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# APOLLO EXPERIENCE REPORT - COMMUNICATIONS SYSTEM FLIGHT EVALUATION AND VERIFICATION

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16. Abstract

Flight tests of the synergetic operation of the spacecraft and earth-based communications equipment were accomplished during Apollo missions AS-202 through Apollo 12. The primary goals of these tests were to verify that the communications system would adequately support lunar-landing missions and to establish the inflight communications system performance characteristics.

To attain these goals, a communications system flight verification and evaluation team was established. The concept of the team operations, the evolution of the evaluation processes, synopses of the team activities associated with each mission, and major conclusions and recommendations resulting from the performance evaluations are presented.

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# ACRONYMS

| | |
|---|---|
| ADE | automatic data evaluation |
| AGC | automatic gain control |
| ARIA | Apollo range instrumented aircraft |
| CSM | command-service module |
| ESTL | Electronic Systems Test Laboratory |
| EV | extravehicular |
| EVA | extravehicular activity |
| FM | frequency modulation |
| g. e. t. | ground elapsed time |
| G. m. t. | Greenwich mean time |
| IPM | incidental phase modulation |
| IU | instrument unit |
| KSC | Kennedy Space Center |
| LM | lunar module |
| MSC | Manned Spacecraft Center |
| MSFN | Manned Space Flight Network |
| PCM | pulse code modulation |
| PM | phase modulation |
| RF | radio frequency |
| UHF | ultrahigh frequency |
| USB | unified S-band |
| VHF | very high frequency |

# APOLLO EXPERIENCE REPORT

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## SUMMARY

The results of the communications system flight evaluation program for each mission are documented in separate reports published by the Apollo Spacecraft Program Office. The purpose of this technical note is to document the experience, conclusions, and recommendations gained through evaluation of the inflight communications system performance during missions AS-202 through Apollo 12.

The major objective of the evaluation program was to verify that the communications link, as designed, would adequately support a lunar-landing mission. With this goal in mind, inflight communications tests were developed to check out spacecraft/ground communications before the Apollo 11 flight (the first lunar-landing mission).

The communications system flight evaluation program was successful. Virtually all the meticulously evolved inflight tests were accomplished in a logical sequence, and the results added to the confidence in the capability of the overall ground-station/spacecraft communications links.

Few communications system hardware problems were encountered during the missions. Most of the problems that occurred were attributable to spacecraft or ground-station operational and procedural errors or to software problems. Therefore, the design, operability, and reliability of the Apollo Program communications system were considered excellent.

Experience from the Apollo communications flight evaluation and verification program has yielded several overall conclusions concerning communications design and performance specifications.

1. The specification of a minimum telemetry bit error rate of $1 \times 10^{-6}$ was too rigid. A more reasonable requirement is a minimum bit error rate of $1 \times 10^{-3}$

2. The voice-channel minimum performance requirement of 90-percent word intelligibility was too rigid. A design goal of 90-percent word intelligibility with a minimum acceptable performance requirement of 70-percent word intelligibility is sufficient.

3. The incorporation of the auxiliary oscillator into the block II unified S-band equipment was unnecessary.

4. The down-link noise-suppression equipment (voice-operated gain-adjusting amplifier) had operational problems that could be overcome with tone-controlled noise suppression. This method could also be used for up-link noise suppression.

# INTRODUCTION

The major goal of the flight evaluation and verification program was to demonstrate that the Apollo communications system was capable of supporting a lunar-landing mission. This goal was accomplished through maximum use of flight-test data, laboratory-test data, and system performance predictions. A communications system flight verification and evaluation team that was organized during the second quarter of 1966 provided technical support during the premission-planning, mission, and postmission-analysis phases of the missions.

The team served as a focal point for (1) consolidation of the results of the tests performed in the NASA Manned Spacecraft Center (MSC) Electronic Systems Test Laboratory (ESTL), (2) predictions of system performance, and (3) feedback of results and conclusions of previous Apollo missions. The team supported mission planners in the definition of mission objectives, communications system test schedules, operational procedures and constraints, and prelaunch test requirements. During the mission, this team also provided technical support to the flight controllers. Immediately following each mission, members of the flight evaluation team analyzed the recorded data, resolved communications system anomalies, and documented the results. The communications system performance was summarized in the mission report and detailed in a supplement to the mission report.

Highlights of the communications system flight verification and evaluation team activities are presented in three phases: (1) the evolution of the evaluation process and techniques, (2) highlights of the activities associated with each mission, and (3) general performance conclusions and recommendations.

# EVOLUTION OF EVALUATION PROCESS

Table I is a list of the flight evaluation test objectives for missions AS-202 to Apollo 11. An illustration of the flight verification team concept is shown in figure 1. Before each mission, a "Communications System Flight Evaluation Program Plan" was published for mission use. Each plan was based on the mission requirements, and each presented inflight tests of the spacecraft/ground communications links. These plans also contained the procedure for evaluating the communications system performance and included the following.

1. A summary of the prelaunch tests to be performed at the NASA Kennedy Space Center (KSC) to verify adequate communications system performance before launch

