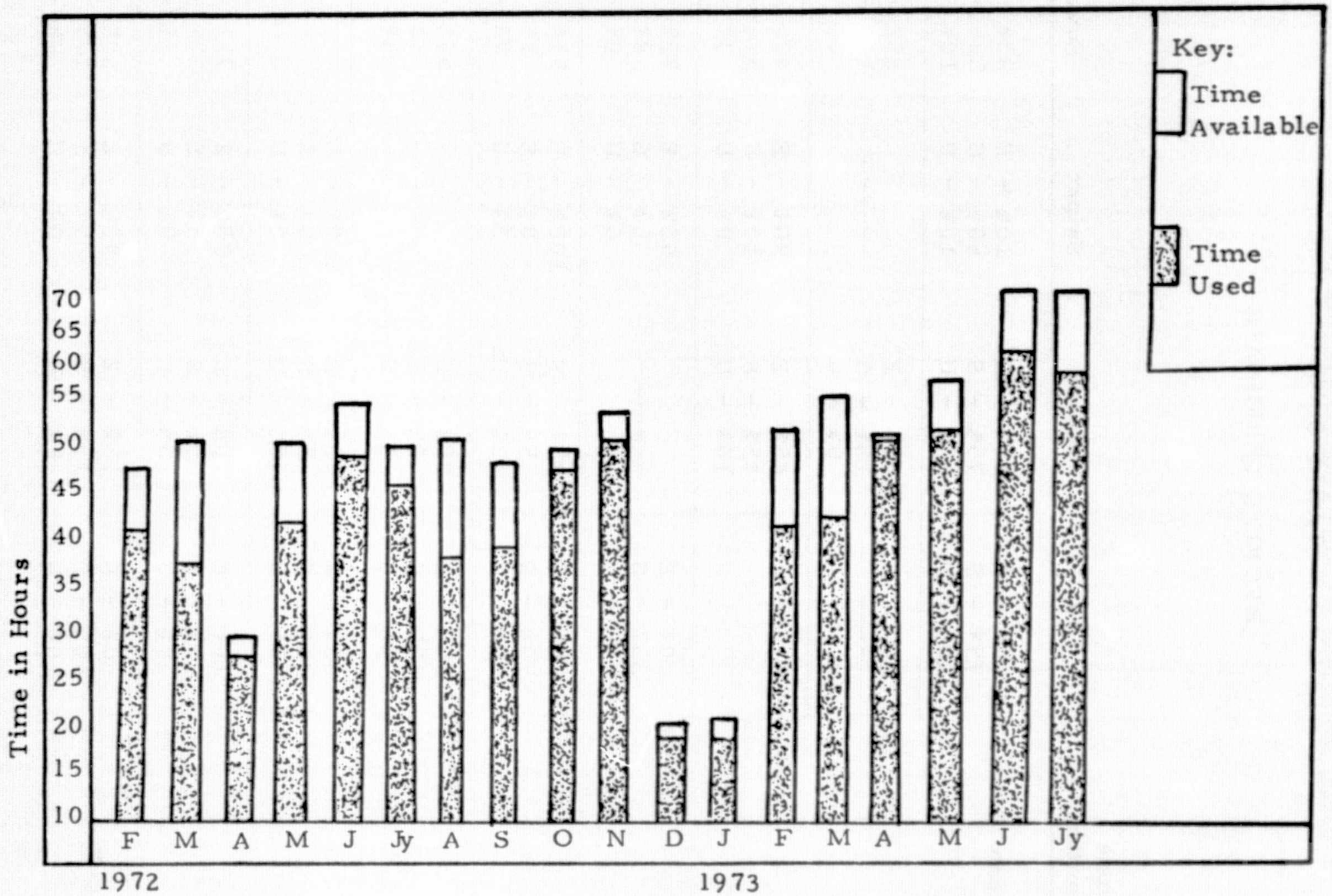

Figure 2.17. Time Use Study.

by the PEACESAT system for educational, health, and community development applications. Monthly usage is shown in Figure 2.17. In no month was all time assigned used. Some of the reasons for this are user "no show", equipment malfunction, atmospheric interference, and scheduling difficulties. Scheduling international exchanges for the morning time period was a persistent problem due to the time zone differences (9:00 am in Hawaii is 7:00 am in New Zealand and Figi, and 5:00 am in New Guinea). Also, a lack of uniform vacation schedule and a variety of local holidays made scheduling difficult.

2.6.6 Experimentation

During the Phase I and II test periods, 124 topics of mutual Pacific concern were shared by approximately 1100 participants from various terminals in the network. Of the 124 topics, 62 involved repeated use and 21 topics were developed into series of three or more exchanges. A complete list of exchange topics is given in Reference 66.

Although the PEACESAT network was classified as experimental in the original proposal to NASA, it appears that little was done in the way of controlled experimentation. In 1973, NASA officials reacted to the PEACESAT report for 1972 by saying that, "The report contains numerous instances of the performance of isolated experiments, without evidence of either associated follow-through experiments or analysis based on experimental data" (Reference 221). In response, John Bystrom, PEACESAT Director, wrote, "The experimental environment makes it difficult to secure reliable data in the form of statistical trends. There are too few terminals and authorized satellite time periods are too short." (Reference 215)

The implication of Dr. Bystrom's remark is that there was very little quantitative data available for analysis prior to 1974, the period covered in this compendium. While there were a large number of exchanges during the experimental period, most of them were simply people discussing a topic of common interest using the satellite as an instrument. It is impossible to present summaries of all the exchanges; therefore, several typical ones with the conclusions of the participants are presented.

2.6.6.1 Classroom Interaction by Satellite

Arrangements were made in early spring of 1971 to interconnect two sections of the basic course in interpersonal communication at the University of Hawaii, one section at the Manoa Campus in Honolulu, the other section at Hilo College in Hilo, on another island, about 200 miles distant. Mr. Thomas Kugler and Mr. Burton Byers of Hilo College and Dr. Elizabeth Kunimoto of the Honolulu-based section were the instructors.

With the two sections of the basic course, Honolulu-Hilo, the central purpose was to discover whether students, widely separated by distance but joined by PEACESAT, could learn to work together in problem solving and the exchange of information. Seven experiments were scheduled: (1) Getting Acquainted; (2) Basic Intelligibility; (3) Giving Directions, or the Communication of Instrumental Information; (4) Affects; (5) Problem Solving; (6) Information Gain; and (7) Attitude Prediction. These experiments were scheduled in twelve hour-long sessions during the six-week summer term.

The "Getting Acquainted" experiment consisted of each of 24 students, 12 at each ground station, giving his name and spelling it, and giving one fact about himself. Students alternated, first a Hilo student, then a Manoa student, etc. Students at both stations kept written notes. Criterion was reached when each student could spell the name and give one fact about every other student in the project.

"Basic Intelligibility" was defined operationally in two ways: the ability to read short lists of phonetically balanced words, and to write down the words spoken; and the ability to select the words spoken from lists of five similar sounding words (multiple choice). This and similar experiments to follow yielded four scores for each participant: a score as source, face-to-face, and satellite-interposed, and a score as respondent, face-to-face, and satellite-interposed.

"Giving Directions" or the "Communication of Instrumental Information", was defined operationally as the ability to describe an abstract figure so that the persons listening, in the classroom or at the other site, could respond that the figure described was the same as, or different from, the figure on their response sheets.

The "Affects" experiments were of several sorts. In the first experiment, students alternated, Hilo-Honolulu, speaking the single word, "Hello", so as to cause other students to mark their response sheets as to their feelings about the person speaking the word.

Another "Affects" experiment required students to give a short explanation of how to get to the nearest airport, restaurant, or library so as to help the respondents check one of five emotions: sad, happy, enthusiastic, indifferent, sincere. Still another asked respondents to mark a scale from "Up" at one end, defined as happy, enthusiastic, or confident, to "Down" at the other end, defined as sad, indifferent, or discouraged. The source spoke in a language not known to the respondents. In this case, one source spoke in Japanese, one in German, and one in Italian.

In the problem-solving experiment, the students worked in groups of four, two from Hilo and two from Honolulu in each group. The students from Hilo were given one part and the students from Honolulu were given another part of the information necessary to discover new information and solve the problem.

The information-gain experiment was the most elaborate of the term. A team of students at both sites chose a topic, analyzed it, and constructed a 15-item, multiple-choice type test measuring the principal cognitions which the team hoped to communicate. This test was given as a pretest to students not involved in the satellite experiment. Then each team had a one-hour period to present its information via satellite, after which the students at the other site took the test. Measures of central tendency were computed for the pre/post tests, giving an indication of the amount of gain achieved by the students using the satellite interconnection. However, these data were not available in the Final Report.

The final experiment in predicting the attitudes of other students was never completed because of the preemption of our satellite time for Apollo Moon Shot tests.

After each satellite interchange between the students, the instructors at each site compiled the scores on a single data sheet, giving a source score, face-to-face, and a respondent score, face-to-face, and satellite-interposed, for each student at his site for that day's experiment.

A student's face-to-face source score was the percentage of correct responses elicited from the other students in the classroom from which he was transmitting. (His source score, satellite-interposed, was the percentage of correct responses elicited from students at the other site. This score became available with the report from the other site.) A student's respondent score face-to-face was the percentage of correct responses given to students transmitting from his own classroom; satellite-interposed, his response score was the percentage of correct responses given to messages from the other site. Both classes surpassed the 80% accuracy criterion level.

Each afternoon these outcomes were exchanged <u>via</u> facsimile, so that on the morning following each transmission the students had a record of how they had done in the experiment of the previous day. Like some other aspects of this project, the data gathering and reporting methodologies were ad-libbed. There is no way to estimate, on the basis of hard data, how powerful a force this quick knowledge of success or failure was in motivating and guiding the learning that took place.

As a result of this experiment, the authors concluded that:

> The project was successful in demonstrating that students, widely separated in distance but connected by voice and facsimile transmission, can get acquainted and can learn to communicate cognitive, instrumental, and affective information at a satisfactory level of accuracy. They can work together to solve problems and they can produce statistically significant information gain in their friends at the other site. The nature and scope of the learning activities can be greatly improved. The participants found that considerable preplanning was necessary in order to make a satellite interchange worthwhile. Participants needed to know in advance what the transmission was expected to accomplish, and what would be expected of them. Frequently, printed materials needed to be prepared and distributed in advance. They also found that sources must elicit constant feedback from the respondents. Questions could be as simple as 'Do you hear me? or as complex as 'Can you summarize the last statement I made on estate planning? One-way transmission or uninterrupted lectures did not seem to be as effective as two-way transmission.

2.6.6.2 Agriculture Seminars

During 1972, six of the stations participated in five satellite seminars (Reference 66) on the future development of agricultural educational communication. The first seminar (July 25) was a general introduction by five stations each reviewing the type of agricultural advisory service they offer. The second (August 23) compared mass communication techniques in agriculture and the third (September 19) discussed, in some detail, the methods and problems involved in the preparation and production of newsletters to farmers and to staff. The fourth (October 18) and fifth (November 1) reviewed small discussion groups and large meetings with agricultural producers. A link (November 29) will deal with specific aspects of beef production.

In reporting the results of this series of exchanges, W. R. Dale of the Ministry of Agriculture and Fisheries, Wellington, New

Zealand, made the following observations regarding the use of the PEACESAT network.

- There is no doubt that the opportunity to discuss matters of common interest is most stimulating. Already beneficial exchange of ideas and literature has encouraged new developments in several fields. This appears to be a satisfying self-help association, effectively motivating respondents to action. Each new contact makes added impact to the group and if this concept is promoted, it could act as a mutual aid exercise in agricultural education in many fields.

- This medium requires rather different skills from those frequently used in extension. All members of the network may listen but only one station may broadcast at any one time. This means a delayed opportunity to respond to queries or to ask questions. It is not possible for other ground stations to 'butt-in' as we do in telephone conversations.

- This puts pressure on participants to state their ideas clearly and briefly and then request comment from other likely respondents. This means improving our listening behavior and could mean clearer communication. There could be value in a local training session for those of us in Wellington using this station to improve our techniques.

- It seems necessary for one person to accept the role of session organizer and circulate a facsimile of the proposed discussion material in advance of the proposed seminar. This gives interested respondents time to review, discuss, collate information and reply and, if necessary, amend the proposals.

- To be useful, discussion must deal in relevant detail. Superficial discussion is of little value. Similarly, any follow-up such as exchange of literature must be relevant and completed as soon as possible after the link or interest is largely lost.

SECTION 3

DATA TRANSMISSION

A number of user experiments were concerned with using the Applications Technology Satellites for communications other than voice. For instance, communications using facsimile and teletype transmissions were investigated extensively. Another important nonvoice use of the ATS was for ranging and position fixing experiments. This section concentrates on the user experiments that are primarily nonvoice data transmissions.

3.1 NAVIGATION AND RANGING EXPERIMENTS

Navigation and ranging experiments have been an integral part of the ATS program since its inception. Table 3.1 chronologically summarizes these experiments, their salient features and identifies the experimenters.

The first successful position location experiment involving the interrogation of a platform electronics package (PEP) through an ATS satellite was conducted on February 19, 1968, employing the Omega Position Location Experiment (OPLE) system (Reference 326). Since that time, numerous experiments and tests involving demonstrations and evaluation of various types of ranging techniques and system configurations have been conducted. Many of the experiments were concerned directly with the precision and accuracy of the measurements of range, line-of-position, and actual position; however, some experiments included measurement of interrogation reliability, data error rate, and carrier amplitude statistics resulting from sea-reflected multipath and atmsopheric fading.

There were two ranging techniques tested during the ATS program. One was a hybrid technique called OPLE in which signals from the OMEGA terrestrial hyperbolic navigation system are relayed through a satellite to a fixed ground station for processing and position calculation, and the other was the ranging-altitude technique sometimes called the two satellite ranging technique.

