PERIODIC PROGRESS REPORT

for

ATS RANGING AND POSITION FIXING EXPERIMENTS

(1 MARCH 1971 - 31 MAY 1971)

Contract No.: NAS5-11634

Goddard Space Flight Center

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SUMMARY

This periodic progress report covers work performed pursuant to Phase III of Contract NAS5-11634 for the period March 19 through May 31, 1971. Phase III is primarily an adaptation of the General Electric tone-code ranging system, successfully demonstrated at VHF frequencies with ATS-1 and ATS-3, to the L-band frequency available on ATS-5. Present equipment will be modified and new equipment designed and constructed so as to provide simultaneous, correlated range measurements from a remote platform to the General Electric Observatory at Schenectady via ATS-5 and ATS-3. The precisely timed transmissions will enable a direct comparison of VHF path anomalies versus the L-band path link. Periodic position fixes will also be made and will reflect the combined effects of both frequencies. These will be compared to results obtained during Phase II of the contract wherein position fixes were obtained at VHF only.

The spinning anomaly of ATS-5 has been observed and analyzed, and suitable means of synchronization have been devised such that the experiment can be conducted satisfactorily.

Power budget analyses have been made and reflect marginal though usable signals available through the ATS-5 window for the modulating frequencies and techniques originally suggested in the work statement.

The VHF portion of the proposed "dual frequency" system has been field tested sufficiently that no difficulties are anticipated.

Conclusions

- The General Electric Observatory is fully cognizant of the limitations of the ATS-5 satellite, through the excellent report of Mr. Frederic Kissel* and through personal observations. "Spin mod" was experienced with ATS-3 and a means was devised so as to make it inconsequential to range measurements, and similar means will be implemented to compensate for the ATS-5 spin rate.

- Newly developed integrated circuits will enable the Observatory to take advantage of higher clock rates than were available in the Phase II development. This will result in increased resolution and more rapid phase matching.

- A "fail-soft" L-band power amplifier will be employed, insuring operation under aggravated circumstances.

*L-Band Performance Characteristics of the ATS-5 Spacecraft, X-731-70-51, February, 1970.

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INTRODUCTION

During this reporting period the General Electric Corporate Research and Development has conducted a study and design phase which will allow application of the General Electric tone-code ranging system (previously demonstrated at VHF frequencies) through the L-band transponder of ATS-5. In order to provide a background for the following discussion, the work statement as originally proposed and accepted for Phase III of this contract will be given below:

Items 1.1 through 1.8 from Statement of Work, ATS L-Band Ranging Experiments

1.1 The Contractor will conduct experiments that will accomplish the following:

1.1.1 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. A sufficient quantity of data will be collected to provide a meaningful statistical evaluation.

1.1.2 Determine the relative reliability of the communication links under the conditions of the experiment at L-band and VHF.

1.2 The above objectives will be accomplished by making range measurements simultaneously at both frequencies. Ranging will be measured from ATS-3 and ATS-5 to a mobile platform and to a fixed ground terminal. The measurements to the platform will provide data on the effects of sea reflection multipath and the ionosphere as they affect ranging precision. Measurements from the satellites to a fixed ground terminal will provide information on the precision and accuracy of range measurements at the two frequencies especially as they are affected by diurnal changes in the ionosphere. The effects of Faraday rotation, scintillation and other variables on signal propagation reliability will also be derived from the experiments.

1.3 Ranging measurements will be made by simultaneous transmissions at VHF and at L-band from the mobile craft or distant ground platform through ATS-3 and ATS-5. The signals will be received separately and time delays measured at the Observatory. A single interrogation at VHF over a forward link from General Electric's Radio-Optical Observatory will be transmitted through ATS-3 to the mobile craft or the fixed ground terminal. The interrogation will initiate a sequence of approximately 100 transmissions from the distant transponder. The transponder transmissions will be timed automatically to be phased with the transmission relay window of spinning ATS-5. Each of the 100 transmissions will provide an independent range at each of the two frequencies. At the end of the 100 measurement transmission sequence, the distant transponder will be interrogated again, the tone generator and the transmission timing circuit rephased, and the next series of 100 transmissions initiated.

1.4 Phase coherence of the ranging tones at VHF and L-Band will be insured by generating the tones from a common oscillator for both frequencies. Range ambiguities will be resolved by the tone-code ranging correlation technique at VHF. The propagation paths at VHF are reliable enough to insure range ambiguity resolution for the L-band signals. The phase coherence of the ranging tones at the distant transponder insures that the L-Band measurements are not affected in any way by signal variability of the VHF transmission link.

1.5 Standard deviations for each set of 100 measurements will be computed for each frequency. The diurnal change in range difference will be a measure of the difference in ionospheric delay when the difference in the diurnal range changes to the satellites has been taken into account. Variations of the individual measurements from the mobile platform will show the relative effects of sea reflection multipath. Signal level measurements will show fading amplitudes at each frequency and indicate relative signal level margins needed for reliable communications.

1.6 The Contractor will plot position fixes using the range measurements from ATS-3 and ATS-5 with one line of position derived at VHF and the other at L-Band. It is expected that these plots will provide the relative accuracy and precision of fixes determined by the two frequencies because one line of position will be affected by VHF propagation factors and the other will have the advantages of the better propagation at L-Band.