2. A schedule of communications system exercises required to meet inflight test objectives

3. A brief description of the postmission evaluation techniques

TABLE I. - FLIGHT EVALUATION TEST OBJECTIVES

| Mission | Communications systems flight evaluation test objectives |
|---|---|
| AS-202 | Verify unified S-band (USB) communications operations for the turnaround ranging mode, down-link pulse-code-modulation (PCM) telemetry, simulated down-voice (400-Hz tone), and turned-around upvoice (1-kHz tone) channels. |
| Apollo 4 | Demonstrate the capability of the block II omnidirectional antennas during the mission phases as well as the deep-space command-service module/Manned Space Flight Network (CSM/MSFN) USB communications capability.<br>Evaluate downvoice (400-Hz tone) and turned-around upvoice (1-kHz tone) channels. |
| Apollo 5 | Demonstrate the lunar module (LM)/MSFN USB communications capability for turned-around upvoice (1-kHz tone), PCM, ranging. |
| Apollo 6 | Verify, before manned CSM operations, that the CSM USB communications system is compatible with the MSFN.<br>Demonstrate operation of the CSM communications subsystem using the block II omnidirectional antennas.<br>Obtain data using CSM/Apollo range instrumented aircraft (ARIA) communications link for support of the development of CSM/ARIA communications. |
| Apollo 7 | Verify the adequacy of the USB system to meet manned mission requirements during long-duration flights.<br>Verify capabilities of the CSM/MSFN functional communications performance interfaces during manned flight operations.<br>Demonstrate the CSM/LM very high frequency (VHF) communications link capability using the CSM/MSFN voice link. |
| Apollo 8 | Demonstrate that the CSM S-band omnidirectional antennas are adequate at lunar distance.<br>Demonstrate that the CSM S-band communications equipment will adequately support a lunar-orbital mission.<br>Demonstrate the capability of the high-gain antenna. |
| Apollo 9 | Demonstrate the LM/MSFN operational S-band communications system capability.<br>Demonstrate LM/CSM/MSFN/extravehicular-astronaut operational S-band and VHF communications compatibility. |
| Apollo 10 | Demonstrate that the CSM S-band communications equipment will adequately support a lunar-landing mission.<br>Demonstrate that the LM S-band communications equipment will adequately support LM/MSFN communications requirements when the CSM and LM are at lunar distance.<br>Demonstrate that the LM S-band omnidirectional antennas are adequate at lunar distance.<br>Demonstrate the adequacy of LM/CSM/MSFN voice and telemetry communications at lunar distance. |
| Apollo 11 | Demonstrate capability of all communications systems to support a lunar-landing mission. |

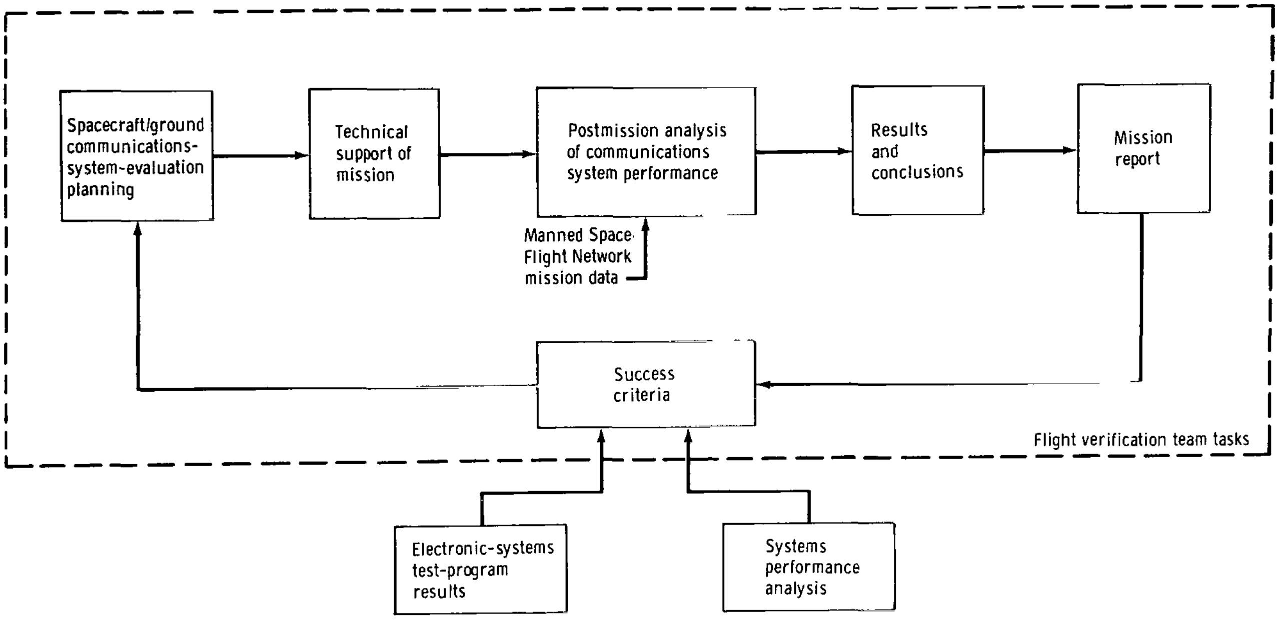

Figure 1. - Communications system flight verification concept.

## Mission Evaluation Team

To complete the evaluation process, a team was placed strategically during each mission to monitor continuously the progress of the mission and the inflight communications tests in order to be of assistance during periods of trouble or communications testing and to aid the flight controllers in making real-time decisions concerning communications.

After each mission, real-time data were combined with the remote-site data available shortly after the end of the mission, and results based on available data were published in a mission report. Problem areas or investigations incomplete at the time of the mission report were incorporated into supplemental reports.

## History of the Evaluation Process

An interesting aspect of the program was the evolution of the evaluation process itself. The majority of the time allotted to evaluation of the earlier missions was spent examining strip charts and laboriously and meticulously plotting up-link and down-link received carrier powers on a point-by-point basis. The method for determining telemetry bit error rate was equally slow and tedious. It entailed examining the telemetry data on a minute-by-minute basis, counting errors in the telemetry frame synchronization word, and averaging the errors.

As longer missions evolved, it was evident that this method of data evaluation would become extremely impractical. After careful examination of the situation and the available alternatives, it was decided that determination of signal strength and telemetry performance would have to be automated. The need thus defined, the automatic data evaluation (ADE) program concept was orginated. The ADE program used a general-purpose digital computer and an X-Y incremental plotter. In concept, as well as in implementation, the ADE program accepts the digitized automatic-gain-control (AGC) voltages, along with the telemetry performance (bit errors in the telemetry frame synchronization word) and Greenwich mean time (G. m. t. ). The AGC voltages are recorded on the remote-site flight-data tapes that are representative of the received carrier powers at the spacecraft up-link receiver and two ground-station receivers. The AGC voltages and telemetry performance are converted, coded, and ultimately run on an X-Y incremental plotter to display the data graphically. A block diagram of the ADE system is shown in figure 2.

The ADE system of data analysis enabled a quicker, broader, and deeper evaluation of mission performance. The system was first used after the Apollo 7 mission. An example of an ADE graph is presented in figure 3.

