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SUPPLEMENT 10

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

# APOLLO 11 MISSION REPORT
## SUPPLEMENT 10

## COMMUNICATIONS SYSTEM PERFORMANCE

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MANNED SPACECRAFT CENTER
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Supplement 10

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## COMMUNICATIONS SYSTEM PERFORMANCE

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# SUPPLEMENTAL REPORT ON COMMUNICATIONS SYSTEM PERFORMANCE DURING THE APOLLO 11 MISSION

# PREFACE

This supplemental report on the communications system performance during the Apollo 11 mission has been prepared for the Tele/Communications System Division of NASA's Manned Spacecraft Center under contract NAS 9-5191. All times used in this report are referenced to range zero, the integral second before lift-off. Range zero for this mission was 197:13:32:00 Greenwich mean time.

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## SECTION 1

## INTRODUCTION

This document presents a discussion of Apollo communications system performance data obtained during real-time support of the Apollo 11 mission and from information derived from a detailed postmission evaluation. This report contains supplemental information which was obtained after the "Apollo 11 Mission Report" was published. This report has been prepared as Supplement 9 to the Apollo 11 Mission Report (MSC-00171).

The lunar module communications performance during lunar orbit and during the extravehicular activity period are discussed in detail.

Minimum command and service module communication performance evaluation was performed on the Apollo 11 mission since nominal performance characteristics have been thoroughly documented for previous lunar missions.

The few reported discrepancies in the command and service module communications system performance are reported and analyzed in this report.

The guidelines for conducting the communications evaluation are contained in the "Communications System Flight Evaluation Program Plan," (Reference 1).

Mission events and nomenclature are generally in accordance with the Apollo 11 Flight Plan (Reference 2).

## SECTION 2

## COMMUNICATIONS SUMMARY

The performance of the communications systems was generally satisfactory throughout the Apollo 11 mission. Both the S-band and very high frequency communication systems provided good quality voice. The performance of command module and lunar module updata links was as expected. Real time and playback telemetry channel performance was excellent. Color television pictures of high quality were received during all the command module transmissions except the first. Good quality black-and-white television pictures were received during the lunar extravehicular activity. Excellent quality tracking data were obtained for both the command and lunar modules. The received uplink and downlink signal powers generally corresponded to predictions. Communications system management, including antenna switching, was generally good.

Some communications discrepancies of general interest are listed and discussed in Table 2-1.

### 2.1 Launch and Earth Parking Orbit

The Merritt Island, Grand Bahama Island, Bermuda Island, and USNS Vanguard stations maintained phase lock from launch through orbital insertion, except during the Saturn IC/Saturn II stage separation, interstage jettison, and from 00:06:01 to 00:06:33. A complete loss of the S-band uplink lock occurred at 00:06:01 because the Grand Bahama Island station terminated the uplink 30 seconds early. Full S-band communications were restored at 00:06:33 when the Bermuda station established two-way phase lock as scheduled.

The data losses during Saturn IC/Saturn II separation and interstage jettison were caused by flame attenuation, booster shadowing, and rapid phase perturbations due to transmission through the plume. As shown in Figure 3-1, these losses can be reduced during the first four-to-five-minutes of the launch phase, through the utilization of a frequency modulation receiver as a source for the telemetry data. Through a comparison of telemetry performance from the frequency modulation and phase modulation receivers, shorter time periods of data dropouts are observed in the FM receiver telemetry performance as compared to the PM receiver case. Although the number of dropouts is the same for the FM and PM receiver cases, it is noted that more data are provided from the FM receiver. This is attributed to the fact that the FM receiver does not have to maintain or reestablish phase lock as in the PM receiver case. It is to be noted, however, that during periods when the PM receiver is in lock, the PM data quality is better than that obtained from the FM receiver. Therefore, after the initial four to five minutes when this type of PM dropouts is not normally experienced, the telemetry data from the PM receiver should be utilized.

The television transmission attempted during the first pass over the Goldstone station was unsuccessful because of a shorted patch cable within the ground station television equipment. Also, the tracking coverage during this pass was limited to approximately three minutes by terrain obstructions.

## 2.2 Translunar Injection and Translunar Coast

During the translunar injection maneuver, approximately 58 seconds of command module data and command capability were lost during the USNS Redstone handover to the USNS Mercury and during the USNS Mercury handover to Hawaii. The first loss was due to an equipment problem onboard the USNS Mercury and their subsequent tracking on an antenna side lobe. The second loss was caused by terrain obstructions at the Hawaii station.

Communications between the command module and the ground were lost during transposition and docking because the crew did not switch omnidirectional antennas during the pitch maneuver. Two-way phase lock was regained at 03:24:00 when the crew acquired the uplink carrier by switching to omni B antenna. The crew switched to the high gain antenna at 03:28:53 for the first time. Between 03:28:53 and 04:00:00, the downlink voice received at the Mission Control Center through the Goldstone station was distorted by a defective cable at the station.

During the second television transmission from the command module, noise spikes were on the electrocardiogram (EKG) data transmitted to the Goldstone station. The characteristics of the noise indicated that the noise spikes were probably caused by electromagnetic interference from the television equipment within the command module.

During the final translunar coast crew rest period, the Parkes, Australia, facility which had not previously supported an Apollo mission was checked to determine if it could support the lunar surface extravehicular activity. The overall performance of the Parkes receiving system was within 1 dB of preflight predictions and was adequate to support the lunar surface activity. A subsequent check of the microwave link between the Parkes facility and Honeysuckle Creek station showed that the link did not degrade the quality of received data.

## 2.3 Command Module Performance During Lunar Orbit

Command module communications performance during lunar orbit operations was generally satisfactory. The quality of the audio and television signals was good. High gain antenna performance during lunar orbit was generally good. During lunar orbit 5, the high gain antenna unexpectedly slewed from the main lobe of the antenna because of a procedural error at the Goldstone station. Refer to section 3.3.2 for additional information. During lunar orbit 9, the command module was acquired by the Honeysuckle station 6 minutes later than predicted. Sufficient information does not exist to determine the cause of this delay.

During lunar orbit 26, the Madrid station was unable to receive the command module backup downvoice because of an equipment malfunction or configuration error at the site.

The command module recorded telemetry data that was played back from the data storage equipment at 32:1 and 1:1 rates through the 85-foot antenna stations were good. The voice played back at the 32:1 rate through 85-foot antenna stations varied from weak to loud and was barely discernable through the 30-foot antenna stations, as expected. The lunar module telemetry data recorded by the command module data storage equipment were good when received through the 85-foot antenna station. The associated voice intelligibility was poor. As expected, stations with 30-foot antennas did not receive the lunar module 32:1 dump rate telemetry data played back from the data storage equipment.

## 2.4 Lunar Module Communications Performance During Lunar Orbit and Descent

During lunar orbit 4, the lunar module communications equipment was activated for the first time. Good quality normal downvoice, poor-to-fair quality backup downvoice, and good high- and low-bit-rate telemetry were received through the 210-foot antenna at the Goldstone station while the spacecraft was transmitting through an omnidirectional antenna. As expected, the pulse code modulation (PCM) telemetry decommutation system frame synchronization could not be maintained on the high-bit-rate data received through the 85-foot antenna at the Goldstone station.

Between acquisition of the lunar module signal at 102:16:30 and the pitch down maneuver during powered descent, valid steerable antenna auto-track could not be achieved (received uplink and downlink carrier powers were 4 to 6 dB below predicted values) and several losses of phase-lock were experienced. Prior to 102:27:22, the line-of sight from the steerable antenna to the earth was obstructed by a lunar module reaction control system thrust deflector. Therefore, the antenna was more susceptible to multipath transmissions off the lunar module and/or the lunar surface. The sharp losses of phase lock were probably caused by the buildup of oscillations in steerable antenna motion as the frequencies of the incidental amplitude and phase modulation approached multiples of the antenna switching frequency (50 Hz). After the unscheduled yaw maneuver at 102:27:22, which was unsuccessful in establishing communications, automatic tracking with the correct spacecraft pointing angles was attempted at 102:40:20. Communications were maintained from this time until lunar landing.

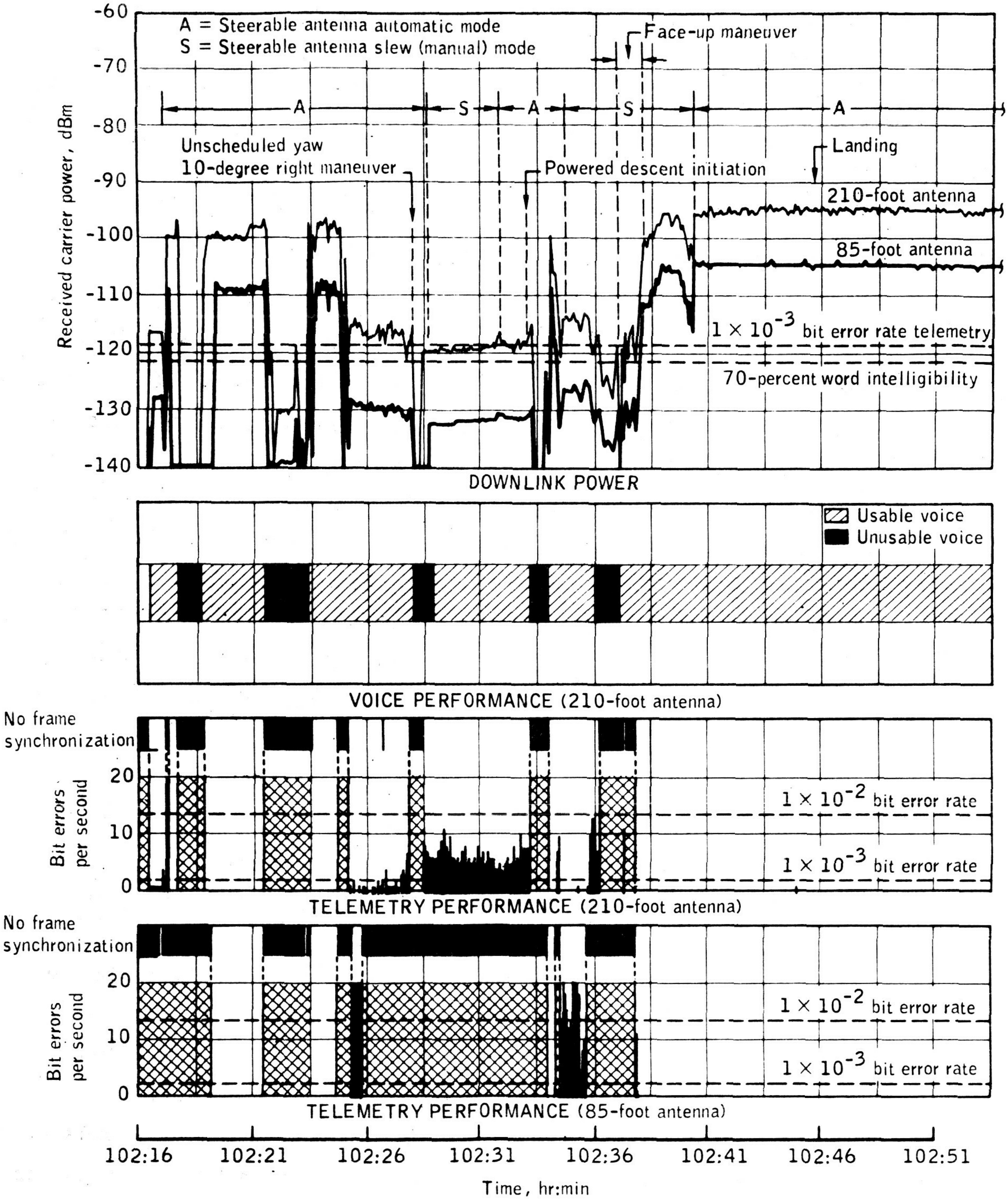



Figure 2-1 Communications System (downlink) Performance During Final Descent

During powered descent (See Figure 2-1), the performance of the downlink voice and telemetry channel was degraded by low received carrier power. The long periods of loss of PCM synchronization on data received at the 85-foot antenna station distinctly illustrated the advantage of scheduling the descent maneuver during coverage by the 210-foot antenna at the Goldstone station.

## 2.5 Communications Performance During Lunar Stay

After landing, the steerable antenna was used in the slew (manual) mode for all communications during the lunar stay. Also, the network was configured to relay voice between the command and lunar modules. This configuration provided good voice while the command module was transmitting through the high gain antenna. However, the lunar module crewmen reported that the noise associated with random keying of the voice operated amplifier within the network was objectionable when the command module was transmitting through an omnidirectional antenna. This noise was expected, and the two-way voice relay should have been disabled, as planned, when the command module omnidirectional antenna was selected. The use of the two-way voice relay through the network was discontinued after the noise was reported.

During the subsequent extravehicular activity, one-way voice relay through the network site to the command module was used. Primary coverage of the extravehicular activity was provided by the 210-foot antennas at Goldstone, California, and Parkes, Australia. Backup coverage was provided by the 85-foot antenna stations at Goldstone, California, and Honeysuckle Creek, Australia. Voice communications during this period were adequate except for a voice operated relay breakup in the lunar module pilot's voice circuity. Throughout the extravehicular activity, an echo or turned around voice was heared on the ground 2.6 seconds after the uplink transmissions. Post mission testing indicated that this echo was probably caused by acoustical coupling between the astronaut's earphone and microphone in conjunction with an oversensitive and/or malfunctioning voice actuated switch (VOX).

Good quality black-and-white television pictures were received through the Mars and Parkes 210-foot antennas. Throughout the lunar surface activities, good lunar module and portable life support system status data were received.

The data recorded by the Honeysuckle station during lunar surface activities were evaluated to determine if an 85-foot antenna station could have supported this mission phase without deployment of the erectable antenna. The results of this evaluation were compared with the results of a similar evaluation of data received through Goldstone's 210-foot antenna. The comparison of slow scan television video received at the two stations showed that although there was a 5 dB average difference in overall signal-to-noise ratios, there was no appreciable difference in picture quality. The differences in downlink voice intelligibility and telemetry data quality were not significant (4 dB average speech-to-noise ratio difference). There was no visual difference in the quality of EKG signals received at the 85-foot and 210-foot antenna stations. Frame synchronization was maintained 88 and 100 percent of the time for the extravehicular astronauts portable life support system status data through the 85-foot and 210-foot antenna stations, respectively. From this data it is apparent that an 85-foot antenna station could have supported lunar surface activities without deployment of the erectable antenna, provided that a 12 percent loss of PAM data is considered acceptable.

## 2.6 Lunar Module Communications Performance During Ascent and Rendezvous

The performance of the communications system during ascent and rendezvous was as expected, except for a 5-second loss of downlink phase lock at ascent engine ignition. This loss may be attributed to either rapid phase perturbations associated with transmission through the ascent engine plume, phase perturbations caused by antenna vibrations, or transients in the electrical system associated with harness severance.

## 2.7 Early Apollo Scientific Experiment Package (EASEP) Communications Performance

Frame synchronization on the telemetry data from the scientific experiments package (early ALSEP) was established at 111:10:30. Good quality telemetry data were received until the package was turned off. The package would not accept commands transmitted through the Texas and Canary Island stations during their first periods of coverage. These uplink command nonacceptance problems were isolated to these stations and were subsequently corrected.

## 2.8 Transearth Coast and Earth Orbit Entry

Communications with the command module were as expected with minor exceptions. Communications through the Goldstone station were lost for 54 minutes beginning at 151:53:00 because spacecraft roll drove the high gain antenna into the gimbal limits. Communications with the command module were also lost for 11 minutes beginning at 154:30:00 when the high gain antenna switch was erroneously placed in the automatic tracking mode instead of the automatic reacquisition mode. This prevented the proper positioning of the antenna for acquisition by the Goldstone station.

TABLE 2-1

SUMMARY OF SIGNIFICANT COMMUNICATIONS DISCREPANCIES

| DISCREPANCY | STATION/PHASE | REMARKS |
|---|---|---|
| Premature Handover Attempt | Grand Bahama Island/ Launch | Premature (30 second) uplink cutoff for handover to Bermuda station (procedural error). |
| First Telecast Not Achieved | Goldstone/Earth Orbit 1 | Trajectory not compatible for good telecommunications (3-minute total pass coverage) and defective cable problem. |
| Automatic Angle Tracking Not Achieved; Updata Link Inhibited | Mercury/Earth Orbit Translunar Injection | Mercury angle tracking receivers improperly phased. Required manual angle track during acquisition and majority of pass (tracked on antenna side lobe). Mercury command computer faulted, inhibiting updata link commands to CSM. |
| Loss of Communications at Transposition and Docking | Goldstone/Transposition and Docking | Spacecraft remained on omni D which was partially occluded during transposition and docking maneuver resulting in loss of communications for approximately 4-1/2 minutes |
| Distorted Voice Remoted to Mission Control Center | Goldstone/Translunar Coast | Voice distortion remoted to Houston was caused by defective input cable at site voice demodulator. |
| Loss of Communications At Handover From Goldstone to Madrid | Madrid/Translunar Coast | Communications interruption occurred at Goldstone to Madrid handover. Loss of downlink was coincident with an increase in power of Madrid transmitter from 1.5 to 2.0 kilowatts. Downlink voice was remoted from site but not received at Mission Control Center. |
| Electrocardiogram Data Noise During Telecast | Goldstone/Translunar Coast | During the telecast between 10:26:50 and 10:49:02 noise spikes were present on each of the three crewmen EKG data. The apparent source of the noise is electromagnetic interference generated by the television equipment. |
| Decrease of 10 to 12 dB in Telemetered Uplink Carrier Power | Goldstone/Translunar Coast | Insufficient data exists to determine the exact cause of this discrepancy. Goldstone transmitter power output was not recorded during this period (78:40:00 to 78:49:00). |
| CSM Loss of Uplink Lock | Goldstone/Lunar Orbit 5 | Loss of uplink lock and subsequent intermittant communications between 84:44:43 and 82:52:59. Goldstone initiated an unnecessary reacquisition of the uplink when their receiver no. 1 lost lock due to a power supply failure. |
| CSM Late Acquisition | Honeysuckle/Lunar Orbit 9 | A six minute delay in acquisition of the Command and Service Module occurred after lunar occlusion for lunar orbit 9. Additional data are necessary to isolate the cause of the discrepancy. |
| LM Steerable Antenna Failed to Autotrack During Descent | Goldstone/Lunar Module Descent and Landing | Blockage of the line of site between the earth and the steerable antenna by a reaction control thruster and multipath signals from the LM structure and/or the lunar surface contributed to the losses of phase lock. |
| Uplink Voice Communications Echos and Down Voice Breakup | Goldstone/Lunar Stay | Echoes of the uplink voice communications 2.6 seconds after transmission caused by acoustical coupling between the astronaut's earphone and microphone. The voice break up was probably caused by the commanders voice operated relay sensitivity setting being set too low. |
| 5-second Loss of Downlink at LM Ascent Engine Ignition | Madrid/Lunar Module Ascent | A 5-second loss of the downlink during ignition and lift off was possibly caused by phase perturbation due to the ascent engine plume, high frequency vibration of the steerable antenna, and/or transients in power supply during umbilical separation. |
| Loss of Backup Downvoice From CSM | Madrid/Lunar Orbit 20 | Madrid received no backup down voice after acquisition, but the Ascension Island station backup down voice was normal. Station configuration error or equipment malfunction at Madrid is suspected. |
| Command Module Loss of Communications for 54 Minutes. | Goldstone/Transearth Coast | Difficulty in establishing desired PTC mode attitude and roll rates was experienced. The high gain antenna tracked into the gimble limits during the maneuver. Goldstone lost two way lock due to low signal strength and was unable to command the antenna switches. The crew restored communications after establishing the proper PTC mode. |
| CSM Loss of Communications for 11 Minutes | Goldstone/Transearth Coast | The high gain antenna was placed in the auto track rather than auto reacquisition mode during PTC causing loss of ground command capability of selecting the auto reacquisition mode and proper ground command antenna management. |

SECTION 3

COMMUNICATIONS PERFORMANCE ANALYSIS

## 3.1 Launch and Earth Parking Orbit

The S-band and very high frequency (VHF) communications systems performed adequately during launch and earth orbit. VHF Duplex B was used during launch, and VHF Simplex A was used for the remainder of this phase. S-band communications signal combinations 6.02 and 6.03 were employed during this phase. A summary of uplink and downlink S-band signal combinations is contained in Appendix E.

### 3.1.1 Merritt Island Station Coverage

The Merritt Island unified S-band station provided VHF voice and S-band support for the Apollo 11 mission through countdown and liftoff and provided the uplink until 00:02:00 (Figure 3-1). At 00:01:27, the Merritt Island station antenna slewed off track for approximately 5 seconds. This occurred when the station attempted automatic tracking at close range. Automatic tracking was then acquired without loss of either the uplink or the downlink carrier lock. At 00:02:42, the Merritt Island station lost the downlink for 8 seconds during the Saturn IC staging and at 00:03:13 for 1 second during the interstage jettison; otherwise good telemetry were received through 00:06:04. The spacecraft transponder switched to the auxiliary oscillator mode at 00:06:04 when the uplink was terminated 30 seconds early by the Grand Bahama Island station. However, the Merritt Island station maintained downlink lock on the auxilliary oscillator downlink during this period. At 00:06:33, normal downlink lock was reestablished by the Merritt Island station, and passive support was continued until 00:09:07 when the signal was lost as expected.

