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APOLLO EXPERIENCE REPORT - ELECTRONIC SYSTEMS TEST PROGRAM ACCOMPLISHMENTS AND RESULTS

by Thomas E. Ohnesorge

Manned Spacecraft Center
Houston, Texas 77058

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16. Abstract

This document presents a chronological record of the Electronic Systems Test Program from its conception in May 1963 to December 1969. The original concept of the program, which was primarily a spacecraft/Manned Space Flight Network communications system compatibility and performance evaluation, is described. The evolution of these concepts to include various levels of test detail, as well as systems-level design verification testing, is discussed. Actual implementation of these concepts is presented, and the facility to support the program is described. Test results are given, and significant contributions to the lunar landing mission are underlined. Plans for modifying the facility and the concepts, based on Apollo experience, are proposed.

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ACRONYMS

AAP	Apollo Applications Program
ACAM	Apollo computer address matrix
ACC	antenna control console
ACS	Apollo communications system
AGC	automatic gain control
ALSEP	Apollo lunar surface experiments package
AM	amplitude modulation
AMQ	analog-multiplexer-quantizer
APL	Applied Physics Laboratory
ARIA	Apollo range instrumented aircraft
ASE	audio support equipment
ASPO	Apollo Spacecraft Program Office
ATC	Apollo time conditioner
ATP	acceptance test procedure
BER	bit error rate
CAM	computer address matrix
CCB	Configuration Control Board
CCDC	central control and display console
CCS	command and communications system
CDR	command distribution rack
CDDT	Countdown Demonstration Test
CM	command module
COMSAT	Communications Satellite Corporation
CRO	Carnarvon, Australia

CSM	command and service module
CV	command verification
DRUL	down-range up link
DSE	data storage equipment
EASEP	early Apollo scientific experiments package
EI	Engineering Instruction
EKG	electrocardiogram
EMU	extravehicular mobility unit
ESCF	Electronic Systems Compatibility Facility
ESTL	Electronic Systems Test Laboratory
ESTP	Electronic Systems Test Program
ETR	Eastern Test Range
EVA	extravehicular astronaut
EVCS	extravehicular communications system
FM	frequency modulation
FMFB	FM feedback
FOD	Flight Operations Directorate
GSFC	Goddard Space Flight Center
H. L.	hardline
IAM	incidental amplitude modulation
ICD	Interface Control Document
IPM	incidental phase modulation
IRIG	Inter-Range Instrumentation Group
IU	instrument unit
JPL	Jet Propulsion Laboratory
KSC	John F. Kennedy Space Center

LEM	lunar excursion module
LM	lunar module
MCC	Mission Control Center
MCC-H	MCC-Houston
MGC	manual gain control
MILA	Merritt Island Launch Area
MPS	mission profile simulator
MSC	Manned Spacecraft Center
MSFC	Marshall Space Flight Center
MSFN	Manned Space Flight Network
NASA	National Aeronautics and Space Administration
NRZ-L	nonreturn to zero-level
PAM	pulse amplitude modulation
PCM	pulse code modulation
PLSS	portable life support system
PM	phase modulation
PMD	payload module decoder
PRN	pseudorandom noise
PSK	phase shift key
RC	resistor-capacitor
RER	receiver exciter ranging
RSSC	remote-site simulator console
SBED	serial bit error detector
SBER	subbit error rate
SCO	subcarrier oscillator
SDD	signal data demodulators

SPA	signal-processor assembly
SSC	space-suit communicator
SSTC	spacecraft system test console
TAR	turnaround ratio
TCSD	Telemetry and Communications Systems Division
TDC	test director console
TDP	tracking data processor
TOB	telemetry output buffer
TV	television
UDB	updata buffer
UDL	updata link
USB	unified S-band
USBSS	USB system simulator
VCO	voltage-controlled oscillator
VOGAA	voice-operated gain-adjusting amplifier
VR	verification receiver
WI	word intelligibility

APOLLO EXPERIENCE REPORT
ELECTRONIC SYSTEMS TEST PROGRAM
ACCOMPLISHMENTS AND RESULTS

By Thomas E. Ohnesorge
Manned Spacecraft Center

SUMMARY

The Electronic Systems Test Program described in this document was established to fulfill a need that developed as manned space-flight communications systems evolved in complexity and required capability. The combining of all communications functions into one unified communications system for the Apollo Program, instead of the multiple communications systems that were used on Project Mercury and the Gemini Program, necessitated the innovation of a combined systems testing concept. For the first time, a concept of simultaneous spacecraft/spacecraft/ground communications system testing was established as a fundamental portion of communications system development and performance verification. The interaction and combination of all information on one radio-frequency carrier required compatibility verification and performance evaluation of the system prior to manned flight. The fact that each type of spacecraft was manufactured by a different contractor and that the ground communications system was provided by several different sources intensified this need for combined systems testing.

The test program began with the first system scheduled to fly — that is, the command and service module Block I (earth-orbital) system — and the Manned Space Flight Network equipment required to support these missions. The program progressed to testing of more advanced systems and complex combinations of these systems to finally arrive at the lunar landing communications system configuration. During this progression, special testing of critical information channels and channels containing updated hardware occurred. A few major compatibility problems were detected and corrective action determined. Many minor problems were noted and solutions recommended. Testing techniques and concepts were developed and evolved as the test program progressed.

The results of the test program have vindicated the combined systems compatibility approach for communications system development and testing. The conduct of the program, including peripheral areas of support, has delineated the need for better specification and testing criteria, as well as for systems testing on a breadboard basis prior to design finalization.

INTRODUCTION

Background and Purpose of This Document

The Electronic Systems Test Program (ESTP) has been established to configure manned spacecraft, extravehicular astronaut (EVA), and NASA Manned Space Flight Network (MSFN) telecommunications systems in combined operation under controlled laboratory conditions for the purposes of verifying systems compatibility and of determining systems performance levels under various conditions of space flight. Established in May 1963 and implemented during the summer of 1964, the ESTP has contributed significantly to the design and successful operation of the Apollo communications system (ACS). The purpose of this report, which is one of a series on Apollo experience, is to present the early history of this test program, to illustrate its growth and development, to describe its accomplishments, and to record its results through calendar year 1969. Capabilities and plans for further development also are discussed.

History of the Test Program

Project Mercury, which was the first U. S. manned space-flight effort, used telecommunications equipment and procedures very much like those used on test and experimental aircraft of the day. Equipment had to be qualified and repackaged for use in space, of course, but the communications techniques employed had been well proven and were accepted. Later manned space-flight programs, however, began to use new techniques. Some of these, such as digital command and telemetry techniques, made their appearance in the Gemini Program, in which the basic systems concepts (multiple transmit and receive links) were not greatly changed from Project Mercury. After some initial debate, however, the Apollo Program settled on an entirely new communications technique — the unified carrier/multiple signal combination capability. By using this technique, for the first time, all voice and data (as well as ranging and tracking functions) were transmitted simultaneously on one prime radio frequency. Experience with telecommunications systems of this nature was essentially nil. Although theoretical analyses and early laboratory tests indicated a reasonable chance of success, NASA management felt that more thorough investigations, including detailed theoretical analysis and extensive laboratory testing, were necessary to prove the feasibility of the technique and to determine inherent systems limitations, if any.

As a result, in the spring of 1963, the NASA Manned Spacecraft Center (MSC) initiated planning and implementation of a program that was subsequently designated the ESTP. This program was given the specific objectives of verifying spacecraft, MSFN, and MSC Mission Control Center (MCC) total systems compatibility and of evaluating the overall performance of the ACS by using operational prototype and production hardware. The task was made a joint responsibility of the MSC Ground Systems Project Office and the MSC Instrumentation and Electronic Systems Division (later renamed "Space Electronic Systems Division"). In June 1964, an MSC reorganization created the Information Systems Division, which was given total responsibility for the ESTP, with support to be provided by other MSC divisions and other NASA Centers as required. In August 1969, another MSC reorganization combined ESTP personnel and spacecraft telecommunications personnel into the same division, the Telemetry and Communications Systems Division (TCSD).

During the first 24 months of its existence, five significant events occurred within the ESTP. First, construction of a facility to house the ESTP at MSC was approved by NASA Headquarters. This facility was officially designated the Electronic Systems Compatibility Facility (ESCF). The laboratory area within this facility in which the actual systems testing takes place was subsequently designated the Electronic Systems Test Laboratory (ESTL). In the interim, a temporary facility located at MSC was authorized and subsequently used until the summer of 1966. Second, support and assistance agreements within MSC and with other NASA Centers were reached. These agreements, as modified by experience and by changes in functional responsibility, are summarized in table I. Third, a decision was made to eliminate testing of Gemini Program communications because the time frame to manned launch was too close for availability of proper equipment, because the rf systems involved were essentially the same as those for Project Mercury (even though the telemetry and command systems using these links were different), and because the time for design finalization of Apollo hardware was rapidly approaching. Coupled with this event was a decision to eliminate all plans for testing any vhf or hf systems since these systems had not changed significantly in several years; however, this decision was later modified for special instances. Fourth, a Jet Propulsion Laboratory (JPL) Deep Space Network (a JPL-NASA network for unmanned satellites and probes) unified S-band (USB) receiver-exciter-ranging (RER) system, modified for Apollo frequencies and parameters, was made available to the ESTP in September 1964, along with command and service module (CSM) Block I equipment, so that systems testing could begin in November 1964. Early testing of these items was necessary so that any problems encountered could be resolved and the necessary modifications could be incorporated into the system prior to the first manned Apollo flight. (The JPL RER system was replaced by a production-model MSFN RER system in early 1965.) Fifth, in January 1965, on the basis of cost and MCC operation schedules, the plans to incorporate the MCC in the test loop were dropped at the request of NASA management. Special tests involving the MCC have been performed, however; and additional tests will be performed at the specific request of the MSC Flight Operations Directorate (FOD).

While the initial purpose of the ESTP was, as stated earlier, to provide information regarding spacecraft/ground telecommunications system compatibility and performance based on tests with operational equipment, this purpose has been broadened somewhat to include design verification testing, mission anomaly investigations, prelaunch problem resolution testing, and exploratory and development tests to improve systems performance. These and other aspects of the test program are described in the following sections.

TABLE I. - ELECTRONIC SYSTEMS TEST PROGRAM PARTICIPATION

Organization	Responsibilities
MSC/TCSD	Implementation of ESTP and ESTL
	Negotiation and coordination of procurement and delivery of ground and spacecraft equipment and supporting documentation
	Design and fabrication of special-purpose test equipment and fixtures
	Procurement of all general-purpose test equipment
	Control of facility configuration
	Preparation of ESTP documents
	Coordination of individual black-box testing and conducting necessary subsystem and system performance tests in accordance with hardware performance requirements
	Obtaining data on TCSD and contractor tests of spacecraft and ground-support hardware that may be related to the ESTP
	Supplying system engineers to support compatibility and performance evaluation tests
	Scheduling of tests and related activities
	Preparation of test plans, procedures, and reports
	Providing all test predictions
	Chairing all test planning, status review, and final review meetings
	Directing tests and providing reduction, analysis, and dissemination of test data
	Coordinating and expediting resolution of problem areas associated either with test results or availability of appropriate equipment for test
	Maintaining adequate systems documentation and expediting flow of test data and results to appropriate users

TABLE I. - ELECTRONIC SYSTEMS TEST PROGRAM PARTICIPATION - Concluded

Organization	Responsibilities
MSC/ASPO	Supporting spacecraft system procurement and assisting ESTP in obtaining appropriate spacecraft contractor participation
	Assisting in the acquisition of spacecraft equipment documentation
MSC/FOD	Participating in the preparation of test plans of interest
	Providing data for use in dynamics tests when requested
	Participation in analyzing results of tests of interest and concern
GSFC	Specification and procurement of MSFN equipment
	Direction or supervision of the installation and checkout of MSFN equipment in the ESTL
	Providing assistance or consultation during subsystems testing and systems tests
	Participation in overall planning, testing, and data evaluation
	Supporting resolution of MSFN-related problem areas associated either with test results or equipment availability
	Providing MSFN equipment operator training
	Updating MSFN equipment at ESTL in accordance with overall MSFN updates and advising MSC personnel of forthcoming changes that may impact or invalidate test results
	Providing data on GSFC- or contractor-conducted tests that may affect the ESTP
MSFC	Essentially the same as MSC/TCSD support activities, but related to booster telecommunications equipment
JPL	Essentially the same as, and in conjunction with, GSFC
KSC	Advising of any unique launch instrumentation system characteristics requiring compatibility and performance testing
	Monitoring test program to keep aware of problems encountered and solutions proposed

PROGRAM CONCEPTS AND DEVELOPMENT

The primary objective of the ESTP has been to provide a high level of assurance that spacecraft, extravehicular, and MSFN telecommunications systems are compatible and that the overall systems performance levels are commensurate with project goals and individual mission requirements. In the process of achieving this objective, several secondary objectives have been realized. These objectives are the performance of tests early enough prior to manned flight to assist in determining overall systems design requirements and specifications, recommendations for modifications where incompatibilities are found to exist or performance levels are found to be insufficient, determination of operational constraints, and recommendations for systems improvements.

To attain these objectives, a test concept consisting of four discrete levels of test effort was devised. These levels were chosen on the assumption that all component qualification, as well as subsystems testing and environmental qualification, occurs at the manufacturing or prime contractor facilities. The four testing levels (fig. 1) are subsystems evaluation tests, systems integration tests, systems compatibility tests, and problem resolution tests. A fifth category of testing, "special tests," is described in subsequent paragraphs.

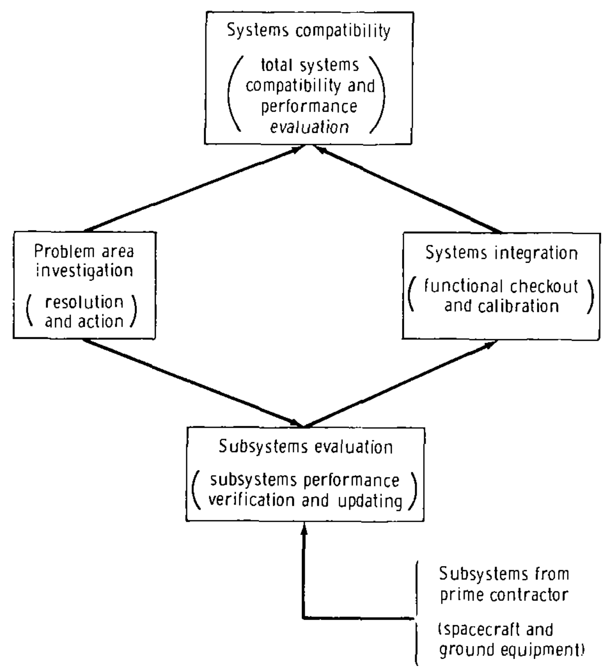


Figure 1.- Test concept of the ESTP.

The subsystems evaluation tests are designed to check each subsystem (or "black box") individually to verify performance according to specification and to obtain important calibration data for following tests. These subsystems evaluation tests (not to be confused with qualification or acceptance tests) have as their primary objective the documentation of important parameters such as bandwidth, dynamic range, power output, and stability which are required before compatibility test data can be properly utilized. Spacecraft and extravehicular subsystems evaluation tests are performed in TCSD laboratories at MSC. The MSFN and special-purpose test equipment subsystems evaluation tests are conducted in the ESTL.

The systems integration testing (or systems evaluation testing) is designed to verify proper operation and interconnection of the spacecraft, extravehicular, or MSFN equipment; to obtain further calibration data as required; and to verify proper interconnection of the overall communications system in preparation for systems compatibility tests. The ultimate objective, then, of the systems evaluation test is to arrive at a fully configured ESTL test bed with which a particular series of compatibility and performance evaluation tests can be performed.

The subsystems and systems evaluation tests are repeated whenever a major change occurs in the ESTL and are periodically repeated (between major test phases) to supplement daily maintenance checks and to verify or detect changes to subsystems and systems calibration. Abbreviated versions of these tests, called brief systems tests, are run more frequently to provide verification of important parameter values.

The third level of testing is systems compatibility testing, which is the heart of the ESTP. It is from this testing level that the primary objective of the ESTP is realized. A generalized systems test configuration is shown in figure 2. These tests are designed not only to ascertain total systems compatibility but also to determine the performance levels and limitations of the system for each communications mode. During these tests, the performance characteristics of each information channel are determined and documented. The information channel tests cover not only transmitters and receivers but also subcarrier equipment and initial modulation and processing equipment (pulse code modulation (PCM) telemetry equipment, audio center equipment, updata buffer (UDB), etc.). These tests are performed on one channel at a time (voice, television (TV), telemetry, ranging, and updata) under various combinations of up-link and down-link modulation. Each channel is tested over the full range of rf levels and Doppler conditions expected during operational missions. In fact, a phase of testing in which the rf levels and the Doppler-shift effects are varied in a time frame simulating that expected during an actual flight can be performed. The following are examples of measurements taken during systems compatibility tests. (The number sequence does not indicate relative significance.)

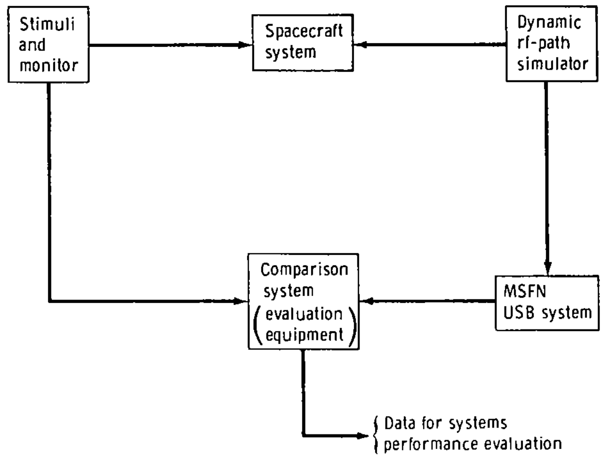


Figure 2. - Generalized systems test configuration.

