122420

HIGH POWER S-BAND EXPERIMENT STUDY

OBJECTIVES, DESCRIPTION, PLANNING AND OPERATION OF EXPERIMENT FOR ATS-G SPACECRAFT

ROBERT M. WALP
SPACE AND COMMUNICATIONS GROUP
HUGHES AIRCRAFT COMPANY
P. O. BOX 92919
LOS ANGELES, CALIFORNIA 90009

(NASA-CR-122420) HIGH-POWER S-BAND EXPERIMENT STUDY: OBJECTIVES, DESCRIPTION, PLANNING AND OPERATION OF EXPERIMENT FOR ATS-G SPACECRAFT Final R.M. Walp (Hughes Aircraft Co.) Mar. 1972 64 p CSCL 22C G3/30
N72-24887
Unclas
30147

MARCH 1972
FINAL REPORT

PREPARED FOR
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND 20771

SCG 20124R

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle HIGH POWER S-BAND EXPERIMENT STUDY/Objectives, Description, Planing and Operation of Experiment for ATS-G Spacecraft

5. Report Date March 1972

6. Performing Organization Code

7 Author(s) Robert M. Walp

8. Performing Organization Report No.

9. Performing Organization Name and Address
Space and Communications Group
Hughes Aircraft Company
P.O. Box 92919
Los Angeles, California 90009

10. Work Unit No.

11. Contract or Grant No. NAS5-21671

12. Sponsoring Agency Name and Address
Goddard Space Flight Center
Greenbelt, Maryland 20771
Technical Officer: Albert Whalen, Code 751

13. Type of Report and Period Covered Final - 20 Oct. 1971 to 18 Feb. 1972

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract Objectives of experiment are: 1) to demonstrate high power technology at S-band frequencies in orbiting spacecraft, 2) to employ high power carrier from spacecraft for conducting interference measurements with Instructional Television Fixed Service (ITFS) systems, and 3) to provide means for performing educationally oriented applications experiments. Experiment organization and operation is described. Experiment hardware for flight on the ATS-G spacecraft is described. Earth stations designed for the experiment as well as other special ground equipment are described.

17. Key Words (Selected by Author(s)) high power satellite communications, frequency sharing, interference measurements, educational applications of satellite technology

18. Distribution Statement

19. Security Classif. (of this report) Unclassified

20. Security Classif. (of this page) Unclassified

21. No. of Pages

22. Price* 5.25

*For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.

PREFACE

The objective of this report is to describe the results of work done on Contract NAS5-21671 to further define the objectives, the hardware, and the plans for the High Power S-Band Experiment for the ATS-G Spacecraft.

The scope of work represented in this report included revising and updating the experiment configuration as originally proposed to NASA in December 1969 under the title, "High Power S-Band Experiment for ATS-G Spacecraft", Hughes Reference No. 69(22)12157/C0963, and subsequently modified by letter of 7 January 1971 from Robert M. Walp of Hughes Aircraft Company to NASA, Code SCS, to the attention of J. R. Burke. The revised configuration represents concepts that have evolved from a continuing dialogue which has developed between the aerospace and educational communities since the original proposal.

Preliminary planning effort was accomplished in order to prepare tentative program schedules and specifications for spacecraft experiment hardware and associated software items represented as Phase I of the experiment. Additional effort was directed toward developing preliminary estimates for scheduling and costing Phase II, for performing interference measurements, and Phase III, demonstrating communications link performance for applications experiments.

CONTENTS

1. INTRODUCTION

This report summarizes the results of a study to develop and define requirements for the High Power S-Band Experiment for the ATS-G spacecraft. It is based on material prepared for the First and the Second Interim Reports issued during the High Power S-Band Experiment Study (NASA Contract No. NAS5-21671) dated 4 December 1971 and 18 February 1972, respectively.

The initial sections of this report discuss the objectives, performance, and operation of the experiment. Next, the spacecraft hardware and ground equipment are defined and interface considerations described. Experiment lifetime is also covered, a test plan outline is given, and plans for data acquisition and data processing, reduction, and analysis are discussed.

2. OBJECTIVES OF EXPERIMENT

The High Power S-Band Experiment is intended to demonstrate high power technology for synchronous spacecraft at frequencies in the vicinity of 2.5 GHz. It provides a means for conducting interference measurements between space and terrestrial systems utilizing these frequencies. The spacecraft hardware and ground equipment developed for this program will also serve as a facility for conducting various preoperational experiments for the development and demonstration of educational applications of communication satellites. The above objectives are separated into three phases, each an experiment in itself. These are described in more detail in the following paragraphs.

HIGH POWER TECHNOLOGY (PHASE I)

The allocation of the frequency band between 2500 MHz and 2690 MHz for satellite communications by the World Administrative Radio Conference (WARC) in mid-1971 implies an increasing demand for S-band transmitters qualified for space use. Some applications will require higher power devices than are now available. Originally it was the primary objective of this experiment to develop a high power traveling wave tube amplifier (TWTA) and associated equipment and to evaluate and demonstrate its performance in space. High efficiency operation becomes increasingly important at higher power levels in order to optimize prime power utilization and to minimize thermal dissipation problems. To obtain the highest RF power output consistent with projected TWT development trends, which are also compatible with power and thermal restrictions imposed on ATS-G experiments, a development goal to produce a TWT with 200 watt output at 60 percent efficiency was established. The overall TWTA efficiency goal, including power supply, is 50 percent. As a further means for conserving spacecraft prime power, the TWT was specified to operate at relatively high efficiencies at saturated output power levels as low as 50 watts.

In addition to the development of a high power amplifier, capable of operating at high efficiencies over a range of power from 50 to 200 watts, this phase of the experiment will also include the development of the ancillary RF equipment needed for a complete transmitter.

The successful completion of the experiment hardware and its demonstration in orbit upon the ATS-G spacecraft will benefit the community of potential users of space communications at S-band frequencies by establishing the feasibility of employing such techniques at an order of magnitude higher power levels than are now available. Potential applications range from deep space probes to transmissions of instructional programming to low cost receiving installations on earth. In addition to the data pertaining to the utilization of high power levels in the space environment (of special interest are problems associated with thermal transfer and secondary electron resonance phenomena), it will be possible to obtain detailed information on propagation for comparison with theoretical predictions for these frequencies.

INTERFERENCE MEASUREMENTS (PHASE II)

In the United States one of the principal uses of 2500 to 2690 MHz band is for the Instructional Television Fixed Service (ITFS). This service is used by school administrations for the distribution of instructional programming. A typical installation comprises a number of receiving installations clustered around a central omnidirectional transmitter. Theoretical analyses have been made to establish criteria for sharing of common frequencies between space and terrestrial systems, including the 2500 to 2690 MHz band. Due to uncertainties in the parameters used in deriving these criteria, a number of assumptions have been made, possibly restricting shared operation more than necessary. It is the objective of Phase II to utilize the high radiated power from the S-band experiment to validate the existing standards.

This effort will provide empirical data that will help reduce uncertainties regarding many of the parameters affecting the sharing of common frequencies between space and terrestrial services. These data should lead to increased opportunities for the shared use of the spectrum, not only in the S-band range of direct interest here but, by extrapolation, in other bands as well.

APPLICATIONS EXPERIMENTS (PHASE III)

The educational community is becoming actively interested in utilizing the S-band frequencies in a number of ways for instructional purposes. Before serious planning for operational systems can be initiated, a substantial amount of experience in the use of satellite communications is needed to evaluate the effectiveness of various techniques, to determine overall costs, and to demonstrate feasibility. The S-band experiment for ATS-G will have ample power and sufficient operational flexibility to allow a number of types of circuits to be established, providing opportunities for experimenting with many types of systems. The objective for Phase III is to demonstrate the types of communications links that can be obtained through the satellite and to make them available for educational experiments as proposed, and to be conducted, by the academic community.

The data derived from Phase III of the experiment plus the operational experience gained by the end users in the educational field will provide an improved foundation upon which to build future systems, either experimental or operational. At this time the educational users who have much to gain from satellite communications are generally unaware of the capabilities and limitations of the technology. Until they become better acquainted with the nature of this service, meaningful progress toward viable applications will be slow. Tests on preoperational systems designed for instructional purposes will provide a background for development of improved user requirement criteria and, ultimately, better long-range planning efforts.

3. PRELIMINARY PERFORMANCE ASSESSMENT

The three phases of this experiment differ greatly in their objectives and their nature. Some aspects of the experiment performance can be accurately predicted, while others, especially the applications experiments, depend greatly upon user-prepared software and cannot be judged yet. Each Phase is briefly discussed below.

PHASE I – HIGH POWER TECHNOLOGY

This effort involves the development and in-orbit testing of advanced technology. As no revolutionary concepts will be employed, it can be assumed that the technology can be successfully developed. Once developed it is highly probable that the high power amplifier will perform in accordance with all specifications in space. The small earth stations developed for this experiment represent no risk whatsoever to mission success as they are employed to demonstrate the type of link performance that can be obtained with representative systems. Except for extremely low elevation angles at the earth stations, propagation at S-band frequencies is well understood; consequently, overall communications link performance will be essentially as predicted.

PHASE II – INTERFERENCE MEASUREMENTS

This phase of the High Power S-Band Experiment offers an opportunity to collect some significant technical data. These measurements were discussed in Section 2 and are expected to contribute greatly to more accurate modeling of situations where space and terrestrial systems in the same geographic area share common frequencies. Unless existing sharing criteria are grossly in error, the ability to use the high power S-band capability to make comprehensive evaluations of the subjective effects of interference will be somewhat hampered by lack of sufficient spacecraft power. It has been shown that at high elevation angles it may not be possible to detect any observable interference from the satellite into the ITFS system. At lower elevation angles, however, it should be possible for observers to notice such interference, especially in the worst geometry cases. Despite this shortcoming, it will be possible to measure relative signal levels from the competing systems as received by terrestrial equipment and, from these data, make accurate determinations of the conditions under which sharing is possible.

PHASE III – APPLICATIONS EXPERIMENTS

It is premature to make any firm predictions regarding Phase III experiments because they are to be performed by users in the educational community. If these experiments are carefully planned to accurately simulate valid systems meeting real educational requirements, and if high quality educational software is employed so that software shortcomings do not jeopardize results, this phase of the High Power S-Band Experiment will contribute greatly to improved understanding of the applications of space technology in the field of education.

4. EXPERIMENT OPERATION

HIGH POWER TECHNOLOGY (PHASE I)

From a functional viewpoint, Phase I of the High Power S-Band Experiment comprises two tasks: 1) collection and analysis of data on the spacecraft experiment hardware and 2) collection and analysis of data on propagation of RF energy at S-band frequencies.

Performance of spacecraft hardware will involve operation of the transmitter at its various power levels while correlating performance, as measured on board and transmitted to earth via telemetry channels against that measured directly from signals received at the NASA ground stations. Because the power dissipated by the transmitter approaches the maximum capability of the spacecraft, it should be possible to make a significant check on theoretically predicted performance by observing (via telemetry) the change in TWT temperature with time after switching to the high power mode. In addition to measuring transmitter power conversion performance, routine tests will be conducted to verify experiment hardware performance as a communications repeater and to measure amplitude and phase response, stability, and overall performance with various signal formats (i.e., video, multiple carriers, pulse, etc.) in order to establish a standard for determining performance of earth stations used in Phases II and III and for a reference in making propagation measurements.

The S-band experiment can be used for making propagation measurements, although it is not specifically designed for this purpose. Because no beacon capability is provided, any S-band signals used in such tests will have to be derived from signals transmitted to the spacecraft. This rules out the possibility of making precise determinations of certain types; however, much data can be collected with respect to ionospheric propagation at low elevation angles in the polar regions. For example, signals transmitted to the spacecraft at C-band (6 GHz) from the Mojave station will be essentially undisturbed in relation to the observations of interest at S-band frequencies as received at near zero elevation in Alaska. The experiment hardware can be operated in a wideband (190 MHz) mode utilizing linear antenna polarization, allowing many significant data to be obtained. It is anticipated that a substantial amount of operating time under Phase III will be done with the antenna pointed toward Alaska, thus making it relatively easy to provide for propagation measurements with minimum disruption to other operational schedules.

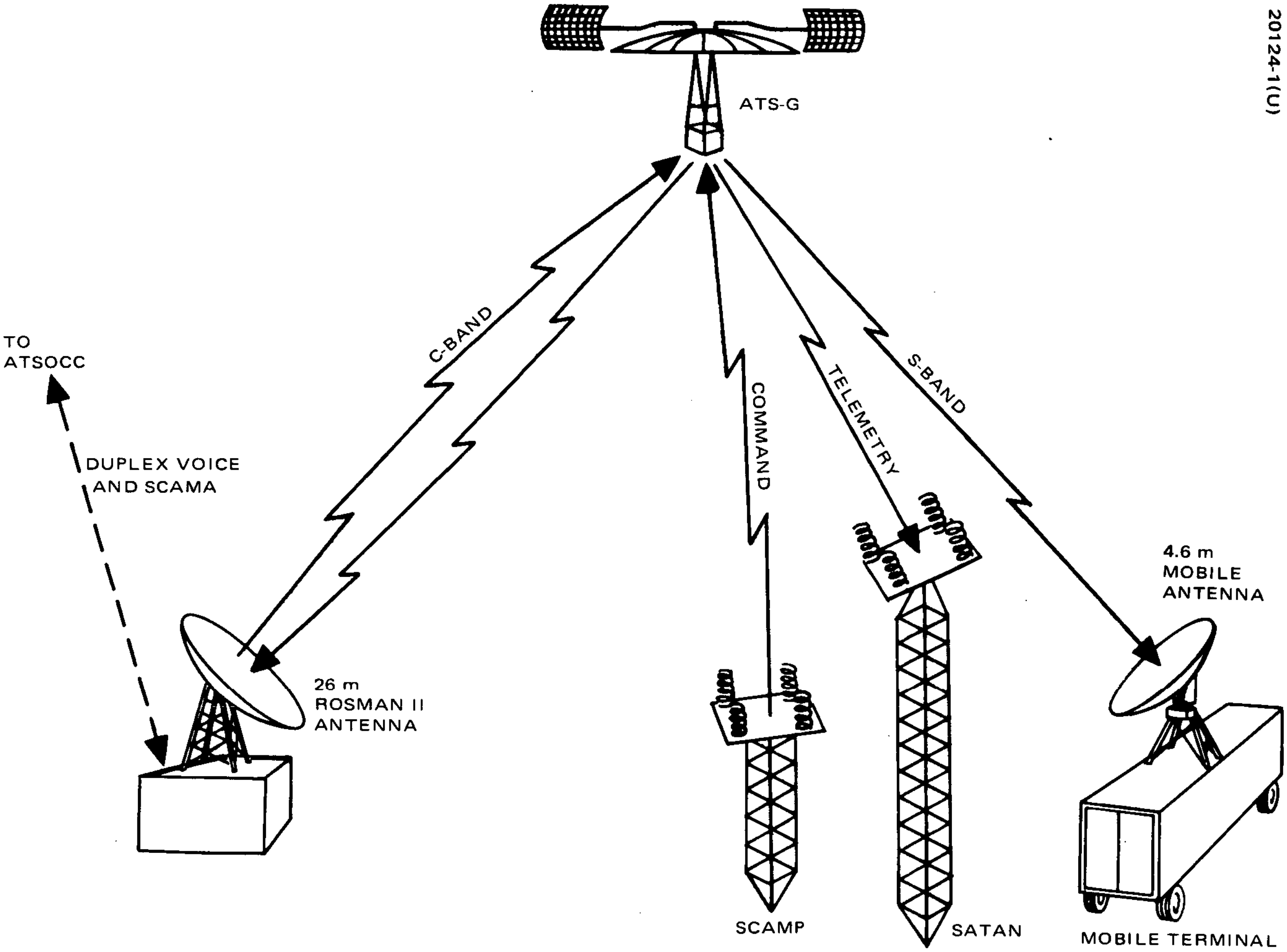


Figure 4-1. Phase I-A System

The basic system for evaluation of the high power S-band hardware performance comprises the ATS-G spacecraft, the 26 meter (85 foot) Rosman II antenna for C-band communications, the 4.6 meter (15 foot) mobile terminal for S-band communications, plus the SATAN and SCAMP facilities for telemetry and command (see Figure 4-1).

For Phase I-B, propagation measurements, control will be shifted to the Mojave station to obtain optimum C-band propagation conditions. (If a master station is installed at Stanford, California for Phase III of the experiment, it could be employed, instead of Mojave, for operational simplicity.) The mobile terminal will not be required for these measurements, but will be supplanted by pairs of receiving installations employing 3 meter antennas of orthogonal polarization at specifically determined locations in Alaska. During periods when the S-band transmitter is being used for Phase III experiments, these receivers will operate in a wideband mode to be compatible with the television or other signals being transmitted. Scheduled operation in a narrowband mode will be provided on a periodic basis, however, specifically to obtain better propoagation data; at these times the receiver predetection bandwidth will be reduced to achieve higher carrier-to-noise ratios.

INTERFERENCE MEASUREMENTS (PHASE II)

Phase II of the S-band experiment utilizes its high power capability to provide a source of interference to an existing ITFS system. Conversely, the effect of the transmitter of an ITFS system upon satellite system earth stations can be evaluated. Because the geometrical relationship between the satellite and the terrestrial system is of prime interest, it is necessary to have as wide a range of elevation angles to the satellite as possible. Consequently, the selection of a system as close to the earth's equator as possible is desirable in order to obtain the highest possible elevation angle. (The satellite can then be moved to get arbitrarily low elevation angles.) The system best suited for these tests is operated by the School Board of Broward County (Ft. Lauderdale), Florida and is tentatively selected for participation.

