CSR-TR-73-4

SURFACE ELECTRICAL PROPERTIES EXPERIMENT
FINAL REPORT, PART 1 OF 3
NASA CONTRACT NAS 9-11540

OCTOBER 1973

SURFACE ELECTRICAL PROPERTIES EXPERIMENT

Final Report, Part 1 of 3

NASA Contract NAS 9-11540

October 1973

Massachusetts Institute of Technology

Center for Space Research

Cambridge, Massachusetts 02139

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ACKNOWLEDGMENT

A special note of appreciation is due all the personnel of the various organizations who participated in the SEP experiment. A high degree of cooperation and harmonious interaction between geographically widely-separated people, active in several disciplines, was essential to the success of the effort to meet a very demanding schedule. The rapid dissemination of information and willingness to accept responsibility, frequently at considerable financial risk; the ability to absorb major changes in direction without producing undue schedule perturbations; the interchange of ideas; the acceptance, in stride, of problems and fast response with solutions; and the ability to negotiate meaningfully were notable characteristics that were displayed by the participating groups to a marked degree.

A listing of all those who contributed to the success of this program and of their contributions would be too long for inclusion, but a list of the principals is included at the beginning of the brochure reproduced in the Appendix; and thanks are due to them and their associates for all their contributions to the program.

This report has been compiled and edited by Walker S. Kupfer from a number of background documents prepared by the many contributors to the SEP experiment.

The publication of this report does not constitute approval by the National Aeronautics and Space Administration of the findings or the conclusions contained herein.

SURFACE ELECTRICAL PROPERTIES EXPERIMENT

FINAL REPORT, PART I

ABSTRACT

This part of the final report discusses the design evolution, hardware development, and production history of the surface electrical properties (SEP) experiment. The SEP transmitter and receiver were designed to be used on the lunar surface during the Apollo 17 mission. The equipment was used to measure lunar surface electrical properties over traverses totalling more than 8 kilometers, for a duration of more than 100 minutes.

A comprehensive introduction outlines the techniques, and a simplified detailed breakdown of equipment description and function is given to outline the principles of operation.

A history of the design evolution with trade-off criteria and emphasis on changes caused by decisions reached in solving problems inherent in a fast-paced development program are presented from the viewpoint of overall design concept and in detail for each item of deliverable hardware.

There is a brief account of lunar operations. Part 2 of this report, scheduled for publication at a later date, will present the scientific results.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont.)

SECTION 1

INTRODUCTION

It is planned that the final report for the SEP experiment will be a comprehensive set of three separate parts. Part 1, the present report, coordinated by the MIT Program Management Office (PMO), is to cover design evolution, hardware development, operational concepts, and production history of the SEP equipment used during the lunar mission of Apollo 17 in December 1972.

Part 2, the Experiment Final Report, and Part 3, the Final Contract Report, are both to be prepared at a later date by the principal investigator and will complete the comprehensive final report required by Contract NAS 9-11540.

References:

        Statement of Work, Exhibit A, paragraph 5.2.21, pages 1–22.

        Contract Clause 74 (7.302-54 of "MSC Contract Guide").

        Statement of Work, Exhibit C, paragraphs 3.3.2 and 3.3.3,
                pages 7–10.

The monthly progress reports submitted by MIT for the period from February 1971 to March 1972 inclusive contained unabridged copies of many reports and memoranda from the various project groups. In this final report, a bibliography of these attachments to the monthly reports is included for those who might wish to further research any particular item, but in general, this report presents only summary outlines of the activities, with the objective of providing continuity to the history of each subject.

As an overview of the goals, techniques, equipment, and operation of the experiment, a reproduction of A Brief Introduction to the Surface Electrical Properties Experiment, by Gene Simmons, James W. Meyer, Richard H. Baker, and David W. Strangway dated August 1972, is presented in full as an appendix. Additional copies of this brochure are available from the principal investigator, Gene Simmons, of the MIT Earth and Planetary Sciences Department.

1

SECTION 2

SEP EXPERIMENT STUDY PHASE, HISTORICAL BACKGROUND

Contract NAS 9-11540 was a logical product and outgrowth of the conclusions drawn in the SEP experiment study phase under Contract NAS 9-10748. The study had been under the direction of Gene Si.....nons, principal investigator, and was performed as part of the NASA Apollo effort by several teams from the MIT Earth and Planetary Sciences Department, The Charles Stark Draper Laboratory (CSDL), the Center for Space Research (CSR) and its Laboratory for Space Experiments (LSE), Lincoln Laboratory, the NASA Manned Spacecraft Center (name subsequently changed to Lyndon B. Johnson Space Center, and designated as JSC in the remainder of this report), and others.

The conclusions drawn in the study are quoted below from the Study Phase Final Report (CSR TR-73-1), dated January 1973.

2.1   Study Phase Conclusions (CSR TR-73-1)

In summary, the work accomplished under the study contract put MIT in a position to proceed with confidence with the fabrication of flight hardware. A conceptual design was evolved, mechanical and thermal configuration studies were carried out, field tests were conducted, radio noise environment was studied, theoretical studies were initiated, and key problem areas were identified. With this experience MIT was able to more accurately define for prospective bidders performance criteria for the experiment equipment, and to evaluate critically the responses to the request for proposals.

Key problems that emerged from this study include:

(1)   Efficient transmitter antenna design for multiple frequency operation with constraints on length and weight while deployed directly on the lunar surface.

(2)   Tri-loop receiver antenna design with emphasis on symmetry of pattern and loop-to-loop isolation.

(3)   The increase of transmitter-radiated power within weight and prime-power constraints.

(4) The achievement of wide dynamic range in the receiver.

(5) The design of an effective interface with the data storage electronics assembly (DSEA) for purposes of recording and returning to earth all experiment data.

(6) The development of a thermal control system for both the transmitter and the receiver that would keep the equipment within the design limits under a variety of lunar environmental conditions.

(7) The derivation from theoretical studies of a mathematical formalism simple enough to permit solution, yet representing the physical situation adequately for correlation with field results.

(8) The design of field tests on earth to provide critical evaluation of engineering approaches, data for comparison with theory, and data to aid in the interpretation of that returned from the moon.

The resolution of these problems made up a major share of the effort necessary to conduct the experiment on the moon along with the resolution of the problems that inevitably arise in connection with the design, development, and manufacture of man-rated space hardware.

2.2 Proposals

The Study Phase Final Report also outlines the events which led to the choice of the Raytheon Company, Equipment Division, Sudbury, Mass., as subcontractor at the end of January 1971.

An abridged extract from that report is presented below to complete the historical record to the time when work on Contract NAS 9-11540 was started.

One objective was the submission of a proposal for the development and manufacture of SEP experiment hardware, in response to Request for Proposal (RFP) No. JC931-88-1-165P. In Proposal No. 70-238, CSDL proposed the in-house development and manufacture of essentially all the SEP hardware, except for the ground support equipment and antennas which were to be designed and built by a subcontractor. The subcontractor was also to furnish resident engineering support, engineering field support, and other local support to supplement the CSDL capability.

Several aspects of the completed proposal were regarded as unsatisfactory by JSC, and the proposal was not accepted. Of particular concern were potential manpower problems attributable to in-house manufacture of all SEP hardware.

CSDL subsequently revised the original proposal by placing the manufacture of the compatibility unit, the qualification unit, and the two flight units with the subcontractor, in addition to the other fabricated items and support defined in the

4

original proposal. Because of the magnitude of the subcontract effort under this revision, it became necessary to solicit competitive bids from competent potential subcontractors. Because of the short time remaining before the Apollo 17 scheduled launch date of July 1972, an accelerated bid effort was dictated, and only two industrial contractors, RCA-Camden and Raytheon, were solicited. Technical and cost proposals subsequently received in November 1970 from both organizations were reviewed by CSDL, and Raytheon was selected as the successful bidder. There were discussions with Raytheon to coordinate details of the subcontract effort with CSDL's revised proposal plan. This effort culminated in November 1970 with CSDL Technical Proposal for the Surface Electrical Properties Experiment, Proposal No. 70-238, Revision 1.

A review of the proposal by JSC raised doubts concerning the successful coordination of the program in which the prototype design was the responsibility of CSDL, and the manufacture of the end items was basically the responsibility of the subcontractor under CSDL supervision. In addition, JSC foresaw possible coordination problems arising from the organizational relationships within MIT as established by the proposal. The revised proposal was not approved. This disposition terminated the role of CSDL as prime bidder for SEP hardware implementation.

A review of the situation by the MIT administration resulted in a decision to proceed with a proposal which placed responsibility for implementation of the SEP experiment in the hands of CSR supported by a SEP PMO to administer a major subcontract with an industrial subcontractor for the design, development, test, and manufacture of the SEP hardware and supporting equipment. This effort required the generation of two documents: (1) a detailed RFP defining the tasks and responsibilities of the industrial subcontractor and (2) a proposal from MIT to the government responsive to RFP JC931-88-1-165P and delineating the role of CSR as prime contractor and as manager-administrator of a major subcontract. The task of preparing these documents on an accelerated basis was performed by CSDL and LSE personnel. The tasks of contract and subcontract definition, proposal preparation, and subcontract bid response evaluation also utilized the services of Dr. L. J. Ricardi of Lincoln Laboratory on antenna problems and Dr. J. A. Kong of MIT on questions relating to electromagnetic propagation. Generation of cost information was accomplished under the supervision of L. E. Beckley, administrative officer of CSR.

The RFP for the SEP subcontract effort was completed early in January 1971 and mailed to prospective bidders on 4 January, with a closing date for response of 18 January. Because of the short time available for preparation of responses by the bidders and for evaluation of the responses by CSR, only two

5

industrial organizations were solicited, RCA-Camden and Raytheon. A bidders' conference, supported by CSDL, CSR, LSE, and Lincoln Laboratory personnel, was held 6 January 1971 at CSR. In response to CSR's invitation, each bidder made an individual interim presentation prior to the proposal deadline.

The CSR technical proposal in response to JSC RFP JC931-88-1-165P was completed in early January, and copies were forwarded to JSC prior to an MIT technical proposal and preliminary budget presentation made at JSC on 20 January 1971.

In the latter part of January, a proposal review committee comprised of personnel from CSR, LSE, the projected PMO, CSDL, and Lincoln Laboratory was formed to review the subcontract proposals from RCA and Raytheon. The team worked from 18 Jan ary to 28 January to review the designs, costs, and other factors as proposed by the two bidders. On the latter date, the committee presented the results of the review to members of MIT management, who concurred in the decision to award the SEP subcontract to Raytheon.

2.3   Organization

Under Contract NAS 9-11540, MIT immediately began negotiations with Raytheon to define and implement subcontract SR-26687.

Because of the diversity of the disciplines involved in the SEP program, the assignment of a major responsibility in the program to an outside industrial sub-contractor, the tight schedule requirements, and the necessity of developing and maintaining an effective interface with NASA, Dr. John Harrington, director of CSR, immediately established the SEP PMO under the direction of Dr. James W. Meyer of Lincoln Laboratory as program manager, to coordinate and direct all aspects of the effort at MIT. Assisting Dr. Meyer were four other people whose backgrounds and timely availability made possible the completion of a balanced PMO staff. They were: Leonard B. Johnson of CSDL, assistant program manager; James A. Lawrence of CSDL, manager of documentation and program control; Melvin G. Murley of CSDL who provided support in the areas of configuration control and documentation; and Walker S. Kupfer who was responsible for sub-contract administration and program cost analysis. The PMO was established and fully staffed in February to carry on the defined tasks and monitor the sub-contractor's performance.

To assist in the technical monitoring, evaluation, and control of the Raytheon effort, the assistant program manager coordinated and drew upon the services of several members of the CSDL technical staff whose expertise was valuable in the development of the SEP hardware.

6

The members of this team provided a continuing review of all technical phases of Raytheon's hardware effort - design; development; the acceptance, qualification, and field total test programs; human factors, safety, and training features; and documentation. Team members regularly supported and participated in the meetings involving not only Raytheon and other MIT personnel but also various groups of JSC, Kennedy Space Center (KSC), Marshall Space Flight Center (MSFC), NASA Headquarters, and contractors responsible for hardware or facilities with which the SEP equipment interfaced. The resulting recommendations by this team provided much of the information required by the PMO to direct and administer the Raytheon contract.

The Raytheon effort was conducted under the direction of Joseph F. Urner, SEP program manager.

The organizational structures which were established at MIT and at Raytheon are shown in the following diagrams (Fig. 2-1 and 2-2). At several times during the life of the contract, organizational changes were made at Raytheon, and the annotated revisions to the Raytheon chart (Fig. 2-2) shows the dates and extent of these changes.

7

SEP PMO
DR. J.W. MEYER, Manager
L.B. JOHNSON, Assistant Manager

SPECIAL TECHNICAL SUPPORT STAFF
ANTENNAS
DR. L.J RICARDI (Lincoln Lab)
PROPAGATION
DR. J.A. KONG (EE Dept)

CONTRACTS
D.C. DRISCOLL

EXPERIMENT DEFINITION (PI)
DR. GENE SIMMONS

UNIVERSITY OF TORONTO
D. STRANGWAY

EXPERIMENT ANALYSIS, DESIGN
AND FIELD TEST (LSE)
R.H. BAKER, Director
L. BANNISTER
G. LaTORRACA
W. COOPER
E. JOHNSTON
V. NANDA
J. GROENER

DESIGN IMPLEMENTATION AND
SUBCONTRACTOR MANAGEMENT
L. JOHNSON

RELIABILITY AND
QUALITY ASSURANCE (CSDL)
G. MAYO
E T. DRISCOLL

ENGINEERING SUPPORT (CSDL)
L. JOHNSON

SUPPORT STAFF
J.F McKENNA
K. KIDO
W. SALTZBERG
E. BLANCHARD
J. MARTIN
W. STAMERIS
I. JOHNSON

PROGRAM CONTROL
J. LAWRENCE

CONFIGURATION CONTROL
AND DOCUMENTATION
M. MURLEY

SUBCONTRACTS
W KUPFER

Figure 2-1. MIT SEP program organization.

8
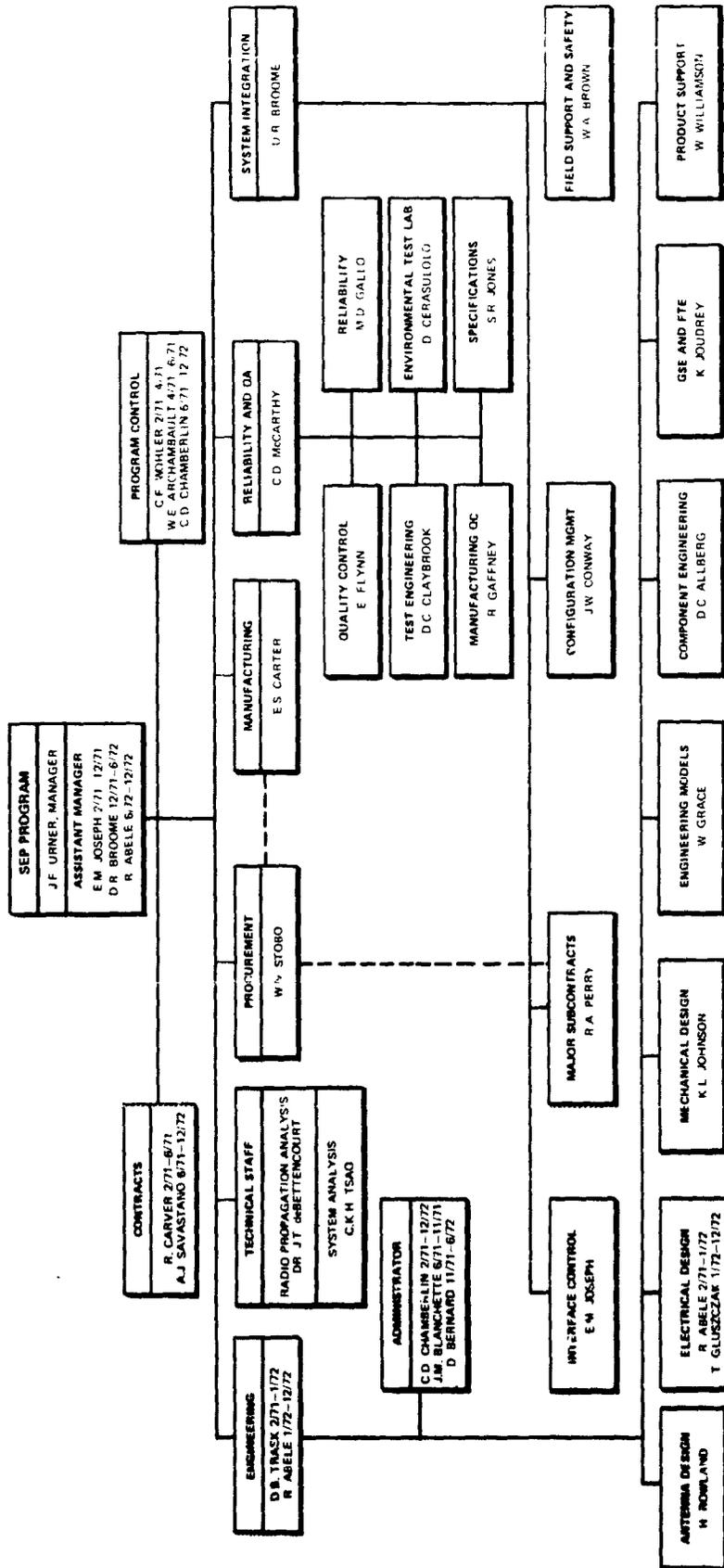
Figure 2-2. Raytheon SEP program organization.

SEP PROGRAM
J F URNER, MANAGER
ASSISTANT MANAGER
E M JOSEPH 2/71 12/71
D R BROOME 12/71-6/72
R ABELE 6/72-12/72

PROGRAM CONTROL
C F WOHLER 2/71 4/71
W E ARCHAMBAULT 4/71 6/71
C D CHAMBERLIN 6/71 12/72

CONTRACTS
R CARVER 2/71-6/71
A J SAVASTANO 6/71-12/72

TECHNICAL STAFF
RADIO PROPAGATION ANALYSIS
DR J T deBETTENCOURT

SYSTEM ANALYSIS
C K H TSAO

ADMINISTRATOR
C D CHAMBERLIN 2/71-12/72
J M BLANCHETTE 6/71-11/71
D BERNARD 11/71-6/72

ENGINEERING
D B TRASK 2/71-1/72
R ABELE 1/72-12/72

PROCUREMENT
W S STOBO

MANUFACTURING
E S CARTER

RELIABILITY AND QA
C D McCARTHY

SYSTEM INTEGRATION
D R BROOME

QUALITY CONTROL
E FLYNN

TEST ENGINEERING
D C CLAYBROOK

MANUFACTURING QC
R GAFFNEY

RELIABILITY
M D GALLO

ENVIRONMENTAL TEST LAB
D CERASUOLO

SPECIFICATIONS
S R JONES

INTERFACE CONTROL
E M JOSEPH

MAJOR SUBCONTRACTS
R A PERRY

CONFIGURATION MGMT
J W CONWAY

FIELD SUPPORT AND SAFETY
W A BROWN

ANTENNA DESIGN
H ROWLAND

ELECTRICAL DESIGN
R ABELE 2/71-1/72
T GLUSZCZAK 1/72-12/72

MECHANICAL DESIGN
K L JOHNSON

ENGINEERING MODELS
W GRACE

COMPONENT ENGINEERING
D C ALLBERG

GSE AND FTE
K JOUDREY

PRODUCT SUPPORT
W WILLIAMSON

SECTION 3

HISTORY OF DESIGN EVOLUTION AND HARDWARE DEVELOPMENT

The principal investigator's proposal of 23 October 1969 suggested the use of at least eight, perhaps ten, discrete frequencies; viz, 0.5, 1, 2, 4, 8, 24, and 32 MHz, each sampled at approximately every second along the traverse. The astronaut was expected to carry the receiver. The need for a navigation system was anticipated and a hyperbolic system concept suggested. Originally a single transmitting dipole was to have a maximum overall physical length of 140 meters.

On 28 October 1970, CSR published TR-70-7 (see appendices to Study Phase Final Report) which detailed the conceptual design. The eight frequencies listed above would have a 100-ms dwell time plus two 100-ms receiver calibration intervals for a total sequence time of one second. Two watts of radiated power were desired at 0.5 MHz, 0.5 watt at 1.0 MHz, and 0.125 watt at the remaining frequencies.

The hyperbolic navigation system was abandoned because of multipath propagation uncertainties and added system complexity and weight. Instead, a turnstile antenna was to produce a beam rotating at 15 r/s for azimuth determination. Range at long distances would be derived from an analysis of field strength as a function of distance, following calibration at short distances by the astronaut walking along one arm of the antenna, which was marked every five meters. This concept formed the basis of the technical part of the RFP to RCA and Raytheon on 4 January 1971.

On 8 January 1971, substantial changes were made.

(1)   The rotating beam antenna was deleted, and switching of transmitter power alternately between orthogonal dipoles was substituted.

(2)   The 4- and 24-MHz frequencies were deleted and the radiated power increased to 6 watts at 0.5 MHz, 3 watts at 1.0 MHz, and 1.5 watts at the remaining frequencies.

(3)   The timing format was specifically described as consisting of eight intervals 400 ms long, half that being the dwell time on each antenna. There were to be two intervals of silence for a sequence time of 3.2 seconds.

The technical specification of NAS 9-11540 specified the technical require-
ments and constraints pertaining to the design, development, manufacturing testing,
and operations of the flight equipment.

3.1 Original Design Baseline

To satisfy the requirements as outlined in the specification, the initial flight
hardware design as presented by Raytheon early in January 1971 was proposed to
consist of:

Transmitter Design

Item	
Structure	Unpressurized cylindrical epoxy fiberglass case housing cylindrical metal modules.
Electronics	(a) One master crystal oscillator and divider chain to generate transmitted frequencies.
	(b) Class B RF power amplifiers of 12 W max capability for each dipole.
Antenna	Two thin-wire multifrequency dipoles with lumped-parameter isolating traps.
Thermal Control	Insulation inside case; passive radiator.
Power	Regulated solar panel, small battery for peak power.

Receiver Design

Item	
Structure	Epoxy fiberglass container housing electronic modules.
Electronics	(a) Tuned radio frequency
	(b) Dual sync channels; coded sync word
	(c) Built-in noise diode sensitivity calibration
Antenna	Triple co-centered orthogonal loops
Thermal Control	Thermal paint on housing, internal insulation, phase change (wax) heat sink
Power	Battery

On 18 January 1971, the Raytheon baseline was amended as shown by the
following proposal design approach (ER71-4023).

I. Proposed Design Approach

    A. Transmitter antenna

        2 70-m dipoles
        Flexible conductor on reels

Manual tuning
Optimized with 0.5-MHz transmission considering
    lunar surfaces with ϵ_r from 2-10
Multiple traps

B. Transmitter

6 separate oscillators
No battery
3 W radiated power at 0.5 MHz
Corona protection by coil location and potting
Metal outside structure
Radiating thermal control
Solar panel prime power
Timing format revision

C. Transmitter subsystem weight - 16 lb

D. Receiver

Superheterodyne, dual conversion
Separate local oscillators
Minimum pre- and post-detection bandpass
Metal outside structure
Automatic oven temperature protection of tape
Primary battery for power
Minimum dynamic range of 100 dB

E. Receiving antenna

3 orthogonal multiturn ferrite rods

F. Estimated receiver subsystem weight - 16 lb

G. Receiver design philosophy

Dynamic range set from thermal noise floor
Insert pads to account for new background noise

II. Operational Constraints

A. Battery activation prior to installation on LM

B. Activated battery must be replaced if landing is delayed more
        than 80 days following activation

C. Astronaut operations required - transmitter

Remove SEP hardware from LM
Carry to site
Deploy solar panel
Spool out antenna
Operate control switch
Read meter
Turn tuning knob

D. Astronaut operations required - receiver

Remove SEP hardware from LM
Operate control switch
Extend mast
Install on rover
Remove data module

E.   Re< eiver operation limited to 5 continuous hours and 10 hours
       max,   8 hours off-time min between operations

F.   Tape recorder must be turned on every 120 days

3.2   Baseline Changes

During the first month of the contract, February 1971, JSC, MIT, and
Raytheon reviewed the proposed design baseline to identify potential problem areas
and on 16–17 February conducted a design review meeting. As a result, Raytheon
embarked on a superheterodyne dual conversion design for the receiver, utilizing
separate local oscillators. Among the 14 action items generated at the meeting was
one to perform a thermal analysis of the receiver, taking into account the possible
reduction of heat sink material and the addition of radiators and shields. Other
agenda items which influenced the later development of the physical design were
discussions of transmitting antenna design problems and unacceptable overweight
declarations. Preliminary design drawings of the transmitter and receiver were
available by 11 March.

3.3   Critical Design Areas

The SEP experiment hardware design was time limited and was tightly con-
strained with regard to size and weight. Some of the more critical design problems
imposed by these constraints were:

(1)   Transmitting antenna. The SEP transmitting dipoles were constrained
       by deployment time-line considerations based on projected walking
       rates to lie on the surface of the moon and have a maximum length of
       70 m end-to-end. There was no body of existing information bearing
       on the practical design of antennas operating at a dielectric interface.
       The experiment required that they have maximum efficiency at several
       frequencies and a radiation pattern exhibiting dipole characteristics.
       Spurious nulls in the pattern were strictly forbidden since they could
       easily be confused with the interference patterns being studied.

(2)   Receiving antenna. The antenna elements were required to fold into a
       small package for stowage, with the output of each of the mutually
       orthogonal elements separately recorded to give a measure of the total
       magnetic field. Loop-to-loop isolation and symmetry of pattern were
       required.

(3)   Dynamic range. A wide range of signal levels was dictated by the
       planned traverses beginning only a few meters from the transmitter
       and extending out to several kilometers.

14

(4) Thermal control. Uncertainties concerning the lunar environment and lunar procedures required flexible temperature control systems, especially for the receiver. A limiting constraint on the receiver was imposed by the use of a previously qualified tape recorder (DSEA) using temperature-limited magnetic tape. The direction to use optical solar reflectors (OSRs) for thermal control of the receiver introduced significant uncertainties with regard to lunar dust degradation and time-line procedures.

(5) DSEA. The tape-recording equipment to be used was government-furnished equipment designed for a different purpose, and the difficulty of acquiring properly functioning, trouble-free equipment for the test of interfaces compromised the designer's confidence in the reliability of the DSEA.

(6) Vibration levels. Throughout the development effort there was uncertainty as to the expected vibration spectrum level during launch and boost.

3.4 Design Modifications

Questions were raised during March concerning the configuration of the receiving and transmitting antennas, the DSEA interface and its reliability, as well as several design areas which had a lesser impact on the final design effort. Because of problems related to designing an efficient transmitting antenna at 0.5 MHz with the 70-meter constraint in total length, with attendant loading coil weight and corona problems, this frequency was deleted and 4 MHz substituted for it. A loop receiving antenna replaced the ferrite rod antenna because of the limited aperture and low efficiency caused by the self-resonances produced by the number of turns needed on the ferrite rods.

On 1-2 April, a formal preliminary design review was held. Evaluation and analysis of solar panels, batteries, and other components were presented and test programs were outlined. JSC directed Raytheon to use OSR receiver thermal control rather than wax. A "Delta" preliminary design review on 14 May disclosed problems in astronaut working heights (affecting the use of legs on the transmitter, which were retained), transmitter antenna deployment procedures to assure orthogonality of the dipoles, further weight increases, definition of the lunar environment, leveling of the transmitter, and thermal controls, resulting in 36 items to be reviewed and requiring further thermal studies and dust studies.

During May it was also revealed that Grumman was contemplating a change in the location of the receiver mounts on the Lunar Rover Vehicle (LRV) pallet. A new ICD was negotiated in June. The receiver antenna placement was changed to reduce interference with the astronaut's seat.

15

There also evolved a problem concerning the stowage location of the SEP in the LM when it was discovered that the location was ambiguously specified.

Also, in May, Raytheon developed a deployable double-split 3-loop receiver antenna of such unique ingenuity in reducing cross-coupling as to qualify as an exceptional design achievement.

Because intermodulation products between the local oscillators could conceivably degrade receiver noise performance, the 2.0-, 8.0-, and 32.0-MHz frequencies were changed to 2.1, 8.1, and 32.1 MHz, respectively, and the preliminary design was finalized.

In June, a modification to increase the specified LM pallet vibration level to be expected during launch and boost, of such a magnitude as to exceed the receiver and transmitter design limits (as well as those for which the DSEA was qualified), made it necessary to plan a complete structural response test on a mockup.

In July the electrical design was complete, and a program review was held at Raytheon on 15-16 July. The thermal design was verified by test of a thermal mockup. The temperature margin of the receiver was further slightly reduced by an increase in power dissipation from 8.4 watts to 10.0 watts. These reported results led to a study of the need for a receiver temperature monitor.

The formal design release review was held 31 August to 1 September and resulted in the generation of 13 added review item dispositions (to a total of 65) and 10 action items. The configuration control board released all but 17 of the 436 drawings during September. A bubble level was added to the transmitter.

At this review, the preliminary results of the Athabasca glacier field trials were presented. These tests indicated the need for an increased data collection rate in order to be able to record sufficiently closely spaced data points when the LRV was moving. In order to define adequately the very sharp nulls being observed, 10 samples per interference wavelength appeared necessary.

A problem of radio interference between the astronauts' VHF PLSS-mounted intercom transmitter and the SEP receiver was uncovered, and a low-pass RF filter in the receiver was added to eliminate the interference.

During October, two alternative timing format modifications were proposed to solve the need for increased data rate. Since this was a major modification, it was also proposed to include the capability to record LRV navigation data on the DSEA tape in the receiver by hard-wire transmission of wheel, range, and bearing pulses to the tape input. Fortunately the change of the Apollo 17 flight date from July 1972 to December 1972 afforded the opportunity and the time to incorporate these major changes. The various proposals for accomplishing them were evaluated on 16 December

1971 by a review panel convened in Washington, and the design approach was retro-actively defined in November 1971, at which time contract change authorization (CCA) #1 was issued, authorizing the redesign.

In December, there were discoveries of mechanical interference between the SEP receiving antenna and the LRV, and of contamination of certain TTL 54L-series integrated circuits similar to those used in the SEP hardware, requiring additional screening.

The higher level vibration testing, necessitated by the expected increase in launch-boost vibration level of Quad III of the LM pallet, was started on the compat-ibility unit transmitter. Vibration testing of the compatibility unit receiver started in January 1972. The test results substantiated the adoption of the higher vibration levels for qualification testing, without requiring hardware modification.

By March 1972, the prototype receiver and transmitter, incorporating the timing format and navigation data modifications, had been completely fabricated, and the design had essentially evolved to its final configuration, with the inclusion of a thermometer in the receiver for visual monitoring of internal temperature.

3.5 Design Criteria and Considerations

Early in the study phase, it was recognized that in applying the principles of RF interferometry for the interpretation and estimation of subsurface electrical prop-erties and physical characteristics, it would be possible to conduct an experiment in either a static mode or a dynamic mode.

In the static mode, the transmitter and receiver would be placed at fixed locations, and the operating frequency would be shifted over a controlled range. This mode would have the advantages of not requiring the recording of navigation data, eliminating radio wave pattern distortions produced by the electromagnetic interference of the transport vehicle, deploying both antennas in close proximity to the dielectric interface, defining the relative orientation of the antennas, and yield-ing radio frequency interference (RFI) data that would probably be simpler in form and easier to interpret.

The overriding disadvantage of the static mode is the limitation on the size of the explored volume, which is constrained to the region between the transmitter and the receiver. For this reason, the dynamic mode was chosen.

In the dynamic mode, the receiver is transported on traverses surrounding the transmitter, and its distance and orientation with respect to the transmitter vary. This mode requires navigational data for proper interpretation of the data. On Apollo 17, it was decided to use several fixed operating frequencies sequentially.