TABLE 3.1

SUMMARY OF ATS NAVIGATION AND RANGING EXPERIMENTS

Date	Agency Contractor	Type Experiment	Frequency Band(s)	Type Ranging	Type Target Station	Remarks
Feb. 1968 thru Sept. 1969	GSFC Texas Instruments	Position Location	VLF VHF		Various Fixed and Mobile	Employed Omega Hyperbolic Navigation Technique with Satellite as Data Relay (OPLE).
July 1968 thru Dec. 1968	Federal Republic of Germany	Ranging Line of Position	VHF	FM Sidetone	Ship, Fixed	Ship in North Sea, Fixed Station in Germany.
Apr. 1969 thru May 1969	USN Gen. Electric	Ranging, Line of Position	VHF	FM Tone-Code	Moored Buoy	Buoy moored off Bermuda. Short test with van in New York.
Jun. 1969 thru Jan. 1971	GSFC Gen. Electric	Position Location	VHF	FM Tone-Code	Ships Aircraft	Ships: Gulf of Mexico, Pacific Ocean A/C: New Jersey, New York, Thule, Iceland.
March - April 1970	NASA/ERC All	Ranging Line of Position	L	PSK Sidetone	Ship, Fixed	Ship: Norfold, Va. to Baffin Bay, (Manhattan) Fixed: New Jersey
November - December 1970	GSFC Texas Instruments	Ranging Position Location	VHF	Sidetone	Aircraft, Fixed	Aircraft in vicinity of Dallas, Texas. Reference Station in Dallas, Texas.
November-December 1970	USAF/ SAMSO All	Ranging	L C	CPSK PN Code	Fixed (Mojave)	Compared C-band and L-band precision and accuracy.
March-April 1971	GSFC Westinghouse	Ranging	C L	PM Sidetone	Fixed (Mojave)	Compared C-band and L-band Ranging Precision and Accuracy.
March-June 1971	GSFC Westinghouse	Position Location	C L VHF	PM Sidetone	Fixed (Mojave)	Measured position precision and accuracy.
April 1971 to Present	FAA Boeing	Ranging	L	PM Sidetone	Aircraft	Measured effects of sea-reflected multipath on ranging accuracy.
June 1971	GSFC Westinghouse	Ranging	C VHF	PM Sidetone	Fixed (Mojave)	Compared C-band and VHF Ranging Precision and Accuracy.
July 1971	NASA-Wallops Sta. All	Line of Position (LOP)	L	CPSK PN Code	Fixed (Approx. 5 mi. apart)	Measured differential LOP precision and accuracy.
March 1971 thru December 1972	GSFC Gen. Electric/ EXXON	Position Location	L	FM Tone-Code	Ships	Use of ATS-5 Transponder network throughout Atlantic.

In the OPLE technique, very low frequency (VLF) Omega Navigation signals were received by a platform electronics package on a remotely located user or target vehicle, Figure 3.1 diagrams the OPLE technique. After receiving an interrogation signal transmitted from an OPLE Control Center (OCC) through a satellite repeater, the PEP replied by transmitting an acquisition and reference tone and the Omega VLF signals which had been up-converted to the very high frequency (VHF) band. The PEP transmissions were relayed back to the OCC by the same satellite repeater. The relayed OMEGA signals received at the OCC were processed to determine the PEP's location. In addition to transmitting the received Omega tones, the PEP had the capability of converting local sensor information to a digital form and relaying it to the OCC.

One of the more attractive and practical navigation techniques for a commercial satellite navigation and traffic control system is the ranging-altitude technique employing two satellites. Since, in a commercial system, it is practical for the user vehicle to be cooperative, there is no need for a passive (receive only) technique which would require either three satellites, the use of highly stable and accurate clock or a highly accurate angle measuring system aboard the user vehicle.

In the ranging-altitude technique, a position fix is obtained by measuring the range between the user vehicle and each of two satellites of known position. If the vehicle is airborne, the altitude is also measured (see Figure 3.2). Each satellite range defines a sphere with its center at the satellite and its surface containing the user vehicle. The altitude plus the radius of the earth defines another sphere containing the user vehicle. Each range sphere intersects the earth's sphere in a circle which is called a line-of-position (LOP) containing the vehicle. When equatorial synchronous satellites are employed, the ambiguous position is on the opposite side of the equator from the vehicle. This ambiguity is therefore easily resolved except for a small band in the vicinity of the equator.

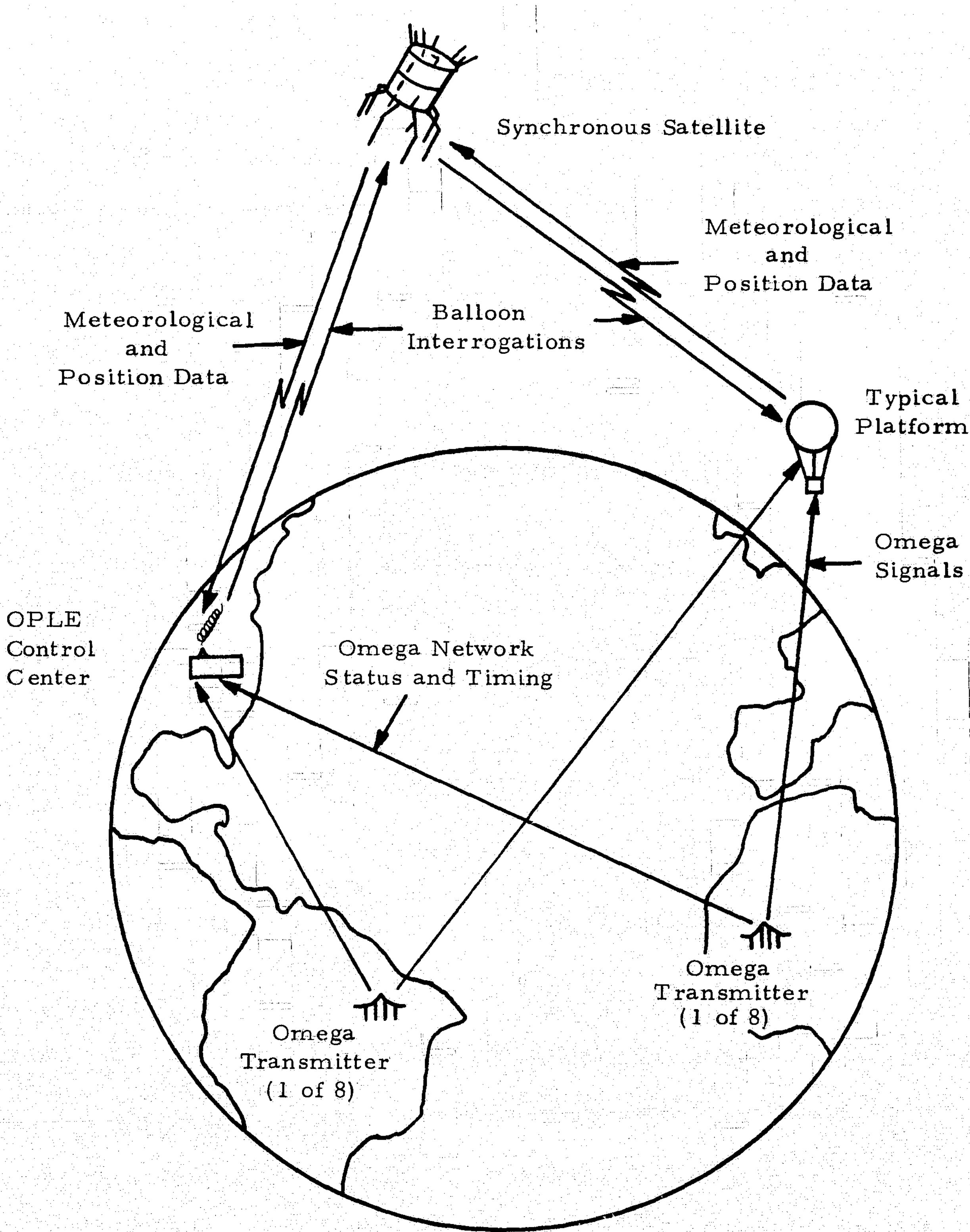

Figure 3.1 OPLE Techniques

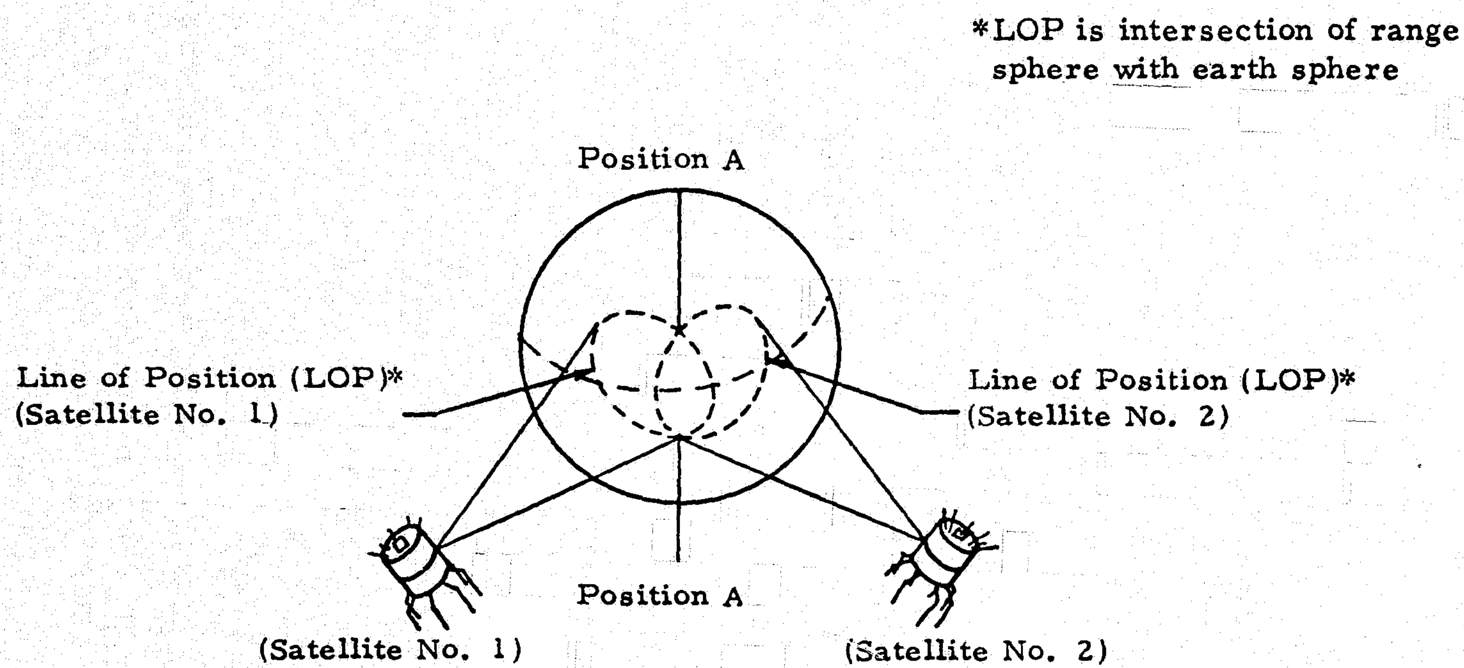

Figure 3.2 Ranging-Altitude Navigation Technique

3-5

Major sources of error in range measurements arise from variations in propagation time due to the earth's troposphere and ionosphere, uncertainties in the knowledge of the positions of the satellites and fluctuations arising from various noise sources and instability in the instrumentation and radio frequency channels. Furthermore, the accuracy of the shape of the earth model and the measurement of altitude of airborne vehicles will affect position accuracy in this technique.

3.1.1 Omega Position Location Experiment

The concept of using the Omega Naviation System for the location of remote meteorological platforms by relaying the Omega signals to another location for processing was originally suggested by the Goddard Space Flight Center in January 1965. Objectives of the OPLE experiment were to demonstrate the feasibility of the OPLE concept for establishing a global location and data collection system, evaluate the experimental equipment performance, and investigate the concept applicability for various types of users. The OCC equipment and processing provided the capability of determining the simultaneous locations of four remote PEP's and locations of PEP's mounted on mobile platforms. The OPLE experiment equipment and signal processing contributed a radial location uncertainty (root mean square error) of about 0.2 nautical miles. The results of the OPLE experiment tests are summarized in Table 3.2. The report concluded that the OPLE technique may be used on a global basis for locating all types of mobile platforms including aircraft with a velocity up to at least 200* knots (References 3 and 4). The significant technical achievement of the experiment was demonstrated that the phase information contained in the VLF Omega signals received by a remote platform could be relayed through the ATS synchronous altitude satellite with sufficient stability to permit position to be computed with an accuracy comparable to that achieved by a conventional Omega navigational receiver at the platform site. The experiment

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*A simulated high velocity test indicated that OPLE could successfully locate an aircraft having a velocity up to 2000 knots (Reference 328).