#### 3.1.1.1 Merritt Island Station Phase and Frequency Modulation Telemetry Performance

During Merritt Island's coverage of the launch phase, both phase modulation (PM) and frequency modulation (FM) receivers were used to demodulate the telemetry in an attempt to reduce the data losses during the Saturn

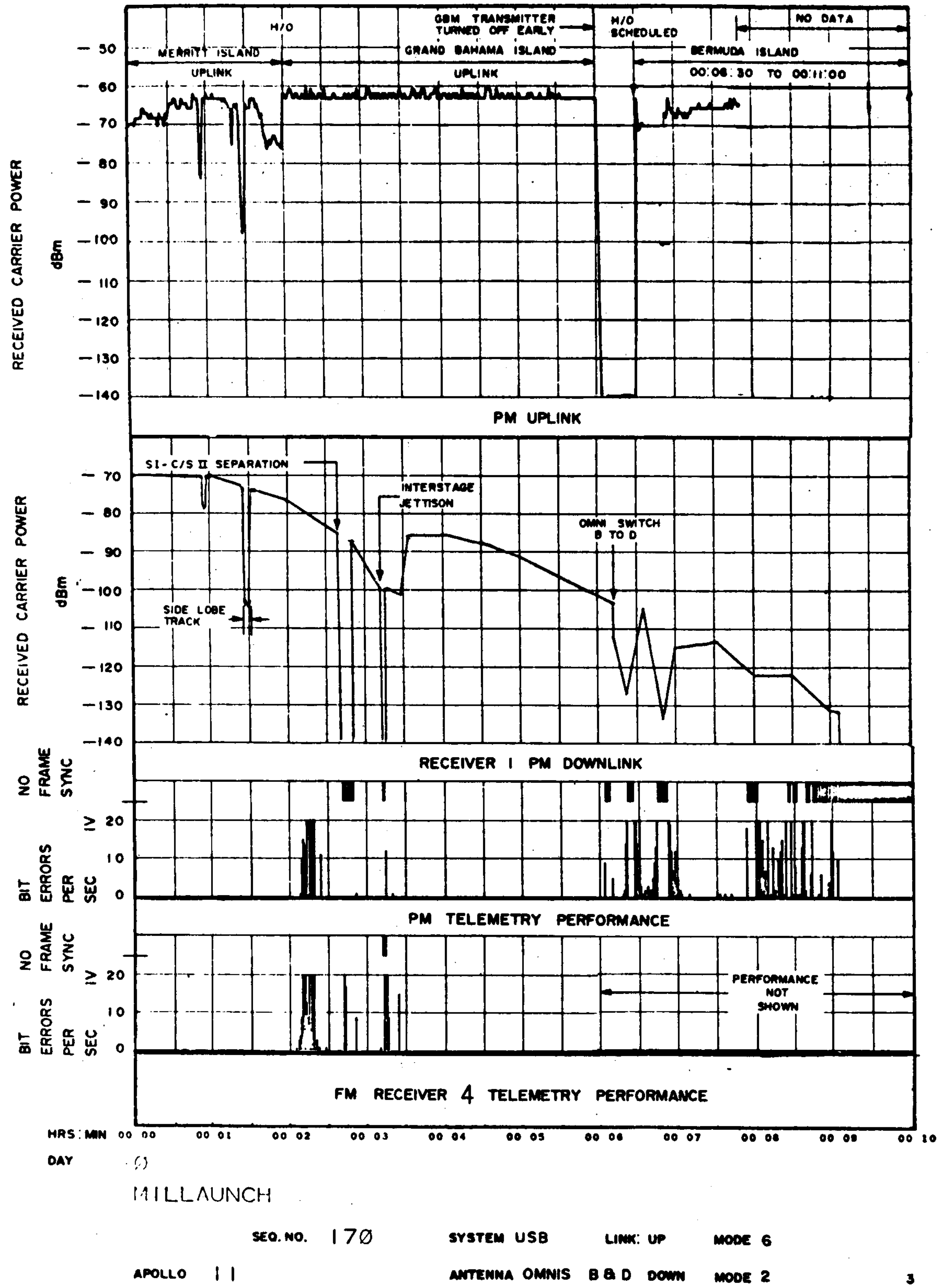



Figure 3-1 Merritt Island Station S-band Communications Coverage During Launch

IC/II separation and interstage jettison. During separation the performance of the FM receiver was superior to that of the PM receiver. The PCM data from the PM receiver was out of telemetry decommutator synchronization more often than the FM receiver data. During the interstage jettison the performance of the receivers was about equal (Figure 3-1).

Although the number of dropouts is the same for the FM and PM receiver cases, it is noted that more data are provided from the FM receiver. This is attributed to the fact that the FM receiver does not have to maintain or re-establish phase lock as in the PM receiver case. It is to be noted, however, that during periods when the PM receiver is in lock, the PM data quality is better than that obtained from the FM receiver. Therefore, after the initial four to five minutes when this type of PM dropouts is not normally experienced, the telemetry data from the PM receiver should be utilized.

A comparison of receiver telemetry performance from the Apollo 9 and 10 missions basically substantiates this same conclusion. A detailed comparison of launch telemetry performance for the Apollo 9, 10, and 11 missions is presented in Appendix A.

#### 3.1.1.2 Merritt Island Station Launch Coverage Comparison For Apollo 8, 10, and 11 (see Appendix B)

### 3.1.2 Grand Bahama Island Station Coverage

The Grand Bahama Island station passively acquired the S-band downlink signal from the command module at 00:01:03 and acquired the uplink at 00:03:00 as scheduled. The downlink received carrier power ranged from -72.5 dBm at handover to -85.5 dBm at loss of signal. The Grand Bahama Island station terminated the uplink carrier prematurely at 00:06:01 causing a 32-second loss of uplink command capability. The spacecraft transponder switched to the auxiliary oscillator mode, resulting in an interruption of the downlink carrier lock at 00:06:04. The Grand Bahama Island station reacquired and monitored the auxiliary oscillator downlink from 00:06:20 to 00:06:33 and then acquired normal tracking until 00:09:13 when loss of signal occurred as expected.

### 3.1.3 Bermuda Island Station Coverage

The Bermuda Island station acquired the command module S-band downlink at 00:03:52 and then lost the signal at 00:06:01 as a result of the premature turn-off of the Grand Bahama Island uplink carrier. The Bermuda Island station reacquired the auxiliary oscillator downlink at 00:06:07. The downlink received carrier power increased approximately 12 dB when the crew switched antennas from omni B to omni D at 00:06:13. Three seconds of transmitter uplink sweep were necessary for the Bermuda Island station to establish the uplink lock. Uplink lock was achieved at 00:06:33. The Bermuda Island station continued uninterrupted active coverage of the flight until 00:11:00 when handover to the USNS Vanguard was initiated.

The downlink received carrier power during the Bermuda Island active coverage ranged from -75 dBm at acquisition to -86 dBm at handover to the USNS Vanguard. The Bermuda Island station provided passive coverage through 00:13:28.

### 3.1.4 USNS Vanguard Coverage

The USNS Vanguard acquired the command module downlink passively at approximately 00:09:00 and acquired it actively on an uplink sideband at 00:11:00, when handover from the Bermuda Island station was initiated. At 00:11:17, the USNS Vanguard broke uplink lock and reacquired 2-way lock to provide active coverage of orbital insertion through 00:16:00 when loss of signal occurred as expected.

### 3.1.5 Goldstone Station Television Coverage, Earth Orbit 1

The Goldstone station acquired two-way lock at 01:21:02 and lost the signal at 01:23:55 as expected. The Goldstone station coverage was of short duration because of low elevation angle tracking. Even though the coverage was minimal, the station was scheduled to receive, record, and remote the first television transmission from the command module. The duration of the television transmission was 1 minute, but the quality was unsatisfactory because of a defective cable in the station signal data demodulator system.

It is recommended that when a station is scheduled for television coverage their equipment should be checked in a more timely manner. The last check at the Goldstone station appeared to have been accomplished almost twelve hours before the actual coverage.

## 3.2 Translunar Injection and Translunar Coast

Translunar injection ignition was at 02:44:16 and cutoff was at 02:50:13. During translunar injection, the omni D antenna was used, and the crew switched to omni B after completion of the transposition and docking maneuver. At 03:28:53, the crew selected the high gain antenna. The passive thermal control for the translunar coast phase was initiated at approximately 10:58:10, and communications were maintained by switching between opposite omni antennas in response to commands from the mission control center for the majority of the translunar coast period. Passive thermal control was initiated at the completion of the first successful television telecast and was interrupted for two additional telecasts, for a midcourse correction at 26:45:00, and for occasional star sightings. The primary S-band communications combinations during passive thermal control were combinations 6.09 and 6.15 during sleep periods, and 6.02 and 6.03, otherwise. High bit rate telemetry was used when the downlink received carrier power was above high bit rate telemetry threshold. During the early portion of the translunar coast, the spacecraft roll rate for passive thermal control was approximately three revolutions per hour. During the later portion of the translunar coast phase, the spacecraft roll rate was increased to four revolutions per hour.

In general, the management of omni antennas and commanding of telemetry during passive thermal control showed a significant improvement over the Apollo 8 and Apollo 10 missions. The translunar coast communications coverage ended with lunar occlusion at 75:41:22.

### 3.2.1 USNS Redstone and USNS Mercury Coverage

The USNS Redstone acquired two-way lock with the command module S-band system at 02:40:20 before translunar injection ignition. Handover from the USNS Redstone to the USNS Mercury was initiated at 02:46:50 and the USNS Mercury reported ready for command transmission at 02:47:40, indicating that two-way lock had been established. However, intermittent acquisition and tracking due to improper phasing of the X and Y axis angle tracking receiver caused the antenna to drive off the main lobe whenever automatic tracking was attempted. The data for resolving the USNS Mercury acquisition and tracking discrepancy were not recorded. At 02:48:07, the uplink and downlink received carrier powers stabilized at -54 dBm and -80 dBm, respectively, and automatic tracking was successfully achieved. Then downlink telemetry data were received by the USNS Mercury until the initiation of the handover to the Hawaii station at 02:49:46. This early handover to the Hawaii station was initiated because of a command computer failure at the USNS Mercury. The USNS Mercury was unable to maintain satisfactory telemetry decommutator lock from 02:49:46 until 02:52:50 because of tracking on an antenna sidelobe.

### 3.2.2 Hawaii Station Coverage

The handover to the Hawaii station was initiated ahead of schedule at 02:49:46, immediately upon Hawaii station acquisition of the downlink. Two-way lock was not acquired until 02:50:10 because of terrain obstructions.

The Hawaii station actively supported the spacecraft from 02:50:10 until the handover to the Goldstone station at 03:00:00.

### 3.2.3 Communications During Transposition and Docking

The Goldstone station acquired the downlink from the command module 5 minutes after translunar injection. A handover from the Hawaii station to the Goldstone station was accomplished at 03:00:00, with downlink received carrier power at approximately -78 dBm. The command and service module separated from the Saturn IVB at 03:17:04 while the received carrier power was approximately -90 dBm. At 03:19:30, the Goldstone station unexpectedly lost the signal. From 03:19:30 until 03:24:00, omni D was active and the signal appeared to have been occluded by the spacecraft. At 03:24:00, the Goldstone station acquired two way lock when the spacecraft completed the maneuver and the crew switched from omni antenna D to B. At 03:28:53, the crew selected the high gain antenna and the downlink received carrier power then averaged -72.5 dBm. Figure 3-2 shows the look angles from the spacecraft to the Goldstone station during transposition and docking.

### 3.2.4 Goldstone Station Remoted Voice Distortion

From 03:30:00 through 04:00:00, the downlink voice remoted to Houston through the Goldstone station was distorted but intelligible. A defective input cable to the station voice demodulator was later discovered to be the cause of the distortion and was repaired.

### 3.2.5 Loss of Signal After Goldstone to Madrid Handover

At 04:00:00, Goldstone handed over the uplink to the Madrid station. The handover procedure was in accordance with high gain antenna operational handover procedures, and there were no apparent interruptions of either the uplink or downlink at the time; however, uplink modulation was not turned on at the Madrid station until 04:00:20, resulting in a 20-second loss of uplink communications. From 04:00:20 until 04:02:25, the Madrid station remoted good down voice to net 1, although it was not received at the Mission Control Center in Houston.

When the handover occurred, the high gain antenna had to slew from the Goldstone station to the Madrid station. Due to the angular distance between Goldstone and Madrid, the high gain antenna switched from narrow to wide beam width, and at 04:01:00, the high gain antenna switched back to narrow beam width. At 04:01:47, a sudden loss of downlink occurred

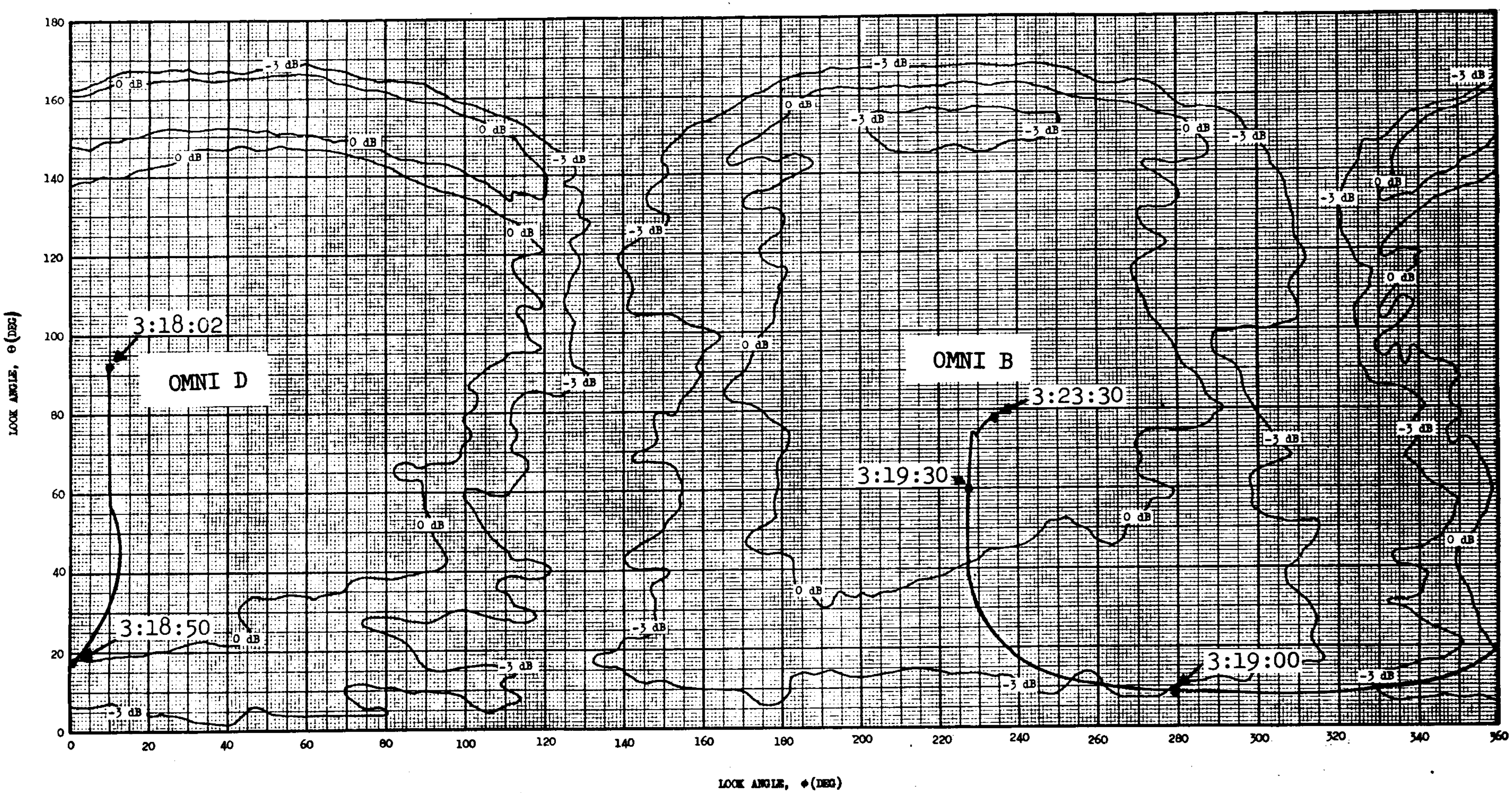



Figure 3-2 Spacecraft To Site Look Angles During Transposition And Docking

on the Madrid and Goldstone S-band receivers simultaneously. There was no indication at either site of any change in the command module uplink received carrier power or static phase error prior to or coincident with the loss of the downlink. Coincident with the loss of signal at both stations at 04:01:47, was an increase in the total power output of the Madrid station transmitter from 1.5 kilowatts to approximately 2 kilowatts. A possible cause for the loss of signal is that concurrent with the power output increase a frequency instability in the uplink signal also occurred which resulted in termination of up-link lock. This caused the command module transmitter to switch to the auxiliary oscillator and break downlink phase lock. At 04:02:06, two-way lock was re-established at the Madrid station, and the Goldstone station acquired the downlink.

### 3.2.6 Translunar Coast Phase Television Performance

Three color television transmissions were received from the command module during the translunar coast. A 20-minute color telecast was received and recorded by the Goldstone station between approximately 10:28:00 and 10:48:00 for later playback. The other color television transmissions were received through the Mars 210-foot antenna. The first occurred between 33:59:00 and 34:35:00 and the second between 55:08:00 and 56:44:26. The audio and video quality of all transmissions was excellent.

### 3.2.7 Electrocardiogram Data Noise

From 10:26:50 to 10:49:02, noise spikes appeared on the astronauts electrocardiogram (EKG) data. The spikes were 40 pulses per second and constant in amplitude. The spikes appeared on all three crewmen's EKG data during some portion of the period and often on at least two crewmen's EKG data simultaneously.

The noise appeared at approximately the same time that Goldstone received television transmission and disappeared at approximately the same time that television transmission was terminated (Figure 3-3).

It appears that interference by the television equipment may have caused the EKG noise. The appearance of noise spikes on each of the astronauts' EKG data may be related to the proximity of the astronaut to the television equipment. However, sufficient data are not available at this time to fully evaluate this discrepancy and determine the exact source of the interference.

3.2.8 Goldstone Station Uplink Carrier Power Deviation

From 78:40:00 to 78:42:00, and from 78:47:00 to 78:49:00, decreases in the received uplink carrier power from the Goldstone wing site of 10 to 12 dB were noted. The synthesizer loop was in lock during these periods. Since the transmitter power output measurement was unrecorded, insufficient data existed to determine the cause of this discrepancy.

3.2.9 Parkes Facility Test

The Parkes, Australia, 210-foot antenna facility was scheduled to support the lunar surface extravehicular activity. The Parkes 210-foot antenna facility is equipped with an FM receiver and an uncooled parametric amplifier. Since this facility had not supported a previous Apollo mission, a test was performed during the translunar coast phase from 61:20:00 to 66:30:00 to confirm the Parkes facility performance capabilities. The test was performed to determine the high bit rate telemetry threshold when the spacecraft was in passive thermal control, downlink signal combination 15. As the downlink signal strength decreased to high bit rate threshold, the received carrier power at the stations was recorded. Using known system gains and relations in performance between downlink signal combinations 10 and 15, comparisons were made between the performances of the Goldstone wing site, Honeysuckle station, Honeysuckle wing site, and the Parkes facility for lunar module downlink signal combination 10. The Parkes facility performance agreed with predictions. The Parkes performance was determined to be 1 dB worse than the Honeysuckle station and 4 dB worse than the Honeysuckle and Goldstone wing site performances. This performance difference was caused by Parkes' reception of a PM downlink through an FM system and differences in system temperatures. During lunar stay, the Parkes performance would show a relative improvement when receiving an FM downlink. The Parkes

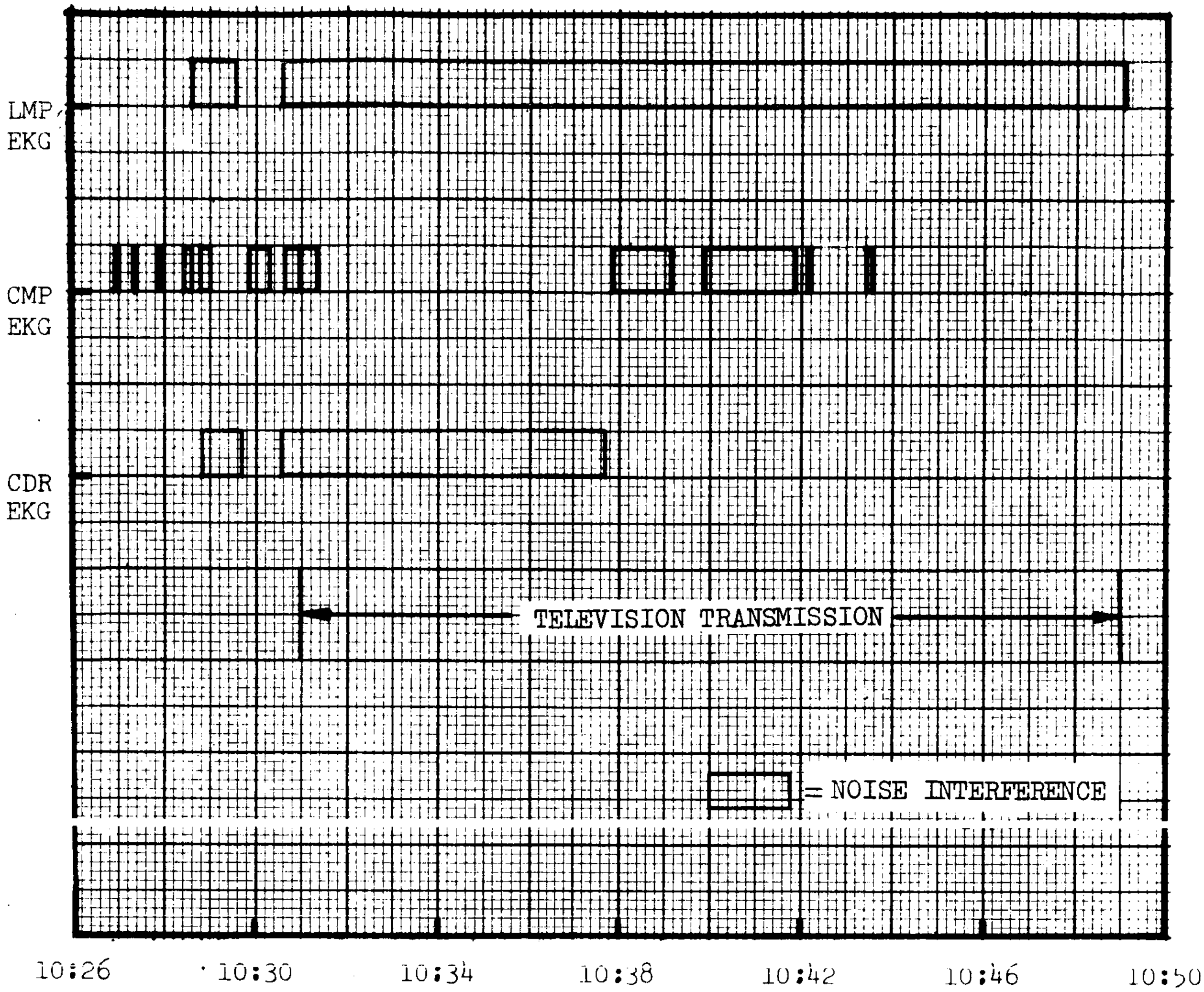



**Figure 3-3** Command And Service Module Electrocardiogram Data Noise Timeline

facility performance was predicted for FM signal combination 10 at lunar distance and corrected for system noise temperature with a moon at zenith. Positive circuit margins for all signal combination 10 channels are listed in Table 3-1.

TABLE 3-1

PARKES FACILITY CIRCUIT
MARGINS PREDICTIONS (LUNAR DISTANCE)

| Channels | Parkes Circuit Margins |
|---|---|
| HBR TLM | 6.1 dB |
| Voice | 8.1 dB |
| Television | 7.9 dB |
| EVC-1 PLSS | 3.9 dB |
| EVC-2 PLSS | 2.3 dB |

The Parkes facility was within 1 dB of preflight predictions.

## 3.3 Command and Service Module Communications Performance During Lunar Orbit

During most of the lunar orbit phase, the command and service module operated on the high gain antenna and utilized signal combinations 6.02, 6.03, and 6.08. During the two sleep periods, the high gain antenna was in the automatic reacquisition mode while the spacecraft was held in a 10-degree deadband by guidance and navigation control.

### 3.3.1 Command Module Lunar Orbit Television

Color television was received through the Mars 210-foot antenna from approximately 78:23:00 to 78:58:00. The quality of the audio and video transmissions was excellent.

### 3.3.2 Loss of Uplink Phase Lock During Lunar Orbit 5

During lunar orbit 5, the Goldstone station experienced an apparent loss of downlink lock on S-band receiver 1 at 84:44:43. The operator immediately initiated reacquisition procedures and swept the uplink transmitter.

The change in uplink frequency at sweep initiation resulted in the loss of uplink lock and caused the high gain antenna on the command and service module to slew off target. Successful reacquisition of two-way lock was accomplished at 85:52:59. Approximately 8 minutes of intermittent data and two-way lock resulted from this sequence of events.

The Goldstone station personnel later reported that the discrepancy was caused by a power supply failure in receiver 1 that falsely indicated a loss of lock. Receiver 2 did not indicate a loss of lock at that time. The operator attempted reacquisition unnecessarily.