1. Spacecraft and ground receiver rf threshold

2. Subcarrier demodulator threshold

3. Ranging subsystem threshold

4. Acquisition and lock times at different rf levels and Doppler rates

5. Received telemetry data error rates

6. Updata message acceptance rate

7. Voice intelligibility

8. Television picture quality

9. Keyed-carrier code-copy accuracy

The fourth level of testing, the problem resolution tests, is conducted in more detail but on restricted portions of the overall system to explore problems detected during the systems compatibility tests. It is this level of testing, primarily, which enables realization of the secondary ESTP objectives discussed earlier. The problem resolution tests are often run concurrently with compatibility tests on simulated spacecraft and ground equipment; only when a resolution is found are the ongoing compatibility tests interrupted to verify the solution on the operational equipment. Problem resolution testing is also conducted when theoretical analyses indicate potential problems and when anomalies are detected during a mission.

A similar but less directly related level of testing, designated simply as special tests, is performed (upon request) to develop systems improvements in the case of marginal performance, to verify new designs in the conceptual stage of hardware development, or to see if the existing system can accommodate new information transfer or relay requirements. This level of testing also includes verification of certain NASA Goddard Space Flight Center (GSFC)-engineered modifications to the MSFN equipment prior to release to all MSFN sites, astronaut demonstrations where voice-conferencing capabilities and procedure tests are conducted with astronaut participation, and high-gain antenna tracking tests with varying up-link transmission modes. Special support to the MCC also is included here by incorporating a temporary hookup to the MCC or simply by making appropriate tape recordings to be replayed in the MCC or over the MSFN to the MCC.

Both the problem resolution tests and the special tests, as separate categories, are relatively late developments in the ESTP. It was found that to stop and reconfigure for testing covered by these categories in the middle of, or between, regularly scheduled systems compatibility tests often jeopardized schedules to the point that data either could not be made available in time to be useful (spacecraft development too advanced), or the data taken were no longer applicable because of systems changes. Therefore, the separate categories were established, and testing was scheduled during off-shift periods, on simulated equipment, or in separate laboratories (the MSC Audio Techniques and Evaluation Laboratory and the MSC Communications Systems Engineering Laboratory) organizationally and electrically connected with the ESTL. However, because of priorities or possible consequences, the mainstream tests often have been delayed so that problem resolution tests or special tests took priority. On each such occurrence, the test personnel worked closely with the requesting organization and established procedures and schedules acceptable to all concerned. In many of these instances, however, the data analysis and final reporting have been left to the requesting organization so that other testing may proceed. In essence, then, the original testing concept of the ESTP has been modified to provide flexible and rapid response to urgent requirements that affect system design, requirement implementation, or crew safety. Also, future program support, where simple exploratory testing can clarify systems capabilities and allow firming up of concepts, has been employed.

A further refinement in the original plan of the ESTP occurred rather early in the program. In many instances at that time, only early breadboard-type equipment was available for testing and only for a short period of time; the prototype or operational equipment on a more permanent basis was not available until several months later. Consequently, systems compatibility testing was divided into two types — gross compatibility testing and detailed compatibility and performance evaluation testing. The gross compatibility tests were designed to obtain maximum information about the equipment in a short time — usually 4 to 6 weeks. Only two major conditions were tested: nominal parameter and range values and combined worst-case values. This testing allowed detection of major incompatibilities, but tended to bypass minor problems. The detailed compatibility tests, which cover all expected conditions, come later and usually last 3 months. Here, minor problems are ferreted out, special testing is inserted upon request, and complete documentation on the operational system is obtained.

Test techniques are continually being developed for the ESTP. Such items as speech-to-noise ratio measurement, frame-synchronization loss-rate measurement, noise-figure measurement, and others have been developed to yield greater accuracy and to reduce test time where possible. A study is now underway on ESTP accuracies based on measurement tolerances and interactions; the down-link telemetry channel portion of the study is complete and the down-link normal voice channel portion is nearly so.

Strict configuration control of the ESTL equipment used for the ESTP is maintained. A detailed description of the ESTL equipment, sample test plans, signal flow, and quality and configuration control procedures are contained in a five-volume report prepared by MSC. All volumes are updated periodically to reflect changes in procedures and equipment. Test program operations and ESTL equipment and support capability are summarized in appendixes A and B, respectively. Similar control is maintained over the Audio Techniques and Evaluation Laboratory and the Communications Systems Engineering Laboratory whenever these laboratories perform tests directly related to the ESTP. A brief description of laboratory capabilities available is given in appendix B. The original program plan and sequence of testing, as proposed in the five-volume report, have been adhered to except for two major causes. One cause, the largest perturbing factor, was that additional tests (extravehicular astronaut demonstration tests, rf tracker tests, Apollo lunar surface experiments package (ALSEP) tests, Apollo range instrumented aircraft (ARIA) performance evaluation tests, etc.) were implemented and completed. The total time added by this cause was over 1-1/2 years. The second cause (of less significance) was that increased test scope, including special testing, took more time than originally forecast. The time increase for the latter cause was approximately 6 months. The total increase in time was, then, approximately 2 years. As a result of this additional testing, many significant contributions — important in design, in development, and ultimately in mission operations — were made by each of the previously listed program phases.

The ESTP has made the following significant contributions to the ACS. (The numbering sequence does not indicate relative significance.)

1. Verification of overall systems compatibility

2. Determination of overall systems performance levels and capabilities

3. Evaluation of impact of incompatibilities and insufficient performance

4. Verification of analyses and predictions

5. Derivation of information not readily available from analysis

6. Aid to all groups requiring understanding and knowledge of systems characteristics, performance limitations, and operational constraints

7. Aid to all groups in resolving problems, establishing performance specifications, and verifying adequacy of changes

8. Verification of equipment design in breadboard stage

The ESTP has resulted in a complete and thorough documentation of the performance capabilities and the limitations of the ACS and can provide similar results for any communications system used for manned space flight.

TEST ACTIVITIES

Testing activities under the ESTP were begun in September 1964, in temporary facilities at MSC, and have continued without interruption, except for brief reconfigurations and update periods (including relocation to the permanent facility), until the present time. The specific tests conducted are described in this section. For convenience and emphasis, they are grouped into three categories: major tests (total spacecraft/ground tests), special tests (partial spacecraft/ground tests), and support tests (special problems of lesser manpower significance than the special tests). A schedule which illustrates the time sequence and relationship of these tests is shown in figure 3. Significant outputs from the tests are discussed in the section entitled "Significant Results."

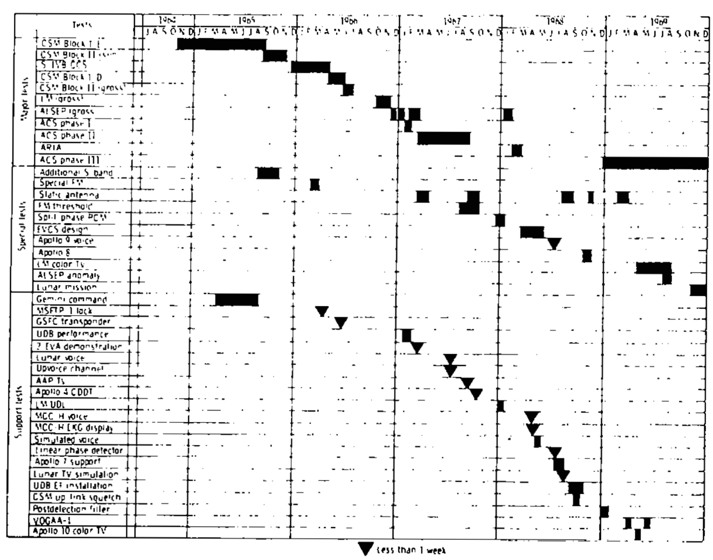


Figure 3. - Test activity of the ESTP from 1964 to 1969.

Major Tests

Major tests (designated "A") are aimed at verifying overall communications systems compatibility and performance for overall program support and do not, as such, cover such special testing as determining systems capabilities to fulfill individual mission objectives where they differ from flight to flight. However, the major tests do establish basic performance criteria and capability and information from which specific mission capabilities can be derived.

The first two tests described (A-1 and A-2) were performed at MSC under contract (NAS 9-2563) with a major supplier of spacecraft and MSFN equipment. The equipment tested was not operational because the spacecraft equipment was the CSM Block I engineering (Block I-E) model, or production prototype equipment, and the MSFN USB RER system was actually a Deep Space Network system modified for Apollo frequencies, codes, and subcarriers. Sufficiently good data were obtained, however, to confirm the basic acceptability of the Block I equipment and to affect significantly the Block II design quite early in the design process. Also, significant and valuable experience was obtained whereby MSC personnel could effectively carry on with the test program after completion of the first two tests. These and other tests are discussed in more detail in the following paragraphs.

Command and service module Block I-E USB tests (A-1). - The primary objectives of the CSM Block I-E USB test series were to verify the Block I ACS overall compatibility and to determine, as early as possible in the manufacturing and assembly stages, the performance that could be expected from the ACS. While final hardware configurations were not available until later (for A-4 tests), the CSM Block I-E equipment tested was sufficiently similar (and in many cases identical) to the final Block I system so that performing the tests became worthwhile. The same can be said of the ground S-band system, which was later converted to the Apollo configuration (frequencies, subcarriers, etc.) from a JPL configuration. Much of the effort expended on this test series became directly applicable to the Block II and lunar-configuration systems design and testing which were to follow.

Two major classifications of tests were accomplished. The first of these was to determine the compatibility and performance of the overall system. These tests determined such characteristics as PCM data quality, voice intelligibility, updata link (UDL) quality, ranging accuracy, and acquisition time, all at various rf received signal levels and carrier thresholds. The second classification of tests included investigation of problem areas detected in the compatibility and performance tests and also included TV demodulation tests, emergency-key demodulation tests, and low-frequency incidental amplitude modulation (IAM) and incidental phase modulation (IPM) tests designed to answer special questions that arose regarding spacecraft (particularly the lunar module (LM)) high-gain antenna pointing accuracy and stability effects on data quality. This series of tests proved the basic compatibility of the Block I ACS. However, as noted previously, several problems that had to be solved prior to a lunar mission were uncovered. At the time of these tests, the Block I ACS was no longer intended for use at lunar distances; some of the problems detected, however, were common to both the Block I and the Block II systems. Other problems were not serious enough to demand major hardware rework but did require systems or operational constraints. Some problems indicated the need for detailed specifications, primarily in regard to systems performances and interfaces. The major problems in each category are presented in table II. Based on results of this test series, the problems were corrected by hardware, documentation, or procedure changes. In many instances, further testing was needed prior to making any definite corrections to the problems. Some of the additional testing performed is discussed in later sections of this report.

TABLE II. - BLOCK I-E PROBLEM AREAS

Problem	Resolution
Problems requiring resolution prior to lunar missions	
Transponder noise-figure degradation of 6 dB in the high-power mode was caused by the passage of the S-band traveling-wave-tube-generated C-band noise through both the transmit and the receive arm of the diplexer.	Block I — A low-pass filter was inserted in the transmit leg of the power amplifier. Block II — No problem was expected because of the presence of a preselector in the transponder receiver and a low-pass filter in the transmit arm.
When the transponder was in the ranging mode, up-link data were turned around and remodulated onto the down link, severely degrading the 51.2-kbps telemetry data.	Block I — The up-link modulation indices were reduced. Block II — The problem was minimized by transponder design.
Incorrect range tally read-outs for certain range-code delays were caused by design error in the ranging subsystem.	Personnel at JPL corrected the problem.
Downvoice distortion was caused by a mismatch between the voice demodulator and the output amplifier.	Personnel at GSFC corrected the problem.
Quality of updata did not correspond to predictions as a result of poor detector design.	Block I — The quality was adequate. Block II — A design correction was incorporated.
400-Hz power to the transponder contained AM as a result of load changes; this condition caused undesired PM on the down link, which degraded received data.	Block I — A much improved inverter was designed by the contractor. Block II — The transponder design included dc regulation.

TABLE II. - BLOCK I-E PROBLEM AREAS - Continued

Problem	Resolution
Problems requiring system constraints	
In certain operational modes of the CM and the LM, the received LM down-link signal strength could be considerably stronger than that of the CM. This situation would degrade CM down-link data quality.	Tests to determine the maximum signal differential for acceptable data quality were performed, and the results were forwarded to appropriate mission planning groups.
Very weak up-link signals caused noise modulation on the transponder voltage-controlled oscillator (VCO).	Tests to determine the point at which this condition affects PCM data quality were performed.
Energizing and deenergizing up-link modulation during range-code acquisition caused the ranging subsystem to reset.	These functions cannot be changed during range-code acquisition.
Design of the audio center was such that upvoice was fed back into the down-voice channel, thereby limiting maximum obtainable voice intelligibility.	Block II specifications were changed to improve this condition.
During PCM 1:1 data-playback mode tests, data quality was degraded approximately 1 dB as a result of recorder characteristics. The 32:1 playback performance was not tested because required equipment was unavailable.	Degradation of 1 dB was considered acceptable.
Problems requiring specification requirements	
Detected UDL subbits could be inverted if one of many interfaces was not properly interfaced.	Polarity at each point in the system had to be specified and closely observed.
Inversion of the TV picture could occur, depending on the amplification used at the ground.	The number of amplification stages or an inverter at the TV monitor input (or both) had to be specified.

TABLE II. - BLOCK I-E PROBLEM AREAS - Concluded

Problem	Resolution
Problems requiring specification requirements - Concluded	
Real-time PCM subcarrier modulation was such that proper frame synchronization could not occur.	The decommutator specification had to include provision for operation on both data and data complement (inverted bit stream).
Long strings of "1's" or "0's" in the PCM data stream could possibly cause loss of lock by the bit-rate clock on the ground.	The PCM bit and word formats had to be specified in such a manner that long series of "1's" or "0's" were not present in the format.

Command and service module Block II (simulated) compatibility tests (A-2). - The primary objective of the CSM Block II (simulated) compatibility test series was to verify the compatibility and performance of the intended CSM Block II design by using simulated CSM communications equipment and operational ground equipment. (The ground USB system used for the Block I-E tests was replaced with an operational system specifically designed for the Apollo Program.) The subcarrier demodulators were simulated; that is, they were not the planned operational units. Simulated CSM equipment had to be used because the Block II design had not been finalized. The Block II equipment was simulated by the Block I "E-5" transponder modified for Block II parameters and by a "Universal" (or adjustable) spacecraft communications system which was provided for this test and is now assigned to the problem resolution phase of the ESTP. Consequently, this test series also served as a design verification test for the CSM Block II communications system. Furthermore, problem areas could be resolved more readily since the design was not firm.

The types of tests performed were very similar to those done for the Block I-E model (A-1), except that some mission profile tests, in which a dynamic Doppler simulator was used to simulate spacecraft velocity and range changes, were performed. Also, the number of data points taken for each channel was somewhat reduced because of the limited time available.

Again, the test series verified the basic compatibility of the communications system design, this time for Block II. Also, as before, some problems were uncovered which had to be resolved. These problems can be categorized as before, and the major ones are presented in table III. All necessary corrective action has been taken. This action has occurred, however, often as a result of further testing, some of which is described in later sections of this report.

TABLE III. - BLOCK II SIMULATED SYSTEM PROBLEM AREAS

Problem	Resolution
Problems requiring resolution prior to lunar missions	
For low spacecraft transmit power and omnidirectional antenna configuration, the total ground-received signal power from lunar distance was 1.8 dB below that required for 80-percent copying accuracy of keyed tones.	GSFC personnel redesigned the filter-demodulator subsystem for detection of emergency key.
Difficulty in acquiring both the up link and the down link was experienced. This was caused by frequency "pushing" effects and spurs generated by intermodulation processes between the signal and VCO.	Hardware changes were achieved by changing filters associated with both the transponder and MSFN phase-lock loops.
Problems requiring system constraints	
Plus-Doppler offsets caused slight degradation of voice and UDL channel performance; negative offsets caused improvement of similar magnitude. This was caused by phase shifts resulting from the transponder carrier loop static-phase error and was most noticeable at weak signal levels.	The problem is a function of rate and magnitude of Doppler and must be accounted for in circuit margin calculations.
Telemetry BER using the DSE was somewhat degraded for the real-time case. Also, for 32:1 playback, the best BER achievable was 1×10^{-5}.	The problem must be accounted for in circuit margin calculations.
Carrier-acquisition difficulties also caused operational constraints.	Prohibition of all up-link modulation during carrier acquisition was found necessary.

TABLE III. - BLOCK II SIMULATED SYSTEM PROBLEM AREAS - Concluded

Problem	Resolution
Problems requiring specification requirements	
The UDL channel performance at baseband (subcarrier only) was degraded from predictions as a result of phase and amplitude distortion and impulse noise of the discriminator.	Proper and complete specification of differential time delays (1-kHz and 2-kHz signal components) was found necessary.
Best telemetry BER of 1×10^{-5} for the DSE conflicted with performance and interface specifications.	The specification was changed to reflect equipment limitations.

Saturn IVB/instrument unit command and communications system/MSFN USB compatibility tests (A-3). - In cooperation with and with the participation of the NASA Marshall Space Flight Center (MSFC), the instrument unit (IU) command and communications system (CCS) transponder of the Saturn IVB (S-IVB) and the MSFN RER subsystems went into test near the middle of December 1965. The tests were completed near the first of May 1966. The telemetry channel performance was found to fall short of expected results, and the up-link modulation in the transponder ranging channel was identified as the source of error. The MSFN receiver acquisition tests encountered a down-link false-lock problem, which was traced to the transponder. It was determined that the switching power supply in the transponder generated spurious signals at 37 decibels below the carrier component, and the MSFN receiver acquired these spurious signals in place of the desired signal. These problems are summarized in table IV.