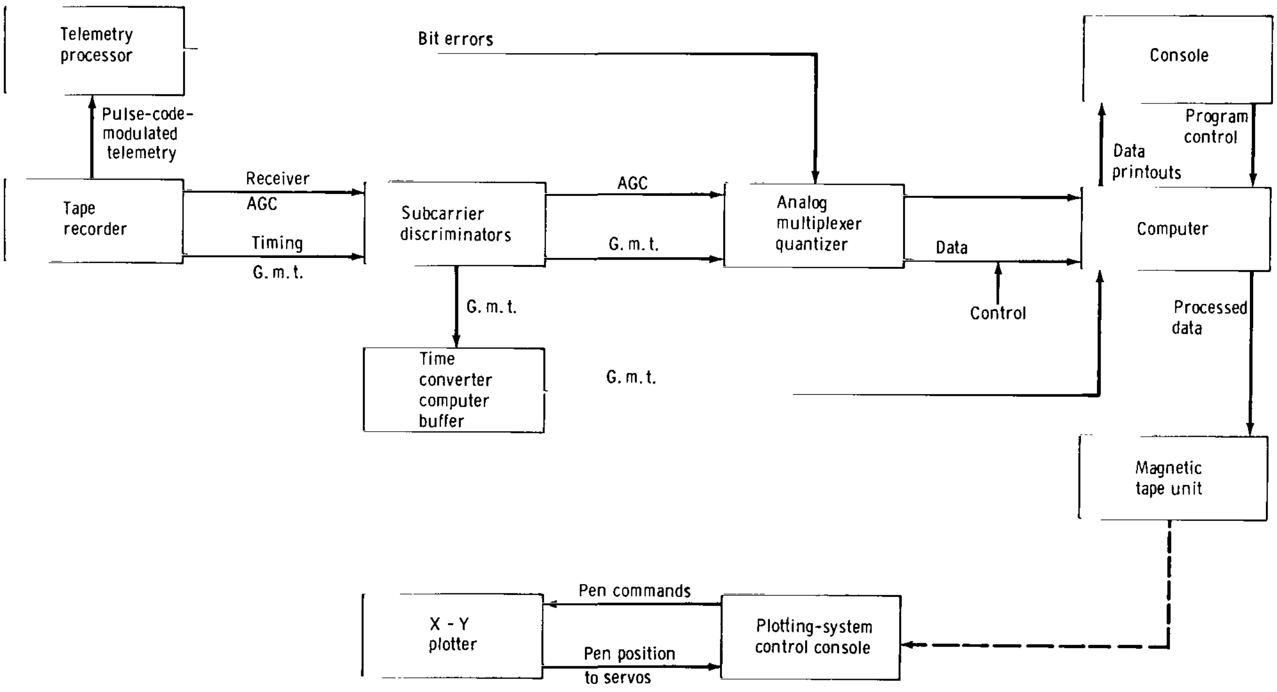

Figure 2. - Configuration of ADE equipment.

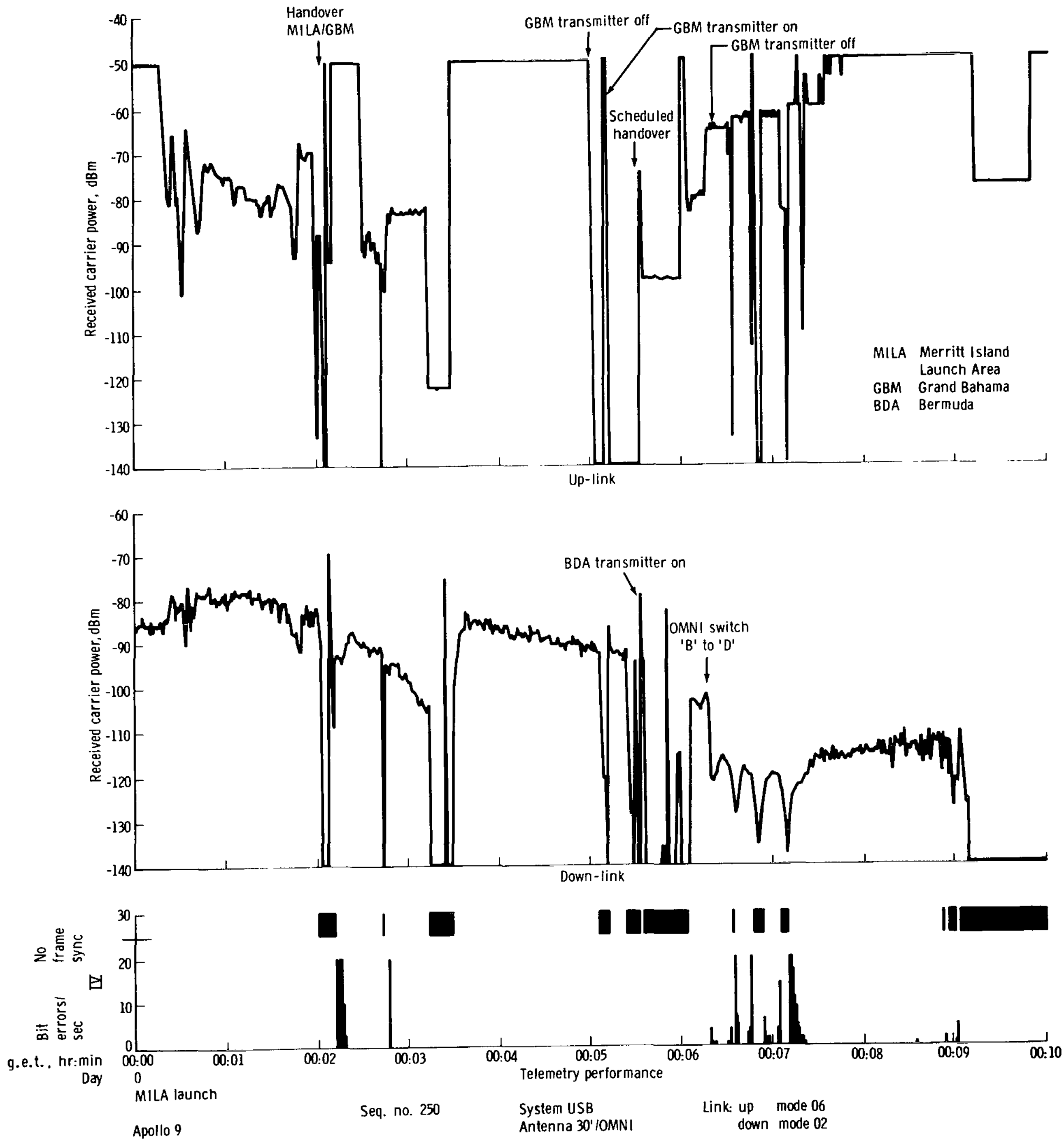

Figure 3. - Sample ADE chart.