17

The operating frequencies had to be chosen so that the radio waves would probe several meters into the medium. Figure 3-1 presents theoretical computations of the depth of penetration as a function of frequency for a few values of dielectric constant and loss tangent of the medium. From consideration of such information, it was decided that frequencies lying in the range below 100 MHz could probably probe several meters. Field tests verified this supposition, and it was decided to use several octaves of the range in order to cope with possible variations in the electrical characteristics of the subsurface layers. This use of several frequencies also yielded a probability of greater resolution in the detection of stratification and scattering objects, as well as a higher degree of reliability through redundancy.
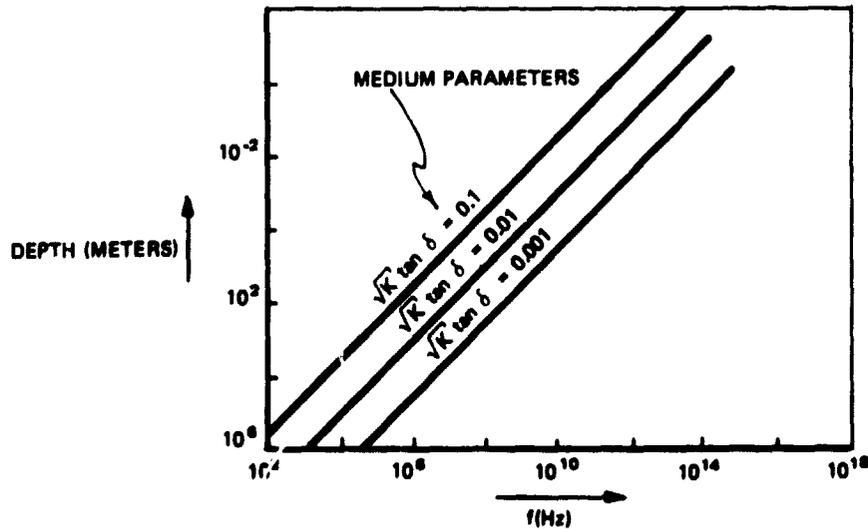
Figure 3-1. Medium-penetration depth versus frequency.

The determination of the transmitter RF power requirement was based on acceptable signal-to-noise ratios at the receiver terminals for the worst-case of a distance 20 wavelengths from the transmitter. This involved calculation of transmitter antenna gain, attenuation coefficients, receiving antenna capture areas, and efficiencies, as well as estimates of the various noise levels. It was determined that 2–4 watts of transmitted power would be satisfactory.

Solid state components were specified early in the program for the state-of-the-art reasons of weight, size, stability, reliability, and efficiency. Crystal oscillators were required in order to meet the frequency stability specification. The operating frequencies (1.0, 2.1, 4.0, 8.1, 16.0, 32.1 MHz) could have been derived by down-conversion from a master oscillator, up-conversion from a master oscillator, or from discrete oscillators for each frequency. The latter approach was chosen

because of its greater flexibility and the probability of data acquisition even if there were a failure in one oscillator.

A comprehensive study of transmitting antennas, including vertical electric dipoles, horizontal electric dipoles, vertical magnetic dipoles, horizontal magnetic dipoles, horizontal electric turnstiles, and horizontal magnetic turnstiles, lying at a dielectric interface, was made. Table 3-1 summarizes the results of this study for a medium of dielectric constant of 4.0. From such studies and other considerations, the horizontal electric dipole was chosen. Figure 3-2 shows the field patterns associated with this choice.

Table 3-1. Properties of basic Hertzian dipoles at
dielectric interface of $\epsilon = 4.0$.

Dipole Type	Max. Gain	Symmetry	Power Rad.	Relative Surface Fields $\sim r^{-2}$					
				H_ρ	H_ϕ	H_z	E_ρ	E_ϕ	E_z
VED	10.6	◯	0.661		1.174 -0.073		+0.508 -0.127		1.174 -0.147
HED-TM	2.4	∞	0.276		1.000 -0.125		+0.433 -0.217		1.000 -0.062
HED-TE	5.1	8	0.460 / 0.736	+0.250 -0.500		+0.125 -0.577		+0.143 -0.289	
VMD	3.7	◯	0.938	+0.131 -0.523		+0.075 -0.604		+0.075 -0.302	
HMD-TM	1u.1	8	0.227		1.624 -0.050		+0.704 -u.088		1.624 -0.101
HMD-TE	1.9	∞	0.239 / 0.466	+0.304 -0.152		+0.304 -0.704		+0.176 -0.088	
HET	2.5	◯	0.736	+0.177 -0.353	+0.707 -0.085	+0.085 -0.408	+0.306 -0.153	+0.101 -0.204	+0.707 -0.044
HMT	5.0	◯	0.466	+0.215 -0.107	1.149 -0.035	+0.215 -0.487	+0.487 -0.062	+0.124 -0.062	1.149 -0.071

The constraints of limited size, weight, and multifrequency operation imposed difficult design problems for the transmitting antenna in trying to achieve well-defined field patterns by reducing spurious excitations and coping with the inherent low radiation efficiency at the lower frequencies.

Antenna configurations of single elements, multiple elements, and cascaded elements with inserted filters were studied. The final choice was a cascaded element with series-connected, uncoupled discrete wire segments. A computer program was

Figure 3-2. Dielectric dependence of field patterns of horizontal electric dipole at dielectric interface.

20

used to determine the filter trap parameters for achieving resonance at the operating frequencies to insure the required field pattern and matching impedances.

The receiving antenna was required to be compact, lightweight, collapsible, and sturdy, with a spherically omnidirectional overall radiation pattern, small cross-coupling between elements, high capture cross-section, immunity to extraneous noise, and ease of matching to the receiver. A set of three mutually-orthogonal, co-centered loops was chosen.

In the design of the receiver itself, several schemes, including tuned RF, superregenerative and phase-locked detection with a countdown chain, were considered. These studies finally resulted in the choice of a double-conversion superheterodyne configuration, preceded by a preamplifier passband front end and followed by a signal compressor logarithmic amplifier and a voltage-controlled oscillator. This configuration was able to meet the requirements of passband, dynamic range, sensitivity, noise ratio, selectivity, reliability, stability, and provision for synchronization and timing circuits, as imposed by the experiment concept. Detailed studies of electromagnetic interference and electromagnetic compatibility with regard to cosmic noise, enhanced solar flares, lunar radiation, earth interference, and LRV noise, were performed. The results of these studies are summarized in Table 3-2 and indicate the compatibility of the SEP experiment design with regard to these noise sources. Extensive testing verified this compatibility.

Size and weight considerations dictated the method used for thermal control of the receiver. The receiver was wrapped in a Kapton insulating blanket with flaps for covering or uncovering an optical solar reflector surface. A temperature indicator was included, and the flaps were to be manually adjusted to maintain the temperature within limits. Lunar dust complicated this control procedure, and in the final operation of the experiment, it proved to be the principal problem that was encountered. No problems were encountered in the thermal control of the transmitter, which used a similar, though static, method of control, because the dust problem was not present.

Table 3-2. Summary of EMC results in SEP experiment.

Frequency	Receiver Noise Temperature	Cosmic Noise Temperature at Receiver Terminals	Approx SEP Transmitter Power at R = 20λ at		Enhanced Solar Noise Power at Receiver Terminals	Lunar Noise at Receiver Terminals	Earth Interference at Loop Antenna for P_{te} - 1K-W	LRV Noise at Receiver Terminals
			Loop Antenna	Receiver Terminals				
30MHz	627°K	0.7°K	3.6×10^{-5}W	2.5×10^{-10}W	2.1×10^{-16}W	2.3×10^{-23}W	10^{-19}W	10^{-15}W
1MHz	627°K	1.62°K	3.6×10^{-5}W	2×10^{-13}W	1.5×10^{-12}W	1.72×10^{-26}W	10^{-16}W	10^{-15}W

SECTION 4

EQUIPMENT DESCRIPTION

The translation of the SEP experiment concept into actual physical measurement equipment required extensive development and design effort in the areas of receiving and transmitting antennas, stable low-noise solid state oscillators and amplifiers, digital circuits, switches, matching networks, synchronization circuits, etc.* A summary of the functional description of the hardware is presented in the following, in order to outline the principles of operation of the equipment. Because all parts and circuits are qualified for manned flight, no unorthodox or tricky designs are incorporated, but proven straightforward approaches are used throughout.

The equipment used to carry out the SEP experiment (S-204 on Apollo 17) consists of two units, a fixed-location transmitter and a transportable receiver capable of being mounted on the LRV. The method used to conduct the experiment consists of sequentially transmitting a series of pulsed RF energy waves (from a fixed location on the lunar surface) at each of six different transmitting frequencies and alternately switching the transmitted energy 90° by means of two dipole transmitting antennas, lying at right angles to each other on the lunar surface. The SEP receiver, mounted on the LRV, picks up signals through three orthogonally-deployed loop antennas and records each of these three signal strengths in terms of calibrated audio frequencies on the DSEA tape. By traversing the lunar surface while mounted on the LRV, the SEP receiver receives energy at varying phase relationships, amplitudes, and densities. Through the use of six different channels corresponding to the six transmitted energy frequencies, the receiver records these varying signal levels along with external noise (also recorded during one of the transmitter off periods) using a 300–3000-Hz voltage-controlled oscillator (VCO) and a magnetic tape recorder housed in a self-contained DSEA. In addition to experiment and noise calibration data, the DSEA also records receiver status information and internal temperature as well as LRV positional data from the LRV navigation system. The

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*A detailed functional description of the hardware is available in the operation and instruction manuals, published by Raytheon (Receiver, ER72-4067A; Transmitter, ER72-4066A), available at the NASA/JSC Technical Library, Houston, Texas.

DSEA is removed from the SEP receiver by the astronaut at the end of the experiment and brought back to earth in the Apollo command module for subsequent data analysis.

4.1   Transmitter, Functional Description

The SEP transmitter is used in the SEP experiment to automatically transmit timed bursts of RF energy from a fixed location on the lunar surface. These energy transmissions are alternately transmitted in equal time segments from each of two orthogonally-deployed dipole antennas lying on the lunar surface. The transmitter consists of four basic subassemblies mounted on a supporting housing. The housing is in turn supported by four deployable legs, facilitating deployment by the astronaut. The functional organization of the SEP transmitter is shown in Fig. 4-1. The transmitter consists of a solar array, the antenna assembly, an oscillator-timing module, and a driver-amplifier module. The solar array provides shunt regulated, +15 Vdc and +5 Vdc primary operating power to the transmitter operating modules. Primary power to each of the two modules is controlled by an on-off-standby switch located on the top of the driver-amplifier module. The on-off-standby switch permits selection of either of two modes of operation. In the ON position, +15 Vdc and +5 Vdc operating power is connected to the operating modules and the transmitter is in the operating mode. In the STANDBY position, +15 Vdc is connected to two wire-wound resistors inside the amplifier module that are used to generate a sufficient amount of heat to maintain the operating temperature of the transmitter electronics during extended use of the standby mode on the lunar surface. The oscillator timing module contains a frequency generator which provides (through the use of six separate oscillators) the six basic operating frequencies for the transmitter. The oscillators are sequentially turned on and off under control of a timing logic network, also contained in the oscillator-timing module, which operates from a 1.04-MHz, temperature-compensated clock oscillator. The output of the clock oscillator is divided down through a divide-by-975 network to provide a 1067-Hz basic timing waveform for the timing logic. The outputs of the six basic frequency oscillators are switched on and off in a timed sequence derived from a special countdown network that is driven by the 1067-Hz timing waveform and sent through individual attenuators to a combiner-divider network. The output of the combiner-divider is sent in parallel to each of two identical driver-amplifier networks in the driver-amplifier module, one of which drives the E-W antenna, the other driving the N-S antenna. The driver and power amplifier stages in the driver-amplifier module contain wideband amplifiers which provide linear gain and frequency response characteristics over the entire 1-32.1-MHz operating range of the transmitter. Selection of the N-S or E-W antennas is accomplished by means of two antenna select signals which are alternately activated within the timing logic. The N-S and E-W antennas are center-fed standard dipoles which are arranged orthogonally on the lunar surface during the transmitter deployment sequence.
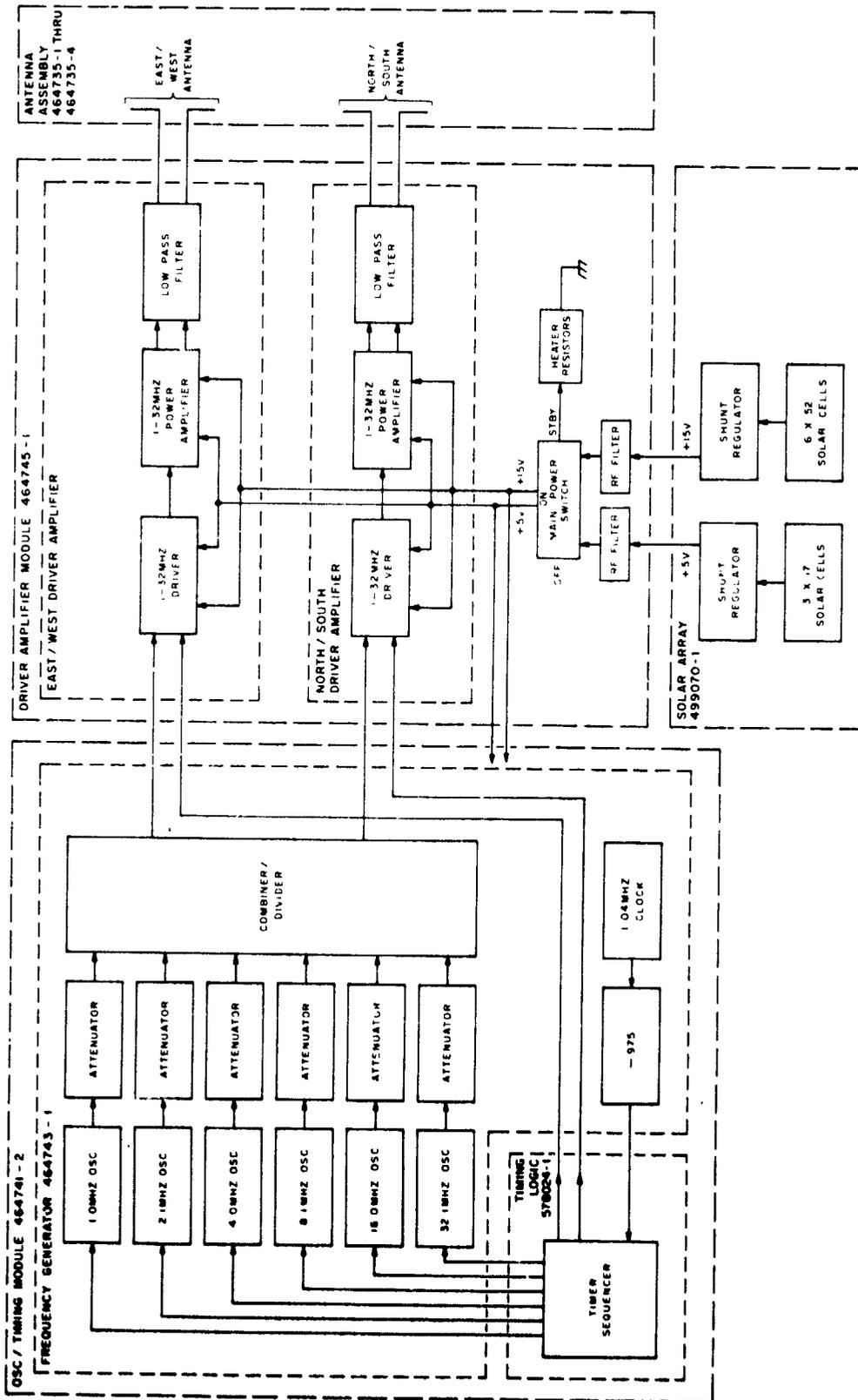
Figure 4-1. SEP transmitter block diagram.

4.2   Transmitter Characteristics

The operating characteristics of the SEP transmitter are as follows:

Dimensions (stowed position):	10. 0 × 13. 0 × 11. 5 in. (max)
Weight:	14. 3 lb
Method of deployment:	Astronaut deployable (time-line procedure)
Operating frequencies:	Six separate switchable frequencies – 32. 1 MHz, 16. 0 MHz, 8. 1 MHz, 4. 0 MHz, 2. 1 MHz, 1. 0 MHz
Frequency stability:	±2 ppm
Type of antenna:	Crossed multifrequency dipoles
Antenna arrangement:	Dipoles lying on the lunar surface at right angles to each other crossed at mutual centers
Antenna deployment:	Manually unwound from storage reels
Method of transmission:	Switched energy output at each of the six operating frequencies, with each transmission equally divided in time between the two dipole antennas

Power Output:

Experiment Frequency	Power Output[*]
1. 0 MHz	3. 75 W
2. 1 MHz	2. 0 W
4. 0 MHz	2. 0 W
8. 1 MHz	2. 0 W
16. 0 MHz	2. 0 W
32. 1 MHz	2. 0 W

Data frame period:	12. 96 s
Data channel (experiment frequency time interval):	0. 2025 s
Antenna switching rate:	0. 10125 s
Guard band between antenna positions:	0. 9375 ms
Sync pattern:	Two complementary symmetrical Williard[**]-code pulse trains transmitted concurrently at the 1. 0-MHz and 2. 1-MHz experiment frequencies during a special sync interval

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[*]Into a nominal load of 100 Ω, ±2 dB from nominal power output at each experiment frequency operating at normal operating temperatures.

[**]Williard, M. W., "Optimum Code Patterns for PCM Synchronization," Proceedings of the National Telemetering Conference, Washington DC, May 1962.

Power input requirements:

Voltage	Current (peak)
+15 V ± 3%	0.666 A
+5 V ± 3%	0.220 A

Power source:

Two solar cell arrays, shunt regulated to provide required input voltages at the required current levels - (1) 3 × 17 array providing +5 Vdc; (1) 6 × 52 array providing +15 Vdc.

Thermal/radiational characteristics:

Susceptibility:

Outside of operating temperature range, electronics modules subject to degradation of operational characteristics

Protection:

Use of thermal control paint on all exposed structural members and low-solar absorption high-emittance thermal control blanket around electronics housing

Operating temperature range:

$0^{\circ}C$ to $+70^{\circ}C$

Operating life:

Condition	Duration
ON or STANDBY	66 h

Several views of the transmitter are presented in Fig. 4-2, 4-3, 4-4, and 4-5 which follow.

4.3 Oscillator-Timing Module

A block diagram of the oscillator-timing module is shown in Fig. 4-6. This module provides the six experiment frequencies used in the amplifiers which drive the antennas. It consists of a timing logic circuit and a frequency generator circuit.

(1) Frequency Generator. The frequency generators are six separate crystal-controlled oscillators which employ fundamental mode frequency generators at the 8.1-, 16.0-, and 32.1-MHz frequencies and frequency dividers to derive the other frequencies.

(a) Basic oscillators. The basic output is +4 dBm. The turn-on of an individual frequency is achieved from a signal supplied from the timing logic assembly.

Figure 4-2. SEP transmitter.

Figure 4-3. SEP transmitter - stowed (quad III) configuration.
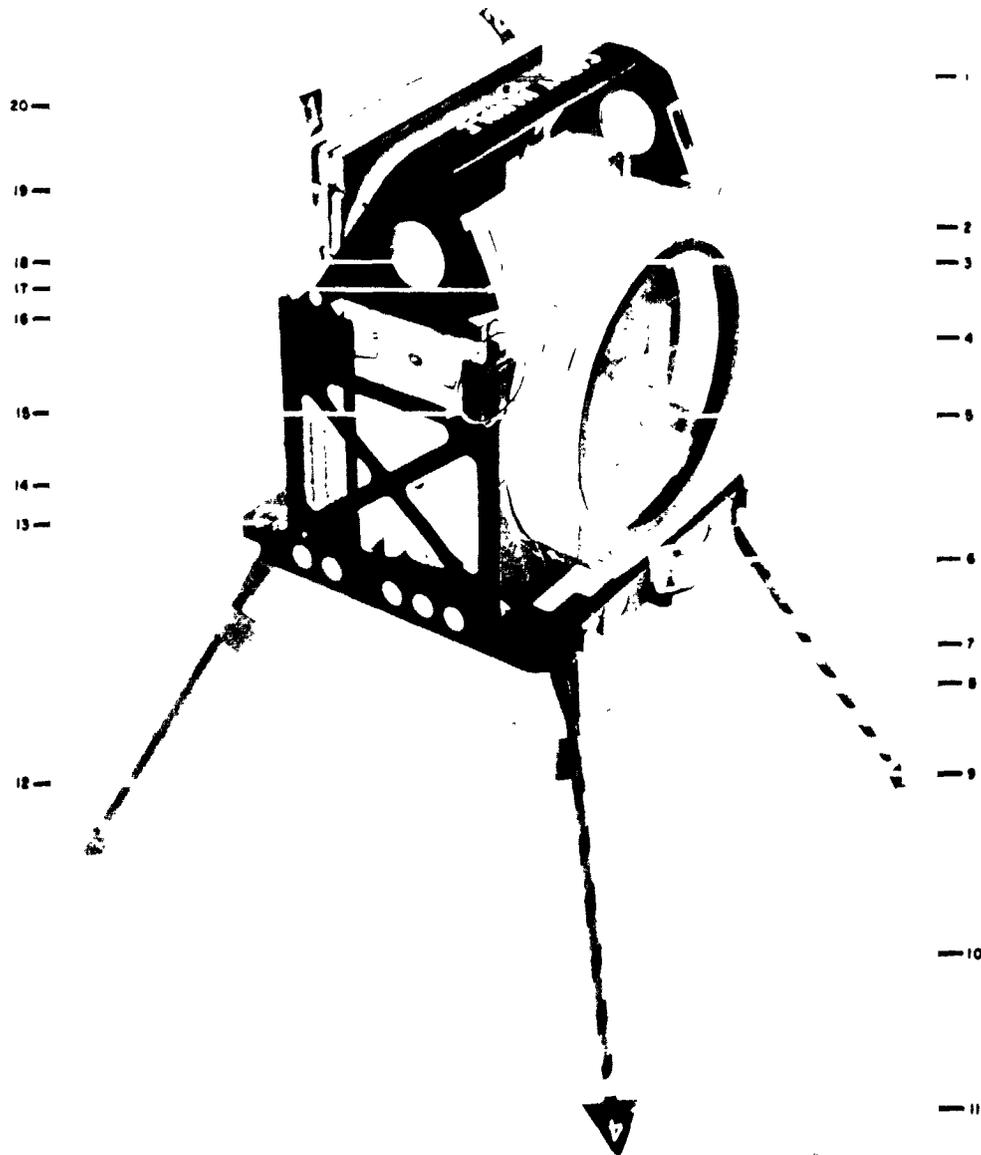
1. CARRY HANDLE
2. ARROW ON TOP OF TRANSMITTER
3. ANTENNA REEL HANDLE
4. ANTENNA REEL
5. ANTENNA REEL RETAINING CLAMP T-HANDLE
6. BUBBLE LEVEL
7. TRANSMITTER RETAINER RING
8. TRANSMITTER LEG
9. ANTENNA LEAD STOWAGE VELCRO TAB
10. ANTENNA ELEMENT
11. TRIANGULAR FEET (USED TO LEVEL TRANSMITTER)
12. ANTENNA CABLE
13. PARTIAL COMPASS ROSE
14. NULL METER GNOMON
15. CARRY HANDLE PIP RETAINER PIN LANYARD
16. "HOT" MISSION ADJUSTING LEVER
17. SOLAR ARRAY MOUNTING PINS
18. THERMAL COVER PULL TAB
19. SOLAR ARRAY
20. SOLAR PANEL DEPLOYMENT TAB

Figure 4-4. Transmitter leveling and alignment.

SOLAR PANEL　　　THERMAL PAINT RADIATOR　　　POWER SWITCH

INSULATION　　　ANTENNA ASSEMBLY

Figure 4-5.　SEP transmitter - deployed configuration.

(b)   Attenuator pads. These pads adjust the power output level at each frequency to yield a flat frequency gain response.

(c)   Combiner-divider. This network affords 30 dB isolation between input terminals and output terminals and is used to combine input signals for transmission to the driver-amplifiers.

(2)   Timing-logic assembly. This assembly controls the sequence of transmission, switching of frequencies, and antenna switching.

(a)   Transmitter timing. The lunar operation transmission sequence is shown in Fig. 4-7.

(b)   Timing-sequencing. To generate timing pulses and produce the transmission sequence shown, a countdown chain, a sync pattern generator, and a series of decoder networks are used. Figure 4-8 shows the timing sequence of the decoder outputs. The sync pattern is shown in Fig. 4-9.

(c)   Basic clock. The basic transmitter clock is a 1.04-MHz oscillator, stable to ±2 ppm. Divider networks provide the 1067-Hz basic timing signal.

(d)   Countdown chain. This chain consists of four frequency divider circuits which provide pulses for the guard interval decoder, the sync pattern generator and the sync pattern gating control.

(e)   Guard interval. This is an interruption of the transmission cycle to insure against the possibility of turning on both driver-amplifiers simultaneously. The circuit also generates a square wave that functions as an interval timer, which controls selection of the antennas, and to gate the sync pattern to the 1.0- and 2.1-MHz decoders. See Fig. 4-8 and 4-9.

(f)   Data timer. The data timer divides the output of the interval timer and uses the outputs to control the decoder networks.

(g)   Ground support equipment (GSE) sync pulse. Further dividing of the data timer pulse train is performed here to provide additional gating for the decoders. One output is used as a sync pulse for the GSE and also controls transmission of the sync pattern.

(h)   Sync pattern generator. Input and output waveforms are shown in Fig. 4-9. These control the 1.0- and 2.1-MHz oscillators for transmission of the sync patterns.

FREQUENCY GENERATOR
ASSY 464743

TIMING LOGIC   ASSY 578024

1.04MHZ
TCXO
Y7

1.04MHZ
9615μS

÷5
U1, U2, U3, U4

208KHZ
0048MS

÷5
U1, U2, U4, U5

41.6KHZ
024MS

÷13
U1, U2, U6,
U7, U8, U9

3.2KHZ
3125MS

÷3
U10

1067HZ   9375MS
E9
E9

J3

(SPARE)

J2

FROM
GSE

STEP   E11

INHIBIT   E12

J4

GATE
U1

1067HZ

÷3
U8A, U8B

29.6HZ
33.75MS

÷3
U5A, U5B

88.9HZ
11.25MS

÷3
U4A, U4B

266.7HZ
3.75MS

÷4
U3A, U3B

SYNC PATTERN
GATING CONTROL
U1, U10,
U12, U13

SYNC PATTERN
GENERATOR
U6, U7,
U9, U10

GUARD
INTERVAL
DECODER
U11, U13

−16 COUNT

Figure 4-6. Oscillator/timing modu
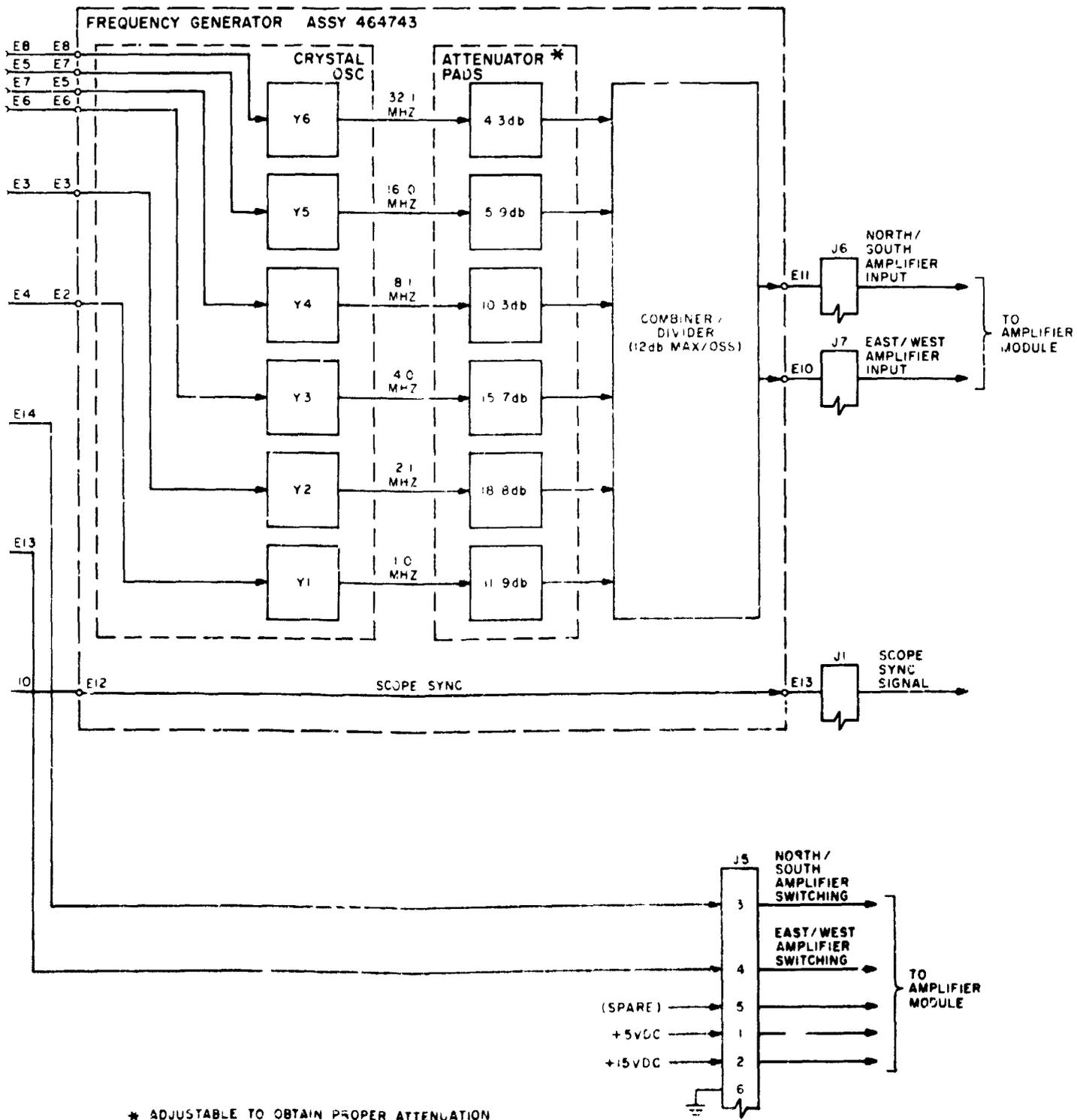
Figure 4-6. Oscillator/timing module block diagram.