TABLE IV. - SATURN IVB/IU CCS/USB PROBLEM AREAS

Problem	Resolution
Telemetry channel performance was degraded by up-link modulation in the transponder ranging channel.	The MSFC personnel were advised of the problem and reduced the turnaround channel gain constant.
Down-link false lock was caused by the transponder switching power supply, which generated spurious signals at 37 dB below the carrier wave. The MSFN receiver would lock onto the spurious signals.	The MSFC personnel were advised of the problem and took corrective action.

Command and service module Block I-D/MSFN USB compatibility tests (A-4). - The CSM Block I-D model USB equipment and the MSFN RER subsystems went into testing near the first of May 1966, and the testing was concluded in mid-June 1966. The results of the tests were compared to the system specifications and to expected performance. This comparison indicated that audio center crosstalk and the presence of excessive noise in the crewmembers' headsets (when the crew audio switch was on with the 30-kilohertz up-link subcarrier off) created problems. Also, the results of antenna switching indicated that the automatic switch affected the USB equipment carrier-acquisition threshold and that conditions existed in which the antenna switch could go into oscillation. This automatic switch was not incorporated into the final Block II design.

The results of incidental modulation tests indicated that 2-percent amplitude modulation (AM) of the 400-hertz spacecraft equipment power at a 35-hertz rate caused IPM of the S-band carrier. This condition affected data and acquisition. The maximum measured effect was approximately 5 decibels on acquisition of the carrier by the USB equipment. This effect occurred for 50° peak IPM at frequencies above 200 hertz. The data degradation, in general, was approximately 1 decibel. These results, as they pertain to the effect of IPM on the down link are, of course, applicable to all sources of IPM that appear on the down link. (Another source is high-gain antenna vibrations.)

Several problems discovered during the Block I-E tests were still present. Many of the problems and their solutions are listed in table V. Several problems, though first noted on Block I, were applicable to Block II also.

TABLE V. - COMMAND AND SERVICE MODULE BLOCK I/MSFN

USB PROBLEM AREAS

Problem	Resolution
Degradation of PCM telemetry was caused by turnaround of up-link channels.	Block I — Uplink modulation indices were reduced. Block II — Transponder TAR was reduced.
System degradation was caused by poor regulation of the 400-Hz power supply, causing AM and PM in the modulator, the VCO, and the power amplifier.	For both Block I and Block II, a much improved inverter system (effective on Apollo-Saturn 202) was designed by the contractor. Block II systems also have regulated dc power supply.
Degradation of UDL at low signal levels was caused by degraded up-link signal-to-noise ratios.	For Block II, an improved diode-type wideband phase detector was implemented.

TABLE V. - COMMAND AND SERVICE MODULE BLOCK I/MSFN

USB PROBLEM AREAS - Concluded

Problem	Resolution
Degradation of the transponder (receiver) noise figure was caused by spurious outputs of the power amplifier.	A low-pass filter for Block I and a preselector for Block II were implemented by the contractor.
The signal margin was inadequate for the emergency key (assuming failure of the power amplifiers and the high-gain antenna).	Personnel at GSFC redesigned the filter-demodulator system to achieve acceptable performance.
Degradation of UDL was caused by IAM of the ground SCO.	Reduced up-link modulation indices minimized this effect. Personnel at GSFC initiated development of improved SCO.
A false lock occurred.	Operational procedures were devised to minimize the possibility of MSFN false lock. Also, spacecraft and MSFN filters were redesigned.
Transponder dynamic tracking-loop parameters were not compatible with operational acquisition and loop tracking requirements.	New tracking-loop parameters (gain, bandwidth, and allowable static-phase error) were specified for Block II. Slower MSFN exciter sweep rates were specified for Block I acquisition procedures.
Data signal polarities were reversed (PCM, UDL, TV, and PRN).	Total system polarities were specified to all concerned; some MSFN hardware wiring changes were also required.
Degradation of PCM telemetry was caused by IPM in the spacecraft system.	The specification to the spacecraft contractors was changed to limit total system IPM to 28° rms (less than 2-dB telemetry degradation).

Command and service module Block II/MSFN USB gross compatibility tests (A-5). - The CSM communications equipment, including the USB equipment and the MSFN RER subsystems, entered testing in mid-June 1966, and the tests were completed in mid-July 1966. These tests were performed to determine whether any problem detected during the earlier tests (A-2) remained in the prototype equipment. The test results revealed two major problems. First, the specified bit error rate (BER) of 1×10^{-6} could not be achieved when the MSFN receiver was tuned to the 700-hertz loop bandwidth, and the backup voice was phase modulated on the carrier with 1.6-kbps telemetry imposed on a 1.024-megahertz subcarrier. The specified BER could be achieved when the receiver was tuned to the 50-hertz loop bandwidth.

Secondly, when the up-link carrier was phase modulated with the pseudorandom noise (PRN) range code at 1.34 radians, the power in the received range code at the MSFN site was so strong that the correct ranging procedure could not be followed unless additional attenuation was incorporated into the MSFN ranging receiver design. The available attenuation in the ranging receiver was 12 decibels, and test results indicated that an additional 5-decibel attenuation was required. These problems are summarized in table VI.

TABLE VI. - COMMAND AND SERVICE MODULE BLOCK II/MSFN USB

GROSS TEST PROBLEM AREAS

Problem	Resolution
Block II PCM performance was degraded in the backup voice mode with the MSFN receiver tuned to the 700-Hz loop bandwidth.	The specified BER could only be achieved when the 50-Hz receiver loop was used.
Block II PRN performance (dynamic range of MSFN receiver to accommodate wide variation in PRN modulation index) was inadequate.	An additional 5 dB of attenuation was incorporated in the ranging receiver, and new up-link modulation indices for ranging modes were specified. Also, MGC capability was added for the MSFN receiver.

Lunar module/MSFN USB gross compatibility tests (A-6). - The LM/MSFN USB tests began in mid-October 1966, and were completed during the first week of December 1966. The tests were necessary to verify that the LM transceiver and the MSFN RER subsystems were compatible with the system specification and with mission requirements. Performance characteristics such as BER, probability of correct acquisition, range-code acquisition time, TV picture quality, and voice quality were observed and recorded. Several major anomalies were observed. These problems are summarized in table VII. Many of the listed recommendations resulted in further tests, some of which are discussed later in this report.

TABLE VII. - LUNAR MODULE/MSFN USB GROSS TEST PROBLEM AREAS

Problem	Resolution
Down-link voice quality (gross WI) tests indicated serious deficiency in the maximum downvoice intelligibility obtainable when space-suit noise was simulated. Suspected causes were audio center automatic volume control amplifier stages emphasizing the input noise and high clipping levels in the backup voice mode (24 dB specified).	Selected redesign of the LM voice channel was accomplished to improve time constants and linear dynamic range.
The ranging modulation index of 1.34 radians required an i.f. attenuation of 16 dB in the MSFN range receiver. The existing systems capability was a maximum of 12 dB.	Attenuation in the MSFN range receiver was increased. New up-link modulation indices for PRN ranging modes were specified. Also, MGC capability in the MSFN receiver was added.
False lock occurred in the transceiver under strong signal conditions (greater than -70 dBm) for $\Delta f = \pm 90$ kHz and df = 36 kHz/sec, where Δf is the range of frequency change and df is the rate of frequency change. A suspected cause was pushing effects as a result of the multiple pole predetection filter in the carrier tracking loop.	The filter was redesigned.
Backup voice mode (signal combination 4) degraded PCM telemetry performance (1.6 kbps). The maximum BER capability when using the MSFN/RER 50-Hz carrier loop bandwidth was 4×10^{-4}. For the 700-Hz carrier loop bandwidth, the maximum BER capability was 1×10^{-3}. A possible cause was interference as a result of clipped voice spectrum.	Further investigation is continuing (presently an operational constraint).
A 28° rms IPM of bandlimited noise 300 to 800 Hz had a significant effect on the PCM BER (approximately 5-dB degradation at 1×10^{-4} BER).	A 28° rms limit for IPM was specified to the contractor.

Apollo lunar surface experiments package/MSFN USB gross compatibility tests (A-7). - The ALSEP communications equipment and a simulated MSFN receiver-exciter entered testing on December 1, 1966, and the work was completed December 22, 1966. Because the MSFN USB system had not been implemented to transmit and receive ALSEP frequencies, a USB system simulator (USBSS) designed to transmit and receive CSM and LM frequencies was modified to transmit and receive the ALSEP frequencies. Since the MSFN modification was not completely defined at the time the USBSS was modified, some assumptions were made to allow for the early implementation of the ALSEP modification. The ALSEP equipment was also not operational but was a "brassboard" model, electrically similar to the design concept.

Test results revealed several problem areas. First, the ALSEP receiver inverted the command phase-shift-keyed (PSK) signal (i.e., logic "1" and "0") with respect to the MSFN signal. Second, the telemetry channel performance was from 1.7 to 3.9 decibels lower than expected for a 1×10^{-4} error rate. This performance was dependent upon the bit rate, the telemetry receiver filter, and the PCM station configuration tested. A relative comparison of a telemetry channel BER test using the ALSEP transmitter showed performance from 1.8 to 2.6 decibels worse than the BER test results when another transmitter was used at the ALSEP frequency. Later tests (February 20 to 24, 1967) on a production-model ALSEP transmitter showed performance close to that expected for PCM.

Additional ALSEP/MSFN compatibility and performance evaluation tests were performed in January and February 1968. The purpose of these tests was, as before, to verify ALSEP/MSFN compatibility and to evaluate the performance levels and circuit margins for the ALSEP/MSFN communications system early in the manufacturing process for the ALSEP equipment. These tests, however, were performed using a production prototype ALSEP unit with the operational MSFN equipment. The tests consisted of the evaluation of UDL (command) and telemetry link performance and included the determination of rf interference effects between the ALSEP, the LM, and the CSM/MSFN communications links. Test results indicated satisfactory performance for the telemetry channel. No detrimental effects were noted during rf interference tests, but two significant problems with the UDL performance were detected: a 3-decibel degradation in ALSEP receiver noise figure, which affects threshold, and a polarity inversion of the received signal, which occurred in the ALSEP receiver.

The polarity inversion problem could be resolved by inverting the polarity of the transmitted ground signal; this solution, however, had to be implemented so as not to make the ground signal incompatible with the LM and the CSM UDL. Therefore, the GSFC personnel decided to utilize inverted PSK data to modulate the ALSEP up-link carrier. Also, the ALSEP manufacturer has accepted a specification requirement that each of the production ALSEP receivers provides the same polarity output signal for a given input signal polarity. This modification does not, however, solve the noise-figure problem, which is still being evaluated.

Apollo communications system phase I compatibility tests (A-8). - The ACS phase I (quick-look) compatibility tests were performed during February 1967. The purpose of this test phase was to provide an early indication of the level of compatibility and performance of a dual extravehicular astronaut communications system by using the space-suit communicator (SSC)/LM/MSFN/CSM system in support of dual extravehicular astronaut activity.

The original Apollo Program requirement for lunar surface operations was for one astronaut to explore the surface while the other stayed in the LM. The SSC system was developed to provide the communications capability for this original mode of operation. The SSC system provided for duplex voice between the extravehicular astronaut and the LM and for the transmission of extravehicular mobility unit (EMU) biomedical and status data to the LM. The LM system provided voice conference (among the extravehicular astronaut, the LM crewman, and the MSFN) and provided the relay of EMU data to the MSFN; the MSFN system could extend the voice conference to the CSM through S-band. In February 1967, the operational plans began to evolve to the "two extravehicular astronaut" procedure which was finally adopted. Because of this change in the lunar surface operational procedure, this quick-look series of communications system tests was performed.

The configuration tested is illustrated in figure 4. The tests consisted of determining voice intelligibility, data quality, and TV/EMU data interference and included an operational demonstration with astronauts manning the SSC and CSM test consoles and the MSFN spacecraft communicator position. Test results indicated that system voice performance did not meet the required 90-percent word intelligibility (WI) for any condition tested. Loss of LM S-band up-link lock or loss of the up-link voice subcarrier completely disrupted extravehicular-astronaut-to-extravehicular-astronaut

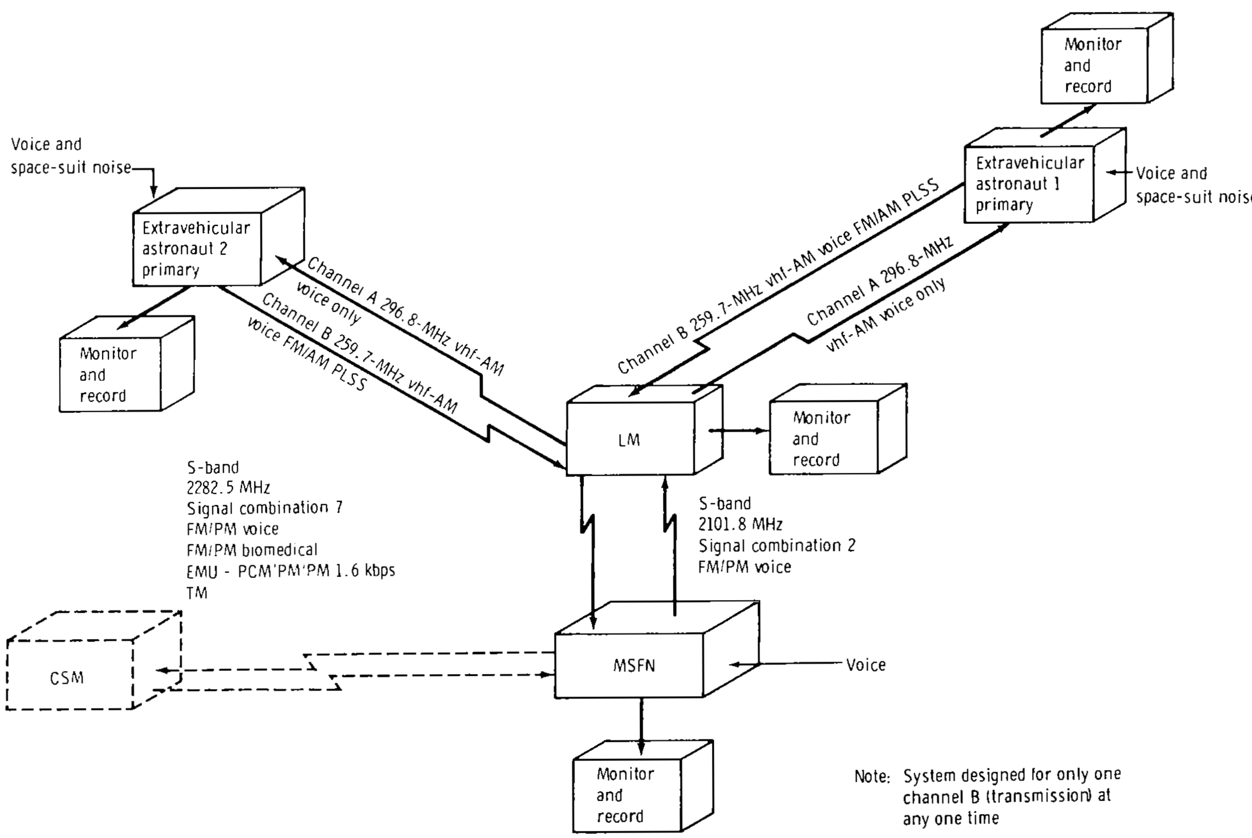


Figure 4. - Two-extravehicular-astronaut/LM/MSFN communication mode.

communications. Also, voice conference was not possible if either extravehicular astronaut transmitted EMU data, because this condition prohibited the other extravehicular astronaut from "breaking in."

The EMU data channels performed satisfactorily, providing that the LM TV deviation did not exceed ±1.5 megahertz. Without the transmission of EMU data, voice "break-in" was possible under careful procedure control. However, the demonstration was troubled by heterodyning and, as expected, by receiver tones caused by interaction with the stronger of the two-extravehicular-astronaut signals.

The tests and the demonstration proved that the ACS could not support the new two-extravehicular-astronaut requirement. Because this was a major problem, equipment redesign and modification were initiated. (See description of test B-6.) This effort led to the implementation of a voice subcarrier squelch for the LM S-band equipment and to the development of the extravehicular communications system (EVCS) to replace the SSC.

Apollo communications system phase II compatibility tests (A-9). - The ACS phase II (extravehicular astronaut/Block II CSM/MSFN) tests were performed during the period from March to September 1967. The purposes of the tests were to investigate in more detail the performance of the extravehicular astronaut/CSM/MSFN portion of the ACS tested in phase I and, in particular, to investigate possible operational modes to be used during the Apollo 9 mission. Updata and upvoice channel performance was found to be slightly better than indicated by Interface Control Document (ICD) circuit margins for most modes of operation. The command module (CM)-to-extravehicular-astronaut vhf voice channel was found to have considerable distortion; but WI was, nevertheless, close to the specified 90-percent level. Down-link telemetry channel performance was as predicted, but only after a premodulation processor problem was identified. The problem was a result of an inherent biphase modulation process for the high bit rate (51.2 kbps) showing up as a decrease in modulation index from the specified value whenever 51.2-kbps modulation of normal transition density was applied to the subcarrier. This appeared to be a general CM problem, not limited to the unit tested. Down-link phase modulation (PM) channel performance was acceptable. No problems were noted on the frequency modulation (FM) down link for 1:1 tape playback; but the 32:1 playback mode performance was, as in previous tests, less than desirable for both voice and telemetry. It was found that the 95-kilohertz scientific data subcarrier was present within the transmitted spectrum of the 32:1 playback voice; as a result, a 64-kilohertz postdetection filter was installed on the MSFN system to clear up this problem. The extravehicular astronaut/CM/MSFN voice relay performance was good, although a high level of between-word interference was heard as a result of extravehicular astronaut/biomedical data carrier interference. (See description of tests B-7 and C-19.) The extravehicular astronaut/CM relay of biomedical data was satisfactory. Television channel performance was acceptable, as was ranging channel performance. Tests included investigation of modified (reduced) modulation indices for up-link subcarriers as well as of specified indices. These reduced indices resulted from attempts to reduce rf tracker problems discussed elsewhere in this report and were tested here to determine their effects on channel performance. The reduced indices were found to be compatible with circuit margin requirements for the performance of the up-link channels.