1.7 The VHF equipment for the experiment is currently at the Contractor's Observatory. The data recording and processing equipment for the VHF and L-Band tests are in place and functioning. The experiment is to be designed so that the L-band measurements can be incorporated quickly and at a low cost so that the major effort will be devoted to data collection analysis and evaluation.

1.8 The L-Band signal design will employ modulating and radio frequency bandwidths which are considered appropriate and within the expected bandwidth allocations at L-band. The tone frequency and radio frequency bandwidth will be selected after consultation with NASA. The final selection will be based on the expected propagation characteristics at L-Band. The measurements must not be limited by bandwidth or equipment time resolution, but only by the propagation factors that are measured in the experiment. However, it is not realistic to use bandwidths greater than the anticipated allocations. It is proposed that the L-Band modulating tone frequency be 9.7656 kHz which is four times the current modulating frequency at VHF. The radio frequency will remain as currently designed unless the system study shows that it will not produce the desired precision.

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By May 31, 1971 the design of equipment required to cover the above objectives was 80 percent complete, all major purchasable items had been received or were on order, and fabrication had begun on certain base-band equipment. In addition, the L-Band receiving system at the Observatory was installed and tested on ATS-5 transmissions satisfactorily. Received signal levels were as expected and validate the power budget previously submitted in the Systems Study Report. Spin rate and daily variations have been noted as an aid in determining the adjustment range required of the platform and Observatory spin rate synchronizers.

- The L-Band modulator/exciter has been received and has undergone a preliminary checkout.

- The solid-state 300 Watt L-Band amplifier has been ordered and is progressing on schedule.

• Base-band equipments (code correlators, code generators, ATS-5 and ATS-3 spin synchronizers, read-out displays, etc.) are in progressive stages of design and fabrication.

DISCUSSION

It is the purpose of this discussion to point out in some detail specific areas of work performed in the reporting period and to make known an alternative approach to certain items contained in the original work statement. In any case, the objectives agreed upon will be retained and the alternatives are suggested only as an improvement and involve no extra effort or cost to the contract.

• L-Band Receiving System and Performance

A block diagram of the L-Band receiving system is shown in Figure 1, and the principal components which determine system sensitivity are detailed as follows:

1. A 30 foot diameter parabolic reflector with a solid surface stretched aluminum skin. Surface tolerance is 0.020" RMS and it is mounted on an Az-El pedestal capable of full azimuth coverage and $\pm$ 92° elevation coverage. The structure is enclosed in a 52 foot diameter air inflated radome.

2. A model ASN116A cavity backed spiral feed (American Electronic Laboratories, Inc.). The feed is left-hand circularly polarized and covers the frequency range of 1 to 12 GHz with a power handling capability of approximately 40 Watts. It is mounted at the prime focus and adjacent to a dual polarized linear log periodic feed which covers the frequency range 0.1 to 1 GHz. Either feed is selectable by remote switching.

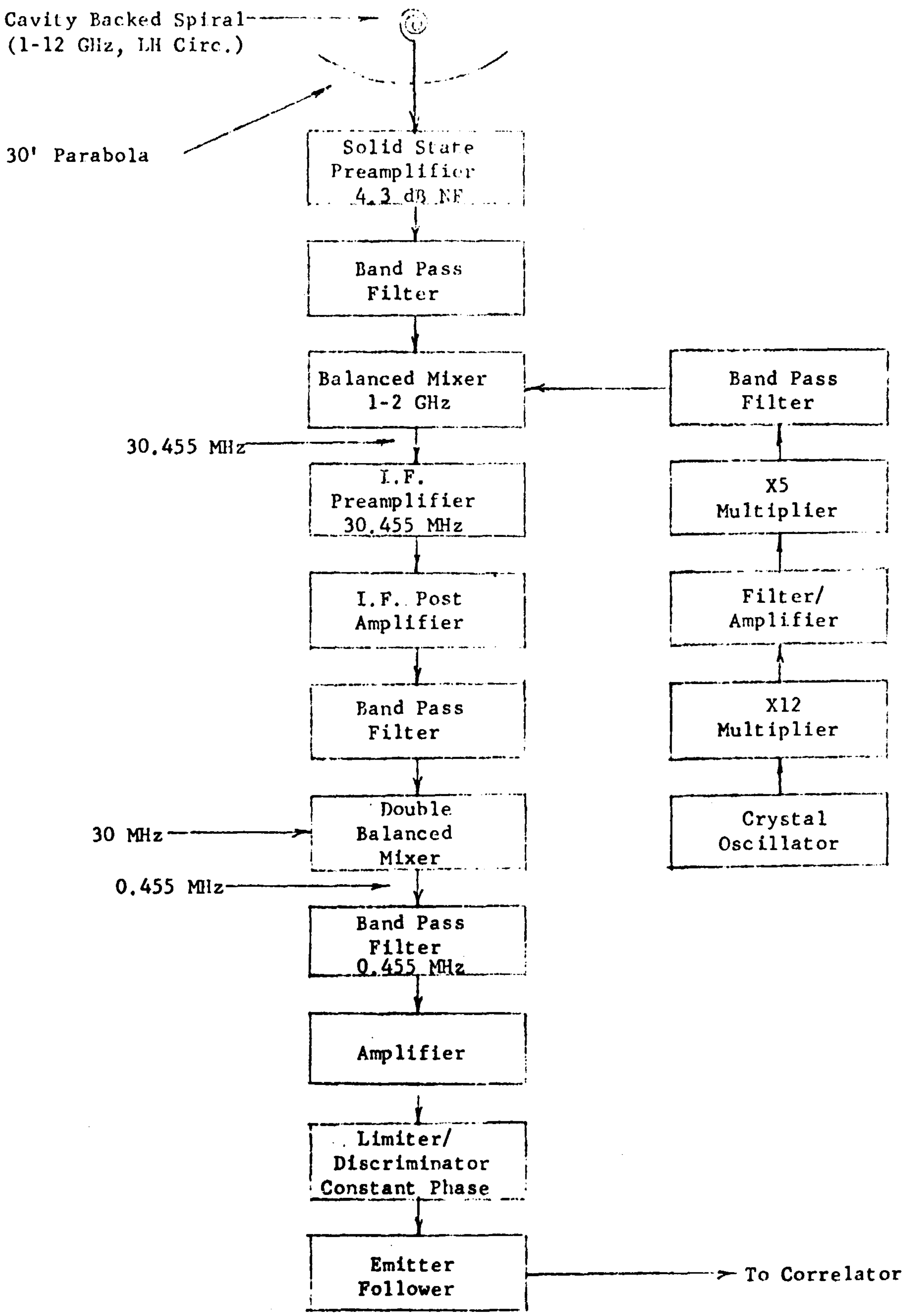
3. A model A4563 transistor preamp (Aertech Industries). The preamp is mounted at the feed via a 10 foot length of 0.5" diameter foam Heliax cable. The preamp bandwidth is approximately 100 MHz centered at 1550 MHz. It has a gain in excess of 25 dB and a noise figure of 4.3 dB.