PREVIOUS DATA FRAME | BEGINNING OF DATA FRAME

SYNC PERIOD = 90 MSEC *

N-S ANTENNA: 1 0 MHZ | SYNC PAT | 16 0 MHZ | 32 1 MHZ | 8 1 MHZ | 32 1 MHZ | 16 0 MHZ | 32 1 MHZ | 4 0 MHZ | 32 1 MHZ | 16 0 MHZ — 1 DATA INTERVAL

DATA TRANSMISSION (HALF INTERVAL) = 101 25 MSEC

E-W ANTENNA: 1 0 MHZ | 16 0 MHZ | 32 1 MHZ | 8 1 MHZ | 32 1 MHZ | 16 0 MHZ | 32 1 MHZ | 4 0 MHZ | 32 1 MHZ | 16 MH

BEGINNING OF SUB-FRAME #2

N-S ANTENNA: 16 0 MHZ | 32 1 MHZ | 8 1 MHZ | 32 1 MHZ | 16 0 MHZ | 32 1 MHZ | 4 0 MHZ | 32 1 MHZ | 16 0 MHZ

E-W ANTENNA: SYNC PAT | 16 0 MHZ | 32 1 MHZ | 8 1 MHZ | 32 1 MHZ | 16 0 MHZ | 32 1 MHZ | 4 0 MHZ | 32 1 MHZ | 16 MHZ

SYNC PATTERN EXPANDED

2.1 MHZ

ONE BIT TIME = 3 75MSEC

1.0 MHZ

90 MSEC SYNC PERIOD (24 BIT TIMES)

SUB-FRAME #1 = 6 48 SECONDS

I DATA INTERVAL — DATA INTERVAL (TRANSMISSION OF ONE EXPERIMENT FREQUENCY FROM BOTH ANTENNAS) = 202 5MSEC

| 40 MHZ | 32 I MHZ | 16 0 MHZ | 32 I MHZ | 8 I MHZ | 32 I MHZ | 16 0 MHZ | 32 I MHZ | 16 0 MHZ | 32 I MHZ | 8 I MHZ | 32 I MHZ | 16 0 MHZ | 32 I MHZ | 40 MHZ | 32 I MHZ |

OFF-1   OFF-2

IO) 25 MSEC

| 32 I MHZ | 40 MHZ | 32 I MHZ | 16 0 MHZ | 32 I MHZ | 8 I MHZ | 32 I MHZ | 16 0 MHZ | 32 I MHZ | 16 0 MHZ | 32 I MHZ | 8 I MHZ | 32 I MHZ | 16 0 MHZ | 32 I MHZ | 40 MHZ |

**

SUB-FRAME #2 = 6 48 SECONDS

| 40 MHZ | 32 I MHZ | 16 0 MHZ | 32 I MHZ | 8 I MHZ | 32 I MHZ | 16 0 MHZ | 32 I MHZ | 16 0 MHZ | 32 I MHZ | 8 I MHZ | 32 I MHZ | 16 0 MHZ | 32 I MHZ | 40 MHZ | 32 I MHZ |

OFF-1   OFF-2

| 32 I MHZ | 40 MHZ | 32 I MHZ | 16 0 MHZ | 32 I MHZ | 8 I MHZ | 32 I MHZ | 16 0 MHZ | 32 I MHZ | 16 0 MHZ | 32 I MHZ | 8 I MHZ | 32 I MHZ | 16.0 MHZ | 32 I MHZ | 40 MHZ |

TIME = 3 75 SEC

MSEC SYNC PERIOD (24 P TIMES)

* SYNC PATTERN (CONSISTING OF SIMULTANEOUS, COMPLEMENTARY ENERGY – SEE EXPANDED SYNC PATTERN) ALTERNATELY TRANSMIT ON ALTERNATE SUB-FRAMES FOR 90 MILLISECONDS DURING SYNC

** TRANSMISSION FROM BOTH ANTENNAS IS INTERRUPTED FOR TWO TO ALLOW THE RECEIVER TO RECORD INTERVAL AND EXTERNAL CALIBRATION MEASUREMENTS

FOLDOUT FRAME

Figure 4-7. Transmission sequence.

IOI 25MS —

S | 16 | 32 | 8 | 32 | 16 | 32 | 4 | 32 | 16 | 32 | 8 | 32 | 16 | 32 | OFF 1 | OFF 2 | 16 | 32 | 8

INTERVAL TIMER (−2) U20-13

2 - INTERVALS (−4) U20- 9

4 - INTERVALS (− 8) U20-10

8 - INTERVALS (−16) U20-12

16 - INTERVALS (−2) U21-13

32 - INTERVALS (−4) U21- 9

SYNC PATTERN ANTENNA SELECT AND SCOPE SYNC − 8 U21-10
(1 DATA FRAME - 64 INTERVALS)

−8 / ÷16 COUNTER OUTPUTS

U2F-12

U12A- 5

U18B-10

U14B-13

U22B- 3

U14A- 9

1 MHz / 2 MHz AND DATA CHANNEL DECODER INTERNAL WAVEFORMS

32 1 MHz UI6A- 2

16 0 MHz UI9D- 3

8 1 MHz U22A- 5

4 0 MHz UI8A- 2

2 1 MHz UI7E-12   S

1 0 MHz UI7B-10   S

1 MHz / 2 MHz DECODER AND DATA CHANNEL DECODER OUTPUTS TO OSCILLATORS

ANTENNA SELECT GATE UI6B-10

SYNC PATTERN GATE UI2B-13

DECODER OUTPUT UI9B-14

N - S DECODER

ANTENNA SELECT GATE UI5A-10

SYNC PATTERN GATE UI5B- 2

DECODER OUTPUT UIOD- 3

E - W DECODER

Figure 4-8. Transr

Figure 4-8.   Transmitter timing.
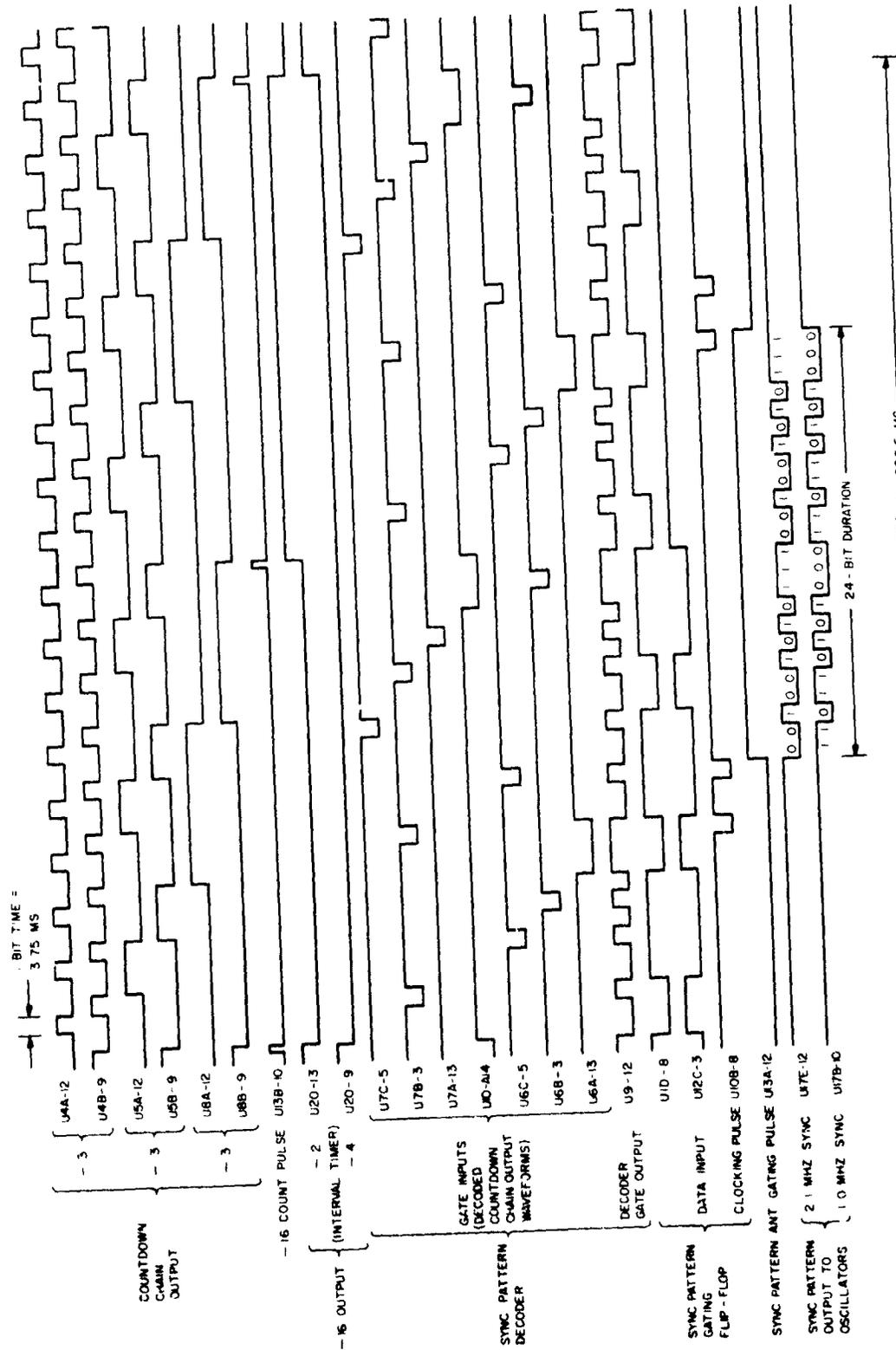
Figure 4-9. Transmitter timing waveforms (sheet 1 of 2)(sync pattern decoding).

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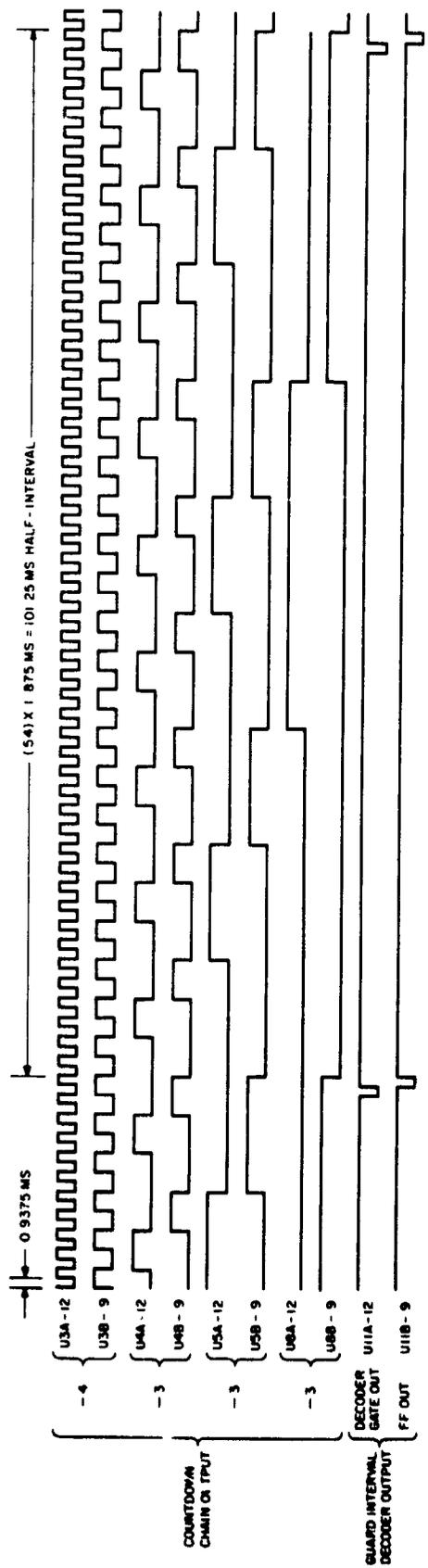
Figure 4-9. Transmitter waveforms (sheet 2 of 2)(guard interval decoding).

(i)   Sync pattern gating control. This control decodes pulses from the countdown chain and interval timer to gate the sync pattern generator. Its output also controls the driver-amplifiers.

(j)   Data channel decoder. This circuit decodes the interval timer waveforms to produce pulses which control the on-off sequence of the six experiment frequencies.

(k)   2.1-MHz decoder. This decoder controls the transmission intervals for the 2.1-MHz oscillator, which is used as one of the experiment frequencies and is also used during the sync interval.

(l)   1.0-MHz decoder. This functions in the same manner as the 2.1-MHz decoder.

(m)   N-S decoder. This decoder uses the interval timer output to select the N-S driver-amplifier on alternate half-intervals for transmission of the experiment frequencies. It also gates the sync pattern during the sync interval, through the N-S driver-amplifier on alternate subframes.

(n)   E-W decoder. This functions the same as the N-S decoder, except that it selects the E-W driver-amplifier on alternate half-intervals.

(o)   GSE test. This is a gate inserted ahead of the countdown chain to permit control of the timing sequence by the GSE operator.

4.4   Amplifier Module

A block diagram is shown in Fig. 4-10. This module consists of two identical driver-amplifiers, one for the N-S antenna, and one for the E-W antenna.

(1)   Low level stages. These are class A two-stage linear amplifiers with a gain of 28–33 dB at all experiment frequencies.

(2)   Power amplifier. These amplifiers consist of two push-pull class B power amplifiers with a balanced power output of 4 watts at 1.0 MHz and 2 watts at the other experiment frequencies, with an output level stability of ±1 dB max for worst-case temperature and supply voltage variation.

4.5   Antenna

A photograph of the stowed antenna is shown in Fig. 4-11. Figure 4-12 shows the physical layout of the two center-fed dipoles when deployed. Nine resonant circuit
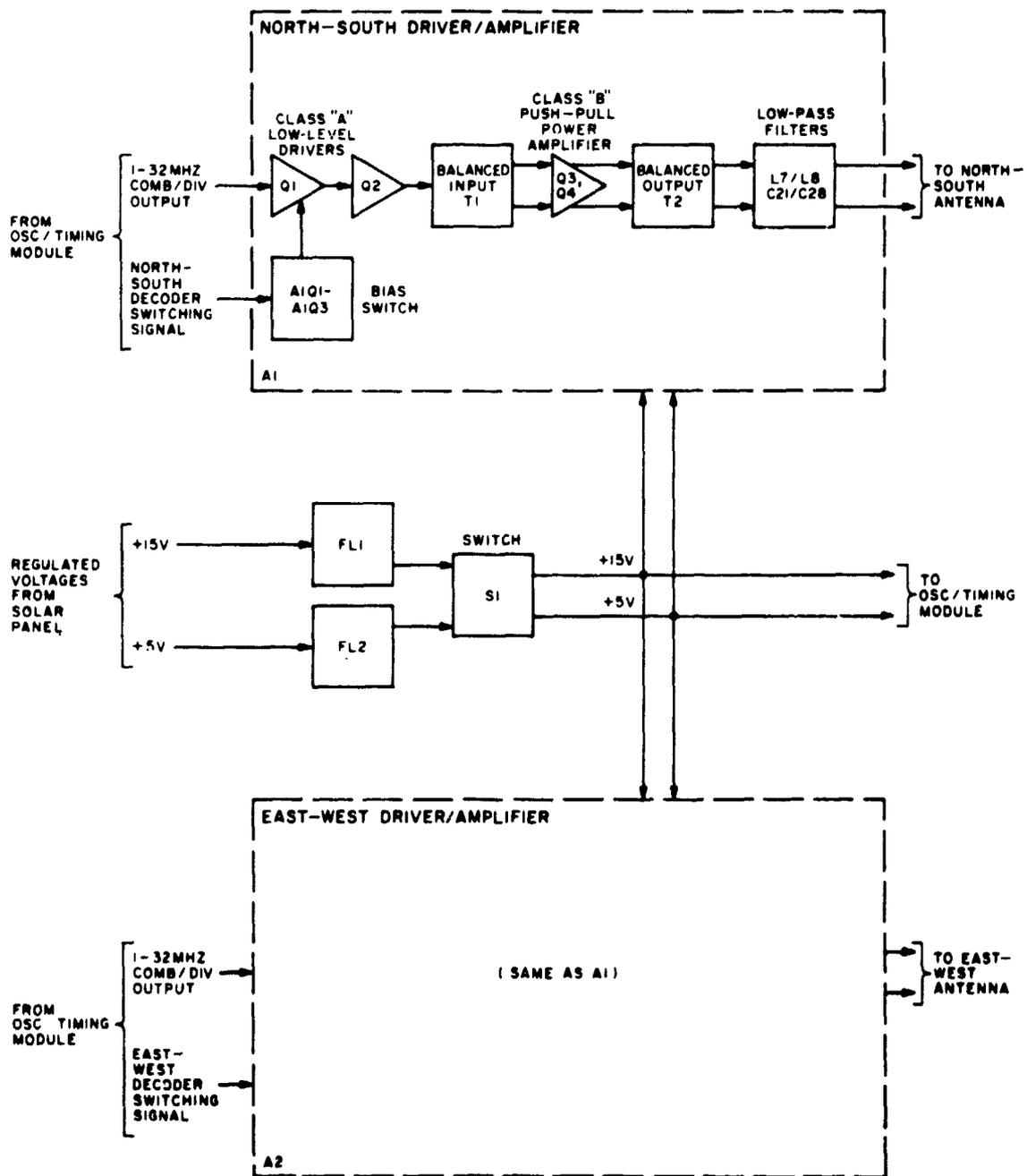
Figure 4-10. Amplifier module block diagram.
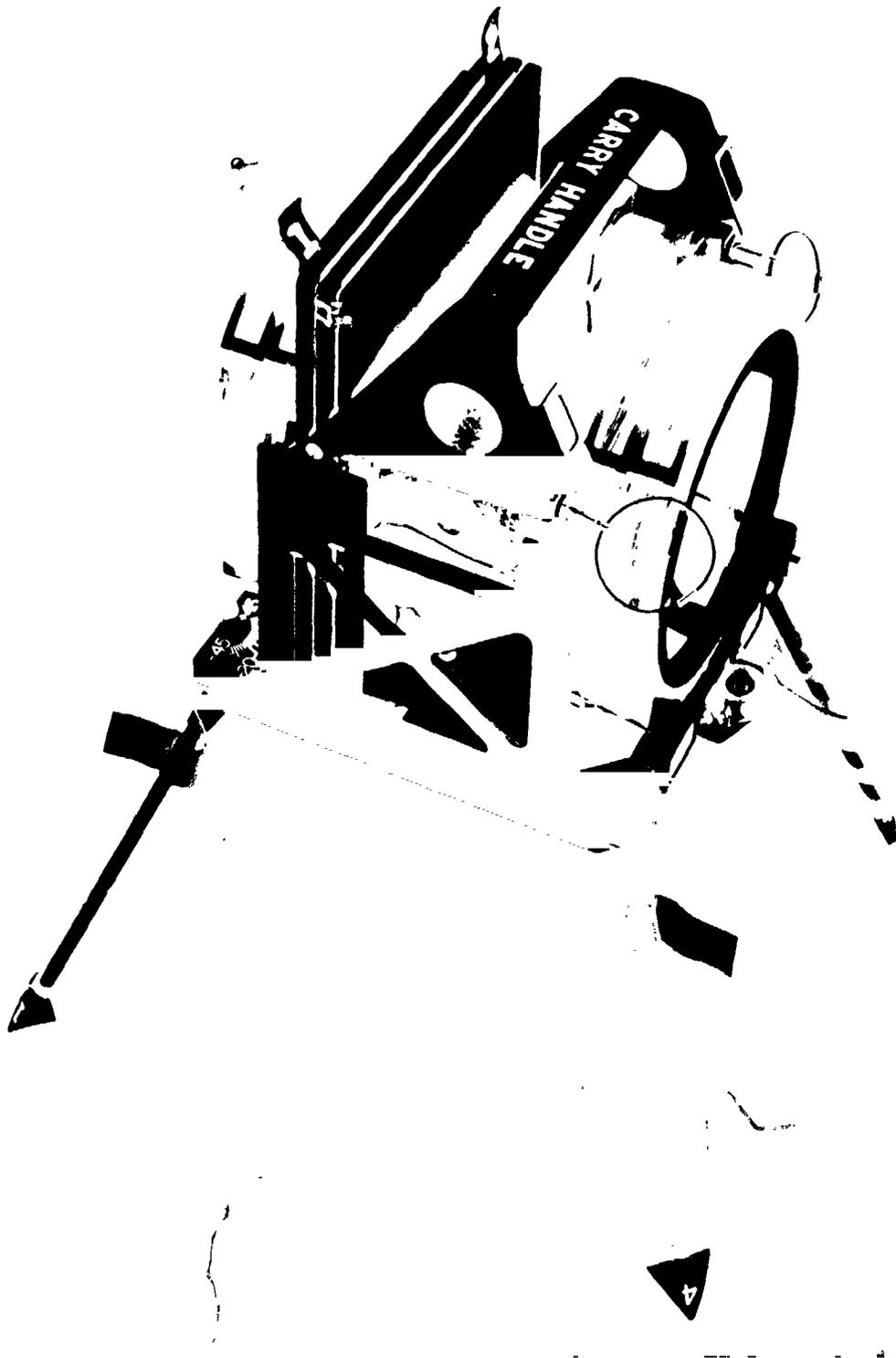
Figure 4-11.   Transmitter antenna - stowed configuration .
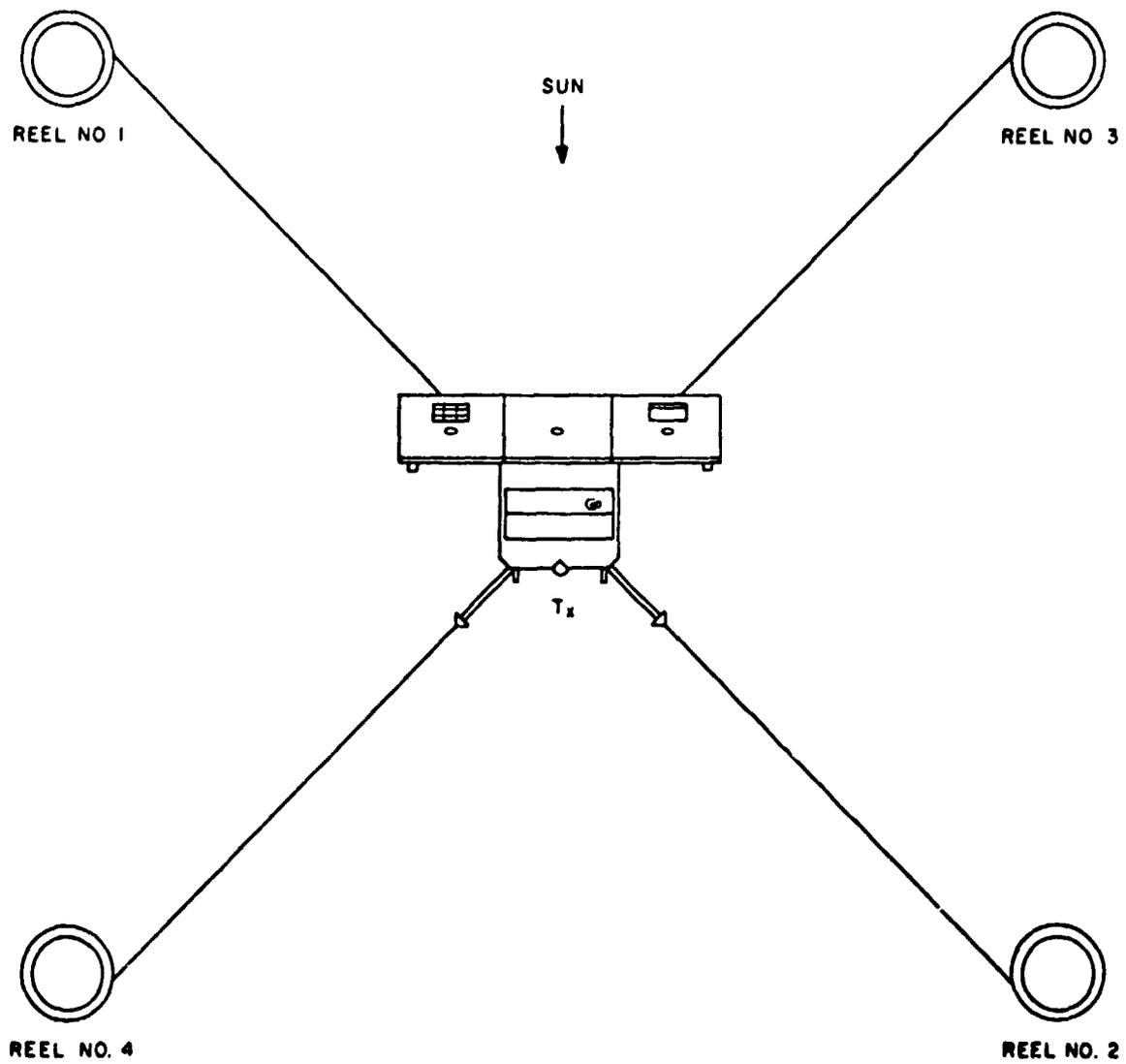
Figure 4-12. Transmitter antenna - deployed configuration.

traps and four loading coils are used in each 35-m antenna element to provide the correct electrical length for each of the experiment frequencies.

4.6   Transmitter Power

A three-panel solar array, shown deployed in Fig. 4-13, provides transmitter power at +15 Vdc and +5 Vdc. The panels are hinged, with positive lockouts for positioning on the transmitter carrying handle. At 15 volts, they provide 10 watts, plus 1.1 watt at 5 volts. A shunt regulator is mounted on the back of one of the panels.

4.7   Transmitter Power Requirements

Total average input power required by the transmitter is 6.5 watts. A breakdown of the requirements for each module is given in Table 4-1, and the demand during one experiment frame is compared with the output power in the three plots of Fig. 4-14.

4.8   Power Distribution

Standard qualified cables, connectors, and module connectors are used throughout.

Table 4-1. Transmitter module power requirements.

Module	Section	Oper. Voltage	Power/Current Req'd (Average)
Amplifier Module	Low-Level Stages	+15V	93 mA
		+5V	16 mA
	Power Amplifier	+15V	420 mA
		+5V	25 mA
Oscillator-Timing Module	Frequency Generator (Experiment Oscillator)	Both (+15V, +5V)	345 mW (Peak) with one OSC "ON" and five "OFF"
	(Clock Oscillator)	Both (+15V, +5V)	85 mW
	Timer Sequencer	+5V (Does not use +15V)	42 mA

45

DEPLOYMENT
PULL-TAB

SOLAR PANEL
ASSY MOUNTED ON
POSTS PROVIDED

FIRST PANEL
DEPLOYED

LAST
PANEL DEPLOYED

CUTOUT FOR
+15V, +5V REGULATOR

INTER-PANEL HINGE
MECHANISMS

DEPLOYMENT
PULL-TAB

+15V, +5V REGULATOR
CIRCUIT

CARRY
HANDLE

PANEL DEPLOYED IN
"HOT" OR "COLD" POSITION

POWER SWITCH
IN "OFF" POSITION
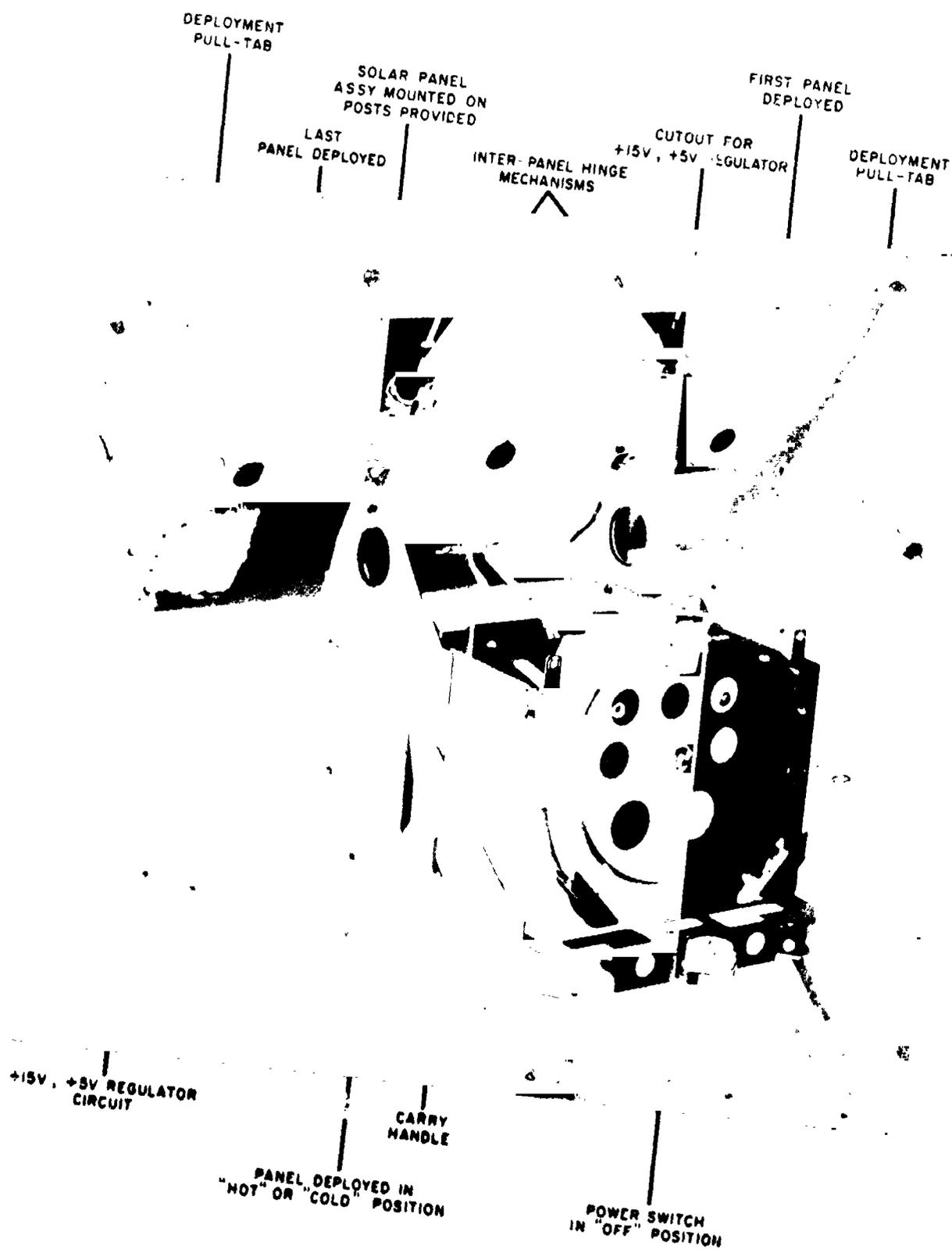
Figure 4-13. Solar panel - deployed configuration.
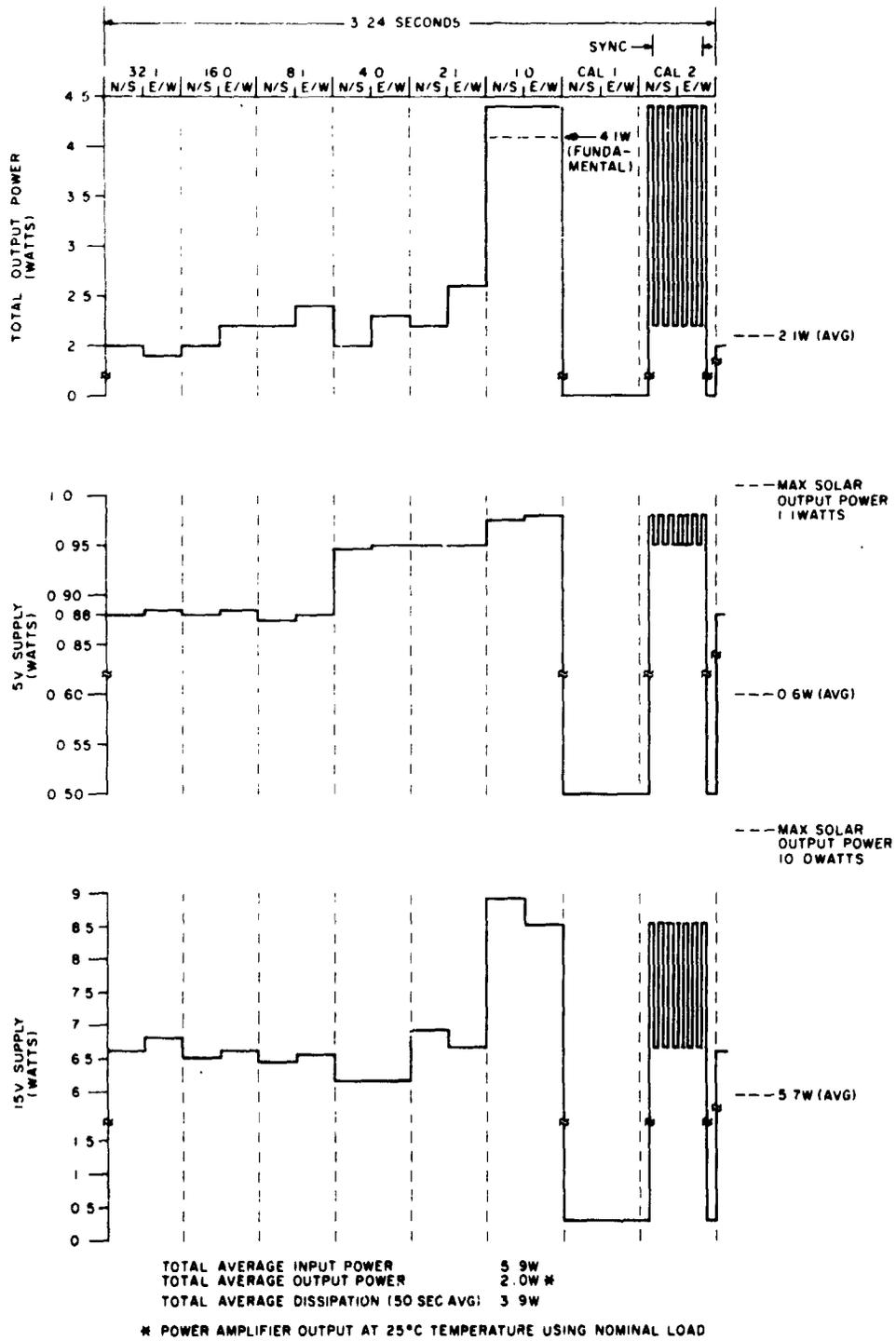
Figure 4-14. Transmitter power output and power consumption.