Command and service module/ARIA compatibility tests (A-10). - The CSM/ARIA communications compatibility and performance evaluation tests were performed in February and March 1968. Tests were performed jointly by representatives of MSC, U.S. Air Force Eastern Test Range (ETR), and GSFC, using an ARIA aircraft on the ground at Ellington Air Force Base connected to CM and simulated S-IVB communications equipment set up in temporary quarters adjacent to the aircraft. The purposes of these tests were to verify ARIA/CSM USB compatibility and to evaluate the performance levels and circuit margins for the CSM/ARIA USB communications system prior to scheduled ARIA mission support. This test program also included tests to determine S-IVB/ARIA telemetry link performance and to determine if any interference between the S-IVB and CSM occurred at the ARIA receiver. The test program consisted of voice tests (ARIA-to-CM and CM-to-ARIA), telemetry tests (CM-to-ARIA and S-IVB-to-ARIA), and data-dump tests (recorded down-link information relayed to the MSFN from the ARIA after completion of active spacecraft coverage).

In general, the test results verified that systems compatibility and performance were commensurate with mission communications support requirements. During data-dump tests, however, the reconstructed PCM data from the ARIA recorder were severely degraded when received at the MSFN. A different modulation technique, using a subcarrier available from the tape recorder, improved the quality and was subsequently adopted. Other minor problems, such as phase-lock loop instability caused by ARIA receiver crystal oven on-off cycling, were also resolved.

Apollo communications system phase III compatibility tests (A-11). - The ACS phase III tests were designed to establish experimentally the actual performance limitations and the communications quality of the operational LM communications links prior to the first manned lunar landing mission. Included in these objectives was design verification of the redesigned (tests A-8 and B-6) EVCS production equipment insofar as the equipment was part of the LM communications link. Primary interest was in the voice channel performance between the LM and MSFN, and in the relay modes with the EVCS.

The original schedule called for test initiation in December 1968 (calibration tests) and completion of all tests by July 1969. Several other priority tests associated with the Apollo 11 and 12 missions, however, caused the schedule for the phase III test series to be extended through December 1969. These priority tests are discussed in later paragraphs. All mission critical modes were nevertheless tested prior to the Apollo 10 mission.

The phase III test series was divided into eight segments consisting of calibration tests; UDL tests; PCM telemetry tests; voice performance tests; an EVCS electrocardiogram (EKG), EVCS pulse amplitude modulation (PAM), and LM hardline (H. L.) biomedical tests; TV tests; a ranging test; and rf-acquisition tests. Calibration tests are a continuing item, a portion being performed for each segment. The UDL, PCM telemetry, voice performance, ranging, rf-acquisition, and EVCS PAM tests are complete. Television tests are complete, based on the new color TV system for the LM. The UDL tests, run from December 16, 1968, to January 10, 1969, showed that the LM UDL system performed within specifications and that performance was comparable to the Block II CM UDL system. Special investigation of the backup upvoice, however, revealed some problems that were related to the LM commander microphone and sidetone circuitry in the LM signal-processor assembly (SPA). The voice output level from the 10-kilohertz channel was too low; therefore, the signal was routed through the LM commander's microphone amplifier. This routing caused the backup upvoice to be turned around and transmitted on the LM down-link wave channel, producing an echo effect at MCC. Operational and hardware solutions were explored and several were found acceptable; because of the delivery and launch schedules, however, operational solutions (ground and spacecraft operator procedures) were recommended.

The telemetry tests were initiated on January 17, 1969, and, after several priority test interruptions, were completed on February 29, 1969. Results showed positive circuit margins in all cases except the baseband modes. Tests also showed that the LM telemetry subcarrier amplitude is reduced somewhat (8 percent) when modulated by the high-bit-rate data when it had a "1-0" transition density; this in turn affects the carrier modulation index and degrades overall performance by approximately 0.5 decibel. Other activity is aimed at correcting these problems.

Voice performance tests were begun on March 5 and were completed in mid-March 1969. Upvoice test results indicated positive lunar-distance performance margins for all voice up-link combinations for the omnidirectional antenna and the MSFN 85-foot-diameter antenna; however, onboard squelch operated at a total received power that was 7 to 10 decibels stronger than the worst-case specified total received power, indicating the possibility of premature loss of up-link voice under certain conditions. The squelch circuit can be switch deactivated, however. Down-link test results showed negative performance margins with the LM steerable antenna for certain signal combinations. The down-link relay voice test showed good performance for all modes of interest. The EVCS receiver tests showed good performance except for the case of EVCS-1 to EVCS-2 where only 70 percent WI was noted, quite possibly caused by EVCS-1 subcarrier interference. The vhf signal received at the LM was satisfactory.

Down-link emergency-key tests also run at this time indicated satisfactory performance for this communications mode. A 15-decibel discrepancy between predicted and measured AM-key demodulator predetection signal-to-noise ratio was observed. Investigation indicated that spurious response in the predetection filter, coupled with a larger than specified noise bandwidth, raised the effective predetection noise power.

The EVCS EKG, EVCS PAM, and LM H. L. biomedical tests were performed from April 1 to June 6, 1969. Results using flight-type hardware showed that system performance was satisfactory and that all worst-case performance margins were positive except for certain instances where the EKG and PAM are on down-link signal combination 10 with the LM steerable antenna and MSFN 85-foot-diameter antenna in use; these negative margins can be overcome, however, by use of the erectable antenna or the MSFN 210-foot-diameter antenna.

Because of the change to color TV equipment, TV tests are discussed in the following section as separate tests, not part of the planned phase III test series. Radio-frequency-acquisition and ranging test results are still being evaluated.

Special Tests

The major special tests (designated "B") are aimed at verifying particular channel compatibility and performance; at resolving real or potential major problems detected during the major tests, flights, or analyses; or at providing data or performance demonstrations to appropriate personnel for purposes of justifying changes, obtaining systems configuration approval, or illustrating effects of special equipment and conditions. These tests are discussed in chronological order in the following paragraphs.

Additional S-band tests (B-1). - The spacecraft equipment that underwent the initial Block I tests (series A-1) entered roughly 5 weeks of additional testing in September 1965. The primary purpose of these tests was to investigate several questions identified from the results of the Block I-E USB tests and from specific analytical studies performed by the MSC Communications System Analysis Branch. In general, the equipment used during these tests was the Block I-E spacecraft system and an updated MSFN RER system (serial number 14). In some instances, the modified E-5 transponder which simulated a Block II unit (and which was used in the simulated Block II tests, A-2) and three different 70-kilohertz UDL discriminators were used. The specific questions which were to be answered by these tests, and the results of these tests, are summarized in table VIII.

TABLE VIII. - ADDITIONAL S-BAND TESTS

Test	Purpose	Results
UDL	Determine the cause of degraded performance by investigating relative phase shift and 70-kHz discriminator FM improvement.	Apparent degradation in the UDL performance was found to be a result of degraded signal-to-noise ratio in the UDL discriminator. The cause was not identified, but areas for possible future investigation were identified. Relative phase shift should be held to less than $\pm 10^\circ$ of the 1-kHz tone. Larger phase shifts (25° to 30°) did not appear to degrade performance more than 0.5 dB, possibly as a result of the impulsive-type noise found in the discriminator output. (Previous direct tests used a Gaussian noise source.)
	Investigate slope difference in S-band and baseband BER curves.	This problem was found to be related directly to the signal-to-noise ratio discrepancy discussed previously.

TABLE VIII. - ADDITIONAL S-BAND TESTS - Continued

Test	Purpose	Results
UDL	Perform S-band tests with worst-case and best-case IAM up-link subcarrier oscillators, using a GSFC-supplied 5-percent AM 70-kHz SCO.	The effect of high IAM on link performance was noticeable. Lower modulation indices, however, minimized the problem for Block I.
PCM	Determine PCM performance by using predicted down-link signal levels as a function of up-link signal level.	Effects of weak up link were not observed when a constant 28-dB difference was maintained between up-link and down-link rf levels, because the PCM channel threshold occurred before the up-link carrier loop threshold.
	Determine the PCM degradation caused by turnaround up-link modulation by using reduced Block I up-link modulation indices for maximum and minimum values of TAR.	The PCM degradation was caused by turnaround of up-link modulation, using Block I turnaround ratios between 0.5 to 1.5 dB. This was considered significant if a marginal operational mode was to be used for Block I.
Upvoice	Determine if upvoice intelligibility could be improved by using pre-emphasis and clipping; and determine the amount of clipping desired, using original Block I modulation indices.	A 2-dB improvement for 90-percent WI was obtained, at carrier threshold, with 12 dB of clipping. Clipping of more than 12 dB did not increase improvement, and the 2-dB improvement was not considered significant for planned operational modes. However, clipping did allow more consistent setting of the upvoice modulation index. During tests, it was observed that the Block I audio center AGC action degraded signal-to-noise ratio by about 5 dB at the 90-percent intelligibility level. This should be considered in circuit margin calculations.

TABLE VIII. - ADDITIONAL S-BAND TESTS - Concluded

Test	Purpose	Results
Special	Establish PCM performance range as a function of IPM.	The IPM effects on BER increased as the modulating frequency decreased. This degradation became significant (2 dB) at PM rates of 50 Hz for a peak phase deviation of 38°. It also was significant for PM rates of 2000 Hz at a peak phase deviation of 45°. Bandlimited voice degradation increased more rapidly with increasing rms phase deviation. The conclusions drawn were that IPM in excess of 28° rms shaped as either a sine wave or Gaussian bandlimited noise significantly degraded the 51.2-kbps telemetry.
	Verify effects of updata phase reversal.	Tests confirmed that, when a 180° phase change was made, all messages were rejected.

Special FM tests (B-2). - The special FM channel tests were conducted jointly with GSFC from March 7 to 21, 1966, to investigate possible problem areas in the LM and the Block II CM FM transmission links. The primary area of concern was that the LM TV channel was ac-coupled; and, for a very-low-frequency video waveform, the information was greatly distorted. Also, when the video was completely differentiated, the transmitter peak-frequency deviation essentially doubled. Other areas of concern included effects of frequency offset caused by oscillator drift and Doppler effects and determination of the optimum FM demodulator configuration for critical FM modes. Both LM and Block II CM FM operational modes were tested. The FM transmitter used for this test was the transmitter associated with the USB test set; the FM transmitter, which is a direct-coupled device, was used to simulate the LM transmitter by the incorporation of an external ac network.

To achieve the test objective, tests of TV picture quality, TV channel signal-to-noise performance, PCM channel signal-to-noise performance, PCM BER, and split-phase telemetry signal-to-noise performance and BER were tested. Results and conclusions for both LM and CSM configurations are presented in table IX.

TABLE IX. - FREQUENCY MODULATION TEST RESULTS

Lunar module configuration	Command and service module configuration
The 4-MHz prefiltered demodulator improved TV channel performance in the threshold region; however, normal operational mode (signal combination 10) picture quality and BER (PCM 51.2 kbps real time) were not significantly improved over the unfiltered configuration when operating at the LM carrier center frequency. Offset frequencies of ± 350 kHz had little effect on TV channel performance for either the prefiltered or unfiltered demodulator configuration; however, bit error rates were degraded in the region from 1×10^{-4} to 1×10^{-6} by such offset frequencies when the 4-MHz prefiltered demodulator was used. (For some cases, degradation was more than for the unfiltered demodulation configuration.) For offset frequencies more representative of lunar operations (150 kHz), the 4-MHz prefiltered demodulator configuration indicated less degradation from the nominal center frequency case than previously noted and still provided improved performance over the unfiltered demodulator configuration at all signal levels of interest. Components caused by intermodulation of the 1.024- and 1.25-MHz subcarrier (226 kHz or multiples thereof) did not appear in the demodulated TV spectrum.	The dc restoration completely restored all low-frequency video information and did not adversely affect system performance. The 4-MHz prefiltered wide-loop demodulator configuration was seriously degraded by carrier offset frequencies of -600 kHz. The unfiltered narrow-loop performance for the TV channel was essentially as good as the 4-MHz prefiltered configuration and considerably better for carrier offset frequencies. Acceptable picture quality was obtained at signal-to-noise ratios into the TV monitor which were less than required by the circuit margin ICD for the Block II CSM. The simulated split-phase telemetry channel test results indicated that improvement obtained by the 1-MHz prefilter (approximately 6 dB) only held true at the nominal carrier center frequency. Channel performance was degraded (for a 1-MHz prefiltered configuration) when offset frequencies of ± 400 or ± 500 kHz (or both) were simulated. Channel performance for all demodulator configurations including conditions of ± 500-kHz carrier offset frequencies was apparently adequate based on expected received signal levels for 85-foot remote sites with cooled parametric amplifiers (assuming no degradation of noise spectral density as a result of received signal levels).

TABLE IX. - FREQUENCY MODULATION TEST RESULTS - Concluded

Lunar module configuration	Command and service module configuration
Black-and-white patterns (low-frequency video signals) could not be reproduced by the LM TV channel when the low frame rate (0.625 frame/sec) system was used without the aid of dc restoration at the TV monitor. The dc restorer corrected for a completely differentiated signal, indicating that adequate performance could be expected for low-frequency patterns by using dc restoration.	All demodulator configurations produced bit error rates of 1×10^{-6} at received rf signal levels weaker than the nominal expected received signal level from lunar distances. It was noted that real-time PCM was used during all of the split-phase telemetry BER tests, and hence effects of the tape recorder were not present in these data.
Acceptable picture quality was obtained at signal-to-noise ratios into the TV monitor which were less than required by the Block II circuit margin ICD. This was thought to be a result of the Block II synchronization burst format providing better monitor synchronization at lower input signal-to-noise ratios than when the synchronization tip format (Block I) was used.	

High-gain/steerable antenna static tests (B-3). - During 1967, several tests were performed to determine spacecraft/MSFN compatibility with the spacecraft high-gain (CM) or steerable (LM) antenna in the link. These tests were performed by using spacecraft electronics, including the antenna, located in the Antenna Test Range/ Anechoic Chamber Test Facility at MSC. The MSFN USB RER equipment used for these tests was located in the ESTL at MSC. Communication between the MSFN equipment and the spacecraft antenna/electronics was effected through a 16-foot-diameter parabolic-dish antenna located on the roof of the ESCF and through a similar (although smaller) antenna located on the roof of the Antenna Test Range/Anechoic Chamber Test Facility. The distance between the antennas was approximately 1500 feet.

The LM steerable antenna compatibility tests were performed in three stages during the spring of 1967. Initial tests that used specified spacecraft and MSFN parameters and transmission modes were run in March 1967. Tests were essentially static in nature; that is, no dynamic spacecraft motion was simulated. Results of these tests revealed that position errors (pointing errors) of the LM steerable antenna were out of specification. Analysis of the problems indicated that the probable cause was IPM on the S-band up-link carrier, which in turn was caused by IAM of the upvoice subcarrier. Further testing confirmed this problem and indicated that upvoice subcarrier oscillators (SCO) with reduced IAM improved tracker performance to within specification; similar improvement was obtained by reduction of up-link carrier modulation indices. Subcarrier deviation changes had no significant effects on tracker error performance.

The CM high-gain antenna tests were performed in November, using subcarriers with improved AM characteristics and using both specified and reduced modulation indices. Results were in agreement with tests run with the LM steerable antenna and showed that the reduced modulation indices and AM parameters allowed antenna performance within specifications for the static conditions tested.

Frequency modulation demodulator threshold-extension tests (B-4). - Study of analysis and testing results up to the summer of 1967 indicated conclusively that performance of the Apollo CM communications system in the FM mode would be seriously degraded under certain operational modes at lunar distances. Particularly, playback telemetry and voice, as well as TV information, were expected to be poor. The identified reasons were the following:

1. The signal level arriving at the MSFN receiver was below the "threshold" of the FM receiver-demodulator combination.

2. The performance of the MSFN FM demodulator, operating in the below-threshold region, was less than specified.

Spacecraft transmit power was increased slightly by various means including shortening of some cable lengths, but the effective increase was not sufficient; and it was determined that the greatest improvement potential was on the MSFN. These problems, and tentative conclusions, were presented to Major General Samuel P. Phillips of NASA Headquarters at the Apollo Communications System Performance presentation on September 25, 1967. Working with GSFC and the NASA Langley Research Center, MSC personnel tested several techniques to achieve improvement. The GSFC personnel supplied a revised procedure for detailed tuning and alinement of the MSFN FM demodulator. After this procedure was implemented, the demodulator was placed in systems tests. A Lunar Orbiter-proven FM demodulator (with feedback) was also tested for basic compatibility and performance, as was an in-house designed and fabricated threshold-extension device (click eliminator). The retuned MSFN FM demodulator did not perform significantly better than it had before. The click-eliminator tests indicated significant threshold extension (2 to 4 decibels) for voice and similar results for telemetry and TV. The FM feedback (FMFB) demodulator results were also quite encouraging and warranted further development.

