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Telecommunications and Data Acquisition Systems Support for the Viking 1975 Mission to Mars

The Viking Lander Monitor Mission May 1980 to March 1983

D. J. Mudgway

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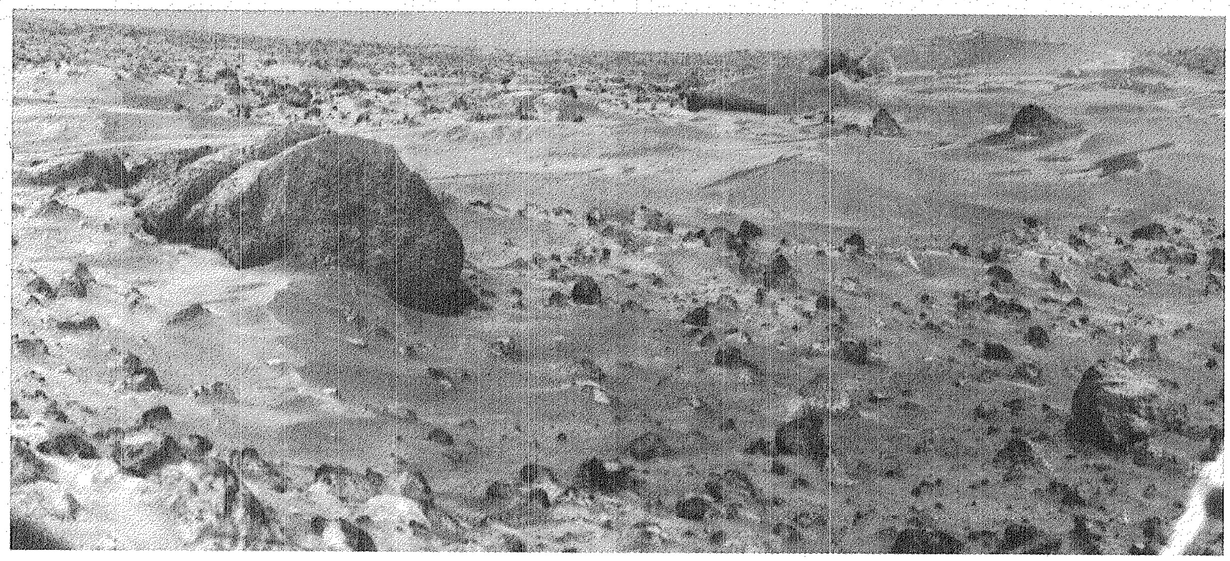

A recent panorama taken by the cameras of Viking Lander 1 on the surface of Mars. The picture is a mosaic of six images taken on separate occasions over the period June through August 1982.

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The research described in this publication was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration

PREFACE

In late 1976 there were two Viking Landers and two Viking Orbiters in full operation on the surface and in orbit around the planet Mars. Of these four spacecraft, only the Viking Lander 1 was active into October of 1982. As the Thomas A. Mutch Memorial Station, this spacecraft represented the United States' presence on Mars. As the Viking Lander Monitor Mission (VLMM), it gathered and regularly transmitted to Earth imaging and meteorology data relative to its local Martian environment.

This report continues the description of the tracking and data acquisition support for the Viking Mission to Mars published in five previous volumes, which are listed in the references.

The first volume describes organization, planning, implementation, and test activity from inception of the Project in 1969 to launch operations in 1975. Cruise activity from the launch of two spacecraft to the landing of Viking 1 in July 1976 is described in Volume II. The third volume covers the landing of the second Viking Lander and Mars planetary operations for two Orbiters and two Landers through the end of the prime mission in November 1976. Viking Extended Mission support activity from November 1976 through May 1978 is described in Volume IV. From June 1978 through April 1980, Viking Mission Operations were conducted under various names related to the condition of the remaining spacecraft and the funding available to support mission operations. This period is described in JPL Publication 82-18.

The Deep Space Network continued to support Viking from May 1980 to the present (March 1983). This phase of the continuing life of the Viking Project was termed the Viking Lander Monitor Mission, and was expected to continue through the year 1994. However, the spacecraft failed in November 1982, and in March 1983, the mission was considered to have ended.

In this document, the tracking and data acquisition support for the Viking Lander Monitor Mission from May 1980 to March 1983 is described together with an overview of the science results. The events leading to the failure and the Network's efforts to recover the Lander signal are also included.

N. A. Renzetti

ABSTRACT

From May 1980 until the Viking Lander Spacecraft failed to transmit a downlink to Earth in November 1982, the Deep Space Network provided tracking and data acquisition support to the Viking Lander Monitor Mission (VLMM).

This report gives the background for the VLMM and discusses the technical and operational aspects of the tracking and data acquisition support that the Network was called upon to provide. An overview of the science results obtained from the imaging, meteorological, and radio science data is also given.

The report concludes with a description of the intensive efforts that were made to recover the mission from November 1982 until the effort was discontinued in March 1983.

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I. INTRODUCTION

In late 1976 there were two Viking Landers and two Viking Orbiters in full operation on and around the planet Mars. Of these four spacecraft, Viking Lander 1 had the longest life; it was still active in October 1982. As the Thomas A. Mutch Memorial Station, Viking Lander 1 represented the United States' presence on Mars. As the Viking Lander Monitor Mission (VLMM), is continued to gather and regularly transmit to Earth imaging and meteorology data relative to its local Martian environment. However, late in 1982, the lander failed to respond to uplink commands for a downlink transmission. Repeated attempts over a period of four months failed to recover the lander signal. Finally, in March 1983, the Viking Lander Monitor Mission was terminated.

Previous tracking and data systems support for the Viking Mission to Mars are described in Refs. 1-1 through 1-5.

II. BACKGROUND

In July 1980, a press release (Appendix A) announced the imminent conclusion of the Viking Orbiter 1 (VO-1) Mission and the beginning of the VLMM. This announcement marked the end of the major Viking operations activity, and the beginning of a new era of low-level support of an automatic lander mission on an "opportunity" basis. The request for telecommunications and data acquisition support from the Deep Space Network (DSN) for the VLMM through 1990 is reproduced in Appendix B.

A comprehensive and informative account of the last year of the Viking Mission is given in Reference 2-1 from the point of view of one of the scientists most closely involved with the project from its inception in 1969. Table 2-1 is taken from Reference 2-1 to show the principal mission events of the final months of Viking Orbiter 1.

On August 7, 1980, at 2015 GMT, the Deep Space Station (DSS) 61 in Spain sent a command to VO-1 to turn off its S- and X-band transmitters. To satisfy international agreements regarding uncontrolled radio transmissions from spacecraft, the S- and X-band transmitters were turned off before ground control was lost. Subsequent RF searches at the VO-1 frequencies verified that both transmitters remained off. These searches were repeated several times over subsequent weeks, but no carriers were detected.

Thus ended the Viking Orbiter 1 Mission to Mars after five years of continuous operational support by the Network. Throughout this period, the Network provided continuous mission support and was effective in developing operational techniques to overcome problems caused by highly reduced staffing levels, obsolete hardware and software, and the steady attrition of experienced Viking operations staff.

The Viking Project Scientist compiled the statistics of general interest given in Table 2-2 regarding the two Viking Orbiters and the Deep Space Network support.

Viking Lander 1 (Figure 2-1) is located in Chryse Planetia at 22°N, 48° and was in an automatic operational mode since March 1979, transmitting stored imaging and meteorology data on activation from one of the deep space stations. This activity became identified as the Viking Lander Monitor Mission (VLMM) on November 6, 1979, and continued to provide regular transmissions of stored engineering, imaging, and meteorological data through October 1982.

The Viking Lander 1 (VL-1) spacecraft radio system had one active receiver (of two) and two active transmitters. A stored program in the lander turned a transmitter on at a specified time corresponding to each Earth view period, and a long-term stored program maintained the antenna's Earth-pointing direction. The Earth-pointing antenna program was written to be valid through 1994. In the period between Network communication passes, imaging and meteorological data were accumulated on the tape recorders for readout during each Network pass.

Table 2-1. Viking Orbiter 1 Survey Mission, 1980

Date	Event
April 23	Orbit trim to begin survey mission
May 17	Last Sun occultation
June 15	Last infrared observation of the planet
July 12	Last Earth occultation
July 14	Final imaging sequence of survey
July 15	First engine burn in propulsion system test
July 17	Second engine burn in propulsion system test
July 18	Third engine burn in propulsion system test fails to exhaust propellant as intended
July 26	Two imaging sequences: global survey from apoapsis, and ground-track strip near periapsis
July 28	Ground-track strip near periapsis
July 30	Final imaging sequence: ground-track near periapsis
July 31	Fourth engine burn in propulsion system test exhausts propellant, Rev. 1485
August 5	Playback of last orbiter picture, Rev. 1488
August 7	Orbiter power turned off by ground command, Rev. 1489

Table 2-2. General Viking Orbiter Statistics

Parameter	VO-1	VO-2
Number of days from launch to end of mission	1813.98	1049.52
Number of orbits of Mars	1488.0	706.1
Number of pictures recorded in orbit	36,622	16,041
Number of data bits played back from the two tape recorders (including lander relay data)	357.7×10^9	161.3×10^9
Tape travel across recorder heads, km	2955	1397
Number of commands sent by the Network	269,500	
Number of tracking passes supported by the Network	7,380	
Amount of tracking time provided by the Network, h	56,500	

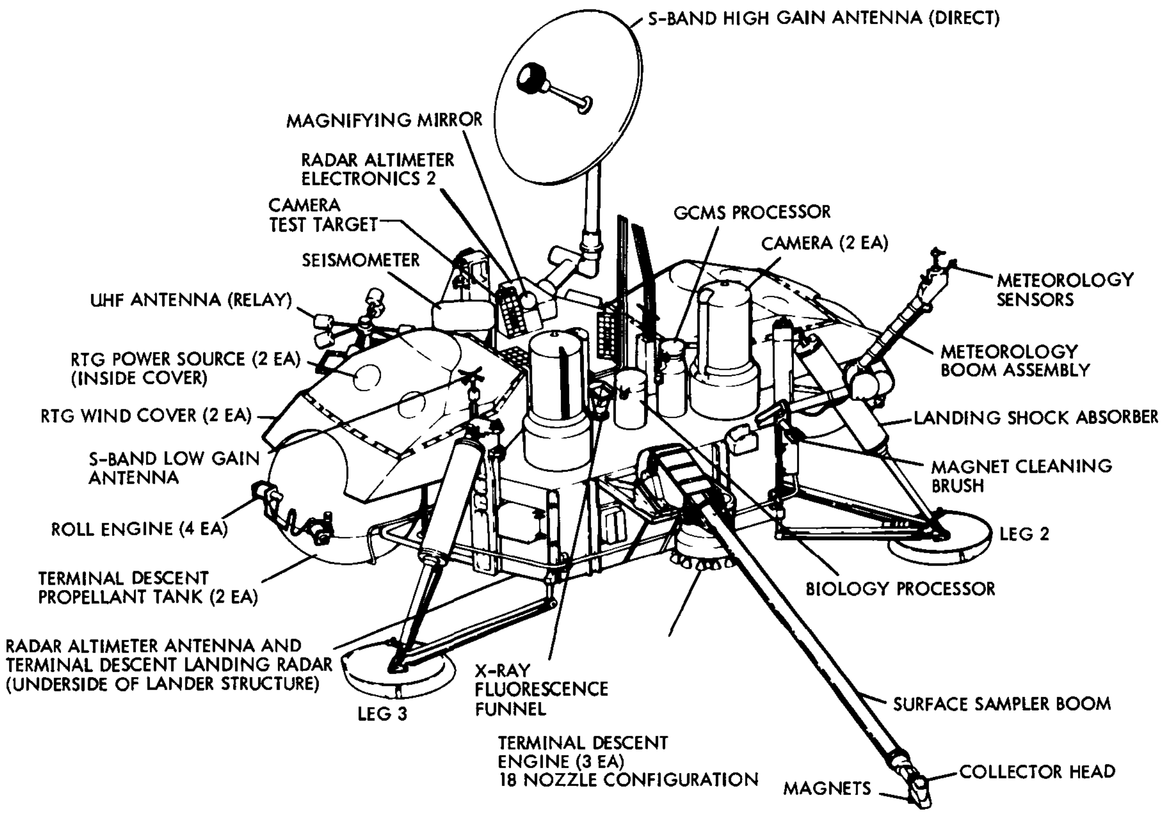


Figure 2-1. Viking Lander

A functional block diagram of the VL-1 radio system is shown in Fig. 2-2. Receiver 1 on that diagram failed prior to the end of VLMM, although its associated command detector and modulator-exciter continued to work satisfactorily, as did all other elements of the radio system. Loss of receiver 1 forced access to either command decoder through receiver 2, which is permanently connected to the high-gain antenna. Thus, both uplink and downlink communication with the spacecraft was dependent upon the high-gain antenna automatic pointing program.

Spacecraft telecommunication characteristics are given in Table 2-3.

By January of 1982, three of the four 8-A·h, nickel-cadmium batteries onboard Viking Lander 1 showed signs of significant loss of energy-storage capacity. An intensive program of deep-discharge battery conditioning was begun in January 1982 in an attempt to return the batteries to levels of capacity approaching early mission levels.

The reconditioning was relatively successful, but the ability of the batteries to retain their energy-storage capacity was poor. In one case, 80% of the gained capacity was again lost only four months after the last reconditioning cycle.

In an attempt to extend the life of the batteries as long as possible, the battery performance and the method of reconditioning the batteries was reviewed in detail by several experts in this field. This review, held in August 1982, led to the adoption of a new battery conditioning and operating strategy. Reduction in the frequency of battery charging, deeper discharging during reconditioning, and shorter duration of recharging were considered key items in prolonging the Viking Lander battery life. These strategies were incorporated in the Viking Lander sequences, and the effects on battery performance were carefully observed.

Following one of the uplink sequences, however, the network was unable to detect the presence of a downlink signal. Subsequent efforts to command the downlink "on," recharge the batteries, and point the lander antenna were unsuccessful in producing a downlink transmission. After four months of unsuccessful recovery efforts, the VLMM was terminated in March 1983.