TABLE 3.2

SUMMARY OF OPLE EXPERIMENT TEST RESULTS

TEST	RESULTS	COMMENTS
Fixed	Daytime position determination error between 1 and 2 nautical miles Nighttime position determination error between 2 and 4 nautical miles.	Using selected data; i.e., correctly resolved lane ambiguity and optimum lane width.
Ship	Average position determination error 1.2 nautical miles.	Using ship's radar as a reference.
Aircraft	Position determination error 1.0 to 1.5 nautical miles before sunset. Position determination error 2.0 to 3.0 nautical miles after sunset. Differential OPLE position determination error 0.5 nautical miles average. Separation of two aircraft as measured by OPLE had an average error of 0.25 nautical miles.	Using ground-based radar as a reference. Errors for closed circular path flown in 3 minutes similar to those for linear trajectories. Radar-determined separation during flight varied from 0.3 to 1.7 nautical miles. OPLE error in most cases between 10 and 20 percent of radar-determined separation.
Buoy	Position determination error had a mean value of 1.2 nautical miles for a moored buoy. Drifting buoy tests inconclusive.	Position reference for moored buoy had an accuracy of ± 25 feet. Accurate references were not available for the drift test.
Balloon	Position determination mean error of 3500 feet and standard deviation of 2260 feet.	Average values for two separate flights using photographic reference. Accuracy of reference is ± 1000 feet.
Differential OPLE	Daytime position determination error less than 0.5 nautical mile if reference and PEP were separated by less than 50 nautical miles. Daytime error less than 1 nautical mile for separations of from 50 to 200 nautical miles. Nighttime position determination error less than 0.5 nautical mile if reference and platform have up to a 50-nautical mile separation. Nighttime position determination error increases by about 0.3 nautical mile for every additional 50 nautical miles as separation varies from 50 to 200 nautical miles.	Results affected by: proximity of Omega Station D, VHF interference by aircraft, and ATS-3 scheduling problems.
Landline	Use of Nimbus Composite Data Link for part of OPLE link caused no apparent increase in position determination error.	Data sample size limited valid statistical conclusions.

also demonstrated that data from sensors co-located on a remote platform could be conveniently combined with the relayed Omega signals to implement a centralized data collection system.

3.1.2 VHF Ranging and Position Experiment

The first opportunity to demonstrate and evaluate the ranging-altitude navigation technique on two geostationary satellites came with the successful launch of ATS-3 late in 1967. The orbital placement of the satellites at 150°W (ATS-1) and between 45°W and 75°W (ATS-3) provided a useful area of mutual visibility from the east coast of the U.S. westward to the eastern portion of the Pacific Ocean. Also, the nearly identical VHF repeaters on ATS-1 and ATS-3 permitted the implementation of the technique with relatively inexpensive mobile transponders.

Under a contract to NASA, General Electric initiated a three-phase experimental position location program. The first two phases of the experimental program, which utilized the ATS 1 and 3, had the following objectives.

- To demonstrate the feasibility of ranging and position fixing from synchronous satellites to small mobile terminals at VHF radio frequencies.
- To demonstrate the advantages of a tone-code (pulse train) ranging technique.
- Obtain data over a large geographical region at various times of the day to indicate the variations in ranging and position fixing accuracies caused by location and time of day.

Phases 1 and 2 of the experimental program involved the use of four different types of mobile platforms. Ranging measurements (from one satellite) were conducted employing an oceanographic buoy between February 13, 1969, through May 1969. Similar measurements were conducted employing a van driven from the village of Many Corners, New York northward for approximately one hour on March 27, 1969. The first position fixes made employing range measurements from two ATS synchronous satellites occurred on July 1, 1969. The test vehicle was the U.S. Coast Guard Cutter VALIANT located in Galveston Bay and fixes were computed from ranging data records at the General Electric ground station in Schenectady, New York. A second ship, the Coast Guard Cutter RUSH, was used for longer term tests from May through July 1970 in the Pacific. Position fixing experiments involving two types of aircraft furnished by the FAA were conducted between July 6, 1970 and January 23, 1971. Tests were run with a DC-6B on a trip between the FAA National Aviation Flight Experimental Center (NAFEC) in New Jersey and the Griffiss Air Force Base at Rome, New York on July 6, 1970. Further tests with the same aircraft took place on a flight from NAFEC to Thule, Greenland in January 1971. Most of the flight path was beyond line-of-sight to ATS-1, but much valuable data was obtained upon departure and arrival at NAFEC. The experiments demonstrated that geostationary satellites could provide high quality, reliable, undelayed communications between distant points on the earth and that could also be used for surveillance. A combination of undelayed communications and independent surveillance from shore provided the elements necessary for the implementation of effective traffic control for ships and aircraft over oceanic regions. These tests provided sufficient information so that it was then possible to consider the design of operational systems for air traffic control, marine traffic control, management control of automated shipping, and the synoptic location and read-out of a widespread network of remote meteorological and oceanographic sensor platforms.

Several conclusions (Reference 23) were drawn from Phases 1 and 2 by the experimenter.

- A simple model of the ionosphere was adequate to correct position fixes to within approximately one nautical mile.
- The largest single source of bias errors in position fixes and lines of position was error in predictions of satellite position.

- A timing error on the received signal at the user transponder could cause the position fix to be displaced along a hyperbolic line of position.
- An error of integral multiples of approximately 75 miles resulted from improper operation of the address code correlator.
- Link reliability for mobile craft was poor to good under most conditions of the experiment and the poor reliability was caused by poor signal levels, ionspheric scintillation fading and occasional interference from the routine air traffic control transmissions.

As the VHF navigation experiments were being conducted, it became apparent that the VHF portion of the spectrum would not be capable of supporting operational satellite navigation or surveillance systems without an extensive frequency reallocation plan to provide a sufficient number of interference-free channels. Since the VHF bands were fully allocated and highly utilized, the World Administrative Radio Conference on Space Techniques (WARC-ST) in 1971 saw fit to allocate a segment of the UHF band between 1535 and 1660 MHz (often referred to as "L-band") for radio communication and/or radio determination purposes. Portions of this band were exclusively apportioned for use by the aeronautical-mobile and maritime-mobile services for space radio techniques. This action created real need for further research and development to determine the following.

- The effects of transionospheric propagation at L-band on communications and navigation systems.
- The impact of the use of this higher frequency band on the need for further development of space and/or mobile equipment technology.

The launch of ATS-5 in August, 1969 provided the first opportunity to perform L-band experiments using a synchronous-altitude satellite. Unfortunately, difficulties experienced during the launch phase prevented the despin of the satellite so that the spacecraft L-band antenna beam swept across the earth once each revolution. Means of employing the approximately 50-millisecond "window" created by the satellite spin for both communication and navigation systems were devised and many navigation and ranging experiments conducted.

Phase 3 of NASA - General Electric Ranging program got underway early in 1971 and was completed in late 1972. It had the following objectives.

- Measure propagation effects such as ionospheric delay and sea reflection multipath simultaneously but separately at the L-band and VHF frequencies for a direct comparison of their effects on ranging precision and accuracy.
- Determine the relative reliability of the communication links under the conditions of the experiment at L-band and VHF.

The technique used in Phases 1 and 2 extended to L-band using the ATS-5 satellite. An automatic tone-coding ranging transponder was designed, constructed, and used to compare ranging measurements and communications reliability at VHF and L-band. The L-band/VHF automatic transponder was used in experiments with the ATS-5 and ATS-3 satellites in January and early February and from June through November of 1972. The L-band receiver of the ATS-5 satellite did not function between Febraury and June 1972.

The transponder was located at General Electric's Radio-Optical Observatory during the test period. Tone-code interrogations were transmitted at VHF from the Observatory through the ATS-3 satellite and back to the transponder. The transponder responded on VHF through ATS-3 and on L-band through ATS-5.

Results of these ranging experiments confirmed that ranging resolution measured in tens or hundreds of feet may be achieved at VHF and L-band within the radio frequency bandwidths used for communications with simple, inexpensive, automatic equipment. The ranging signals can be compatible with communications and the range measurements can be accomplished in a time that is negligibly short compared to the signal durations used for communications.

3.1.3 VHF Navigation Experiment

The VHF Navigation Experiment was also a Ranging Altitude Navigation experiment which utilized equipment modified from the OPLE experiment. It was performed by Texas Instruments, Incorporated to fulfill the need for on-line (or real-time) position location and display. Such a real-time demonstration of position location with comparative radar ground truth data would be more effective in showing the utility of satellites to enroute surveillance of air traffic. This technique made use of the modified OCC and the ranging transponder (Reference 300). The major technical objective of the experiment was to evaluate the performance of the alternate position location techniques and to compare the accuracy of the differential ranging technique with its predicted performance. To establish reasonable estimates for the predicted position location error, extensive measurements were made of the RF link performance.

This experiment successfully demonstrated the implementation of the ranging-altitude navigation technique with real-time display of in-flight aircraft position at a ground control center. The experiment also demonstrated the following.

- The utility of synchronous satellites in the master/slave configuration using differential techniques to remove large common mode errors in the ranging measurements.
- The capabilities of narrow-band sidetone ranging yielding position location accuracies of approximately two nmi for a 941-Hz sidetone.
- The facility for real-time computation and display of aircraft position, using differential or absolute ranging techniques.

3.1.4 Position Fixing Using ATS-3

Following an invitation by NASA, the Bundes-Republic Deutschland (BRD) carried out an experimental program with the ATS-3 satellite. The object of the program was to determine the system parameters for a navigator satellite system. The test program consisted of line-of-position determination based upon range measurements using the VHF transponder of the ATS-3 satellite as well as speech and data transmission between ships and the mainland. Range measurements were made from the research ship METEOR during July and August 1968 while the ship was on an expedition to the Faroe Islands. Range measurements wer e also made from a fixed station located in Oberpfaffenhofen Germany (approximately 48°N, 11°E) during November and December of 1968.

The distance between the ship and the satellite was measured by a sidetone ranging technique whereby two sinewave tones (24.4141 Hz and 3125 Hz) were modulated onto the VHF carrier. The 3125 Hz sidetone was used to obtain range resolution and the 24 Hz tone was used to resolve ambiguities. The phase differences between the transmitted tones and their respective received tones were measured using a phasemeter capable of $\pm$ 2° accuracy. This allowed an accuracy of $\pm$ 260 meters in the distance measurements. The earth stations employed antenna gains between 0 and 12 db with transmitter powers of 50 to 200 watts. After elimination of all instrument dependent phase errors, the distance was determined from a computer tabulation which listed individual distance calculations for all possible combinations of phase values of the different frequencies. The position of the ship during the 0.3 kHz measurements were determined precisely by Loran. The position of the satellite was computed from orbital elements supplied by NASA and the geometrical distance was calculated.

The difference between measured and computed distance between ATS-3 and METEOR amounted to about 14 Km. Measurements from a fixed location at Oberpfaffenhofen resulted in a root square deviation of $\pm$ 450 m. The shape of the daily distance variations from the movement of the satellite about its mean position was very similar to the deviations of the range measurement. For this reason the experimenters concluded that the measured deviations arose from a drifting motion of the satellite rather than from the measurement method of ionospheric effects. A recommendation was made that the true position of the satellite be given at short intervals (a maximum of one hour) for future users.

3.1.5 Multipath/Ranging Using ATS-5

In May 1970, the Federal Aviation Administration performed an L-band experiment involving over-ocean multipath and one-way ranging measurements through the ATS-5 satellite between a ground station and a KC-135 jet airplane. The objectives of the experiment were to study L-band propagation between a geostationary satellite and an aircraft and in particular it was desired to measure and evaluate the effects of multipath transmission on both communications and on ranging measurements used for position location. The data gathered with the specially instrumented aircraft was to be used in determining design criteria for aircraft antennas.

Several significant conclusions were drawn from analysis of the experimental ranging and multipath data acquired during the first half of the flight test program. The ratio of the mean scattered power to the direct path power, was approximately equal to the product of the divergence factor and the smooth-earth reflection coefficient for all cases to date. A significant sense reversal effect was present when the signal incident on the ocean surface was circularly polarized. The power spectrum of the multipath signal had a Gaussian shape with 1/e bandwidths of a few hundred Hertz for the flight paths and elevation angles flown where $e = 2.71828$.

3.1.6 L-Band - ATS-5 ORION - SS. MANHATTAN Marine Navigation and Communications Experiment

In the spring of 1970, a ranging experiment was conducted employing the ATS-5 L-band repeater in which measurements were taken aboard the icebreaking tanker S. S. MANHATTAN on voyage from Newport News, Virginia to a point 73.5°N latitude, 60°W longitude in Baffin Bay. This experiment was sponsored by the NASA Electronics Research Center and supported by the NASA/GSFC ATS project (Reference 2). The objective of the experimental program was to conduct a series of navigation and communications experiments via ATS-5 spacecraft to an ocean craft over wide variations of latitude, longitude, weather conditions, and elevation angle to provide a basis to demonstrate the feasibility of navigation via synchronous satellites and to correlate measured quantitative data with theoretical predictions.

Ranging and data transmission were accomplished using the Optimum Ranging in Oceanic Navigation (ORION) system developed by Applied Information Industries. This system employs biphase PSK modulation of three tones for ranging. Line of position accuracies achieved with this system were on the order of 1 mm.

The experiment concluded that L-band signal transmission via a synchronous satellite would produce precise and stable range measurements; and that an uncomplicated equipment complement was possible for widespread marine use. This passive navigation system could provide instantaneous position fixing across broad areas of the globe.

3.1.7 System 621 B/ATS-5 Signal Demonstration Test

The System 621 B/ATS-5 Signal Demonstration Test Program (Reference 39) comprising equipment development, testing at Mojave, and data reduction was begun in July 1970 and all test phases were completed during January of 1971. The program achieved the two primary objectives.

- To demonstrate the ability of System 621 B receiver equipment to provide accurate and precise ranging data using a pseudo-noise code technique.
- To evaluate ionospheric propagation delay for L-band signals using the ATS-5 satellite.

3.2 METEOROLOGY

A satellite is an important meteorological tool because it can "see" things which ground stations and aircraft cannot. A policy statement* of the American Meteorological Society (AMS) on meteorological satellites describes the advantages of a satellite as:

> Meteorological satellites observe all parts of the earth's atmosphere and surface from space. From these satellites certain observations, needed in meteorological analysis and forecasting, are made with instruments that measure the upward radiance in the visible, infrared, and microwave portions of the spectrum. Satellites are the only practical means whereby these global observations can be made with a useful frequency and time scale. Equivalent global coverage from ships, aircraft, or any alternative means would be impractically expensive. Moreover, in some instances, the observations of parameters such as global cloud patterns can be made only from satellites.