## Performance Predictions

An important measure of the performance of the communications system during each mission was the comparison of the measured signal strength with predictions based on the communications system mathematical model. No particular problem arose when the lunar module (LM) was using the steerable antenna or the command-service module (CSM) was using the high-gain antenna. Both antennas are directional with automatic tracking features. Both have constant gain, which makes it relatively easy to predict signal strength. When a spacecraft omnidirectional antenna is in use, however, signal-strength predictions are more difficult because of antenna gain distribution characteristics.

To analyze system performance while using omnidirectional antennas, a computer program was generated. This program determined the look angle to a particular ground station using telemetered data and the best-estimate trajectory. Use of the look angles, measured omnidirectional antenna patterns, and the mathematical model enabled precise prediction of signal strengths.

## MISSION SUMMARIES

This section contains short summaries of the performance and evaluation techniques used for each mission. Each summary includes a discussion of the problems and conclusions associated with communications system performance.

### Mission AS-202

Mission AS-202, an unmanned suborbital flight, was the second flight test of a production Apollo block I type spacecraft. The AS-202 mission communications subsystem included the onboard equipment required for very-high-frequency (VHF) telemetry data, ultrahigh-frequency (UHF) command, C-band tracking, and (for the first time) unified S-band transmission and reception. The spacecraft communications system performed satisfactorily throughout the mission. However, several problems required additional investigation.

Virtually all anomalies were primarily results of a lack of experience with the systems and equipment. Typical causes were (1) inability of the ground-station operator to recognize quickly the valid two-way S-band phase lock, (2) improperly adjusted up-link modulation indexes, and (3) improper up-link frequencies. These problems were corrected for later missions through experience and operator training.

The spacecraft UHF command subsystem failed to accept the command to separate the command and the service modules, which was transmitted unsuccessfully eight times by the ship Coastal Sentry Quebec. This was investigated in the ESTL. A tape recording of the transmitted signal was used to measure the command-bit structure, transmitted-signal level, frequencies, and phase delays. The test phase then progressed to determining the susceptibility of the spacecraft updata-link equipment to various phase delays and frequency offsets. The test results showed that the command to separate was not accepted because the synchronization-signal frequency was out of tolerance.

The AS-202 communications evaluation effort represented the first opportunity to use and evaluate the S-band communications link, and the analysis showed that spacecraft and earth-based hardware were compatible.

## Apollo 4 Mission

The Apollo 4 mission was the first earth-orbital mission of the Apollo Program. The primary purpose of the Apollo 4 mission was to demonstrate the capability of the heat shield by simulating conditions to which a spacecraft returning from a lunar flight is subjected. The Apollo 4 mission presented the first opportunity for the complete Manned Space Flight Network (MSFN) to acquire, track, and hand over the Apollo S-band signals. The overall performance was good throughout the mission.

The onboard communications system was composed of block I equipment configured similarly to the AS-202 mission system. The primary difference between the communications equipment for the Apollo 4 mission and for the AS-202 mission was in the antenna hardware. The Apollo 4 mission used four block II S-band omnidirectional antennas mounted on the periphery of the aft heat shield and two block II VHF/UHF scimitar antennas mounted on the service module. The S-band antennas, located in the quadrants between the +Y and +Z and between the -Y and -Z spacecraft body axes, were used simultaneously throughout the mission. This choice of antenna pairs, necessitated by the flight trajectory, produced an unusual problem (sideband distortion), which is discussed in the following paragraphs.

Three communications problems were observed during the Apollo 4 prelaunch activities at KSC. The first problem, a radio-frequency (RF) interaction between the CSM and the launch-vehicle instrument-unit (IU) S-band down-link signals, resulted in a loss of IU telemetry data. Subsequent flight-hardware tests at KSC and qualification equipment tests in the ESTL attributed the interference to the following causes.

1. Nonlinear operation of the MSFN ground station caused by a strong (greater than -70 dBm) received CSM carrier power

2. The amplitude of the fourth harmonic of the CSM down-link voice subcarrier becoming greater than the amplitude of the IU carrier

A narrow-band filter was subsequently installed in the receiving system at all MSFN S-band sites to preclude the possibility of interference because of the nonlinear operation during the mission. As a result, no down-link telemetry degradation was noted during the Apollo 4 mission.

The second investigation concerned the effects of incidental phase modulation (IPM) on the CSM down-link S-band telemetry during the prelaunch test activities. Tests conducted in the ESTL had shown that 50° of IPM could increase, by as much as 5 decibels, the down-link signal power required to attain a telemetry bit error rate of $1 \times 10^{-4}$ and could limit system performance to bit error rates greater than $1 \times 10^{-6}$. The CSM contractor had informed MSC personnel that IPM on the S-band down-link for the Apollo 4 mission could be as great as 50° peak. Because preflight predictions indicated that the Apollo 4 telemetry performance would be marginal at times, a procedure was developed for determining the effects of IPM. The test results showed that IPM would not be a serious problem during the Apollo 4 mission because the total effect on telemetry-channel performance was expected to be no worse than a 2.4-decibel degradation.

The third problem concerned a loss of spacecraft S-band telemetry data during the countdown demonstration test at down-link signal strengths known to be sufficient for good telemetry. The telemetry loss resulted from asymmetrical sidebands. It was subsequently predicted mathematically that the sideband cancellation could be an indirect result of unequal radiation paths (cable lengths) to the two spacecraft antennas. Tests in the ESTL simulated the conditions within the Apollo 4 spacecraft and showed that telemetry-channel-performance degradation of up to 12 decibels could be caused by asymmetrical sidebands resulting from spacecraft RF cable unbalance. The tests also showed that this phenomenon occurred only when the line of sight to the receiving system was in a region approximately halfway between the two radiating antennas. This problem did not significantly affect mission performance because the line of sight to the ground stations in the problematic region was normally avoided in the planned vehicle attitude and trajectory profiles.

During the Apollo 4 and 6 missions, the received up-link and down-link carrier powers averaged 6 to 10 decibels below predicted values. Although the exact cause of this discrepancy was not isolated, the results obtained during subsequent missions indicate that the discrepancy was associated with the parallel antenna configuration.