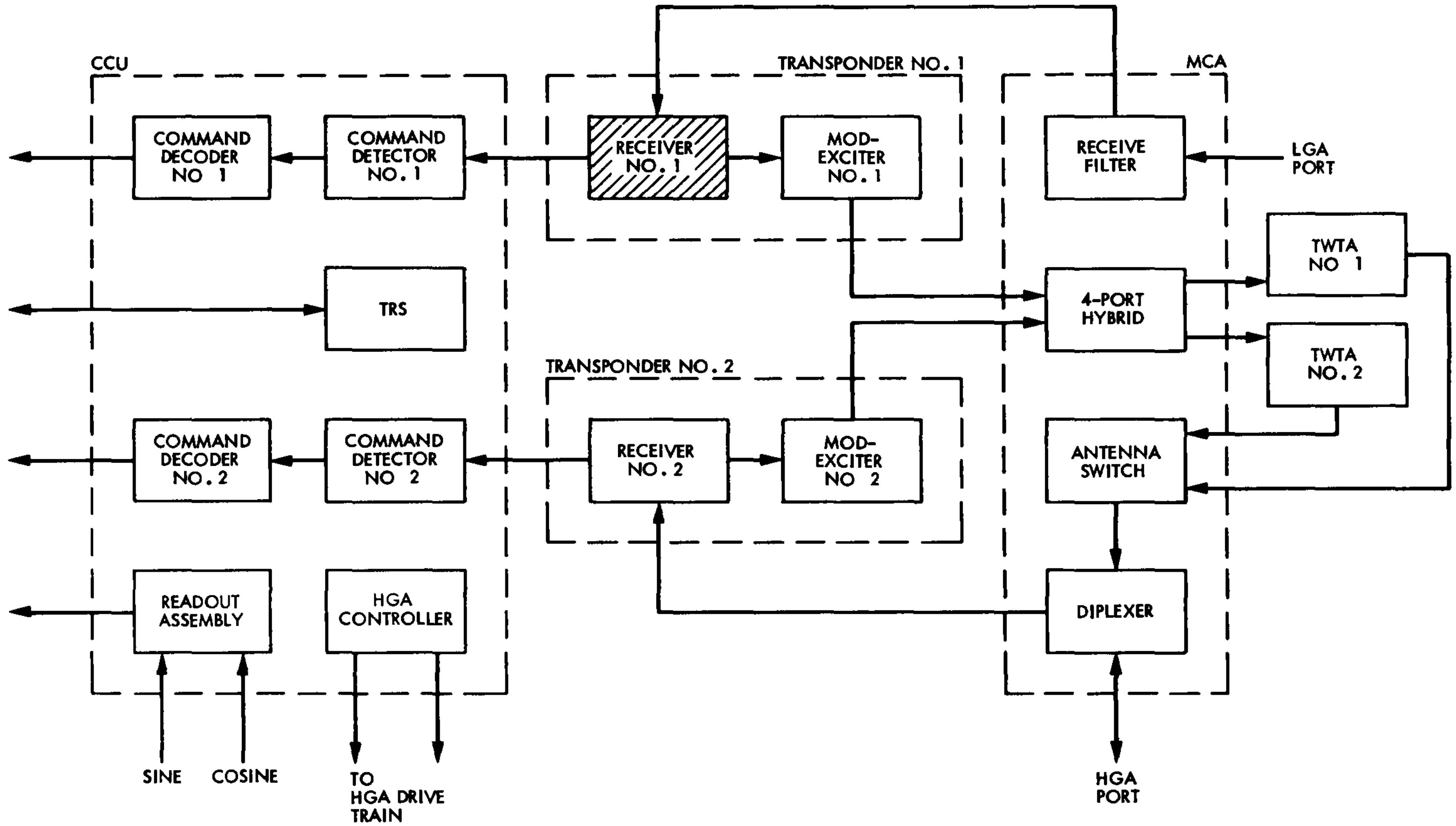


Figure 2-2. Viking Lander 1 Radio System, Functional Block Diagram

Table 2-3. Viking Lander 1 Spacecraft Telecommunication Parameters

Parameter	Value
Transmit frequency, MHz	2294.629630 (channel 13a)
Transmitter power, dBm	42.6
High-gain antenna, dB	22.3, transmit; 21.3, receive
Low-gain antenna, dB	4.5, receive only
Receiver noise figure, dB	7.8
System noise temperature, K	1549, high gain; 1150, low gain
Receive frequency, MHz	2112.971451 (channel 13b)
Science bit rate, bits/s	1000, 500, and 250
Coding	Biorthogonal block coding (32:6)
Engineering bit rate, bits/s	8-1/3, uncoded
Subcarrier frequency, kHz	12, engineering; 72, science
Command bit rate, bits/s	4

III. DSN SUPPORT

The history of tracking and data acquisition support for the Viking Project from its inception through mid-1980 is given in Refs. 1-1 through 1-5.

A. OPERATIONS

A comprehensive report on all the direct DSN to VL-1 downlink opportunities from the beginning of the Viking Lander Monitor Mission in August 1980 to October 1982 is given in Appendixes C and D. Over this 2-yr period, the success rate for the entire Network was 90% for telemetry (TLM) and 80% for radio metric (Tracking System (TRK)) data. Success rate is the ratio of good passes to total passes scheduled for the Network. Passes are judged "good" or "no good" on the basis of the amount and quality of the data return. A comparison of the data acquisition success rate for 1980, 1981, and 1982 is given in Table 3-1. Success rates for all stations over the 3-yr period are in the region of 80% to 90%. A summary of the direct-link requests is given in Appendix C, with the details of each pass given in Appendix D. These data afford a good insight into the overall performance of the Network in supporting these rather random Viking Lander passes over an entire 3-yr period.

The VLMM did not enjoy a high priority in the assignments of tracking time. Frequently an available view period was lost because antenna time was not available, or a pass scheduled for Viking was preempted for another flight project. Examples of this are given in Appendix D.

The VLMM created some operational difficulties for the Network operations teams. During the Viking prime mission, command sequences developed by the flight teams were loaded into IBM 360-75 computers located in the JPL Mission Control Center. From there, all interactions with the Deep Space Station Command System — including verification, transmission, and confirmation — were automatic. With the decommissioning of these three computers at the end of the prime mission, the Network accepted responsibility for sending all VL-1 commands manually, although the small VLMM operations staff remaining with the project actually designed the desired command sequences. The command sequence desired for the pass was transmitted by the Network Operations Project Engineer (NOPE) to the station by teletype (TWX). An example of a Viking Lander sequence of events is given in Appendix E. At the DSS, the TWX command sequence was loaded manually into the command buffer, recalled by the NOPE, and verified for accuracy.

A typical lander pass is illustrated in Fig. 3-1. During the first 60 min of the pretrack preparation (PTP), the station counted down the telemetry, command, monitor, and radio metric data systems. During the last 30 min of the PTP, the station turned over the command system to Network Analysis Team (NAT) command for a command-system validation. After NAT command validated the command system, the DSS entered the commands required for the pass; these commands were received by TWX message from the NOPE into the manual buffer. NAT command then recalled the manual buffer and validated the command bit pattern. Following verification by NAT command, the DSS then transferred the contents of the manual buffer to Module 1 of the DSS Command System.

Table 3-1. Comparative Success Rates for Viking Lander Data Acquisition

		Passes					
Year	Station	Good		Bad		Success Rate, %	
		TLM	TRK	TLM	TRK	TLM	TRK
1980	Goldstone	2	2	1	1	67	67
	Australia	3	2	0	1	100	67
	Spain	3	3	0	0	100	100
1981	Goldstone	4	3	1	2	80	60
	Australia	9	9	2	2	82	82
	Spain	11	11	2	2	85	85
1982	Goldstone	8	7	1	2	89	78
	Australia	13	10	0	3	100	77
	Spain	12	11	0	1	100	92
1980	All stations	8	7	1	2	89	78
1981	All stations	24	23	5	6	83	79
1982	All stations	33	28	1	6	97	82

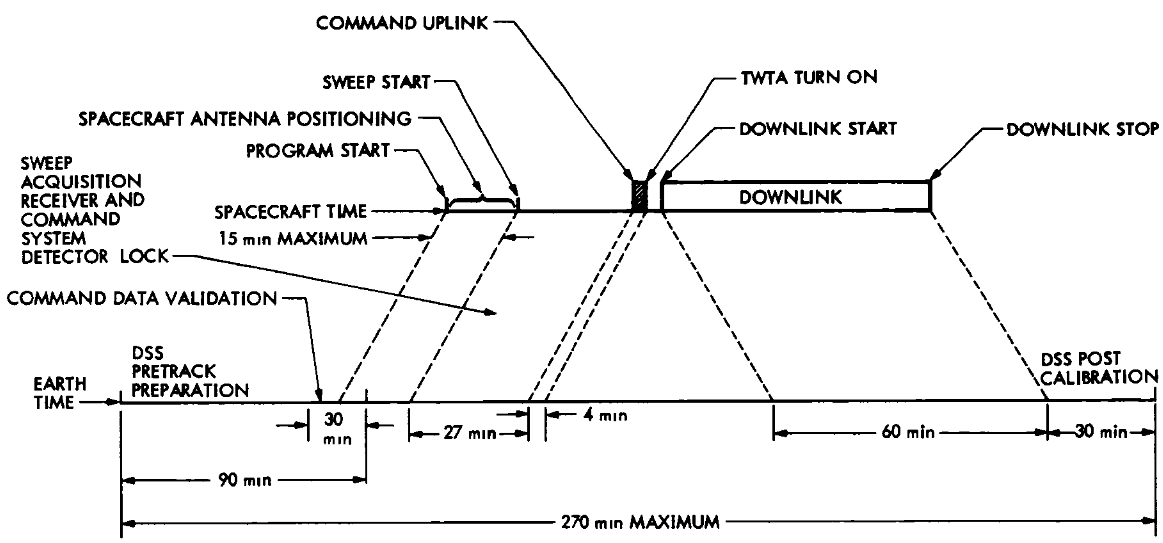


Figure 3-1. Typical Lander Pass

Following the start of track, approximately 15 min were required for the uplink acquisition sweep; there was a pad of 12 min in which to turn on command modulation before the command window opened. The command window was usually of 15 min duration.

The actual downlink lasted 60 min when the spacecraft was configured on TWTA1. Allowing a 30-minute postcalibration on the ranging system and the maximum one-way light time expected during the mission, the maximum VLMM track was 270 min.

Because of the temperature-sensitive nature of the oscillators onboard the Viking Lander and the large temperature excursion on the planet's surface, a non-conventional acquisition sweep procedure was devised to insure reliable two-way tracking. Figure 3-2 illustrates this procedure.

Because the lander transmitter was programmed "off" after each successful direct-link pass, the lander uplink was always acquired in the blind. Unlike normal acquisition sweeps, the initial transmit XA was always above that shown on the predicts, and the first ramp was always in the negative direction. Under normal conditions, the spacecraft receiver was captured during this portion of the sweep. The next portion of the sweep was at a slower rate and in the positive direction over the same range. The final downward ramp took the spacecraft receiver to a nominal center frequency, which was designated the track synthesizer frequency (TSF) for the pass.

This process was time-consuming and cumbersome, and very susceptible to human error, particularly if a long command sequence was called for. It is a tribute to the Network Operations Team that mistakes seldom occurred; this fine record has been recognized by the Project Manager in a memo of commendation. In contrast to commanding, the telemetry operational procedures became much simpler. There was no real-time processing of telemetry engineering or science data at JPL. Instead, a real-time record of the telemetry stream was made by the data records generator in the Network Operations Control Center (NOCC). From this, and using recalls if necessary, an Intermediate Data Record (IDR) was made and shipped immediately to the University of Washington where the telemetry processing was carried out. The VLMM spacecraft engineer accessed this source for spacecraft engineering data and the imaging and meteorological investigators also obtained their data from this source.

Signal levels on the up and down telecommuncation links between the DSN and VL-1 were quite high and generally allowed the DSN the option of supporting the VL-1 passes on a 64-m or 34-m antenna. A plot of downlink signal level and Earth-Mars range through 1988 is shown in Fig. 3-3. Typical S-band downlink telecommunications parameters in October 1982 were:

Downlink received carrier power, dBm	-148.2
DSS receiver margin, dB	26.9
Telemetry SNR at 8-1/3 bits/s, dB	20.9
Telemetry SNR at 1000 bits/s, dB	6.1
Uplink received carrier power, dBm	-119.1
VL-1 command receiver margin, dB	26.2

For elevations other than 90 deg, the above data must be reduced accordingly; the maximum correction at 10-deg elevation was 2.00 dB.