Prior to this, the World Meteorological Organization said regarding a satellite:

- "It provides observations and measurements of conditions in the earth's atmosphere and on the earth itself from positions beyond the atmosphere."
- "It provides a means of relaying telecommunications signals from a point on or near the earth's surface to another similar point or points."
- "It provides observations and measurements of conditions in outer space itself and, in some cases,

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*Bulleting of the American Meteorological Society, January 1976.

on or near other planets in the solar system as well as the earth's natural satellite, the moon."

These two sources reflect the prevailing opinion of meteorologists and describe succinctly the advantages of meteorological satellites. The ATS series, designed primarily for communications, fulfilled to a high degree the above requirements.

Because of their geosynchronous orbits and the cameras on-board, the ATS-1 and ATS-3 allowed, for the first time, large areas of the earth to be photographed so that the earth was fixed and the changes seen were changes in cloud patterns. An example of ATS photographs is shown in Figure 3.3. Pictures taken every twenty minutes by these cameras make it possible to investigate the dynamics of cloud motion and the development of cloud systems. Of special importance is the observation of remote ocean area which previously had not been observed in any detail.

3.2.1 Cloud Pictures

The most important meteorological use made of the ATS was taking and transmitting cloud pictures to ground stations. These cloud pictures taken over large segments of the earth, complement data from other sources and gives to the research meteorologist a total picture of those parameters which effect and display weather patterns. Thus these cloud pictures can be used to forecast weather and to investigate cloud characteristics associated with thunderstorms, tornadoes and hurricanes.

ATS-1 placed in a stationary orbit at 152°W over the equator at an altitude of 36,000 Km has provided a wealth of such meteorological information from the Pacific Ocean since December 1966. ATS-3 launched into a stationary orbit at 35,000 Km over Brazil on 05 November 1967, is in a similar orbit but about 95° further east and north of the Amazon Basin and provides simultaneous information from the Atlantic Ocean. Thus, complete coverage of day time cloud distribution and short-term variations over an area from New Guinea across the Pacific Ocean, South America and the

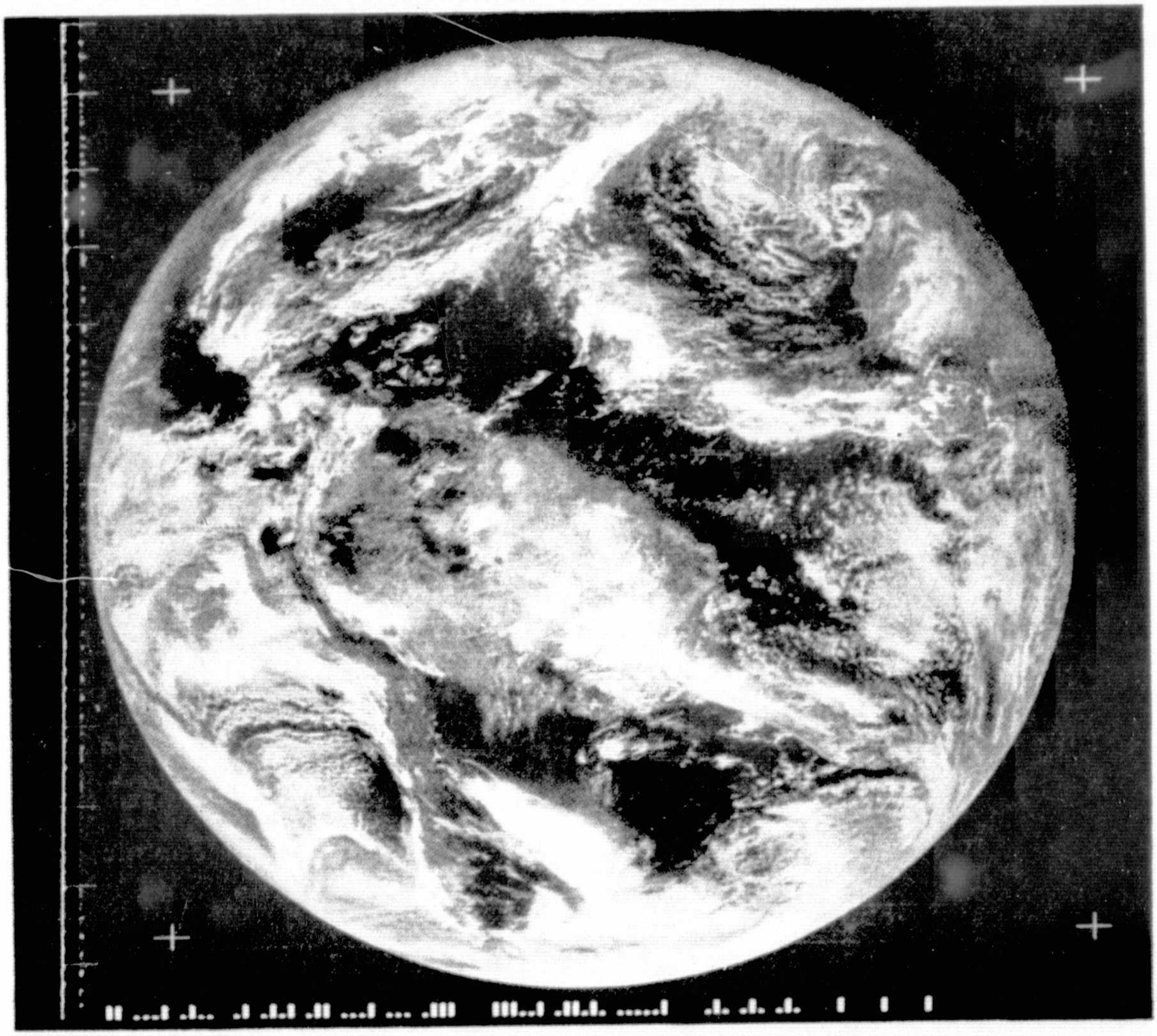

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Figure 3.3 ATS-1 Spin Scan Cloud Camera Picture

Atlantic Ocean to the West Coast of South Africa was achieved by these two satellites.

3.2.2 Spin Scan Cloud Cameras

The Spin Scan Cloud Camera (SSCC) installed on ATS-1 provided black and white coverage of the earth only from 52.5°N to 52.5°S whereas the ATS-3 Multicolor Spin Scan Cloud Camera (MSSCC) allowed a full disc color picture. The color pictures were an improvement over the black and white pictures because of improved color contrast of clouds against the earth's background, and because the full earth disc also made navigation on the picture much easier which in turn allowed for an easier computerized method of determining cloud displacements.

Professor V. E. Suomi, Department of Meteorology, University of Wisconsin and Professor Robert J. Parent, Department of Electrical Engineering, were principal and co-investigators for the monochrome and color spin scan camera development. Dr. Suomi's opinion is that the MSSCC was overwhelmingly successful in almost every aspect and due to its long lifetime, very cost effective.

3.2.3 The Use of ATS Data

After the ATS-1 and ATS-3 were launched and the method of processing the cloud pictures established, there were three further problems. The first was to design particular experiments that would combine ground, aircraft and satellite observations into one data base from which an analysis of weather patterns could be made. The second problem was how to utilize the daily cloud pattern picture for forecasting purposes and the general study of storms. The third problem was determining cloud motion from the cloud pictures. To solve the first of these, the Line Island Experiment was designed.

3.2.4 Tropical Weather Data Collection

The Line Island Experiment (LIE) conducted during February - April 1967 was one of the first field programs in the tropics. The Line Island Experiment Plan was for an intensive series of weather observations to be made from ground stations on the island, from shipboard stations and from research and reconnaissance aircraft. These conventional observations along with observations made by NASA and ESSA using polar orbiting meteorological satellites were to be used to evaluate the photographs taken by ATS-1. The objectives of the experiment were to make a detailed investigation and description of meteorological events in and near the equatorial trough zone which is an important source of energy transport. The experimenters felt that the large-scale cloud systems as seen by the satellite had never been adequately compared to and correlated with corresponding observational data obtained by conventional means. They had further felt that this lack of such a comprehensive evaluation had seriously hampered progress in achieving understanding of tropical weather and its effects on global atmospheric behavior. From this initial experiment up to the present time, the ATS-1 and 3 and their successors, the SMS/GOES have been used in this manner, that is, an attempt to correlate the motion of clouds and their pattern with atmospheric measurements of wind, temperature and humidity. Unfortunately, this problem is still with us so that no conclusions can be drawn regarding the success of the Line Island Experiment and others like it such as BOMEX.

BOMEX was a joint project of seven U.S. departments and agencies conducted during the period 03 May to 28 July 1969. The ATS provided "real time" camera coverage of the BOMEX area as well as the WEFAX Broadcast link in support of the project.

The second problem, that of using cloud pictures as a forecasting tool is of course, coupled with the first in this manner. Forecasting models require input from both ground and space sensors. These models are still being developed and until the cloud pictures are useful in forecasting, there is still much work to be done. Cloud patterns are very useful for studies of storms and as a monitoring device.

3.2.5 Severe Weather Monitoring

If a forecast method can be developed that will predict severe storms using cloud data then monitoring clouds becomes effective. To study this problem, thunderstorms and hurricanes have been monitored by ATS-1 and ATS-3 and the resulting data analyzed in order to better understand and hence predict severe storms. Hurricane Gladys which occurred on 17 May 1968 and Hurricane Debbie of 16 August 1969 were both monitored by ATS-3. Papers describing the build-up and description of the storm were prepared by scientists at the University of Chicago.

The third problem to determine cloud motions from cloud pictures has been addressed by the University of Chicago and Stanford Research Institute Satellite Center. This has met with some success and has proved to be an aid in forecasting storm movements and circulation patterns. The MSSCC camera of ATS-3 was a help here because the color helped identify the altitude of them, giving a wind at an altitude.

3.2.6 Interrogation of Remote Unattended Sensors

A further important use of a meteorological satellite is to interrogate remote and unattended sensors. The first attempt was made by General Dynamics Convair for the Coast Guard using ATS-1. The buoy was located at about 160°W by 45°N in the Pacific. The second was made by the Royal Norwegian Council for Scientific and Industrial Research in December of 1970 through January of 1971. The Satellite Communication Oceanographic and Meteorological Buoy (SCOMB) built by the Norwegians was developed to evaluate the possibilities of satellite relayed data transmission from ocean platform operation at high latitudes. This buoy used ATS-3 and was positioned at 60.5°N and 4°E. It appears from the literature that neither attempt was successful enough to warrant further experiments in the area. The transmission from buoy to satellite to ground station was satisfactory but the ability to command the buoy was unsatisfactory.

Another example of transmission of data from a remote unattended sensor is the experiment called Seek Storm performed by Sierra Research Environmental Lab under the direction of J.A. Kleppe. In this experiment weather radar data was transmitted in real time, using the VHF transponder of the ATS-1 and ATS-3 satellites. The conclusion of the report describing this experiment stated that digital data could be transmitted in this manner.

The most important part of the communication aspect of the ATS as seen by the meteorologists was WEFAX, i.e., the Weather Facsimile Experiment. This experiment was designed to study the feasibility of broadcasting processed cloud pictures as well as other meteorological data from the ATS to ground stations. This was a different type of meteorological satellite experiment because it had no unique flyable hardware, i.e., it used the VHF transponder on-board the spacecraft. The ATS-WEFAX experiment, which began in December 1966 originally transmitted selected cloud cover photographs taken by ATS-1 spin scan cloud camera and then used ATS-3 pictures. The WEFAX experiment has proved extremely useful to meteorologists, especially those companies with airlines in that they receive hard copies of cloud pictures in near real time using relatively inexpensive ground recorders.

3.2.7 Spectroscopic Sun Glitter

This experiment performed by Suomi and Parent of the University of Wisconsin was to show the feasibility of spectroscopic studies of the earth's atmosphere using the sun as a radiation source and an ATS-3 to detect the solar radiations reflected from the earth's surface. The conclusion by the authors states that the experiment shows the feasibility of studying the east-west component of the waves slope distribution from a synchronous satellite by using the sun as the radiation source with its movement, relative to the earth as a scanning mechanism.

3.2.8 Conclusions

Meteorologists need an abundance of frequent environmental data to prove or disprove theory and to make realistic forecasts of weather. A satellite is an almost perfect tool to acquire this data in real time and to transmit it to ground stations where and when needed. The ATS provided to the meteorologist an experimental device for evaluating the usefulness of such a tool and led the way for development of more sophisticated satellites for both acquiring and dissemination of environmental data. The satellite has now become an indispensable tool to them and has increased the knowledge of the movement and development of weather patterns enormously. It is now possible to monitor on a real time basis the development of large and small scale weather patterns on a global scale. The question that now remains is to utilize and condense these data into realistic forecasting models. The meteorological satellites will continue as a vital part of this development. However, without the initial impetus the ATS program gave to the meteorologist such models would still be in an extremely preliminary state. While a cost-effective analysis of the ATS program from the point of view of meteorologists is impossible, it is certainly obvious that the program was absolutely vital to the development of better techniques for predicting weather and for modeling the behavior of many atmospheric phenomena.

3.3 TIME AND FREQUENCY DISSEMINATION

During the course of two years beginning in August 1971, the WWV time and frequency signals, usually heard only on the National Bureau of Standards (NBS) high frequency radio stations, were transmitted from the NBS laboratories in Boulder, Colorado, and relayed by ATS-1 and 3 satellites to a major portion of the earth (Reference 19). The signals covered the North and South American continents, much of the Atlantic and Pacific Oceans and parts of Europe and Africa, a total of about forty percent of the earth's surface.

A standard frequency tone, seconds ticks, a time code, voice announcements of the time of day, and satellite position were transponded by the satellite to the earth twice a day for 15-minute periods. The time and frequency information was referenced to and derived from the NBS Frequency Standard and the NBS Coordinated Universal Time scale (UTC), both of which are maintained at the Boulder NBS laboratories.