4.9   Receiver, Functional Description

The SEP receiver (Fig. 4-15) is designed to operate automatically in the lunar environment in either of two operating modes. Mode 1 is the sync acquisition mode. This indicates the operation of searching for the sync pattern, which is transmitted during the transmitter sync interval. Mode 2 is the normal operating mode of the receiver when it has acquired synchronization and is receiving data normally at the six experiment frequencies. As soon as the receiver is turned on, it automatically goes into operating mode 1. When it acquires synchronization (by recognizing the sync pattern), it automatically switches to mode 2 and begins recording data at the six experiment frequencies, using the DSEA. The block diagram of Fig. 4-16 illustrates the functional organization of the SEP receiver.

4.10   Receiver Characteristics

The operating characteristics of the SEP receiver are as follows:

Dimensions (stowed position):	11.0 in. × 13.0 in. × 13.25 in. (antenna extension, stowed position: 10 in.)
Weight:	21.7 lb
Method of deployment:	Astronaut-deployable (time-line procedure)
Receiver type:	Superheterodyne, double conversion
Receiving frequencies	Six individually-selectable frequencies - 32.1 MHz, 16.0 MHz, 8.1 MHz, 4.0 MHz, 2.1 MHz, 1.0 MHz
Method of reception:	Three individually-selectable loop antennas, orthogonally deployed
First IF:	21.4 MHz
Second IF:	1.085 MHz
Receiver output:	Log amp on: 300–3000 Hz audio tone, varying in accordance with RF input signal strength variations
	Log amp off: depending on logical state of the receiver status signal, 900–2500 Hz (determined by internal receiver temperature) or 5700 ± 700 Hz
Data storage medium:	Magnetic tape
Storage device:	Self-contained tape recorder, housed in a removable assembly (DSEA)
Data retrieval:	DSEA manually recovered by astronaut
Energy requirements:	20 Wh, warmup 81 Wh, operate*

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*Nominal for 9 hours of lunar operation.
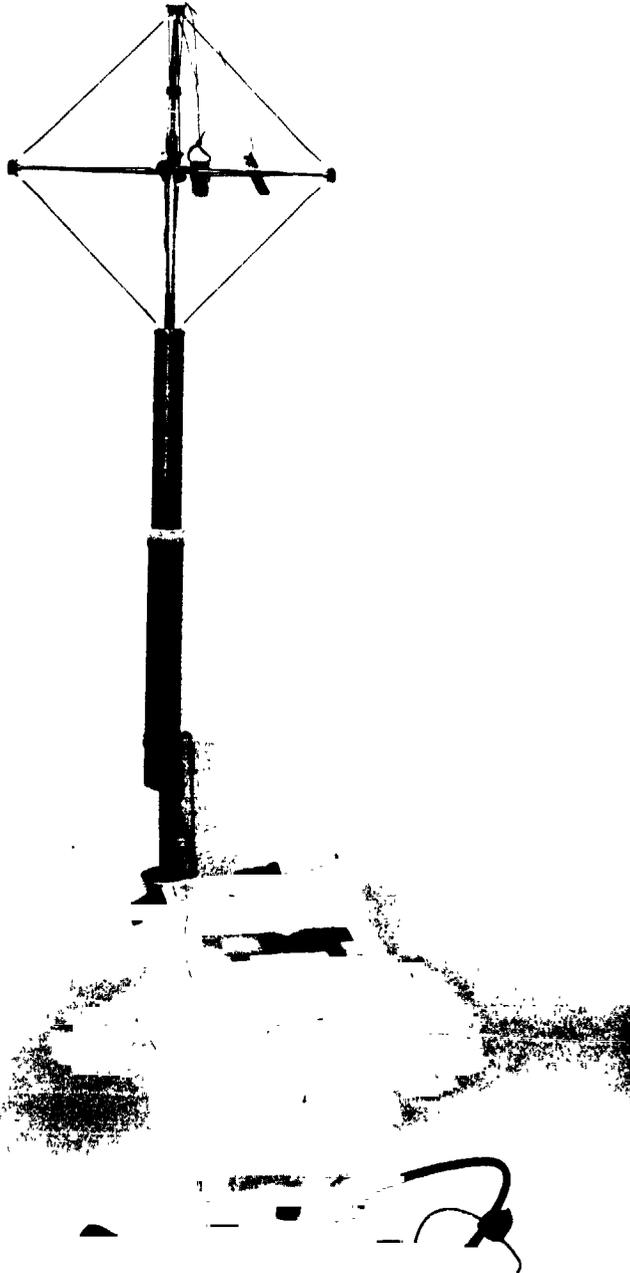
Figure 4-15. SEP receiver.

Power source:	Self-contained silver-zinc battery
Electrolyte:	Potassium hydroxide (KOH)
Battery output capacity:	116 Wh @ 12V (nominal)
Battery voltage:	Peak open circuit 14.8 Vdc Maximum operating 13.4 Vdc Minimum operating 11.2 Vdc
Operating temperature range:	$+20^{\circ}F-+115^{\circ}F$, $\pm 5^{\circ}F$
Thermal-radiational characteristics:	Outside of operating temperature range, DSEA and battery subject to degradation of operational characteristics
Protection:	Receiver housing protected by thermal blanket. Internal heat radiated to deep space by means of an OSR mounted at top of receiver. Internal, thermostatically-controlled heater strips maintain operating temperature of DSEA and battery during standby mode of operation
Operating life:	9 hours (limited by amount of tape on DSEA tape recorder)

4.11 Antenna Assembly

The receiver antenna assembly is comprised of three separate orthogonally-deployed loop antennas, each of which receives energy (figure-eight pattern) principally from one of three separate directions (X, Y, or Z), each direction being mutually perpendicular to the other two. The antenna assembly is shown in Fig. 4-17 and provides three separate inputs to the receiver, one from each of the three loop antennas.

(1) Antenna loop. Figure 4-18 shows the Y-loop. All three loops are electrically identical to the Y-loop. Each operates as two separate loops in parallel.

(2) Antenna Y-loop electrical connection. The receiving loops are made of coaxial cable, with the shield functioning as the receiving element, and the center conductors are the feed wires to the antenna switch in the receiver. Note that the RF currents in the common center arm cancel, so only the outer sides of the loop function as RF energy pick-ups.

4.12 RF-Synchronizer Module

This consists of an antenna switch assembly, a 1.0-MHz sync receiver, and a 2.1-MHz receiver. It selects the X, Y, and Z loop of the antenna and detects sync patterns. It also contains two noise sources for calibration.

578034-1 OSC / TIMING MODULE ASSY (A4)

578026-1 SYNCHRONIZER ASSY (A2)

GSE INTERFACE { INHIBIT / STEP }

SR

TIMING RESET

SUB-FRAME CLOCK

MODE 1

MODE 2

TIMIN

464730-2 CLOCK / TIMING ASSY (A1)

FRAME COUNTER

MODE CTRL

XTAL OSC 22 4MHZ

XTAL OSC 23 5MHZ

XTAL OSC 25 4MHZ

OR GATE

SYNC ASSY (A2)

6PST SW

2 1MHZ SYNC

1 0MHZ SYNC

BUFFE

464729 SWITCH CIRCUIT BUFFER ASSY (A3)

464725-2 RF / SYNC MODULE ASSY (A3)

SR

2 1MHZ SYNC CHNL (A2)

1 0MHZ SYNC CHNL (A1)

+5V
-5V

464716-2 ANTENNA ASSY (A7)

X
Y
Z

464848-2 (A2)   464787-1 (A1)

464785 ANTENNA SWITCH ASSY (A3)

+10db   -0 5db   +17db

NOISE/ ANTENNA SELECT SWITCH

PREAMP

RF BPF

RF AMP

RF OUT

MIX

FROM TIMING { X SELECT (SX) / Y SELECT (SY) / Z SELECT (SZ) / NOISE SELECT (SR) }

HIGH NOISE SOURCE

LOW NOISE SOURCE

FROM TIMING { SN2 / SN1 }

Figure 4-16. SEP receiver bloc`

Figure 4-16. SEP receiver block diagram (sheet 1 of 2).

400HZ SQUARE WAVE
FROM TIMING

LSC360-12-5 DATA STORA
ELECTRONICS ASSY (AI)

VCO FROM
VCO ASSY (A2)

VOICE
INPUT

578045-1 NAV DATA
MODULE ASSY (A8)

NAV MULTIPLEXER CLOCK
FROM TIMING

DIGITAL
NAV DATA

TCD
INPUT

TAPE
RECORDER

7-BIT SHIFT REGISTER

END OF
TAPE
(SHUTDOWN
CONTROL)

FRAME SYNC TO
GSE INTERFACE

SHIFT/LOAD
LOGIC

REGISTER
LOADING GATES

+5V

-5V

G
IN

DOWN BEARING
UP BEARING
DOWN RANGE
UP RANGE
RIGHT FRONT WHEEL PULSE
LEFT REAR WHEEL PULSE

RANDOM
POSITION
DATA FROM
LRV SPU

SPU / RCVR
LEVEL
INTERFACE

TEMPORARY
STORAGE

RESET
LOGIC

41.6KHZ SYNC
FROM TIMING

Figure 4-16. SEP receiver block diagram (sheet 2 of 2).

HOLDER A

VERTICAL FEED ASSY

ANTENNA LOOP (PLANE X)

HOLDER E

HORIZONTAL FEED ASSY

HOLDER B

HOLDER D

ANTENNA LOOP (PLANE Y)

ANTENNA LOOP (PLANE Z)

HOLDER F

Z LOOP FEED WIRE

HOLDER C

Figure 4-17. SEP receiver antenna.

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HOLDER
E

ELECTRICAL
WIRING
DIAGRAM

RG-178B/U COAXIAL
CABLE CONNECTED
AS SHOWN

LOOP 1

HOLDER
C
(BOTTOM)

HOLDER
A
(TOP)

LOOP 2

SEP
RCVR

TO
ANTENNA
SWITCH

HOLDER
F

FUNCTIONAL
EQUIVALENT

LOOP 1

TO
ANTENNA
SWITCH

COAXIAL
CABLE
GROUND AT
RECEIVER
INPUT
CONNECTOR

LOOP 2
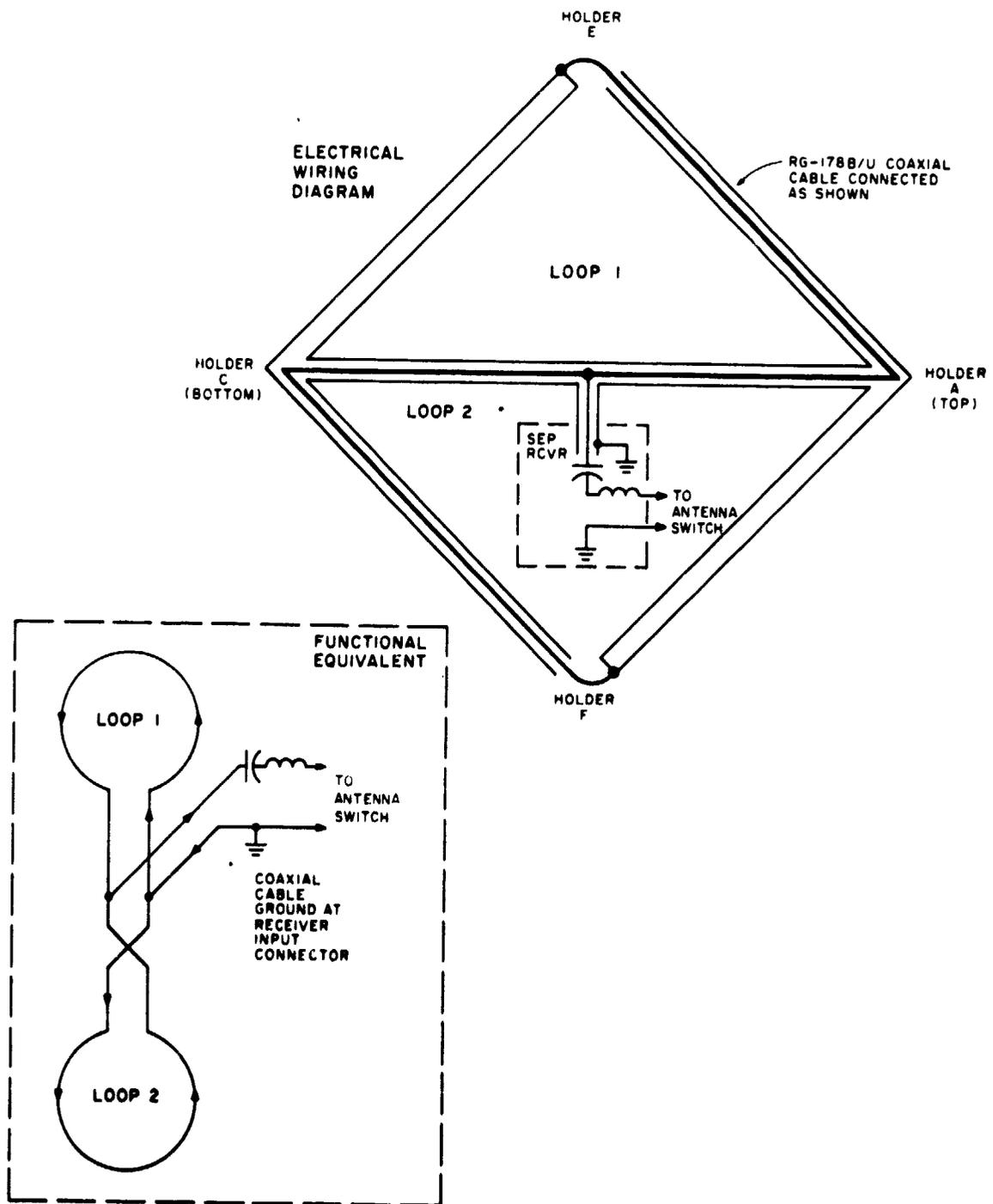
Figure 4-18. Y-loop diagram.

(1)   Antenna switch assembly. A block diagram is shown in Fig. 4-19,
        showing the capability for antenna switching and RF amplification.

   (a)   Noise-antenna switching. During mode 2 operation, signals
         from the antenna signal generator in the oscillator-timing
         module to the antenna switch assembly control the selection
         of antenna loops. During transmitter-off intervals, a noise
         source (galactic, low-level diode, or high-level diode) is
         switched in for experimental calibration.

   (b)   RF amplification. The output of the RF amplifier in the antenna
         switch assembly is a low-level signal about 28 dB higher than
         the antenna input.

(2)   1.0-MHz and 2.1-MHz sync receiver assemblies. These are dia-
        gramed in Fig. 4-20. Their primary function is to recover the
        transmitted 1.0-MHz and 2.1-MHz oscillator waveforms.

4.13   Oscillator-Timing Module

This module consists of the sync assembly, clock and timing assembly, and
the switch circuit buffer assembly. These provide all necessary timing signals for
signal selection.

(1)   Synchronizer network. This consists of two functionally-identical
        sync circuits (1.0 MHz and 2.1 MHz) for synchronization of the re-
        ceiver timing with that of the transmitter. A flow diagram of the
        sync acquisition sequence is shown in Fig. 4-21, and a block diagram
   of the sync circuit is shown in Fig. 4-22. The receiver has two
        modes of operation. Mode 1 is sync search. Mode 2 is synchron-
        ized. The receiver remains in mode 1 until the sync pattern is ac-
        quired. In mode 2, the sync circuits continue to re-synchronize
        every subframe. If there is failure to recognize the sync pattern
        after 48 subframes, the receiver switches to mode 1.

(2)   Clock and timing network. Figure 4-23 shows a block diagram of
        this network, which generates the timing signals, using the same
        method as in the transmitter.

   (a)   Clock-frequency divider. This circuit divides down the 1.04-
         MHz clock-oscillator output to establish sets of control fre-
         quencies.

   (b)   Countdown chain. This consists of eight divider circuits in
   series, operating from the 800-Hz square wave pulse train
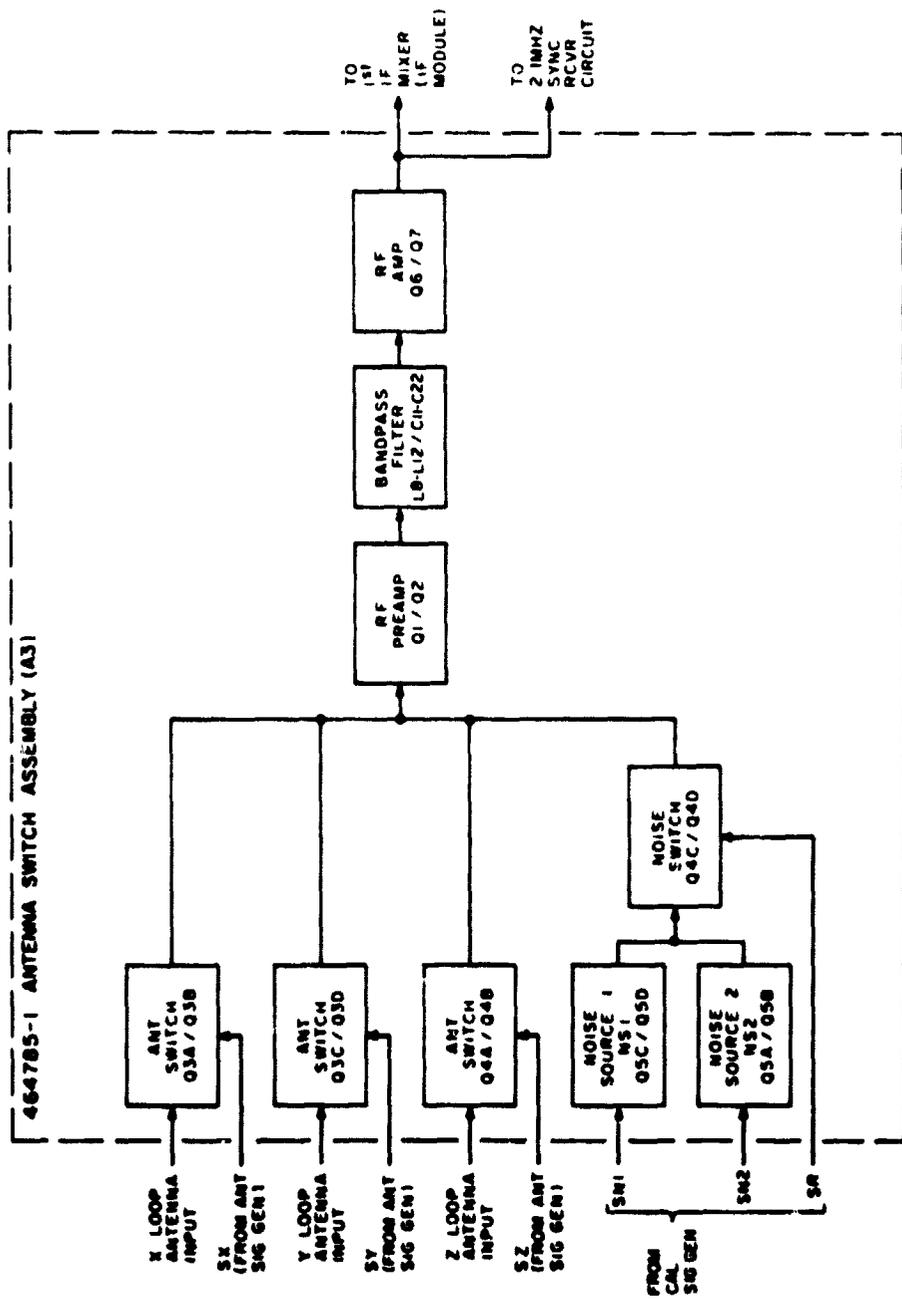
Figure 4-19. Antenna switch assembly.

58
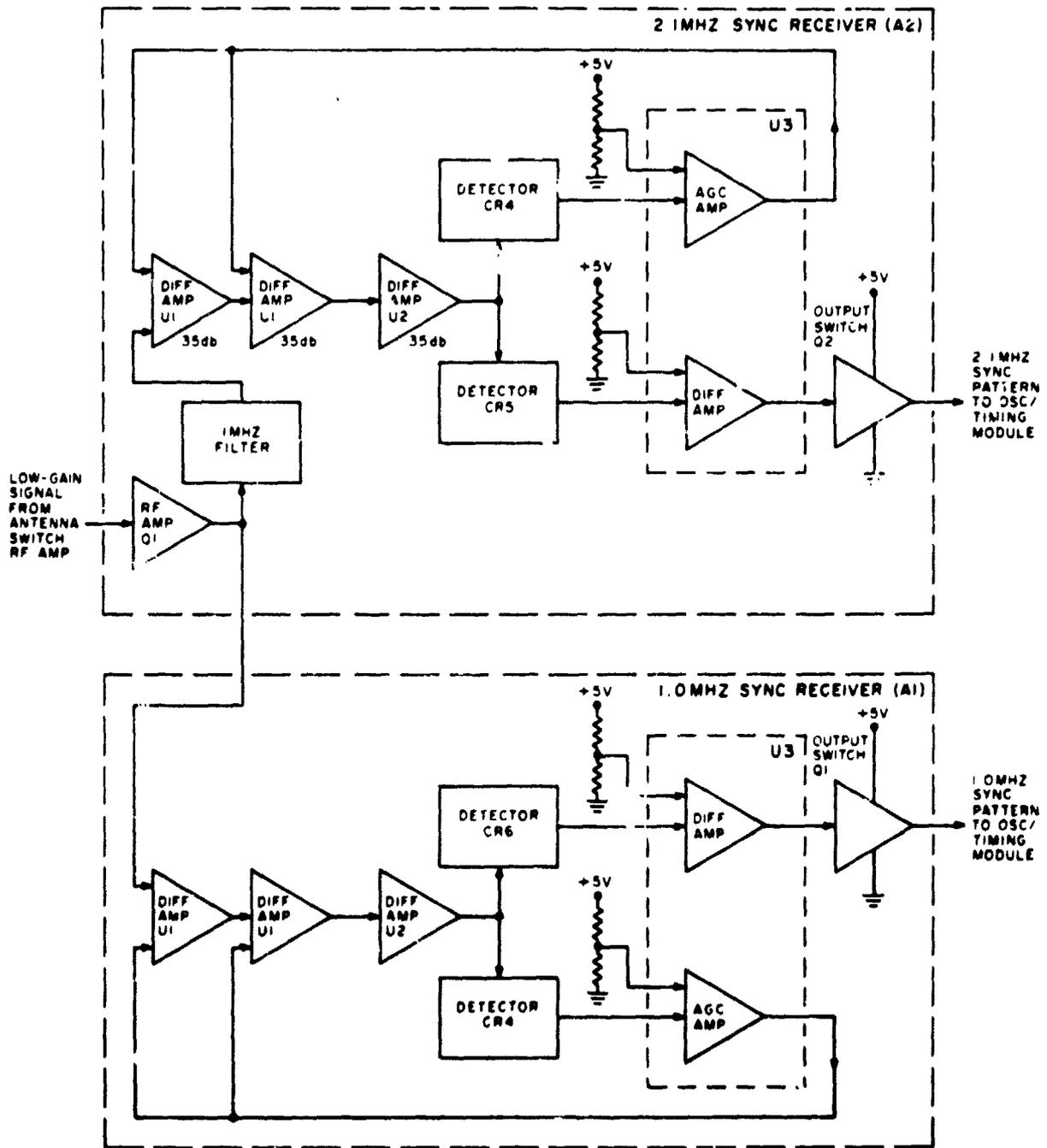
Figure 4-20. 1.0 and 2.1 MHz sync receiver assemblies.
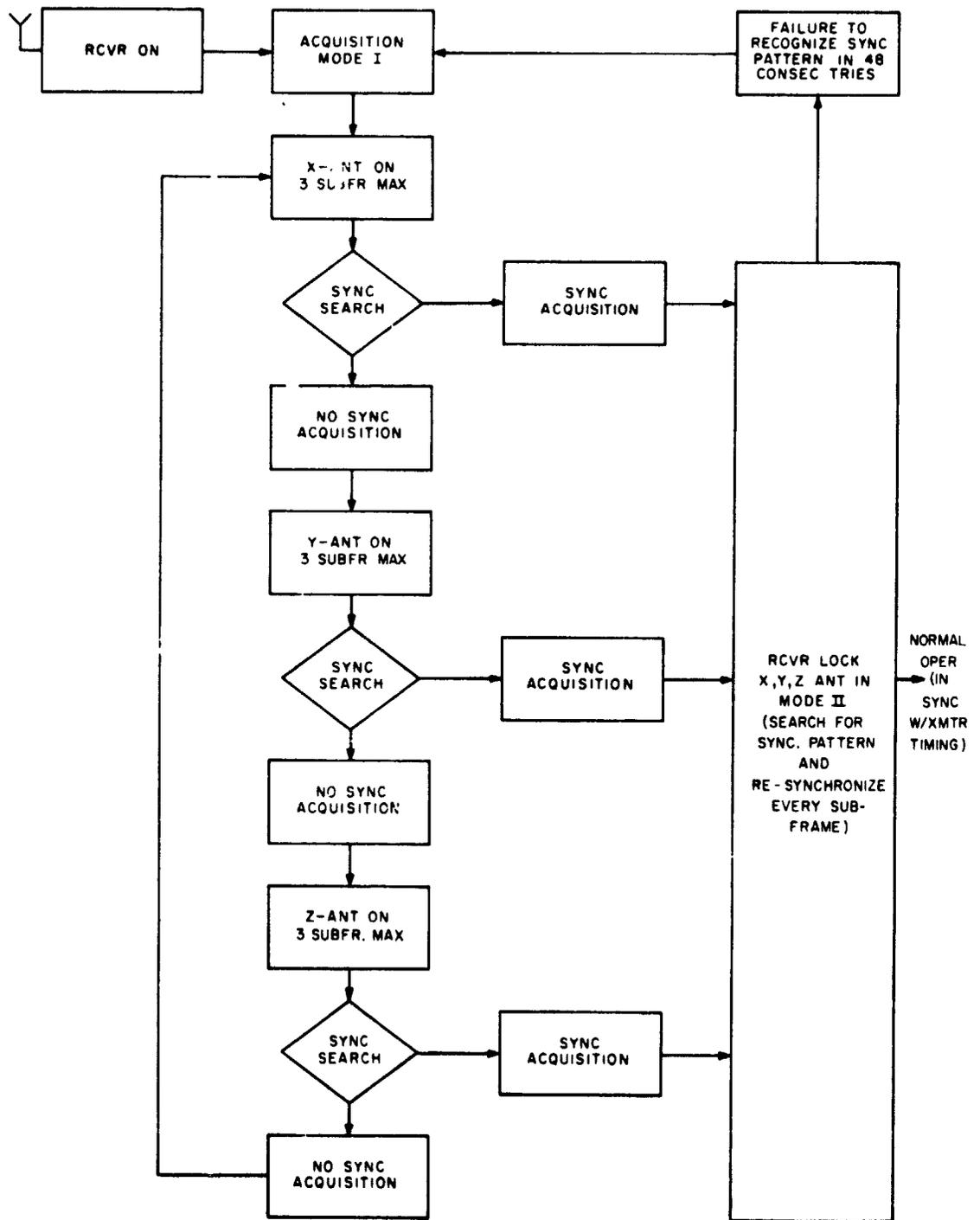
Figure 4-21.   Receiver sync acquisition flow diagram.
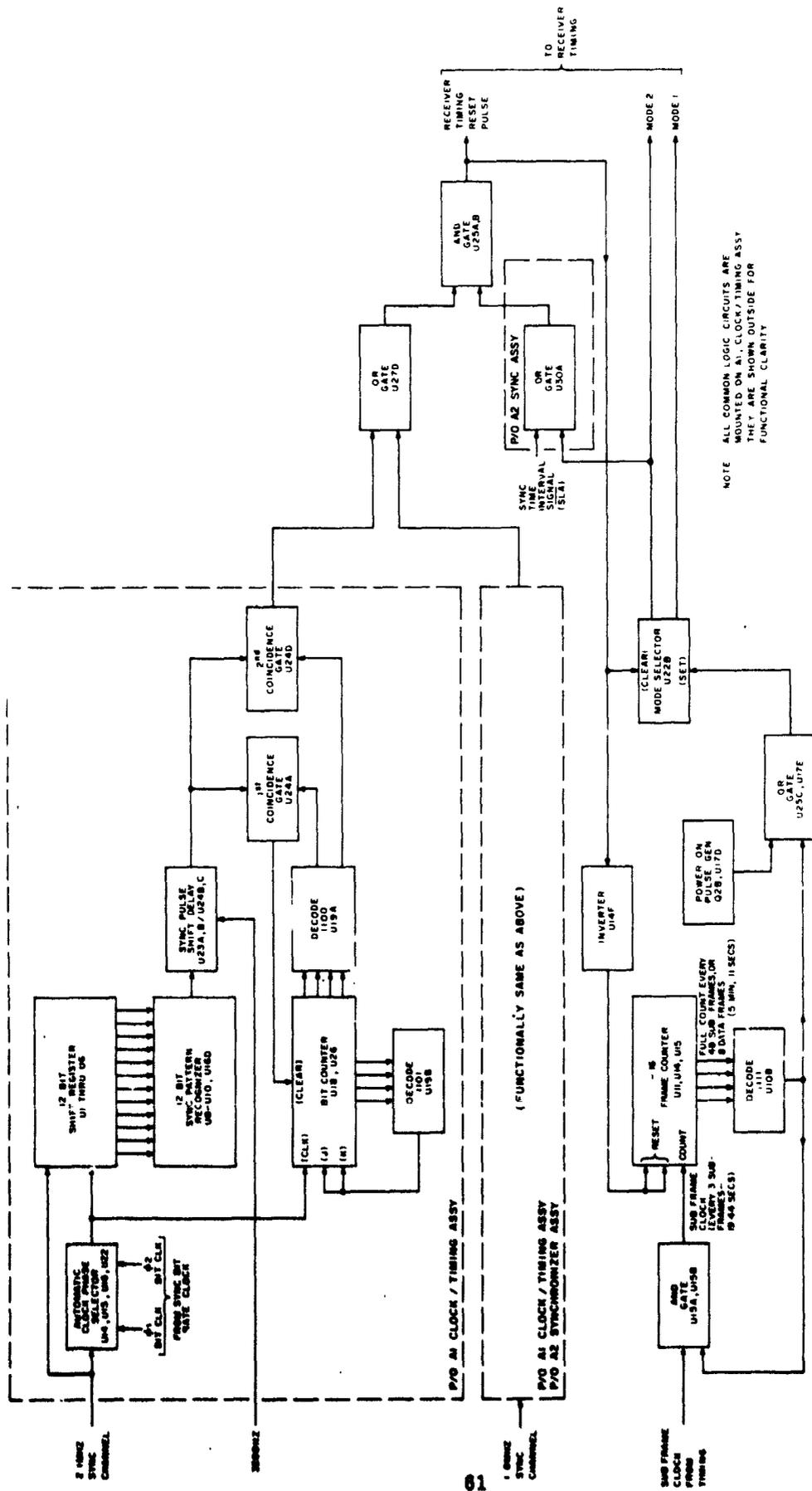
Figure 4-22. Receiver synchronization block diagram.

Figure 4-23. Receiver clock/timing block diagram.

output of the frequency divider. The outputs control the antenna, oscillator and calibration signal generators, and the receiver status code generator.

(c) Signal generators, status code generator. Figure 4-24 (3 sheets) shows the output waveforms produced by these generators.