## Apollo 5 Mission

A flight configuration LM was flown for the first time during the Apollo 5 mission, the primary objectives of which were to flight-verify the ascent and descent propulsion systems and the abort-staging function for manned flights. Except for two problems, performance of the development-flight instrumentation and communications systems was as expected.

The first problem concerned abrupt changes in the received-signal power at the development-flight-instrumentation command receiver. Postflight analysis of several possible causes of the abrupt changes was inconclusive because no testing could be accomplished on the hardware. The fault, however, was traced to either the RF stage of the command assembly or the coaxial-cable assembly connecting the diplexer and the digital command receiver. Within the RF stage, several places exist where a faulty connection would result in intermittent operation.

The second problem concerned large, rapid variations of the received down-link S-band carrier power. Careful examination of all existing postflight data revealed that the problems invariably occurred when the spacecraft antenna was facing away from the ground station. The Apollo 5 spacecraft flew in a fixed-antenna configuration. If the capability had existed to switch to the opposite antenna, this problem would not have been encountered.

During Apollo 5 prelaunch activities, a bit-error-rate test was conducted at KSC to determine if IPM existed within the spacecraft. No IPM was found. However, it was discovered that the measured bit error rates (as functions of received carrier power) departed from predictions by 1 to 2 decibels. Reevaluation of the predictions showed two areas of error: (1) antenna temperature and (2) circuit loss. The original antenna-temperature prediction considered a Merritt Island antenna elevation angle of 5°, resulting in an antenna temperature of 90° K. For the KSC bit-error-rate test, however, a 0° elevation angle with a 150° K antenna temperature was more realistic. The original prediction assumed a 0.5-decibel circuit loss between the antenna and preamplifier at Merritt Island. The bit-error-rate test, however, required additional attenuation. The combined effect of the additional attenuation and the updated antenna-noise temperature increased the system-noise temperature prediction from 300° to 480° K. This change resulted in a 2-decibel increase in the system noise, which caused a shift in the predicted bit-error-rate curve and resulted in much better correlation with the measured data. The conclusion is that the discrepancy was caused by an oversight in calculation of the system-noise temperature.

Before the Apollo 5 launch, tests in the ESTL were prompted by concern over the effects of a noise-modulated, voltage-controlled oscillator (because of the absence of an up-link carrier) on the down-link S-band telemetry-channel performance. Test results showed that no detectable degradation would occur and that telemetry-channel performance should not be dependent on the presence of an up-link carrier.

## Apollo 6 Mission

The performance of the communications system — including up-link command, down-link telemetry, and ranging — was satisfactory during the Apollo 6 mission, and no major communications problems existed. The mission was successful in all respects and helped provide the assurance necessary for making the decision to fly the first manned mission, Apollo 7.

Because of the relative newness of the Apollo range instrumented aircraft (ARIA) and the general interest associated with it, a review was held for interested organizations to discuss the series of tests run in the ESTL. The tests were all-inclusive in nature and demonstrated that no serious system-performance limitations existed.

## Apollo 7 Mission

The Apollo 7 mission was the first manned flight of the Apollo Program. The communications system satisfactorily supported the mission, and the applicable mission objectives were achieved. The S-band and VHF links provided good-quality voice communications except during the launch phase, when the crew failed to receive certain up-link transmissions; and the downvoice was garbled because of improper procedures or malfunctioning receivers, or both, at the ground stations.

The VHF/amplitude-modulation voice communications during the prelaunch testing of the Apollo 7 spacecraft were garbled and unintelligible. Investigation of the problem at KSC was inconclusive; therefore, the ESTL was used to investigate the problem. No clear-cut cause could be found for the garbled voice; however, detuning the receiver duplicated the prelaunch problem. Because an improperly tuned receiver was the probable cause of the voice problem, a receiver tuning procedure was formulated.

Before the Apollo 7 mission, the block II S-band RF acquisition procedure had been set up for ±90-kilohertz deviation and 70-kHz/sec sweep rate. During the prelaunch check, it developed that the MSFN was occasionally locking up on a spurious 51.2-kilohertz signal. The ESTL tests indicated that a ±37-kilohertz deviation and

30-kHz/sec sweep rate would give nearly 100-percent probability of correct acquisition. When the new acquisition method was incorporated in the MSFN station procedures, acquisition problems were minimized.

## Apollo 8 Mission

The Apollo 8 mission was the second manned flight of a block II spacecraft and the first manned lunar-orbital flight.

One of the major objectives of this mission was to demonstrate communications and tracking capabilities at lunar distances. Because of the well-planned inflight testing of communications on previous missions, the communications system supported the mission adequately, and the applicable mission objectives were accomplished.

The S-band system provided good-quality voice, telemetry, ranging, television, and played-back telemetry. Played-back voice quality varied from very good to unusable. Communications system management, including antenna switching, was very good.

The flight evaluation tests accomplished during the Apollo 8 mission demonstrated that the CSM S-band omnidirectional antennas were adequate at lunar distance and that the CSM S-band communications equipment adequately supported a lunar-orbital mission.

This mission was the first involving the use of the CSM high-gain antenna. It was also the first Apollo mission requiring precise management of the controllable communications parameters to maintain adequate voice, telemetry, tracking, television, and updata functions. The Apollo 8 mission afforded the first opportunity to demonstrate the feasibility of the newly developed communications-management techniques for translunar-coast and lunar-orbital mission phases. These techniques proved very successful and have not changed in concept or application since the Apollo 8 flight.

In formulating these new techniques, four basic constraints had to be considered.

1. Antenna switching — Because the antennas were not command selectable from the ground, most communications system management had to be accomplished aboard the spacecraft.

2. Circuit margins — Selection of the high-gain-antenna beamwidth had to be consistent with the range capabilities of the S-band signal combinations and type of ground station being used. Because the 30-foot sites were required for tracking data during translunar- and transearth-coast phases of the mission, beamwidth selection was influenced by the ranging channel circuit margin at these sites. Consideration also had to be given to the fact that less margin would exist when the ground antenna was pointed at the moon rather than at a quiet sky.