Further effort during the ensuing 12 months resulted in tests during September 1968 of five FM demodulators and of a refined click eliminator. The four demodulators were (1) the MSC MSFN demodulator, (2) a retuned and realined (by the Applied Physics Laboratory (APL) at Johns Hopkins University) MSFN demodulator furnished by GSFC, (3) an MSFN demodulator modified by GSFC (to improve alinement procedures), (4) a conventional demodulator furnished by GSFC, and (5) a modified (for Apollo modes) Lunar Orbiter FMFB discriminator provided by MSC. The tests were witnessed by GSFC personnel. None of the MSFN or MSFN-type demodulators performed as expected, with the possible exception of the APL-retuned unit. The conventional unit also was disappointing. The FMFB demodulator showed significant improvement but, in its existing state, was difficult to interface with the MSFN receiver. The click eliminator worked quite well.

Further effort by GSFC resulted in their contracting for new MSFN FM demodulators. A prototype unit was brought to MSC by GSFC in early December 1968, along with the APL-realined unit, to compare performance of these units with the MSC MSFN demodulator for the specific purpose of determining the optimum unit to use on the 85-foot-diameter antenna sites for the Apollo 8 mission. The results of these tests clearly indicated that the new GSFC prototype unit was the best, and the unit was subsequently used on the Apollo 8 mission. The MSC personnel supplied six click eliminators (built in-house) to the three 85-foot-diameter antenna sites (one prime and one backup) for the Apollo 8 mission, and these were installed and operational on one site in time for the Apollo 8 mission with generally satisfactory results. During the last week of March 1969, a production version of the new demodulator was loaned to the ESTL for a series of tests involving the LM in a lunar surface (relay) FM configuration and the CSM in various FM configurations. These tests used the Communications Systems Engineering Laboratory breadboard EVCS system throughout the program. In general, the new demodulator showed significant improvement (4 to 6 decibels) in performance for CSM voice-dump modes and increased performance for CSM slow-scan TV. The LM signal combination 10 performance was deemed adequate to support the lunar mission but was not significantly improved over the original demodulator system. It should also be noted that good picture quality for the commercial TV signal format was expected to require use of the JPL 210-foot-diameter antenna system. Because of somewhat different characteristics of the new GSFC demodulator, the click-eliminator effort is being continued to optimize its performance with these units.

Split-phase PCM tests (B-5). - In the preoperational period of LM development, a serious potential problem in PCM channel performance was uncovered. The instrumentation loading and grounding scheme for the LM allowed the possibility of several periods in the bit stream being without transitions as a result of open or floating channels, with resultant pickup of electrical noise in the spacecraft. Lack of transitions for extended periods of time (relative to frame length) could possibly cause the ground telemetry processors to lose data. As a result, serious consideration was being given to changing the PCM encoding on the down-link from nonreturn to zero-level (NRZ-L) to split phase because a split-phase output was already being generated in the LM for the LM-to-CM relay at 1.6 kbps. (This encoding scheme guarantees a transition during each bit period.) Because of these considerations, tests were performed in the ESTL during December 1967 and January 1968 to determine the performance of the LM PCM channel when using split-phase encoding under simulated operational conditions and to determine if any detrimental effects on downvoice and ranging were present as a result of this encoding.

Tests were performed to analyze both NRZ-L and split-phase PCM channel performance using the existing LM SPA configuration and also using a simulated LM SPA with the output bandwidth modified (widened) for split-phase operation. Results of tests with the existing SPA configuration indicated that split-phase performance was poorer than NRZ-L performance by about 2 decibels and that the split-phase encoding was more sensitive to ranging signal interference. The test results obtained by using the modified SPA indicated that split phase performed slightly better than NRZ-L, probably as a result of a more stable clock reference. An interesting result was that the NRZ-L also performed better with the wider output bandwidth, indicating that the existing SPA design was not optimized. Nevertheless, because of time and cost impacts, the changes to split-phase encoding for the PCM channel were not approved, and increased monitoring of channel loading for each LM was effected.

Unified S-band/EVCS system design verification tests (B-6). - Extravehicular communications system (two-extravehicular-astronaut mode)/LM/MSFN voice and data relay communications compatibility and performance evaluation tests were performed during April, May, and early June 1968. These tests were performed as a result of a new mission requirement for two-extravehicular-astronaut operation on the lunar surface. The inability of the original Apollo extravehicular astronaut communications system to meet this requirement (test A-8) required that a new (redesigned) system be implemented. The new system, designated EVCS, was to be designed, fabricated, and qualified with minimum impact (change) to the LM communications system prior to the planned first lunar landing.

Major changes made to achieve the dual-EVCS system were (1) implementation of an FM transmit link from EVCS-2 to EVCS-1 for relay of EVCS-2 voice and data to the LM through EVCS-1 in the primary mode of operation and (2) reduction of the number of subcarriers (seven for the old case) to a total of four for dual-EVCS operation. As a result of the short period of time available for development and qualification of the new system, major emphasis was placed on performing end-to-end rf system (dual EVCS/LM/MSFN) design verification and performance evaluation tests. Of major concern at the time (and also the specific objective of the test program) was the experimental determination of minimum performance requirements for (1) the EVCS subcarrier levels to be modulated onto the 1.25-megahertz subcarrier (the LM SPA had been designed for seven subcarriers) and (2) the deviation of the 1.25-megahertz subcarrier on the S-band carrier. (Analysis of vendor acceptance test procedure (ATP) data showed that, although within specification limits, all signal-processor assemblies were performing at or near the minimum (worst-case) deviation level.)

The TCSD constructed a dual-EVCS system (engineering breadboard) which was used along with a "special" LM SPA (modified to provide the capability to adjust the EVCS subcarrier levels and, consequently, the deviation of the 1.25-megahertz subcarrier) and existing LM/MSFN systems in the ESTL. The configuration tested is illustrated in figure 5. Major results of the test were that the EVCS minimum specified performance for LM signal combination 10 (EVCS voice, telemetry, portable life support system (PLSS), EKG data, and TV) was unacceptable and that this minimum specified performance could be improved to an acceptable level, as shown by test data, by increasing either the EVCS subcarrier levels or the 1.25-megahertz subcarrier deviation on the carrier.

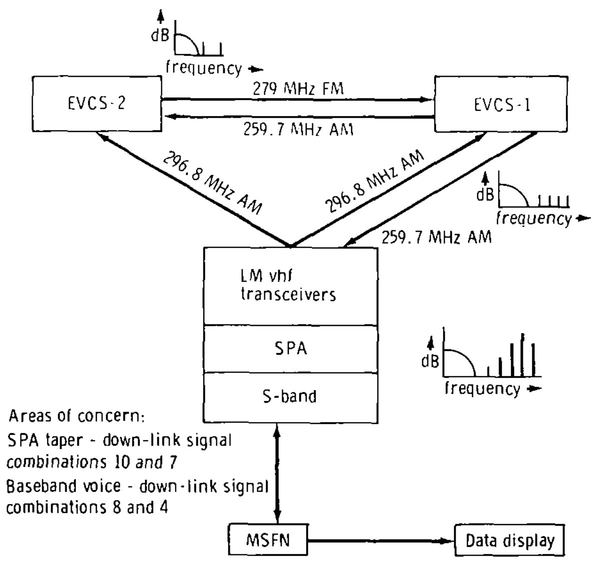


Figure 5. - Design verification test of the EVCS-LM-MSFN system.

In an effort to prevent the necessity for modifications to the SPA, a review of vendor ATP data related to the S-band modulator sensitivity was initiated. It was found that, for most cases, the modulator sensitivity was near the "high" limit of the specification, a factor that compensates for the minimum 1.25-megahertz level output of the SPA. Test results and related information presented to the CCB on June 14, 1968, resulted in the decision "not to modify" the SPA, but to monitor ATP data to ensure that a worst-case system would not be assembled (i.e., a system which had three simultaneous conditions of (1) minimum deviation of the EVCS subcarriers onto the 1.25-megahertz subcarrier, (2) minimum 1.25-megahertz output from the SPA, and (3) minimum S-band modulator sensitivity).

Test results on the EVCS performance for two extravehicular astronauts with LM PM signal combination 7 (voice/H.L. biomedical/EMU data/1.6-kbps telemetry) indicated that the EVCS would not perform properly in the low-power signal combination — the design configuration. The board agreed that all extravehicular astronaut activity requiring this mode would be performed with the S-band power amplifier operating in the high-power mode.

In addition to performing EVCS design verification tests during this time period, an attempt was made to resolve the problem of low-bit-rate telemetry BER degradation caused by baseband voice interference with the telemetry channel (occurs for signal combinations 4 and 8). Test results were presented to the June 14 CCB, resulting in the decision to accept momentary telemetry data dropouts during speech periods.

Apollo 9 mission voice demonstration (B-7). - An Apollo mission D (Apollo 9) simulation was conducted in the ESTL in June and July 1968, with participation by the prime and backup crews for the Apollo 9 mission and the prime crew for the Apollo 10 mission. This simulation was an effective demonstration of the complexity of switching and controlling required to properly communicate in the communications system configuration planned for the Apollo 9 mission. A system problem occurred when the CM was configured to relay extravehicular astronaut voice and PLSS telemetry signals on the S-band down link. The configuration involved a combination of duplex and simplex vhf, which required the operation of both vhf receivers in both the CM and the LM (a nonstandard configuration peculiar to the Apollo 9 spacecraft). During this configuration, frequency mixing occurred in the CM vhf transceiver unit which caused a significant increase in audio background interference at the ground station as a result of beat frequencies and harmonics of the PLSS telemetry subcarriers. When the CM vhf-A receiver was not activated, the interference level was reduced to that normally expected; however, in this configuration, the CM could not communicate with the LM. It was observed that the interference problem also adversely affected performance of the PLSS telemetry channels. Resolution of the extravehicular astronaut voice and PLSS telemetry problem was achieved by later special testing. (See description of test C-19.) The Apollo 9 CM vhf transceiver was modified to correct the frequency-mixing problem peculiar to the Apollo 9 configuration.

Special Apollo 8 mission tests (B-8). - A series of special tests was performed to verify certain operational modes (including a nonstandard signal combination having backup voice, low-bit-rate telemetry subcarrier, and ranging on the carrier) and procedures planned for the Apollo 8 mission. These tests were performed in November and early December 1968, and involved evaluation of proposed MSFN ranging and acquisition procedures and of performance of PM down-link mode 8 under expected mission conditions. Test results indicated that the GSFC-proposed ranging and acquisition procedures were acceptable, that down-link emergency-key channel performance was acceptable, but that up-link automatic gain control (AGC) key (not a normal mode but evaluated at the request of the MSC Flight Support Division) copying was limited to three words per minute as a result of slow onboard AGC and meter response. Voice and telemetry tests indicated telemetry channel performance degradation of approximately 2 decibels when ranging was also on the carrier, indicating, as was expected, a need for more stringent control of omnidirectional antenna switching when ranging was to be used. The baseband voice channel performance was affected very little by the ranging code or clock.

Lunar module color TV tests (B-9). - Several tests were performed from May to August 1969 to evaluate possible use of the CM sequential color TV system (configured to operate in a lunar surface environment) with the lunar module FM TV transmission channel. The two basic areas investigated were (1) performance of the color TV with postdetection bandwidth limiting to prevent interference caused by the 1.024-megahertz (telemetry) and 1.25-megahertz (voice) subcarriers and (2) degradation (interference effects, etc.) of the PLSS/biomedical data and telemetry data caused by the color TV modulation. Tests were performed as a function of total received power with various premodulation and postdetection filters.

Test results indicated that TV postdetection filtering would be required to remove the interference caused by the 1.024- and 1.25-megahertz subcarriers. Premodulation filtering at the LM was not necessary. The recommended postdetection filter was band-limited to 900 kilohertz with resistor-capacitor (RC) characteristics. Other filters were evaluated but have not been successfully demonstrated to date. The 900-kilohertz filter used was 3 decibels down at 320 kilohertz, 14 decibels down at 900 kilohertz, and 17 decibels down at 1.024 kilohertz.

It was also determined that the sequential color TV deviation could be increased to a maximum of 1.6 megahertz with the telemetry, voice, EKG, and PAM channel performance remaining approximately (1 decibel or less) equal to the case using slow-scan black-and-white TV. Preemphasis was not recommended for the LM because of additional degradation (1 to 2 decibels) to the EKG and PAM channels.

Tests also showed that the rf power margins for good-quality sequential color TV are such that the MSFN 210-foot-diameter receiving antenna would be required if the spacecraft steerable antenna was to be used. With the erectable antenna, an MSFN 85-foot-diameter antenna receiving station would provide adequate performance margins.

Apollo lunar surface experiments package command anomaly tests (B-10). - The objective of the ALSEP command anomaly tests, which were performed in August 1969, was to determine, by experimental means, the performance of the ALSEP command channel under different MSFN-to-ALSEP up-link conditions. Of particular interest was a determination as to whether previously experienced problems could be repeated and explained.

During checkout of the ALSEP at the manufacturer's facility, at the NASA John F. Kennedy Space Center (KSC), and during the Apollo 11 mission (early Apollo scientific experiments package (EASEP) operation), conditions which required special investigation were experienced. One of the conditions was a command verification (CV) problem. When the ALSEP received a valid up-link command, it sent a down-link verification of the received command followed by an extraneous verification of a 177 command (approximately one time for eight valid up-link commands). However, because the 177 command is not an allowable command, it was not executed by the ALSEP and caused no harm. Cursory circuit analysis indicated that the CV-177 condition discussed will always produce a verified but unexecuted command. Another unexpected condition was the receipt of a CV without an up-link carrier. The EASEP, left on the lunar surface by the Apollo 11 crew, sent false verifications of nontransmitted commands at the rate of approximately three per hour during periods when no up-link signal was present. In addition, because ground testing performed with more than one up-link rf carrier showed that false command verifications occurred, additional data concerning the effects of two simultaneous up-link rf carriers with several possible combinations of modulation were needed. Therefore, tests to measure performance characteristics — such as received carrier power, commands sent, commands verified, and commands executed — were initiated.

For a single up link, operating near command threshold with all "1's" modulated on the carrier, a random CV was received on the average of one each 1.7 seconds. None of these commands was executed; but, given enough time, it is likely that an execute would have occurred. For a single up link near command threshold with a 1-kilohertz sine wave modulated onto the carrier, random commands were executed an average of one each 1.3 minutes, and an average of 1.4 random command verifications were received each second. The latter condition could result if the 2-kilohertz component of the PSK signal failed at a site. If this were to happen and up-link modulation were not removed quickly, several undesirable commands could be executed.

False verifications of 177 commands occurred after proper execution and verification of a valid command, and the frequency of these occurrences was approximately one time in eight commands for normal down-link telemetry bit rate and one time in 16 commands for low bit rate. Even though this is an anomaly, it was not considered a serious problem. For dual up link, the ALSEP was jammed for signal levels within 0.5 decibel of each other. It was found that there must be at least a 3-decibel difference in total received power between the two up-link signals to ensure execution of commands sent on the stronger up link. For most dual-up-link conditions tested, it was possible to have random commands executed. The rate at which this occurred depended on relative PSK phasing and relative power levels. On the average for all dual-up-link tests conducted, one random command was executed each 7 minutes.

With no up-link carrier, a test was run for a 10.5-hour period; and 23 random command verifications were received. This was an average of one CV each 27 minutes and agreed with the results obtained from the EASEP left on the lunar surface during the Apollo 11 mission. None of these commands was executed; but there is unity probability that, in some finite time, a random command would be executed. The time required has been calculated to be approximately 1000 years per command execute.

As a result of the tests, it was concluded that the execution of random commands and the reception of random command verifications could occur under many different conditions. The random command verifications could be confusing to an operator, and the execution of random commands could cause loss of a one-time experiment capability or the interruption of data from an experiment package. Furthermore, probability analysis has indicated that the occurrence of commands as noted previously agrees closely with expected random occurrences based on coding structure of the command words. Some of the commands that were randomly executed included such things as the removing of dust covers and the arming and firing of grenades. In view of this, it was recommended that crew safety considerations be reviewed to ensure that no danger to an astronaut exists. If safety is deemed a problem, one possible solution is to completely deploy the ALSEP with power off and to activate the ALSEP only at the time the crew is preparing to leave the lunar surface.

To minimize the likelihood of execution of random commands, it was recommended that no more than one up-link signal be transmitted to the ALSEP at any one time. It was further recommended that one up link be transmitted to the ALSEP at all times the unit is activated (except during MSFN site-handover times) and that care be taken to ensure that the total received power at the ALSEP remains well above threshold. A signal level greater than -95 decibels referenced to 1 milliwatt (dBm) was considered desirable.

Apollo Lunar Scientific Data System/MSFN design verification tests (B-11). - Apollo lunar mission tests associated with the evaluation of the spacecraft 112 (CSM) configuration were performed in the ESTL. This configuration involved two modes of operation. These were (1) real-time data modulation of the scientific data subcarriers (95 kilohertz, 125 kilohertz, and 165 kilohertz) on S-band with no telemetry (1.024-megahertz subcarrier) or baseband voice and (2) recorded scientific data modulation mode with telemetry and baseband voice on S-band. To evaluate these configurations, signal-to-noise ratio and BER tests were performed in the ESTL. An initial calibration test was performed to determine the level of data modulation of the scientific data subcarriers. In the real-time mode, a maximum frequency deviation of ±7.5 percent of the subcarrier center frequency could be obtained. In the recorded data mode, the level of subcarrier modulation was limited by the data storage equipment (DSE) electronics. (Note: the recorder used was not the one planned for use with the scientific data system.)

Test results showed that real-time data modulation of the scientific data subcarriers (95 kilohertz, 125 kilohertz, and 165 kilohertz) was possible only when the S-band transmission contained only the scientific data subcarriers: that is, the S-band transmission excluded telemetry (1.024-megahertz subcarrier) and baseband voice. The recorded data modulation of the scientific data subcarriers was apparently limited (by DSE electronics) to a level which did not provide a frequency deviation of ±7.5 percent of the subcarrier center frequencies. Positive scientific subcarrier predetection signal-to-noise margins were indicated for the real-time and tape modes.