Historically, the first satellite time experiments were conducted in August 1962 using Telstar. The purpose of those experiments was to compare the clocks at the U.S. Naval Observatory in Washington, D.C., and at the Royal Greenwich Observatory in England. Signals were relayed between these locations by Telstar's microwave transponder. A two-way exchange resolved the round trip path delay and assumed that the paths were reciprocal. If the satellite motion was negligible, which is assumed to be the case for geostationary satellites over a short period of time, the one-way path delay was one-half the round trip delay. The major advantage of the two-way exchange was that knowledge of the location of the satellite and of the ground stations was not required. The major disadvantage was that both ends of the path needed a transmitter and receiver and that only one user could be synchronized in any one exchange. Similar experiments were carried out with the Relay communications satellite in February 1965 and again with ATS-1 and ATS-3 in 1971. Those experiments reported accuracies ranging from 0.01 μs to 1 μs. All of these experiments were conducted in the microwave radio region using wide signal bandwidths. Although great accuracy can be obtained under these conditions, the equipment costs are too great for many users. The need for a low cost technique led NBS in 1967 to conduct two-way experiments using the ATS-1 satellite VHF transponder. Accuracies of about 5 μs were achieved using inexpensive VHF receiving and transmitting equipment.

NBS, motivated by an emphasis on low cost and simplicity, directed its efforts in 1967 to the one-way mode for time transfer. Experiments were conducted with the ATS-1 and ATS-3. Accuracy in the one-way mode is limited primarily by errors in the path delay predictions.

For high accuracy synchronization of the user's clock, the user had to compute the total signal delay from the master clock at NBS through the transmitting equipment to ATS-3, through its equipment, to the user's position, and through the receiving equipment. Since geostationary satellites move about, a complicated calculation of path delay was necessary, assuming the user began with the fundamental orbital elements. If the user was only interested in time to the nearest second, no calculation was needed other then a mental note to remember that the signals arrived at the earth's surface approximately one-quarter of a second later.

Even for the higher accuracy, sophisticated time user, the effort required to calculate path delay was deemed to be intolerable. Consequently, NBS developed a circular slide rule to compute propagation delays. This slide rule, in addition to voice announcements of satellite position relayed by satellite, enabled the user to compute path delays with high accuracy, at a minimum of effort.

As a means of evaluating the performance of the ATS-3 time and frequency dissemination experiment, NBS set up four observation sites. These sites were selected to be as widely dispersed about the subsatellite point as possible. These sites were NBS-Boulder (which was also the location of the transmitter), Air Force Cambridge Research Laboratory (AFCRL) in Massachusetts, and the Smithsonian Astrophysical Observatory (SAO) sites in Arequipa, Peru, and Natal, Brazil. Each site was equipped with a receiving system and a high accuracy time reference to UTC. NBS generated UTC and acted as the master clock with all signals sent to the satellite being derived from the NBS Frequency Standard and UTS (NBS) time scale. AFCRL maintained its time with a commercial cesium beam clock referenced to UTC through LORAN-C monitoring and portable clock carries by the standards laboratories of the Department of Defense. Arequipa and Natal also had cesium clocks for reference and were synchronized by portable clock carries from

NBS with frequency "steering" from VLF monitoring of the Navy station, Balboa, Canal Zone.

Each site measured the arrival of the time signals from ATS-3 relative to its local clock. Because each site's clock was previously synchronized to the master clock at NBS, the measured arrival time was equal to the total signal delay between the transmitter and the site. These measured signal delays were compared to computed values derived from orbital elements and complete descriptions of perturbative forces. It was estimated from the results that the accuracy and precision for the satellite time signals were approximately 25 μs and 10 μs respectively. It has generally been accepted that WWV and WWVH can offer timing accuracies and resolution of 1 ms and 0.3 ms respectively. A comparison between standard HF transmission and ATS-3 usage is given in Table 3.3.

A problem area in the ATS-3 experiments was evident whenever an orbit maneuver was experienced. The maneuver created an entirely new orbit for the satellite which required new orbital elements for satellite position prediction. Operationally, NASA would track the satellite immediately after the maneuver. The tracking process required a day or two, after which an orbit was fitted to the data. Consequently, it was a week or two before NBS had the information necessary to broadcast satellite position to the user for delay calculations. For an operational service, this delay in orbit determination would be unacceptable.

Although the level of operation obtained in the experiment was not fully satisfactory for a national service such as provided by WWV, it was indeed obvious that satellites are a very real candidate to meet the growing needs for higher accuracy and more reliable time and frequency signals. The experiment provided much of the insight necessary to specify and direct further work to develop the level of competence required for such a service.

TABLE 3.3

WWV AND ATS-3 PERFORMANCE SUMMARY

	HF	ATS-3
Coverage (Continuous non-interrupted)	10-15%	40% of earth
Cost to user (receiver and antenna)	\$100-500	\$100-500
Resolution	0.3 ms	10 μs
Accuracy	1 ms	25 μs
Path Delay Computations	Complex	Simple
Time Recovery Technique	Medium Complexity	Simple

As a result of this experiment, the authors (Reference 47) offered the following observations.

- Using a moderate receiving bandwidth and power, a potential accuracy of 10 μs or better was indicated and, in some periods of the experiment, achieved.
- The signals were highly reliable in that they were avilable to 40% of the earth's surface without interruption due to fading or other propagation anomalies. This implied a continuous uninterrupted performance to the full coverage area of a permanent service.
- The cost of user equipment was inexpensive and not substantially different from the equipment required for the reception of the NBS stations WWV and WWVH.
- To realize the high-accuracy timing potential, only very simple delay calculations were required and were readily satisfied by the simple and inexpensive circular slide rule.
- The time recovery techniques were basically identical to those used with WWV or WWVH except that greater path predictability and higher sampling rates enhanced the user's ability for time recovery and reduced his involvement to obtain the highest accuracy.
- The signal quality was in every respect superior to the WWV/WWVH broadcasts and resulted in a clearer voice channel.

3.4 COMPUTER COMMUNICATIONS EXPERIMENT

In January, 1972, the Spacecraft Data Systems Branch of the Ames Research Center, NASA, initiated an experiment in Computer Communications via the ATS-1 satellite (Reference 227). This experiment was designed to demonstrate the feasibility of utilizing satellite communication links to provide computer-computer and terminal-computer communications between remotely located sites. In order that the experiment be conducted under realistic conditions, computing facilities at the University of Hawaii (UH) and the University of Alaska (UA) were connected to the Advanced Research Projects Agency (ARPA) computer net (ARPANET) via ATS-1 to the NASA-Ames Research Center (ARC). The ATS-1 VHF transponder was utilized as a broadcast repeater for a satellite network operated in the ALOHA* random access burst mode.

The initial experiments were conducted by UH with NASA designed modems and interface hardware. The equipment supplied by NASA/AMES (other than the radio) consisted primarily of a PCM Bit Synchronizer, a NASA-built Formatter/Synchronizer, and a Convolutional Coder/Decoder. A standard 9.6 K bps ALOHA modem was modified for rapid burst-acquisition and low false-alarm rate. Minor modifications were made to the ATS-1 radio to interface the ALOHA modem and a simple interface unit was built to go between the modem and the radio. Efforts were directed toward investigation of the ATS-1 channel characteristics, development of bit error analysis software, and investigations of an improved modem design for use on the ATS-1 channel.

Measurements of bit-errors per packet and packet throughput using both the ALOHA and the NASA modems at various data rates were conducted. Measurements indicated that the ALOHA modem had superior packet throughput in comparison to the NASA-supplied equipment. Overall, the ALOHA modem had a throughput of 80 to 90 percent of all its packets without any error. These measurements were taken with the satellite operating in the full power mode. With the satellite in the low power mode (6 db less) the throughput was seriously degraded for both systems to the order of about 10 percent packet throughput without errors. The above measurements were made on the basis of receiving

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*The ALOHA System is an experimental UHF radio, packet switched computer communications network in operation at the University of Hawaii since June 1971.

a signal level of about one microvolt at the receiver preamp with the satellite in the full power mode.

The data modulation technique chosen by ARC for this experiment was synchronous frequency shift keying (FSK) since it is the easiest and least expensive to implement. Initial testing consisted of continuous psuedorandom bit sequence transmissions from ARC to UH/ALOHA, and vice-versa, using the ATS-1 VHF transponder. The University of Alaska also cooperated in these tests. The recovered clock from the bit synchronizer and the error output from the error detector were fed to a ratio counter to provide direct reading of error rate.

Tests, using the present equipment configurations, with the ATS-1 VHF transponder in the full-power mode, and during the daylight hours, indicated error rates in the order of 1×10^{-3} at 10 KBPS. Measurements of the power received from the spacecraft indicated an average C/N ratio of 17 db for the 20 kHz bandwidth receiver. Since this was well above the threshold level of the receiver, the researchers concluded that the errors were due primarily to impulse noise bursts and signal interference due to the density of man-made noise in an urban area, such as automobile ignition noise, and not to receiver front-end thermal noise.

To combat the effects of noise in the channel and to improve the channel reliability, ARC chose to use convolutional coding for forward error-correction on this channel. A LINKABIT Model LV7015 Convolutional Encoder/Viterbi Decoder unit was sent used for this purpose by UH/ALOHA. The channel performance was significantly improved with error rates in excess of 1×10^{-5} very seldom being recorded. Considering that the channel was exhibiting an un-coded error rate of about 3×10^{-3} at the time the tests were made, the convolutional encoder/decoder improved the channel bit error rate by a factor greater than 300, on the average, and probably more for peak error rates.

In December, 1972, a Packet Formatter/Synchronizer device was received by UH/ALOHA from ARC. This device, designed and fabricated at ARC for the burst communication experiment, provided the capability to transmit and receive data packets over the ATS-1 VHF satellite link.

The burst communications experiment was implemented in two phases. The first phase involved UH/ALOHA and ARC. UH/ALOHA operated as remote terminal accessing the ARPANET through ARC, with the interface computer at ARC performing necessary error detection, message formatting, and network protocol, similar to the functioning of the Interface Message Processor (IMP) in the ARPANET. The ground station at UH/ALOHA used an ALOHA Terminal Control Unit connected to the ARC Formatter/Synchronizer Unit. The terminal used was a standard Model 33 TTY. The ALOHA TCU performed the necessary packet buffering and control functions and the unit used was a standard unit from the local ALOHA ground system. Tests were made at 20, 10, and 2 KBPS. Throughput at 20 KBPS was very poor, of variable quality at 10 KBPS, and usually good at 2 KBPS. However, even at 2 KBPS one out of four packets frequently had errors, indicating the burst nature of the noise.

Phase II consists of implementing a fully connected network between ARC, UH/ALOHA, and University of Alaska. However, no data is available on the outcome of this test.

3.5 FACSIMILE TRANSMISSION

The geostationary satellite offers considerable potential for transmitting pictures, documents and graphics using facsimile equipment. A number of ATS communications experiments investigated the quality of various facsimile transmissions. Facsimile equipment was investigated extensively as part of the Alaska, the PEACESAT, and the Maritime experiments. (The GE/EXXON test results were discussed in subsection 2.4.3.3). Typical of these experiments was the work done by Alaska personnel. Facsimile equipment was also used for the transmission of x-rays, finger prints, and ECG's.

3.5.1 Alaska

The objectives of the Alaska facsimile hardware experiment (Reference 40) were to:

- Evalute the quality of the facsimile copies, as relayed over ATS-1, in terms of their medical usefulness.
- Compare several facsimile methods and options and rate them in terms of their advantages and disadvantages.
- Investigate the effects upon copy quality when ATS-1 system parameters, such as uplink power, are varied.
- Determine and document practical ways of interfacing the facsimile equipment with the satellite radio system.

Three types of facsimile machines were tested over the ATS-1 link: a Xerox 400 Telecopier, which works best for documents; a Litcom Colorfax photocopier, which is designed for Polaroid photographs; and a Scanatron M4-2 copier which has two modes, optimized for either documents or for photographs (the "photofax" mode has an increased gray-scale resolution). Facsimile tests were conducted during twelve scheduled periods, for a total time over the satellite of 7.0 hours.

The Xerox 400 Telecopier is a document facsimile transceiver with a maximum scanning resolution of 92 lines per inch. Maximum copy size is 8-1/2 x 11 inches. Documents are attached to a rotating drum. Scanning rates of four or six minutes may be selected. The four-minute scan expands the line spacing and, hence, reduces the vertical resolution by two-thirds. Copy is reproduced electrostatically in a dry process on special paper supplied by the manufacturer.

The Telecopier was installed at Stanford early in December 1971, and first checked out by exchanging copy with the University of Hawaii which had been using similar equipment on the satellite circuit between its Manoa and Hilo campuses.

On February 10, 1972, the University of Wisconsin transmitted three runs to Stanford using the Xerox Telecopier Pattern for copy. All runs were tape recorded: the tape playback copy initially suffered from sync "tear" caused by varying speed of the Stanford tape recorder on playback. With the recorder properly synchronized, copy was excellent.

The last facsimile test between Stanford and Wisconsin was made on February 24. Wisconsin transmitted copy at both six- and four-minute rates and Stanford transmitted the IEEE test chart at the six-minute rate. This copy was of excellent quality: seven steps on the gray scale were discernable.

Four transmissions of the IEEE test chart were made from Stanford to College, Alaska on March 6. The first was made with the ATS-1 satellite repeater in the half power mode. This copy suffered some noise specking but was very legible with the satellite at full power. The second and third copies were good.

A series of eleven documents of medical significance were transmitted from Stanford to the University of Washington on March 28, 29, and 30. All documents were transmitted with the satellite VHF repeater in the full power mode except the first half of one document which was sent with the repeater at half power, evidenced by noise specking.