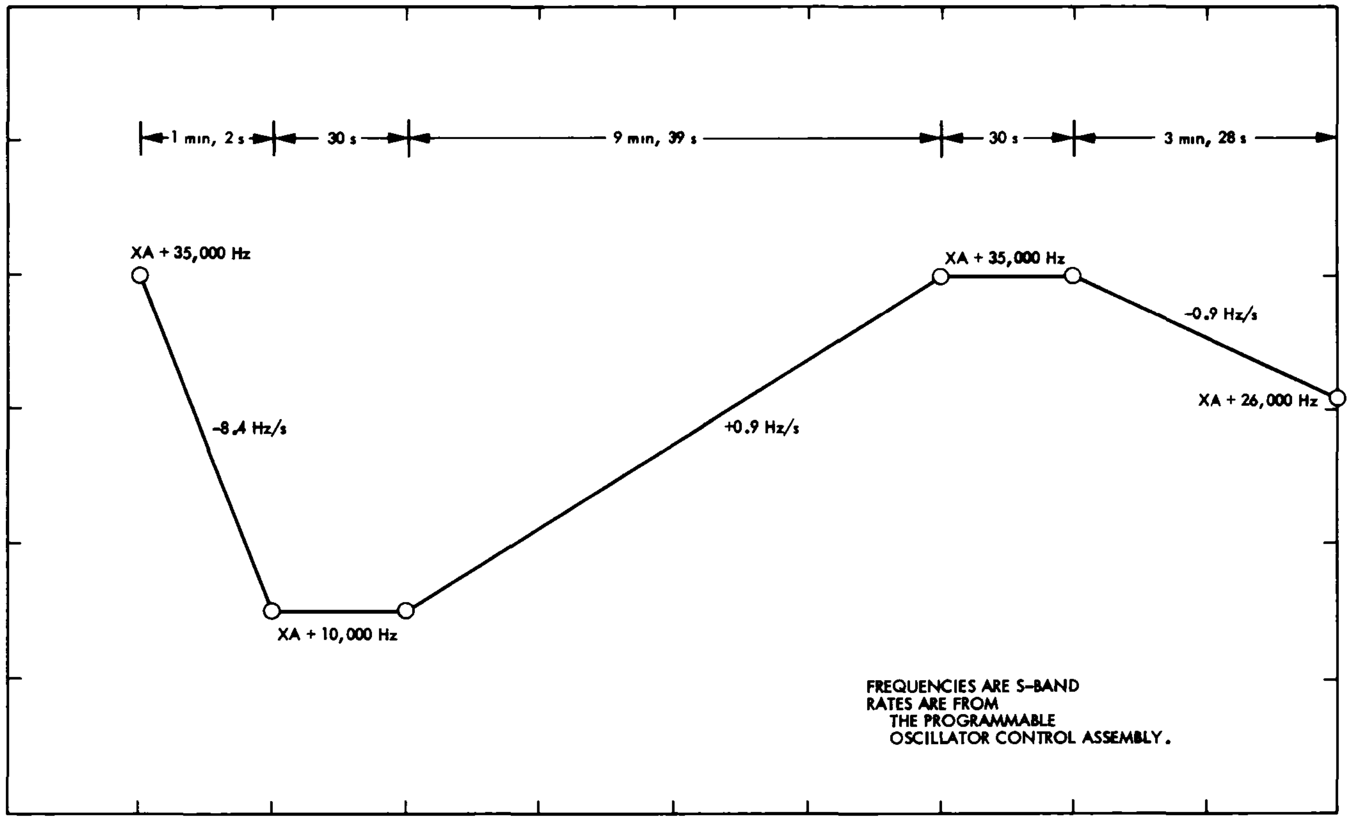


Figure 3-2. Viking Lander Uplink Acquisition Sequence

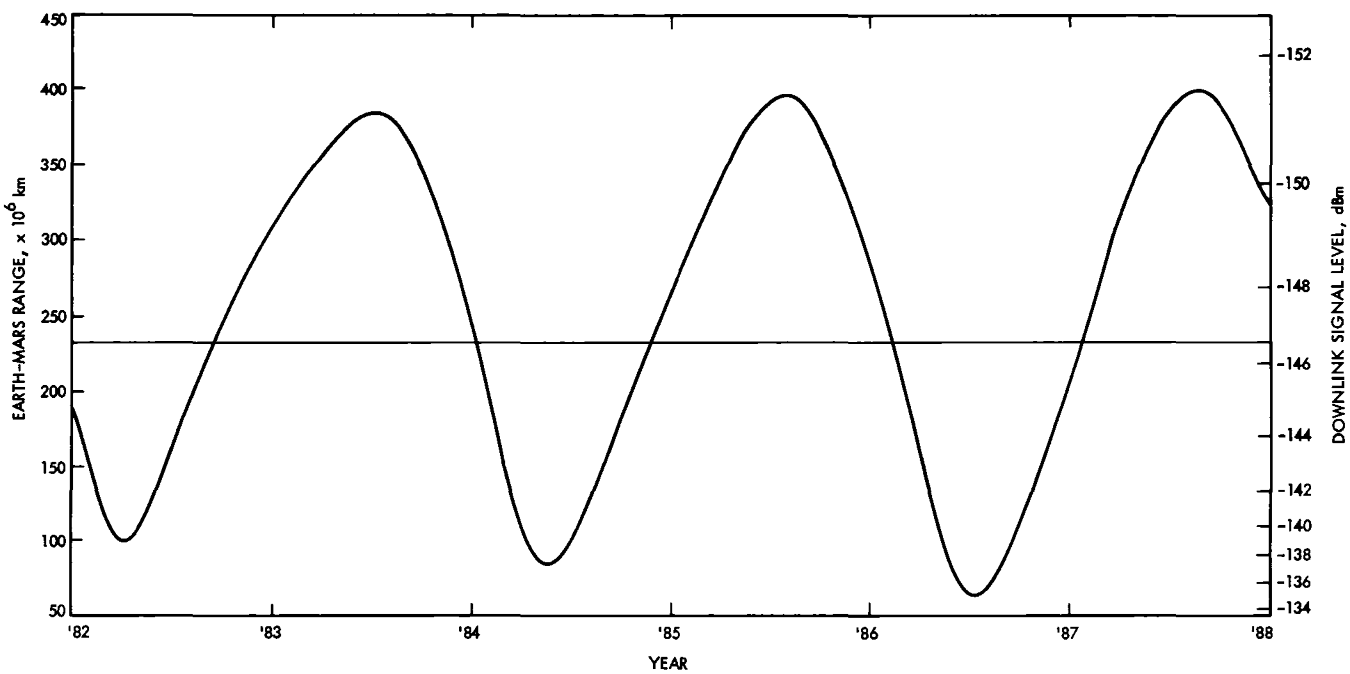


Figure 3-3. Predicted Downlink Signal Level From Viking Lander 1

Over the years of the primary mission, the operational complexities of the Network ranging system frequently resulted in the loss or degradation of the ranging data. This situation improved in later years, and the Network provided excellent radio metric data return and high-quality ranging data, as seen from the ranging performance statistics given in Appendixes C and D. The substantial contribution to the radio-science investigations resulting from the improvement in ranging data quality is reflected in the radio-science discussion in Subsection II-A.

B. CONFIGURATIONS

The basic Network capabilities required to support the VLMM follow:

(1) Telemetry: process two telemetry subcarriers simultaneously at data rates of 8.333 bits/s uncoded and up to 1000 bits/s block coded.

(2) Command: command a single spacecraft at a bit rate of 4 bits/s.

(3) Tracking: generate S-band doppler ranging and differenced range versus integrated doppler (DRVID) radio metric data.

(4) Monitor: output the standard Network status and configuration blocks.

The ways in which these requirements were translated into a typical station configuration (DSS 14 at Goldstone) are shown in Figs. 3-4 through 3-7.

The standard 64-m DSS configuration for telemetry is shown in Fig. 3-4. It is obvious that the Block Decoder Assemblies (BDA) required for the higher 16-kbits/s block-coded data rates of the Viking Orbiters were deleted. In other respects, a standard station configuration was used.

The tracking configuration required to generate radio metric data is shown in Fig. 3-5.

Provision for manual commanding through the terminet connected to both command processor assemblies (CPA) is apparent in the command configuration of Fig. 3-6.

Monitor and operations control provided by the configuration in Fig. 3-7 afforded the high degree of interactive control between the NOCC and the DSS required for the short passes, complex acquisition procedures, and manual commanding procedures that resulted from the reduced scope of Viking operations in this period.

C. REAL-TIME LINK TO THE UNIVERSITY OF WASHINGTON

Early in 1982, Dr. James Tillman of the University of Washington proposed a real-time data link between JPL and the University of Washington (UW) to transfer the VLMM telemetry data directly to UW for processing and display. It was envisaged that these and other supplementary data would eventually be transmitted from UW to the Smithsonian Air and Space Museum in Washington, D.C., for display to the general public.

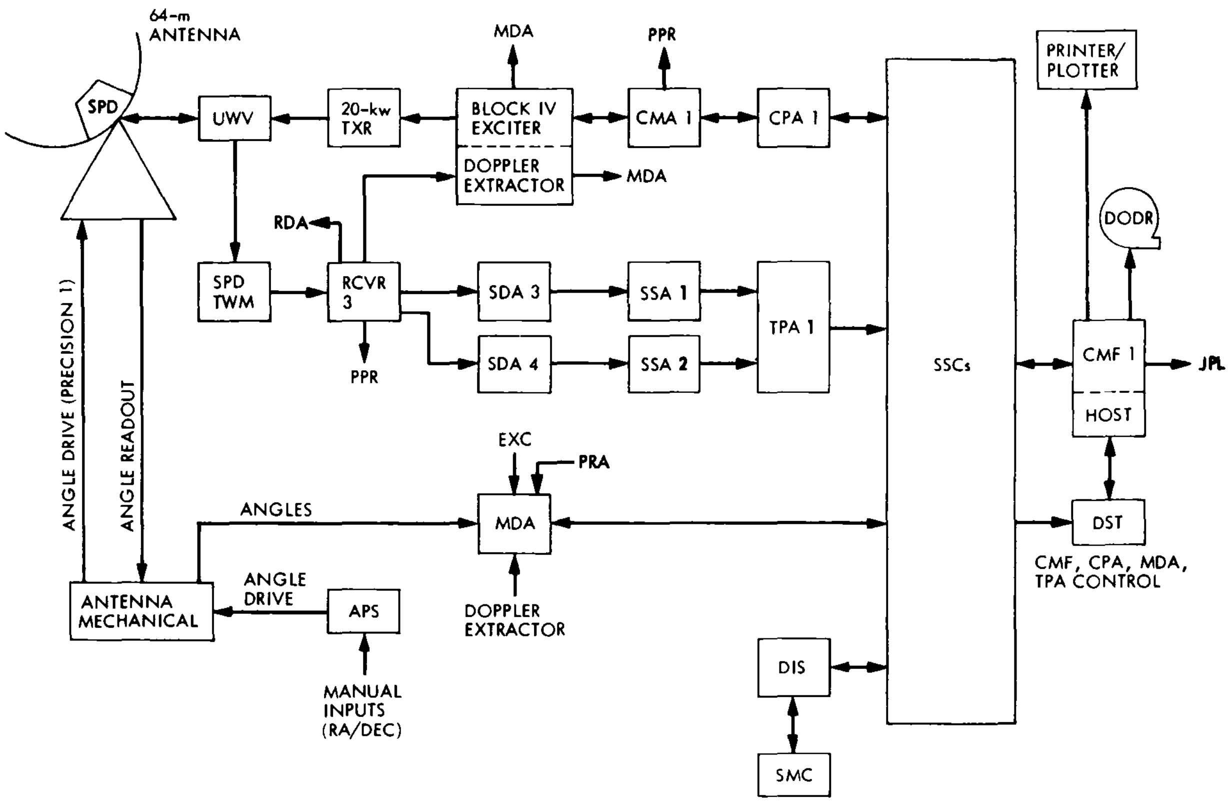


Figure 3-4. Viking Lander Telemetry Configuration — DSS 14

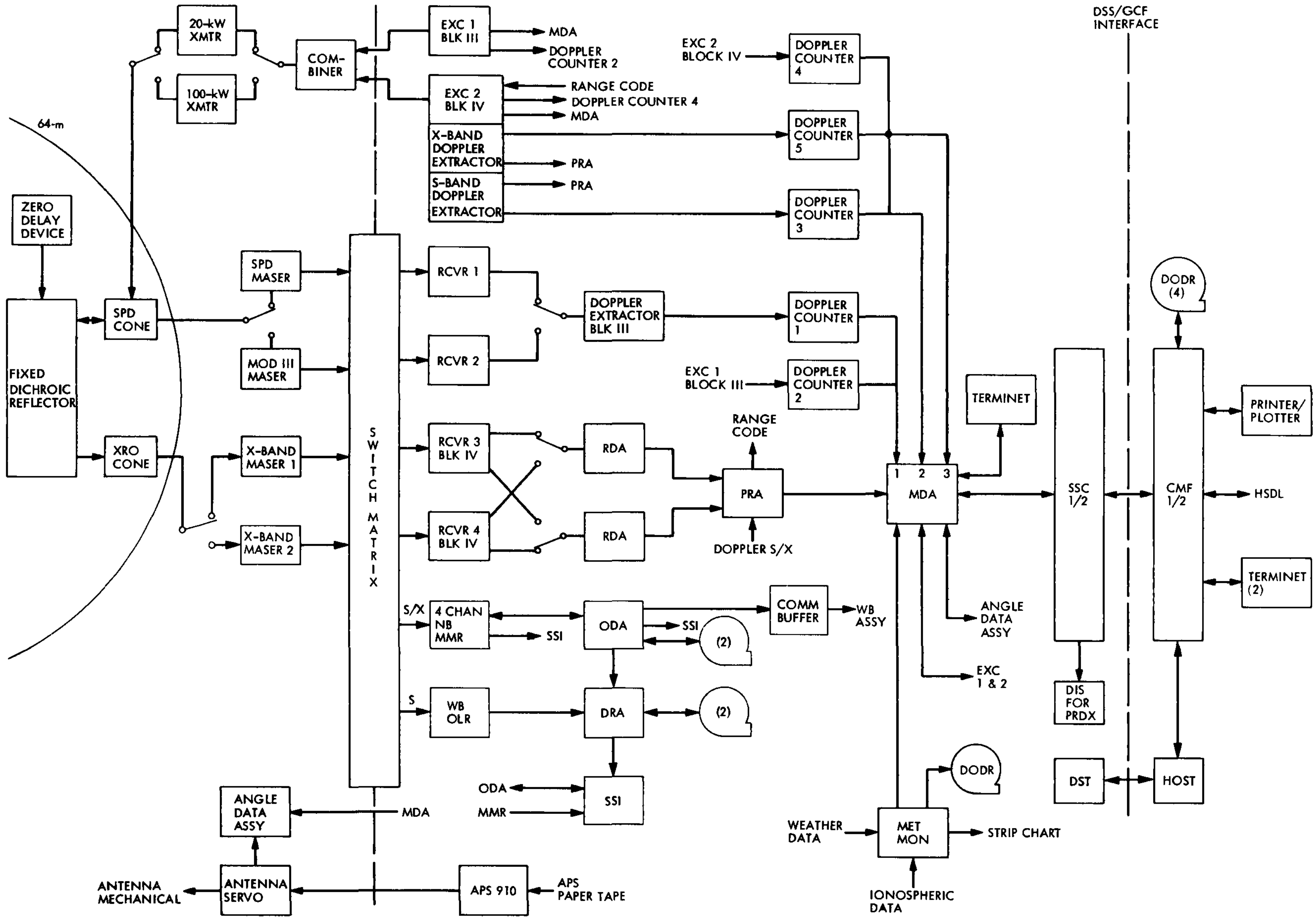
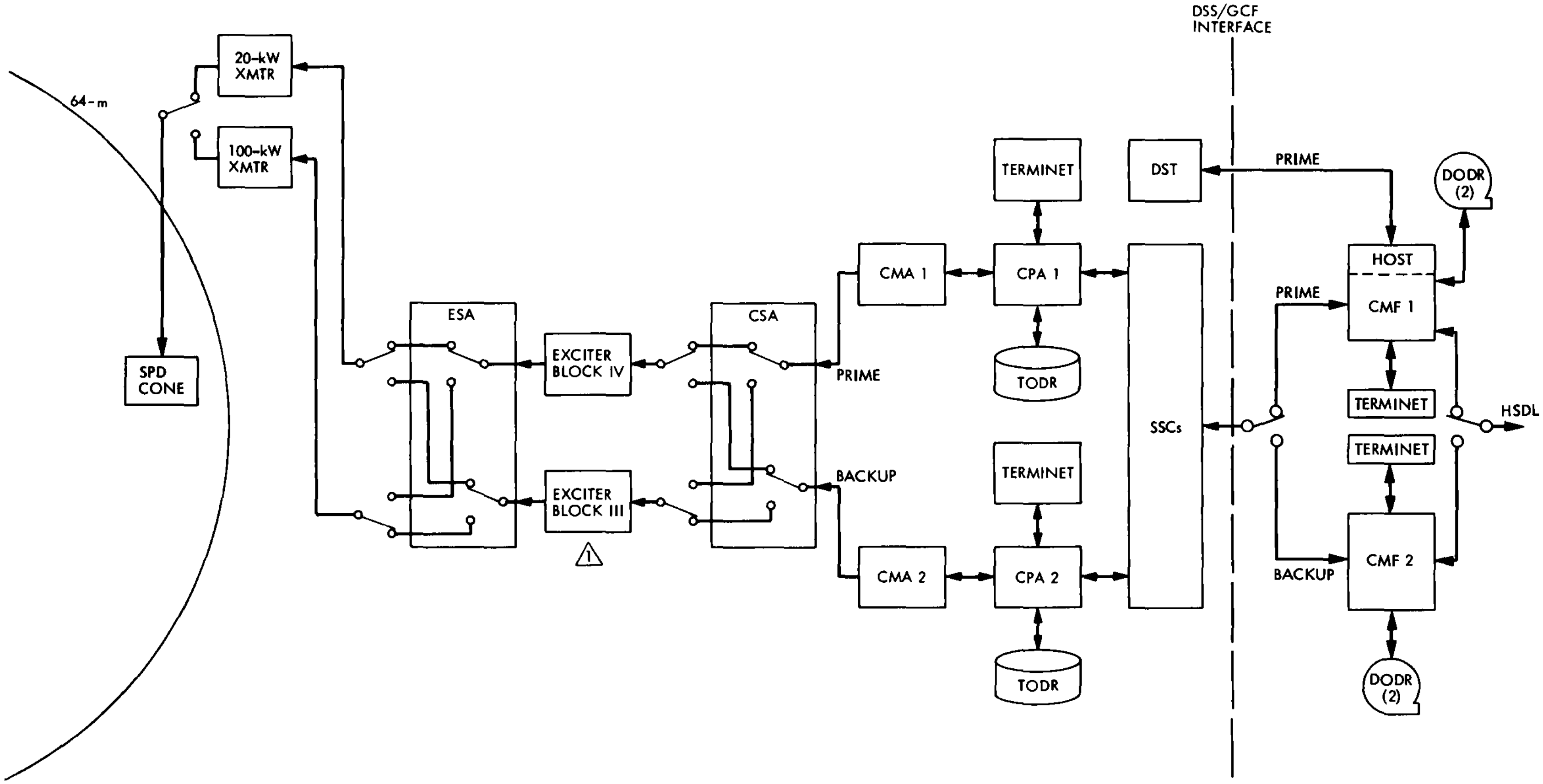