### 3.3.3 Late Acquisition for Lunar Orbit 9

Acquisition for lunar orbit 9 was established approximately 6 minutes later than the predicted time of 92:23:28. The crew was asleep, the command and lunar modules were docked, and the high gain antenna was in the automatic reacquisition mode. From the predicted acquisition time until 92:29:30, the Honeysuckle station reported extremely weak downlink S-band signals of approximately -150 dBm. In addition, the uplink received signal (as recorded in the data storage equipment and later dumped to the station) showed that the uplink received signal strength was sufficient for automatic reacquisition in a wide beam mode. Figure 3-4 shows the plot of the uplink received signal strength when the Honeysuckle station was attempting acquisition. The uplink received signal power appeared to be sufficient for the high gain antenna to acquire and track the uplink signal with the transponder in loop lock. Figure 3-5 shows the look angles from the spacecraft to the station at 92:31:00 when uplink and downlink lock were established, indicating that the antenna was free from the antenna scan limits. These data appeared to show that proper high gain antenna and uplink power level criteria were present for effective automatic reacquisition, so additional data are necessary for isolation of the problem.

3.3.4 Madrid Station Cooled Parametric Amplifier Failure

During the acquisition for lunar orbit 26, the Ascension Island 30-foot antenna station signal levels from the command module were 3 dB higher than the signal levels received at the Madrid 85-foot antenna station. This difference was traced to a cooled parametric amplifier failure at the Madrid station. Following the substitution of an uncooled parametric amplifier, the Madrid station reported a received downlink signal strength of -127 dBm (8 dB higher than the 30-foot antenna site), as expected.

3.3.5 Madrid Station Loss of Backup Downvoice During Lunar Orbit 26

After acquisition of signal for lunar orbit 26, the Madrid station personnel reported no backup downvoice from the command module; however, the Ascension Island station did receive backup downvoice during this time. Postmission evaluation showed that no usable downvoice was recorded at the Madrid station from 125:53:00 to 126:40:00. This period coincided with the failure of the cooled parametric amplifier during lunar orbit 26 (see above paragraph). The Madrid station data indicated that backup downvoice modulation was present on the downlink carrier. Therefore, a station configuration error at the Madrid station is indicated.

3.3.6 Data Storage Equipment Performance During Lunar Orbit

During the Apollo 11 mission all command module telemetry data dumped by the data storage equipment were good. The voice quality on high dump rate (32:1) was weak to good when received by 85-foot antenna stations and barely audible to weak when received by 30-foot antenna stations. The voice quality on low dump rate (1:1) was excellent as received by all stations. The quality of the lunar module telemetry data at the high dump rate through the command module data storage equipment was good when received by 85-foot stations, but the voice quality was weak. No high dump rate voice or telemetry data were reported as being received by any 30-foot station. Appendix C presents a comparison of Apollo 10 and 11 data storage equipment performance.

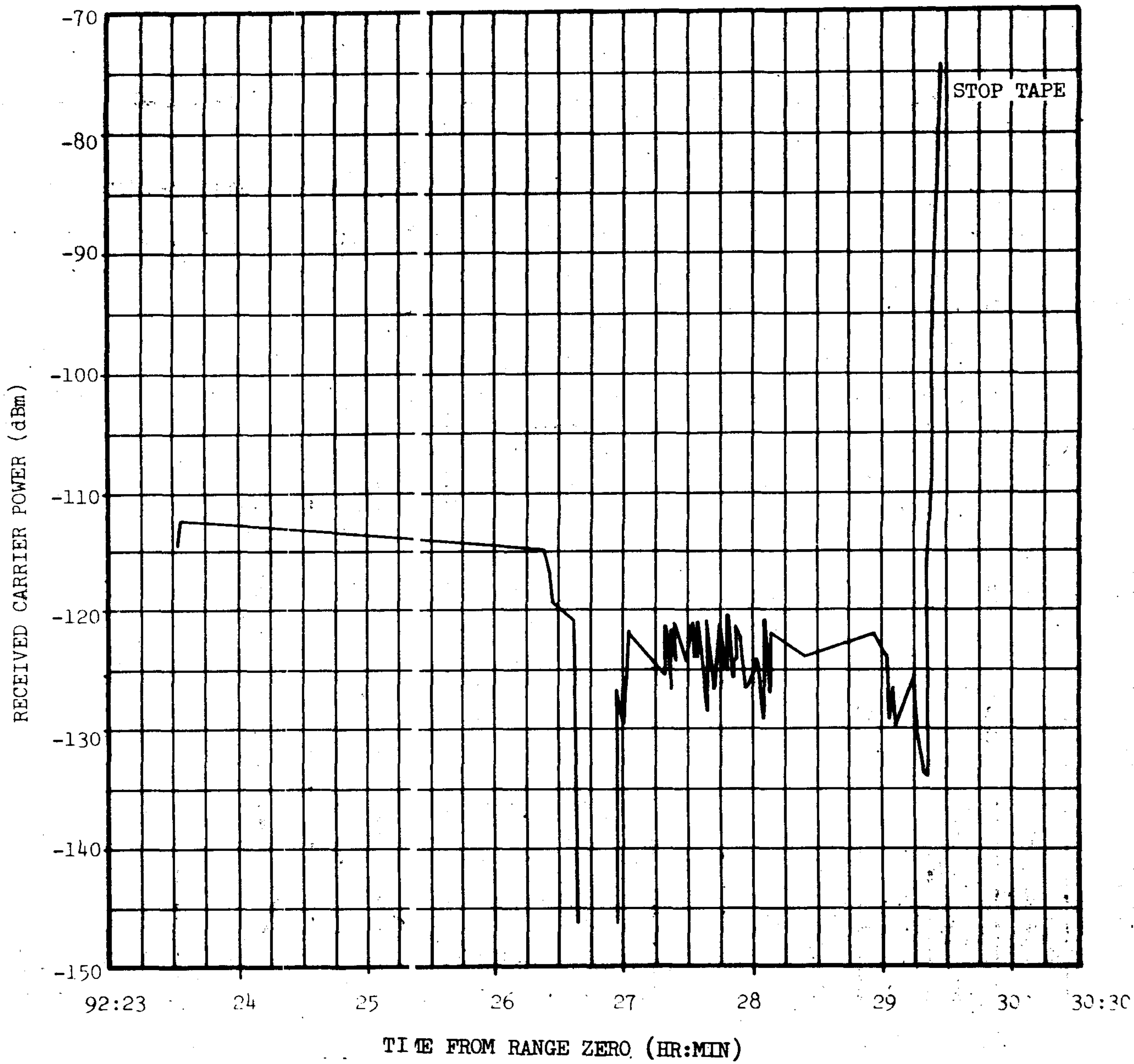
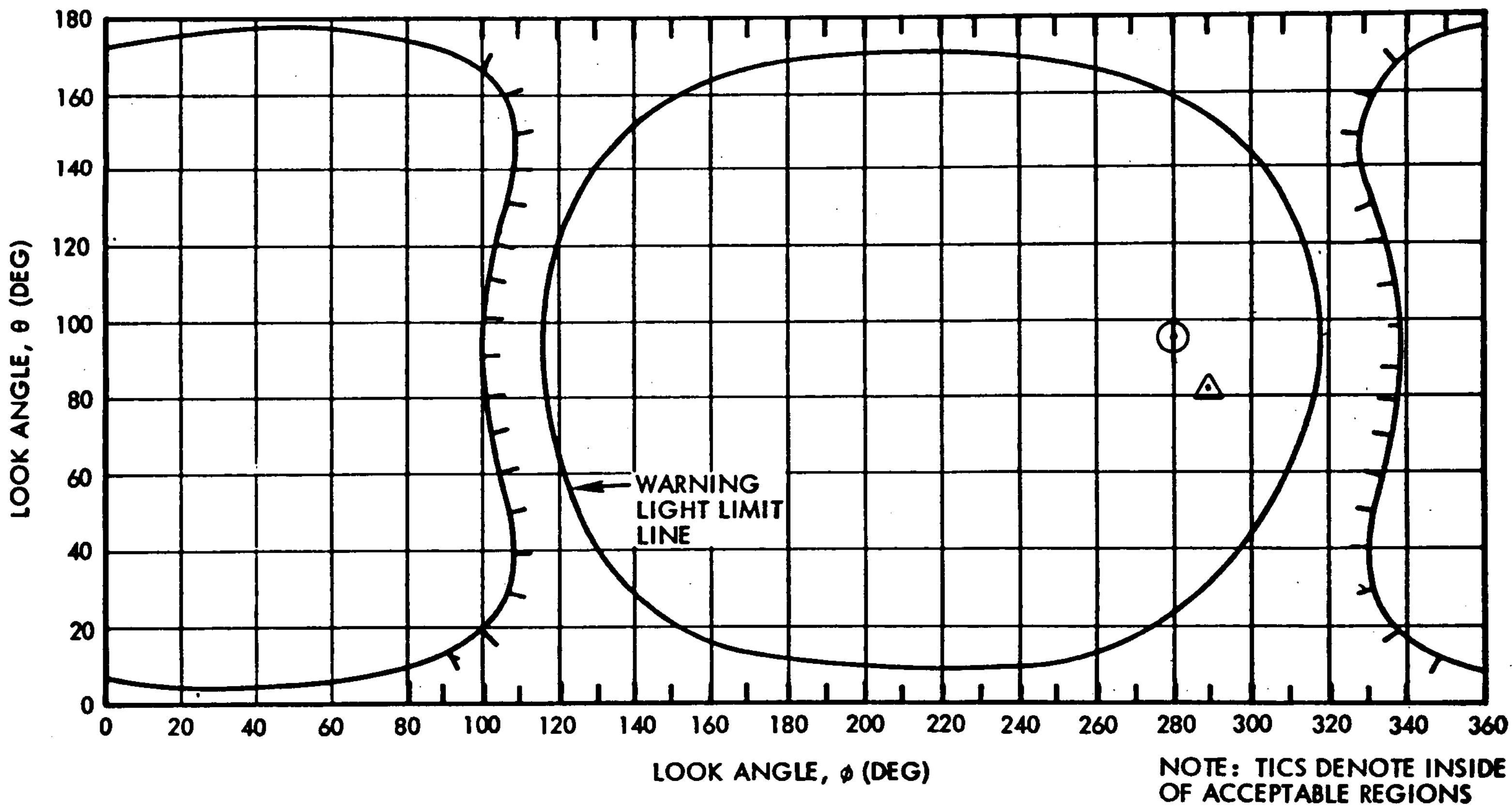



Figure 3-4 Lunar Orbit 9 Received Uplink Carrier Power Prior To Two-Way Lock (DSE Data)




⊙ Predicted Look Angles at Acquisition of Signal

△ Look Angles After Acquisition of Signal

Figure 3-5 Spacecraft To Site Look Angles During Late Acquisition, Lunar Orbit 9

## 3.4 Lunar Module Performance During Lunar Orbit

The lunar module S-band equipment was checked out for the first time on Apollo 11 during lunar orbit 4 when the omni antennas were checked using signal combinations 7.1 and 7.4, high and low bit rate telemetry. The steerable antenna was checked during lunar orbit 11. The primary communications combinations for lunar surface communications were 7.1 for normal operations and 7.10 for the lunar surface television transmission.

### 3.4.1 Lunar Module Communications Check

During lunar orbit 4 between 83:06:00 and 83:43:00, voice and telemetry data checks were performed between the lunar module and the Goldstone 85-foot antenna wing site and Mars 210-foot antenna site. With the lunar module using an omni antenna, four downlink signal combinations were checked. Solid frame synchronization was maintained on all telemetry data through the Mars site. As expected, solid frame sync for high bit rate telemetry data through the 85-foot antenna at the Goldstone wing site could not be maintained; however, low bit rate telemetry data were good. Normal downvoice received through the Mars site was good with a speech-to-noise ratio 7 dB better than backup downvoice. The backup downvoice quality measured poor to fair as received through the Mars site. Analysis of the backup downvoice indicated degraded quality.

### 3.4.2 Lunar Module Backup Downvoice Degradation

During lunar orbits 4, 11, and 12 the lunar module backup downvoice quality was degraded. The received carrier power at the 85-foot antenna site was above the threshold level for backup downvoice (approximately -132 dBm for 70 percent word intelligibility). An analysis of backup downvoice performance during lunar orbits 11 and 12 indicated that the station configuration was possibly the cause of the degradation. Therefore, tests were run in the Electronics Systems Test Laboratory (ESTL) to investigate station configuration which could have degraded the backup downvoice. Pertinent data are listed in the following paragraphs as station data analysis and laboratory analysis.

3.4.2.1 Station Data Analysis

During lunar orbit 4, the lunar module downvoice was received through the 210-foot antenna at the Mars site at a signal strength of -114 dBm to -117 dBm. The results of the voice evaluation during this orbit are contained in Table 3-2.

TABLE 3-2

LUNAR MODULE DOWNVOICE QUALITY AT MARS SITE FOR LUNAR ORBIT 4

| | LM A/G | | NET 1 | |
|---|---|---|---|---|
| Voice Mode | Speech-to-Noise Ratio | Intelligibility | Speech-to-Noise Ratio | Intelligibility |
| Backup | 3.3 dB | Good | 4.07 dB | Good |
| Normal | 10.99 dB | Good | 11.49 dB | Good |

Although this was the only time the Mars site supported lunar module back-up downvoice, these data show that the speech-to-noise ratios of backup and normal downvoice improved as the received signal moved to the output from the Goldstone station audio center (net 1 output). However, as can be seen from the following lunar orbit 11 and 12 data, the reverse is true during lunar orbits 11 and 12 at the Madrid station.

During lunar orbit 11, the received downlink signal levels from the lunar module for backup downvoice varied from -126 dBm to -128 dBm. An evaluation of the data from the Madrid wing site provided the information in Table 3-3.

TABLE 3-3

LUNAR MODULE BACKUP DOWNVOICE QUALITY AT

MADRID WING SITE FOR LUNAR ORBIT 11

| Source | Speech-to-Noise Ratio | Intelligibility |
|---|---|---|
| Net 1 | 0.37 dB | Poor - Fair |
| Backup Downvoice | 1.11 dB | Fair - Good |
| EVCS Baseband | 1.46 dB | Fair - Good |

During the time when signal levels of -125 dBm to -128 dBm were received, the normal downvoice characteristics through the Madrid wing site are listed in Table 3-4.

TABLE 3-4

LUNAR MODULE NORMAL DOWNVOICE QUALITY AT MADRID WING SITE FOR LUNAR ORBIT 11

| Source | Speech-to-Noise Ratio | Intelligibility |
|---|---|---|
| Net 1 | 6.53 dB* | Fair - Good |
| 1.25 MHz EVCS Composite | 9.14 dB | Good |

*Steerable antenna

The result of this evaluation clearly indicated that backup and normal downvoice were degraded between the input to the station and the point at which voice was remoted to net 1.

A number of Madrid wing site recording discrepancies existed for lunar orbit 11.

1. From 96:23:10 to 96:23:45, command module normal downvoice was recorded on the lunar module 1.25 MHz EVCS composite track. When the lunar module switched from backup downvoice to normal downvoice, the command module downvoice disappeared from the lunar module 1.25 EVCS composite.

2. Lunar module pilot speech was weak but readable on the command module air-to-ground recording.

3. Speech from the command module pilot, capcom, and lunar module pilot was weak and readable on the lunar module air-to-ground recording.

4. There was a constant high noise level associated with lunar module air-to-ground voice. When normal voice was used, the high noise level disappeared.

These four discrepancies indicated either configuration errors or equipment malfunctions at the Madrid wing site.

During lunar orbit 12, the received downlink signal levels from the lunar module for backup downvoice varied from -124 dBm to -126 dBm. Lunar module backup downvoice information for the Madrid wing site is contained in Table 3-5.

TABLE 3-5

LUNAR MODULE BACKUP DOWNVOICE AT MADRID WING SITE FOR LUNAR ORBIT 12

| Source | Speech-to-Noise Ratio | Intelligibility |
|---|---|---|
| Net 1 | 0.72 dB | Poor - Fair |
| Backup Downvoice | 1.46 dB | Poor - Fair |
| EVCS Composite | 0.7 dB | Fair - Good |

The speech-to-noise measurements were not conclusive for analysis purposes. Slight degradation of backup downvoice within the station equipment was indicated.

A summary of lunar module normal downvoice performance at received signal levels from -124 to -126 dBm is contained in Table 3-6.

TABLE 3-6

LUNAR MODULE NORMAL DOWNVOICE AT MADRID WING SITE FOR LUNAR ORBIT 12

| Source | Speech-to-Noise Ratio | Intelligibility |
|---|---|---|
| Net 1 | 1.93 dB | Fair |
| 1.25 MHz EVCS Composite | 9.5 dB | Good |

These data also indicated degradation of the lunar module normal downvoice through the Madrid wing site equipment. The following Madrid wing site recording discrepancies existed for lunar orbit 12:

1. From 98:18:44 through 98:25:57, command module air-to-ground voice was recorded but not remoted to net 1 until selection of lunar module normal downvoice.

2. Lunar module air-to-ground and net 1 were extremely noisy until selection of lunar module normal downvoice.

These two items indicated a site configuration error or equipment malfunction which was partially corrected between lunar orbits 11 and 12.

3.4.2.2 Electronics Systems Test Laboratory Investigation

The low speech-to-noise ratios for lunar orbits 11 and 12 and the suspected configuration inconsistencies at the Madrid wing site prompted laboratory testing. It was found that an improper selection of downvoice pushbuttons at the communications technician console could cause similar problems. A test was performed in the Electronics System Test Laboratory simulating the normal site configuration for lunar module backup downvoice and then lunar module normal downvoice. Then the two outputs were simultaneously selected producing approximately the same measurements as were made from the Madrid wing site data during lunar orbits 11 and 12. The data measurements are listed in Appendix D for reference.

3.4.2.3 Modulation Indices Effect

In conjunction with the laboratory testing, a comparison of lunar module 4 (flown during Apollo 10) and lunar module 5 (flown during Apollo 11) modulation indices was made. Lunar module 4 modulation index was measured as 0.78 radian and lunar module 5 modulation index was measured as 0.65 radian at Kennedy Space Center.

The lunar module backup downvoice on omni antenna was of good quality during the Apollo 10 flight but was degraded for Apollo 11. Using information in the Communications Simulation Program Report (Reference 13), the effect of changes in the modulation index for backup downvoice was calculated. With the reported modulation indices of 0.78 radian for Apollo 10 and 0.65 radian for Apollo 11, speech-to-noise ratios could have been increased by 2 to 3 dB if Apollo 11 had used the same modulation index as Apollo 10.

#### 3.4.2.4 Backup Downvoice Degradation Conclusions

The conclusions based on the analysis and testing for lunar module backup downvoice degradation are as follows:

1. A site configuration error or equipment malfunction contributed to the degradation at the Madrid wing site during lunar orbits 11 and 12.

2. The decrease in lunar module modulation index (different from Apollo 10) may also have contributed to the voice degradation.

3. Testing at the 85-foot antenna sites is necessary to pinpoint the exact cause of voice degradation since the degradation has not been isolated to the spacecraft or tracking station.

### 3.5 Communications Performance During Lunar Module Descent and Landing

Between acquisition of signal at 102:16:30 and the pitch down maneuver during the powered descent, lunar module steerable antenna automatic tracking could not be maintained. Reacquisition was tried several times without success. At this time, the line of sight to the Goldstone wing site was obstructed by a reaction control system thrust deflector (See Figure 3-6). At 102:27:22, the crew was requested to yaw the spacecraft 10 degrees, but automatic tracking with the correct spacecraft antenna pointing angles was not attempted until 102:40:20. During the time the steerable antenna was not obstructed by the lunar module structure, the antenna was in the manual tracking mode. Valid automatic tracking was achieved at 102:40:02 and maintained through lunar landing.

From the scheduled acquisition time of 102:16:30 until 102:34:05, several sharp losses of phase lock were observed. Figure 3-7 presents the downlink received carrier power recorded at the Goldstone wing site. The losses of phase lock were probably caused by a buildup of approximately 1 Hz oscillations in the steerable antenna motion (See Figure 3-8) as the frequencies of multipath from the lunar module and/or lunar surface approached multiples of the steerable antenna switching frequency. The oscillations occurred at approximately the same time that the predicted lunar surface multipath fade frequency approached a multiple of the antenna electronics switching frequency. As shown in Figure 10, some of these oscillations were of sufficient amplitude to cause loss of phase lock while other oscillations built up and decreased without loss of phase lock.

All sharp losses of phase lock occurred when the received uplink and downlink carrier powers were below expected values and also indicated a correlation between oscillations of steerable antenna and the predicted lunar surface multipath fade frequencies. However, there are insufficient data to determine if oscillations of the steerable antenna and loss of lock would have occurred if the line-of-sight to the ground station had not been obstructed.

The lunar module downvoice received through the Mars site during powered descent and landing was generally of good intelligibility. The total time period evaluated was from 102:16:00 to 102:52:00. Powered descent started at 102:32:53 and lunar landing occurred at 102:45:39.9.