Since the characteristics of the scientific data information were not fully known at the time of these tests, a conclusive performance test could not be performed on the scientific subcarriers. The results of the tests performed in the ESTL, however, do indicate that adequate performance can be expected for the usual type of data encountered.

Additional Apollo lunar mission systems tests were performed in the ESTL with a simulated spacecraft 113 system configuration. The results indicated that the signal performance was not adequate to support mission requirements. Based on the results of these tests, the signal design has been changed to improve channel performance.

Support Tests

The primary purpose of the support tests (designated "C") was, for the most part, to obtain more information on specific problem areas identified or suspected within a channel, as opposed to overall channel or overall systems performance evaluation. Some of the tests preceded major special tests or major test phases and were intended to evaluate fixes to problems or to gain critical information as soon as possible in the test series. Several of the support tests are discussed briefly, in chronological order, in the following paragraphs.

Gemini command processing tests (C-1). - From March until August 1965, the command equipment (digital command system and down-range up link (DRUL)) and the communications terminal (201A and R028) equipment of the ESTL were used in conjunction with the ESTL Univac 1218 computer to support test and operations of the MCC-Houston (MCC-H) down-range command link (to ETR, Corpus Christi, and Bermuda). The support was performed during prelaunch preparation and in real time during the flights of Gemini III, IV, V, and VI. The purpose was to provide monitoring of the command data originating in the MCC-H and, after processing the data to check for valid coding, bit dropout, and so forth, to return the results of this processing to a teleprinter in the MCC-H. The testing included checkout of a program to do the task and the fabrication of a high-speed data line buffer to interface the 201A equipment with ESTL equipment. Subsequent to the Gemini VI mission, MCC-H developed an internal capability to perform the effort; and the ESTL was released from this support requirement.

Manned Space Flight Network PCM data processor (MSFTP-1) improper lock and transition density tests (C-2). - Tests were performed in the ESTL during April 1966 to determine the performance of the CSM PCM data channel as a result of the absence of the 40-bit guidance and navigation computer word in the PCM bit stream. It had been established that periods of no transitions in the PCM wave train could possibly extend to 54 bits during actual flight. Tests were performed with the MSFTP-1 (serial number 19) in the test setup. An unexpected result of the tests, and one which subsequently took up most of the time scheduled, indicated the possibility of the PCM ground station maintaining improper frame-synchronization lock under conditions in which the signal conditioner input signal-to-noise ratio was equal to or less than that required for a 1 in 10^{-4} BER, when two or more "lock frames" were selected and when a 1-bit window was programed in the frame synchronizer.

The problem first appeared when the Univac 1218 computer was utilized to determine BER as a check on the serial bit error detector (SBED) used in previous tests. The Univac 1218 print-out indicated more errors than the SBED for a simultaneous run. It thus became apparent that the data, which should have been inhibited from the computer when frame synchronization was lost, were not being inhibited and that they were not being decommutated into the proper 8-bit groupings. Additional tests indicated that the frame synchronizer was not losing lock even though circuit tests indicated that correlation was occurring at the wrong time in the data. By further testing, it was found that the improper lock was caused by an overlap of approximately 20 to 30 nanoseconds of control and timing pulses at the digital-to-analog control gate in the decommutator. This condition was apparent when the bit-rate clock (as a result of noise on the input to the signal conditioner) became a 1-bit period behind in phase with the data. The GSFC personnel were notified of the problem and took corrective action on the MSFTP-1. Transition density tests were inconclusive, as the SBED results showed very little degradation caused by lack of transition for up to 54 bits, but effects on the decommutation process were masked by the improper lock problem. (Later tests on an MSFTP-2 PCM processor indicated no effects for lack of transitions of up to 200 bits.)

Goddard Space Flight Center aircraft transponder test (C-3). - On June 20 and 21, 1966, the ESTL, at the request of GSFC personnel, performed exploratory tests on a CSM Block I-D model USB equipment package from one of the GSFC flyby aircraft. In brief, the tests pointed out that one of the transponders performed within specification when specified nominal power voltages were used in the ESTL and that the other transponder performed within specifications when nominal power was applied, except that the turnaround ratio (TAR) for the PRN range code was too high. When applied power voltage was reduced to attain low test-point voltage outputs (13.5 volts dc) as experienced in the aircraft, circuit margins and thresholds were adversely affected on both units. The high-TAR transponder, in UDL tests, leveled off at a PCM subbit error rate (SBER) of 5×10^{-5}, which could not be improved. An inspection and check of the aircraft 400-hertz power supply indicated a problem in filtering of the three-phase power. Shorting one of these filters raised the voltage at transponder 15-volt test points to within specification. Normal transponder operation, except for the high TAR on one unit, was then experienced in the aircraft environment.

Apollo UDB performance tests (C-4). - Special Apollo UDL quick-look tests were performed in the ESTL to investigate UDB output distortion relative to the DRUL and digital command system output (1- and 2-kilohertz composite). Representatives from GSFC had reported the existence of this distortion and had indicated that the UDL performance might be below the expected performance.

The specification for the UDB modulator (PSK) output was the same as for the DRUL. The PSK waveform for all "1's" and all "0's" was the same as for both the UDB and the DRUL; however, the PSK waveforms were not the same for data transitions. The UDB PSK signal was amplitude distorted when a "0" to "1" transition occurred. The SBER tests were performed as a function of received power with the Block II UDL decoder to determine if UDL channel performance was degraded by this distorted PSK signal. The specific tests performed were (1) SBER as a function of received power, (2) comparison of UDB and DRUL waveforms, and (3) comparison of UDB and DRUL modulator alinement methods.

The results of the SBER as a function of received power tests indicated no degradation in the UDL channel performance when using the UDB. It was noted, however, that the DRUL had been in operation for some time and had been tested with several different UDL decoders and that the DRUL performance was satisfactory with each UDL decoder. Until the UDB was tested with other UDL decoders, such as the ALSEP command decoder, it was not considered practical to assume that its performance (under the then current configuration) was completely satisfactory.

The unsymmetrical 2-kilohertz sine wave of the UDB appeared to be the result of crosstalk from the 1-kilohertz sine wave at the PSK summing point. Better isolation in the summing network was judged capable of preventing this distortion of the

2-kilohertz sine wave. This would also improve the accuracy of the amplitude setting and the zero-crossing alinement of the UDB modulator.

The UDB alinement method was not easily understood, but basically, the designated alinement procedure was to obtain the best PSK signal under steady-state conditions (no transitions) with little concern for the independent relative amplitude and phase relationship of the 1- and 2-kilohertz sine waves. The zero crossings of the DRUL sine waves occur at the same point and were positive slopes as defined for a DRUL "1" bit. The zero crossings of the UDB sine waves for a positive slope 2-kilohertz sine wave and a negative slope 1-kilohertz sine wave occurred approximately 100 microseconds apart. It appeared that the most desirable method for modulator alinement would be with a scope presentation of both sine waves and not with one shorted to ground. It also appeared that the 1- and 2-kilohertz sine waves were enough out of phase that, when the transition from "0" to "1" occurred (180° phase shift), the transition occurred at some point other than 180°; and this produced the distorted waveform.

While more extensive testing of the UDB was considered necessary, the basic purpose of this series of tests was satisfied; that is, the UDB performed satisfactorily with the Block II UDL decoder, and the distorted PSK waveform did not degrade the UDL channel performance. As a result of these and subsequent tests, GSFC personnel issued changes to the UDB modulator to correct the situations noted previously.

Astronaut demonstration of two-extravehicular-astronaut communications (C-5). - During the later phases of the ACS phase I compatibility tests (A-8), a demonstration of the two-extravehicular-astronaut communications links relayed to earth through the LM was conducted for a group of astronauts on March 10, 1967. The SSC that was not changed for two-extravehicular-astronaut conferencing was used. In general, the astronauts' comments were that system performance was not satisfactory and that several changes would be needed. This appraisal agreed, in general, with test results up to that point.

Lunar CSM/MSFN voice configuration demonstration (C-6). - A demonstration was performed with the Apollo lunar CSM/MSFN voice configuration in the ESTL on July 24, 1967, with attendees including Robert R. Gilruth, Maxime A. Faget, Christopher C. Kraft, John D. Hodge, George M. Low, and others. Because LM equipment was not available, the demonstration was performed with CSM spacecraft equipment only. The general conclusion on the demonstration results, drawn from the comments of the attendees, was that the system was satisfactory for its intended purpose.

Upvoice channel demonstration (C-7). - A demonstration of the effects on the CSM upvoice channel performance from loss of up-link lock or of the up-link 30-kilohertz subcarrier was performed during July 1967 for the MSC Astronaut Office. The stated opinion of the astronaut representative was that the system could be used satisfactorily in its current configuration, although noise present was undesirable, and a control had to be adjusted to reduce it each time the up link or the 30-kilohertz SCO signal was lost. (See description of test C-18.)

Apollo Applications Program TV demonstration (C-8). - During late September 1967, a demonstration of commercial scan-rate TV through the CSM Block II FM system and the MSFN equipment was conducted at a simulated range of 2000 miles to test the TV capability planned for the Apollo Applications Program (AAP) (Skylab). The results were favorable.

Apollo 4 (AS-501) countdown demonstration test support (C-9). - During the Apollo 4 Countdown Demonstration Test (CDDT) in October 1967, the Merritt Island Launch Area (MILA) S-band station and several other receiving sites at KSC experienced fluctuating signals and asymmetrical sidebands, resulting in degraded PCM telemetry at various times in the count. These stations were in a relatively poor area of the spacecraft antenna pattern (between the two radiating elements). Since the JPL station (number 71) was almost directly in the major lobe of one element, this station was requested to examine the signal during the final terminal count. The report was that the signal appeared excellent at all times. This tends to confirm that the problems at MILA and the other stations were caused by interfering signals radiating from both antenna elements and reflections from other objects (multipath). An intensive investigation was initiated to determine if any phase and amplitude differences between the two radiating elements could cause telemetry degradation in flight (other than that indicated in the composite antenna patterns).

Tests in the ESTL confirmed that the variations in signal spectrum could be caused by the interferometer phenomena associated with radiation from two sources. These tests also showed that telemetry reception could be degraded if the signal received from one of the two sources was not at least 6 decibels greater than the signal received from the other source. As a result, the JPL station was asked to support the final countdown and launch phases.

Application of the test results to the high-apogee portion of the Apollo 4 mission showed that the USB telemetry might be degraded near the end of the Carnarvon, Australia (CRO), pass and for portions of the Guam pass as the antenna patterns were not favorable at these times. Analysis was done to show that vhf telemetry coverage of the final service propulsion system burn over the Guam station would be adequate during those times when USB was expected to be poor.

Lunar module UDL verification tests (C-10). - A test was performed in the Communications Systems Engineering Laboratory in January 1968 to verify, under conditions of no thermal noise degradation, that the newly designed LM updata PSK demodulator operation was compatible with the MSFN-remote-site-transmitted 1- and 2-kilohertz UDL signals. This was accomplished by using tapes especially recorded by the MSFN remote sites (Bermuda, Texas, Hawaii, and CRO) for this test, and the LM breadboard PSK demodulator. The tapes of updata transmissions were made in the same manner as during an actual mission. As an additional check, two of the tapes used were also decoded with a payload module decoder (PMD) similar to the CSM commander decoder. Also, an additional tape, one of the AS-501 mission tapes from CRO, was used.

All the tapes were successfully demodulated and decoded. The CRO test tape, however, contained inverted data which were successfully demodulated when the interface lines to the demodulator were inverted. It was concluded from this test that no inherent compatibility problems between the MSFN-transmitted UDL signals and the LM PSK demodulator would be encountered.

More detailed tests (effects of phase shift, sensitivity, etc., on demodulation) in the Communications Systems Engineering Laboratory also confirmed probable acceptability of the PSK demodulator design. These tests were run in late winter 1968.

Extravehicular astronaut/LM/ MSFN/MCC-H voice demonstration test (C-11). - At the request of FOD, a test to exercise the entire voice link from a simulated lunar distance to the MCC-H was conducted in May 1968 to verify that acceptable voice communications could be received at the MCC-H when an astronaut had traveled one-half mile from the LM on the lunar surface. The MSFN equipment output recordings of downvoice were made in the ESTL with suited astronauts talking into the SSC (old extravehicular astronaut) equipment through the LM to the MSFN. Selected portions of these MSFN-recorded voice tapes were forwarded to the MSFN site at CRO and relayed from CRO to the MCC-H by way of a communications satellite and commercial land lines (fig. 6).

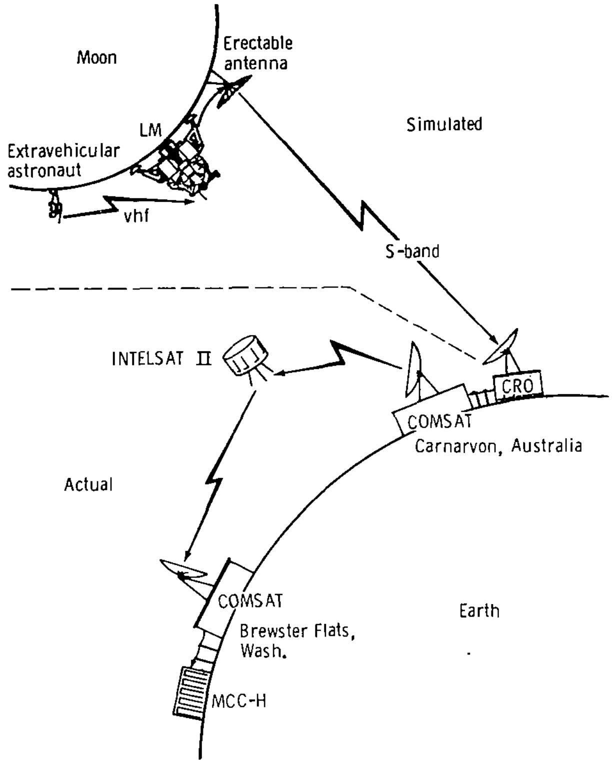


Figure 6. - Extravehicular astronaut/LM/ MSFN/MCC-H voice paths.

The resultant voice signals received at the MCC-H and monitored on the intercommunications loops were very good. Subsequent analysis indicated that the voice intelligibility through the complete system from the extravehicular astronaut to the MCC-H was in excess of 90 percent. This was achieved with a minimum down-link received carrier power of -99.8 dBm (85-foot-diameter dish antenna configuration).

Mission Control Center-Houston EVCS EKG display performance test (C-12). - At the request of the MSC Medical Research and Operations Office, a test to determine MCC-H-displayed EKG acceptability for real-time clinical analysis was conducted. To conduct the test, the ESTL was configured to simulate various lunar-distance transmission modes for the EVCS through the LM to the MSFN transmission levels. The EKG source was a live subject. The MSFN-received EKG was remodulated on an Inter-Range Instrumentation Group (IRIG) subcarrier and mixed with other IRIG subcarriers to form a composite signal in such a way as to simulate fully the signal normally relayed from the remote sites to the MCC-H. This composite was recorded on magnetic tape and replayed into the MCC-H system. The EKG display equipment in the MCC-H performed very well and met requirements for clinical analysis as defined by the Medical Research and Operations Office. All strip-chart recordings exceeded minimum requirements for "R" wave interval detection under all test conditions.

Simulated voice spectrum (C-13). - During May 1968, calibrations were made on the relationship of USB modulation index caused by voice to the modulation index caused by a sine-wave input. The calculations agreed with test results for signal combination 8 but fell down for signal combination 4, indicating that precise LM processing characteristics had to be known. The calculations were thus abandoned, and a simulated voice spectrum was developed by the Audio Techniques and Evaluation Laboratory for possible application in setting and measuring the mode indices. The spectrum was produced by using a noise source and band-pass filters. The peak-to-rms ratio of the simulated spectrum was measured and compared with the peak-to-rms ratio of the three separate speakers on the "top dog" WI test tapes. The peak-to-rms ratio (15.2 decibels) compared favorably (within 0.133 decibel) with the average of the three speakers.

Goddard Space Flight Center linear phase detector tests (C-14). - Tests with a GSFC linear phase detector were initiated on July 23, 1968, in an effort to improve the down-link modes (both LM and CM) that have 1.6-kbps telemetry on the 1.024-megahertz subcarrier and backup voice at baseband on the carrier. Previous test results showed that the telemetry data were severely degraded when voice was present. The tests were terminated on July 25, 1968. Test results indicated that the GSFC linear phase detector was performing approximately 7 to 8 decibels worse than the normal MSFN configuration and also experienced similar telemetry channel degradation when the carrier was modulated with baseband voice.

Apollo 7 prelaunch test support (C-15). - During prelaunch testing of Apollo 7 equipment at KSC, problems with MSFN-received vhf voice quality and with spurs on the S-band down link (causing false receiver lock) were noted. An intensive series of tests was performed in the ESTL in cooperation with GSFC to investigate these problems. It was found that the MSFN-received vhf voice-quality problem was probably caused by improper alinement and tuning of the vhf receivers. The S-band down-link spur problem was found to be resolvable by limiting the sweep amplitude of the ground station to ± 37 kilohertz to avoid acquiring the spurs. Both solutions were coordinated with GSFC, which issued appropriate instructions to the MSFN.

Lunar mission TV simulation test (C-16). - A lunar mission TV simulation test was successfully completed on September 5, 1968. For this test, a Block II camera, located near a LM mockup at MSC, was interfaced with the ESTL and the signal played through the LM to MSFN equipment, scan converted, and then transmitted to the MSC TV Switching Center for recording. Satisfactory performance was obtained for all conditions except when the high-resolution format was used. No success was obtained in transmitting the high-resolution video to the ESTL and monitoring synchronization with the slow-scan monitor. (The camera used for the test was modified to eliminate every other line in the 1200-line, high-resolution format.)