Potential interference effects between satellite services and terrestrial users have been previously investigated from a theoretical standpoint. In particular, United States Study Group IV of the CCIR and a CCIR Special Joint Meeting have addressed themselves to this problem. Calculations pertinent to Phase II have been presented in the "Second Interim Report for the High Power, S-Band Experiment Study;" it may be referred to for additional information.

In addition to establishing valid protection criteria for terrestrial systems, it is also the purpose of the experiment to determine the protection required for satellite earth stations from ITFS transmitters. Assuming a 3 meter diameter antenna for community reception of satellite broadcasting signals, the closest approach to an ITFS transmitter for

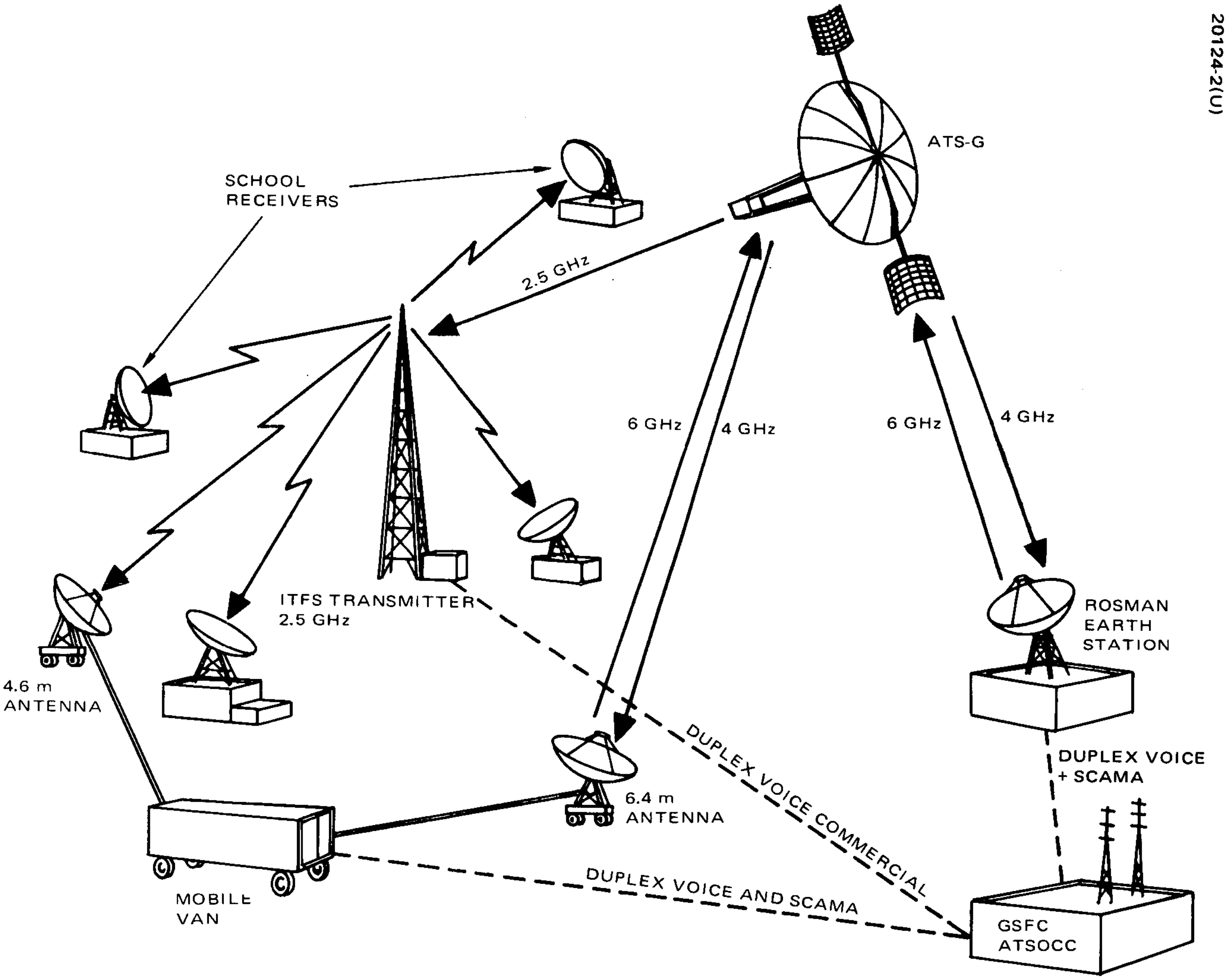


Figure 4-2. Interference Measurement Experiment Configuration

interference free reception is beyond the 50 km maximum ITFS coverage area. Again, this affords the opportunity to establish on an experimental basis the criteria for frequency sharing between the two systems.

With a transportable or mobile earth station, satellite signals, terrestrial signals, and both combined, can be measured under all possible favorable and unfavorable geometric conditions, including the use of buildings or variations in terrain for site shielding.

Ideally, measurements of desired and interfering carrier powers should be made at numerous ITFS coverage area locations. Since ITFS receiver antennas vary in size and orientation depending on their distance from the transmitter, considerable data on discrimination against satellite signals can be obtained. At each selected location the desired carrier power plus noise power, C + N, is measured. The ITFS transmitter is turned off, the satellite transmitter is activated, and the interfering carrier power plus noise, I + N, is measured. Then the noise power alone is determined. From these data, C, I, and C/I are determined. Then with full modulation on both systems, the subjective effects of a given C/I can be determined by observing an ITFS TV monitor. The satellite power is varied in calibrated steps to determine the relationship between C/I and subjective interference effects. From these data, the required protection ratio is obtained.

Figure 4-2 shows the relationship of the major components of the experiment. Signals will be transmitted to the spacecraft from Rosman. The mobile terminal will be used to calibrate signals received from the ATS-G as well as evaluate possibilities for obtaining effective shielding from the ITFS transmitter. Portable test equipment, not shown, will be employed to make signal level measurements at a selected number of ITFS receiving installations. These tests will be made for several spacecraft orbit locations in order to obtain data for a range of elevation angles. The initial series of measurements will be made with the spacecraft located near the longitude of Ft. Lauderdale, approximately 80°W, to obtain the maximum elevation angle. Tests will be made as the spacecraft is moved toward the west until an elevation angle as low as 10 degrees is obtained; this corresponds roughly to an orbit location at 150°W. The spacecraft will then be moved to a more easterly location for more permanent operational use.

APPLICATIONS EXPERIMENTS (PHASE III)

User experiments are to be performed during Phase III of the High Power S-Band Experiment. These experiments will be conducted by a number of activities representing the federal and state governments, regional educational associations, public broadcasting, colleges and universities, etc. NASA's task will be to make the spacecraft available to approved experimenters and to demonstrate representative types of small earth stations needed to establish various communication services. At this time only generalized plans for these experiments have been made. Before

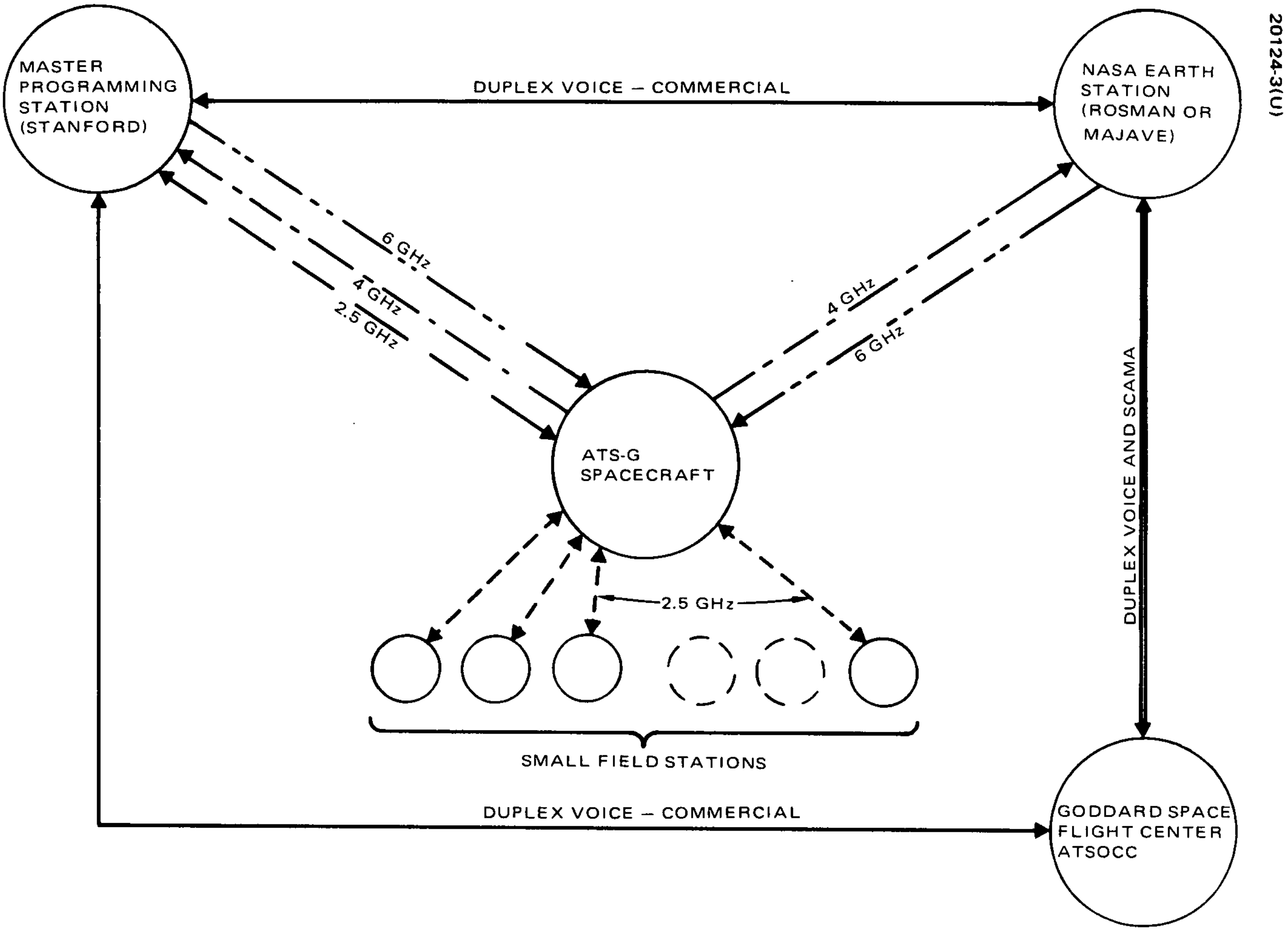


Figure 4-3. Applications Experiments Communications Links (Generalized)

detailed planning can be done, additional meetings will be required among the principal investigator's office, interested members of the educational community, and ATS projects personnel to coordinate the planning effort. It will be necessary to establish operating constraints such as the hours per day for such experiments, prime power availability, orbit and pointing conditions, etc. This will require close cooperation among all users of the spacecraft and demand the careful selection of educational experiments. It will be necessary to limit the user experiments to a reasonably small number so that each will have ample time for significant results. Only experiments that make good use of the unique features of the S-band capability will be developed; uses that are appealing only because the satellite link represents a free service will be discouraged. It is further expected that users will supply experiment software and the needed ground equipment. NASA's function would be only to develop and make available designs for the ground stations.

Of the potential areas for user experiments, the State of Alaska offers many opportunities. Because of the large distances between virtually isolated communities, the terrain, the weather, and the relatively large percentage of natives, Alaska presents unique problems which emphasize the need for modern telecommunications and, to a greater extent than elsewhere in the United States, require applications where communications by satellite is relatively superior to other means. The S-band experiment offers means for transmitting instructional television to schools and to employ student response techniques, either voice or data, for feedback in real time lecture sessions. Medical communications can be expanded to include full duplex television for consultative services and to employ multiple access demand assignment (MADA) telephony for high quality interconnection throughout the state.

The Federation of Rocky Mountain States has aggressively begun to exploit the S-band capability to be provided on ATS-F. The increased power available from the ATS-G S-Band Experiment will enable additional user experiments to be made in the Rocky Mountain area on an improved basis, as well as their extension to other areas, including the Appalachia region.

An interuniversity network can be established to interconnect a number of centers of higher learning. Experimental circuits of many types can be established so that various resources may be shared among many users. This would provide a broad base for supporting development of high quality software for instructional television, library access, computer assisted instruction, and other purposes. Computers at large institutions could be made available to small schools, and large interconnected computer networks could be established and operated.

The main components for all applications experiments are shown schematically in Figure 4-3. The system comprises the ATS-G spacecraft, one of the NASA earth stations at either Rosman or Mojave, a master programming station tentatively to be located at Stanford University, an arbitrary number of small earth stations in the field, and the ATS Operation Control Center (ATSOCC) at the Goddard Space Flight Center. The primary

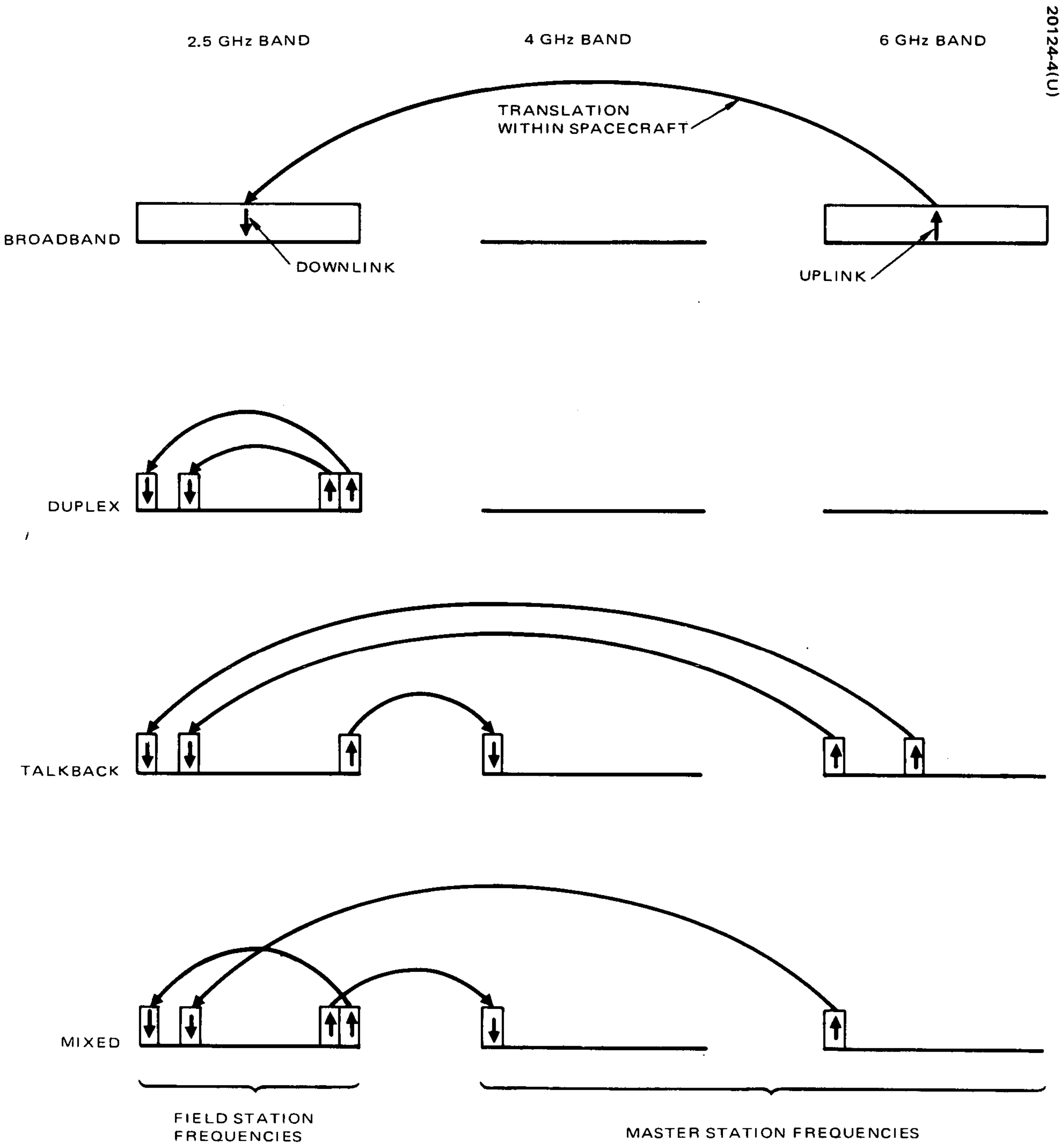


Figure 4-4. Experiment Operational Modes

function of the NASA earth station and the ATSOCC is to maintain control of the spacecraft; their role as direct participants in the educational user experiments is otherwise limited. The small stations utilize frequencies within the 2500 to 2690 MHz band; some of them will have a receive only capability while others will be equipped to transmit signals to the spacecraft. The master station has the capability of communicating with the ATS-G via the standard C-band links using an 11 meter antenna, or via the S-band frequencies through a 5 meter antenna. Land lines interconnect the two earth stations with the ATSOCC.