(d) Antenna signal generator. The output waveforms are shown in Fig. 4-24.

(e) Calibration signal generator. The output waveforms are shown in Fig. 4-24.

(f) Receiver status code generator. The output waveforms are shown in Fig. 4-24. The output is modulated to form a six-bit word to indicate the status of the receiver at the beginning of each subframe. Table 4-2 shows the ten code words used.

(3) Switch circuit buffer. A block diagram is presented in Fig. 4-25. The circuit includes the local oscillators for heterodyning the experiment frequencies to the first intermediate frequency of 21.4 MHz.

Table 4-2. SLA modulation code (receiver status).

AMPLITUDE LEVEL OF RECOVERED DSEA SIGNAL						RECEIVER STATUS
S	T	M	X	Y	R	
0	1	0	0	1	0	Mode 1, X-Ant On, Y-Ant Off, No Reset
0	1	0	1	0	0	Mode 1, X-Ant Off, Y-Ar. No Reset
0	1	0	1	1	0	Mode 1, X-Ant Off, Y-Ant No Reset
0	1	1	0	1	1	Mode 2, X-Ant On, Y-Ant Off, Reset (Cal 32, 16)
0	1	1	1	0	1	Mode 2, X-Ant Off, Y-Ant On, Reset (Cal 8, 4)
0	1	1	1	1	1	Mode 2, X-Ant Off, Y·Ant Off, Reset (Cal 2, 1)
0	1	1	0	1	0	Mode 2, X-Ant On, Y-Ant Off, No Reset (Cal 32, 16)
0	1	1	1	0	0	Mode 2, X-Ant Off, Y-Ant On, No Reset (Cal 8, 4)
0	1	1	1	1	0	Mode 2, X-Ant Off, Y-Ant Off, No Reset (Cal 2, 1)
0	1	0	0	0	1	First Sync Code Recognition, Mode 2 Next Frame

0 = Low amplitude (equivalent to digital logic 0)
1 = High amplitude (equivalent to digital logic 1)
S   Subframe indicator (always 0) indicates beginning of subframe
T - Gates temperature data to DSEA (always logic 1)
M - Mode (0 = Mode 1, 1 = Mode 2)
X, Y - Antenna position (0 = antenna connected, 1 = antenna disconnected)
R - Reset (0 = no reset pulse generated, no sync acquisition , 1 = reset
      pulse generated, sync acquired)

Figure 4-24. Receiver mode 2 timing diagram (sheet 1 of 3).

Figure 4-24. Receiver mode 2 timing diagram (sheet 2 of 3).

Figure 4-24. Receiver mode 2 timing diagram (sheet 3 of 3).

464729-1
SWITCH CIRCUIT BUFFER ASSY (A3)

22.4MHZ OSC Y1 → OSC SWITCH Q1A / Q1B

1.0MHZ SELECT S6

23.5MHZ OSC Y2 → OSC SWITCH Q3C / Q3D

2.1MHZ SELECT S5

25.4MHZ OSC Y3 → OSC SWITCH Q1C / Q1D

4.0MHZ SELECT S4

FROM OSC SIG GEN

29.5MHZ OSC Y4 → OSC SWITCH Q3A / Q3B

8.1MHZ SELECT S3

37.4MHZ OSC Y5 → OSC SWITCH Q2A / Q2B

16.0MHZ SELECT S2

53.5MHZ OSC Y6 → OSC SWITCH Q2C / Q2D

32.1MHZ SELECT S1

BUFFER NETWORK Q4 / T1

1st LOCAL OSCILLATOR OUTPUT TO IF MODULE

Figure 4-25.   Switch circuit buffer assembly block diagram.

67

4.14 IF Module

Figure 4-26 is a block diagram showing the logarithmic amplifier and the voltage-controlled oscillator, whose output is recorded on the DSEA. The logarithmic amplifier decreases the dynamic range of the IF output to a voltage ratio of 10:1, so that the output frequency of the voltage-controlled oscillator (3000 Hz:300 Hz) is directly related to the variation of the received signal strength.

4.15 Navigation Data Module

This module receives asynchronous wheel, range, and bearing pulses from the LRV navigation computer and records the data on the DSEA tape. A block diagram is shown in Fig. 4-27. Figure 4-28 shows the timing.

4.16 Power Module

A block diagram is shown in Fig. 4-29 for the ac circuit and in Fig. 4-30 for the dc circuit.

4.17 Battery

Primary power for the receiver is from a 12-V silver-zinc battery.

464731-1 IF MODULE ASSY (A5)

464790-1 AMPLIFIER ASSY (A1)

2nd LOCAL OSCILLATOR (20 315MHZ) Y1

1st LOCAL OSCILLATOR OUTPUT FROM OSC/ TIMING MODULE

RF OUTPUT FROM RF / SYNC MODULE

1st IF MIXER M1

1st IF BANDPASS FILTER (21 4MHZ) FL-BP-1

IF AMP Q1/Q2

2nd IF MIXER M2

2nd IF BANDPASS FILTER (1 085MHZ) FL-BP-2

1 085MHZ OUT TO GSE

464792-1 LOG AMP/VCO ASSY (A2)

LOGARITHMIC AMPLIFIER Q1, Q2, Q4 THRU Q7

SLA

FROM OSC/ TIMING MODULE

SLA

INTERFACE SWITCH Q3A/Q3B CR1

INTERFACE SWITCH Q3C/Q3D CR18

VOLTAGE-CONTROLLED OSCILLATOR AR3A/AR3B Q8

300-3000HZ VCO OUT TO DSEA

DC OUT TO GSE

TEMP SENSOR RT2

Figure 4-26. IF module block diagram.

69
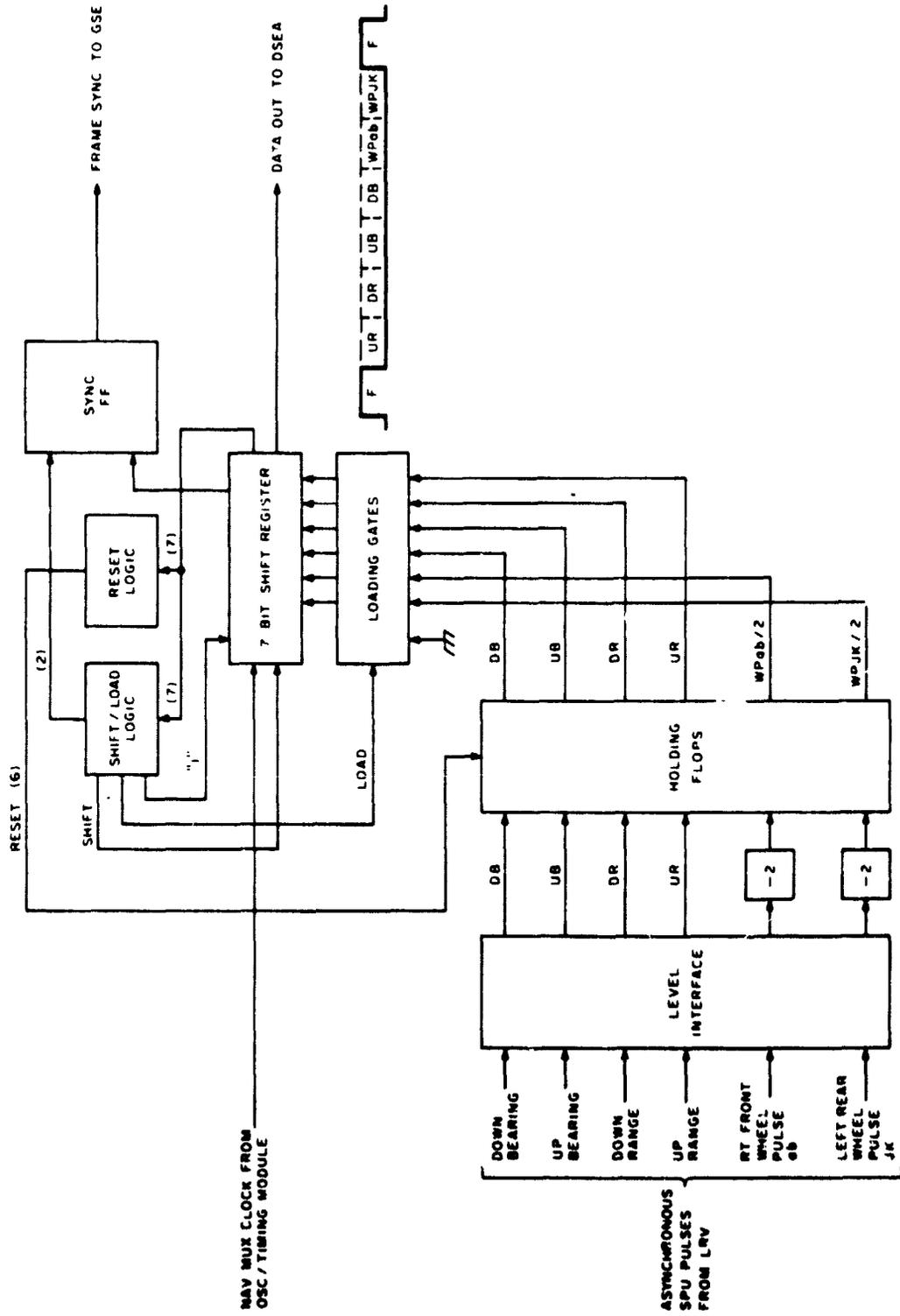
Figure 4-27. Nav data module block diagram.

70

Figure 4-28. Nav data timing.

71
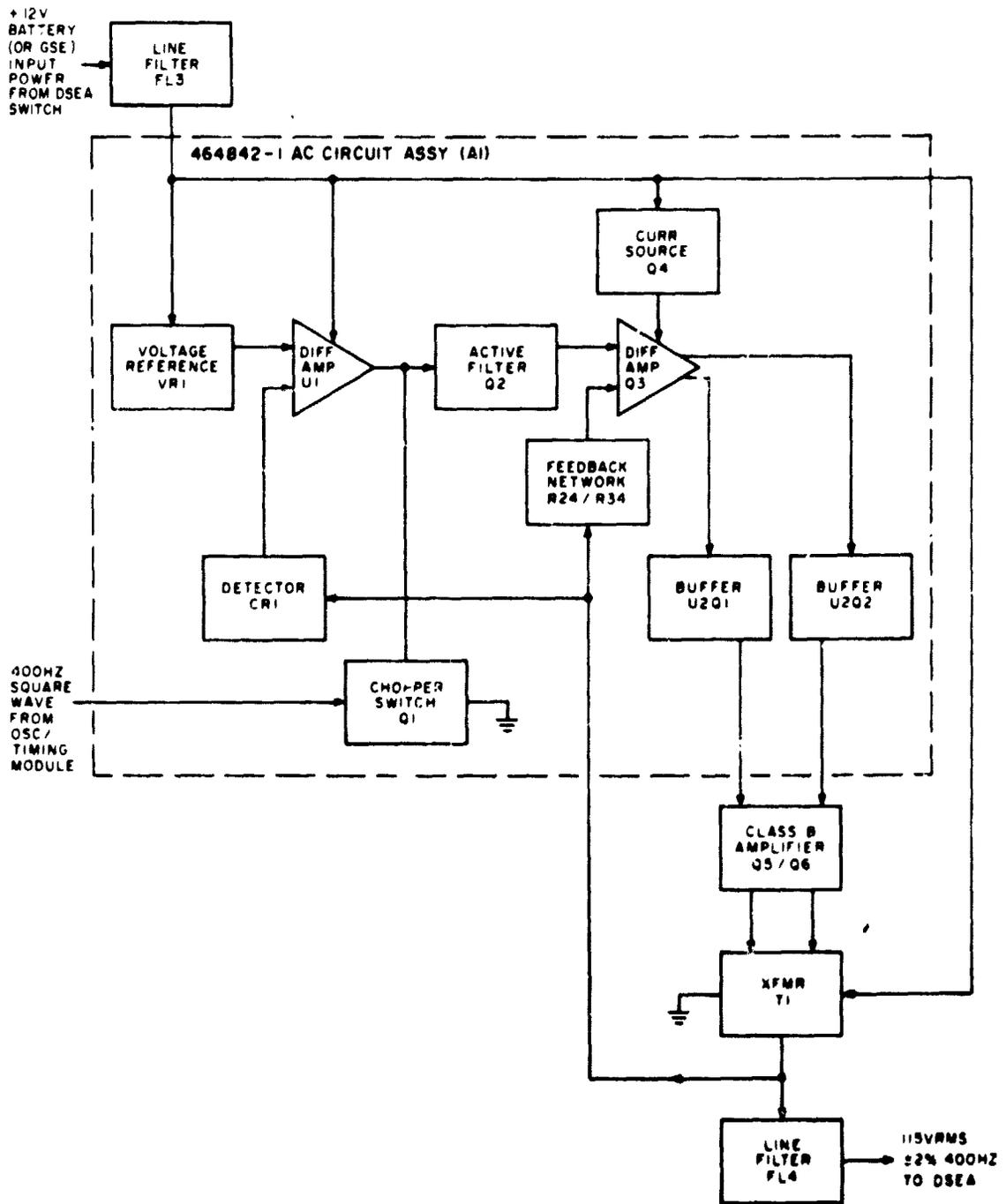
Figure 4-29. AC circuit block diagram.
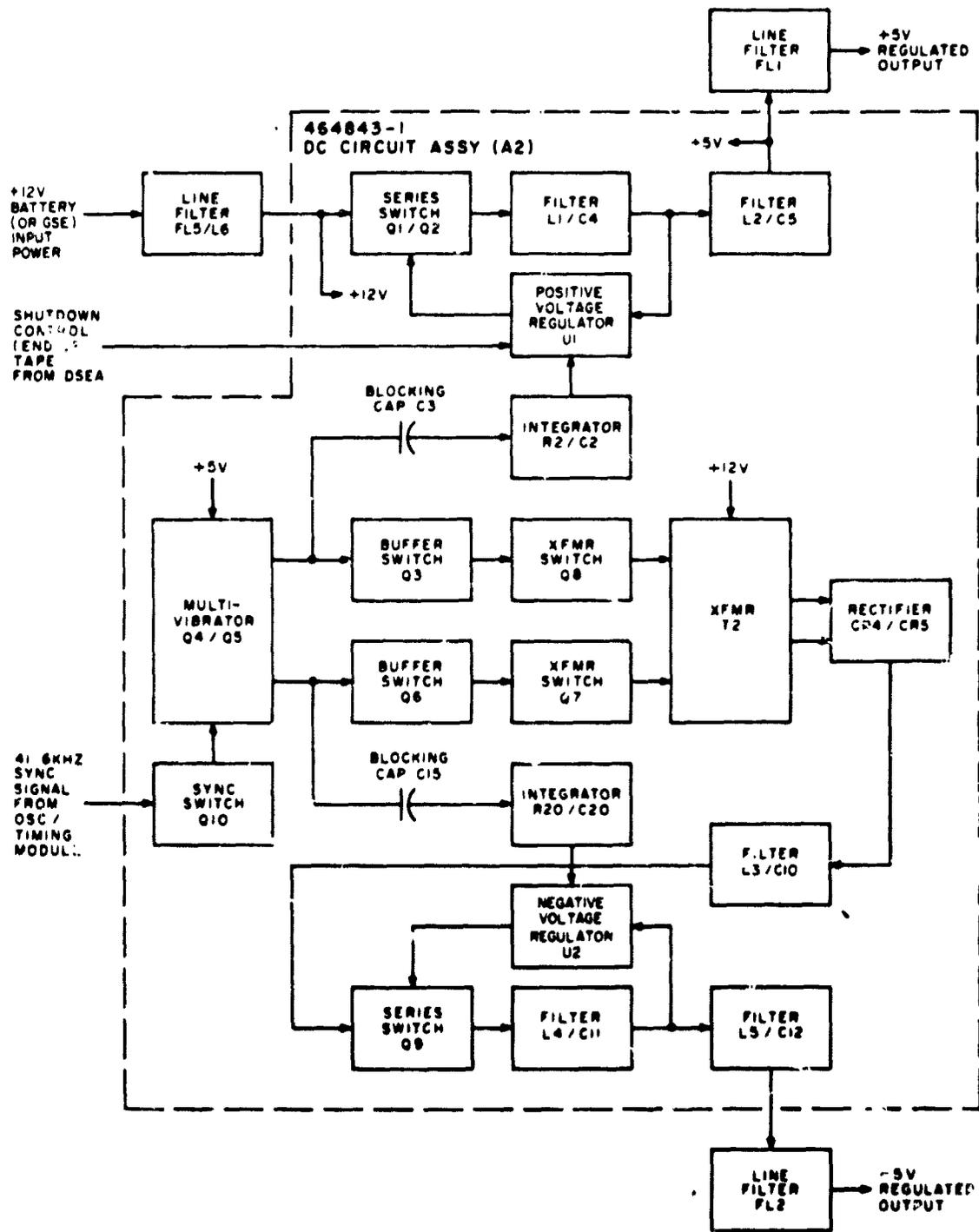
Figure 4-30. DC circuit block diagram.

SECTION 5

ENGINEERING TESTING

In addition to the standard tests required for equipment used on a manned lunar mission, such as quality tests, qualification tests, acceptance tests, pre-launch tests, certification tests, and acceptance tests, the SEP program included several specialized series of major experimental tests which affected the hard-ware configuration. These included glacier trials, electromagnetic interference investigations, vibration testing, and thermal/vacuum testing. These extra tests each required the fabrication and use of special equipment and the expenditure of significant engineering time.

5.1 Glacier Testing

The glacier tests had a greater impact on hardware modification than the other tests and are discussed in greater detail. They contributed valuable design information and increased confidence in the ability of the equipment to perform on the lunar mission. A brief description of the glacier testing philosophy and opera-tion has been presented in Section 1.1. The following section is intended to present details of the tests and of the design problems relating to the hardware development as revealed by the tests.

During March, April, and May 1971, plans were made for the design and support of a field test program. These plans required the use of a field evaluation model (FEM) of the SEP transmitter and receiver.

5.2 FEM Description

Technical direction was issued in May from MIT to Raytheon to implement the FEM in accordance with the features, characteristics, and capabilities described below:

(1) The transmitter (Tx) shall be battery operated, with four (4) battery packs supplied, three as spares. Each transmitter battery pack shall have capacity sufficient for continuous transmitter operation of four hours in an ambient of $-20^{\circ}F$.

(2) The Tx shall incorporate circuitry with associated front-panel controls to maintain operation of the Tx at any of the design frequencies and on any transmitting dipole.

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(3)   The Tx shall incorporate an on-off switch and a battery monitor.

(4)   The Tx enclosure shall be sealed from snow with the access for the battery pack to be on the top. Thermal radiative surfaces of the transmitter shall be sufficient to ensure continuous transmitter operation without requiring ventilation holes that would permit entry of snow driven by a 40-knot wind. There shall be no external leads other than the transmitting dipoles.

(5)   The transmitter shall be capable of operation at $0^\circ F$.

(6)   The equipment shall be designed to allow access to the antenna feed terminals for VSWR and other electrical testing.

(7)   The transmitter circuitry shall be designed to permit the injection of excitation signals from an external source at the inputs of the final amplifiers.

(8)   The receiver (Rx) shall be powered by commercial power supplies operating from 115V, 60 Hz.

(9)   The receiver shall mechanically interface with a standard 19 in. equipment rack.

(10)   The Rx antenna shall have provisions for mounting external to the equipment bay, including connecting cables from antennas to the receiver.

(11)   The Rx shall have circuitry with associated front-panel controls for selection of individual frequencies and individual Rx antenna loops.

(12)   The Rx shall be provided with three sample-and-hold circuits with outputs proportional to the signal amplitudes received on the X, Y, and Z receiving antennas. Receiver controls shall permit synchronization of the sampling time so that the data output will correspond to a selectable 200-ms interval during which the transmitter is radiating a designated frequency from a designated dipole. The output circuit shall hold the sampled value for one frame time of 3.2 s with less than 3 percent droop.

(13)   The Rx shall operate over the temperature range of $0^\circ F$ to $70^\circ F$ with the typical temperature anticipated to be $40^\circ F$ to $50^\circ F$. In no one experimental run is the temperature variation expected to exceed $\pm 10^\circ F$.

(14)   The receiver electronic circuitry shall be protected by conformal coating against a high humidity environment.

(15)   Rx testing shall include but not necessarily be limited to the following:

   (a)   All modules shall undergo temperature testing.

   (b)   The entire FEM package shall undergo temperature testing from 0°F to 80°F.

   (c)   Final acceptance test shall be of an engineering nature with data recorded by engineering memo.

Raytheon, working in cooperation with LSE, completed construction and testing of the FEM and delivered the hardware to MIT on 29 June 1971.

5.3   Athabasca Trip

Following logistic preparations in May and June, the SEP FEM with supporting test equipment arrived at the field test site on the Athabasca glacier, Alberta, Canada on 8 July 1971.

Tests and final design of the transmitting antenna were conducted from 10 July through 20 July, the final 'glacier' configuration transmitting antenna being deployed on 18 July. Trial runs with the complete field test equipment started on 15 July.

The data acquisition system arrived at the test site on 20 July. After correction of some electrical malfunctions in the tape recorder, program debugging, and the formulation of some new programs, this system was in full operation by 2 August using the data collected in the preliminary traverses.

The objectives of the glacier tests were:

(1)   To confirm the experiment configuration under lunar equivalent conditions.

(2)   To provide a rigorous check of the experiment hardware.

(3)   To provide real data as a basis for development of data reduction hardware and software.

(4)   To provide a backlog of baseline data under known conditions as an aid to the scientific evaluation and interpretation of the ultimate lunar data.

All of these objectives were met. The experiment configuration proved to be satisfactory with the single exception that the data sampling rate was too low. The hardware performed well with the single exception of an electrical difficulty in the synchronizing section of the receiver. A first model of the data reduction hardware was employed at the test site and was able to produce graphical output of about 10 percent of the data prior to the end of the field trip. A backlog of 73 data

77

runs was collected on magnetic tape to provide a set of baseline data representative of the different topographic configurations available on the Athabasca glacier.

All planned tests were accomplished with the single exception of the comparative signal-to-noise ratio tests. Refurbishment of the 'noise' receiver required for these tests was not completed so the equipment was not shipped to the test site.

Comparison of data derived from different transmitting antennas including a resonant half-wave dipole, a loaded dipole, a single trapped antenna, and the full set of orthogonal trapped antennas, showed no important differences. The patterns observed when using the orthogonal trapped set were similar to those observed when using the more elemental radiators.

The 'glacier' trapped antennas, designed after measurement of the actual effective dielectric constant of the glacial surface, gave very good results throughout July and most of August. Toward the end of August the radiated power decreased by two or three decibels; this was probably caused by the lower average temperature and the concomitant reduction in the amount of free water present on the glacier. If the field trials had been extended by another week or two it probably would have been desirable to re-optimize the antenna trap placement.

Additional co-linear wires were extended from the orthogonal trapped antenna set to simulate the effect of deploying the lunar geophone experiment in the vicinity of the SEP transmitter. The chart recorder data available in real time showed no deleterious effects; this was confirmed subsequently by a more complete printout of the data recorded on magnetic tape.

The transmitting antenna set was deployed a total of eleven times at eight different transmitting sites; deployment lines were selected by eyeball estimation of straight lines and right angles relative to marker flags placed at the ends of the first three deployed legs. Subsequent accurate surveying of the deployed antennas showed a worst-case placement error of 2°. Field test personnel recommended strongly that the lunar equipment include flags or other markers to be deployed at the ends of the first three deployed legs as an aid in antenna placement.

Tests were run with one leg of the transmitting antenna deliberately displaced by 20°, with the two antennas non-orthogonal by 10°, and with the entire transmitting antenna set rotated by 20°. Real time chart recorder data showed no deleterious effect from these displacements.

The 'copper pipe' FEM receiving antenna was used throughout most of the field trial period; this proved quite satisfactory. The lightweight lunar receiving antenna was used for about one week. Test data was comparable with the two antennas but, as expected, the lightweight antenna was unable to withstand the rigors of use on the glacier.

Overall test results, together with a re-appraisal of LRV performance based on the Apollo 15 experience, showed the need for a substantial increase in sampling rate at the higher experiment frequencies. A new sampling format was proposed to meet this need. The format was eventually adopted and included ir subsequent models of the SEP equipment.

The only electrical problem occurring in the experiment hardware was in the receiver synchronization. With signal strengtl.ʳ in the order of 30 to 40 dB above the noise floor, the receiver cycled between mode 1, the acquisition mode, and mode 2, the locked mode. This discrepancy did not prevent the collection of data, so the problem was not investigated in detail at the field test site. Later laboratory investigation revealed an electrical design error that was corrected in both the FEM and later models.

The field trip gave evidence that ten samples per interference wavelength would be necessary to define adequately the very sharp nulls being observed. Experience with Apollo 15's LRV indicated it could operate comfortably at speeds of 10 km/h. To get this much data, certain restrictions would have to be placed on LRV operations, or the data format would have to be changed, or both. With no change in the format or frame time, the LRV speed would have to be limited to 1.05 km/h for the first 20 wavelengths dist. ace.

A number of possible approaches were proposed:

(1)   Format modification that would produce a constant number of data points per wavelength for any speed (increases allowable LRV speed by factor of 4, but records a larger number of "blanks" at lo₁ ₃ ranges).

(2)   Eliminate the 32-MHz frequency and double the rate at 16 MHz (increase by factor of 4).

(3)   Eliminate one transmit dipole; retain all frequencies (doubles allowable LRV speed).

(4)   Eliminate one transmit dipole and the 32-MHz frequency (increase by factor of 4).

(5)   Halve the dwell time at each frequency to 200 ms (doubles allowable LRV speed).

(6)   Impose operational constraints on the LRV. (Although such constraints çan be shown to be minimal under several reasonable experimental conditions, operational constraints were never exhaustively deliberated.)

Eventually, a combination of proposed approaches (1) and (5) was chosen, and a rede.. ᵢn including the recording of navigation data as well as the change in timing format was authorized by CCA #1.

5.4   Juneau Icefields Trip

A second glacier field test was conducted during June and July of 1972 on the Taku glacier in the Juneau Icefield, Alaska. The FEM was refurbished and used for the collection of scientific data to aid in relating SEP data to glacier and lunar surface electrical properties and morphology. A field-site data reduction system provided quick-look capability and was used in guiding the selection of traverses. The equipment functioned satisfactorily.

During this field trip on 4 July, a one-day end-to-end test of the prototype transmitter and receiver was also performed. Special containers were constructed for weather protection of the two units and associated battery packs which were used to power them, plus an external tape recorder. The receiver was transported along the traverses on a Cushman trackster.

The prototype test was desirable because of the major changes in hardware and data format that had occurred after the FEM had been constructed. The prototype was very nearly flight configuration, so that the test was considered to be a valid simulation of the lunar experiment.

During the prototype tests, 20 traverses were made over tracks previously surveyed with the FEM, mostly over deep ice. The external tape recorder was inoperative during most of these tests, but the DSEA tape recorder recorded valid data throughout.

This exercise of the prototype was valuable in providing confidence in the soundness of the hardware design.

Also, on the Juneau icefields, the results of the field trials provided a bank of scientific data and insight into operational requirements, and the satisfactory functioning of the hardware indicated no need for any further hardware design changes.

5.5   EMI Testing

Because of their importance, EMI and electromagnetic compatibility (EMC) tests were accorded continuing attention and were conducted as a series of progressively more sophisticated tests throughout the program, first to establish SEP design parameters and later to determine functioning compatibility bilaterally with the LRV, the astronaut equipment, and other experiments.

CSDL had prepared an EMI test receiver as a part of the study phase, and this equipment was used at JSC and at KSC as part of the formal LRV EMI testing. Coordinated testing on the Apollo 15 LRV at JSC started in March 1971. As a result, because of the existence of a potential problem caused by the proximity of the SEP receiver loop antenna and the astronaut communications radio antenna, which might overload the SEP receiver front end stages during astronaut transmission

at 250 MHz, a three-section low-pass filter with cut-off at 50 MHz was introduced in the RF section of the SEP receiver.

In addition, the SEP engineering prototype was used at KSC, with the filter incorporated, for comprehensive SEP/LRV EMI/EMC tests from 28 October to 1 November 1971 under a controlled set of experiment conditions.

5.6   Vibration Testing

The SEP vibration testing program itself did not differ from standard testing sufficiently to warrant detailed discussion, but the uncertainties concerning the launch/boost dynamic environment and the early completion of the mechanical design dictated by the extremely tight schedule combined to cause a time-consuming series of engineering meetings whose purpose was to find a solution to the problem.

The problem arose in May 1971 when it was reported that the structural dynamic characteristics during launch and boost might be approximately double the value originally specified for the experiment vibration qualification level. At this time the SEP experiment structural design had been completed, deliberately designed for minimum weight, with marginally positive design margin. It was feared that imposition of the new vibration load would result in negative design margins on several specific structural items. A redesign would require new structural analyses with attendant lost time and a probable increase in weight of the equipment at a large dollar cost. The new level exceeded the qualified limit for the DSEA, as well as exceeding the receiver and transmitter design limits.

By August, it became apparent that the higher levels would have to be met, but it still was not known whether the SEP components and structure as then designed could survive under the new environment. MIT and Raytheon together recommended the following approach:

(1)   Instead of imposing   new vibration specification as a revised design environment and/or a revised qualification requirement, the new level should be incorporated as an additional added-scope test to be performed on the compatibility unit during the informal pre-qualification test. The plan would be to conduct the pre-qualification test to the original environments as currently planned, and after successfully meeting these environments, the compatibility unit would then be exposed to the new vibration profile plus a 30 percent margin as an additional test.

(2)   Should the SEP equipment successfully survive the added vibration test, then this result would be interpreted as a high-confidence demonstration that the qualification and flight units would survive this level, and

therefore Raytheon would at that time agree to have he requirement for formal qualification testing changed to add the new vibration level test (without the 1.3 margin) as an extra test for the qualification test program.

(3) Should the unit fail the new vibration pre-qualification test, having passed the original environmental test, then MIT and NASA would have the choice of either suitable redesign of the SEP to the new level, or modification of the pallet to reduce the input vibration to the old profile, plus refurbishment of the failed compatibility unit.

The SEP compatibility model (transmitter and receiver) was subjected to a test program (December 1971–February 1972) in accordance with the requirements of this approach. In addition to the purpose of verifying the ability of the SEP design to structurally and functionally survive vibration, the additional purposes of this test were to determine acceptable vibration qualification levels and to develop confidence in the GFE tape recorder performance during and after appropriate mission data collection phases.

Based upon the performance of the SEP compatibility model, the following conclusions were drawn from the tests performed:

(1) The structures and functions of both the receiver and transmitter successfully survived all the dynamic environments including the overstress envelope profile of 16.2-grms wideband level.
   Electrical malfunctions of both transmitter and receiver occurred after the envelope profile test of 13.6-grms wideband level. These malfunctions, frequency shifts of receiver filter and opening of a capacitor lead in both transmitter and receiver, were such that experiment scientific function at lunar base would have been only slightly degraded or distorted, but not aborted. A mechanical redesign corrected the possibility of recurrence.

(2) Based upon the results of this testing, the acceptable qualification vibration levels were those at the higher level.

(3) The performance of the GFE tape recorder was evaluated in gross terms. It was determined that the tape transport did function during this test and that data was stored on the tape.

Thus, by exercising some flexibility in the interpretation of the contract requirements, it was possible to arrive at a change in specification without necessitating an equipment redesign which might have had a serious effect on the hardware schedule and cost.

5.7 Thermal Vacuum Testing

Early in the program, thermal-vacuum testing was performed on a thermal mockup at Arthur D. Little in Cambridge, Mass. because no facility was available at Raytheon. These tests verified the design and gave no evidence of the problems which were uncovered later during qualification testing of the qualification model at Chamber D, Building 33 of JSC. It is to be noted that there are no facilities in the USA where testing with simulated lunar dust conditions can be performed in a thermal vacuum chamber.

Constraints on the thermal environment of the transmitter were not as restrictive as those which were imposed on the receiver because of the DSEA.