Updata buffer engineering instruction installation (C-17). - During October 1968, GSFC personnel visited the ESTL to install an Engineering Instruction (EI) (number 3046) in the UDB prior to implementing it on the network. The reason for this was that the EI was for new modulators and demodulators in the UDB, and GSFC personnel wanted to check the EI against actual spacecraft equipment. (See description of test C-4.) The installation and checkout were successful, but no compatibility tests could be run because the spacecraft equipment was unavailable at the time. In later tests, the modification was found desirable but not absolutely necessary — that is, it improved circuit margins slightly, but these were already acceptable.

Command and service module S-band up-link squelch control tests (C-18). - Tests on the LM up-link voice squelch were performed in August 1968 to provide data that could be related to a CM squelch proposal. Preliminary evaluation of earlier test results indicated that the squelch was not as sensitive as required. Tests showed, however, that the squelch circuit did not degrade signal performance. These tests indicated that WI was on the order of 95 percent at squelch threshold and that WI reduced to about 80 percent at 3 decibels below threshold. The squelch action exhibited a gradual decrease in output noise level with decreasing received signal strength after squelch operation, rather than exhibiting an instantaneous squelch of noise. The squelch point had very little hysteresis; that is, the squelch point remained essentially the same whether approached from strong signal (above threshold) or weak signal (below threshold). Preliminary evaluation indicated that the squelch is, in general, acceptable. October 1968 tests on actual CSM squelch circuitry indicated operation as desired; however, the rf level at which the squelch operated did not appear optimized. A squelch-disable switch is available, however, to avoid premature loss of the voice signal.

Postdetection audio filter tests (C-19). - The inclusion of the extravehicular astronaut communications equipment on the Apollo 9 mission and on all lunar missions caused some concern as to MSFN-received voice quality when the astronauts were on the lunar surface or in any extravehicular astronaut activity. This concern resulted from an examination of ESTL test results by the Audio Techniques and Evaluation Laboratory which showed biomedical subcarrier interference with voice at the MSFN because some of the subcarriers were low enough in frequency to appear at the audio discriminator. A series of developmental tests was run in the Audio Techniques and Evaluation Laboratory during January 1969 for determining an optimized filter to remove these unwanted components; and, as a result, a 2.5-kilohertz low-pass filter was decided upon. Subsequent tests in the ESTL confirmed satisfactory voice reception with the filter in place, and the GSFC personnel were notified of the results.

Manned Space Flight Network voice-operated gain-adjusting amplifier test (C-20). - A plan to implement a voice squelch device, called a voice-operated gain-adjusting amplifier (VOGAA-1), on all MSFN sites prior to the F mission (Apollo 10) was discussed at the Apollo F and G Mission Communications Status Review meeting held at MSC in the spring of 1969. As all parties concerned were not thoroughly familiar with this device, the MSC personnel were requested to test the device in a representative Apollo configuration to determine its performance characteristics. Tests in the Audio Techniques and Evaluation Laboratory were initiated to answer this request. Results showed that the VOGAA would inhibit all speech if the instantaneous peaks were not more than 6 decibels above the ambient noise level. Also, interfering tone amplitudes within 15 decibels of speech peaks would cause syllable and word dropouts. Interfering tone amplitudes equal to, or in excess of, speech peaks would inhibit speech. In some transmission modes, it appeared necessary to bypass the VOGAA altogether. The GSFC personnel were informed of these characteristics, and MSC Flight Control Division and Flight Support Division personnel witnessed demonstrations of the unit for familiarization with these effects.

As a result of the previous findings and because of still less than optimum performance during the Apollo 10 mission, a task was initiated in the Audio Techniques and Evaluation Laboratory to develop modifications that would eliminate or reduce the undesirable VOGAA operating characteristics. As a result of this task, a 560-hertz center-frequency (standard telemetry) filter with a 3-decibel band pass of 84 hertz was installed at the input to the detector circuit. Also, the maximum release time of the VOGAA was increased from 750 to 1190 milliseconds.

After these modifications were made, the VOGAA was subjected to all of the tests previously performed on the unmodified VOGAA. These tests indicated that the modified VOGAA had less word dropouts for speech-to-noise ratios less than 6 decibels, that it was not subject to tones outside its 500- to 600-hertz detector band pass, and that it minimized the "crashing" effects produced by the VOGAA when it triggers on receiver impulse noise.

It should be noted that the band-pass filter caused certain words to be lost if good-quality laboratory speech was used as an input. However, the VOGAA modifications were designed for optimum performance with Apollo speech. The speech processing of the Apollo microphones and communications system ensures — based on power spectral density analysis — that sufficient speech power will be available in the filter band pass. In tests, word dropouts were not a problem when MSFN-recorded Apollo down-link voice was used as an input. These changes to the VOGAA have not been implemented on the MSFN; however, further development is expected.

Apollo 10 color TV tests (C-21).- A test was accomplished May 9, 1969, in the ESTL by using the flight color TV camera working through the CSM/MSFN system, including both the old FM demodulator and the new demodulator. The test was quite successful, with no evidence of the clipping of white-level signals which had been evident on a KSC-MILA test on May 6, 1969. A simulated TV signal (color bar), originating at the Goldstone 210-foot-diameter antenna station, was observed at MSC on May 13, 1969, and appeared to be satisfactory at approximately the expected signal levels.

SIGNIFICANT RESULTS

As evidenced by the foregoing, there have been many significant results from the ESTP in terms of "revelations" regarding system performance. While not wholly unexpected based on systems analysis, these results pointed out some deficiencies in prior theoretical work and, empirically, defined these deficiencies in a quantitative manner, often providing information for updating system mathematical models. In particular, the effects of intermodulation, cross modulation, incidental modulation (AM and PM), and noise-figure constants (and other phenomena and parameters) were determined on a system basis. As the systems investigated were among the first to utilize coherent up links and down links with several modulation components on each, the significance of some of the findings cannot be overemphasized in terms of gaining an understanding of all the interrelationships involved. For example, the content of the up-link modulation was expected to have some effect on the down link; the full effect was, however, not apparent until tests were run under various system configurations. A few specific examples will be discussed in this section. Perhaps of prime significance, however, in terms of ESTP results, was the development of a test team and a laboratory which are unexcelled anywhere in the country. This team and laboratory represent a highly responsive test capability for the resolution of anomalies which develop during countdowns or missions, for demonstration (to management, to the mission operations team, and to the flight crew) of the actual performance to be expected of the communications system during any mission, and for verification, experimentally, of design modifications prior to finalization of change decisions. These developments are significant because, in the process of creating a capability for and an understanding of the state of the art, the state of the art of communications testing has been advanced. The techniques and knowledge developed are applicable not only to the Apollo Program and to future manned space-flight programs, but to any communications system of the present or future. Because of the extensive effort put into each test to ensure that all systems performance requirements were met, even results indicating "no problems" can be considered significant (e.g., a large amount of data to verify analysis, empirical data to complement analysis, intimate knowledge of systems capability and limitations, and an extensive store of information on data quality capability). A discussion of significant results based on these criteria would then, necessarily, be a repeat of the previous section. Therefore, for purposes of this section, significant results are defined as those having direct and long-range (lunar mission) effect on overall system design or those which resolved an immediate problem related to continuance of a countdown or a mission. With these criteria in mind, the following discussion presents the most, not necessarily all, significant results of the ESTP.

Command and Service Module Block I-E Test (A-1) Results

A very significant result of the CSM Block I-E tests was the determination that up-link modulation (up-link subcarriers) could not be switched (be turned off if on, or on if off) during range-code acquisition if ranging was to be obtained in any reasonable length of time, because the ranging subsystem would reset each time this happened. This effect was, of course, extremely critical for earth-orbit Block I flights, but was applicable also to Block II flights while in parking orbit and, to a lesser extent, later in the mission. As a result, the ranging procedures in the Network Operations Directive and other mission documents were modified to account for this effect. Also significant was the greater understanding obtained of the degradation of down-link performance caused by turned-around up-link modulation appearing on the down link, and a quantitative determination of two major methods of correcting this problem: reduce up-link carrier modulation indices and reduce transponder TAR. In addition, the discovery that up-link voice was turned around in the audio center because of crosstalk and was fed directly into the down link enabled an early remedy for Block II systems. The tests also delineated the various points in the system at which updata polarity could be inverted and pointed out the necessity for strict control over configuration of this link for all spacecraft.

While not directly significant to lunar missions under the ground rules established previously, the detection and resultant correction of the receiver degradation caused by power amplifier harmonics did allow successful performance of the communications system during the early development flights which used Block I equipment.

Command and Service Module Block II (Simulated) Test (A-2) Results

The CSM Block II tests were, essentially, design verification tests and, as a result, had significant impact on the total design, including the less important characteristics of the CSM Block II communications system. Carrier-acquisition difficulties, a significant problem from an operational sense, were traced to less than optimum filter design in both spacecraft and MSFN receiver phase-lock loops; correction included filter redesign and a constraint on operations that prohibits any modulation on the up link during spacecraft carrier acquisition since time did not permit further optimization of the system. Also, poor emergency-key performance was noted and, as a result, the detection circuitry for this signal was redesigned at GSFC and was thereby made acceptable for all operational conditions expected.

Saturn IVB CCS Test (A-3) Results

Perhaps the most significant result of the S-IVB CCS tests was a demonstration that the ESTP can support other NASA Centers and produce meaningful results which are acted upon in a positive manner by the supported Center. Two significant problems, degradation of down-link telemetry by up-link modulation and transponder power-supply-generated spurious signals, were detected; hardware changes were implemented by MSFC personnel to correct the problems.

Command and Service Module Block I-D Test (A-4) Results

Many of the problems noted during the CSM Block I-D tests were the same as those noted during the Block I-E tests because the D units had not been completely reworked to resolve all difficulties discovered. A significant new result was the determination of maximum allowable down-link IPM as a result of all causes. This value (28° rms) was then specified for all future hardware. Degradation of UDL performance at low signal levels (not a Block I problem) had resulted in the implementation of an improved detector for the Block II configuration. It was determined also that the transponder dynamic tracking-loop parameters were not compatible with operational acquisition and tracking requirements; as a result, hardware gains, bandwidths, and allowable static-phase errors were specified for Block II equipment. Reduced sweep rates were scheduled for Block I acquisition procedures.

Command and Service Module Block II Gross Test (A-5) Results

Significant results from the brief CSM Block II gross tests (A-5) were the operational configuration change from a 700- to a 50-hertz receiver loop bandwidth for the 1.6-kbps telemetry to correct a degradation in performance when backup downvoice was present, and the increase of available attenuation in the MSFN ranging receiver as well as addition of manual gain control (MGC) and a change in up-link modulation indices to allow correct ranging procedures to be used. The latter change also reduced to acceptable levels the UDL degradation caused by IAM on the ground SCO.

Lunar Module Gross Test (A-6) Results

The LM gross tests (A-6) were the first real tests of LM equipment with the MSFN system and included LM preproduction prototype hardware. A major problem, very poor intelligibility of the downvoice channel when space-suit noise was simulated, resulted in redesign of portions of the LM voice channel but also caused a change in test procedures which had long-range implications applicable to all future testing. A series of standard test tapes more representative of the actual Block II suit environment was made (speaker recorded from inside a typical suit which had airflow and pressures typical of operational conditions), and a standard for voice intelligibility rating was established.

The theoretical required numbers of word samples and listeners were determined to achieve an accuracy of at least 90 percent (with 95-percent confidence) for intelligibility ratings. Also, high-quality tape recordings were made by using acoustical isolation for the speaker and balanced audio cabling. Other problems noted were similar to those detected during CSM Block I and Block II tests and were significant in that they demonstrated the repeatability of the test approach and also the wide applicability of results to similar systems.

Apollo Lunar Surface Experiments Package Gross Test (A-7) Results

Perhaps the most significant result of the ALSEP tests was the effect of a problem on the overall ALSEP effort. An updata phase-inversion problem which was recurrent in testing the ALSEP during various stages of its development sparked considerable discussion between personnel from two NASA Centers and between personnel from MSC and its contractors as to the resolution of the problem. In the end, the ESTP ALSEP results were the mediating "hard" evidence that resolved the problem to the satisfaction of all concerned.

Apollo Communications System Phase I Test (A-8) Results

The most significant outcome of the ACS phase I test was the determination of quantitative requirements for redesign of the extravehicular astronaut electronic package to enable the two extravehicular astronauts to converse with each other and with the ground. The SSC systems tested were not capable of meeting these requirements as designed. The redesigned units underwent design verification testing in the ESTL in the spring of 1968, thereby providing continuity in the performance evaluation and support of two-extravehicular-astronaut requirements. (Also see results of B-6 tests.)

Apollo Communications System Phase II Test (A-9) Results

Problems noted in the ACS phase II tests were the reduction of carrier modulation index when 51.2-kbps data were modulated on the 1.024-megahertz subcarrier, the biomedical data interference with extravehicular astronaut voice, and the scientific data subcarrier interference with 32:1 playback voice. The first problem was simply recognized as inherent to the CM and was accounted for in predicting mission performance and constraints. The second and third problems resulted in filter design efforts which, in turn, resulted in a set of specific filter characteristics for insertion in the MSFN.

Apollo Range Instrumentation Aircraft Test (A-10) Results

The most important result of the ARIA tests was the establishment of a precedent in not only inter-Center but also inter-Agency (NASA Department of Defense/U.S. Air Force) cooperation on all levels to determine compatibility of a subsystem with other portions of an overall communications system. In addition, the data and resulting analysis provided more detailed information on the ARIA communications support capability than had been obtained before or after these tests. The successful and cooperative tests were significant in that ARIA communications capabilities and limitations were defined for the use of all parties involved.

Apollo Communications System Phase III Test (A-11) Results

Results of the ACS phase III tests showed that all lunar landing mission critical parameters were generally acceptable. Some minor problems were resolved by changes to ground and spacecraft operating procedures. All results have not been fully analyzed, and some unsatisfactory (but tolerable) conditions are still being investigated. As noted, however, mission critical parameters were investigated and resolved prior to the first lunar landing, at least to the point of knowing the operational constraints required. Verification of no danger to crew safety was achieved.

Additional S-Band Test (B-1) Results

The most significant results of the additional (B-1) S-band tests were the obtaining of a quantitative understanding of the effects of a wide range of 1- and 2-kilohertz relative phase shifts on the UDL performance and of the effects of incidental carrier phase modulation on PCM BER for a wide range of modulating frequencies and carrier phase deviations. These results were extremely helpful in analysis of later problems and in the design of the LM and ALSEP updata links.

Special FM Test (B-2) Results

For the overall program, the most significant result of the special FM tests was the understanding of the requirements and the operational expectations for the LM black-and-white TV used on the first lunar landing. The change to color TV, effected 3 years later, negated the significance of the other test efforts insofar as the criteria for significance in this report are concerned. Future applicability is possible, however, depending on space exploration TV requirements now being decided, particularly in relation to slow-scan, high-resolution TV.

Antenna Static Test (B-3) Results

The antenna static tests led to reduced up-link subcarrier modulation indices for the MSFN. The new indices caused less IAM (which showed up as IPM on the carrier) and thereby improved the performance of the high-gain (CSM) and steerable (LM) antennas by putting less perturbations on the carrier, which is used by the antenna electronics for antenna pointing. Test results also indicated that redesigned up-link subcarrier oscillators having less inherent IAM properties would help resolve this problem.

Frequency Modulation Demodulator Threshold-Extension Test (B-4) Results

Besides being significant in terms of long-term inter-Center cooperative effort to resolve an operational problem and in terms of actual impact on coverage of the lunar missions, the FM demodulator threshold-extension tests were significant in that they contributed greatly to extension of the state of the art of FM demodulation. The click eliminator, a new operational demodulator, and other devices tested in various states of design finalization are distinct advances for which the ESTP is in part responsible.

Split-Phase PCM Test (B-5) Results

While split-phase usage on real-time telemetry was never approved, the emphasis placed on this effort and the critical reason for it caused a greater awareness of the telemetry loading problems and a greater concern for proper distribution of data inputs.

Extravehicular Communications System/USB System Design Verification Test (B-6) Results

The EVCS/USB design verification tests were significant in that the EVCS equipment and the LM SPA were new designs based on previous ESTP tests and were, in part, tunable (or variable) units such that parameters could be varied to optimize the system performance. The tests were a continuation of earlier efforts and were designed to prove the correction of earlier difficulties. (Also see results of A-8 tests.)

Apollo 9 Mission Configuration Voice Demonstration (B-7) Results

The participation of prime and backup flight crews in the Apollo 9 voice demonstration test points out the excellent crew-familiarization capability of the ESTL. The complexity of selecting communications modes and the quality and condition of the modes selected can be accurately demonstrated to the crews without expensive, schedule-disrupting use of the flight vehicle and ground-support equipment, which cannot in any event fully simulate all the conditions expected during a mission.

Apollo 8 Mission Test (B-8) Results

The Apollo 8 mission tests illustrated the rapid-response capability and the flexibility of the ESTP to support mission planning and special requirements. Proposed backup and operational concepts can be checked out under specific mission conditions and evaluated as to the effectiveness or usefulness of techniques.

Lunar Module Color TV Test (B-9) Results

The extensive, and often hectic, series of tests of the LM color TV provided management with quantitative and timely information enabling the decision to include color TV on the LM for Apollo 12. All possible contingencies were tested and all doubts and objections overcome by the thorough evaluation of the color TV signal effects on the LM down-link FM communications channel.

Apollo Lunar Surface Experiments Package Command Anomaly Test (B-10) Results

The ALSEP command anomaly tests illustrate the prelaunch support capability of the ESTP as well as the capability for combining corresponding experimental and analytical information to verify theory and to duplicate actual mission anomaly conditions. The test results explained the causes of the problem and pointed out possible dangers to astronauts during the deployment phase of the ALSEP operation.