A number of operational modes are available from the S-band experiment and the spacecraft integrated transponder. These are shown in Figure 4-4. Section 5, on spacecraft hardware, describes the means by which these modes are made available. It is seen from the figure that the broadband capability can be realized only when the 6 GHz uplink band is used, and further that the greatest operational flexibility, as represented by the talkback and mixed modes, requires the use of the 4 and 6 GHz links. Past experience shows that the cost of using land lines to transmit video information to the NASA earth stations from other points for small amounts of time is a large portion of the overall expense. These charges are prohibitive if any significant use is made of the ATS-G for instructional purposes. Thus, in order to maximize the utility of the S-band experiment for educational purposes, it is necessary to simulate more closely configurations that would be employed in operational systems. It is therefore necessary to locate a master earth station, which has comprehensive communications capabilities, near an academic center where the software is generated and stored and where educational personnel are available for participation in real time operations. Stanford University is tentatively selected for the location of this station. The Center for Radio Astronomy at Stanford has available a large area in which the earth station might be placed, parts of which appear to be adequately shielded from commercial microwave repeaters operating in the 6 and 4 GHz bands. Further, the Center has done extensive work on contract to NASA in the development of 2.5 GHz receiving stations for educational use, as well as in systems studies for instructional applications. Stanford is also well equipped as a software center; the Institute for Communication Research has participated in many projects involving the production and evaluation of educational systems using television, including those employing two-way transmission. Extensive work in the development of computer assisted instruction techniques has been conducted at the Stanford Institute for Mathematical Studies in the Social Sciences. While there are other similar capabilities elsewhere in the United States, Stanford appears to have a combined capability that gives it an outstanding potential.

Each experiment conducted under Phase III will have its particular earth station requirements; thus the nature and quantity of small field stations shown in Figure 4-3 will be determined as the experiments are selected and their plans firmly developed. Four representative types of stations are summarized in Table 4-1. These stations provide a range of capabilities that enable many types of services to be supplied under various conditions of spacecraft transmitter power and antenna beam coverage on earth.

TABLE 4-1. PERFORMANCE SUMMARY OF SMALL FIELD STATIONS

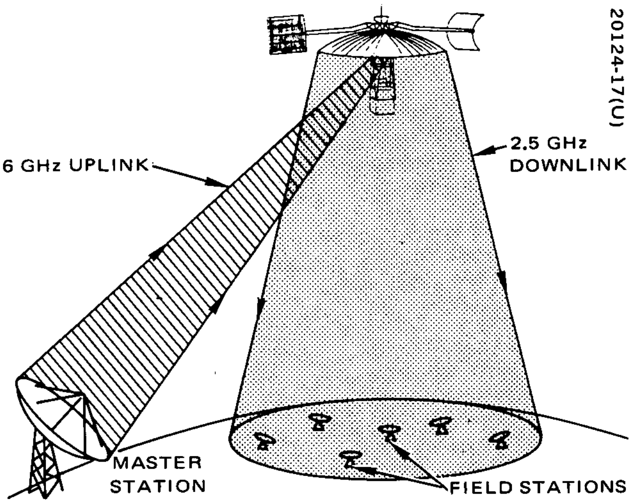
Type	I	II	III	IV
Service	TV down voice return	Duplex TV	Voice	50 megabits/ sec data
Satellite coverage area	48 states	Alaska	Alaska	48 states
Satellite transmitter power, watts	200	50	0.5	100
Earth station antenna diameter, meters	3	2	1	5
Earth station noise temperature, °K	1000	1000	1000	1000
Earth station transmitter power, watts	1	50	1	200
RF bandwidth, MHz	30/0.1	30	0.1	<100

Figure 4-5a is a pictorial representation of the configuration of a system which might employ Type I stations in a receive-only capacity to distribute television programming over an area containing a number of receiving installations. In the broadband mode, a number of channels could be transmitted via a 6 GHz uplink from a master station to the spacecraft, where they would be converted and broadcast to earth at S-band.

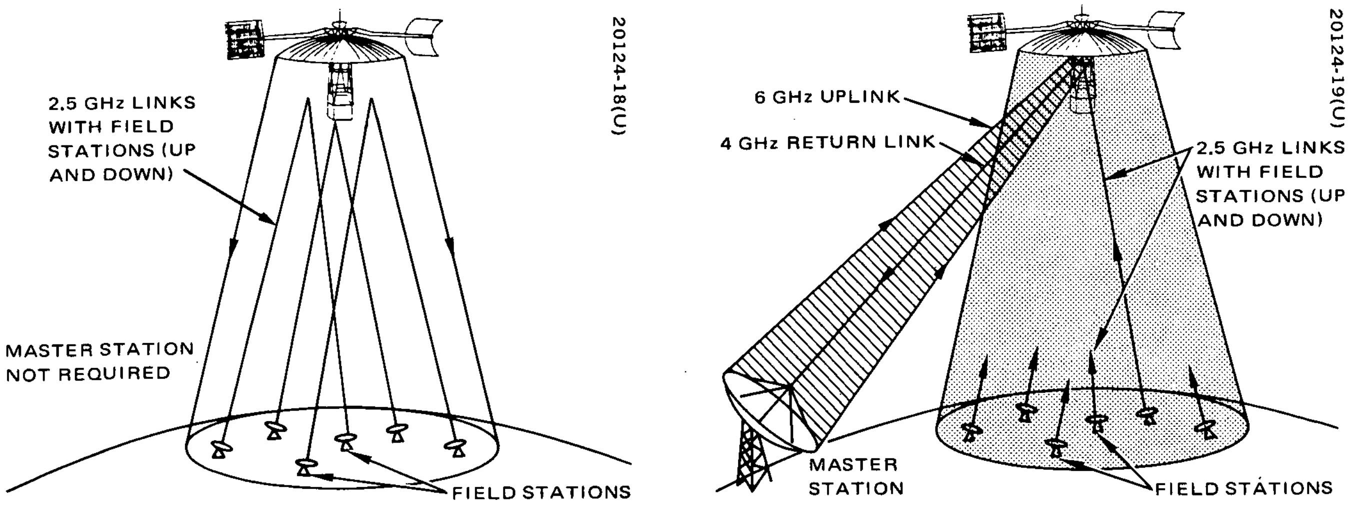
Figure 4-5b shows operation in the duplex mode, where Type III stations could be employed to establish a multiple access demand-assigned telephony service or Type II stations used in a full duplex video system. Only S-band frequencies are utilized in this case, and the master station is not needed.

In Figure 4-5c, the talkback mode of operation is shown. Type I stations would be used to receive wideband signals originated by a master station, as shown in Figure 4-5a and also to transmit via an S-band channel, narrowband signals back to the spacecraft and then to the master station at 4 GHz. This mode allows responses to be obtained from viewers of video programming and provides a means for other interactive forms of communication needed for computer assisted instruction, library access, etc.

Requirements for specific capabilities not covered with the described earth stations could be met by other combinations of the hardware developed for these stations. The stations listed in Table 4-1 would be developed and a few of each constructed to allow demonstrations of link performance to be made during the first phase of the experiment. It would be the responsibility of the experimenters to supply the stations required for their particular applications. These stations, as well as the master programming station, are described in Section 6.



a) Distribution Mode of Operation



b) Duplex Mode of Operation

c) Talkback Mode of Operation

Figure 4-5. Phase III Configurations

5. SPACECRAFT HARDWARE

CONFIGURATION

A block diagram of the spacecraft hardware required by the experiment is shown in Figure 5-1. Four signal inputs designated as IF 1 through IF 4 are obtained from the spacecraft transponder. The first is a wideband input in the 4 GHz range derived from the radio frequency interference (RFI) experiment circuitry. The other three inputs are supplied by the spacecraft IF switching matrix at a center frequency of 150 MHz. These inputs are converted to output frequency bands as shown in the figure. IF 1 is converted to cover the entire allocated 2500 to 2690 MHz band. IF 2 and IF 3 are translated to provide two closely spaced downlink channels at the lower edge of the 2500 MHz band. The fourth input is used to supply an out-of-band signal for other experiments, utilizing the broadband capability of the TWT power amplifiers.

Several modes of operation are provided by switching in the input and output circuits of the high power amplifiers. These were shown in Figure 4-4. They are further described in the following paragraphs.

Broadband Mode

A C-band (6 GHz) uplink carrier from a master earth station provides, via IF 1, a wideband signal to the driver amplifiers and TWTs in a redundant configuration. The broadband output from the TWT is switched to the antenna feeds for broadcast to S-band receivers on earth. The gain of the driver amplifier is adjustable in several steps to provide the proper drive level for the various modes of operation that are available. In this configuration it is possible to operate the transmitter at any power level within its range of capability.

It is assumed that the higher power modes would be used due to the possibilities for multicarrier operation provided by the large instantaneous bandwidth; although many potential applications exist in which large bandwidth is needed at lower power levels.

The wide bandwidth allows sufficient flexibility to accommodate many types of system requirements: 1) multiple channel TV transmission through a single RF system can be accomplished by employing individual carriers or by multiplexing several baseband signals on a single wideband carrier;

2) multiple access systems employing various modulation formats and/or operating disciplines can be evaluated; and 3) very high data rate transmission systems for digital communications can also be established.

Duplex Mode

Two adjacent 30 MHz channels at the high end of the S-band allocation (2630 to 2690 MHz) are received via the transmit-receive diplexer where they are fed to the integrated transponder and converted to IF 2 and IF 3. These are then converted by experiment hardware to two closely spaced carriers (center frequencies 2515 and 2557 MHz) that are amplified simultaneously and separately by the TWTs and then combined in the transmitter diplexer and fed to the antenna feeds via the transmit-receive diplexer. Because the TWTs would be operating simultaneously, they would be operated at a 50 watt level in this mode to avoid exceeding the spacecraft prime power capability. In this and the following modes, delay equalizers are used to compensate for the nonlinear delay characteristics of the relatively narrowband diplexer filters. These equalizers are placed in the IF circuit to eliminate switching and cumbersome filters at S-band frequencies.

The primary application for this mode is to enable full duplex TV circuits to be established between points for two way transmission of video information in real time. A number of other applications can be developed, among these simultaneous multiple access demand assignment (MADA) telephony systems and a combination MADA telephony system with a video network.

Talkback Mode

This mode is similar to the duplex mode, except that the two S-band downlink channels are derived from C-band uplink carriers from a master station. One S-band uplink channel is returned via a C-band downlink to the master station. This would provide a service allowing narrowband responses to instructional TV programming.

Mixed Mode

Crossband operation between master and field stations can be obtained simultaneously with operation among field stations at S-band as shown in Figure 4-4. Applications involving simultaneous operation of different types of services can be demonstrated with this mode.

HARDWARE DESCRIPTION

Until recently the high power S-band experiment had been designed around a high power, high efficiency TWT. During this study, concern had been expressed over risks in developing such a tube and the consequent impact upon the spacecraft launch schedule. In order to provide a backup to the original plans, alternative approaches were considered. This

FOLDOUT FRAME 1

FOLDOUT FRAME 2

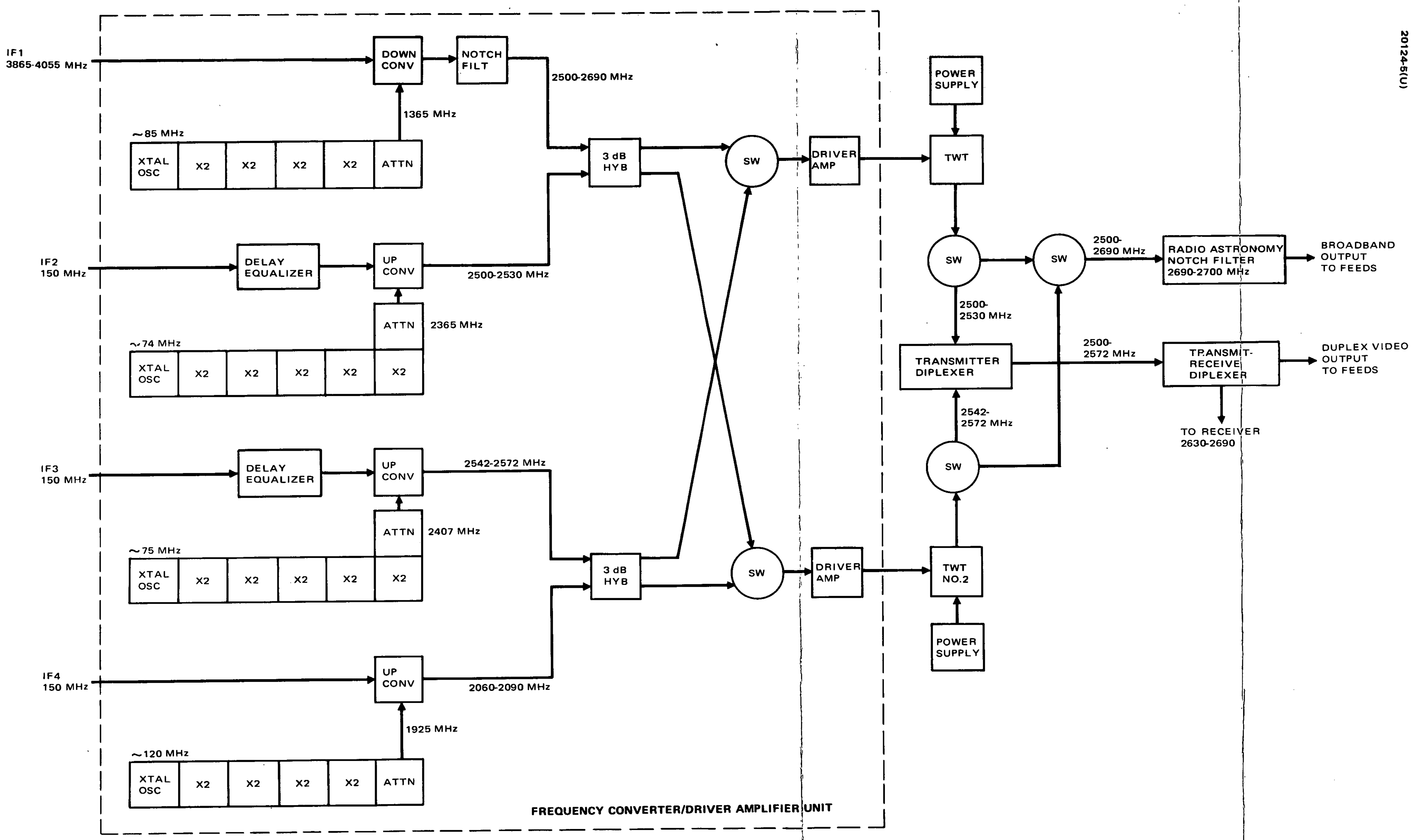


Figure 5-1. Spacecraft Hardware for S-Band Experiment

subsection covers means for combining power from several lower power TWTs in order to obtain the desired high power level. The following two subsections cover the high power TWT and the alternative approaches.

Multimode 50/100/200 Watt TWT Amplifier

The basic experiment concept is to develop and deliver for use in the ATS-G program, a high power, multimode TWT tube and associated power converter. The design will include special technical features for highly efficient operation, for lowest possible thermal density associated with dissipation of waste heat, and for minimum change in the thermal profile as RF operating conditions are changed from linear to saturation operation. The development is based on extension of techniques that have already demonstrated the required power level.

The features desired in the proposed design have already been demonstrated in two tubes that are now under development.

The Hughes 281H S-band TWT generates 40 to 50 watts of power at over 50 percent efficiency. Figure 5-2 shows power, gain, efficiency, and bandwidth performance. Also, a transfer characteristic shown in Figure 5-3, illustrates the high linearity obtainable with a velocity tapered design, as opposed to one in which severe overvoltage operation is used to enhance efficiency. Additional data on the impact of backed off operation on power consumption and power dissipation is included in Figure 5-4. Note that for either the high or low power mode the difference between dc power input and RF power output is a constant, representing a fixed thermal load on the spacecraft, regardless of the amount of backoff employed.

Another tube, the Hughes 279H, under development for the Space Shuttle, operates at nominally 100 watts at a frequency of 6 GHz. At this level the thermal flux in its circuit and in the collector is equivalent to those expected in the larger S-band tube proposed for ATS-G. Figure 5-5 illustrates efficiency, output power, and gain achieved to date.

This tube uses a heat pipe to move energy from the tube collector, 2300 volts off ground, to the grounded mounting surface. It also uses heat pipes to redistribute the dissipated energy at the tube collector to a large baseplate, lowering the energy density from 1.5 to 0.15 w/cm^2. The associated power converter uses a primary bus of 28 volts, nominal, and generates 3700 volts for the cathode supply. This voltage level has been used in spaceborne power supplies previously made by Hughes and equals the highest voltage required in the 200 watt tube proposed for the High Power S-Band Experiment.

The proposed tube will be a scaled version of the 279H tube. It will use a conservatively rated oxide cathode and an all metal-ceramic construction. The collector will be of the double depressed type and will use heat pipe cooling.