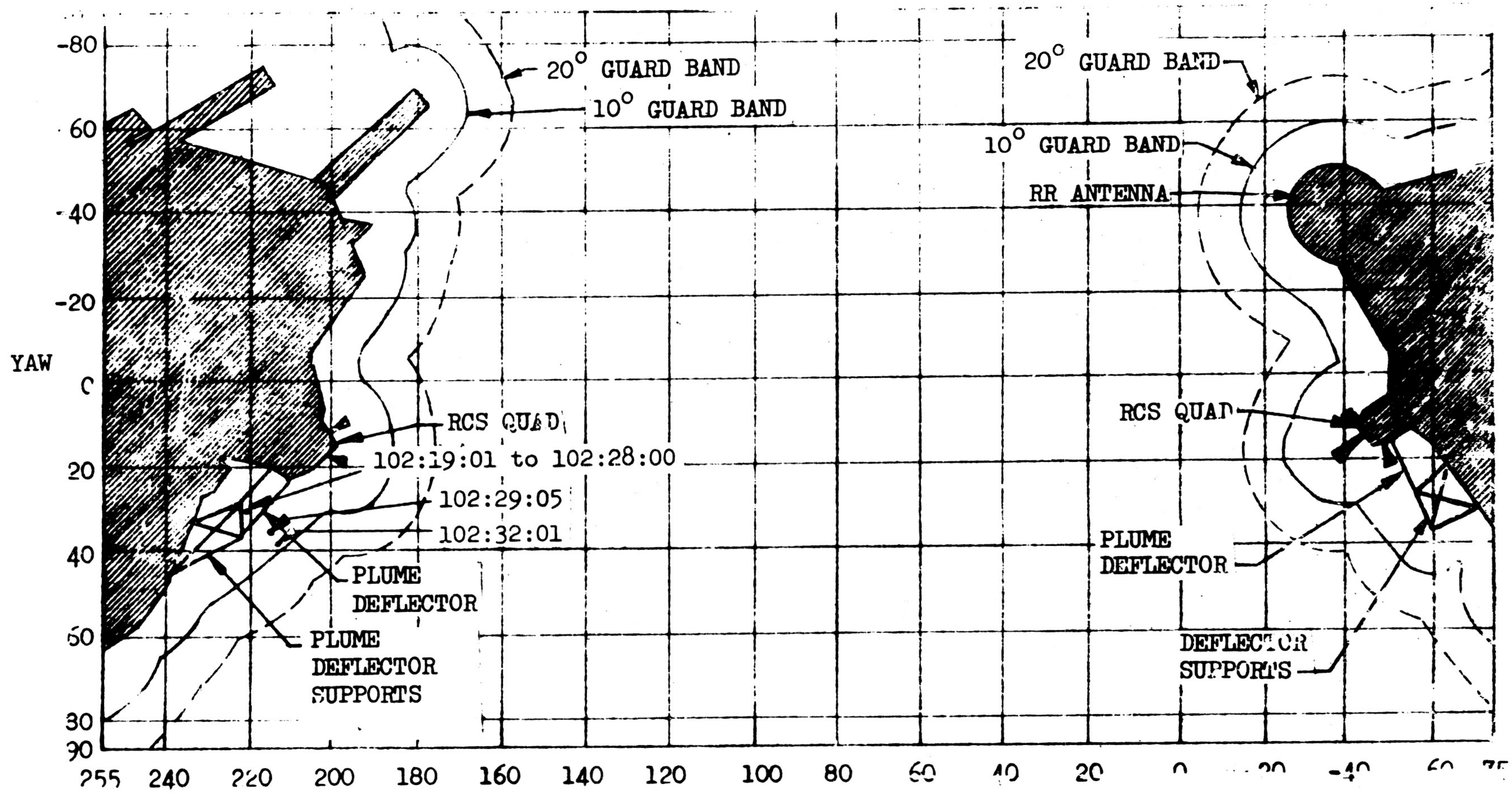



Figure 3-6 S-band Steerable Antenna Vehicle Blockage Diagram

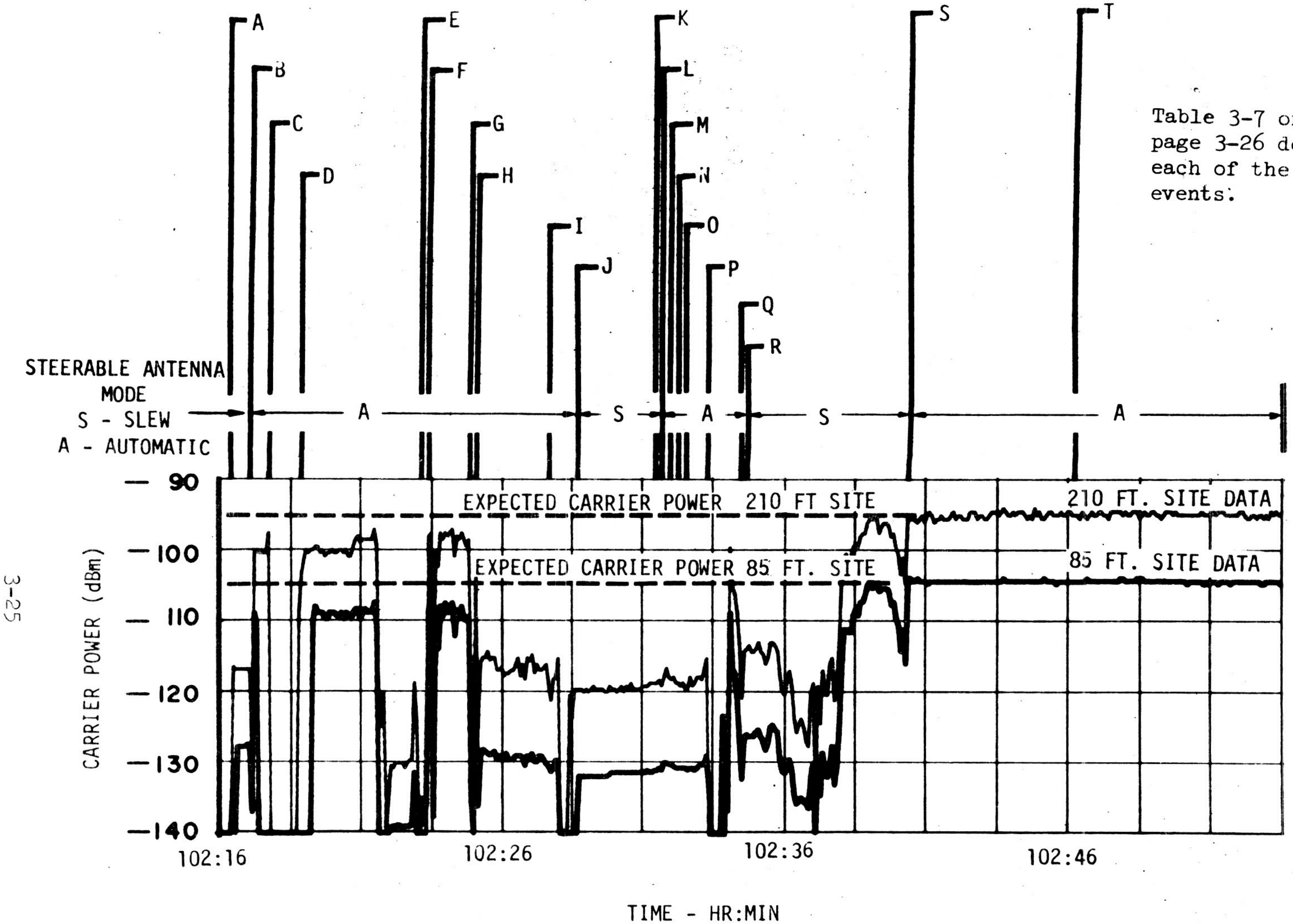



Table 3-7 on page 3-26 describes each of the indicated events.

Figure 3-7 Received Downlink Carrier Power, Goldstone, Descent Phase (Apollo 11)

TABLE 3-7 APOLLO 11 DESCENT PHASE EVENTS

A. 102:16:30........................ACQUISITION OF SIGNAL (OMNI ANTENNA)

B. 102:17:09........................STEERABLE ANTENNA, AUTO

C. 102:17:48........................LOSS OF SIGNAL

D. 102:18:50........................ACQUISITION OF SIGNAL

E. 102:22:50........................LOSS OF SIGNAL

F. 102:23:22........................ACQUISITION OF SIGNAL

G. 102:24:59........................LOSS OF SIGNAL

H. 102:25:05........................ACQUISITION OF SIGNAL

I. 102:27:22........................"EAGLE, HOUSTON. WE RECOMMEND YOU YAW 10 RIGHT."

J. 102:28:33........................STEERABLE ANTENNA SWITCHED TO SLEW

K. 102:31:22........................"EAGLE, HOUSTON. IF YOU'D LIKE TO TRY HIGH GAIN, PITCH 212, YAW 37. OVER."

L. 102:31:41........................STEERABLE ANTENNA SWITCHED TO AUTO

M. 102:32:03........................"SAY THE ANGLES AGAIN, THOUGH."

N. 102:32:08........................"ROGER. PITCH 212, YAW PLUS 37."

O. 102:32:24........................"ANGLES IN."

P. 102:33:18........................LOSS OF SIGNAL.

Q. 102:34:05........................ACQUISITION OF SIGNAL.

R. 102:34:11........................STEERABLE ANTENNA SWITCHED TO SLEW.

S. 102:40:20........................STEERABLE ANTENNA SWITCHED TO AUTO.

T. 102:46:04........................"THE EAGLE HAS LANDED."

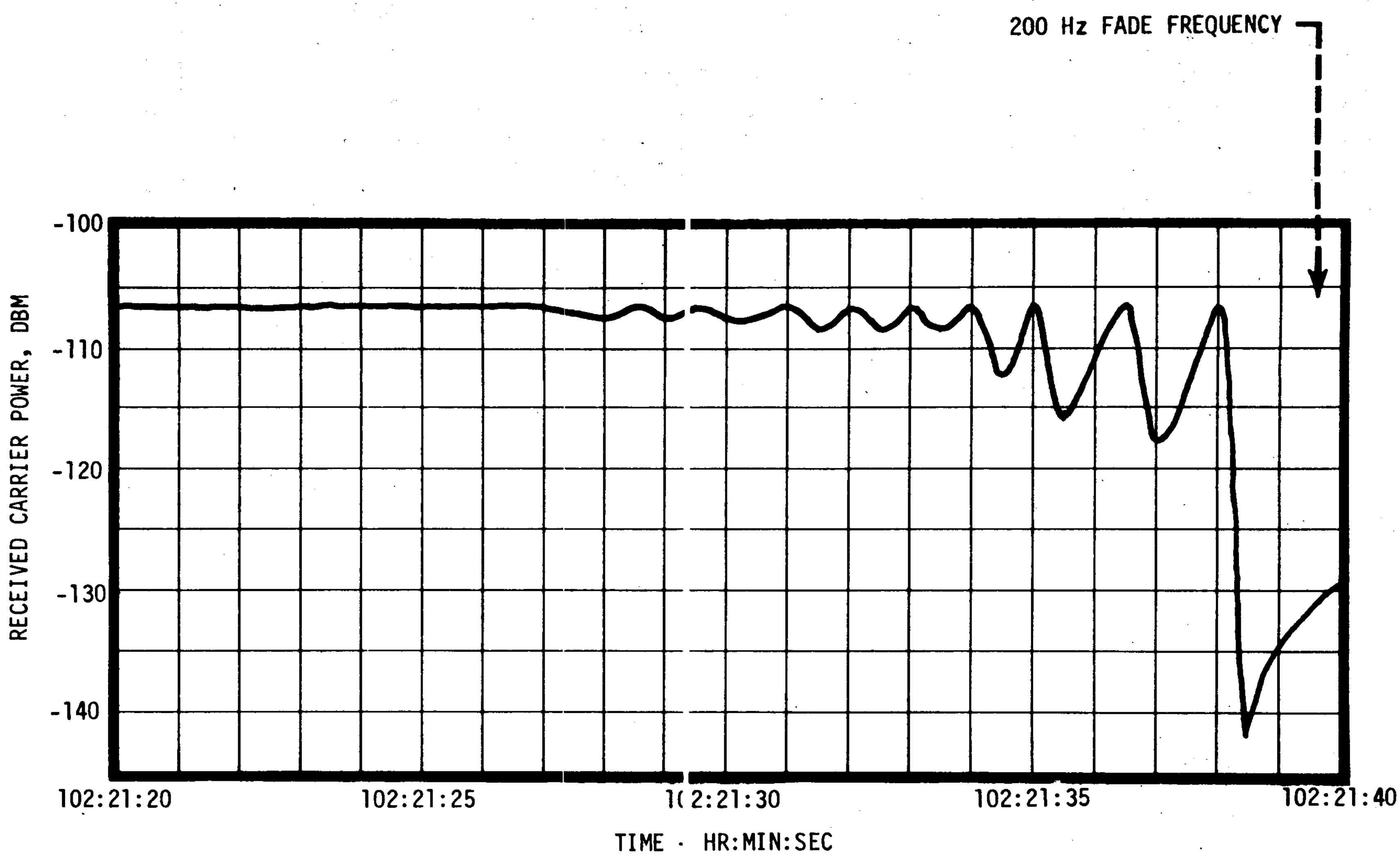



Figure 3-8 Oscillations in Steerable Antenna Motion

## 3.6 Communications Performance During Lunar Stay

During the lunar stay period of approximately 22 hours, the lunar module communications were through the S-band steerable antenna.* Three 10-minute periods during extravehicular activity were selected for comparing the performance of these two stations. The periods were approximately ten minutes after egress, ten minutes before ingress, and ten minutes in the center of the extravehicular activity period. However, since the Honeysuckle station was changing configuration to support the lunar module at egress, no pulse amplitude modulation (PAM) or FM telemetry were recorded for the first comparison period. Television and voice through the 85-foot antenna were recorded.

The PM downlink received carrier power averaged -106 dBm at the 85-foot antenna station during these periods and -98 dBm at the 210-foot antenna site. The FM downlink total received power averaged -101 dBm at the 85-foot antenna station and -93 dBm at the 210-foot antenna site. The PM uplink received carrier power level averaged -83 dBm during this period. The uplink and downlink received power levels generally equalled the premission predictions for both the 85-foot and the 210-foot antenna sites. Table 3-8 presents the measured and predicted signal levels for the lunar stay. The pulse code modulation telemetry decommutator stayed in lock during the entire lunar stay.

After EASEP deployment and activation by the astronauts, good quality telemetry data were received from the scientific experiements package starting at 111:10:30. The package would not accept commands transmitted through the Texas and Canary Island stations during their first periods of coverage, but these nonacceptance problems were isolated to the stations and were subsequently corrected.

*Satisfactory performance was provided by the Parkes facility, Mars site, Goldstone wing site and Honeysuckle station during their respective support periods of the extravehicular activity.

TABLE 3-8

LUNAR STAY RECEIVED CARRIER POWER COMPARISONS

(MARS SITE AND HONEYSUCKLE STATION)

| ANTENNA | COMBINATION | MEASURED | | PREDICTED | |
|---|---|---|---|---|---|
| | | UPLINK | DOWNLINK | UPLINK | DOWNLINK |
| 85' | 7.1 (Non EVA) | -83 dBm | -106 dBm | -86 dBm | -108 dBm |
| 210' | 7.1 (Non EVA) | N/A | - 98 dBm | N/A | -100 dBm |
| 85' | 7.10 (EVA) | -83 dBm | -101 dBm | -86 dBm | -101 dBm |
| 210' | 7.10 (EVA) | N/A | - 93 dBm | N/A | - 93 dBm |

### 3.6.1 Downlink Voice Quality During Lunar Stay

From 109:07:00 to 111:39:00, the quality of the voice received from the Mars 210-foot antenna site varied from fair to good. The quality of the voice received from the Honeysuckle 85-foot antenna station was fair. The speech-to-noise ratio of the downvoice received through the Mars site averaged 4 dB better than the downvoice received through the Honeysuckle station. Although the voice quality through the Mars site was definitely better than that received through the Honeysuckle station, the intelligibility was not significantly different. Adequate voice coverage during lunar surface activity can be satisfactorily provided by an 85-foot antenna station. Figure 3-10 is an overall block diagram of the EVCS communications link.

### 3.6.2 Television Quality During Lunar Stay

The black and white television transmitted during the lunar extravehicular activity was recorded by the Mars site and the Honeysuckle station. The lunar module steerable antenna was used throughout the period. Table 3-9 compares the signal-to-noise ratio of the Honeysuckle 85-foot antenna station with the Mars 210-foot antenna site.

The television signal recorded at the Honeysuckle station from 109:20:00 to 109:34:00 had an overall signal-to-noise ratio of 14 dB. (These television data were recorded prior to support by the Parkes facility.) The television signal recorded at the Honeysuckle station from 110:18:30 to 110:32:30 had an overall signal-to-noise ratio of 12 dB. The picture quality for both time periods was good as observed and evaluated subjectively (refer to Figure 3-11 and 3-12).

No horizontal jitter was observed in real time. However, some horizontal jitter, possibly introduced by the wideband recording process, was observed in postmission evaluation. The television signal recorded at the Honeysuckle station from 111:27:00 to 111:42:00 had a good picture quality (18 dB signal-to-noise ratio) and horizontal jitter was observed.

TABLE 3-9

TELEVISION SIGNAL-TO-NOISE RATIO COMPARISON OF 85-FOOT AND 210-FOOT ANTENNA SITES

| Mission Time | Honeysuckle Station | | Mars Site | |
|---|---|---|---|---|
| | Signal-to-Noise Ratio | Quality | Signal-to-Noise Ratio | Quality |
| 109:20:00 to 109:23:00 | 14 dB | Good | Not evaluated | |
| 110:18:30 to 110:32:00 | 12 dB | Good | 16 dB | Good |
| 111:18:00 to 111:32:00 | Overlapping evaluation | | 17 dB | Good |
| 111:27:00 to 111:42:00 | 18 dB | Good | Overlapping evaluation | |

The television signal recorded from the Mars site from approximately 110:18:00 to 110:28:00 had an overall signal-to-noise ratio of 16 dB. The picture quality was good. Horizontal jitter was noticed in the post-mission evaluation of the Mars television picture similar to that observed in the picture obtained from the Honeysuckle station. From 111:18:00 to 111:32:00, the television signal recorded at the Mars site had the same picture quality and characteristics as the previous time period and the overall signal-to-noise ratio was 17 dB.

The overall television quality from the Honeysuckle station was about the same as the overall television quality from the Mars site. (See Figures 3-11 and 3-12.) This similarity in quality is explained by the difficulty in subjectively evaluating the differences in picture quality in the region from 11 to 21 dB signal-to-noise ratio. The total received power required to meet the rated good television performance is -102.5 dBm. The total received power level received at the 85-foot antenna station was approximately -101 dBm and at the 210-foot antenna site was approximately -93 dBm.

### 3.6.3 Pulse Amplitude Modulation Telemetry and Electrocardiograph

Table 3-10 compares the pulse amplitude modulation (PAM) and electrocardiograph (EKG) data recorded by the Honeysuckle station and Mars site

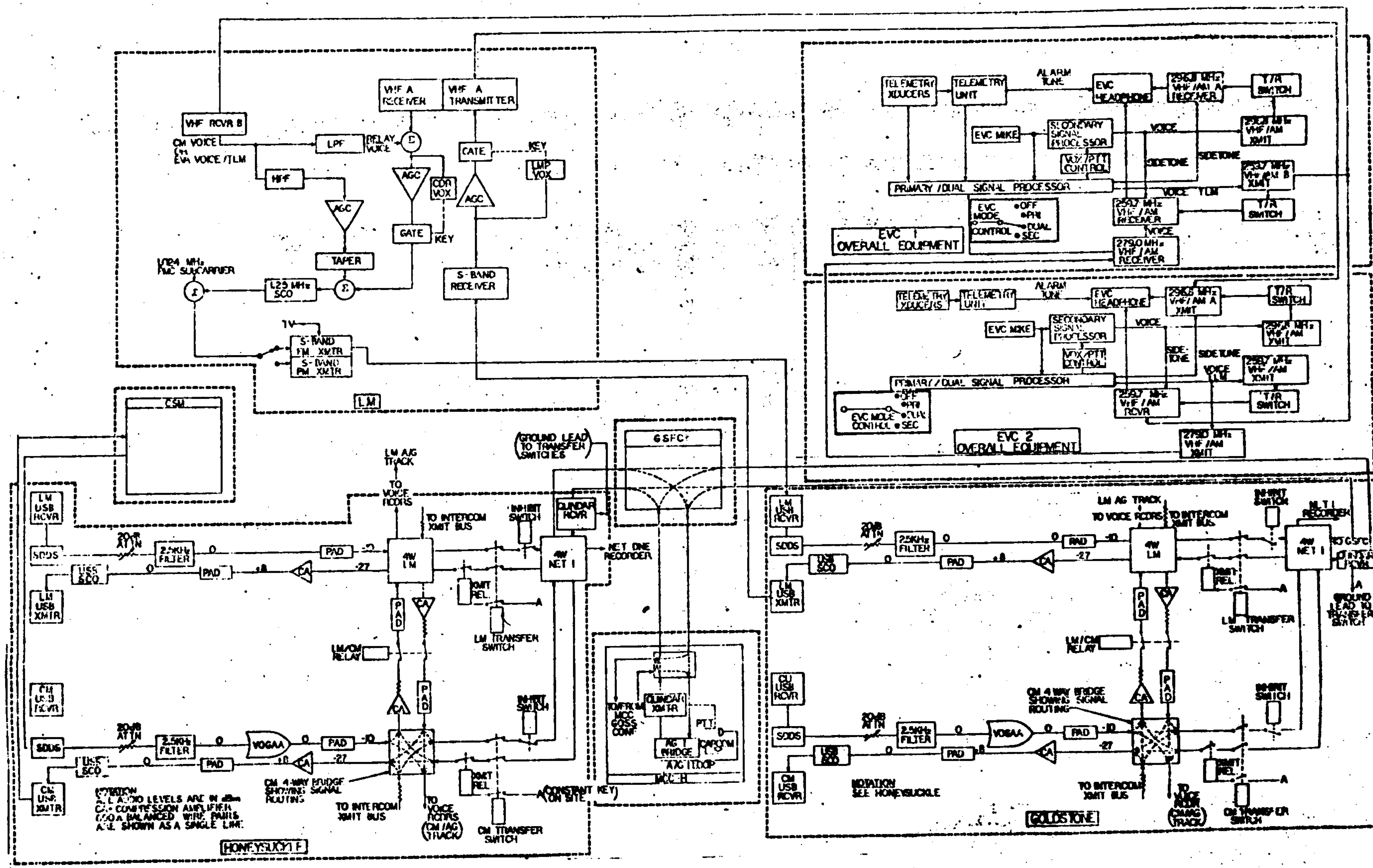



Figure 3-9 System Block Diagram of EVA Communications

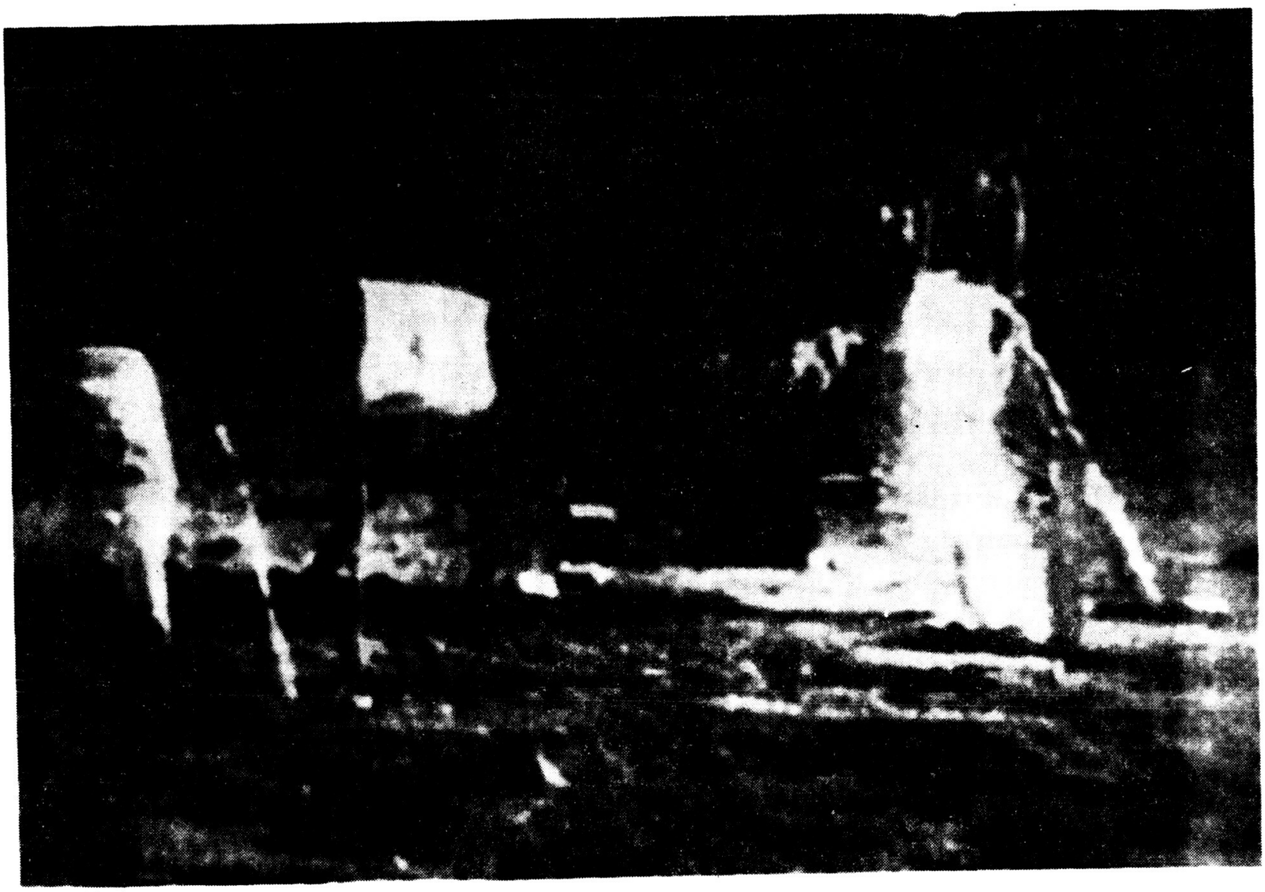


Figure 3-10 Television Picture, Mars 210-Foot Antenna Site, Extravehicular Activity