At Chamber D, the transmitter was tested and found to run about $15-20^{\circ}F$ hotter than predicted, but this was not a matter of concern because the equipment was still well below the upper temperature limit at which it would perform satisfactorily.

The qualification model receiver arrived at JSC for the qualification test on 11 October 1972, with evidence that it had been dropped, sustaining a shock in transit. Testing started within a week and is commented on here because of the major effort involved, the changes which were dictated in configuration, and the potential impact on schedule. During the first series of tests the temperature seemed to be about $30^{\circ}F$ above that expected, and it was believed that this was caused by large instrumentation cables producing heat leaks. By 19 October, it was thought that the solar illumination of these cables and conductive flow to them from the simulated lunar surface were producing the problem, so testing was scheduled to continue over the weekend. The cables were thermally isolated, the load ring and T-structure were checked for thermal shorts, the OSR installation was checked, and thermocouples were installed to check gradients in the cables. Retesting began on 23 October, and again the results were disappointing. The temperature rose as expected, but with a $30^{\circ}F$ positive offset during a simulation of the Extra Vehicular Activity (EVA) #2 cold run, and during a simulation of EVA #3, the temperature rose at twice the predicted rate. These qualification tests had now taken on the character of mission simulations.

On 1 November, the receiver was inspected, and it was found that there were five sheared rivets, apparently the result of the shipping shock. No valid reason could be proposed for the high temperature, and suspicion of tank contamination caused by sputtered paint from a preceding test was voiced. The suspicion was that there was stray infrared (IR) input to the apparatus which could possibly have come from the solar mirror.

Modification kits were prepared for the two flight units and one trainer, consisting of:

(1)   Portion of navigation data cable wrapped with 0.25 mil aluminum Kapton tape, transferred adhesive and then wrapped.

(2)   Two corner torque tubes covered with aluminum tape.

(3)   Lower LRV mount covered with aluminum tape.

(4)   Portion of navigation data cable wrapped with multilayer insulation.

(5)   Top surface of load ring covered with tape.

(6)   Antenna wire leads covered with multilayer insulation and tape.

(7)   Four pallet mounts insulated.

(8)   New thermal blanket installed.

(9)   An "improved view factor kit" installed.

(10)   A and B edge protection provided.

(11)   Ten-layer, 0.25 mil insulation added to the bottom box edges.

(12)   Flap over side closure installed.

(13)   The pallet attachment points were not insulated.

In addition, radiometers were installed near the corner of the receiver and in other locations in the chamber.

With these modifications, the testing was again performed. Results did not match predictions throughout the test, but during the first cool-down and heat-up there was correlation, and during the second cool-down and heat-up the observed temperature was 12°F lower than that predicted. It was decided that the equipment, as modified with added insulation and tape, was qualified for lunar use, and an IR survey of chamber D was planned following MIT release of the chamber. The flight unit was turned over to Grumman for stowing on 28 November.

SECTION 6

LUNAR MISSION PERFORMANCE

The SEP experiment was transported to the r oon on Apollo 17, lifting off at 12:33 a.m. EST on 7 December 1972. Apollo 17 was commanded by Navy Captain Eugene A. Cernan, with Navy Commander Ronald E. Evans, command module pilot, and Dr. Harrison B. Schmitt, civilian scientist-astronaut, lunar module pilot.

The lunar landing site was a combination of mountainous highlands and lowland valley designated Taurus-Littrow, about 20° north and 30° east of the center of the moon as viewed from earth. It was just beyond the southeast edge of Mare Serenitatis, one of the largest lunar mascons, with steep-sided light-colored 7000-ft mountains dominating the lurain. Dark-colored non-mare material filled the valley, and a rockslide from one of the mountains covered the valley floor near the landing site.

Figure 6-1 is a photograph of the Taurus Mountains and the Littrow Crater area, with the area of the landing site indicated within the outlined portion.

Figure 6-2 is a high-resolution 4-cm radar map (courtesy of Dr. Stanley Zisk, Haystack Observatory) of the easterly edge of Mare Serenitatis including the Taurus Mountains and the Littrow Crater.

Figure 6-3 is an artist's perspective of the area and the traverses made by the astronauts during the Apollo 17 lunar mission.

The SEP experiment transmitter and receiver were deployed during the first EVA but were not put into operation until the second and third EVAs on 12 and 13 December. The photograph of Fig. 6-4 shows the astronaut deploying the transmitter. A portion of one leg of the dipole antenna is visible in the foreground. Figure 6-5 shows the transmitter in the center background, and the receiver with its tri-loop antenna is visible on the LRV. The third lunar photograph, Fig. 6-6, shows another view of the deployed transmitter, with the solar panel opened and facing the camera. A portion of one dipole is visible in the rut of the LRV wheel track in the foreground, and another dipole leg can be seen extending to the left of the transmitter.

NASA-S-72-097-V

TAURUS-LITTROW

Figure 6-1.   Taurus-Littrow landing site.
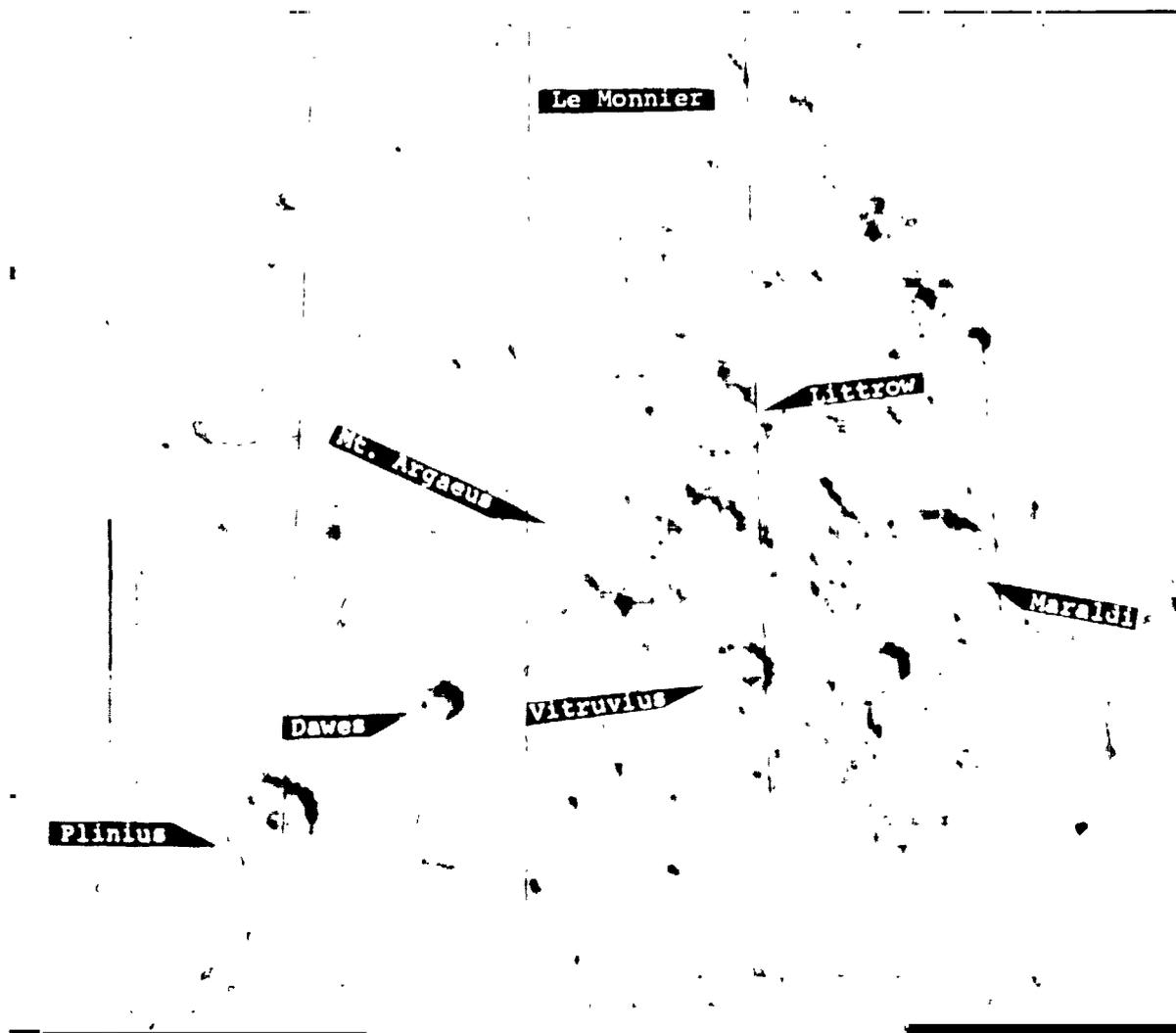
Figure 6-2. Radar view of Taurus-Littrow.

Figure 6-3. Lunar area traversed by Apollo 17 astronauts.
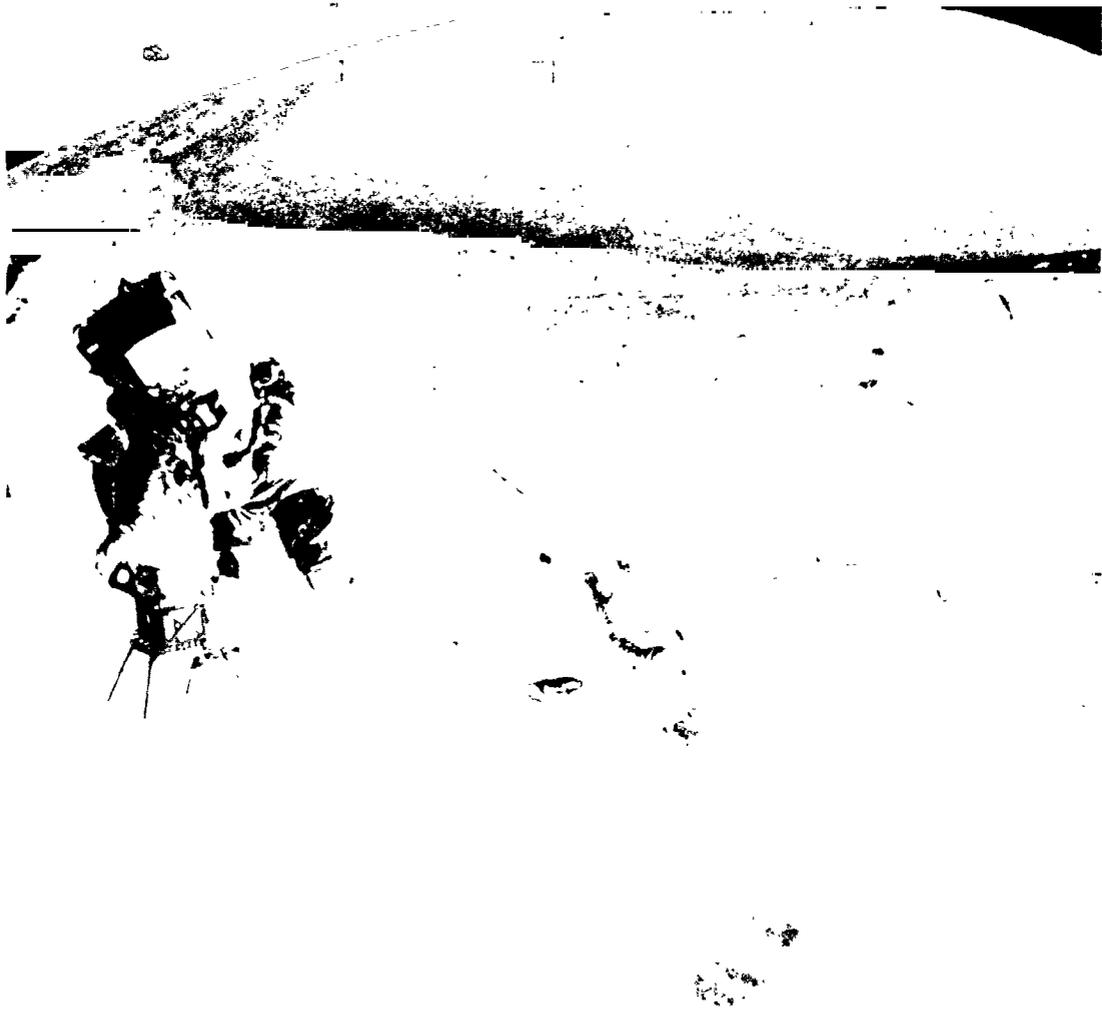
Figure 6-4. Lunar deployment of the transmitter.

Figure 6-5. SEP on the moon.
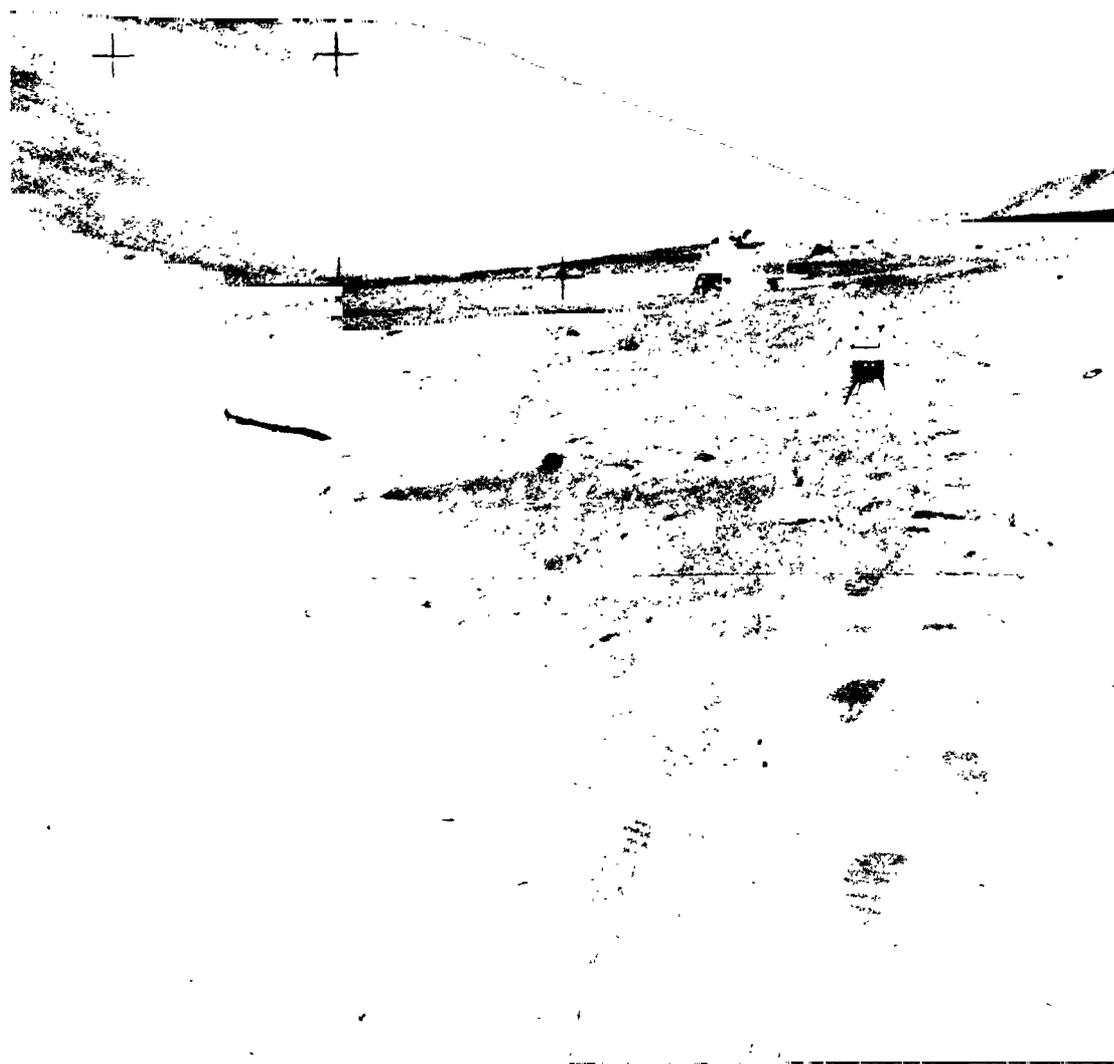
Figure 6-6. SEP transmitter with antenna deployed on the moon.

During the deployment, it was found that despite spade tips on the transmitter legs, the transmitter slid horizontally when the antenna wires were pulled. Also, the leveling of the transmitter required more grinding of the legs into the surface than was expected. A question was raised as to whether the legs were fully locked. The transmitter seemed unstable. Initially, the solar panels would not lie flat, but eventually flattened out. There was at least one spill of the transmitter antenna wire from the reel, requiring that the separable lanyard used in deploying the wire from that reel be opened to untangle the wire. None of these problems contributed to any equipment malfunction, although they were annoying. Transmitter deployment was completed within the allocated time.

Unexpected extremely dusty conditions at the landing site were aggravated by a broken right rear fender on the LRV, adjacent to the SEP receiver location. The receiver had been mounted on the LRV before the first EVA, but was left in the standby mode for the traverse. It was covered by dust thrown up by the right rear wheel, as were the astronauts, during the traverse. The SEP receiver heat radiators were covered by flaps during the first EVA, and the receiver temperature rose only 5 degrees, from $40^{\circ}F$ to $45^{\circ}F$, as expected.

At the end of the first EVA, when the crew opened the covering flaps and brushed the receiver radiator to clean it prior to cool-down, they experienced difficulty in brushing the dust from the OSRs on the receiver because of the heavy accumulation both on the receiver and on their helmets (impairing their vision). Preliminary evaluation was that the smeared dust could have been a basic cause of thermal control problems which later developed into an experiment hazard.

The expected cool-down from $45^{\circ}F$ to $28^{\circ}F$ with the radiator uncovered during the rest period between the first and second EVAs did not occur. Instead, the temperature rose to $80^{\circ}F$. Since the receiver had been designed with an upper thermostatic cut-off temperature of $115^{\circ}F$ to prevent degradation of the DSEA tape, most of the operating temperature margin was used up during the cool-down period. During the dusting operation, it was also discovered that one of the Velcro pads used to fasten the radiator cover flaps to the receiver thermal blanket had pulled loose. The cause has not yet been determined. The material used for the flap hold-down was NOMEX HI-AIR with Pre-Coat 1 in. hook #65 tape 0327 (100-066-017-0327AB) and NOMEX HI-AIR with Pre-Coat 1 in. pile - 2000 tape 0327 (100-003-017-0327AB). The adhesive was Adhesive Polyurethane FR-127A and B by Velcro.

In spite of the environmental problems encountered during the operation of the experiment, a valuable body of data was collected and returned to earth. At the beginning of the second EVA, the transmitter was turned on, and then the

92

receiver was operated on the west-bound traverse from the transmitter site to Station 2 at the base of South Massif. This operation yielded about 77 minutes of good clean data from the 7.7-km traverse. At Station 2, the receiver was turned off, and the flaps were opened to cool down from the $105^{\circ}F$ temperature as read on the receiver thermometer. On leaving Station 2, the thermometer read $98^{\circ}F$, but it was up to $104^{\circ}F$ on arrival at Station 3, 2.9 km away, indicating a dusty radiator inadequately covered. At Station 3, the temperature dropped to $100^{\circ}F$ but was up to $102^{\circ}F$ on arrival at Station 4. The receiver was turned on for the short runs from Station 4 to Station 5, and from Station 5 back to the LRV. About 25 minutes of recorded data resulted from this final series, apparently being cut off by the protective thermostat just short of Station 5. This data has numerous dropouts, probably caused by tape degradation at elevated temperatures. The receiver was in mode 2, and properly synchronized to a range of about 2.5 km and then switched to mode 1, about as expected.

EVA 3 started with a receiver temperature indication of $102^{\circ}F$, which rose to $110^{\circ}F$ when Station 6 was reached at the end of the 5.0-km run north from the transmitter site to North Massif. This led to the expectation of a good data recording on this run, but it developed that the receiver had not been turned on, so no data was recorded, and the temperature increase could be attributed to a dusty radiator surface inadequately covered. No further operation of the receiver was attempted on this final EVA and the astronauts gave up trying to clean the radiator. At Station 9, the temperature read $123^{\circ}F$, and the astronauts were directed to retrieve the DSEA. Station 10 was bypassed, and the transmitter was turned off at 23:19 CST.

SECTION 7

ITEMIZED DEVELOPMENT EVENTS

The purpose of this section of the report is to summarize the tasks per-
formed in accomplishing the delivery of each item of equipment. It is also in-
tended to record the contract changes which occurred as problems were uncovered
and the decisions made to solve them. These events had a profound effect on
delivery schedules as originally proposed, but ingenious work-around manipu-
lation of the hardware usage and cooperative management enabled the finished
experiment to be placed on the moon.

7.1 Deliverable Hardware

The hardware items to be delivered were:

Quantity	Item	Original Delivery Date
1	Interface mockup	8/1/71
1	Training mockup	9/1/71
1	Prototype	After all field testing
1	Flight unit	2/13/72
1	Flight unit	4/1/72
1	Qualification unit	2/1/72
1	GSE	With compatibility unit
1	GSE	With qualification unit
1	GSE	With first flight unit
1	Compatibility unit	12/1/71

Other hardware items which were constructed either as normal develop-
ment products or for special tests and experiments included:

(1) FEM for glacier tests

(2) Thermal structural mockup

(3) Transmitter articulation mockup

(4) DSEA recovery and interface mockup

(5) Spare receiver training mockup

The history of problems, uses, and events of note for each of the deliverable hardware items is summarized below:

(1)   Interface mockup. Design and fabrication was initiated in April 1971. During June, fabrication was placed on hold to permit incorporation of changes expected from information to be gained from the prototype design. Fabrication was completed in August, but some discrepancies with the ICD were present, for which waivers (002-006) were requested. The mockup was placed in a bonded warehouse in August to await waiver disposition. Waivers were accepted and delivery was made on 14 October 1971.

(2)   Training mockup. Production of this mockup had started in April 1971, but in July fabrication was deliberately slowed down to provide for the inclusion of changes suggested by the astronauts when the articulation mockup was exercised on 6 July. Suggestions by the flight crew included re-orientation of the transmitter leg release PIP pins, provision for the prevention of the possibility of picking up two transmitter antenna reels simultaneously, and the operational use of the solar panel to determine dipole orthogonality, rather than sighting on the legs. In August, a new design of the receiver antenna was proposed, and some weight-reduction proposals caused mechanical changes that had to be incorporated. The receiver case supplied by a vendor was found to be 1/8 in. too large, requiring a revision to the assembly procedures. The transmitter base required re-work, and the fabrication of both antennas was still a problem. The adhesive specified for fastening Velcro flaps to the thermal blankets did not bond satisfactorily, so the order for blankets was purposely delayed. The equipment was finally delivered, after acceptance on 21 October 1971, with four minor waivers, and shipped to JSC on 22 October. A suited test of transmitter deployment was held on 10 November, resulting in several suggestions for modification. The major update of the equipment was made in February and March 1972, including a new case electronics assembly, navigation data cable stowage bag, cabling, transmitter chassis and legs, load ring, LRV monitoring brackets, and a new antenna outer-mast assembly. After further updating in April and a flight crew exercise in June, the units were again refurbished to include a new receiver antenna with double lanyard and a complete new spare receiver training model.

(3)   Prototype unit. Design of this unit was started in April 1971. By
        June, all circuit boards had been fabricated, but transmitter oscil-
        lators and clocks were not available. In July, the structural design
        was changed to incorporate modifications issuing from tests with
        the articulation mockup and proposed weight reduction. It was pro-
        posed that this unit be modified so that it could be used for glacier
        testing, but since this would have been added scope to the contract,
        this work was held in abeyance. In August the change in design of
        the receiver antenna and the transmitter base introduced delay into
        the fabrication. Two printed circuit boards were redesigned. A
        critical problem developed in the fabrication of the receiver case,
        and Raytheon made the case themselves, using soft tooling. GSE #1
        was used for checkout and integration testing on the transmitter and
        receiver which had been fabricated by September. The transmitter
        was satisfactory, but the receiver and the GSE for the receiver both
        had problems. The experience with the prototype fabrication and
        assembly procedures resulted in several significant design improve-
        ments being incorporated into the released design. The transmitter
        antenna traps were encapsulated and temperature tested from $-200^{\circ}F$
        to $+200^{\circ}F$, showing a center frequency stability of 0.5% (satisfactory).
        The thermal blankets were kept on hold, searching for a solution to
        the Velcro adhesive peeling problem.

            The units had been assembled using commercial soldering tech-
        niques rather than the NASA standards. Acceptance testing of the
        prototype unit was interrupted to send the unit to KSC on 21 October
        to support Apollo 16 compatibility and EMI tests from 26 October to
        1 November. The unit was returned to Raytheon on 3 November and
        acceptance testing was resumed 10 November. In the interim the
        receiver antenna was improved and the Velcro bonding was changed.
        On 15 November acceptance testing was again halted in order to
        follow the re-design direction of CCA #1. Changes which resulted
        from the EMI tests (lowering the receiver antenna, adding a tem-
        perature indicator) were also incorporated. On completion, the
        prototype was used during July 1972 on the Alaska glacier trip, and
        acceptance of the unit by the government was changed to "as-is" con-
        figuration after all testing. Acceptance by MIT took place on 11
        January 1973.

(4)   Two flight units (S/N003, 004). Fabrication and assembly of these
        units proceeded slowly, without major problems, since the many

design changes were tried and tested in other units before incorporation. Sell-off of both transmitters occurred in late June 1972, and the receivers were delivered in early July 1972.

(5) Qualification unit (S/N002). All material had been ordered for this unit by September 1971, but fabrication of the transmitter was not completed until March 1972. The transmitter was delivered on 14 April 1972, after a complete CARR/QTRR. The transmitter then was subjected successfully to qualification testing at Raytheon's environmental facility (short of thermal-vacuum testing). It was shipped to JSC and used in Chamber D for thermal-vacuum testing starting 15 June 1972, and concluded 29 June 1972. The receiver delivery was delayed even more because of problems in procuring the case, and it was finally delivered on 13 September 1972.

(6) Three GSE units. Plans for the location and use of the GSE equipment were changed frequently as circumstances dictated, and the eventual logistics became:

(a) GSE unit #1. This unit was used in August and September 1971 for checkout and integration testing of the prototype unit. It was redesigned in September and kept at Sudbury for prototype acceptance tests. These tests disclosed deficiencies. In December, the unit was redesigned to handle requirements of CCA #1. In April 1972, the modification was completed, and the unit was sold in July for use at Waltham and later shipment to JSC in Houston.

(b) GSE unit #2. This was ready for operation in October 1971, and in November it was transferred to Waltham for checkout and integration testing of the compatibility unit and the flight unit acceptance tests. In May 1972, the modifications required by CCA #1 were completed and the unit was accepted on May 23. The unit was sent to KSC on July 5, 1972.

(c) GSE unit #3. This unit was in operational readiness by December 1971. CCA #1 modifications were not incorporated in this unit. Its acceptance test was completed in January 1972, acceptance was 9 February 1972, and on 6 March it was transferred to Waltham for use with the qualification model transmitter.

(7) Compatibility model (S/N001). Fabrication and assembly was initially delayed by the late release of the antenna designs. Crystal oscillators were also a gating item. Fabrication of this unit disclosed

the need for enhanced thermal bonding between the oscillator case and its mounting surface. CCA #1 imposed a requirement for special vibration testing, which was started in December 1971 on the completed transmitter. These tests were completed in February 1972. The transmitter was accepted 14 April 1972 (as is).

7.2 Contract Changes

The contract change authorizations (CCAs) by JSC are listed below:

Date Authorized	CCA Number	ECP Number	Subject
11/15/71	1	8	Launch vibration analysis
		11	Timing data format evaluation
		15	Navigation data evaluation
		26	Receiver/LRV, connecting cabling and packaging
		27	Additional vibration tests and repair of compatibility model
		43	Modify GSE for navigation data
		45	Navigation data re-work
3/1/72	2	3	Receiver, RF filter
3/13/72	3	–	Delete battery charger from GSE
3/13/72	4	5	LRV EMI tests, add 2 flight batteries
3/13/72	5	6	Spare FEM antenna
3/13/72	6	12	Support LRV EMI tests
2/22/72	7	17	Add DSEA switch
3/22/72	8	24	LRV mechanical interface redesign
4/18/72	9	35	Thermal analysis
6/8/72	10	33	Receiver temperature indicator
7/11/72	11	16	Check-out and refurbish FEM
		19	Modify transmitter antenna reels
		22	Spare transmitter, handles for training mockup
		34	Update training mockup
		36	Redesign transmitter antenna reel handles
8/25/72	12	–	Delete DSEA heater
9/1/72	13	20	Screening of 54L integrated circuits
9/1/72	14	28	Repair DSEA power supply
9/1/72	15	29	DSEA vibration tapes
9/1/72	16	4	Leach subcontract on DSEA
9/1/72	17	42	Parametric thermal analysis
		44	Expanded thermal analysis
10/27/72	18	46	Lanyard, Velcro, and tape
12/5/72	19	–	Cancel CCA #17

The following engineering change proposals (ECPs) were made, and work was performed according to the proposals made in most of them, but they were never formalized into CCAs. Instead, a package negotiation was conducted on 17 May 1973, and they were incorporated as part of the work performed. It is recognized that the procedure should not normally be followed, but the extremely short time available for the development of the SEP experiment forced the contractor and the major sub-contractors to work ahead on a calculated risk basis to prevent serious schedule delays. Some of the following were considered to be in-scope:

Date Proposed	ECP Number	Subject
2/22/72	7	est MIT EMI antenna
12/21/71	9	Test DSEA
11/18/71	10	Receiver thermal design
12/21/71	14	Transmitter thermal analysis, no legs
4/18/72	21	Acceptance vibration test, antenna deployed
3/23/72	25	Glacier antenna analysis (computer)
12/8/72	30	Design studies to modify receiver
8/7/72	32	Integrated system test
7/27/72	37	Raytheon portion of CCA #16
12/8/72	38	Hardware support to prototype tests
8/7/72	39	Pre-flight support program
8/11/72	41	Prepare supplemental manual
12/8/72	47	Additional thermal analysis
12/8/72	48	EVA technical standby

The following ECPs were withdrawn, cancelled, or dropped:

ECP Number	Subject
13	Outline drawings
18	Operating indicator
23	Translunar transmitter thermal analysis
31	Glacier test support
40	Prototype hardware

ECP #1 and #2 were modifications to the configuration plan which had no effect on the contract.

SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

Participants in the MIT SEP program were pleased to have their effort result in the use of the SEP hardware for lunar exploration. It is unfortunate that reduction in the Apollo effort and the cessation of manned lunar missions resulted in the equipment being used only on the terminal flight, thus denying the opportunity for future manned investigations to take advantage of the valuable experience gained. The scientific results of the analysis of the data collected by the Apollo 17 astronauts will be discussed in Part 2 of this Final Report, due from the principal investigator after the analysis is completed.

Preliminary quick-look analyses, and results of the development studies, indicate that the SEP technique permits sub-surface exploration to depths greater than those achievable by drilling, and with greater resolution than is possible with seismic techniques. This suggests that experiments similar to SEP are feasible and could be conducted with unmanned vehicles, not only for further lunar exploration, but for exploration of other planetary surfaces as well. Perhaps this could be accomplished by an international cooperative space effort. Another intriguing possibility is exploration of certain parts of the earth's surface with modified SEP equipment.

There are a few recommendations concerning hardware development that MIT offers for consideration should these follow-on experiments, or a resumption of manned lunar flights be undertaken.

(1) The environments in which the equipment must survive and operate need precise definition. With SEP, many anxiety-filled days occurred because of uncertainties with regard to vibration levels, dust conditions, and thermal environment. Specification of these parameters affects the test equipment design and test programs. The test environment should match the expected actual environment, and analysis of the matching of the simulated to the actual environment, should lead to confidence in the test results. In the testing of the SEP hardware, the disparity of test results from two different thermal chambers

(Arthur D. Little in Cambridge, Mass., and chamber D of JSC) required compromise and manipulation of calculations and assumptions, with resultant last-minute hardware modifications.