The last document sent by Stanford was the IEEE test chart which was transmitted to the spacecraft at four progressively decreasing power levels, of 340, 170, 85, and 40 watts, thus reducing power in 3 db steps. The received document had bands of noise for the lower three power levels. The noise was not well correlated with power reduction: some of the copy sent at the lowest level was as clean as the full power section.

The Japanese color picture facsimile equipment (made by Matshushita, marketed by Litton Industries, comes as two separate units: a transmitter and a receiver. Pictures must be of standard Polaroid size (2-3/4" x 3-7/8"). Black and white copies take a little over two minutes; color copies, seven minutes. The equipment was loaned to Stanford for the experiments.

During April and May of 1970, a colorfax transmitter/receiver pair was tested in an up/down loop through ATS-1 from Stanford. Received color copies of a picture of a native child with a cleft palate were excellent; they were virtually indistinguishable from the originals. Because of the colorfax signal bandwidth, the transceiver bandwidth was widened by using an audio preamplifier equalizer.

The Scanatron equipment is designed to operate in two modes: "DATAFAX" and "PHOTOFAX". In the DATAFAX mode, the scanning resolution is 100 lines per inch with a five-step gray scale and running time of 4-1/2 minutes for eleven inches of copy. When switched to PHOTOFAX, the scan slows down to give an improved gray scale resolution of nine to ten steps taking nine minutes to scan an eleven-inch document. Copy is produced using electrolytic paper processed in the machine. Linear resolution is about the same in both modes. Separate transmitting and receiving units are used, making it possible to transmit and receive simultaneously (duplex operation). This equipment was loaned to Stanford for use in these experiments by the Victor Electrowriter Corporation, which has recently acquired the marketing rights for the Scanatron.

The Scanatron was tested in an up/down satellite circuit test at Stanford using the IEEE facsimile test chart as the originating document. A series of six transmisstions were made on January 25, 1972 with full power from the ATS-1 satellite, a 4 kHz FM deviation, and received (S+N)/N ratio of 29.5 db. Copies were good. Further test transmissions were made on January 27 and 31. (S+N)/N ratio was excellent (33 and 32.5 db, respectively). There were some phasing problems with the instrumentation, but document quality was excellent. Afterwards, a hardwire test was run in both DATAFAX and PHOTOFAX mode to confirm running times and to calibrate copy quality.

The experiments concluded the following.

- Facsimile transmissions made over the ATS-1 VHF repeater were of equal quality to wire circuits.
- Degraded signal-to-noise conditions specking of the copy. Such conditions were observed when the repeater was operating at half power, which reduced the received power by 5 db, and when local interference at the receiver became of significance.
- Reduced power at the transmitting stations had little effect on copy quality so long as reasonable saturation of the spacecraft repeater receiver was maintained.
- Color facsimile transmission of photographs was highly successful.

3.5.2 X-ray Transmission

This first transmission via a space vehicle of fluoroscopic information took place on November 15, 1971 and lasted approximately 60 minutes (Reference 298). Signals were sent over a closed loop approximately 50,000 miles long, extending from the NASA Tracking and Data Acquisition Center at Rosman, North Carolina, ($\approx 83^{\circ}$W, $\approx 35^{\circ}$N) to the synchronous satellite ATS-1 stationed above the Pacific Ocean, and back.

Because there were no radiologic facilities at the ground station, the transmitted fluoroscopic information was derived from video-tape recordings previously made at Duke Hospital and then transported to Rosman. The tapes were made with a conventional image-intensification system using 525-line vidicon cameras and commercially available one-inch recorders. The recorded signals were used to frequency-modulate a

6.2 GHz carrier radiated by a 1-kW transmitter working into the Rosman antenna.

The "up" fluoroscopic picture was watched during transmission on a video monitor at Rosman; the "down" picture, which lagged the other image by approximately one-third of a second, was displayed on an adjacent monitor and simultaneously taped. A kine was later made from this tape for demonstration purposes. The "up" and "down" monitors gave indistinguishable pictures in all cases, demonstrating conclusively that the information capacity of the satellite link is more than adequate for fluoroscopic transmissions at normal frame rates.

Static images obtained by viewing back-lighted standard radiographs with a commercial vidicon camera were also transmitted. The images in this case were unsatisfactory for diagnostic purposes. This was due to the poor quality of the vidicon images fed to the transmitter rather than to inadequacies in the transmission link. With a sensor such as a transmitted-light facsimile scanner or a high-resolution camera of the type used for cloud-cover studies in the ATS satellite series, satisfactory radiographic transmission is clearly possible; further, with the information capacity available, the transmission time per image would be short.

The researchers' experiments concluded that an earth-satellite system can transmit radiologic information of diagnostic quality on a real time basis using existing technology.

In 1972, methods of transmitting x-rays using small, inexpensive ground terminals were investigated by PEACESAT personnel under a contract with Lister Hill Center. Transmission of x-rays was one facet of an experiment to attempt to increase the capability of the PEACESAT system to transmit medical data, collected at remote locations, to urban medical centers for diagnosis.

Based on the advice of medical personnel with experience in the Pacific area (Reference 66), two types of data were determined to be most useful; namely the x-ray and the ECG. If x-rays and ECG's prepared at remote locations can be transmitted by lesser trained personnel to medical centers for expert appraisal, it would improve the delivery of health care in remote areas.

The reverse or negative characteristics of the x-ray film was identified as a major problem in transmission via facsimile since the telecopier is limited to transmitting positive prints. To meet this problem, a Polaroid photograph of the x-ray film was used. An x-ray was attached to a viewing box, which allowed light to penetrate the transparency, and the image was reproduced using an MP3 Polaroid Camera, producing a 3" x 5" positive print. Satellite transmission of a Polaroid print provided by the Clinic was initiated 22 September 1972. The resulting facsimile was very poor and inadequate for diagnostic use. An example of the facsimile received at Wellington is shown in Figure 3.4.

A second method tested involved the use of wire photoequipment, similar to that used by the Associated Press, with the capacity for sending half-tone dot screened glossy prints. Two prints were made of a skull x-ray. One print was produced using a 60-dot screen (the standard for newspaper prints); the other was made with a 100-dot screen. Both copies were judged to be of insufficient quality for diagnosis; although the 100-dot screen produced a more detailed image. Plans for additional testing were dropped due to the expense and technical complications involved.

In March 1973, a meeting of PEACESAT personnel was called to discuss further action. It was agreed that it would be necessary to limit technical preparation and transmission of radiograph information according to several factors existent in remote areas: (1) lack of adequately trained personnel would limit the use of sophisticated printing techniques; (2) lack of resources would limit any major investments in equipment and personnel;

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OF POOR QUALITY

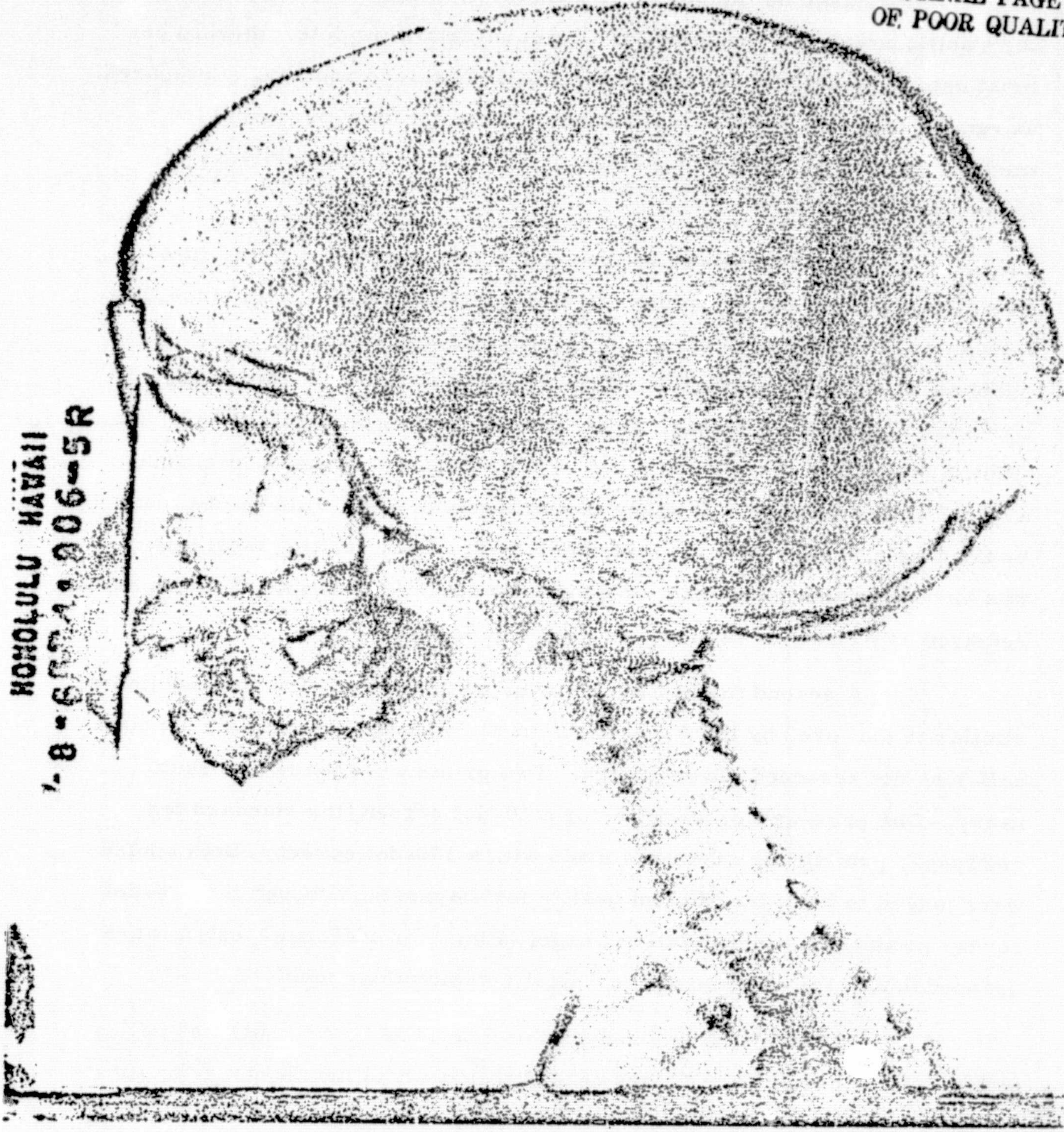

Figure 3.4. Facsimile copy of skull X-ray transmitted via the PEACESAT satellite communications system from the University of Hawaii, Honolulu, Hawaii to Wellington, New Zealand, 13 October 1972.
Note: Some definition lost during reproduction process.

and (3) availability of equipment would determine the feasibility of providing a functional service. Tests were designed to determine the minimum technical conditions necessary for reliable transmissions meeting specified performance criterion.

A third approach was initiated in 1973 to test the effectiveness of positive photograph transmissions. In preparation for the transmission tests, a series of photographic steps were undertaken. A test pattern was established using an x-ray of an aluminum ten-step wedge, the standard tool of radiology technicians, which represents a constant change of density resolution at an increase of one-eighth of an inch per step. A number of films were made using different power levels while holding the exposure time and current level constant (kv = 40, 60, 70, 80, 90; exposure = 1/30 sec; current = 200 mA). The final film selected as a test pattern was made with the following specifications: 80 kv, 200 mA, at 1/30 sec. The contrast among the ten steps can be enhanced by increasing the power and current level or reducing the exposure time; however, the technical capacity to manipulate these variables to any significant degree is not often available in remote areas.

Applying standard photographic techniques, a positive print was produced from the x-ray film. The photographer was requested to duplicate the information as accurately as possible with minimum photography equipment. A 35 mm Nikon camera with Kodak Tri-X Pan film was used, varying the exposure time at a constant speed, to produce a series of negatives. Using a Besseler Enlarger at 40 seconds exposure time, f/5.6, the contact print that most nearly matched the original x-ray image was enlarged to an 8" x 10" glossy print on medium-grained paper. This print was used to test the density capacity of the telecopier and the resolution capabilities of satellite facsimile transmission.

To explore the conditions necessary for optimal density resolution, a series of telecopy pretests were performed in the Xerox

Laboratory in mid-April 1973. This experience provided the specifications necessary for adjustment of the machine to produce maximum resolution. Minimal differences were found using the three models of Xerox telecopiers available on the market. In addition, speed and stylus current variability were explored. It was recommended that: (1) the present TC 400 Telecopier used by PEACESAT is adequate; (2) speed variability does not affect density resolution; however, reduced speed (six minutes) does produce more detail; and (3) adjustment of the stylus current from 32 mA to 26 mA does produce slightly better copy.

Following completion of lab tests at Xerox, the telecopier was adjusted accordingly at the PEACESAT Remote Terminal in George Hall and a compatible unit installed in the Physical Science Building, both on the University of Hawaii, Manoa Campus. Facsimiles of the test print were exchanged 01 May 1973 between these two points, first using the telephone line alone, then coupling the telecopier to the satellite at a speed of six minutes per copy. Result: all copies were comparable in density resolution and detail, at about 30 percent readability, which is similar to results in the lab. However, the satellite transmission from the Physical Science Building to George Hall displayed background noise not apparent on the other copies. The cause was not determined.

A review of these experiences indicated several possible areas for further investigation: (1) image enhancement to produce maximum contrast in the original material; (2) Xerox technical developments to identify critical sensitivity elements in the telecopier machine; (3) investigation of field interference to minimize signal to noise ratio experienced in satellite facsimile transmission; and (4) elimination of built-in deficiencies in satellite receiver.

3.5.3 Fingerprint Transmissions

In December 1972, Project SEARCH of the California Crime Technological Research Foundation (Reference 280) conducted a feasibility demonstration of transmissions of fingerprint data via satellite link. A total of 200 fingerprint cards were transmitted from Los Angeles and Sacramento, California to Tallahassee, Florida, over a two-week period.