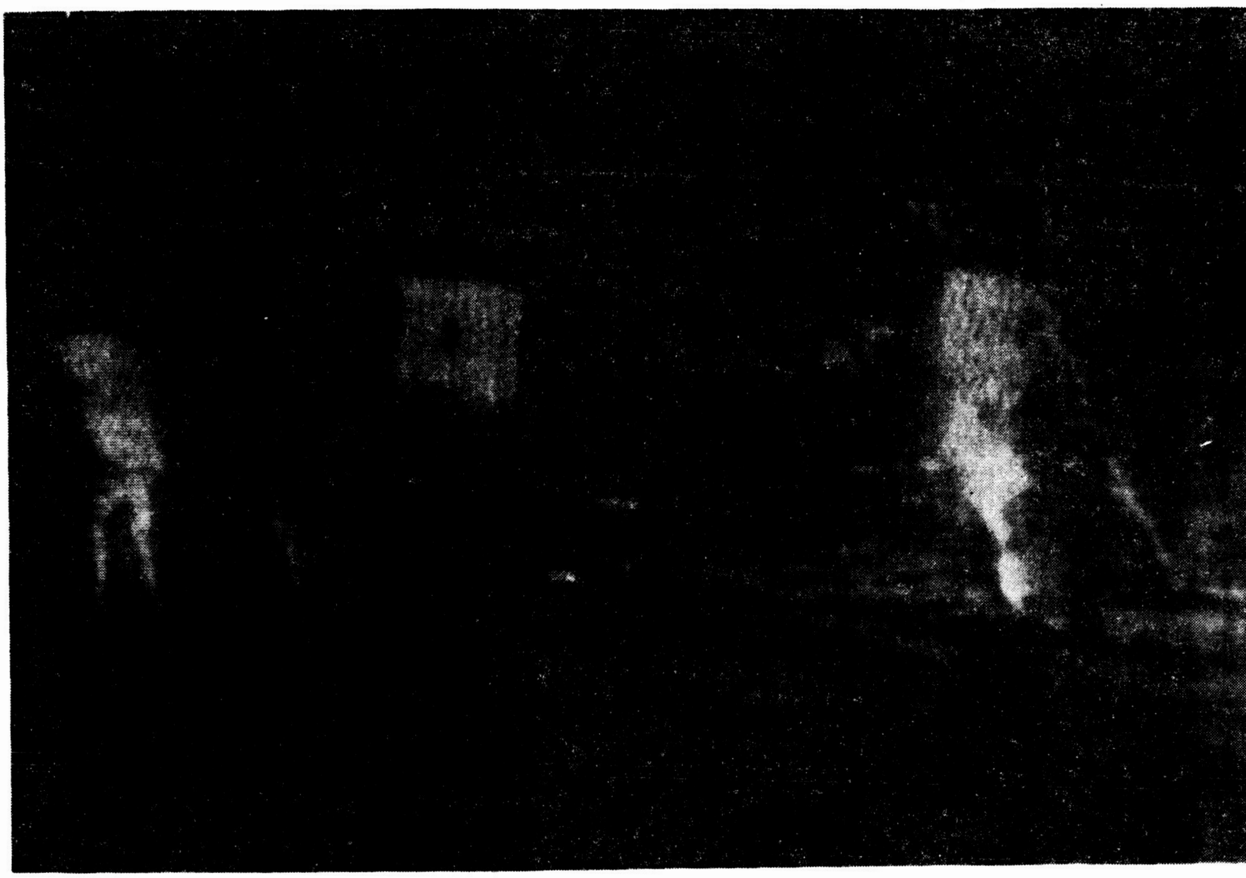


Figure 3-11 Television Picture, Honeysuckle Station
(85 Foot Antenna), Extravehicular Activity

during the dual extravehicular activity. Figure 3-13 compares a typical 20-second sample of the PAM and EKG data from the two sites. A click as used in Table 3-10 is defined as an impulse of noise whose amplitude is equal to at least 20 percent of the peak to peak amplitude of the EKG heart beat pulse and deviates in either direction from the modulation at that time. The FM total received power levels were -93 dBm and -101 dBm at the Mars site and the Honeysuckle station respectively. The EKG data at the Honeysuckle station was better than expected and nearly equaled the Mars site performance. Adequate EVC-1 and EVC-2 PAM and EKG data were available at both stations. (see References 7 and 8).

TABLE 3-10

PULSE AMPLITUDE MODULATED TELEMETRY AND ELECTROCARDIOGRAM DATA COMPARISON BETWEEN MARS SITE AND HONEYSUCKLE STATION

| | EVC-1 | | EVC-2 | |
|---|---|---|---|---|
| ANTENNA | EKG (Clicks/Minute | PAM (% Data Loss) | EKG (Clicks/Minute) | PAM (% Data Loss) |
| 85' | 2 | 1 | 2 | 12 |
| 210' | 0 | 1 | 0 | 0 |

### 3.6.4 Uplink Echo During the Extravehicular Activity Period

During the lunar extravehicular activity, the capsule communicator's voice appeared as an echo on downvoice. Investigations and tests were performed in the Spacecraft Systems Test Laboratory to determine the possible causes of the echo. The apparent break-up of the speech of one of the extravehicular astronauts was also investigated. The results of these investigations are included in a report entitled APOLLO 11 COMMUNICATIONS INVESTIGATION, 21 August 1969, Document 21-170.

The conditions for both the echo and a speech breakup discrepancy were repeated in the laboratory. The echo was simulated by poorly fitting the communications carrier and by having the extravehicular communications systems transmitter keyed. The speech breakup was simulated by decreasing the commander's voice operated relay sensitivity in the lunar module one thumbwheel setting from the maximum setting.

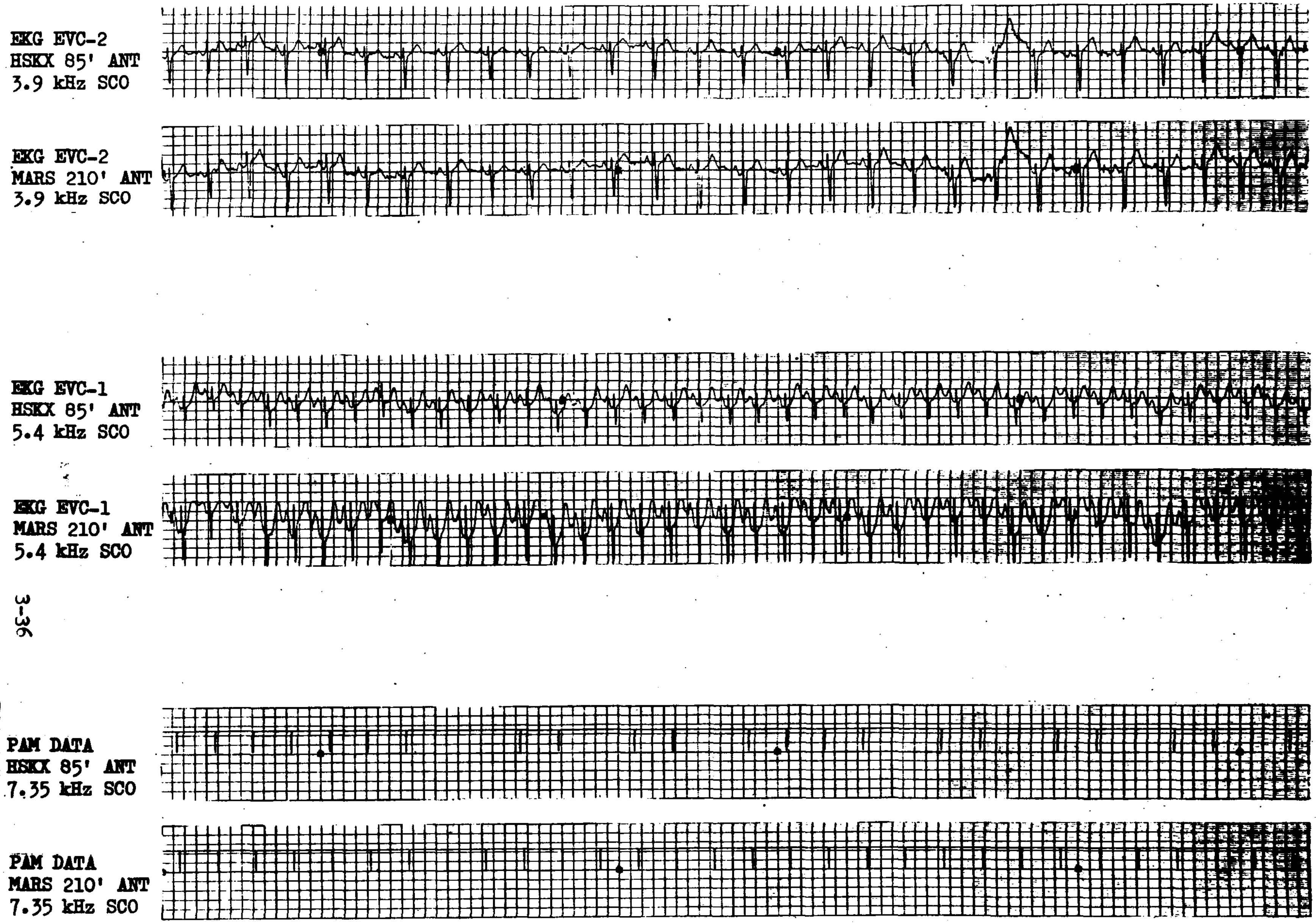



Figure 3-12 EVCS Data Sample Comparison

An evaluation of the test results provided the following conclusions:

1. A communications carrier introduced acoustical coupling between the earphone and microphone at a sufficient level to be heard as a retransmission if the transmit circuits were energized. The extravehicular communicator (EVC), lunar module, and automatic volume control circuitry combination provided sufficient gain to allow relatively low audio levels from the EVC to appear as nominal levels at the receiving station.

2. The EVC voice operated circuitry can be activated by moderate breathing, bumping, or rubbing the communication carrier microphone boom on the pressure helmet.

3. During the pre-egress checkout procedures, the commander apparently turned down his VOX setting to eliminate squeals. Other laboratory testing did not provide sufficient information to conclusively determine other possible causes of the echo.

As a result of the voice turnaround, a request has been made to provide a muting relay at the Capsule Communicator's console and the Public Affairs Officer's console to inhibit the lunar module downvoice while upvoice is being transmitted if downvoice turnaround reoccurs.

### 3.6.5 Apparent Lunar Module Downlink Power Deviation

At 124:04:00, 16 minutes prior to the lunar module liftoff, an abrupt 7 dB decrease was observed in the S-band downlink received carrier power at the Madrid wing site. Postmission analysis revealed no downlink received carrier power change at the secondary receiver, receiver 6, but receiver 5 which was remoting the downlink received carrier power from the lunar module showed a change in automatic gain control voltage equivalent to 7 dB carrier power decrease. This was apparently due to an instrumentation or receiver problem and was not an actual decrease in received carrier power within receiver 5. No degradation of communications performance was observed.

## 3.7 Ascent Communications Performance

Figure 3-14 shows the Madrid wing site receiver 6 receiver power and telemetry performance from 124:00:00 to 124:30:00. Two seconds after ignition of the ascent propulsion engine at 124:22:02, a 5-second loss of downlink lock was observed. With the exception of this momentary loss of signal, the telemetry and voice communications performance was excellent. This loss of signal may be attributed to rapid phase perturbation caused by transmission through the ascent engine plume or vibrations during ascent.

Predicted received carrier power levels indicate that sufficient positive power margins would be available to allow the S-band PM receiver carrier tracking loop bandwidth to be increased from the 50 Hz to the 700 Hz bandwidth before ascent to make the phase lock receiver less susceptible to phase perturbations from either ascent engine plume or steerable antenna vibration.

## 3.8 Transearth Coast and Earth Orbit Entry

Except for the discrepancies noted in the following paragraphs, the S-band communications coverage was satisfactory during the transearth coast, entry, and recovery. For the major part of the transearth coast phase, the command module was in the passive thermal control mode with roll rates of approximately 3.5 revolutions per hour. Communications in this mode were maintained primarily through switching the high gain antenna and the omni D antenna by commands from Mission Control Center. Passive thermal control was interrupted for a midcourse correction at 150:29:56 and for two color telecasts.

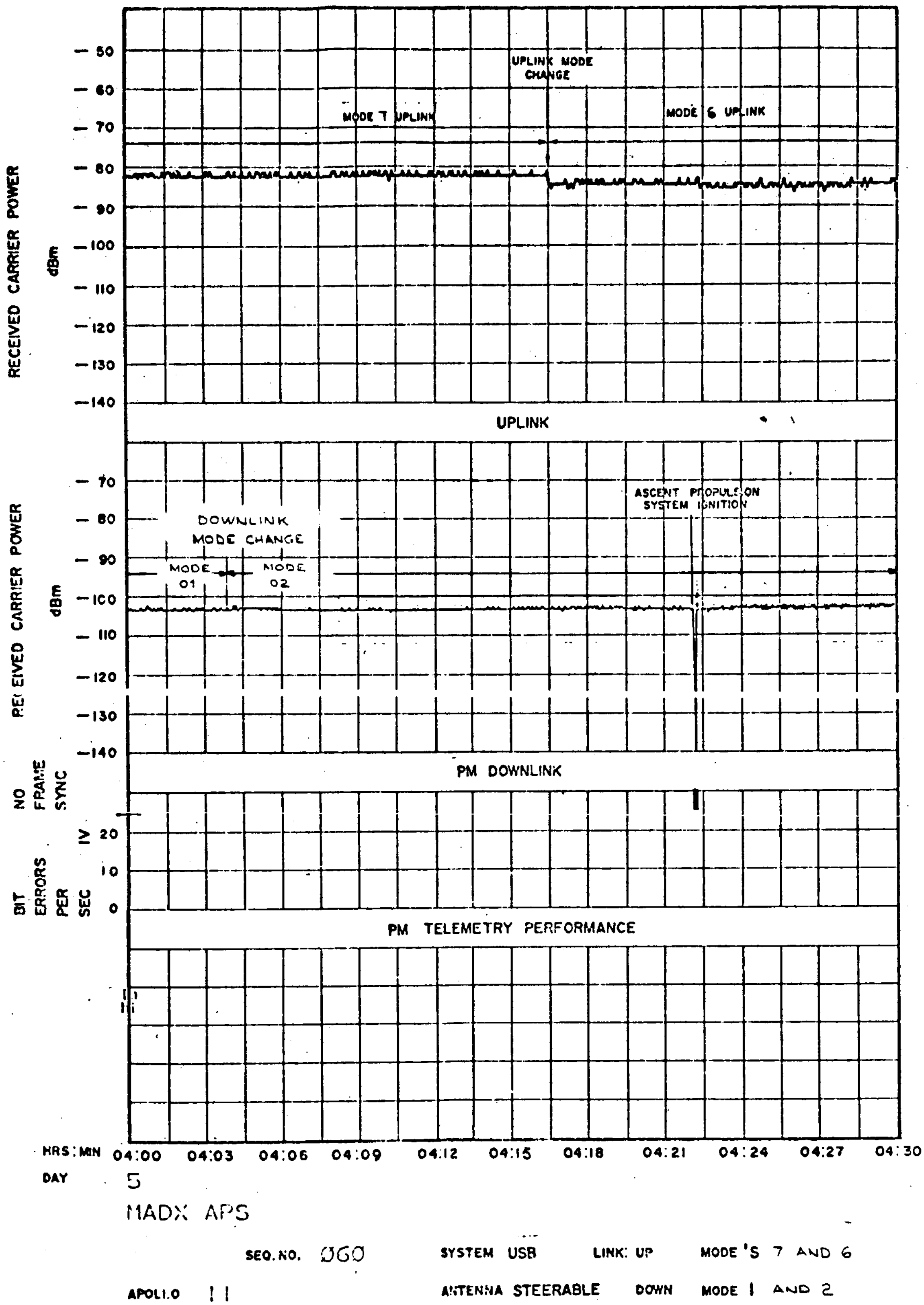



Figure 3-13 S-band Communications Performance, Lunar Ascent Propulsion System Burn, Madrid Wing Site

### 3.8.1 Loss of Communications Through the Goldstone Station

Communications with the command module through the Goldstone station were interrupted for approximately 54 minutes. After the midcourse correction, the crew experienced difficulty in establishing the roll rates for passive thermal control. The spacecraft rolled in excess of one degree per second causing the high gain antenna in the automatic tracking mode to be driven into the gimbal limits at 151:45:00. A buildup of error signal caused the high gain antenna to switch from narrow to wide beamwidth. The signal continued to deteriorate and the omni D antenna was selected by command from the ground at 151:51:12. The spacecraft attitude continued to change and the signal continued to deteriorate until loss of signal occurred at 151:53:00. At 151:53:36 the Goldstone station commanded an antenna switch from omni D to the high gain antenna in the automatic tracking mode but were unsuccessful because the uplink signal strength was below command threshold. The crew reestablished high gain antenna communications at 152:46:46.

Communications with the command module were lost for approximately 11 minutes from 154:30:00 to 154:40:58. This loss occurred during passive thermal control when the Goldstone station could not establish two-way lock. Subsequent crew comments disclosed that the high gain antenna switch had been left in the autotrack position rather than the auto-reacquisition position, preventing the high gain antenna from going to a preset position where it could be effectively managed by ground commands. When this was recognized, the crew reacquired the uplink signal with the high gain antenna and selected the automatic reacquisition mode, thereby, restoring communications.

### 3.8.2 Transearth Coast Echo

During the transearth coast phase, there appeared to be an echo on the command module downlink. From 155:36:00 to 155:54:00, portions of the uplink voice transmissions through the Goldstone station were heard on the command module downlink, but were 40 to 50 dB below the normal down-voice. The time delay was approximately 1.9 seconds between uplink voice transmission and the downlink echo. The time corresponded to the delay of the two-way transmission at that range in the lunar return trajectory. The echo was not detected on the downlink voice remoted from the site because it was masked by noise when remoted to net 1.

### 3.8.3 Transearth Television Performance

Two color television transmissions were received at the Goldstone station during the transearth coast phase. The audio and video quality of both television transmissions was good.

## 3.9 Earth Entry Communications

The command module entry interface (400,000 feet altitude) began at 195:03:07. S-band communications blackout began at approximately 195:03:24 and ended at 195:06:59. S-band communications up to blackout and very high frequency communications from blackout to splashdown were satisfactory.

## APPENDIX A

## MERRITT ISLAND PHASE AND FREQUENCY MODULATION RECEIVER TELEMETRY PERFORMANCE

Figure A-1 shows the phase modulation (PM) uplink and downlink S-band carrier power levels received during the Merritt Island coverage of the Apollo 11 launch phase. Telemetry performance for the PM downlink (receiver 1) is shown for the total pass coverage and the performance of the PM downlink (receiver 4) which was used for frequency modulation (FM) is shown from liftoff until 00:04:00. There were no frame synchronization losses or bit errors greater than $10^{-3}$ for either receiver from 00:04:00 to 00:06:00. During the first 4 minutes after liftoff, the telemetry system processing PCM data from the PM receiver was out-of-synchronization more than the system that was processing PCM data from the FM receiver.

In comparing the communications performance of the Apollo 9, 10, and 11 launches, there was greater coverage with progressively fewer data losses from one launch to the next. Figure A-2 compares the PM and FM receiver performance for these missions. During the Apollo 9 launch, the telemetry data through the PM receiver from 00:02:00 to 00:04:00 was out of frame synchronization for approximately 30 seconds. During the Apollo 10 mission loss of frame synchronization was slightly less than 30 seconds and less than 15 seconds during Apollo 11. However, a higher bit error rate existed for a longer period during Apollo 11 than during Apollo 9 or 10 for the telemetry from the PM receiver.