Figure 3-5. Viking Lander Tracking Configuration — DSS 14



⚠1 BLOCK III EXCITER USED DURING BACKUP MODES ONLY

Figure 3-6. Viking Lander Command Configuration — DSS 14

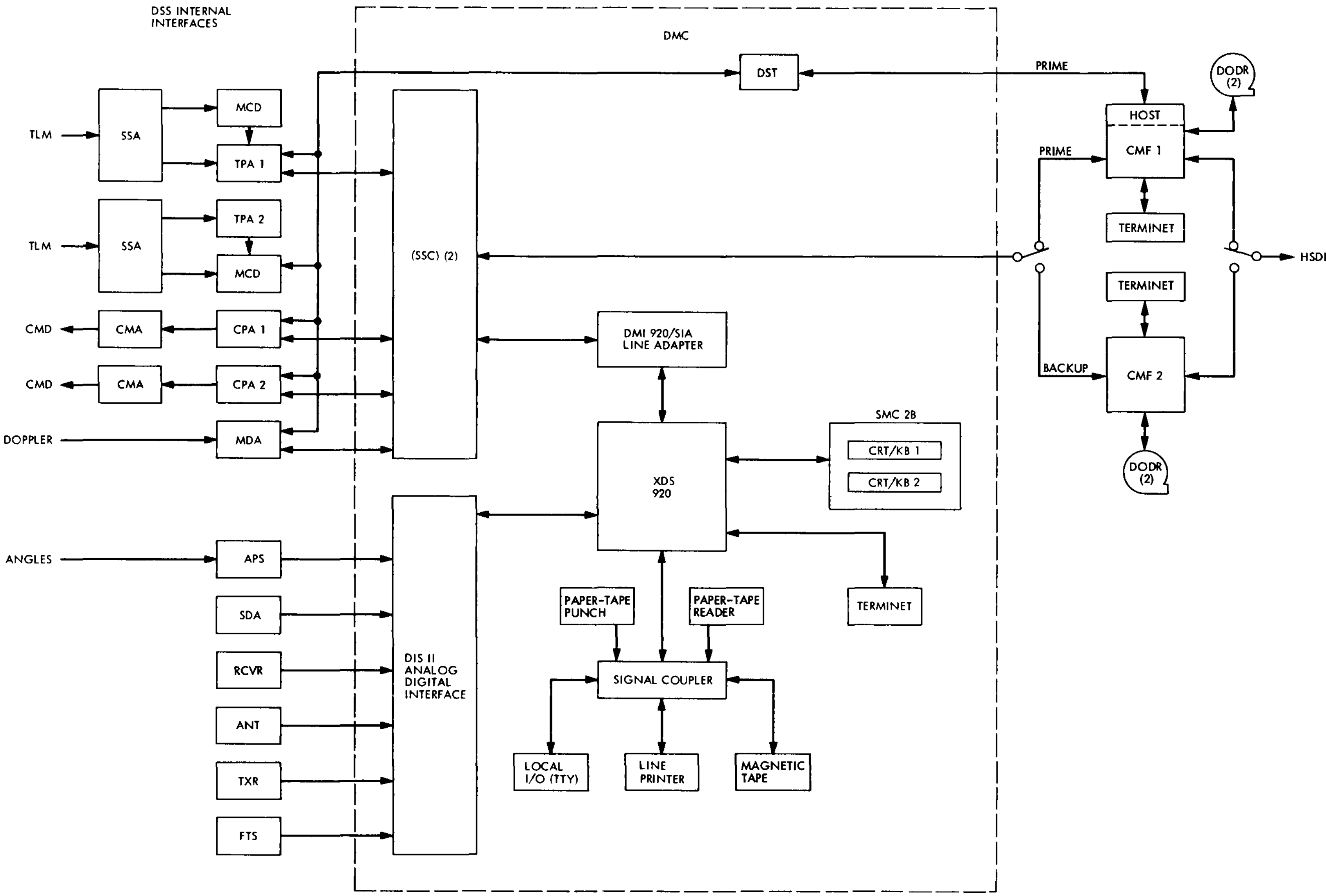


Figure 3-7. Viking Lander Monitor and Operations Control Configuration — DSS 14

The planned configuration is shown in Fig. 3-8. In the central communications terminal (CCT) at JPL, the incoming Viking Lander engineering data (8-1/3 bits/s) and science data (1 kbits/s) was fed to a data set with FTS dial-up capability to a corresponding data set at UW. The data stream was buffered at this point prior to entry into the UW data processor. In addition to the real-time link described above, the Data Records Generator in the CCT at JPL continued to record the incoming data to make the IDR for nonreal-time delivery to UW.

By May 1982, the real-time system had been set up, and on May 14 real-time Viking Lander data was transmitted to UW from JPL. The purpose of the transmission was to test the 4.8-kbits/s data-link modifications at JPL, and to test the capability of receiving and decoding the data at UW. This was accomplished successfully on interim data processing equipment then available at UW. By October 1982, regular Viking transmissions were taking place using a permanent installation at UW.

Implementation of the link to the Smithsonian was well advanced by October 1982, and plans were being made to open the display in the Air and Space Museum to the general public by the end of the year.

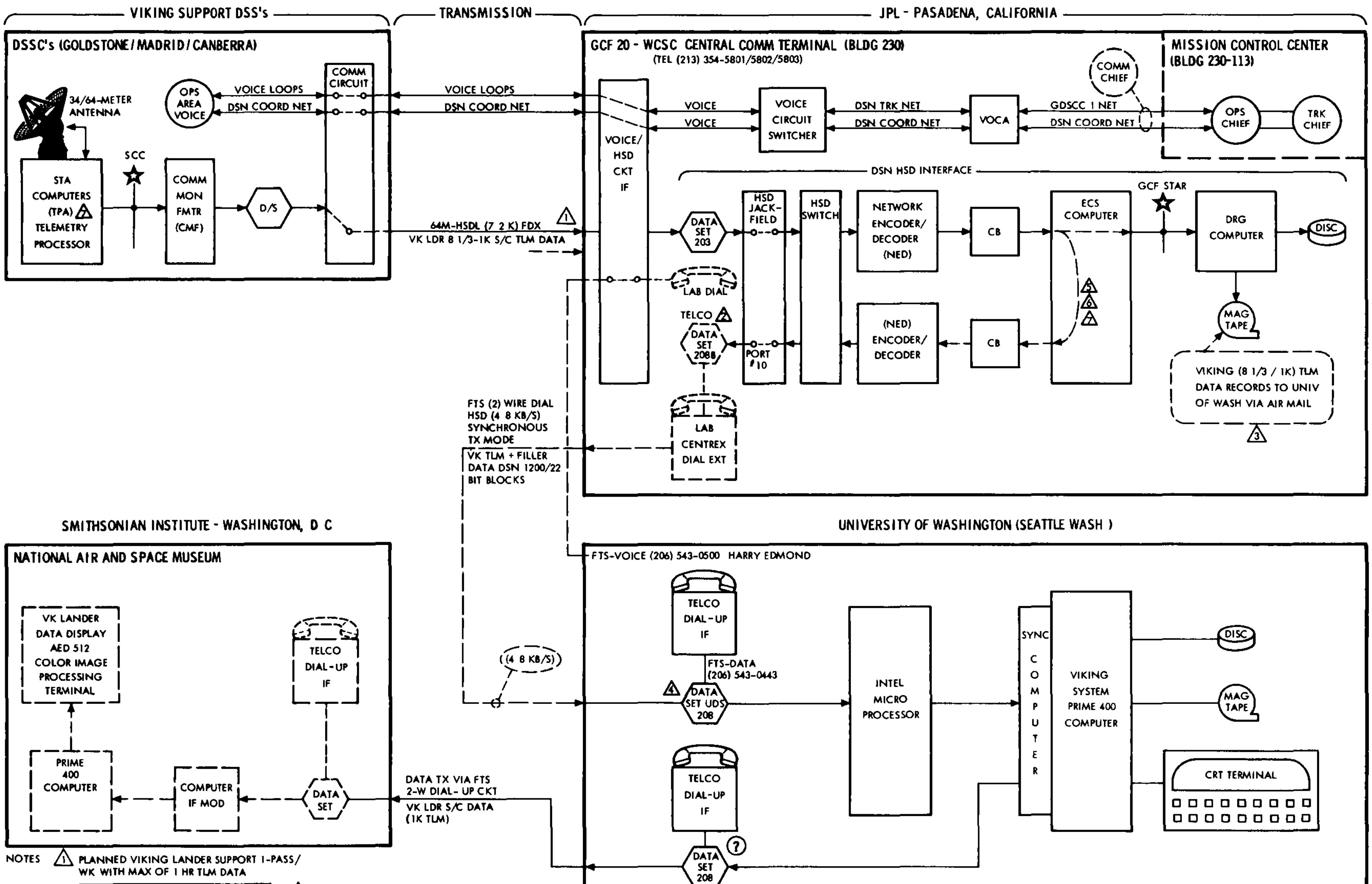
D. AUTOMATIC S-BAND DOWNLINK

During the Viking extended missions, one of the two VL-1 command receivers failed, leaving only Command Receiver 2 (CR2) in service for the Viking Lander Monitor Mission. CR2 had a temperature problem that caused it to drop lock when its case temperature exceeded 25°C. As a result, downlink transmission periods that required activation of the spacecraft transmitters were limited to one hour to avoid the temperature-sensitive operating condition.

In November 1981, A. Britting, Jr., proposed that an automatic sequence be designed for VL-1, one that would activate the downlink transmission in the event of failure of the one remaining command receiver. The sequence would include a timer initiated at the end of each successful downlink transmission. If the time since the last transmission exceeded a preselected value (e.g., 2 mo), the next downlink would be initiated automatically and repeated at regular intervals through December 5, 1994, at which time the existing high-gain antenna Earth-pointing program would expire.

Such a scheme was considered an expedient to ensure a continuum of regular VL-1 data in the event of a potential loss of uplink capability.

Approval for a waiver to the National and NASA Directive (NMI 2570.3) requiring on/off telecommand capability for NASA spacecraft was sought on the grounds that the VL-1 would continue to use its approved transmission Channel 13, and the transmitter would be programmed to shut down in 1996. Additionally, should the programmer fail, it was considered that the RTG performance would have degraded by 1996 to the point where the RTG power output could not support further VL-1 transmissions. The waiver was approved on January 20, 1982 (Refs. 3-1 and 3-2). The automatic program was transmitted to VL-1 on January 27, 1982.



NOTES 1 PLANNED VIKING LANDER SUPPORT 1-PASS/ WK WITH MAX OF 1 HR TLM DATA

STANDARD VK LDR PASS DATA RATES		
← 8 1/3 b/s →		
← 1 KB/S →		
COMMAND WINDOW		
RANGING	RTE	T/R PLAYBACK
← 27 MIN →	6 3	← 26 7 MIN →

2 DIAL-UP DATA CKT CONNECTION AND PARALLEL DATA STREAM SWITCHING TO BE ESTABLISHED BY GCF 20 CCT ON REAL-TIME REQUEST OF NOC (BASED ON TIME IDENTIFIED IN VIKING PASS MSG SOE)

3 VK LDR IDR WILL CONTINUE TO BE PROVIDE UNIV OF WASHINGTON VIA MAIL

4 OCT 82 IS PLANNED DATE FOR VIKING REAL TIME DATA SWITCHING TO UNIV OF WASH

5 JPL (CCT) ECS COMPUTER WILL BE CONFIGURED/UTILIZED TO SWITCH VK LDR TLM DATA IN REAL TIME TO UNIV OF WASHINGTON VIA FTS DIAL UP CKT INTERFACE

6 NO ATRS OR POST PASS REPLAY DATA TO BE ROUTED TO UNIV OF WASHINGTON RECALL DATA TO BE PROVIDED ON IDR ONLY

7 FOR ALL ECS SWITCHING TO UNIV OF WASH, DSS TO ADDRESS ALL VKG LDR TLM DATA TO DESTINATION CODE (AE)- - - - ECS OPERATOR TO REROUTE DATA WITH ANY UNUSED AMES ALT ROUTE DESTINATION CODE (AA THROUGH AD) UTILIZING PORT 10 AT THE HIGH SPEED LINE SWITCH (HLS)

Figure 3-8. Real-Time Data Transfer to University of Washington

As of that date, the automatic S-band downlink transmission was activated after eight consecutive downlink intervals elapsed without an uplink reception. Because of the difference in the lengths of Mars and Earth days, the interval between downlink transmissions varied from 7 to 8 Earth days. Thus, an automatic downlink was initiated between 56 and 64 days after the previous downlink had been completed, unless a scheduled uplink had been successfully completed.

The program was interrupted and the counter reset to zero at any time in the event that the absence of an uplink was due to the unavailability of antenna time, rather than a VL-1 receiver failure.

E. THE VL-1 RECOVERY EFFORT

Although the Viking Lander Monitor Mission continued successfully for several years, signs of a serious battery problem began to show in late 1981. The advice of experts in this field from all over the country suggested a change to the battery-charging strategy described in Section II; this strategy involved discharging the batteries to a known voltage rather than for a fixed time. A command sequence intended to make these changes to the battery-charging sequence was uplinked by DSS 43 on November 19, 1982, and an acquisition sequence for the expected downlink was carried out.

However, the expected downlink did not appear, and the Project declared a spacecraft emergency on November 20, 1982.

It was assumed that the battery under-voltage (UV) switch and tripped, and the Project directed its strategy for subsequent passes to closing the UV switch and increasing the battery-charging cycles.

However, shortly thereafter, it was recognized that the new battery-charging sequence had been written into spacecraft memory locations occupied by the lander high-gain antenna pointing parameters. It followed, therefore, that the VL-1 antenna was no longer pointing to Earth. Using the old Lander simulation program, a new set of antenna pointing angles was developed based on the erroneous battery parameters then residing in the lander computer memory. The lander antenna then continued to execute regular antenna pointing sequences, but these did not cross the Earth-Mars line except fortuitously on specific days and times.

Most of the following recovery strategy was based on this assumption. As shown in the chronology of events in Appendix F, many attempts were made to transmit commands to the spacecraft, close the UV switch, and undo the erroneous pointing parameters in the computer.

This involved a great deal of manual commanding at the DSSs usually in much longer sequences than had previously been used on the Viking extended missions. Some mistakes resulted in lost passes, but these were quickly rectified, and after the first week or two, Network support for the long manual command sequences and the high-power transmitter running at 80 kW was very good.

A telecommunications uplink analysis showed that, at a transmitter power of 100 kW nominal (actual power of 80 kW), there was a 10- to 14-dB margin for command with the pointing angle passing through the side lobes of the VL-1 antenna polar diagram. There was no concern for limitations in the uplink margin on this basis. Nevertheless, because of uncertainty in the polarization effects at angles well off the main beam of the VL-1 antenna, some transmissions were made in the left circular and linear modes, as well as the normal right circular polarization.

By the end of December 1982, the spacecraft had not responded to these repeated efforts to initiate a downlink, and further efforts were suspended pending an in-depth investigation by Martin Company engineers.

Although all options for improving the uplink margin had been tried, it was decided that the uplink margin was adequate even with the antenna off point. It was thought that the VL-1 antenna might not be pointing in the direction indicated by the simulation program, and that the VL-1 computer had also been switched off by the UV switch. Other failure modes were also proposed. The outcome of the Martin-JPL investigation was a strategy involving reconditioning the batteries, reinitializing the lander computer, closing the UV switch, and various other lander housekeeping activities.

This strategy would require much longer Network command sequences, repeated many times during the limited view periods. It became obvious that this was beyond the capability of the existing manual command system, and some form of automating the command sequences would be necessary.

Over the preceding several years, a manual command procedure had been used in which a maximum of 24 commands could be sent manually from the station. The station required 2 minutes per command to load and verify. Once the loaded set of commands was transmitted, the process had to be repeated for any further command sequences.

Since the new VL-1 strategy called for command sequences of at least 30 commands in length to be transmitted every 20 minutes, it was apparent that such a strategy was too time consuming and too prone to errors for use in the then-current command procedures.

Therefore, new software was developed to permit the MCCC multimission command system to convert 360-75 card-based command sequences into files that could be accepted by the CPA at each DSS. A spacecraft ID previously used for HELIOS simulation enabled the NOCC to overlay Viking "standards and limits" tables on the unused HELIOS tables, and cause the CPA to respond to continuous transmission of Viking command files from the MCCC. This capability was first tested with CTA 21 and worked satisfactorily in all respects.