4. A model TTF-2250-5-5EE tunable band pass filter (Telonic Engineering Corporation). Frequency tuning range of the filter is 1.5 to 3 GHz and the bandwidth is <5 percent. The filter is interposed between items 3 and 5 to suppress the introduction of image frequency noise to the mixer which follows.

5. A model MP1-2/2C mixer preamp (RHG Electronics Laboratory, Inc.). The mixer is double balanced and covers 1-2 GHz. The integral I.F. preamp has a 10 MHz bandwidth centered at 30 MHz. After post amplification, the I.F. is routed to various receivers dependent on predetection bandwidth and demodulation requirements. At this point, however, the system sensitivity has already been established, and serves as the basis for the system performance which follows.

Figure 2 is a chart recording of signal level obtained from ATS-5 during an L-Band propagation test. For this test, the satellite was configured in the half-power mode and the on-board VCO provided a saturated, unmodulated carrier. This signal was received at the Observatory with the system described above,

FIGURE 1. L-BAND RECEIVING SYSTEM - OBSERVATORY



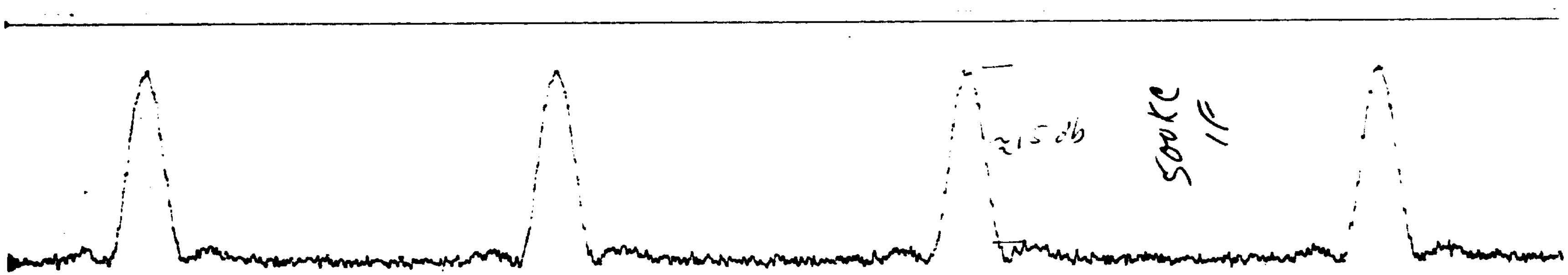


FIGURE 2

ATS-5 L-BAND TRANSMITTER, HALF-POWER MODE DETECTED SIGNAL VOLTAGE IN 500 KHZ BANDWIDTH and the 30 MHz I.F. was directed to a Nems Clarke model RFT-30-260 receiver. An I.F. bandwidth of 500 kHz (57 dB noise bandwidth) was selected and the developed AGC voltage was recorded. The energy received from the side lobes of the satellite antenna are evident in the recording. The difference between peak main lobe and side lobe signal is >15 dB per Mr. Kissel's report; therefore the chart recording depicts a peak C+N/N ratio greater than 15 dB for a received signal-to-noise density greater than 72 dB/Hz (57 dB noise bandwidth plus 15 dB C+N). The solid-state preamplifier, coupled with approximately 1.0 dB line, fittings, and switch loss represent a sensitivity of -169 dBm. It can then be said that the total received power out of the antenna and into the receiver is -169 dBm + 72 dB = -97 dBm. This is within 1 dB of the Observatory expected signal based on Mohave's tests.