The telemetry data from the FM receiver contained a higher bit error rate during the Apollo 11 mission than during the Apollo 10 mission from 00:02:00 and 00:04:00. However, there were only two 1-second out-of-lock conditions for the Apollo 11 telemetry; whereas, during Apollo 10, five out-of-lock conditions, each lasting from one to four seconds occurred during that period. It appears that a high bit error rate must be accepted while maintaining frame synchronization with the FM receiver. Even though the FM receiver will threshold 4 to 6 dB

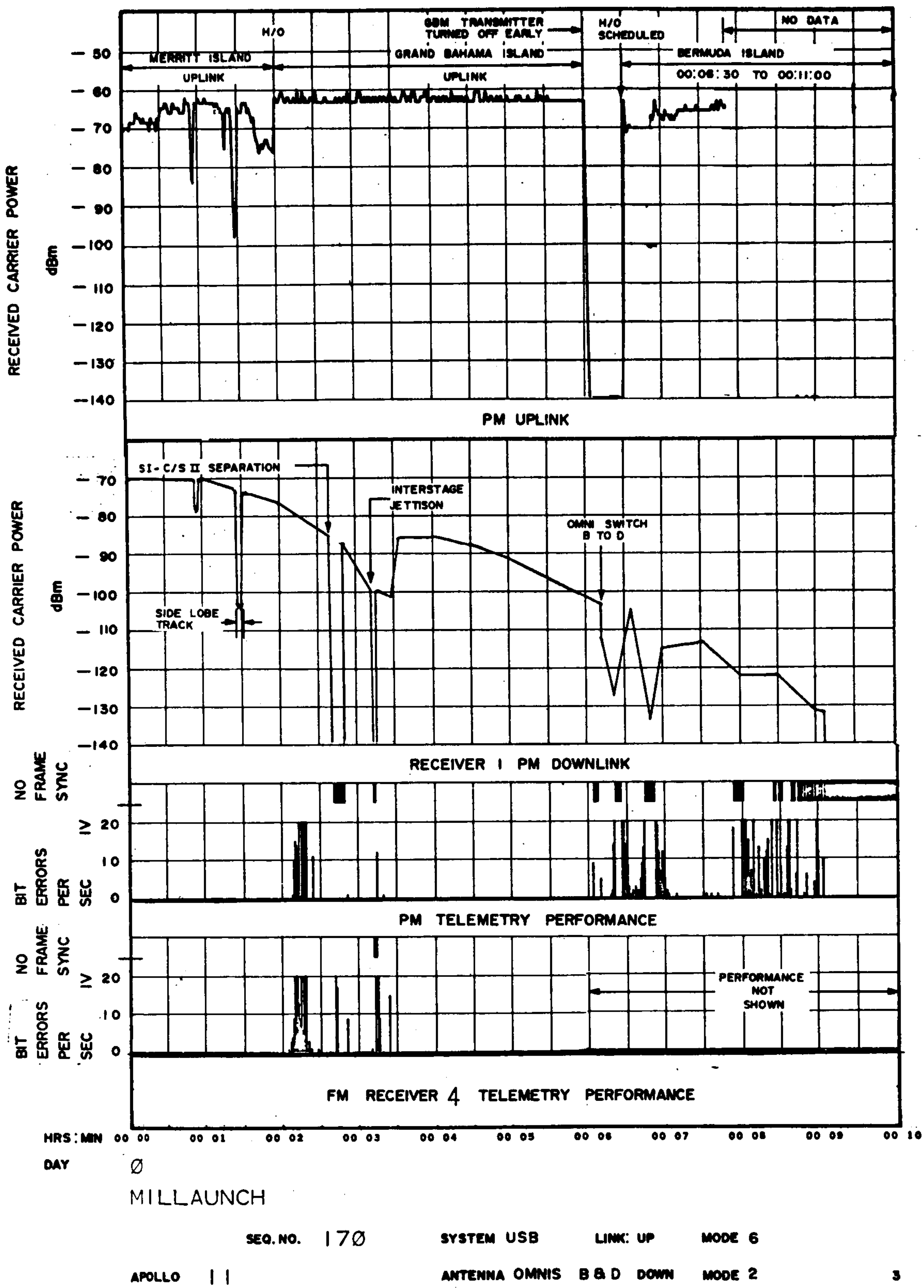



Figure A-1 Merritt Island Station S-band Communications Coverage During Launch

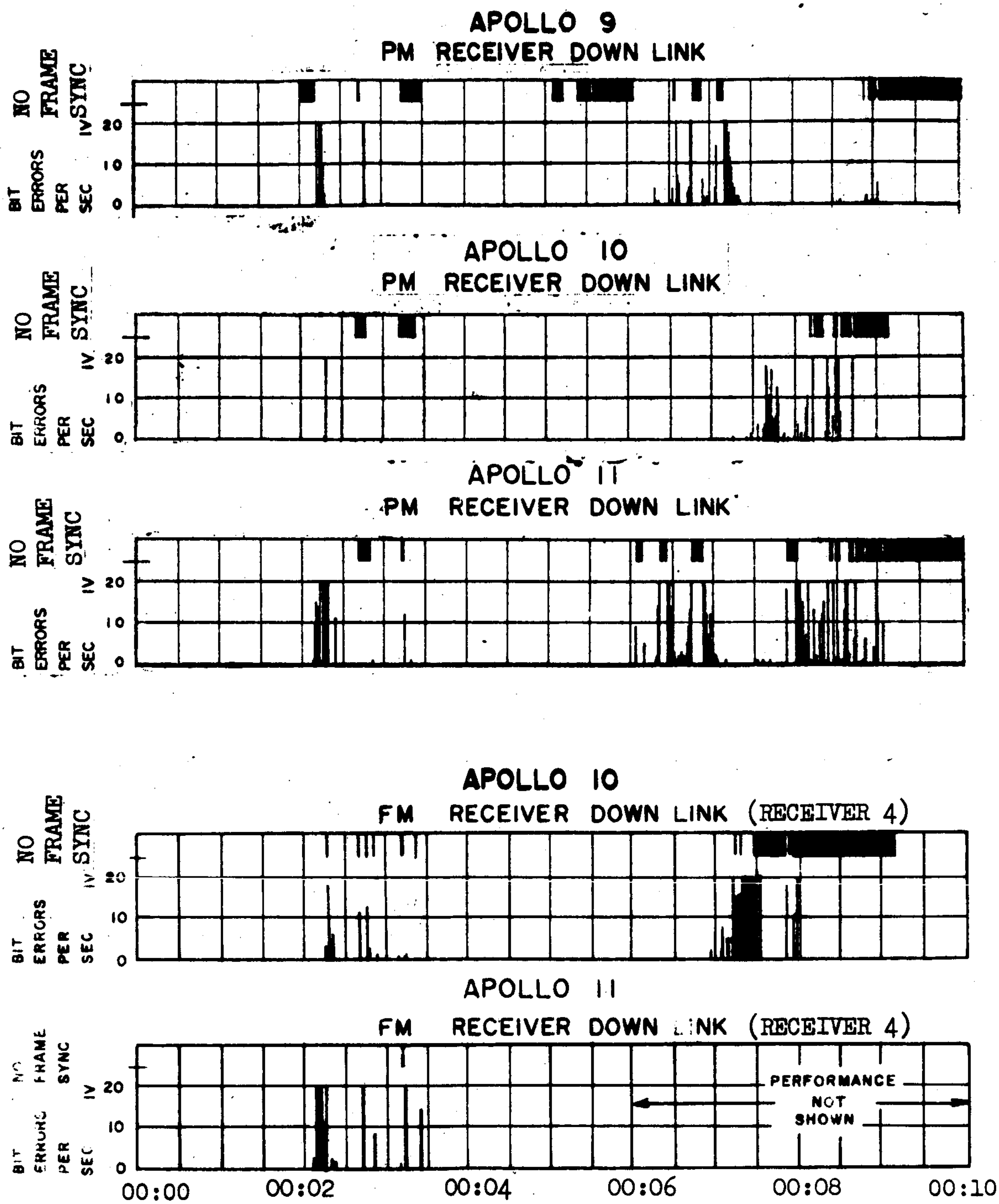



Figure A-2 PM and FM Receiver Performance Comparison sooner than the PM receiver, the signal levels during launch are well above threshold. The overall performance for these three missions shows that the use of the FM receiver offers considerable performance improvement over the use of the PM receiver during the first 5 minutes after launch.

# APPENDIX B

## MERRITT ISLAND STATION LAUNCH COVERAGE COMPARISONS

A comparison of predicted and measured downlink received S-band carrier power levels during the Merritt Island station coverage of the Apollo 8, 10, and 11 launch phases is contained in this section. The data from the first six minutes of each mission are compared with the predictions. During this period, the command module signal combination was 6.02 using omni antenna B, and the Merritt Island station maintained downlink carrier lock. The predictions used in this report account for the spacecraft transmitted power, the transmit and receive losses, antenna gains, the carrier power loss due to modulation, and space loss. Mission parameters were used to generate predictions of downlink received carrier power for comparison with the measured downlink received carrier power.

The following general equation was used to generate the predicted downlink received carrier power levels.

$$P_c = P_T - L_T - L_R + G_T + G_R - A_P - A_S - L_{m/c}$$

where

$P_c$ = received carrier power

$P_T$ = transmitted power

$L_T$ = transmit losses

$L_R$ = received losses

$G_T$ = transmit antenna gain

$G_R$ = receive antenna gain

$A_P$ = Saturn V exhaust plume attenuation

$A_S$ = space loss

$L_{m/c}$ = carrier power loss due to modulation

The space loss term can be replaced by

$$A_S = 20 \log R_{NM} + 20 \log f_{MHz} + 10 \log K$$

where

$R_{NM}$ = slant range from spacecraft to ground site in nautical miles

$f_{MHz}$ = transmitted frequency in megahertz.

$K$ = space constant = $[c/4\pi\ (\times 10^6)]^2$

$c$ = speed of light

Table B-1 presents the respective mission constants of the equation.

The general equation can be simplified to include a constant plus variables for each mission. The variables are the omni B antenna gain, the Saturn V exhaust plume attenuation, and the slant range term of the space loss equation.

The final equation used is

$$P_c = C + G_T + A_P - 20 \log R_{NM}$$

where C is the mission constant equal to -27.7 dB for Apollo 8, -25.7 dB for Apollo 10, and -26.7 dB for Apollo 11.

Measured flight data were used to compute the look angles to the Merritt Island station for the transmit antenna gain and the exhaust plume attenuation. The slant range from the spacecraft to the Merritt Island station was used to compute the space loss. One effect that was not taken into account in the predictions was the shadowing of the omni antenna by the Saturn V. Reliable information as to the amount of radio frequency signal degradation caused by shadowing of the active omni antenna was not available.

TABLE B-1

MISSION CONSTANTS FOR RF PREDICTIONS

| Parameter | Apollo 8 | Apollo 10 | Apollo 11 |
|---|---|---|---|
| $P_T$ | 40.9 dBm | 41.5 dBm | 40.6 dBm |
| $L_T$(for omni B) | 3.7 dB | 2.3 dB | 2.4 dB |
| $L_R$(included in $G_R$) | - | - | - |
| $G_R$(30 foot antenna) | 44 dB | 44 dB | 44 dB |
| 20 log $f_{MHz}$(2287.5 MHz) | 67.2 dB | 67.2 dB | 67.2 dB |
| 10 log K | 37.8 dB | 37.8 dB | 37.8 dB |
| $L_{m/c}$ (approximately) | 3.9 dB | 3.9 dB | 3.9 dB |

The effects of shadowing the omni B antenna can be seen in the comparison of the prediction data to the actual flight data.

Figure B-1 presents a plot of omni B antenna gain as a function of look angles, theta and phi. Theta is the smallest angle from the X-body axis of the spacecraft to the line of sight vector to the ground station. Phi is the angle measured from the minus Z-body axis positively about the X-body axis to the vector projection in the Y-Z plane. Each mission launch phase look angles are plotted and time correlated (see References 11 and 12). Therefore, the omni B antenna gain can be computed as a function of mission time.

The launch trajectory for Apollo 10 from launch pad 39B resulted in better look angles to the Merritt Island station in terms of omni B antenna gain than either Apollo 8 or 11. Apollo 8 and 11 were launched from pad 39A and have similar launch trajectories. However, on Apollo 8 the look angle theta remained in the Saturn V omni shadowing region, theta equal to or greater than 176 degrees, from 00:03:00 through 00:06:00.

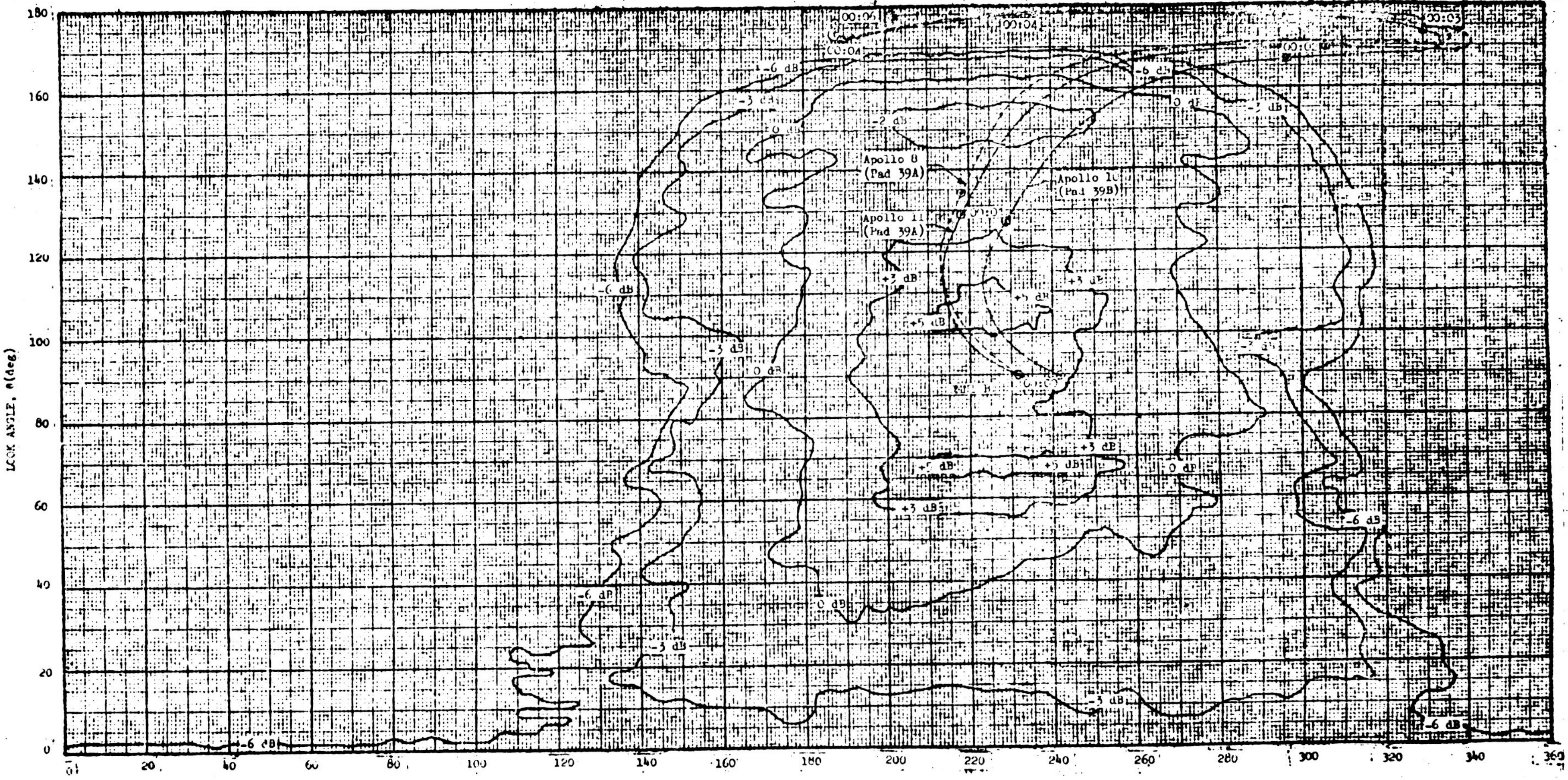



Figure B-1 Command and Service Module Omni B Antenna Gain for Apollo 8, 10, and 11

Figure B-2 presents plots of Saturn V exhaust plume attenuation as a function of look angle, theta. The exhaust plume is symmetrical about the minus X-body axis; therefore, the exhaust plume attenuation is independent of the look angle, phi. Method 1 of computing the exhaust plume attenuation was derived by Dr. J. C. Chang of Lockheed Electronics Company and considers only the conduction current in the plume plasma (see Reference 5). Method 2 derived by Dr. Chang considers not only the conduction current in the plasma, but also includes the displacement current introduced by the equivalent electron dipole moment. Both methods of computing the exhaust plume attenuation are used in this report to predict the downlink received carrier power. The exhaust plume attenuation data presented in Figure A-2 are computed to only 177 degrees because after 176 degrees the main attenuation effect is omni antenna shadowing by the Saturn V. The exhaust plume considered by Dr. Chang and used in this report is for the Saturn IC first stage. The Saturn IC and Saturn II separation occurs at approximately 00:02:30.

The Saturn II has a smaller plume and the attenuation could be less than the attenuation for the Saturn IC. However, no information was available on the Saturn II. Therefore, the plume attenuation should probably be less after 00:02:30 than shown in Figure B-2.

Figure B-3 is a plot of slant range from the spacecraft to the Merritt Island station as a function of mission time. It can be seen that there is very little difference in slant range for the respective missions.

Figures B-4, B-5, and B-6 present a comparison between the predicted and the measured downlink received carrier power levels for Apollo 8, 10, and 11 respectively. The measured values are truncated at an upper level of -70 dBm by the Automatic Data Evaluation program used to plot the measured data.