This new capability was used operationally for the first time on February 1, 1983, to transmit 30 commands every 20 minutes for the total duration of the DSS 43-view period. The first command load restarted the VL-1 computer and initialized the battery-charging sequences. The second command closed the UV switch and parked the antenna. The first part of this load was transmitted over DSS 43 and the second part over DSS 63 on February 10. The third load on February 11 turned on the downlink, and the station carried out the appropriate downlink search. All this was accomplished by February 11, 1983, without any appearance of a downlink. Two further strategies were proposed. The first of these was to change to the spare TWTA-modulator/exciter string, even though there was no evidence to suggest that the original string had failed. These commands were sent on February 16, but no downlink could be found.

The second strategy presupposed that the antenna position and the computer instructions were out of alignment, possibly because the antenna stuck or slowed during earlier repositioning sequences. The antenna was driven to its limits to realign the computer and antenna at a common reference point, and then moved to an Earth-point position. A downlink was then activated on February 25.

The correct uplink commands were sent on February 18 to reposition the antenna, and the downlink "flag" was sent on February 25; this was followed by a downlink search over Goldstone. No downlink could be found.

Next, a highly sensitive wide-bandwidth spectrum analyzer used for RFI detection purposes at Goldstone was also used for the search. The threshold detection sensitivity of this instrument was -186^{+3}_{-0} dBm, but subsequent analysis of the resulting integrated spectra revealed nothing.

At this point the Project announced that no further action was warranted and it was presumed that the lander was unable to communicate with Earth.

IV. VLMM SCIENCE RETURN

A. RADIO SCIENCE

During the course of the Viking Mission, a substantial contribution to the field of radio science was made by investigators using the orbiters or landers or both.

Specific areas in which papers have been published are:

(1) Ranging validation.

(2) Relativity investigation.

(3) Dynamical constraints of Mars.

(4) Solar-wind scintillation.

(5) Shape of Mars.

(6) Mars gravity.

(7) Radio beacon for deep space navigation.

(8) Gravity waves.

(9) Solar gravity.

(10) Solar-wind electron density.

(11) Ephemeris refinement.

Some of this work carried over into the VLMM, particularly in the areas of gravitational theory and ephemeris development.

VLMM radio science data generated by the Network was gathered over a period of ten successful VL-1 ranging passes and delivered as a package to the investigators I. Shapiro and R. Reasenberg at the Massachusetts Institute of Technology and to W. Michael at the Lewis Research Center. Each package delivered contained the following items:

(1) A tape containing a Master Tracking Data File of doppler and ranging data from ten successful passes.

(2) A ranging calibration summary and a set of punched cards containing the summary data.

(3) A current set of Range "Z" corrections to adjust the measured range to the station reference location.

(4) A copy of the pass folder containing a log of station events during each pass.

(5) A copy of the latest status report on the VLMM written by the Project Engineer.

(6) A commentary summarizing the quality of the data return and noting significant events for each pass during the period covered by the package.

This substantial package of data was assembled by one of the engineers supporting the VLMM on a part-time basis. Much of the data was handwritten to save costs. Seven packages containing the data described above were transmitted to the investigators during the period 1980 to 1982.

Two recent papers describing the Viking Relativity Experiment are given in Refs. 4-1 and 4-2. Analysis of ranging data from the Viking spacecraft, including the landers, verified a prediction of the General Theory of Relativity relating to the influence of solar gravity on the round-trip light time of signals passing between Earth and Mars.

The estimated accuracy of these results was 0.1% based on observations over a period of about one year. Further reduction in the uncertainty of this test of general relativity was dependent on the collection and refinement of additional data.

More recently, the VLMM radio metric data was used by Shapiro, et al., to evaluate evidence for the time variation of the gravitational constant as a function of atomic time.

In investigating these long-term effects, precise measurements of the orbital periods of Earth and Mars (representing a gravitational clock) are made with hydrogen-maser time standards (representing atomic time). In an effort to reduce the residuals between predictions and models, the quality of the radio metric data, the computer programs, and the models themselves are being investigated, as well as perturbations of the Earth and Mars orbits by the gravitational effects of several asteroids and planets.

B. METEOROLOGY

Two meteorology experiment sensors on VL-1 were the Local Ambient Pressure Sensor and the Local Ambient Temperature Sensor. Under the leadership of Dr. James Tillman of the University of Washington, the long periods of continuous Viking observations from these two instruments have provided major insight into many Martian atmospheric processes, such as frontal systems, annual climate measurements, interannual climate variations, and dust storms.

Typical daily records of pressure and temperature from VL-1, which have been processed at UW as described in Subsection C, are shown in Figs. 4-1 and 4-2.

Similar data covering a span of 3 Martian years is shown in Fig. 4-3. In this diagram, 669.0 sols equal 687 Earth days. This is typical of the analytical data developed by Tillman, and reveals the presence of dust storms in wide

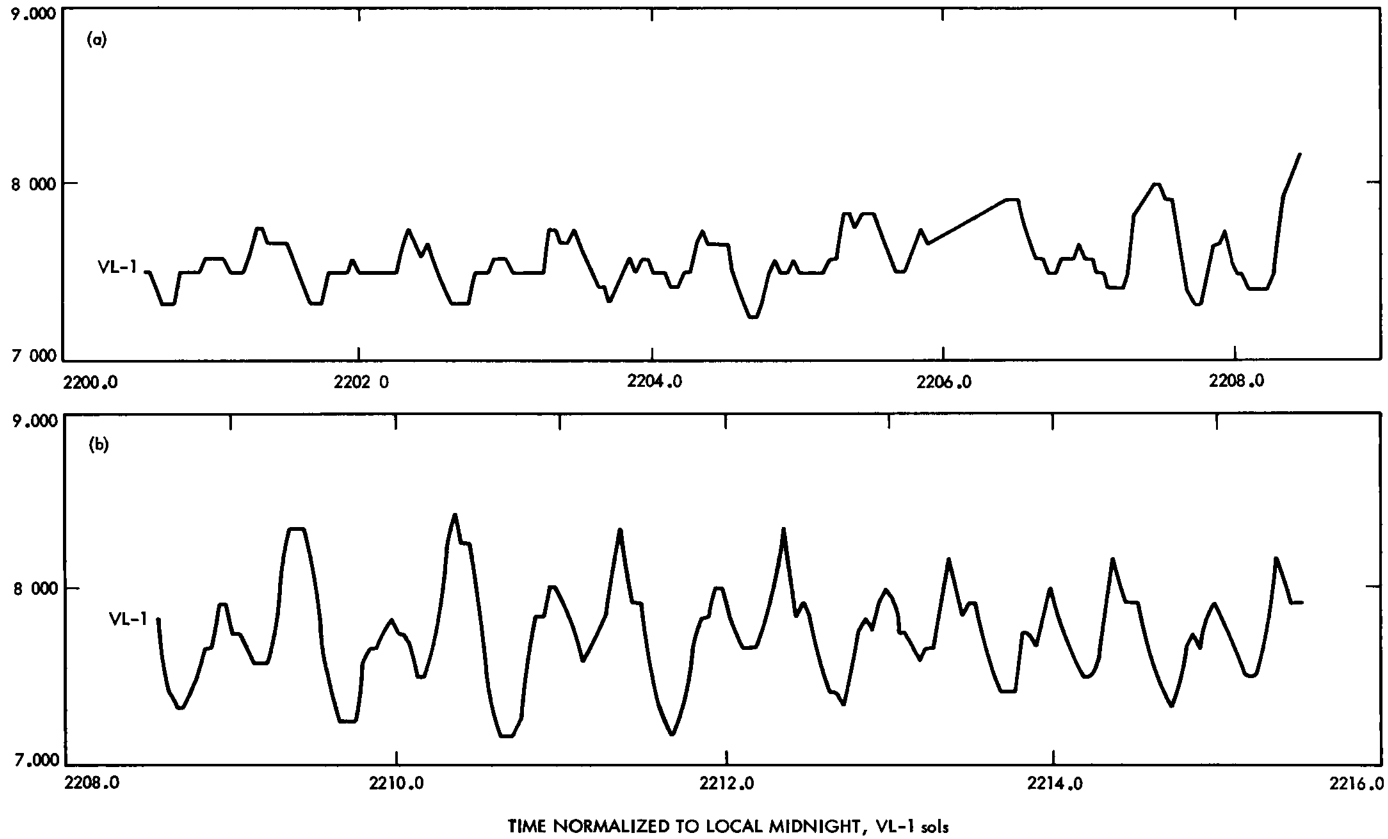


Figure 4-1. Typical Viking Lander 1 Pressure Record: (a) Wednesday, October 6, 1982, 16:04:58; (b) Wednesday, October 13, 1982, 03:38:44 (Courtesy of the University of Washington Department of Atmospheric Sciences)

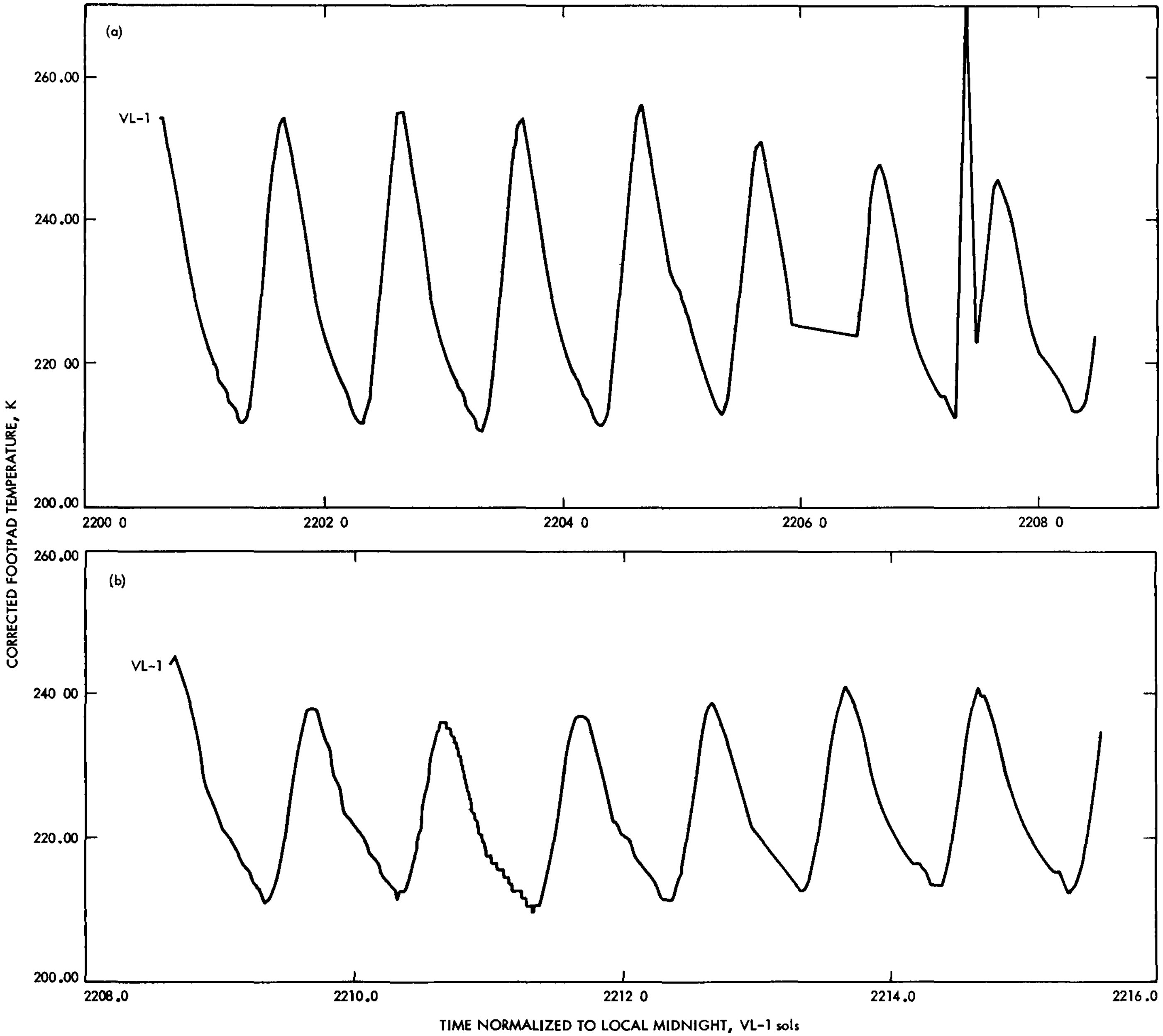


Figure 4-2. Typical Viking Lander 1 Local Ambient Temperature Record: (a) Wednesday, October 6, 1982, 16:07:21; (b) Wednesday, October 13, 1982, 03:39:14 (Courtesy of the University of Washington Department of Atmospheric Sciences)

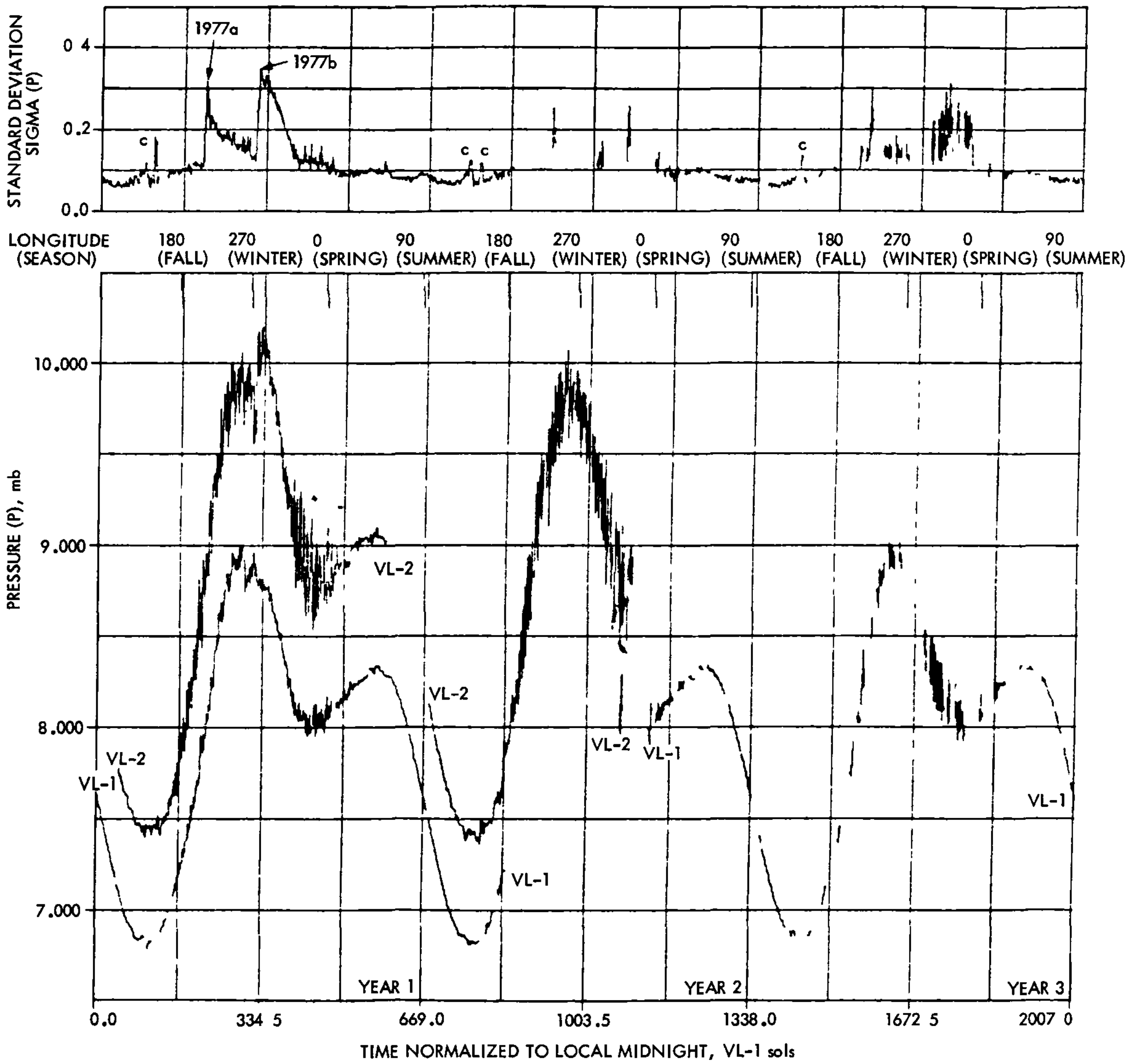


Figure 4-3. Viking Landers 1 and 2 Local Ambient Pressure for 3 Martian years. Lower Plot: Daily Average. Upper Plot: Standard Deviations of Pressure Around Daily Mean at Viking Lander 1, Which is an Indicator of Atmospheric Dust for Values of Sigma ≥ 0.1 and Longitude (Season) (L_S) Between 180 and 300; After 300, Synoptic Systems Generate Large Variations Within a sol at This Tropical Site (Courtesy of the University of Washington Department of Atmospheric Sciences)

perturbations of the daily pressure patterns due to solar heating of atmospheric dusts, at, for example, 1977a and 1977b. Features of interest identified by Tillman are shown by the small pressure spikes labeled "C" occurring at approximately 1-Martian-year intervals. These spikes seem to be associated with the passage of large-scale dust storms and appear at almost the same Martian season each year. Because these disturbances were being sought in the 1982 data, the Network received requests for as much continuous tracking data as possible to maximize the chance of recording these data for further study and analysis.