All of the equipment shown in Figure 1, and that described above is furnished by the General Electric Company.

• Modulator/Exciter

The L-Band modulator/exciter consists of a General Electric Progress Line UHF transmitter operating at a nominal frequency of 415 MHz followed by a passive X4 multiplier for conversion to L-Band. Both items have been delivered and preliminarily tested, and performance is satisfactory. The General Electric exciter is a console model identical in physical appearance to the VHF transmitter flown in previous aircraft experiments. An improved oscillator has been incorporated, however, for greater RF frequency stabilization. This oscillator is designated as ICOM (integrated circuit oscillator module) and is a crystal-controlled temperature-compensated oscillator with a rated stability of 0.0002 percent over the temperature range of -35°C to +60°C. Compensation is accomplished at both ends of the temperature range. When multiplied to L-band (≈1651 MHz) the total drift measured by the Observatory was less than 150 Hz over a two hour period at room ambient temperature.

The X4 passive multiplier is a model VM-1650-4 supplied by Applied Research, Inc. It provides a filtered, circulator-protected output of 800 milliwatts at L-Band when driven with <2 Watts of RF at UHF. The varactor/filter/circulator assembly is mounted on a 3.5" x 10" panel and will be mounted within the exciter console.

• L-Band Power Amplifier

A 300 Watt power amplifier is ordered and is being fabricated by the General Electric Heavy Military Electronic Systems. The specifications of this amplifier, mutually agreed upon, are as follows:

Frequency	1651 MHz
Bandwidth	10 MHz at 1 dB points
RF Power Output	300 Watts minimum (CW)
Power Gain	30 dB minimum
DC-RF Efficiency	30 percent minimum
Input VSWR	≤ 1.6:1
Load VSWR	Circulator protected output
Operating Temperature	40°F to 100°F
Noise Figure	≤ 20 dB
Supply Voltage	105-125 AC, 60-400 cycle

This amplifier is of laboratory-proven design, and is completely solid state. Multi-parallel output stages allow relatively fail-safe performance with slight degradation, and the latest power supply design incorporates a minimum of two AC/DC converters, each furnishing a proportionate share of the required DC power. This will provide a reduced power mode in the event of a single power supply failure. In keeping with the Observatory request for flexibility, the 110V AC primary power (40-400 cycle) is acceptable to both ground and airborne use, and may be split, dependent on available aircraft power.

Figure 3 is a photograph of a 10 Watt amplifier module and a brief status report submitted by the supplier is given as Appendix A.

Anticipated Platform Performance - Fixed and Mobile

A C-135 aircraft will be equipped with a VHF transponder and an L-Band transmitter for mobile platform tests. An interrogation from the Observatory through ATS-3 to the aircraft at VHF will trigger VHF and L-Band transmissions from the aircraft. The L-Band aircraft-to-satellite link and satellite-to-Observatory link are shown in Tables 1 and 2. The tables assume optimum performance for both the aircraft and Observatory equipment, and normal operation of the spacecraft transponder.

User Base-Band Equipment (Figure 4)

The necessity for tone-code transmissions synchronous to the ATS-3 spin modulation rate was recognized during the Phase II portion of the contract when the satellite began to exhibit excessive amplitude modulation at its spin stabilized rate. The modulation presented a notch in excess of 7 dB relative to normal operation. Although tolerable with high gain antennas, definite effects were noted with medium gain (10 dB) antennas. As the antenna gain approached 0 dB, transmissions could not be received during the notch period resulting in a partial loss of tone or code and a resultant noise disturbed measurement or no measurement at all. At that time, the Observatory synchronized and phased the tone-code burst such that the transmission arrived at the satellite and was retransmitted outside of the notch window. The users were thus guaranteed a full strength transmission from the satellite.

A similar method will be employed to compensate for the ATS-5 spin rate, insuring that the code transmitted by the user arrives at the satellite within a desired portion (<3 dB down) of the main lobe. Adjustable spin rate synchronizers with phasing capability will be provided for each satellite. The VHF concept is basically identical to that already demonstrated. The correlator has been modified to take advantage of advanced techniques and improved performance components. Integrated circuits are now available which will allow a higher basic clock than was available previously. The equipment will therefore incorporate a 10 MHz temperature compensated clock oscillator with 10^8 stability at ambient temperatures. This will provide an instrumentation resolution of 0.1 microsecond. In addition, the phase matching circuitry will be modified to allow a full correction in a shorter period of time necessitated by the short duration of the ATS-5 window. The maximum time required for phase matching will be 105 milliseconds for a modulating tone frequency of 2.4 kHz and 26 milliseconds for a tone frequency of 9.6 kHz. This represents 256 cycles of the modulating frequency.