3. Earth coverage — It was highly desirable to manage the high-gain-antenna beamwidth selection so that the angle between the lines of sight to two 85-foot ground stations was kept within one-half of the antenna 3-decibel beamwidth under worst-case conditions. The minimum spacecraft altitudes required for this coverage were calculated.

4. Spacecraft-receiver saturation — The spacecraft-antenna beamwidth and ground-station transmitted power had to be controlled in a manner such that the spacecraft receiver would never be saturated. If a high-gain-antenna beamwidth/ground-station transmit power combination had been used at a slant range smaller than the calculated minimum, the spacecraft receiver would have been saturated, and degraded high-gain-antenna performance could have resulted.

An important function of the flight verification effort was the premission and postmission briefings. The premission briefings were designed to coordinate the efforts of all concerned divisions and centers and to reach an agreement on the basic techniques of communications management. The postmission performance-review briefing concentrated on those aspects of the mission that could cause communications problems during future missions. The postmission briefing supported the success of the lunar-communications techniques and the need for only minor modifications on a premission basis.

Before the flight, up-link and down-link S-band range capability predictions for all expected signal combinations and antenna/equipment configurations were generated. These predictions were compiled into a form that could be used for premission planning and for quick-reference real-time configuration changes or troubleshooting. This form proved to be a useful tool for both flight control and flight evaluation personnel. Another helpful tool was a set of tables that provided an expedient means of converting the CSM high-gain-antenna pitch and yaw data to spacecraft look-angles ($\theta$ and $\phi$). Such information was needed for real-time determination of spacecraft attitude and its relationship to antenna patterns and configurations and for real-time optimization of antenna management, which, in turn, would maximize communications.

Special laboratory tests were conducted in the ESTL in support of the Apollo 8 mission. The tests were concerned primarily with the capability of ranging at lunar distance in case the high-gain antenna was not available (because of failure or attitude constraints). It was determined from the tests that, with the best omnidirectional antena, optimum spacecraft attitudes would support low-bit-rate PCM telemetry, backup voice, and pseudorandom-noise ranging, plus full up-link (voice, updata, and ranging).

Probably more planning, testing, and premission-review effort was put into the Apollo 8 communications flight evaluation than into any other mission, for the Apollo 8 mission was the culmination of all efforts to assure that lunar-distance communications would be available with the Apollo CSM communications equipment.

## Apollo 9 Mission

The Apollo 9 mission was the first manned flight of the LM. Before the mission, a voice demonstration was conducted by the prime and backup Apollo 9 crews. The demonstration presented the astronauts an opportunity to become familiar with the Apollo voice-communications characteristics and to evaluate the system compatibility for the extravehicular activities (EVA). During the demonstration, four basic communications configurations were simulated. For all four configurations, up-link S-band combination 6 and down-link combination 2 were used for the CSM; up-link S-band combination 2 and down-link combination 10 were used for the LM. The first configuration demonstrated VHF simplex B communications between the LM and CSM. Also included was VHF duplex B (extravehicular (EV) astronaut secondary) communications between the EV astronaut and both the CSM and LM with EV astronaut voice relayed through the LM. The second configuration demonstrated VHF simplex A communications between the LM and CSM. This configuration also presented VHF duplex A (EV astronaut primary) communications between the EV astronaut and both the CSM and LM with the EV astronaut voice and telemetry relayed through the LM. The third configuration demonstrated up-link VHF (primary) simplex A communications among the MSFN, LM, CSM, and EV astronaut. Also included was VHF duplex A (EV astronaut primary) communications between the EV astronaut and both the CSM and LM with the EV astronaut voice and telemetry relayed through the CSM to the MSFN by means of S-band. Using voice quality as the evaluation criterion, performance of the four proposed Apollo 9 operational configurations was demonstrated to be acceptable. However, excessive noise and voice distortion occurred at the ground station during the demonstration. The excessive noise resulted from nonlinear mixing when CSM VHF receivers A and B were operated simultaneously. As a result of these tests, the mixing network in the Apollo 9 CSM VHF receivers was modified. No problems were noted during the mission.

Some astronauts were surprised at the complexity in setting up for the relay mode and at the effect of voice-operated transmission and squelch controls on the relay voice. Even though some problems were encountered that detracted from the demonstration, the primary purpose was served.

Performance of the communications system, including the CSM and LM equipment, was generally satisfactory during this mission. However, several procedural errors and improper equipment configurations degraded the overall system performance and temporarily inhibited voice, telemetry, command, or tracking capability.

During the first television transmission from the LM, no voice was received at the Mission Control Center until the Merritt Island station was requested to use VHF voice instead of S-band. Subsequent investigations showed that good-quality S-band voice was received and recorded at Merritt Island and that transmission to the Mission Control Center was inhibited by improper operation of the voice-operated gain-adjusting amplifier within the station.

Excellent-quality voice transmissions were received from each of the crewmen during EVA. However, the crew did not receive Mission Control Center transmissions relayed through the Texas, Merritt Island, Bermuda, and USNS Vanguard stations. Only one of the transmissions relayed through the Guaymas station was received by the crew. As a result of improper configurations at the Guaymas, Texas, Merritt Island, and USNS Vanguard stations, all voice transmissions, except one, were on the S-band uplink only. Reception of the S-band transmissions was inhibited, as planned, by the spacecraft volume-control settings being at minimum gain. Voice transmissions through Bermuda were unsuccessful, because they occurred during periods of intervehicular communications when the VHF receivers were captured. Good-quality uplink voice was received by each of the crewmen during transmissions through USNS Huntsville, USNS Redstone, and the Canary Island stations.

## Apollo 10 Mission

The Apollo 10 mission was the first lunar flight of the complete spacecraft. It was the fourth manned flight of the CSM and the second manned flight of the LM. The purpose of the mission was to confirm all aspects of the lunar-landing mission exactly as it would be performed, except for the actual descent, landing, lunar stay, and ascent from the lunar surface. Performance of all communications systems — including those of the CSM, LM, and MSFN — was satisfactory and generally as expected.

Before the Apollo 10 mission, the MSC ground-support-team guidelines on communications system operation and management during the lunar mission were formulated. Also prepared in support of the Apollo 10 mission was a set of tables for determining LM steerable-antenna pitch and yaw look angles when the CSM high-gain-antenna pitch and yaw look angles are given and the CSM and LM are docked. The tables also provided the inverse transformation.