C. IMAGING EXPERIMENT*

Viking Lander 2 ceased operation in February 1980 because of onboard battery failure. At that time both cameras were fully active after 3-1/2 years of Mars operations, during which they had performed 2156 camera events (imaging sequences). Fortunately, both cameras on VL-1 also remained operational, and continued to perform programmed camera events throughout the VLMM. During the VLMM, there were 164 possible imaging opportunities, of which 88 resulted in images received and delivered to the investigators. The difference is due mainly to the lack of available antenna time in the early years because of higher priority Voyager Jupiter and Saturn support.

The VL-1 cameras were activated by a stored program that set all the camera parameters including pointing, so that the same scene was viewed once each Martian year. Comparison of successive annual images was used to check for dust or condensate deposition or erosion over the interval of time. A recent example of comparative imaging is shown in Fig. 4-4, where the time interval between the two photos extended from February 1979 (left) to July 1981 (right). The subject was a 5-cm pile of soil placed beside and partly atop an 11-cm rock by VL-1's soil-sampling arm. Comparison of the two photos shows that some of the soil had been removed by Martian winds to reexpose the rocks. The small change is important, scientists say, because it shows that deposition and removal of fine material is a continuing cycle on Mars, as it is on Earth.

The IDRs made by the DSN in the NOCC contained the 1-kbit/s imaging and 8-1/3 bits/s engineering data; they were delivered to the Image Processing Lab (IPL) at JPL for processing. The IDRs were processed into prints and digital tapes, and 10 copies of each were distributed by the VLMM Project to the seven regional planetary imaging facilities throughout the U.S.A. The others were archived. Investigators in various areas had access to the continuing flow of Mars imaging products from these regional facilities.

A recent Lander 1 picture sequence showing a unique Mars event, a dust storm, is shown in Fig. 4-5. The seven-picture sequence was acquired over a period of 16 mo from individual Viking Lander imaging sequences. Such images allow researchers to observe the year-to-year surface changes around the lander — changes that help quantify the magnitudes of the geological processes acting to shape the surface of Mars. The predominant type of surface changes are due to dust — both erosional and depositional. In the sixth frame (June 14, 1981), the entire scene was darkened by the passage of what apparently was a localized dust storm. Prior to and after this image, the sky and surface were brighter. The change in

*A listing of NASA publications relating to the Viking Orbiter and Lander imaging experiments is given in Appendix G.

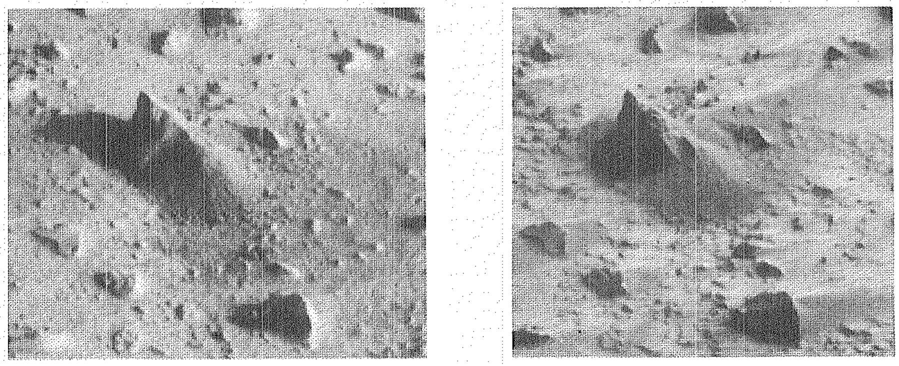


Figure 4-4. Viking Lander 1 Comparative Mars Images

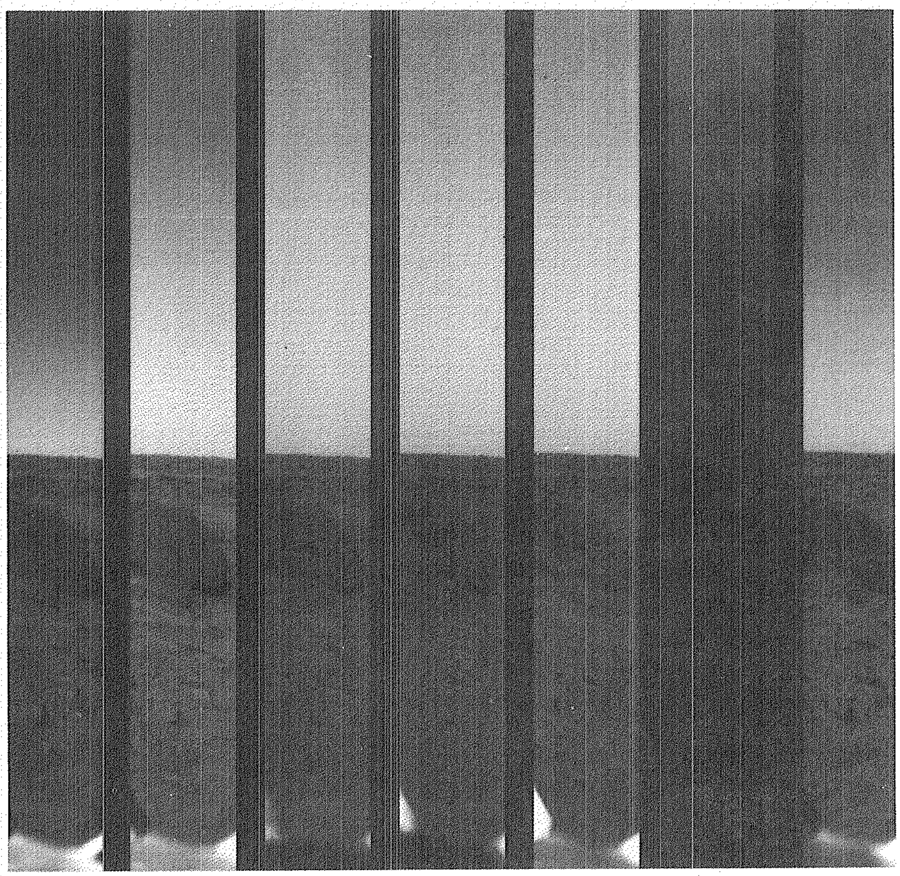


Figure 4-5. Viking Lander 1 Seven-Picture Sequence

apparent brightness of the large boulder named "Big Joe" early in the mission was due to seasonal changes in the Sun's angle. After one complete Mars year, the Sun returns to the same position in the sky, and images can be compared by computer to search for differences.

The Mars imaging program was to continue throughout the VLMM, systematically returning images of the same Mars scene, each Mars year, until End of Mission (1994).

V. CONCLUSION

The Network has been involved with the Viking Project through its various phases since its inception in 1968 to the present time, 1983.* Throughout the pre-launch planning and the prime mission, the Network responded to the project's requirements for support with total commitment and an extremely high standard of performance. This was achieved under the difficult conditions of limited staff, obsolete hardware and software, and sparse documentation.

Following the prime mission, the "extended" and "continuation" missions received the same level of technical support, although competition for antenna time by flight projects of higher priority resulted in reduced tracking time for the VLMM. As NASA interest in the remaining operational Viking spacecraft declined, it became more difficult to schedule all the requested antenna time, even though scientific interest in the reduced data return quickened. This placed much more emphasis on achieving "good passes" to reap maximum return from the limited opportunities available.

During the final phase of the VLMM, the Network was called upon to develop and carry out many innovative technical and operational strategies to support the effort to recover the VL-1 spacecraft.

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*Facts relative to the Viking missions are given in Appendix H.

DEFINITION OF ABBREVIATIONS

ANT	antenna
APS	Antenna Pointing Subsystem
CB	circuit breaker
CCT	Central Communications Terminal
CCU	command control unit
CMA	Command Modulation Assembly
CMD	Command System
CMF	Communications Monitor and Formatter Assembly
COMM	communications
COORD	coordination
CPA	Command Processor Assembly
CRT	cathode-ray tube
CSA	Command Switch Assembly
DCO	digitally controlled oscillator
DEC	declination
DIS	Digital Instrumentation Assembly
DODR	Digital Original Data Record
DRA	Digital Recorder Assembly
DRG	Data Recorder Generator
D/S	data set
DST	Data System Terminal Assembly
ECS	error correcting and switching
ESA	Exciter Switch Assembly
EXC	Exciter Assembly
EXT	external

FDX	full duplex (two-way)
FMTR	formatter
FTS	Federal Telecommunications System
GCF	Ground Communications Facility
GDSCC	Goldstone Deep Space Communications Complex
HGA	high-gain antenna
HOST	HOST software program
HSD	high-speed data
HSDL	high-speed data line
IF	intermediate frequency
I/O	input/output
JPL	Jet Propulsion Laboratory
KB	keyboard
LGA	low-gain antenna
MAG	magnetic
MCA	Microwave Control Assembly
MDA	Metric Data Assembly
MET	meteorological
MMR	Multimission Open-Loop Receiver Assembly
MON	Monitor and Control System
NB	narrow band
NOC	Network Operations Chief
ODA	Occultation Data Assembly
OLR	Open-Loop Receiver Assembly
OPS	operations
PPR	Pre- and Postdetection Recording Subsystem
PRA	Planetary Ranging Assembly

PRDX	predicts
RA	right ascension
RCVR	receiver
RDA	Ranging Demodulator Assembly
S/C	spacecraft
SDA	Subcarrier Demodulator Assembly
SIA	star switch interface adapter
SMC	Station Monitor and Control Subsystem
SPD	S-Band Polarization Diversity
SSA	Symbol Synchronizer Assembly
SSC	Star Switch Controller
SSI	Spectral Signal Indicator
STA	Stimulus Assembly
S/W BD	software block decoder
SYNC	synchronization
TODR	temporary original data record
TPA	Telemetry Processor Assembly
TRS	transmit/receive selector
TWTA	traveling-wave tube amplifier
TX	transmitter
TXR	Transmitter Subsystem
UWV	Antenna Microwave Subsystem
VOCA	Voice Communications Assembly
VK LDR	Viking Lander
WB	wideband
WBDL	wideband data line

WCSC	West Coast Switching Center
XMTR	transmitter
XRO	X-Band Receive Only

ACKNOWLEDGMENT

The Viking Lander Monitor Mission depended for its successful data return upon the individual efforts of a small number of people in and associated with, the Network. Some of these persons made substantial contributions to this report by furnishing data, reports, or opinions to the author. In this regard, the contributions of P. Eshe, S. La Voie, A. Britting, Jr., J.C. Nash, and J.P. Brenkle are gratefully acknowledged.

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APPENDIX A

SAMPLE NEWS RELEASE

OFFICE OF PUBLIC INFORMATION
JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
PASADENA, CALIF. PHONE (213) 354-5011

FOR IMMEDIATE RELEASE

After more than four years exploring Mars, NASA's Viking Orbiter 1 has almost reached the end of its mission.

The orbiter has used almost all its attitude-control gas, that keeps its solar panels pointed to the Sun and the antenna aimed at Earth. When the gas is exhausted -- probably about July 23 -- controllers at Jet Propulsion Laboratory will send commands to turn off Viking Orbiter 1 to end its long and productive mission.

Meanwhile, Viking Lander 1 is programmed to operate unattended on Mars into 1990, perhaps to be extended into 1994.

During the most recent phase of Viking's mission the orbiter has taken about 30 pictures a day of a region southwest of Olympus Mons and the three volcanoes on the Tharsis Ridge, an area of particular interest for its large, river-like channels. That sequence will continue through July 12.

Project officials plan a full program for Orbiter 1's final days. How much of the program can be completed will depend on the amount of attitude-control gas remaining. Here is a timeline of events that are proposed to be carried out if the orbiter continues to be cooperative:

July 13, 14: The spacecraft will take a series of high-resolution photos of the summit caldera of Olympus Mons. These should be the highest-resolution ever obtained of the caldera of the solar system's largest known volcano.

July 15 through 18: The spacecraft will perform three controlled burns of its rocket engines. Those burns are part of a series of engineering tests to provide data that will benefit future space missions. One effect of the burns will be to change the spacecraft's orbit from its present 370 kilometers (230 miles) periapsis and 34,000 kilometers (21,127 miles) apoapsis to 350 kilometers (220 miles) periapsis and 56,000 kilometers (34,800 miles) apoapsis. The new orbit will satisfy the condition, in accordance with planetary-quarantine provisions, of not impacting, and thereby not contaminating, the planet before the year 2019.

July 20 to 23: Additional engineering tests will be conducted, principally on the radio system, and the final orbit will be determined.

Current extrapolation of the supply and usage rate of attitude-control gas indicates July 23 is the approximate date of depletion, but flight controllers say there is probably a one-week uncertainty in that date, so the orbiter could run out of gas as early as July 16 or as late as July 30.

If it should turn out that there is still gas remaining, then about July 27 Orbiter 1 will make a final high-altitude global survey of the visible portion of the Mars disk -- 25 pictures through each of three filters, for a total of 75 frames.

When the gas is exhausted, the orbiter's radio transmitter will be commanded off for the last time, and the spacecraft will continue silently orbiting Mars for many decades.

Viking 1 was launched to Mars Aug. 20, 1975, and arrived June 19, 1976. Viking Lander 1 touched down on the Martian surface

July 20, 1976, with a 90-day mission expectation. That mission completed, it has now observed the planet for more than two full Mars years -- four Earth years on July 20.

As long as it survives, Viking Lander 1 will continue to collect photos and weather data from the Martian surface and, on command from Earth, transmit them on approximately a weekly basis.

Viking Orbiter 2 ran out of attitude-control gas and was commanded off July 24, 1978. Viking Lander 2 was turned off after its last relay transmission April 11, 1980.

The Viking Project -- today with fewer than 30 people engaged in flight operations and science data processing -- is managed for NASA's Office of Space Science by Jet Propulsion Laboratory.