As a specific example of this uncertainty, consider some typical deliberations occurring during the qualification testing at chamber D. This series of tests was performed during the last two weeks of October and the first two weeks of November, 1972. On November 7, during the analysis of a test run, an effort was made to match the test results to calculated results. To achieve a reasonable match, the following changes in assumed characteristics were made:

(a)   The solar constant was increased from 443 BTU/ft^2 to 500 BTU/ft^2, to account for stray radiation in the tank.

(b)   The heat leakage of a new navigation data cable was assumed to be double that of the old cable because added insolation caused the cable to heat up.

(c)   The thermal conductance of the bag on the sun side and on the top, was assumed to be degraded by a factor of ten.

(d)   The IR input from the top of the tank and the mirror was added by assuming a total emittance of 0.03 (mirror) × 0.85 (OSRs).

(e)   The emittance of the walls was degraded from 1.0 to 0.9.

Since all of these assumptions had to be justified, the test program was extended and the confidence level was not as high as desired. This commentary is presented to demonstrate the need for a better understanding of the thermal characteristics of experimental test chambers, and the relationship to actual environment.

(2)   In a redesign, the use of OSRs should be discouraged for equipment that is used on a vehicle moving on the dusty lunar surface. The susceptibility to dust contamination, even when attended by astronauts, is too great. OSRs have been kept clean by astronauts, but the cleaning process exacts a cost in valuable EVA time. For SEP, OSRs were selected because they showed potential for reducing equipment weight - of paramount importance during initial design.

To generalize on past experience, the implication is that adequate simulation of the lunar surface environment in a test chamber is a difficult problem. It must be borne in mind that the

objective of these tests is to guarantee proper performance in the
ultimate environment. Proper performance has both a lower and
an upper temperature limit. Nothing in the nature of equipment
modification that is performed to adapt equipment to a test facility
environment should jeopardize operation at the other limit.

OSR cooling systems have been demonstrated to work well
in a variety of space applications, but their effectiveness is reduced
by dust accumulation.

Most of the sun's energy is concentrated in the visible por-
tion of the spectrum, which the OSR second surface mirrors reflect
effectively. The emissivity of these mirrors is high in the infrared,
hence also is their absorptivity. The very feature that allows OSRs
to dump heat effectively makes them susceptible to the absorption
of heat through stray infrared energy that may occur in test chambers
to a greater degree than on the moon.

All things considered, phase-transition thermal control would
have been preferable for the SEP receiver. This preference is docu-
mented in an unpublished CSDL memo from J.H. Martin to Dr. J.W.
Meyer, dated 5 May 1971, and the arguments presented therein should
be reviewed in any redesign.

If, in spite of the above overall considerations, OSR control
is indicated, packaging and thermal blankets must be designed in
such a way as to prevent the possibility of dust entrapment.

(3)   It should be emphasized that the design should be such that proper
        functioning of the equipment preferably does not require astronaut
        intervention.

(4)   A contingency sunshade over the apparatus, either manually or auto-
        matically deployed, would have been useful.

(5)   The inclusion of a STANDBY position on the on-off switch requires
        careful consideration. A loss of experiment data was experienced
        during an Apollo 17 EVA because of the inclusion of this switch
        position, and the overall operation might have been more satisfactory
        is there had been only ON and OFF positions.

        There was much discussion of the need for an operational
        indicator. Several design approaches were evolved. Indicator
        reliability, cost, and schedule affected a decision to omit an indicator.
        This subject should be reviewed in light of the above experience, when
        designing future hardware.

(6)   In a redesign, the possibility of a specially designed tape recorder
        should be considered. Initially, the SEP concept was to have each
        experiment on the LRV be an independent entity. As the designs
        progressed, such items as the inclusion of navigation data on the
        SEP tapes provided interconnections between some of the systems.
        Thus, the concept of a radio relay to earth of the SEP-type data,
        permitting real-time evaluation of the operation, should be explored,
        since this would involve the interaction of only two of the probable
        systems. For space use, if direct radio-relay to earth were not
        used, a lighter, temperature insensitive recorder might be designed.
        Originally, the DSEA was adapted to the SEP requirements because
        of budgetary constraints. The binder for the oxide coating of avail-
        able tape proved to be a contributing factor to the equipment temp-
        erature limitations. Other designs could be developed, and other
        data formats formulated to work around this problem. In earth
        explorations, less expensive and more reliable models of tape re-
        corders could be substituted.

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APPENDIX

A BRIEF INTRODUCTION

TO THE

SURFACE ELECTRICAL PROPERTIES EXPERIMENT

by

Gene Simmons
James W. Meyer
Richard H. Baker
David W. Strangway

111

APOLLO XVII

LUNAR SURFACE ELECTRICAL PROPERTIES EXPERIMENT

Conceived and Developed at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

with support from the

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HARDWARE SUBCONTRACTOR

Raytheon Company, Equipment Division

INTRODUCTION

One of the experiments to be done on the Moon by the Apollo 17 astronauts uses radio waves to "see" down into the Moon, possibly as far as a few kilometers.* We will look for layering in the Moon's rocks and soils. We will look for large boulders that are completely buried and so hidden entirely from the astronauts' eyes and also from telescopes. We will even look for water although we do not really expect to find any subsurface water. And finally, we will measure the electrical properties of the Moon. We expect to study a large portion of the landing site. Our experiment will be carried on each traverse made during the second and third EVAs (Extra Vehicular Activity).

The SEP experiment is extremely important for many reasons. First, the values of the electrical properties of the Moon's outer few kilometers of rock and soil measured in situ for the first time may help interpret observations already made with both earth-based radar and with bistatic radar. (For an elementary discussion of bistatic radar and some preliminary results see On the Moon with Apollo 16—Guidebook to the Descartes Region, EP 95, available from Government Printing Office, Washington, D.C., $1.00.) Secondly, SEP will provide data that are needed to interpret the observations to be made with an Apollo 17 orbital experiment, the Lunar Sounder. In that experiment, the times required for radio waves to penetrate the Moon, be reflected, and return to the surface of the Moon are measured. Yet rather than times, Lunar scientists are really interested in depths which are obtained by the simple procedure of multiplying the travel times by the speed. And SEP measures the speed with which radio waves travel in the Moon. Thirdly, SEP will provide background data that will be useful for many years. Undoubtedly, the major exploration of the other planets as well as the continued exploration of the Moon will be done remotely using radio waves. Thus the experience, as well as the data, gained with SEP on the Moon, will be invaluable in the future study of planets. Fourthly, we expect to learn much about the Apollo 17 landing site. Visual observations made both by the astronauts and with cameras are restricted to the very surface of the Moon. Yet SEP can "see" to depths of a few kilometers. Thus, SEP will extend to depth those visual observations made at the surface. But even more importantly, SEP can see features at depths that do not reach the surface.

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*A kilometer is about 0.6 miles. A meter is 39 inches, slightly more than 1 yard.

THE TECHNIQUE

The basic principle of SEP, interferometry, is a familiar one in science, engineering, and technology. It involves only the interference of two or more waves to produce a "synthetic wave". For example, the pattern produced by the two sets of waves on the surface of water when two pebbles are dropped into a pond at the same time, but separated by a few feet, is an interference pattern (see Fig. 1). So is the pattern produced in a bathtub by the combination of (1) original waves caused by dropping a small object into the water and (2) reflected waves from one side of the bathtub. A third example from everyday life of interference phenomena is the beautiful colors associated with a thin film of oil floating on water. Light waves interfere, in this example, to produce the various colors.

In SEP, the waves are radio waves, similar to those used in commercial radio broadcasting and in television. We use a radio transmitter and antenna to launch a radio wave on the Moon's surface. See Fig. 2 for a view of the transmitter, Fig. 3 for one of the receiver, and Fig. 4 for the arrangement to be used on the Moon. Part of the energy in the wave travels <u>in</u> the Moon, just below the surface. Part travels just <u>above</u> the Moon's surface with the speed of light. The part that travels beneath the surface is slower. Therefore, near the surface of the Moon these two waves interfere to produce a wave that is sometimes called "beat frequency wave" or a "synthetic wave". By detecting and measuring the properties of this interference wave, we can determine two things about the Moon: (1) the speed of radio waves in the subsurface and (2) the ease of propagation of radio waves in the Moon. This second property is termed attenuation and it is determined by measuring the strength of the interference wave at several distances from the transmitter. (Actually, these measurements are made continuously and automatically as the Lunar Rover moves along.)

In addition to the two waves that we have discussed, another wave may also be present. Energy is radiated by the transmitting antenna downward into the Moon. If layers exist in the subsurface, then part of this energy is reflected back towards the surface (path 3 in Fig. 4) where it then interferes with the other two waves. This additional interference makes the analysis of the data more complicated but it also adds considerable information about the Moon's interior. This additional complexity is small when compared with the gain in information.

Fig. 1 *This is the pattern of two interfering waves as shown by a ripple tank. It is possible to simulate an idealized model of the SEP experiment showing different velocity waves above and below the interface and their interference at the interface. Even a reflecting layer can be included.*

THE EQUIPMENT

The principles on which the experiment is based are simple. So are
the equipment concepts. Indeed the equipment is no more
complicated than a good quality, hi-fi FM home receiver. At the same
time, do not let us mislead you. Considerable design effort, exacting
controls in manufacturing, and extensive testing combine to make
this equipment extremely reliable. The environment of the Moon is
hostile not only to human life but also to equipment.

On the Moon, the astronauts will set out a small, low power trans-
mitter, shown in Fig. 2, and then they lay on the surface two crossed
dipole antennas. Readers who are unfamiliar with dipoles can easily
visualize them by realizing that the familiar TV rabbit ears, with both
arms extended along the same line, is really just a dipole. The SEP
dipoles are longer; they are 70 meters tip-to-tip.

The receiver and receiving antennas, shown in Fig. 3, are also
unpacked from the pallet on which they will be carried to the Moon.
The astronauts mount both on the Lunar Roving Vehicle (LRV).
An artist's sketch of all the equipment set out on the Moon and
ready to operate is shown in Fig. 5.

Inside the receiver, there is a tape recorder that is similar to the
familiar home portable cassette tape recorder. The data are recorded
on magnetic tape. The entire tape recorder, which incidentally carries
the awesome official designation of "Data Storage Electronics
Assembly" (DSEA), will be returned to Earth so that the data can be
analyzed. In addition to our SEP data, information on the location
and speed of the Rover, obtained from the Rover's navigation system,
are also recorded on the tape.

In addition to the preceding general description of the equipment,
some readers may desire a technical description. Those readers not
interested in the technical description should omit the rest of this
section and flip ahead to Data Interpretation.

EQUIPMENT DESCRIPTION

The six SEP frequencies are transmitted and received according to
the scheme shown in Fig. 6. One frame, which is 38.6 seconds in
duration, consists of six 6.4 second subframes that are identical
except for the receiver calibration and synchronization process. In
Subframe 1, for example, the receiver is calibrated at 32.1 MHz and
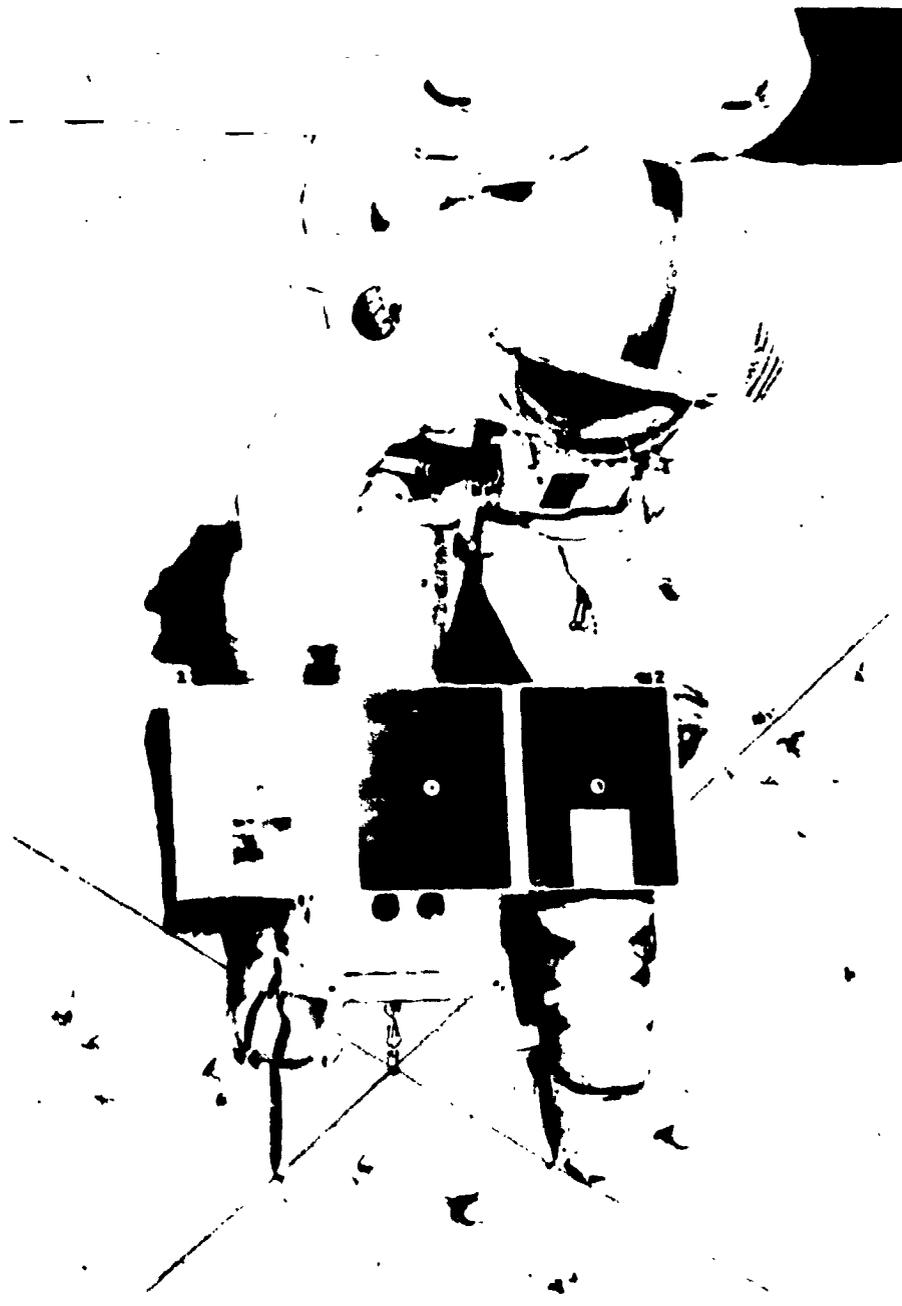
Fig. 2 *Astronaut Cernan, who will set up this part of SEP on the Moon, practiced many times on Earth. Shown here is the compact SEP transmitter with its solar panel power source and dipole antennas deployed. The transmitter electronics package is covered on the bottom five sides with a thermal blanket. Because the top of the unit is shaded by the solar panel, the uncovered surface needs only a coat of thermal paint to provide adequate cooling for the enclosed electronics. The balance between heat lost to cold space by radiation and that generated inside the unit by the electronics equipment is very delicate and requires careful thermal design.*

16 MHz and the synchronization signal is transmitted on the N-S dipole and received on the X antenna. In Subframe 2 the receiver is calibrated at 8.1 MHz and 4 MHz while the synchronization signal is transmitted on the E-W antenna and received on the Y antenna. Each experiment frequency sequence is repeated exactly as shown in all six subframes. Each individual experiment frequency is transmitted first on the N-S antenna for 100 milliseconds and then on the E-W antenna for 100 milliseconds. During each 100-millisecond transmission interval, the receiver "looks" at the transmitted signal for a period of 33 milliseconds with each of the three orthogonal (X,Y,Z) receiving loops. In addition to the above, once each subframe the receiver observes environmental noise and records its amplitude.

The receiver acquires the transmitter signal sequence automatically as long as the signal exceeds a given threshold. Synchronization of the receiver is accomplished when both (or either) the 1 and 2.1 MHz signals exceed a given threshold. A block diagram of the SEP receiver is shown in Fig. 7.

The loop antennas are connected sequentially to a low noise amplifier section which amplifies, converts (in frequency) and logarithmically compresses the amplitude of the received signal. A constant amplitude, variable frequency signal (in the band 300 to 3000 Hz) corresponding to the logarithm of the received signal amplitude is recorded on magnetic tape in the DSEA. The DSEA can record nearly 10 hours of data. Upon completion of the experiment, the astronaut removes the DSEA from the receiver, as indicated in Fig. 8, for return to earth.

Signal synchronization, frequency mixing, and antenna switching, etc., are all controlled by the timing section which is in turn crystal controlled for stability. The entire receiver assembly is battery powered using primary cells (cells that cannot be recharged) and is enclosed, except for the antenna assembly, in a thermal blanket (roughly corresponding to a thermos bottle) which has two flaps that may be opened to expose OSRs (Optical Solar Reflectors) which form a thermal radiator for internally produced heat, while reflecting that from the sun to control the internal temperature of the receiver.

The SEP transmitter, shown in Fig. 3 and in block diagram form in Fig. 9, is powered by solar cell panels which are designed to provide a minimum of 10.0 watts output at +15 volts, and 1.10 watts at +5 volts. Each panel is constructed with an aluminum honeycomb substrate utilizing Heliotek bar contact 2 x 2 cm, blue sensitive, N on

P type solar cells. Individual cells are insulated from the aluminum substrate with a Micaply sheet that is covered with a six-mil, micro-sheet cover. The +15 volt source consists of a 6 x 52 cell matrix, and the +5 volt source consists of a 3 x 17 cell matrix. The cells are interconnected utilizing the Spectrolab "SOLAFLEX" interconnect system, which uses silver-plated copper 0.002 inches thick. The cell matrices are connected to the power output cable using 24 guage, teflon coated stranded copper wire which is bonded to the panel. The power output cable is connected to the Amplifier Module through a Deutsch 7-pin, socket-type connector. Both the +15 volt and +5 volt power sources are shunt regulated by means of a regulator circuit mounted on the back of the right-hand solar panel. The regulator circuit is protected from solar radiation by an OSR in the lower center of the front of the panel. The left-hand panel contains a cutout to permit the closing of the panel over the regulator circuit in the stowed configuration. Like the receiver, the transmitter timing sequence is crystal controlled for stability. Also, separate stable crystal oscillators generate the signals which are radiated by the dipole antennas placed on the lunar surface. Because the antennas are required to radiate energy at six different frequencies they are constructed in sections (Fig. 10) where each section is electrically separated by electrical filters (signal traps). Each section of the antenna is of the proper electrical length for optimum performance. Each dipole, 70 meters long (tip-to-tip), is made of insulated wire between traps which are stored on reels until deployed by the astronaut.

DATA INTERPRETATION

The SEP experiment is entirely new. The reader may think, "If the experiment is so great for studying the Moon, why has it not been used to study the Earth?" The answer is simple. The Moon is an excellent electrical insulator but the Earth's rocks near the surface are fairly good conductors. Therefore, the radio waves that travel to depths of a few kilometers in the Moon would travel in the Earth only to a few meters. Because the depth of penetration is so limited on the Earth, no use had been made previously of the SEP technique and the method remained undeveloped. Fortunately data interpretation requires only three things: (1) good geophysical insight, (2) understanding of the physics of electromagnetic waves and especially of interferometry, and (3) experience in known test situations. The geophysical insight is provided for the SEP experiment by several members of the SEP team who have interpreted other geophysical data for many years. The background in physics and interferometry

is gained from the formal training of several team members in physics and electrical engineering. And finally, the experience is being gained rapidly by applying the SEP technique to the study of several terrestrial glaciers. Perhaps glaciers seem to be peculiar places to test a lunar experiment. We chose them because ice is an insulator and hence radio waves travel in glaciers much as they travel in the Moon.

Although the principles of interferometry are well known, the application of them to our particular experiment had not been made explicitly. So we have developed our own analysis techniques. In this section, we describe only the simplest schemes. The reader interested in advanced techniques should consult the original articles listed in the bibliography.

In an idealized case in which the interferometer is used on a surface separating two semi-infinite media, an interference is produced by the two waves travelling just above and just below the interface (paths 1 and 2 in Fig. 4) because the velocities of the two waves differ. If the two media are (1) a vacuum and (2) a loss-free dielectric material, the wavelength, λ_i, of the interference pattern is given:

$$\lambda_i = \frac{\lambda_o}{n_1 - 1}$$

where λ_o is the wavelength in vacuum, and n_1 is the index of refraction (see the top curve of Fig. 11). For low loss media, the index of refraction is equal to the square root of the dielectric constant, a parameter commonly used to describe the electrical properties of materials. Typical values of the dielectric constant for several materials are the following:

Water	81
Glacial Ice	3.4
Dry Granite	3 to 4
Porcelain	6 to 8
Plexiglass	2.5
Diamond	5.5
Lunar Rocks	3 to 10
Pyrex Glass	4 to 5

So from the observed interference pattern we determine the value of the dielectric constant of the surface material to depths of about one wavelength for each of the SEP frequencies. And from the dielectric constant, we obtain the velocity of radio waves.

We have mentioned a second electrical property, the attenuation or relative loss. Its value can also be estimated from the observed interference curve. We merely compare the decrease of strength at various distances with the decrease known to occur in a loss-free medium. Free space is the "standard" normally used. The excess loss which is always present (except in free space) is due to the medium itself. The losses, which may be dependent on frequency, are measured in this way at all six SEP frequencies.

If the lunar surface is layered, and these layers have significantly different electrical properties, then the incident radio waves will be reflected as in path 3, Fig. 4. As a result there is superimposed on the first interference pattern another one created by the difference in path length between the direct and reflected wave. Maxima will occur for $n\lambda_m = 2d \sin \theta$ where n is an integer 1, 2, . . . , and d is the depth of the reflecting layer. θ is the angle of incidence, and λ_m is the wavelength in the medium. (Strictly speaking, the interference pattern results from the addition of all waves, but the analysis is simpler, and also correct, when the several interference patterns are considered separately.) Incidentally this expression $n\lambda_m = 2d \sin \theta$ has much broader application. It was first obtained by Sir William Bragg and forms the basis for the interpretation of X-ray diffraction data.

The distance from the transmitter at which the nth maximum can be expected, if there is adequate signal from both the direct and reflected waves, is given by:

$$R(n) = 2d \left[(2d/n\lambda_m)^2 - 1 \right]^{1/2}$$

Roughly speaking, the number of maxima that can be seen as a result of the presence of a reflecting layer at depth d is

1 for $d > \lambda_m/2$
2 for $d > \lambda_m$
3 for $d > 3\lambda_m/2$

and so on.

The actual interference patterns depend upon several things—whether the receiver is within two wavelengths of the transmitter, losses in the media (technically, loss tangent), the "reflection strength" of the second interface (technically, reflection coefficient), and so on. These interrelationships are indeed complex. In Fig. 11, we show a family
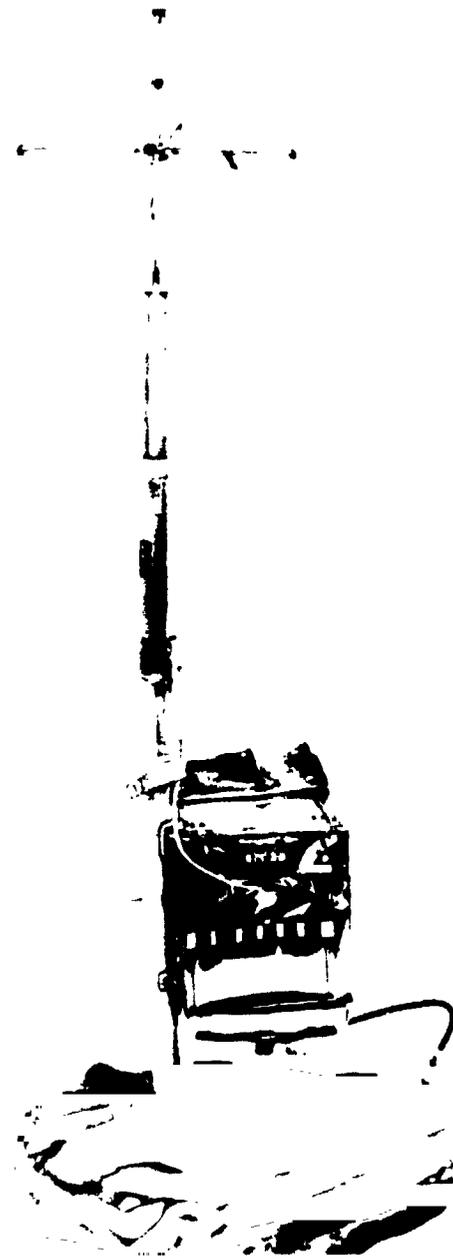
Fig. 3 The SEP receiver electronics including tape recorder and battery are contained in a
nine inch box which is completely enclosed in a thermal blanket. Optical solar reflectors,
which act as one-way mirrors to release internally generated heat into space and simul-
taneously reflect sunlight, are shown here with the thermal blanket opened. The three-loop
antenna, folded during the journey to the Moon, is shown unfolded as it will be used on the
Moon. The astronaut at the end of the experiment removes the tape recorder from the box
and brings it back to Earth.

122

of curves for a model that may be applicable to the Moon. One purpose in showing the illustration is to indicate the additional interferences caused by a reflector. The second purpose is to illustrate the great effect of water. Compare the rest of the family of curves with the thicker top curve. Because the dielectric constant of water is 81 and dry rock is 3–4, small amounts of water have large effects on the interference pattern and can be readily detected.

The transmitting antenna lying directly on the interface between vacuum and the Moon will cause the radiation from the antenna to be concentrated in certain specific directions with profound effects on the interference pattern. In Fig. 12, we show a sketch of the radiation pattern (the distribution in space of the radiated energy) of a dipole antenna on the interface between free space and a medium that approximates the Moon. One of the principal directions of such concentration of energy is approximately along the line of the critical angle for total reflection at the interface. If a reflecting surface exists below the interface, this lobe will be "bounced back" to the surface where a maximum field strength will be observed even in the absence of surface waves sufficiently strong to produce the interference pattern already described above.

Still another phenomenon, scattering, can affect significantly portions of the interference pattern. If there exist in the Moon objects with properties that differ significantly from those of their surroundings and their sizes are comparable to a wavelength, these objects scatter the incident radio waves. Some of the energy in the scattered waves will arrive at the surface of the Moon and interfere with the other waves that we have already discussed. Such scattering bodies in the Moon might be large boulders (10 to 300 meters in size), concentrations of certain minerals, or even voids. At wavelengths large or small compared with the object's dimensions, the nature of the scattering is different. The comparison of interference patterns at different wavelengths will not only indicate the presence of such scatterers, but also will allow us to estimate their size and number.

Let us summarize here this discussion of data interpretation. From the observed interference patterns, we can (1) measure the electrical properties to a depth of a few wavelengths, (2) determine the depth to reflecting interfaces, and (3) detect the presence and determine the characteristics of scattering bodies. Finally, we may even detect the presence of water.
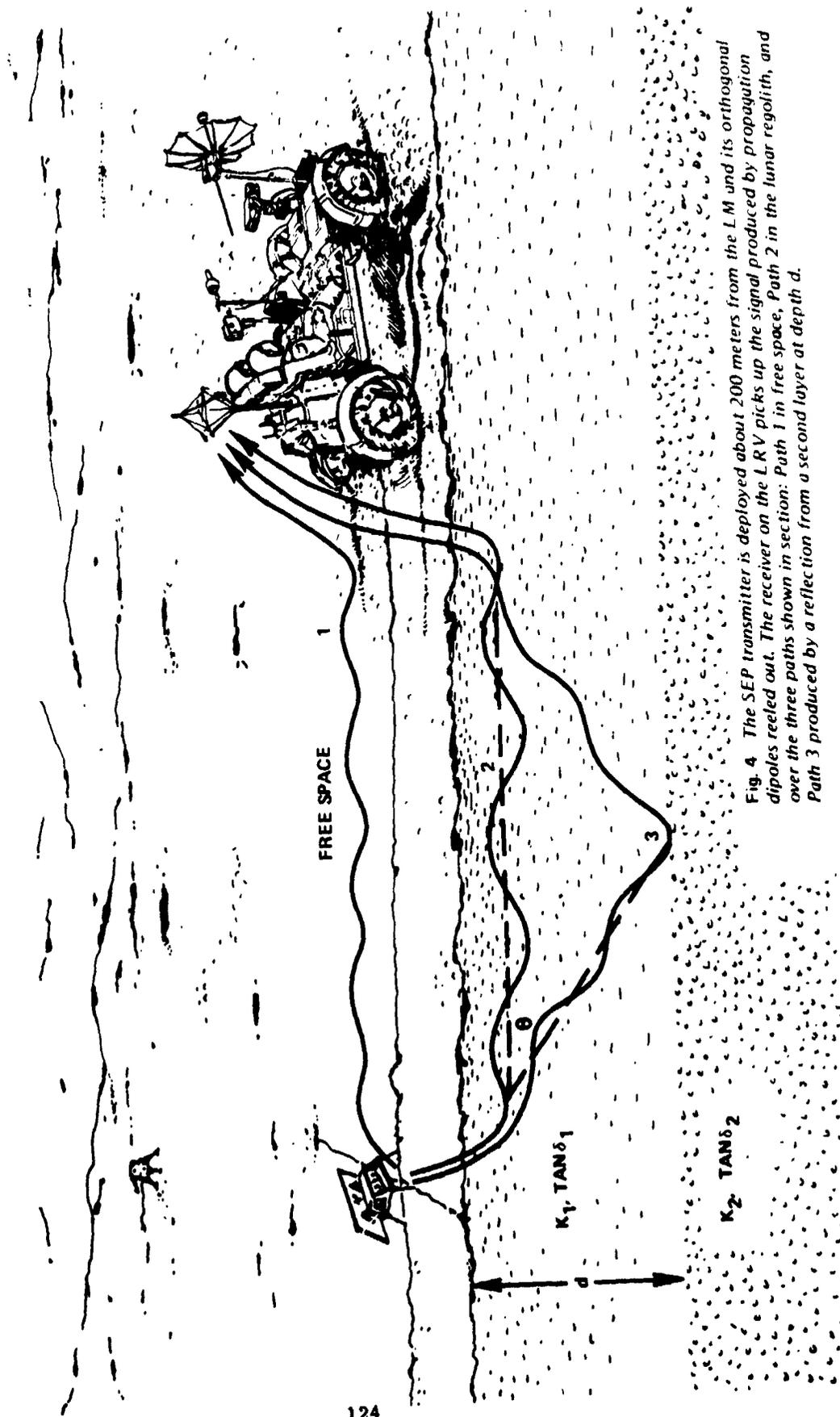
Fig. 4 The SEP transmitter is deployed about 200 meters from the LM and its orthogonal dipoles reeled out. The receiver on the LRV picks up the signal produced by propagation over the three paths shown in section: Path 1 in free space, Path 2 in the lunar regolith, and Path 3 produced by a reflection from a second layer at depth d.

GLACIER TESTS

If the SEP technique has not been used on Earth, how can we be sure that it will work on the Moon? Why do we think the methods of data interpretation will give us valid results? These questions and many related ones concerned us greatly in the early stages of designing and building SEP. So we searched for terrestrial analogues on which to test our experiment. All rocks at the surface of the Earth are too conductive and hence the losses are too great for radio waves to travel sufficiently far to provide a suitable test. Laboratory models which have been scaled down in size by factors like 1000 could be studied. Such models have been very useful for certain studies but could not be used to test full scale equipment or experiment concepts. Only two geological environments appeared to be suitable— glaciers and large salt deposits (either the layered tabular bodies, such as occur in the subsurface below Kansas and New York, or the cylindrical bodies, such as occur in Texas and Louisiana). The salt deposits have slightly better values of electrical properties than the glaciers but the geometry of the mines in them is undesirable. Glaciers, on the other hand, have acceptable electrical properties (the losses are slightly higher than we expect for the Moon) but the geometries are ideal.

So we selected several glaciers which had already been studied extensively with other techniques. Various versions of our SEP equipment have now been used for study of the Gorner glacier in Switzerland (in 1968), the Athabasca glacier in Alberta, Canada (in 1970 and 1971), and several glaciers that drain the Juneau, Alaska ice fields (in 1972).