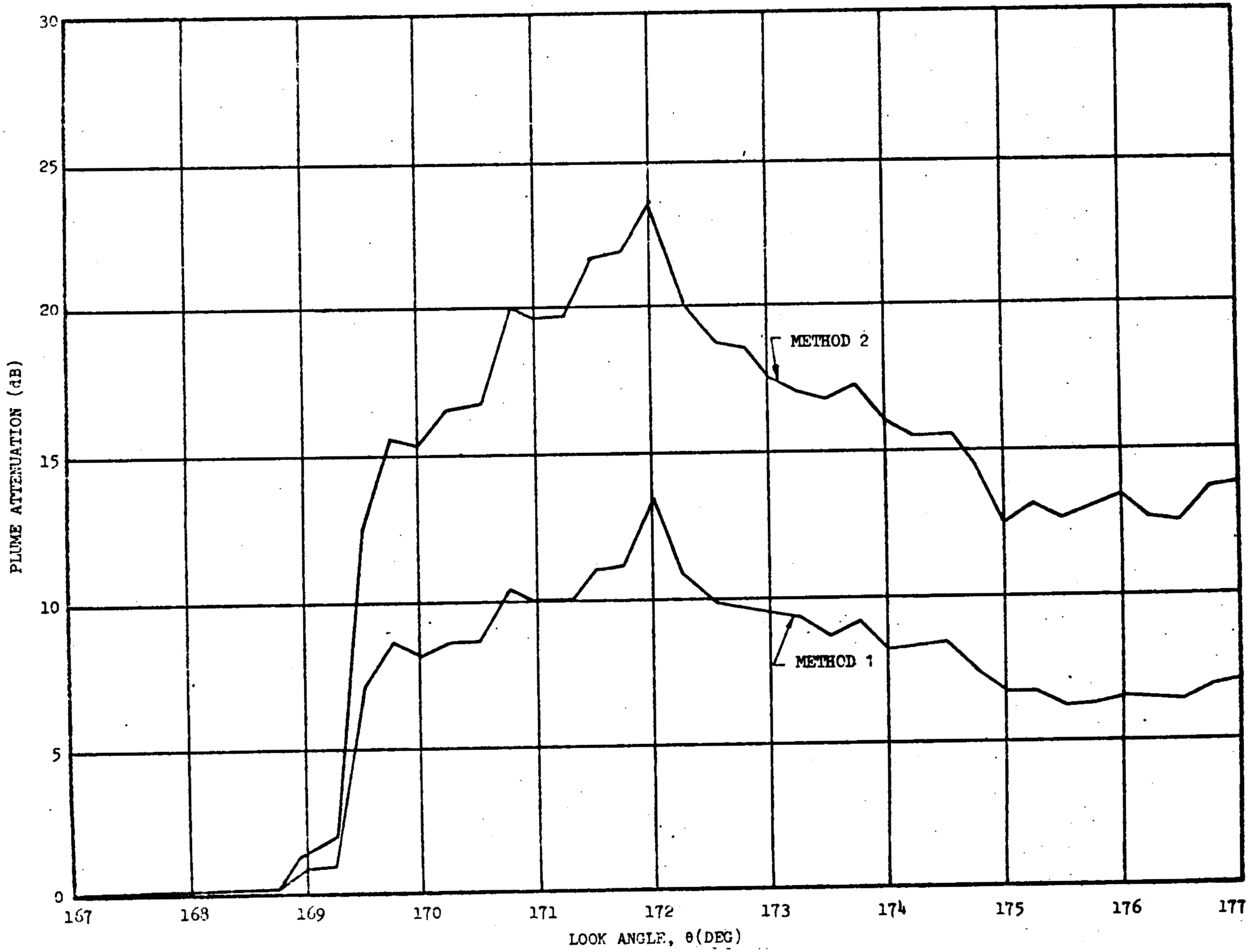



Figure B-2 Saturn V Exhaust Plume Attenuation

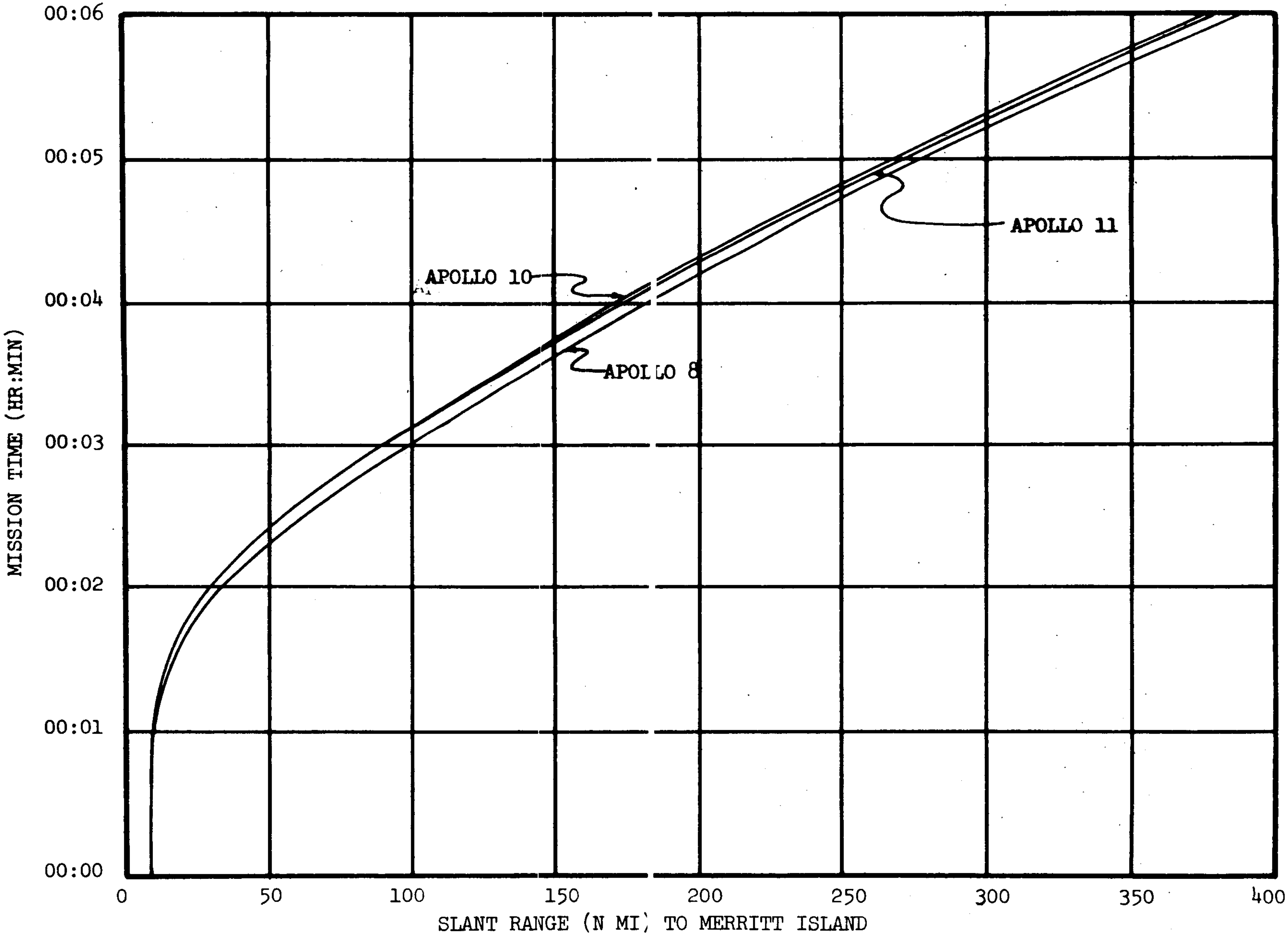



Figure B-3 Apollo 8, 10, and 11 Slant Range Comparison During Launch

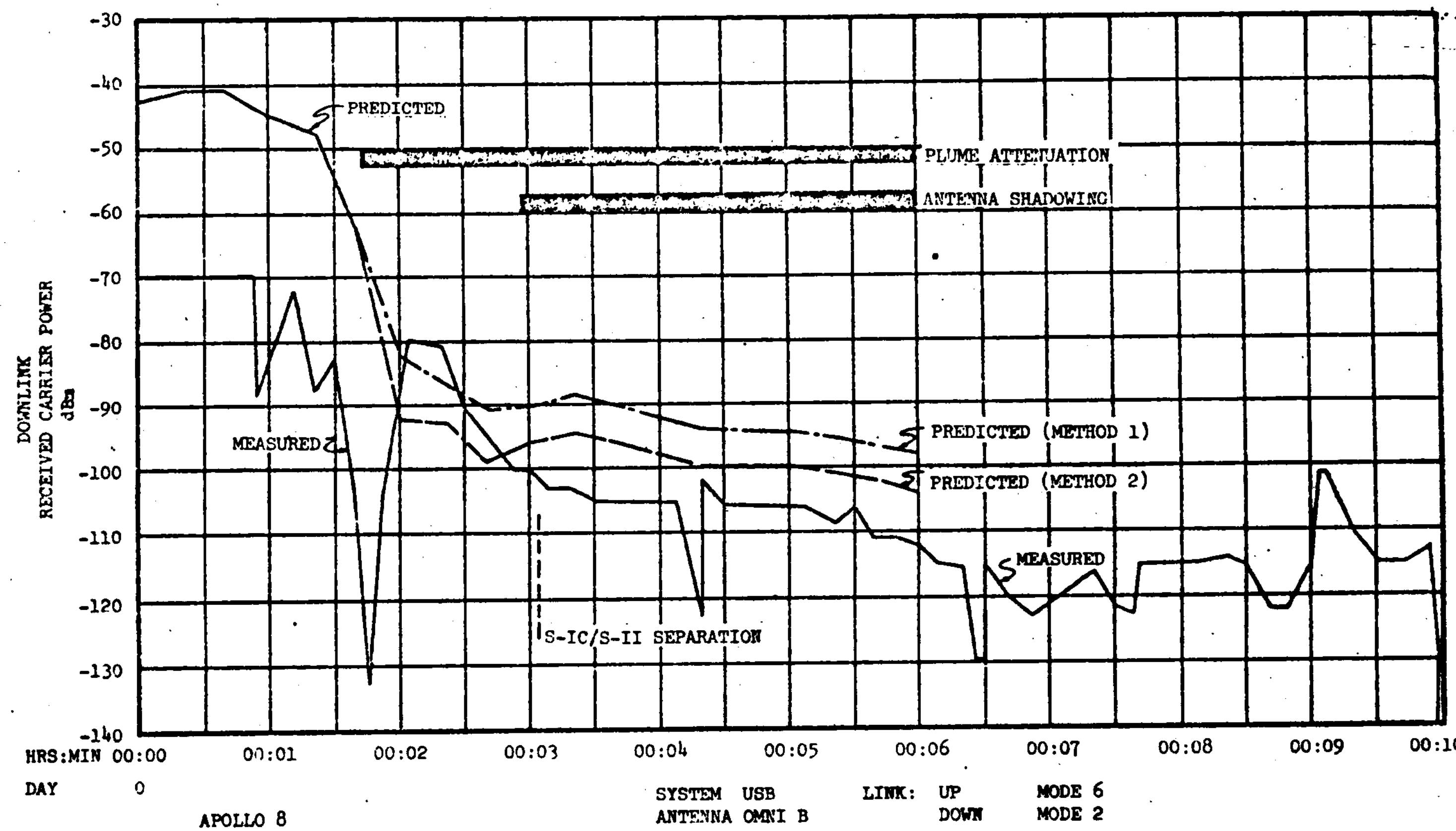



Figure B-4 Downlink Received Power Levels During Apollo 8 Launch

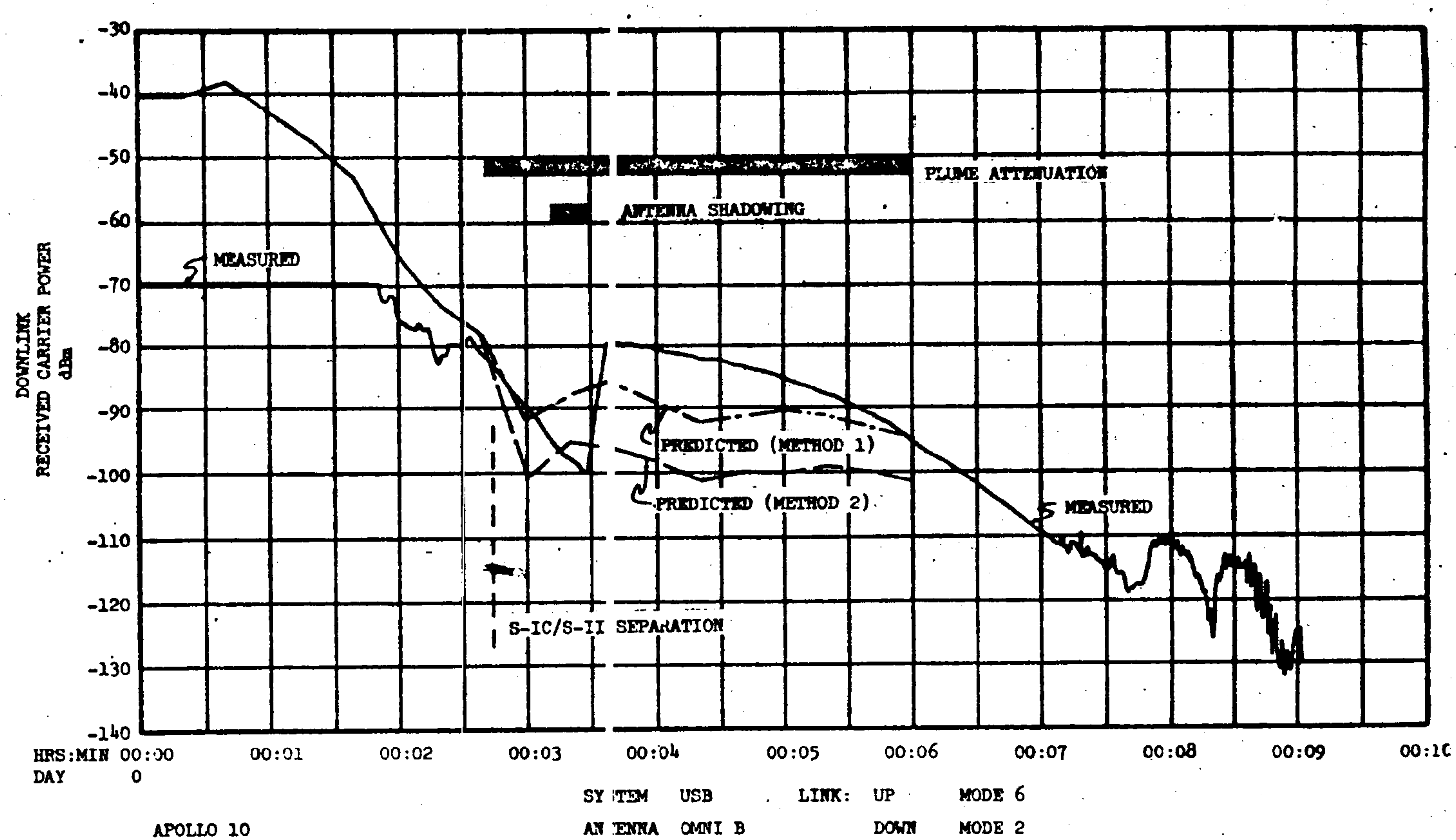



Figure B-5 Downlink Received Power Levels During Apollo 10 Launch

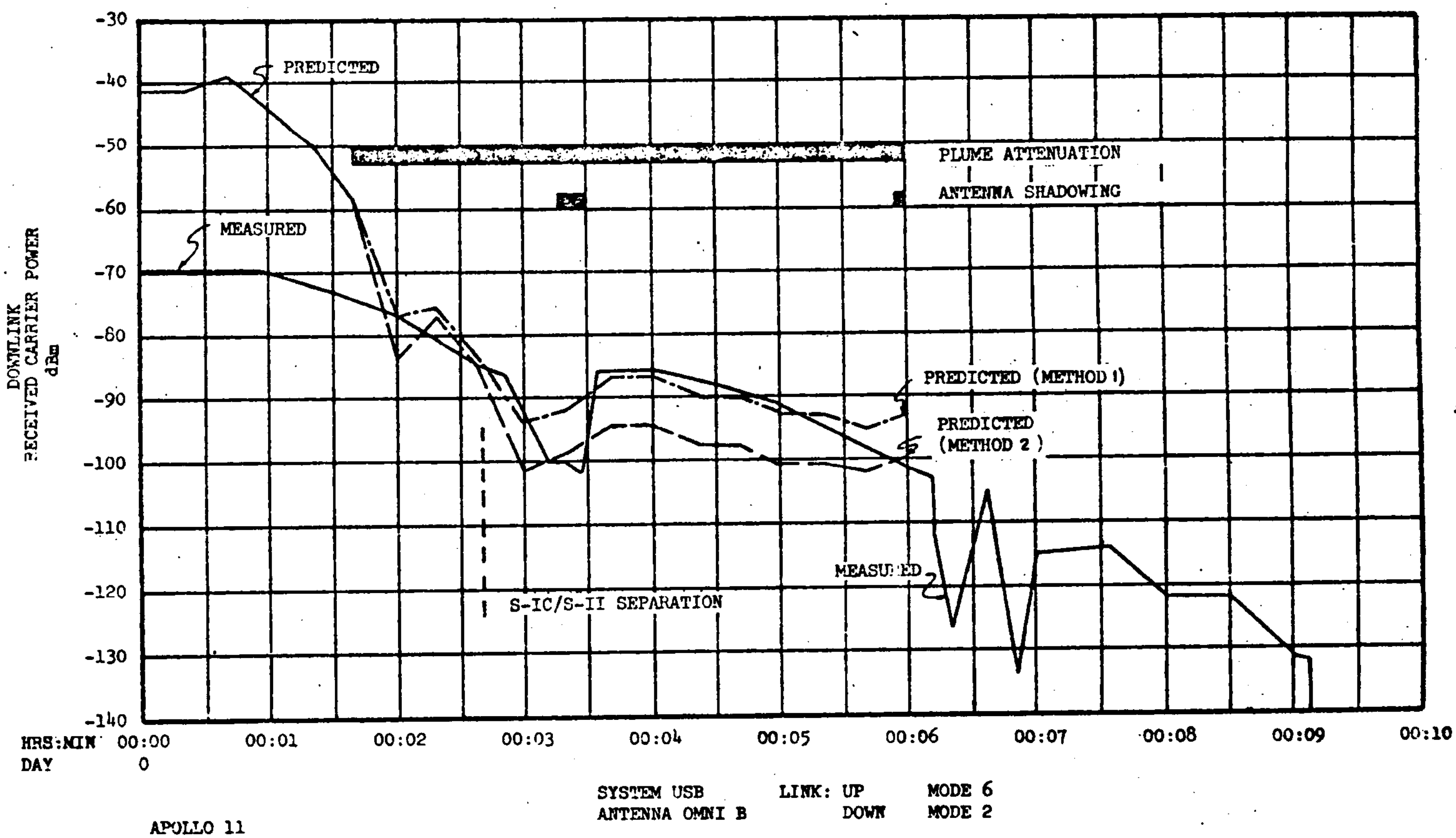



Figure B-6 Downlink Received Power Levels During Apollo 11 Launch

The Apollo 8 predictions (Figure B-4) did not closely agree with the measured downlink received carrier power after 00:03:00. From Figure A-1, the spacecraft look angle, theta, for Apollo 8 was equal to or greater than 176 degrees beginning at 00:03:00. In this region the Saturn V shadowing of the omni B antenna degraded the RF signal level.

The Apollo 10 predictions (Figure B-5) agreed with the measured data. Method 1 of computing the exhaust plume attenuation provided predictions approximately 4 dB less than the measured value. Saturn IC/Saturn II separation occurred at approximately 00:02:40. After this time, the exhaust plume attenuation should have been less than indicated. If this were the case, the predicted values for the downlink received carrier power would more closely approximate the measured values. From 00:03:20 until 00:03:30, the omni antenna was shadowed by the Saturn V. The effects of shadowing can be seen in Figure B-5 with the decrease in measured downlink received carrier power.

The Apollo 11 predictions (Figure B-6) agreed with the measured downlink received carrier power. Method 1 of computing the exhaust plume attenuation gave predictions averging only 1 dB less than the measured values. If the plume attenuation for the Saturn II was actually less than the computed values for the Saturn IC, the prediction data would approximate the measured values. From 00:03:20 until 00:03:30 and after 00:05:50, the omni antenna was shadowed by the Saturn V ($\theta \geq 176$ degrees).

The predicted values of the downlink received carrier power generally agreed very closely to the measured values when the omni antenna was not shadowed by the Saturn V. If an evaluation could be done to compute the exhaust plume attenuation for the Saturn II, the predictions would probably agree more closely with the measured downlink received carrier power after Saturn IC/Saturn II separation.

In conclusion, while the exhaust plume does degrade the RF performance, the most important factor in signal degradation is the omni shadowing by the Saturn V. This is clearly evident in the degraded RF performance during the Apollo 8 launch phase. It appears that launch trajectories could be defined such that the theta look angle to the Merritt Island station would never exceed 175 degrees. This would greatly improve the RF communications coverage by the Merritt Island station during the launch phase, and the Merritt Island station could actively support the missions throughout the first six minutes of the flight.

## APPENDIX C

## APOLLO 10 AND 11 DATA STORAGE EQUIPMENT PERFORMANCE COMPARISON

A comparison of the data storage equipment dumps for voice and telemetry data at the 85-foot and 30-foot antenna sites is presented in Tables C-1, C-2, and C-3.

TABLE C-1

COMMAND MODULE DATA STORAGE EQUIPMENT PLAYBACK OF LUNAR MODULE DATA FOR APOLLO 11

| ANTENNA | DUMP RATE | DATA QUALITY |
|---|---|---|
| 85' | 32:1 | Good With Some Noise |

TABLE C-2

COMMAND MODULE DATA STORAGE EQUIPMENT DATA QUALITY FOR APOLLO 10

| ANTENNA | DUMP RATE | VOICE QUALITY | DATA QUALITY |
|---|---|---|---|
| 85' | 32:1 | Weak to Loud | Good |
| 85' | 1:1 | With Background Noise | Good |
| 30' | 32:1 | Mostly Good | Good |
| 30' | 1:1 | With Background Noise | Good |

TABLE C-3

COMMAND MODULE DATA STORAGE EQUIPMENT DATA QUALITY FOR APOLLO 11

| ANTENNA | DUMP RATE | VOICE QUALITY | DATA QUALITY |
|---|---|---|---|
| 85' | 32:1 | Weak to Good With Noise | Good |
| 85' | 1:1 | Loud With Noise (Whine) | Good |
| 30' | 32:1 | Barely Audible to Weak With Noise | Good |
| 30' | 1:1 | Loud With Noise | Good |

## APPENDIX D

## LUNAR MODULE DOWNLINK VOICE TESTS IN THE ELECTRONIC SYSTEMS TEST LABORATORY (ESTL)

Lunar module downvoice tests were performed in the Electronic Systems Test Laboratory on 20 August 1969. The test number was TPET 082069-3, and the test configuration is shown in Figure D-1. The data from these tests were on annotated voice tape that was evaluated for speech quality and intelligibility in the voice laboratory. The tests consisted of three parts: lunar module downlink signal combination 1, lunar module downlink signal combination 4, and lunar module downlink signal combination 4 with the 1.25 MHz discriminator output summed to the backup downvoice output. The tests were performed simulating the conditions observed during lunar orbits 11 and 12 for the lunar module during Apollo 11. The total received power levels for each part of the test were decreased from -110 dBm in 2 dB steps to -120 dBm or until the received signal became unusable.

Because the flight data from lunar orbits 11 and 12 were referenced as received carrier power levels and not total received power levels, carrier suppression values were used to correlate the laboratory results to the flight results and are summarized in Table D-1.

TABLE D-1

CARRIER SUPPRESSION SUMMARY

| SIGNAL COMBINATION | SUBCARRIER (OR MODULATION) | SUPPRESSION |
|---|---|---|
| 1 | Voice | 1.86 dB |
| | TLM | 3.80 dB |
| | | TOTAL 5.66 dB |
| 4 | Voice | 1.45 dB |
| | TLM | 3.80 dB |
| | | TOTAL 5.25 dB |

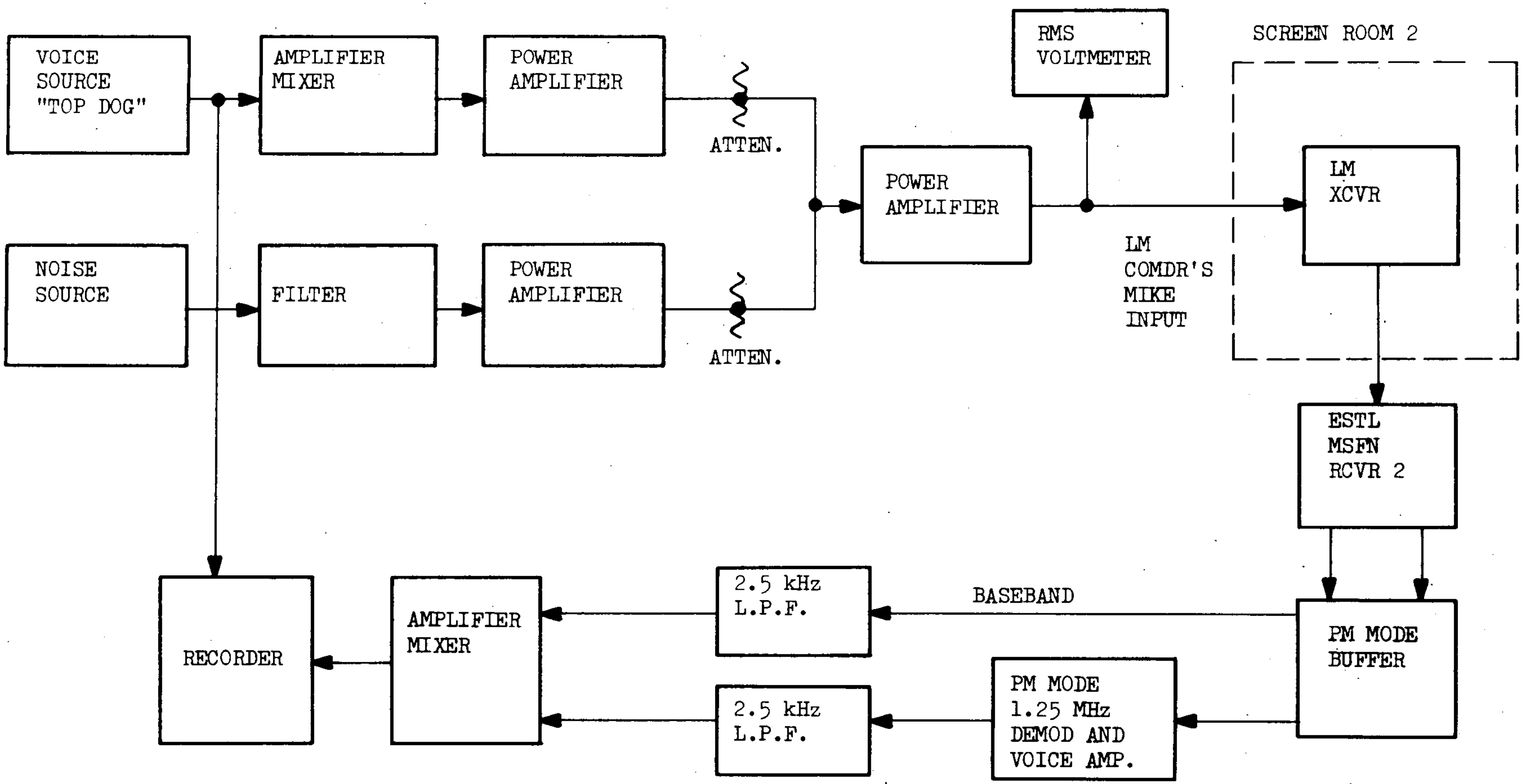



Figure D-1 Electronic Systems Test Laboratory (ESTL) Test Configuration

A Manned Space Flight Network station using a cooled parametric amplifier results in approximately a 10 dB improvement in sensitivity when compared to the Electronic Systems Test Laboratory configuration. Therefore, for signal combination 1 a correction factor of approximately 15.7 dB exists between the total received power as referenced in the laboratory to the received carrier power as obtained from station data. Also, for periods of no voice modulation for signal combination 4, a correction factor of approximately 13.8 dB exists between the laboratory data and station data.

The normal and backup downvoice data for the three conditions are summarized in Table D-2. The speech-to-noise ratios are listed as a function of received carrier power after performing the power conversion discussed above.

The Apollo 11 flight data for normal and backup downvoice appear in Table D-3 and is compared with the test data from the Electronic Systems Test Laboratory in Figure D-2.