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#940/7/9/80/DB

APPENDIX B

VIKING LANDER MISSION SUPPORT EXTENSION REQUEST

LANDER (VL-1) MONITORING MISSION

JULY 20, 1979 THROUGH DECEMBER 29, 1990

OBJECTIVES

1. Obtain S-band ranging data from the surface of Mars periodically over a long time span for the conduct of Radio Science.

2. Obtain meteorology and imaging data from the surface of Mars periodically over a long time span to monitor and disseminate information relative to any significant changes with time.

SUPPORT REQUIREMENTS

DSN

1. Retain existing DSS lander telemetry and command software capability.

2. At least two 64-meter passes of 3 hours duration per month through 1980.

3. At least one 64-meter pass of 3 hours duration per month through 1981.

4. Subsequent years - to be negotiated on a yearly basis.

MCCC

1. Support requirements contained within the orbiter requirements until 2/1/80. No MCCC dependency or requirements thereafter.

PROJECT/DSN INTERFACE

1. The project shall provide a person to act as a focal point for all lander/ DSN interactions.

2. The project inputs to the DSN shall include scheduling, predictions, sequences, commands and operational direction during passes.

3. The DSN shall provide lander IDRs and data packages to this person.

K S Watkins

K. S. Watkins
Viking Project Manager

Thomas A. Mutch
Associate Administrator for
Space Science

Bruce Murray, Director
Jet Propulsion Laboratory for

W. C. Schneider
Associate Administrator for
Space Tracking and Data Systems

APPENDIX C*

VIKING LANDER MONITOR MISSION DIRECT-LINK REQUEST SUMMARY

*The information in this appendix was taken from Interoffice Memorandum 3394-82-122 from P. Eshe to G. Gianopulous, "Viking Lander Monitor Mission Direct Link," Jet Propulsion Laboratory, Pasadena, Calif., Oct. 7, 1982.

First year of the VLMM August 13 to December 28, 1980:

19 total passes available

9 passes scheduled

9 passes unable to schedule (information not available)

1 pass was out of station viewperiod

Good low-rate and/or high-rate data: 8 passes

Good ranging data: 7 passes

Bad low-rate and/or high-rate data: none

Bad ranging data: 1 ranging pass bad due to locked sideband

Lost direct link: 1 - bad pass due to digitally controlled oscillator (DCO) sweep problem

Second year of the VLMM January 4 to December 27, 1981:

48 total passes available

31 passes scheduled

17 passes unable to schedule. Reasons:

- 4 passes given up to Pioneer
- 7 passes given up to Voyager
- 1 pass given up to Helios
- 3 passes given up due to Station 14 being down
- 2 passes were out of station viewperiod

Good low-rate and/or high-rate data: 22 good passes of low-rate and high-rate data

1 pass good high-rate data

Good ranging data: 23 passes

Bad low-rate and/or high-rate data: 1 pass no low-rate data; no sync

1 wrong TPA configuration; lost battery data

Bad ranging data: 1 pass PRA RED

Lost direct link:

1 - Sun-Earth-probe (SEP) angle 1.2 deg

1 - transmitter tripped off

1 - wrong command sent

2 - DCO sweep problem

2 - DSS 14 was scheduled; station was down

Third year of the VLMM January 4 to December 28, 1982:

48 total passes available

41 passes scheduled at this time (Dec. 12 to Dec. 28 have not been scheduled yet). To this day, we have had 36 passes available.

3 passes unable to schedule. Reasons:

1 pass given up to radio astronomy for Australian experiment

1 pass out of station viewperiod

1 pass unable to schedule DSS 63 due to gearbox repair. Tried for DSS 61 instead of DSS 63, but Voyager needed DSS 61.

Good low-rate and/or high-rate data: 32 passes

2 passes of good low-rate data

Good ranging: 29 passes

Bad low-rate and/or high-rate data: 1 - unable to lockup on high rate data, probably due to being only one way.

1 - no high-rate data due to only 34-m station available

Bad ranging: 1 - unknown

1 - PRA declared RED

1 - wrong tuning

1 - downlink only

Lost direct link: 1 pass DSS-14 radial bearing problem

APPENDIX D*

VIKING LANDER MONITOR MISSION DIRECT-LINK REQUEST DETAIL

*The information in this appendix was taken from Interoffice Memorandum 3394-82-122 from P. Eshe to G. Gianopulous, "Viking Lander Monitor Mission Direct Link," Jet Propulsion Laboratory, Pasadena, Calif., Oct. 7, 1982.

Year	Date	Day of Year	Sol No.	DSS	Scheduled	Comments
1980	8/13	226	1445	12	Yes	Good pass
	8/20	233	1452		No	
	8/28	241	1460		No	
	9/5	249	1468	63	Yes	Good pass
	9/12	256	1475		No	
	9/20	264	1482	42	Yes	Good pass
	9/27	271	1489		No	
	10/5	279	1497	63	Yes	Good pass
	10/13	287	1505		No	
	10/20	294	1512	14	Yes	No good DCO sweep problem
	10/28	302	1519		No	
	11/4	309	1526	43	Yes	Good pass 1:10 late
	11/12	317	1534		No	
	11/20	325	1542		No	No viewperiod
	11/27	332	1549	14	Yes	Good pass 00:35 late
	12/5	340	1556		No	
	12/12	347	1563	43	Yes	LR/HR data OK. No ranging data locked on sideband
	12/20	355	1571	63	Yes	Good pass
	12/28	363	1579		No	
1981	1/4	004	1586	43	Yes	Wrong TPA config.; lost battery data; good ranging

Year	Date	Day of Year	Sol No.	DSS	Scheduled	Comments
1981	1/12	012	1593	43	No	Gave up for PN-12
	1/19	019	1600	43	Yes	Good pass
	1/27	027	1608	63	Yes	Good pass
	2/4	035	1616	14	No	Gave up for PN-12
	2/11	042	1623	14	Yes	Good pass
	2/19	050	1630	43	Yes	Good LR/HR date; no ranging (PRA RED)
	2/26	057	1637		No	No viewperiod
	3/6	065	1645	63	Yes	Good pass
	3/14	073	1653	14	No	DSS-14 maintenance
	3/21	080	1660	14	Yes	SEP 2.6 deg; acceptable LR/HR data; no ranging
	3/29	088	1667	43	Yes	SEP 1.2 deg; no LR/HR Data
	4/5	095	1674	63	Yes	SEP 0.8 deg; No data. High-power transmitter tripped off
	4/13	103	1682	63	No	Gave up for Pioneer 12
	4/21	111	1690	14	No	Gave up for Pioneer 12
	4/28	118	1697	43	Yes	Good pass One ranging point
	5/6	126	1704	43	No	Gave up for Voyager 2
	5/13	133	1711	63	Yes	Good pass
	5/21	141	1719	63	Yes	Good pass
	5/29	149	1727	14	Yes	Good pass
	6/5	156	1734	43	Yes	Good pass
	6/13	164	1741		No	No viewperiod

Year	Date	Day of Year	Sol No.	DSS	Scheduled	Comments
1981	6/20	171	1746	63	Yes	Good pass; gave up
	6/28	179	1756	63	No	For Voyager 2
	7/6	187	1764	14	Yes	Good pass
	7/13	194	1771	43	Yes	Good pass
	7/21	202	1778	63	Yes	Good pass
	7/28	209	1785	63	No	Gave up for Voyager
	8/5	217	1793	63	No	Gave up for Voyager
	8/13	225	1801	14	No	Gave up for Voyager
	8/20	232	1808	43	No	Gave up for Voyager
	8/28	240	1815	63	Yes	Good pass
	9/4	247	1822	63	No	Gave up for Voyager
	9/12	255	1830	14	Yes	DSS 14 down
	9/20	263	1838	14	Yes	DSS 14 down
	9/27	270	1845	43	Yes	Good pass
	10/5	278	1852	63	Yes	Good pass
	10/12	285	1859	63	Yes	Good high rate and ranging; no low rate
	10/20	293	1867	14	No	DSS-14 gearbox repair
	1/28	301	1875	43	Yes	No good Wrong command sent
	11/4	308	1882	43	Yes	Good pass
	11/12	316	1889	63	Yes	No good; DCO problem
	11/19	323	1896	63	Yes	Good pass
	11/27	331	1904	14	No	DSS 14 down
	12/05	339	1912	43	Yes	Good pass

Year	Date	Day of Year	Sol No.	DSS	Scheduled	Comments
1981	12/13	347	1919	63	Yes	Good pass
	12/20	354	1926	63	No	Gave up for Helios
	12/27	361	1933	14	Yes	No good; DCO problem
1982	1/4	004	1941	43	Yes	Good pass
	1/12	012	1949	43	Yes	Good low- and high-rate data; ranging no good
	1/20	020	1956	63	Yes	Good pass
	1/27	027	1963	63	Yes	Good pass
	2/3	034	1970	14	Yes	Good pass
	2/11	042	1978	43	Yes	Good pass
	2/19	050	1986	43	Yes	Good pass
	2/27	058	1993	63	Yes	Good pass
	3/6	065	2000	14	Yes	Good low- and high-rate data; ranging no good
	3/13	072	2007	14	Yes	Good pass
	3/21	080	2015	42	Yes	Good pass
	3/29	088	2023	63	Yes	Good pass
	4/6	096	2030	14	Yes	No good; radial bearing problem
	4/13	103	2037	14	Yes	Good pass
	4/20	110	2044	43	No	Gave up for Radio Astronomy Australian Experiment
	4/28	118	2052	63	Yes	Good pass
	5/6	126	2060	63	Yes	Good pass
	5/14	134	2067	14	Yes	Good pass

Year	Date	Day of Year	Sol No.	DSS	Scheduled	Comments
1982	5/21	141	2074	43	Yes	Good low- and high-rate data; ranging no good; commanding no good
	5/28	148	2081	43	Yes	Good low- and high-rate data; ranging no good
	6/5	156	2089	63	Yes	Good pass
	6/13	164	2097	12	Yes	Good pass
	6/21	172	2104	43	Yes	Good pass
	6/28	179	2111	43	Yes	Good pass
	7/5	186	2118	63	Yes	No uplink available; no ranging available; lost high-rate data, low-rate ok
	7/13	194	2126	63	Yes	Good pass
	7/21	202	2134	12	Yes	Good pass
	7/29	210	2141	43	Yes	Good pass
	8/5	217	2148	43	Yes	Good pass
	8/12	224	2155	63	Yes	Good pass
	8/20	232	2163	63	Yes	Good pass
	8/28	240	2171	14	Yes	Good pass; two ranging points
	9/5	248	2178	43	Yes	Good pass
	9/12	255	2185	43	Yes	Good pass
	9/19	262	2192	61	Yes	Good pass; no HR data
	9/27	270	2200		No	No viewperiod
	10/5	278	2208	14	Yes	
	10/13	286	2215	43	Yes	

Year	Date	Day of Year	Sol No.	DSS	Scheduled	Comments
1982	10/20	203	2222	43	Yes	
	10/27	300	2229	61	No	Unable to have DSS 63 due to gearbox repair; VGR needed DSS 61 for test
	11/4	308	2237	14	Yes	
	11/12	316	2245	14	Yes	
	11/20	324	2252	43	Yes	
	11/27	331	2259	43	Yes	
	12/4	338	2266	63	Yes	
	12/12	346	2274	14		
	12/20	354	2282	14		
	12/28	362	2289	43		

APPENDIX E

AN EXAMPLE OF VIKING LANDER SEQUENCE OF EVENTS

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OUTGOING MESSAGE

DE JJPL 001A
02/0001Z
FM J NASH/R NEVAREZ
TO ANBE/STADIR/43 OPS
JOCC/NOC/TRKCHF/NATCMD/NATRK/NATEL
INFO JZED/PAG
DLD W JENSEN/G REED/E BURKE/A BERMAN/D MUDGWAY/K LUDWIG/R GILLETTE/
P ESHE/A BRITTING/G GIANOPULOS/J BRENKLE/E HAMPTON/R HOLLINGSWORTH/
J HODDER/S BENEDICT/T BOREHAM/COMM CONTROL

SUBJECT: VIKING LANDER SOE FOR DSS-43, SOL-2178 DOY-248

1. ON DOY 248 DSS-43 WILL BE SUPPORTING A VIKING LANDER RADIO SCIENCE RANGING PASS. PROJECT HAS REQUESTED THAT BATTERY CONDITIONING COMMANDS BE TRANSMITTED DURING THIS TRACKING PASS. THREE TRANSMISSIONS WILL BE REQUIRED. THE FIRST TRANSMISSION WILL BE THE DOWNLINK "ON" COMMANDS, THE SECOND TRANSMISSION WILL BE THE BATTERY CONDITIONING COMMANDS, AND THE THIRD TRANSMISSION WILL BE THE DOWNLINK "ON" COMMANDS FOR THE TRACKING PASS SCHEDULED OVER DSS-43 ON DOY 255.
   IT IS REQUIRED THAT 9 LANDER (S/C-26) COMMANDS BE MANUALLY LOADED INTO THE MANUAL BUFFER DURING PTP.
2. UPLINK TRANSMITTER POWER WILL BE 10KW.
3. DURING THE FIRST HOUR OF THE 1 1/2 HOUR PTP, CONFIGURE THE STATION FOR LANDER SUPPORT. CONFIGURE ONE TPA FOR LANDER SUPPORT (CH-1, IK AND CH-2, 8.33 HSD). USE SOFTWARE BLOCK DECODING FOR LANDER 1K CODED DATA. ENSURE THAT THE SSA TO BE UTILIZED IN SUPPORT OF THE IK CODED DATA IS SET WITH A THRESHOLD OF 0.0 DB.
4. CONFIGURE THE PRIME CPA FOR LANDER COMMANDING. MANUAL COMMANDS WILL ENTERED FOR THE FIRST AND SECOND TRANSMISSION DURING THE PTP AND AFTER NATCMD HAS VALIDATED THE COMMANDS SYSTEM PER SOE. THE THIRD SET OF COMMANDS WILL BE LOADED INTO THE MANUAL BUFFER DURING THE LAST HOUR OF THE TRACKING PASS.
5. DURING THE PTP PERFORM RANGING PRE-CALS FOR LANDER.
   COMP: 0 6
   TO: 3E
   T1: 90
   T2: 9
   T3: 60
   CARRIER SUPRESSION: 9DB
6. SEQUENCE OF EVENTS FOR LANDER SUPPORT
   02:25:00 DSS-43 CONFIGURE STATION FOR LANDER SUPPORT
   03:10:00 DSS-43 TURN COMMAND SYSTEM OVER TO NATCMD FOR VALIDATION
   03:20:00 DSS-43 AFTER COMMAND VALIDATION, RETURN TO MANUAL AND ENTER THE COMMANDS INTO THE FOLLOWING ORDER.