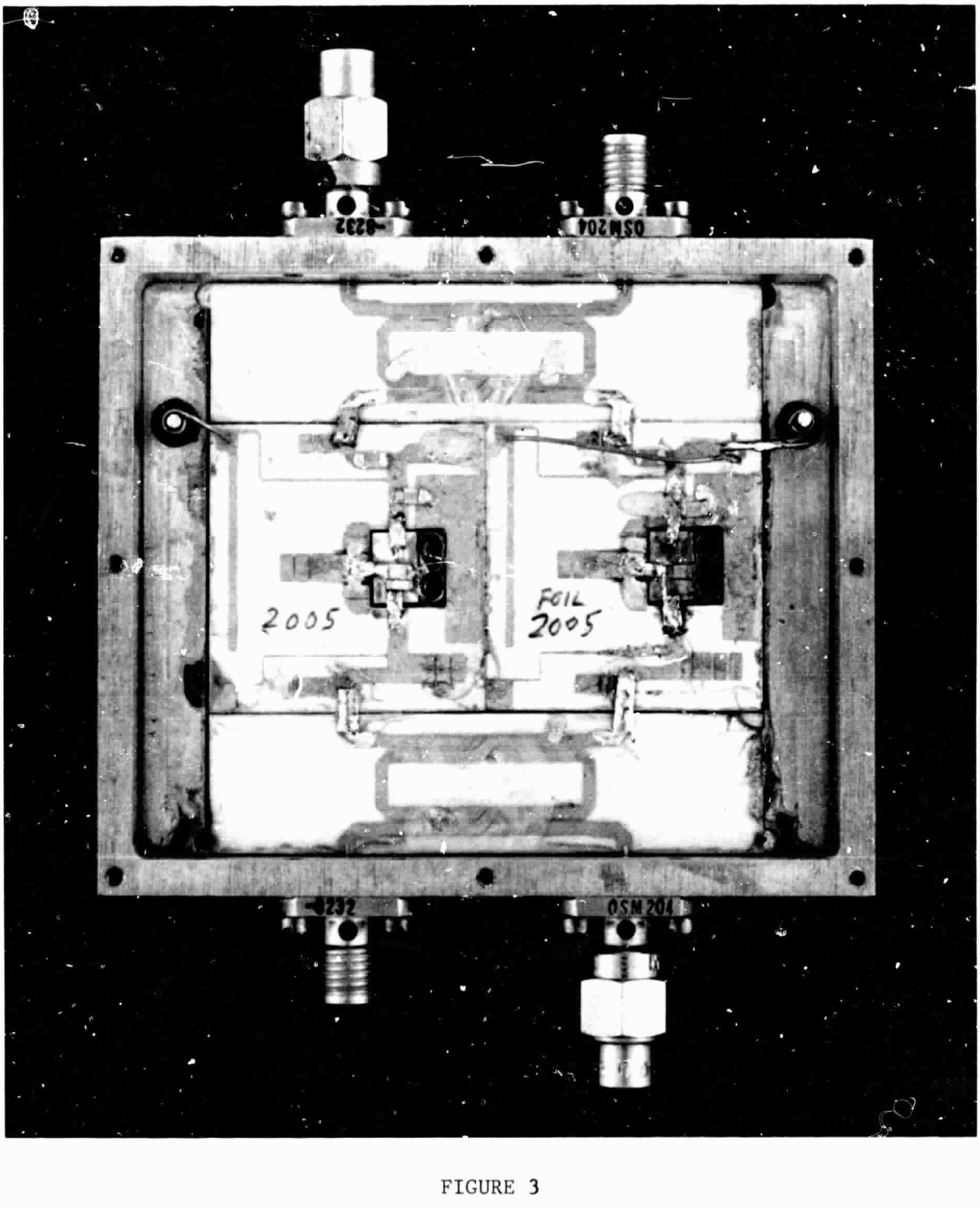


FIGURE 3

10 WATT AMPLIFIER MODULE

TABLE 1

POWER BUDGET ANALYSIS FOR AIRCRAFT TO SATELLITE LINK

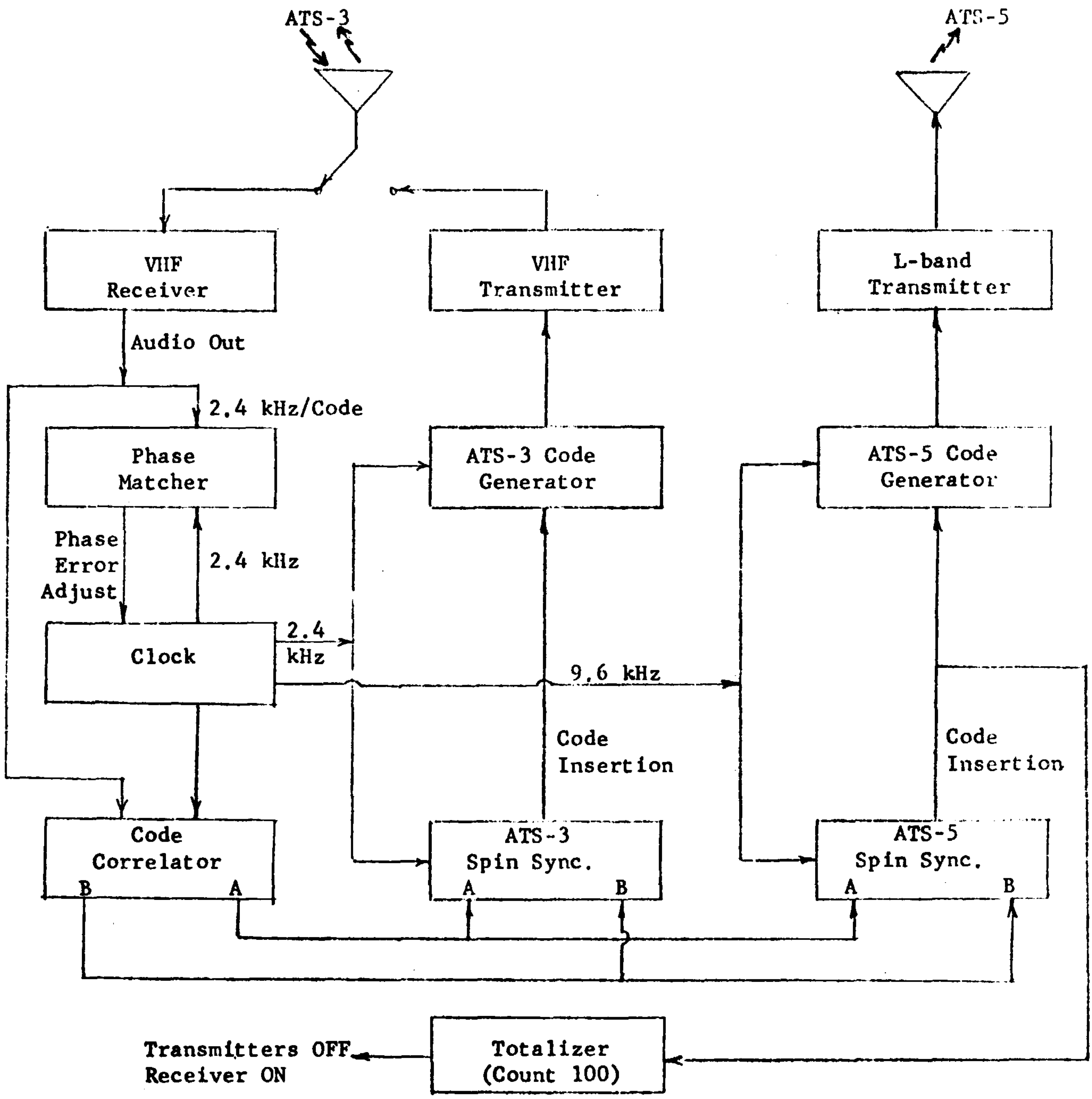
Aircraft Transmitter Power (300 W)	54.8 dBm
Circuit Loss	-2.0 dB
Antenna Gain	15.0 dB
Pointing Loss	-1.5 dB
ERP	66.3 dBm
Space Loss	-188.0 dB
Polarization Loss	-0.5 dB
Receive Antenna Gain	15.5 dB
Circuit Loss	-1.3 dB
Pointing Loss (Spin)	-2.0 dB
Total Received Power	-110.0 dBm
Noise Power Density	-169.0 dBm/Hz
Signal-to-Noise Power Density	59.0 dB
Noise Bandwidth (2.5 MHz)	64.0 dB/Hz
Output Signal-to-Noise Ratio	-5.0 dB
Limiter Loss	-1.0 dB
Output Signal-to-Noise Power Density	58.0 dB/Hz (-6 dB)ratio

TABLE 2

ATS-5 TO GROUND (OBSERVATORY) LINK

Satellite Transmitter Power	44.0 dBm
Circuit Loss	-2.0 dB
Antenna Gain	15.0 dB
Pointing Loss (Spin)	-2.0 dB
ERP	55.0 dBm
Space Loss	-187.6 dB
Polarization Loss	-0.5 dB
Observatory Receive Antenna Gain	40.5 dB
Circuit Loss	-0.5 dB
Pointing Loss	-0.5 dB
Total Received Power	-93.6 dBm
Loss for Noise Power Sharing	-6.0 dB
Effective Power Received	-99.6 dBm
Receiving System Noise Power Density	-169.7 dBm/Hz
Signal-to-Noise Power Density	70.1 dB/Hz
Satellite Output Signal-to-Noise Power Density	58.0 dB/Hz
Resultant Signal-to-Noise Density	57.6 dB/Hz
Receiver IF Noise Bandwidth (60 kHz)	48.0 dB/Hz
Signal-to-Noise Ratio, IF	9.6 dB

FIGURE 4. PLATFORM VHF - L-BAND SYSTEM



Code A - "Delay code insertion 0.43 second to both satellites. Send one transmission, then go to receive mode."

Code B - "Delay code insertion 0.43 second to both satellites for one transmission, then insert at 0.60 second intervals to ATS-3, 0.78 second intervals for ATS-5. Count 100 transmissions at ATS-5 rate then command transmitters OFF - Receiver ON."