TABLE D-2

ELECTRONIC SYSTEMS TEST LABORATORY (ESTL)
LUNAR MODULE DOWNVOICE TEST RESULTS SUMMARY

| LUNAR MODULE DOWNLINK SIGNAL COMBINATION | RECEIVED CARRIER POWER, dBm WITH VOICE MODULATION | RECEIVED CARRIER POWER, dBm WITHOUT VOICE MODULATION | SPEECH-TO-NOISE RATIO, dB |
|---|---|---|---|
| 1 | -125.7 | | 1.5 |
| | -127.7 | | 0.7 |
| (normal downvoice) | -129.7 | | 0.2 |
| | -131.7 | | No reading |
| 4 | -125.2 | -123.8 | 5.6 |
| | -127.2 | -125.8 | 4.8 |
| | -129.2 | -127.8 | 4.0 |
| | -131.2 | -129.8 | 3.1 |
| (backup downvoice) | -133.2 | -131.8 | 2.3 |
| | -135.2 | -133.8 | 0.5 |
| 4 | -125.2 | -123.8 | 0.8 |
| plus 1.25 MHz demodulator noise | -127.2 | -125.8 | 0.6 |
| | -129.2 | -127.8 | 0.6 |
| | -131.2 | -129.8 | 0.6 |
| (backup downvoice) | -133.2 | -131.8 | 0.6 |
| | -135.2 | -133.8 | 0.4 |

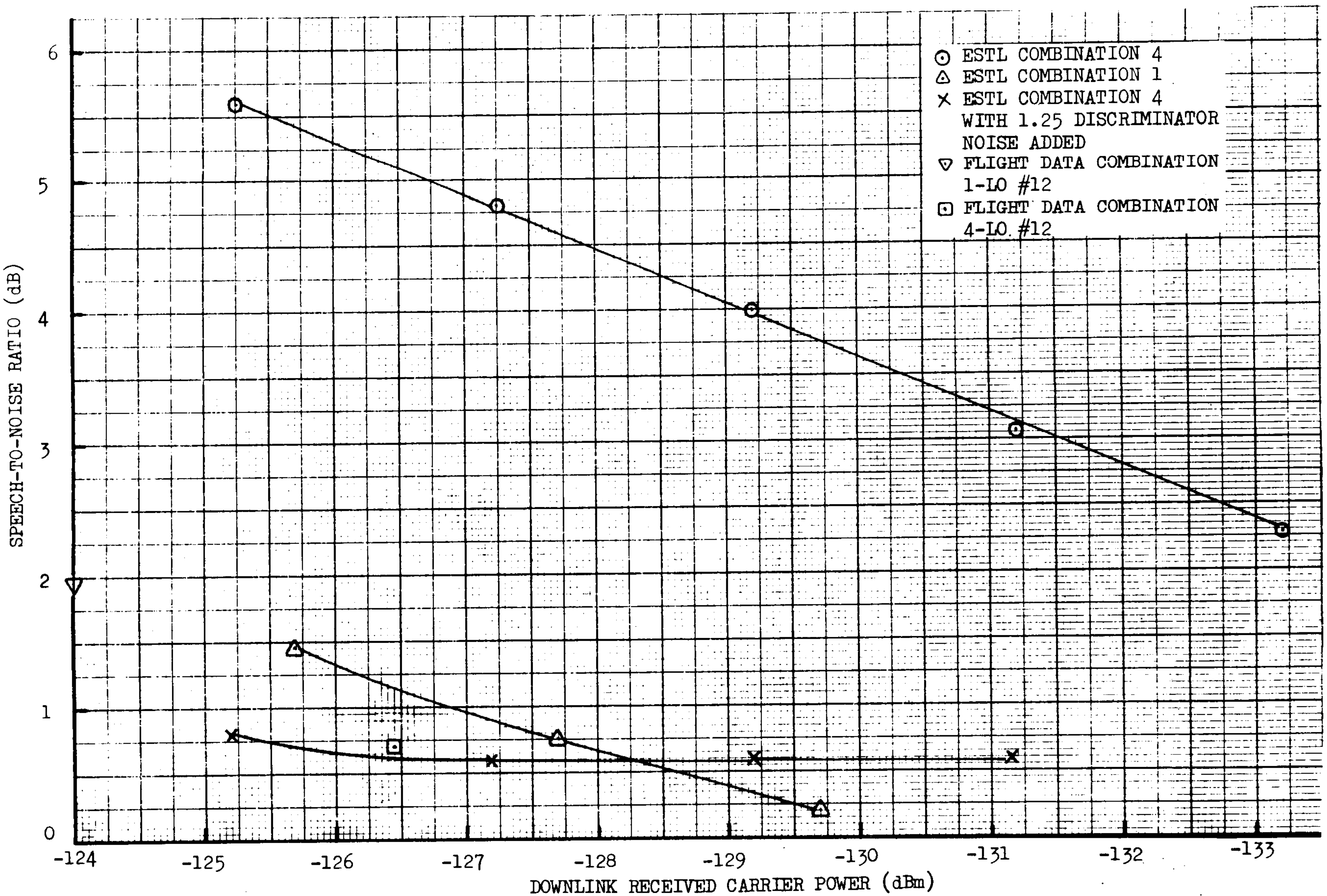



Figure D-2 Speech-To-Noise Ratio Versus Downlink Received Carrier Power For Apollo 11 Downvoice Combinations 1 and 4

TABLE D-3

APOLLO 11 FLIGHT DATA

| LUNAR MODULE DOWNLINK SIGNAL COMBINATION | LUNAR ORBIT | RECEIVED CARRIER POWER, dBm | SPEECH-TO-NOISE RATIO, dB |
|---|---|---|---|
| 1 (normal downvoice) | 11 | -128 | Not available on omni antenna |
| | 12 | -124 | +1.9 |
| 4 (backup downvoice without voice modulation | 11 | -128 | +0.37 |
| | 12 | -125 | +0.72 |

# APPENDIX E

## MSFN/LM/CSM SIGNAL COMBINATIONS

This appendix is composed of PM and FM communications signal combinations, presented in tabular form. It is presented as a quick reference source.

TABLE E-1

MSFN TO CSM/LM S-BAND PM COMMUNICATIONS SIGNAL COMBINATIONS (UPLINK)

| SIGNAL COMBINATION | INFORMATION | MODULATION TECHNIQUE | SUBCARRIER FREQUENCY | SUBCARRIER DEVIATION kHz PEAK | (SPECIFIED) CARRIER DEVIATION RADIANS PEAK |
|---|---|---|---|---|---|
| 0 | NO CARRIER | ---- | ---- | ---- | ---- |
| 1 | PRN RANGING | PM ON CARRIER | ---- | ---- | 1.34 ± 10% |
| 2 | VOICE | FM/PM | 30 kHz | ± 7.5 | 1.85 ± 10% |
| 3 | UP-DATA | PSK/FM/PM | 70 kHz | ± 5.0 | 1.85 ± 10% |
| 4 | PRN RANGING<br>VOICE | PM ON CARRIER<br>FM/PM | ----<br>30 kHz | ----<br>± 7.5 | 0.38 ± 10%<br>1.20 ± 10% |
| 5 | PRN RANGING<br>UP-DATA | PM ON CARRIER<br>PSK/FM/PM | ----<br>70 kHz | ----<br>± 5.0 | 0.38 ± 10%<br>1.20 ± 10% |
| 6 | PRN RANGING<br>VOICE<br>UP-DATA | PM ON CARRIER<br>FM/PM<br>PSK/FM/PM | ----<br>30 kHz<br>70 kHz | ----<br>± 7.5<br>± 5.0 | 0.44 ± 10%<br>1.00 ± 10%<br>1.00 ± 10% |
| | VOICE<br>UP-DATA | FM/PM<br>PSK/FM/PM | 30 kHz<br>70 kHz | ± 7.5<br>± 5.0 | 1.10 ± 10%<br>1.10 ± 10% |
| 8 | PRN RANGING<br>BACKUP VOICE | PM ON CARRIER<br>FM/PM | ----<br>70 kHz | ----<br>± 5.0 | 0.38 ± 10%<br>1.20 ± 10% |
| 9 | CARRIER | ---- | ---- | ---- | ---- |

TABLE E-2

CSM TO MSFN S-BAND PM COMMUNICATIONS SIGNAL COMBINATIONS (DOWNLINK)

| SIGNAL COMBINATION | INFORMATION | MODULATION TECHNIQUE | INFORMATION FREQUENCY | SUBCARRIER FREQUENCY | PEAK SUBCARRIER DEVIATION | (MEASURED) PEAK CARRIER DEVIATION (RADIANS) |
|---|---|---|---|---|---|---|
| 0 | ---- | ---- | ---- | ---- | ---- | ---- |
| 1 | *VOICE | FM/PM | ---- | 1.25 MHz | 7.5 kHz[1] | 0.73 |
| | 51.2 kbps TLM | PCM/PM/PM | ---- | 1.024 MHz | Biphase (±90°) | 0.96 ** |
| 2 | PRN | PM ON CARRIER | ---- | ---- | ---- | α *** |
| | *VOICE | FM/PM | ---- | 1.25 MHz | 7.5 kHz[1] | 0.73 |
| | 51.2 kbps TLM | PCM/PM/PM | ---- | 1.024 MHz | Biphase (±90°) | 0.96 ** |
| 3 | PRN | PM ON CARRIER | ---- | ---- | ---- | α*** |
| | *VOICE | FM/PM | ---- | ---- | 7.5 kHz[1] | 1.26 |
| | 1.6 kbps TLM | PCM/PM/PM | ---- | 1.024 MHz | Biphase (±90°) | 0.73 |
| 4 | *VOICE | FM/PM | ---- | 1.25 MHz | 7.5 kHz[1] | 1.26 |
| | 1.6 kbps TLM | PCM/PM/PM | ---- | 1.024 MHz | Biphase (±90°) | 0.73 |
| 5 | 1.6 kbps TLM | PCM/PM/PM | ---- | 1.024 MHz | Biphase (±90°) | 1.70 |
| 6 | KEY | AM/PM | ---- | 512 kHz | 100% AM | 1.0 |
| 7 | PRN | PM ON CARRIER | ---- | ---- | ---- | α*** |
| 8 | BACKUP VOICE | PM ON CARRIER | ---- | ---- | ---- | 0.72 |
| | 1.6 kbps TLM | PCM/PM/PM | ---- | 1.024 MHz | Biphase (±90°) | 1.26 |

TABLE E-2

CSM TO MSFN S-BAND PM COMMUNICATIONS SIGNAL COMBINATIONS (DOWNLINK)

(CONTINUED)

| SIGNAL COMBINATION | INFORMATION | MODULATION TECHNIQUE | INFORMATION FREQUENCY | SUBCARRIER FREQUENCY | PEAK SUBCARRIER DEVIATION | (MEASURED) PEAK CARRIER DEVIATION (RADIANS) |
|---|---|---|---|---|---|---|
| 9 | PRN | PM ON CARRIER | ---- | ---- | ---- | α*** |
| | 1.6 kbps TLM | PCM/PM/PM | ---- | 1.024 MHz | Biphase (±90°) | 1.70 |
| 10 | BACKUP VOICE | PM ON CARRIER | ---- | ---- | ---- | 1.25 |
| 11 | PRN | PM ON CARRIER | ---- | ---- | ---- | α*** |
| | *VOICE | FM/PM | ---- | 1.25 MHz | 7.5 kHz[1] | 1.26 |
| 12 | *VOICE | FM/PM | ---- | 1.25 MHz | 7.5 kHz[1] | 1.26 |
| 13 | 51.2 kbps TLM | PCM/PM/PM | ---- | 1.024 MHz | Biphase (±90°) | 1.70 ** |
| 14 | BACKUP VOICE | PM ON CARRIER | ---- | ---- | ---- | 0.72 |
| 15 | PRN | PM ON CARRIER | ---- | ---- | ---- | α*** |
| | 51.2 kbps TLM | PCM/PM/PM | ---- | 1.024 MHz | Biphase (±90°) | 1.70 ** |
| 16 | BACKUP VOICE | PM ON CARRIER | ---- | ---- | ---- | 1.25 |
| | 51.2 kbps TLM | PCM/PM/PM | ---- | 1.024 MHz | Biphase (±90°) | 1.70 ** |

NOTES:

* Can be CSM voice or LM voice relay or EVA voice relay.

** Expected value based on test data and accounts for reduction in TLM subcarrier modulation index with bits on subcarrier

*** Down-link PRN ranging code modulation index (α) depends on up-link signal combination and received signal power.

Note 1: 9.0 kHz for LM relay.

TABLE E-3

CSM TO MSFN S-BAND FM COMMUNICATIONS SIGNAL COMBINATIONS (DOWNLINK)

| SIGNAL COMBINATION | INFORMATION | MODULATION TECHNIQUE | INFORMATION FREQUENCY | SUBCARRIER FREQUENCY | PEAK SUBCARRIER DEVIATION | (MEASURED) PEAK CARRIER DEVIATION |
|---|---|---|---|---|---|---|
| 0 | ---- | ---- | ---- | ---- | ---- | ---- |
| 1 | P/B VOICE, 1:1 | FM BASEBAND | ---- | ---- | ---- | 87.1 kHz |
| | P/B 51.2 kbps TLM, 1:1 | PCM/PM/FM | ---- | 1.024 MHz | Biphase ($\pm 90^{\circ}$) | 596.0 kHz |
| | P/B SCI, 1:1 | FM/FM | ---- | 95 kHz | ---- * | 75 kHz ± 15% ** |
| | P/B SCI, 1:1 | FM/FM | ---- | 125 kHz | ---- * | 110 kHz ± 15% ** |
| | P/B SCI, 1:1 | FM/FM | ---- | 165 kHz | ---- * | 170 kHz ± 15% ** |
| 2 | P/B VOICE, 32:1 | FM BASEBAND | ---- | ---- | ---- | 87.1 kHz |
| | P/B 1.6 kbps TLM, 32:1 | PCM/PM/FM | ---- | 1.024 MHz | Biphase ($\pm 90^{\circ}$) | 596.0 kHz |
| | P/B SCI, 32:1 | FM/FM | ---- | 95 kHz | ---- * | 75 kHz ± 15% ** |
| | P/B SCI, 32:1 | FM/FM | ---- | 125 kHz | ---- * | 110 kHz ± 15% ** |
| | P/B SCI, 32:1 | FM/FM | ---- | 165 kHz | ---- * | 170 kHz ± 15% ** |
| 3 | P/B LM 1.6 kbps TLM, 32:1 | FM BASEBAND | ---- | ---- | ---- | 146.0 kHz |
| 4 | TV | FM BASEBAND | ---- | ---- | ---- | 990.0 kHz |
| 5 | SCI | FM/FM | ---- | 95 kHz | ---- * | 75 kHz ± 15% ** |
| | SCI | FM/FM | ---- | 125 kHz | ---- * | 110 kHz ± 15% ** |
| | SCI | FM/FM | ---- | 165 kHz | ---- * | 170 kHz ± 15% ** |

TABLE E-3

CSM TO MSFN S-BAND FM COMMUNICATIONS SIGNAL COMBINATIONS (DOWNLINK)

(CONCLUDED)

| SIGNAL COMBINATION | INFORMATION | MODULATION TECHNIQUE | INFORMATION FREQUENCY | SUBCARRIER FREQUENCY | PEAK SUBCARRIER DEVIATION | (MEASURED) PEAK CARRIER DEVIATION |
|---|---|---|---|---|---|---|
| 6 | 51.2 kbps TLM | PCM/PM/FM | ---- | 1.024 MHz | Biphase ($\pm 90^\circ$) | 596.0 kHz |
| 7 | 1.6 kbps TLM | PCM/PM/FM | ---- | 1.024 MHz | Biphase ($\pm 90^\circ$) | 596.0 kHz |
| 8 | 51.2 kbps TLM | PCM/PM/FM | ---- | 1.024 MHz | Biphase ($\pm 90^\circ$) | 596.0 kHz |
| | P/B SCI, 1:1 | FM/FM | ---- | 95 MHz | ---- | 75 kHz ± 15% ** |
| | P/B SCI, 1:1 | FM/FM | ---- | 125 MHz | ---- | 110 kHz ± 15% ** |
| | P/B SCI, 1:1 | FM/FM | ---- | 165 kHz | ---- | 170 kHz ± 15% ** |
| 9 | 1.6 kbps TLM | PCM/PM/FM | ---- | 1.024 MHz | Biphase ($\pm 90^\circ$) | 596.0 kHz |
| | P/B SCI, 1:1 | FM/FM | ---- | 95 kHz | ---- | 75 kHz ± 15% ** |
| | P/B SCI, 1:1 | FM/FM | ---- | 125 kHz | ---- | 110 kHz ± 15% ** |
| | P/B SCI, 1:1 | FM/FM | ---- | 165 kHz | ---- | 170 kHz ± 15% ** |
| 10 | P/B 1.6 kbps LM TLM, 8:1 | FM BASEBAND | ---- | ---- | ---- | 146.0 kHz |
| 11 | P/B VOICE 1:1 | FM BASEBAND | ---- | ---- | ---- | 87.1 kHz |
| | P/B 51.2 kbps TLM, 1:1 | PCM/PM/FM | ---- | 1.024 MHz | Biphase ($\pm 90^\circ$) | 596.0 kHz |
| 12 | P/B VOICE, 32:1 | FM BASEBAND | ---- | ----- | ---- | 87.1 kHz |
| | P/B 1.6 kbps TLM, 32:1 | PCM/PM/FM | ---- | 1.024 MHz | Biphase ($\pm 90^\circ$) | 596.0 kHz |

* For this mission, there will be no scientific data and therefore the subcarrier will not be deviated.

** Specification.

TABLE E-4

LM TO MSFN S-BAND COMMUNICATIONS SIGNAL COMBINATIONS (DOWNLINK)

| SIGNAL COMBINATION | INFORMATION | MODULATION TECHNIQUE | INFORMATION FREQUENCY | SUBCARRIER FREQUENCY | (SPECIFIED) SUBCARRIER DEVIATION | (SPECIFIED) CARRIER DEVIATION |
|---|---|---|---|---|---|---|
| 1 | Voice | FM/PM | ---- | 1.25 MHz | 5.5 to 10.45 kHz | 0.9 RADIANS |
| | H.L. Biomed | FM/FM/PM | 14.5 kHz | ↕ | 2.9 to 3.8 kHz | ↕ |
| | EMU | FM/FM/PM | 10.5 kHz | ↕ | | ↕ |
| | | | 7.35 kHz | ↕ | | ↕ |
| | | | 5.40 kHz | ↕ | | ↕ |
| | | | 3.90 kHz | 1.25 MHz | | 0.9 |
| | 51.2 kbps TM | PCM/PM/PM | ---- | 1.024 MHz | Biphase ($\pm 90^{\circ}$) | 1.25 RADIANS ** |
| 2 | PRN | PM ON CARRIER | ---- | ---- | ---- | α* |
| | Voice | FM/PM | ---- | 1.25 MHz | 5.5 to 10.45 kHz | 0.9 RADIANS |
| | H.L. Biomed | FM/FM/PM | 14.5 kHz | ↕ | 2.9 to 3.8 kHz | ↕ |
| | EMU | FM/FM/PM | 10.5 kHz | ↕ | | ↕ |
| | | | 7.35 kHz | ↕ | | ↕ |
| | | | 5.40 kHz | ↕ | | ↕ |
| | | | 3.90 kHz | 1.25 MHz | | 0.9 |
| | 51.2 kbps TM | PCM/PM/PM | ---- | 1.024 MHz | Biphase ($\pm 90^{\circ}$) | 1.25 RADIANS ** |
| 3 | 1.6 kbps TM | PCM/PM/PM | ---- | 1.024 MHz | Biphase ($\pm 90^{\circ}$) | 1.25 RADIANS ** |

TABLE E-4

LM TO MSFN S-BAND COMMUNICATIONS SIGNAL COMBINATIONS (DOWNLINK)

(CONTINUED)

| SIGNAL COMBINATION | INFORMATION | MODULATION TECHNIQUE | INFORMATION FREQUENCY | SUBCARRIER FREQUENCY | (SPECIFIED) SUBCARRIER DEVIATION | (SPECIFIED) CARRIER DEVIATION |
|---|---|---|---|---|---|---|
| 4 | Backup Voice | PM ON CARRIER | ---- | ---- | ---- | 0.8 RADIANS |
| | 1.6 kbps TM | PCM/PM/PM | ---- | 1.024 MHz | Biphase (+90°) | 1.25 RADIANS ** |
| 5 | Backup Voice | PM ON CARRIER | ---- | ---- | ---- | 0.8 RADIANS |
| 6 | Key | AM/PM | ---- | 512 kHz | 100% AM | 1.4 RADIANS |
| 7 | Voice | FM/PM | ---- | 1.25 MHz ↕ | 5.5 to 10.45 kHz | 1.3 ↕ RADIANS |
| | H.L. Biomed | FM/FM/PM | 14.5 kHz | | 2.9 to 3.8 kHz | |
| | EMU | FM/FM/PM | 10.5 kHz | | | |
| | | | 7.35 kHz | | | |
| | | | 5.40 kHz | | | |
| | | | 3.90 kHz | 1.25 MHz | | 1.3 |
| | 1.6 kbps TM | PCM/PM/PM | ---- | 1.024 MHz | Biphase (±90°) | 0.74 RADIANS ** |

TABLE E-4

LM TO MSFN S-BAND COMMUNICATIONS SIGNAL COMBINATIONS (DOWNLINK)

(CONTINUED)

| SIGNAL COMBINATIONS | INFORMATION | MODULATION TECHNIQUE | INFORMATION FREQUENCY | SUBCARRIER FREQUENCY | (SPECIFIED) SUBCARRIER DEVIATION | (SPECIFIED) CARRIER DEVIATION |
|---|---|---|---|---|---|---|
| 8 | Backup Voice | PM ON CARRIER | ---- | 300 to 3000 Hz | ---- | 0.73 RADIANS |
| | H.L. Biomed | FM/PM ON CARRIER | | 14.5 kHz | 750 kHz | 0.20 RADIANS |
| | EMU | FM/PM ON CARRIER | | 10.50 kHz | | 0.36 RADIANS |
| | | | | 7.35 kHz | | 0.31 RADIANS |
| | | | | 5.40 kHz | | 0.18 RADIANS |
| | | | | 3.90 kHz | | 0.16 RADIANS |
| | 1.6 or 51.2 kbps TM | PCM/PM/PM | ---- | 1.024 MHz | Biphase (±90°) | 1.30 RADIANS |
| 9 | Voice | FM/FM | | 1.25 MHz | 5.5 to 10.45kHz | 200 kHz ** |
| | H.L. Biomed | FM/FM/FM | 14.5 kHz | ↕ | 2.9 to 3.8kHz | |
| | EMU | FM/FM/FM | 10.50 kHz | ↕ | | |
| | | | 7.35 kHz | ↕ | | |
| | | | 5.40 kHz | ↕ | | |
| | | | 3.90 kHz | 1.25 MHz | | |
| | 1.6 or 51.2 kbps TM | PCM/PM/FM | ---- | 1.024 MHz | Biphase (±90°) | 358 kHz ** |

TABLE E-4

LM TO MSFN S-BAND COMMUNICATIONS SIGNAL COMBINATIONS (DOWNLINK)

(CONTINUED)

| SIGNAL COMBINATIONS | INFORMATION | MODULATION TECHNIQUE | INFORMATION FREQUENCY | SUBCARRIER FREQUENCY | (SPECIFIED) SUBCARRIER DEVIATION | (SPECIFIED) CARRIER DEVIATION |
|---|---|---|---|---|---|---|
| 10. | Voice | FM/FM | ---- | 1.25 MHz | 5.5 to 10.45 kHz | 200 kHz ** |
| | H.L. Biomed | FM/FM/FM | 14.5 kHz | | 2.9 to 3.80 kHz | |
| | EMU | FM/FM/FM | 10.50 kHz | | | |
| | | | 7.35 kHz | | | |
| | | | 5.40 kHz | | | |
| | | | 3.90 kHz | 1.25 MHz | | |
| | 1.6 or 51.2 kbps TM | PCM/PM/FM | | 1.024 MHz | Biphase ($\pm 90^{\circ}$) | 358 kHz ** |
| | TV | FM | ---- | ---- | ---- | 1100 kHz ** |
| 11. | PRN | PM ON CARRIER | ---- | ---- | ---- | $\alpha$ * |

* Down-Link PRN ranging code modulation index ( $\alpha$ ) depends on up-link signal combination and received signal power.

** Measured Data.

## APPENDIX F

## RECOMMENDATIONS FOR COMMUNICATIONS PERFORMANCE IMPROVEMENTS

A listing of suggested changes for the communications system for Apollo 12 and subsequent Apollo missions follows.

1. It is recommended that the Merritt Island unified S-band station configure the frequency modulation channel of the phase modulation receiver for remoting command and service module telemetry data during launch through 00:05:00 using the main antenna.

   Purpose: To eliminate or reduce data losses during Saturn IC/Saturn II staging and interstage jettison.

2. It is recommended that when television coverage is scheduled through a unified S-band station that the station perform a systems checkout within two hours of the actual support.

   Purpose: To prevent loss of television recordings during single station coverage of television transmissions.

3. It is recommended that unified S-band stations be advised of the importance of system calibration and recording monitoring.

   Purpose: To insure all recording devices are calibrated in accordance with the Network Operations Directive and that recording devices are operating properly.

4. It is recommended that compatibility of the biomedical harness and the television equipment within the spacecraft be assessed.

   Purpose: To determine if electrocardiogram data are affected by television equipment interference in any spacecraft operation.

5. It is recommended that lunar module backup downvoice tests be accomplished with 85-foot antenna stations in a mission configuration.

Purpose: To determine if lunar module backup downvoice is degraded by station equipment. (Tests are being accomplished subsequent to this recommendation.)

6. It is recommended that Apollo 12 and subsequent Apollo missions be investigated for lunar module blockage of the lunar module steerable antenna during the ascent phase.

Purpose: To assure continuous communications with the ascent stage of the lunar module during lunar liftoff. (Apollo 12 investigation is in progress.)

7. It is recommended that S-band phase modulation receiver carrier tracking loop bandwidth be increased from 50 Hz to 700 Hz during lunar module ascent.

Purpose: To prevent loss of downlink carrier lock during lunar module ascent.

## APPENDIX G

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