On the Gorner glacier, we used very simple and inexpensive equipment; home-made antennas, a ham operator's receiver, and a laboratory signal generator for the transmitter. We recorded data by hand. We moved equipment literally on our own backs. Daily progress on the glacier was very slow. None of the equipment was automatic. But we proved unequivocally that the experiment concept was valid and we could then proceed with our experiment.

By the second season on the Athabasca glacier, we had built equipment that embodied many of the features that would be used in the actual flight equipment. The electrical aspects of the two sets of equipment were almost identical. Both used the same six frequencies. Both had crossed dipoles for transmitting antennas. Both used loop receiving antennas. And both had similar receivers. We did have an

RECEIVER ANTENNA—

RECEIVER

TAPE RECORDER

SEP XMTR, DEPLOYED CONFIGURATION

SOLAR PANEL

THERMAL RADIATOR

THERMAL INSULATION

POWER SWITCH

ANTENNA ASSY
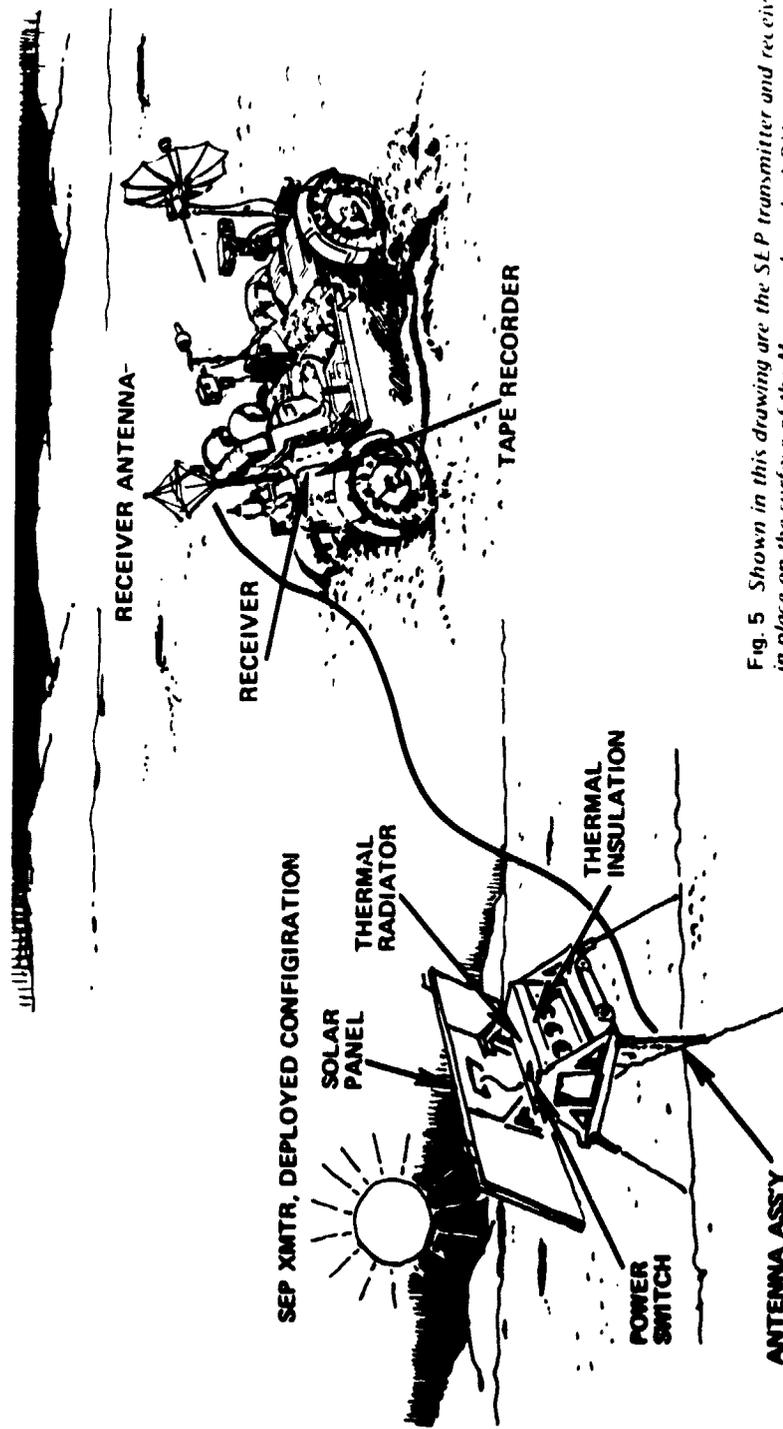
Fig. 5 Shown in this drawing are the SEP transmitter and receiver in place on the surface of the Moon and on the LRV respectively. Many other items (such as experiments and lunar sampling tools) will be mounted on the rear of the Rover during the lunar excursions but are omitted here for simplicity.
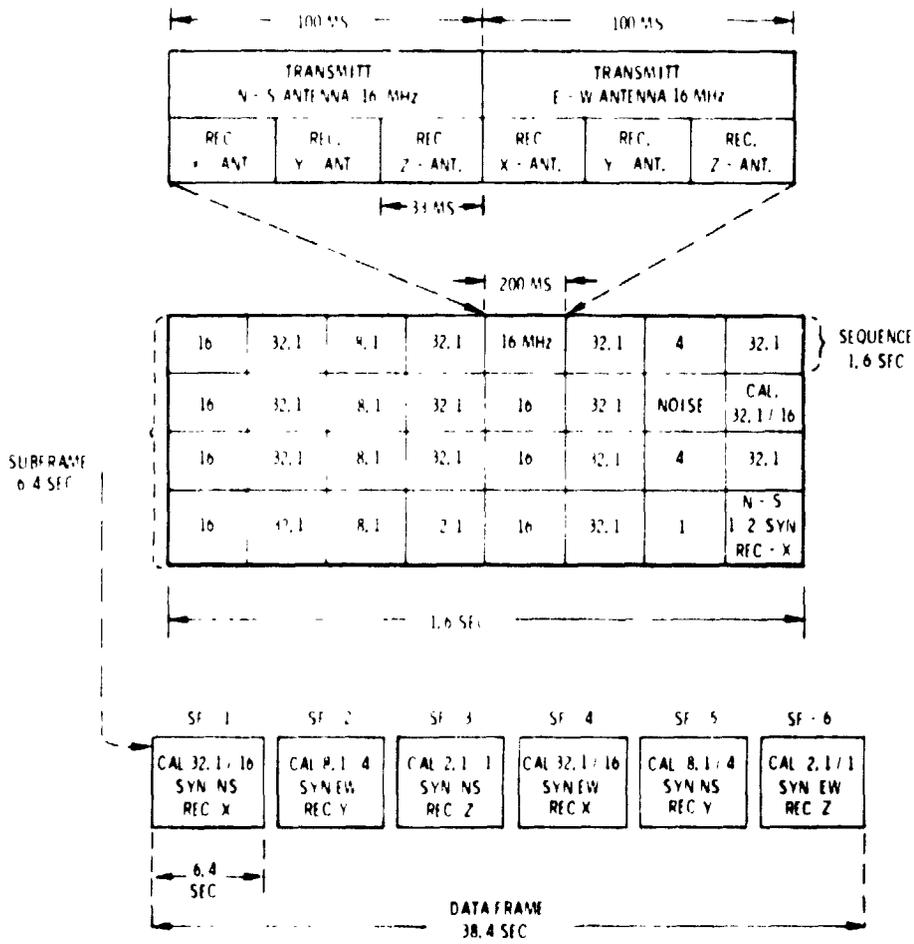
Fig. 6 SEP Data Format
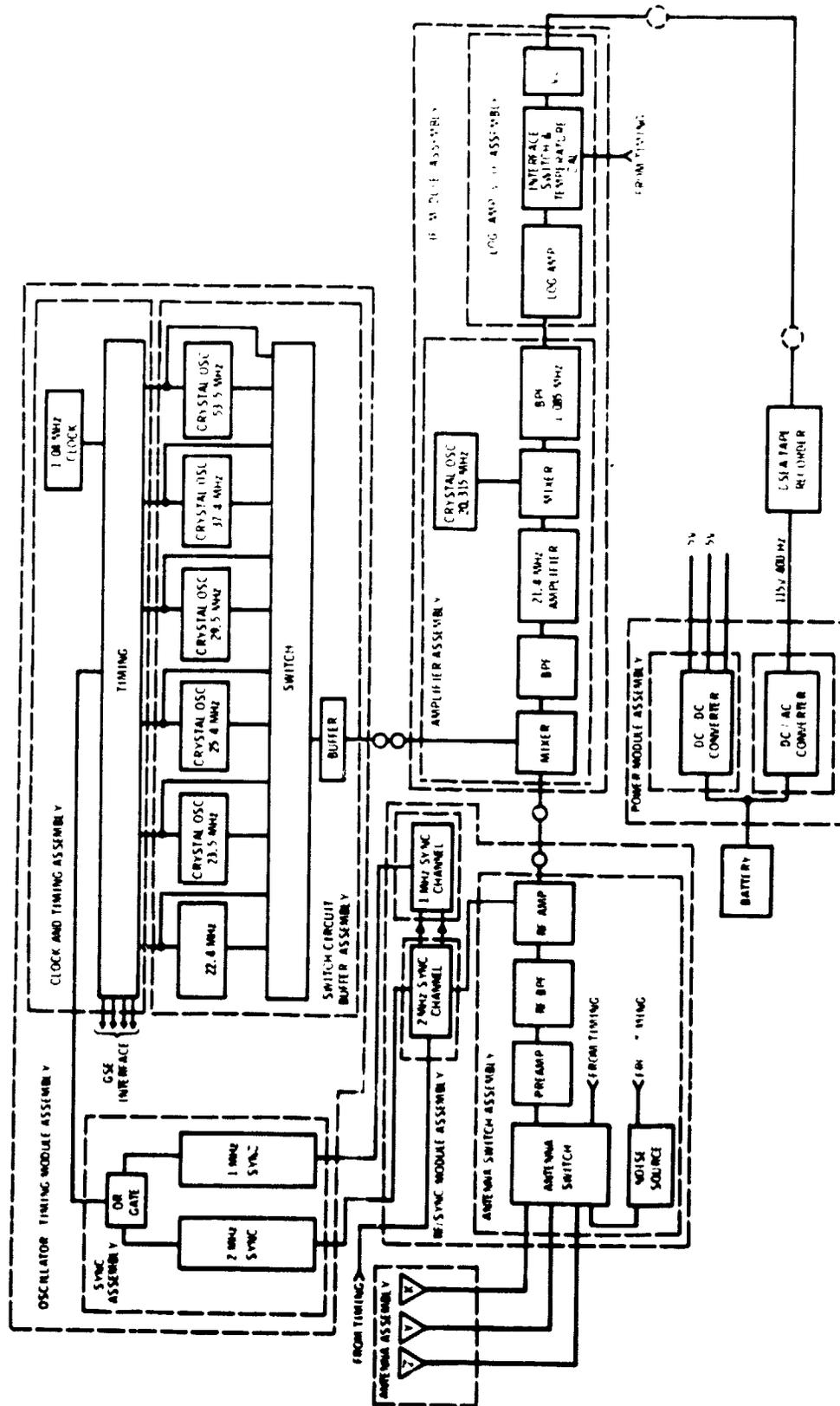
Fig. 7 Block Diagram of SEP Receiver

Fig. 8   This photograph illustrates how the astronaut will remove the DSEA tape recorder from the receiver at the end of the last EVA for return to Earth.
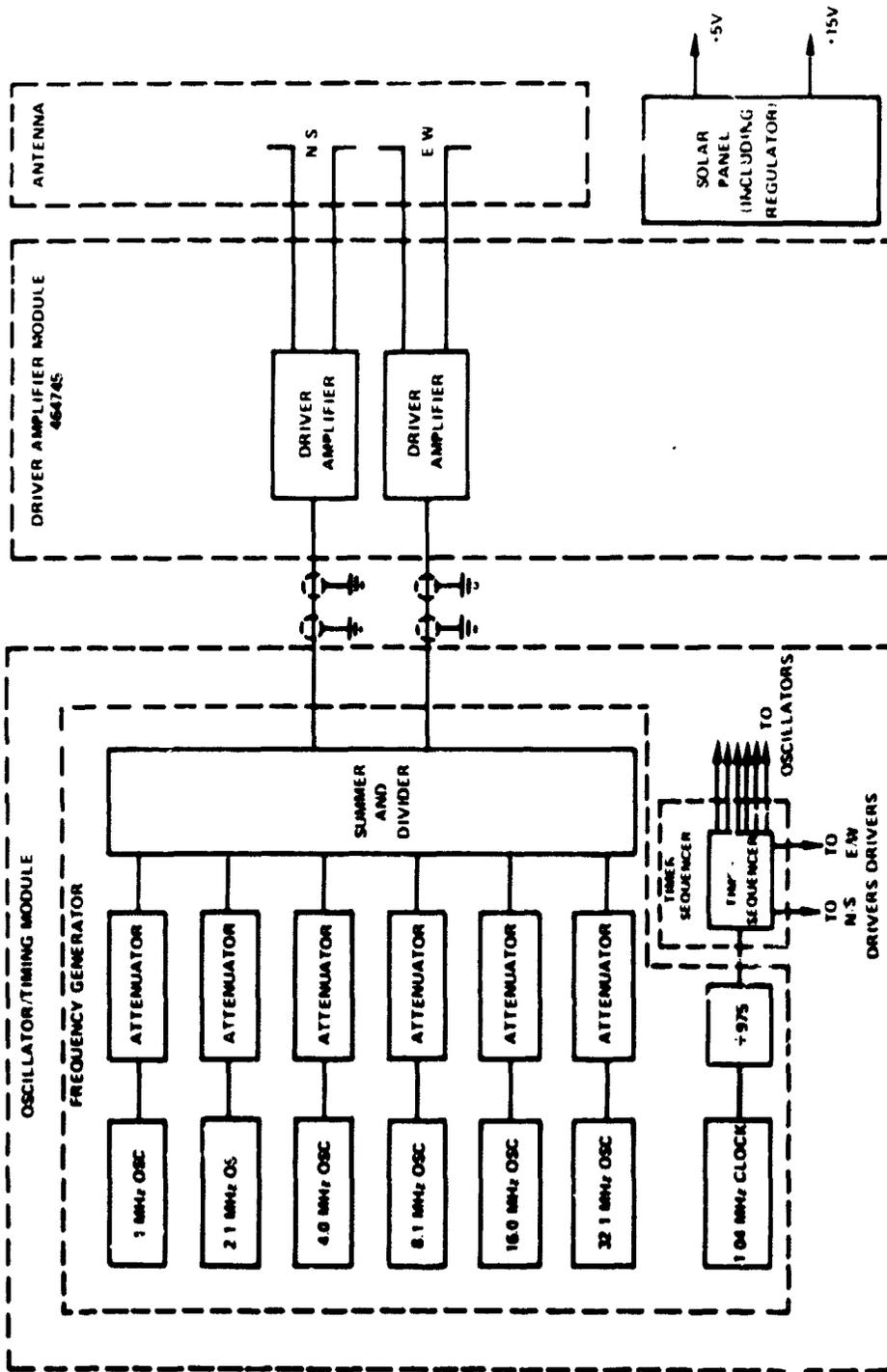
Fig. 3 Block Diagram of SEP Transmitter
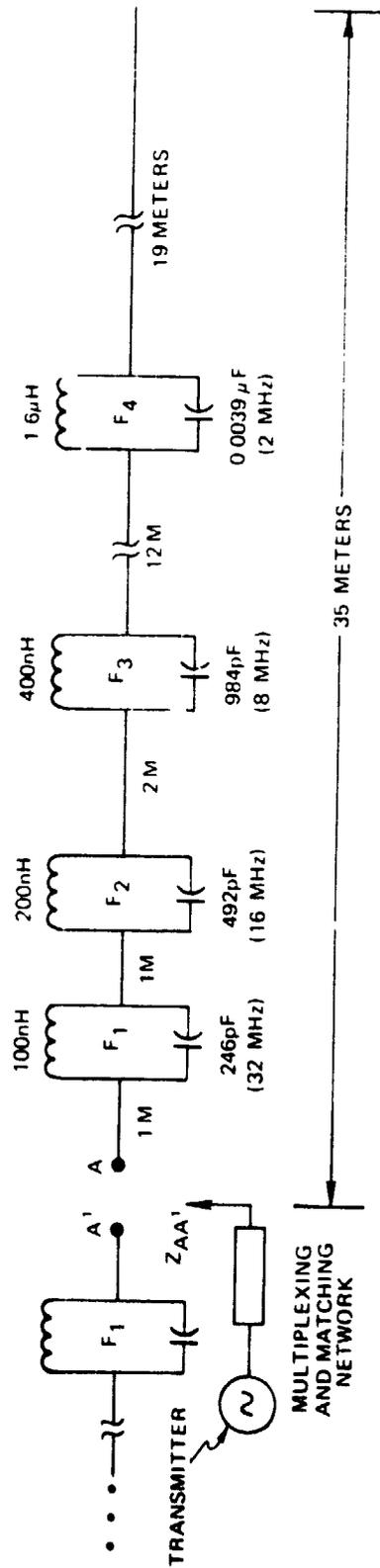
Fig. 10 *This is an electrical schematic of the SEP transmitting antenna. Only one-half is shown because the antenna is symmetric about the mid-point. Total length (tip-to-tip) of the physical length of the antenna for each frequency used in SEP is 2, 4, 8, 32, and 70 meters.*
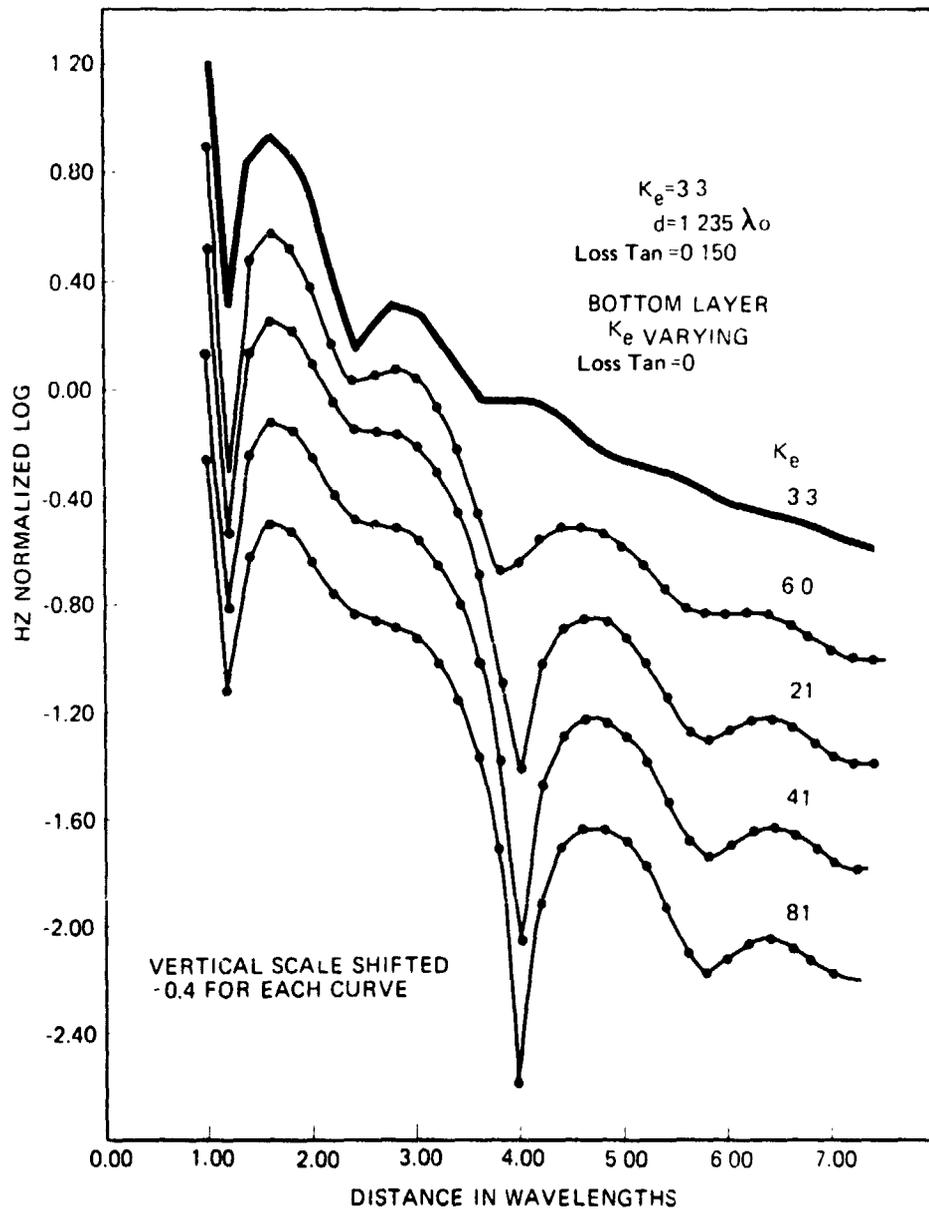
Fig. 11 *These are the curves showing the theoretical vertical component of the magnetic field strength of the electromagnetic wave, normalized and plotted on a logarithmic scale versus distance in free space wavelengths between the transmitter and receiver. The top curve of this set represents what is expected for an infinite half space because there is no change in dielectric constant at the bottom layer. The interference pattern is that produced between parts of the wave traveling immediately above and below the interface. As the dielectric constant of the bottom layer is increased, reflections from the bottom layer have a more pronounced effect on the interference, becoming greatest for the dielectric constant of water (81). (After Kong and Tsang, private communication)*

FREE SPACE

K_e 1

LUNAR   SURFACE

ENDFIRE
PATTERN

K_e - 3 2

BROADSIDE
PATTERN

CRITICAL
ANGLE
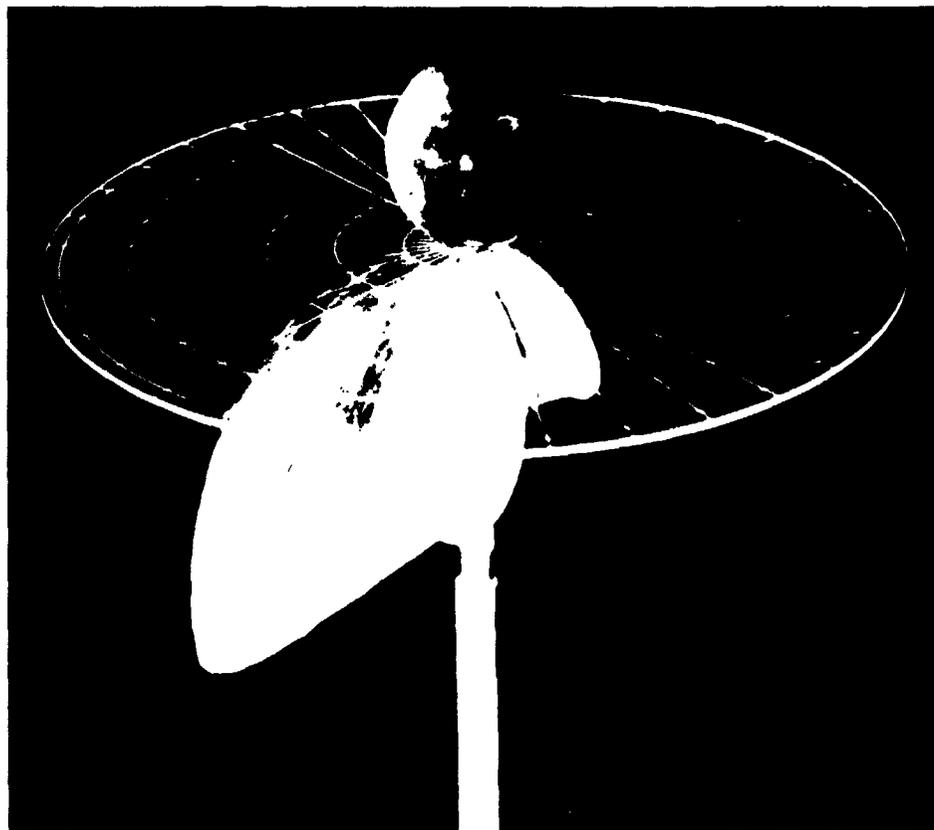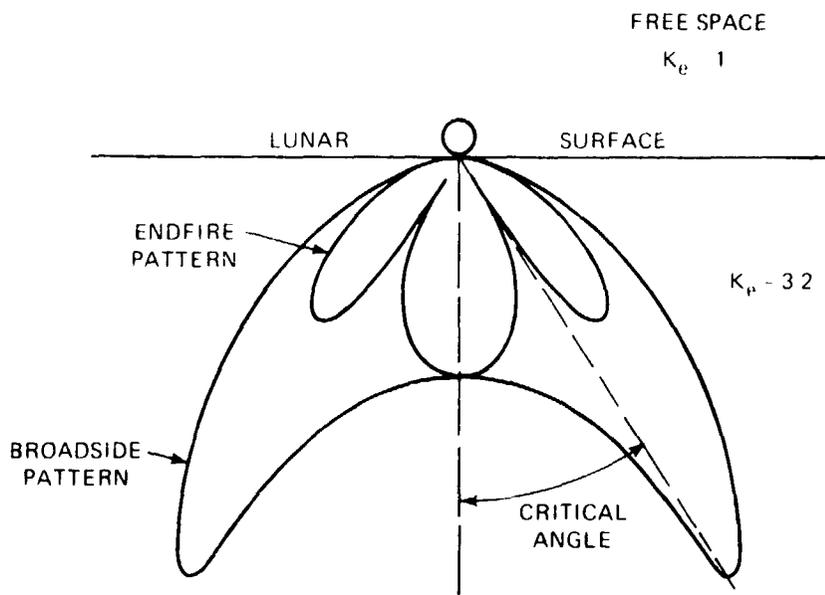
Fig. 12 *This is a model of the idealized radiation pattern for the SEP transmitting antenna on the Moon.*

133
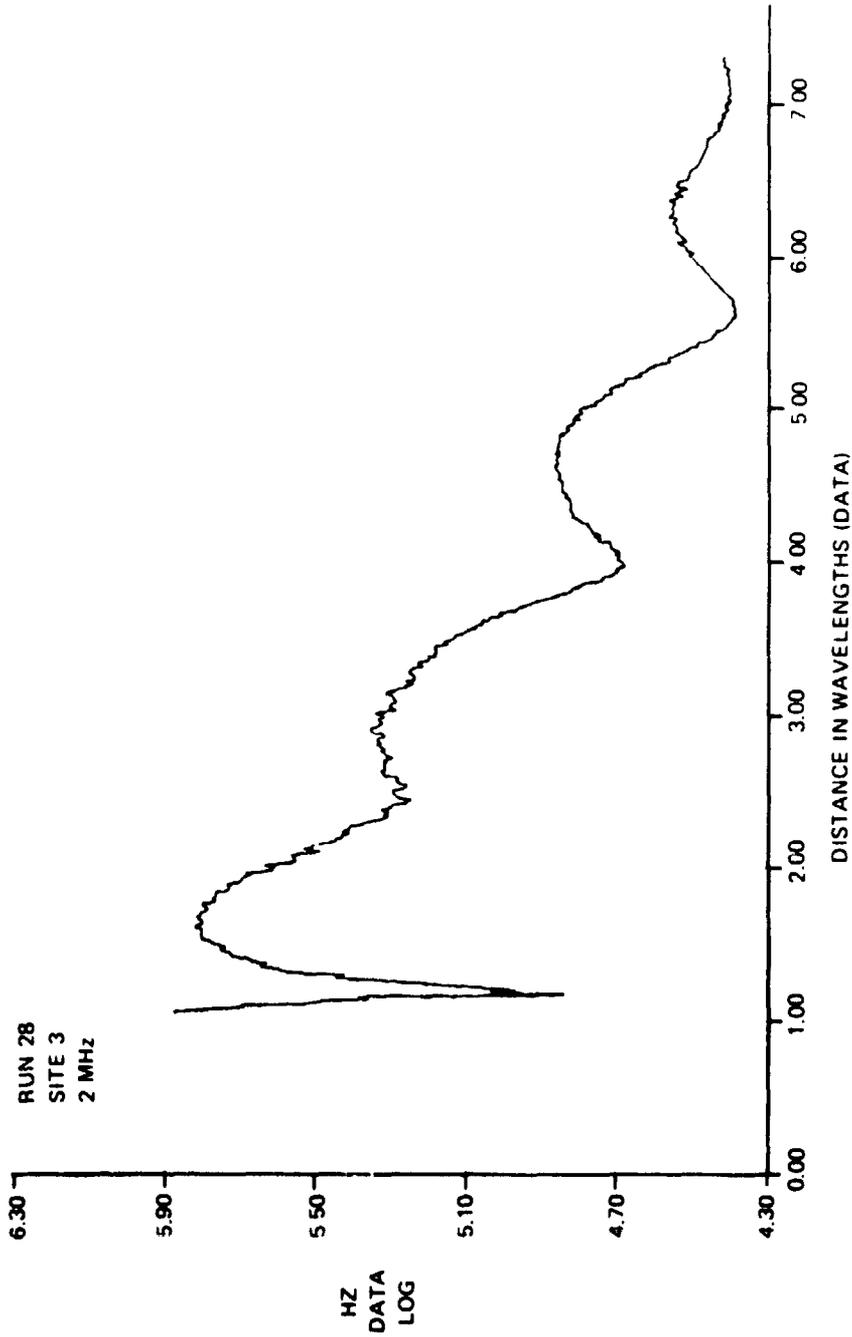
Fig. 13 *This field data, taken on the Athabasca Glacier, shows the vertical component of the magnetic field strength of the electromagnetic wave at a wavelength of 150 meters. Note the similarity between this curve and the set of theoretical curves shown in Fig. 11.*

extra recorder connected to the Field Evaluation Model (FEM), in addition to a magnetic tape recorder, that will not be used with the actual flight model. Why? To see the results immediately and thus save time in the event of difficulties with equipment. Remember, at that time, we were actually testing the equipment concepts as well as gathering data that would be used to gain experience in the interpretation process.

The FEM was used in 1972 in the tests on the Juneau ice fields. The objective there was to obtain data on several well-studied glaciers with which to increase our experience in the interpretation of SEP data. We obtained traverses over many features that may occur also on the Moon: semi-infinite half-space, buried ridge of rock beneath the ice, crevasses, and the condition of snow and ice with low density (about 0.2) at the surface and increasing steadily with depth (to about 60 meters where the density increases abruptly because the snow turns to ice). We even created a crater on one glacier in order to study its effect on our experiment.

In Fig. 13, we show a sample of data from the Athabasca glacier. The dielectric constant (or speed of travel of the radio waves) and the losses estimated from this pattern correspond well with the same quantities measured by previous investigators using different methods. The thickness of the glacier estimated from the interference pattern matches very closely the thickness as determined seismically and actually measured by others in boreholes. Such excellent correspondence between the results obtained with our SEP equipment and those obtained by other investigators with entirely different methods has given us great confidence in our equipment and techniques.

OUR HOPES

The scientific exploration of the Moon in the Apollo program has led to surprise after surprise. The magnetic fields were much higher than expected. The lunar rocks brought back to Earth were extremely old (from 3 to greater than 4 billion years), showed strange compositions (compared with Earth rocks), and, perhaps most surprisingly, contained absolutely no water. The temperatures deep inside the Moon seem to be unexpectedly low but the heat flowing from the interior to the surface of the Moon is high—a paradox that is not yet resolved. If we receive SEP data back from the Moon, then we are sure that we can estimate the values of the electrical properties of rocks in situ on the Moon. Just that alone will be valuable. But we are also sure that we will "see" any layering that may be present. We will "see" any

lateral changes in electrical properties. We will easily "see" scattering objects, a very significant contribution towards understanding the local landing site.

We have designed our equipment to work in the hostile environment of the Moon. We are sure that it will work. We are less certain about exactly what we will find in the analysis of our data. Remember that the Moon has been full of surprises. We shall be disappointed if the SEP experiment does not uncover several more surprises. Their correct interpretation is likely to be far more valuable than the routine verification of the expected. Such surprises are the excitement of Science.

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