The correlator will be equipped to recognize two specific codes and react accordingly. The demands of codes A and B are listed in the footnotes of Figure 4.

A further explanation of the term "100 transmissions" is desirable at this time. The user transmitter is activated immediately after code correlation is achieved. This is a tone transmission which lasts approximately 0.43 second, with a code inserted during the last 30 cycles. In code A, the transmission will cease after the code has been sent. In code B, the transmitters (VHF and L-Band) will send tone continuously and the 30 cycles of coded information will be inserted approximately 100 times -- once per spin rate of each satellite and totalized at the ATS-5 spin rate. During the time period required for 100 ATS-5 transmissions (0.78 x 100) 78 seconds, the VHF transmitter will have sent ≈130 transmissions based on a present spin period of 0.6 second. To allow the data recording equipment at the Observatory to function properly, the extra 30 transmissions will be "ignored" individually at predetermined times so that a total of 100 each are recorded with time coherence.

Observatory Base-Band Equipment (Figure 5)

The interrogating and data collection ground station for the experiment will be the Corporate Research and Development Center's Radio-Optical Observatory at Schenectady, New York.

This station will initiate VHF transmissions to the user synchronized to the ATS-3 spin rate (if required) and will receive the user transmissions at VHF and L-Band.

Two synchronizers (transmit) will establish the timing of the interrogating transmission to the user. The interrogation will occur automatically whenever the ATS-3 and ATS-5 windows are coincident for a user transmission. Based on nominal spin periods of 0.6 and 0.8 second, this will occur every 2.4 seconds.

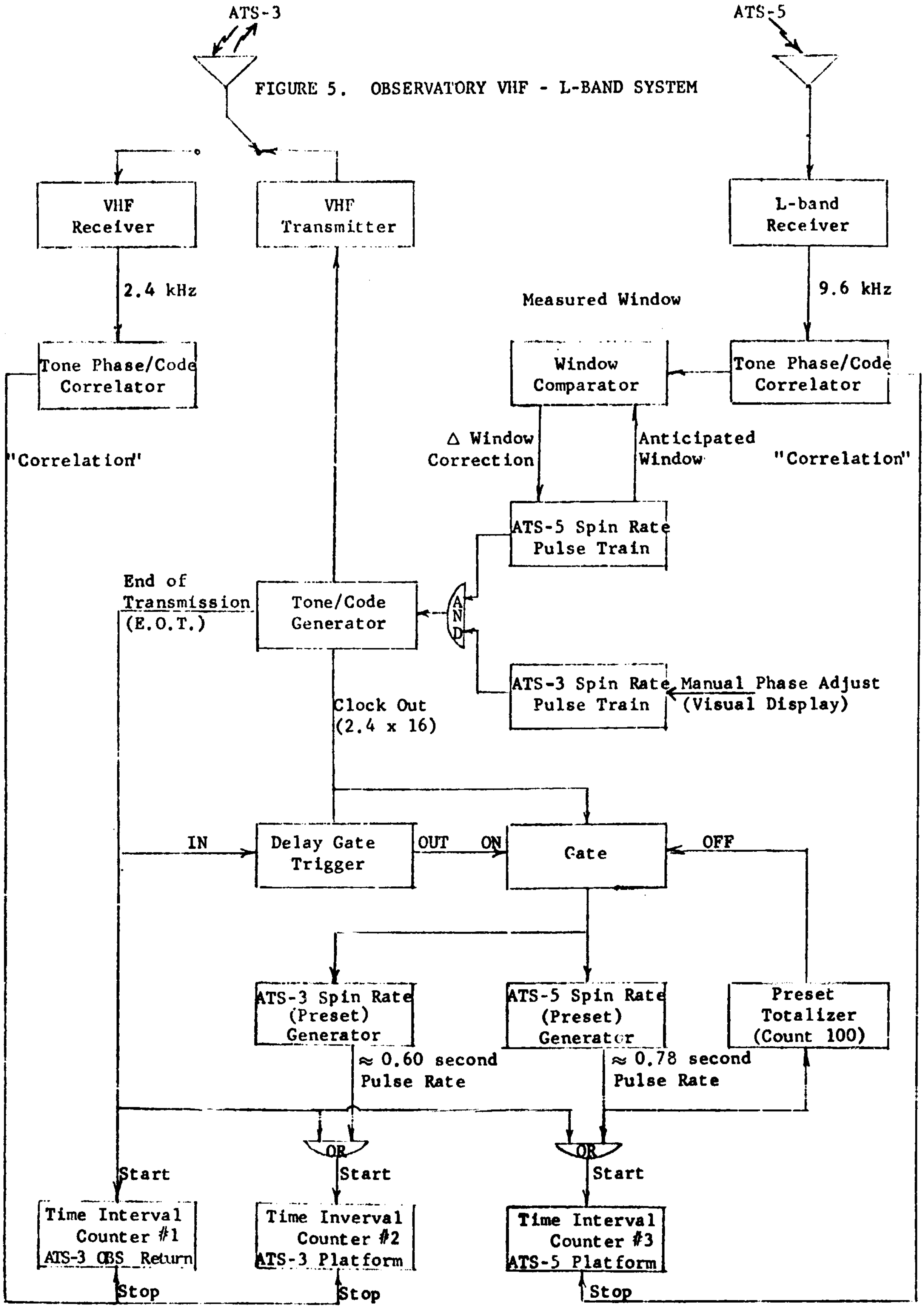
Two synchronizers (measurement) will provide start commands for range measurement counters. The commands will occur at a rate identical to the transmit synchronizers, but phased to approximate the time of the user transmission. Stop commands are furnished by code correlators. Should a correlation fail to occur on a user's transmission, the counter will be automatically commanded to stop prior to the next start command. This no-correlation stop will produce a fixed, programmed number immediately identifiable as such.