MOUDLE	MSG NBR	TIME	BIT PATTERN
1	1	248:04:23:00	5 5 5 5 5 5 5 5 5 5 5 5 5 5 E 2 5
	2	NONTIMED	6 8 2 0 1 7 0 1 6 F 4 5 0 0 B D 8
	3	NONTIMED	5 F 4 4 0 0 B 9 5 F A C E 8 C A 8
MODULE	MSG NBR	TIME	BIT PATTERN
2	4	248:04:38:00	5 5 5 5 5 5 5 5 5 5 5 5 5 5 E 2 5
	5	NONTIMED	6 8 2 0 1 D 7 2 7 D 3 9 0 0 D 9 8
	6	NONTIMED	7 1 E A 2 0 C 6 B 4 D D 0 0 F A 8
	7	NONTIMED	C 2 D C 0 0 E 2 F 4 D D 0 0 A 2 8
	8	NONTIMED	0 0 0 0 0 0 D E C 9 B 9 0 0 9 5 8
	9	NONTIMED	2 2 D C 0 D 1 9 1 4 B E 0 9 0 6 8

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PAGE TWO

Ø3:35:ØØ	DSS-43	REMAIN IN MANUAL AND RETURN COMMAND SYSTEM BACK OVER TO NAT CMD FOR MODULES 1 AND 2 VALIDATION.
Ø3:36:ØØ	NATCMD	RECALL MANUAL BUFFER AND VALIDATE COMMAND BIT PATTERNS.
Ø3:51:ØØ	DSS-43	AFTER NATCMD HAS VALIDATED COMMAND BIT PATTERNS, RETURN TO REMOTE.
Ø3:52:ØØ	NATCMD	VERIFY CORRECT COMMAND TRANSMIT TIME DISPLAYED ON FORMAT 3Ø1.
Ø3:55:ØØ	DSS-43	START OF LANDER TRACK SOL-2178
Ø4:Ø1:ØØ	DSS-43	TRANSMITTER ON (1ØKW) LANDER FLAG S/C-26, S-BAND ONLY, 2-WAY, BAD DATA, ROL IN THE MDA. MDA DATA RATES: 1 SAMPLE/1Ø SEC. AT AOS TO LOS OF LANDER PASS.
Ø4:Ø1:27	DSS-43	START ACQUISITION SWEEP AS PER SWEEP MESSAGE.
Ø4:18:ØØ	DSS-43	COMMAND MODULATION ON
Ø4:19:ØØ	DSS-43	SEND IDLE-2/ACTIVE ON
Ø4:24:ØØ	NAT/DSS	CONFIRM FIRST COMMAND TRANSMISSION
Ø4:39:ØØ	NAT/DSS	CONFIRM SECOND COMMAND TRANSMISSION
Ø4:4Ø:ØØ	TRKCON	VERIFY RANGING PARAMETERS
Ø4:41:ØØ	NATCMD	AFTER ALL NINE (9) COMMANDS HAVE BEEN TRANSMITTED AND CONFIEMED, RETURN TO IDLE-1/ACTIVE OFF.
Ø4:49:ØØ	DSS-43	RANGING MOD ON
Ø4:49:58	DSS-43	TRANSMIT FIRST RANGE ACQUISITION
Ø5:12:52	DSS-43	START SWEEP FOR DOWNLINK ACQUISITION
Ø5:14:22	DSS-43	AOS (2-WAY) S/C-26 LOW RATE CHANNEL 8 1/3 UNCODED
Ø5:14:52	DSS-43	RECIEVE FIRST RANGE ACQUISITON
Ø5:15:ØØ	DSS-43	RETURN COMMAND SYSTEM TO MANUAL MODE
Ø5:16:ØØ	DSS-43	CLEAR THE MANUAL BUFFER AND ENTER THE THIRD SET OF COMMANDS IN THE FOLLOWING ORDER.

MODULE	MSG NBR	TIME	BIT PATTERN
1	1Ø	248:Ø5:34:ØØ	5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 E 2 5
	11	NONTIMED	6 8 2 Ø 1 7 Ø 1 6 F 4 5 Ø Ø B D 8
	12	NONTIMED	5 F 4 4 Ø Ø B 9 5 F A C E 8 C A 8

Ø5:16:57	DSS-43	RANGING MOD OFF
Ø5:21:ØØ	DSS-43	REMAIN IN MANUAL MODE AND RETURN COMMAND SYSTEM OVER TO NATCMD FOR MANUAL BUFFER VALIDATION.
Ø5:22:ØØ	NATCMD	RECALL MANUAL BUFFER AND VALIDATE COMMAND BIT PATTERN
Ø5:27:ØØ	DSS-43	AFTER NATCMD HAS VALIDATED COMMAND BIT PATTERN, TRANSFER MANUAL BUFFER TO MODULE-1 AND RETURN TO REMOTE.
Ø5:29:ØØ	NATCMD	VERIFY CORRECT COMMAND TRANSMIT TIME DISPLAYED ON FORMAT 3Ø1.
Ø5:3Ø:ØØ	NATCMD	SEND IDLE-2/ACTIVE ON
Ø5:35:ØØ	NAT/DSS	CONFIRM THIRD COMMAND TRANSMISSION
Ø5:37:ØØ	NATCMD	AFTER ALL THRE (3) COMMANDS HAVE BEEN TRANSMITTED AND CONFIRMED, RETURN TO IDLE-1/ACTIVE OFF.
Ø5:41:51	DSS-43	HIGH RATE CHANNEL ON (1K) DUAL SUBCARRIER SSA THRESHOLD SHOULD BE SET AT Ø.Ø DB.

MORE

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DE JJPL 005A
02/0001Z

PAGE THREE
   06:04:00 DSS-43 COMMAND MOD OFF
   05:54:00 DSS-43 TRANSMITTER OFF
   06:14:53 DSS-43 LOS S/C-26
7. TELEMETRY IDR REQUIREMENTS (NOCC)
   A. LOW RATE ENGINEERING
      DOY-248/05:14:22Z TO DOY 248:06:15:00Z
   B. HIGH RATE SCIENCE
      DOY-248:05:41:00Z TO 248:06:15:00Z
8. IF THERE ARE ANY QUESTIONS CALL J. NASH X-4491 OR R. E. NEVAREZ X-7163 REGARDS, REN.

END OF MESSAGE
02/0105Z SEP 82 JJPL

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APPENDIX F

RECOVERY STRATEGY LOG FOR VIKING LANDER 1

November Through February 1983

The chronology of events that followed the spacecraft emergency declared on November 20, 1982, and the subsequent efforts to recover the spacecraft signal are given below:

November 19:DOY 324:SOL 2252: DSS 43:
No downlink obtained during this regular downlink pass.

November 20:DOY 325:SOL 2253:
Spacecraft emergency declared by the Viking Project at 0000 hours because of failure to receive a scheduled downlink transmission from VL 1. The opening of an undervoltage switch on the lander electrical equipment buss was suspected.

November 23:DOY 325:SOL 2256: DSS 43:
Transmit uplink only to Lander. The commands were to increase battery-charging frequency, close the undervoltage switch, and cause a downlink to occur on DOY 331.

November 26:DOY 331:SOL 2253: DSS 43:
While transmitting commands to initiate the downlink, the DSS 43 antenna halted due to a hydraulic coolant leak; the pass was canceled. Project discovered that the lander antenna pointing parameters in the lander computer memory had inadvertently been overwritten with the battery-charging parameters. A new strategy that recognizes the lander antenna as being off point will have to be developed for all future uplink transmissions.

December 02:DOY 336:SOL 2264: DSS 63:
Transmit commands for a downlink on DOY 338 with VL-1 antenna in a parked position.

December 04:DOY 338:SOL 2266: DSS 63:
No downlink observed during this pass.

December 06:DOY 340:SOL 2268: DSS 63:
Transmit commands for downlink on DOY 341 with VL-1 antenna in a parked position.

December 07:DOY 341:SOL 2269: DSS 63:
Further set of commands for a downlink on DOY 343 with antenna in parked position.

December 09:DOY 343:SOL 2271:
Ops team discovers that 256-bit idle sequence was inadvertently omitted from the untimed commands sent on SOL 2264, 2266, and 2268, thus invalidating those uplink sequences.

December 11:DOY 345:SOL 2273: DSS 14
Command transmissions from DSS 14 now included the correct 256-bit idle sequence. This sequence was to move the VL-1 antenna to a known favorable Earth-point position, for a downlink on SOL 2274. The attempt to reposition the high-gain antenna was only partially successful because the high-power transmitter failed several times during this pass. However, 36 commands of the planned 60 were successfully transmitted.

December 12:DOY 346:SOL: 2274: DSS 14:
This was intended to be a downlink-only pass. However, the commands to initiate the downlink flag were not transmitted because an operations problem prevented the proper idle sequence being executed before the command window closed at 2004Z. The failure to initiate the command sequence correctly was subsequently investigated, but no conclusive problem could be found.

December 17:DOY 351:SOL 2279: DSS 63:
Commands were transmitted to park the antenna and initiate a downlink on SOL 2282.

December 20:DOY 355:SOL 2282: DSS 14:
Searched for a downlink after transmitting the downlink flag, but no downlink detected.

December 23:DOW 358:SOL 2285: DSS 14:
This uplink sequence was to park the antenna and cause a downlink to occur on SOL 2289. Approximately 2/3 of this pass was conducted with the transmitter on right circular polarization (RCP) and 1/3 on left circular polarization (LCP).

December 27:DOY 362:SOL 2289: DSS 43:
Searched for a downlink after transmitting the downlink flag, but no downlink detected.

December 31:DOY 365:SOL 2292: DSS 43:
Uplink commands to park the antenna. First part of this pass in RCP, second part in linear polarization at the 45-deg and 90-deg phase positions, with transmitter at 80 kW.

January 04:DOY 004:SOL 2296: DSS 43?63:
This was a split pass with DSS 43 transmitting the uplink turn-on commands. The second part of the pass with DSS 63 initiated a downlink search with the SSI and open-loop recording, but no downlink could be detected.

January 05, 1983
Project announced suspension of further DSN support pending an in-depth investigation into the lander antenna pointing program.

February 1:DOY 003:SOL 2324: DSS 43:
The pass over DSS 43 on February 1 was satisfactory, with 23 of the planned 25-command sequences being transmitted. The high-power transmitter tripped off four times causing the lost sequences. The automatic command facility worked perfectly. Any one of the commands would have been sufficient to reprogram the VL. The 11-hour pass allowed for a full-Earth pass as viewed from Mars.

February 03:DOY 035:SOL 2326: DSS 43:
This was the second of the automatic D/L transmissions following an 8-week U/L absence. (Assumed by the lack of response of the spacecraft.) No signal was seen on the SSI by DSS 43.

February 06:DOY 036/37:SOL 2328: DSS 43:

This pass consisted of a continuous command to close the UV switch and park the antenna. (It will be completed over DSS 63 on February 11) TX power was 80 kW, and the new automatic CMD S/W was used. Commands were separated by 40 min to ensure that the spacecraft could execute one command before receiving the next and before processing the next. 312 commands were sent. There were no transmitter trips.

February 10:DOY 41:SOL 2332: DSS 63:

This was the remainder of the CMD sequence sent February 6. Because the DCO did not start on time, the first block of commands was missed; otherwise all commands were sent ok.

February 11:DOY 42:SOL 2333: DSS 63:

The sequence consisted of a TX sweep followed by an idle sequence and short set of commands to activate the downlink. Even if the spacecraft had not received any of the commands in the past, an automatic downlink should have occurred at this point. None was found. A two-way sweep was then made and a search for the downlink using the spectrum signal indicator and openloop receivers. No downlink was found.

February 16:DOY 047:SOL 2338: DSS 63:

Following an uplink acquisition sweep, a 25-command sequence was sent to change the spacecraft radio configuration from TWTA1/MOD-EXC1 and to activate a downlink. However, an intensive search failed to find a downlink signal.

February 18:DOY 49:SOL 2340: DSS 63:

A long series of commands to move the antenna to its limit and then park at Earth point were now sent from DSS 63. This should have enabled the antenna and computer drive to come into registration at the limit point. It had been thought that some kind of sticking and friction may have caused the antenna and computer drive to lose alignment. Since the antenna pointing direction was not known, commands were sent through the whole view period (10 h). On the next available pass, an immediate downlink will be initiated.

February 25:DOY 56:SOL 2347: DSS14:

A short uplink-acquisition sequence followed by a search for the downlink failed to find a signal. The RFI van at Goldstone was also used to search for the downlink with its spectrum analyzer at a minimum detection level of -186 dBm. No signal was detected.

APPENDIX G

ANNOTATED BIBLIOGRAPHY

The entries below may be ordered from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C., 20402.

Images of Mars (1980, 32 pp.)

NASA SP-444, Stock No. 033-000-00793-1
A collection of 39 of the best orbiter photographs from the Viking Extended Mission, 1977 to 1979, with descriptive test.

Mars: The Viking Discoveries (1977, 32 pp.)

NASA EP-146, Stock No. 033-000-00703-5
A nontechnical account of the findings of the first few months of the Viking Mission with 28 pictures, including 7 in color.

The Martian Landscape (1978, 160 pp.)

NASA SP-425, Stock No. 33-000-00716-7
A large book containing over 200 Viking Lander photographs in color and black and white, including 19 stereopairs. Includes a first-person account of the preparations for and actual photographing of Mars from its surface.

Viking-Mars Exhibit Package (1977)

Stock No. 033-000-00711-6
A set of posters, including one 76.2 by 101.6 cm, two 61 by 89 cm, and many smaller ones. In addition to pictures, mostly in color, there are descriptions of each scientific instrument on the orbiters and landers and some of the results of each experiment.

Viking Orbiter Views of Mars (1980, 182 pp.)

NASA SP-441, Stock No. 033-000-00795-7
The various types of geologic features on Mars are described and illustrated by some of the best orbiter pictures from the first year of the Viking mission; more than 200 illustrations.

Viking Pictures of Mars: Set No. 1 (1977)

Stock No. 033-000-00691-8
A set of four color and five black-and-white reproductions, 30.5 by 63.5 cm, of Mars taken by the cameras on the Viking Orbiters and Landers.

Viking 1 Early Results (1976, 67 pp.)

NASA SP-408, Stock No. 033-000-00675-6
The Viking Project, the orbiting and landing spacecraft, and the results obtained in the first few weeks at Mars are described with photographs, graphs, and diagrams.

The entries below may be ordered from the National Technical Information Service, Springfield, Virginia, 22151.

The Mosaics of Mars as Seen by the Viking Lander Cameras (1980, 75 pp.)

Stock No. N80-32311
This publication describes the 10 panoramic mosaics and various other image products that were derived by computer processing from the individual pictures obtained by the Viking Landers. 20 illustrations.

Viking Lander Imaging Investigation During Extended and Continuation Automatic Missions, Volume 1: Lander 1 Picture Catalog of Experiment Data Record (1981, 650 pp. Available soon)

The format is the same as that of the primary mission catalog, below. It details the operation of the Lander 1 cameras from December 1976 to February 1979. Volume 2 on Lander 2 will be issued later.

Viking Lander Imaging Investigation Picture Catalog of Primary Mission Experiment Data Record (1978, 560 pp.)

Stock No. 78N-20042
A technical encyclopedia of the performance of the cameras on the two Viking Landers during the first four months of the mission. Included is a reproduction of every photograph (small size and mediocre in quality) along with complete information about where, when, and how each picture was taken.

APPENDIX H

VIKING FACTS

Event	Viking 1	Viking 2
Launch	Aug. 20, 1975	Sept. 9, 1975
Arrival	June 19, 1976	Aug. 7, 1976
Landing	July 20, 1976	Sept. 3, 1976
Site	Chryse Planitia	Utopia Planitia
Coordinates	22.3°N, 48.0°	47.7°N, 225.8°
Orbiter in orbit	1,509.9 days	718.8 days
Lander on surface	2,100 days (4/20/82	1,316.1 days
End lander operations	(predicted) 1994	April 11, 1980
End orbiter operations	Aug. 7, 1980	July 25, 1978
Orbiter photos	51,539	
Lander photos	More than 4,500	
Photo coverage	97% of planet with resolution of 300 m (1,000 ft) or better. 25% of planet with resolution of 25 m (82 ft) or better.	

Lander weather reports: more than 1 million

Orbiter infrared observations: more than 1 million

Orbiter weight: 2,325 kg

Lander weight: 571 kg

Orbiters built by Jet Propulsion Laboratory

Lander built by Martin Marietta Aerospace

NASA—JPL—Coml L A Calif

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