Apollo Lunar Scientific Data System/MSFN Design Verification Test (B-11) Results

The Apollo lunar scientific data system/ MSFN design verification tests illustrate the applicability of the ESTP to all design changes and modifications occurring in manned spacecraft communications systems. The continued usefulness of this program is shown in the early evaluation of the spacecraft 113 configuration and the resulting design changes being made as a direct result of these tests.

Support Test (C-1 to C-21) Results

Many of the support tests resolved small problems that kept reoccurring or that appeared as the result of major tests and major special tests, illustrating the continuity of the test program. Other tests show the flexibility of the program to support non-test-related activities. Still others show the extent of usefulness of the program to areas outside of MSC. Support tests detected problems (MSFTP-1 improper lock), resolved operational problems (Apollo 4 CDDT and Apollo 7 prelaunch testing), assisted in design or verification of design of new systems (AAP TV and LM UDL), supported network configuration and verification (UDB EI installation, extravehicular astronaut/ LM/ MSFN/ MCC-H voice demonstration, and MCC-H EVCS EKG display performance), developed test techniques (simulated voice spectrum), and (in general) provided wide support to the Apollo Program. These tests, in conjunction with the major test series, served to make the ACS the most thoroughly understood and predictable communications system in existence. Many of the details normally not reached in overall systems tests were covered in the lesser tests. As a result, these tests served to fulfill the continuity of the overall ESTP.

PLANS

Immediate plans for the ESTP concentrate on evaluating new communications links (e.g., lunar communications relay unit) and modifications to old communications links (e.g., Apollo lunar scientific data system) to be used on forthcoming Apollo missions. Also, an effort is underway to clear up a backlog of test requests by referencing prior results if applicable, by conducting tests where the results are not available, or by closing the requests that are no longer required.

While these activities are expected to consume the major portion of available test time for the remainder of calendar year 1970 (and perhaps beyond, depending on developments of the Apollo Program), a serious effort is underway to evaluate the experiences and the operations of the ESTP during the past 6 years. In particular, during the ACS phase III tests, a concurrent study has been in process to compare measured and predicted data by using probability and statistical techniques to try to understand in detail the effects of various instrument inaccuracies and human errors on the end results of the tests. On a limited basis, this had been done very early in the test program but only to the extent necessary to assure the test personnel that nothing was grossly wrong with the test configurations and that reasonable caution in test setup would assure meaningful results. This study is also envisioned as the basis for a much more extensive review of test techniques, performance criteria, and specification criteria.

Briefly, an indepth study effort is planned to optimize the performance criteria used in communications specifications such that the specifications called out can be accurately, quickly, and unambiguously measured in the laboratory. Many test results, especially from the earlier tests, led to difficulty either in interpreting the results or in implementing changes to hardware. These difficulties were concerned, in part, with the poor agreement, in some areas, between predicted and measured values. Also, the definitions of terminology and of "equivalent" signals for use in tests of various information channels, especially the voice channels, were often a cause for confusion and disagreement between agencies or between contractors (or both). Much work has been done (see description of support tests C-1 to C-21) to improve this situation, but several areas that need study still remain. Also, the current manual techniques used in the ESTL require, as a "rule of thumb," 4 hours of analysis and reporting for every hour of test. This imbalance is caused by the time required for collection of data, for formatting and plotting, and for evaluation and reporting on the test results — each of which, except the reporting, is very amenable to automation. An optimum situation, and one that should be achievable by automation, would be 1 hour of reporting for 1 hour of testing. This concept, if all testing were organized accordingly, could be applied to future communications systems testing, design simulation, and mission support. In the ultimate concept, a complete communications systems mission profile could be performed in the laboratory prior to each mission with very little perturbation to other test requirements. Each step of automation would, however, require evaluation of practical achievement as a function of utilization and cost.

Communications systems for planned and proposed manned space-flight programs indicate a significant increase in complexity and capacity over previous programs. While the nature of the communicated data will not change significantly, the methods of formulating and processing the information will vary considerably as will the quantity of the information communicated. The impact is that hardware and performance specifications become more complex, which in turn increases the complexity of the testing required to verify the hardware against requirements. Meanwhile, as discussed previously, the existing specification criteria, such as WI and BER as a function of signal-to-noise ratio, and so forth, are inadequate to fully define system performance. Also, the test methods available remain limited to one channel at a time, one signal-to-noise ratio at a time, and so forth, with all other variables held constant (a very time-consuming method). An effort to improve the performance criteria as well as the techniques for measuring the parameters associated with these criteria will be of great value to all future communications systems in that an accurate and rapid determination of requirements and actual performance could be achieved early in the development phases of these systems, at a minimum cost in time and dollars.

A long-range (1-1/2 year) effort to improve both the communications systems performance criteria and the test techniques to verify these criteria is planned. Specifically, a study and development effort consisting of four discrete phases, including a demonstration of results, is planned to achieve needed improvements in specification and test techniques.

The first phase of the effort will be a study directed toward the refinement or development (or both) of communications systems performance criteria that are both significant and reasonable. Samples of ACS performance criteria; of basic requirements for future communications systems; of test plans, procedures, data packages, and reports; and of ESTL accuracy study reports now in preparation will be used. Communications and measurement theory will be applied, and measurement technique developments, including availability of new instruments, will be investigated to arrive at a set of realistic communications systems criteria covering all phases of telecommunications systems performance that can easily, accurately, and economically be measured in the ESTL and associated laboratories.

The second phase of the effort will be a study making use of the phase I results to develop a plan for upgrading the ESTL to accurately measure the performance criteria parameters determined from phase I. This plan will include alternate methods of automating the testing wherever practicable by making use of limited programable devices, including any existing or adaptable equipment available at the time. New measurement hardware development may be indicated. The study will also include evaluation of the approach of using a "universal breadboard" communications system, comprised of commercially available hardware and existing spacecraft hardware, for the purpose of concept and design verification testing of advanced communications systems prior to availability of flight breadboards. If the evaluation is favorable, components to assemble such a breadboard, based on minimum new buys for each new system proposed, will be recommended.

The third phase of the effort will be dependent on the results of phases I and II and will be concerned with implementing the results of phase II. This phase will consist of an in-house effort to assemble and integrate existing equipment and commercially available hardware according to the results of phase I and the plan developed in phase II. Development of new instruments, if any, recommended by phase II results will be contracted out and integrated into the appropriate laboratories as an in-house effort. A final phase, to demonstrate on a systems basis the results of phases I, II, and III, will complete this effort.

In summary, the ultimate end product of the effort is the ability to make the best measurements as easily, quickly, and economically as possible with concurrent accuracy and repeatability. Phases I and II will have comprehensive study reports as products. Phase III will have as its end product a test laboratory equipped to implement the results of this effort. Phase IV will work out imperfections and prove the concepts developed. Figure 7 shows a preliminary schedule for the planned effort.

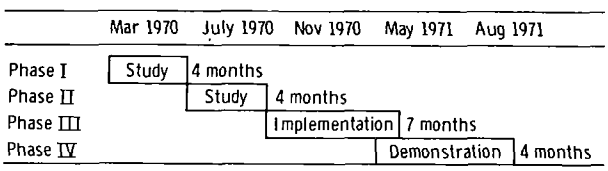


Figure 7. - Performance criteria study and test automation schedule (preliminary).

Barring successful completion of the planned effort described previously, the ESTP and its associated laboratories can still provide a useful and critical function in support of future programs. The goal of the study is to find a way to provide this function with the best results possible at the lowest long-term cost. Hardware costs are dependent on the results of phases I and II (as discussed earlier) and, aside from regular in-house operating costs, will be dependent on the quantity and type of new items to be developed and procured. Phase IV costs are expected to be funded from normal ESTL operating budgets, and additional funds should not be required for this effort.

CONCLUDING REMARKS

The Electronic Systems Test Program has contributed significantly to the development, implementation, and operation of the Apollo communications system. In addition to the achievement of a high confidence level in systems performance prior to the first manned lunar landing, the test program has effected many cost savings in that early detection of problems requiring hardware changes, including determination of the scope of these changes and the optimum point in the system to effect them, has been achieved and verified. A unique but flexible test concept and capability has been developed where none existed previously. Test techniques and methods have been derived and implemented. Improvements in these concepts and techniques, based on experience with the Apollo Program, are now being investigated. The Electronic Systems Test Program concept, along with the associated facilities, personnel, and techniques, is considered a success. This program stands ready to support the remaining Apollo Program missions as required and can easily adapt to the support of future space-flight programs, manned or unmanned.

Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas, June 22, 1971
914-13-00-00-72

APPENDIX A

TEST PROGRAM OPERATIONS

The procedure and the sequence of operations for test programs and clarification of areas of support generally required to accomplish test objectives are briefly discussed herein.

Figure A-1 is a flow diagram of program operation, from test plan review to completion of the final report. The operations of major events shown in figure A-1 are summarized in the following paragraphs.

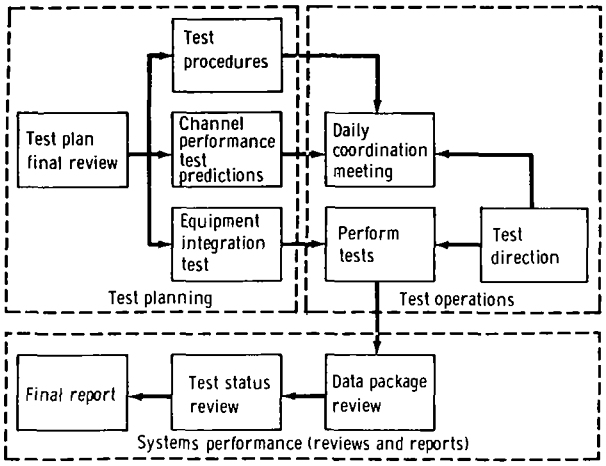


Figure A-1. - Test program operations flow chart.

TEST PLAN REVIEW

A formal review of each test plan is usually held at MSC. Participants in this review are representatives of MSC, appropriate representatives of other agencies, and appropriate contractor personnel. The purposes of this review are to discuss in detail the planned tests and to ensure that all the test requirements necessary to achieve the primary objectives of the test program are adequately identified in the test plan.

TEST PROCEDURES

The formal test procedures are provided by TCSD through an MSC laboratory-contractor effort. Test procedures can be modified at any time during the test program; however, all changes in the scope of the testing must be approved by the MSC Test Director.

TEST PREDICTIONS

Channel performance predictions are provided by TCSD. The test predictions are based on measured systems parameters, except in cases where measured parameters are not available. Specified parameters will be used in these cases.

TEST OPERATIONS

The test operation requires participation of TCSD and appropriate MSC laboratory and manufacturing contractor personnel. Manufacturing contractor participation consists of the following:

1. Systems engineer (provide quick response to contractor management for problem resolution and quick response from contractor engineering relative to design and test changes)

2. Test engineer (participate in detailed test planning and conduction)

3. Other support as required during critical test phases

During the test program, a coordination meeting is held at the ESCF at 8:45 a.m. each working day. The purpose of this meeting is to discuss the test results of the previous day, tests planned for the current day, test procedure modifications, and any problems associated with the test program operation.

DATA PACKAGE REVIEW

Approximately 10 working days after completion of the tests, the laboratory contractor provides, at a review meeting, copies of all raw and reduced data along with an updated test procedure.

TEST STATUS REVIEW

Approximately 10 working days after completion of the data package review, a test status report is prepared by MSC/TCSD. Selected material from the test status report is formally presented at a review meeting.

INTERIM TEST REPORT

Interim test reports covering all test results are prepared by the laboratory contractor and submitted to TCSD. These documents are given limited distribution approximately 30 working days after completion of the test program.

FINAL TEST REPORT

The final test report, covering all test results, is prepared by MSC/TCSD. This document usually is distributed 45 working days after the test status review.

APPENDIX B

TELEMETRY AND COMMUNICATIONS SYSTEMS DIVISION, COMMUNICATIONS SYSTEMS ENGINEERING AND TEST BRANCH LABORATORY, ESTP SUPPORT CAPABILITY

The following is a brief summary of the laboratory capability available from the ESTP.

1. Electronic Systems Test Laboratory

a. Capability: The ESTL is capable of spacecraft-ground tracking and data-acquisition systems compatibility and performance evaluation testing. This is primarily USB with (dual extravehicular astronaut) vhf capability. Spacecraft equipment is isolated in shielded enclosures. Static and dynamic rf-path simulation is provided, as is PCM and PAM telemetry, upvoice and downvoice, updata, ranging, and TV channel evaluation capability. Table B-I lists the major equipment (except spacecraft) available in the ESTL.

TABLE B-I. - ESTL GROUND EQUIPMENT

Equipment	Designation	Remarks
PCM simulator	Dynatronics	Similar to equipment on Apollo MSFN stations
PCM decommutator	MSFTP-2	Similar to equipment on Apollo MSFN stations
PCM decommutator	MSFTP-1	Similar to equipment on Apollo MSFN stations
Telemetry output buffer	TOB	Similar to equipment on Apollo MSFN stations
Wideband tape recorder	VR-3600	Similar to equipment on Apollo MSFN stations
Wideband tape recorder	VR-3600	Similar to equipment on Apollo MSFN stations
Radio-frequency path simulator	rf path	
Down-range up-link unit	DRUL	

TABLE B-I. - ESTL GROUND EQUIPMENT - Continued

Equipment	Designation	Remarks
Central control and display console	CCDC	
Remote-site simulator console	RSSC (located in CCDC)	
Time standard	Mercury time standard	
Apollo time conditioner	ATC	
Chart recorder	Brush	
Chart recorder	Techni-rite	
Datagraph	CEC	
Time converter and displays	Time converters (located in RSSC)	
On-site processor system	1218	
Apollo on-site processor system	642B (modified)	Similar to equipment on Apollo MSFN stations
Computer address matrix	CAM (located in RSSC)	
Apollo computer address matrix	ACAM (located in RSSC)	
Command distribution rack	CDR	
Updata buffer	UDB	Similar to equipment on Apollo MSFN stations
Tracking data processor	TDP	
Comparison system	Comparator	
Intercommunications system	Intercom	
Spacecraft system test console	SSTC	
Unified S-band RER system	USB/RER	Similar to equipment on Apollo MSFN stations
Signal data demodulators and subcarrier oscillators	SDD/SCO	Similar to equipment on Apollo MSFN stations
Verification receiver	VR	Similar to equipment on Apollo MSFN stations
TV monitors	TV Mon	Similar to equipment on Apollo MSFN stations
Audio support equipment	ASE (located in comparator)	
Test director console	TDC	

TABLE B-I. - ESTL GROUND EQUIPMENT - Concluded

Equipment	Designation	Remarks
Card processor	1004	
Keypunch	Keypunch	
Shielded enclosures (3)	Shielded enclosures	
Antenna control console	ACC	
Mission profile simulator	MPS	
PAM-to-PCM converter	PAM/PCM conv.	Similar to equipment on Apollo MSFN stations
Analog-multiplexer-quantizer	AMQ	Similar to equipment on Apollo MSFN stations

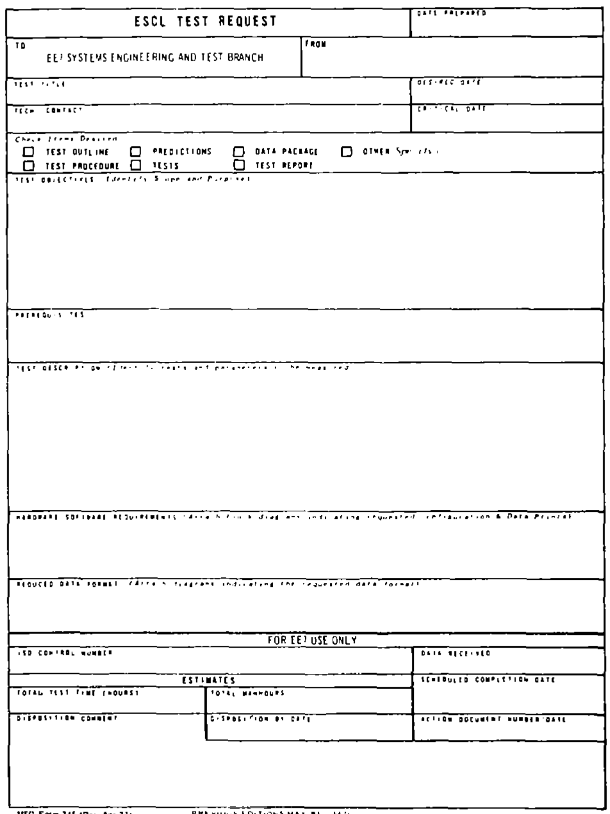
b. Status: The ESTL is operational.

c. Support Requests: The ESCL Test Request (MSC Form 745, dated April 1971) is used to request support. See figure B-1.

2. Audio Techniques and Evaluation Laboratory

a. Capability: The laboratory is capable of analysis of voice tapes (speech-to-noise ratio, spectrum), limited tape dubbing, preparation of audio tapes, audio tape library, and testing/analysis of audio circuits/components/systems. This includes the capability of discrimination of Apollo USB voice subcarriers and limited TV testing/analysis capability. Access to ESTL and to the remotely located TV scan converter by way of building interlaboratory signal distribution system exists.

b. Status: The laboratory is operational.



ESCL TEST REQUEST

TO

EE2 SYSTEMS ENGINEERING AND TEST BRANCH

FROM

FOR EE2 USE ONLY

ESTIMATES

Figure B-1. - Form for requesting ESTL test support.

c. Support Requests: The ESCL Test Request (fig. B-1) is used to request support.

3. Communications Systems Engineering Laboratory

a. Capability: Capability of the laboratory includes analysis of flight PCM telemetry, analysis of UDL performance, and special ACS problem resolution. Access to ESTL by way of the building interlaboratory signal distribution system exists.

b. Status: The laboratory is operational.

c. Support Requests: The ESCL Test Request (fig. B-1) is used to request support.

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