In the course of the experiment, the following parameters of the facsimile equipment were varied.

- Vertical and Horizontal Resolution
- Gray Scale
- Scan Speed

The original fingerprint card was scanned at the Los Angeles County Sheriff's Department in downtown Los Angeles. The scanner was capable of varying the resolution and transmission speed. The signal was then processed by the DACOM processing equipment which permitted the digitization of the signal, the variation of the gray scale and the use of data compression techniques. The signal then went through a straight 9600 bit per second digital modem before being transmitted over a 25-mile long C-2 conditioned land line to the satellite earth station located at the Los Angeles International Airport. The signal was then transmitted to the satellite and received at the Sacramento earth station.

The signal output from the modem went two different ways. The first was to the digital tape recorder where the signal was recorded and stored for total recall and later retransmission to Florida. The second path was to the single processing equipment and the facsimile recorder. The output was a photofacsimile copy of the original fingerprint card.

From Sacramento, fingerprint data was transmitted to Florida from one of two sources. The first was the Store and Forward Tape Recorder. The second was from a facsimile scanner located at Sacramento. Data from the tape recorder was processed through a transmitting 9600 bit per second data modem before it went to the earth station outside the building for relay to the satellite. A similar route was also used by the facsimile scanner.

At Florida the signal was received by the NASA Earth Station complex. From the satellite terminal the signal went via coaxial cable to a nearby van containing the receiving facsimile signal processing equipment and the facsimile receiver. Florida acknowledged the receipt of the fingerprint data by using a teletype machine linked via satellite with Sacramento.

In addition to facsimile fingerprint data, criminal history information and fingerprint cards were also transmitted via the Ampex videofile system between Sacramento over satellite to Florida. The experiment configuration was designed to simulate a potential system concept for a national Satellite Communication fingerprint facsimile system. That is, Los Angeles represents a major city local agency; Sacramento represents a state or regional bureau while Florida simulated the role of a national bureau.

Based on a detailed statistical analysis of data, the authors reached the following conclusions.

1. A satellite-based fingerprint transmission system using facsimile equipment to transmit and receive fingerprint images is clearly a technically feasible system, and such a system could also accommodate video transmissions, digital data, and voice transmissions.

2. A number of findings were obtained with respect to the operating parameters of a facsimile system.

- The level of gray scale appears to have little or no effect on the classification of fingerprints. That is, black and white capability appears to produce reliable results equivalent to a full analog (photographic) image transmissions for print classification and identification purposes.

- The resolution of the input facsimile equipment has a minor effect on system performance within the 150 lines per inch to 300 lines per inch resolution tested in this experiment. A resolution of 150 lines per inch appears to be adequate for classification and identification functions.
- The minimum acceptable communication system signal-to-noise quality ratio was found to be 30 db for useful transmission of digital facsimile, and 19 db for analog images.

3. A store and foreward capability, using digital techniques, does not appreciably reduce the transmitted image quality and could be developed for use by identification bureaus.

3.5.4 WEFAX Transmission

During 1967, NASA-GSFC conducted experiments on the feasibility of transmitting weather facsimile (WEFAX) data directly from a central processing facility to widely scattered remote weather stations via ATS satellite.

The material chosen for the experiment consisted of ATS-1 Spin Scan Cloud Cover photographs selected from those processed and sent to the National Environmental Satellite Center (NESC). The picture data was transmitted through ATS-1 using the VHF repeater from the Mojave ATS Station to a variety of Automatic Picture Transmission (APT) stations. The satellite signal format consisted of a 135.6 MHz carrier frequency modulated by a subcarrier of 2400 Hz. This subcarrier was, in turn, amplitude modulated by the facsimile "video" signal of 0 to 1600 Hz yielding a baseband spectrum between 800 and 4000 Hz.

During the year of experimentation, reports were received from 12 to 27 different APT stations. Often as many as 4000 reports were received each month. The cumulative results of this year of reports showed that more than 90 percent of the pictures received were usable and more than 70 percent of these usable pictures were good to excellent. Less than 10 percent of the pictures were unusable. Analysis of the reports indicated that much of the usable reception was caused by local problems. Data from stations at the periphery of the radio coverage area of the satellite showed that APT stations could even receive weather data with a receiving antenna elevation angle as low as three degrees with a 90 percent assurance of usable data.

APT ground station equipment, which was normally used to receive pictures from NIMBUS and ESSA satellites, was modified to receive the WEFAX transmissions from the ATS satellite. In some cases, the required modification was only the addition of a suitable crystal for the ATS frequency. At some locations, where a radio frequency band-pass filter was used, it was necessary to change or modify the filter system. At the end of the experimental period, the WEFAX system was turned over to NOAA by NASA to be used for 16 hours per day as an operational WEFAX system. A survey showed that at the end of 1972 WEFAX data was being received in 100 different countries by more than 550 APT stations. This system was used to transmit WEFAX signals through ATS-1 and ATS-3 for an extended period until an operational Synchronous Meteorological Satellite (SMS) was launched.

3.6 ELECTROCARDIOGRAM (ECG) TRANSMISSION

Patients with arrhythmias (speed disorders or irregular rhythm of the heart beat), and patients who have problems with implanted pace-makers (artificial heartbeat stimulators) often require the immediate attention of an expert who can monitor and interpret the ECG and give advice. The telecommunications satellite offers a means of monitoring pacemaker patients in isolated, rural villages without the necessity of the patient traveling long distances at great personal expense. Undoubtedly, such service can save lives. For this reason, both Alaska and PEACESAT personnel experimented with the transmission of ECG data.

Four major ECG tests were conducted as part of the Alaska Biomedical Experiment with Lister Hill Center (Reference 40). Three of the four used the ATS-1 link and are reported on in this section.

On September 24, 1970, an initial ECG transmission was tested over the ATS-1 link from Wisconsin to Stanford. The electrocardiographs used were Marquette Electronics, Incorporated units, costing over $3,000 each. These units produce and receive three channels of multiplexed tones and require full telephone-channel bandwidth. An audio preamplifier was used to extend the bandwidth of the transceiver for this purpose. Results were somewhat noisy, but were pronounced acceptable by medical personnel.

While a patient is being monitored, access to the communications satellite may not be available or there may be no cardiologist on duty at the other end. Situations such as this pose no problem if the ECG signals are tape recorded, either at the transmitting or receiving location, for later playback.

For the test, a 23-year-old male patient was connected to the electrocardiograph by an unskilled person. The original data was traced by the paper chart recorder, while also being relayed through the satellite, received at the same site and recorded on the tape recorder. The recorded signal was then transmitted back through the satellite, received, and traced by the paper chart recorder for comparison with the original.

The following equipment was used.

Hewlett-Packard 1500A Electrocardiograph, including 12 ECG leads and a single channel strip chart recorder	$850.00
Johnnie Walker PW-9B FM modulator ("transmitter" or "signal conditioner")	95.00
Johnnie Walker PW-11B FM demodulator (receiver)	350.00
Audio preamplifier	100.00 (aprox.)
Ampex FR 1100 tape recorder	10,000. (approx.)

The FM modulator and demodulator are required to translate the ECG baseband spectrum upwards so that it falls within the passband of the telephone circuit. The FM subcarrier is at 1300 Hz. Both units are battery powered. Without these units, low frequencies would not pass through. The telephone circuit passband was modified, however, to achieve a flatter response between 300 Hz and 3300 Hz. The large seven foot track one-half inch FM tape recorder unit was already available at the station. It is not recommended for bush service because of its higher cost and bulk.

Test results were evaluated by personnel of the Stanford Medical School as being very acceptable for clinical purposes. No distortion was evident.

A low-price tape recorder, the Panasonic RQ-2035 ($50.00) was used to record a short ECG tape. This tape, as relayed by ATS-1, introduced undesirable distortion in the form of "artifact" humps in the resulting chart recorder tracings. These artifacts were caused by excessive flutter ($\pm$ .6 percent peak): the recorder does not use a synchronous motor.

The twelve leads employed by most electrocardiographs are redundant. Theoretically, signals from three leads should suffice to reconstruct all x, y, and z dimensions of heart activity. There do seem to be some problems with inconsistent results with the three lead technique. but adequate health aide training should solve this problem.

A low-cost ($220.00) three-lead, shielded "Paramedic Cardiac Screener", manufactured in Vancouver, British Columbia, by Paramedic Instrumentation Limited, was evaluated by the University of Washington in a number of tests, including field trials in several Alaskan bush locations.

To use the device the patient puts a cylindrical electrode in each armpit and a flat metal ground in the mouth. The electrodes then pick up the ECG signal which is amplified by the screener. The amplified signal then frequency modulates a 1.5 kHz subcarrier which is sent by telephone or radio to the receiving station which consists of a telephone (automatically or manually answered) and a tape recorder. The signal which is stored on the magnetic tape, is then played through a decoder (demodulator) which presents the signal (lead one) to an ECG machine in electrical analog form. The ECG machine then prints out lead one in standard form which is diagnostic according to AMA standards for screening, and will adequately demonstrate arrhythmias and pacemaker artifacts.

All three ECG experiments using the ATS-1 link generated traces that were of diagnostic quality. Although each experiment, conducted by the University of Washington, eclipsed those of the others, since it successfully used the least expensive equipment, on location, in the bush, in both live and recorded codes.

Beginning in September 1972, transmissions of electrocardiogram tracings using the PEACESAT system were undertaken over a period of three months to verify the technical feasibility of providing the service of a cardiologist to remote areas in the Pacific Basin that lack the resources to maintain such a specialist.

Electrocardiogram tracings, recorded on heat-sensitive paper strips, were obtained from Straub Clinic in Honolulu for test material. The strips represent graphic recordings of physiologic changes associated with the functioning of the heart. Using the Xerox TC 400 telecopier machine, they were successfully transmitted to the Wellington Terminal (New Zealand), where the copy was judged by the terminal manager to be readable.

Another test was initiated to explore the technical requirements and feasibility of transmitting ECG signals by satellite. This test consisted of two different transmissions. A preliminary transmission to insure that the technical requirements for transmitting ECG signals were compatible with available satellite transceiving equipment was made under the direction of the Medical Electronics Department, Wellington Hospital. Cambridge Electrocardiogram Telemetry System served as interface to recorded audio signals which represent biomedical data signals. This machine is a frequency modulated sub-carrier unit which is hooked up to an electrocardiograph. It is designed to either send or receive ECG signals by any voice communication system. The recorded audio signals, originating at the Manoa Terminal, were transmitted by satellite to Wellington where the tones were demodulated by the Cambridge data set and were graphically reproduced on electrocardiogram strips. Observers at the Wellington Terminal judged the material to be readable.

The final transmission was made under real-time conditions using a live patient at Kahuku Hospital, located about 45 miles from the Manoa Terminal. Kahuku technicians hooked a patient to the EKG machine and transmitted one full 12 lead ECG for one minute. The signal, an FM tone sub-carrier, was sent over common carrier lines to the Manoa PEACESAT station. This received signal was coupled using the Universal Hybrid Coupler unit and transmitted to Wellington over the ATS-1 satellite. At the Wellington terminal these signals were tape recorded and put onto a de-modulator, then onto an ECG recorder for print out. The EKG tape from Kahuku was mailed to Wellington for comparison with the transmitted signal print out. The resulting tracings were reviewed by a cardiologist who judged them to be of sufficient quality for diagnosis. Copies of these transmissions are shown in Figure 3.5.

3.7 VHF AND UHF PROPAGATION EXPERIMENTS

The reliability of electromagnetic signals in a space system is dependent upon the characteristics of the earth's atmosphere. Two irregularities that effect signal propagation are ionospheric scintillation and multipath fading. These phenomena are especially noticeable when using VHF and UHF bands.

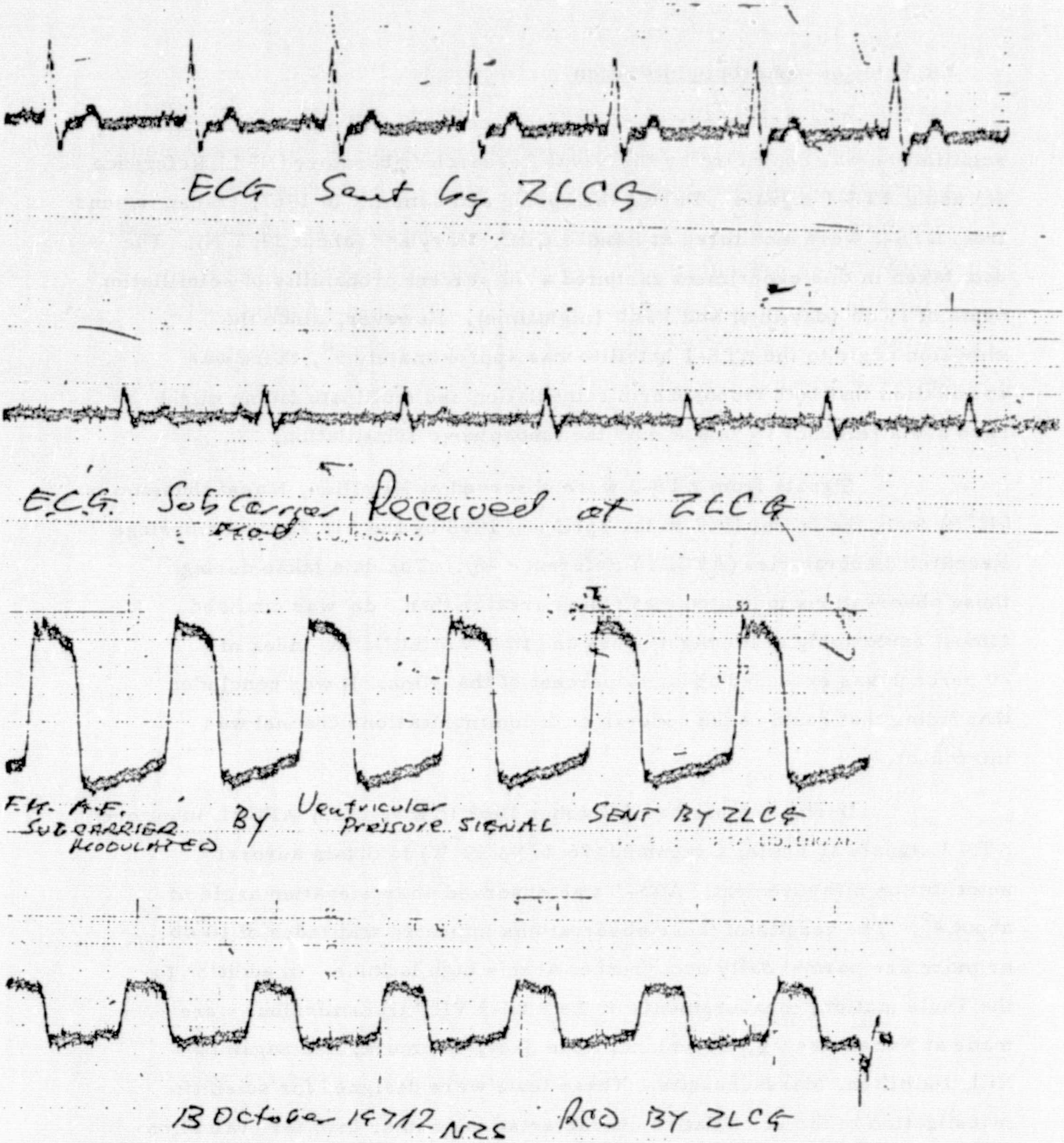

Figure 3.5. First test of electrocardiograph signal transmissions via the PEACESAT satellite communications system Wellington Polytechnic, Wellington, New Zealand; University of Hawaii, Honolulu, Hawaii; University of the South Pacific, Suva, Fiji. Medical Electronics Department, Wellington Hospital. 13 October 1972 (Signal quality can be substantially improved by technical adjustments.)