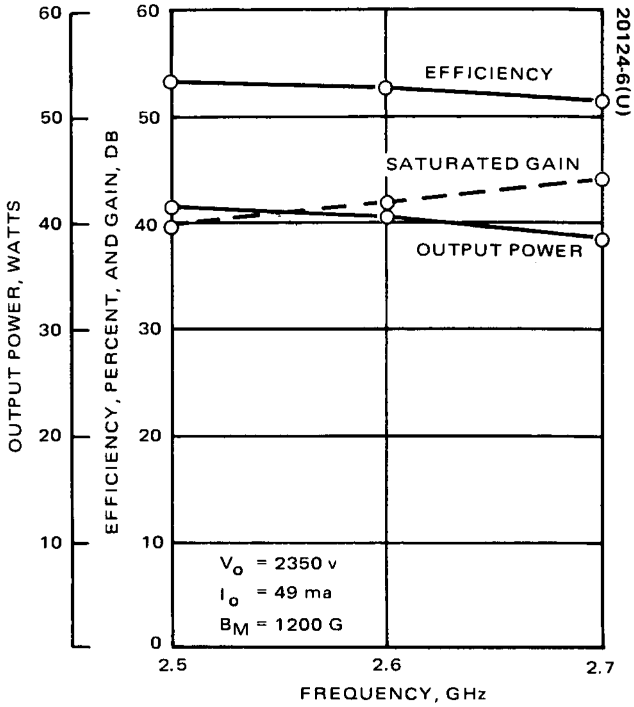


Figure 5-2. Performance of Hughes 281H TWT

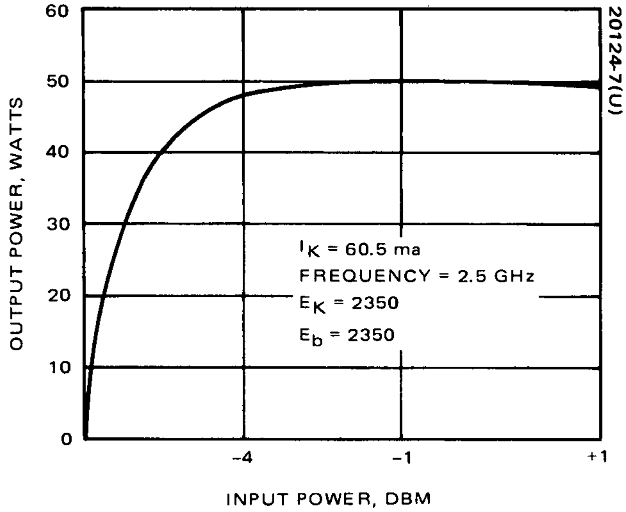


Figure 5-3. 281H TWT Transfer Characteristics

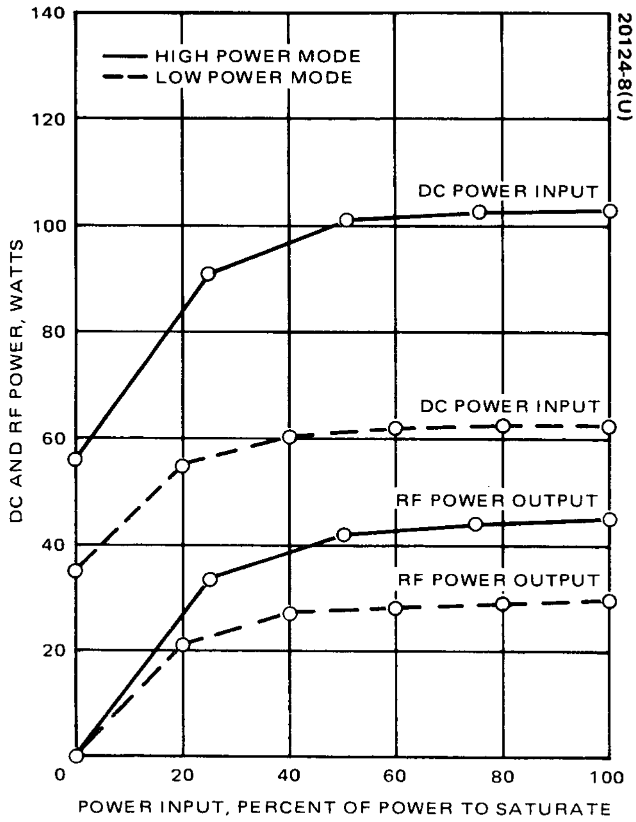


Figure 5-4. DC Power Input and RF Power Output Versus RF Drive for 281H No. 2

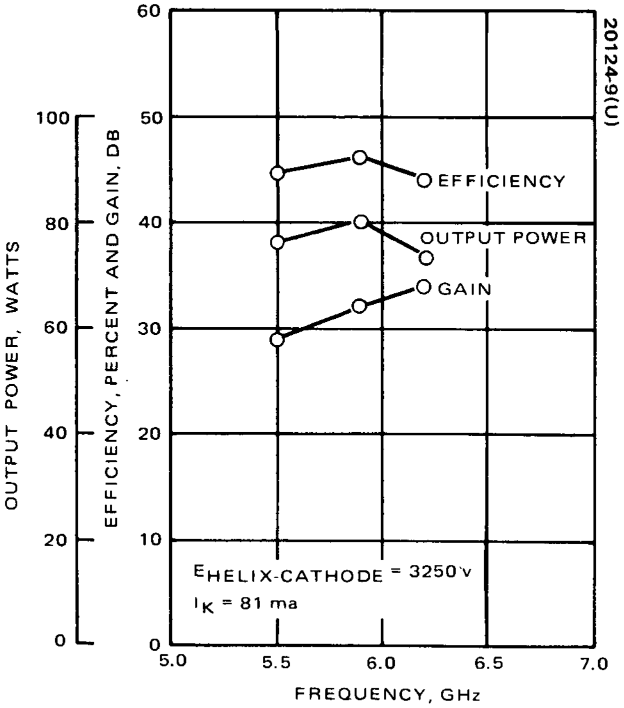


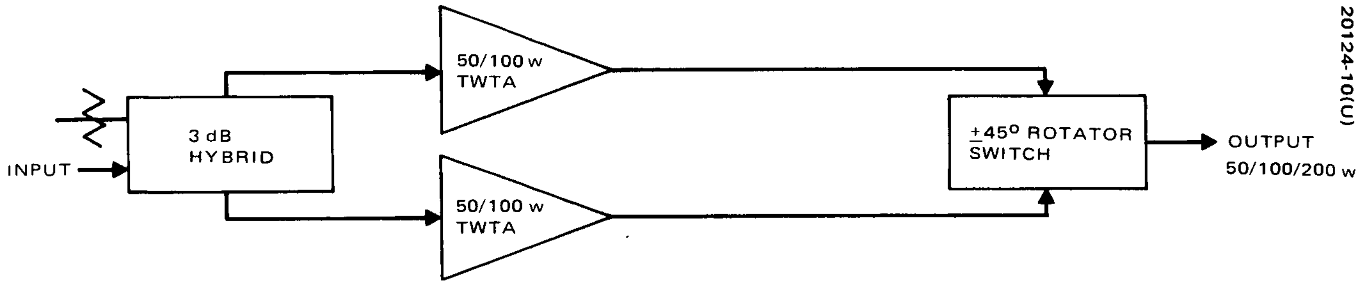
Figure 5-5. 279H TWT Performance

The power converter will be scaled from the existing 1221H design. Solid state switching will be used to extend command to select the desired operating mode. The tube and power supply will be mounted on a 25 by 50 cm baseplate. The baseplate will contain heat pipes for creating an isothermal surface and the lowest possible power density. The unit will be fully enclosed to meet RFI requirements. Table 5-1 summarizes the TWT amplifier specifications.

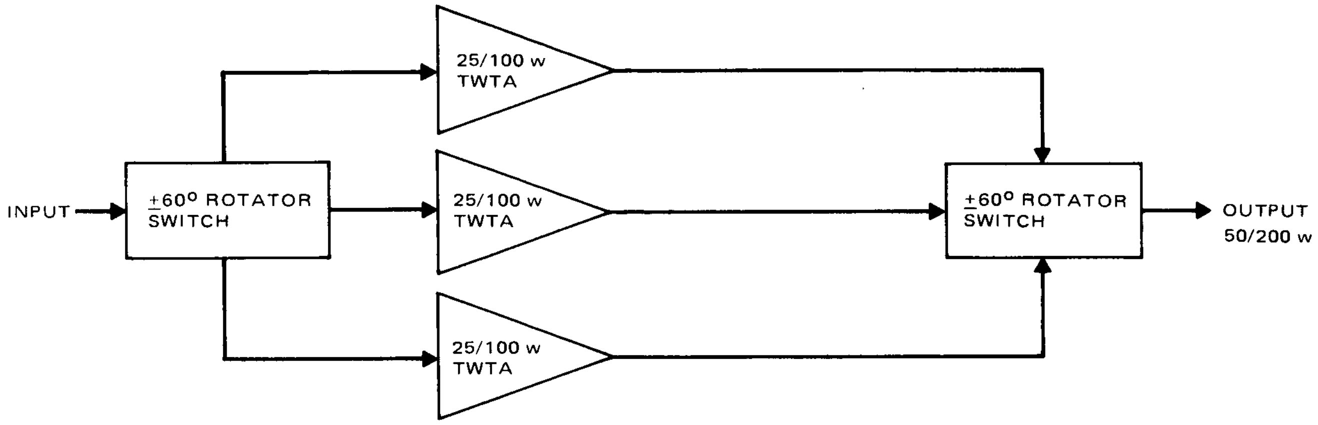
TABLE 5-1. TENTATIVE SPECIFICATIONS FOR MULTIMODE TWT AMPLIFIER

Electrical Characteristics	
Prime supply	28 volts vdc ±2 percent 400 watts maximum
Telemetry and command	per S-460-ATS-38
Output power (RF)	200/100/50 watts
Efficiency (overall)*	50/45/40 percent
Frequency range (±0.5 dB)	2500 to 2690 MHz
In-band spurious products	-60 dB
AM to PM conversion	10°/dB maximum
Noise figure	35 dB maximum
Intermodulation products (third order)	-8 dB maximum
Group delay	0.1 ns/MHz maximum 0.01 ns/MHz^2 maximum
Mechanical Characteristics	
Size	10 x 25 x 50 cm
Mass	16 kilograms
RF connectors	TNC input and output

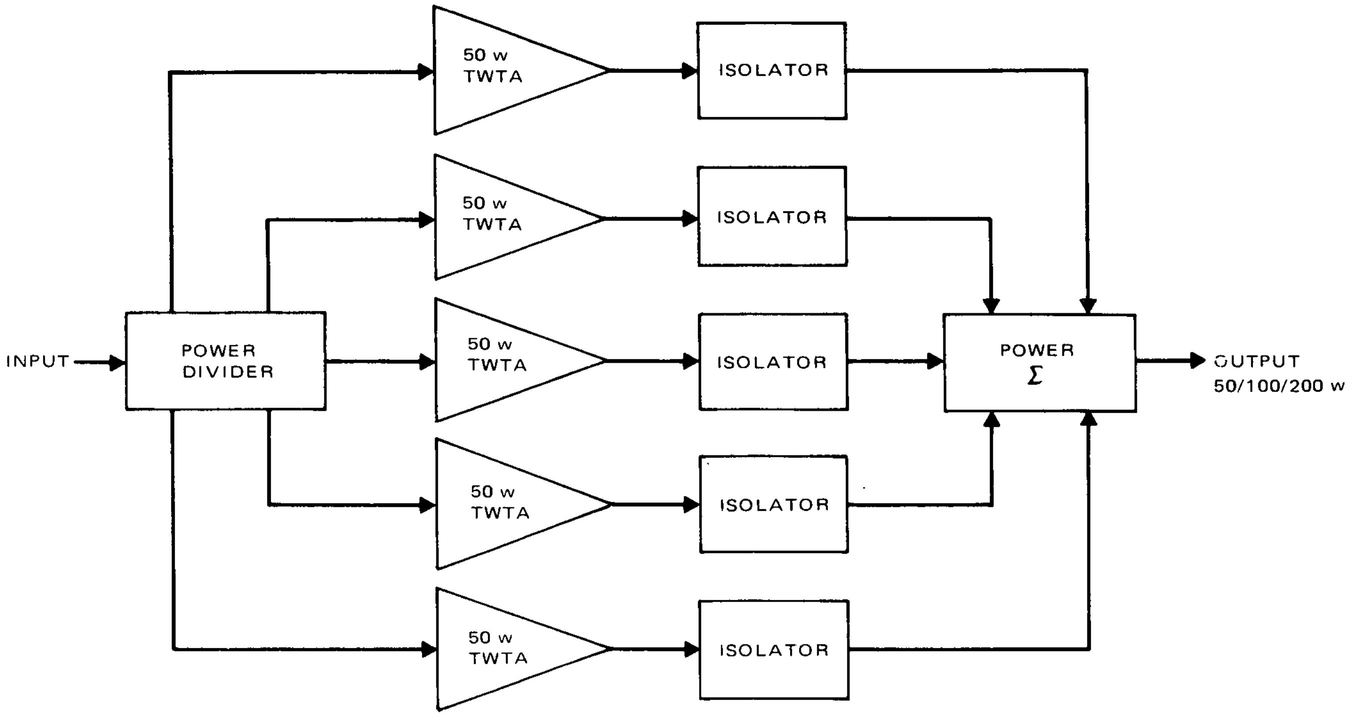
*Efficiencies are design goals corresponding to power levels above. Maximum output power level will be determined by efficiency and prime supply limitations and can be adjusted after tube is fabricated.



a) **TWO TWTS**



b) **THREE TWTS**



c) **FIVE TWTS**

Figure 5-6. TWT Amplifier Configurations

Phased TWT Configurations

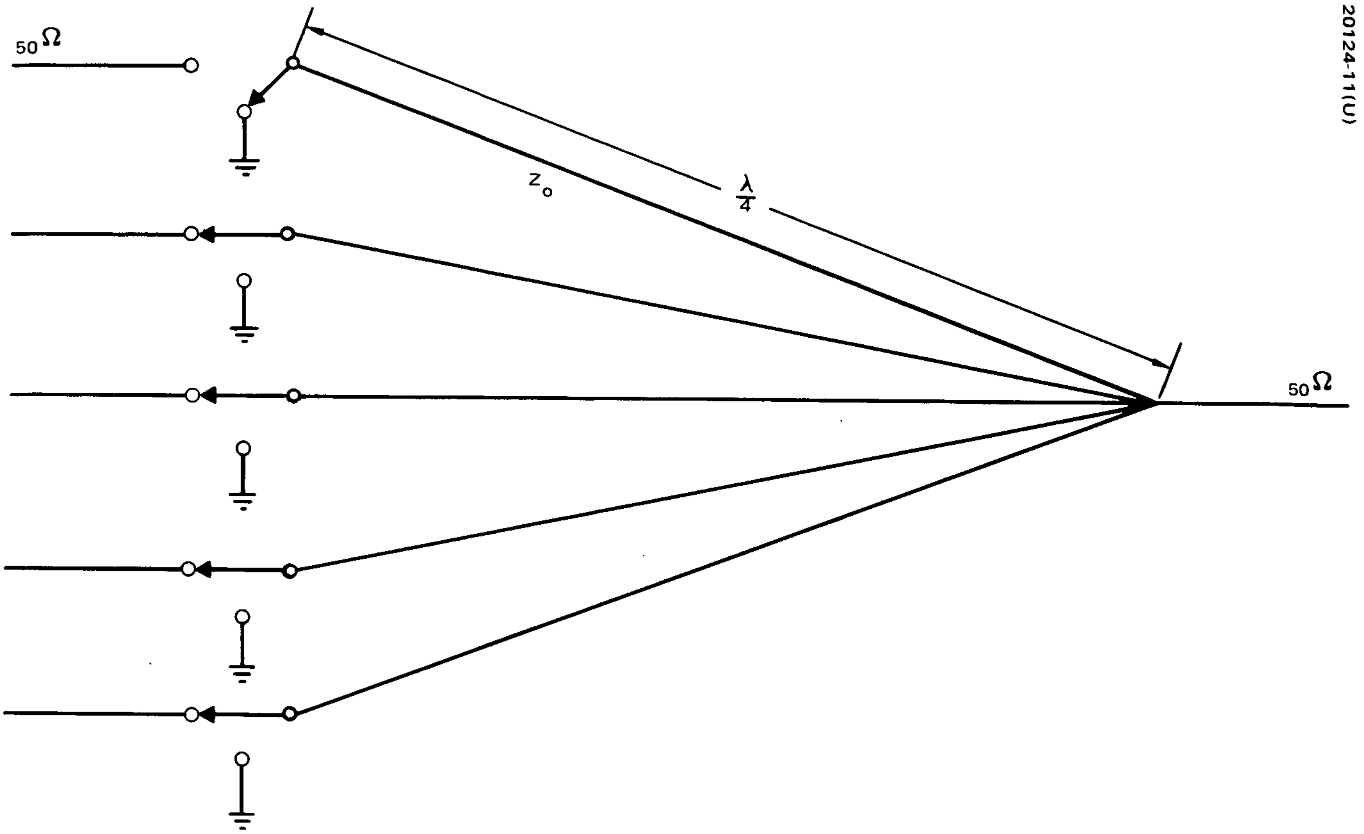
Several configurations employing phased TWTs were considered during this study program because of the concern about risk in developing a high power (200 watt) TWT. Transmitters using phased TWTs have been developed by Hughes for several spacecraft. Notable examples are the TACSAT and the Intelsat II. TACSAT has three 20 watt, X-band TWTs, of which any two can be operated simultaneously to provide an output of 40 watts. The Intelsat II has four 6 watt, C-band TWTs; two, three, or four of these can be operated in parallel with very low switching losses. Bandpass flatness of the Intelsat II TWTs is within 0.5 dB peak-to-peak over a 125 MHz bandwidth and over a power output range from saturated to 5 dB backoff.