Test Procedures

1. Prior to each test period, the Observatory will attempt to establish the individual spin rates of ATS-3 and ATS-5 through consultation with NASA or personal observation. This a priori information will be stored identically on user and Observatory synchronizers.

2. The Observatory will establish the correct transmission time phasing by transmitting to ATS-3 and observing the returns (code A). Phasing will be adjusted until the return is positioned in a predetermined area insuring maximum user/Observatory reception (near coincident). The return from the user is a fixed delay designed to fall within a similar portion of a following spin cycle.

FIGURE 5. OBSERVATORY VHF - L-BAND SYSTEM



3. A close comparison of the actual spin rate versus the assumed spin rate can be accomplished within one minute. If a correction is considered necessary, the user will be requested to adjust accordingly.

4. The user is interrogated with code B for multiple transmissions to both satellites. The position of the received code in the L-Band window is compared with a desired position. If the code remains stationary in a fixed window location, the spin rate synchronizers have been set correctly and only a phase adjustment may be required for more desirable positioning. Should the code position change progressively with each transmission, it indicates that the spin synchronizers are out of sync with the actual spin rate and an adjustment is required.

Although lengthy in discussion, the phasing and synchronization procedures are accomplished in a short period of time by means of a digital window comparator and digital display panel which indicates the amount and direction (+ or -) of the necessary correction based on each individual transmission. Since this information is available only to the Observatory, correction updating is passed to the user via ATS-3 voice link during the test period. Provision has been made so that the user need only adjust thumb wheel switches to numbers designated by the Observatory for phase or spin rate corrections. (Implementation of digital request and automatic correction has been investigated and considered entirely feasible, but not within the scope of the present contractual agreement.)

NEW TECHNOLOGY

There is no applicable data to be reported at this time.

PROGRAM FOR THE NEXT REPORTING PERIOD

• The UHF modulator/exciter will be modified to accept the modulating frequencies and deviations proposed for the experiment and will be mated to the L-Band converter. In-house tests will be conducted to determine optimum operation of both exciter and receiver.

• Design and fabrication of user and Observatory base-band equipment will continue and are expected to be completed by the end of the next (quarterly) reporting period.

• ATS-3 satellite tests will be made as components are completed for subsystem check out. Satellite time required would be approximately one to two hours per week from the end of June through August. This test period will provide data to aid in evaluating the modified phase match method and increased resolution against previous data obtained at VHF. The VHF synthesizers will be tested during this time period also. The present calibration stations will be asked to participate in these tests.

• L-Band transmissions of ATS-5 will continue to be monitored to establish proper operation of the synthesizers.

CONCLUSIONS AND RECOMMENDATIONS

No difficulties have been experienced to date which would indicate the Phase III experiment cannot be carried out successfully (excluding satellite failures). The improved phase matching technique will allow full use of the resolution available from the range measurement counters so that the experiment will not be instrumentation limited.

The necessity for spin synchronization will not adversely affect the results obtainable. The technique required has been demonstrated and will be implemented.

The base-band equipment is being designed with flexibility in mind so that modulation frequencies may be changed if desirable. Phase modulation may also be employed in place of the present frequency modulation if this appears advantageous, and will be considered. Provision for data transmission at the tone frequencies by the Observatory or user (or both) can be incorporated with a minimum of equipment interface.

It is recommended that the program continue in accordance with the original planning.

APPENDIX A

STATUS REPORT ON L-BAND AMPLIFIER

(Supplied by Heavy Military Electronic Systems)

Performance characteristics of dual L-band module:

Center frequency:	1.65 GHz
Output Power:	10 W CW
V_{CC}:	26 V
I_C:	.6 a/transistor
Gain:	6 dB at fc

Description:

This amplifier module consists of two quadrature hybrid coupled transistor amplifiers. Each individual amplifier is capable of CW operation at 5 watts output at 1.65 GHz. The final transmitter will consist of a similar circuit using packaged transistors combined as necessary to achieve the overall power output and gain requirement.

Status:

Initial lot of 14 transistors has been received and evaluated. Circuit modifications necessary to optimize for packaged transistor have been incorporated and first lot of circuits have been scheduled for delivery 6/18/71.

Second lot of 50 transistors has been ordered and is scheduled for delivery 6/16/71.

Mechanical parts have been ordered and delivery is scheduled sufficient to accomplish initial evaluation.

Some difficulty has been encountered with delivery times of substrate material and chip capacitors.