<u>Note</u>: Some definition lost during reproduction process

3.7.1 Ionospheric Scintillation

The first experiment to report comprehensively on ionospheric scintillation was conducted by the Naval Research Laboratory (NRL)(Reference 46) using ATS-1 signals. During the spring and summer of 1967, transmissions from ATS-1 were monitored at Randle Cliff, Maryland (about 39.5°N). The data taken in this experiment exhibited a 50 percent probability of scintillation depth of 10 db (daytime) and 14 db (nighttime). However, since the elevation angle to the ATS-1 satellite was approximately 5°, there was speculation that both tropospheric scintillation and multipath fading might have had a tendency to "mask out" the ionospheric scintillation.

Signals from ATS-3 were observed at Hamilton, Massachusetts (42°N) from the fall of 1967 to the spring of 1968 by the Air Force Cambridge Research Laboratories (AFCRL) Reference 48). The data taken during these observations indicated that fading greater than 3 db was confined almost exclusively to the night hours and that a scintillation index of 20 percent was exceeded about 10 percent of that time. It was concluded that fading that could cause concern on a communications channel was infrequent.

During the period of October 1968 to May 1969, AFCRL monitored ATS-3 signals at Thule, Greenland (76.6°N, 69°W) to obtain auroral scintillation measurement. ATS-3 was observed at an elevation angle of about 4°. The results of these observations indicated that fades of 10 db or more are normal daily occurrences at this high latitude. In addition to the Thule station, measurements of the ATS-3 VHF transmissions were made at Narssarssuag, Greenland; Rude Skov, Denmark, and Sagamore Hill, Hamilton, Massachusetts. These tests were designed for scientific investigation of the scintillation characteristics, rather than for evaluation of communications systems performance. However, the intensity and time duration of the scintillations suggested that the ionospheric scintillation phenomena would be more damaging to communications in the auroral and polar regions than in the mid-latitude regions.

More recent auroral scintillation tests were conducted between July 1971 and April 1972 at Churchill, Manitoba (geomagnetic latitude 69°) by the Canadian Department of Communications (Reference 50). During these tests, 1550 MHz signals from ATS-5 were monitored simultaneously with 254 MHz signals from LES-6. The 254 MHz signals exhibited relatively deep fading margins up to 12 db or more as opposed to the 1550 MHz fading margin of less than 1 db.

The effects of scintillation in the equatorial zone was investigated in an experiment conducted at Ancon, Peru (geographical latitude 11°46'S) between March 11 and April 9, 1971 encompassing the vernal equinox period (Reference 52). Signals at 1550 MHz and 136 MHz were monitored simultaneously in an attempt to obtain information on the frequency dependence of equatorial scintillation. The data taken during this period exhibited a distinct diurnal trend with the VHF scintillation sometimes exceeding 30 db and the L-band peak-to-peak magnitudes reaching 6 db. A cumulative distribution of L-band data taken previously (fall equinox 1970) at the same location indicated that the probability of 2 db fades would be about 0.1 percent while similar data at 136 MHz indicated about 11.5 db for 0.1 percent.

3.7.2 Multipath Fading

Multipath fading is a problem encountered in transmitting and receiving between mobile stations and satellites. Because the station is moving, two transmission paths are possible: a direct path and a reflected one. The multipath fading problem is considered more severe for airplanes than ships because of the higher speed. Because of the complexity of the problem, two experiments were devised and conducted to investigate the characteristics of multipath fading employing an aircraft as a test vehicle.

The first experiment was conducted on a Douglas DC-8 and a Boeing 707 aircraft in 1967 (Reference 53). A series of tests were performed with the VHF repeaters on the ATS-1 and ATS-3 satellites employing a 30 kHz test spectrum designed to permit evaluation of the correlation bandwidth of the medium.

One of the results of the tests was a three-dimensional fading model with amplitude, time, and frequency as coordinates. The model demonstrated a selective fading pattern with a period of approximately five seconds and a slight time skew over a $\pm$ 12 kHz band. The conclusions drawn from these tests suggested that multipath fading could be expected to cause short term variations of up to 13 db at the lower elevation angles from 0° to 30°.

In 1970, the FAA (Reference 54) began a series of tests) to investigate L-band multipath fading. A KC-135 was instrumented with an L-band system including a quad-helix antenna, a crossed dipole array and port and starboard slot dipole antennas. The eight element crossed dipole array was installed to permit reception of the sea-reflected signals with some degree of discrimination against the direct signals.

An initial series of tests were conducted in 1971 directed primarily toward evaluating the effect of multipath on the accuracy of ranging between the satellite and aircraft. The results of these tests suggested that vertically polarized signals were less affected by multipath than horizontally polarized signals and also that greater interference is obrained as the evaluation angle increases.

3.8 MILLIMETER WAVE EXPERIMENTS

The recent history of radio communication has been characterized by a continual extension to higher and higher frequency bands to support the increasing data handling requirements of an expanding technology. The frequency bands between 10 and 300 GHz, commonly called "millimeter waves", offer a promising area of reducing the overcrowded situation in the lower bands. In addition to relieving spectrum crowding, millimeter wave systems offer extremely wide bandwidth capabilities, high gain-small aperture antenna characteristics, and reduced size and weight of components.

A Millimeter Wave Propagation Experiment was launched aboard the Applications Technology Satellite (ATS-5) on August 12, 1969. The prime objective of this experiment was to provide sufficient information on the propagation characteristics of the earth's atmosphere so that this relatively unexplored and unused portion of the electromagnetic spectrum can be most effectively utilized for communications and data handling applications.

The ATS-5 Millimeter Wave Experiment has been providing amplitude and phase measurements on two indepedent test links at 15.3 GHz (satellite-to-earth) and at 31.65 GHz (earth-to-satellite) during measured and defined meteorological conditions. Several stations in the continental U.S. and Canada have been operating with the satellite transmission since October 1969.

NASA operationally supports a number of stations which provide a representative sample of the predominate weather profiles in the continental U.S. These stations are as follows.

> The NASA/GSFC Transportable Station located at Rosman, North Carolina (receive and transmit capability).
>
> The Naval Electronics Laboratory Center (NELC), La Posta, California (receive capability).
>
> The Ohio State University (OSU), Columbus, Ohio (two receive sites on variable base line for spatial diversity tests).
>
> University of Texas (U of T), Austin, Texas (receive capability).

In addition, a number of independent experimenters are participating in downlink measurements with the ATS-5 satellite. Table 3.3 lists all of the stations presently equipped to operate with the ATS-5 Millimeter Wave Experiment, in order of increasing elevation angle.

TABLE 3.4

ATS-5 MILLIMETER WAVE EXPERIMENT PARTICIPATING STATIONS

STATION		LATITUDE (NORTH)	LONGITUDE (WEST)	NOMINAL ELEVATION ANGLE	ANTENNA SIZE	RECEIVER TYPE
AIR FORCE CAMBRIDGE RESEARCH LABS, BEDFORD, MASS.		42°23'	71°15'	30°	28 FT.	MCW
DEPT. OF TRANSPORTATION, CAMBRIDGE, MASS.		42°36'	71°29'	30°	10 FT. (2)	SB
COMMUNICATIONS RESEARCH CENTRE, OTTAWA, CANADA	PRIME SITE	45°21'	75°54'	30°	30 FT.	SB
	SECOND SITE				8 FT.	MCW
ROME AIR DEV. CENTER, ROME, N.Y.		43°08'	75°37'	32°	15 FT.	SB
BELL TELEPHONE LABORATORIES, HOLMDEL, N.J.		40°23'	74°11'	34°	20 FT.	CW
U.S.A.S.C.A., LAKEHURST, N.J.		40°00'	74°25'	34°	30 FT.	MSB
COMMUNICATIONS SATELLITE CORP., CLARKSBURG, MD		39°12'	77°16'	36°	15 FT.	SB
GODDARD SPACE FLIGHT CENTER, GREENBELT, MD.	RECEIVE SITE	39°42'	76°48'	36°	15 FT.	MCW
	TRANSMIT SITE*				10 FT.	-
NAVAL RESEARCH LABORATORIES, WALDORF, MD				36°	60 FT.	MCW
OHIO STATE UNIVERSITY, COLUMBUS, OHIO	FIXED SITE	40°00'	83°02'	39°	30 FT.	MSB△
	MOBILE SITE				15 FT.	MSB△
GODDARD TRANSPORTABLE STATION, ROSMAN, N.C.*		35°12'	82°53'	42°	15 FT.	MSB△
ESSA WAVE PROP. LAB., BOULDER, COLO.		40°00'	105°16'	44°	10 FT.	MCW
WESTINGHOUSE GEORESEARCH, BOULDER, COLO.		40°00'	105°09'	44°	12 FT.	MCW
MARTIN MARIETTA CORP., ORLANDO, FLA.		28°26'	81°26'	48°	12 FT.	MSB
NAVAL ELECTRONICS LABORATORY CENTER, SAN DIEGO, CAL.		32°40'	116°26'	50°	60 FT.	MSB△
UNIVERSITY OF TEXAS, AUSTIN, TEX.		30°23'	97°43'	54°	10 FT. (2)	MSB△

* -TRANSMIT STATION
△-NASA/GSFC PARTICIPATING STATION
MSB -MARTIN SIDEBAND RECEIVER
MCW-MARTIN CW ONLY RECEIVER
SB -SIDEBAND RECEIVER
CW - CW ONLY RECEIVER

Millimeter waves are attenuated by absorption and scattering as the waves pass through the atmosphere. The following fade duration data was obtained at Rosman.

Fade Level	Less than 10 Sec.	No. of Occurrences Between 10 and 100 Sec.	Greater than 100 Sec.
$\geq$ 6 db	912	54	3
$\geq$ 9 db	857	49	2
$\geq$ 15 db	134	11	2

The higher number of fades of less than ten seconds duration reflected in large part the effects of system noise, since most of these fades were in the region of two to five seconds. The fades of duration ten seconds or greater were caused predominantly by atmospheric attenuation.

The effects of rain rate on attenuation was also investigated at Rosman. While good correlation of attenuation with rain gauge measurements has been demonstrated for terrestrial millimeter wave links, the extension to earth-satellite links could not be demonstrated (Reference 238). The poor correlation was probably due to one or a combination of the following: a potential offset in the data; the effect of wind, air turbulence, and foilage interference on the rainfall measurements; a "nonstandard" drop size distribution in the signal path; and finally, the limited dynamic range of the receiving system at the higher rainfall rates.

The use of path diversity to reduce the percentage of time a given amount of path attenuation is exceeded is reasonable because the precipitation characteristics of the two paths at a given time may differ considerably. During the 1970 time period, OSU conducted a diversity experiment at a spacing of 4.03 Km. From the data collected, it was shown that path diversity would substantially reduce the outage time of a system for high attenuation levels. However, the amount of diversity improvement might differ with different locations for the same site separation since cell size and cell movement may differ.

From the preliminary data available as a result of the ATS experiments, considerably more is known now than previously regarding millimeter wave propagation between the ground and satellites. More data will be required from future experimental programs before operational systems are built and installed. However, these early results indicate that if space diversity with ground station separations of a few miles are used, the use of these frequencies is fully practical for satellite communications, at least in temperate climates. In many cases, it may be practical without this diversity.

APPENDIX A

KEYWORD - ACCESSION NUMBER LISTING

The material presented in the body of this report was compiled from over 300 reports each of which has been assigned an accession number. The reference numbers in the text correspond to these accession numbers. A source of much of the technical information was an unpublished report entitled "Applications Technology Satellite Series", prepared by Westinghouse for NASA-GSFC (Reference 137). In some instances the information in the Westinghouse report was transcribed directly.

In addition to the summary of user experiments, UDRI has generated an ATS information system. Pertinent information such as author, subject category, abstract, and keywords were transcribed to IBM cards and various listings made from these cards. This appendix is a listing of keywords identified by accession number.

APPENDIX B

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