A two TWT configuration is shown in Figure 5-6a. This configuration is basically half that of the circuit used in the Intelsat II. The ±45 degree ferrite rotator switch has three positions allowing either or both TWTs to be operated, and thus saturated power outputs of 50, 100, or 200 watts each. The ±45 degree rotator switch can be developed to handle 100 watts at a nominal degree of risk. A 200 watt switch would entail relatively high development risk. These switches consist of a pencil of ferrite suspended in the middle of a circular waveguide making it difficult to dissipate heat generated in the ferrite. An attempt would be made to evolve a design in which the ferrite completely fills the waveguide to provide heat paths through conduction directly to the waveguide walls. A dual mode transmitter with outputs at either 50 or 100 watts could be obtained using 50 watt single mode TWTs in this configuration. Since Hughes has already completed considerable development work on a 50 watt TWT, this configuration offers a simple means of obtaining a medium power transmitter at a low risk.

A three TWT configuration is shown in Figure 5-6b. This configuration is the same as used in the TACSAT. Any two of the 25/100 watt TWTs may be operated simultaneously to provide an output of 50 or 200 watts. A redundant TWT is provided by this configuration. Development of a ±60 degree rotator switch involves the same problems associated with high power handling capacity as with the ±45 degree rotator switch discussed above.

A five TWT configuration using single mode tubes is shown in Figure 5-6c. Either one, two, or four TWTs could be operated simultaneously to provide 50, 100, or 200 watts of output power. A Wilkinson type switched power summer is used as shown in Figure 5-7. Z_0 would be selected (70.7 ohms) to optimize the design with two TWTs operating. This would give mismatch losses of 0.5 dB with one or four TWTs operating. Resistive losses produce an additional 0.25 dB loss.

Table 5-2 summarizes weight and efficiency of these phased TWT configurations. These are compared to the triple mode 50/100/200 watt TWT. Generally, the efficiency decreases and the weight increases as the number of TWTs in the phased configuration is increased.



Z_o, OHMS	4 TWTs ON		2 TWTs ON		1 TWT ON	
	LOSS, dB	VSWR	LOSS, dB	VSWR	LOSS, dB	VSWR
200	0	1.0	0.5	2:1	1.9	4:1
70.7	0.5	2:1	0	1:1	0.5	2:1

Figure 5-7. Switched Wilkinson Power Summer

TABLE 5-2. COMPARISON OF TRANSMITTER CONFIGURATIONS

Circuit Configuration		Mass, kilograms	Anticipated Efficiency, percent	
Number of TWTs	TWT Power, watts		TWT	Transmitter
1	50/100/200	14	60	54
2	50/100	24	60	48
3	25/100	37	60	48
5	50	60	60	46

FILTER DESIGN

Transmit/Receive Diplexer

The transmit/receive diplexer consists of two filters combined in such a way as to permit the transmitter and receiver to be coupled to a single antenna feed. Insertion loss must be a minimum for the transmit and receive paths, while at the same time the receiver must be protected from the transmitter output. It is desirable to limit the transmitter leakage power to no more than 10 dB below the receiver noise level. For a receiver noise figure of 4 dB and bandwidth of 30 MHz, the noise power level is -127 dBw. Therefore, the maximum transmitter leakage power should not be more than about -137 dBw. For 200 watts of transmitter power, the isolation between the transmitter and the receiver, therefore, must be 160 dB. This isolation dictates the skirt requirements of the receiver filter.

The skirt characteristics of the transmitter filter are dictated by the maximum amount of transmitter noise that can be permitted to leak into the receiver. As before, this noise should be kept at least 10 dBw below the receiver noise level. The required isolation of the transmitter filter at the receive band edge is determined as follows:

Boltzmann's constant, k = -228.6 dBw/Hz-K

TWT NF = 35 dB = 59.6 dB °K

Bandwidth (30 MHz) = 74.8 dB Hz

$$\text{TWT gain} = 40 \text{ dB}$$

$$P_n = -228.6 + 59.6 + 74.8 + 40 = -54.2 \text{ dBw}$$

From the preceding paragraph, the permissible noise leakage power is -137 dBw. Therefore, the required isolation of the transmit filter at the receive band edge is

$$137 - 54 = 83 \text{ dB}$$

A 12 section receive filter and a 9 section transmit filter will meet the requirements stated above. A 0.01 dB equal ripple Chebyshev filter design is proposed. The characteristics of these filters are listed in Table 5-3.

Transmitter Diplexer

The purpose of the transmitter diplexer is to add the outputs of two transmitters to allow their simultaneous operation. This diplexer will be used with the TWTs operating in the 50 watt mode and therefore must handle 100 watts of power. TWT 1 operates in the frequency range from 2500 to 2530 MHz and TWT 2 operates between 2542 MHz and 2572 MHz, providing a 12 MHz guard band. The important criteria for this diplexer are to obtain minimum insertion loss and to prevent harmful leakage of RF power from one transmitter into the other. If the amount of leakage power

TABLE 5-3. FILTER CHARACTERISTICS

Parameter	Receive Filter	Transmit Filter
F_o, MHz	2660	2536
Equal ripple bandwidth, MHz	60	72
Insertion loss, dB	0.5	0.35
Number of cavities	12	9
Length, cm	98	83
Mass, kilograms	0.9	0.8

is permitted to be large, the insertion loss will be adversely affected. An isolation between transmitters of 20 dB is adequate. The diplexer consists of two filters of six sections each, using an 0.01 dB equal ripple Chebyshev design. Each filter has an equal ripple bandwidth of 30 MHz and employs six cavities. Their length is approximately 57 cm; their mass is of the order of 0.6 kilogram.

Astronomy Band Notch Filter

At the World Administrative Radio Conference (WARC) for Space Telecommunications meetings in Geneva in July 1971, Committee 5 (Allocations) adopted the following provision:

> "In the design of systems in the Broadcasting Satellite Service, administrations are urged to take all necessary steps to protect the Radio Astronomy Service in the band 2690-2700 MHz."

In order to provide maximum protection to the radio astronomy band without greatly penalizing the spacecraft, the use of a notch filter with an attenuation of 60 dB at the astronomy band edges of 2690 and 2700 MHz is proposed. This filter would consist of six cavities, would be 56 cm long and have a mass of approximately 0.7 kilogram.

DELAY EQUALIZERS

The transmitter and transmit/receive diplexers introduce considerable delay distortion making it necessary to compensate for their nonlinearity with delay equalizers. Delay equalization can be inserted at any point in the communications link. In the interest of reducing spacecraft weight and complexity, it would be desirable to implement delay equalization in the ground receiver equipment; however, this is precluded, since a large number of ground stations are involved in the experiment.

Delay equalization at the 150 MHz frequencies is preferred if it is to be implemented in the spacecraft. The use of bridged T configured circuits or hybrid coupled filters would result in a relatively compact package. In order to obtain the high Qs required at these frequencies, the use of helical filter elements is indicated.

HIGH POWER SWITCHES

Latching single pole, double throw switches capable of handling 200 watts CW are required for this experiment. A junction circulator type switch using coaxial transmission line terminations is proposed. The coaxial approach is preferred due to the excessive size and weight of waveguide units. The advantage of a waveguide design is primarily its heat conducting capability. In order to develop a coaxial switch that will successfully handle 200 watts, special care must be used to limit the dissipated power by reducing the insertion loss as much as possible, and also by removing the generated heat by conduction to avoid thermal runaway. It is anticipated that about 0.2 dB insertion loss would be incurred; at the 200 watt level this corresponds to 10 watts dissipation. The switch contains two ferrite pucks so that 5 watts would be dissipated in each puck. The pucks are located against the walls of the switch allowing the heat to be readily conducted out of the ferrite material. The estimated size of such a unit would be 5 by 5 by 4 cm. Its mass would be approximately 0.3 kilogram.

DRIVER AMPLIFIER

The driver amplifier must provide outputs from the order of 0 to more than +20 dBm at the 1 dB compression point to drive a multimode TWT amplifier. Under the assumption of an input of approximately 0 dBm to the S-band experiment and with the TWT amplifier parameters as described earlier, simple signal flow analysis shows that gains of from about 15 to 35 dB are required. A detailed design was not conducted during this study; however, it appears that an amplifier employing four stages of the HP 21 transistor plus an output stage using the new HP 35 transistor would provide an appropriate design. A PIN diode attenuator would be inserted between stages to provide the commandable gain control.

LOW LEVEL CIRCUITRY

The remaining circuitry consists of straightforward designs that have been used on many spacecraft in the past. The crystal oscillators and multiplier chains for the local oscillator sources are similar to those used on the Canadian Domestic satellite program. The downconverter and notch filter in the IF number 1 circuit also are similar to that used in the Canadian Domestic satellite. The ferrite switches are low power latching types using stripline techniques.

6. GROUND EQUIPMENT

EARTH STATIONS

For the third phase of the ATS-G High Power S-Band Experiment, five different types of earth stations are being considered. Their differences lie largely in the size of the parabolic dish antenna and the different types and quantities of information that they will transmit and receive.

Small Earth Stations

Type I earth station uses a 3 meter dish antenna and is used to receive video (television, CAI, slow-scan, etc.) and audio and to transmit voice band (voice, facsimile, low speed data, etc.). This station is shown in block diagram form in Figure 6-1. Voice band input is amplified at baseband, which then phase modulates a carrier before being multiplied to the final 2.5 GHz frequency. The 1 watt output from the power amplifier is filtered and diplexed with the receiver and then fed to the dish antenna. The downlink received signal is amplified by a low noise transistor RF amplifier and converted to IF, where it is amplified and demodulated to baseband where the video is separated from audio.

Type II earth station has a 2 meter antenna and is used primarily to receive and transmit television and associated audio program material. A block diagram of this earth station is shown in Figure 6-2. The information flow and the functions performed are largely identical to those of the type I earth station, except for the smaller antenna which has about 3 dB less gain.

Type III earth station, shown in Figure 6-3, uses a 1 meter dish antenna which can be rapidly set up and torn down, thereby achieving a degree of transportability. Its use in the ATS-G experiment for Phase III can be demonstrated in the remote regions of Alaska where its full duplex telephony capability can satisfy a presently unfulfilled need. The complete earth station package is envisioned as being capable of being erected, installed, and operated by a single individual.

Type IV earth station has a 5 meter diameter dish antenna. Its use is in the multichannel broadband/multiplex video service. The data handling capability in this station is expected to be on the order of 50 megabits/sec or its equivalent analog. The block diagram for type IV earth station is shown in Figure 6-4. Except for the size of the dish antenna, this station is identical to type II earth station.

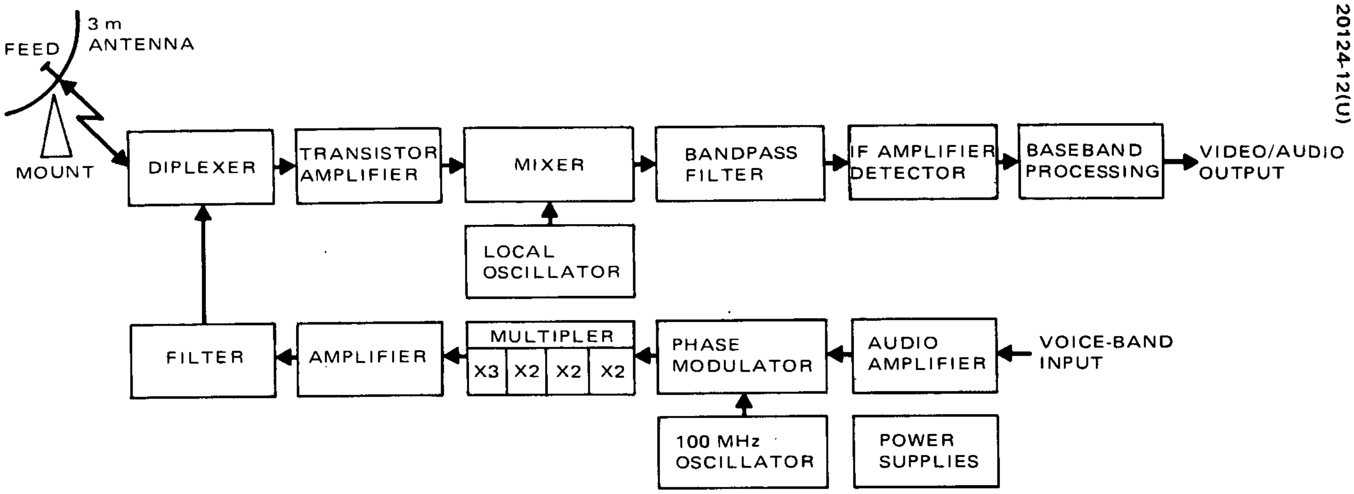


Figure 6-1. Type I Station - Television Receive, Voice/Data Transmit

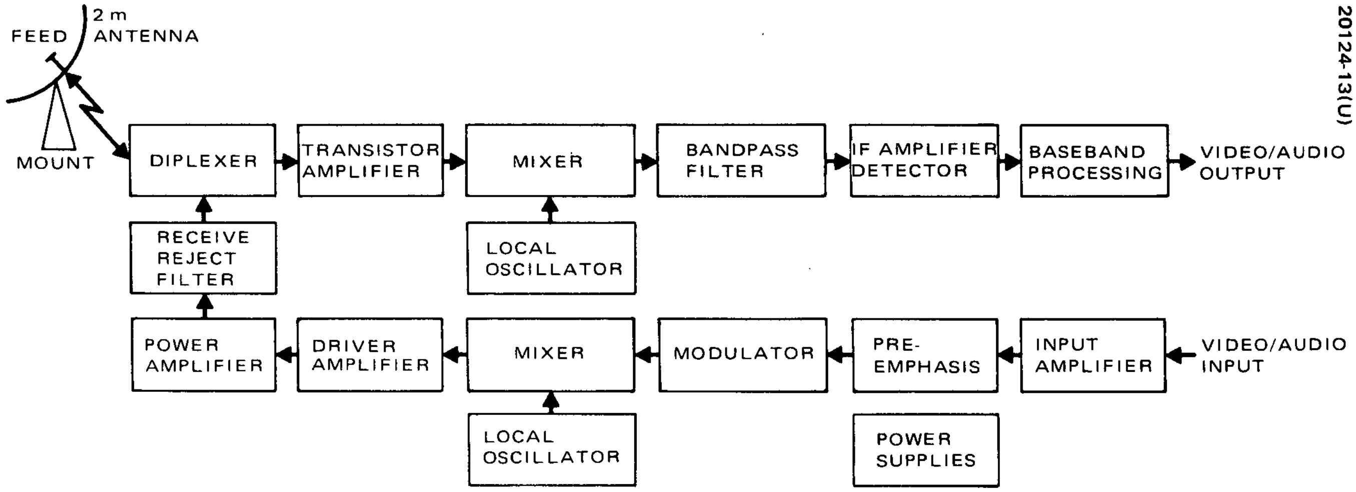


Figure 6-2. Type II Station - Television Transmit and Receive

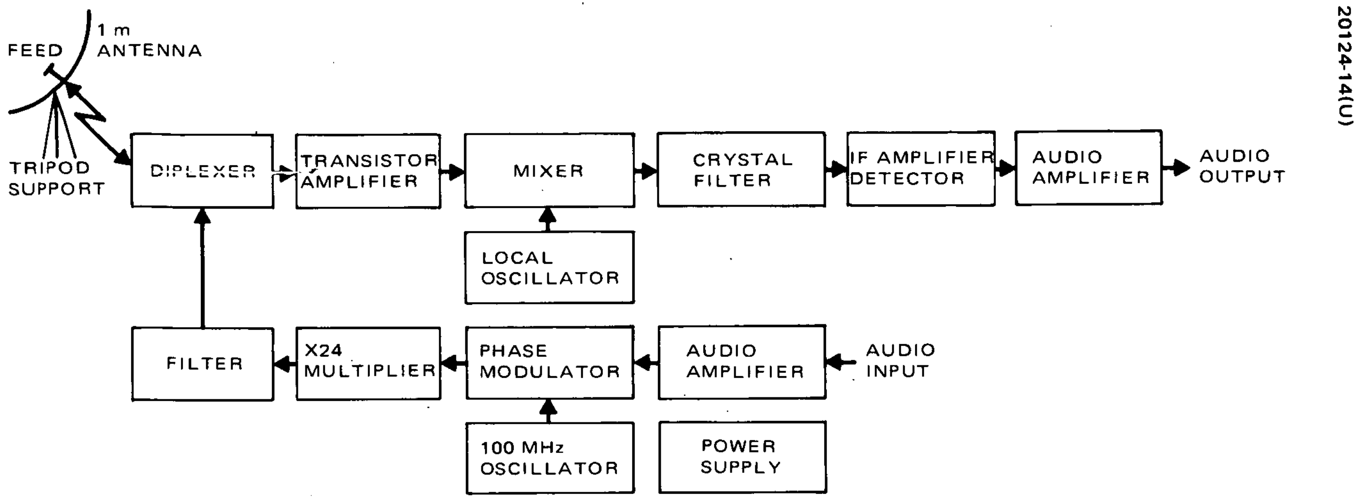


Figure 6-3. Type III Station - Telephony Service, Full Duplex Capability

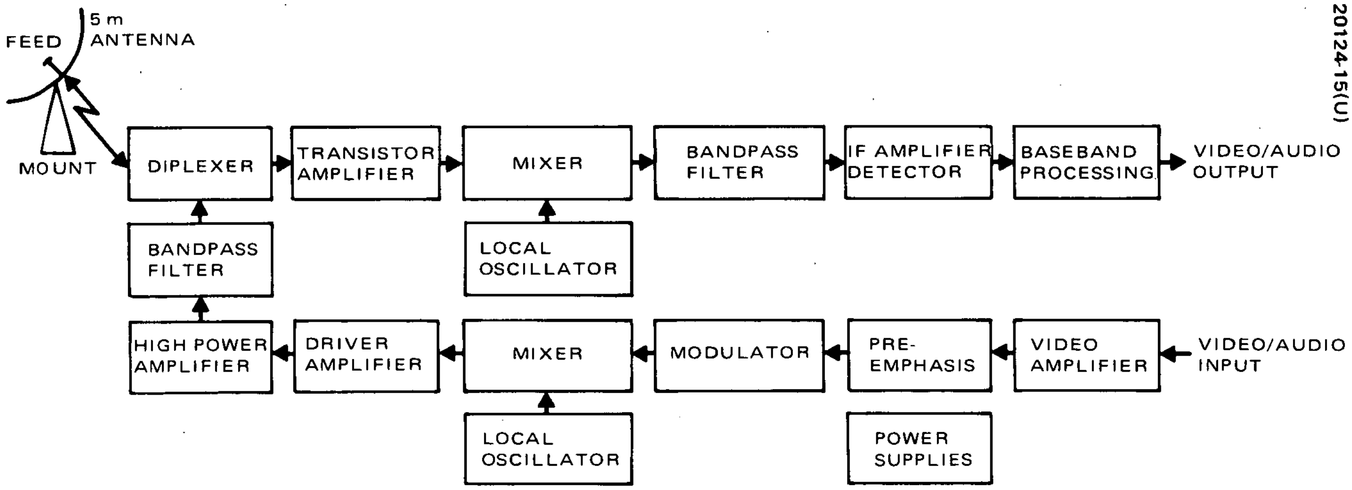


Figure 6-4. Type IV Station - Television/Data Transmit-Receive

In order to demonstrate and evaluate communications performance of the small earth stations, three each of types I, II, III, and IV, as described above will be procured. A tentative plan for locating these stations for evaluation during Phase I of the experiment is given below.