Special remote-site briefings were held for most of the MSFN sites that were required for support of the Apollo 10 and 11 missions. These briefings were designed to increase the understanding of the site operators concerning requirements during the missions. The objective was a better understanding of the operating philosophy and performance of the overall spacecraft/MSFN communications link.

## Apollo 11 Mission

The Apollo 11 mission was the first lunar-landing mission. The performance of the communications system was good and was consistent with that of previous flights.

Because of the successfully completed flight evaluation tests conducted on previous Apollo missions, it was expected that the Apollo 11 communications system would support all phases of the mission adequately. Performance was as expected except for a short period before and during LM powered descent.

As shown in figure 4, between acquisition of the LM signal and the face-up maneuver during powered descent, valid steerable-antenna autotrack could not be achieved, and received down-link carrier power was at least 4 to 6 decibels below nominal. Several losses of phase lock were experienced. Before the unscheduled yaw maneuver, the line of sight from the LM steerable antenna to earth was obstructed by a reaction control system thruster plume deflector. Therefore, the antenna autotrack capability was degraded. The sharp losses of phase lock were probably caused by the buildup of oscillations in steerable-antenna motion as the frequencies of incidental amplitude and phase modulation approached multiples of the antenna switching frequency (50 hertz). After the mission, errors in steerable-antenna coverage-restriction diagrams were found. The corrected and premission-blockage diagrams are shown in figure 5.

Before the Apollo 11 mission, the preliminary trajectory had the LM descent occurring one lunar revolution before coverage by the Goldstone 210-foot station. Studies were performed to determine system capabilities in the event of a steerable-antenna failure, because (1) problems with the LM steerable antenna had occurred on the Apollo 10 flight during the low pass over the lunar surface and (2) it was necessary

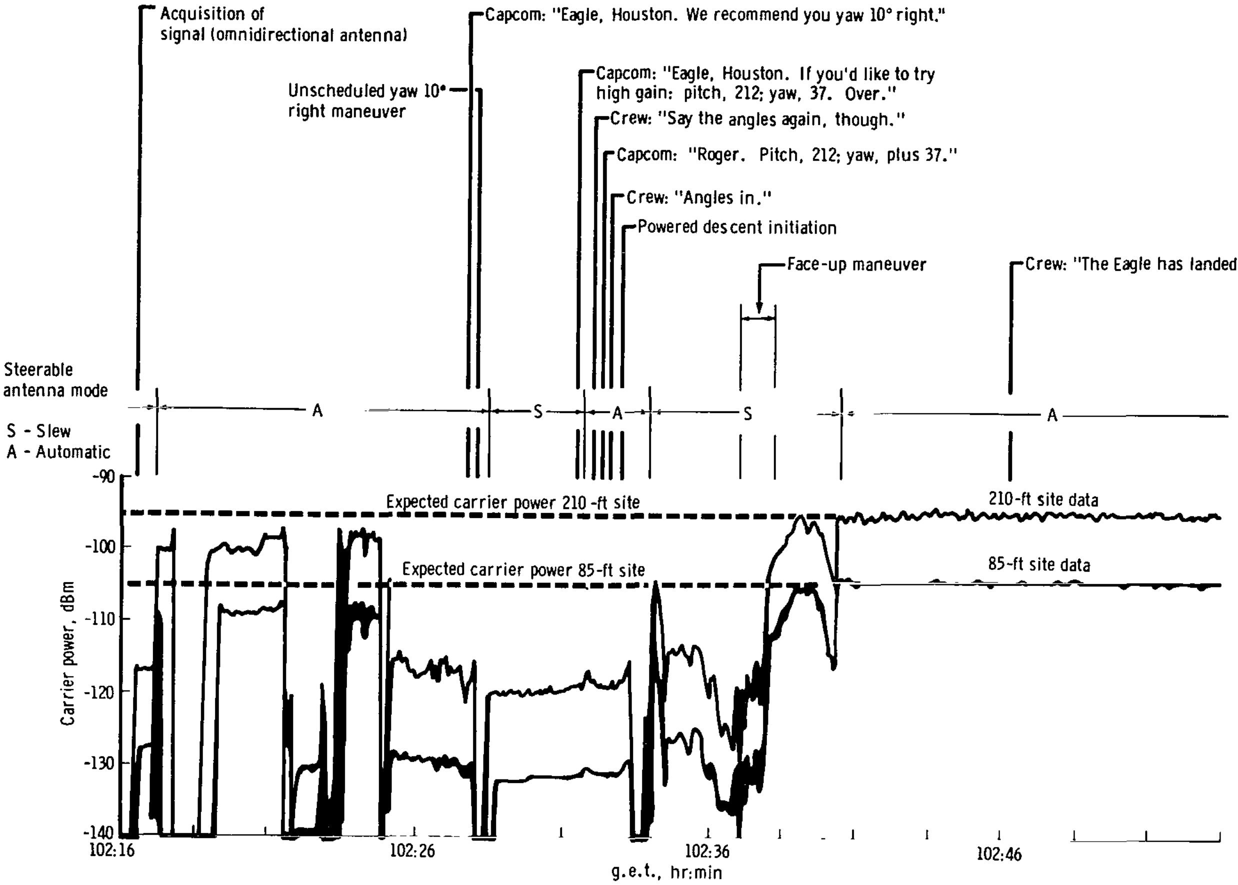

Figure 4. - Received down-link carrier power, Goldstone, descent phase (Apollo 11 mission).

to receive high-bit-rate telemetry data throughout powered descent. These studies indicated that, in the event of a steerable-antenna failure, the LM omnidirectional antennas could support high-bit-rate telemetry only in conjunction with a 210-foot ground station. Therefore, it was recommended that the powered-descent phase be delayed one revolution to allow coverage by the Goldstone 210-foot station. Even though the omnidirectional antennas were not used during descent, the high-bit-rate telemetry data required for lunar landing would not have been received without the use of a 210-foot station.

During the Merritt Island coverage of the launch phase, phase-modulation (PM) and frequency-modulation (FM) receivers were used to demodulate the received telemetry data. Normally, only the PM receiver is used. The purpose of this configuration was to provide additional data on the possibility of improving telemetry coverage during S-IC/S-II staging and interstage jettison. As expected, telemetry performance during this period was improved with the use of an FM receiver.