Type I station:	Goddard Space Flight Center Rosman Earth Station Site Stanford University
Type II station:	Goddard Space Flight Center Rosman Earth Station Site Washington University
Type III station:	Goddard Space Flight Center Rosman Earth Station Site Washington University
Type IV station:	Goddard Space Flight Center Rosman Earth Station Site Stanford University

The university locations allow early checkout and familiarization in preparation for Phase III. Washington University, at St. Louis, was chosen for the two types of stations that require the use of narrow antenna beams from the ATS-G to obtain sufficient antenna gain; this enables a university station to be in the net with the Goddard and Rosman stations under conditions in which Stanford lies outside the usable geographical coverage area. For Phase III, these small stations would be used for demonstration purposes. The small stations at Rosman, and possibly Goddard, could be relocated to other areas in the United States for demonstration purposes.

Master Programming Station

This facility, designated as Type V station, would be constructed at Stanford University according to present plans. Its function is to provide access to the satellite for educational software without incurring the cost of land lines needed to interconnect an academic center and the NASA stations at either Rosman or Mojave.

This station uses an 11 meter diameter antenna and operates at 6 and 4 GHz. Note in Figure 6-5 the completely redundant high power transmitting amplifiers and the low noise receiving parametric amplifiers. Only one earth station of this type is expected to be required. The power amplifier has a 3 kw peak capability, and the receiving parametric amplifier has a system noise temperature of 150°K.

FOLDOUT FRAME 1

FOLDOUT FRAME 2

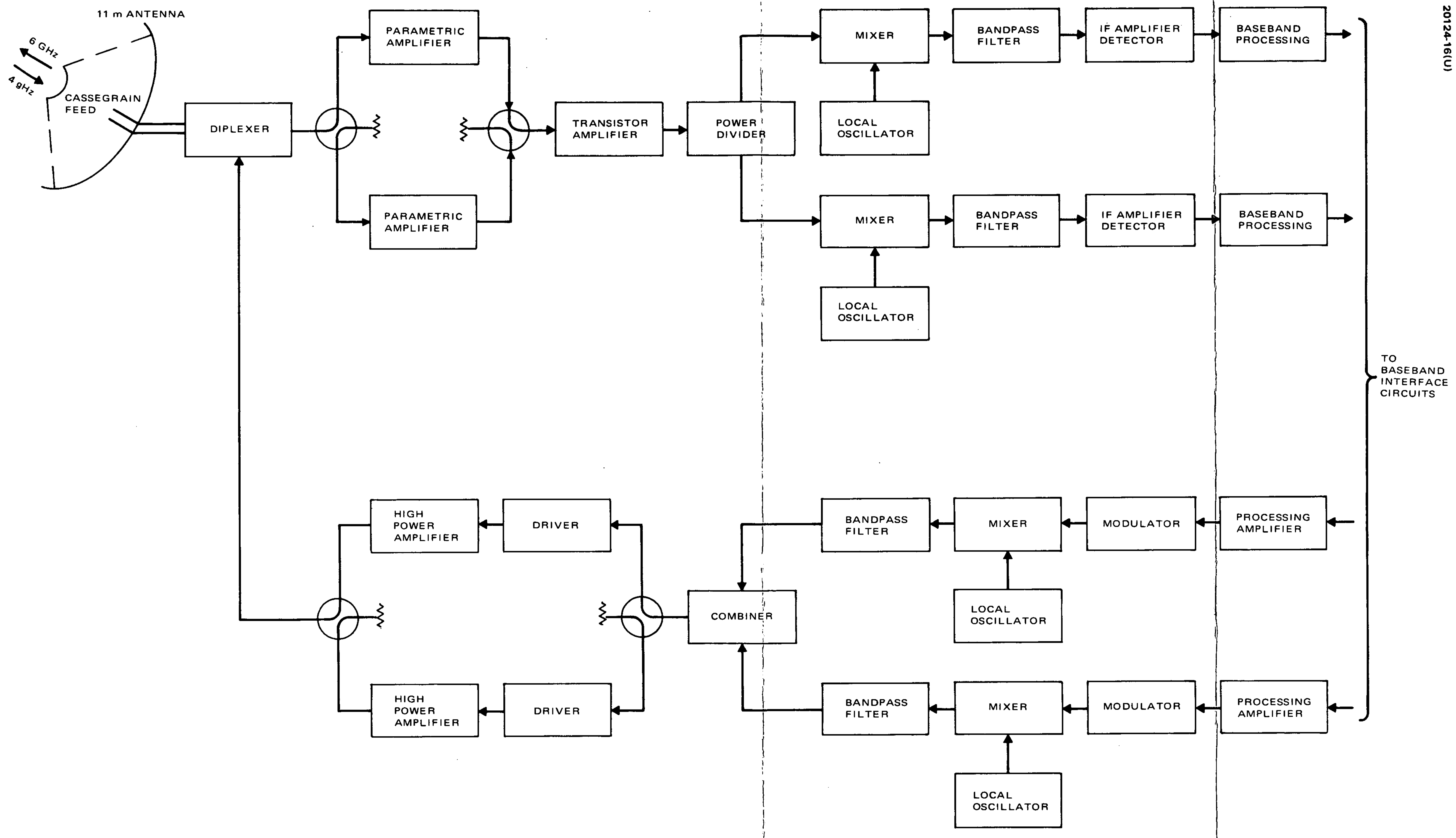


Figure 6-5. Type V Earth Station — C-Band Master Station

PRECEDING PAGE BLANK NOT FILMED

SPECIAL GROUND EQUIPMENT

Except for the earth stations, which are designed to provide various representative services with the S-band experiment, little unique equipment will be required to conduct the tests required for Phases I and II. The earth stations that will be used in the field for the applications experiments in Phase III will be supplied by the experimenters and are not discussed here, although they are expected to be similar to those procured for this experiment.

Transmit Interface Equipment

The function of this equipment is to condition signals and to provide an interface between the communications test equipment and transmitter at the Rosman earth station and the mobile terminal during Phase I and Phase II tests. This equipment accepts video and audio inputs from the communications test evaluation console and provides a composite baseband signal, which modulates a 70 MHz signal. The 70 MHz IF signal is fed to the earth station upconverter, which furnishes RF drive to the power amplifier stages of the transmitter. Because of the extensive modifications required to transmit broadband signals through the NASA earth stations, wideband (190 MHz) transmission will be handled only by the master programming station, tentatively intended for location at Stanford University.

Receiver Interface Equipment

This equipment conditions signals from the earth stations and provides an interface from the receivers to the communications test equipment at the Rosman and mobile terminals. The equipment accepts the 70 MHz IF from the receiver, demodulates it to obtain the video baseband, and the FM audio carrier, which is subsequently demodulated to provide the audio baseband signal. The video output is nominally 1 volt p-p into 75 ohms; the audio output is 0 dBm into a 600 ohm balanced load.

Test Instrumentation Requirements

The following equipment list represents estimated requirements to accomplish the measurements needed during Phases I and II.

Strip-chart recorder, HP 7704B

Microwave link analyzer/transmission generator, HP 3701A

Microwave link analyzer/demodulator display, HP 3702A

Oscilloscope camera, HP 196 or 197A

TV monitor camera, Beattie-Coleman model K-50

Vacuum tube voltmeter (VTVM)/true rms, HP 3400 A

Microwave analyzer/group delay detector, HP 30703A

Signal generator-audio, HP 651A

Television waveform monitor, Tektronix model 525

Waveform generator, Telemet Model 3508

Low frequency wave analyzer, Marconi model 2330A

Low frequency spectrum analyzer, Panoramic model SPA 3/25C

Sweep delay oscilloscope, Tektronix model 585A with type CA dual input plug-in unit

Wave analyzer, Marconi model 23304R

Distribution amplifier, Telemet model 3506

Television monitor, Dage 100645

Baseband test set, W&G receiver/LOE-1, Attachment/LOS-1, signal generator/TFPS-42, CRT display/SG-1

The above equipment would be employed at the Rosman and mobile earth stations. Additionally, for Phase II measurements, true RMS voltmeters, such as the HP 3400A, will be required for selected ITFS receiving installations, the quantity to be determined later.

7. SPACECRAFT/EXPERIMENT INTERFACE

Figure 5-1 shows the points at which signals between the experiment hardware and the spacecraft are exchanged. DC power connections are not shown. These requirements are summarized in Table 7-1.

The frequency converter/driver amplifier unit, as shown in Figure 5-1, contains the frequency converters, oscillators, multipliers, delay equalizers, low power switches, and driver amplifiers. The TWT amplifiers, high power switches, diplexers and monitors will be mounted directly to the spacecraft structure. Size and weight estimates are given in Table 7-2.

TABLE 7-1. DC POWER REQUIREMENTS

Mode of Operation	Unit		DC Power, watts
Broadband	Low level electronics		3.2
	TWT amplifier (200 watts)*		400.0
		Total	403.2
Duplex video, talkback or mixed	Low level electronics		6.4
	TWT amplifier 1 (50 watts)		125.0
	TWT amplifier 2 (50 watts)		125.0
		Total	256.4
Single 30 MHz channel	Low level electronics		3.2
	TWT amplifier (100 watts)		222.0
		Total	225.2

*200 watts output based on design goal TWT amplifier efficiency of 50 percent.

TABLE 7-2. SIZE AND WEIGHT ESTIMATES

Unit	Quantity	Size, cm	Total Mass, kilograms
Frequency converter/ driver amplifier unit	1	17 x 30 x 35	9.5
TWT amplifier (200/100/50 watts)	2	10 x 25 x 50 each	32.0
Power monitor	2	5 x 10 x 10 each	0.5
Switch and driver	3	5 x 5 x 5 each	1.0
Transmitter diplexer	1	61 x 18 x 18	1.2
Transmitter/receiver diplexer	1	100 x 18 x 18	1.8
High power cabling			2.5
		Total	48.5

Seventy commands and 86 telemetry functions are required. The large number is partially due to numerous driver amplifier gain settings required to allow a wide range of operating conditions. Table 7-3 itemizes these functions.

Based upon an overall TWTA efficiency of 50 percent, the maximum thermal load upon the spacecraft should not exceed 245 watts. This includes conservative allowances for RF losses in the switches and filters.

The experiment hardware will be located in the communications module to allow good access to the spacecraft transponder and antenna feeds. Because of the nature of this experiment, there are no special requirements regarding viewing, alignment, or torques transmitted to the spacecraft. The environment provided by the spacecraft is satisfactory in all respects.

TABLE 7-3. COMMAND AND TELEMETRY LIST

Command

1. TWT 1 50 watt mode
2. TWT 1 100 watt mode
3. TWT 1 200 watt mode
4. TWT 1 on
5. TWT 1 off
6. TWT 2 50 watt mode
7. TWT 2 100 watt mode
8. TWT 2 200 watt mode
9. TWT 2 on
10. TWT 2 off
11. IF 1 on
12. IF 1 off
13. IF 2 on
14. IF 2 off
15. IF 3 on
16. IF 3 off
17. IF 4 on
18. IF 4 off
19. Switch 1 position 1
20. Switch 1 position 2
21. Switch 2 position 1
22. Switch 2 position 2
23. Switch 3 position 1
24. Switch 3 position 2
25. Switch 4 position 1
26. Switch 4 position 2
27. Switch 5 position 1
28. Switch 5 position 2
29. Driver amplifier 1 gain position 1
30. Driver amplifier 1 gain position 2
31. Driver amplifier 1 gain position 3
32. Driver amplifier 1 gain position 4
33. Driver amplifier 1 gain position 5
34. Driver amplifier 1 gain position 6
35. Driver amplifier 1 gain position 7
36. Driver amplifier 1 gain position 8
37. Driver amplifier 1 gain position 9
38. Driver amplifier 1 gain position 10
39. Driver amplifier 1 gain position 11
40. Driver amplifier 1 gain position 12
41. Driver amplifier 1 gain position 13
42. Driver amplifier 1 gain position 14
43. Driver amplifier 1 gain position 15
44. Driver amplifier 1 gain position 16
45. Driver amplifier 1 gain position 17
46. Driver amplifier 1 gain position 18

Table 7-3 (Continued)

Command

47. Driver amplifier 1 gain position 19
48. Driver amplifier 1 gain position 20
49. Driver amplifier 2 gain position 1
50. Driver amplifier 2 gain position 2
51. Driver amplifier 2 gain position 3
52. Driver amplifier 2 gain position 4
53. Driver amplifier 2 gain position 5
54. Driver amplifier 2 gain position 6
55. Driver amplifier 2 gain position 7
56. Driver amplifier 2 gain position 8
57. Driver amplifier 2 gain position 9
58. Driver amplifier 2 gain position 10
59. Driver amplifier 2 gain position 11
60. Driver amplifier 2 gain position 12
61. Driver amplifier 2 gain position 13
62. Driver amplifier 2 gain position 14
63. Driver amplifier 2 gain position 15
64. Driver amplifier 2 gain position 16
65. Driver amplifier 2 gain position 17
66. Driver amplifier 2 gain position 18
67. Driver amplifier 2 gain position 19
68. Driver amplifier 2 gain position 20

Telemetry

1. TWT 1 E_K
2. TWT 1 I_K
3. TWT 1 I_F
4. TWT 1 I_H
5. Power supply 1 input current
6. TWT 2 E_K
7. TWT 2 I_K
8. TWT 2 I_F
9. TWT 2 I_H
10. Power supply 2 input current
11. TWT 1 temperature
12. TWT PS 1 temperature
13. TWT 2 temperature
14. TWT PS 2 temperature
15. TWT 1 power output
16. TWT 2 power output

17. to 84. Command status corresponding to commands 1 through 70

8. EXPERIMENT LIFETIME

The lifetime of the experiment hardware is, for all practical purposes, equivalent to the lifetime of the TWT power amplifiers. Experience has shown that reliability of spare tubes far exceeds the requirements for this application and that cathode lifetime will be the limiting factor.

The combination of design, life, and reliability requirements for the proposed TWT are such that the use of an impregnated cathode is highly recommended. The oxide cathodes typically utilized in space communication satellites are not capable of achieving long life at the design required cathode loading, as shown in Figure 8-1. Impregnated cathodes are presently used successfully in many TWTs, gas lasers, magnetrons, and klystrons.

The impregnated tungsten cathode is a dispenser cathode. The term "dispenser cathode" is used to describe any cathode on which a thin film of emitting material is produced at the surface and continuously replenished at the operating temperature of the cathode. The semiporous substrate contains the film-forming agent which is dispensed to the surface.

Once the life is established through the basic design (and verified through life testing), the only problems associated with space tube designs have been those associated with quality control. Thus, the overall reliability is ensured through detailed traceability and quality control procedures. To date, this method of reliability control has been used because of the large expense of running a statistical program, as is done with components such as resistors and capacitors.

A long life design is good when the device will operate within specified limits at the end of the design time period. However, it is not possible to operate a device for 2 to 5 years prior to use in the experiment, and no realistic way of accelerating life tests of microwave tubes is known. Confidence in meeting the long life goal is based on assurance that the particular device selected for operation will last and survive any reasonable stress or strain to which it is exposed.

Looking at a typical curve for failure rate (Figure 8-2), this means:

- Weeding out all infant mortality cases in the test, screening, and burn-in period

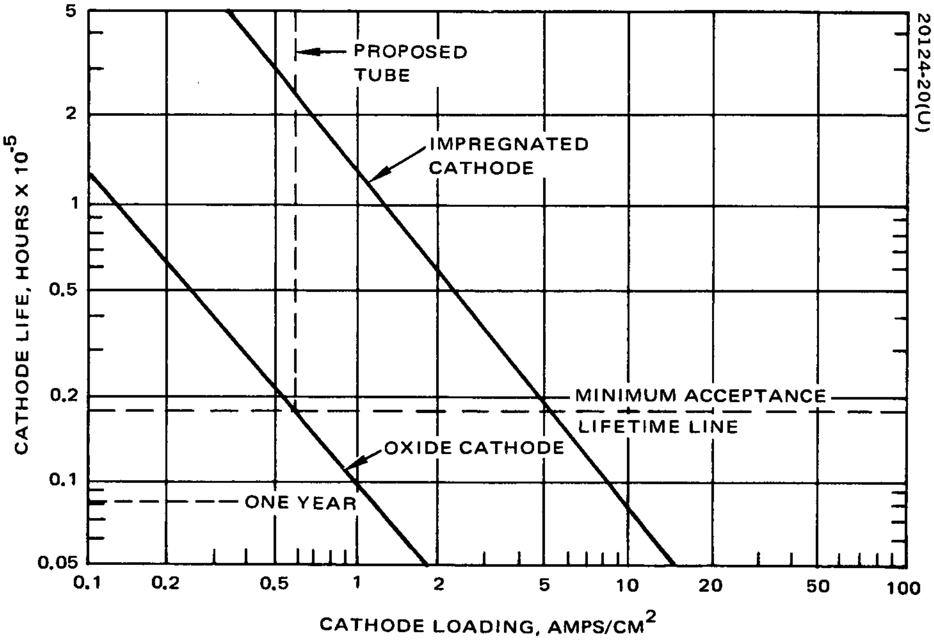


Figure 8-1. Life Versus Cathode Loading

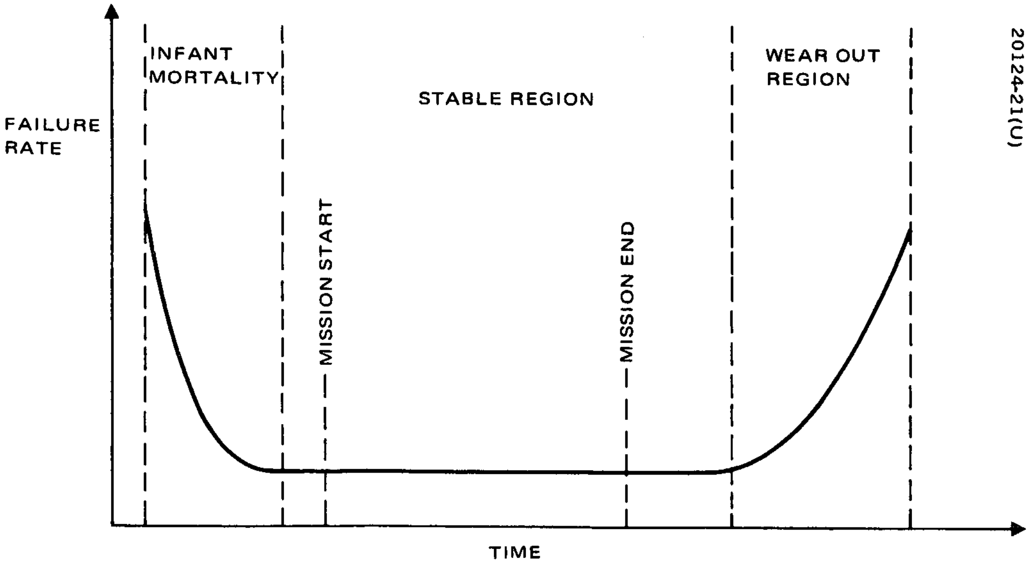


Figure 8-2. Failure Rate as Function of Time

- Controlling by design of all wearout processes so as not to degrade the device performance during mission life
- Designing reliability in to the lowest possible failure rate

Infant mortality is weeded out by the following procedures:

- Maintaining traceability to raw materials and processes for elimination of questionable lots
- Eliminating substandard piece parts and assemblies by quality assurance inspections
- Using screening tests to check survival (operational times 1.5 stress levels)
- Conducting a minimum 500 hours burn-in
- Using a holding period to detect minute leaks
- Using state-of-the-art test equipment to detect any changes in performance

Reliable design is obtained by:

- Using well-proven processes, materials, and techniques
- Favoring simple design details, reducing number of potential problem areas (number of metal-ceramic seals or voltage gradient regions)
- Using conservative design, stress levels for failure well beyond levels normally incurred
- Using experience in design to reduce susceptibility to any known failure mode and improve chance for survival of malfunctions in a system from which rest of system could recover
- Performing of thorough failure mode analysis
- Maintaining life test programs to prove earlier design concepts and evaluations thereof
- Performing thorough evaluation programs, including life tests, for qualification of new materials or processes prior to usage in space hardware programs
- Implementing complete configuration control for flight hardware
- Assuring rigid obedience to and control of "clean and proper" working habits

Wearout life well in excess of mission life is provided by the following:

- Utilizing a cathode life tested to over 60,000 hours and projected to last almost 200,000 hours. (This is the only wearout process so far encountered on space tubes.)
- Evaluating two other potential wearout processes — depletion of attenuator coating or erosion of helix; selecting materials and processes, as discussed in body of report
- Eliminating harmful film deposition on insulators through shielding and temperature control

9. EXPERIMENT TEST PLAN

This document defines all experiment-related activity during the time the spacecraft is in orbit. A tentative outline is given below.

Experiment Test Plan Outline

1.0 INTRODUCTION
1.1 Scope
1.2 Experiment Objective
1.3 Experiment Description
2.0 SYSTEM DESCRIPTION
2.1 System Configuration
2.2 Spacecraft System Description
2.3 Ground System Description
3.0 APPLICABLE DOCUMENTS
3.1 High Power S-Band Experiment Summary
3.2 Spacecraft Performance Requirements
3.3 Ground System Support Requirements
3.4 Support Instrumentation Requirements
3.5 Experiment Interface Agreement
3.6 Field Test Procedures
3.7 Data Reduction and Analysis Plan
3.8 Experiment Handbook

4.0	GROUND HARDWARE REQUIREMENTS
4.1	Experimenter Unique Equipments
4.2	Ground Station Facilities
4.3	Ground Station Interface Drawings
5.0	DETAILED TEST PLAN
5.1	Broadband Mode
5.1.1	RF Signal Power and Path Loss
5.1.1.1	Time Required
5.1.1.1.1	Setup Time
5.1.1.1.2	Spacecraft Test Time
5.1.1.2	Test Procedure
5.1.1.2.1	Step 1
5.1.1.2.1.1	Time
5.1.1.2.1.2	Measurement
5.1.1.2.1.3	Remarks
5.1.1.2.2	Step 2
	.
	.
	.
5.1.1.2.n	Step n
5.1.2	RF Signal Power and Path Loss Variations
	.
	.
	.
5.1.3	Transmitter-Receiver Linearity
5.1.4	Transmitter-Receiver Group Delay

5.1.5 Weighted (Video) Noise

5.1.6 Video Differential Gain

5.1.7 Video Insertion Gain

5.1.8 Video Low Frequency Response

5.1.9 Video Transient Response

5.1.10 Video Noise and Distortion

5.1.11 Monochrome Test Pattern Analysis

5.1.12 Color Vector Analysis

5.1.13 Baseband Frequency Response

5.1.14 Audio Channel Periodic and Crosstalk Noise

5.1.15 Audio Channel Frequency Response

5.1.16 Audio Channel Idle Noise

5.1.17 Audio Channel Insertion Gain Stability

5.1.18 Audio Channel Harmonic Distortion

5.2 Duplex Mode

.

.

.

5.3 Talkback Mode

5.4 Mixed Mode

6.0 DATA MANAGEMENT PLAN

6.1 Data Collection

6.1.1 Ground Station Equipment

6.1.1.1 Hardware Requirements

6.1.1.2 Software Requirements

6.1.2 Experimenter Unique Equipment

6.1.2.1 Hardware

6.1.2.2 Software

6.2 Data Transfer

6.2.1 Real-Time Requirements

6.2.2 Data Package Marking Instructions

6.3 Support Data Requirements

7.0 COMMUNICATIONS REQUIREMENTS

Repetitive portions have been omitted to avoid unnecessary duplication in this outline.

10. DATA ACQUISITION

PHASE I

Data required for performance evaluation of the spacecraft experiment hardware are listed below:

Earth Station Data

Coordinates (location, pointing)

Weather conditions (as a function of time)

EIRP, transmit frequency

Transmitted signal format (bandwidth, modulation, etc)

G/T, receive frequency

Received signal strength (including fading)

Spacecraft Data

Antenna mode

Antenna gain

TWT operational status

TWT power level

IF amplifier operational status

Output switch status

Driver amplifier gain setting

TWT voltages and currents

Power supply input current

TWT temperature

Power supply temperature

PHASE II

In addition to the data required for Phase I, as listed above, the following parameters will be monitored during the interference measurement tests:

ITFS Transmitter Power

ITFS transmitter antenna gain

ITFS receiver(s) antenna size, gain

ITFS receiver(s) noise power

ITFS receiver(s) signal plus noise power

ITFS receiver(s) interference plus noise power

ITFS receiver(s) orientation with respect to spacecraft

ITFS transmitter orientation with respect to spacecraft

Field station received signal power

Field station received interference power

Field station received noise power

Observable (perceptible) interference data (from video monitor)

Monochrome test pattern analyses

Color vector analyses

Weather at ITFS site

Fade data at ITFS site.

PHASE III

Because Phase III experiments have not yet been developed, no requirements can be established at this time. In addition to data required by the user to evaluate educational factors, data similar to that listed above will be needed to evaluate communication link performance.

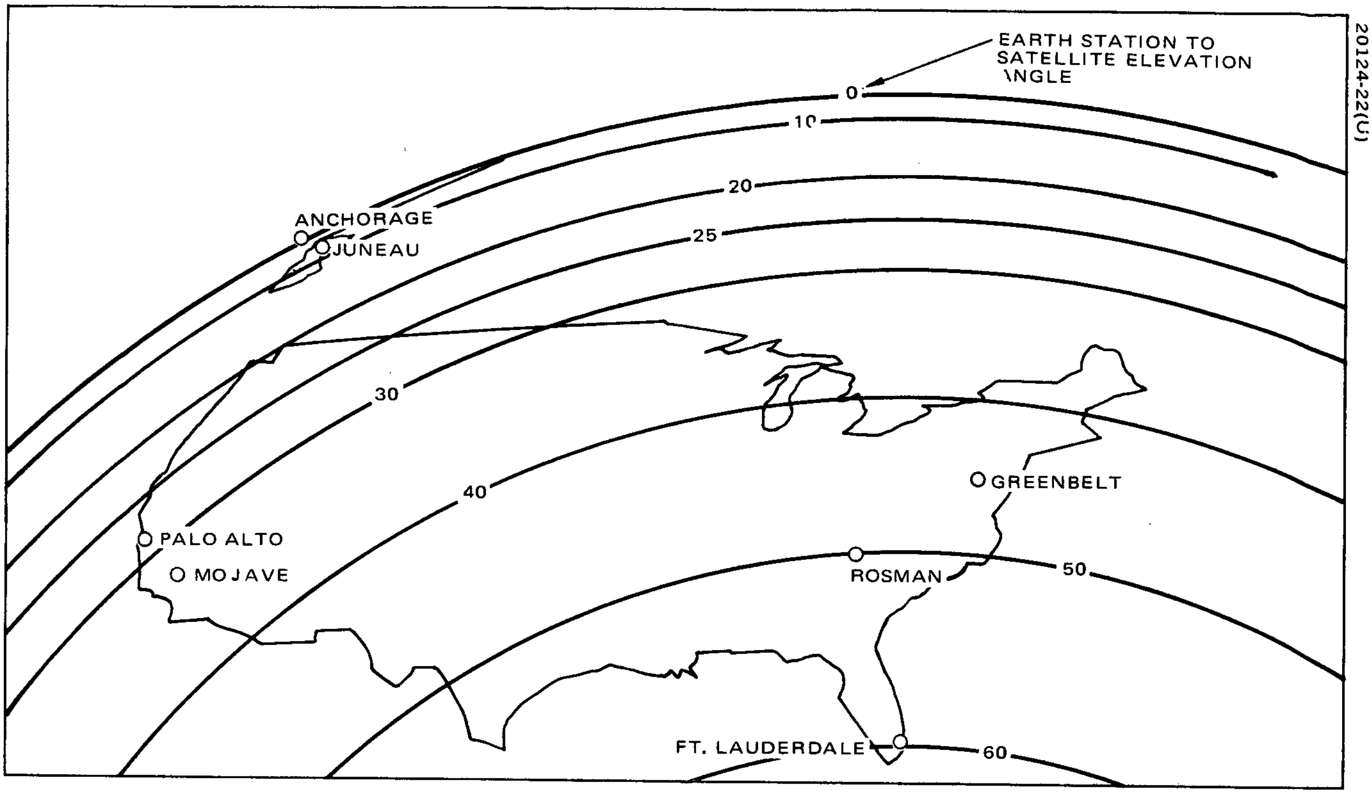
SCHEDULING REQUIREMENTS

Phase I tests can be conducted during the initial checkout of the spacecraft after insertion into orbit. Other than good access to the Rosman Station, there are no unusual requirements. Scheduling of tests can be integrated with other tests used to evaluate overall communication performance of the spacecraft and could be conducted at periodic intervals over a several week period. After initial checkout, less frequent tests would be made to determine performance over the lifetime of the spacecraft.

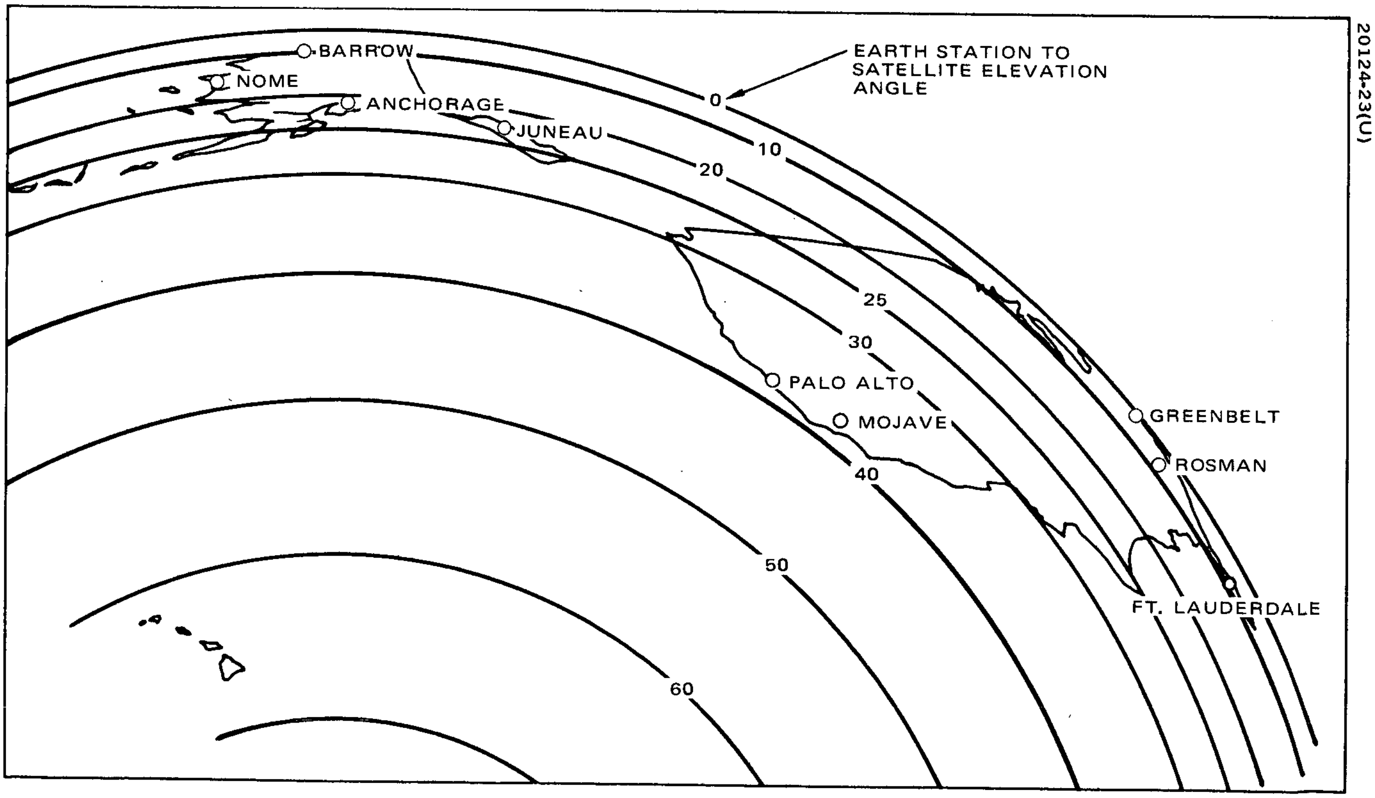
During Phase II, there are unique orbital requirements. In order to obtain the maximum elevation angle from the ITFS system in Fort Lauderdale to the spacecraft, the initial tests require positioning the ATS-G at a longitude of approximately 80°W. Figure 10-1a shows a projection of the United States from this location. It is premature to establish the time required at this location; however, a minimum of 1 month seems appropriate, with several 15 to 30 minute test periods per day. To obtain as low an elevation as possible, the spacecraft should be moved as far west as 150°W. At this location, Fort Lauderdale would see the ATS-G at approximately 10 degrees elevation, as shown on Figure 10-1b. Four weeks at this location should be adequate. During transit from 80° to 150°W over a 1 month period, many measurements at intermediate elevation angles could be made.