During the translunar-coast phase of the mission, an evaluation of the Parkes, Australia, receiving system and microwave link was conducted. Based on the test data and data obtained in the ESTL, the absolute performance capabilities of the Parkes site could be estimated. The reason for this test was to determine whether the Parkes site would be able to support the EVA adequately. The tests showed that the Parkes site would support this mission phase, and performance was as expected.

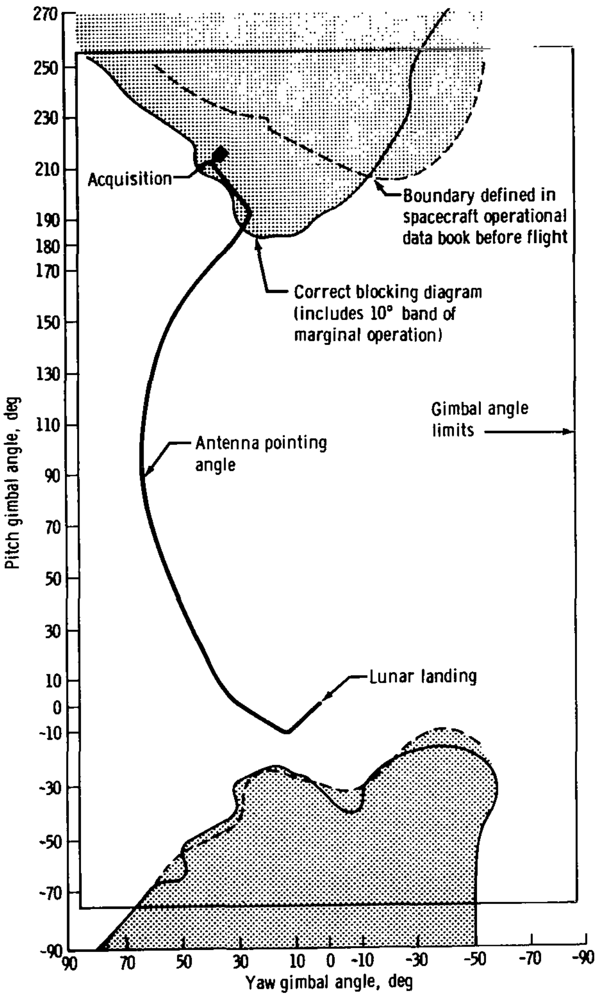

Figure 5. - S-band steerable-antenna coverage restrictions.

A postmission review of the communications system performance during the Apollo 11 descent phase was held about a month after the mission to minimize the possibility of a recurrence of the loss of steerable-antenna autotrack on the Apollo 12 mission. The primary conclusion of the review was that the regions of LM body blockage of steerable-antenna line of sight must be redefined. As a result of the review and subsequent redefinition of the LM blockage, the Apollo 12 descent phase had no communications dropouts at all.

## Apollo 12 Mission

The performance of all communications systems — including those of the CSM, LM, portable life support system, and MSFN — was generally as expected during the Apollo 12 mission and consistent with results on previous flights. The only disappointment concerning communications came shortly after deployment of the LM television camera. Color television pictures of lunar-surface activities were of good quality until the camera was inadvertently pointed at the sun, destroying a portion of the photosensitive surface of the camera.

As was to be expected, Apollo 12 was an anticlimactic mission, as all the applicable communications objectives had been met in the previous missions. The only area that had remained untested was the newly developed LM color television system. Before the Apollo 12 mission, several series of laboratory tests were conducted in the ESTL to evaluate possible use of the command module color television system (configured to operate in a lunar-surface environment) with the LM FM television transmission. Results of these tests showed that the color television presentation would be acceptable (minimal voice subcarrier interference) if the postdetection bandwidth were limited to 900 kilohertz.

# CONCLUDING REMARKS

Experience from Apollo missions yielded several interesting conclusions concerning the communications system design and performance specifications. It was thought, early in the program, that a telemetry bit error rate (measure of data accuracy) of $1 \times 10^{-6}$ or better was necessary for real-time decisions. Telemetry utilization during the Apollo 8 mission showed that adequate data accuracies were achieved for all telemetry bit error rates better than $1 \times 10^{-3}$. Consequently, the tolerance on the telemetry accuracy was too rigid. Also, mission results showed that a word intelligibility of 70 percent (measured using the standard intelligibility tests) is sufficient for excellent sentence intelligibility.

The auxiliary oscillator, built into the block II unified S-band equipment, presented operational problems. Laboratory testing of the block I Apollo command module communications system (in the Electronic Systems Test Laboratory) had shown that, because of the gain of the turnaround ranging channel, a loss of up-link carrier would degrade down-link telemetry and voice performance. This fact, coupled with the flight experience of the Jet Propulsion Laboratories, led to the incorporation of an auxiliary oscillator in the unified S-band equipment. The function of the auxiliary oscillator was to produce a phase-stable down-link signal when no up-link signal was detected by the spacecraft receiver. Later, the auxiliary oscillator proved troublesome during station handovers. Ideally, no loss of down-link phase lock should occur during handovers; however, if during handover the up-link signal strength decayed to the point where the auxiliary oscillator was selected, an instantaneous down-link frequency shift caused a loss of down-link lock. Data were lost during many handovers because of the auxiliary oscillator. Subsequent testing showed that a reduction of the ranging-turnaround gain-constant in the block II design solved the down-link performance degradation noted during the block I tests. Thus, the incorporation of the auxiliary oscillator was unnecessary.

The down-link voice-channel noise-suppression techniques could be greatly improved. The ideal criteria for noise-suppression devices are (1) to pass all usable voice and (2) to suppress noise when no usable voice is present. The system used on later Apollo flights (voice-operated gain-adjusting amplifier) was triggered under certain conditions when no voice was present and also suppressed portions of intelligible sentences. These drawbacks resulted from the method of noise suppression; threshold adjustment was extremely difficult. In future programs, consideration should be given to (1) transmitting a tone from the spacecraft to the ground station with the voice, (2) detecting the tone in the ground station, and (3) activating the audio circuitry connecting the ground station and Mission Control Center during tone presence. The tone could be controlled within the spacecraft by a push-to-talk switch and voice-operated relays.

Even though noise suppression in the up-link voice channel has not been as much of a problem as it has in the down-link voice channel, the tone system should be considered in future up-link signal designs.

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