The ultimate orbital location, consistent with best coverage of Alaska and compatible with the U. S. and Canadian Domestic Satellite Systems appears to be between 120° and 130°W longitude. Figures 10-1c and 10-1d show the U. S. from these positions.

To evaluate the impact of these requirements upon other experiments, views of the entire earth for orbit locations from 80°W to 150°W longitude are given in Figure 10-2.

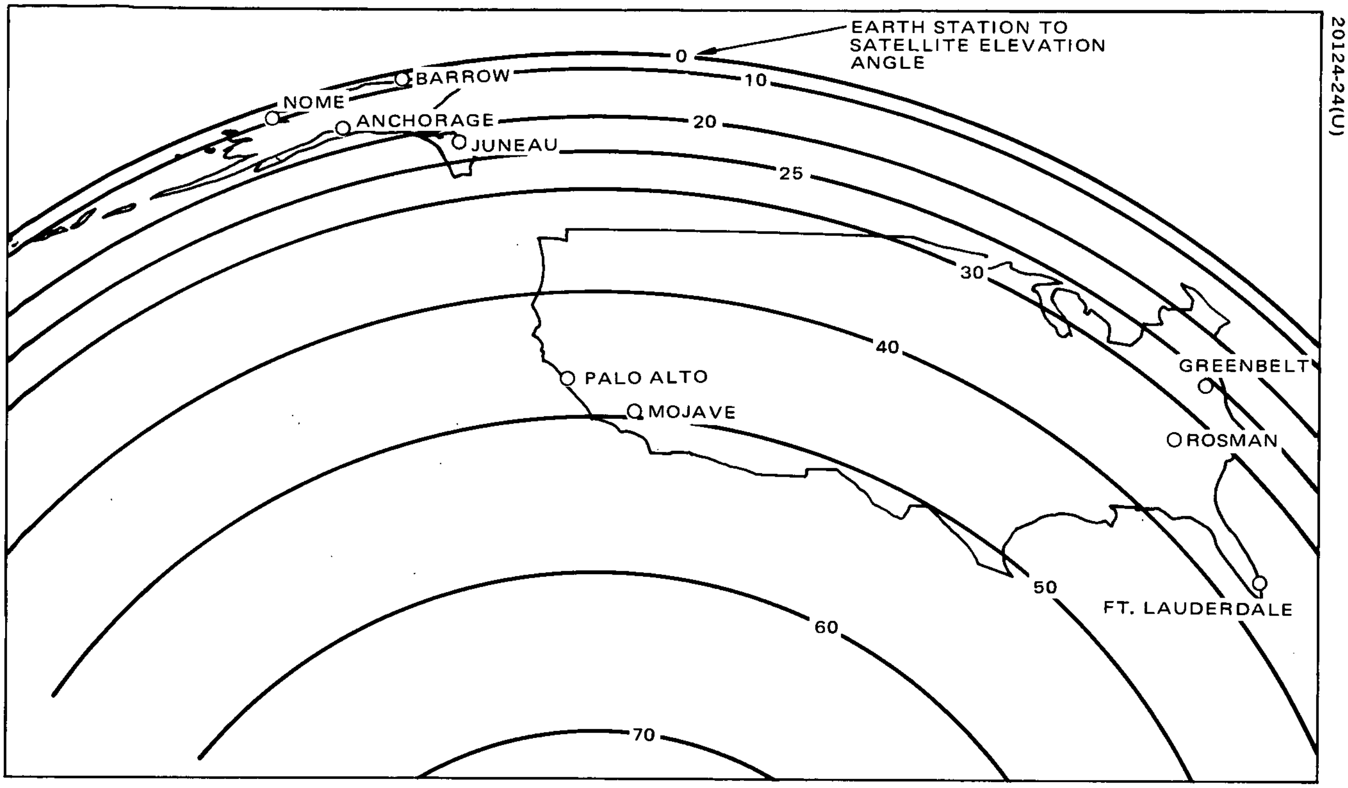


a) 80° W

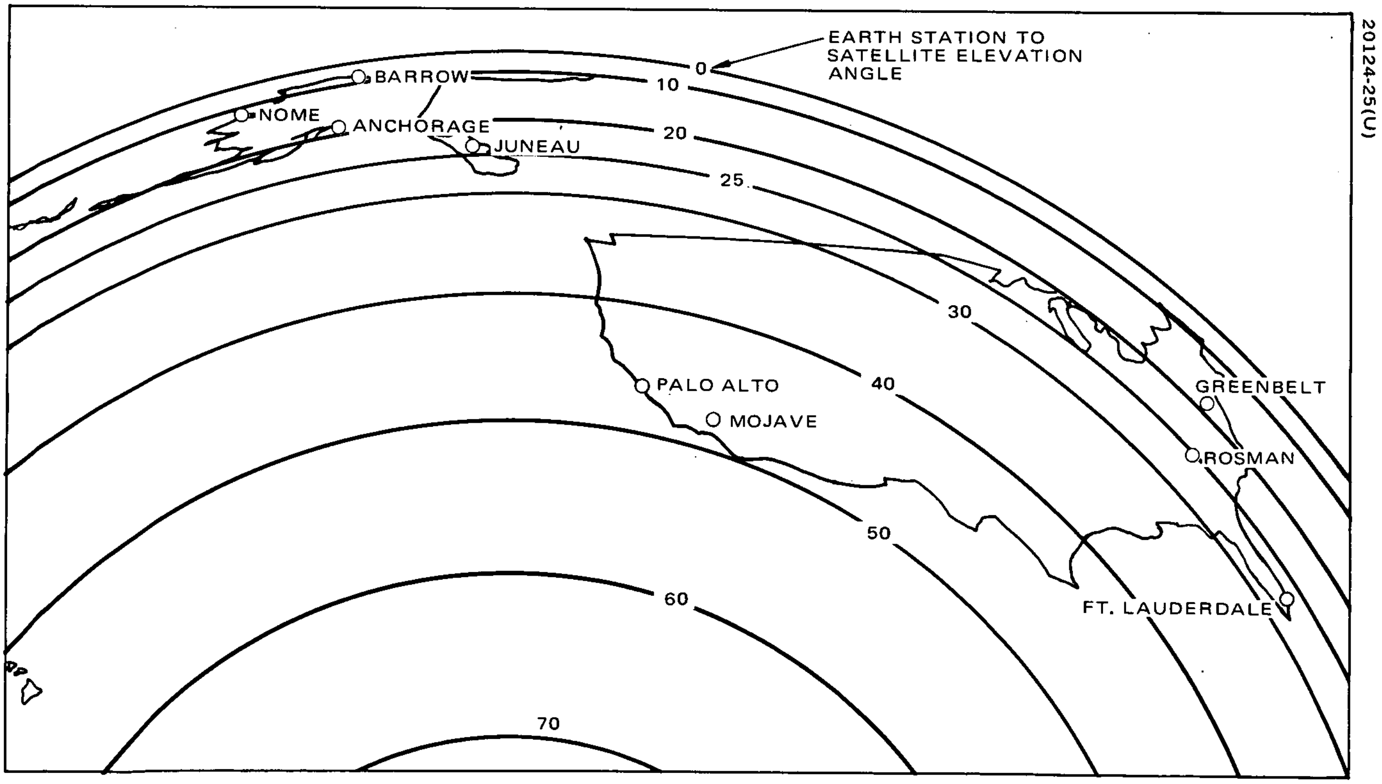


b) 150° W

Figure 10-1. United States as Seen From Spacecraft at Various Longitudes



c) 120° W



d) 130° W

Figure 10-1. (Continued). United States as Seen From Spacecraft at Various Longitudes

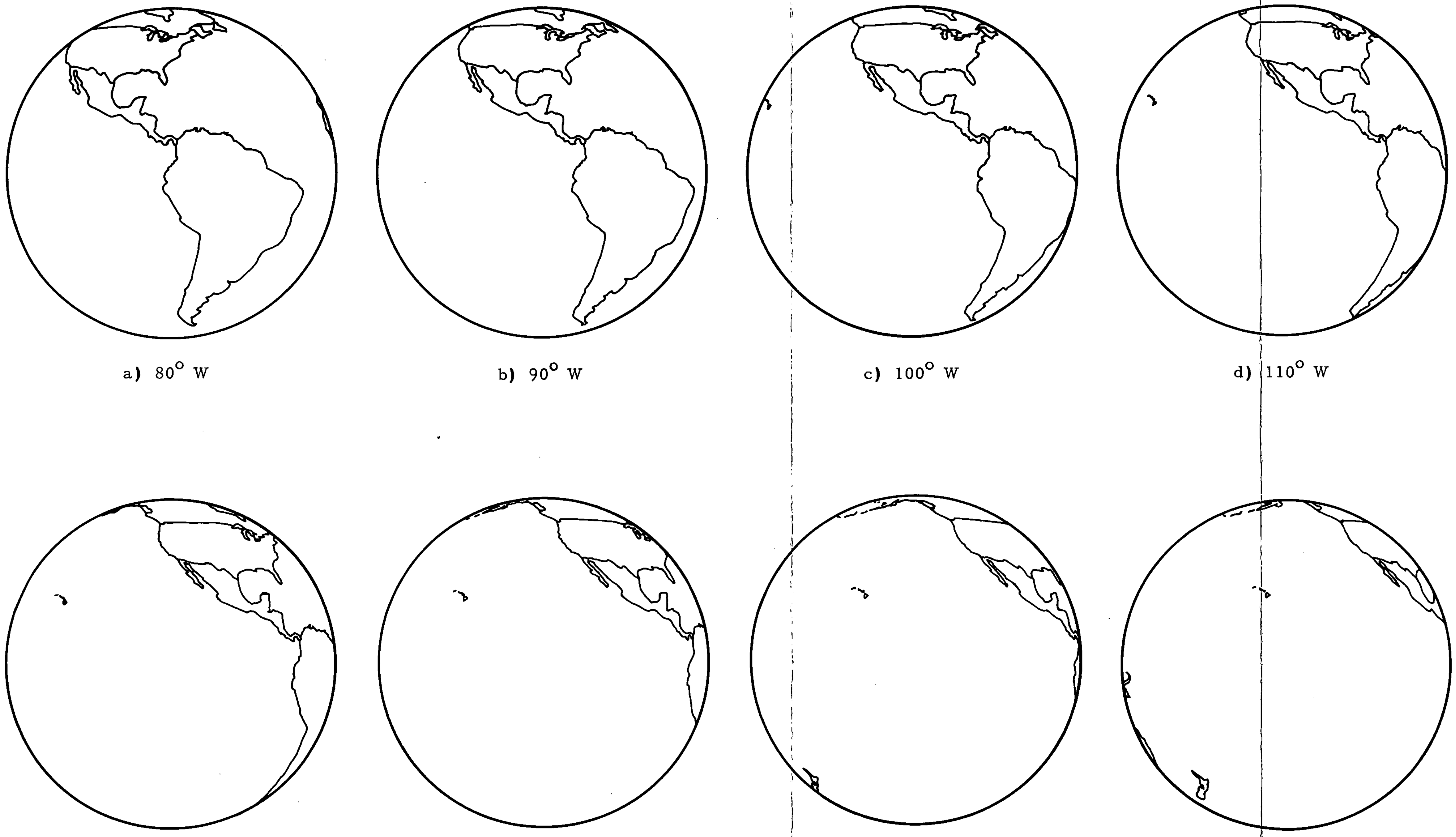
C.2

PRECEDING PAGE BLANK NOT FILMED

FOLDOUT FRAME 1

FOLDOUT FRAME 2

20124-26(U)



a) 80° W

b) 90° W

c) 100° W

d) 110° W

e) 120° W

f) 130° W

g) 140° W

h) 150° W

Figure 10-2. Earth Viewed From Spacecraft at Various Longitudes

11. DATA PROCESSING, REDUCTION AND ANALYSIS

DATA PROCESSING

Minimal computational requirements exist for this experiment. There is no anticipated need for real time computation other than that employed routinely in the operation of the ATS-G spacecraft.

Experiment data will be recorded on data sheets, strip charts, and photographs. All telemetry will be recorded on these data sheets. Time will be recorded on strip charts and data sheets where specified and correlated with experiment log sheets. All data will be mailed to the experimenter.

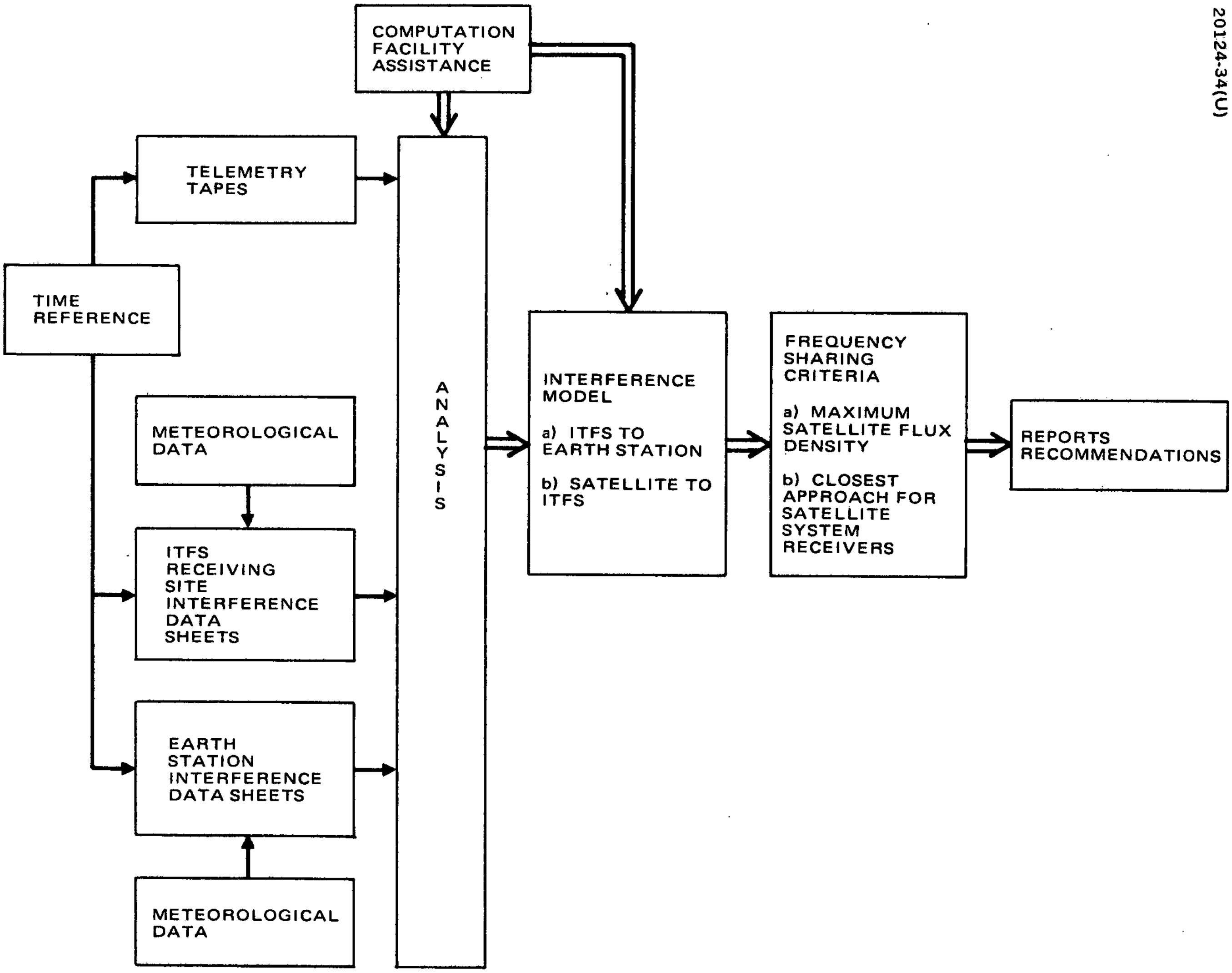
Any off-line computational effort would develop from propagation measurements and would involve correlation analyses among the data collected at various sites. Due to the tentative nature of this effort, it is not possible to define these requirements until a later date.

DATA REDUCTION AND ANALYSIS PLAN

Collection of data for Phase I will be limited to the use of log sheets, recorder strip charts, oscilloscope screen photographs, and telemetry tapes. Little, if any, data processing will be required for this phase since the experiment does not concern itself with the collection and reduction of large volumes of statistical data. Phase I, therefore, largely involves the corroboration of prelaunch system parameters with those measured after orbital insertion.

A data flow chart for Phase II, the interference measurement phase, is shown in Figure 11-1. The major factor to be noted here again is the lack of requirements for processing large amounts of data. Instead, the routine use of a computational facility is envisioned to aid in the analysis of collected data and the synthesis of the interference model.

Since Phase III covers experiments performed by users from the educational community, all data reduction and analysis for this phase is expected to be performed by the users themselves.



20124-34(U)

Figure 11-1. Phase II Data Flow Chart